

**Compendium  
in Low-cost  
Wind-mills**

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**Dedicated to the memory**

**Eilmer of Malmesbury - Aviator, Monk.**

**William the Almoner - Leading civil servant, Administrator, Monk.**

**Arnold Wood - Estate manager.**

**Dr. Gilbert of Belgrave - Venture investor.**

**The Windmill Cooperative of Wigston Magna.**

**The first true pioneers and enthusiasts of the windmill era and the further development of renewable energy machine power technology.**

**NB:**

**It should be noted that this Compendium is for the express use of students, workers, research and production engineers and technicians, and for political decision-makers at all levels - concerned with development of production capability.**

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**Indeed, this Compendium is intended and presented in grateful thanks, and to perhaps bring these authors to a wider public.**

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## Chronology of Wind-turbine Development.

- Period nr. 0 Dutch type, F. Nansen, USA 1894
- Period nr. 1 La Cour, Denmark 1890 - 1925. La Cour from Askov in Denmark, was the pioneer of modern large-scale wind electrical power generation. - 3kW.- 30 kW. [ co-generation systems ].
- Period nr. 1.5 Lykkegaard, Denmark 30 - 75 kW. 1920 - 1945. Series-production period.
- Period nr. 2 F.L. Smidth, Denmark [ 60 - 70 kW. with effective gear-box developed from cement-ovens ], Hütter in Germany, Darrieus in France, Putnam in USA, and especially, very large-scale mass-production in the USSR. 1930 - 1945. [ small wind-generators for battery charging, mass-produced in USA ].
- Period nr. 2.5 J. Juul, Denmark 1950, 13kW.- 45 kW.
- Period nr. 3 J. Juul, 200 kW. Gedser wind-turbine, 1955 - 1967, and from 1977 [ operated under Danish and USA-NASA research contract ]. Plus UK and West-Germany. [ Gedser was the first modern, reliable wind-turbine ].
- Period nr. 4 Re-discovery phase, 1968 - 1978, USA and Denmark. This phase results in 2 different development strategies: - Top-down, and Bottom-up.
- a: Mega turbines; Tvind-college in Denmark & official Danish state research program, West-Germany, USA. - [ Development of glass-fiber Tvind-wing ].
  - b: The Riisager wind-turbines from Denmark, 10kW.- 30kW. These pioneered the development of the cost-effective wind-turbine
- Period nr. 5 Large-scale Danish commercial development and production; - 55kW.- 100 kW. 1978 - 1985.
- Period nr. 6 150kW.- 225 kW. 1985.
- Period nr. 6.5 300 kW. 1991.
- Period nr. 7 Large-scale production of cost-effective 500 kW. units, Denmark and Germany. 1993. Development of wind-turbines without gear-box, [ Ring-generator -- Enercon, Germany ]

There is at the present time [ 1997 ] small-scale production in Denmark of Mega-sized wind-turbines, [ between 800 kW. and 1.7 MW. ]. However great consideration, must be paid to eventual dis-economies of scale, maintenance, siteing, etc. etc.

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A: Field Engineering. F. Longland - [P. Stern, ed.], UK 1936/93 0-903031-68-X  
B: Mini HydroPower, T. Jiandong et al. UNESCO/John Wiley & Sons UK 1996 0-471-96264-3  
C: Compendium in Hydraulic Ram-pumps. J. Furze, 1995

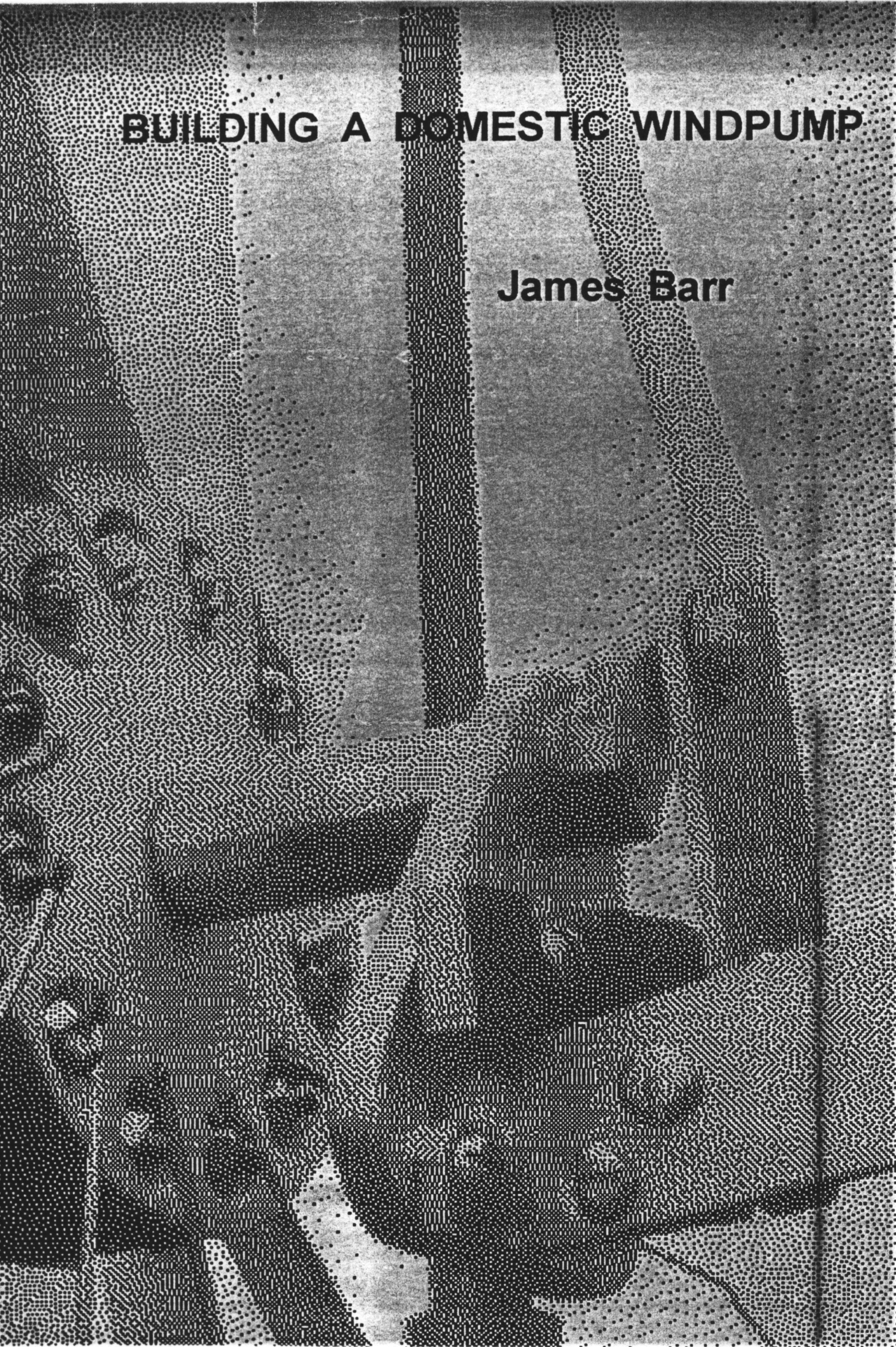
- # NB: It should be noted that a comprehensive multimedia6 program on renewable energy on 3 CD's, is issued by the Danish Technological Institute. E-mail - infove@dti.dk  
- The Danish branch organization for heat and ventilation: CD - "Multi-Sol", showing mounting/assembly work processes for solar-collectors. http://www.vvsu.dk  
- During 1998, a CD on access to wind-energy info. - should be issued under a common EU project, with as the coordinating Danish partner; - Handelshøjskole in Århus DK.  
- A CD with a database on Renewable Energy is available from UNESCO-Publishing Paris.  
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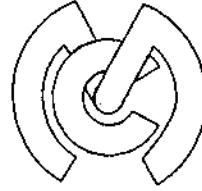
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# BUILDING A DOMESTIC WINDPUMP

James Barr





# **BUILDING A DOMESTIC WINDPUMP**

ISBN 1 870653 29 7

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Hub Editions for Machine Conversation

**Leaves rustle,**

**Blades turn,**

**Water moves.**

**To Ian Harrisson who understood the wind**

## **PREFACE**

I hope that most people who use this book to build a windpump will do so by recycling old materials and not buy too many new bits, taking advantage of available materials that are near enough to those specified. With this in mind, the reader will need to judge where the dimensions given should be strictly adhered to and where they are only a guide. Generally the exact dimensions of one component are only determined when the dimensions of another related component have been decided.

As I write the final bits for this book (January 1994), the weather men tell us that we have had a record rainfall in 1993. I wish I had written it in 1987 when water was *really* worth pumping!

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## WHAT KIND OF WINDPUMP

The type of windpump discussed in this book is known as a multi-blade direct drive windpump, this description distinguishes it from wind powered electric pumps, geared windpumps and several other designs most of which are usually more complex from the DIY engineer's point of view. This windpump is not a toy but it is small ; in a light wind, the system will only pump about 1000 litres (200 gallons) per day with a head of 3 metres.

Most windpumps of this type function better when working against a larger head of water than that quoted above. This windpump has evolved for use in the domestic environment and most of the applications I have come across do not require large heads of water to be moved.

The pump and turbine described here should work OK with increased heights, but you may encounter some mechanical problems when you try to extend the distance between turbine and pump by too much. These problems result from my use of light-weight flexible materials for the transmission system.

## WHY HAVE A WINDPUMP

Even if you live in a semi-rural part of England, your reasons for choosing wind energy to pump domestic water are unlikely to be based on sound economics. There are, however, many other good reasons for using wind instead of a fossil fuel based energy source for a water pump.

Long before it became fashionable to be green, I derived some pleasure from utilising this free, renewable energy source; by recycling domestic grey water to the garden, I was able to save our fruit trees and bushes during several dry summers.

To me, the windpumps in my garden are attractive to look at even when stationary and the pumps do useful work irrigating the garden. Electric pumps could do this but they would incur running costs and are not so attractive (to me!).

As an engineer, I get pleasure from watching the simple mechanisms which convert energy into work; I imagine that some people go to traction engine rallies or build model steam locomotives for similar reasons.

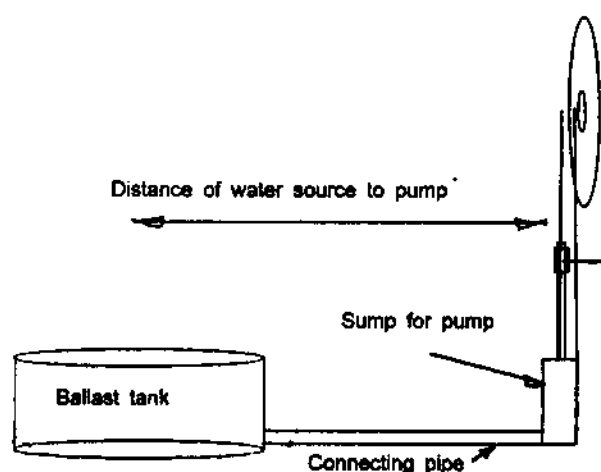
For the amateur, there is very little invention left in windpump design these days since the majority of successful designs have been around for a long time, but there are opportunities for the amateur/experimental engineer to make minor changes to established designs and observe the resulting changes in performance.

## WHERE TO SITE A WINDPUMP

There are three important considerations when selecting a site for a windpump. The first relates to how near your neighbours are and whether they will object to a 20 foot tower overlooking their garden!

The second two problems to be considered relate to positioning the windpump for optimum performance.

First, the wind turbine and hence the mast of a direct drive windpump need to be directly above the pump to which it is attached. For this reason you will try to site your windpump as near to the source of the water to be moved as possible. Some degree of latitude may be allowed here especially if the water is being pumped from a storage tank; it may be possible to pipe the water some distance (downhill) from the tank to the foot of the windpump.



**Figure 1 [Site the turbine above the pump]**

Second, the wind turbine needs to be in clean (non turbulent) air. For most domestic gardens this presents the main problem since buildings, trees and other structures will disrupt the airflow to varying degrees.



## HOW TO APPROACH THE MAKING OF A WINDPUMP

For many people, this text will be no more than a design catalyst to prompt your own methods of construction. If however, you are relying on the detailed descriptions within this book to help you build your first windpump, then read all the relevant sections to get a clearer picture of how to do it. Some parts of the windpump described in this book are covered in more than one section, eg. the foot valve is part of the pump body and is also described in detail under the heading of valves.

*Most* of the components described in this book are over engineered and some latitude may be exercised in implementing the design, I hope that common sense will decide where, and to what extent it is OK to depart from the suggestions in the book.

Just remember that the turbine weighs several pounds, it moves quite fast, has sharp edges and has a fair way to fall if bits of it break off!

## COST OF MAKING A WINDPUMP

My first windpump was 1m diameter; it was built entirely from scrap and was almost useless - no, it *was* useless: it barely illustrated the principles on which windpumps work. Given a hacksaw and a few other basic hand tools, you could build one like it for under £10. You can do the same, or you can buy a commercial machine for between £1000 and £16000. The third option is to learn from my mistakes and build a basic 12 blade windpump as described in this book. If you have to buy everything from iron mongers and get a few parts machined or pressed, it could cost £250 but if you have access to a reasonable workshop and a metal scrap bin then the cost could be under £50.

## THE WINDPUMP

### MATERIALS

All components of the windpump are described in some detail and the materials are part of that description; however, it may be useful to have an overview of the whole project to establish what technologies are required.

You will need to be able to accurately cut, bend, drill, rivet and hard solder, soft solder and/or glue a variety of materials. The actual processes are summarised below.

**Figure 2 [Avoiding turbulence]** shows the turbulent envelope to be avoided up and down wind of buildings and trees of height  $H$ . In an urban environment you are very unlikely to be able to site a windpump outside this envelope but it is not a simple on or off situation and the windpump I shall describe will operate in some pretty turbulent areas. One serious problem with a small wind

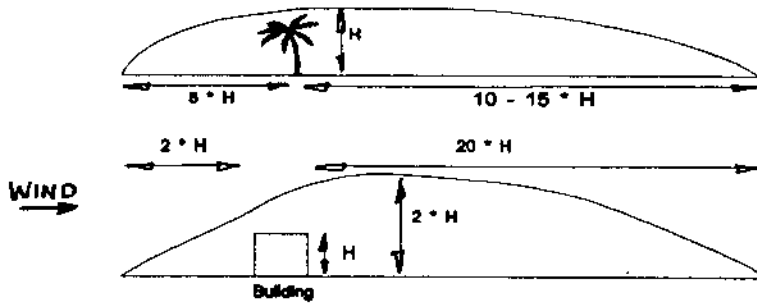


Figure 2 Avoiding turbulence

turbine in turbulent air is the way in which the rotor can be buffeted to all points of the compass; this is not good for the mechanisms and is of course very inefficient.

This problem can be reduced by selecting a site for the windpump after careful examination of the wind over the available ground over a period of time. A cheap comparative test for clean air flow is to stick several long poles in the ground at points of interest each with a piece of light cloth or plastic tied to the top. By observing the wind's effect on the different flags, a picture of the air flow will develop. It is important to differentiate between rapid random turbulent agitation (no good) and a steady though less aggressive flow (better).

Since the wind direction changes seasonally in most areas of the world, these tests should be carried out during the seasons for which pumping is required!

	Line Cut	Circle Cut	Drill	Tap	Screw	Bend	Rivet	Glue	Solder	Turn
Aluminium	3	3	4	4	2	6	2	0	0	0
Brass	3	3	4	3	3	0	0	0	5	7
PVC	0	3	4	5	2	0	0	3	0	4
Wood	2	0	0	0	0	0	0	0	0	3
Steel	2	2	2	4	3	0	0	0	0	3

The numbers in the chart indicates the degree of skill required for the associated process: eg. 0 means you don't have to do this; 1 means very basic skill level; 9 means that you may need precision skills and/or possibly specialist tools.

As a guide I would say that, using this scale, building a typical tissue and balsa wood 26 inch wing-spans model airplane from a kit rates as 6.

#### EQUIPMENT      HAND TOOLS

A normal set of workshop hand tools for metal working is essential including hammers, a hacksaw, files, hand drill etc.

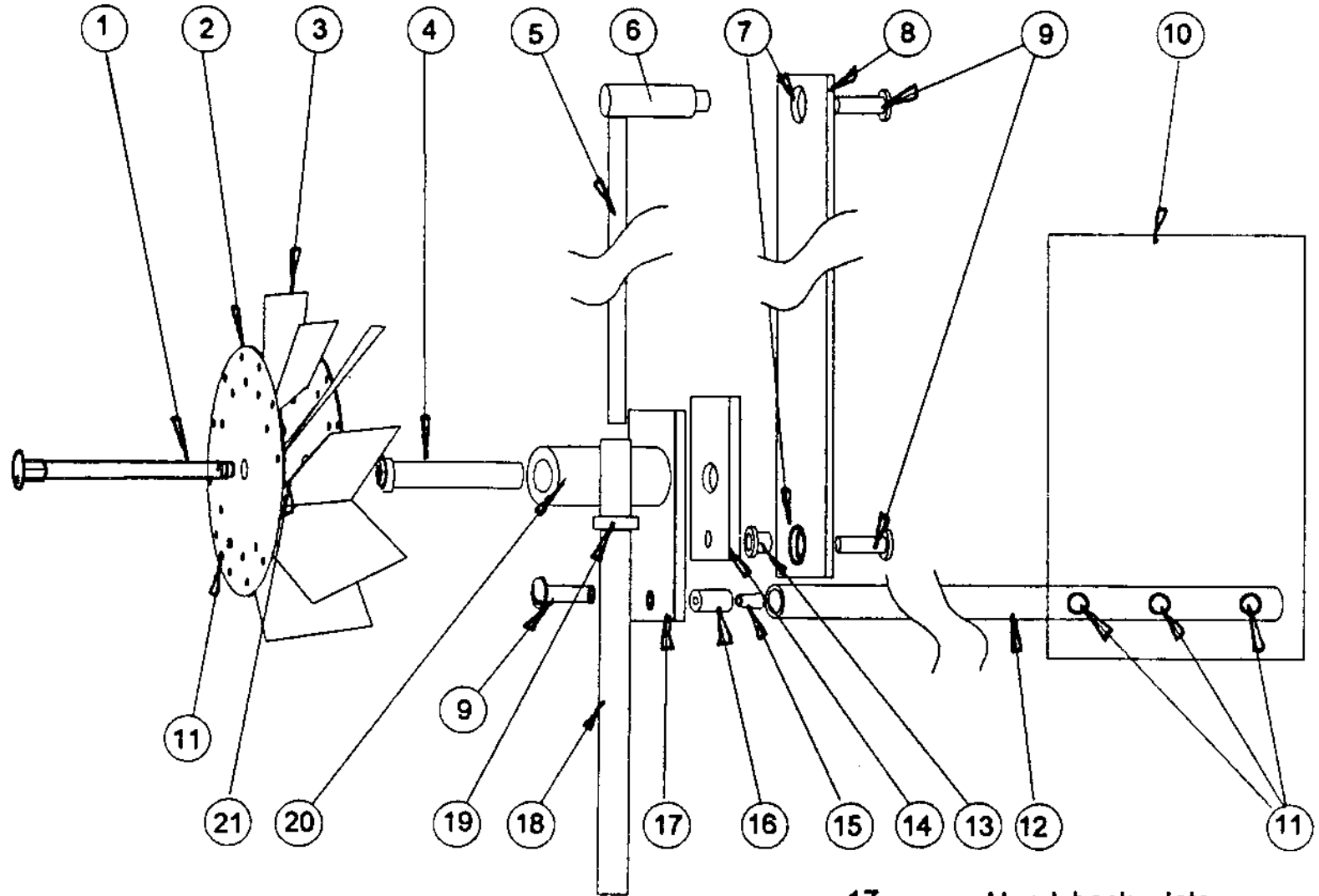
#### EQUIPMENT      POWER TOOLS

A small pillar drill will make some operations simpler but it is not essential. A lathe capable of turning 20cm between centres and a throw of 10cm is probably essential if you intend making everything yourself, but only a very few components rely on such equipment.

#### OTHER TOOLS

A fly press or a device for bending sheet metal would be useful, but not essential. A lot of the repetitive tasks are rendered easier if hard wood or 'dural' jigs are made to ensure consistency. This is especially true of the turbine blades; if you do not wish to make a jig to help bend the blades, then I still recommend the use of patterns to help mark them out: one to check that each blade is the same and a one to help drill all the holes in the same place.

# Exploded view of main turbine components



- |   |                     |    |            |    |                       |    |                                    |
|---|---------------------|----|------------|----|-----------------------|----|------------------------------------|
| 1 | Spindle             |    |            |    |                       |    |                                    |
| 2 | Hub plate           |    |            |    |                       |    |                                    |
| 3 | Blade               |    |            |    |                       |    |                                    |
| 4 | Spindle bush        |    |            |    |                       |    |                                    |
| 5 | Push rod            | 9  | M5 bolt    | 13 | Bush                  | 17 | Head back plate                    |
| 6 | Push rod top        | 10 | Tail fin   | 14 | Crank                 | 18 | Head vertical tube                 |
| 7 | Nutsert (not shown) | 11 | Pop rivets | 15 | Tail stick locknut    | 19 | Head step                          |
| 8 | Con rod             | 12 | Tail stick | 16 | Tail stick taper lock | 20 | Head horizontal tube               |
|   |                     |    |            |    |                       | 21 | Turbine hub spacer<br>( not shown) |

## **CONSTRUCTION**

### **TURBINE COMPONENTS AND ASSEMBLY**

**Figure 3 [Exploded view of main turbine components]** gives an overall idea of what the components look like together.

The whole turbine assembly comprises two groups of parts. Group one is the rotor itself: it has four basic components, a front hub plate, a back hub plate, wooden spacer and the 12 blades. Group two consists of five parts: the spindle, the spindle bush, the crank, the connecting rod and the push rod. To these components must be added the 48 pop-rivets and two screws or pegs to lock the turbine and crank to the spindle.

## HUB

The hub is comprised of two 10cm diameter circular plates of 2mm thick aluminium as shown in **Figure 4 [The turbine hub plates]**, **Figure 5 [The hole positions in the hub plates]**, **Figure 6 [The turbine hub plate spacing]**. Note that the rear hub plate has a larger central hole to

accept the front of the spindle bush. The hub plates are kept apart by the blades with the assistance of a central wooden block: the turbine hub spacer. The turbine hub spacer is made from a section of broom handle and serves the added purpose of locking the turbine to the drive spindle.

Because the whole turbine is so small (only 700mm) across, it is possible to make the blades strong and heavy enough to be a structural part of the assembly. When the blades are pop-riveted to the front and back hub plates, the resulting structure is very solid indeed.

Central hole :- 8mm in front hub plate;  
12.5mm in rear hub plate.

If you leave the square section on the turbine spindle, then the front hub plate needs a square hole. See section on turbine construction

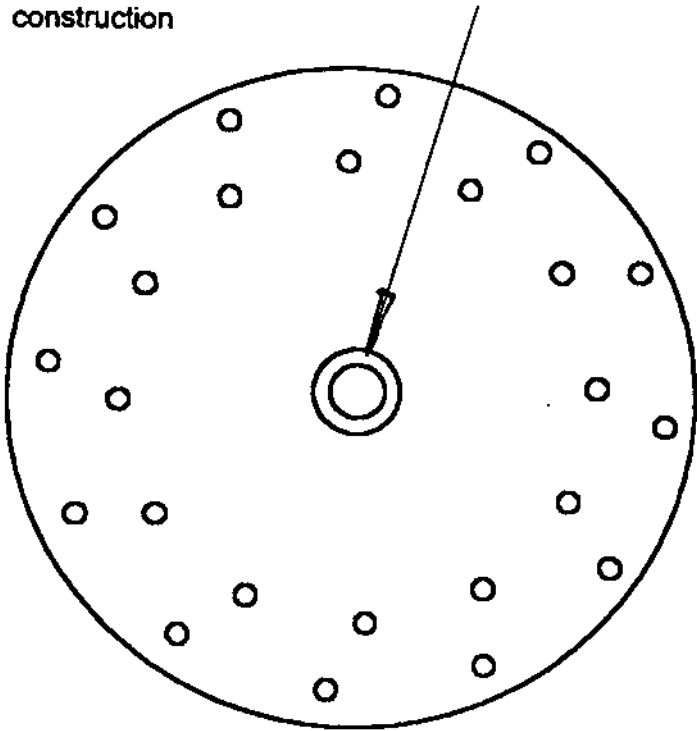


Figure 4 The turbine hub plate

12 sets of holes set symmetrically about the hub plate.

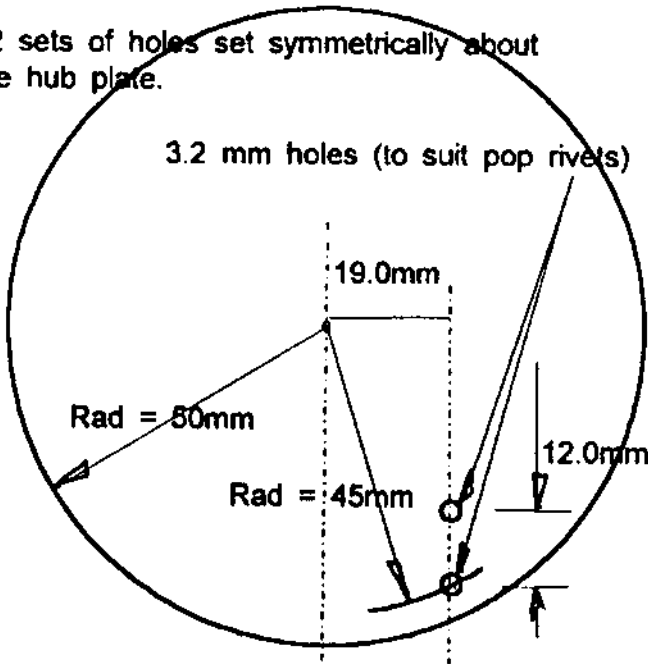


Figure 5 Hole positions in the hub plates

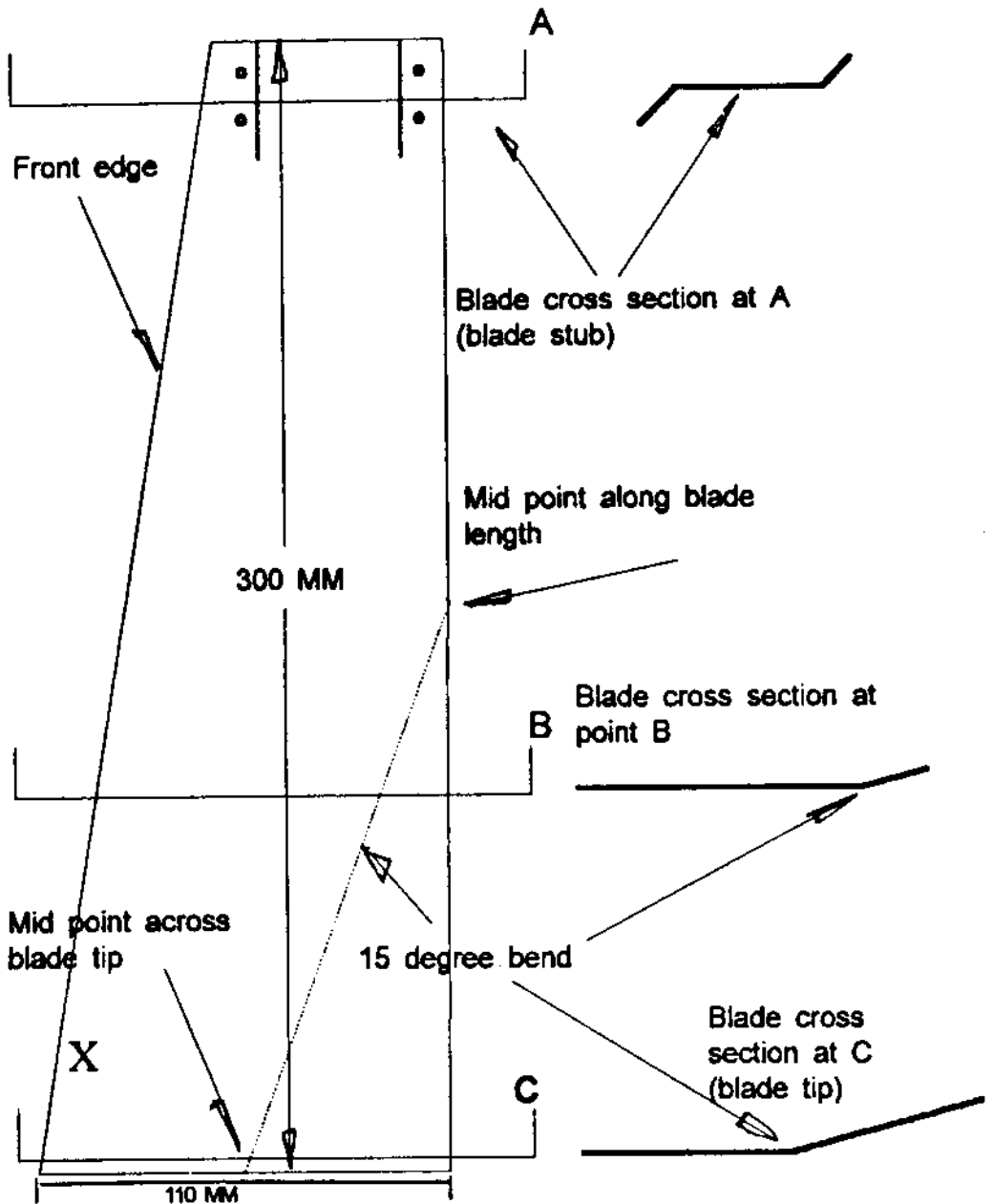


Figure 7 The turbine blades



## BLADES

The blades are cut from 2mm thick aluminium. The pattern for blades is shown in **Figure 7 [The turbine blades]** and **Figure 8 [The hole positions in the turbine blades]** The forming process is simple and only needs a vice with 10cm jaws. It is essential that the holes in the blades line up with the holes in the hubs; this requires that the marking, cutting, drilling and bending is done with great accuracy. The most important point is that all the blades are identical

and that the hole spacing of the blades is the same as that of the hub plates. If the width between the

pairs of holes at the stub of the blade is a millimetre wider or narrower than drawn, ie.

50mm, then the turbine hub plates will be further apart or nearer together, but this is not a problem.

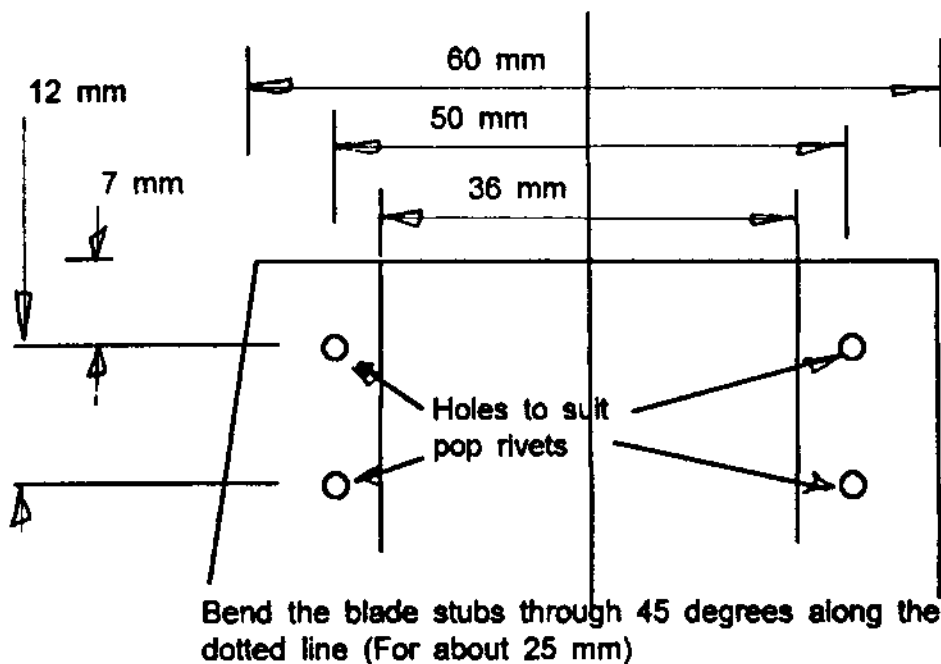
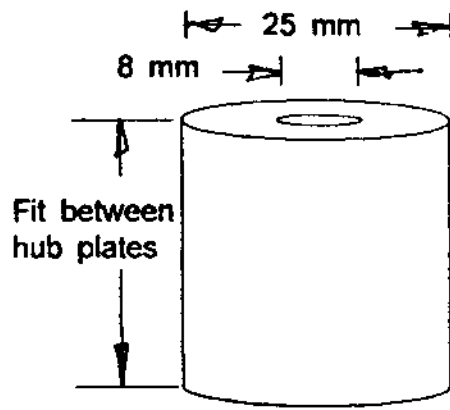


Figure 8 The hole positions in the turbine blades



## WOOD SPACER

Figure 9

This is a piece of 25mm dia dowel axially drilled 8mm and cut square to length 29mm. It is important to make sure that the ends of the spacer are perpendicular to the axis. **Figure 9 [The turbine hub spacer]**

Provided that the plates are identical and that the plates are parallel, the exact distance between the plates is unimportant

The length of the turbine spindle is affected by the distance between the plates.

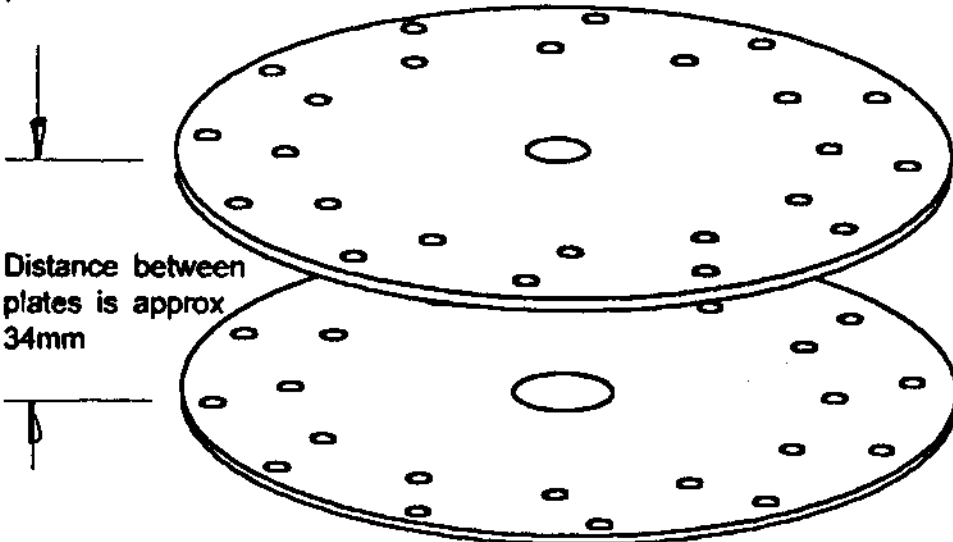


Figure 6 The turbine hub plate spacing

## ASSEMBLY (TURBINE)

Assembly of the turbine is simple. The blades are attached to the hubs using 3.2mm pop rivets. *The blades are not symmetrical and care must be taken that they are all installed with the angled leading edge, (X), facing forward.* The hub plate with the larger central hole (12.5mm) faces to the rear.

Start by loosely bolting the two hub plates together with the wooden hub spacer between them; make sure the holes in the hub plates do not line up, (if they do, just turn one hub plate upside down).

The order of fitting the blades to the hubs is optional but it may be simpler to fit two opposite blades to one hub (180° apart), then rivet each blade to the other hub. Doing it like this will give a sturdy structure to add to.

Do not be tempted to use rivets in oversize holes or widen holes to accommodate badly prepared hubs or blades: if the rotor fails because of one blade and subsequently loses that blade, the whole turbine will be unstable and may fly to bits.

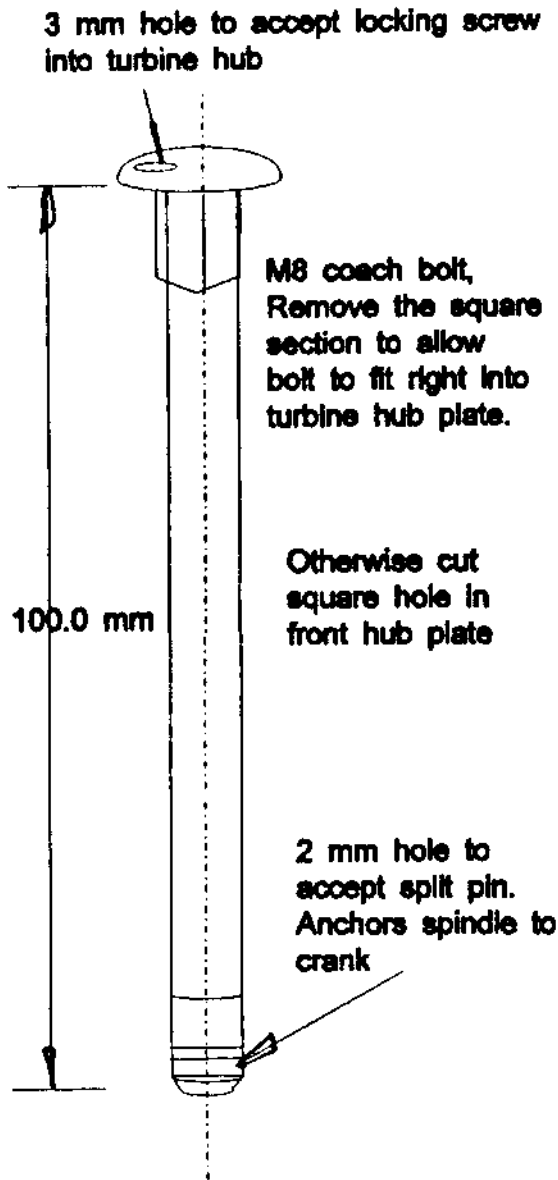


Figure 10 The turbine spindle.

## SPINDLE

The spindle is a modified 8mm \* 100mm coach bolt. The square section of the stem at the head of the bolt is turned down to the same diameter as the round section. If the square section is left on, it would serve well to key into the centre of the turbine, however, some skill would be required to ensure that the square cut in the turbine hub is symmetrical... I think there is a simpler way to key the turbine to this shaft. **Figure 10 [The turbine spindle and attachment].**

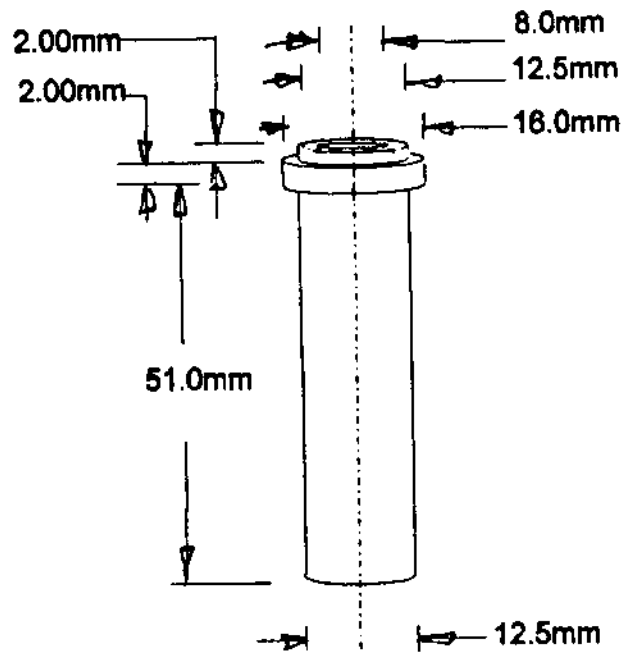
Rather than key the spindle into the hub plate, I chose to drill a 3mm hole in the head of the spindle bolt parallel to the axis and screw through this hole into the hub plate and the wooden spacer. If you choose to leave the spindle head square, just remember you will have to modify the turbine hub plate to suit.

**Do not forget to fit a split pin through the spindle and crank; the turbine is potentially dangerous without it.**

## SPINDLE BUSH

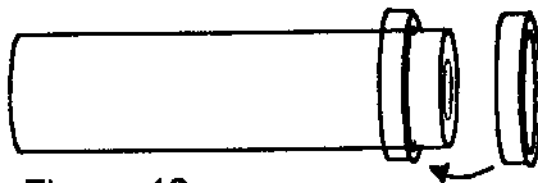
The spindle bush is turned from brass. I hope that it is apparent that if convenient sizes of brass stock tube are to hand, this component, and several others, can be made by simply sawing off suitable lengths of tube and silver soldering them together. **Figure 11 [The spindle bush].**

**Figure 12 [Fabrication of the spindle bush]** shows how to fabricate the spindle bush from two bits of tube.



**Figure 11 The spindle bush**

Suitable brass tubing cut and brazed



**Figure 12**  
Fabrication of spindle bush

When assembled, the spindle bush is locked to the spindle; the spindle is not supposed to rotate in the spindle bush as might be thought.

## CRANK

The crank can be made from steel aluminium or brass.

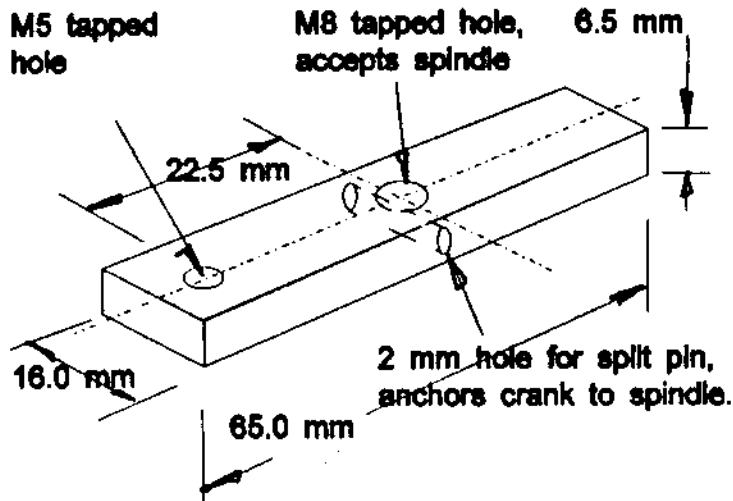


Figure 13 The crank

**Figure 13 [The crank].** Brass is ideal: it is strong enough; machines nicely; and is durable in the hostile environment.

The split pin that passes through the crank and the spindle is essential: it prevents the crank from unscrewing from the spindle; if that happened, the turbine could fall free from the top of the mast.

It is not necessary to make the crank symmetrical about the spindle axis, but the extension opposite the connecting rod end can be used to carry experimental counter-weights.

# CONNECTING ROD

The connecting rod (con rod) is steel or aluminium; it can be fashioned from a length of 3mm thick sheet or bar. The exact dimensions are unimportant but the length must obviously be compatible with the length of the push rod. **Reducing the length of the push rod and the connecting rod by too much will reduce the efficiency of the turbine.** Play around with the recommended sizes by all means, but you need a good reason to shorten them by much! **Figure 14 [Connecting rod ]**.

There is a bearing hole at each end of the con rod and if the con rod is aluminium, these holes must be reinforced. To do this, I have used a suitable sized nutsert with the thread bored out and attached to the con rod in the normal way.

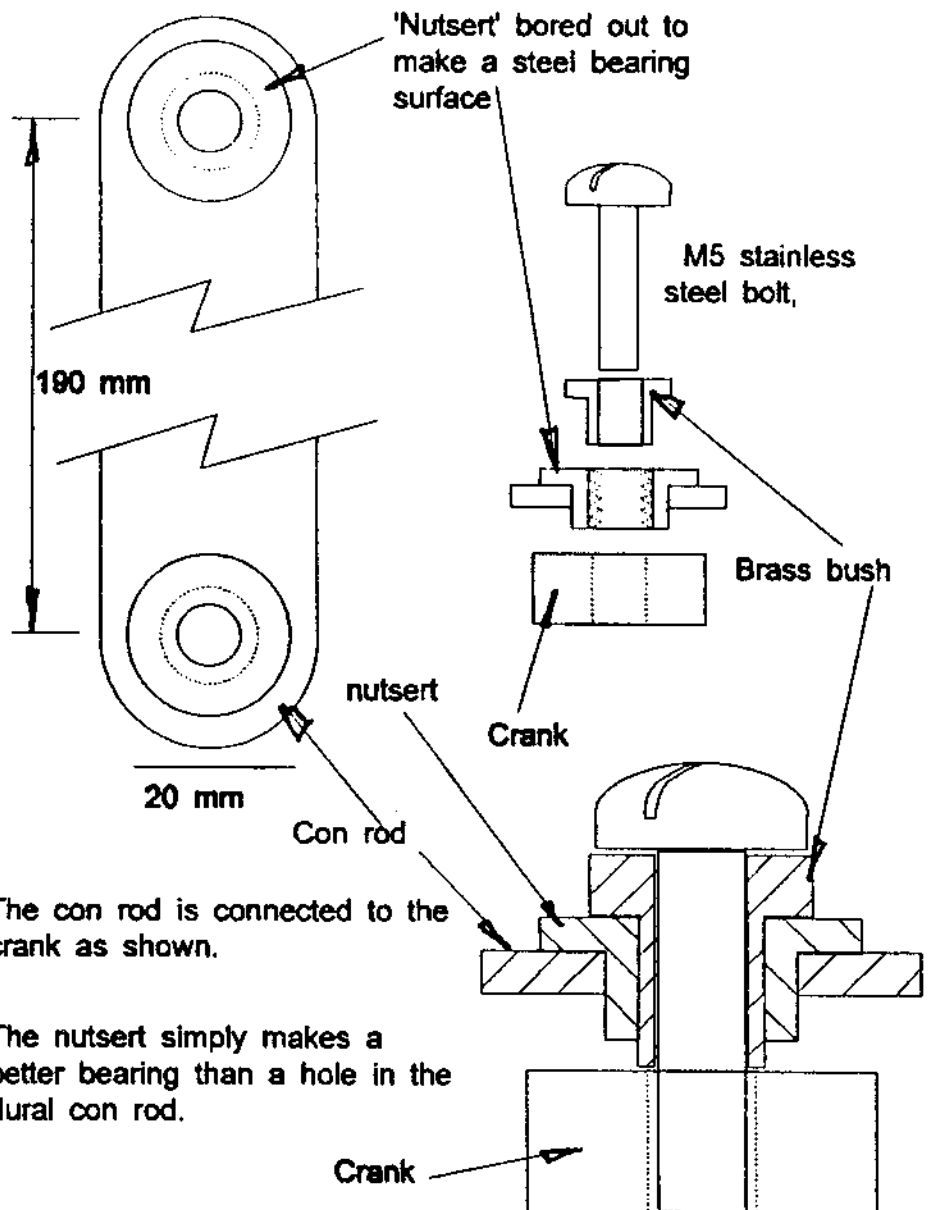


Figure 14  
Connecting rod

# PUSH ROD

The push rod is a length of steel rod 5/16" diameter. **Figure 15 [Push rod and push rod top]** The reason for suddenly going Imperial is that 5/16" rod is widely available for some reason, probably as pram axle! Having said that, if a suitable rod is available near enough to 5/16" that is a slide fit in the head vertical tube of the turbine head, then use it. The only real constraint is that it has to be drilled axially to take the M5 stud for the long transmission rod and turned down at the other end for the push rod top.

Con rod attached to push rod top using same method as for attachment to crank, but no need for a bush

Length of push rod top depends on the horizontal distance between push rod and crank.

The con rod may have a small dog leg bend to help align

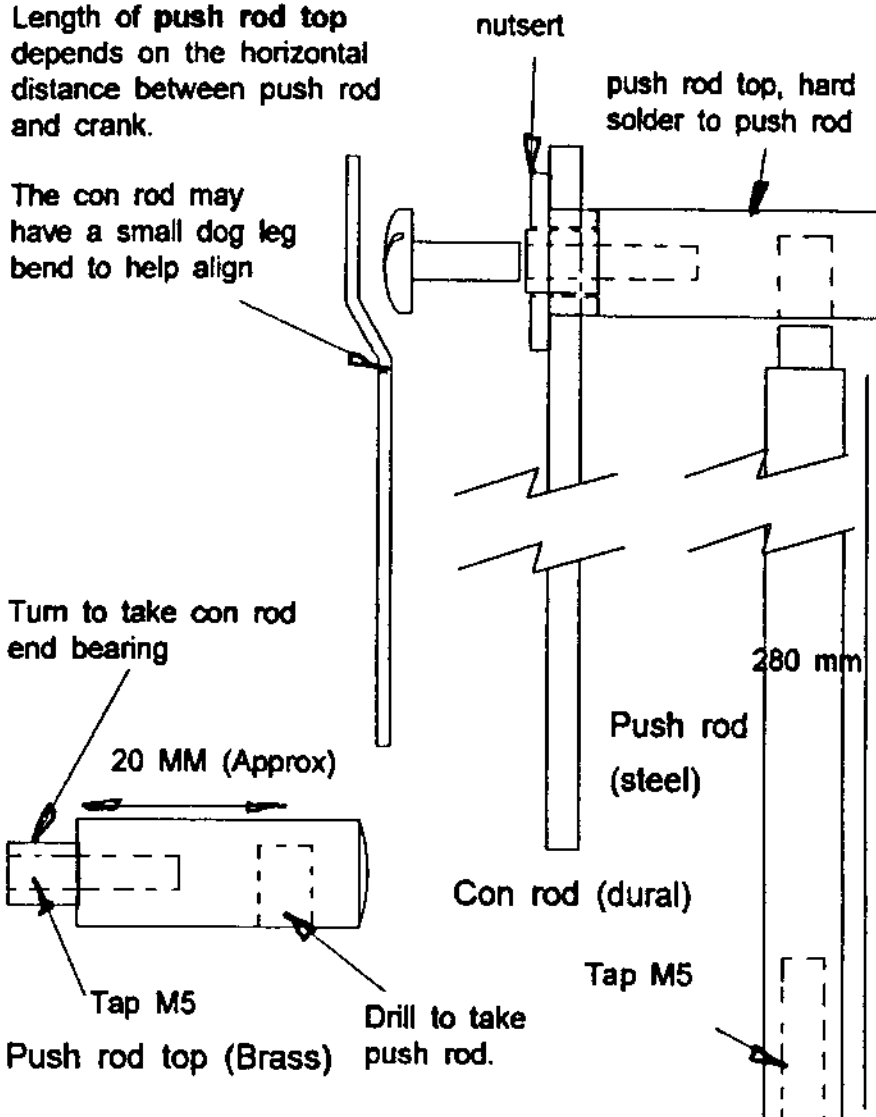


Figure 15 Push rod and push rod top



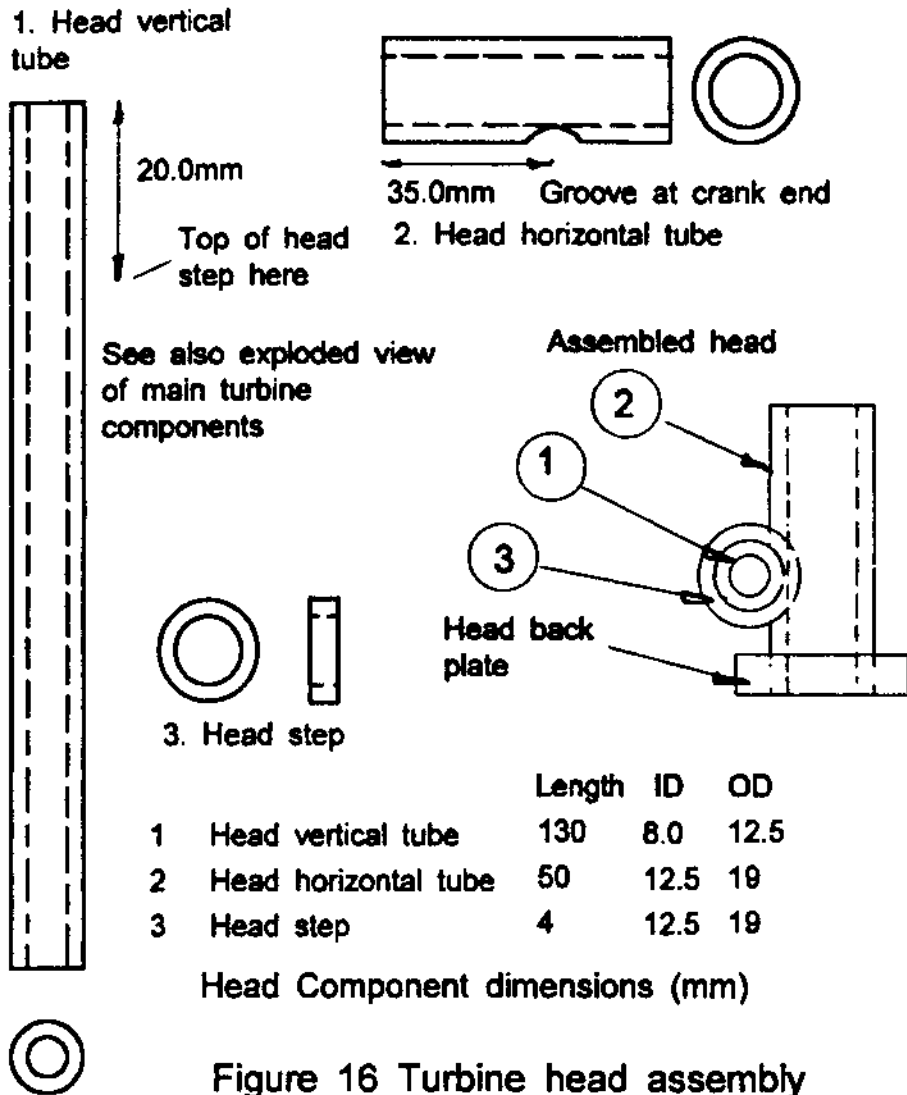
## TURBINE HEAD ASSEMBLY

This is the only part of the windpump where a lathe really makes life easy. Without a lathe, the components of the turbine head assembly can be fabricated from suitable brass tube stock and attached using brackets instead of machining to close tolerances and hard soldering.

### HEAD

The head **Figure 16 [Turbine head assembly]**, is constructed of two brass tubes braised together at right angles. A circular groove is cut in the horizontal larger tube (the head horizontal tube) to let in the vertical tube (the head vertical tube). The head back plate is brazed to the back end of the head horizontal tube. The head step is soldered on to the head vertical tube just below where it meets the head horizontal tube.

The spindle bush runs inside the head horizontal tube, so the inside bore of the head horizontal tube needs to match the outside diameter of the spindle bush; the actual size is immaterial so long as the wall thickness is greater than 3mm. A 2.5 mm hole drilled down into the bore of the head horizontal tube allows oil to be fed to the spindle bush. (This oil hole is not shown in the Figure 16.)

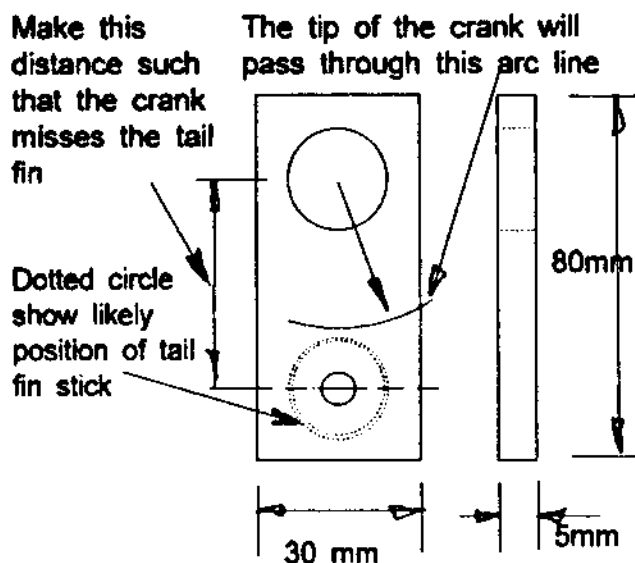


The head vertical tube has two functions: the inside is the bearing surface for the push rod which slides snugly inside; the outside of the tube sits in the support tube that is attached to the windpump tower. The bottom surface of the head step rests on the top surface of the support tube. This allows the whole turbine assembly to rotate on a vertical axis. The motion of the push rod is up and down the same vertical axis.

## HEAD BACK PLATE

This can be any size up to 80mm square provided that it extends beyond the radius of the turbine crank. This is so that a tail fin can be attached to it without obstructing the crank and connecting rod as they move.

**Figure 17 [Head back plate]** The head back plate is brass and needs to be 3mm thick and brazed to the head with sufficient strength to carry the tail fin.



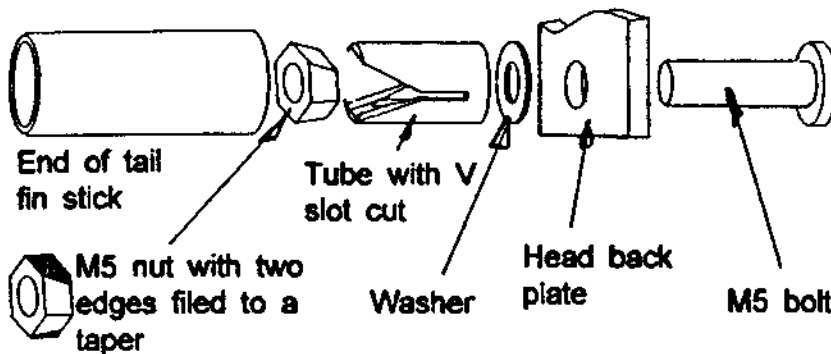
**Figure 17 Head back plate**

In the sketches, the 'Head back plate' is shown with its longest dimension vertical; if all the associated dimensions have been calculated as shown in the book, the 'Head back plate' will foul the 'Support tube'. There are several ways to avoid this problem: the simplest is to fit the 'Head back plate' horizontally; the effect of this modification is that the tail fin stick will be mounted slightly to one side of the turbine spindle which is not a problem.

## TURBINE TAIL STICK AND TAIL FIN

The stick can be made of any light material provided it is not too flexible: a 12mm - 20mm plastic water pipe is perfect.

The fin needs to be light, the actual shape is not critical but for maximum rigidity, it needs to be fairly square. An oblong fin 300mm \* 250mm attached to a 600 mm stick is adequate.



The inner tube is a sliding fit in the tail stick. The bolt and taper nut expands the tube outwards to grip the tail fin stick and tighten on the head back plate

Figure 18

Fixing the tail stick to the head back plate

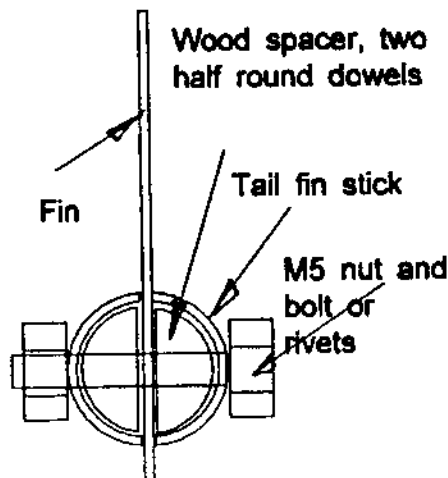


Figure 19

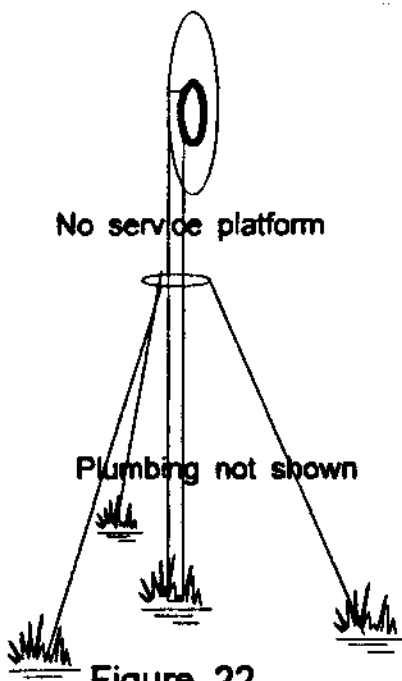
Fixing tail fin to tail stick

## MAST

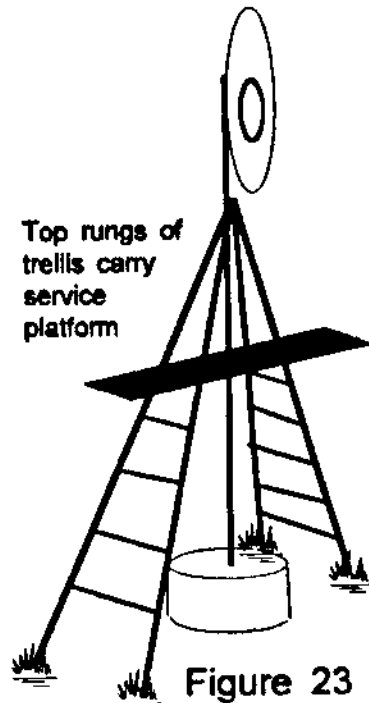
The mast is probably where the greatest compromise is tolerated between requirement, design and actual fulfilment. You need to get your turbine into a good clean air flow; for this you probably need a tower 20 metres high!.. OK, settle for 6 metres, this compromise is for the neighbours as much as for your bank balance.

An 8 metre scaffold pole buried 2 metres in the ground is perfect except that it may not be aesthetically pleasing to you and how do you get up to the top to do repairs or modifications. One plan is a small trellis tower of timber or light steel tube to about 3 metres with a flat top 30cm square top to stand on. The mast is then fixed vertically as part of the trellis and extending up a further 3 metres.

A suitable pole attached to the side of a single storey flat topped building can work, provided that the building does not have too much effect on the clean air flow.



Tower using scaffold pole and guy ropes



Trellis tower

**Figure 22 [Tower using scaffold pole and guy ropes], Figure 23 [Trellis tower] may prompt further thoughts on solving this problem.**

## TRANSMISSION

The transmission covers the mechanism between the bottom of the push rod in the turbine head and the top of the pump. Now in experimental windpumps frequent changes may take place in the exact distance between the pump and the turbine so a cheap method has evolved which allows quick modifications to be carried out.

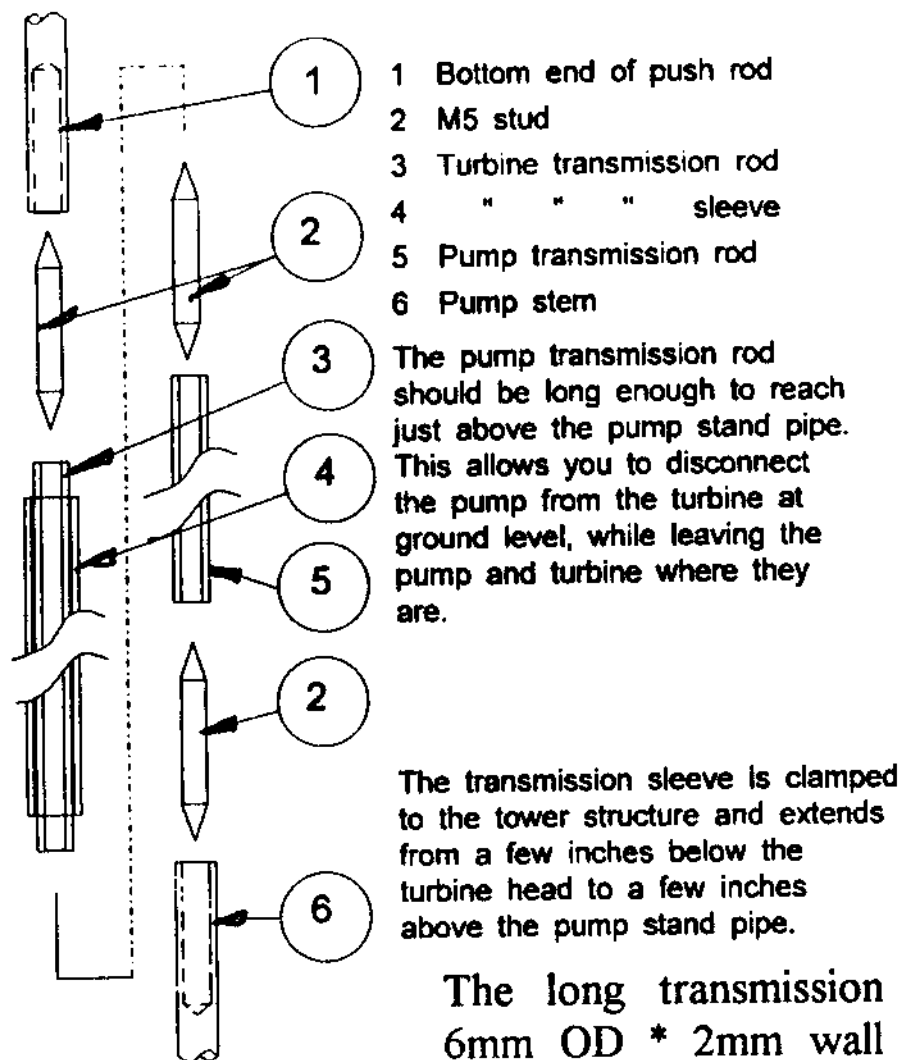


Figure 24 The transmission rod

**Figure 24 [The transmission rod].** This is very light but far too flexible so it runs in a similar PVC tube with a 9mm bore. The outer tube is rigidly held in position between the turbine and the pump by clamps.

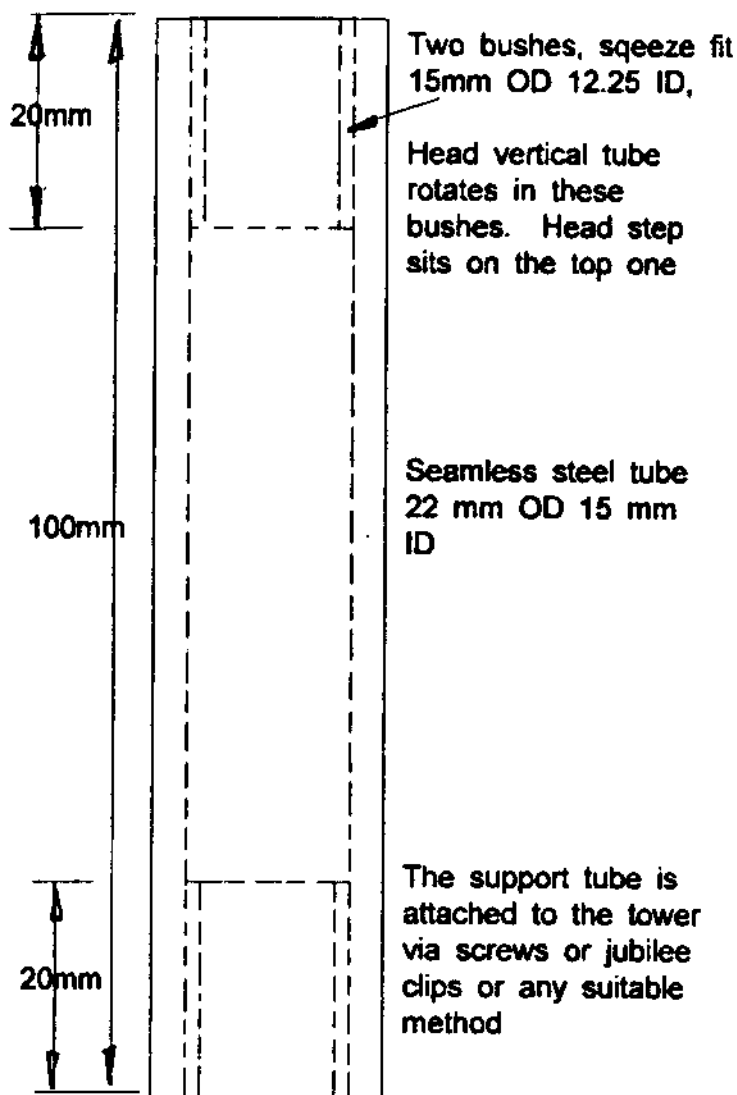


Figure 20 The support tube

The transmission rod sleeve must be firmly attached to the mast and aligned both with the pump at the base of the tower and with the push rod at the top. **Figure 20 [ The support tube]** shows the support tube; this is attached to the tower at the top and allows the head vertical tube to rotate freely about a vertical axis. The support tube may be attached to the mast in many ways but the important point is that the whole fixture must not be too wide or the turbine blades will hit it!

Bear in mind that the trailing edge of each blade passes within 30mm of the centre line of the support tube so the maximum diameter of the top 400mm of the mast assembly must be less than 60mm

The push rod is attached to the transmission rod by means of a 20mm length of M5 studding. If the studding is filed to a 60° point, it can be used to tap the bore of the transmission rod like a self tapping screw. The other end of the stud screws into the axially tapped hole in the push rod.

The top of the piston rod is joined to the transmission rod in a similar manner... see the pump details.

## PUMP

### BODY

This is a lift pump, the body of which is constructed entirely from off the shelf plumbing fixtures, available from most large DIY retailers. Once you see the general design, you will probably be able to adapt it to suit the fittings that are available to you locally.

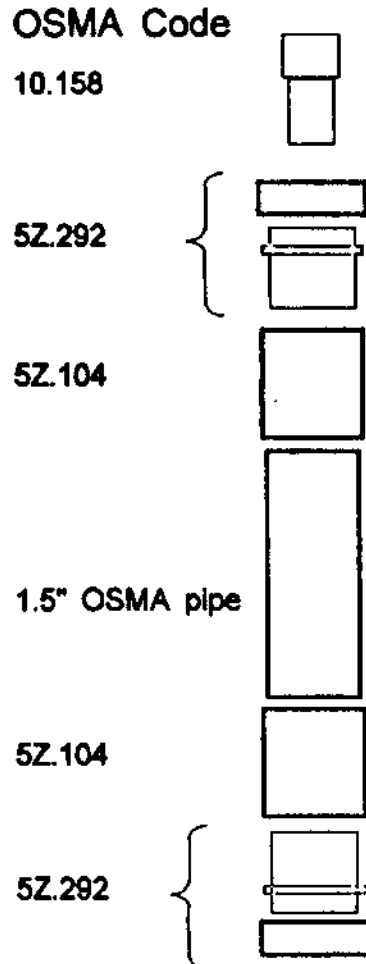


Figure 25 Pump body



## Building a domestic windpump

The manufacturer of the bits I used is OSMA and I have shown their codes for the fittings used in the design in **Figure 25 [Pump body]**.

The cap on the top of the body has to be bored out to take a pipe reducer. If care is taken, this can be done without power tools; the important thing is strength not precision. The pipe reducer which is glued into the cap from above takes the vertical stand pipe for delivering water from the pump.

The cap at the bottom of the pump is a bit more tricky: it has to be reinforced by gluing a solid round block 5mm thick to the inside of the cap.

The block has holes bored in it through which the pumped water flows; the block is also the main surface of the foot valve and detail on this component is covered in the section on valves. A similar block performs a similar task as part of the piston assembly.

The diameter of the various bits inside the pump will be governed by the size of fixtures available but the pump body should be long enough to allow the piston to travel 100mm without striking the ends of the body. If you are likely to adjust the turbine height or pump depth much during experiments, you would be wise to allow 50mm

above and below the stroke of the piston. Failure to do this may result in the piston hitting the foot valve or the top of the pump body. 50mm may seem a large tolerance but you may be adjusting the vertical position of the pump when you cannot even see it under the water.

### PISTON

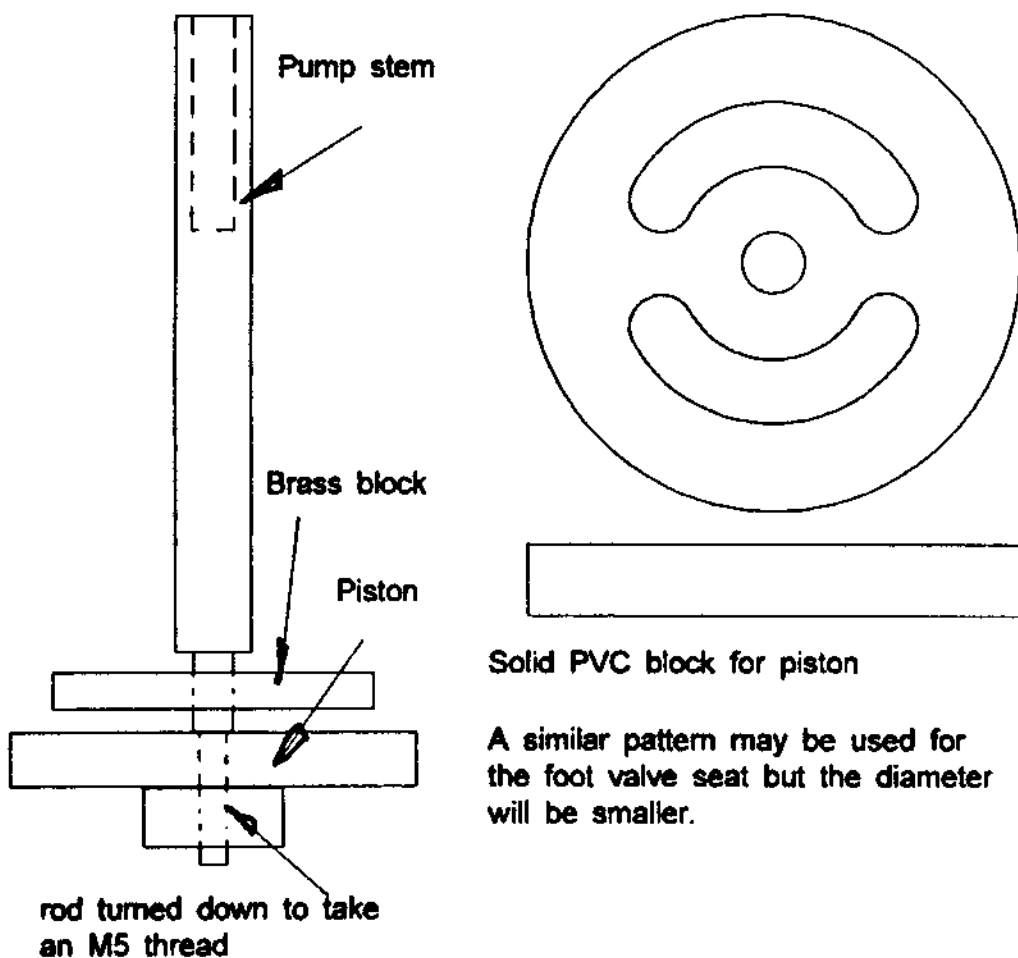
The piston is a disc of PVC sheet about 5mm thick. It needs to fit loosely inside the tube part of the pump body, about 0.5mm clearance all round is fine. If the piston seals well, it may pump better, but the tube is probably not perfectly round, so it will still need to be a bit loose to avoid jamming in some positions!

The large industrial or agricultural pumps have leather or rubber seals to make good contact with the tube wall of the pump, the light weight nature of this windpump means that the friction introduced by such a refinement outweighs the benefit.

The piston stem is a piece of 6-7 mm steel rod about 100 to 200mm long (actual size does not matter but a long stem will increase the weight). The stem is attached to the piston by threading the rod M5, for about 10mm and similarly

## Building a domestic windpump

tapping the piston. Sufficient of the threaded stem should protrude through to permit a lock nut to be screwed on to the end of the stem. **Figure 26 [Piston and stem.]**



**Figure 26** Piston & stem

**The piston incorporates a valve which is covered in detail in the next section.**

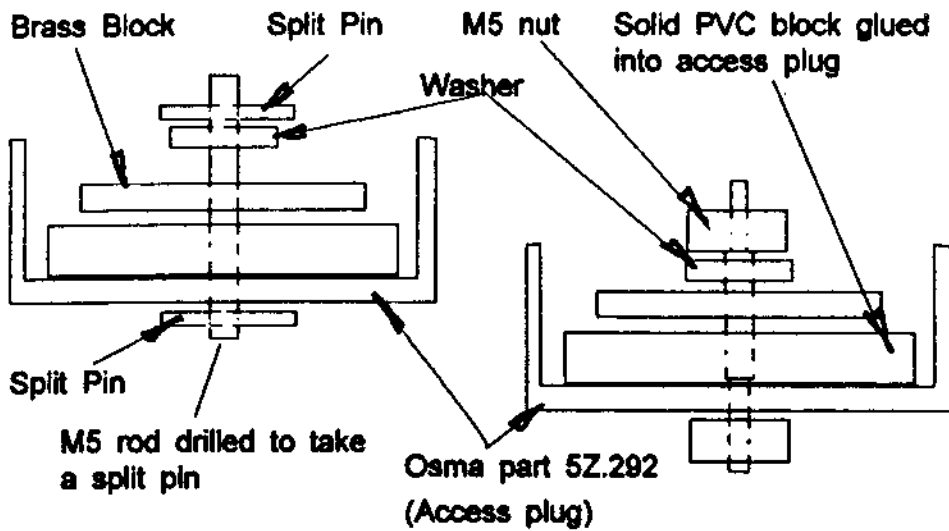


Figure 27 The foot valve detail

## VALVES

The foot valve is part of the pump body, **Figure 27** [**The foot valve detail**] shows two possible arrangements for the foot valve. In both cases the base is a 5mm thick block of PVC.

When attaching the block, precision takes second place to strength but remember that one of the most critical factors in maximising the efficiency of the pump is the seal in the foot valve. So try to ensure that the metal valve flap (a disc of brass) seats flat and square in the bottom of the pump body.

The operation of both valves relies on the fact that a heavy metal disc sits over the holes in a larger PVC plate preventing water from flowing through. When the water pressure changes on one side of the valve, the plate is lifted allowing the water to flow. The heavy plate is restricted in its movement by a loose fitting bolt or pin passing through to the base plate. This simple process is more obvious when looking at the sketches but to watch the valves in action is best of all... You can buy a child's bathroom toy lift pump that operates on this principle, it has a clear perspex tube so you can observe the mechanism!

The greater the head of water above the pump, the better the valves work.

The holes in the foot valve and the piston are shown as partial annular slots; they could equally be a ring of holes.

The piston has a valve which operates in an identical manner; the construction is similar but the seal is not quite so critical since the piston is going to leak anyway.

## **PUMP STAND PIPE**

**In action, the water will rise up the stand pipe until it reaches the T piece where it will leave the pump assembly and join the general plumbing. Assuming that there are no restrictions in this plumbing, the water will flow away with no problems. If however the plumbing has a long journey through fairly narrow bore pipe, the restrictions will cause a back pressure and water will rise higher up the stand pipe.**

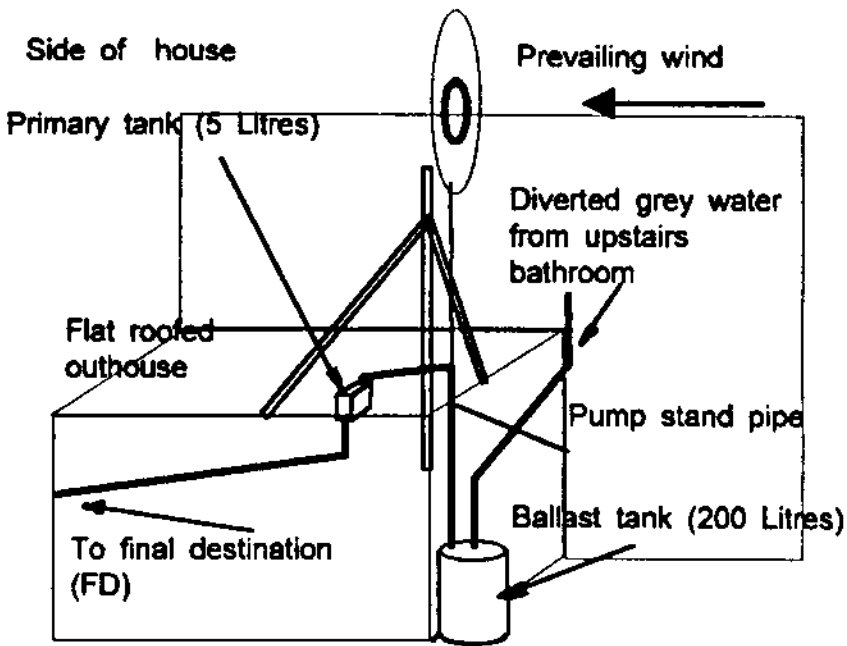
**In a large windpump the problem of back pressure is overcome by a 'gland' also known as a stuffing box, which seals the top of the stand pipe while permitting the movement of the transmission rod. Such a device would introduce too much friction on a small unit and the best way to accommodate the back pressure is to continue the stand pipe up above the T piece to a distance found by trial and error.**

**In any event, it should be apparent that using this method you cannot pump water above the height of the turbine!**

# PLUMBING

The detail of your plumbing arrangements will be peculiar to your own situation and requirements. You may need to bring grey water and rain water to a central point, you may have one source of water only, these and other considerations will be very important to your choice of layout. Most of these choices are made by common sense but one or two factors have affected my own final system where I have needed to store the water.

There are several reasons for storing water. They usually relate to the fact that the wind may not blow when you have water to pump! Or you may not want to move all the water when the wind does blow.



**Figure 21 [Turbine tower showing a plumbing arrangement],**

You may wish to reduce or delay the flow of water for many reasons like :-

1. Slow down flow through a filter.
2. Maintain an 'ornamental trickle'.
3. Save water for later.

None of the above headings actually describes what to me is the main reason for storing water.

A major source of domestic grey water is the bath tub and this supplies sudden surges of up to 15 gallons that must be drained from the bath fast but may need to be stored for a while before there is a breeze to pump it away.

I will describe a typical scenario which will illustrate the conflicting needs to be met by the system.

To collect grey water from all domestic outlets may involve quite complex arrangements. The example here simply looks at the bath tub.

The scheme as shown in **Figure 28 [A plumbing system]** may be useful.



## Building a domestic windpump

It is quite likely that the upstairs bath outlet is higher than

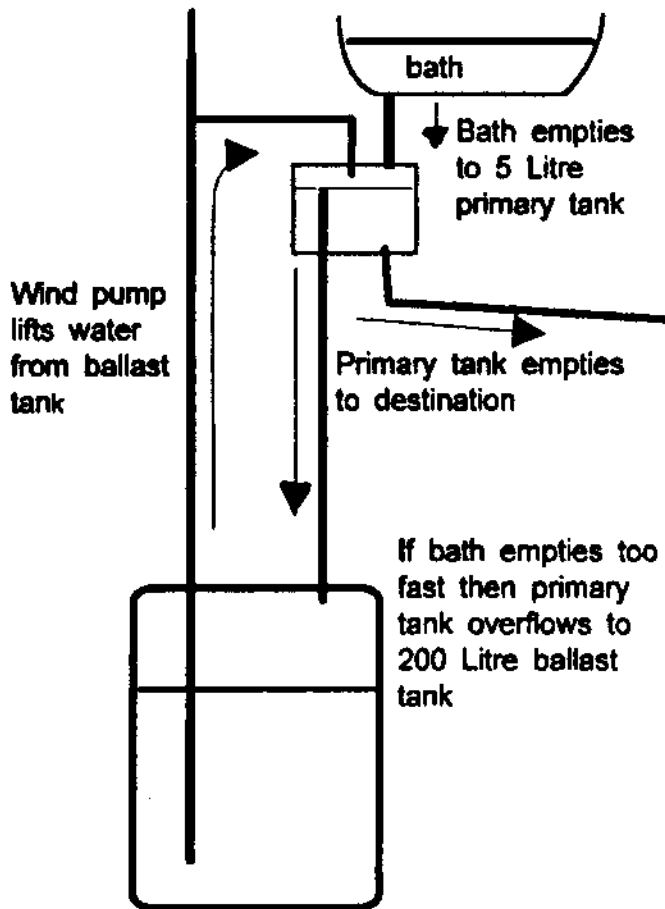


Figure 28 A plumbing layout

the final destination for the water, here the problem is to empty the bath as fast as possible but still allow gravity to get the water as near to its destination as possible. Let us suppose that the bath outlet is 3 metres above and 40 metres from the final destination (FD);

The water will flow from bath to FD quite well but to make sure that the bath empties fast, the plumbing needs to be about 50mm bore, this is expensive!

Instead, a tank could be placed close to the bath outlet and 1 metre below it and connected via a 50mm pipe. This tank would fill fast and still drain by gravity to the FD via a normal hose pipe. But can you fit a 15-30 gallon tank in such a position safely and aesthetically..? probably not.

If the tank is at ground level and is fed direct from the bath outlet, the bath will drain well even with a hose pipe since the syphon principle will take effect. Once the tank is full the windpump is essential since all the head advantage of the bath to FD has been lost.

Let's assume that with an 'average' wind blowing, your wind pump will move a certain amount of water and that the pipe work to the FD is designed and costed to allow that flow rate. On a good day, when the wind is a bit stronger, or when the wind is gusting, there will be surges of flow from the pump that the plumbing will not cope with. To accommodate these surges, I have fitted a 5 litre primary tank level with the top of the pump outlet. During short bursts of pump activity, this tank will fill briefly because the pipe to the FD will not empty the tank fast enough. The 5 litre tank is shown on the roof of the outhouse in Figure 21, Turbine tower showing plumbing arrangement.

## Building a domestic windpump

One final refinement, Figure 28 shows the small primary tank between the bath outlet and the ballast tank. In this position, the primary tank will still smooth out surges in the pump rate, but it can also divert the bath water to the FD, and because the flow is too much for the pipe to the FD to cope with, the excess water will overflow to the ballast tank. So even with no wind, some water will be diverted to the FD. This idea only works if the FD is lower than the bath outlet!

### WATER STORAGE (contamination and souring)

In the last section, a requirement for water storage was identified, however, the grey water that accumulates in the ballast tank (water butt!) may quickly go sour and smell if there is no wind and the pump is not working. Water in long runs of pipe will suffer a similar fate.

If the water is going straight to irrigation the souring of the water may not pose a problem, if however the water is ultimately going to a pond then some filtering and aeration may be required. Passing the water through a bed of shingle in which reeds are growing does take out quite a lot of the visible and aromatic contamination but this slows down the flow. If the contamination is not too severe, a reed bed 1 metre square for every member of the household should be adequate; but don't expect the water

to be always perfect after such a small filter.

You need to experiment to establish the optimum flow rate for the system to minimise the deterioration of the water being stored while at the same time, slowing the flow down to maximise cleaning by any filter system.

If the ballast tank is too large, the water will stagnate; on the other hand, a large ballast tank will have the effect of diluting the occasional large single dose of bathroom cleaner which is accidentally routed to the fish pond via the pumping system!

### MAINTENANCE

A commercial windpump would be expected to run for weeks on end with no attention at all, but, in some parts of the world, where for instance cattle are depending on the water supplied by a series of windpumps, the stockman cannot risk a water supply drying up and the pumps on a cattle station will be visited every few days, just to check all is well. There may be several pumps spread over many hundreds of square miles and the stockman may take 2 or 3 days to visit all the pumps in one round trip so the job is a bit like painting the Forth Bridge! The value of the

## Building a domestic windpump

windpump is small compared to the value of the stock that would die if the pump failed for more than a couple of days.

The small windpump described in this book is not as robust or reliable as the commercial ones described above but the circumstance of its use are also very different. You are probably going to see the system most days and will hear any odd noises it makes. If it fails, the cost will be measured more by what it falls on or the cost of repair of the windpump itself.

The parts that suffer from wear are the main turbine spindle bush, the ends of the con rod, push rod and crank and the push rod sliding in the head vertical tube. All these parts should be fairly quiet apart from a gentle 'swoosh' and 'click'; any squeaks usually mean that some oil or grease is needed. Take care to avoid letting oil reach the pump and the pumped water, especially if the water is going to a fish pond etc.

This sort of attention should be given every few weeks or when needed. Whenever the system is being examined for any reason, always check the structure of the whole machine, this means the rivets in the turbine, the tail fin, the brazing of the head and all connections and screws etc.

## FURLING

When the wind turbine is subject to wind speeds in excess of a certain maximum, a number of things can happen. In extreme cases the whole pumping system will be destroyed, garden sheds and trees along with it; under less stressful conditions the pump and turbine may be damaged through over-speeding. The normal solution to this problem is to brake or 'furl' the turbine rotor.

The idea of furling is to point the turbine out of the wind and thus reduce the cross section gathering energy from the wind. Furling mechanisms require energy to operate and so far I have not managed to find an economical way of including a viable mechanism on these small wind turbines. If the wind looks as if it is getting too high, I stall the turbine with a rope or physically remove it from the mast; it only takes me 4 minutes!

**Do *not* paint any parts of the turbine assembly. Painting simply covers up any tell-tale cracks in the structure.**

The pump is usually more accessible than the turbine and bits will wear out and fail. You can engineer the mechanism far more robustly than I have and this may pay off, but at a cost. My attitude is to keep an eye on the pump and if it breaks, fix it, otherwise leave it alone. An exception to the wait till it breaks attitude arises if you notice a slow drop in performance; it may be worth stripping the pump down to look for leaking valves or cracks in the body etc.

### **Further reading**

Reading this book may prompt more questions; I recommend one book for many of the answers :-

#### **Windpumps**

**A guide for development workers.**

**by**

**Peter Fraenkel, Roy Barlow, Frances Crick, Anthony  
Derrick and Varis Bokalders**

**Intermediate Technology Publications in association with  
the Stockholm Environment Institute 1993**

**ISBN 1 85339 126 3**

# Addendum

## Nutserts:

These handy fixtures are like a normal nut except that the normally hexagonal shape at one end is turned down to a smaller diameter circle. In use, this round section is inserted through a suitable hole in sheet metal and the round section is expanded outwards to engage with the hole in the sheet. The process of expansion is usually done by squeezing an oversize ball bearing into the bore of the round section.

A suitable nutsert for the purpose described is an M6 plated mildsteel. They may be bought from:-

Alfast Ltd, 2 Gloucester Road, Luton, Bedfordshire LU1 3XH

Telephone 0582 418498

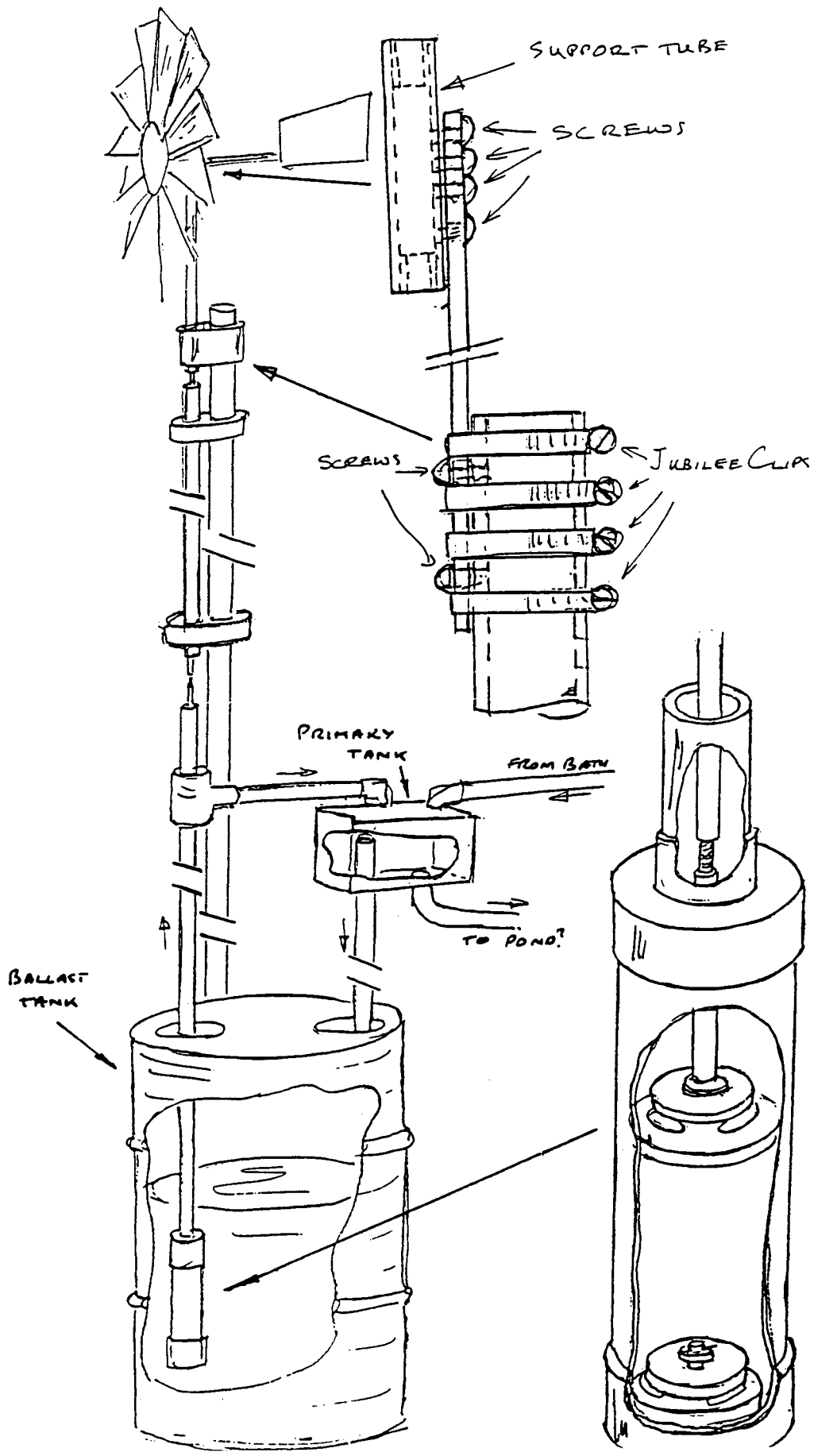
## Small-bore rigid PVC tube:

The PVC tube mentioned in the text for use as transmission rod and transmission rod sleeve may be obtained from: Wilford (Plastics) Ltd, Cosgrove Way, Luton. Tel 0582 36961.

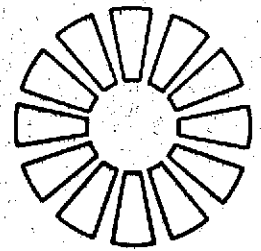
## Scaffold tower:

The 8 metre length of scaffold pole referred to in the text (page 28 para 3) needs to be made by joining two shorter lengths. (The maximum standard length is about 17 feet.) If you have access to this type of material, it is a very convenient method of construction.





# D.I.Y. PLAN 2



## WATER PUMP (20ft. HEAD)

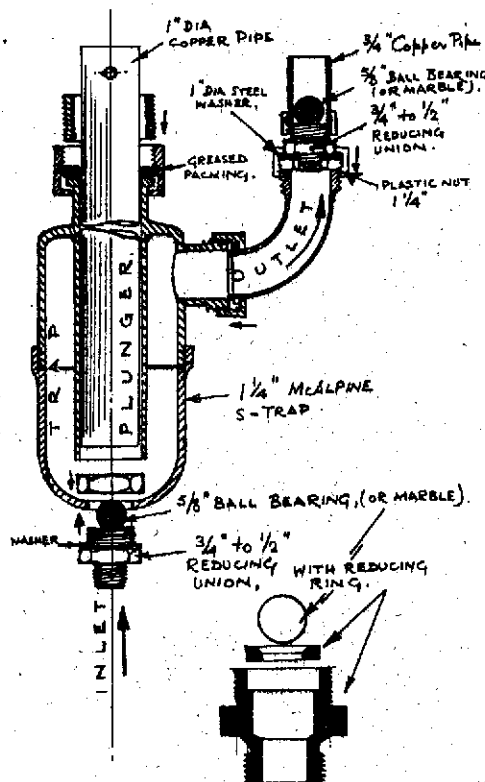
A small capacity single action force pump, capable of up to 10ft lift and about 20ft delivery. Of small (2" - 3") stroke, it was made to be used in conjunction with a Savonius Rotor; it is only suitable for hand operation if leverage is carefully considered. But it is a very simple, trouble-free and positive action pump.

### COST and MATERIALS 1976

McAlpine plastic sink bottle trap, S trap. 1 1/4"  
1 off 90° plastic bend to suit bottle trap outlet  
1 off 1" steel (or other metal) washer, to fit plastic nut  
2 off 3/4" to 1/2" brass reducing unions  
2 rings for above  
1" copper pipe x 1'0"  
2 ball bearings, 5/8" diameter, or marbles  
Total cost of all materials ..... approx. £2.25

### TOOLS

D.I.Y. a wrench: no power tools



### METHOD

A standard sink waste bottle trap is fitted with 2 non-returning valves and a plunger, to become a single acting force pump with delivery of about 1 1/2 cu. ins. per 2" stroke.

## CONVERSION

The trap is unscrewed for a ball valve to be fitted in its end. Bore a 1" hole to take a  $\frac{3}{4}$ " -  $\frac{1}{2}$ " reducing union, and fit this, with a  $\frac{3}{4}$ " ring, in place (Fig. 1). The ring has a bevel on its inner edge exactly suited to a ball of " diameter. A steel ball bearing or a marble of this size will serve.

This is the inlet valve complete.

Into the end of the 90° bend - the end with the loose nut - we fitted the outlet valve; a  $\frac{1}{2}$ " -  $\frac{3}{4}$ " reducing union will fit through a 1" steel washer; it can then be tightened with its nut to make a watertight joint. The steel washer, by chance, fitted the plastic nut on its outside diameter: so the plastic nut could be tightened to contain washer and union in a watertight unit. By placing the brass reducing ring into the  $\frac{3}{4}$ " end we had a seat for the second ball, thus completing the outlet valve (Fig. 2).

We found the neck of the bottle trap had to be filed with a half-round file to take the plunger - a foot length of 1" copper pipe (pre-metric size). It is only a ridge that has to be filed - we found the copper pipe then loosely fitted the inner pipe of the bottle trap.

The purpose of this plunger is, of course, to displace water: the watertightness being effected by a gland continued at the neck of the bottle trap, not by a tight fitting piston.

One end of the copper pipe was stopped up by the end of a piece of broom whittled down lightly and driven into it (with Araldite if you wish - the wood will swell and fit anyway).

Assemble the parts and the pump is complete. There is (we found) very little leak of water round the plunger. But there is a large nut on the neck of the trap that invites the fitting of a gland against future wear. We found a 2" piece of threaded bath outlet pipe (plastic) that matched the nut; with a round or two of greased string it provided a serviceable gland.

The inlet pipe is  $\frac{1}{2}$ " copper - or hose  
The outlet pipe is  $\frac{3}{4}$ " copper - reduce to  $\frac{1}{2}$ " copper - or hose - for cheapness and convenience.

.....

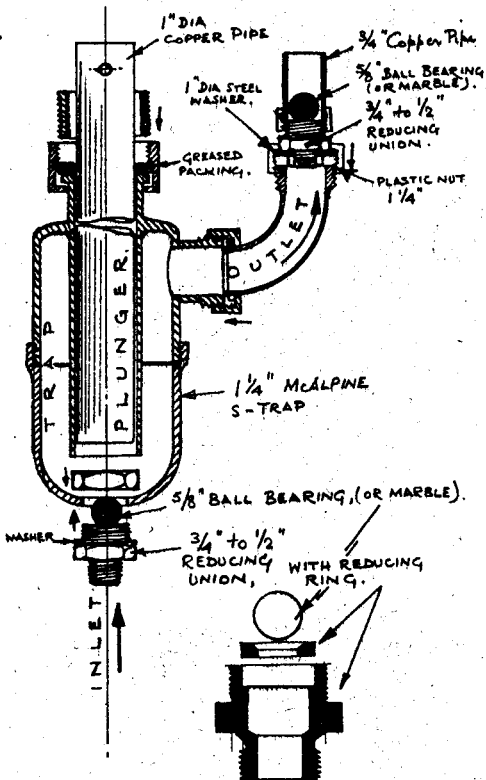
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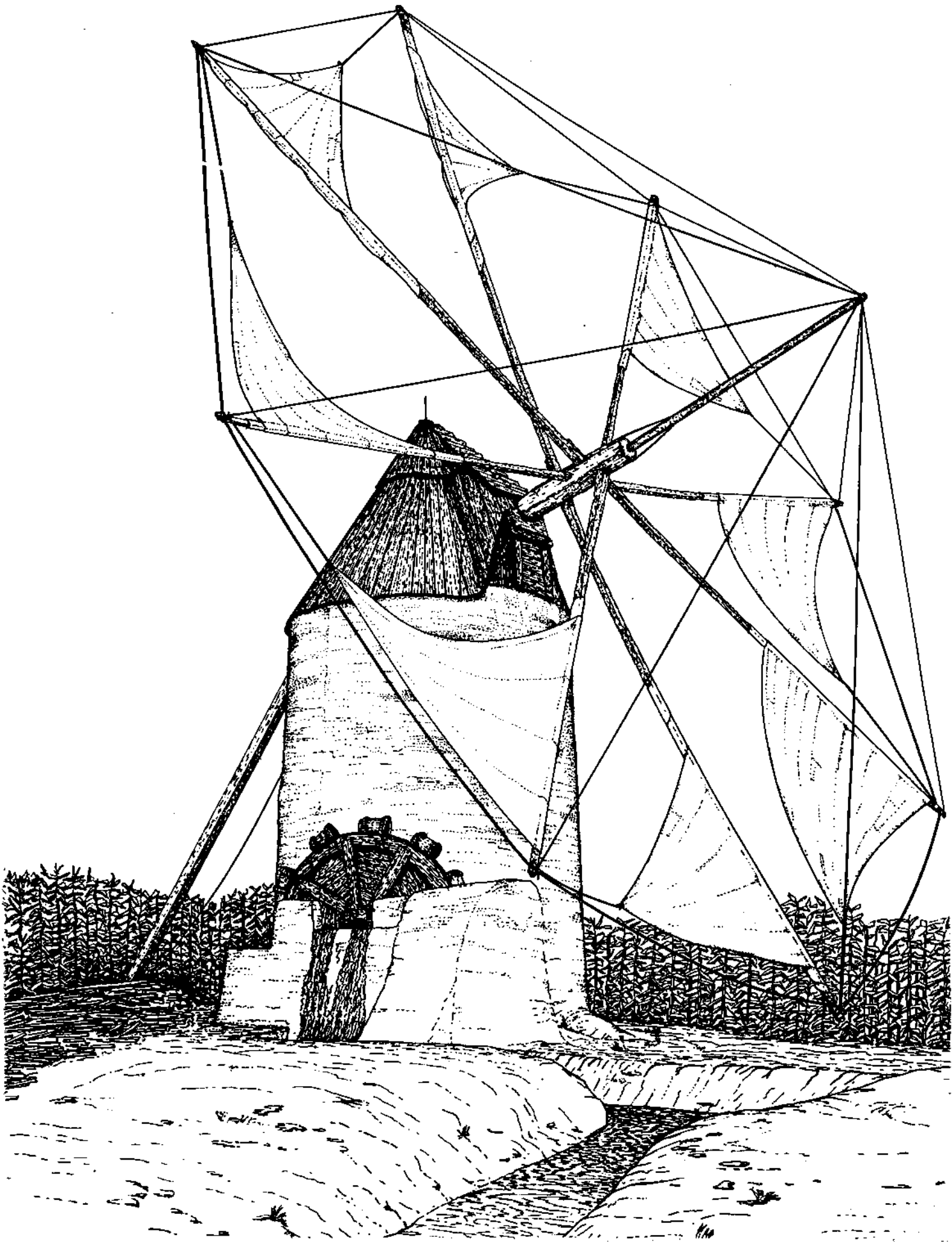
This D.I.Y. plan has been prepared for the Centre of Alternative Technology by John Eyles ©. Other D.I.Y. plans are available, including the Savonius Rotor to power this pump. For further information on the Centre, please write, enclosing a s.a.e. to:

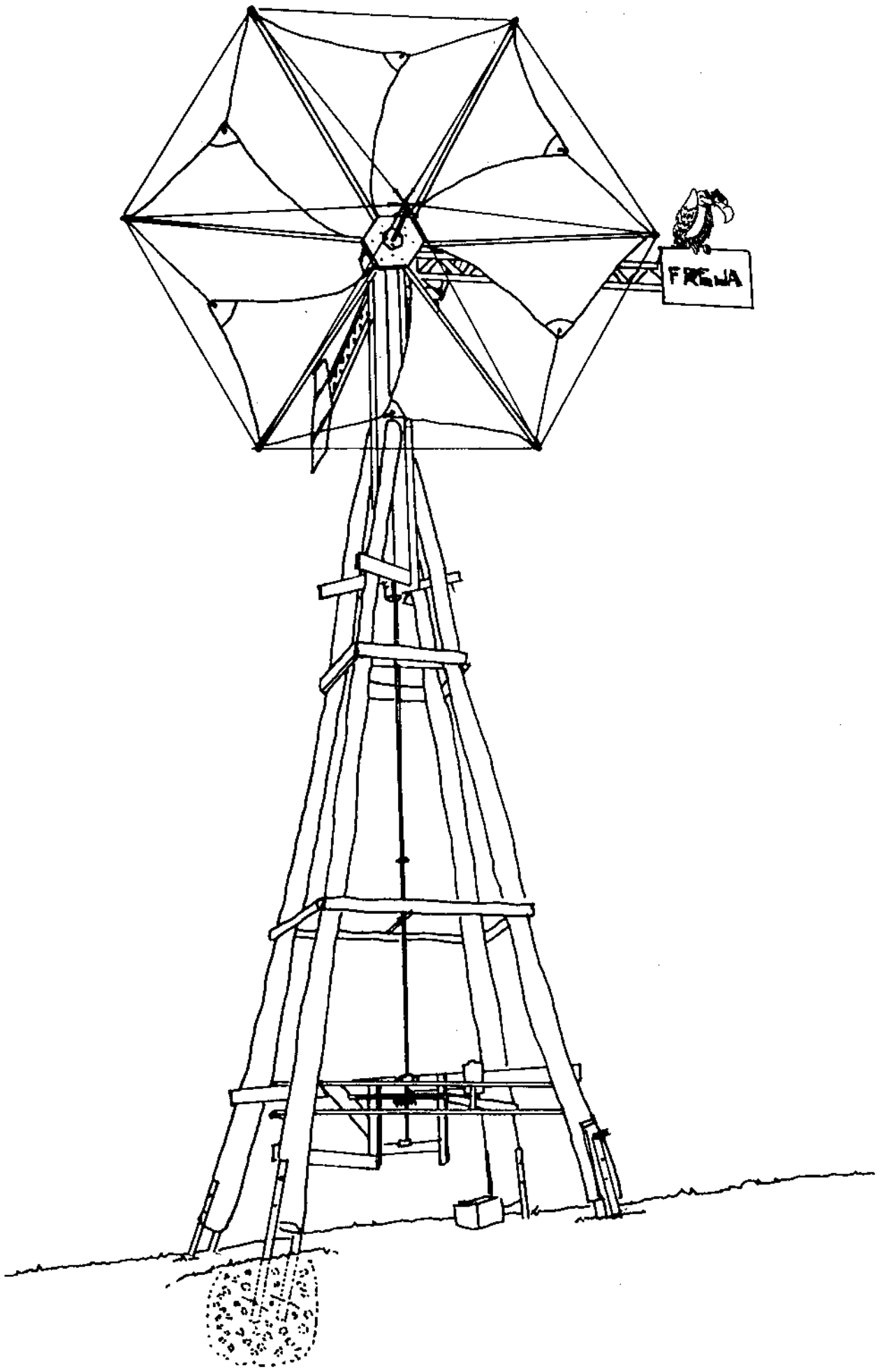
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Reprinted March 1977

Printed on 100% recycled paper

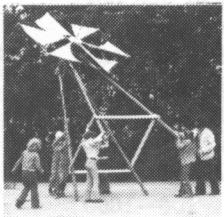
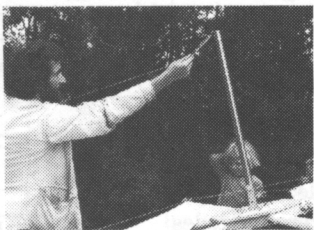
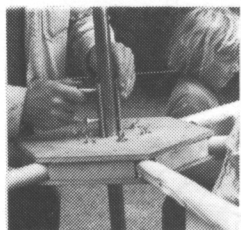
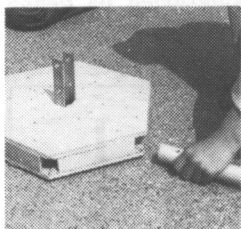
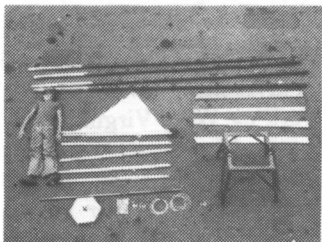


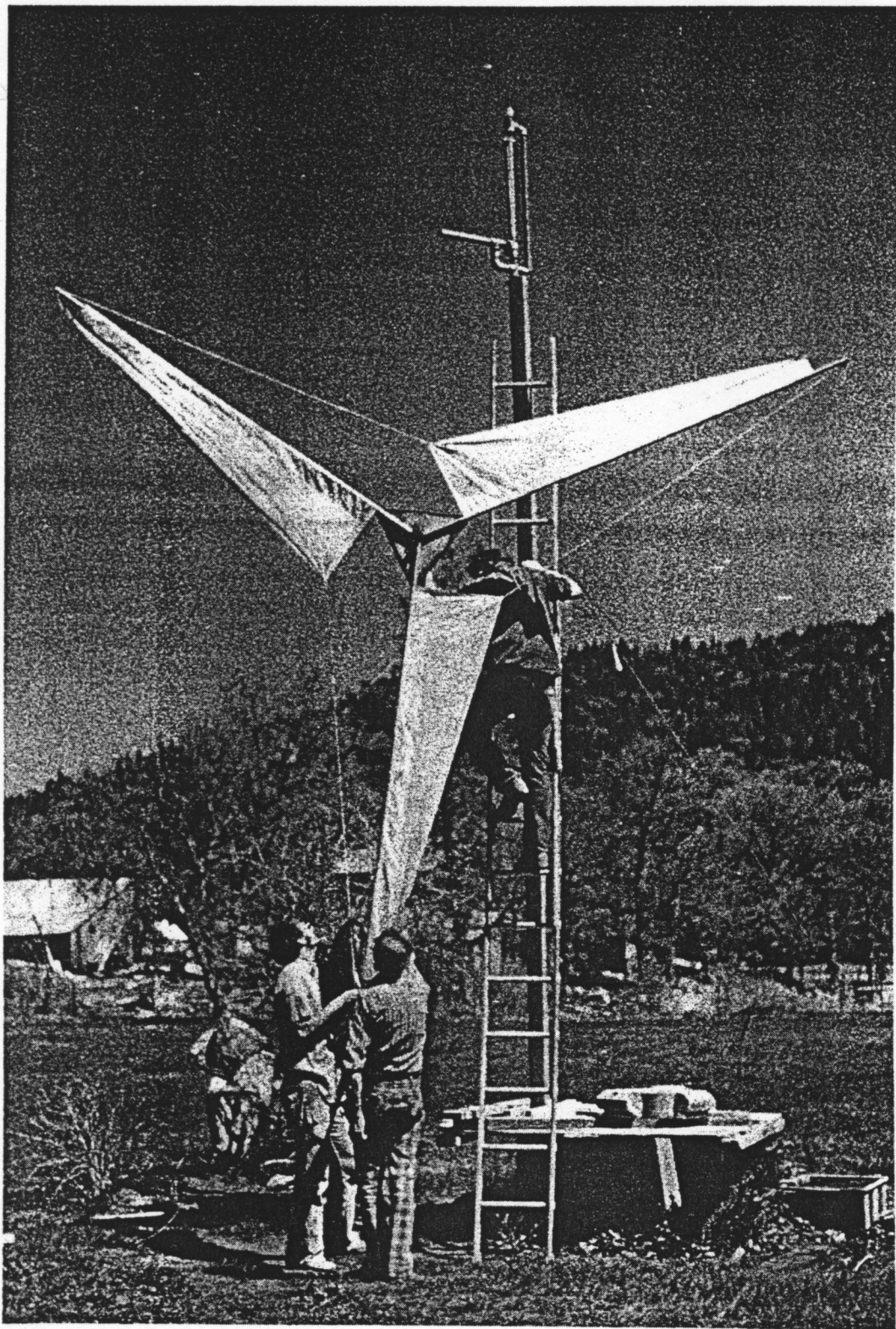




# En god begyndelse

fra Bagsværd Ny Lilleskole





Installation of a sail-wing rotor at the Park ranch in California. This 16-foot diameter rotor was eventually replaced by a larger version.



## A Sail-Wing Water-Pumper

John Welles is an inventive tinkerer who has installed a number of wind-powered water-pumping systems around Northern California. In 1977, John loaded a "sail-wing" wind machine into the back of his Volkswagen Beetle and delivered it to my ranch. We set it up in only two days.

Water is available at this site from an artesian spring close to the surface; it does not need to be raised from deep in the ground. Wind power supplies the pressure needed to transport that water along 300 feet of plastic pipe and up 2 feet of elevation to a stock-water tank used as a reservoir for a small goat dairy and a trickle irrigation system for the organic gardens at the ranch. Much of this water pressure occurs because friction forces work against water flowing swiftly through a long water pipe. This friction back-pressure is referred to as the *friction head*. The total power the wind pump must generate is based on the total height water must be lifted (in this case only a few feet), the friction head, and the rate at which the water flows.

The design of this sail-wing windmill evolved from a notion that only hardware store components and materials would be used. The entire rotor, support structure, and pump are made from iron and plastic plumbing components. The sail spars are made from electrical conduit tubing. And the "tower" is a redwood fence post with clothesline-cable guy wires.

Originally the three sails spanned a diameter of 16 feet, but they now span 20 feet. In water pumping systems, the wind rotor (blades, hub and powershaft) must start turning under wind power against a heavy load of water. Rotor design for this type of load usually calls for a fairly large total blade surface area. This is why the familiar farm water-pumper has so many blades—it needs high starting torque. The term for the ratio of blade area to frontal area is *solidity*. The more blade surface area, the more "solid" the frontal area. The sail-wing machine at my ranch has few blades—or a small blade area relative to the large frontal area of the entire three-bladed rotor. Hence, it doesn't have much starting torque; fortunately, it doesn't need much because it only lifts water a few feet. With the 16-foot diameter rotor, the machine began pumping when the windspeed reached about 10 mph. The larger diameter rotor lowered this "cut-in windspeed" to about 7 mph. More blade area means higher starting torque and a lower cut-in windspeed. Extra area can be

added by sewing wider sails or by adding more sails similar to those already installed. More blade area, however, means greater loads on the guy wires or cables that support the tower, because there is more surface area for the wind to push against.

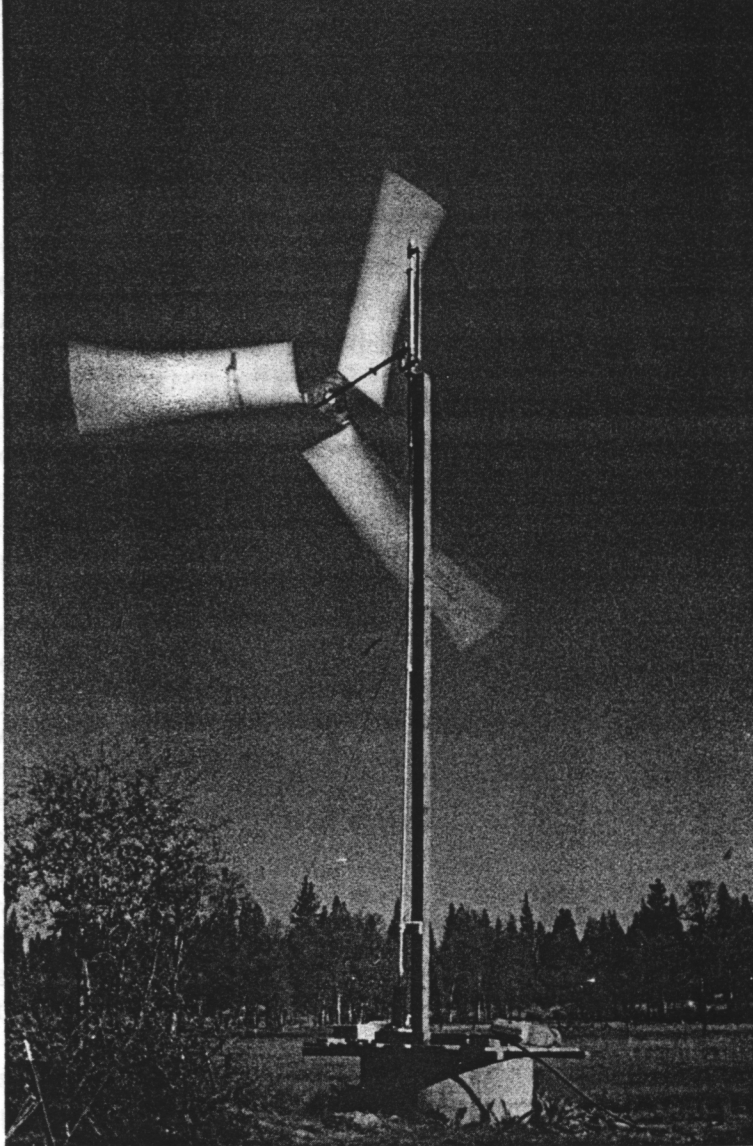
Sail shape also plays an important role in determining the ability of the wind machine to pump water. These sails billow and flap about in the wind a bit too much. It's probably impossible to achieve perfection in sail design, but government and private research programs are exploring windmill sail designs to improve performance.

The sails on the rig at my ranch are sewn from sailboat-quality dacron cloth, although canvas or other materials could be used. Dacron is lightweight and very strong. It's also one of the few fabrics that can last a few years in an extreme outdoor climate. Freezing weather and strong sunlight combine to destroy the fabric eventually, but it lasts long enough to make a sail machine worthwhile. Screendoor springs connected to the sails hold them taut for normal operation. These springs stretch under sail loads imposed by high winds, allowing the sails to "luff," or flap, out of the wind. This simple "governor" protects the sails from damage. Because the governor lessens the sail loads, tension loads in the guy wires that support the tower remain low enough during high winds that short stakes such as goat-tether stakes are adequate for tie posts.

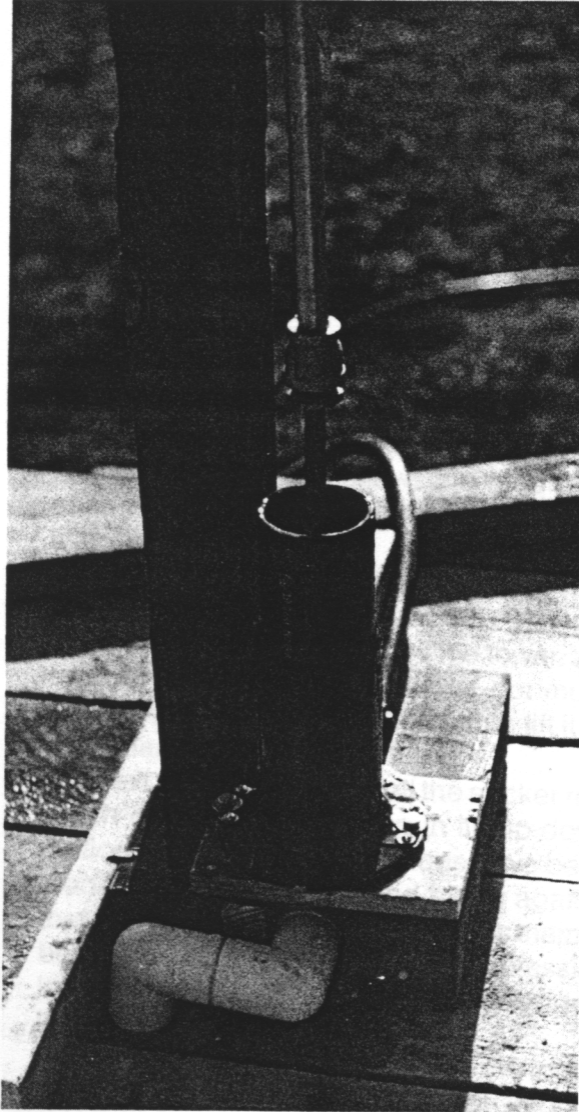
A simple crankshaft translates rotary blade motion into the up-down stroke needed to drive a water pump. This pump, a piston 3 inches in diameter with leather pump seals, is a "single-acting" pump. That is, it pumps only on the down stroke. This pump pushes water into the pipe in pulsing streams. However, peak water flow rates can be too fast for efficient operation. The faster that water flows in a pipe, the higher the friction and the resulting back-pressure against the pump. By installing a surge chamber (a simple tank with trapped air) in the water line near the pump, we created an air space where strong water pressure pulses could expand and slow down the peak flow rate. More continuous water flow resulted, and more water was pumped because of improved pump performance.

This sail-wing water-pumper has worked well for over a year, with only minor problems associated with the realities of a do-it-yourself system. For example, the 300-foot plastic water pipe was not buried at first, and whenever a horse stepped on the flexible poly-





The sail-wing machine in action, pumping water from an artesian well close to ground level.



Sucker rod and water pump used with the sail-wing. The sucker rod pushes down on leather pump seals, driving a pulsing stream of water into the plastic pipe at rear.

ethylene, a water lock was created that stopped the pump. Occasionally this occurred during high winds and broke a "sucker rod"—the long, thin tube that connects the crankshaft to the pump. Solutions included a stronger sucker rod and—finally—burying the water pipe.

Performance has been adequate. The storage tank requires about 400 gallons of pumped water per week. The wind resource at the site is minimal, about 8 mph annual average, but evening breezes of about 11 mph drive this sail machine long enough

to keep the stock full.

This sail-wing water-pumper can be readily adapted to many sites. With deeper water, however, more sail area would be required to provide the necessary starting torque. The reliability of such a machine is directly related to the amount of care you put into the project and the time you devote to solving its early problems.

Choose a design for the task. Mechanical loads like piston water-pumps, washing machines, or piston compressors usually need high starting torque. Here, a recycled multiblade water-pumper or a Savonius rotor make sense. For loads like generators that do not "kick in" until they are spinning quite fast, choose a high-speed lifting rotor such as the two- or three-bladed propellor or a Darrieus rotor.

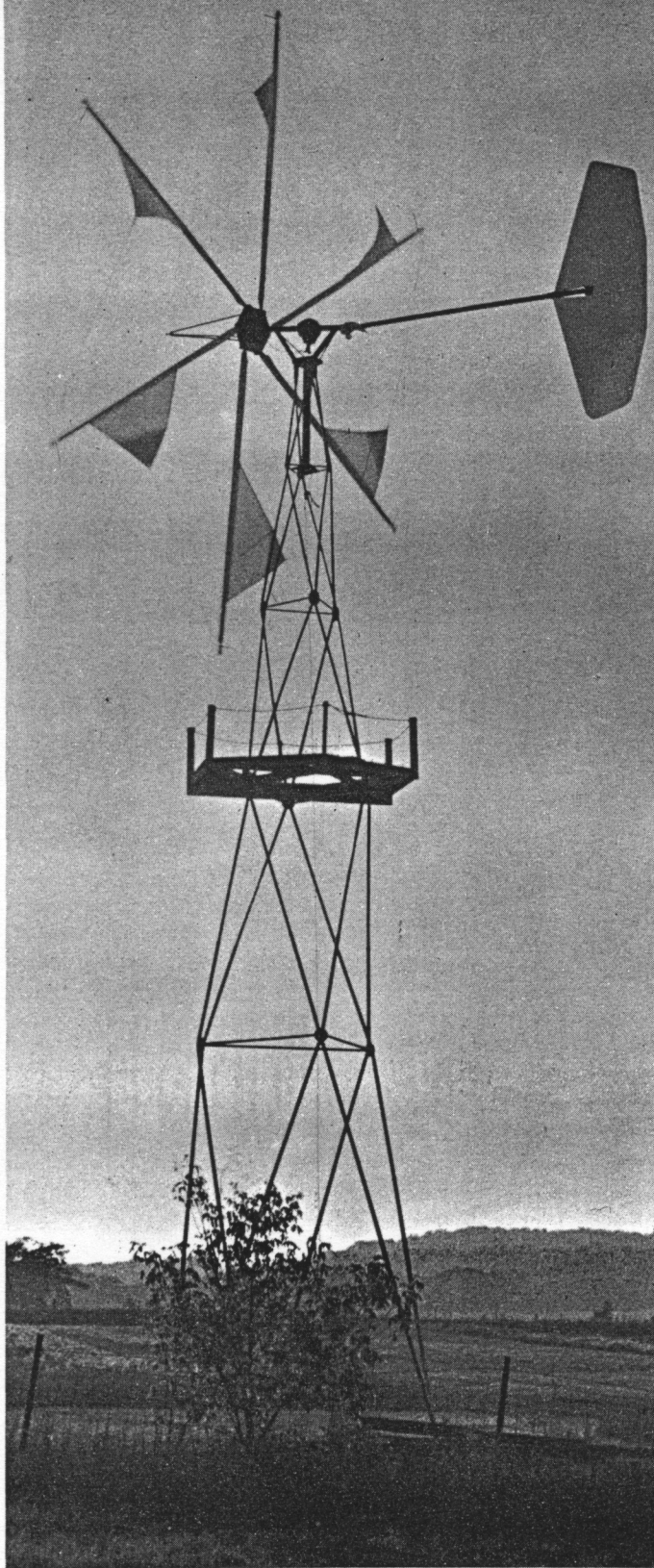
One overlapping design is the sail-wing rotor. Sew large sails and you have a high-torque, slow-turning rotor for water pumping. Sew smooth, narrow sails, and the rotor rpm increases—making electrical generation reasonable. The sail-wing rotor is also very appropriate for low-cost, low-technology systems constructed by owner-builders.

This mill, as opposed to the other two types, is slow speed, allowing much cruder construction and less demanding operating restrictions. This permissible roughness brings with it a proportionate decrease in efficiency, but this may or may not be significant. The fuel is essentially free, making the investment for a given power output relatively more important.

The sail windmills are the most suited to junk parts and home-made construction with a minimum of exotic components. Spars can be cedar saplings or laminated up with a hollow section. The hub can be wooden pillow blocks and a few pieces of metal. A differential can be used to transmit the power directly to the ground where any number of pieces of equipment can be hooked up. Sails can be home-sewn out of canvas, dacron, or cotton.

The difficulties with this type of windmill are pretty much the same as the advantages. In that it is slow speed, it is not easily adapted to electrical generation, at least not without a lot of gearing. Its slow speed results in good light wind operation and high starting torque, but then it operates at lower efficiency in all but the very lightest winds. Its efficiency in converting wind to mechanical power is about half that of the hard foils.

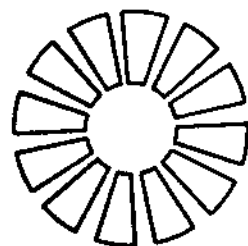
Sail windmills are self-regulating to the extent that they will accelerate until the sails start to luff. By changing the trim of the sails, the speed can be effectively regulated. This windmill though is the least automate-able. Changes in wind speed may require changes in sail trim, and heavy winds or storm conditions will require reefing.



*Windworks sail windmill, 1974. Since the photo, driveshaft to base has been added to drive buzz saw and electric generator.*

# D.I.Y. PLAN 5

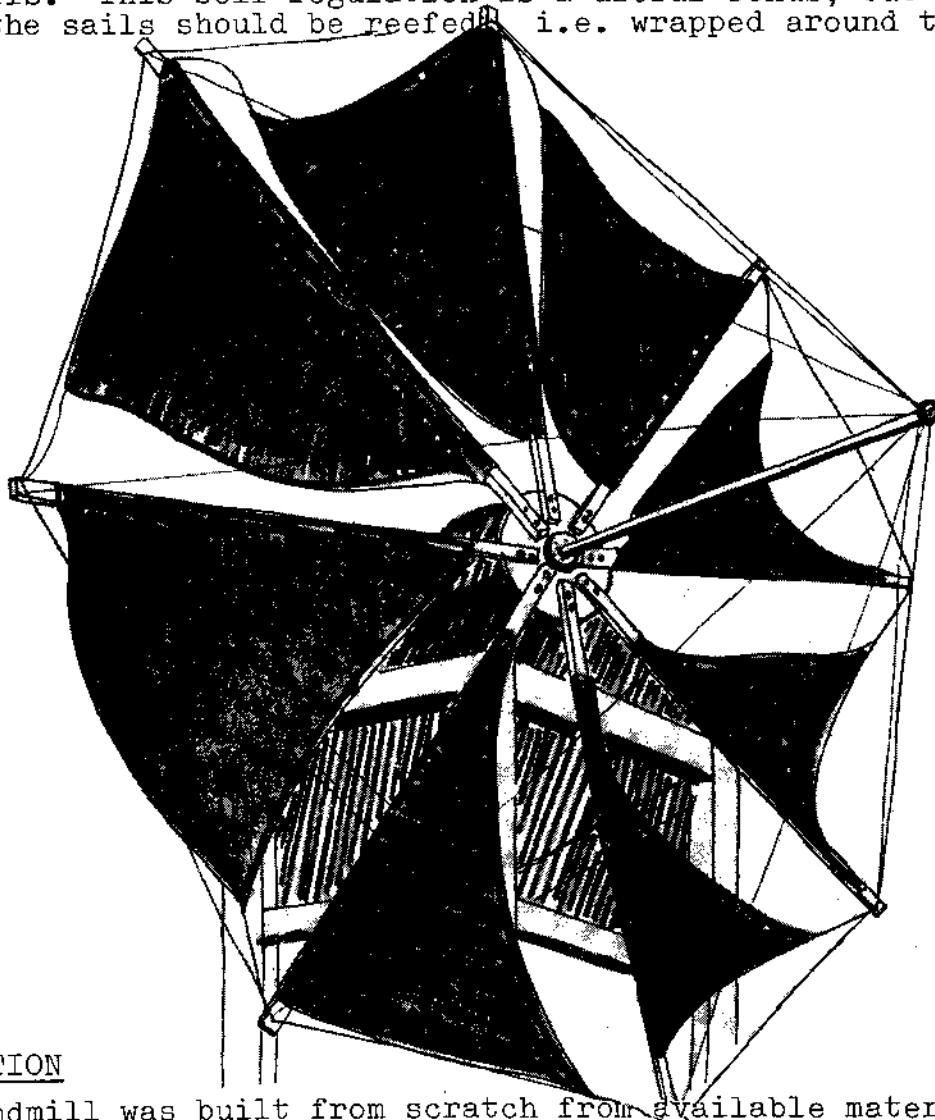
## SAIL WINDMILL (CRETAN) PART 1.



A 12ft. diameter sail windmill, useful as prime mover for lathe and grindstone, or for pumping water; with a step-up of about 1:50 it may be used for electrical generation up to 700 W.

This plan deals with the windmill as Prime Mover. Part 2 includes turntable, tail and electricity generation, and is available from the Centre.

The Cretan is a slow speed machine, tip speed to wind speed of about  $\frac{2}{3}$ :1, which has a high starting torque in winds upwards of 8mph, and in our experience, rarely exceeds 50rpm, when the wind spills from the sails. This self-regulation is a useful bonus, but in high winds the sails should be reefed, i.e. wrapped around the spars.



### ADAPTATION

The windmill was built from scratch from available material and scrap and some bought parts. It may be made in a number of ways. In Crete, chain is often used instead of rope for example, and iron spars instead of wood. We describe what we have done ourselves and would like to hear of variations others come up with.



## TOOLS

Basic D.I.Y.. We made ours without the use of a power drill, but if you have one and a  $\frac{3}{8}$ " bit, it would be useful on the tower structure.

## COST

As in other plans in this D.I.Y. series, cost depends on the ability to find materials around. This applies even more to the Cretan, which may be made from all sorts of scrap. All we can do is to give prices of new materials, in the firm belief that like us you will be able to get most of it for a fraction of the cost.

## MATERIALS - TOWER

<u>Timber</u> Sawn:	Length:	Quantity:	Price:
3" x 2"	7'6"	4	{ Approx. £10
	3'0"	8	
	5'0"	8	
6" x 1 $\frac{1}{2}$ "	3'0"	4	{ Approx. £12
	15'0"	4	
$\frac{3}{8}$ " carriage bolts	5"	34	£ 3
	6"	22	
$\frac{1}{4}$ " bolts and screws			
Iron straps 1 $\frac{1}{2}$ " x $\frac{1}{4}$ " x 2'0"		4	?

## CONSTRUCTION - Tower

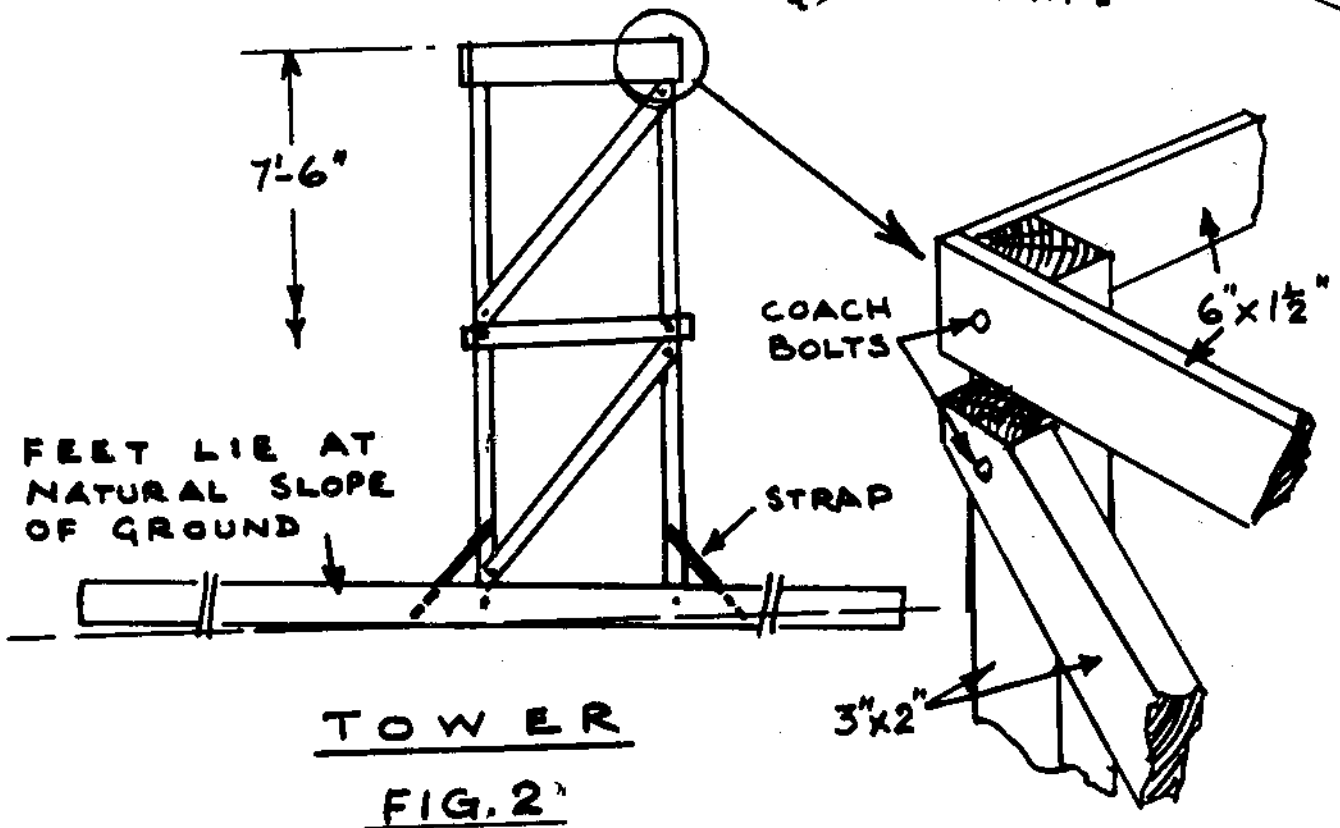
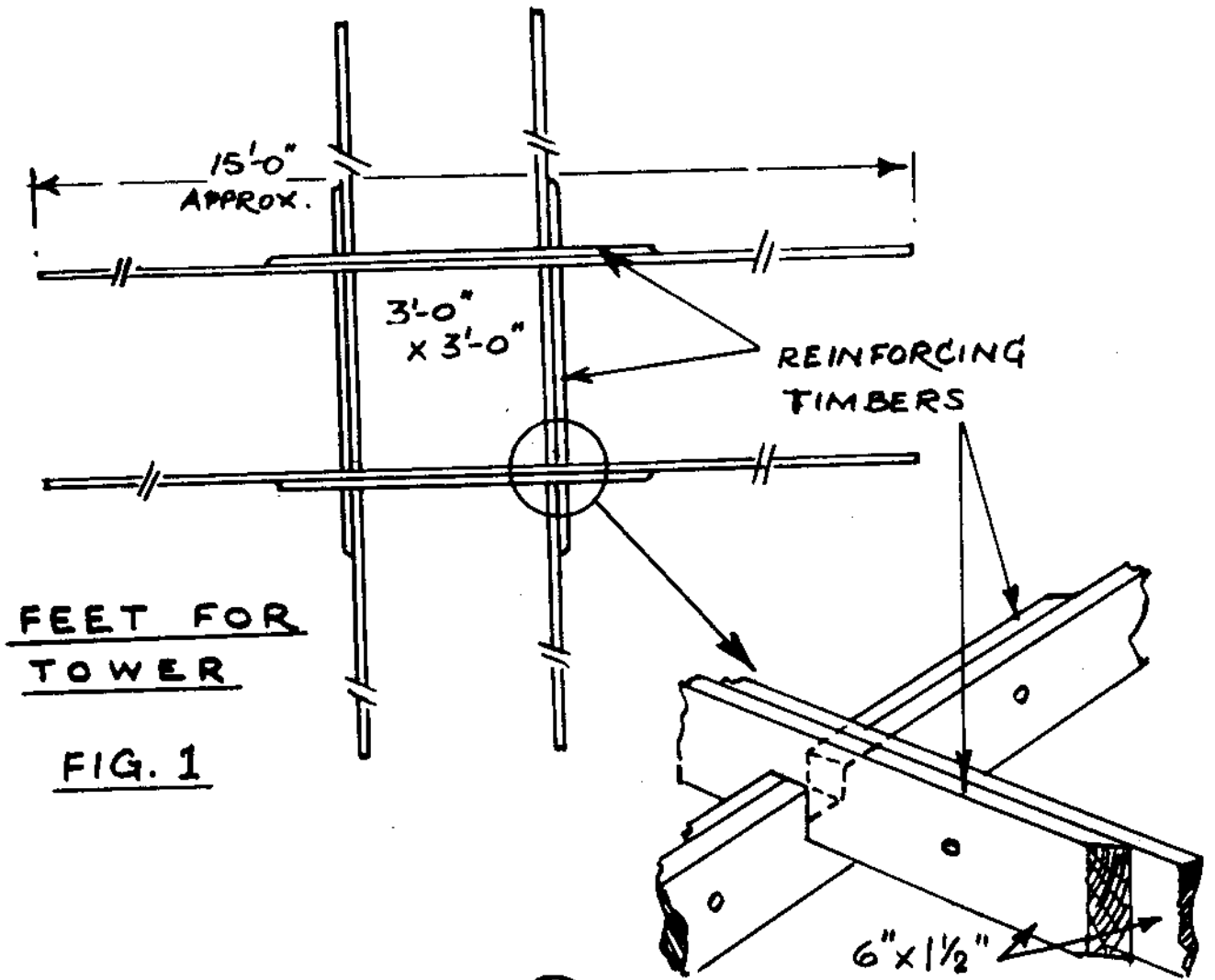
Fig.1 Because we live on the slate tip of a disused quarry, digging for concrete foundations is very difficult. We therefore mounted our tower on extended feet of 6" x 1 $\frac{1}{2}$ " timber, and weighted them down with lumps of slate. This method obviated all but approximate levelling, the feet being allowed to lie at their natural angles on the uneven ground, and the tower bolted and strapped in a vertical position to the feet. A sort of universal joint. It has withstood a couple of 70mph gales without trouble, and, in our locations, seems a satisfactory way of anchoring.

The tower itself is triangulated; 3" x 2" diagonal braces being bolted to 3" x 2" uprights, as shown, making a structure 3ft. square by 7'6" high. The merits of a low tower are that it is safer, and also - just as important - the spars are within reach for dealing with the sails. An unobstructed position for the windmill is, of course, necessary, but the large size of the rotor and its high solidity ensures some power output even in very low wind speed areas.

Fig.2 The tower (built, if possible, beside the egg-box type foundation feet) may be lifted by four people and dropped into the central square of the feet, and chocked up at the corners until it is exactly vertical.  $\frac{3}{8}$ " holes were then drilled through the feet and the bottoms of the vertical tower struts, and bolted.

Iron straps were then bolted to the feet and tower at each corner. We laid railway sleepers over the ends of the feet and weighted them down with slate.

# - CRETAN WINDMILL -



## MAINSHAFT ASSEMBLY - MATERIALS

<u>Timber Sawn</u>	Length:	Quantity:	Approx. price 1976:
3" x 2"	4'6"	2	{ £1.50
	2'0"	3	
Plummer blocks 1 $\frac{1}{4}$ " diameter		2 rigid	3.50 each
		or self-aligning	6.50 each
4" Pulley (Fenner)		1	{ 9.50
6" Pulley (Fenner)		1	
Taper lock bushes (Fenner) 1 $\frac{1}{4}$ " diam.		2	
Steel pipe 1 $\frac{1}{4}$ " O.D.	5'0"	1	3.00
Spars, ash, 2" x 1 $\frac{1}{2}$ "	6'0"	8	15.00
'Bowsprit' 1" O.D. pipe	4'6"	1	0.50
Plywood ring 1" thick, 3'0" O.D., 2'0" I.D.		1	{ 3.50
Plywood face plate 1" thick, 1'6" diameter (cut from inside of ring)		1	

## CONSTRUCTION

Fig.3 We made a cradle of sawn 3" x 2" timber on which to mount plummer blocks and shaft and brake; whatever power take-off needed; the faceplate; and the windmill spars.

The cradle should be carefully made with shallow half and half joints and bolted squarely together. The shaft and rigid plummer blocks must be mounted together to ensure the shaft turns easily, (Use shims under the bearings if necessary) or use the more expensive self-aligning bearings.

Fig.4 The spars are mounted on an 1" plywood faceplate, 1'6" diameter, and bolted to it with 2 $\times$  $\frac{3}{8}$ " bolts each. Large washers, or better still strips of metal, should be drilled and placed against the spars to lessen the bending stresses around the bolts. Each outer end of the spars is drilled with 2 $\times$  $\frac{3}{8}$ " holes, at right angles to, and just avoiding, each other.

The ply faceplate, bored 1 $\frac{1}{4}$ " diameter, to take the shaft, is mounted onto a Fenner pulley, which is drilled and bolted to it. The Fenner taper lock bush is an excellent way of fastening the pulley to the shaft.

The shaft should protrude 2" in front of the ply faceplate, and be drilled for  $\frac{1}{4}$ " bolt as cotter pin. This is to hold in place the 'bowsprit' - a 4'6" length of metal pipe - for instance, electric conduit - which will fit easily into the bore of the 1 $\frac{1}{4}$ " pipe that serves as shaft. This bowsprit, in our case, has a round metal plate screwed onto the end with 8 holes round the edge; this has caused

Fig.6 fraying of the cords: we suggest a hardwood block about 4" x 4" x 1 $\frac{1}{2}$ " thick, with the corners chamfered off and 8 holes drilled, plus a central one to fit the bowsprit. This should then be drilled and pinned with  $\frac{1}{4}$ " bolt to the sprit.

It is important to tighten all bolts well, and to locknut those on the faceplate: there is a lot of movement in high wind.

To return to the shaft and cradle: the brake on ours is from an old Morris. The drum was bolted to another Fenner pulley - 4" diameter - and a taper lock bush fastened to the shaft. The faceplate was anchored to a short length of dexion, fixed to the cradle.

Fig.3

# - CRETAN WINDMILL -

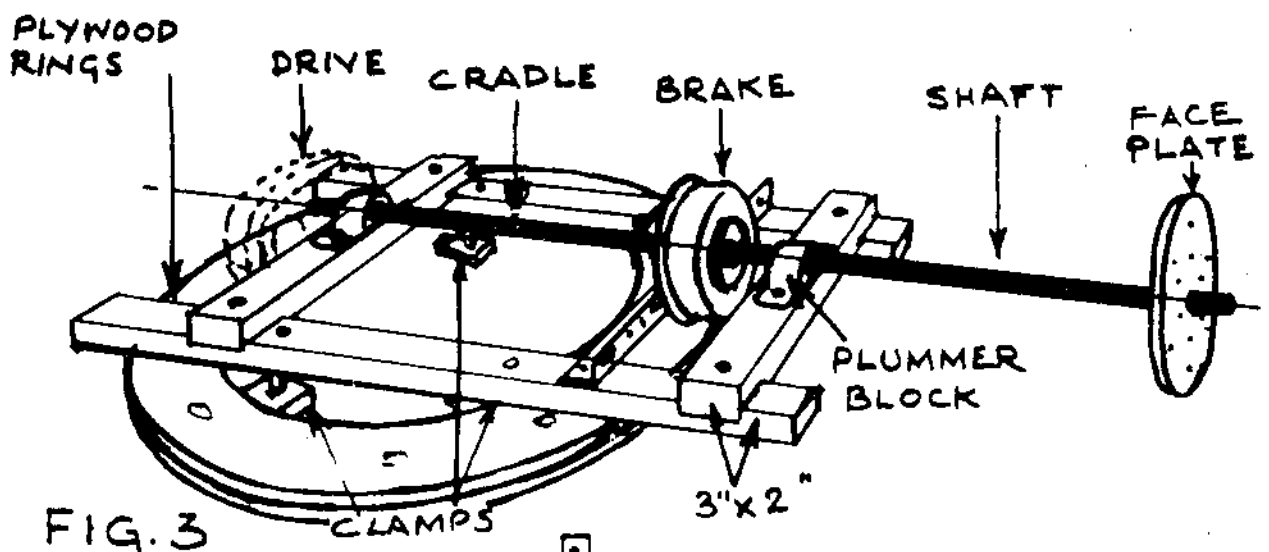


FIG. 3

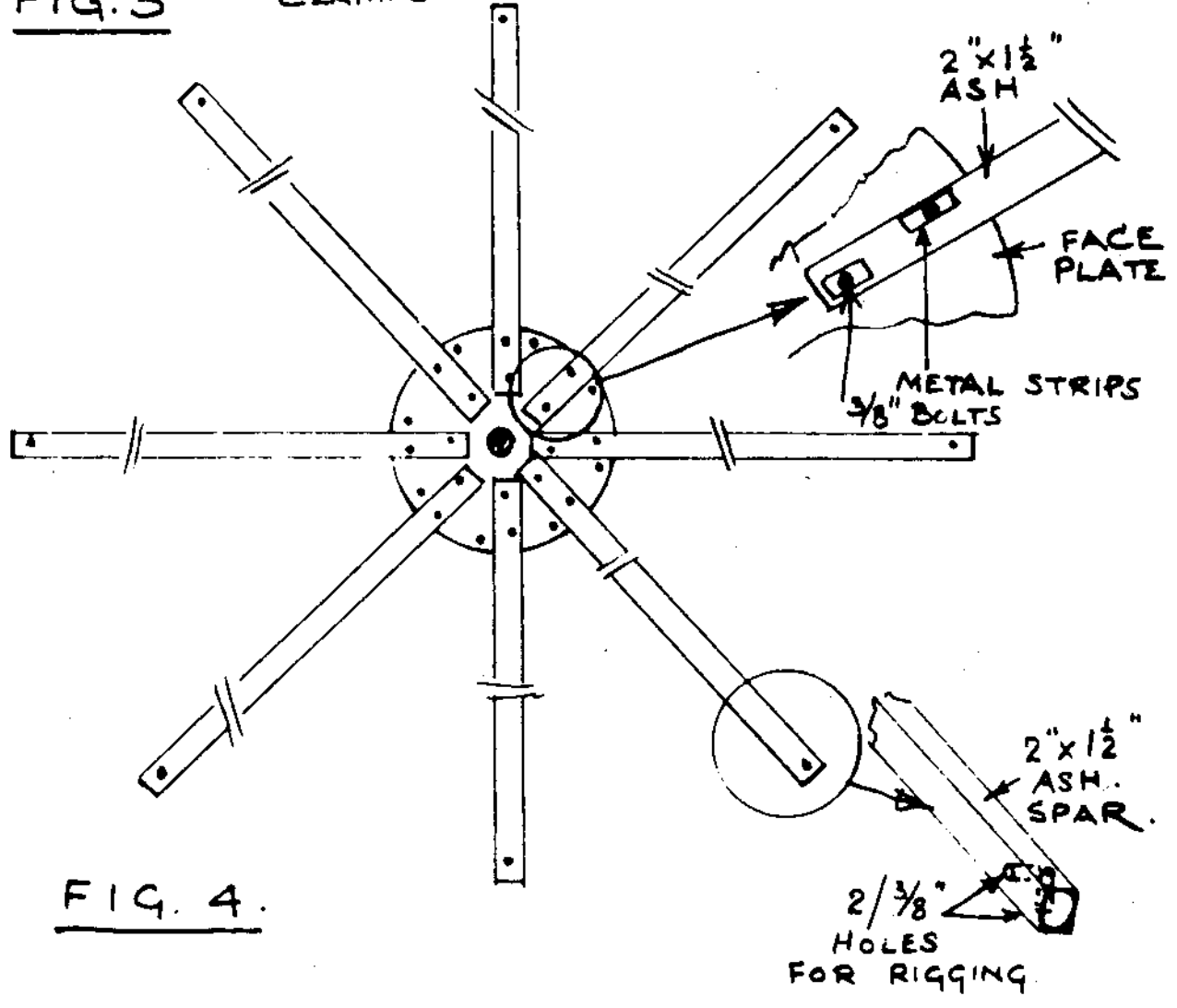


FIG. 4.

# CRETAN WINDMILL

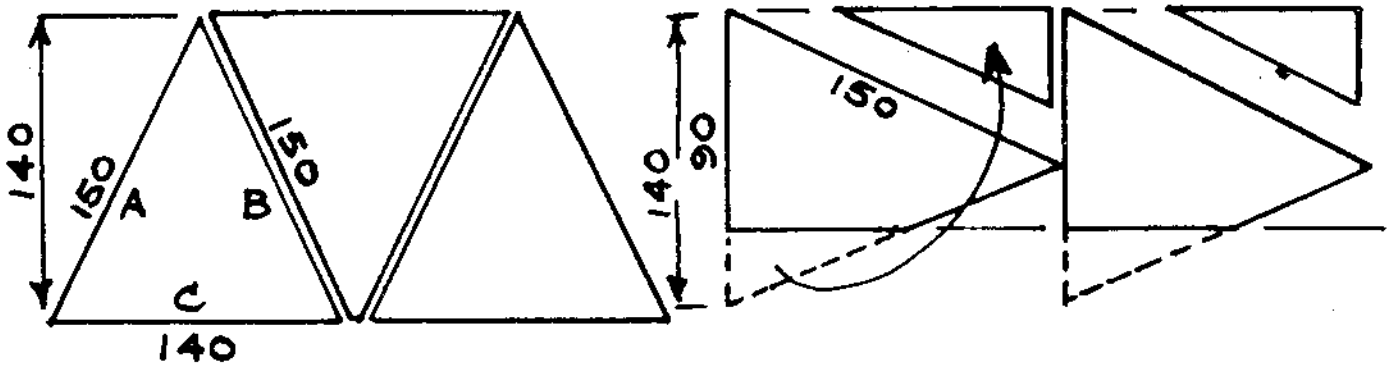


FIG. 5

SAIL PATTERN

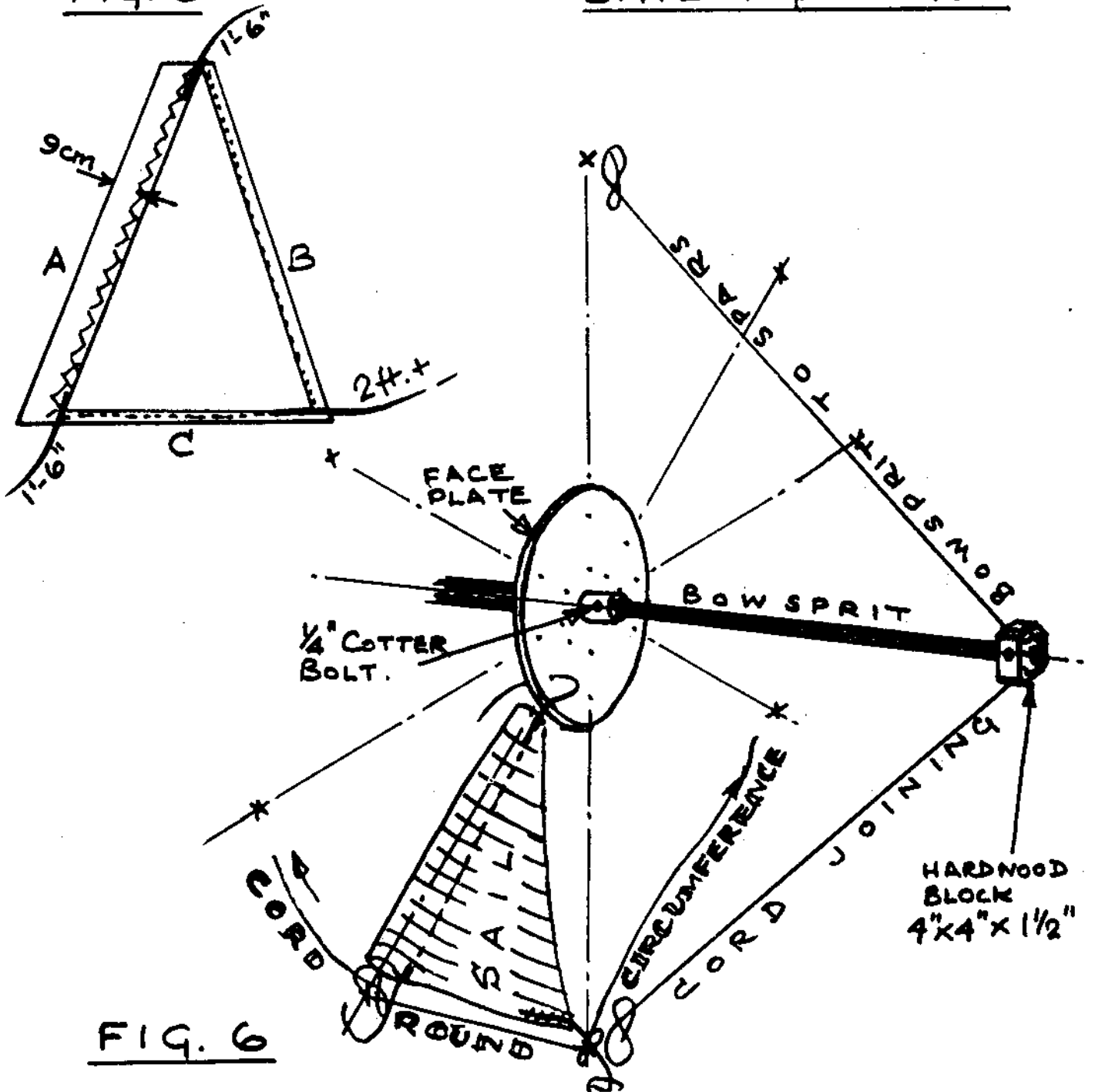


FIG. 6

This Cretan worked for 9 months without self-orientating. It took wind well from the prevailing S.W. quarter, and when the wind blew from the N. or N.E., we turned the sails into the wind by hand. However we now have a tail and turntable and D.I.Y. plan 5 part II describes how to build the tail, turntable and electricity generation.

We have a 1" thick plywood ring, 3'0" diameter outside, 2'0" diameter inside; this was screwed to the top skirt of the tower, and the cradle rested on it, as far forward as is necessary so that the spars will well clear the corners of the tower. The cradle we clamped with long 3/8" bolts and 6" pieces of 4" x 1" wood to the ring. The same bolts act to hold down the cradle and to locate it as it is rotated on the disc. This mounting method allows for power take-off down the centre of the tower.

SAILS

You will need:

6.30m of 140cm wide canvas, or  
11.20m of 1yd wide canvas, 12oz approx. Approx. £25

Fig. 5 28ft terylene cord, about 1/2" circumference  
120ft terylene cord, 3/4" circumference Total £3.70

1. Cut out 8 triangles as shown
2. Join very securely if using narrower canvas
3. Turn under 3cm hem on sides B and C, and double stitch with zig-zag if possible.
4. Turn under 10cm on side A for spar (folding in extra fabric at point X of triangle) and double stitch with zig-zag, leaving both ends open for spar. Check that spars are an easy fit.
5. Cut terylene cord into 1'6" lengths for top and bottom of sails, and 2' for the sheet lines. Sew them very firmly with through and through stitching.

RIGGING

Choose a calm day!

Measure lengths of 3/4" circumference terylene cord for bowsprit and thread them through holes in bowsprit block. Allow plenty of tie through spar ends. Slide sails over spars and tie them top and bottom - through holes in faceplate and through spar ends.

Now take single length of cord and tie end to one spar. Take it through next one on circumference and knot it on itself, then to the next and so on. Make sure the distance between each pair of spars is the same, and that they are still the same when cord is pulled tight and knotted.

Next take the bowsprit cords and tie them in pairs to opposite pairs of spars. Turn the spars and make sure the bowsprit end doesn't wave about too much. Tie each sheet line through the neighbouring spar. Wait for wind .....

Many refinements will occur to you - wooden sliding guys, as on tent guy ropes may be used to adjust the sheet; a snag is that these work their way along the cord, allowing the sheet to billow, and even (as happened to ours) to tear on the tower.

A better method of fastening the sails should be devised to facilitate sail replacement.

## ELECTRICITY GENERATION (introduction)

The low tip speed ratio 0.75 calls for a high speed ratio drive to the alternator, which has a cutting-in speed of 1,050rpm.

In order to achieve a cutting-in wind speed of 9mph, a 1:55 ratio is required. This is provided by a 1:20 industrial gearbox (Fenner: size B.20, shaft mounted, £85. 1977) and a 1:2.75 belt drive. Starting in low winds is no problem due to the high stall torque of this type of rotor.

A standard marine alternator type AC5, 24 volt 33 amp (Lucas) is used; this feeds central 24 volt lead acid storage batteries of 20 kWh capacity. The maximum power output of 700 Watts is reached at approximately 22mph wind speed.

A vee belt or a timing belt may be used for this alternator drive. The vee belt has the advantages of slipping under shock loads, thus relieving stresses on the rest of the system, and of being cheaper. The timing belt offers better efficiency at low wind speeds. We are using a single Fenner SPZ, V-belt at present, with good results.

The rotor is turned into the wind either manually, or in areas of constantly varying wind direction like ours, a tail vane is used with slip rings, or alternative electrical connections. Details of this are included in D.I.Y. Cretan plan, part II.

We are very grateful to Dr. N.G. Calvert of the Department of Mechanical Engineering, Liverpool University, for supplying some of the components and giving much useful advice.

Canvas for the sails may be obtained from Russell and Chapple Ltd., 23, Monmouth Street, London WC2H 9DE, 01.836.7521. They will also make the sails.

This D.I.Y. plan has been prepared for the Centre by John Eyles ©

The information contained in this leaflet has been given in good faith and is believed to be accurate at the time of printing. However, both the author and the National Centre for Alternative Technology decline all responsibility for errors and omissions.

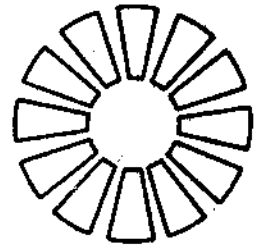
Other D.I.Y. plans, information sheets and books are available from the 'Quarry Bookshop' at the Centre. Please enclose a s.a.e. with any correspondence as we are a charity. Visitors are welcome.

Centre for Alternative Technology, Machynlleth, Powys, Wales  
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November 1975  
Reprinted April 1977 with Part II.

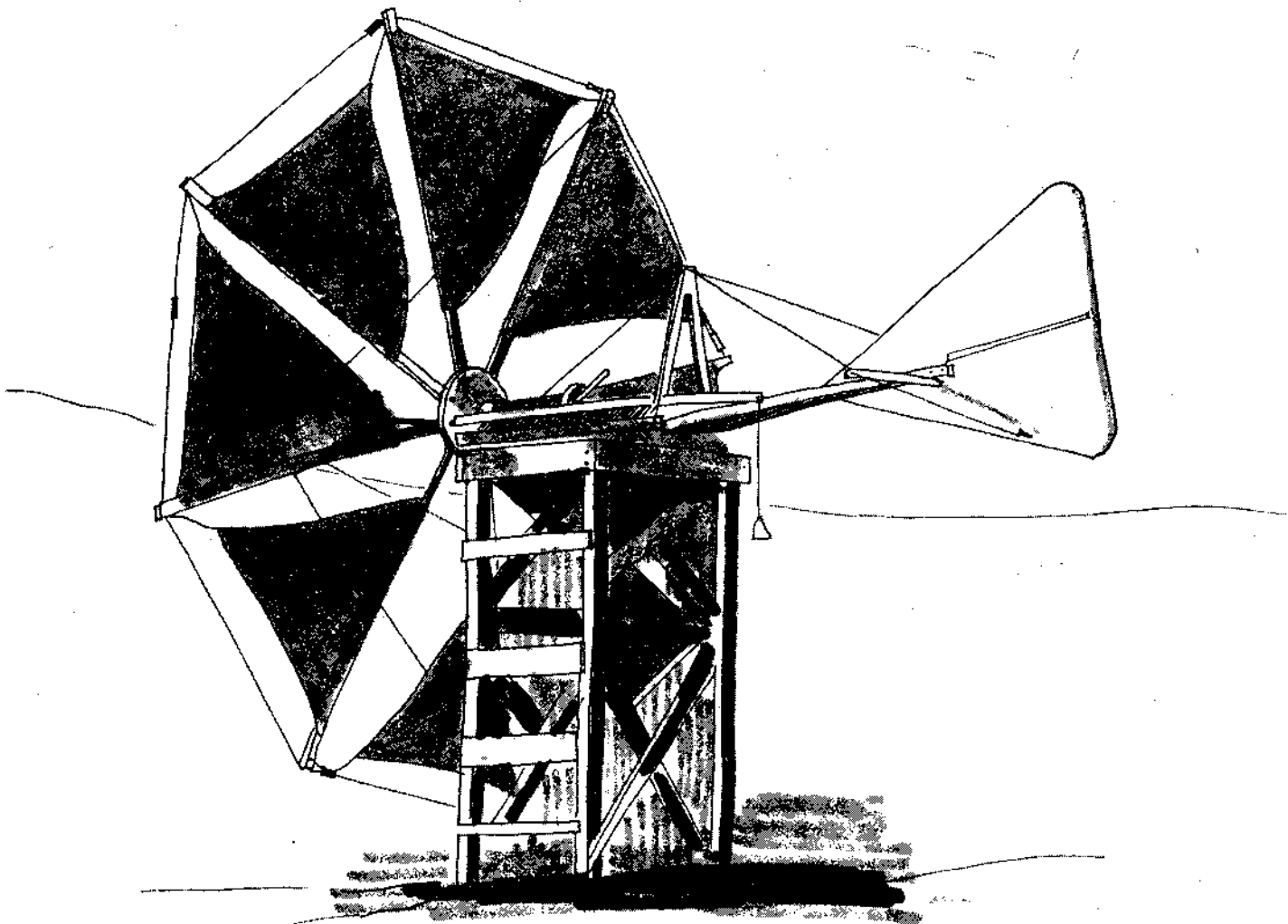
# D.I.Y. PLAN 5

## SAIL WINDMILL (CRETAN) PART 2.



### PURPOSE:

The Cretan Sail Windmill described in its basic form as prime mover (DIY No 5 Part I) was in due course coupled to an alternator for generating electricity of maximum output of about 700 watts. The following is an account of our experience.



### Gearbox

Dr G. Calvert of Liverpool University gave us an industrial gearbox of 20:1 reduction which was coupled back-to-front onto our main  $1\frac{3}{4}$ " dia mill shaft, overhung beyond its bearing by about 8" to receive it. (DIY 5 Part I). The gearbox had a lug and single anchor link which obviated the need to line it up, the only points to watch being that the output shaft was sufficiently clear of the carriage timbers to take an 8" pulley; and to fasten the anchor link on the tension side.



In the first experiments we made, with a vehicle dynamo, we were cautious of using more than a 40:1 step up ratio, largely on the grounds that the low speed torque at the dynamo magnified 40 times at the main shaft, would impede starting and make the cutting-in windspeed (when generation commences) unduly high.

We need not have worried: the Cretan has been working for nearly a year with a step up of 1:60 between main shaft and generator. At a mere 16 rpm of the sails - which takes place in a very light wind - we already had the generator turning at 960 rpm - about cutting-in speed.

The alternator we used is a CAV (Lucas) type AC5 marine alternator with built in rectifier, delivering 30 amps at 24V d.c. at 2,200 rpm. In areas of relatively low average windspeed, say less than 10 mph, it would be better to use a smaller alternator, perhaps with a slightly higher gear ratio to reduce the cutting-in speed. The loss in maximum power in rare high winds will be more than compensated by better operation at low wind speeds. The power is used for charging batteries. A large cross-section cable is needed to avoid excessive voltage drop between alternator and battery - for a 50 metre run, 10mm<sup>2</sup> cross section is suitable (at 24V). Required cross section increases proportional to length.

For the final drive from gearbox to alternator we settled for Fenner toothed timing pulleys and toothed belt to give a 1:3 increase, an overall step up of 1:60. With the high belt speed involved of around 1,300 ft/min at 2,000 rpm at the alternator pulley of approx. 2½" dia, we thought this a good solution. The friction losses involved with a normal vee belt would, we know, be very significant in light winds. However, due to shock loads caused by momentary breaks in the electrical circuit at the experimental slip ring unit, we broke several belts. We therefore reluctantly had to return to a vee belt with its lower efficiency. As we hoped, its slip cushions the snatch and we have had no more trouble. It must be remembered that this snatch travels through the whole system, and if the toothed belt was stronger - or two were used, for example, side by side, - then something else would be overstressed: the spar face plate bolts for instance, or the main shaft key, could shear. We were lucky, the slip ring device for transferring power from the rotating head was adopted after experiments with direct cable connection. In theory cables will only rarely be twisted more than once or twice in the same direction consecutively, but, we found in our wind conditions, the cable twisted seriously and broke. We have recently removed our slip ring assembly and reverted to direct cable connection but with the addition of the device shown in fig. 4. A weight, running in a length of plastic drainpipe, acts via a rope and pulley system on the turntable wheel thus turning the head back to the same position each time the wind drops. Allow enough cable and rope for a couple of turns in each direction. This method is working well.

TURNTABLE AND TAIL: A car back axle casing and half shaft, or large ball races set on the cradle, and rolling around the circular ring on the tower were both considered for the turntable but a storm that felled a tree across one of our caravans gave us the ideal thing - the axle and wheel unit that we salvaged from the wreckage. We cut through the solid steel 1½" x 1½" axle near one end, giving a long rigid support and wheel bearing unit, which, with tyre removed, provided an excellent turntable on which to bolt the windmill head (or cradle). First, however, we had to make the tail, so that we would know a bit more about the weight to be supported and balanced.

THE TAIL: What shape and size? Ours was guesswork informed by a year's acquaintance with the vagaries of wind and windmill alike. It is probably too big.

# CRETAN WINDMILL - THE GENERATOR & GEARBOX

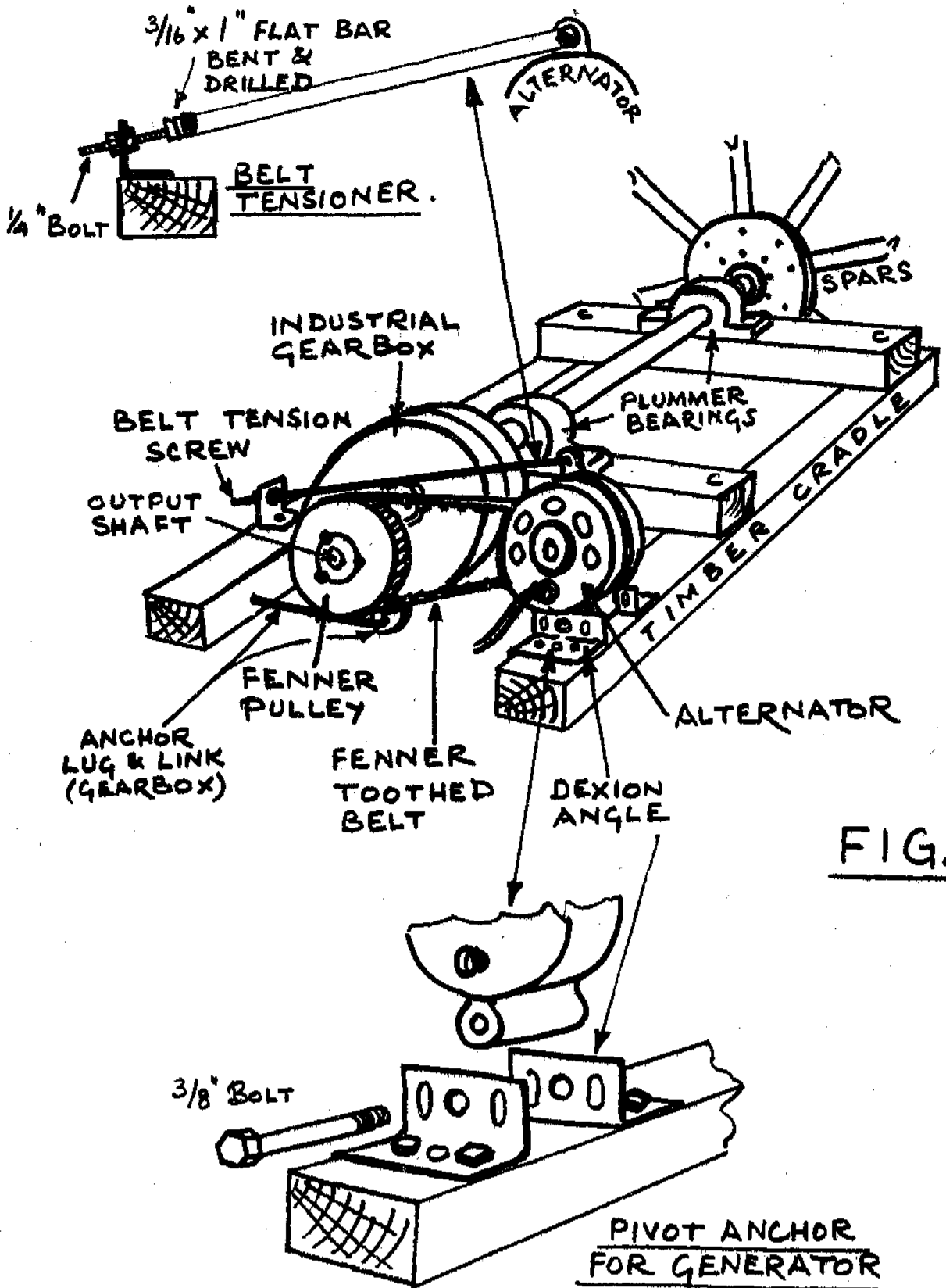
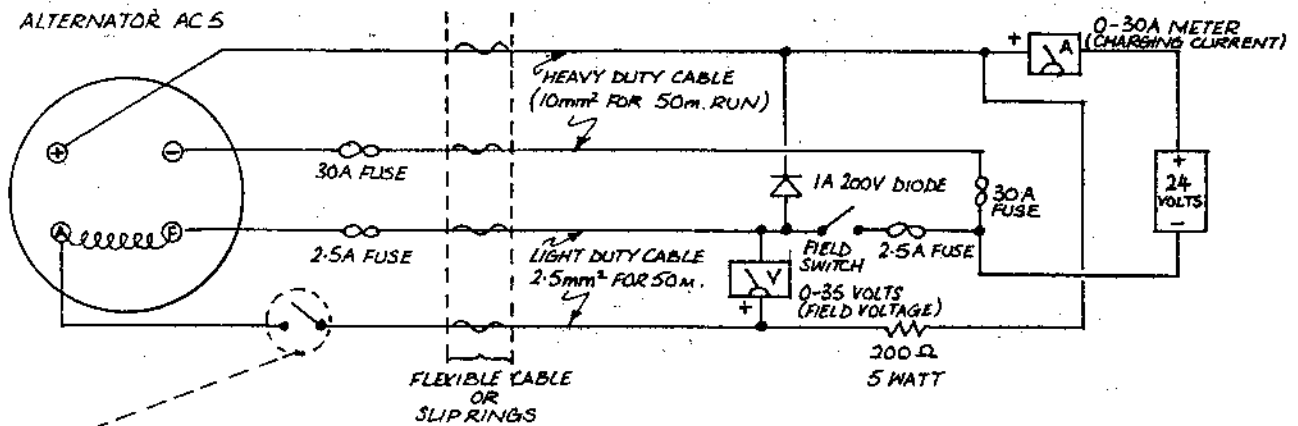


FIG. 1



OPTIONAL WIND PRESSURE SWITCH TO AVOID SLIGHT BATTERY DRAIN DUE TO FIELD CURRENT IN VERY LOW WINDS. CONTACTS ARRANGED TO CLOSE WHEN WIND EXCEEDS ABOUT 7 MPH.

- NO VOLTAGE CONTROL IS PROVIDED - TURN OFF MANUALLY WHEN BATTERY FULLY CHARGED.
- CHARGING CURRENT IS SELF LIMITING.
- FIELD VOLTAGE METER RISES AT LOW WIND SPEEDS REACHING ABOUT 24 VOLTS AT CUTTING IN SPEED & THEN RISING MORE SLOWLY TO A MAX. OF 33 VOLTS AS CHARGING CURRENT INCREASES.

CIRCUIT DIAGRAM.

Too small a tail could allow the canvas sails to override it, a gust might easily, we thought, sweep the head round tail to the wind, when the spars would certainly snap. Too large a tail, and the head would follow each tiny change of wind direction like a demented weather cock, imposing undue stress on the rotor.

The size and shape of tail we settled on was an isosceles triangle of 5'9" sides and 4'0" base, made from  $\frac{1}{2}$ " exterior ply, well primed with aluminium paint. Figure 2 shows the method of triangulation used to sling the tail out in an effective position. The length of boom or strut seems uncritical - ours is about 9'0". The criterion is achieving some balance of tail weight with that of the spars and sails (with gear box and generator between) to avoid undue stress on the turntable bearing.

Two lengths of 3"x1" pine were bolted ( $\frac{1}{4}$ " bolts) one either side of the triangular tail, centrally through one apex (1). A 3"x1" hole was made through the tail immediately beneath them, about  $1\frac{1}{2}$  ft from the back edge of the tail, to receive the cross brace (2). This was centred and screwed to the pieces of 3"x1" to keep it in place while working. It should be noted that the rigidity of the whole tail structure depends entirely on a successful system of triangulation, and not on individual joints.

The struts (3) were bolted at one end to the tail as shown, constrained in a shallow curve to be screwed with  $\frac{3}{8}$ " coach screws (or bolted) to the insides of the cradle timbers. They are pivoted there, and should be left thus to allow for movement - stretch of the wire, warping of the timber, hammering by the wind. The stretcher (4) is a simple method we used to keep the struts constrained to their curve. The heads of the bolts, on tightening, bed themselves into the wood and thus stay put.

Two short pieces of 3" x 1" are drilled alike to take  $3\frac{1}{4}$ " bolts (5) and these are used to clamp members (1) and (3) together. It will be seen that drilling the struts would seriously weaken them: further, clamping ensures that slight freedom of movement necessary to working structures exposed to the elements.

The shear legs (6) may be fixed in any of several ways: we screwed ours with  $\frac{5}{16}$ " coach screws into the end grain of the cradle, and gave them extra support with two steel brackets. The metal plates at the apex we cut from an oil drum, and bolted with  $\frac{1}{4}$ " bolts to the shear legs. The  $\frac{3}{8}$ " tube may be a bit of gas pipe - its function is to prevent the steel wire from chaffing.

# CRETAN WINDMILL — THE TAIL

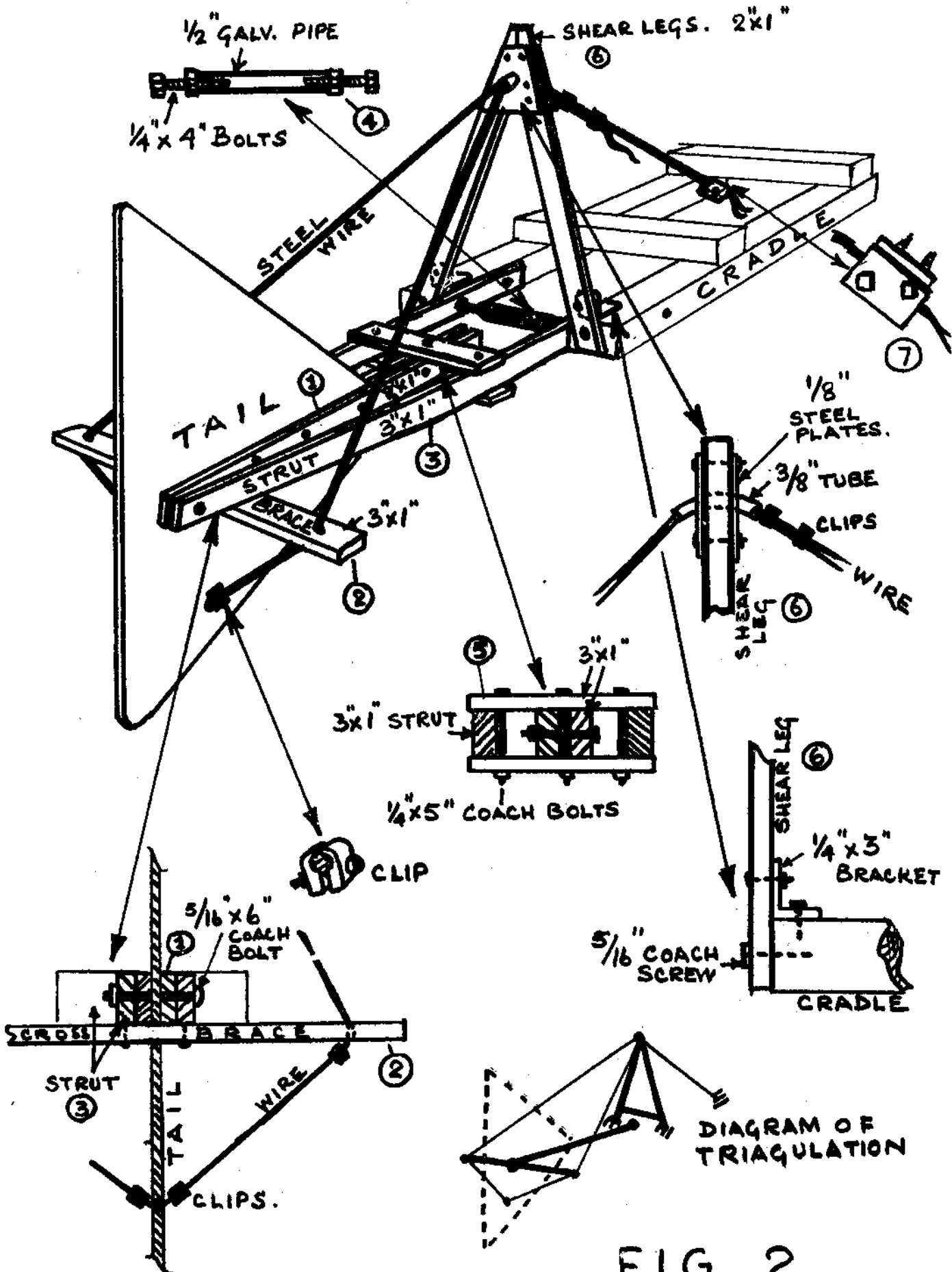


FIG. 2

The wire we used to complete the triangulation was ex-P.O. twisted, fairly high tensile, wire as used to tie telephone poles to ground stakes. The clips came from the same source. The wire, in one length, and starting from an anchor point at the further end of the cradle, was threaded in turn through the tube in the shear leg apex; a hole in one end of the crossbrace; the tail; the further end of the crossbrace; back through the shear leg tube and either clipped to the first length of wire, or anchored with it to the cradle by means of two steel plates and  $\frac{1}{4}$ " coach screws (7).

Care should be taken to get rid of all kinks and bends in the wire, and to have neat sharp turns at each point. This took us some time, ensuring the tail was inclined slightly upward to allow for subsequent droop, and working the wire through each hole until we were satisfied it was taut.

It will be seen how important it is to leave the inner end of the boom "pivoted", and not to be tempted to add further screws: the maximum moment occurs here, and the slightest drop of the tail would either wrench the screws or more likely split the booms. The tail thus described has weathered severe storms. Perhaps it could be smaller in area, otherwise it has proved satisfactory. Everything was well painted with aluminium primer.

#### MATERIALS:

2" x 1" pine approx. 6'	$\frac{1}{4}$ " bolts - 3 x 5"
3" x 1" pine approx. 20'	4 x 3"
$\frac{1}{2}$ " ext. ply approx. 5'6" x 4'0"	6 x 2"

$\frac{1}{4}$ " Coach screws 2 x 2"	$\frac{5}{16}$ " bolts - 1 x 6"
2 x 3"	
$\frac{3}{8}$ " Coach screws 2 x 3"	
$\frac{5}{16}$ " Coach screws 2 x 3"	

2 Steel Brackets  $\frac{1}{4}$ " x 3" x  $1\frac{1}{2}$ " or dexion  
Ex-P.O. wire and clips - approx. 18 ft

TURNTABLE: With the tail in place and the cradle complete with gearbox and generator standing on a bench, we bundled up spars and sails and hung them from the face plate so that we had the total weight of the head in its working distribution. We could now find the point of balance of the head, that is the centre line for the turntable. We rolled a broomstick under the cradle until the whole thing balanced, and marked the place on the cradle. We removed the tyre from the roadwheel of the caravan axle unit, and drilled the wheel so that we could bolt on two pieces of 6" x  $1\frac{1}{4}$ " hardwood, in length that of the width of the cradle (1) (Figure 3). These in turn were bolted to the cradle so that the centre of the wheel accorded with the marked point of balance. We checked there was room to replace the hub nuts on the wheel to refasten it to its brake drum and axle when the time came. The brake itself may be left intact - just check that it is not binding - as ours was after long disuse - it will be a useful way to check rotation of the head if maintenance is needed in a strong wind.

The mounting of the axle, vertically in the tower, is shown in Fig. 3. We used a length of 5" x  $1\frac{1}{2}$ " pine, bored centrally and chiselled to a square hole to allow the square axle to slide through and this was attached with Dexion brackets and  $\frac{1}{4}$ " bolts to the timber skirt at the top of the tower. It will be seen that the weight of the complete head is supported on an 1" dia bolt and nut in a bottom cross beam. We used 3" x 2" pitch pine; if white or yellow pine is used an unflawed piece of 3" x 3" minimum should be used. This beam was bored centrally to take the 1" bolt, and counter-bored and chiselled to accommodate the nut as shown. A further short length of 3" x 3" is then bored and cut with a square hole to act as lower guide to the axle, and screwed or bolted to the crossbeam as shown (3) (4).

# CRETAN WINDMILL - THE TURNTABLE

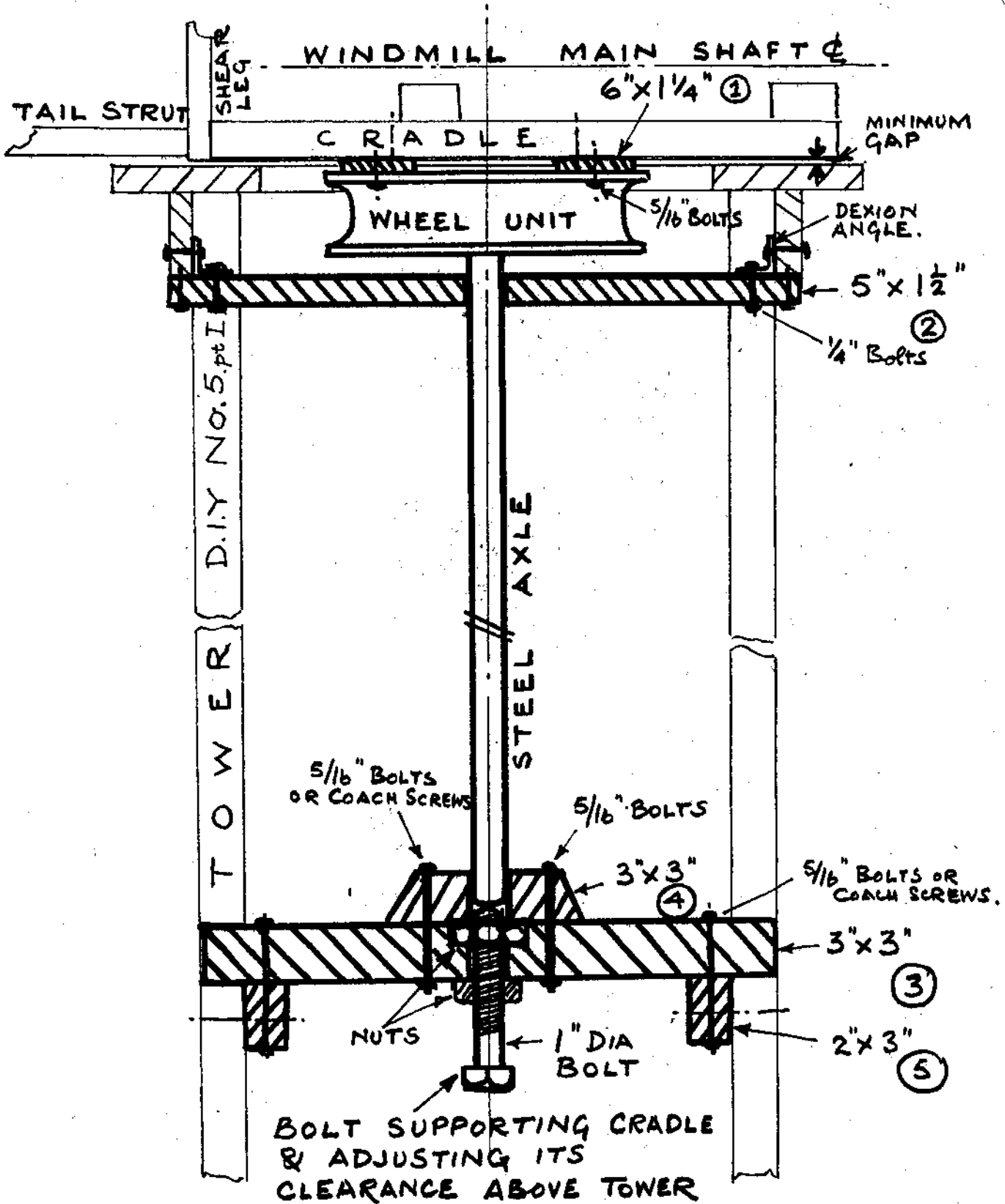


FIG. 3.

# CRETAN WINDMILL - HEAD RETURN DEVICE

(ROAD WHEEL) TURNTABLE CARRYING CRADLE

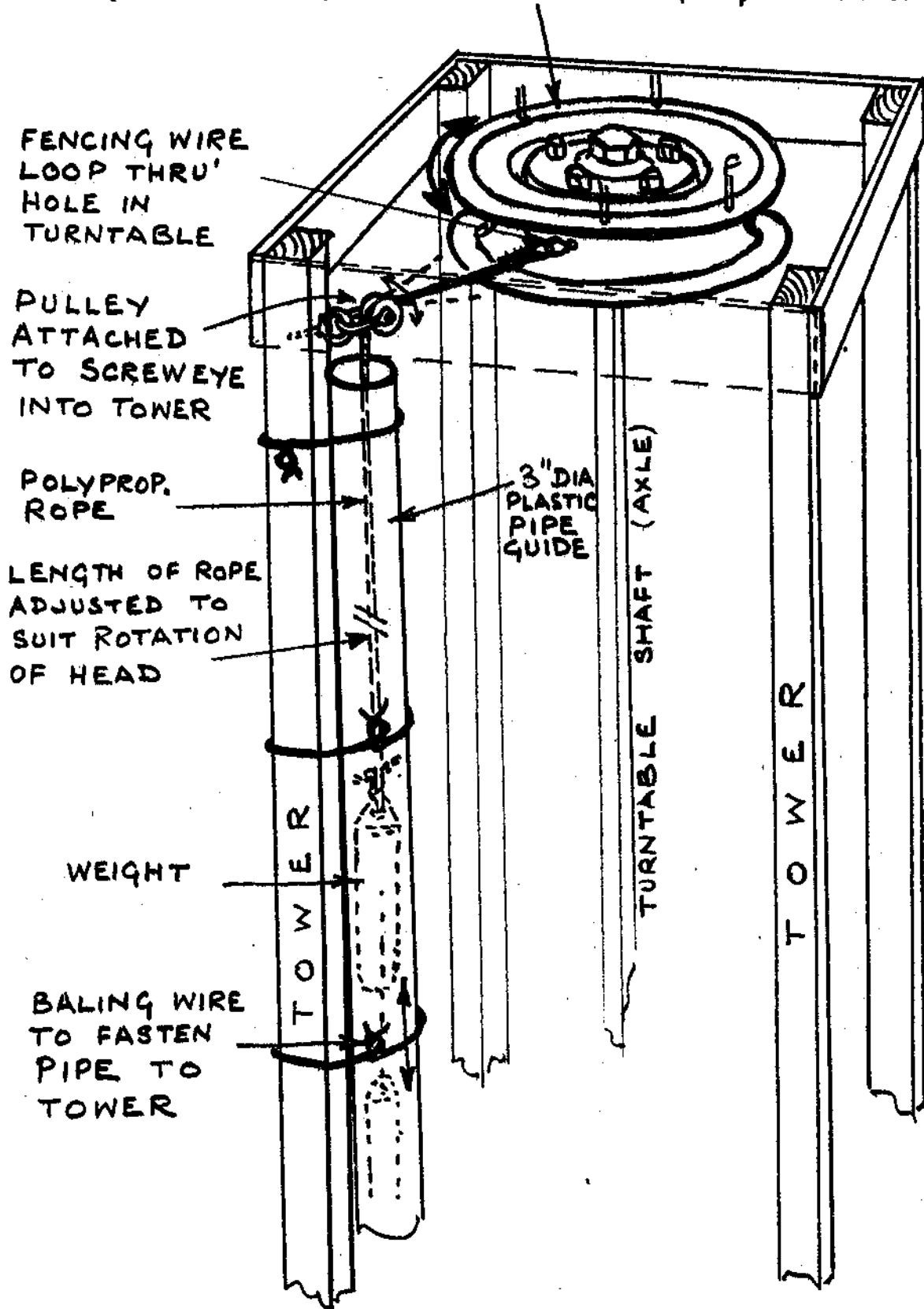


FIG. 4

Thus we have a bottom fixing which allows adjustment of the head to the minimum clearance necessary to allow the head to turn free of the tower. so that the rocking of the head in gusts of wind is reduced to the minimum.

We dismantled the tail, and as much of the head as necessary to carry it to the tower, and assembled the turntable on the tower. The top guide (2) of course has to be central and with that bolted to the skirt, the axle was passed through it until the hub unit rested on it. The cradle was then lifted onto the tower, and the caravan road wheel, already bolted to the cradle, was in turn bolted onto the brake drum hub unit. Ensuring that the axle was hanging quite vertically, the bottom beam (3) was then guided over the end of the axle, and its position marked for the two cross pieces (5) to be bolted to the tower. The adjusting bolt should be proud of the top nut by about  $\frac{1}{8}$ "

Drilling the tower and cross pieces should be done accurately so that the axle remains absolutely vertical, and the supporting beam horizontal. The tail should now be rigged, and the spars and sails, gearbox and generator replaced and made ready for work. The supporting bolt in the bottom beam may then be screwed upward until the head swings with the wind with no interference. The checknut beneath the beam should be tightened.

#### MATERIALS:

1 5" x 1 $\frac{1}{2}$ " pine approx. 3'7"	5/16" bolts - 4 x 2"
1 3" x 3" pine approx. 3'0"	5/16" 4 x 6" or Coach Screws
1 3" x 3" pine approx. 1'0"	5/16" 4 x 5" (x4 $\frac{1}{2}$ ")
2 2" x 3" pine approx. 3'0"	1/4" bolts - 8 x 2"
2 Dexion Angles x 5"	1" bolts - 1 x 5" + 2 nuts

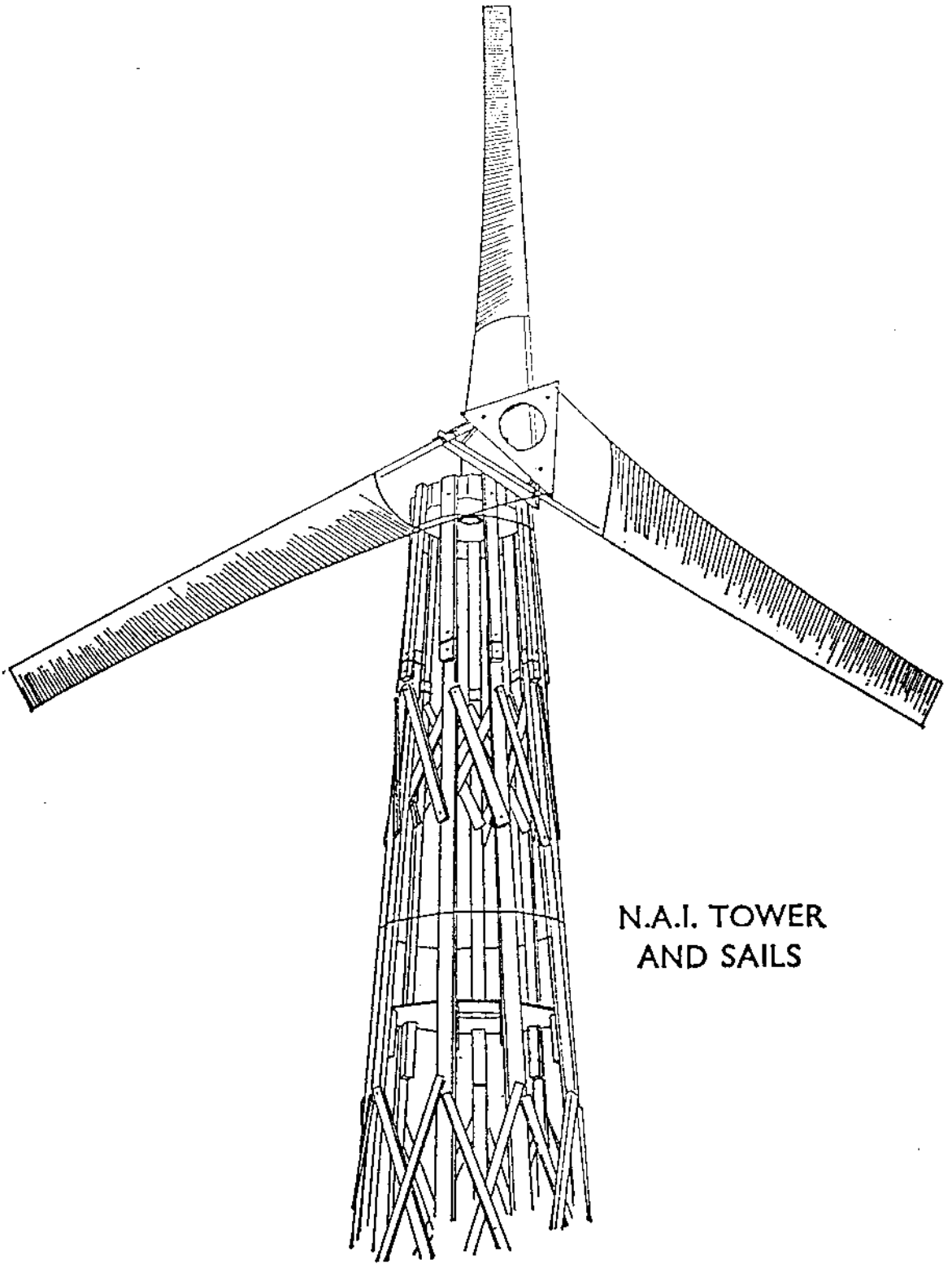
Canvas for the sails may be obtained from Russell and Chapple Ltd., 23 Monmouth Street, London WC2H 9DE, telephone 01-836 7521. They will also make the sails.

This DIY plan has been prepared for the Centre by John Eyles. © The information contained in this leaflet has been given in good faith and is believed to be accurate at the time of printing. However, both the author and the National Centre for Alternative Technology decline all responsibility for errors and omissions.

Other DIY plans, information sheets and books are available from the 'Quarry Bookshop' at the Centre. Please enclose a S.A.E. with any correspondence as we are a charity. Visitors are welcome.

Centre for Alternative Technology, Machynlleth, Powys, Wales  
Telephone: Machynlleth 2400





N.A.I. TOWER  
AND SAILS

When building windmills, always  
overestimate the strength of the wind and the forces involved. It  
pays to be safe.

This platform problem is so acute that there is a good case to be

made for building a tower and not using a mast. The top platform then adds strength to the tower, and another half-way up as well will help even more. The best design I know is for a 26-foot high tower built by the New Alchemy Institute-East on Cape Cod and fully described in the *Journal of the New Alchemists*, No. 2. The basic structure is made from 8 lengths of  $4 \times 2$  timber each 26 feet long (all timber must be treated with wood preservative). The 2 platforms are fixed to the tower by nailing down into short lengths of  $4 \times 2$  bolted to the main uprights (with eye bolts, on the centre platform, to provide a fixing for the guy wires). The NAI wires run inside the tower but anchoring them outside would in my view provide a better hold. The tower is tapered to a shape given by making the top platform an octagon 28 inches across and the centre one a circle of 48 inches diameter. The main uprights are fixed at the bottom with large bolts to 8 bits of telegraph pole 6 feet long driven deep into the ground. The top half of the tower is braced with 16 40-inch lengths of  $1 \times 3$ , and the bottom half with 16 58-inch lengths.

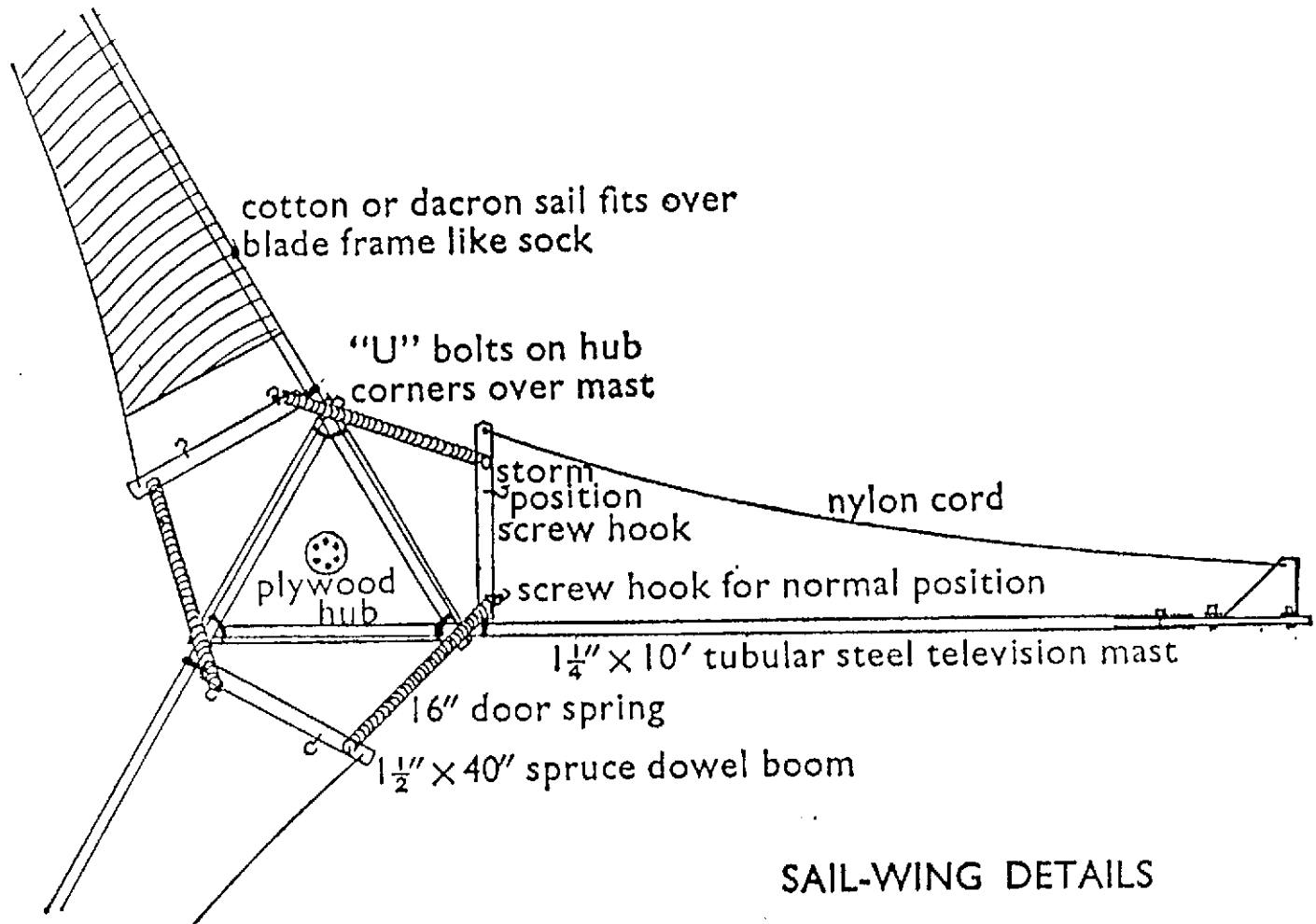
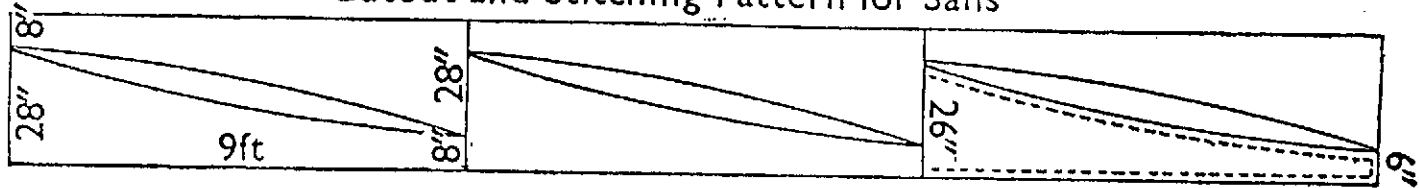
Such a tower (this one was designed for a 18-foot diameter sail machine) will give pretty good service. Bits of wood attached up the lee side will make a safe ladder, and some more pieces mounted all round about 3 feet from the top will give an easy toe-hold for working on the machine. If you want even more strength (and who doesn't?) the price of a third platform will be miniscule and help out of all proportion to its cost. By the time you've finished, such a tower is going to cost £100 or more, but a metal, commercially-available model to do the same job will add up to 3 or 4 times as much when you've finished paying for transport and import duty and all the other extras people can manage to think up. Build your own.

### *Sails and propellers*

There are two nice things about windmill sails. First, they're easy to make, which means they're also easy to replace. Second, they'll never be as strong as the rest of your machine. That's an advantage because in a gale the sail is likely to get ripped up first, and once that's happened, of course, the wind machine will stop turning and no more harm can come to it. A rigid propeller, by contrast, can go on and on turning in a gale until the whole machine disintegrates.

The sailing idea has been recently developed by a team of

# Cutout and Stitching Pattern for Sails



SAIL-WING DETAILS

## WIND POWER

scientists at Princeton University who were struck by the efficiency of a glider wing, with its blunt, rounded leading edge. The New Alchemy Institute has adapted the idea to make an 18-foot diameter water-pumping mill which works pretty well, even in a very low wind speed. The Princeton idea led to a 25-foot diameter machine, designed to produce 7 kW in a 9 metre per second wind.

The leading edge of the NAI sail is a  $1\frac{1}{4}$ -inch diameter steel television mast, while the trailing edge is made from a taut wire or nylon cord. As a result, the shape of the sail changes with windspeed, to take up the most efficient aerodynamic shape. The sail itself, made from cotton or, better, dacron (as in boat sails), slips over the steel and nylon cord frame like a sock. The drawing on page 141 shows the essentials. The steel masts are fixed with U-bolts to a 1-inch thick triangle of plywood, which serves as the hub, each side of the triangle measuring 30 inches. The rest is apparent from the diagram. Note the door springs fitted to give an automatic governing device for high winds. These have two positions, one for use in storm conditions. The NAI design has, however, come through gale force winds in the normal spring position. I would recommend an additional governing device (see next section), so I think you could dispense with the storm position for the springs – not a very practical idea, in any case, for they involve climbing the tower in a high wind to make the adjustment.

This unit has been tried and tested, and if you get into problems write to Marcus Sherman, c/o New Alchemy Institute-East, Box 432, Cape Cod, Massachusetts, for advice. The NAI machine was for water pumping, so the hub was connected to a crank shaft used to power the pump. Our machine will be an aerogenerator, so we will use a different system (see below). But it's worth pointing out now the main disadvantage of sails for electricity generation. The rotor will revolve relatively slowly, and will be far too slow to turn a car alternator at the right speed. Even with propellers, you need to gear up by about 10 to 1. For a sail machine of this type, you will need to gear up 20 or even 25 to 1. But, even allowing for the frictions that introduces, you'll still make more efficient use of slight winds than would a propeller machine.

When you've made your sails or propeller you have to fix it to something which will rotate in a bearing which can be anchored to the mast. The best thing is the complete rear axle and differential of a scrap car, which can now be obtained very cheaply from a junk yard (see next section). But assuming for the moment you've done that, you must now balance the rotor. This is important: if you don't balance the thing, the vibrations and the uneven weight will certainly be enough to shake the whole contraption loose. Your rotor, electrical equipment and probably your tower will crash to the ground. So balance you must.

Any good engineer will tell you you must balance dynamically – that is, when the thing is revolving fast. You can't – it needs complicated equipment. So you have to balance statically, which means first setting the thing up with the rotor in a vertical plane and spinning the rotor hard by hand a few times. Watch the point at which it settles to rest. If it's always the same point, you are unbalanced, and you'll have to weight the lighter arms. With a propeller you do this by cutting out an oval shape of metal and screwing it to the lighter blade with the screw offset from the centre. Find the right point by trial and error to screw in, which will give you rough balancing. Then twist the metal oval round on its screw to give you fine balancing. Then tighten the screw. To balance a sail, use your common sense; some pieces of lead flashing cut into thin strips and twisted round the metal strap at the tip of the wing might be good – but make sure they're firmly fastened or they'll come off in a high wind.

*Transmission and governors*

The problem of how to transmit power from a rotating sail or propeller to a device for producing electricity can be solved in two ways. You can build a shaft which will turn pulley wheels linked by a belt to an alternator. That will take you into buying and fitting bearings and pillow blocks from small mail order firms, or finding the right junk pieces in the right place. Jim Sencenbaugh has built a pretty successful 500-watt aerogenerator in this way and for \$15 he'll send you a complete set of plans. They'll take you through not only all the mechanical problems, but round the electrical circuit (see below) as well. Even if you don't intend copying someone else's plans exactly, it's not a bad idea to get them because they contain many hints which you might otherwise spend much time puzzling over (address: 673 Chimalus Drive, Palo Alto, California 94306).

The second way of doing it, which I reckon is much easier, is to buy a complete rear axle and differential from a junk car dump. If you don't know much about what happens inside a car, now is the time to find out; the information will not only help you make the windmill, but it'll be very handy later on if you're still running a car. The beauty of this scheme is that it is cheap – and that you can use a wheel hub to solve your main bearing problem. Leave one hub on, and bolt a plywood plate on which the propeller is mounted to it. You then have to mount the entire axle and differential on a 1-inch piece of marine plywood, or a steel plate which is even better. This is the platform which will carry all the gubbins at the top of the machine – notably the axle, the alternators and some electronics.

Your second bearing problem is how to mount this platform on top of the tower. It must rotate freely so that the propeller or sail can always face the wind. The expensive way of solving this is to buy, as the New Alchemy Institute did for their sail mill, a steel turntable. For the record, theirs was a model no. M4-1214 series 1,000 Econotrak bearing (9-inch inside diameter) from Rotek Inc., 220 West Main Street, Ravenna, Ohio 44266, and it cost them about \$129. It's undoubtedly a splendid device but you can do the same thing with another wheel hub. Ideally, I would buy a scrap tractor hub and axle. Disconnect it from the differential and bolt the differential housing to a platform near the top of the tower. The

top platform can be cut out to take and support the axle housing near the hub. Now mount the propeller platform onto the wheel mounts on the tractor hub.

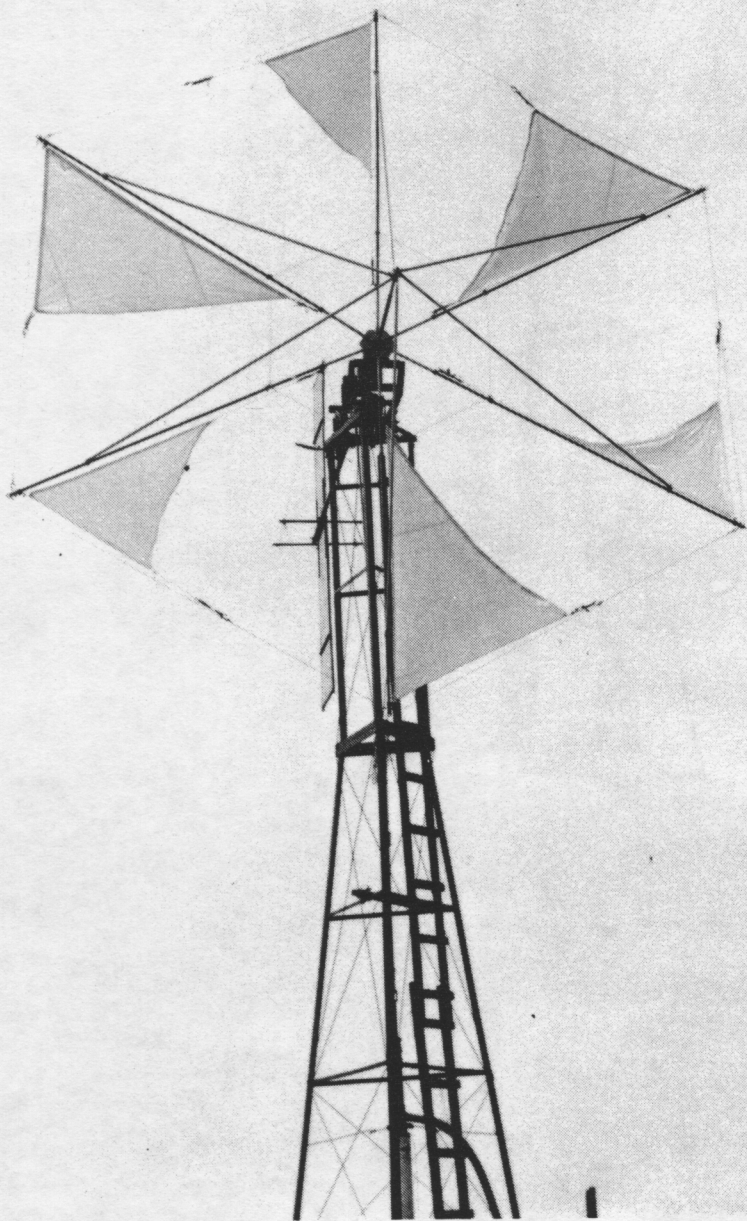
It's a good idea to leave the handbrake cable trailing from both these hubs – the propeller mounting hub and the platform hub. That will then give you a manual method of (a) stopping the propeller from turning in a gale; and (b) stopping the turntable at a position where the propeller is at right angles to the prevailing wind in a gale. A double precaution.

The axle and differential can be mounted most easily on the platform with the differential sticking up – in other words, the vehicle drive shaft, were it still attached, would be pointing vertically towards the heavens. It then remains to attach a pulley wheel, spinning horizontally, to the car drive shaft mounting, and to link that pulley with a belt drive to the alternator(s). When you've done all that, you've got another balancing problem. It's very important that the platform, and all that you've installed on it, is weighted in such a way that the centre of gravity falls immediately over the mounting on the tower. If it doesn't, the weight, plus the vibrations from the rotation, is certainly going to tear the top platform out of its tower mounting, and you'll lose the lot. If you are using more than one alternator, the balancing can probably be done by positioning them to achieve the desired effect. Otherwise you'll have to devise some other method of weighting the platform.

Mounting the differential this way may lead to two problems. The lubrication may not work well and pulley belts may slip off. There is a case, therefore, for mounting the thing as it was in a vehicle – with the differential horizontal and the pulley wheels vertical – but it's usually more difficult.

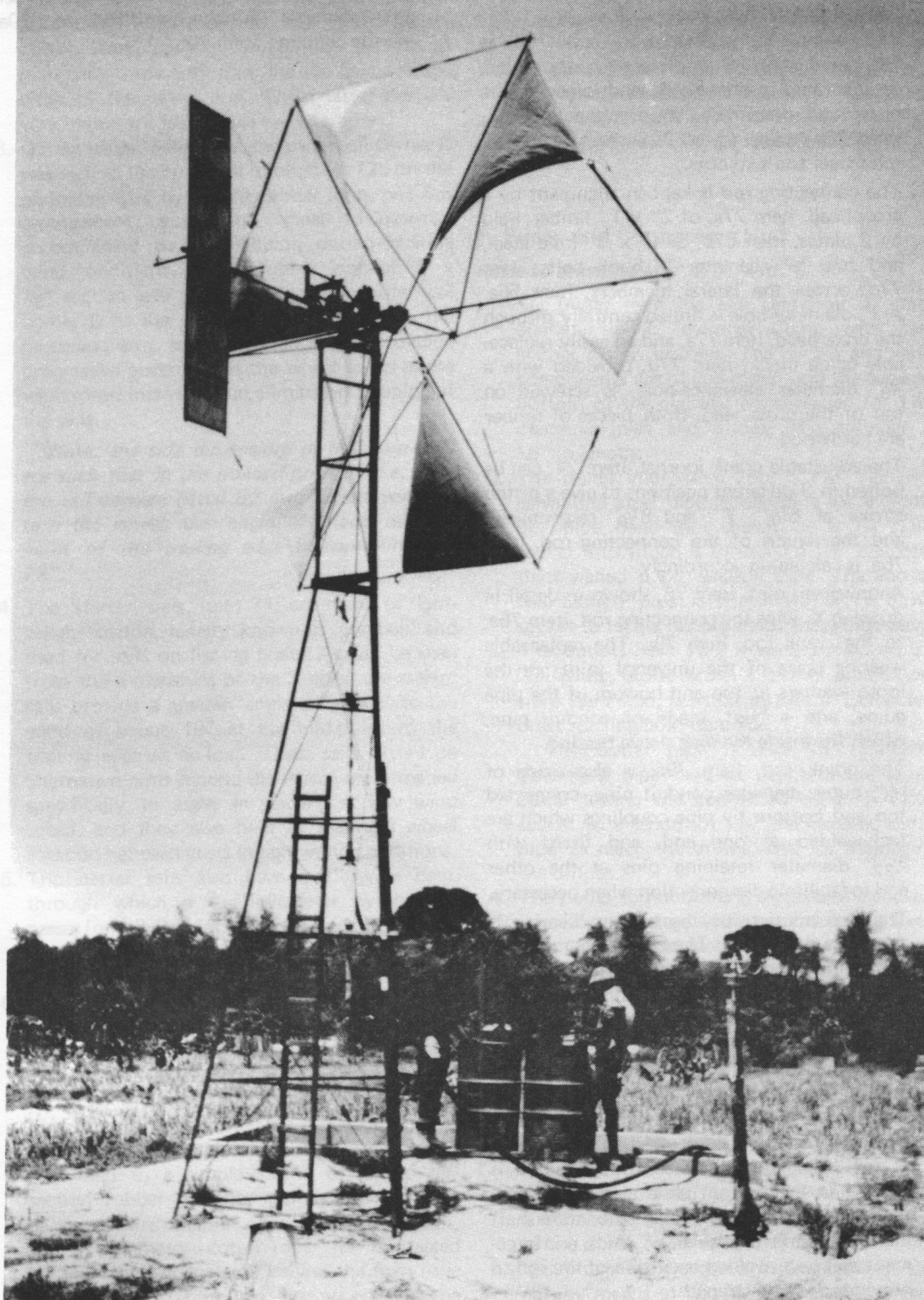
The drawing on page 146 shows the main elements of the platform and its mounting. You must now build a fairly substantial vane, and attach it to the rear axle at the opposite end to the propeller or sail. This is what will turn the mill to face the wind. And you're now straight up against the problem of governors.

If you just leave your mill to go faster and faster in stronger and stronger winds, make no mistake but that you will lose the lot. Maybe not in the first gale – but certainly within a few months. You must therefore install some device either for slowing the propeller down in strong winds, or for turning it somewhat out of the wind.

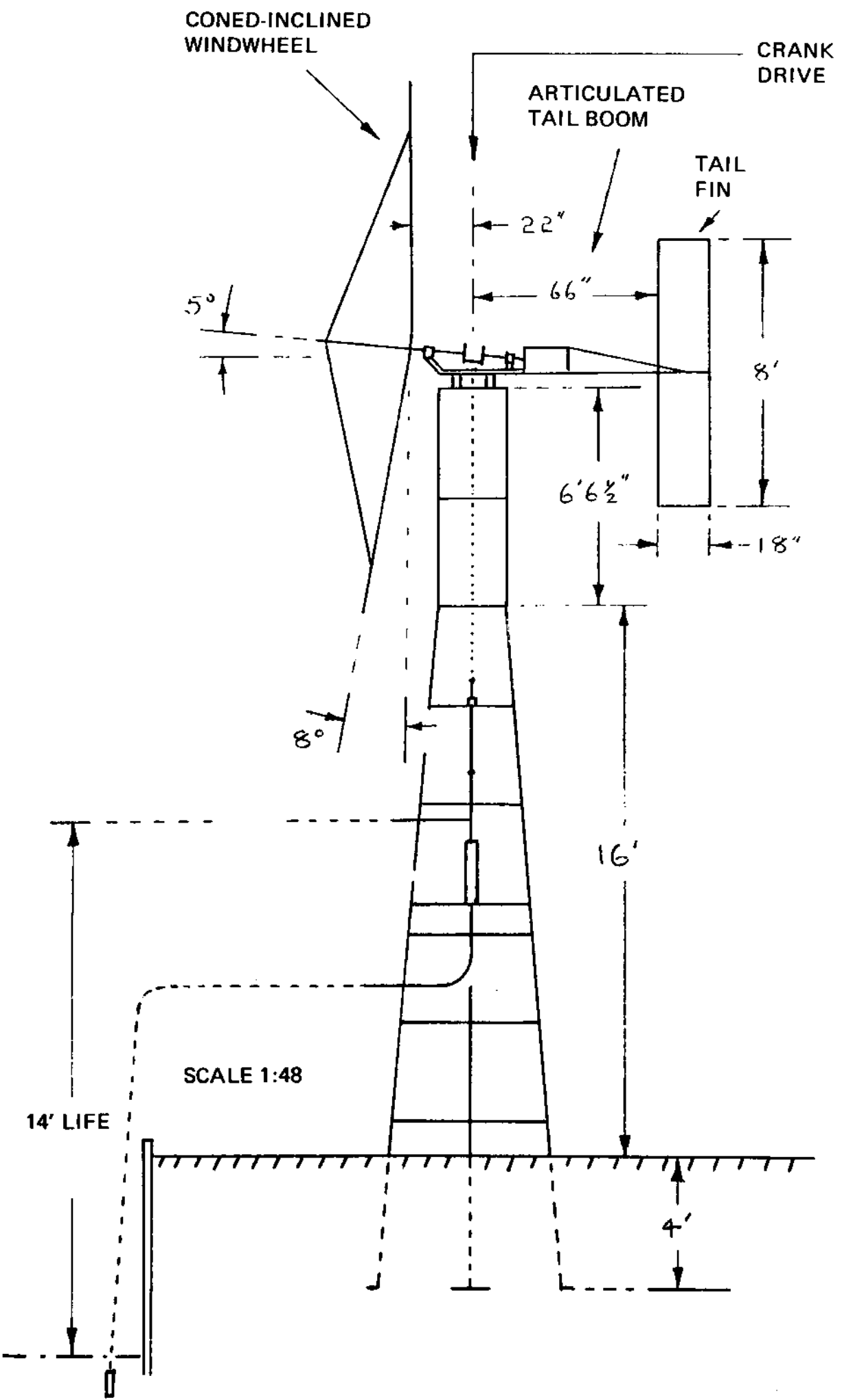


*The sails in operation.*

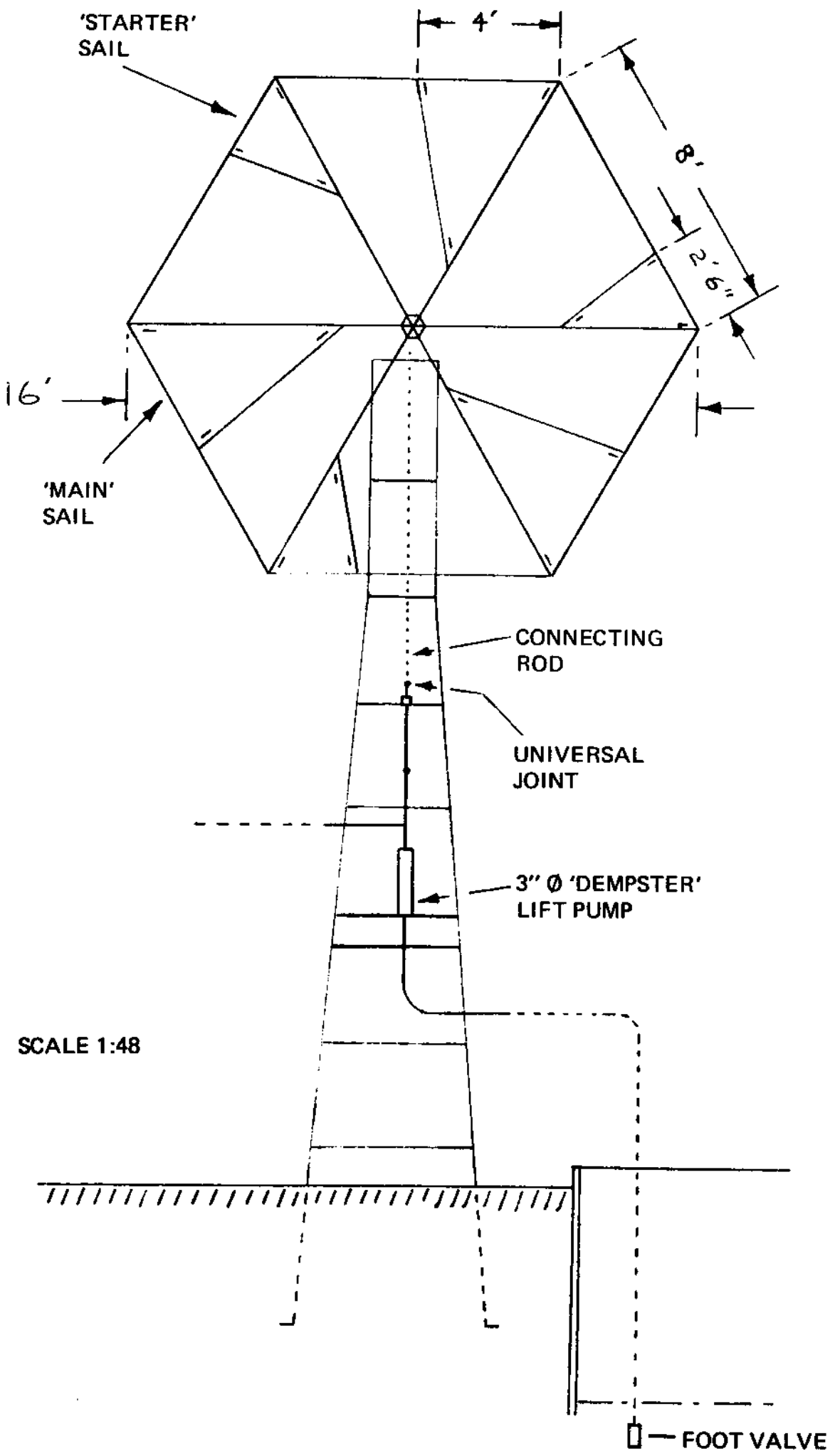




*The erected wind-pump in action.*



(B)



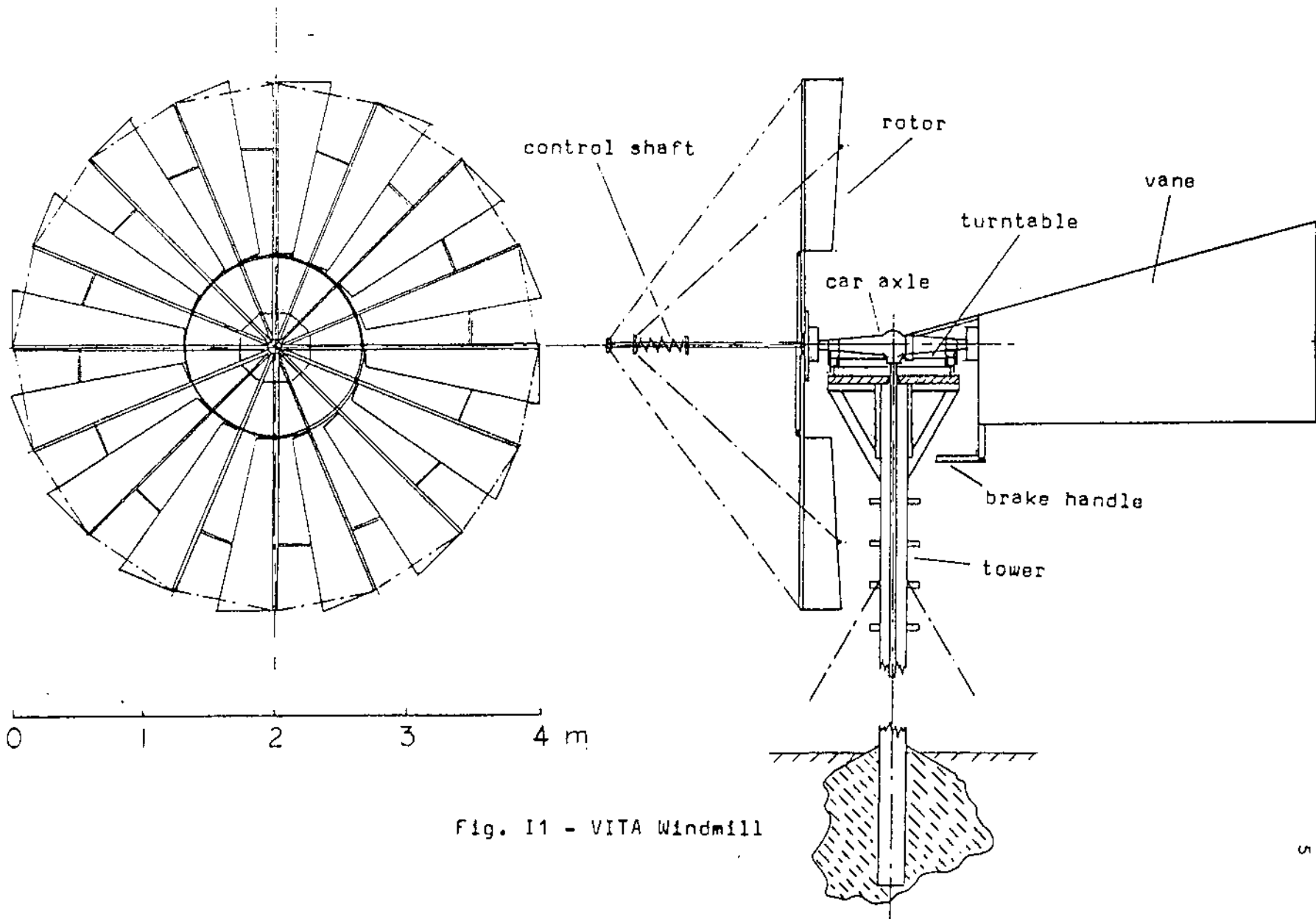
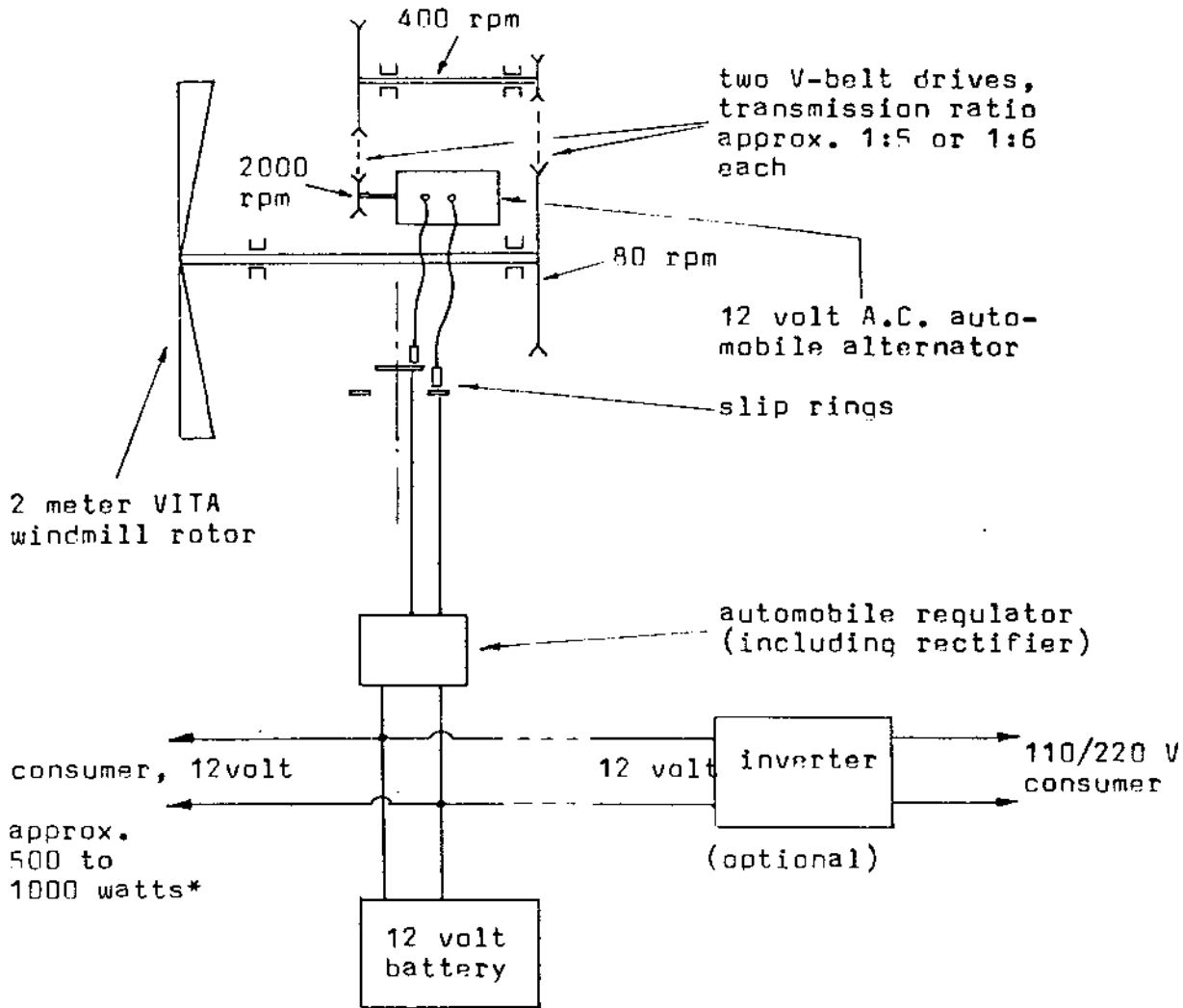


Fig. 11 - VITA Windmill

Suggestion for

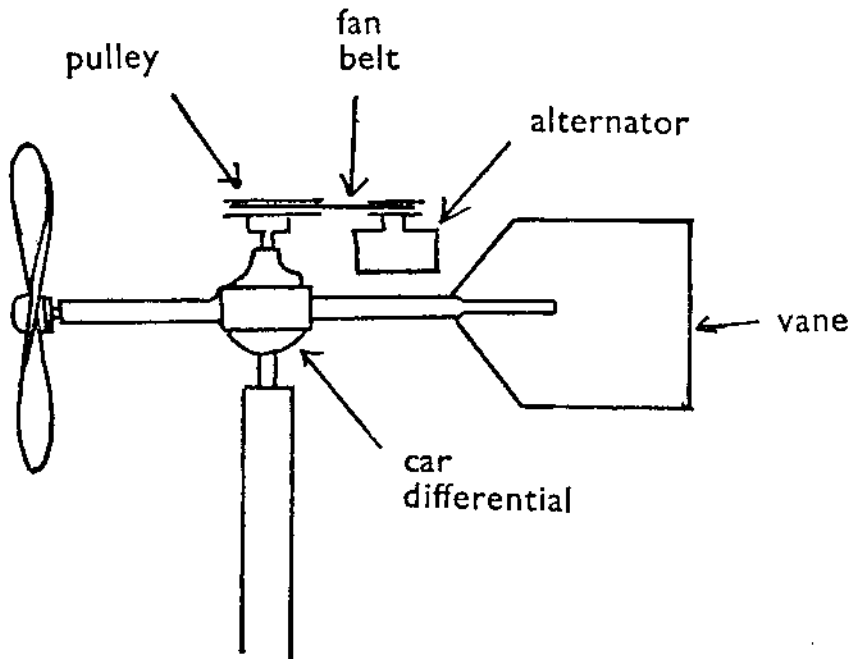
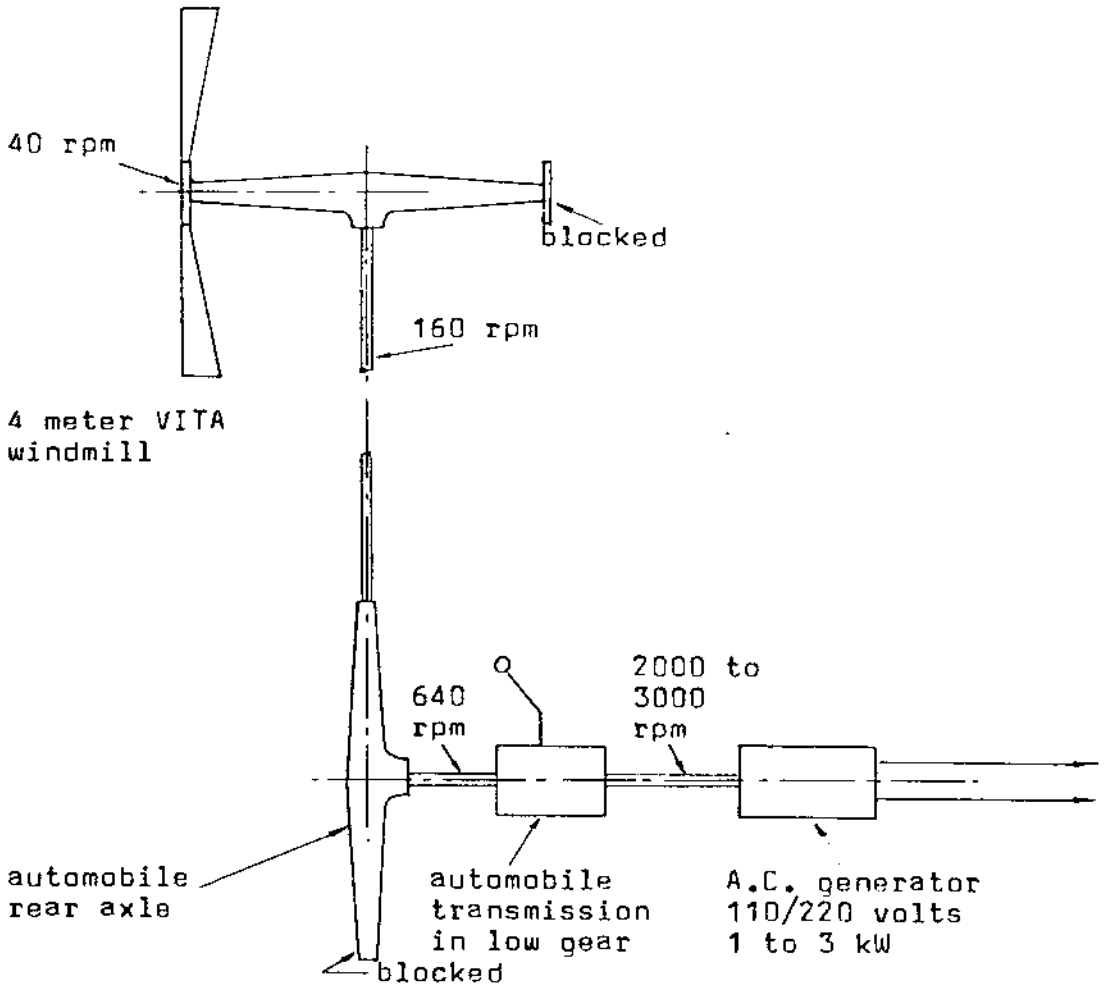
Electric Power Generation Using VITA 2 meter Windmill



\*depends on alternator used

Suggestion for

Electric Power Generation Using VITA 4 meter Windmill

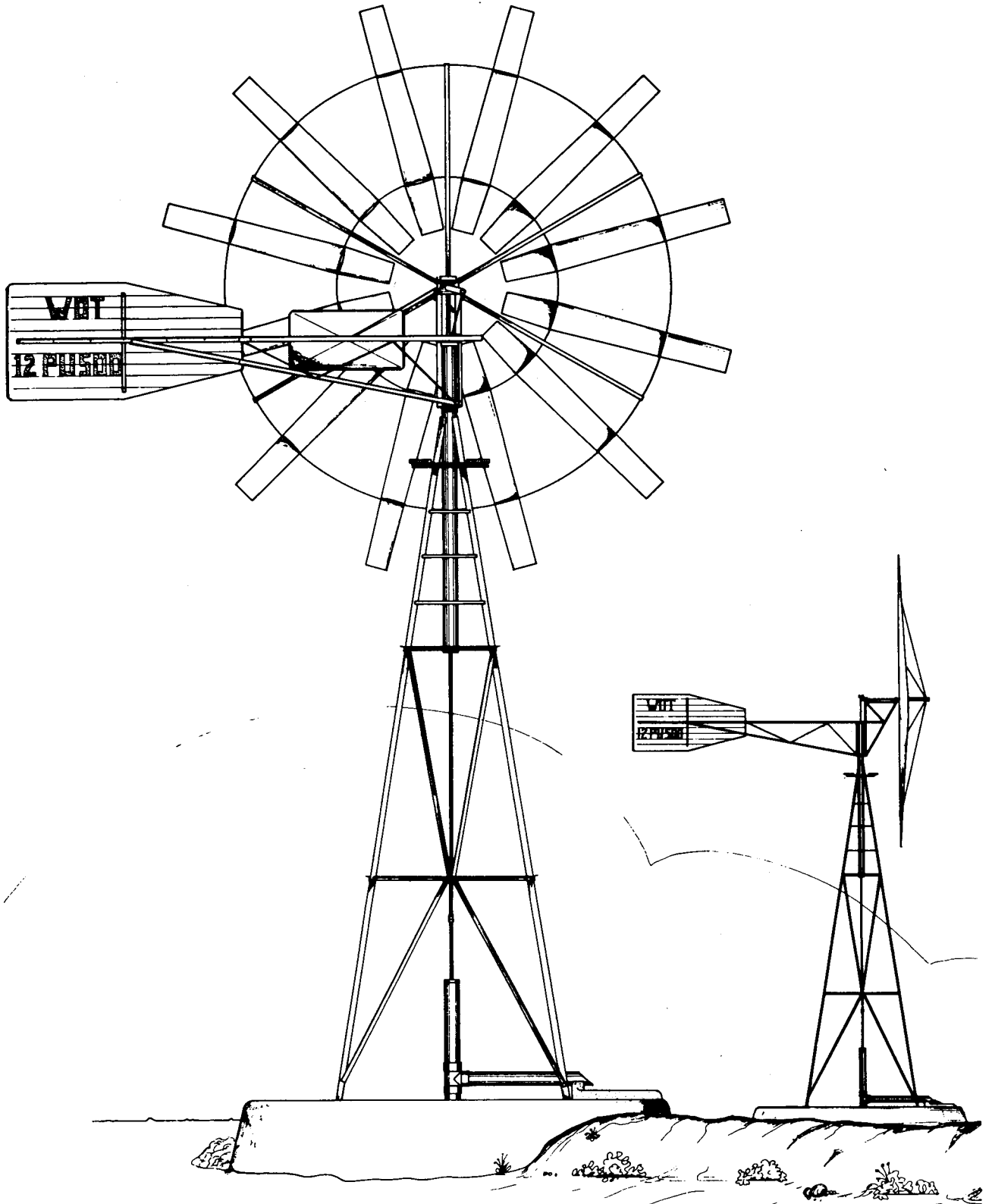


DIFFERENTIAL MOUNTING

let us consider the design, development and production of windmills. The windmills as produced in industrialised countries use high technology, requiring well-developed associated technologies to assist the design. Some of the complex blades used in certain windmills are actually the result of complicated computer programmes, complex materials and sophisticated presses to fashion the shapes. It would be inappropriate to introduce to a developing country a technology which is either static, or too advanced for manufacture in the country. In other words, a starting point has to be established which is compatible with technological skills available in the country at that particular time, so that as and when the country acquires high technology, a linkage can be readily created

whereby products or equipment are naturally and automatically improved through the use of that high technology. The drawings supplied in Figures 6.8 to 6.23 for the manufacture of windmills take into account that 'starting point', fully utilising available skills and technology, while leaving ample room for further development and improvement.

The windmill designated 12 PU 500 Windmill for Irrigation has been designed by Niek van de Ven for the Working Group on Development Technology (WOT), Twente University of Technology, Vrijhof 152, P.O. Box 217, 7500 AE ENSCHEDE, The Netherlands. Any technical assistance or further information needed will be gladly supplied by the Working Group on request.





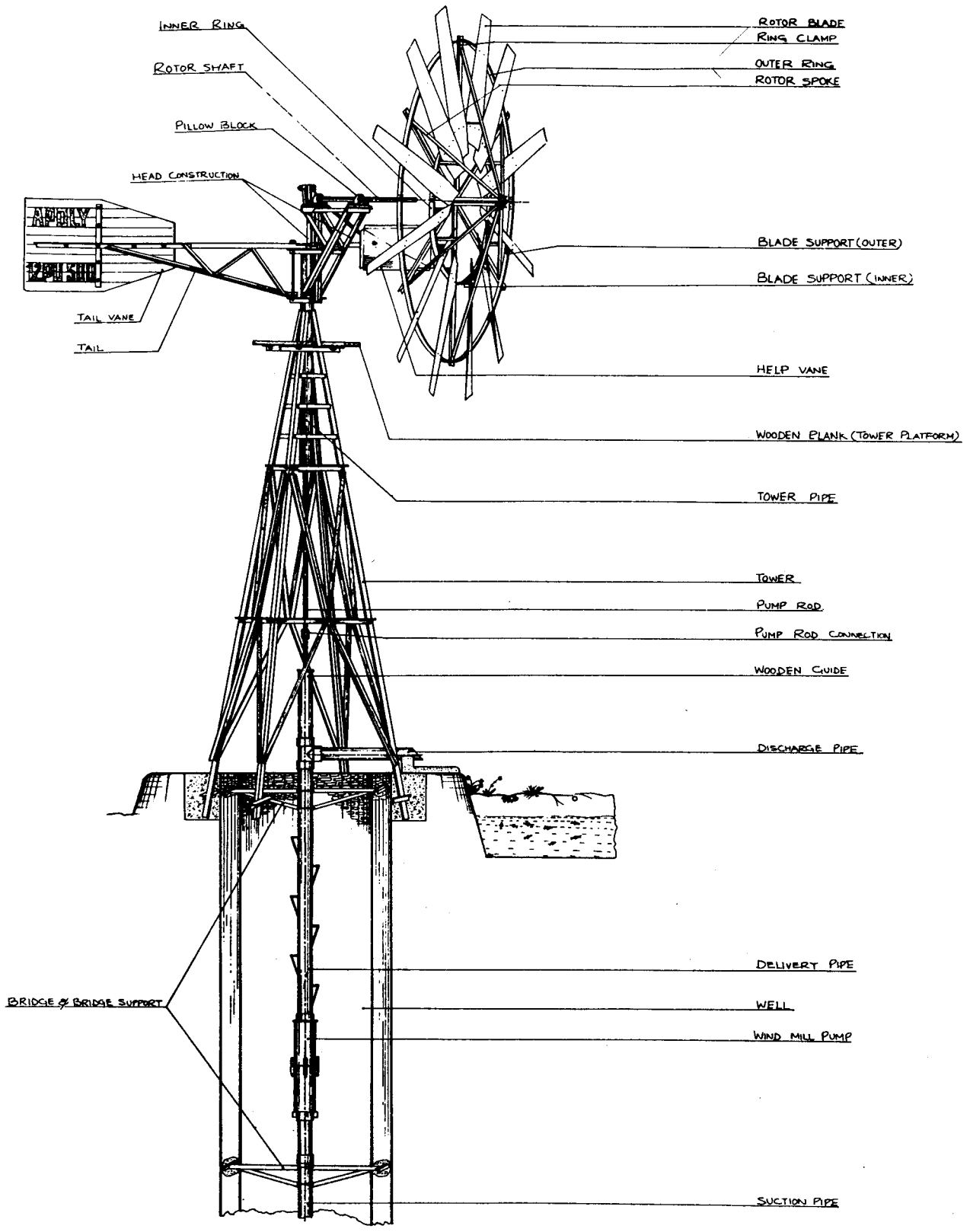
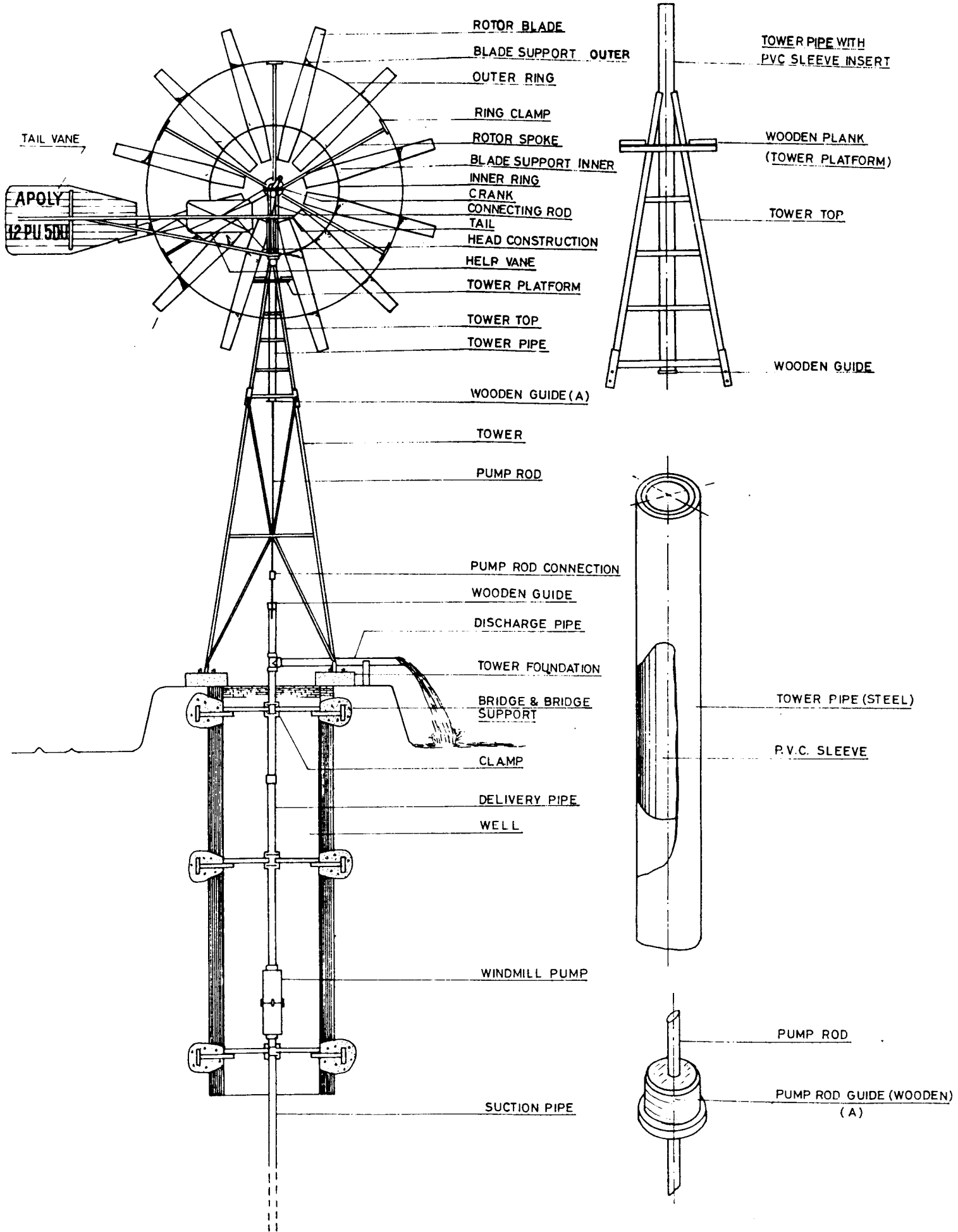
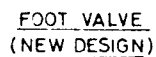
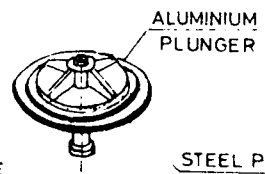
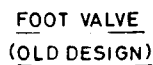
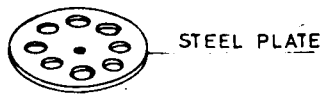
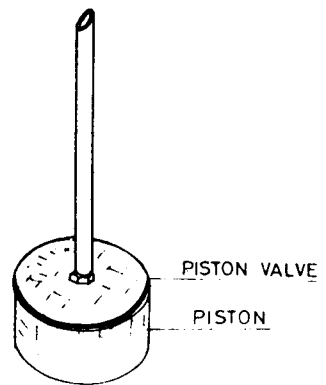
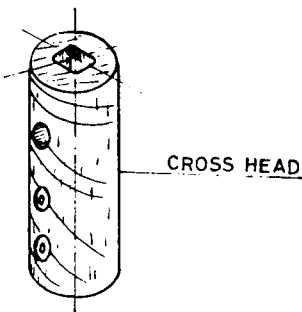
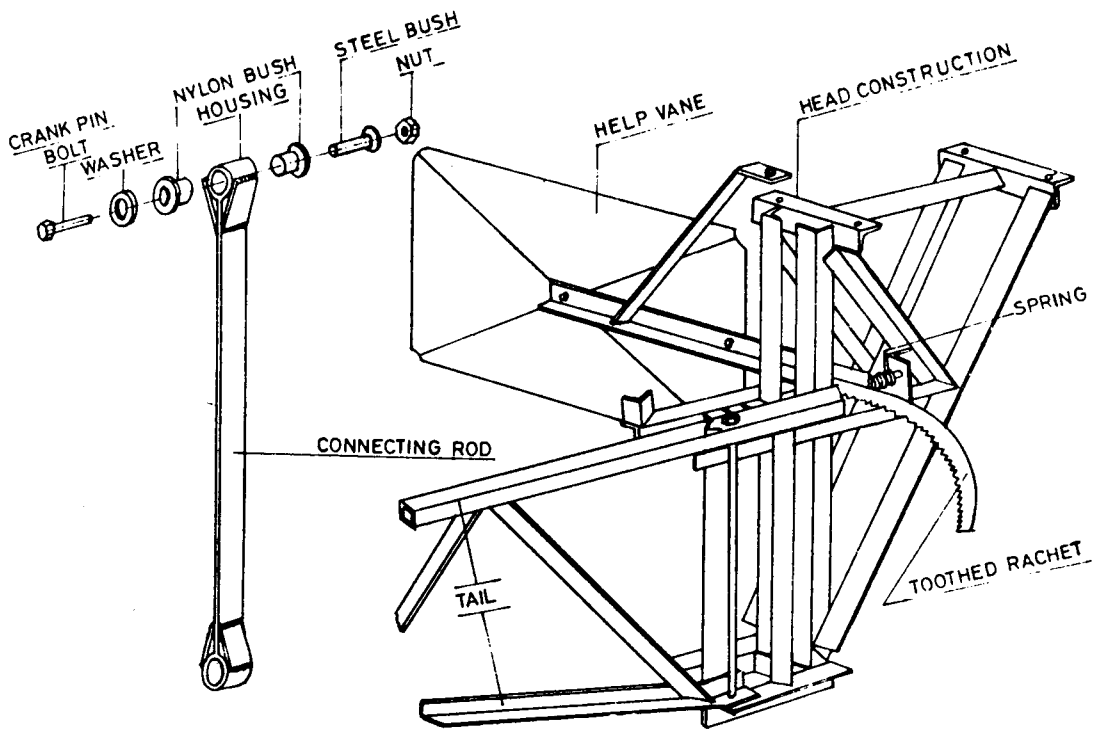


Fig. 5 12 P U 500 Water Pumping Windmill





SCHEMATIC OF  
12 PU 500 WATER PUMPING WINDMILL  
INSTALLATION

WIND ENERGY R & D CENTRE  
INSTITUTE OF ENGG. & RURAL TECHNOLOGY

ALLAHABAD  
211002

**7. Guidelines for Site Selection for  
12-PU-500  
Water Pumping Windmill**

**GUIDELINES FOR SITE SELECTION**

**7.0 General**

Water pumping windmills can be installed on an open well, a tube well, or near a canal, stream, pond, creek etc.

**7.1 Surroundings of the Site**

Taking the site as the centre there should not be any obstacle of more than 4 meter high height within an area of 100 m radius. If any such obstacle is there it should be cleared before the installation of the windmill. Alternatively, the height of the tower has to be increased suitably.

**7.2 Well and Boring**

- (a) If the diameter of the well is not small enough to accommodate "tower leg pitch", some modification has to be carried out in the tower design. In case the well is of a larger diameter than the tower, the legs have to be increased in length. Two legs then will be supported over a steel bridge or a girder spanning over the well and the remaining two legs will be outside the well.
- (b) The well should be in proper condition, otherwise repairs in the masonry work and cleaning of the well should be carried out before the installation.
- (c) The refilling capacity of the well should be about 25 cubic metre/hr. otherwise cleaning/ boring of well has to be done. If it is a cavity boring, it should be cleaned preferably by compressor unit so as to achieve a discharge rate not less than 35 cubic metre/hr.
- (d) When the installation has to be done over a borewell, a masonry pit is prepared. The diameter of the pit may be 1.5 m, and its depth shall be the same as spring water level below the ground.
- (e) The total head over which the water is to be pumped should preferably be within 15 m and not more than 20m in any case.

**7.3 Water Storage Tank**

Before the construction of water storage tank near the windmill, it is necessary to test or evaluate the soil characteristics, specially its permeability. This will help in deciding whether the tank be an earthen one or lined by a suitable material.

A proforma has been designed to collect relevant site information to select a suitable installation site.

## 7.4 Proforma for Site Selection

1. (i) Name and address of the organisation. ....  
.....
- (ii) Name and address of the representative of the organisation. ....  
.....
2. Exact location of the place where the windmill is to be erected .....  
.....
3. End use of the windmill
- (a) If drinking water supply, population to be served .....  
.....
- (b) If minor irrigation, cultivated area in hectares with cropping pattern .....  
.....
- (c) If brine pumping, quantity of salt water to be pumped in litres. ....  
.....
4. Distance of the windmill site from the collaborating organisation (please mention the details of the route to the windmill site. ....  
.....  
.....
5. Surroundings of the site :
- (a) Obstacle, if any, within metre radius (taking site as centre) :
- (i) Nature of the obstacle .....  
.....
- (ii) Distance of the obstacle from the windmill site .....  
.....
- (iii) Height of the obstacle .....  
.....
- (b) Whether it can be removed or not .....  
.....
- (c) Whether it should be removed or not (considering main wind direction) .....  
.....  
.....

6. Available sources for water pumping

Open well/pond/river/sea/tube well/  
canal/any other. ....

(a) If open well -

(i) Inside diameter/size/depth  
Please give dimensions  
A,B,C,D,E and F on figure 7. ....

(ii) Average depth of water  
table in summer season .....

(iii) Average depth of water  
table in rainy season .....

(iv) Refilling capacity of  
well/tube well .....

(v) Whether the capacity can be  
increased or not .....

(b) If bore well -

(i) Depth of boring .....

(ii) Size of tube well .....

(iii) Position of the boring at the  
centre/out of centre .....

(iv) Age of the boring/well .....

(v) Whether the boring has been  
cleaned. ....

(vi) Date of boring .....

Type of system used for  
cleaning. ....

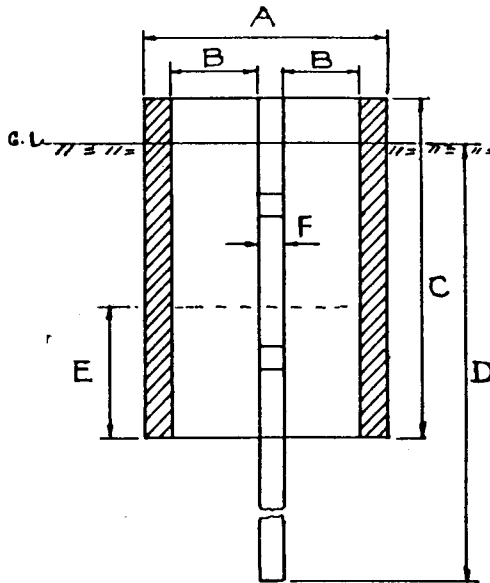
(vii) Vertical distance between  
the top of bore pipe and  
the water table. ....

(ix) Height of the boring pipe  
above water level. ....

In rainy season .....

In summer season .....

Approximate value of soil bearing  
capacity of the soil .....



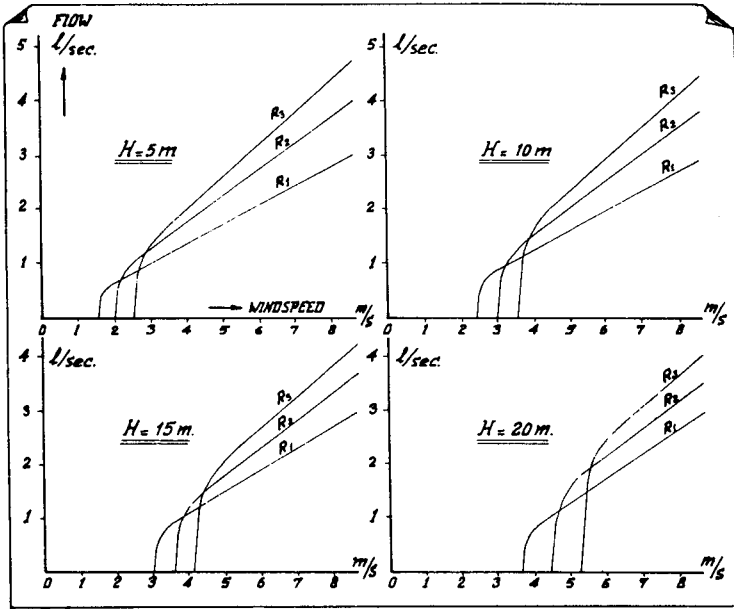
*Fig.7 Dimensions of Well and boring to be measured and recorded*

- 8. Approximate value of soil permeability (in view of water retention in storage tank built at the ground level) .....
- 9. Whether auxiliary structures are to be made in view of windmill erection like masonry pit boring in the open well, special foundation for the tower legs open wells or some odd situation .....
- 10. Further details, if any .....
- 11. Remarks .....

Signature of representative of organisation

Signature with seal of head of organisation.

# Water output graphs



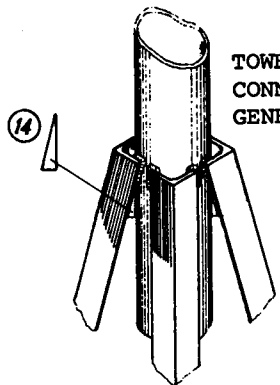
H = elevation head  
 R<sub>1</sub> = 60 mm  
 R<sub>2</sub> = 90 mm  
 R<sub>3</sub> = 120 mm  
 for 150 mm piston pump

## Materials for a tower

No	Number required	Materials, particulars and measurements	
1	1	Tower pipe	4" gaspipe × 2650
2	4	Angle iron	40 × 40 × 5 (1½" × 1½") × 6500 ÷ 7000
3	2	"	30 × 30 × 4 (1¼" × 1¼") × 660
4	2	Flat iron	30 × 6 (1¼" × ¼") × 360
5	2	"	" × 480
6	2	"	" × 600
7	4	Angle iron	30 × 30 × 4 (1¼" × 1¼") × 750
8	16	"	" × 2000
9	4	"	" × 1350
10	4	"	" × scrap
11	2	Plank	30 × 200 × 700
12	4	Bolt, nut, washers	M 8 (W ¾")
13	4	Flat iron	30 × 6 (1¼" × ¼") × 460
14	8	Flat scrap	

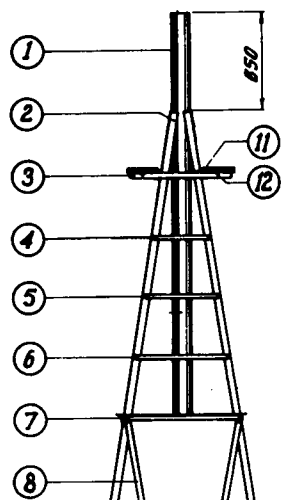


TOWERPIPE-TOWERLEG  
CONNECTION BY  
GENEROUS WELDING

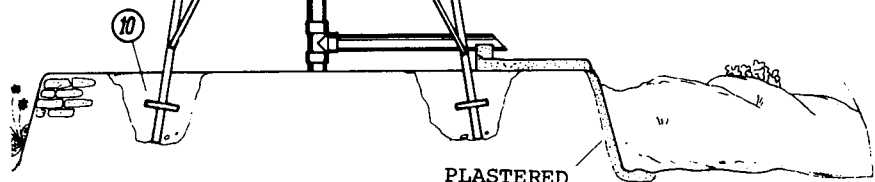
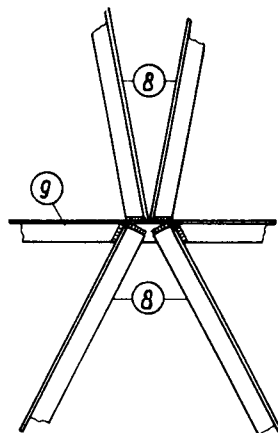
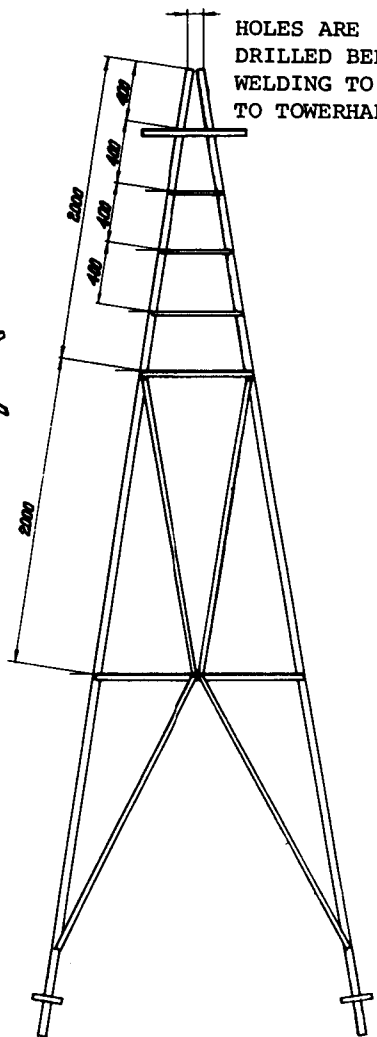
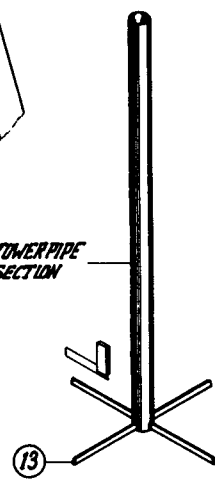


OUTSIDE DIA.  
TOWERPIPE

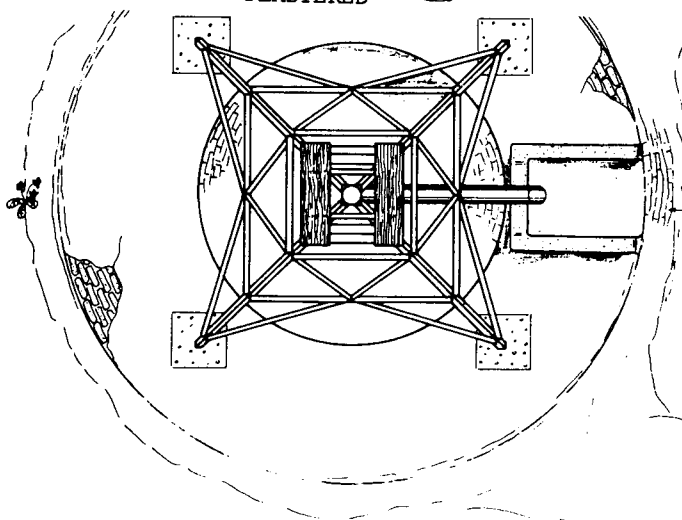
HOLES ARE  
DRILLED BEFORE  
WELDING TO ③  
TO TOWERHALVES



TOWERPIPE  
SECTION



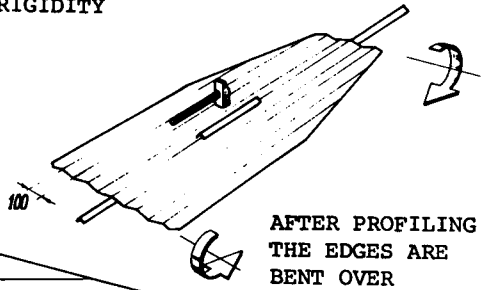
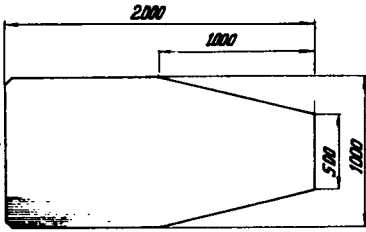
FIRST TWO OF THESE TOWER-  
HALVES ARE PREFABRICATED  
BOTH HALVES ARE COMPOSED  
& THE TOWERPIPE SECTION  
IS SHIFTED IN AND A  
COMPLETE TOWER RESULTS



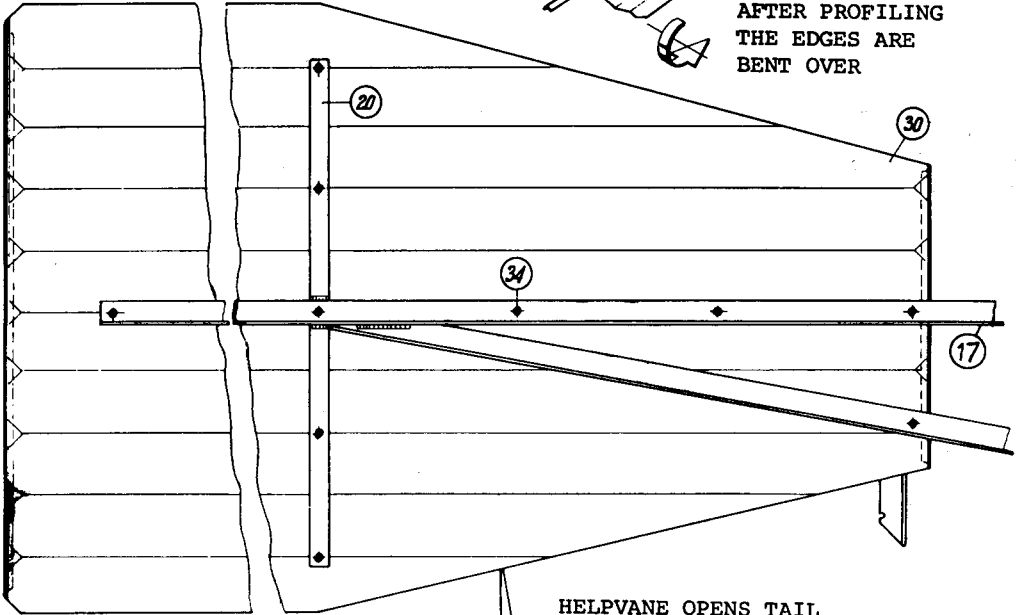
# Head Construction

No	Number required	Materials, particulars and measurements		
1	2	Angle iron	$50 \times 50 \times 5$ (2" $\times$ 2")	Length 220
2	1	"	$40 \times 40 \times 4$ (1½" $\times$ 1½")	500
3	2	"	"	1080
4	2	"	"	460
5	2	"	"	1000
6	2	"	"	550
7	4	"	"	tower pipe dia.
8	1	"	"	Length 180
9	1	"	"	45
10	1	"	"	1000
11	1	"	"	580
12	1	"	"	200
13	1	"	"	280
14	1	"	"	60
15	1	"	"	120
16	1	"	"	1500
17	1	"	"	4000
18	1	"	"	3000
19	3	Flat iron	$30 \times 6$ (1¼" $\times$ ¼")	Length 750
20	1	"	"	830
21	5	"	"	80
22	1	"	"	360
23	1	"	"	900
24	1	"	"	115
25	1	"	"	130
26	2	"	"	40
27	1	"	"	100
28	2	Spring	Appr. $\phi 30 \times 1000 \times \phi 4$	
29	1	Helpvane	1 mm sheet	1000 $\times$ 500
30	1	Tailvane	1 mm sheet	2000 $\times$ 1000
31	3	Washer	$\phi 18$ inside	
32	1	Rod	$\phi 18 \times 650$	( $\phi 3/4"$ $\times$ 2'2")
33	1	Split pin	$\phi 6$	( $\phi 1/4"$ )
34	12	Bolt, nut, washer	M 6 $\times$ 25	(W ¼" $\times$ 1")
35	1	"	M 12 $\times$ 100	(W ½" $\times$ 4")
36	1	"	M 10 $\times$ 150	(W ¾" $\times$ 6")
37	2	"	M 12 $\times$ 40	(W ½" $\times$ 1½")

HAMMERING PROFILES INTO  
THE VANE SHEET INCREASES  
RIGIDITY



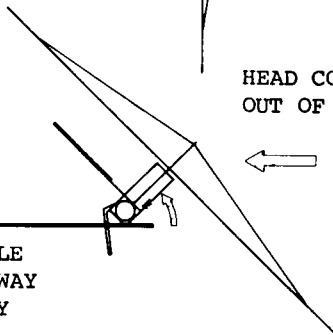
AFTER PROFILING  
THE EDGES ARE  
BENT OVER



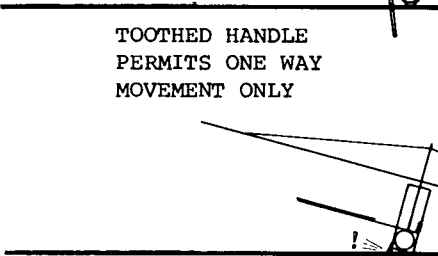
HELPVANE OPENS TAIL  
LOCKS DUE TO HIGH WIND PRESSURE



HEAD CONSTRUCTION TURNS BACKWARDS  
OUT OF THE WIND

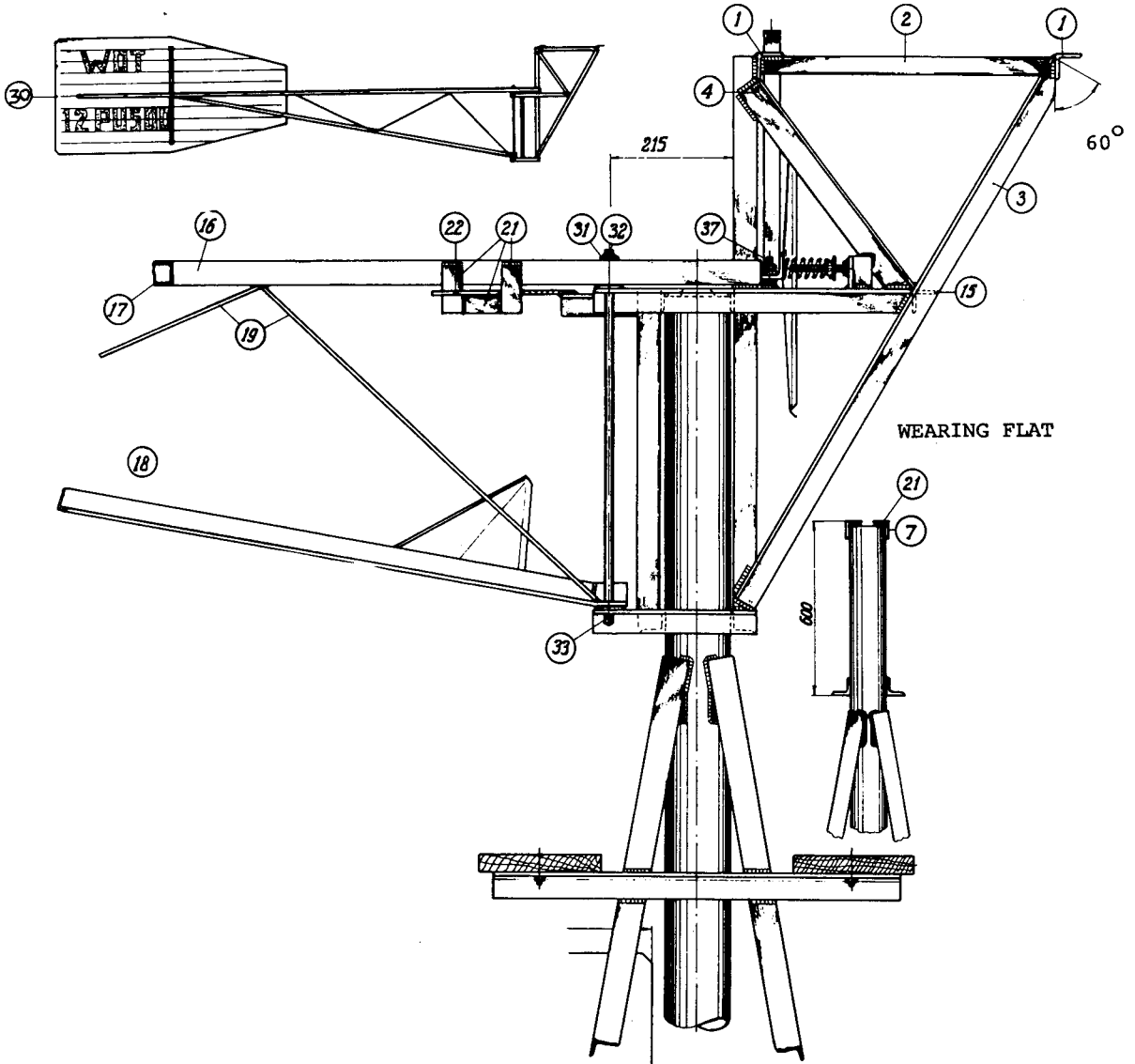


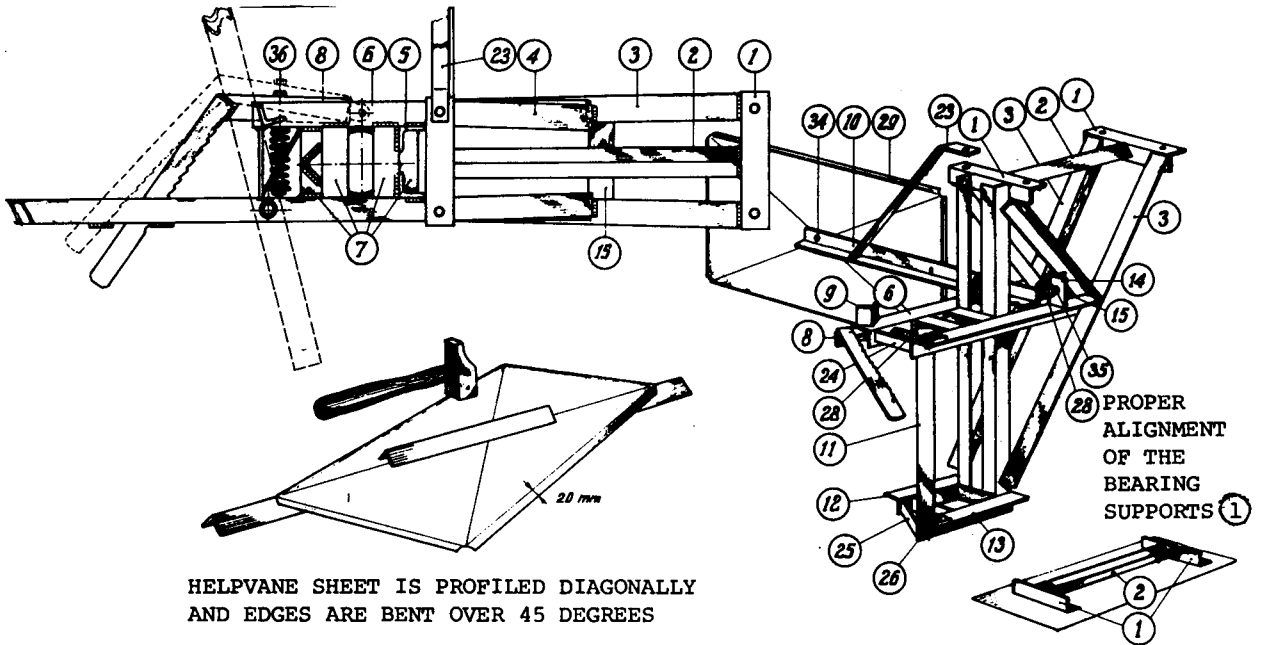
TOOTHED HANDLE  
PERMITS ONE WAY  
MOVEMENT ONLY



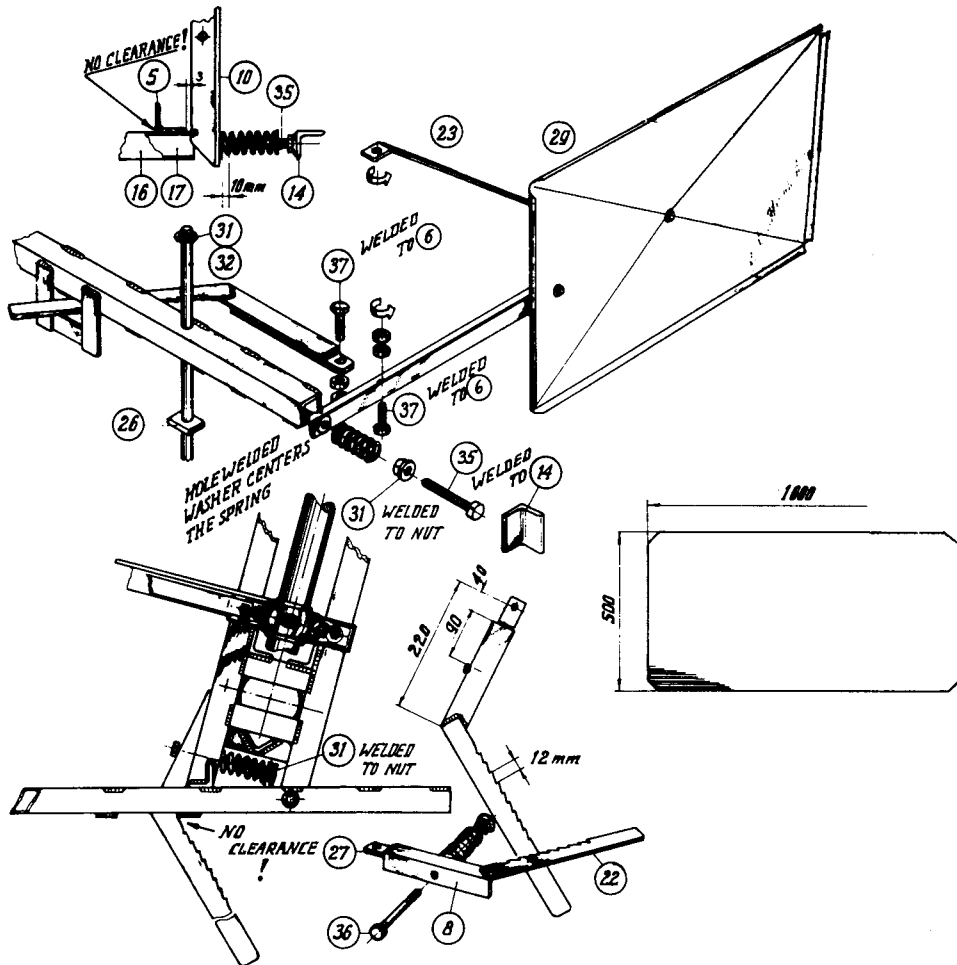
IMPACT IS TAKEN BY  
LIMIT-STOP ANGLE ⑨

LOCK MECHANISM KEEPS WINDMILL IN  
SECURED POSITION (75° OUT OF THE WIND)





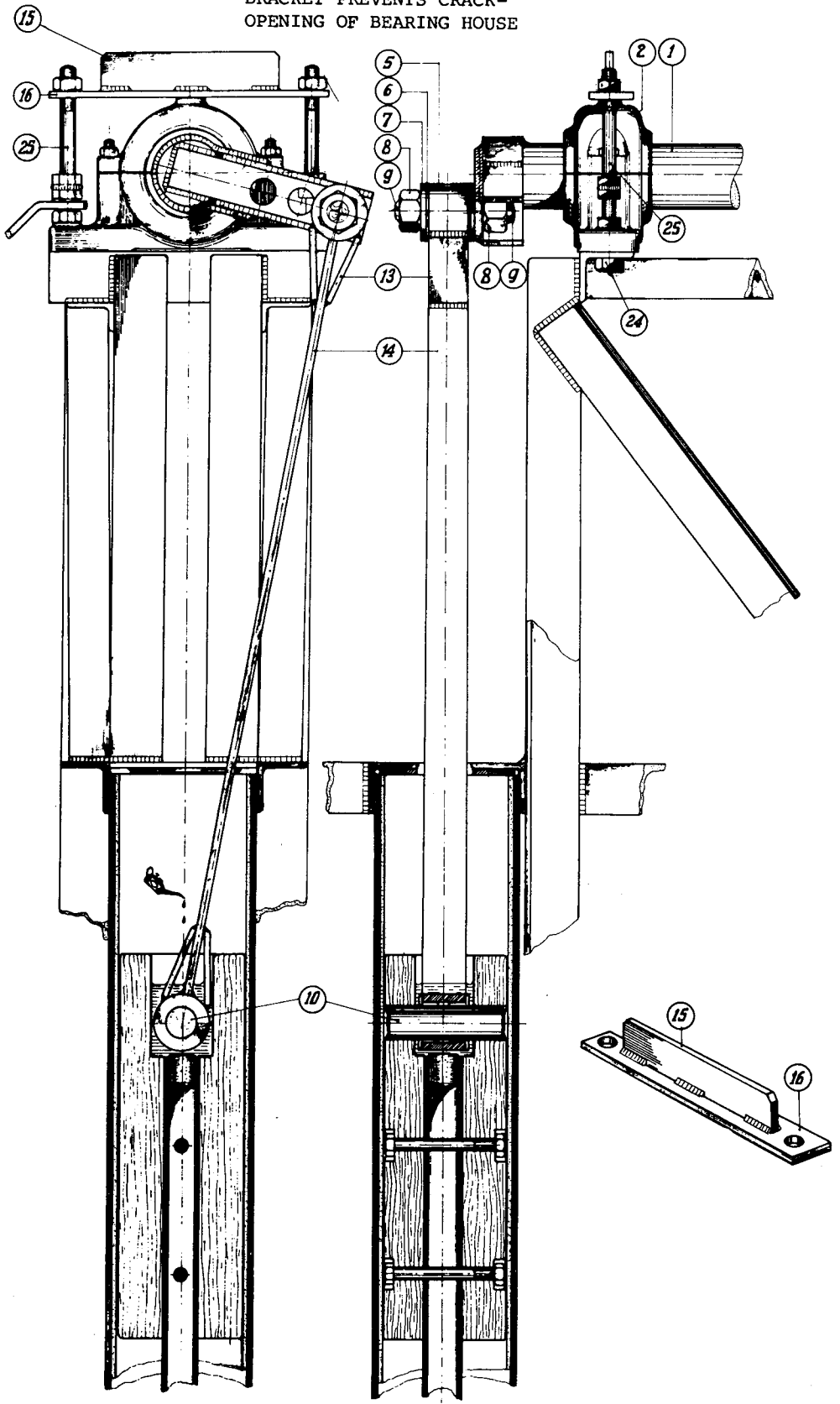
HELPPVANE SHEET IS PROFILED DIAGONALLY AND EDGES ARE BENT OVER 45 DEGREES

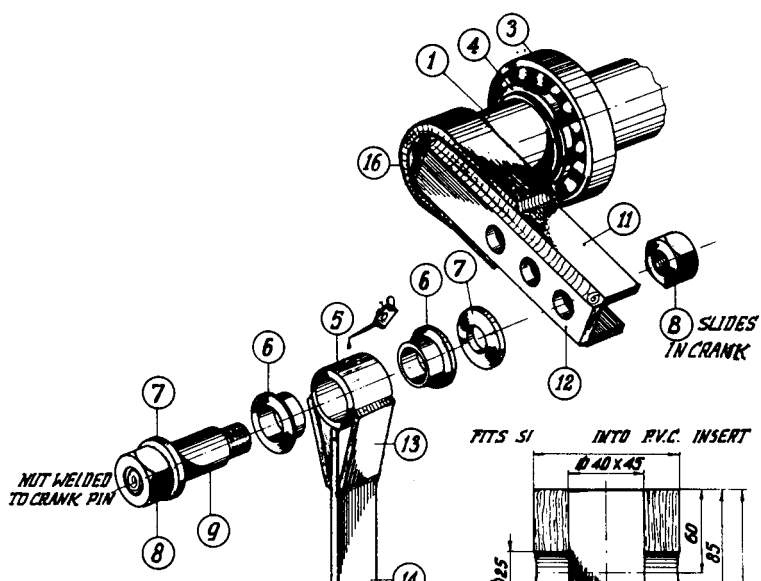


## Moving parts

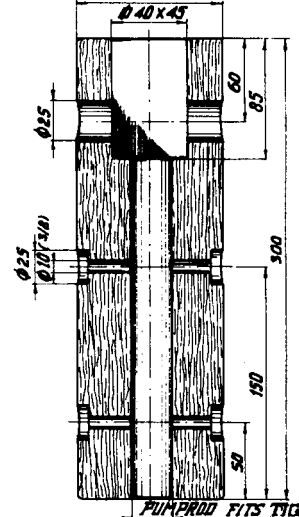
No	Number required	Materials, particulars and measurements	
1	1	Shaft	$\phi 50 (\phi 2") \times 1250$
2	2	Bearing housing	
3	2	Ball bearing (best quality)	
4	2	Bearing bush (best quality)	
5	2	Bearing housing	
6	4	Nylon bearing bush	$\phi 1\frac{1}{2}"$ nylon rod
7	2	Washer	
8	3	Nut M 20 (W $\frac{3}{4}"$ )	
9	1	Crank pin $\phi 25 (\phi 1")$	
10	1	Cross pin $\phi 25 (\phi 1")$ remove sharp edges	
11	2	Flat iron $30 \times 6 (1\frac{1}{4}" \times \frac{1}{4}"$ )	Length 120
12	1	„	150
13	4	„	50
14	1	„	600
15	1	„	140
16	2	„	220
17	1	Cross head	Sesam wood soaked in oil
18	1	Cork	
19	1	Pump rod	Gaspipes $\phi \frac{3}{4}" \times 4700$
20	1	PVC insert	$\phi 100 \times 700$
21	1	Thread, stud	M 24 $\times$ 75 (W $\frac{7}{8}" \times 4"$ )
22	2	Bolt, nut, washers	M 6 $\times$ 25 (W $\frac{1}{4}" \times 1"$ )
23	1	„	M 10 $\times$ 100 (W $\frac{3}{8}" \times 4"$ )
24	4	„	M 12 $\times$ 50 (W $\frac{1}{2}" \times 2"$ )
25	2	„	M 12 $\times$ 80 (W $\frac{1}{2}" \times 3"$ )
26	1	Pump rod guide	Sesam wood soaked in oil

BRACKET PREVENTS CRACK-  
OPENING OF BEARING HOUSE

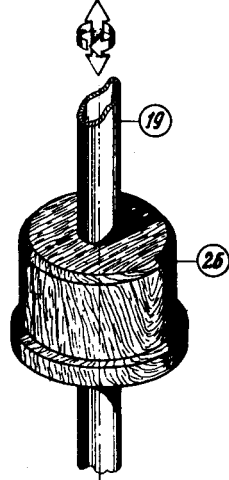
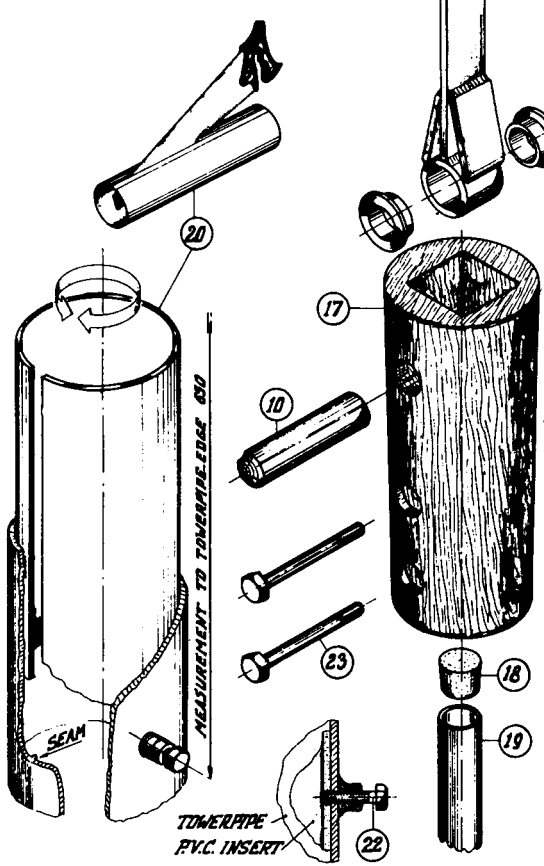
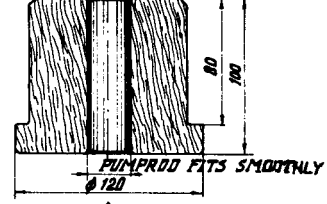




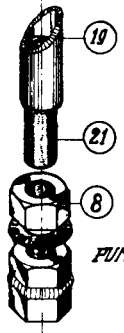
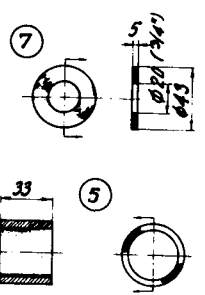
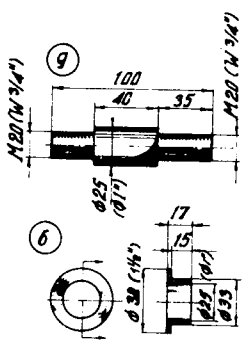
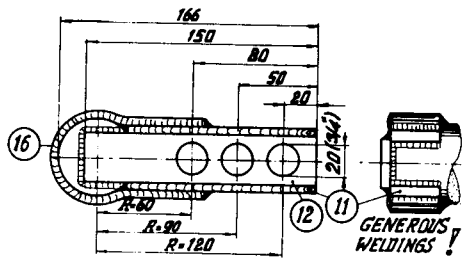
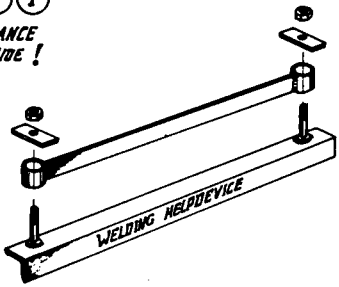
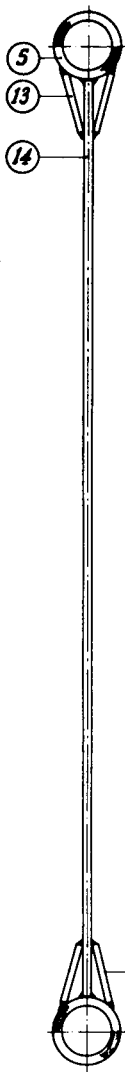
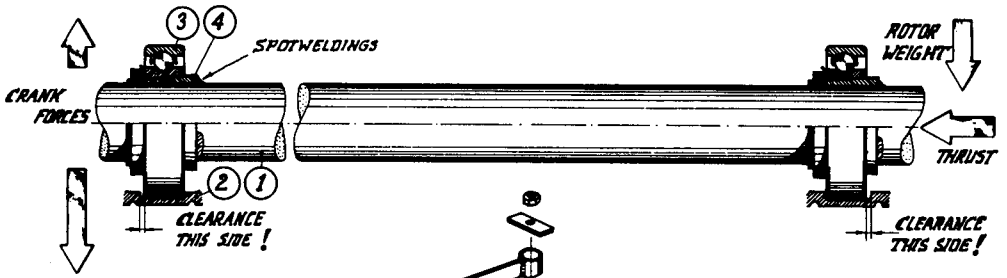
FITS SI INTO P.V.C. INSERT



FITS BY HAMMERING INTO BOTTOM END OF TOWER PIPE







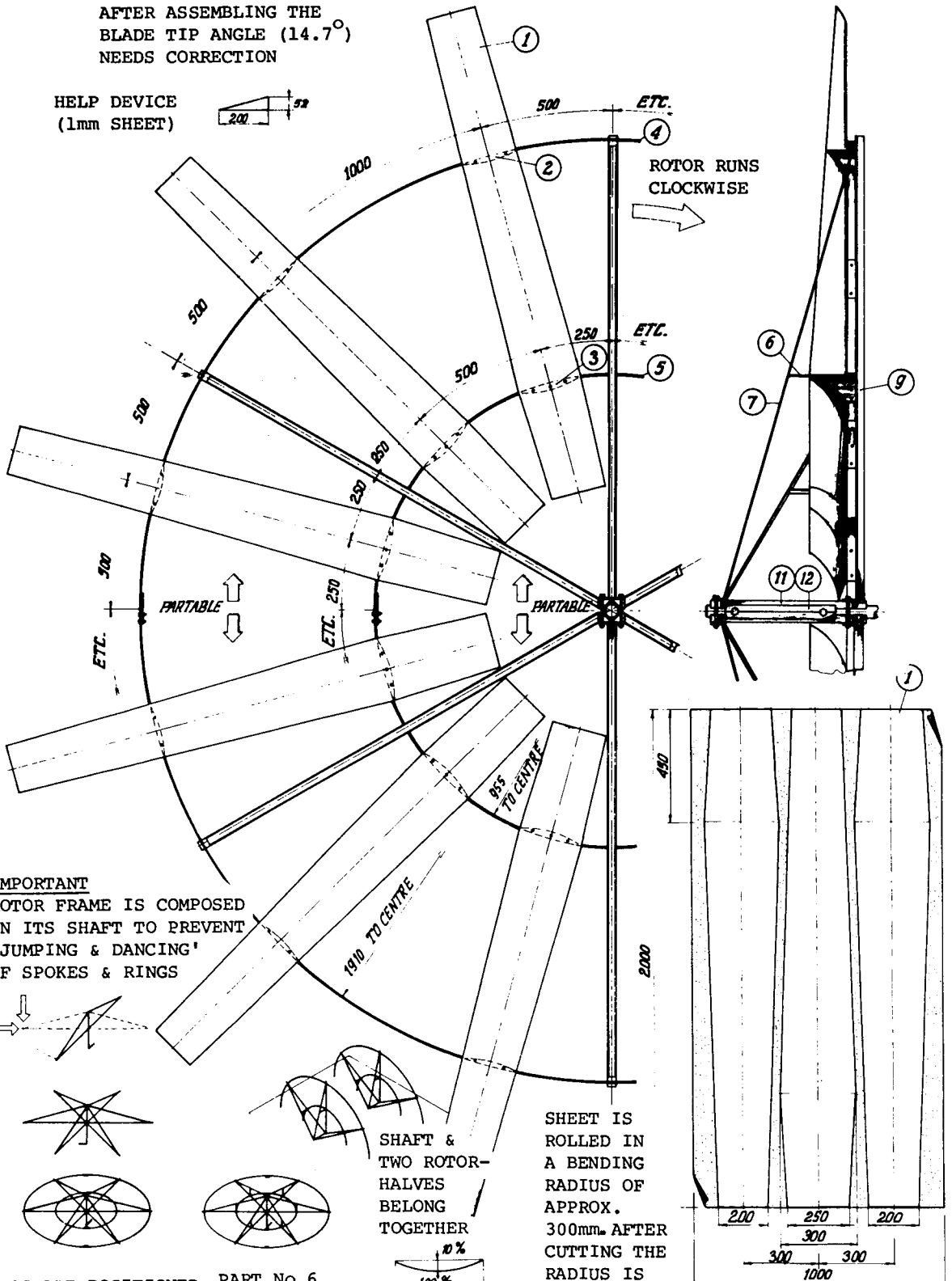
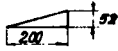
PUMP ROD CONNECTION

# Rotor

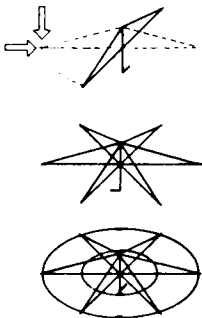
No	Number required	Materials, particulars and measurements		
1	12	Blade	4 standard sheets 1000 × 2000 × 1	
2	12	Blade support	2 mm sheet	
3	12	„	„	
4	1	Flat iron	30 × 6 (1¼" × ¼")	2 × 6000
5	1	„	„	2 × 3000
6	6	„	„	× 250
7	6	„	„	× 1900
8	4	„	„	× 120
9	6	Angle iron	40 × 40 × 4 (1½" × 1½")	× 1900
10	4	„	„	× 100
11	2	„	„	× 625
12	2	„	„	× 350
13	2	Bolt, nut, washer	M 12 × 125 (W ½" × 5")	
14	4	„	M 12 × 100 (W ½" × 4")	
15	120	„	M 6 × 20 (W ¼" × ¾")	

AFTER ASSEMBLING THE  
BLADE TIP ANGLE ( $14.7^\circ$ )  
NEEDS CORRECTION

HELP DEVICE  
(1mm SHEET)



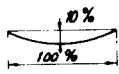
**IMPORTANT**  
ROTOR FRAME IS COMPOSED  
ON ITS SHAFT TO PREVENT  
'JUMPING & DANCING'  
OF SPOKES & RINGS



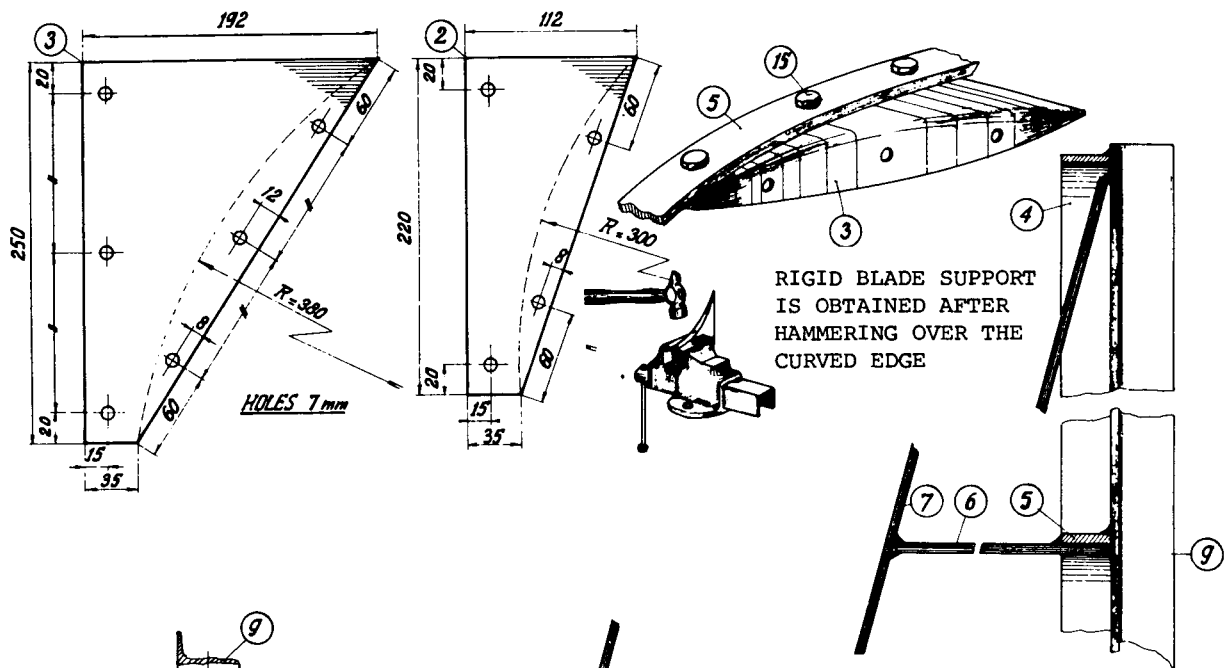
RINGS ARE POSITIONED,  
CENTRED AND WELDED

PART No.6  
IS WELDED

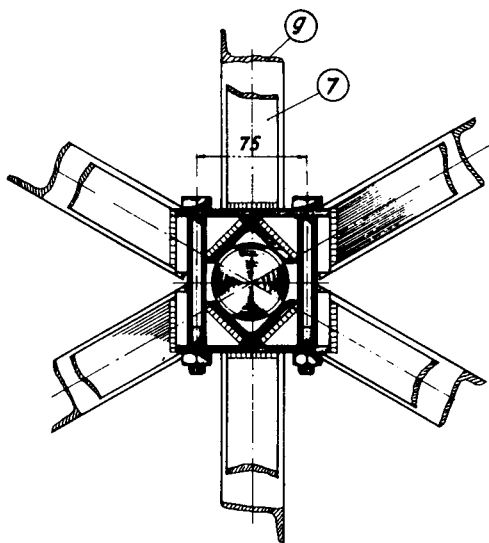
SHAFT &  
TWO ROTOR-  
HALVES  
BELONG  
TOGETHER



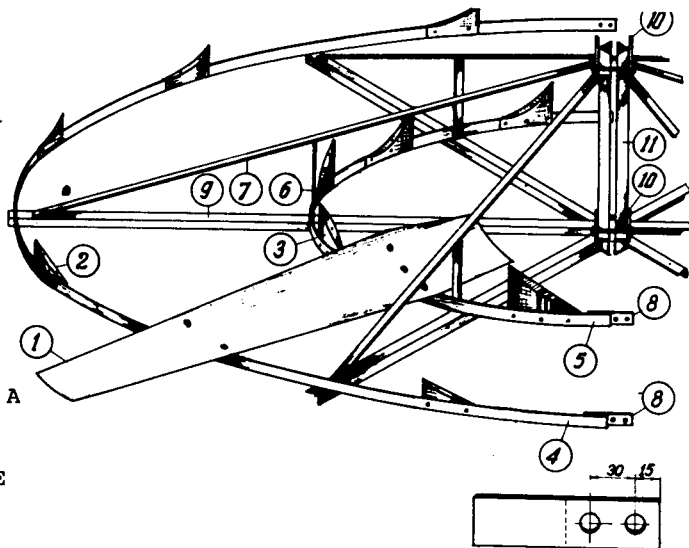
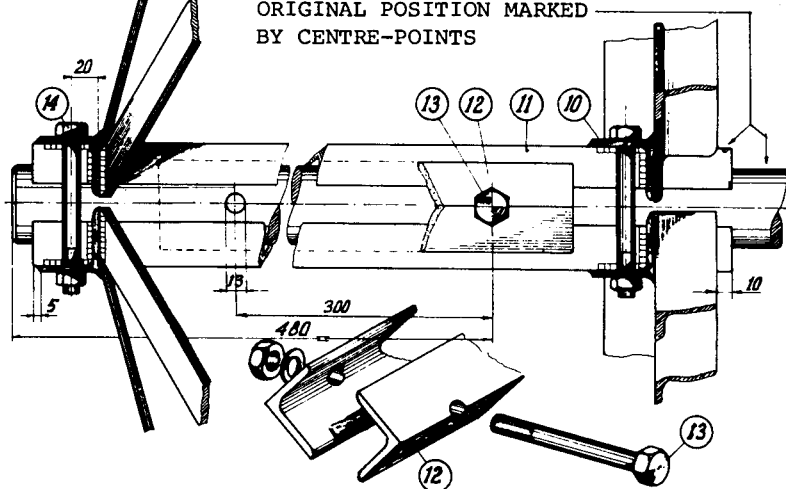
SHEET IS  
ROLLED IN  
A BENDING  
RADIUS OF  
APPROX.  
300mm. AFTER  
CUTTING THE  
RADIUS IS  
CORRECTED SO  
THAT 10% CURVED  
AIRFOILS WILL  
RESULT



RIGID BLADE SUPPORT IS OBTAINED AFTER HAMMERING OVER THE CURVED EDGE



ORIGINAL POSITION MARKED BY CENTRE-POINTS

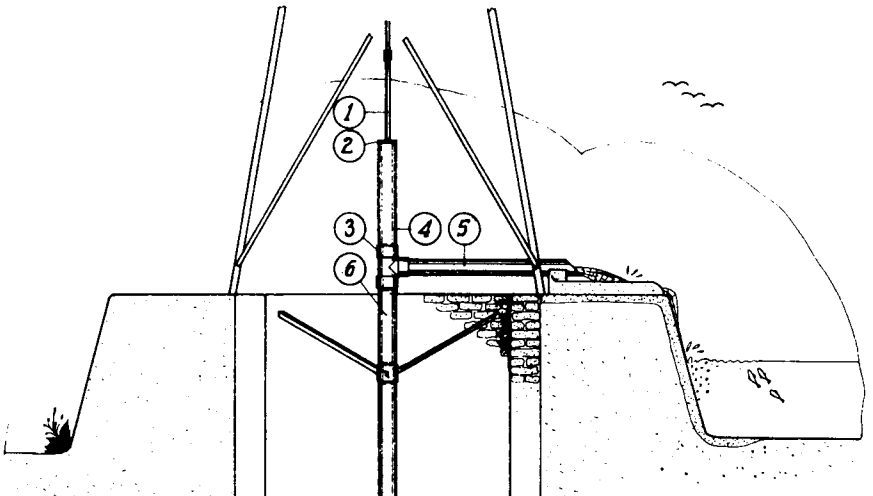


ONE OF THE BLADES IS MOUNTED ON A WELL POSITIONED SET OF SUPPORTS (AVERAGE MEASUREMENTS) AND IS USED AS A DRILLING MOULD FOR THE OTHER 11 BLADES

# Piston pump

No	Number required	Materials, particulars and measurements	
1	*	Pump rod extension	$\phi 3/4"$ gaspipe *
2	1	Wooden pump rod guide: 26 in Fig. 6.14	
3	1	T-socket	4" gaspipe Length 750
4	1	Delivery pipe	"
5	1	"	4" gaspipe or PVC pipe *
6	*	"	" *
7	1	PVC pipe	$\phi 4" \times 700$
8	1	Gaspipe (threaded)	$\phi 4" \times 800$
9	*	Steel socket	G 4"
10	1	PVC end cap	
11	2	Flange (blind):	four 12 mm holes at 190 mm pitch
12	1	PVC pipe	$\phi 150 (\phi 6") \times 1250$
13	1	"	" $\times 740$
14	1	Piston	teakwood
15	1	PVC socket	
16	1	Foot valve	teakwood
17	3	Flat iron	25 $\times$ 5 (1" $\times$ 1/4")
18	*	"	30 $\times$ 6 (1 1/4" $\times$ 1/4")
19	*	Angle iron	40 $\times$ 40 $\times$ 4 (1 1/2" $\times$ 1 1/2") *
20	2	Sole-leather valve	$\phi 150 \times$ at least 6 mm
21	4	" packing	$\phi 140 \times \phi 200 \times 4$
22	1	Steel bush	
23	1	Nylon bearing bush	
24	*	Pump rod gaspipe	$\phi 3/4" \times 1300$
25	*	Thread stud	M 24 (W 7/8") $\times$ 75
26	*	"	" $\times$ 150
27	*	Nut	
28	*	Spring washer	
29	4	Rod	$\phi 12 (\phi 1/2") \times 2100$
30	1	Bolt, nut, washer	M 12 (W 1/2") $\times$ 150
31	*	"	" $\times$ 30
32	1	Bicycle tube valve	(apply rubber washers)
33	1	Distancer	steel $\phi 50 \times 50 (\phi 2" \times 2")$

\* Amount and size depend upon total elevation head



EXISTING BRICK WELL

'UMBRELLA' STRUCTURE CENTRES DELIVERY PIPE (ANGLES ARE APPROX. 10% LONGER THAN THE RADIUS OF WELL)

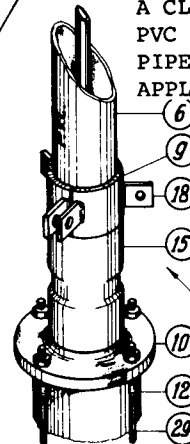
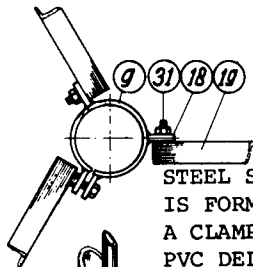
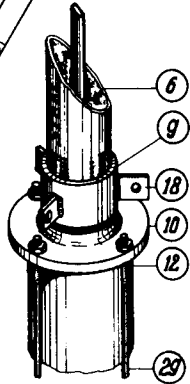
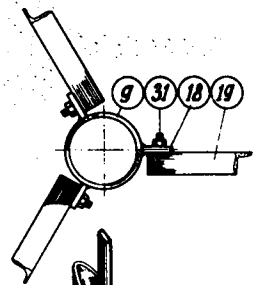
PRESSURE SECTION

SUCTION SECTION

4" TUBEWELL INCREASES WELL CAPACITY (MIN. APPROX. 30M<sup>3</sup>/H)

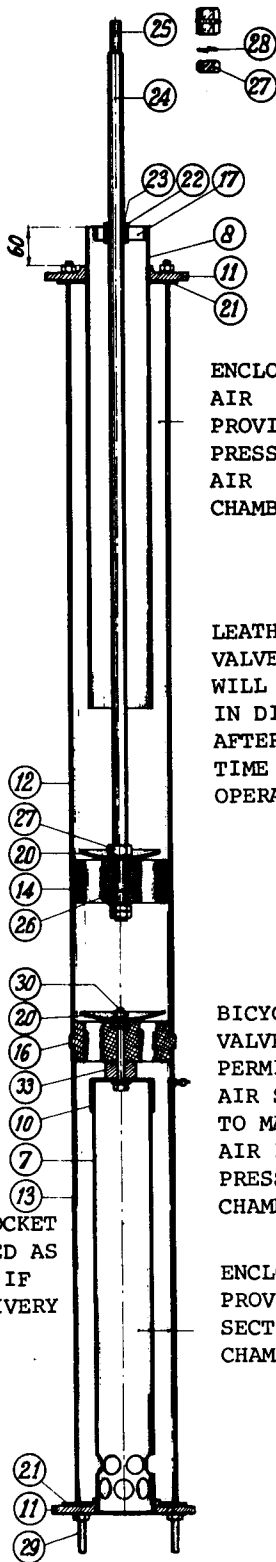
TO AQUIFER





STEEL SOCKET IS FORMED AS A CLAMP IF PVC DELIVERY PIPE IS APPLIED

IF PVC PIPE IS USED (6) AN EXTRA PVC SOCKET 15 IS FIXED TO THE UPPER END OF (7)

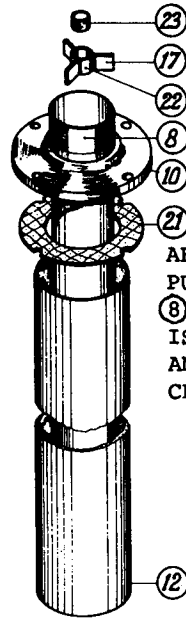


ENCLOSED AIR PROVIDES PRESSURE AIR CHAMBER

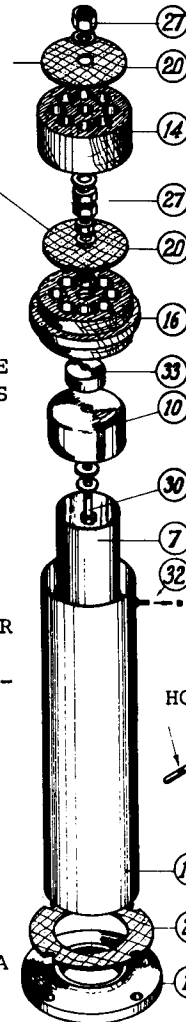
LEATHER VALVES WILL SHRINK IN DIAMETER AFTER SOME TIME OF OPERATION

BICYCLE TUBE VALVE CAUSES PERMITTED AIR SUCTION TO MAINTAIN AIR IN PRESSURE CHAMBER

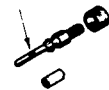
ENCLOSED AIR PROVIDES SECTION AIR-CHAMBER

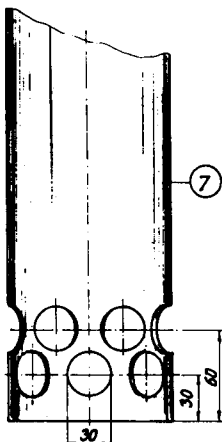
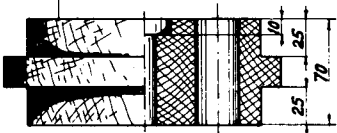
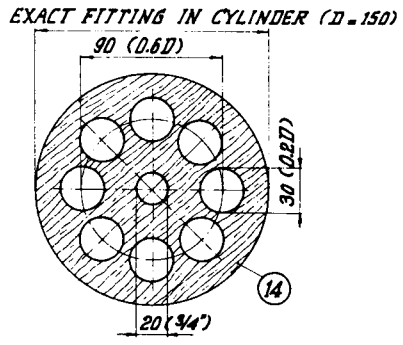
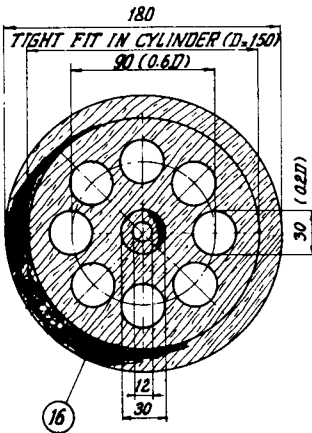
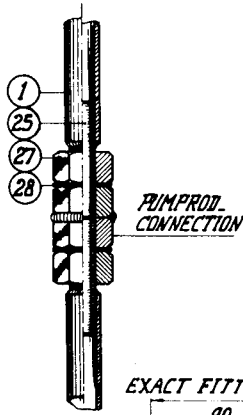
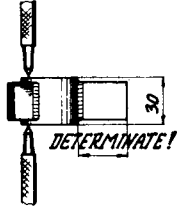
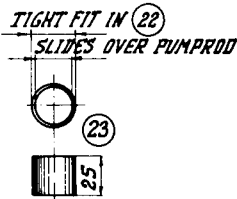
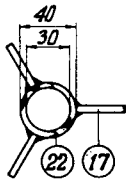


AFTER WELDING THE PUMPROD GUIDE IN (8) THE NYLON BUSH IS FORCED IN (22) AND LOCKED BY CENTRE PUNCHING



HOLE REMAINS OPEN





TWO ROWS OF 6 HOLES FOR WATER ENTRANCE.

AFTER SOAKING THE WOOD IN WATER FOR AT LEAST ONE WEEK, THE PISTON IS MACHINED TO A PERFECT SLIDING FIT.

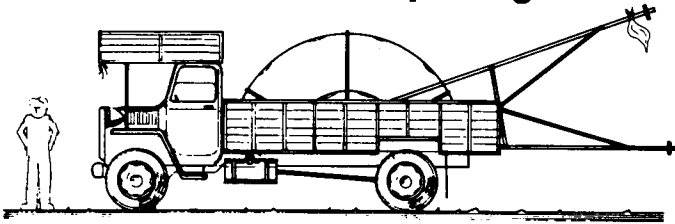
THE SEALINGLESS PERFORMANCE DECREASES STARTING TORQUE REQUIRED DUE TO ACCEPTABLE LEAKAGE SO THE WINDMILL BEGINS TO MOVE AT LOW WIND SPEEDS



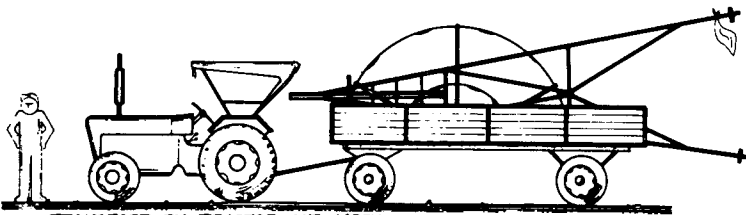
# Installing the windmill

No	Number required	Materials, particulars and measurements
1	1	Pulley shaft and rope or steel cable (30 M)
2	1	Gaspipe $\phi 3'' \times 4500$
3	2	Angle iron $40 \times 40 \times 4 (1\frac{1}{2}'' \times 1\frac{1}{2}'')$ $\times 2000$
4	3	„ „ $\times 750$
5	1	„ „ $\times 800$
6	1	„ „ $\times 200$
7	1	„ „ $\times 550$
8	3	Flat iron $30 \times 6 (1\frac{1}{4}'' \times \frac{1}{4}'')$ $\times 200$
9	1	„ „ $\hat{=}$ tower pipe dia.
10	1	„ „ $30 \times 6 (1\frac{1}{4}'' \times \frac{1}{4}'')$ $\times 100$
11	1	Rod $\phi 10 (\phi \frac{3}{8}'')$ $\times 200$
12	2	Bolt, nut, washer M 12 $\times 50$ (W $\frac{1}{2}'' \times 2''$ )
13	1	„ M 12 $\times 150$ (W $\frac{1}{2}'' \times 6''$ )
14	2	„ M 12 $\times 75$ (W $\frac{1}{2}'' \times 3''$ )

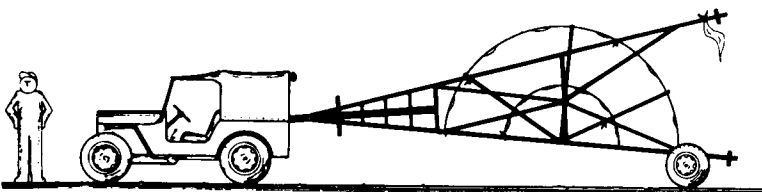
## Three methods of transporting the windmill



TRANSPORT BY TRUCK

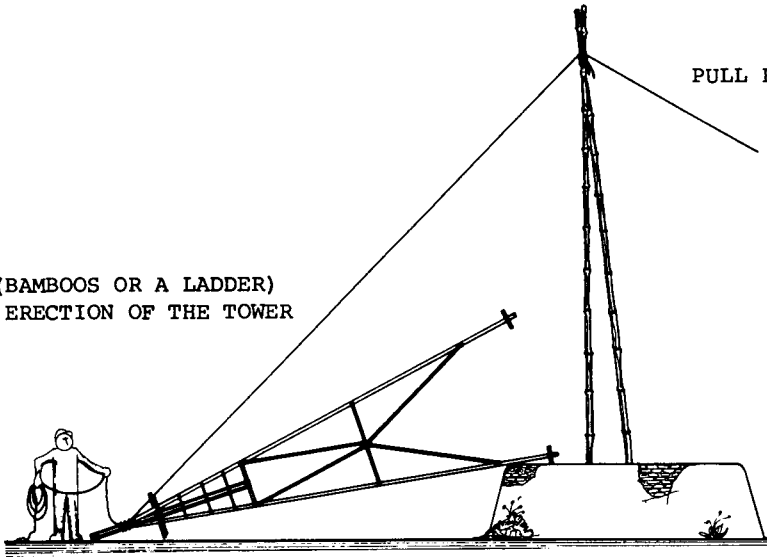


TRANSPORT BY TRACTOR AND LORRY



TRANSPORT BY JEEP AND ROLLING HELPDEVICE

TWO POLES (BAMBOOS OR A LADDER)  
FACILITATE ERECTION OF THE TOWER

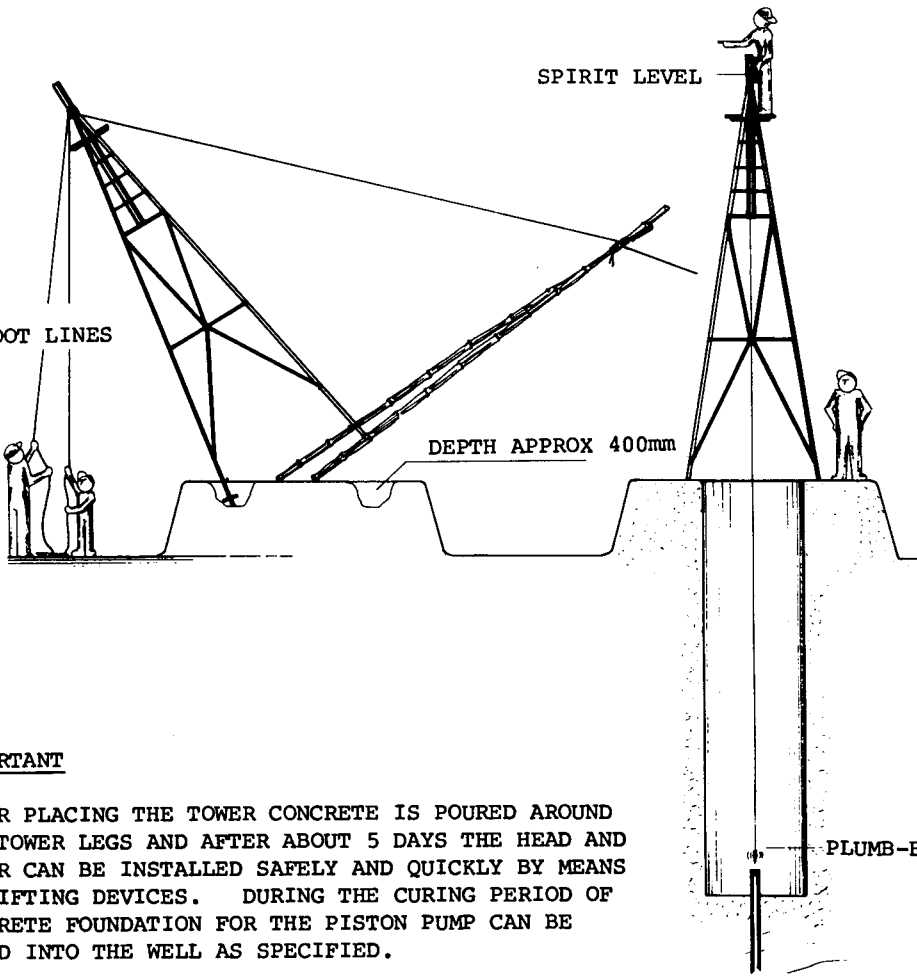


PULL ROPE BY MEN

OVERSHOOT LINES

SPIRIT LEVEL

DEPTH APPROX 400mm



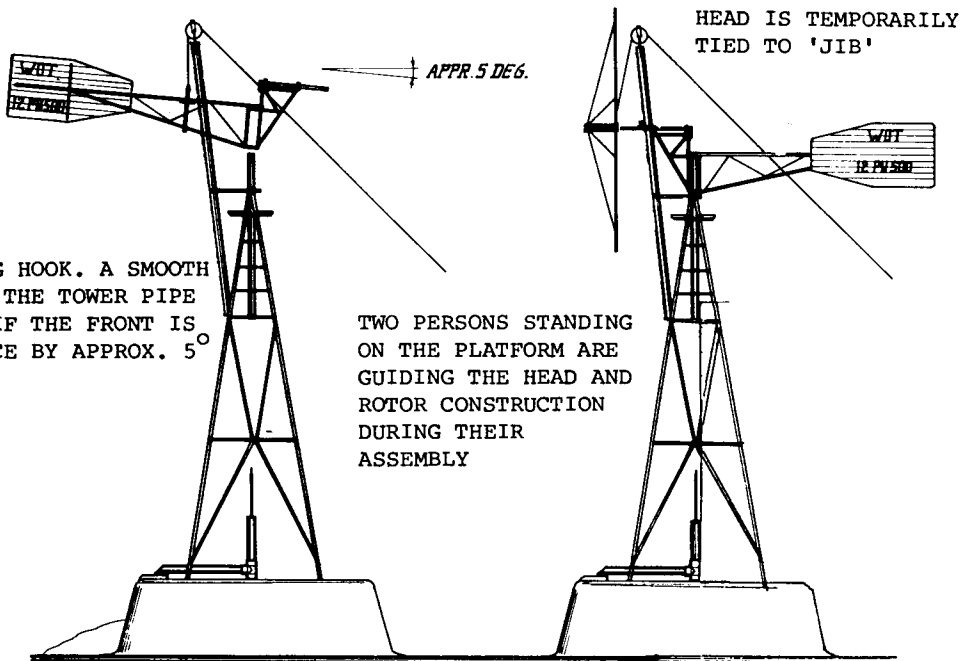
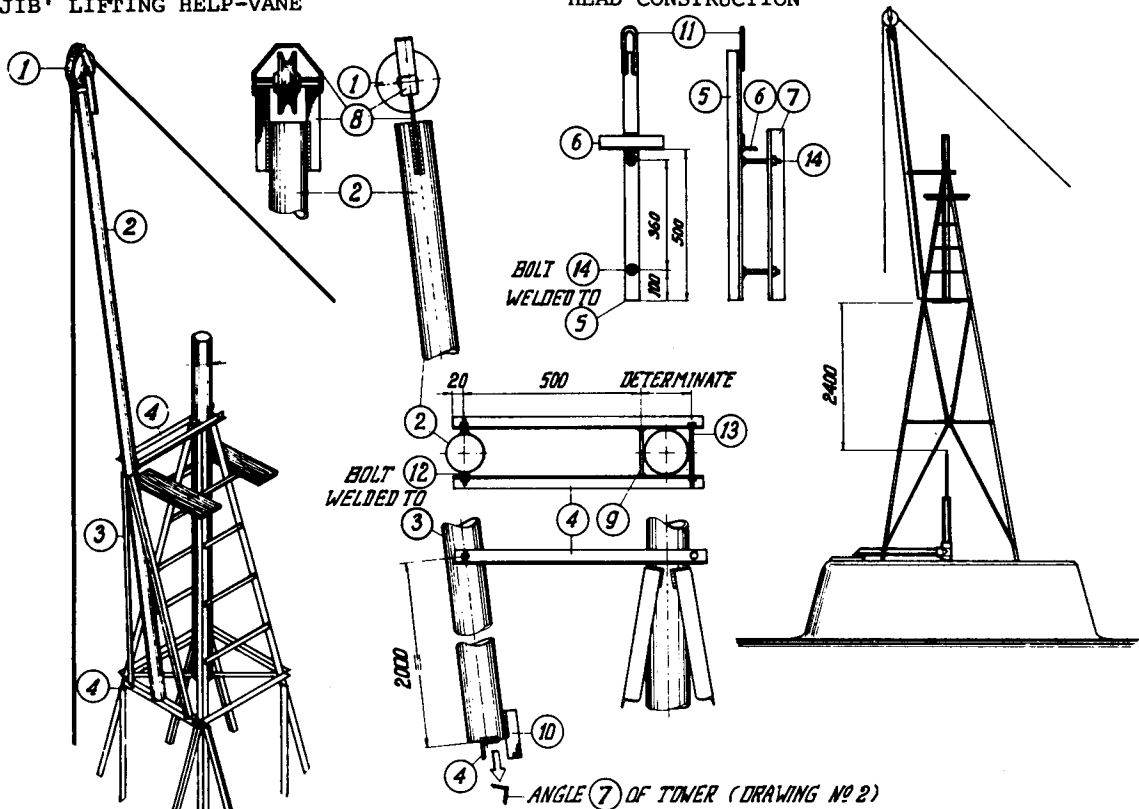
PLUMB-BOB

**IMPORTANT**

AFTER PLACING THE TOWER CONCRETE IS POURED AROUND THE TOWER LEGS AND AFTER ABOUT 5 DAYS THE HEAD AND ROTOR CAN BE INSTALLED SAFELY AND QUICKLY BY MEANS OF LIFTING DEVICES. DURING THE CURING PERIOD OF CONCRETE FOUNDATION FOR THE PISTON PUMP CAN BE FIXED INTO THE WELL AS SPECIFIED.

'JIB' LIFTING HELP-VANE

LIFTING HOOK FOR HEAD CONSTRUCTION



ROTOR IS LIFTED AND POSITION AT THE TOP OF ITS SHAFT AND SHIFTED IN ITS ORIGINAL POSITION AND FIXED. REMOVE 'JIB' AND ASSEMBLE BLADES, SAFETY DEVICE AND MOVING PARTS.

**8.0 Installation**  
**12-PU-500**  
**Water Pumping Windmill**

**INSTALLATION OF WINDMILL:**

**8.1 General**

The following windmill parts are supposed to be prefabricated: tower, head construction, moving parts, rotor frame and blades, and the pump section. In addition to these, some more essential steps to be taken are listed here. First of all the parts are composed partly in order to check the fit. The head construction may be put on the tower to find out if it rotates smoothly over the crosshead and the connecting rod. The fit of some blades is also to be checked (at random). Until and unless these checks are confirmed the windmill is not ready for transport. Another important thing with regard to windmill installation should not be forgotten. Help devices like the jib crane and lifting hook, which are represented in the drawing, are not only helpful but are a must from the safety point of view.

The use of the jib crane is really necessary for lifting the head construction and rotor both. While fabricating the jib crane care should be taken to see that the pulling rope runs nicely in the pulley and cannot run off:

The lifting hook is a help device which provides a suitable attachment to the head construction which is situated above the point of gravity of the latter. One can imagine what happens if no lifting hook is applied: the head construction tumbles over and nobody will be able to handle it during the procedure of lifting and installing it.

**8.2 Tools & tackle required during installation:**

1. Spirit level	1
2. Plumb with 20 m fisher nets string	1
3. Steel tape (15 metre)	1
4. Manila rope 1½" x 30 metre long	one
5. Manila rope ¾" x 20 metre long	one
6. Mason's tool kit set	one set
7. Jib crane	1
8. Winch and wire rope 20 metres long x ½" or (chain pulley with chain 1½" size x 20 metres long)	one
9. Chain wrench (4" pipe size)	1
10. Chain wrench (4" B.S.P. pipe size)	2
11. Pipe wrench (2" pipe size)	1
12. Ball pin hammer 2 lb. with handle	1
13. Hand hacksaw with 6 spare blades	1
14. Double ended spanner set	1 set
15. Ring spanner set	1 set
16. Adjustable slide wrench 12" long	1
17. Bastered double cut flat file 12"	1
18. Round file rough 10" x 3/8" Dia.	1
19. Wood file 12"	1
20. Small grease gun	1

21. Chisel 6" (Flat)	1
22. Water Pump Plier	1
23. Screw Driver 6"	1
24. Screw driver 8"	1
25. Centre Punch	1
26. Hand drill with drilling capacity 1/2" Dia.	1
27. Drill bits (Straight Shank) 1/2"	1
28. Drill bits 3/8" Dia.	3
29. Drill bits 5/8" Dia. with reduced shank	1

\* Hand tools should be of standard make such as Gedore, Taparia, Everest or equivalent.

8.3 Illustration showing the position of Tower Foundation Bolts.  
(Refer. Fig. 8)

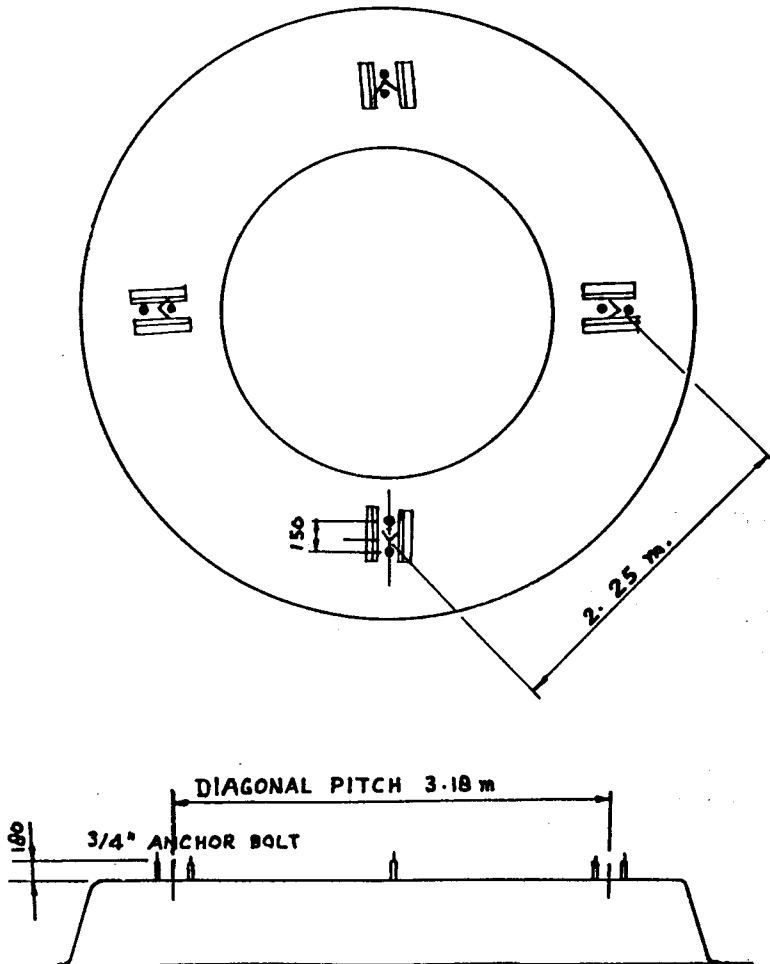


Fig.8 Position of Tower Foundation Bolt

- 8.4 Details of Infra-structure to be prepared before the erection of the windmill.  
(Refer Fig. 9, 10 & 11)
- 8.5 Details of Sub-structure and Puca alignment fixture of 12-PU-500  
Water Pumping Windmill  
(Refer Fig. 12)

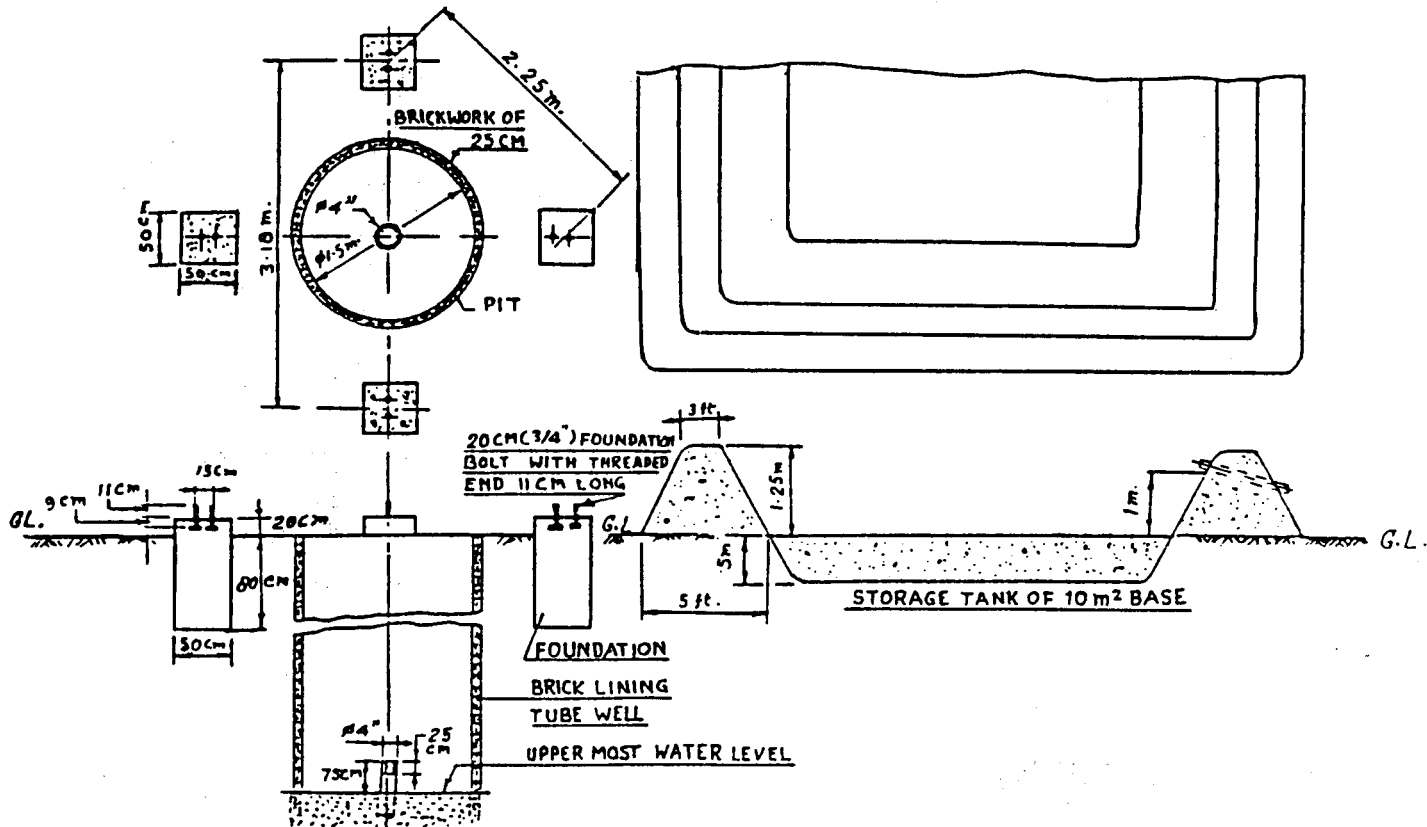
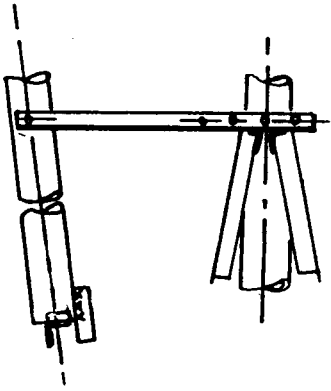
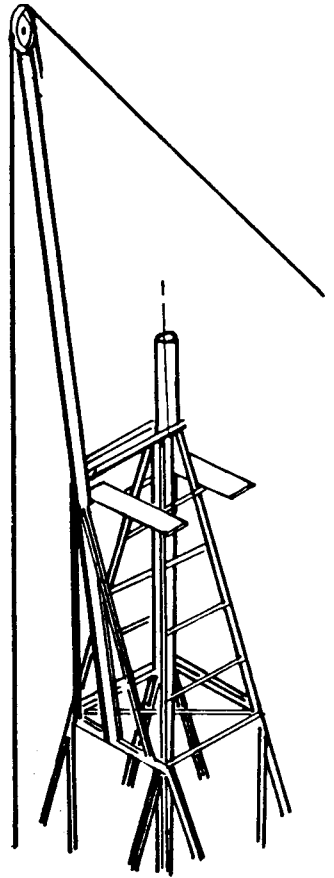


Fig. 9 Details of infrastructure to be prepared before erection of windmill

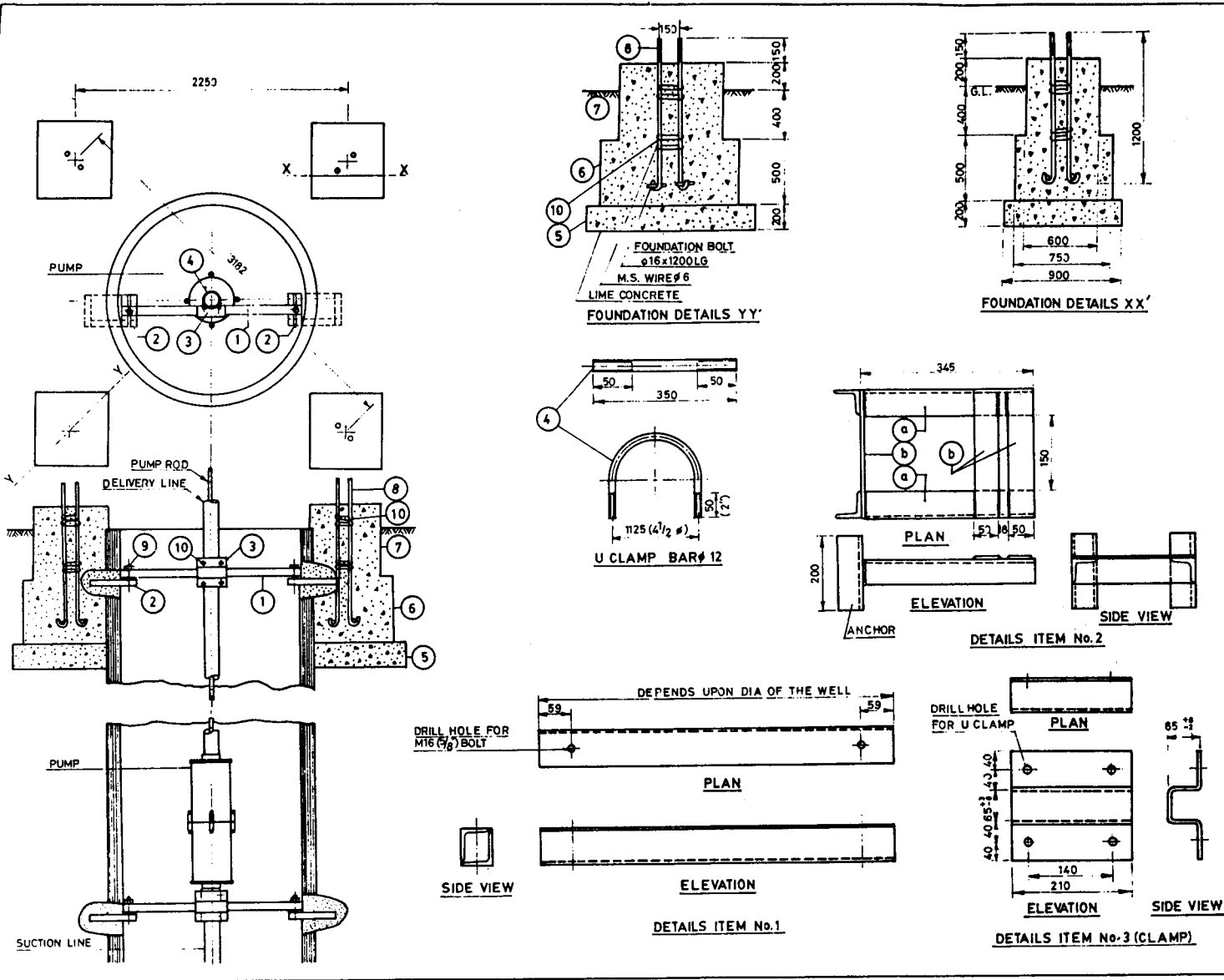


*Fig. 10*



*Fig. 11*

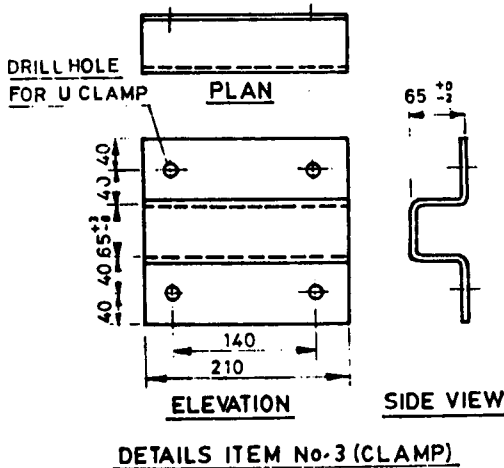
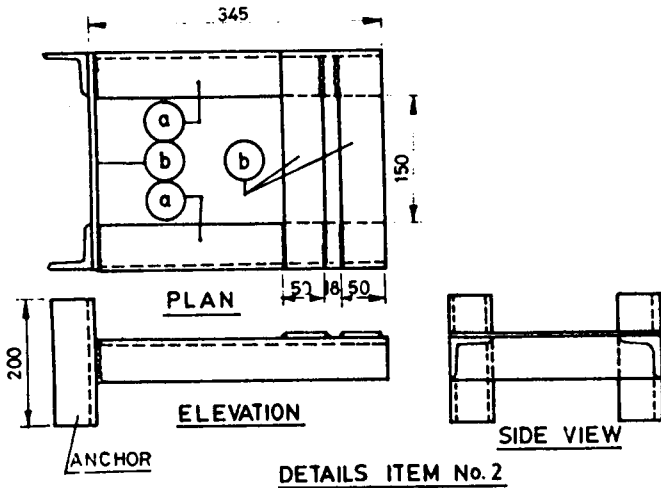
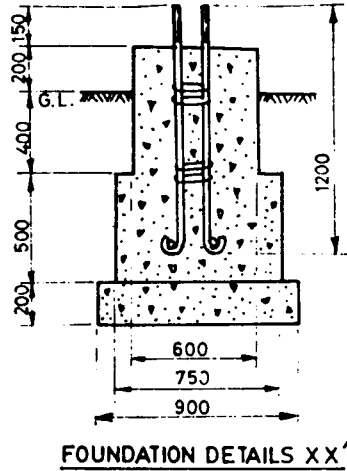
*Fixing of Jibcrane on the Tower*



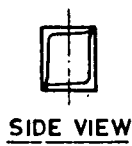
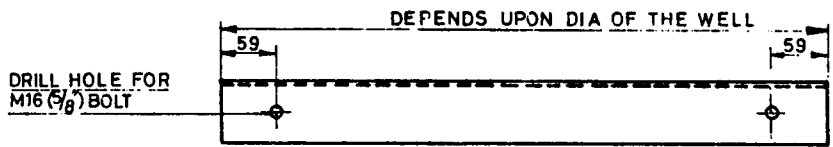
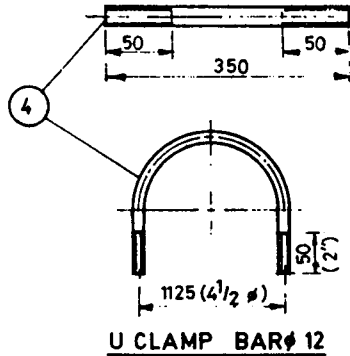
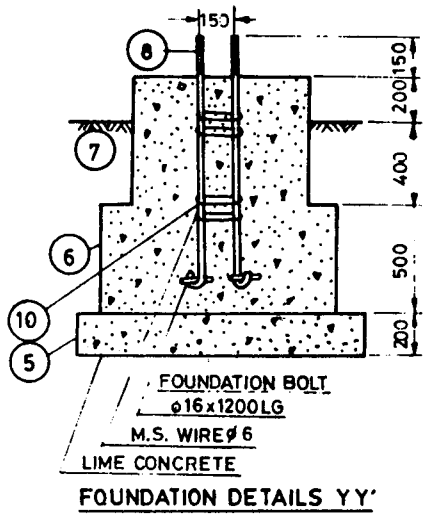
10.	WIRE	φ 8		
9.	NUT, POLT, WASHER	φ M16 x 100 (5/8" x 4)		
8.	FOUNDATION BOLT	φ 16 x 1200 LONG		
7.	SECOND STEP		M15 MIX CONCRETE 1:2:4 CEMENT FINE AGGREGATE COARSE AGGREGATE	
6.	FIRST STEP	750 x 750 x 500	DO	
5.	BOTTOM STEP	900 x 900 x 200	1:2:4 LIME CONCRETE	WELL RAMMED
4.	U CLAMP (4 No.)	BAR φ 12 (1/2") LENGTH 350 ± 14"	FOR φ 4" PIPE	FOR ONE TRUSS
3.	M. S. PLATE (1 No.)	THICKNESS 4 SIZE 355 x 250		FOR ONE TRUSS
2.	a M.S. ANGLE (2 No.) b M.S. PLATE (3 No.)	SIZE 50 x 50 x 6 LENGTH 345 SIZE 50 x 4 LENGTH 250		
1.	TRUSS M.S. ANGLE (2 No.)	LENGTH IN INSIDE OF WELL OR PIT SIZE 65 x 65 x 6		TRUSS DIMENSION WILL VARY WITH THE φ CONSIDER THE WELL DIA.
SL No.	ITEM	L B D H	SPECIFICATION	REMARKS
DETAILS OF SUB STRUCTURE AND PUMP ALIGNMENT FIXTURE OF 12 PU 500 WINDMILL				
FOR INFORMATION	INSTITUTE OF ENGG. & RURAL TECHNOLOGY (Near Prayag Rly. Stn.) ALLAHABAD 211002			

Fig. 12

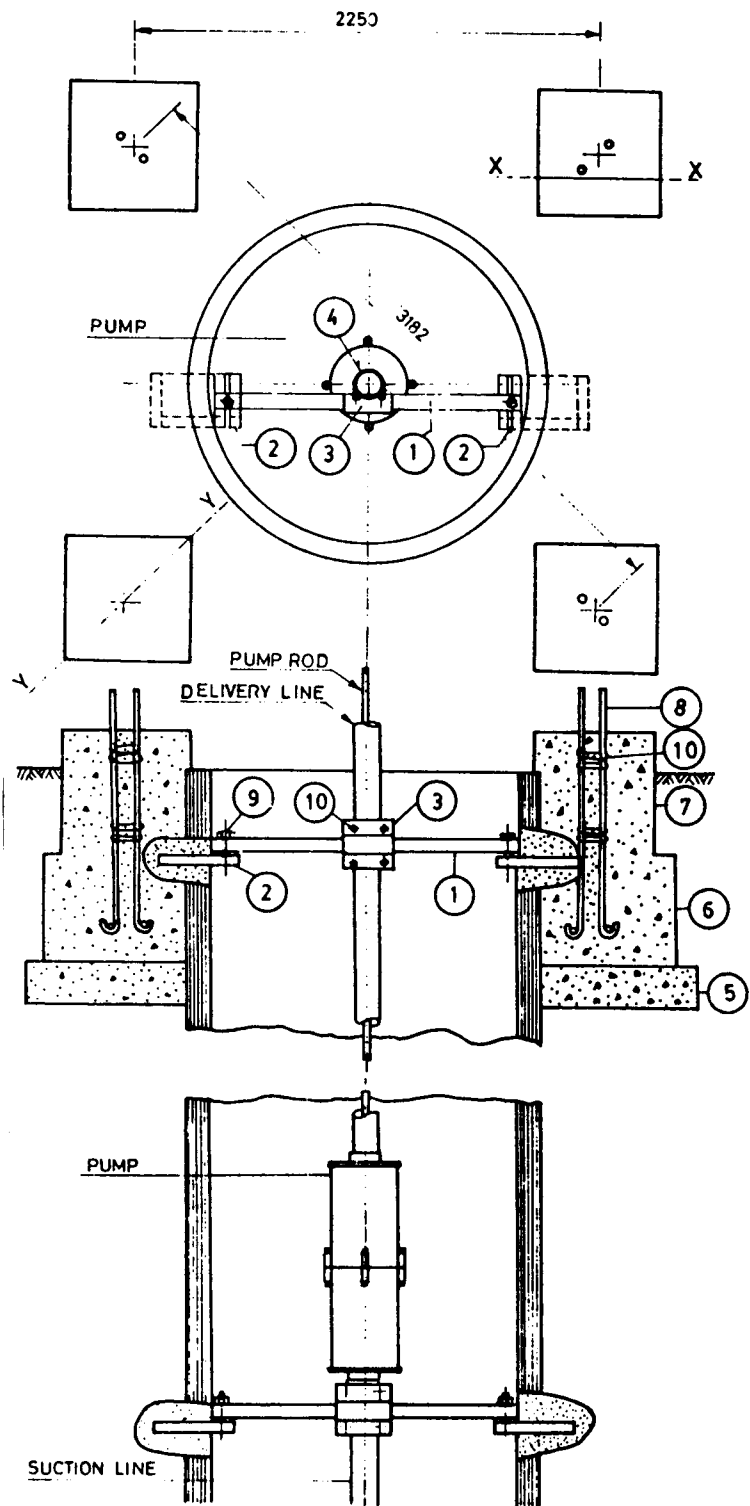




10.	WIRE	φ 6		
9.	NUT, BOLT, WASHER	φ M16 x 100 (5/8" x 4")		
8.	FOUNDATION BOLT	φ 16 x 1200 LONG		
7.	SECOND STEP		M15 MIX CONCRETE 1:2:4  CEMENT FINE AGGREGATE  COARSE AGGREGATE	
6.	FIRST STEP	750 x 750 x 500	DO	
5.	BOTTOM STEP	900 x 900 x 200	1:2:4 LIME CONCRETE	WELL RAMMED
4.	U CLAMP (4 No.)	BAR φ 12 (1/2") LENGTH 350 = 14"	FOR φ 4" PIPE	FOR ONE TRUSS
3.	M. S. PLATE (1 No.)	THICKNESS 4 SIZE 355 x 250		FOR ONE TRUSS
2.	a M S ANGLE (2 No.)	SIZE 50 x 50 x 6 LENGTH 345		
	b M.S. PLATE (3 No.)	SIZE 50 x 4 LENGTH 250		
1.	TRUSS M.S. ANGLE (2 No.)	LENGTH IN INSIDE OF WELL OR PIT SIZE 65 x 65 x 6		TRUSS DIMENSION WILL VARY WITH THE φ (INSIDE OF THE WELL PIT)
SL No.	ITEM	L B D H	SPECIFICATION	REMARKS
<b>DETAILS OF SUB STRUCTURE AND PUMP ALIGNMENT FIXTURE OF 12 PU 500 WINDMILL</b>				
FOR INFORMATION		INSTITUTE OF ENGG. & RURAL TECH- NOLOGY (Near Prayag Rly. Stn.) ALLAHABAD 211002		



**DETAILS ITEM No.1**



## 8.6 INSTALLATION OF THE TOWER

The Tower is supplied in a knocked-down state and has to be assembled. The holes for the foundation are dug at the desired pitch. They are made of equal depth and wide enough to provide sufficient space for the towerleg anchors and to enable the tower to shift to a certain extent. The tower is laid in position and a rope is connected to the top portion. A ladder (or some bamboos) are kept vertically over which the rope is laid. Before pulling the tower upright one has to be sure that the ladder (bamboos) as well as the tower itself will not fall sideways. Some extra hands can prevent this by guiding and supporting them with ropes. After the erection procedure the tower is placed vertically. This is checked by means of water level gauge which is kept beside the tower pipe (not at top of the tower pipe edge). Some filling material (e.g. bricks) are shifted under the tower leg angles temporarily during the adjustment in vertical sense. The desired position of the centre is checked by means of a rope and plumb bob with reference to the alignment of the tower with the centre of the well or the tubewell. The vertical position is checked again, and if both the positions are satisfactory the tower legs are grouted by means of cement and stone or brickchips.

The curing of the foundation needs at least 5 days, meanwhile, the time consuming fixation of the pump is carried out. For the grouting needed for pump fixation, the required mortar is made available during grouting the tower legs.

## 8.7 INSTALLING THE HEAD CONSTRUCTION

The jib crane is pulled and pushed up beside the tower and is finally set on angle of the tower. The jib is installed on the 'wind shadow' side of the tower (see drawing) while its two clamping angle-iron arms enclose the tower pipe on most outward position.

Now the complete head construction without the help vane is brought under the jib. The lifting hook is bolted to the tail at about 1.5 metres distance from the tail hinge. the head tends to turn towards the tail, since the lock mechanism of the help vane is kept out which makes the entire head construction difficult to handle. A locking device is arranged temporarily either by roping the upper tail-beam to the head construction or by putting a clamp overthere. A pin stuck through the head and ending up in the upper tail-beam may also serve the purpose very well.

The rope is connected to the lifting hook and 'balancing' of the head construction is tried out in such a way that the front part of the head is out of balance; (say: 5 degrees). This is essential to ensure that the framing of the head construction, which is going to surround the tower pipe, will grip and throttle it. (This is a most essential precaution which seems to be even contradictional).

The head is now lifted slowly by pulling the rope (by about 6-persons) and two persons guide the head while climbing the tower. The head is allowed to seek its position in the wind (do not force it and lift it till it floats just above the tower pipe). The two persons, each standing on the platform now, guide the bottom part of the head just over the tower pipe. The head is lowered down very slowly and the persons keep the head pressed down over the tower pipe. Actually they should maintain the '5 degrees out of balance' state of the head while the head itself is lowered down stepwise. The last few centimetres may be difficult as the inside angles of the head might touch the tower pipe edge and so obstruct a further sliding over of the head. If extra attention is paid to a proper centering, no problems appear and the head sinks into its final position. Loosen the rope and remove the lifting hook, and preparations are undertaken now to install the rotor frame.

## 8.8 INSTALLING THE ROTOR

First of all the position of the jib crane is adjusted. The jib crane is put in the most upright position, and the head construction is turned 180 degrees so that the front part of the head is touching the jib crane. For security reasons a rope connection is made overthere so that the head on which the rotor, shaft and bearing blocks are going to be placed, remains under the pulley of the jib crane. This is necessary as appearing wind might turn the head construction.

Both the rotor halves are connected now and the shaft is slid into the hub to take its normal position. The hub bolts are tightened stepwise as well as the securing clamping angle iron, care-

fully the rotor frame is lifted and carried to the tower where it is put in vertical position, standing on one of its six spokes. Now it sets against the tower, right under the jib crane. Care should be taken of the extending shaft pointing into to lattice of the tower construction, as this may cause problems.

The rope is lowered down now from the jib crane and it is connected to the hub of the rotor frame, so that the rope passes both the inside and outside ring from the back of the rotor.

Carefully and slowly the rotor is lifted and two persons guide it while climbing the tower. Extra attention is paid to the extending shaft which tends to get stuck in the lattice of the tower. Finally, reaching the level of the platform it is seen that the shaft is positioned on the correct side of the jib crane, since the latter itself will be an obstacle.

The entire rotor and shaft are hovering above the head now. With some effort the bearing blocks are positioned above their supports and the rotor is lowered down very slowly. The bolts are put quickly and the nuts are screwed on by hand first. The position is secured now and the rope is removed from the rotor and jib crane and the latter is lowered down. The rotor is revolved through a few revolutions in order to enable the bearing blocks to settle on their supports. The bolts of these bearing blocks are tightened.

The windmill is put in a secured position and the mounting of the blades can start now. One person sits on the platform and the other stands on angle 6 of the tower. The bolts, nuts and the tools can be kept conveniently in a basket which is hung temporarily from the platform during this bolting activity. It is necessary that the blades are mounted in crosswise sequence e.g. 1-7, 8-2, 3-9, 10-4 etc.

After this the crosshead, assembled with connecting rod and the pump rod both, is pushed into the tower pipe and the crank bush and central bolt are assembled. It is to be seen that the locking bolt of the PVC tower pipe insert is removed temporarily in order to allow the crosshead to pass in. Also important is to install the crank bush with its collar facing the crank plane and the application of the washer in between the bolt head and the bush edge is to be removed. The bolt is tightened up strongly and the locking screw for the PVC tower pipe insert is re-installed. The wooden pump rod guide is fitted on the bottom side of the tower pipe and locked with the bolt.

Now the help vane arrangement is assembled and the windmill can be put to face the wind.

## 8.9 INSTALLING THE PUMP

It is preferable to have the pump section installed and completed by the time the windmill itself has been assembled.

As expressed earlier the installation of this very essential part should not be underrated as many difficulties are felt with regard to the alignment and fixation in the well. The reciprocating forces, which act on this section, can be considerable and a minor play in the suspension, either in axial or in radial sense, can lead to a "noisy dancing and swinging" performance of the pump. In the long run the grouted parts of the suspension will come out, the nuts and bolts will run loose and hammer their way through their counterparts.

A good deal of attention, therefore, is to be paid to the proper alignment and strong fixation of the pump and delivery pipe in order to prevent the above mentioned malfunctioning.

Though the wells for windmill sites differ in depth of water table, diameter and structure, at least some general guidance can be given to obtain suitable suspension :

In case of centrally situated installation of the windmill above the well it is advisable to fix at least one "bridge construction". This structure lends the needed suspension, provided of course, that its legs are grouted thoroughly in the well casing.

Centralisation at the bottom part of the pump section is provided by the tube well (if applied) or by the application of a similar "bridge construction" which embraces the suction pipe on which the pump has been screwed.

In the latter case grouting of the bridge into the well casing might be complicated since the bottom part of the pump is situated preferably under the water table in order to make the pump

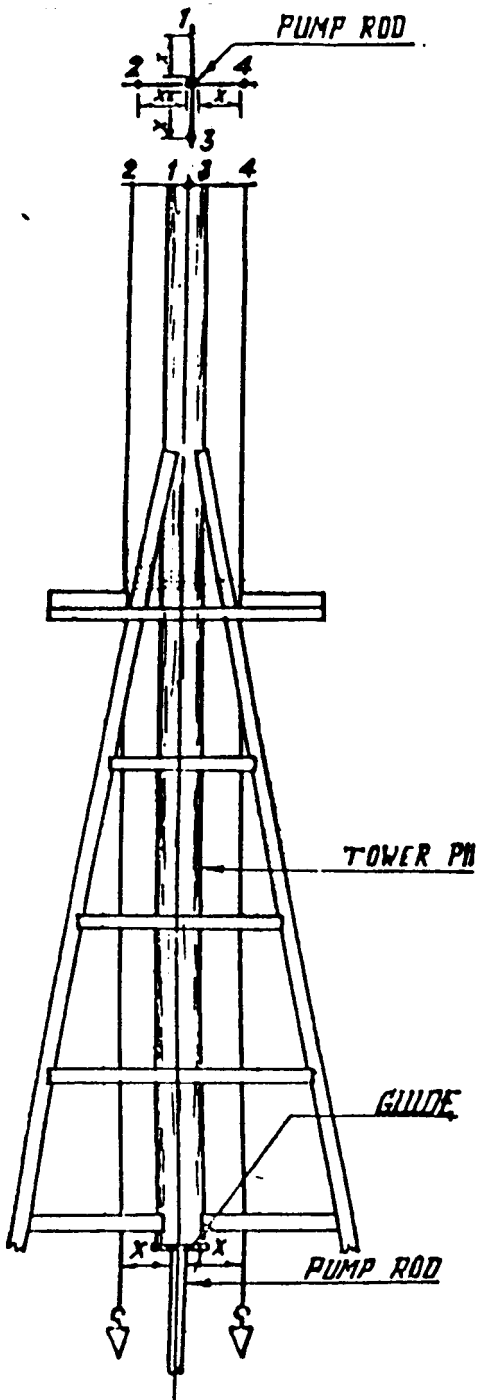
self priming and to assure the desired minimum suction head. The problem is overcome either by grouting the bridge legs during a period for which the lowest water level exists (dry season, after excessive water removal by another pumping device) or by using an expanding clamp mechanism in the bridge legs themselves. This can be obtained by applying at each leg a bolt/nut combination in such a way that by screwing out the bolt the expanding effect occurs.

In case of an off-centre installation of the windmill not much choice is left and clamps, equipped with strong anchors which are grouted into the well casing, prove to be the best solution.

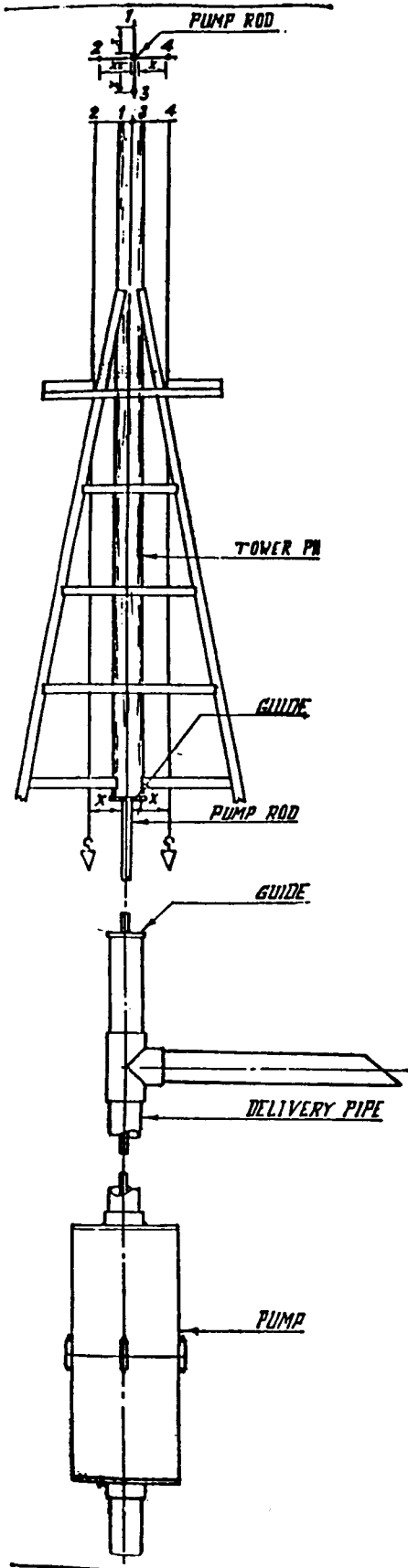
As far as the fixation under the waterline is concerned (in case of no tube well) it is advisable to apply a connection in the well casing based on key-wedge principle.

### **IMPORTANT NOTE**

After the completion of the erection the installation should be checked with reference to the check list, and a record of all readings taken, be maintained.



## 8.10 Check List for Installation of Windmill



### CHECKS IN WINDMILL INSTALLATION

पवन चक्की स्थापना के समय निरीक्षण

(A) Verticality (Sahul, Scale Try-square, Spirit Level)

(अ) सम्बन्धित निरीक्षण (साहुल, स्केल, गुनिया, स्प्रिट लेवल)

(a) Tower pipe (Take 4 readings)

(ए) टावरपाईप (चार रीडिंग लीजिए)

(b) Pump rod with reference to lower pipe (about 150 mm below the upper wooden guide)

(ब) टावर पाईप के सापेक्ष पम्प राड का निरीक्षण (टावर पाईप से गाइड १५० मि० मी० नीचे)

(c) Perpendicularity of tower top Face with reference to the side of the pipe.

If the distance between the two wooden guides is more than 3 metres then.

(क) टावर टॉप सतह की सम्बन्धिता पाईप के चारों ओर के सापेक्ष।

अगर पम्प राड की सम्बन्धिता दोनों गाइड के मध्य तीन मीटर से अधिक हो तब।

(d) Measure perpendicularity of pump rod at a distance of about 150 mm above the lower guide.

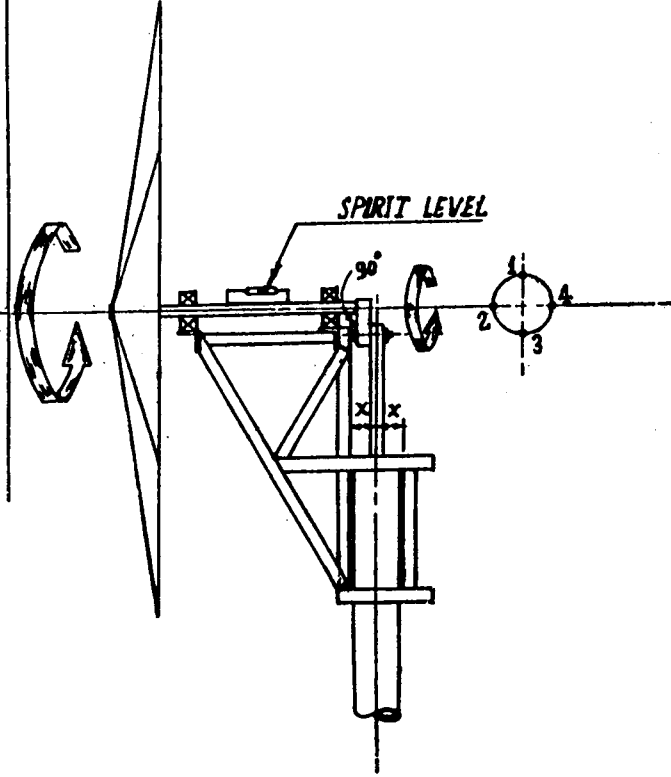
(ख) पम्पराड की सम्बन्धिता निचली गाईड से १५० मि० मी० ऊपर निरीक्षण कीजिए।

(e) Measure verticality of delivery pipe.

(ग) डिलीवरी पाईप सम्बन्धिता का निरीक्षण कीजिए।

1	2	3	4





(B) SHAFT ( Spirit level & Scale )

(ब) साफ्ट (स्प्रिट लेवल और स्केल)

(a) Turn the rotor around tower axis, measure level in rotor facing North, West, South & East (NWSE) w. e. at 4 positions.

(१) टावर के अक्ष के चारों तरफ रोटर घुमाइये एवं सतह का निरीक्षण कीजिए । (दूरब, पश्चिम, उत्तर, दक्षिण) चारों स्थितियों में ।

(b) Rotate rotor around the axis of the shaft and measure perpendicularity of the crank with reference to the shaft. (Measure distance between the connecting rod and head construction X).

(२) साफ्ट के अक्ष के चारों ओर रोटर को घुमाइये और क्रांक की लम्बवता जात कीजिए ।

(c) Measure clearance between the head construction & tovertop pipe surface.

(३) (हेड कन्स्ट्रक्शन एवं कनेक्टिंग राड के बीच की दूरी नापिये)

Position  
स्थिति

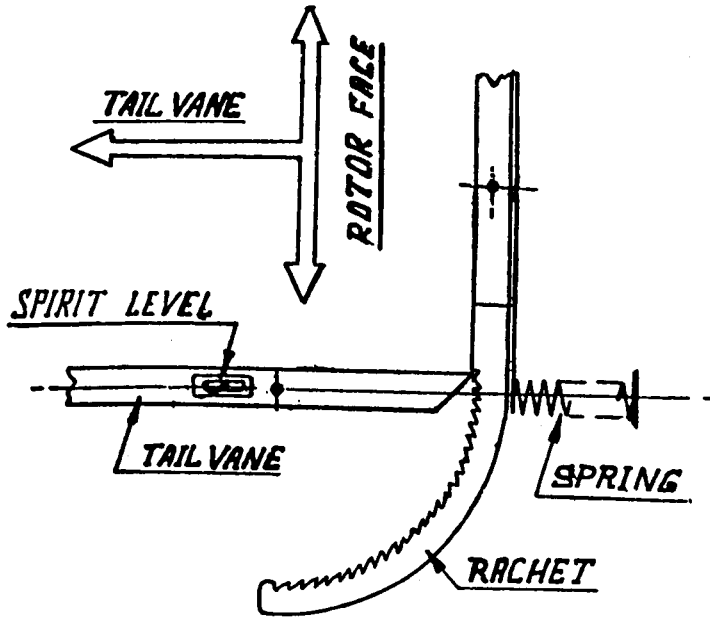
Reading  
प्रेक्षण

1.	.....	mm मि० मी०
2.	.....	mm मि० मी०
3.	.....	mm मि० मी०
4.	.....	mm मि० मी०

I II

1.	.....	mm मि० मी०
2.	.....	mm मि० मी०
3.	.....	mm मि० मी०
4.	.....	mm मि० मी०

gauge / mm  
शेज / मि० मी०



(B) Measure spring tension of the tail with the help of spring balance.

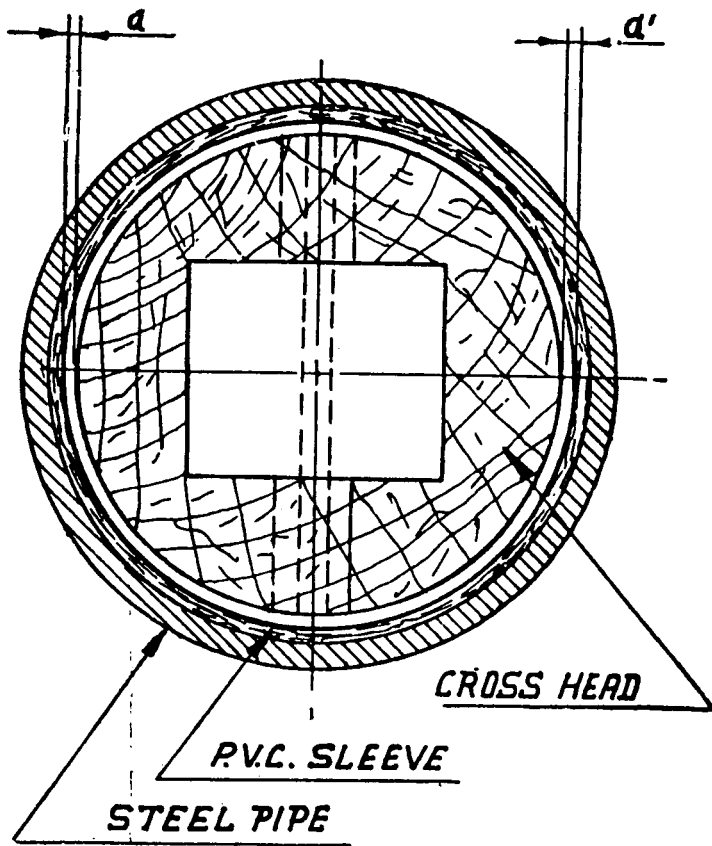
..... kg.

(१) स्प्रिंग बैलेंस की सहायता से टेल स्प्रिंग का तनाव ज्ञात कीजिए ।

(C) (a) Check meshing of the tail with toothed sector.  
 (b) Measure horizontality of the tail with the help of spirit level & scale.

... .. mm.

(२) टुपेड रचेट भाग का टेल के साथ मैचिंग का निरीक्षण कीजिए ।  
 टेल की क्षैतिजता स्प्रिट लेबल एवं स्केल की सहायता से ज्ञात कीजिए ।

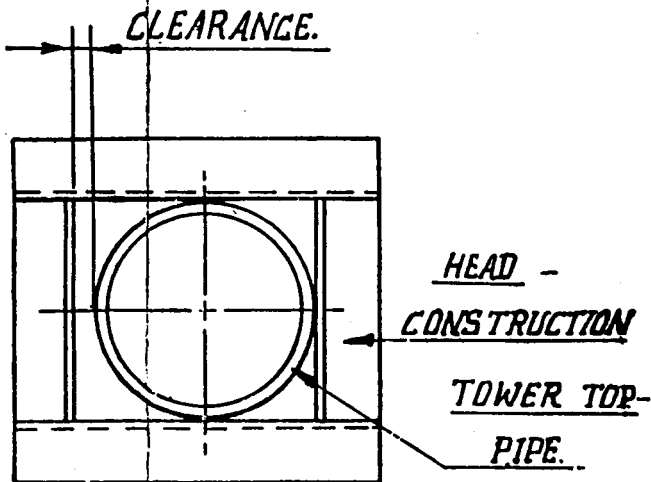


(E) Measure clearance  $d \times d$  between the PVC sleeve & cross head.

..... gauge/mm.

(१) पी० वी० सी० स्लीव एवं क्रॉसहेड के बीच अन्तराल डी एवं डी, नापिए ।

गेज/मि० मी०



(D) Measure clearance between the head construction & tower top pipe surface.

..... gauge/mm.

(१) हेड कन्स्ट्रक्शन एवं टावर टॉप पाइप सतह के बीच अन्तराल ज्ञात कीजिए ।

गेज/मि० मी०

## 9. MAINTENANCE OF THE WINDMILL

Though the number of moving parts in the windmill is limited yet certain regular checkups and lubrication services should be undertaken from time to time. Also, in the long run some moving parts might wear out and need replacement. Fortunately, in this design, such parts are cheap in the material costs. They can be made easily and replaced.

### 9.1 THE OVERALL STRUCTURE

Actually corrosion of the steel structure is the greatest enemy of the windmill. If the corrosion problem is tackled in the right way the technical lifetime of the windmill is expected to reach at least 15 years and probably far beyond this figure.

It is advisable, therefore, to have the structure painted thoroughly with one coat of primer and two coats of finish, after chipping off the weldings. The need for these preventive measures is more in areas where the air is humid or saline as along a coast-line. The best anticorrosive zinc-based paints should be applied.

### 9.2 TOWER

Generally it is expected that the tower will not need any specific attention with regard to wear and tear, since it is a static structure. One should realise however, that the tower pipe serves multiple functions:-

- o It carries head construction the edge (this is in axial sense).
- o Its outside provides support to the head construction by enclosing it at the top and bottom parts (in radial sense).
- o Its inside provides the guidance to the crosshead via the contact of PVC insert.

The 'steel to steel' contact of tower pipe and head construction needs some lubrication (grease) from time to time. As long as the grease is present no excessive wear is going to occur there. Also, as long as the PVC insert remains locked in the tower pipe, the insert will serve its purpose well.

However, corrosion of the tower has to be taken into account and check-ups should be undertaken at half yearly intervals.

### 9.3 HEAD CONSTRUCTION

Besides its contact with the tower pipe only a few moving parts of this structure need attention for maintenance. It should be ensured that the locks of the security device remain free of any play. The functioning of the hinges of the help vane and tail vane both should be checked up from time to time since they have the tendency either to run loose or to corrode: The former will lead to loose and noisy, and hence clumsy joints, and the latter to a struggling and faltering functioning of the mechanism. The best remedy is to apply a few oil drops from time to time.

If, the help vane lock or the final lock is worn out. It would be better to take it out, apply some welding and reshape it by filing, and get it re-installed properly. There is no need to explain the necessity of a proper functioning of storm security device.

## 9.4 MOVING PARTS

It is assumed that the main bearings have been positioned and tightened properly. Generally the lubrication is sufficient for millions of revolutions and as long as no dust particles enter the "grease" no complications are expected. However, in course of time the grease is "rolled out" of the bearing and will change its lubricating properties. This takes years, though, to happen, but moment it is noticed, new grease (not oil) should be applied. If no grease nipple is there, the bearing housing has to be opened to apply fresh grease.

Generally the nylon (or bronze) bearings of the connecting rod keep their lubricant well. Some fresh oil drops from time to time will serve the purpose satisfactorily. The same counts for the wooden cross-head and pump rod guides. Properly soaked in oil they contain the lubricant themselves and from safety point of view it is best to keep them in that condition. Generally a "generous filling up" of the square hole in top of the crosshead with oil, provides the best guarantee that these essential wooden parts will maintain their functioning. The appearance of play in these parts after some time of functioning might seem to be bothersome, but they have a long way to go before replacement is really necessary. In short, the wear is acceptable as long as no noisy and clumsy malfunctioning occurs. The replacement is cheap and easy to carry out specially, as far as the wooden pump rod guides are concerned. With regard to replacement of the crosshead it is advisable to drill complete new holes for the pump rod crosshead connection. It will be evident that in case of replacement of worn out crosshead the replacement of the PVC insert is also recommended.

## 9.5 THE ROTOR

Besides maintenance concerning corrosion, the rotor does not need any maintenance. However, in some cases bolts and nuts become loose due to the alternating character of the load on them. A "cracky" noise indicates such fault.

The remedy is to check-up all bolt and nut connections, especially at the start. In a fair number of cases some fatigue cracks appear either in the outside blade supports (shearing fatigue) and/or in the blades somewhere at their edge. If it happens, supports and/or blades should be replaced by new ones.

## 9.6 THE PISTON PUMP

In the windmill the pump section remains the most bothersome part. Besides the checks of its suspension, checks are to be made with regard to its delivery. Depending on the purity of the lifted water the piston wears out sooner or later, resulting in a poor delivery. It should be replaced then.

If time has come to change the piston, it is better to replace the valves too. This will ensure that the newly overhauled pump will serve its purpose for the next period of time without any failure. The span of this time will depend on the purity of the water which is pumped from the source. Presence of sand particles play a significant role in the life of the piston and precautions should be taken. In case of water delivery from a tube well, a proper "washing" procedure is necessary.

Maintenance checks as given in the following pages should be carried out at half yearly intervals.

**9.7 Preventive Maintenance Schedule  
Water Pumping Windmill  
12-PU-500**

Sl. No.	Major Parts	Sub Components	Insepction Schedule				Suggested Remedial measures.
			D	M	Q	Y	
1.	Rotor	Hub bolts			✓		If loose, tighten
		Hub clamp bolt			✓		-do-
		All the Rotor Fasteners			✓		-do-
		Upper and lower tips of the blades	✓				If bent, remove the blades with bent tips, straighten and fix again, If badly damaged, replace it.
		Condition of paint				✓	Retouch/Repaint
		Blade supports			✓		If cracked, replace
		Inner and outer rings			✓		Repair/Replace
		Blades	✓			If damaged badly, replace.	
2.	Head Construction Tail and the security mechanism	All the fasteners and joints			✓		If loose, tighten
		Condition of security lock in both secured and operational positions.			✓		If functioning is improper and it suffers from vibration check the ratchet arm and spring and the locking edge of the tail, replace the worn out part.
		Movement of head construction around the tower pipe.		✓			If the rotation around the tower pipe is not smooth, lubricate with grease. if the clearance between the tower pipe and head construction is abnormal put a shim in the gap.

Sl. No.	Major Parts	Sub Components	Inseption Schedule				Suggested Remedial measures.
			D	M	Q	Y	
3.	Mechanical Power Transmission system.	Condition of the bearing block		✓			If cracked replace the complete bearing with housing immediately.
		Condition of the bearing for any unusual sound axial movement or play.		✓			If running dry, lubricate, if sound still persist or there is axial movement or play then replace the complete bearing.
		Bearing fixing bolts.		✓			If loose, tighten firmly.
		Rear bearing safety bracket		✓			If loose, tighten firmly.
		Hub screw of bearing		✓			If loose, tighten firmly.
		Condition of crank holes		✓			If holes are enlarged, remove the shaft with crank repair by welding and drilling repairing and reinstall properly.
		Welding joint of the crank with main shaft.		✓			If cracked or deformed remove the shaft with the crank, repair and refix properly.
		Crank bolt		✓			If loose tighten firmly.
		Collar Bush				✓	If sign of wear appears change and lubricate with grease.
		Connecting rod		✓			If broken, bent or crack appears on any joint, replace.
		Nylon bushes at both ends of connecting rod				✓	If play has developed or bushes have worn out replace them.
		Crosshead				✓	If unusual sound or play appears, replace.
		PVC Sleeve				✓	If worn out replace.
Pump rod joints				✓	If loose, tighten firmly.		
Wooden/Polypropelene guides				✓	If wornout, replace.		

Sl. No.	Major Parts	Sub Components	Insepction Schedule				Suggested Remedial measures.
			D	M	Q	Y	
4.	Piston Pump	Pipe line joints	✓				If there is any leakage check the flange and socket joints, repair.
		Coupling bolts			✓		If there is any leakage from middle section through the rubber gasket, replace the gasket, open the pump and check.
		Abnormal noise from the pump	✓				The complete assembly consisting of the piston rod, nut, brass guide, foot valve, piston barrel, replace the faulty component.
5.	Tower	All the fasteners of joints		✓			If loose, tighten firmly.
		Condition of tower pipe				✓	If bent change the tower top.
		Welded joint of tower pipe with stand legs.				✓	If cracked remove the tower top, repair and reinstall.
		Condition of protective coating.				✓	If peeled off, carry out touching with primer and paint.
6.	Foundation and Aux. Structure	Physical insp. of work	✓				If any vibrations have caused cracks, stop the windmill and repair the civil constructions.
		Supporting bridges & clamps		✓			If the clamps are loose tighten them.
		Delivery pipe bracket		✓			If fitting is disturbed, fix it correctly.

*D = Daily; M = Monthly; Q = Quarterly; Y = Yearly*



## 9.8 PART LIST OF 12-PU-500 WINDMILL

### TOWER :

Sl.No.	Item	Material	Size mm	Measurements mm	No. Regd.
T/1	ANGLE IRON	M.S.	35x35x5	250	8
T/2	ANGLE IRON	M.S.	40x40x5	4500	4
T/3	ANGLE IRON	M.S.	35x35x5	1940	16
T/4	ANGLE IRON	M.S.	35x35x5	1400	4
T/5	ANGLE IRON	M.S.	50x50x6	250	4
T/6	ANGLE IRON	M.S.	35x35x5	700	4
T/7	ANGLE IRON	M.S.	40x40x5	2000	4
T/8	ANGLE IRON	M.S.	35x35x5	660	2
T/9	FLAT IRON	M.S.	32x6	580	2
T/10	FLAT IRON	M.S.	32x6	460	2
T/11	FLAT IRON	M.S.	32x6	340	2
T/12	WOODEN PLANK	WOOD	30x200	700	2
T/13	PIPE (SLEEVE)	PVC	4" BORE	710	1
T/14	TOWER PIPE	M.S.	4" N.B.	2650	1
T/15	FLAT	M.S.	32x6	410	4
T/16	PLATE	M.S.	170x160x6		4
T/17	NUT,BOLT,WASHERS	M.S.	M12x40(W½"x1½")		52
T/18	MACHINE SCREW		½" Ø x 2" long		4
T/19	MACHINE SCREW		½" Ø x 1" long		4

**HEAD CONSTRUCTION :**

01/15/2017

Sl.No.	Item	Material	Size mm	Measurement mm	No. Regd.
HC/1	ANGLE IRON	M.S.	40x40x5	200	1
HC/2	ANGLE IRON	M.S.	40x40x5	200	1
HC/3	ANGLE IRON	M.S.	40x40x5	155.5	4
HC/4	ANGLE IRON	M.S.	40x40x5	555	2
HC/5	ANGLE IRON	M.S.	40x40x5	590	1
HC/6	ANGLE IRON	M.S.	40x40x5	1000	2
HC/7	ANGLE IRON	M.S.	40x40x5	1110	2
HC/8	ANGLE IRON	M.S.	40x40x5	540	2
HC/9	ANGLE IRON	M.S.	40x40x5	460	2
HC/10	ANGLE IRON	M.S.	40x40x5	500	1
HC/11	ANGLE IRON	M.S.	65x65x6	250	2
HC/12	ANGLE IRON	M.S.	40x40x5	1500	1
HC/13	ANGLE IRON	M.S.	40x40x5	4000	1
HC/14	ANGLE IRON	M.S.	40x40x5	3000	1
HC/15	ANGLE IRON	M.S.	40x40x5	125	1
HC/16	ANGLE IRON	M.S.	40x40x5	60	1
HC/17	ANGLE IRON	M.S.	40x40x5	45	1
HC/18	ANGLE IRON	M.S.	40x40x5	1000	1
HC/19	FLAT IRON	M.S.	32x6	115.3	2
HC/20	FLAT IRON	M.S.	32x6	65	2
HC/21	FLAT IRON	M.S.	32x6	150	1
HC/22	FLAT IRON	M.S.	32x6	115.5	1
HC/23	FLAT IRON	M.S.	32x6	830	1
HC/24	FLAT IRON	M.S.	32x6	750	3
HC/25	FLAT IRON	M.S.	32x6	200	1
HC/26	RACHET (FLAT, HARDENED)	M.S.		480	1
HC/27	TAIL VANE (1mm SHEET)	M.S.		2000x1000	1
HC/28	HELP VANE (1mm SHEET)	M.S.		1000x500	1
HC/29	ROD	M.S.		30Diax650	1
HC/30	WASHER	M.S.		M12(½" Dia.)	1
HC/31	NUT	M.S.		M22(W 7/8")	1
HC/32	BOLT,NUT,WASHER	M.S.		M12x40(W½"x1½")	1
HC/33	BOLT,NUT,WASHER	M.S.		M12/100(W½"x4")	1
HC/34	BOLT,NUT,WASHER	M.S.		M6x25-(W¼"x1")	12
HC/35	SPRING	SPRING STEEL	App. 30Dia.x1000x14		1

# MOVING PARTS

Sl.No.	Item	Materials	Size mm	Measurements mm	No.
MP/1	MAIN SHAFT	M.S.	∅ 50(∅2")	1300	1
MP/2	PILLOW BLOCK (BEARING)-FYH & NTN		P210J-50±0.01 bore		2
MP/3	BUSH	M.S.	33x43x33		2
MP/4	BUSH (MOULDED)	NYLON	∅ 25x∅38x18		4
MP/5	BUSH	M.S.	∅20x∅40x44		1
MP/6	WASHER	M.S.	∅20x40∅x3		1
MP/7	CRANK BOLT (GKW MAKE)	M.S.	M20x75(W3/4"x3")		1
MP/8	NUT	M.S.	M20(W3/4")		1
MP/9	BOLT,NUT,WASHER	M.S.	M12x50(W1/2"x2")		2
MP/10	BOLT,NUT,WASHER	M.S.	M10x100(W3/8"x4")		2
MP/11	CROSS PIN	M.S.	∅ 25x92		1
MP/12	CROSS HEAD	WOOD	∅97x5x300		1
		(SEASONED In OIL)			
MP/13	CONNECTING ROD (FLAT)	M.S.	30x6	650	1
MP/14	FLAT	M.S.	30x6	50	4
MP/15	FLAT	M.S.	15x6	300	2
MP/16	FLAT	M.S.	40x10	165	1
MP/17	FLAT	M.S.	25x6	135	2
MP/18	FLAT	M.S.	25x6	250	2
MP/19	GREASE CUP				1
MP/20	PIPE (Q.S.T. MAKE) CLASS 'A' G.I.		∅1"		*
				(Amount or size depend upon - circumstances)	
MP/21	PUMP ROD GUIDE	(TEAK WOOD)	∅120x100		1

**ROTOR:**

Sl.No.	ITEM	MATERIAL	SIZE mm	MEASUREMENTS mm	NO. REQD.
R/1	PLATE	M.S.	260Dia.x6		2 (Two piece in one)
R/2	ANGLE IRON	M.S.	50x50x5	625	2
R/3	ANGLE IRON	M.S.	50x50x5	100	4
R/4	ANGLE IRON	M.S.	50x50x5	350	2
R/5	ANGLE IRON	M.S.	40x40x5	1880	6
R/6	FLAT IRON	M.S.	30x5	1880	6
R/7	FLAT IRON	M.S.	30x5	495	6
R/8	FLAT IRON	M'S'	30x5	275	6
R/9	RING CLAMP (FFLAT)	M.S.	40x10	150	12
R/10	OUTER RING (FLAT)	M.S.	30x5	2000	6
R/11	INNER RING (FLAT)	M.S.	30x5	3000	2
R/12	ROTOR BLADE (SHEET)	M.S.	2000x300x1.5		12
R/13	OUTER BLADE SUPPORT (SHEET)	M.S.	220x157x2.65		12
R/14	INNER BLADE SUPPORT (SHEET)	M.S.	250x247x2.65		12
R/15	BOLT, NUT, WASHER	M.S.	M16x100(W5/8"x4")		12
R/16	BOLT, NUT, WASHER	M.S.	M16x125(W5/8"x5")		2
R/17	BOLT, NUT, WASHER	M.S.	M10x25(W3/8"x1")		64
R/18	BOLT, NUT, WASHER	M.S.	M6x25(W1/4"x1")		120

# PISTON PUMP

Sl.No.	Item	Material	Size mm	No. Reqd.
PP/1	PUMP ROD EXTENSION	G.I. PIPE	3/4"-----x*	*
PP/2	PUMP ROD	G.I. PIPE	3/4"-----x900	1
PP/3	PIPE	G.I. PIPE	5/8"-----x100	4
PP/4	TOP PIPE	BLACK PIPE	4"-----x750	1
PP/5	EXHAUST PIPE	BLACK PIPE	4"-----x*	1
PP/6	DELIVERY PIPE	BLACK PIPE	4"x-----x*	*
PP/7	T-SOCKET	G.I.	4"-----	1
PP/8	SOCKET	BLACK	4"-----	*
PP/9	DELIVERY PIPE	BLACK PIPE	4"-----	1
PP/10	CYLINDER	SEAMLESS BLACK PIPE	6" GASPIPE X 460	1
PP/11	CASING FLANGE	M.S.	φ 290	2
PP/12	CASING FLANGE	M.S.	φ 290	1
PP/13	CASING	C.R. SHEET	500x900	2
PP/14	FOOT VALVE	8 mm M.S. SHEET	φ 170	1
PP/15	FLAT IRON		-----35	12
PP/16	FLAT IRON		-----80	4
PP/17	FLAT IRON		-----x180	1
PP/18	FLAT IRON		-----x450	1
PP/19	FLAT IRON		-----x300	*
PP/20	FLAT IRON		40x6(1½"x¼")	3
PP/21	ANGLE IRON		40x40x4(1½"x1½")	2
PP/22	FILLING PIECES	M.S. ROD	φ 8mm x 10mm	8
PP/23	RING	M.S. ROD	φ 8(0 3/8")x870	1
PP/24	VALVE	NITRILE RUBBER WITH NYLON FABRIC INSERT/ LEATHER	φ 150 x 5	2
PP/25	GASKET	NITRILE RUBBER SOLE LEATHER	φ 290 x 6 mm	1
P/26	PISTON	POLYPROPELENE/ TEAK WOOD POLYPROPELENE		1
PP/27	STEEL BUSH		φ 43 x 33	*
PP/28	GUNMETAL BUSH		φ 33 x 30	*
PP/29	THREADED STUD	C.I.	M24x150(W7/8"x65)	1
PP/30	THREADED STUD	C.I.	M24x100(W7/8"x4")	*
PP/31	NUTS	G.I.	M24x(W7/8")	*

Sl.No.	Item	Material	Size mm	No. Reqd.
PP/32	SPRING WASHER	G.I.	M24(W7/8")	*
PP/33	BOLT,NUT,WASHER *	G.I.	M12x125(W1/2"x5")	4
PP/34	BOLT,NUT,WASHER *	G.I.	M12x120(W1/2"x3/4")	1
PP/35	CLAMP (U BOLT)	M.S.	φ 12 (1/2") x370	
PP/36	TEAK WOOD/POLYPRO- PELENE GUIDE	TEAK WOOD	(5"x5"x4")	1

*\*Nylock bolts x nuts are preferred to avoid their frequent loosening.*

## 9.9 INVENTORY OF MINIMUM SPARES OILS AND LUBRICANTS

Sl. No.	Component	Qty.	Reference of fabrication drawing	Part number on the drawing
1.	Help vane spring	1	Head construction 12-PU-500	35
2.	Help vane frame with ratchet	1	"	18,25,26
3.	Tail pin	1	"	29
4.	Connecting rod	2	Moving parts	3,13,14,15,19
5.	Nylon bush (4 nos. at a time)	8	"	4
6.	Crank pin	2	"	5
7.	Crank pin bolt and nut	1	"	7 & 8
8.	Cross head with cross pin	1 st.	"	11 & 12
9.	Wooden guides	2 pairs	"	21
10.	Pillow blocks N.T.N. Japan	1 pairs	"	2
11.	PVC sleeve for tower pipe	1	Tower 12-PU-500	13
12.	Blades coated with 90% zinc rich primer and enamel paint	3	Rotor & blade	12
13.	Blade supports (inner & outer)	3 pairs	"	13 & 14
14.	Piston valve & suction valves	3 each	Windmill pump	18,37,38,4
15.	Pump gasket	1	"	17
16.	Piston (polypropelene)	2	"	27
17.	Pump rod guide (brass)	2	"	25
18.	Pump rod guide bush	2	"	23
19.	Pump rod connection	1	"	30,32
20.	Galvanised fasteners with nylock nuts and plain washers (1/4" x $\phi$ x 1" long)	10	"	-
21.	Galvanised fasteners with nuts and plain washers (3/8" $\phi$ x 1 1/2")	40	"	-
22.	Galvanised fasteners with nylock nuts and plain washers 1/2" $\phi$ x 1 1/2" long)	10	"	-
23.	Galvanised fasteners with nylock nuts and plain washers 5 1/8" $\phi$ x 1 1/2" long)	10	"	-
24.	Grease for bearings	1/2 Kg.	"	-
25.	SAE 40 mobile oil	1 Lit.	"	-

## 9.10 SOURCES OF AVAILABILITY OF SPARES

### (a) State Nodal Agencies:

1. Andhra Pradesh (BHEL) Bharat Heavy Electricals Ltd.  
Vikas Nagar,  
Hyderabad-500 593.
2. Andhra Pradesh (NEDCAP) Non-Conventional Energy Development Corporation  
10-2-318/1/A/5/1, Indranagar Colony  
Hyderabad-500 457.
3. Bihar Executive Engineer,  
Solar Division,  
Sone Bhawan,  
Beer Chand Patel Marg,  
Patna.
4. Delhi (DEDA) Delhi Energy Development Agency,  
11, Lancer Road, Timarpur,  
Delhi-110 007.
5. Gujarat (GEDA) Gujarat Energy Development Agency,  
P.N. Chambers, 3rd Floor,  
Vadodra- 390 005.
6. Himachal Pradesh (HPSEB) Himachal Pradesh State Electricity Board,  
Shimla, H.P.
7. Madhya Pradesh (MRUVN) Madhya Pradesh Urja Vikas Nigam,  
B-Block, G.B.T. Complex, T.T. Nagar,  
Bhopal, M.P.
8. Maharashtra (MEDA) Maharashtra Energy Development Agency,  
3rd Floor, Mantralaya,  
Bombay-400 023.
9. Orissa (OREDA) Orissa Renewable Energy Development Agency,  
5-57, Mancheswar, Industrial Estate,  
Bhubaneswar-751 010.
10. Rajasthan (REDA) Rajasthan State Agro Industries Corporation Ltd.  
O.I. Subhash Nagar, Ghotwara Road,  
Jaipur-6.
11. Tamilnadu (TEDA) Tamil Nadu Energy Development Agency,  
Jhaver Plaza, IVth Floor,  
1-Nungambhakkam High Road,  
Madras.
12. Uttar Pradesh (NEDA) Non-Conventional Energy Development Agency,  
B-46, Mahanagar Extension,  
Lucknow-226 006.



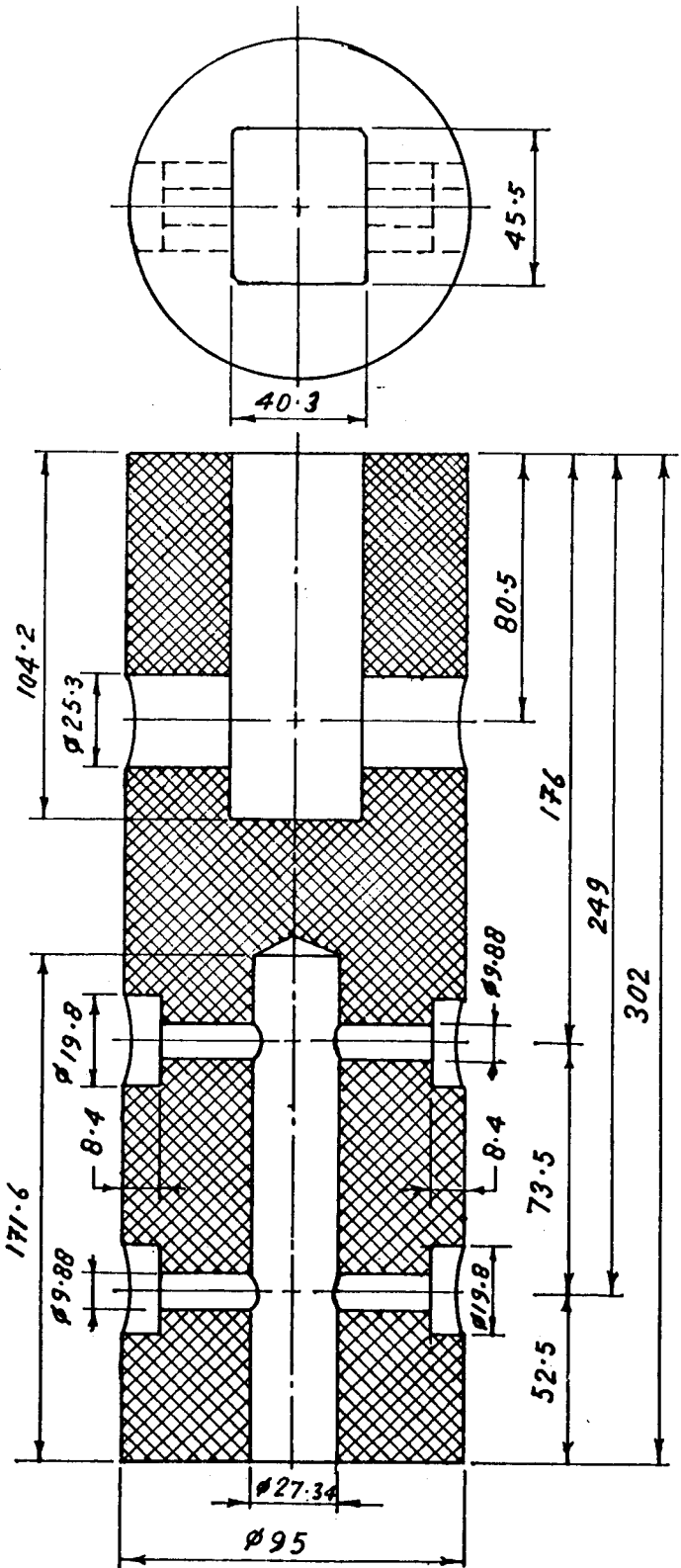
## 9.11 FABRICATING AGENCIES

### (b) Fabricating Agencies:

(Involved during demonstration Programme)

1. Andhra Pradesh Non-Conventional Energy Development Corporation,  
10-2-3/8/1/A/5/1, Indranagar Colony,  
Hyderabad-500 457.
2. Gujarat Principal,  
Community Polytechnic Wing,  
Government Polytechnic,  
Porbandar,  
Gujarat-360 577.
3. Madhya Pradesh Principal,  
Government Polytechnic,  
Khurai,  
Distt. Sagar-470 117, M.P.
4. Orissa Chief Executive,  
Orissa Renewable Development Agency,  
5-57, Mancheshwar Industrial Estate,  
Bhubaneswar-751 010.
5. Punjab Principal,  
Ramagarthia Polytechnic  
Phagwara  
P.O. Satnampura-144 402.
6. Uttar Pradesh Works Manager,  
Training-Cum-Production-Centre,  
Institute of Engineering & Rural Technology,  
26, Chatham Lines,  
Allahabad-211002, U.P.  
  
LORP  
(TOOL-ORP Project)  
Kusumikalan,  
Gazipur, U.P.
7. Tamilnadu Principal,  
Murugappa Polytechnic  
Satyamurthy Nagar,  
Avadi,  
Madras-600 062.

# 10.1 POLYPROPELENE CROSS HEAD



Fig, 13 Polypropelene cross head

## 10.2 BALL & SOCKET JOINT

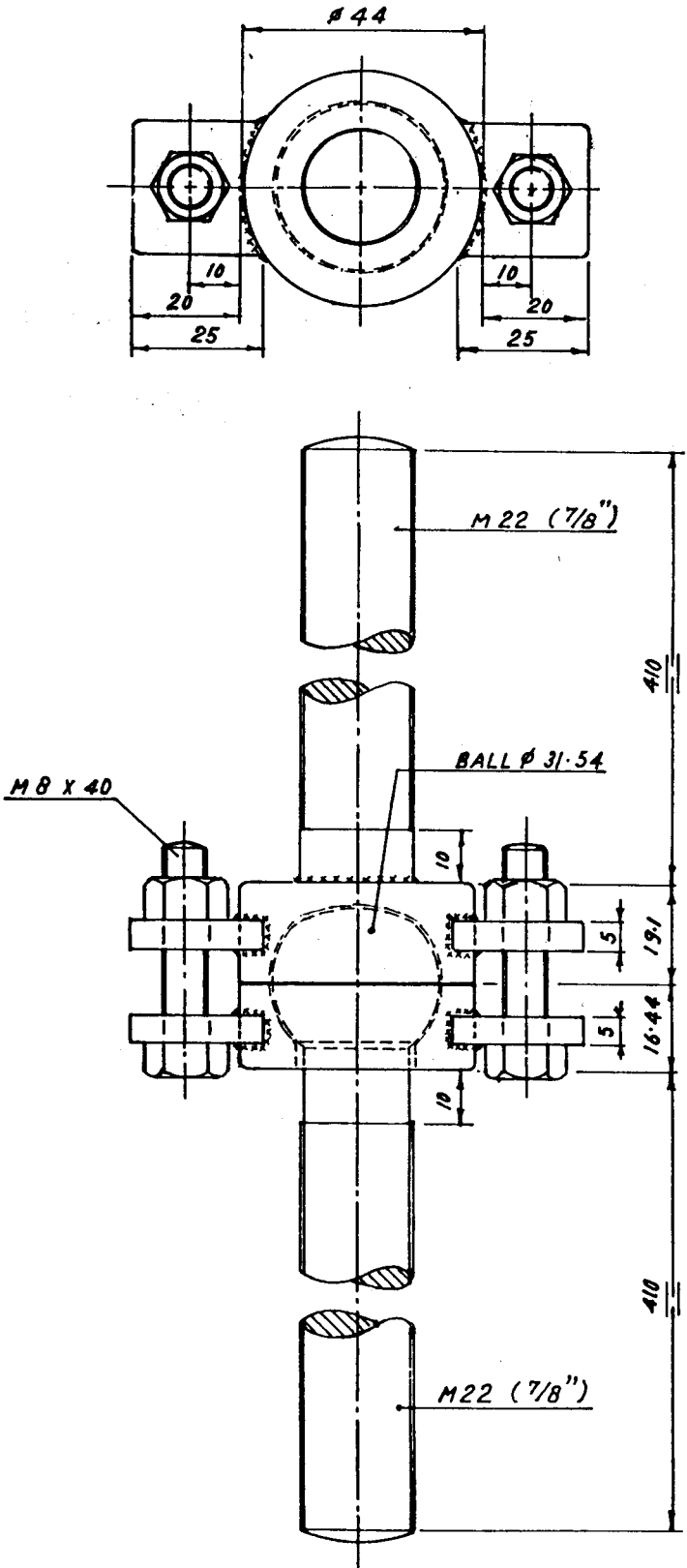
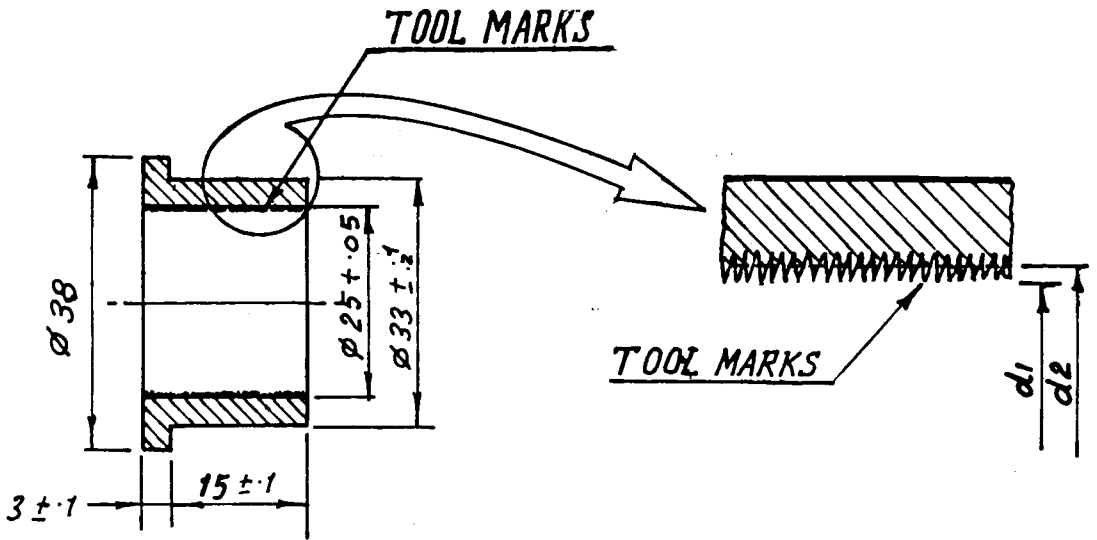
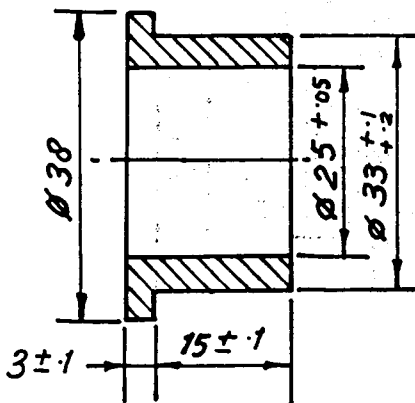


Fig. 14 Ball & Socket joint

### 10.3 NYLON BUSH FABRICATED AND NYLON BUSH MOULDED



*Nylon Bush (fabricated)*



*Nylon Bush (Moulded)*

# 10.4 NEOPRENE VALVE WITH NYLON FABRIC INSERT

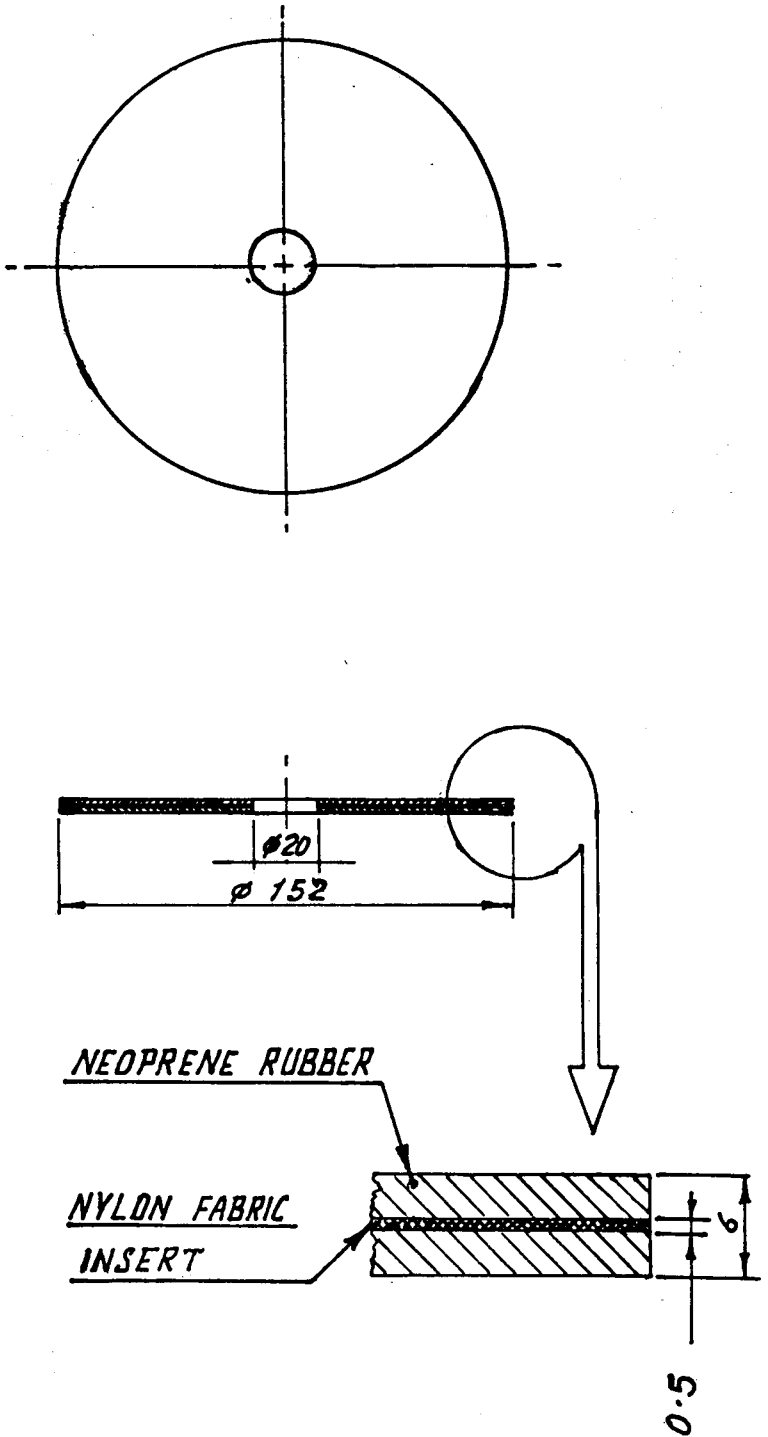


Fig. 16 Neoprene Valve with Nylon Fabric Insert

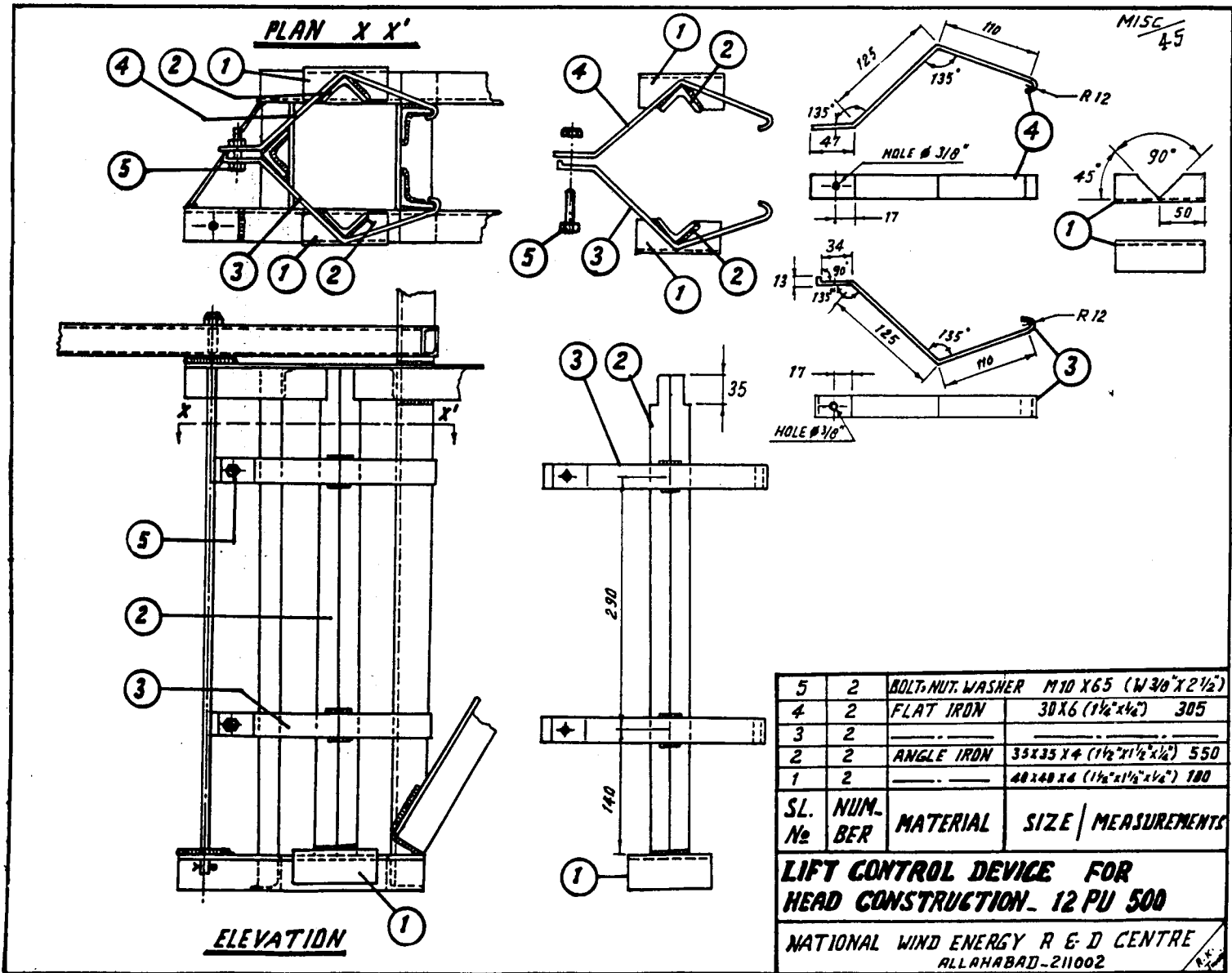
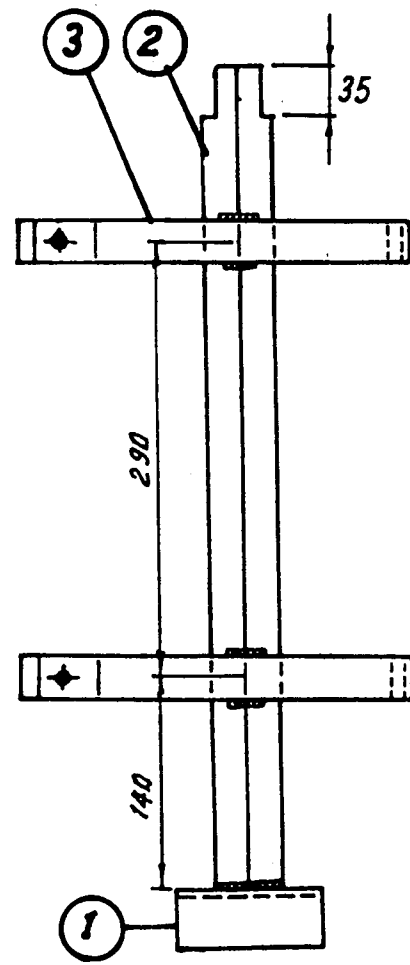
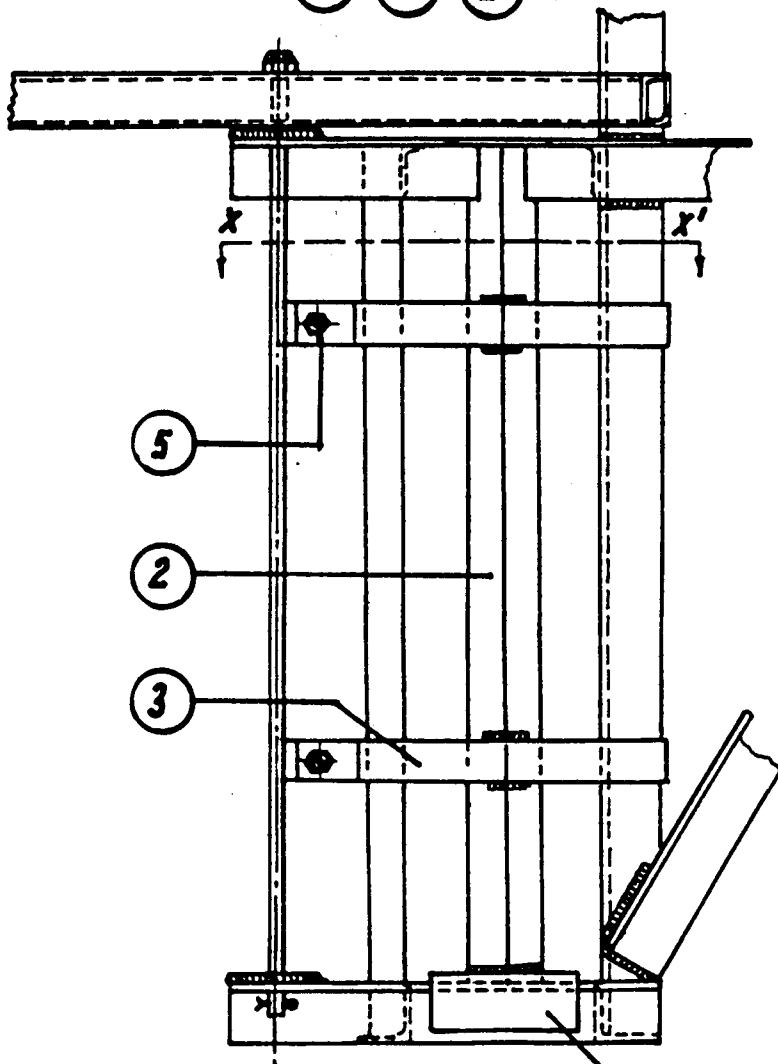
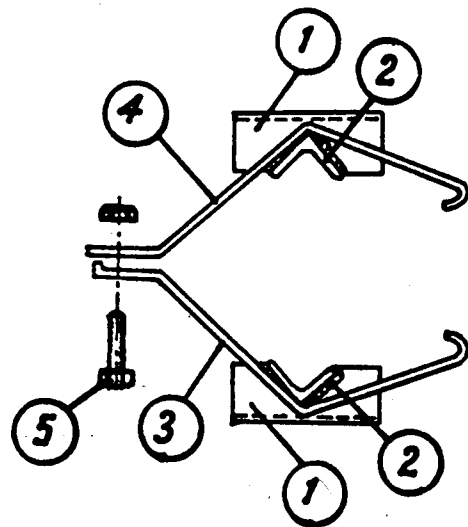
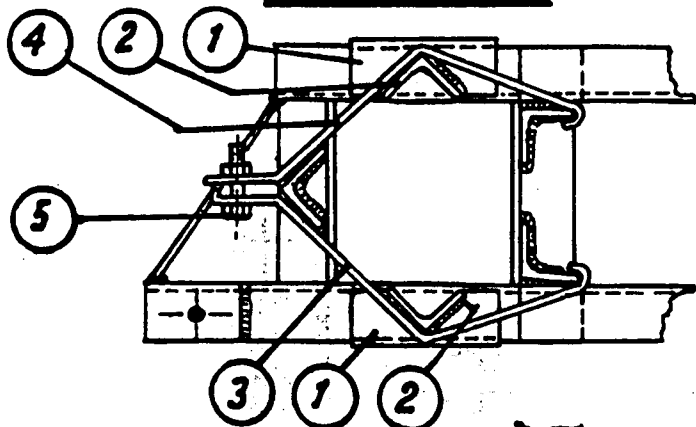


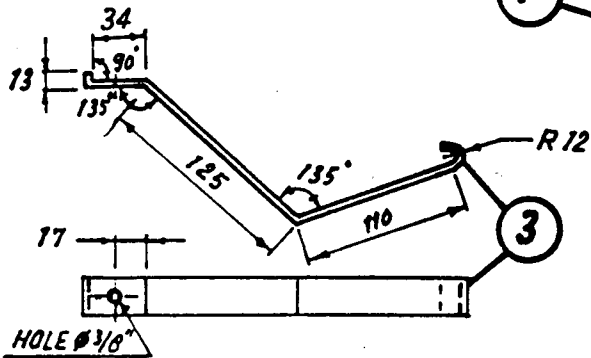
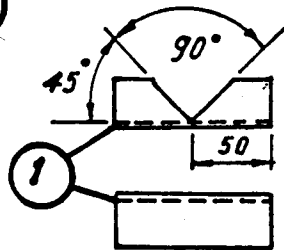
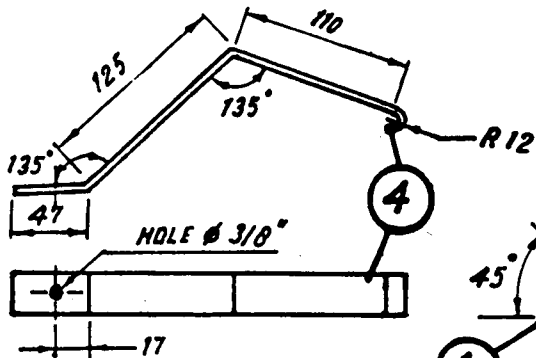
Fig. 17

PLAN X X'



ELEVATION

1







## **11. MERITS OF THE NEW PUMP "A RECIPROCATING PUMP WITH C.I. CYLINDER"**

### **NEW WINDMILL PUMP WITH CAST IRON CYLINDER:**

**(Special features over the old pump of Nick design).**

- (1) Volumetric efficiency is comparable. It is as high as 95.00 percent as compared to 69.00 percent of old pump of Nick design.**
- (2) Can be installed above the well, integrated with tower structure, so that pump axis coincides with the axis of the tower pipe thus eliminating the problem of misalignment which has hitherto being treated as difficult to achieve practically. This is because of the fact that the suction valve is all metallic (brass) and does not contain leather or rubber washers.**
- (3) Accurately machined and honed cylinder gives uniform bore and eliminates the ovality which is almost impracticable in the case of cylinders made out of M.S. pipes.**
- (4) Clearance between the bore and the piston has also been reduced to 0.1 mm uniformly. (The minimum achievable clearance in case of old pump of Nick design is 0.75 mm) with further decrease in clearance, the cylinder wall which is made of M.S. pipe, becomes too thin. The corrosion sets in the thin wall which leads to leakage within a short period.**

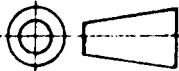
**The cylinder made of cast iron, ensures longer operational life and makes it rust resistant.**

- (5) Spherical suction valve makes it priming free provided, of course, the water is free from substances, like coarse grit, pebbles, floating leaves, twigs etc.**
- (6) Light in weight, fully galvanised pump body ensures corrosion and rust free service in adverse atmospheric conditions.**
- (7) Totally metallic suction valve assembly offers long life and trouble free service.**
- (8) Detachable suction valve of the pump makes the inspection of the suction valve and the piston of the pump easier and simplifies the replacement if necessary, unlike the old system where the complete heavy pump is to be taken out of the well for even petty repairs.**
- (9) Inspection and repairs can be further simplified because of convenience in installation of the pump above the well.**

18	120	NYLOCK NUT, BOLT, WASHER, M6 X 25 (W 1/4" X 1")	
17	64	NUT, BOLT, WASHER, M10 X 25 (W 3/8" X 1")	
16	2	" " " M16 X 125 (W 5/8" X 5")	
15	4	" " " M16 X 100 (W 5/8" X 4")	
14	12	1' BLADE SUPPORT M.S. SHEET, 11 B.G. 2.80 MM. THICK	9.90
13	12	0' BLADE SUPPORT " " " " " " "	5.04
12	12	ROTOR BLADE " " 16 B.G. 1.6 MM. " "	90.00
11	2	INNER RING M.S. FLAT 30 X 5 3000	7.2
10	6	OUTER RING " " " " 2000	14.4
9	12	RING CLAMP " " 40 X 10 150	5.58
8	6	M.S. FLAT ————— 30 X 5 275	2.22
7	6	" " ————— " " 495	3.6
6	6	" " ————— 1880	13.56
5	6	ANGLE IRON ————— 40 X 40 X 5 1880	8.8
4	2	" " ————— 50 X 50 X 5 350	2.6
3	4	" " ————— " " 100	1.52
2	2	" " ————— " " 625	4.5
1	2	M. S. PLATE ————— $\phi$ 260 X 6	2.4

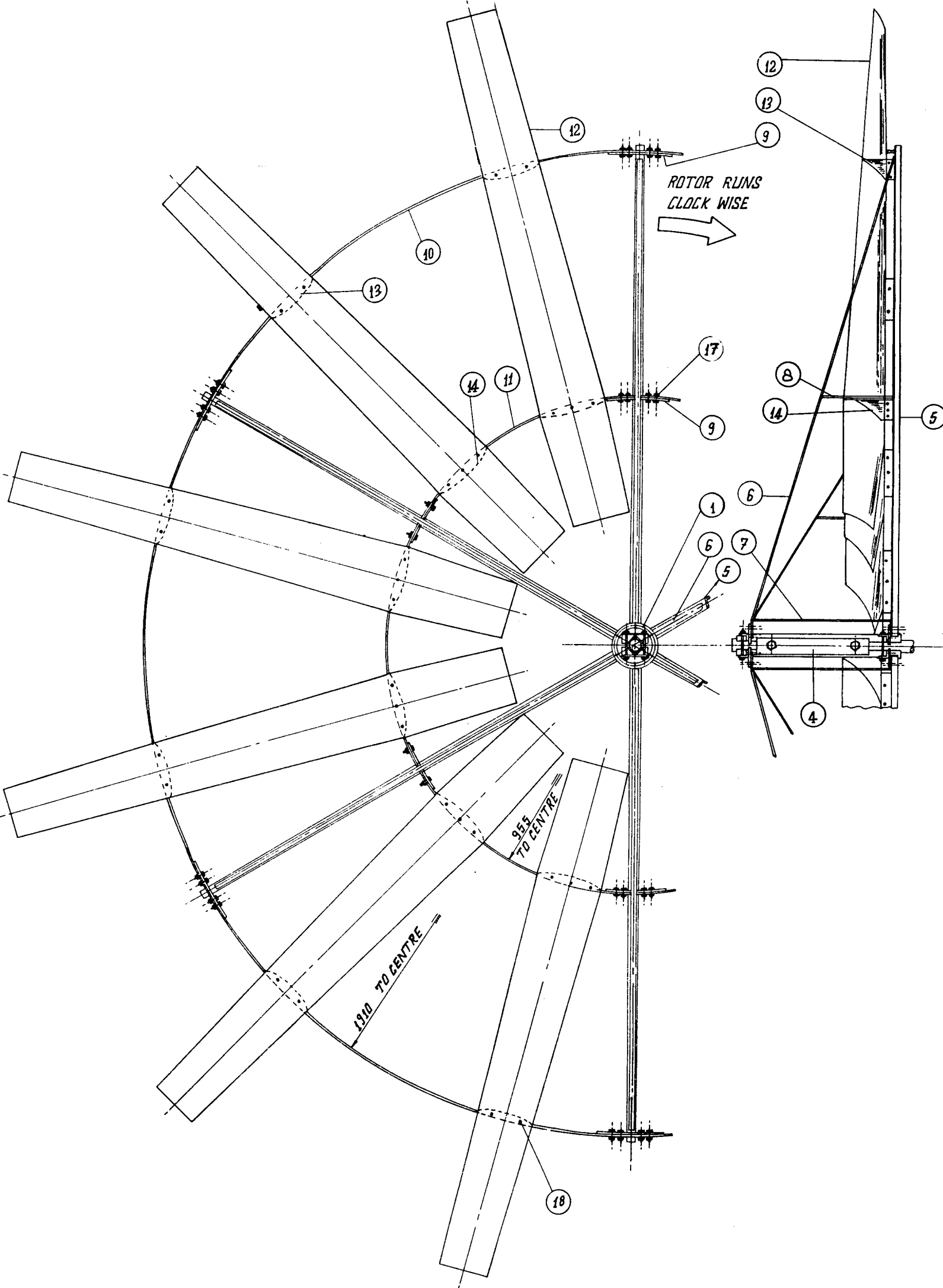
SL. No.	No REQD.	MATERIAL NAME / SIZE / MEASUREMENTS	Wt. IN KG.
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## ROTOR - FOR - 12 PU 500 WINDMILL

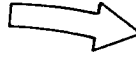
	DESIGNED BY	DRAWN BY <i>(K.K. Tiwari)</i> TRD. - Man Singh	CHECKED BY <i>(Signature)</i> PRATAP SINGH	APPROVED BY	SCALE  N.T.S.
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**FOR  
INFORMATION**

WIND ENERGY R.-E.-D. CENTRE  
I. E. R. T. ALLAHABAD-211002 INDIA



ROTOR RUNS  
CLOCK WISE



180 TO CENTRE

95.5 TO CENTRE

12

13

9

12

10

13

17

14

11

9

8

14

5

1

6

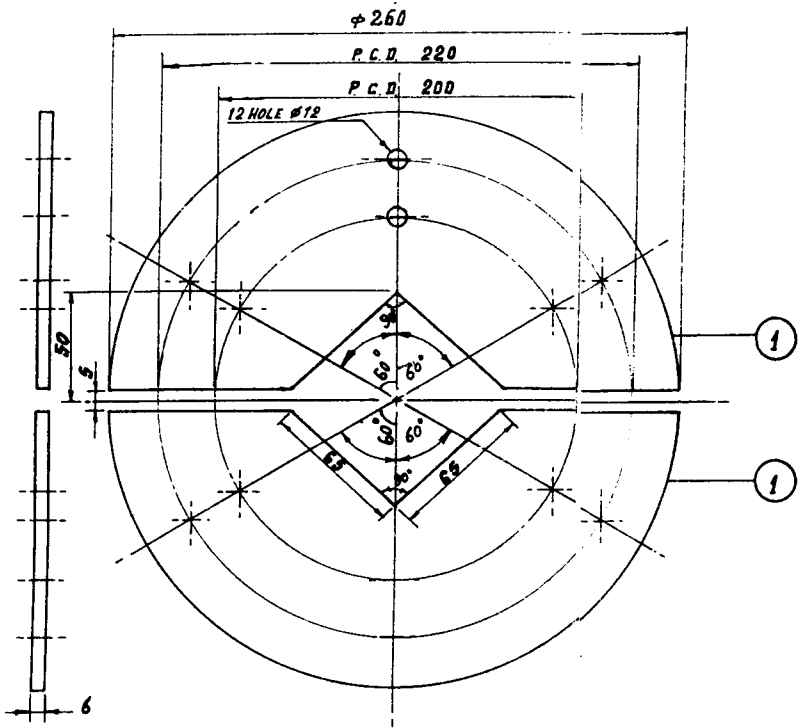
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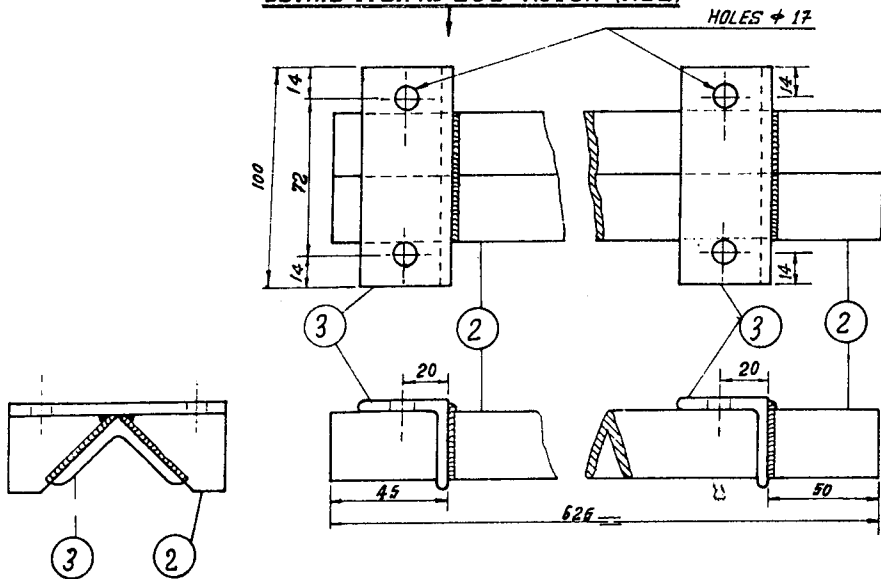
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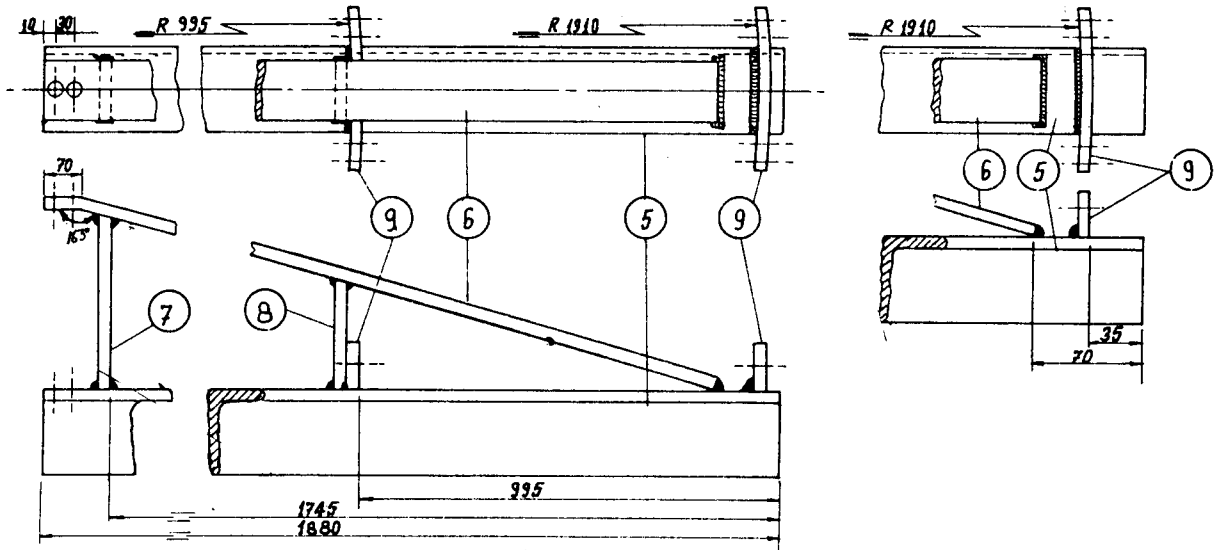
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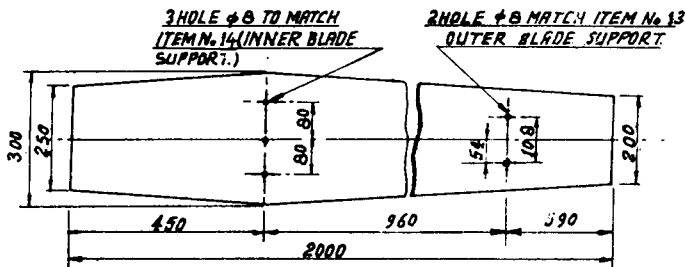
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**DETAIL ITEM No 2&3 ROTOR (HUB)**

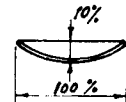




**DETAIL ITEM No 5, 6, 7, 8, 9, ROTOR SPOKE**

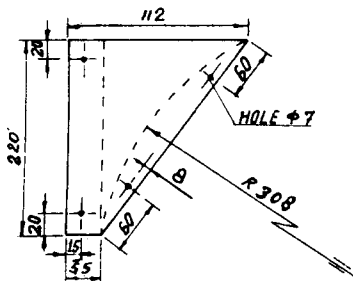


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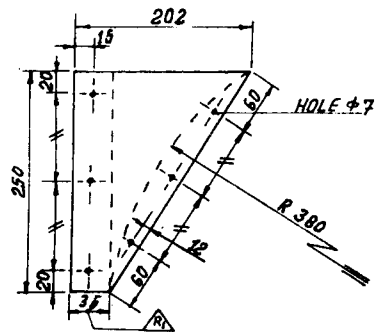


SHEET IS ROLLED IN A BENDING RADIUS OF APPR. 200 mm.

**AFTER CUTTING THE RADIUS IS CORRECTED SO THAT 10% CURVED AIRFOILS WILL RESULT.**

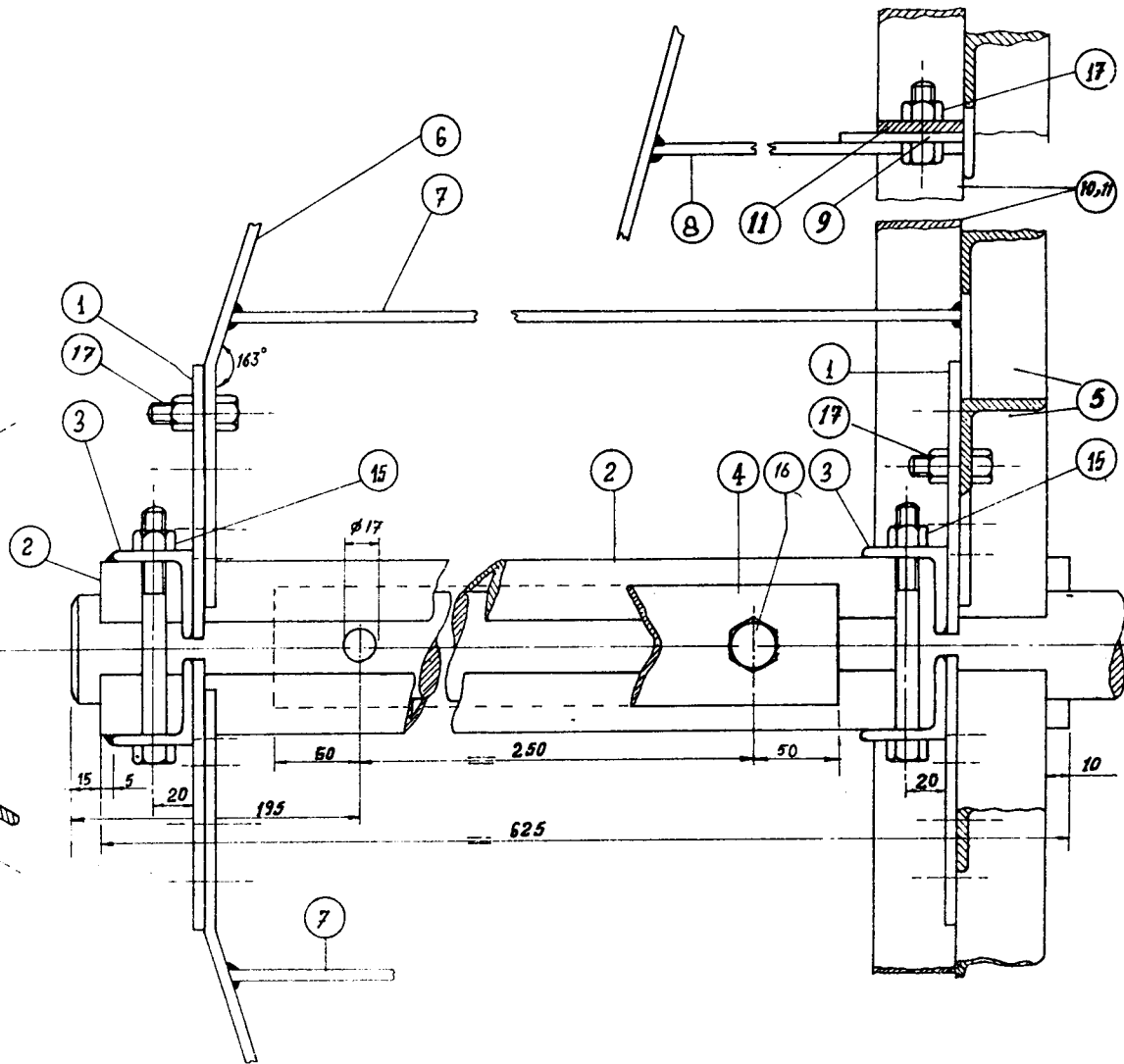
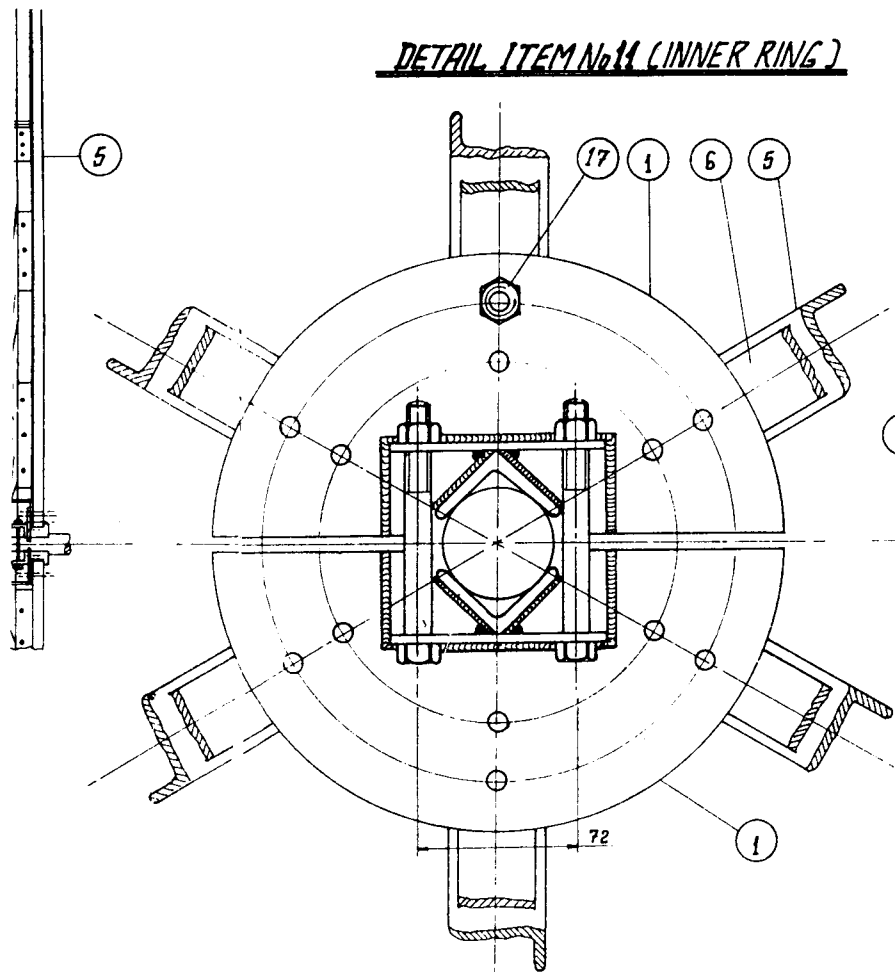


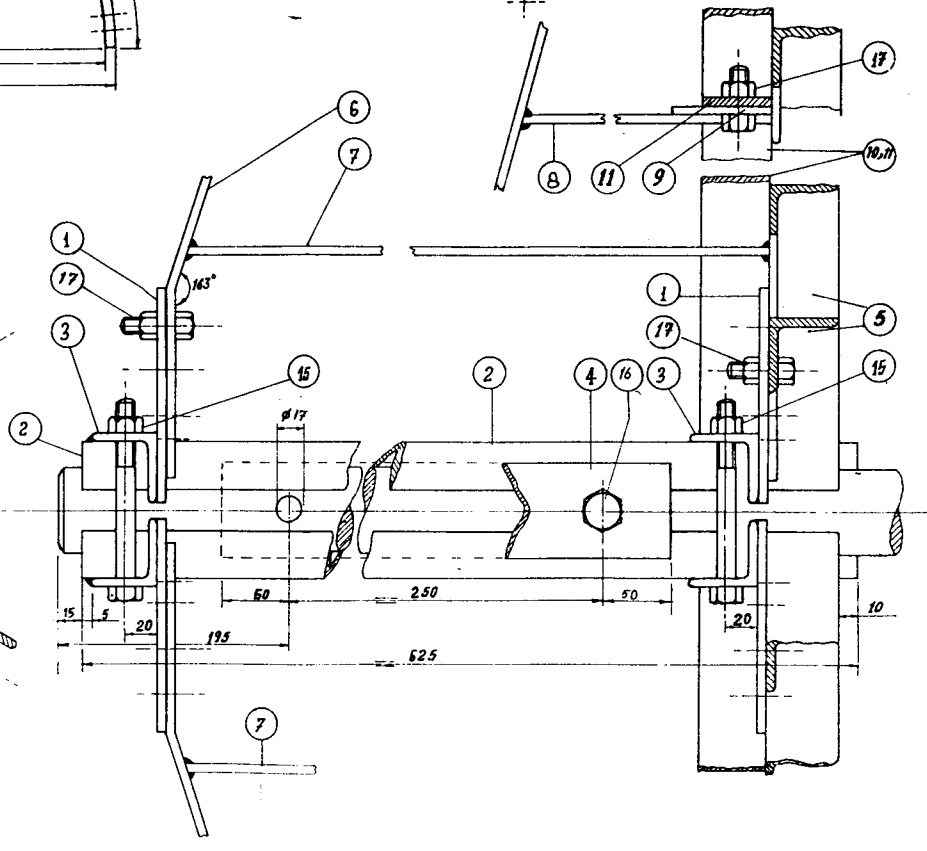
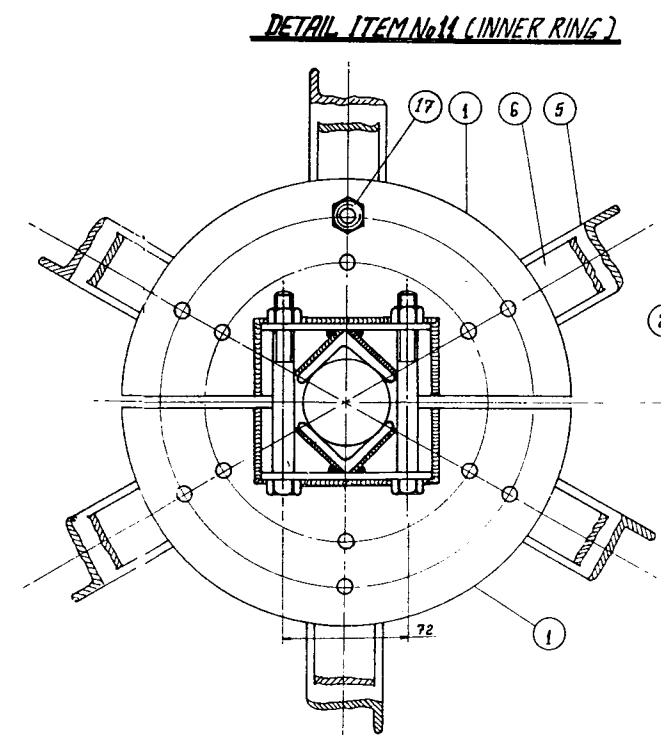
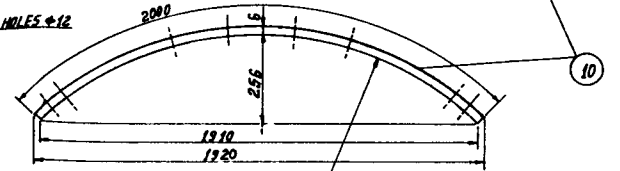
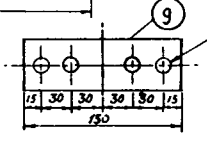
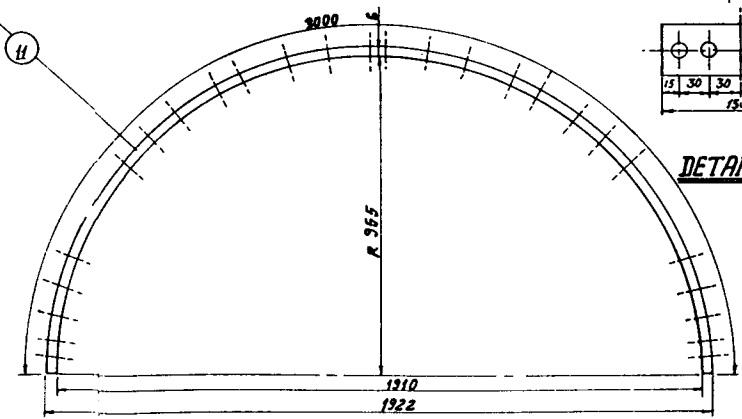
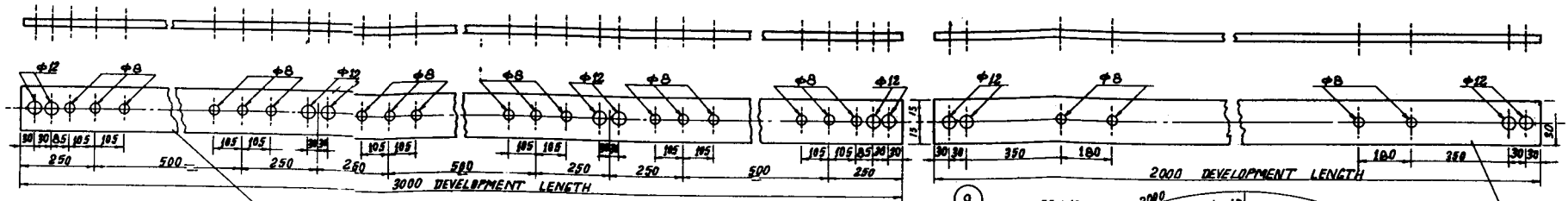
**DETAIL ITEM No 13  
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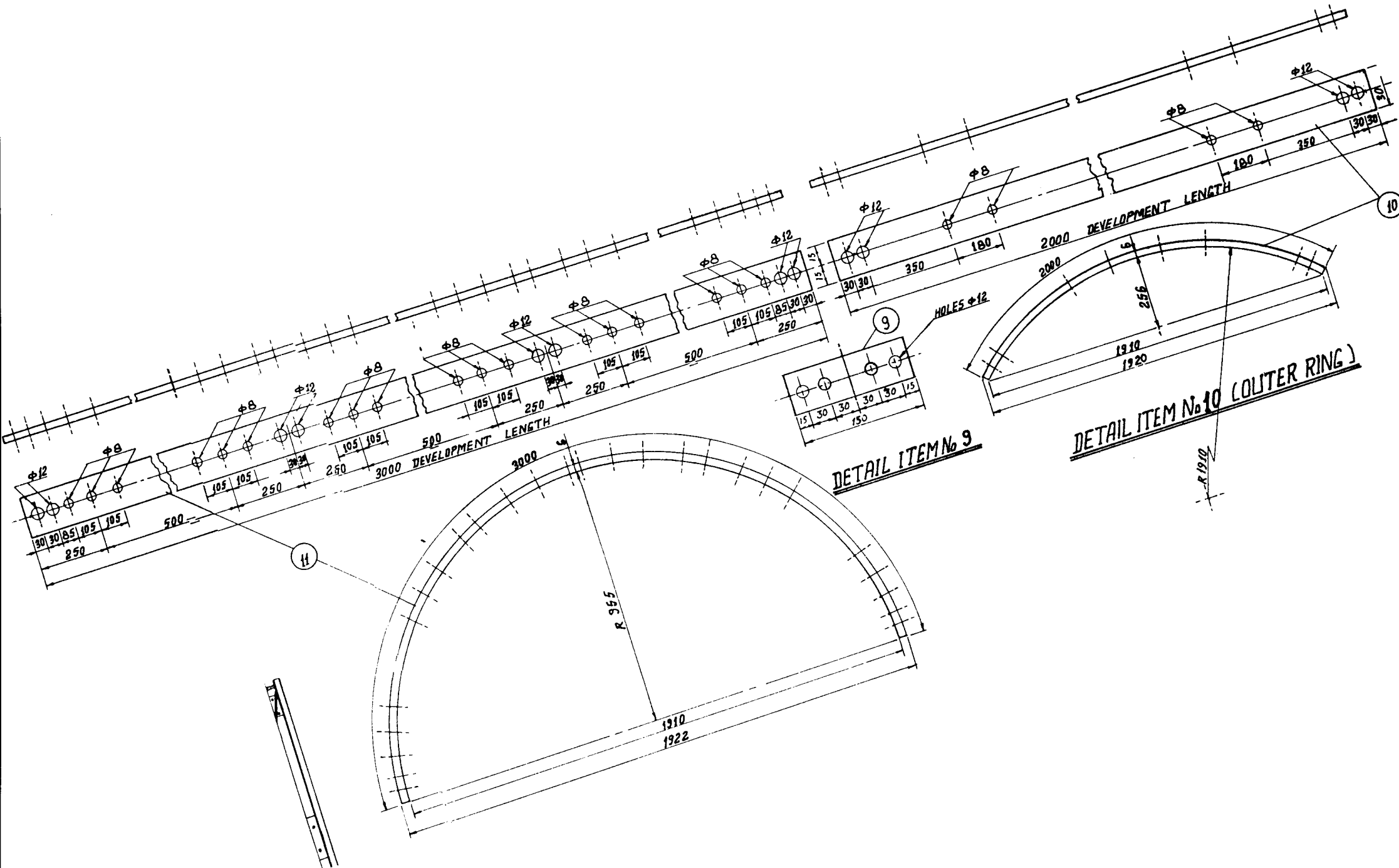
**DETAIL ITEM No 14  
INNER BLADE SUPPORT**

DETAIL ITEM No 11 (INNER RING)









17	52	NUT, BOLT, WASHER, M12 X40 (W $\frac{1}{2}$ " X1 $\frac{1}{2}$ " )	
16	4	M.S PLATE ----- 170X150X6	
15	4	FLATE IRON ----- 32X6	410
14	1	TOWER PIPE ----- (4" N.B) B-GRADE	2650
13	1	P. V. C SLEVE PIPE - (4" BORE)	710
12	2	PLANK ----- 30X200X700	
11	2	FLATE IRON ----- 32 X 6	340
10	2	" " ----- " "	460
9	2	" " ----- " "	580
8	2	ANGLE IRON ----- 35X35X5	660
7	4	" " ----- 40X40X6	2000
6	4	" " ----- 35X35X5	700
5	4	" " ----- 50X50X6	250
4	4	" " ----- 35X35X5	1400
3	16	" " ----- " " "	1940
2	4	" " ----- 40X40X5	4500
1	8	" " ----- 35X35X5	250

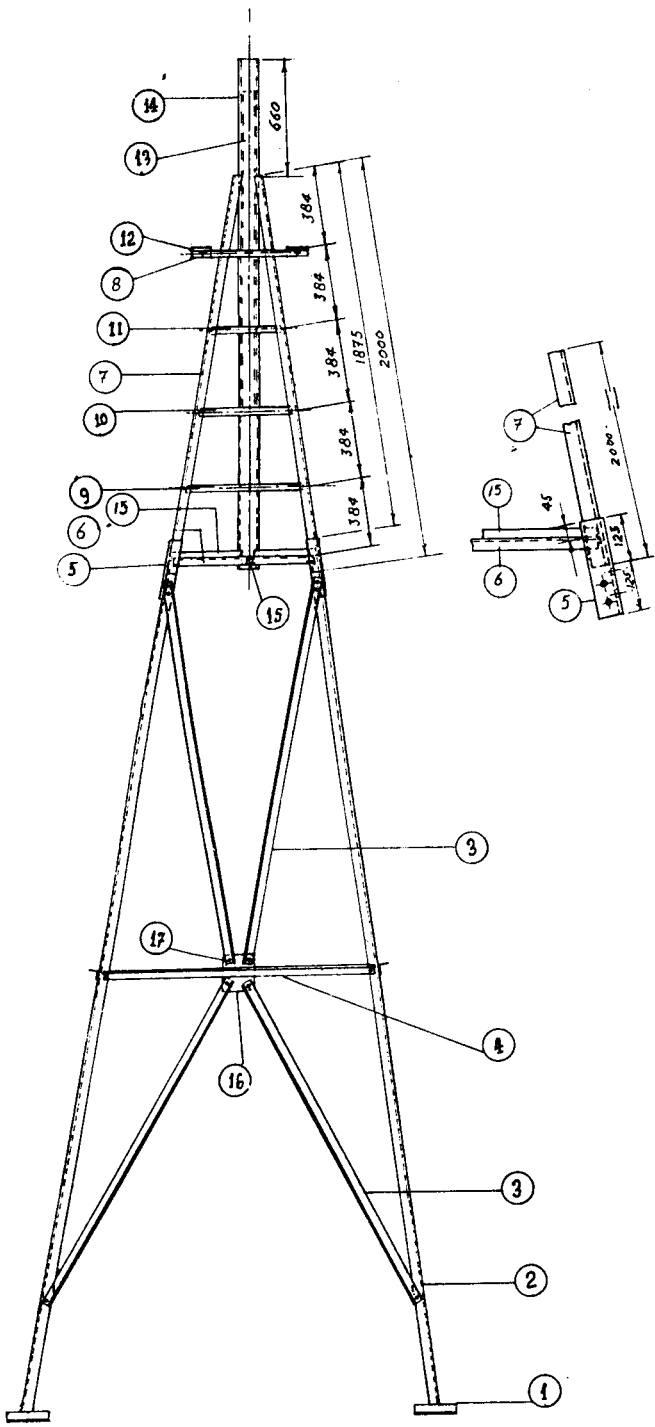
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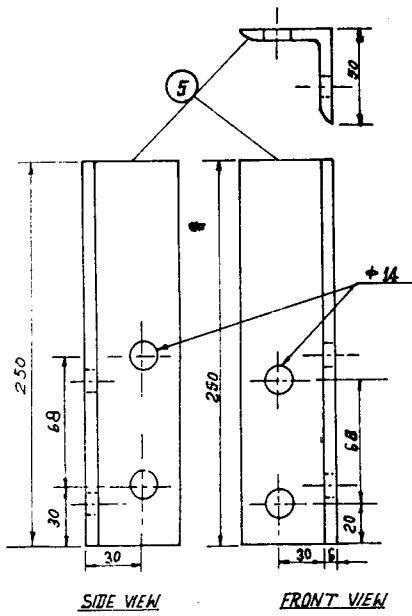
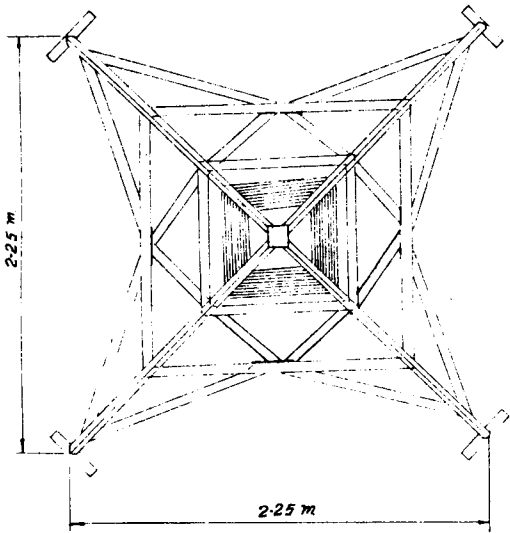
TOWER-FOR 12 PU 500 WIND MILL

DESIGNED BY	DRAWN BY E.H.H. SHARMA J.N.G.H.	CHECKED BY <i>[Signature]</i> PRATAP SINGH	APPROVED BY	SCALE, N.T.S.
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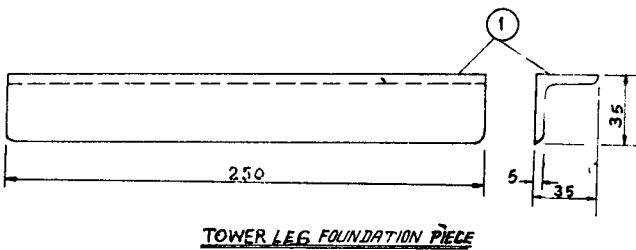
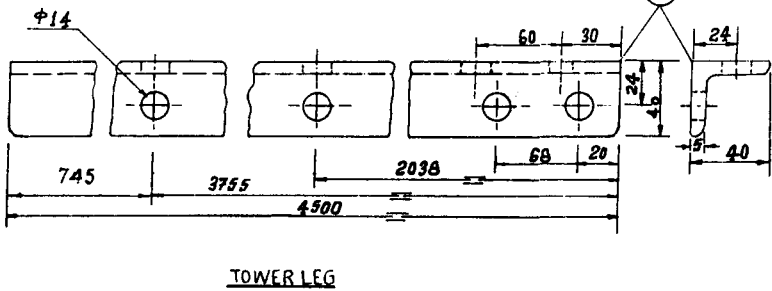
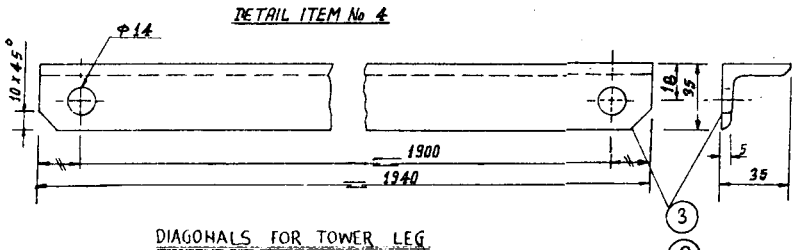
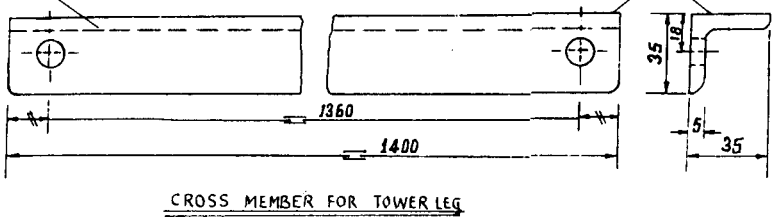
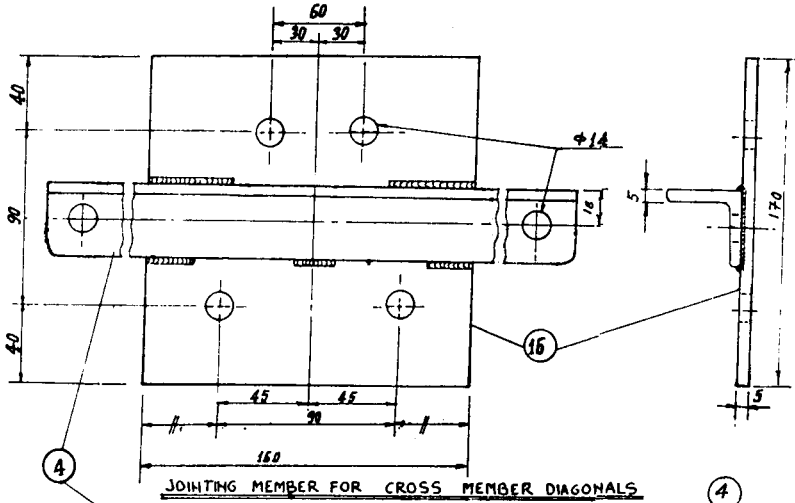
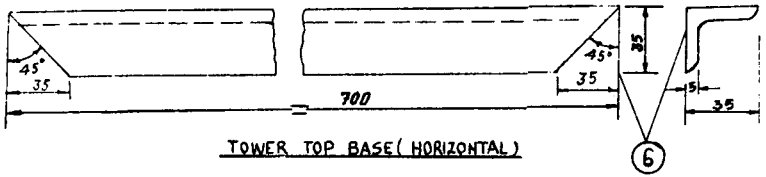
FOR  
INFORMATION

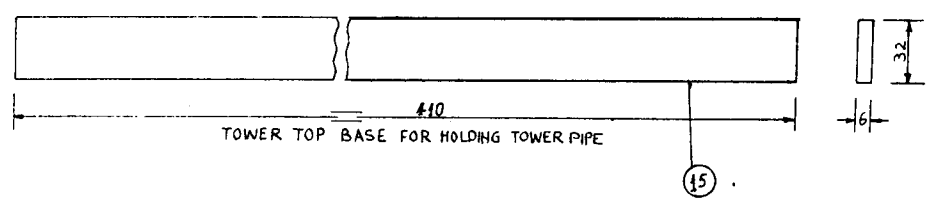
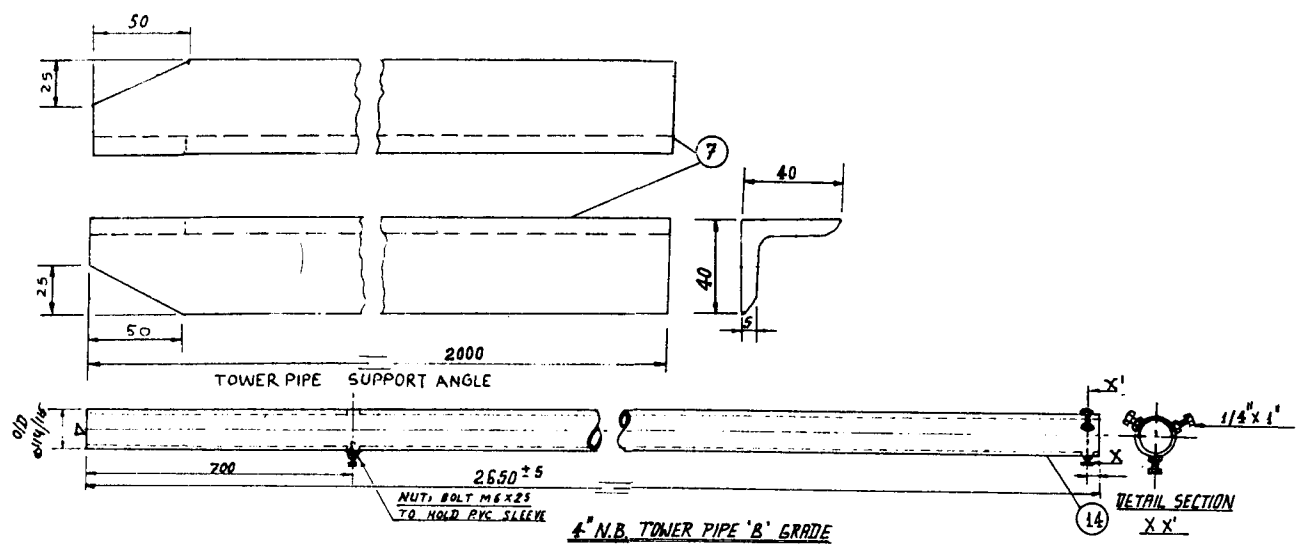
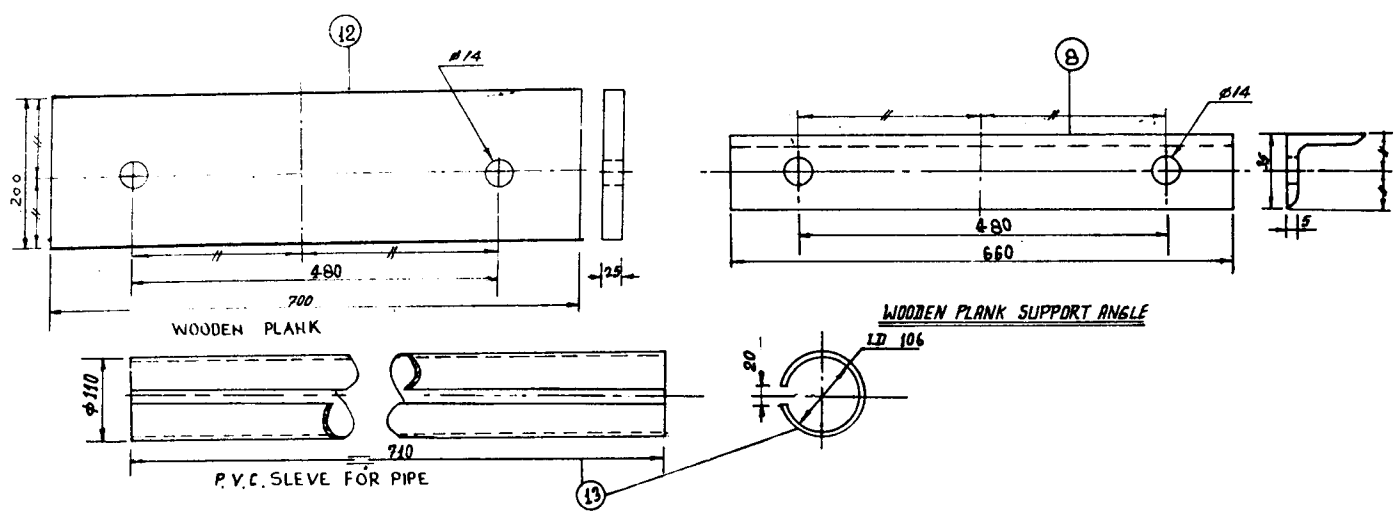
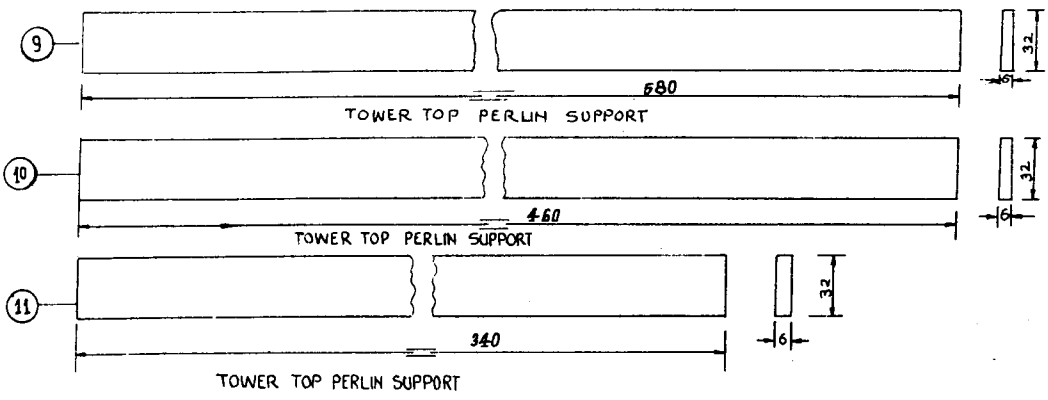
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TOWER TOP & TOWER LEG JOINTER (OUTER)

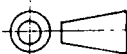




35	1	SPRING APP	$\phi 30 \times 100 \times \phi 4$	
34	12	M.S. BOLT, NYLOCK NUT, WASHER	M6 X 25 (W $\frac{1}{2}$ " X 1")	
33	1	M.S. BOLT, " " "	M12 X 100 (W $\frac{1}{2}$ " X 4")	
32	1	M.S. BOLT, " " "	M12 X 40 (W $\frac{1}{2}$ " X 1 $\frac{1}{2}$ ")	
31	1	M.S. NYLOCK NUT	M22 (W 7/8")	
30	1	M.S. WASHER	M12 (W 1/2")	
29	1	M.S. ROD	$\phi 20 \times 690$	
28	1	HELP VANE 1 M.M SHEET	1000 X 500	
27	1	TAIL VANE	2000 X 1000	
26	1	RACHET FLAT IRON HARDEND	32 X 6 LENGTH - 480	
25	1	FLAT IRON	32 X 6 " - 900	
24	3	" "	" " - 750	
23	1	" "	" " - 830	
22	1	" "	" " - 115.5	
21	1	" "	" " - 130	
20	2	" "	" " - 60	
19	2	" "	(WEARING FLATES) " " - 115.5	
18	1	ANGLE IRON	40 X 40 X 5 - 1000	
17	1	" "	" " - 45	
16	1	" "	" " - 60	
15	1	" "	" " - 125	
14	1	" "	" " - 3000	
13	1	" "	" " - 4000	
12	1	" "	" " - 1500	
11	2	" "	65 X 65 X 6 - 250	
10	1	" "	40 X 40 X 5 - 500	
9	2	" "	" " - 460	
8	2	" "	" " - 540	
7	2	" "	" " - 1110	
6	2	" "	" " - 1000	
5	1	" "	" " - 590	
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1	1	" "	" " - 200	

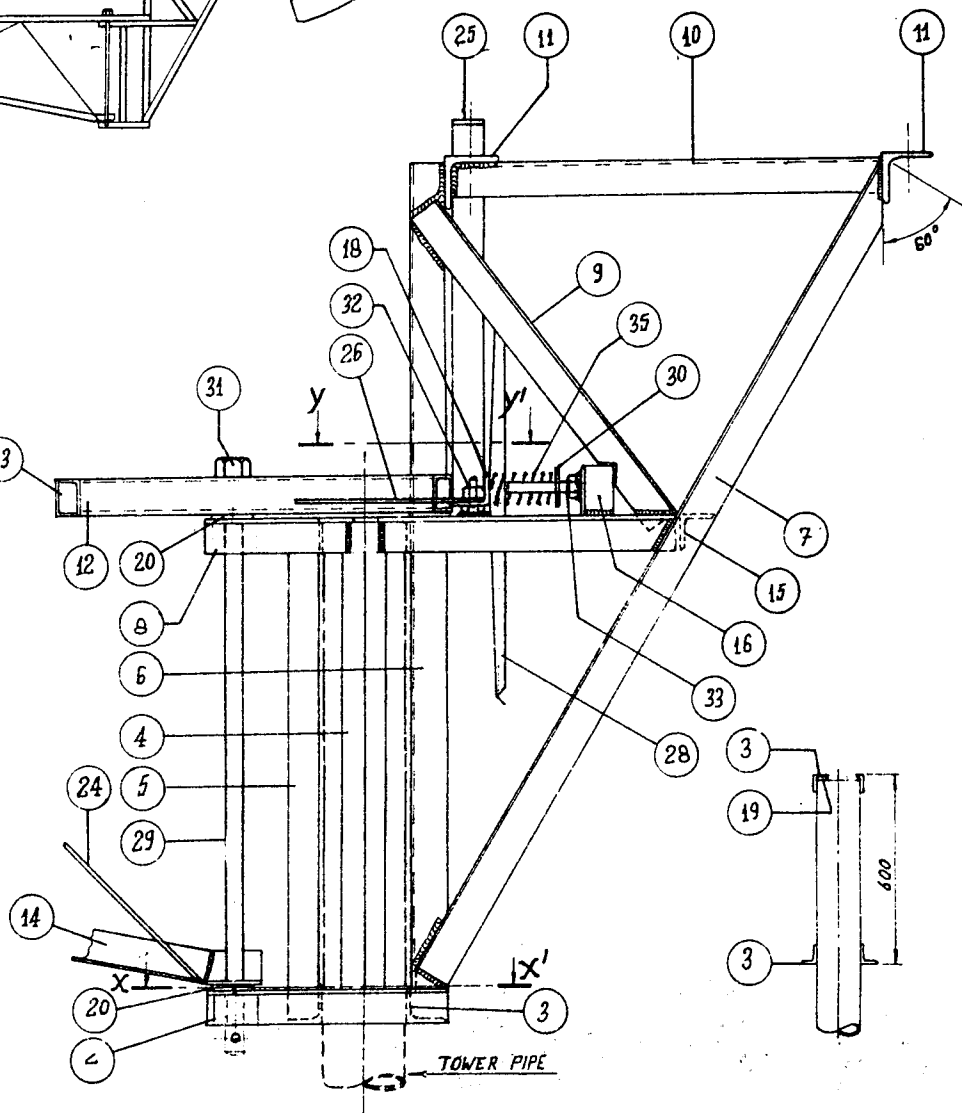
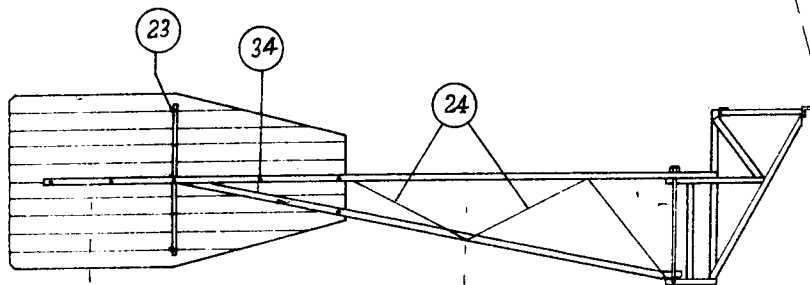
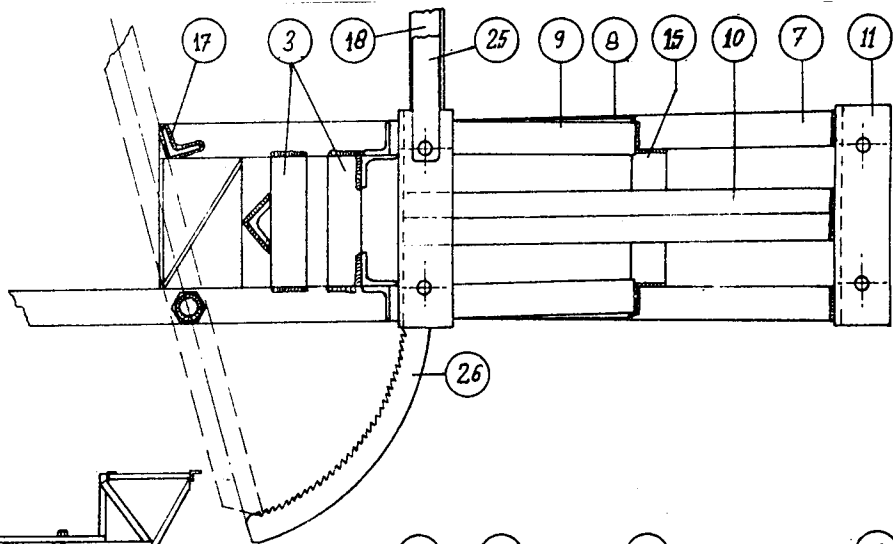
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## HEADCONSTRUCTION-12 PU 500 - WINDMILL

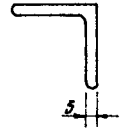
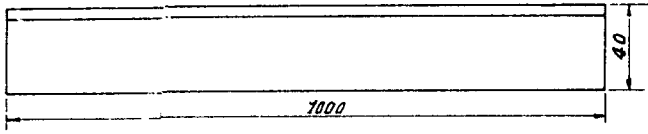
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		By. No. 2/94	PRATAP SINGH		

**FOR  
INFORMATION**

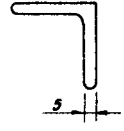
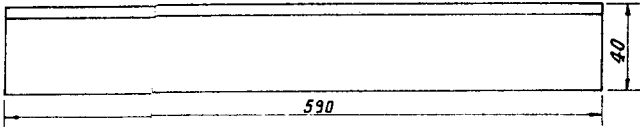
WIND ENERGY R-&D CENTRE  
I.E.R.T. ALLAHABAD - 211002-INDIA



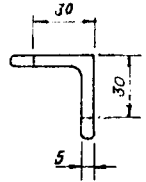
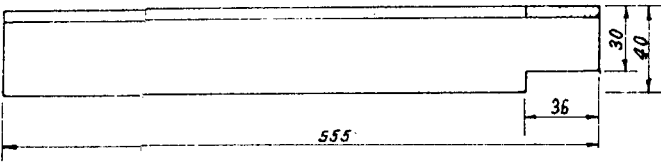




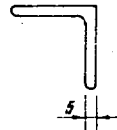
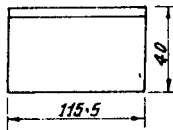
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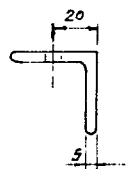
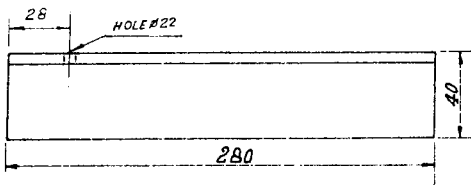
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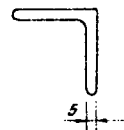
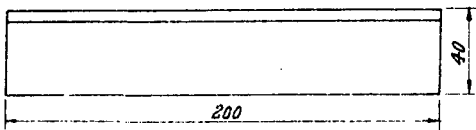
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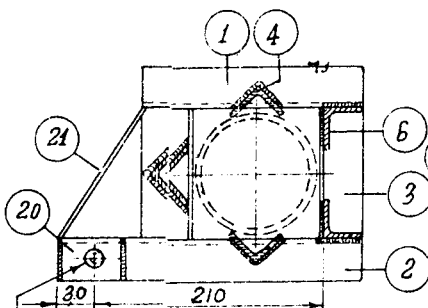
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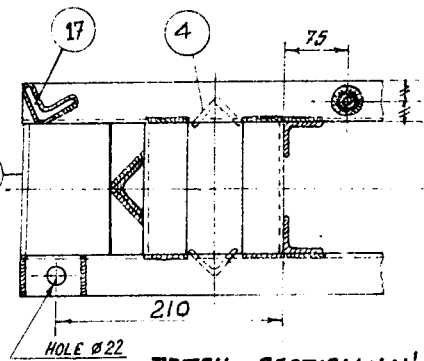
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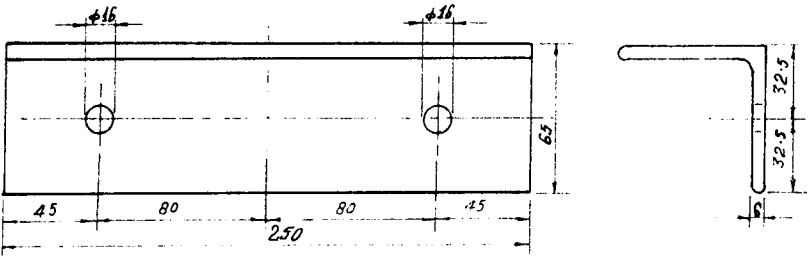
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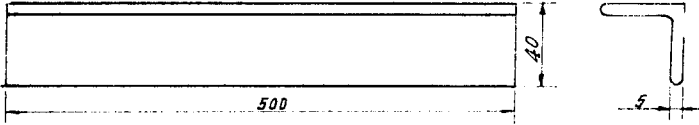
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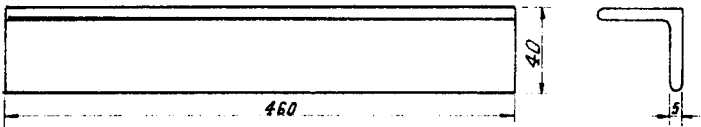
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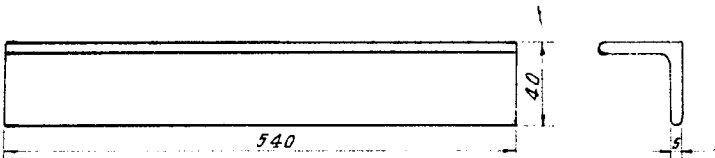
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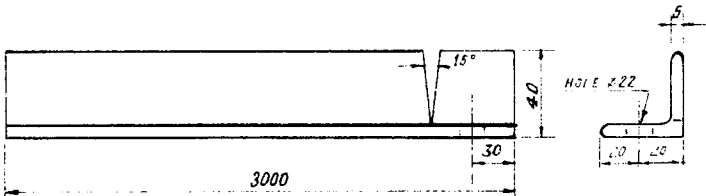
DETAIL ITEM No 10



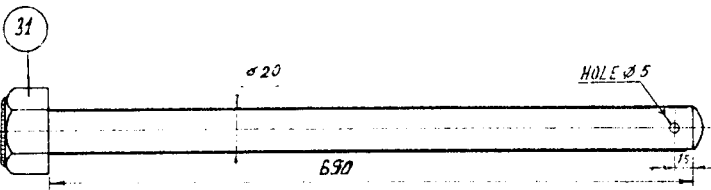
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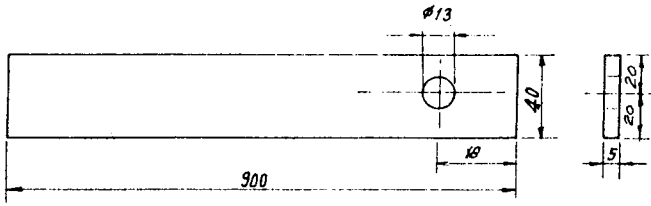
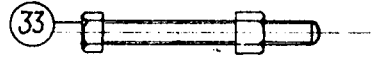
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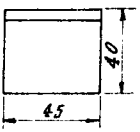
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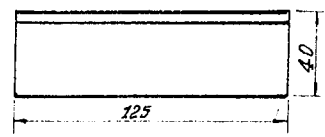
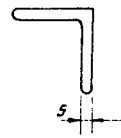
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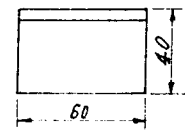
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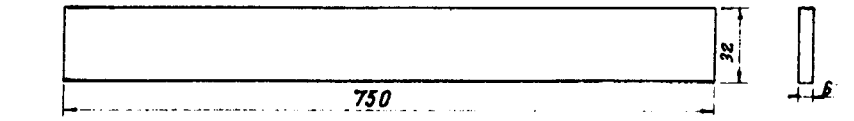
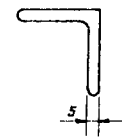
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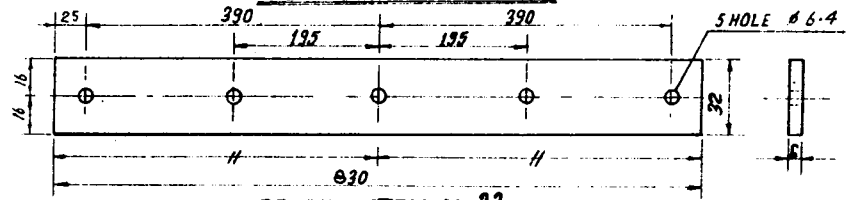
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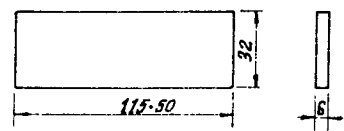
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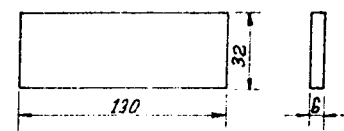
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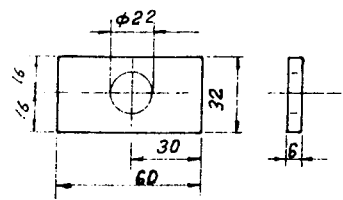
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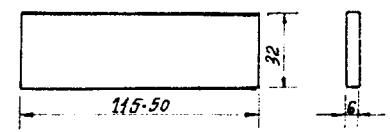
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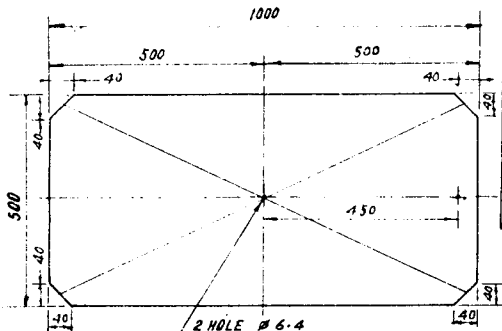
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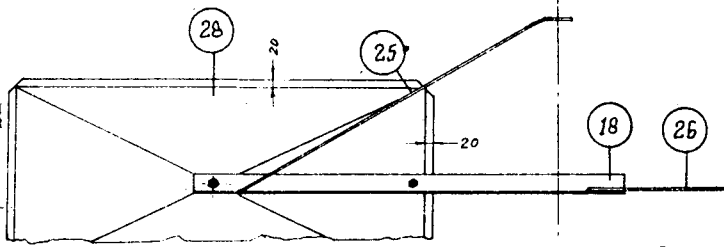
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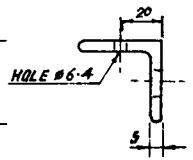
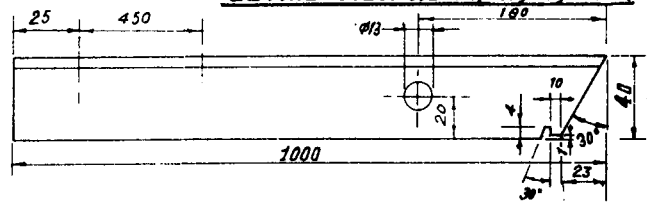
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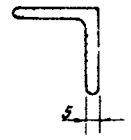
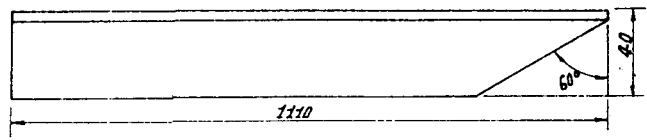
DETAIL ITEM No 28



DETAIL ITEM No 18, 25, 26, & 28



DETAIL ITEM No 18



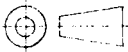
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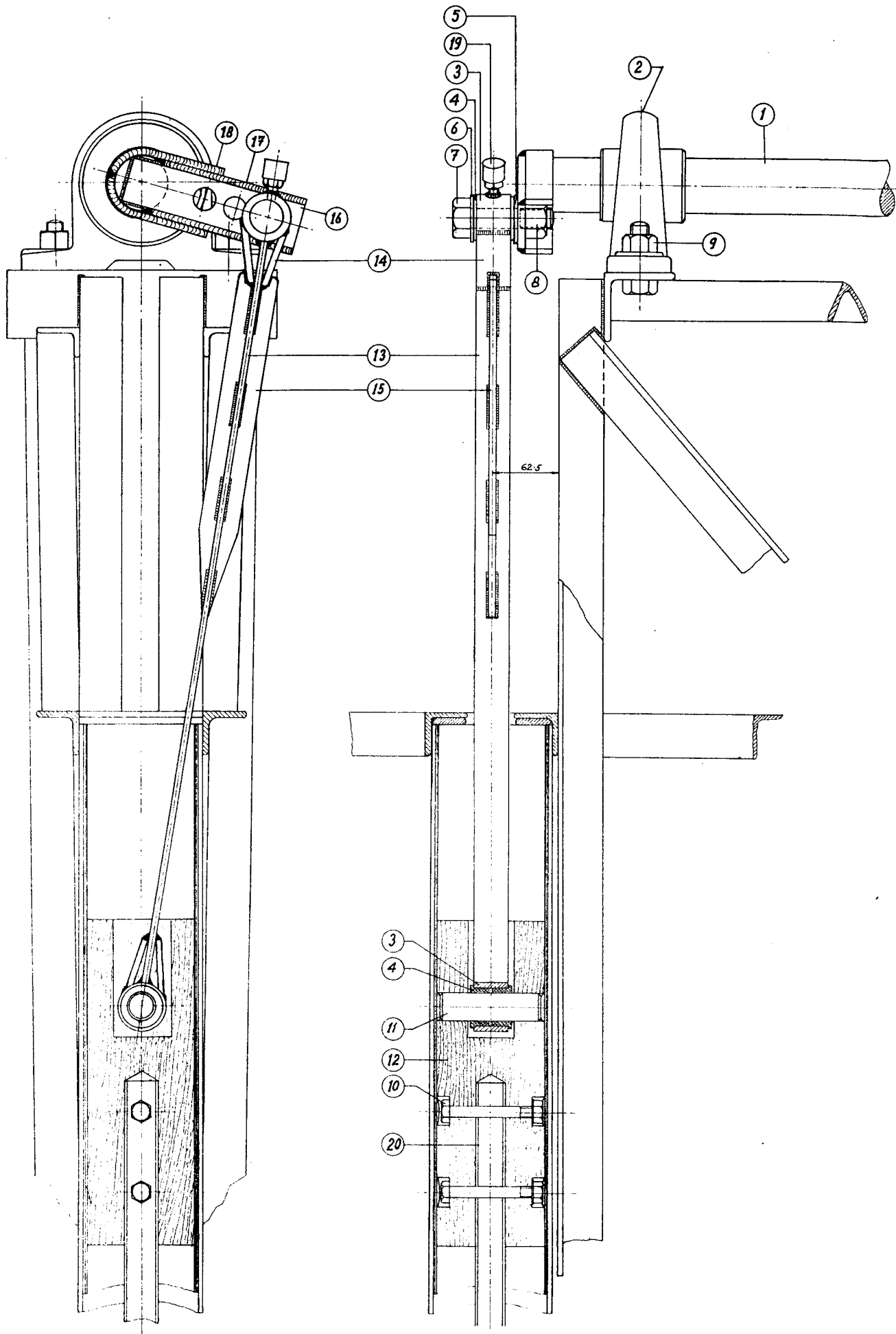


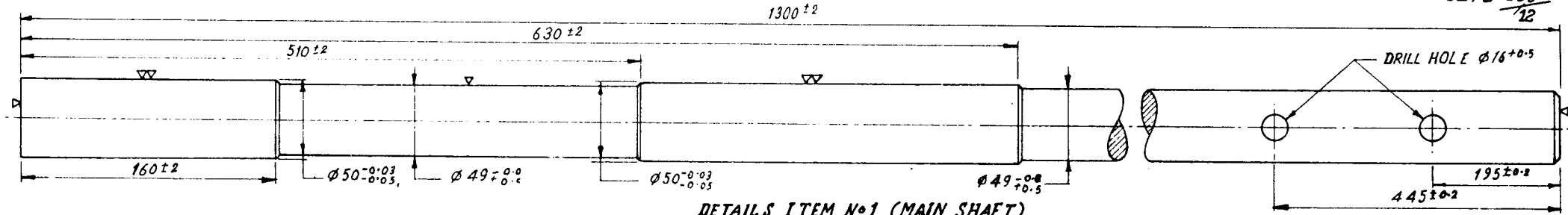
\* LENGTH DEPEND UPON CIRCUMSTANCES.

21	2	TEAK WOOD PLUMP ROD GLIDE _____	
20	*	G.I. PIPE (B.S.T. MAKE) CLASS 'A' _____	
19	1	GREASE CUP _____	
18	1	FLAT IRON _____ 25x6 250	
17	2	" " " " _____ 135	
16	1	" " _____ 40x10 165	
15	2	" " _____ 15x6 300	
14	4	" " _____ 30x6 50	
13	1	" " CONNECTING ROD-30x6 650	
12	1	POLYPROPELENE _____ CROSS HEAD.	
11	1	M.S. CROSS PIN. _____ $\phi 25$ 92	
10	2	M.S. BOLT, NUT, WASHER _____ M10x100 (W $\frac{3}{8}$ "x4")	
9	4	M.S. BOLT, NUT, WASHER. _____ M12x50 (W $\frac{1}{2}$ "x2)	
8	1	M.S. NUT. _____ M20 (W $\frac{3}{4}$ "x")	
7	1	M.S. CRANK BOLT (G. K.W MAKE)-M20x75 (W $\frac{3}{4}$ "x3")	
6	1	M.S. WASHER _____ $\phi 20 \times \phi 40 \times 3 \text{mm}$	
5	1	M.S. BUSH _____ $\phi 20 \times \phi 40 \times 44$	
4	4	NYLON BUSH (MOLDED) _____ $\phi 25 \times \phi 38 \times 18$	
3	2	M.S. BUSH _____ $\phi 33 \times \phi 43 \times 33$	
2	2	PILLOW BLOCK (BEARING) $\phi 50$ C.F.Y.H & NTN P 210J 50mm $\pm 0.01$ BORE	
1	1	M.S. MAIN SHAFT _____ $\phi 50 \times 1300$	
SL. No	N. REQD.	MATERIAL NAME / SIZE / MEASUREMENTS	REMARKS.

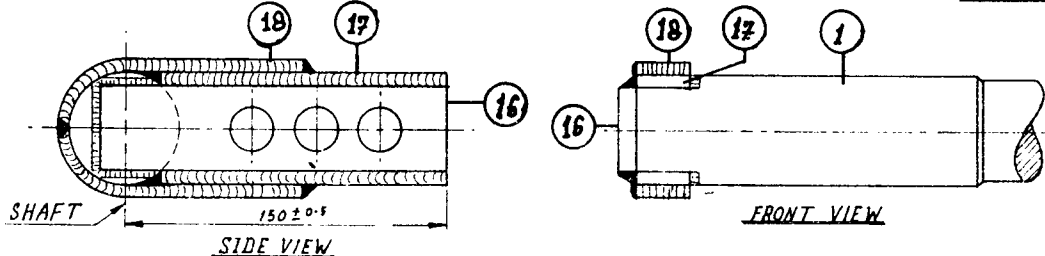
## MOVINGPARTS OF 12 PU 500 WINDMILL

	DESIGNED BY	DRAWN BY <i>Bhavani</i>	CHECKED BY <i>Pratap Singh</i>	APPROVED BY	SCALE N.T.S.
		TRD. BY <i>Bhavani</i>	PRATAP SINGH		
<b>FOR</b> <b>INFORMATION</b>	WIND ENERGY R.S.D CENTRE INSTT. OF ENGINEERING AND RURAL TECHNOLOGY ALLAHABAD - 211002				

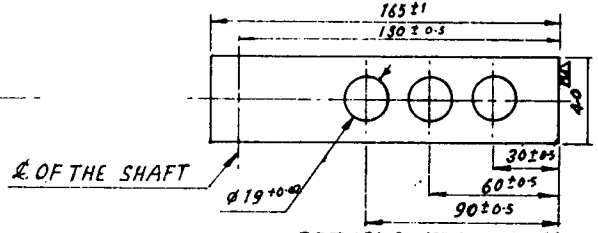




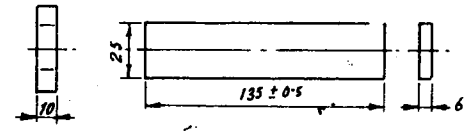
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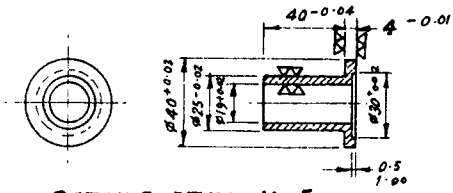
(CRANK) DETAILS ITEM No 16, 17 & 18 WITH SHAFT ASSY. (WELDING)



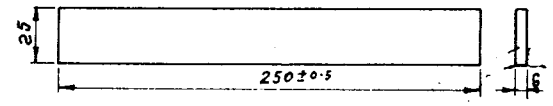
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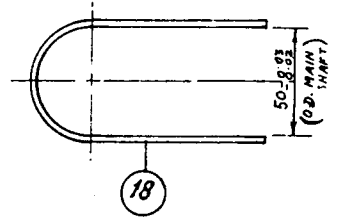
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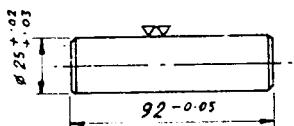
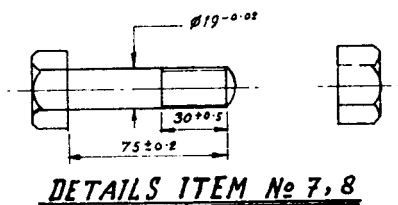
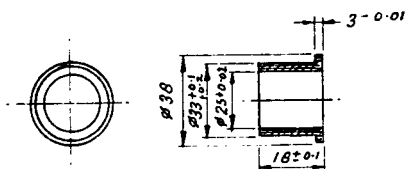
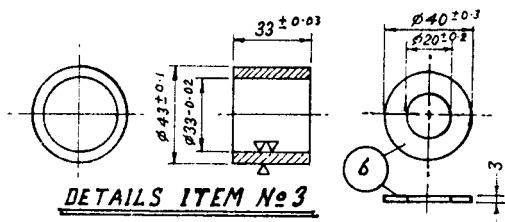
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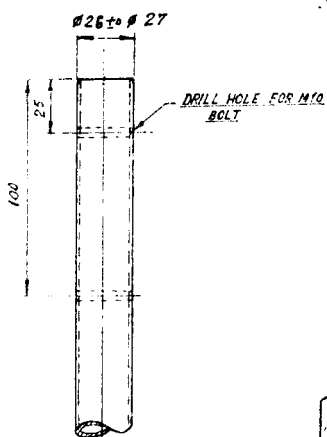


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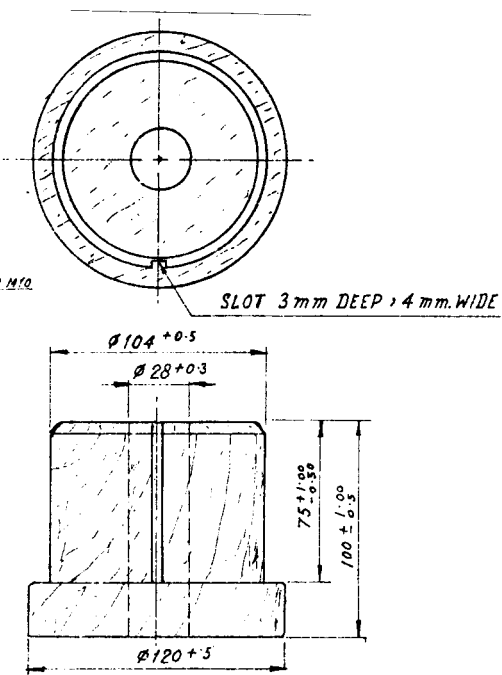




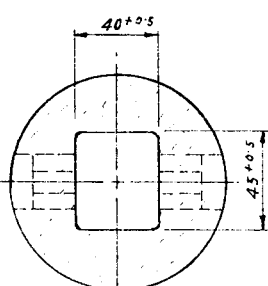




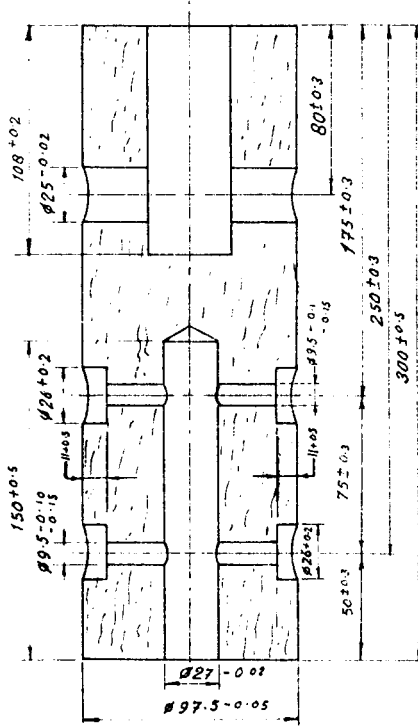
PUMPROD & PISTON ROD  
ITEM No 20



PUMPROD WOODEN GUIDE  
( SL.No 42 ON 12 PU 500 PUMP DESIGN)



TOP VIEW



SECTIONAL FRONT VIEW

(CROSSHEAD)- DETAILS ITEM No 12

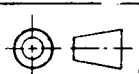
NOTE :—

\* MARKED THUS INDICATES THAT  
LENGTH OR QUANTITY WILL VARY  
ACCORDING TO CIRCUMSTANCES

36	1	TEAK WOOD / POLYPROPELENE	TEAK WOOD	5"X5"X4"
35	2	CLAMP	ROD	φ 12 (1/2")X370 mm.
34	1	BOLT, NUT, WASHER		M12 X 20 (W 1/2" X 3/4")
33	4	BOLT, NUT, WASHER		M12 X 125 (W 1/2" X 5")
32	*	SPRING WASHERS		M24 (W 7/8")
31	*	NUTS		M24 (W 7/8")
30	*	THREADED STUD		M24 X 100 (W 7/8" X 4")
29	1	THREADED STUD		M24 X 125 (W 7/8" X 5")
28	*	GUN METAL BUSH		φ 33 X 30 mm.
27	*	STEEL BUSH		φ 43 X 33 mm.
26	1	PISTON	TEAK WOOD / POLYPRDPELENE	
25	1	GASKET	NITRILE RUBBER / SOLE LEATHER	φ 290 X 6 mm
24	2	VALVE		φ 150 X 6
23	1	RING	ROD	φ 8 (3/8") — 870 mm.
22	8	FILLING PIECE	ROD	φ 8 (3/8") — 40 mm.
21	2	ANGLE IRDN		40 X 40 X 4 (1/2" X 1/2") — *
20	3	FLAT IRDN		30 X 6 (1/4" X 1/4")
19	*	"	"	" — 700 mm.
18	1	"	"	" — 450 mm.
17	1	"	"	" — 180 mm.
16	4	"	"	" — 60 mm.
15	12	"	"	" — 85 mm.
14	1	FOOT VALVE	3mm. SHEET	φ 170 mm.
13	2	CASING		500 X 900 mm.
12	1	CASING FLANGE		φ 290 mm.
11	2	CASING FLANGE		φ 290 mm.
10	1	CYLINDER	SEAMLESS	6" GAS PIPE — 460 mm.
9	1	DELIVERY PIPE		4" " " — 560 mm.
8	*	SOCKET	FOR	4" " "
7	1	T- SOCKET	"	" " "
6	*	DELIVERY PIPE		4" " " — *
5	1	EXHAUST PIPE		4" " " — *
4	1	TOP PIPE		4" " " — 750 mm.
3	4	PIPE		5/8" " " — 100 mm.
2	1	PUMP ROD		3/4" " " — 900 mm.
1	*	PUMP ROD EXTENSION		3/4" " " — *

SL. No. No. REQD. MATERIAL NAME / SIZE / MEASUREMENTS / REMARKS

### PISTON PUMP FOR 12 PU 500 WIND MILL



DRN. BY  
*Biswas*  
(R. K. Tiwari)

TRD. BY  
*Biswas*  
(R. K. Tiwari)

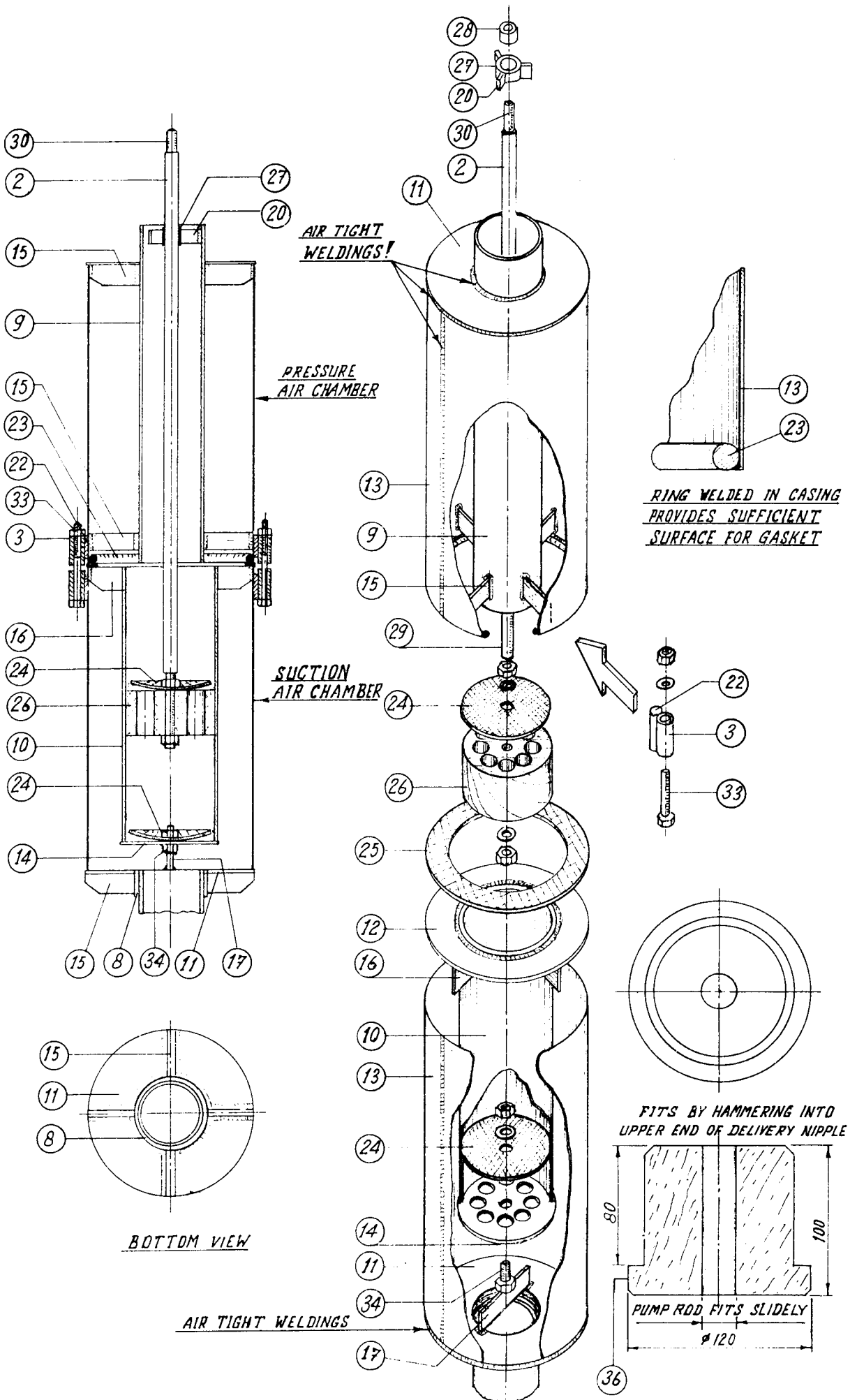
CHD. BY

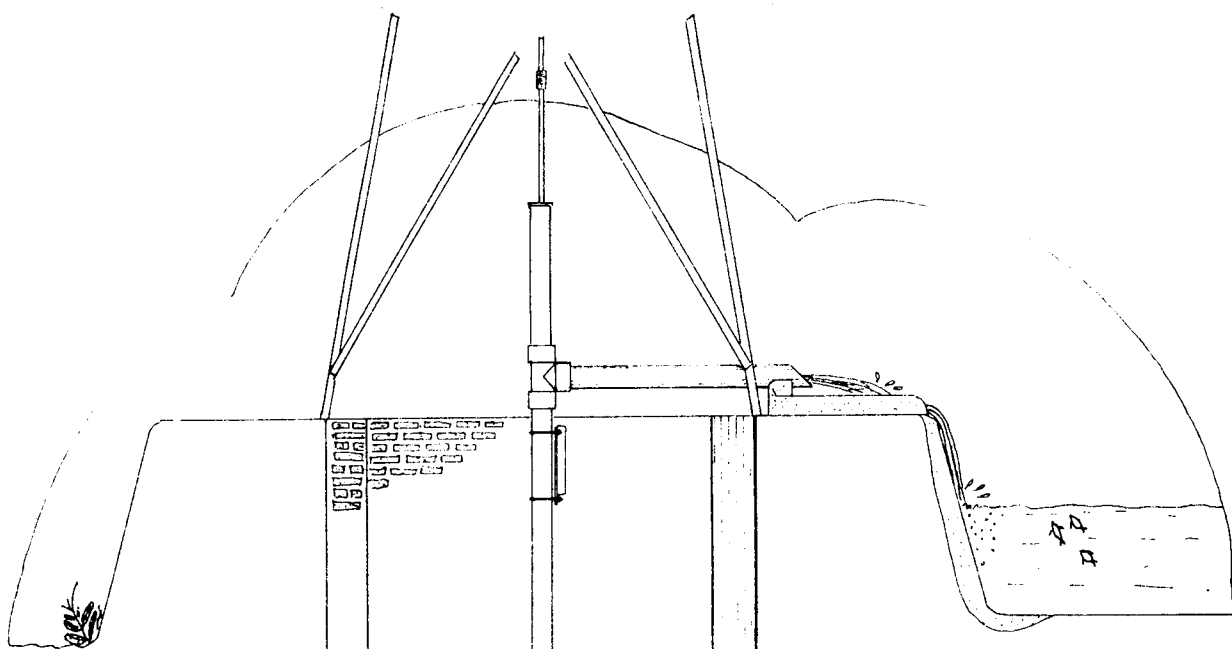
APPVD. BY

SCALE  
NTS

FOR  
INFORMATION

WIND ENERGY R. & D. CENTRE  
I. E. R. T. ALLAHABAD - 211002 - INDIA

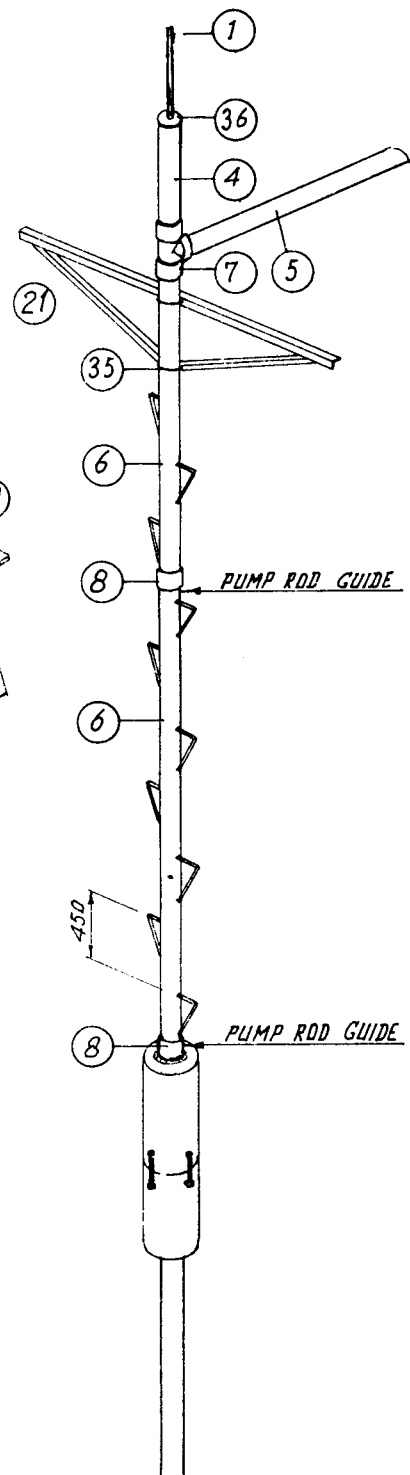
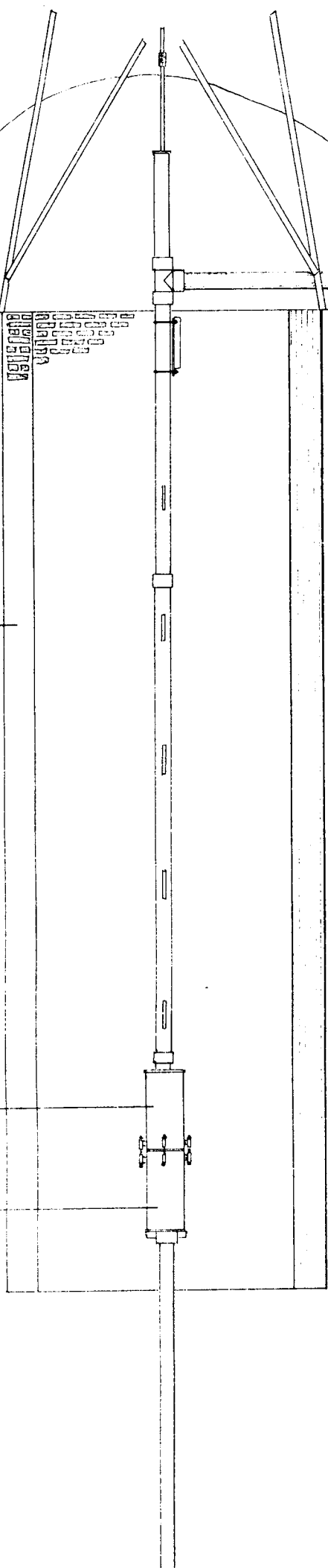




BRICK MASONED WELL

PRESSURE SECTION

SUCTION SECTION

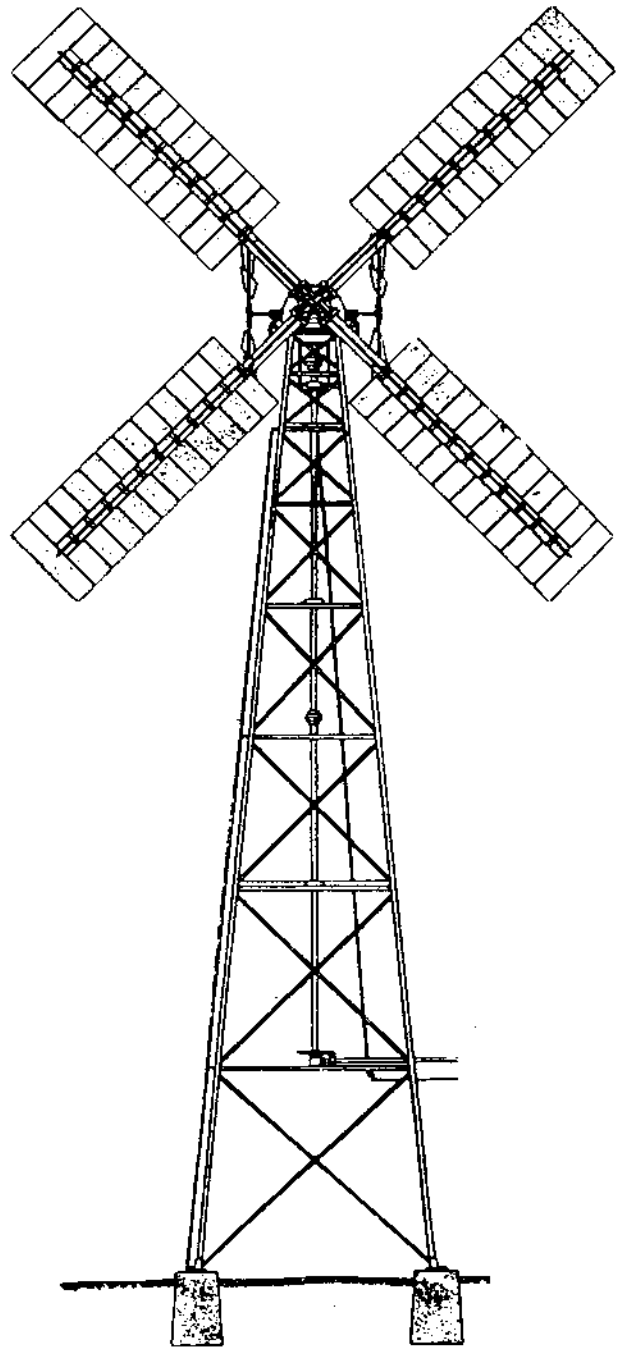


PUMP ROD GUIDE

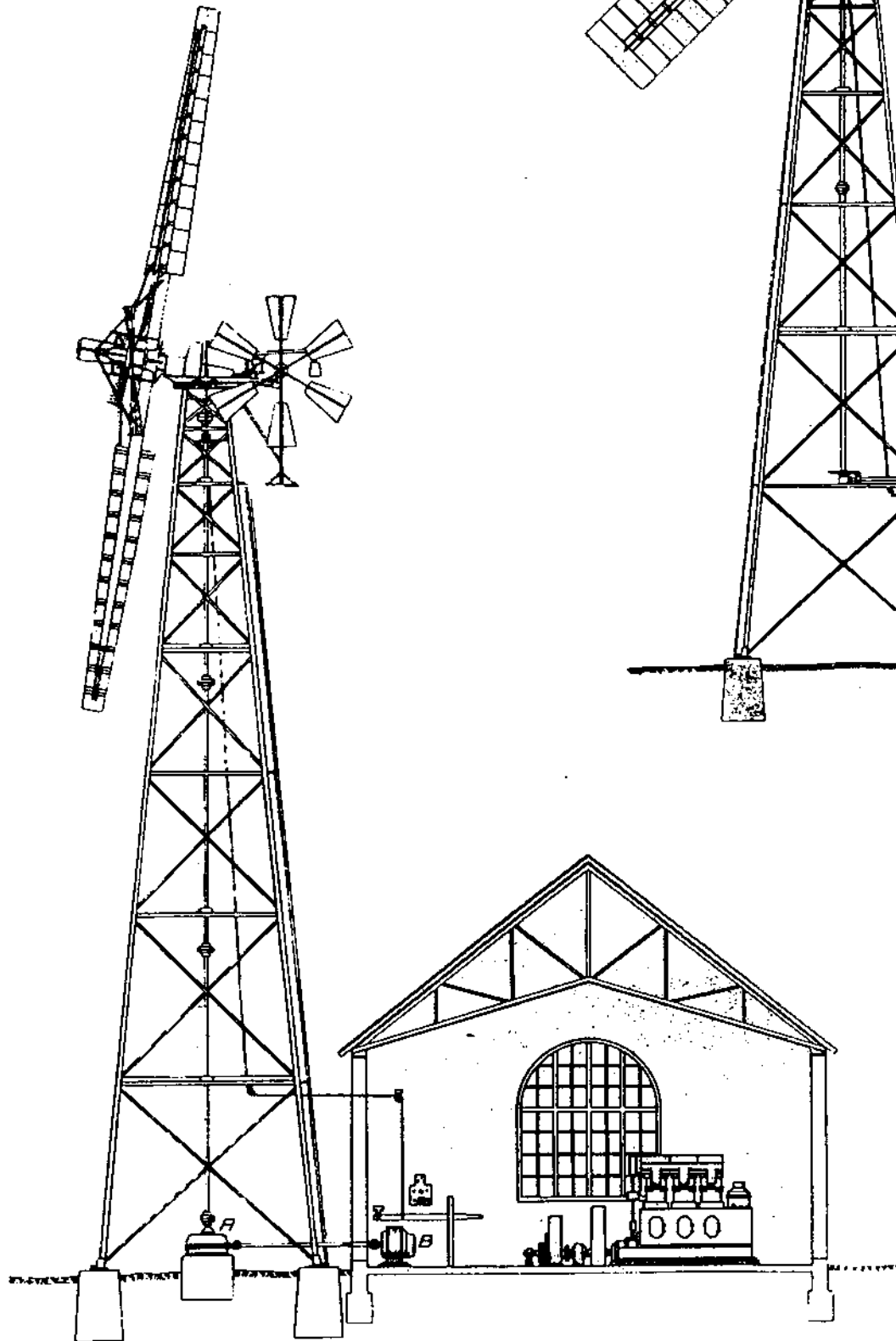
PUMP ROD GUIDE

**La Cour-type Windmill for Electricity Production:  
Lykkegård model Denmark 1928.**

**Danske elproducerende vindmøller 1892 -1962:  
Jytte Thorndahl. Elmuseet. DK. 1996.  
87-89292-36-7.**



*Fig. I*



*Fig. II*

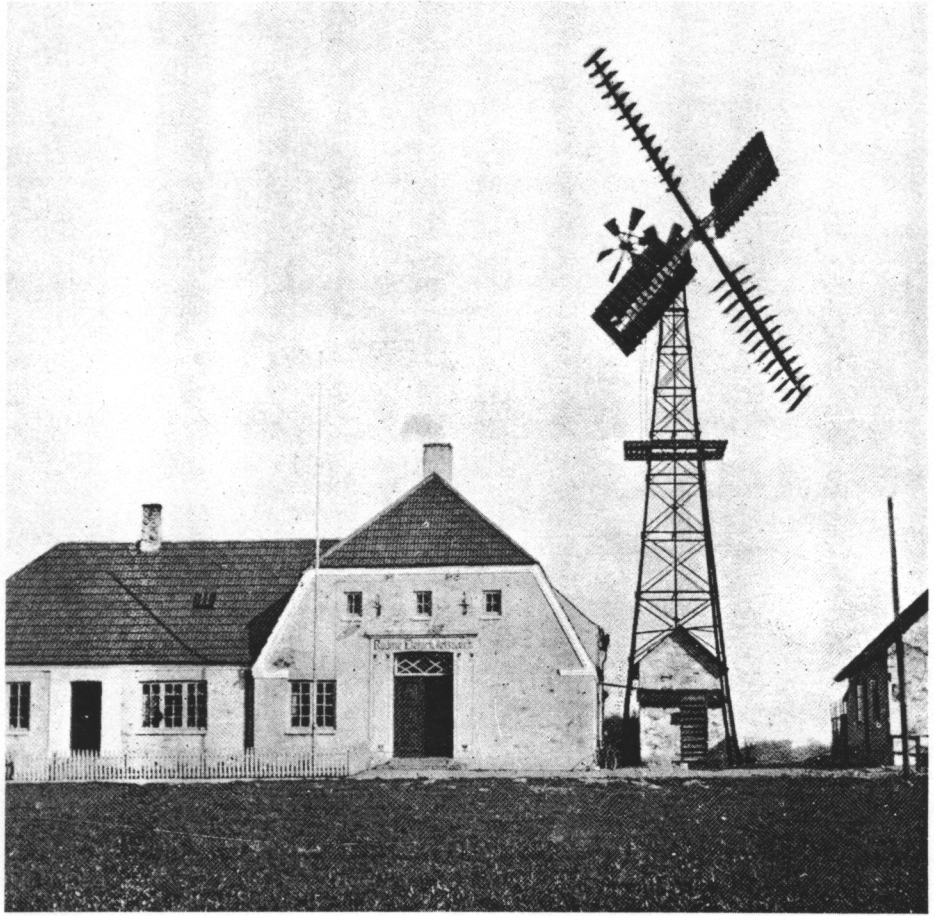
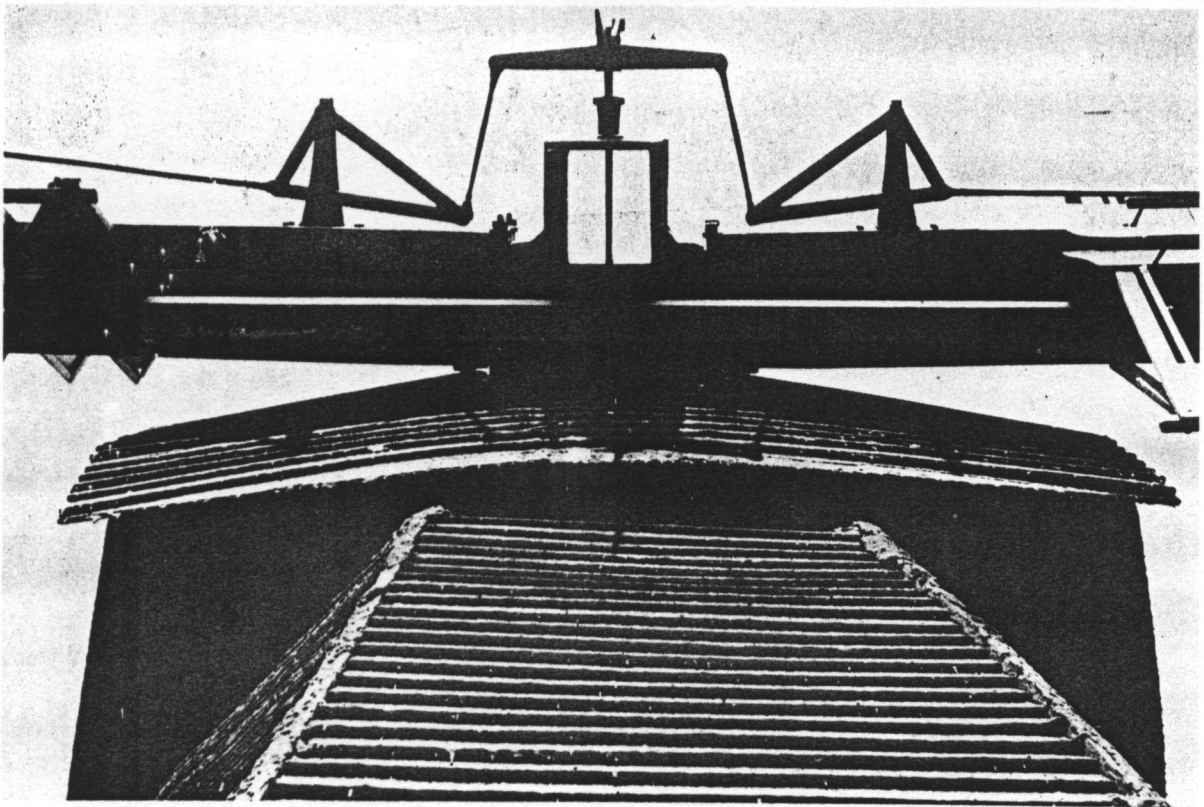
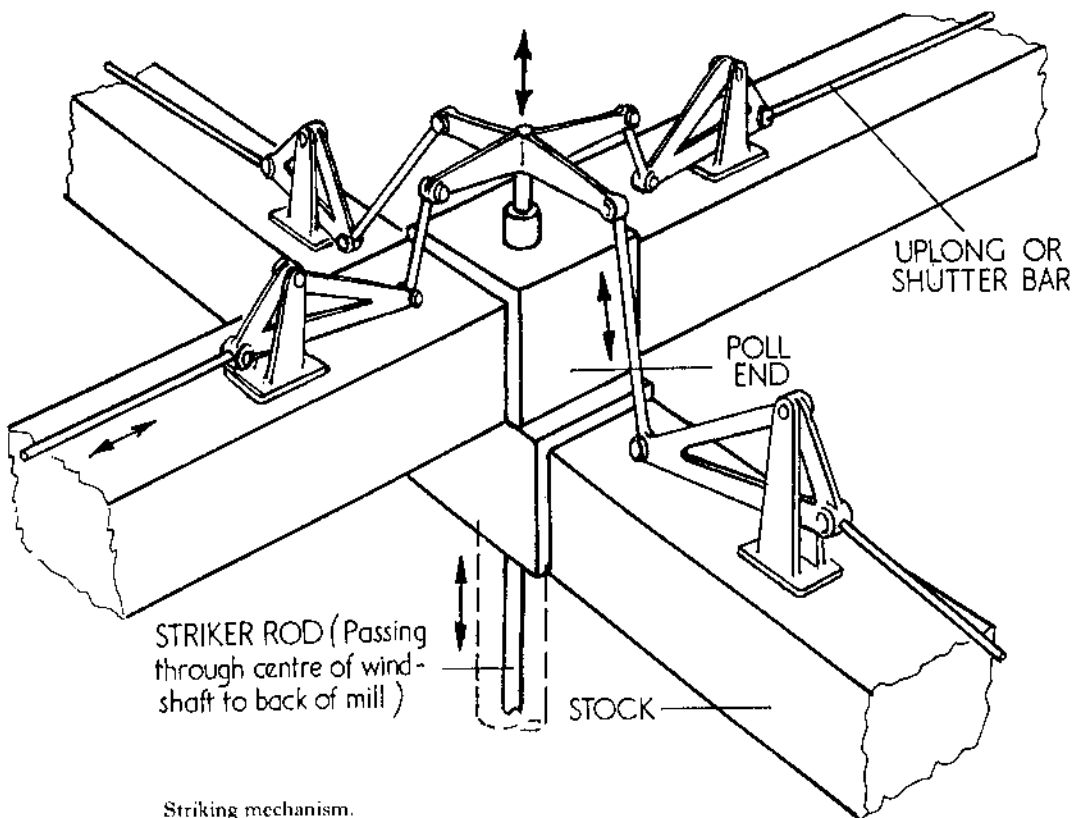
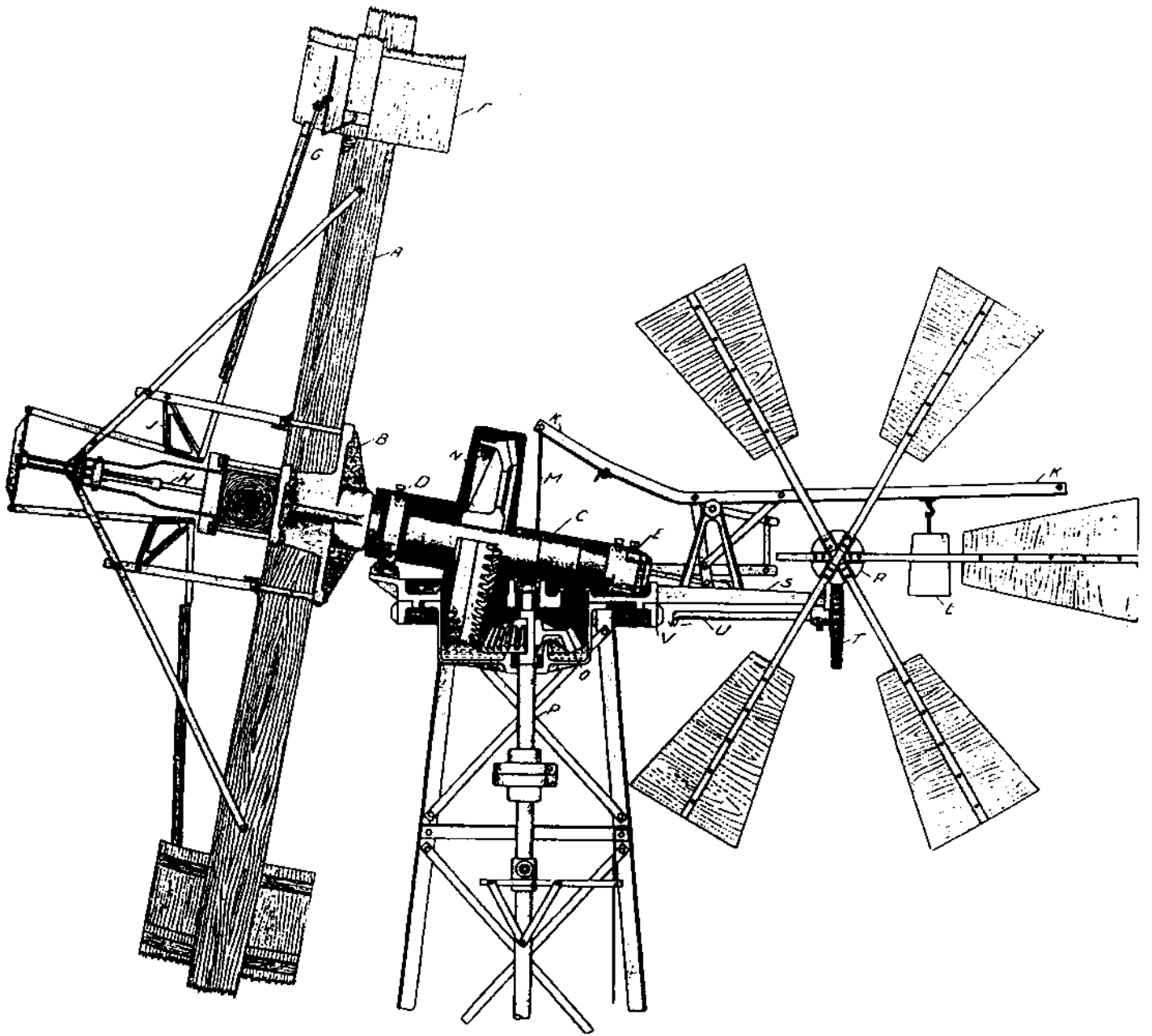


Figure 4. Rudme power plant.



**Windmills: Suzanne Beedell. David & Charles Publ. Newton Abbot, London UK. 1975. 0-7153-6811-7**  
**Stelling Minnis Windmill, Kent UK.**  
Looking up from the bottom and showing the spider striking gear. Stelling Minnis - is a 4-bladed windmill. In this photograph only the horizontal blades are in place. The striking rod can be clearly seen passing through the empty section of the canister, into the windshaft.



Striking mechanism.



## **Combined Windmill and Fuel-oil Electrical Power Generating Station.**

**Period Type 1.5 Lykkegård model 1928.  
18 m. rotor diameter. 30 kW DC - Dynamo.  
[These models were in series production for 50 years].**

The blades are made from wood. The blade stocks **A** are held in place by a cast-iron cross-type canister **B** fastened on the main windshaft **C** which runs in two sets of ball bearings, - one at the front and one at the rear end of the windshaft.

The blade shutters **F** are all connected by a steel shutter bar or rod **G** which runs the length of each blade. The four steel rods meet in the center of the blade rotor, where they are joined together with the control or striker rod **H** - through a system of counter-balanced rods, where the control striker rod is joined to the lever arm **K**. The counter-weight **L** maintains the shutters in a closed or shut position.

When the pressure from the wind increases, the shutters will tend to gradually be pressed open. With increased wind speeds that could possibly endanger the safe operation of the windmill itself, or of the machinery that the windmill is driving, - the shutters will further open. The blades and rotor will thereby be maintained at a, more or less, constant speed of rotation.

If the shutters are completely opened, - the windmill will come to a standstill. The windmill can be stopped at will by pressing down on a shutter-release lever arm placed at the foot of the tower. Likewise the windmill can be re-started by raising the same lever arm.

The main windshaft drives the main gear wheel, - the so-called "brake wheel" **N** - that engages the horizontal wallower gear wheel, **O** on top of the long vertical shaft **P** that transmits the wind energy down to the bottom of the tower. The power from the vertical shaft is transmitted to the dynamo through a right-angled gearbox, as shown from **A - B**.

The windmill powered dynamo generates electrical energy for a battery bank or for direct use in a local grid, with a back-up petroleum, diesel or fuel-oil engine driving another dynamo.

The following suggestions are based entirely on the excellent work recently done and published by Prof. P. la Cour in Denmark on behalf of that Government, which has in that particular placed itself ahead of other countries—considerably to the advantage of many of its villages and isolated dwellings. The reader must be prepared to experiment a little—not indeed in principles but in details of apparatus to suit his own case—but may rest absolutely assured that the method is quite practical and satisfactory.

There are two main difficulties in applying a power so variable and intermittent as wind to the production and supply of electricity. There must, first, be a means of automatically switching on the dynamo to a set of accumulators whenever the former is in a position to deliver current, the same apparatus cutting it out when the power falls away. Secondly, means must be adopted whereby an increase of wind-power beyond the normal amount required to just work the dynamo shall not affect the output by increasing either voltage or current. Both these ends have been attained by La Cour with the simplest apparatus imaginable.

A consideration of the second question raised will show why it is necessary to decide on a definite wind-velocity as being that at which any given windmill shall supply its "normal" output. By rating it low, say a wind of 9 miles per hour, it is possible to keep a dynamo working nearly every day in the year and for twelve hours out of the twenty-four. But the power of the wind at 9 miles an hour is only a quarter of that at 15 miles an hour, and although the latter only blows about half the total number of days in a year, and then for only about nine or ten hours a day, its total output is greater than the other. Another point to be considered is that a very small dynamo is much less efficient, so that a double loss is experienced if too much constancy of work is aimed at. Of course, in a large installation these points have less emphasis, and it becomes desirable to run the plant at a lower wind-rating (in other words, use a comparatively large mill), the only limiting factor being the initial cost of the plant.

In a wind-driven generating plant the following points should be noted. The windmill itself should be self-regulating (as, for example, that described in Chap. V.), and fitted with tail so as to turn to face all possible winds. The dynamo should be shunt-wound, so that an increase in the external resistance tends to raise the terminal voltage. If necessary, this tendency may be increased by having one or two resistance coils in series with the shunt-winding, these coils being automatically cut out as the external resistance rises and current falls. A low-speed machine is certainly preferable, the speed of a windmill being rather low itself. The accumulator is a vital point: it should have a large

capacity, as on this depends its ability to maintain a supply over a longer period of calm; yet as it is undesirable for any accumulator to remain long at a low state of charging, care must be taken to avoid draining it—especially if a spell of calm weather seems likely.

The whole of the electrical apparatus is shown diagrammatically in fig. 73, the only part needing much description being the automatic switch, further illustrated in three views in fig. 74. This consists of two electro-magnets, EM, each like an ordinary bell-magnet, and wound with fine wire, but with an extra winding of a few turns of thick wire, exactly like a compound-wound dynamo field magnet. A horse-shoe permanent magnet, PM, is suspended so that its poles lie opposite and near to the poles of the electro-magnets, and swings by means of the pivot screws which work in a brass (or non-magnetic) block, B. This block also carries the copper rod CR, each end of which turns downward into the wooden cups 1 and 2, containing mercury, matters being so arranged, however, that the end 1 is always in the mercury whichever way PM is swung, while 2 only touches the mercury when that end of CR is drawn downwards.

The switchboards present no special features. By following out the connections it will be seen that any agreed number of cells can be switched on to the dynamo, while any independent number can be caused to supply the lamps. This latter arrangement is desirable to allow for drop of voltage during discharge, also to provide for losses in mains and for an extra cell or two in case of accident to others.

The action of the automatic switch is as follows: Assuming the dynamo to be still, or running at too low a speed to furnish current, it will be seen that the battery is energising the electro-magnets EM through the fine wire-coils, the current passing also through the armature of the dynamo. The winding of EM is such that the current in this direction attracts the poles of PM to the right and so raises the end, 2, of CR out of the mercury. Only a very small current is required, or allowed, to be thus wasted. Supposing now the wind to increase sufficiently to raise the speed of dynamo so much as to be able to supply current, the first effect will be to reduce the current in EM to nil and then to reverse it, altering the polarity of the electro-magnets and throwing the lower end of magnet PM over to the right. This, by dipping the end 2 of CR into the mercury, makes connection between the dynamo and accumulator, the charging of which at once begins. The effect of the thick-wire coils on EM is to hold the magnet switch more securely during charging. The opposite action—that of throwing out the dynamo when the speed fails—is obvious on inspection.

There would be twelve accumulator cells, each of from 150 to 200 ampere-hour capacity, which would be easily capable of dealing with the full current for twenty-four hours' continuous charging. The capacity mentioned is the maximum suitable for the given plant, but the minimum may be anything down to twelve pocket-batteries, if so desired. Within the limits given, the greater the capacity the more the independence of conditions of wind.

With regard to the automatic switch, a little experimenting and adjusting will be needed to ensure its correct working. The electro-magnets may be two ordinary bell-magnets, wound with No. 36 wire, the bobbins being about  $1\frac{1}{4}$  inches long and 1 inch diameter outside. A resistance may be needed in series with this winding, or the effect may be tried of connecting up only six of the cells to these coils, the six on the left-hand side in fig. 73 being, of course, selected. All four bobbins will be joined in series. Over the fine wire on each bobbin will be wound from six to twelve turns (to be determined by experiment) of No. 16 or 14 gauge cotton-covered wire, the winding being in same direction as the fine wire in each case, so that the current is a reinforcing one when being supplied from the dynamo. The balance of the permanent magnet can be adjusted by moving the copper rod CR either to right or left.

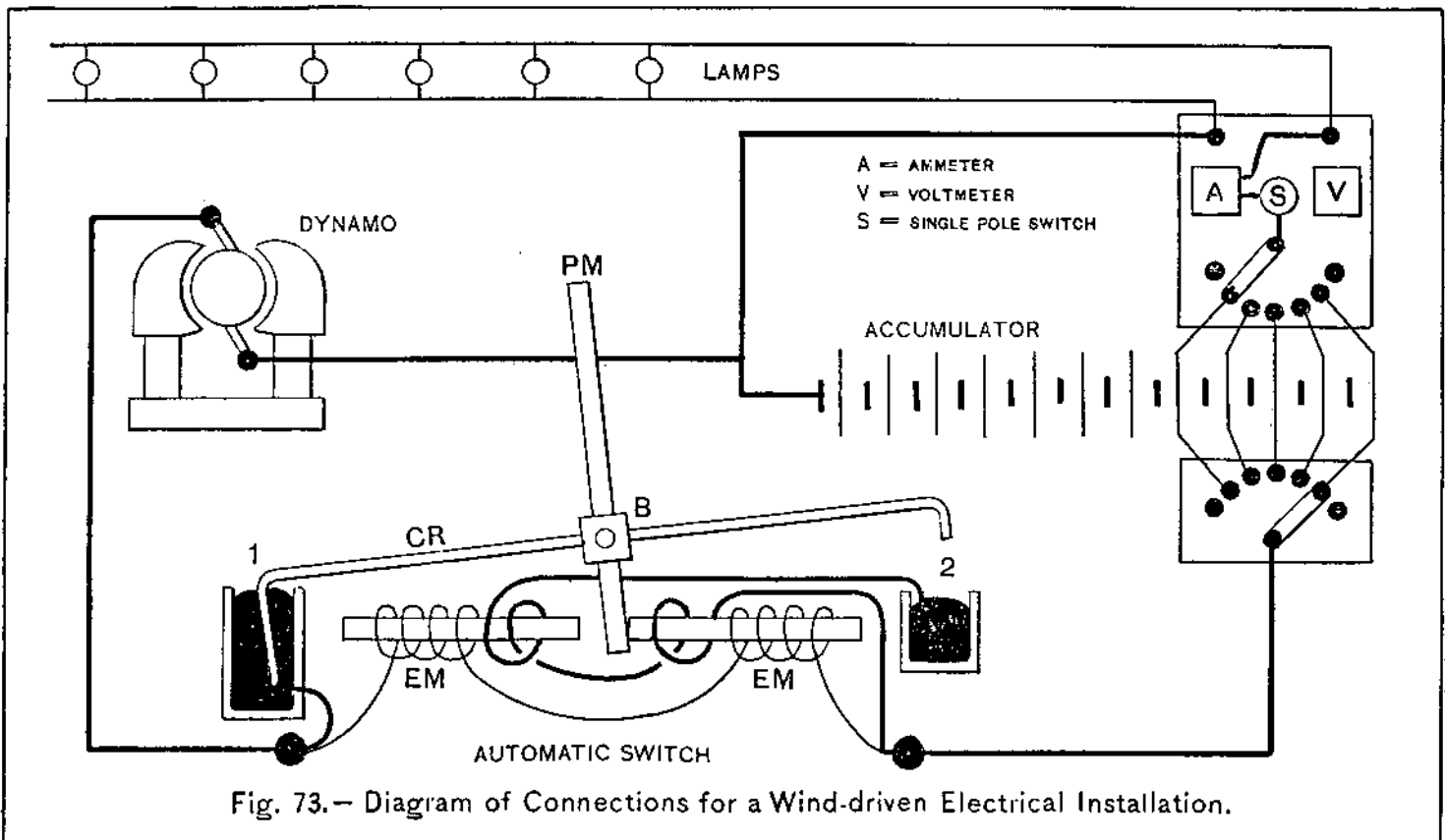


Fig. 73.— Diagram of Connections for a Wind-driven Electrical Installation.

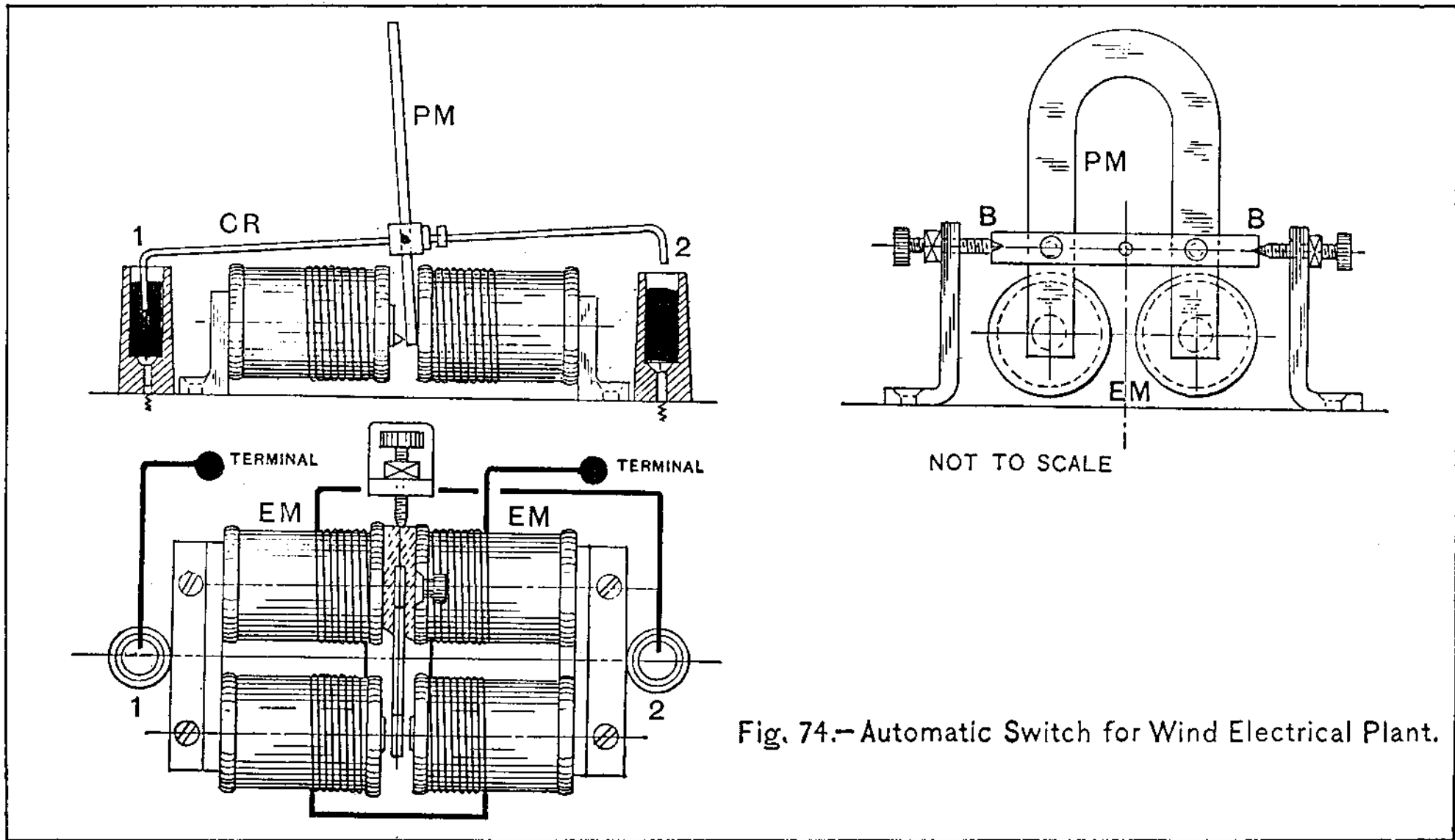


Fig. 74.—Automatic Switch for Wind Electrical Plant.

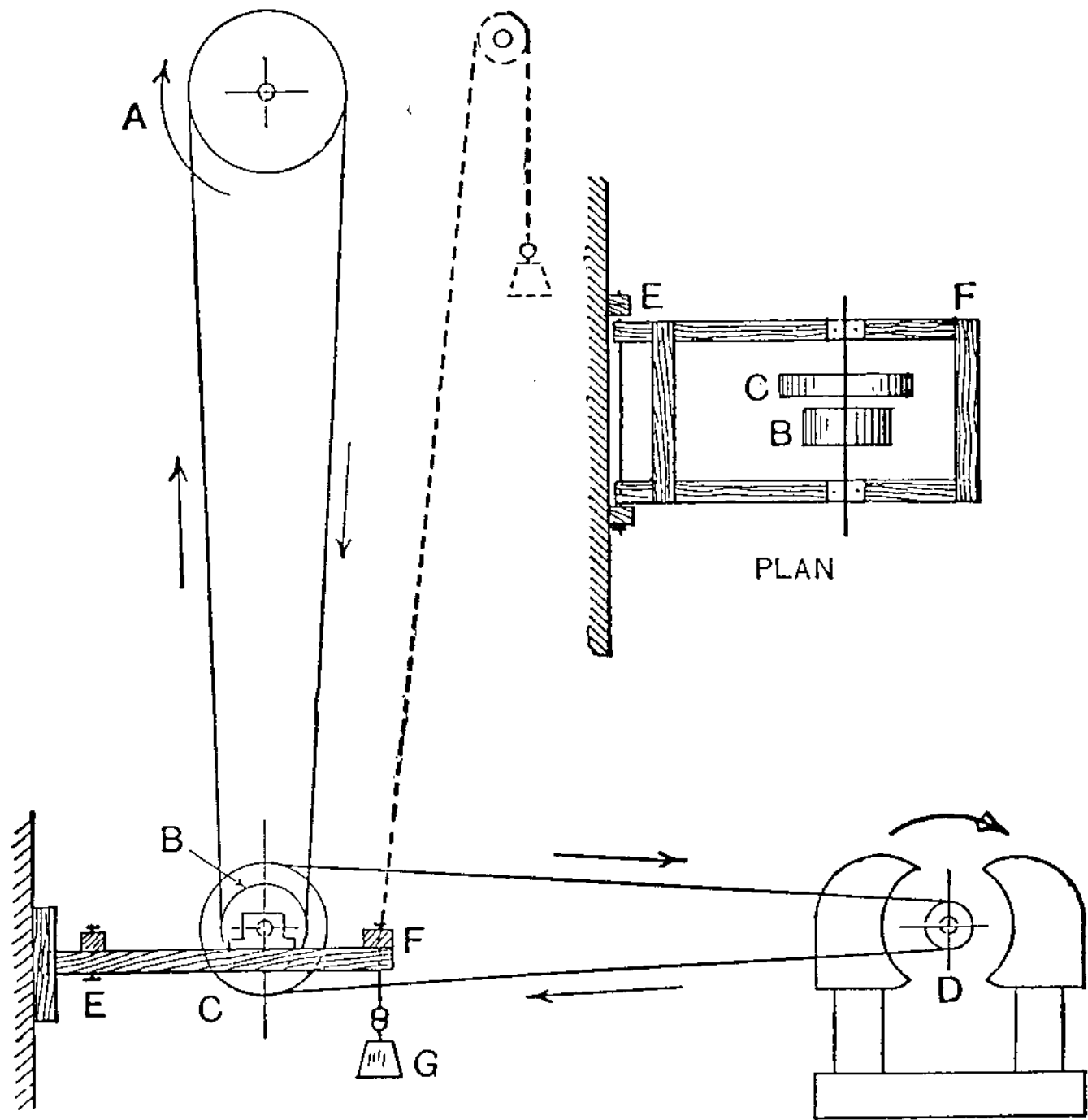


FIG. 75.—Driving Belt Arrangement for Wind Electrical Plant.

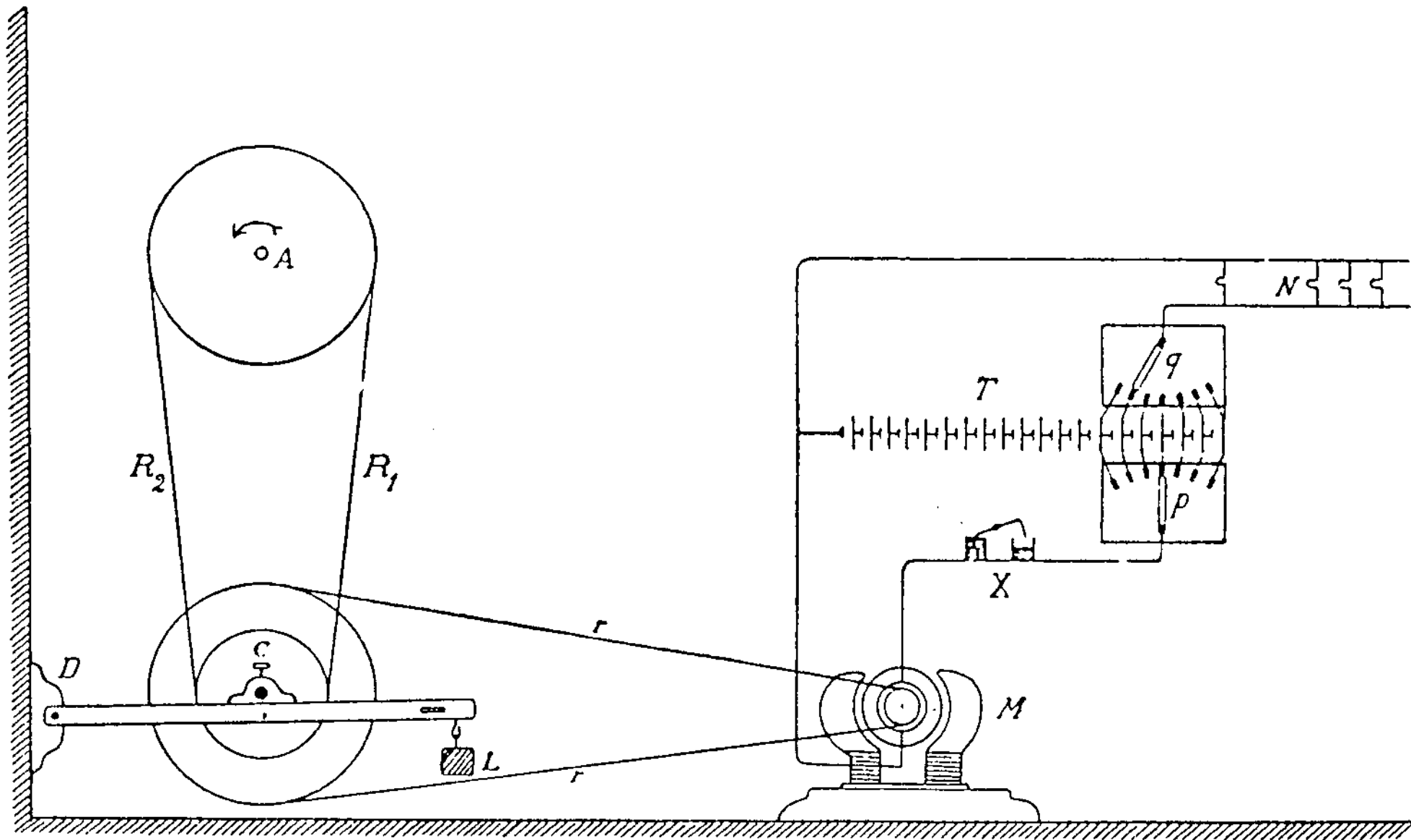


Fig. 5. Konstant elektrisk Strøm.



Wind machine for mechanical power, for farm or small factory use. Photographed in March 1994.



Wind-turbine of Type 1 - 1.5 built 1904. 10 kW DC Generator  
Tower height 17 m. Blade diameter 16 m.  
Sited in Copenhagen Harbour, in operation until 1957.  
This was a combined wind-turbine - petroleum spark ignition motor generator.

## *The electrics*

The simplest way of generating electricity with a windmill would be to hook it up to an alternator which provides you with a.c. current, as in your domestic supply. But it's the worst way. Domestic a.c. comes to you at a constant 50 or 60 cycles a second. What your windmill alternator will produce will be very a.c. – so a.c., in fact, that its frequency will change with every gust of the wind (the frequency depends on how fast the rotor is turning). With such a supply you could run only two things – heating elements of an electric stove, and incandescent electric light bulbs. Even those will blow hot and cold as the wind gusts.

If you're building a windmill, as distinct from buying one (see last section), it means you don't have much cash. In which case you don't want to go out and buy a new alternator or generator. That would cost you a lot of money. Instead you can get one for almost nothing from a junk vehicle lot. There are two types of device used on vehicles – earlier models had a generator which produced 12 volts d.c. direct, and later models (and most trucks) produced a.c. but incorporated a rectifier to change the a.c. back into 12 volts d.c. It is the latter, the alternator, that you want – it's simpler, more effective and produces current at a lower rotational speed than the old-fashioned generator. You'll find



alternators on all trucks, and on the larger and newer cars. When you've found the alternator you want, it's a good idea to purchase a service manual for the vehicle from which it came. The manual will tell you the performance of the alternator, and give you some idea of how to treat it, test it, and service it. When you disconnect the alternator from the vehicle make sure you take the voltage regulator that goes with it. You need this to ensure your batteries get charged at the proper rate.

At this point you need to know some basic electricity – power in watts equals volts times amps. For instance, if you get hold of the alternator from a Volkswagen bus with a 1,700 cc engine, you'll find it's rated at 14 volts and 55 amps. Multiplying those together tells you you can get up to 770 watts from the device. That's only the nominal rating. You can take more power from it than that, providing you do it intermittently. That's quite a lot of power, and you certainly won't need more than two such alternators.

You'll also find the optimum power of the alternator comes at 2,200 revolutions a minute. If your aerogenerator ever gets up to that speed, you'd better run for your life because the surrounding countryside will shortly be spattered with bits of windmill. In fact, the sailing type will not produce more than, say, 150 rpm and the propeller rotor no more than 300 rpm – unless conditions are exceptional. As I've said, you must therefore gear up – by, say, 10 to 1 for a propeller and 20 to 1 for a sailing. Don't forget there is already a gear up between your rear axle and the drive shaft. If you don't know what it is, then test it by rotating one and counting the number of revolutions of the other. It'll be something between 2.5 and 5 to 1. The rest of the gearing up is done with different sized pulley wheels fixed to the drive shaft mounting and the alternator (when calculating the effect, it's the ratio of the diameter of the wheels to each other which gives the gear ratio). Use a fan belt to connect the pulley wheels. Don't worry too much about the exact ratios – you can't know what will give the perfect result, and anything roughly right will give you the power you need.

If you're using two alternators, you can connect them both via one belt drive to one pulley wheel on the axle. But I'd recommend you use two belts and two pulleys. For one thing, if one belt snaps or some other fault develops, you've still one left and the batteries will go on being charged. Further, you may find that the heavier winter winds will work two alternators all right, but that in the

## WIND POWER

summer you're better off with one. It's then easy enough to remove one of the belts.

The alternator has three connections. One must be earthed to the differential. The second, to which will have been originally connected a very thick cable, is the stator terminal which supplies the juice. This you connect to the positive pole of the battery, using very thick cable capable of carrying whatever current the alternator is rated at (the VW alternator, for instance, should carry 55 amps). Now to get the current from the top of the tower to the bottom, where the batteries will be, is a bit of a problem. It is done on manufactured wind generators by a complicated series of slip rings which transfer the current to some part of the tower. The reason is that the platform on which the alternator is mounted is constantly revolving to follow the wind. If you connect a cable from the alternator on this platform to the battery on the ground it will eventually get twisted round the tower. Now I reckon that the design of slip rings for a 55 amp current is beyond my, and probably your, capabilities. You must therefore use plenty of cable – enough to allow it to get twisted round the tower two or three times – and provide a plug and socket for it before it enters the battery. You can then periodically disconnect the plug, untangle the cable, and start again. No good using an ordinary 13-amp plug and socket, though. You'll need to find a special one capable of carrying the 55 amps.

A solemn warning. You must never disconnect the plug when the alternator is turning (that is, when the propeller is going round). If you do, you will damage the alternator, as you also will if you ever connect the battery terminals to it the wrong way round. If alternator and batteries are ever separated from each other, the propeller must be anchored or the alternator disconnected from its drive belt.

There is an obvious danger that your power cable will twist round the tower and eventually pull itself off one of its connections. To prevent that you must attach a length of strong wire, slightly shorter than the cable, from the platform to some point on the tower so that it will physically restrain the platform from making that last revolution which will snap the power cable. A bit of common sense will see you through all right.

The third connection on the alternator is to the field coils, and this provides you with your last problem on top of the tower. It is

connected by ordinary electric cable to the positive side of the battery, and draws only a small current. But it's a crucial one, because it provides the magnetic effect which causes the alternator to produce current when it is rotated. The trouble comes in calm periods when the wind is too feeble to turn the blades. If you leave the field coils connected to the batteries, the latter will soon drain away, and you'll lose a lot of valuable stored juice. Some system has to be devised for breaking this connection when the wind isn't blowing, and for making it when it starts to blow. For that you need a relay.

The first way of operating it is to mount a small additional vane on the side of the platform. Spring-load it so that it will trip a mechanical relay, and thus connect battery to field coil, when the wind gets to the desired speed. Jim Secenbaugh operated his machine this way, adjusting the spring to work the relay when the wind got to 8 mph, and he says it works very well.

Possibly a better way is to use an electrically operated relay. For this you need one of those bicycle dynamos which rub up against the rim of the bicycle tyre. Set this dynamo to rub against one of the drive belts to the alternator, and use it to operate the relay which will connect the battery to the field terminal. When the wind starts to blow, the alternator will begin to revolve, and the belt will start to turn the bicycle dynamo. The current produced will close the relay and the alternator will start to charge the batteries.

An advantage of both these systems is that they overcome another starting problem. Propellers and sails do not get under way very easily in light breezes. If the field connection is made, they also have to turn against the load of the alternator, and so will not start to move until the wind is fairly strong. But if in a calm the field connection is broken, there is no load to work against. The rotor will start to turn in calmer conditions and, once turning, will close the field connection and you'll get power at lower wind speeds than would otherwise be possible.

All your electrical units on the tower – alternator, voltage regulators, relays, must be well earthed to the differential. They must also be protected from the rain by some kind of cover. At ground level earthing is provided by a long stake driven deep into the ground. As your windmill is a perfect target for lightning, you must arrange at some point for there to be a  $\frac{1}{4}$ -inch gap between the positive lead from alternator to battery and a lead coming from the earthing stake. You can either make such a gap, or buy one designed for use on a television aerial.

WIND KRAFT?  
ECHT STARK!



FÜR NUR  
**6,-**  
MARK!

Windräder 2,5-4 m  $\phi$ , 500 W-4 kW, 12-380 V.  
Anleitung für sehr einfache, stabile Bauweisen aus Schrott.

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Wenn's extra - einfach sein soll...

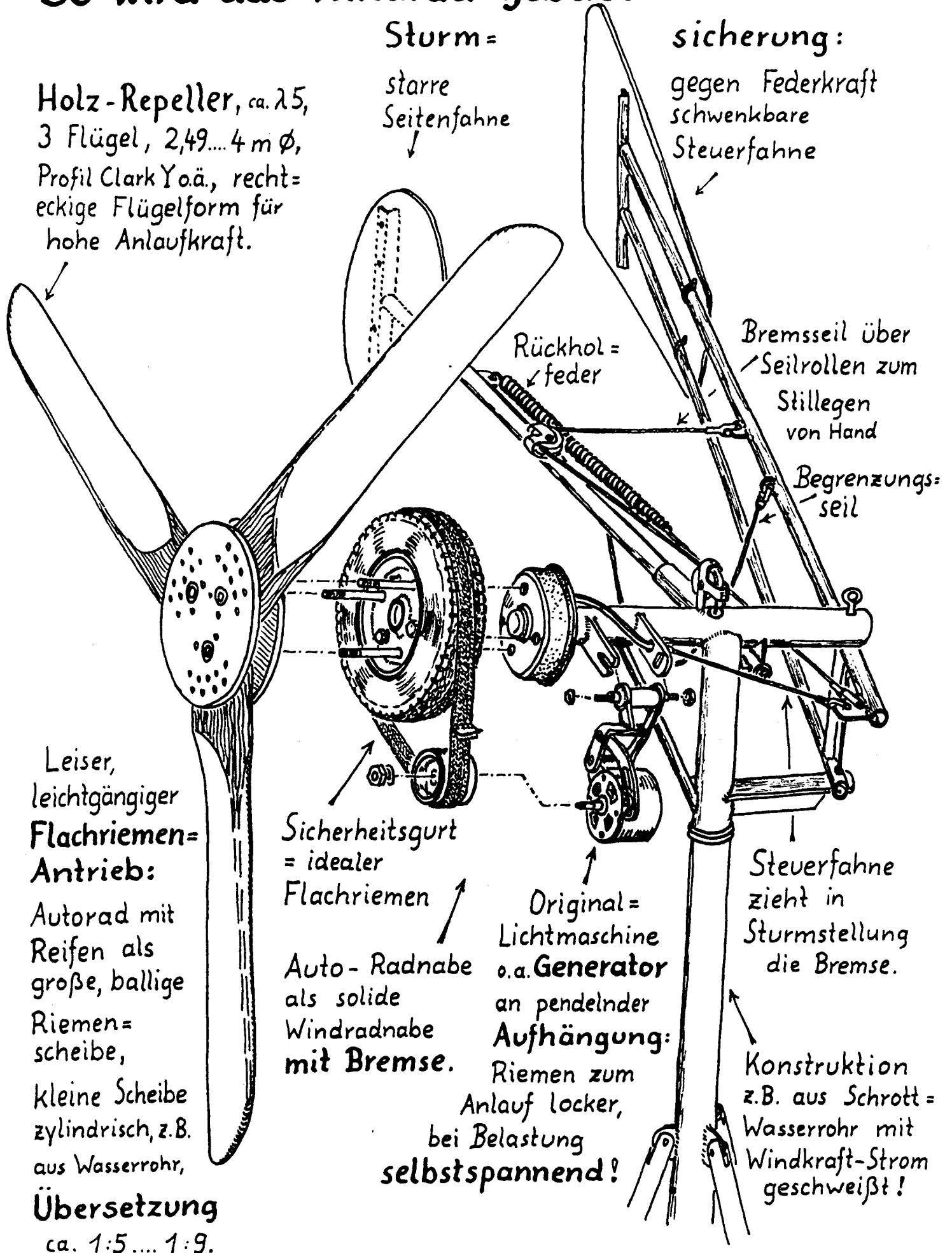
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( Einband-Photo: Aufstellen  
des 4-m-Windrades von 1988 )

# So wird das Windrad gebaut:



Holz-Repeller, ca. 25,  
3 Flügel, 2,49... 4 m  $\phi$ ,  
Profil Clark Y o.ä., recht-  
eckige Flügelform für  
hohe Anlaufkraft.

Sturm=  
starre  
Seitenfahne

sicherung:  
gegen Federkraft  
schwenkbare  
Steuerfahne

Rückhol=  
feder

Bremsseil über  
Seilrollen zum  
Stillegen  
von Hand

Begrenzungs-  
seil

Leiser,  
leichtgängiger  
Flachriemen=  
Antrieb:

Autorad mit  
Reifen als  
große, ballige  
Riemen-  
scheibe,  
kleine Scheibe  
zylindrisch, z.B.  
aus Wasserrohr,

Übersetzung

ca. 1:5... 1:9.

Sicherheitsgurt  
= idealer  
Flachriemen

Auto-Radnabe  
als solide  
Windradnabe  
mit Bremse.

Original=  
Lichtmaschine  
o.a. Generator  
an pendelnder  
Aufhängung:

Riemen zum  
Anlauf locker,  
bei Belastung  
selbstspannend!

Steuerfahne  
zieht in  
Sturmstellung  
die Bremse.

Konstruktion  
z.B. aus Schrott=  
Wasserrohr mit  
Windkraft-Strom  
geschweißt!

# Zur Bauweise dieses Windrades: ① Hintergründe für die Auswahl der Teile und Materialien

Im Heft 1, "Windkraft - ganz einfach", haben wir die Grundlagen zum Windradbau im kleinsten Maßstab kennengelernt. Mit dieser Vorübung gelangen uns große Windräder leichter, denn vieles bauen wir hier im gleichen Prinzip. In Heft 2, "Windkraft - ja bitte", hat das Windrad (ebenso wie bei Heft 1) kein Getriebe, damit die mühsam gewonnene Windkraft ohne Verluste in den Generator kommt und das Windrad klein und handlich bleibt.

Das funktioniert aber nur mit einem sehr niedertourigen Generator, den man zum Glück nicht teuer kaufen muß, sondern durch Umwickeln aus alten Autolichtmaschinen machen kann. Das Ankerwickeln ist eigentlich nicht schwierig, aber viele haben solche Arbeiten noch nie gemacht, während ihnen der (an sich mühsamere) Bau eines größeren Windrades mit Getriebe leichter fällt, weil man das Mechanik - Basteln sowieso schon kennt. Außerdem ist die Größe eines getriebe-losen Windrades mit umgewickelter Autolichtmaschine auf ca. 1,8 m  $\varnothing$  und max. 300W begrenzt.

Getriebe-Windräder können wir praktisch in beliebiger Größe mit unveränderten LiMas, einfachen Drehstrom - Motoren o.ä. als Generator bauen. Und: in manchen Gegenden, z.B. Baden-Württemberg, sind erst Windräder ab 4 m  $\varnothing$  genehmigungspflichtig, in anderen Gegenden über 2,5 m  $\varnothing$ . Mit 2,5 m  $\varnothing$  kann man leicht 500W und mehr Höchstleistung erreichen, mit 4 m  $\varnothing$  einige KW...

Hier bauen wir mit möglichst einfacher Technik aus häufigen Schrotteilen ein sehr zuverlässiges, ruhig laufendes, starkes Windrad, mit dem wir den genehmigungsfreien Spielraum voll ausnutzen können.

Der Repeller ist aus Holz, was sich bei minimaler Pflege Jahrzehnte bewährt hat. Es ist leicht und angenehm zu verarbeiten, vermeidet die giftige Herstellung und unangenehme Verarbeitung von Glasfaser - Kunststoff, der letztlich im Sondermüll landet. Er braucht, dank Getriebe, nicht schnell zu laufen und macht daher besonders wenig Windgeräusche. Als Dreiflügler verschont er alle übrigen Teile von Vibrationen. Ein Zweiflügler (S.70) ist einfacher zu bauen, beachte hierzu aber unbedingt den "Massenträgheitsmomenten - Ausgleich", sonst verursacht er Erschütterungen, die alles zermürben (s. Windheft 2).

Als ideales Repeller - Lager finden wir überall Auto - Radlager, die ja für höchste Belastungen gebaut sind, eine starke Bremse und die große Riemenscheibe (in Form des aufgepumpten Reifens) sind gleich mit dabei! (s.S.26)

Als Sturmsicherung verwenden wir die bewährte Seitenfahne (s.S.36). Den Rahmen, der alles verbindet, bauen wir aus Schrott (s.S.42) oder sogar (mühsamer) aus Holz (s.S.71,72).

Der Generator ist beliebig, sollte nur robust, zum Verwendungszweck des Stromes passend und nicht extrem hochtourig sein. Auf dem Schrott gibts reichlich Auswahl. Zum Batterie - Laden bieten sich alte Autolichtmaschinen an, ihr schlechterer Wirkungsgrad wird durch die ersparte Trafo- und Regeltechnik wettgemacht.

Einfache Drehstrommotoren (220/380V) sind äußerst robust (s.S.59) und haben als Generator sehr gute Wirkungsgrade, aber nur, wenn wir den Strom verheizen (denn Wärme entsteht immer, egal wie die Spannung und Frequenz mit dem Wind schwanken). Doch zum Verheizen ist der edle Strom eigentlich zu schade, wo wir Wärme mit 1/10 des technischen Aufwandes aus einfachsten

②

Sonnenkollektoren gewinnen können (s. Heft "Sonnenwärme"). Laden einer Hochspannungs - Batterie - Kette (z.B.  $18 \times 12V = \text{ca. } 220V$ ) macht noch nicht allzuvielen Verluste, Runtertransformieren zum Laden mit 12 oder 24V ist dagegen besonders bei niedriger Frequenz (Schwachwind) so verlustreich, daß eine Auto - LiMa hierfür viel besser ist.

Wenn wir den Strom in Batterien speichern, dann bitte nur in welchen von der Schadstoffsammlung, auch wenn die Verluste höher sind! (s. Kapitel "Strom erzeugen und verwerten" S.65).

Als Getriebe hatten unsere ersten Versuche Keilriemen, naheliegender, die kleine Scheibe ist an der LiMa gleich dran, große Scheibe und Riemen gibt's in Waschmaschinen: leider viel zu schwergängig für schwachen Wind, nur an Standorten mit starkem Wind einigermaßen brauchbar (S.71).

Daher probierten wir Fahrradketten: zwar wunderbar leichtgängig, sogar in Wind und Wetter ohne Pflege jahrelang zuverlässig. Doch ihr schauriges Gerassel bringt in dicht besiedelten Gegenden bestimmt eine Schar von Windradgegnern auf die Barrikaden!

Professioneller geht's mit Zahnriemen. Teile dafür sind im Auto - Schrott, aber passen nur mühsam ans Radlager. Korrosion (schon bei Stillstand und hoher Luftfeuchte) macht die Scheibe rau, der Riemen ist schneller hinüber, als er die Scheibe wieder blankwetzt. Ohne superguten Wetterschutz unbrauchbar! Und Tauwasser durch feuchte Luft gibt's auch im feinsten Gehäuse...

Richtig edel kann ein Zahnradgetriebe sein, doch ist etwas Passendes sehr selten zu finden (z.B. in Elektromotoren mit eingebautem Getriebe). Die Achse ist als Nabe für den Repeller meist zu schwach, der Motor enthält auch keine Bremse. Eine Verbindung mit einem Autorad mit Antriebswelle ist möglich, aber mühsam.

Da mag manchem modernen Betrachter unser Flachriemen - Getriebe "vorsintflutlich" erscheinen, doch hat es sich in zahlreichen Versuchen als mit einfachster Technik realisierbare, sehr günstige Möglichkeit erwiesen (S.25). Die Tricks, die wir zur Verbesserung anwenden, macht es fast unübertrefflich. Es funktioniert in Wind und Wetter ohne jeden Schutz, das spart ein sperriges Gehäuse. Nur die Elektrik muß abgedeckt werden.

Zum Aufstellen kann ich nur immer wieder den Dreibeinmast (Windkraftheft 2) aus dünnen Baumstämmen empfehlen. Die Stämme gibt's im Wald fast geschenkt. Er ist viel stabiler als ein abgespannter Einzelmast und, mit alten Wasserrohren und Backsteinen etc. im Boden verankert, verrottungsfest und trotzdem ohne Bauschutt demontierbar. Würdest Du einen Mast auf Betonfundamente setzen, beachte, daß Dein Windrad Jahre laufen muß, um die bei der Zementherstellung verbratene Energie wieder wett zu machen. Das Zusammenschweißen des Rahmens aus Schrott verbraucht nur einen winzigen Bruchteil davon an Energie, außerdem geht das statt mit Atomstrom mit Windkraftstrom! (S. 68)

Suche den Aufstellort sorgfältig aus, vermeide jeden Windschatten. Schon 20% weniger Wind halbiert die Leistung! Also lieber einen 2m höheren Mast als ein doppelt so großes Windrad.

Obwohl dieses Windrad gegenüber denen nach Heft 2 weitaus mehr Energie liefert, beachte auch hier bei jedem Schritt: Abfall benützen heißt Umwelt schützen! (und den gibt's in Massen). Möglichst nimm natürliche Rohstoffe! Kaufst Du neues Industriematerial, richtest Du damit viel Schaden an, von dem Du leider fast nichts merkst, denn unsere Ausbeuterwirtschaft läßt immer mehr umweltschädliche und energieverbrauchende Herstellungsprozesse (Stahl, Alu, Kunststoff usw.) in der "Dritten Welt" stattfinden. Ob die Leute dort an solcher "Entwicklungshilfe" sterben oder nicht, sollte uns nicht egal sein.





Das erste Windrad dieser Bauart (1986), 2,5 m  $\phi$  mit Drehstrommotor als Generator, am Giebel einer Scheune befestigt.



„Wild-romantisch“ auf einem Dreibeinmast aus Baumstämmen, fast 12 m hoch, ein Windrad 2,7 m  $\phi$  mit LiMa. (1993)

4

# Planung: „Was soll das Windrad bringen?“

Wie groß soll (oder darf) es sein?

Mehr Wind möglich? (Mast höher, Standort besser)

Tabelle: Ein Repeller (unser 3 - Flüglter,  $\lambda=5$ ) mit ...m  $\varnothing$  leistet bei Wind mit ...m/sek. so viel, wenn er mit zugehöriger Drehzahl laufen kann:

Wind m/sek	2,5 m $\varnothing$		2,8 m $\varnothing$		3 m $\varnothing$		3,5 m $\varnothing$		4 m $\varnothing$	
	Drehz. U/min	Leistung Wmech.	U/min	Wmech.	U/min	Wmech.	U/min	Wmech.	U/min	Wmech.
3	115	25	103	31	96	36	82	45	75	63
4	153	60	137	75	128	86	109	118	100	152
5	191	115	170	145	159	165	136	225	124	290
6	229	200	202	250	191	290	164	390	149	500
8	305	460	272	575	254	660	219	900	198	1150
10	380	900	339	1125	317	1300	272	1760	247	2300
12	455	1550	405	1950	380	2230	325	3200	295	3900
16	600	3600	535	4500	500	5200	430	7000	390	9100

Leistung  $\hat{=}$  Durchmesser <sup>2</sup>, aber Wind <sup>3</sup>. Doppelter  $\varnothing$  bringt 4 - fache Leistung, aber 4 - fache Stabilität an Windrad und Mast nötig, da 4 - fache Sturm - Angriffsfläche (Bauaufwand!). Doppelter Wind bringt 8 - fache Leistung, aber nur 1 - fachen Bauaufwand, da Windrad und Mast an jedem Standort sturmsicher gebaut sein müssen.

# Welcher Generator paßt dazu ?

⑤

Was für einen Generator wir nehmen, ist beliebig, wenn die Kraft, die er verlangt, zum Windrad paßt, und der Strom, den er abgibt, zum Verwendungszweck. Daß sein Wirkungsgrad hoch sein sollte, ist klar, besonders bei schwachem Wind ist das wichtig.

Zu hochtourig darf er auch nicht sein, sonst läßt sich die passende Übersetzung nicht bauen.

Er muß aus dem Stillstand heraus leicht zu drehen sein, sonst läuft das Windrad erst bei starkem Wind an. Ob es Dauermagnet-Generatoren in der hier nötigen Größe gibt, die leicht genug anlaufen, weiß ich nicht. Ein Generator mit Elektromagnet macht keine Anlaufschwierigkeiten, bei Stillstand ist der E-Magnet unmagnetisch und bremst nicht.

Die Leistung des Generators muß zum Windrad passen: Ein sehr starker Generator taugt bei schwachem Wind nichts, weil sein E-Magnet evtl. mehr Strom verbraucht, als das Windrad bei schwachem Wind erzeugen könnte. Und meistens weht schwacher bis mäßiger Wind. Ein zu schwacher Generator verlangt schon bei mäßig starkem Wind zu wenig Kraft vom Repeller, so daß der Repeller viel schneller läuft als für die Windstärke richtig und Krach statt Strom macht.

Nicht zuletzt wollen wir den Generator auch auf dem Schrott finden oder billig beschaffen und mit der Technik zurecht kommen können. Da bleiben uns Kompromisse nicht erspart.

Die Anpassung ans Windrad ist besonders interessant: Ab welcher Windgeschwindigkeit soll das Windrad Strom erzeugen? Wie stark ist der Wind an den meisten Tagen und wieviel Strom soll es da erzeugen? Sind Tage mit starkem oder stürmischem Wind so häufig, daß es sich lohnt, das Windrad hierfür anzupassen, oder sind stürmische Tage so selten, daß es besser ist, wenn das Windrad bei schwachem Wind gut arbeitet, aber Sturm nicht nutzen kann?

Wieviel Leistung vom Repeller kommt, hängt von Repellergröße und Windgeschwindigkeit ab. Nimmt die Windgeschwindigkeit zu, steigt die Drehzahl des Repellers wie die Windgeschwindigkeit, die Leistung aber hoch 3! d.h.: 25 % mehr Wind = fast doppelte Leistung, doppelter Wind = 8-fache Leistung. Ideal wäre ein Generator, dessen Leistungsaufnahme sogar stärker steigt als die Leistungsabgabe des Repellers. Der würde nämlich den Repeller bei Sturm überfordern und damit drehzahlbegrenzen = sturmsicher ohne Aus-dem-Wind-drehen!

Schon einen Generator zu finden, dessen Leistung über einen weiten Bereich gleichermaßen wie die des Windes steigt, ist schwer. Ohne teure Spezialanfertigungen wird man nur in einem kleinen Windstärkenbereich Repeller und Generator gut aneinander anpassen können. Und dieser Bereich soll zu den Windverhältnissen am Ort passen. Ein Vergleich der Drehzahl-Leistungskennlinie des Generators verglichen mit der des Repellers verrät alles Weitere.

## Praktisches Beispiel mit Autolichtmaschine

Ein Repeller, 2,5 m  $\varnothing$ , bringt an mechanischer Leistung: bei 4m/sek 60W, bei 5m/sek 115W, bei 8m/sek 460W. (s. Graphik). Am Ort ist die mittlere Windgeschwindigkeit ca. 4m/sek, also ist es wichtig, damit schon Strom zu erzeugen.

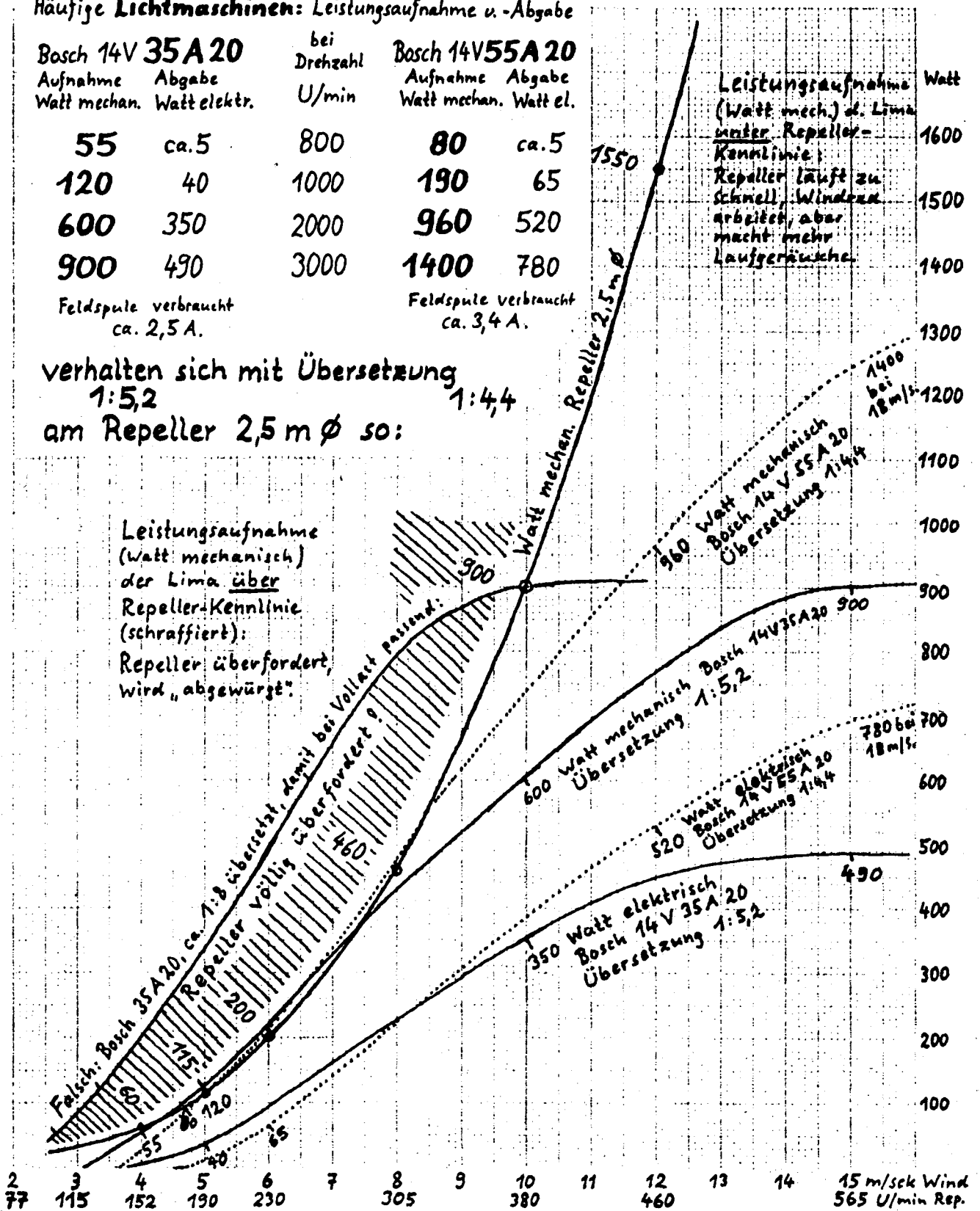
Eine alte Autolichtmaschine paßt als Generator, der Wirkungsgrad ist zwar mäßig (50-60 % minus Eigenbedarf für den E-Magneten), aber die Technik einfach und passend zum Batterieladen, der Preis fast geschenkt. Wir müssen eine LiMa nehmen, die bei Ladebeginn weniger als 60W mechanische Leistung verlangt. Eine Bosch 14V 35A 20 braucht ca. 55W bei 800 U/min

6

Häufige Lichtmaschinen: Leistungsaufnahme u. -Abgabe

Bosch 14V 35A 20			Bosch 14V 55A 20		
Aufnahme Watt mechan.	Abgabe Watt elektr.	bei Drehzahl U/min	Aufnahme Watt mechan.	Abgabe Watt el.	
55	ca. 5	800	80	ca. 5	
120	40	1000	190	65	
600	350	2000	960	520	
900	490	3000	1400	780	
Feldspule verbraucht ca. 2,5 A.			Feldspule verbraucht ca. 3,4 A.		

verhalten sich mit Übersetzung  
1:5,2  
am Repeller 2,5 m  $\phi$  so: 1:4,4



zum Ladebeginn. Das schafft der Repeller bei 4m/sek gerade eben. Die nötige Übersetzung ist 1:5,2.

Wieweit die LiMa bei anderen Windstärken auch zum Repeller paßt, zeigt die Graphik (Kurve B): leider nur bis ca. 8m/sek, darüber ist der Repeller zunehmend unterfordert, d.h. er läuft schneller als für die Windgeschwindigkeit optimal, wandelt nur noch einen kleinen Teil vom Wind in Kraft um, den Rest in Laufgeräusche.

Übersetzung vergrößern bringt nichts, die LiMa würde so zwar z.B. bei 10m/sek zum Repeller passen, aber der Repeller würde gar nicht erst so schnell werden, denn bei kleineren Drehzahlen fordert die LiMa viel mehr Kraft als der Repeller bringt (siehe Graphik Kurve C).

Wollen wir stärkeren Wind gut nutzen, hilft nur eine größere LiMa, z.B. paßt eine Bosch 14V 55A 20 mit 1: 4,4 Übersetzung so, daß sie den Repeller nicht "abwürgt" und bis ca 10m/sek. recht gut angepaßt ist. Nachteil : Für Ladebeginn ist schon fast 5m/sek nötig, der Stromertrag erst über 8m/sek Wind besser als mit der 35-A-LiMa (Kurven D, E und F).

Wir sehen: Die Kennlinie des Repellers steigt erst langsam, dann immer drastischer. Die Kennlinien von LiMa's haben erst einen steilen Anstieg und bei ca. 2/3 Vollast einen "Buckel", von dem ab der Anstieg immer schwächer wird.

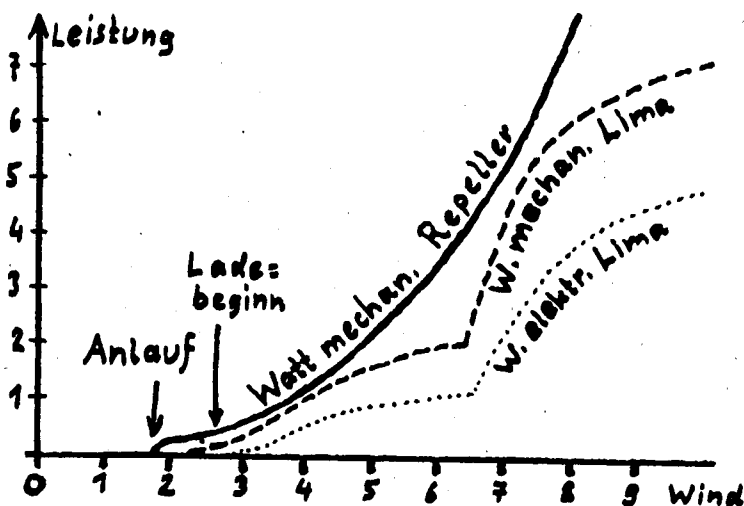
Wichtig ist hier nicht die Kennlinie Drehzahl/elektr. Leistungsabgabe, die man beim Autodienst auf dem Prüfstand mißt, sondern Drehzahl/mechan. Leistungsaufnahme. Die ist schwieriger zu messen (Drehmomentwaage nötig). Als Schätzung kann man die Drehzahl/elektr. Leistung-Kennlinie messen, außerdem den Stromverbrauch der Feldspule (E-Magnet), dann durch den geschätzten Wirkungsgrad (erfahrungsgemäß bei LiMa's ca. 60% bei schwacher Last, 50% bei starker Last) teilen und die für die Feldspulen-Stromversorgung nötige Leistungsaufnahme zuzählen.

Beispiel: LiMa erzeugt bei 1000 U/min 3A = 36W. Feldspule verbraucht auch 3A, LiMa muß zusammen 6A = 72W erzeugen. 60% Wirkungsgrad: mechanisch sind 120W Leistung nötig.

LiMa und Repeller verhalten sich also genau gegensätzlich. Deshalb muß man LiMa-Größe und Übersetzung so hinjonglieren, daß der Bereich des steilen Anstiegs der LiMa-Kennlinie gut zur Repeller-Kennlinie paßt. Doch die einfache Form des Flügelblattes hilft, indem sie sich in gewissen Grenzen selbst anpaßt (s. "Repeller" S.8):

Ist der Repeller ein wenig überfordert, läuft er noch mit guter Leistungsabgabe weiter, langsamer als er könnte, aber mit Glück besser passend. Der nur teilweise ausgelastete Repeller läuft zu schnell, ohne daß die Anströmung gleich überall schlecht wird und leistet dabei weniger als er könnte. So nähert er sich ( zwar mit Laufgeräuschen) doch der Drehzahl- und Leistungsanforderung der LiMa an. Allerdings wird man die Höchstleistung einer LiMa nur mit laut fauchendem völlig unterfordertem Repeller nutzen können.

Wer geschickt im Elektrobasteln ist, kann Drehstromlichtmaschinen deutlich verbessern: z.B. erreichen wir eine "2-Stufen-LiMa" (außerdem selbsterregend!) mit Schaltung S.54 und Fliehkraftschalter (Blechstreifen am Lüfterrad). Die Kennlinie sieht dann so aus:



Etwa erreichbare Anpassung mit "2-Stufen-LiMa" (kleines Windrad) oder Schwach- und Starkwindgenerator (großes Windrad) Graphik ohne Maßstab!

⑧

Für ein 4-m-Ø-Windrad im Schwachwindgebiet (Nähe Basel) mit Starkwindtagen bei bestimmten Wetterlagen habe ich zwei LiMa's als Generator verwendet und so übersetzt, daß die schwache LiMa schon bei 3m/sek lädt, die starke LiMa aber erst bei 5,5m/sek Ladebeginn-drehzahl erreicht. Auf die Weise war das Windrad gut angepaßt. Große Industrierindräder haben auch einen Schwachwindgenerator und einen starken.

Auto-Gleichstrom-Lichtmaschinen sind schon selten geworden, aber z.B. in alten Treckern und Lastwagen noch zu finden. Sie laufen leicht an, da bei Stillstand unmagnetisch. Ich habe kaum Messungen machen können, da diese LiMa's selten sind und nicht auf meinen Prüfstand passen, aber festgestellt: Ladebeginn bei PKW-LiMa Bosch 14V 25A mit 2 Feldspulen ca. 1200 U/min., bei LKW-LiMa mit 4 Feldspulen (ohne Typenaufdruck) ca. 700 U/min und, für uns sehr interessant: Bei beiden LiMa's Kennlinie wesentlich besser zum Repeller passend als die von Drehstrom-LiMa's! Weitere Vorteile (s. S.56 "Funktion und Anschlußweise").

Drehstrom-Asynchronmotoren, die man auf dem Schrott häufig findet, sind ebenfalls als Generator gut verwendbar. Für Auto-LiMa's habe ich mir einen speziellen Prüfstand gebaut und etliche Versuche und Messungen gemacht, für Drehstrom-Asynchronmaschinen (kurz: Asyms) nicht, weil ich die Hochspannung selten am Windrad verwenden konnte. Im Vergleich mit der Leistung von Drehstrom-LiMa's am Windrad gleicher Bauart fiel die gute elektrische Leistung auf, d.h. trotz der einfachen, nur durch Probieren ermittelten "Regeltechnik" mit Kondensatoren und Starthilfekondensatoren erfreulich guter Wirkungsgrad. Hier ein Beispiel: Standort hat starken Wind (Mittel über 5m/sek), Windrad 2,5 m Ø. Übersetzung 1:6,5. Generator: Asym 220/380V mit 1500 U/min Synchron-drehzahl, 1,1KW Nennleistung. Geladen werden 10 in Reihe geschaltete Autobatterien, d.h. mindestens 120V für Ladebeginn waren nötig, also weit unter Nennspannung. Asym in Dreieckschaltung geschaltet (= original für 220V),  $3 \times 12 \mu\text{F}$  in Sternschaltung als Erregerkondensatoren dran,  $3 \times 16 \mu\text{F}$  in Sternschaltung als Starthilfekondensatoren. Bei gut 4,5m/sek Erregung, die das Windrad aber zu sehr abbremste für Dauerladen (Ein-Aus-Effekt). Bei knapp 5,5m/sek Dauerladen, bei 6m/sek ca. 120W elektrische Leistung, bei 8m/sek ca. 320 W, bei 12m/sek ca. 800W elektrisch, über 12m/sek Unterforderung des Repellers hörbar (wird deutlich schneller und rauscht stark) aber noch Anstieg der elektrischen Leistung. Funktion und Anschlußweise s.S.

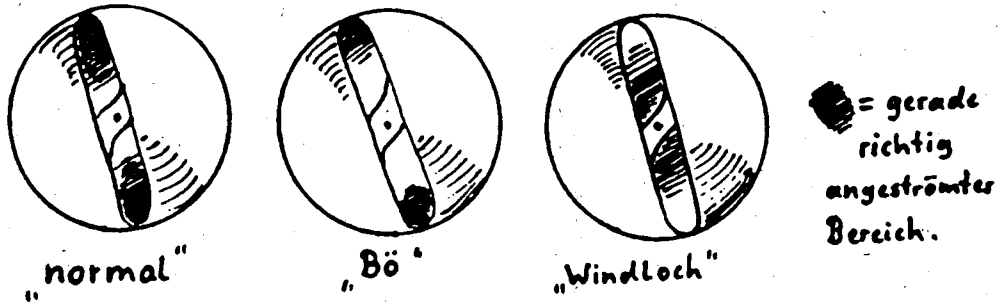
## Bau des Windrades

### Vereinfachung des Repellers für die Praxis:

Unser guter Dreiflügel - Repeller (S.12) hat auf ganzer Länge gleiche Blattbreite (erhöht die Anlaufkraft) und nur wenig Verwindung. So läßt sich der größte Teil des Flügels einfach mit geraden Hobelstrichen herstellen. Der "Primitiv-Repeller" (S.70) funktioniert sogar mit auf ganzer Länge gleich dickem Profil und gleichem Anstellwinkel!

Damit sind wir von der theoretisch richtigen Form weit entfernt. Die Repeller laufen aber trotzdem gut, u.U. sogar besser als ein perfekt geformter, denn unsere Windräder sind in einer Höhe, wo der Wind sehr böig ist, die Windgeschwindigkeit also schneller wechselt, als die Repellerdrehzahl folgen kann. Ein Theorierepeller würde hier ein paar Sekunden richtig angeströmt und bringt Bestleistung, einen Moment später überall falsch und er bringt nichts.

Selbst unser "Primitiv-Repeller" pendelt sich in der Drehzahl so ein, daß das äußere Drittel des Blattes, das die meiste Kraft bringt, etwa richtig angestömt wird. Bei plötzlichen Böen oder "Windlöchern" wandert der im richtigen Winkel angeblasene Bereich mehr nach außen oder zur Nabe, der Repeller läuft aber gleichmäßig weiter.



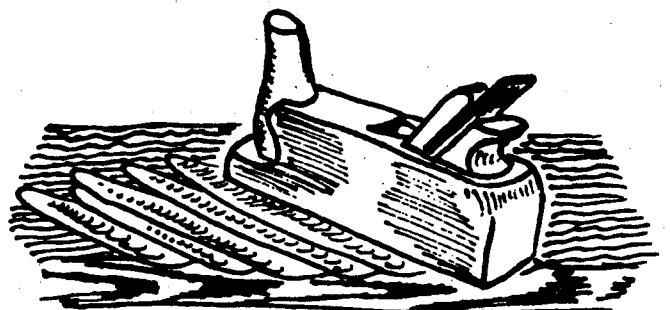
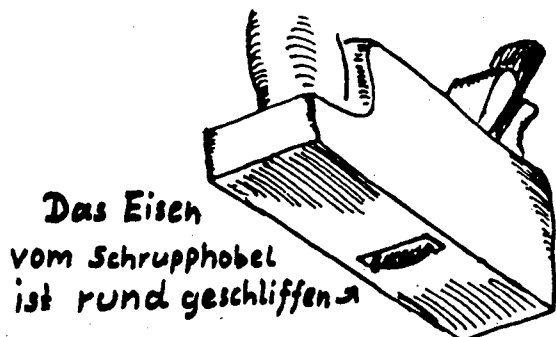
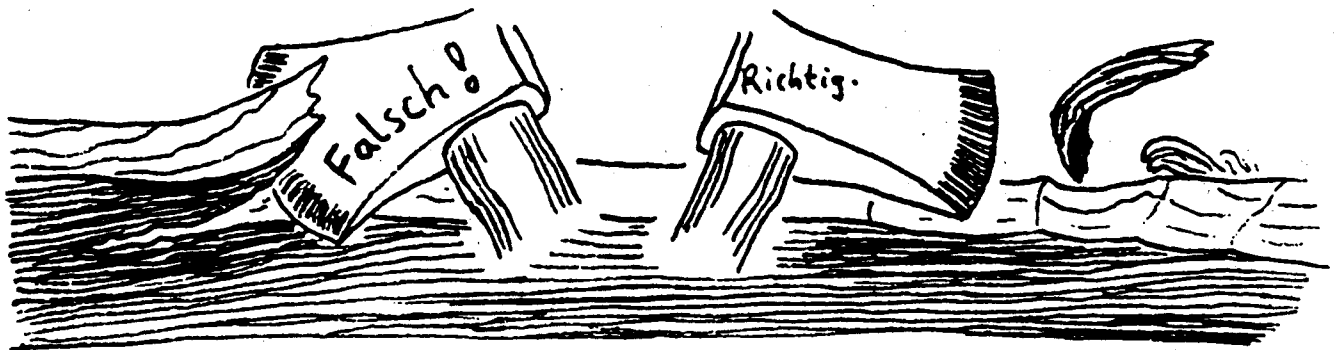
Dieser Repeller ist zwar besonders einfach zu bauen, aber macht Laufgeräusche, bei starkem Wind weit hörbar. Wenn Du befürchten mußt, die Nachbarn zu Windkraftgegnern zu machen, nimm lieber mehr Mühe in Kauf und baue den "Edel-Repeller" ( S.12)

## Die Werkzeuge und der Umgang damit

Du brauchst nicht alle Werkzeuge. Arbeite mit denen, die Dir gewohnt sind, Du kannst beispielsweise den ganzen Bau mit der Raspel machen, es dauert dann etwas länger. Ich möchte zeigen, welches Werkzeug für welchen Arbeitsgang besonders gut geeignet ist.

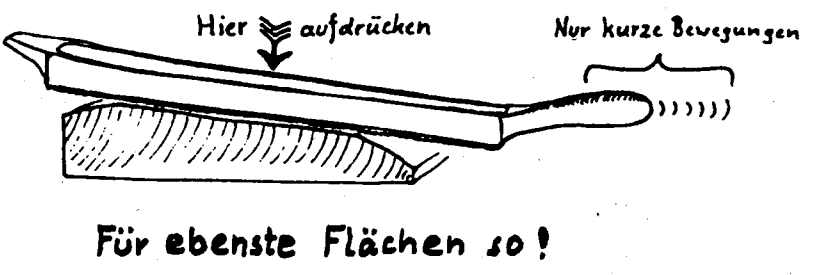
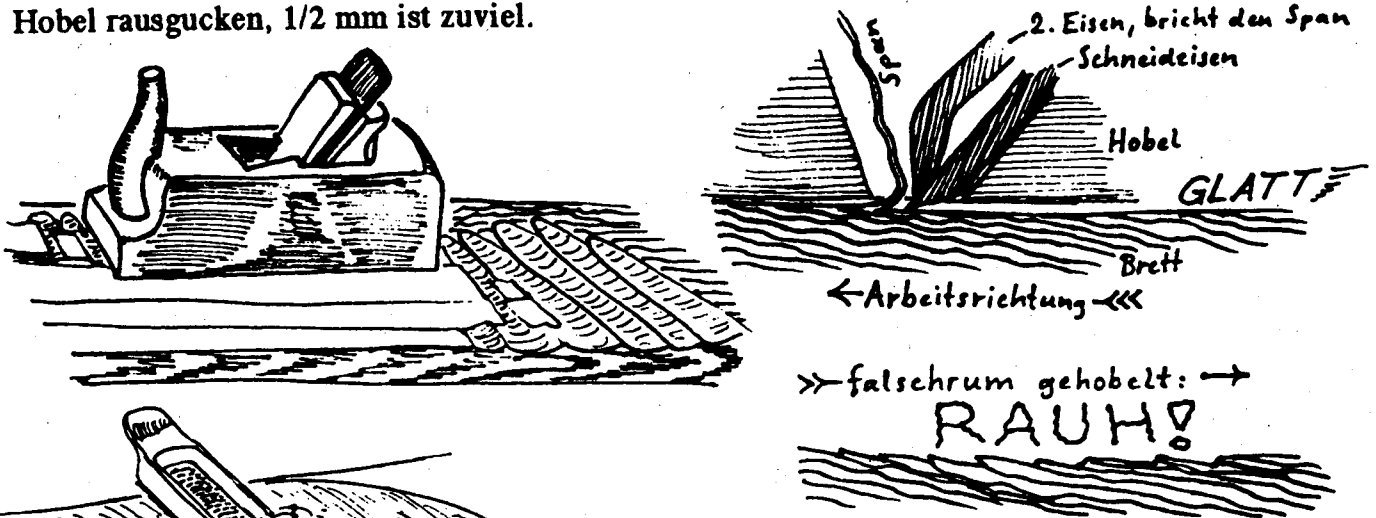
**Säge:** Zum Absägen des Brettes auf die richtige Länge.

**Zimmermannsbeil (sehr scharfes, leichtes Beil):** Überall dort, wo viel Holz weg muß (Breite herstellen, grobe Vorarbeit). Nicht zu viel Holz abhacken, nie in die Richtung, in der die Fasern ins Holz hinein laufen (Riß)!



**Schrupphobel:** Für die grobe Form, geht sehr schnell, wird aber wellig. Wenn er scharf ist, kann man schräg und fast quer zur Faser arbeiten. Nicht zu viel abhobeln.

Doppelhobel: Für die feine Form, der Repeller wird wie von selber gerade. Längs der Faser arbeiten und nicht so, daß es ins Holz hinein reißt! Hobeisen darf nur ganz wenig aus dem Hobel rausgucken, 1/2 mm ist zuviel.



Raspel: Nötig an den nach innen gewölbten Stellen beim Übergang zur Nabe, für die Profile bei den Meßpunkten und für Feinarbeiten. Die Raspeln mit gelochtem Stahlblechblatt schaffen viel mehr weg und es wird glatter als mit denen aus Massivstahl. Damit die Fläche nicht wellig wird, raspele nie zu lange auf einer Stelle, sondern bewege die Raspel auch etwas seitlich. Nie gegen die Faser raspeln, wird rauh (s. Hobel).

Ebene Flächen erreichst Du, wenn Du mit einer Hand in der Mitte über dem Buckel auf die Raspel drückst, mit der anderen die Raspel nur wenig vor- und zurück bewegst. Auf dieselbe Art kannst Du Metall mit der Feile auf wenige Hundertstel (!) Minimeter genau eben kriegen.

Feile: nicht nötig, jedoch bei Feinarbeiten eventuell nützlich.

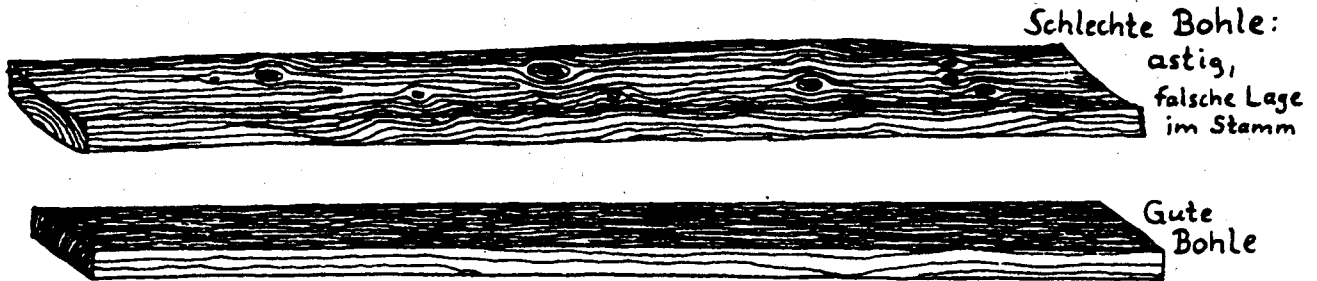
Schmirgelpapier: Unentbehrlich für glatte Oberflächen: erst mit grobem (50 - 60er), dann feinerem (80 - 100er) schmirgeln. Mit feuchtem Lappen abwischen, trocknen lassen und nochmal ganz fein schmirgeln (120er oder feiner). Auf glatten oder wenig gewölbten Flächen benutze einen Schleifkork, ein Stück Latte mit einem weichen Lappen drumgewickelt tut's auch. Vorsicht: Bei Holz mit groben Jahresringen (verschieden hart) kann das Schmirgeln Kuhlen in den weichen Zonen geben, die das Profil verschlechtern. Aufpassen!

## Gutes Holz erkennen...

Es muß fest, zäh und an der Luft beständig sein und so wenig wie möglich "arbeiten". Und es muß gerade und gleichmäßig gewachsen sein, denn wenn die Holzfasern den Repeller nicht der ganzen Länge nach durchziehen, wird er sich stark verziehen oder im Extremfall brechen!



Eschenholz ist nicht zu schwer, aber ganz besonders zäh, fest und beständig. Nicht ohne Grund wurden früher Wagenräder und Fuhrwerke daraus gebaut. Zwar ideal, aber nur in Spezial - Holzhandlungen zu bekommen und sehr teuer. Ich habe für meine Repeller bisher sehr gerne altes Kiefern- oder Fichtenholz verwendet. Es ist auf dem Müll leicht zu finden und auf diese Weise garantiert gut abgelagert. Ganz besonders gut sind z.B. Fußbodendielen aus Abbruchhäusern.



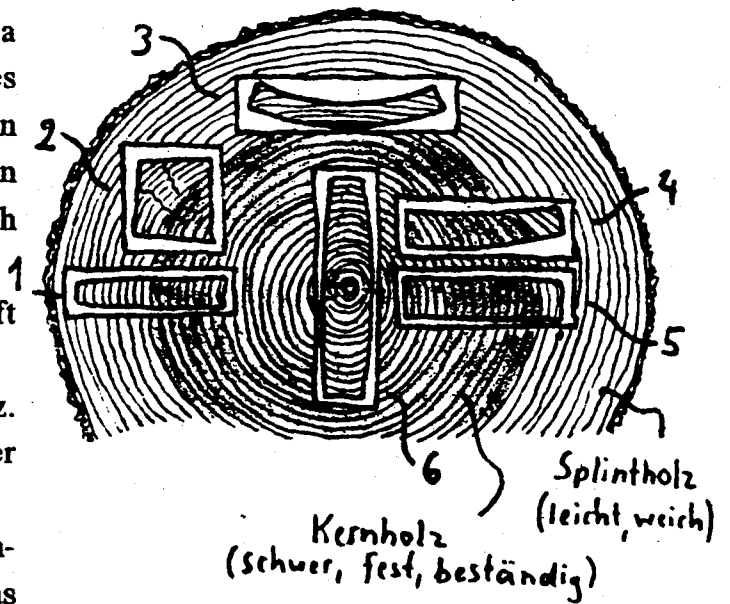
Auch für Türfüllungen oder Türrahmen wurde früher gutes Holz verwendet. In alten Möbeln sind ebenfalls oft sehr schöne Stücke zu finden, aber selten lang genug für einen Repeller. Holz mit vielen schmalen Jahresringen ist wesentlich besser als gleichartiges mit groben Ringen. Es soll so im Stamm gelegen haben, daß es möglichst wenig arbeitet:

Brett Nr. 1 ist für Zweiflügler ungeeignet, da zur Hälfte leichtes Splintholz, ungleichmäßiges Gewicht. Für Dreiflügler aber brauchbar, wenn Gewicht und Schwerpunktlage mit den anderen Brettern übereinstimmt (s.S. 12 ). Es wirft sich fast nicht.

Nr. 3 ist sehr schlecht: nur Splintholz, wirft sich sehr, wenig Festigkeit.

Nr. 4 ist notfalls geeignet, wenig Splintholz. Man sollte die glatte Seite des Repellers aus der Seite machen, die sich hohl wirft.

Nr. 5 ist ideal geeignet, fast nur Kernholz. Jahresringe durchziehen das Brett senkrecht; da das Holz quer zu den Jahresringen arbeitet, verändert das Brett höchstens seine Breite, wirft sich aber nicht.



Nr. 6 ist auch gut, Jahresringe senkrecht. Die Kernbohle arbeitet am wenigsten. Aber am Kern Gefahr für Ribbildung. Entweder nur die am Kern gespaltene Hälfte des Brettes verwenden, oder, wenn die Hälfte zu schmal ist, beide Teile mit den Außenseiten gegeneinander verleimen (nur mit Leim Güte B4!, s.S. 16)

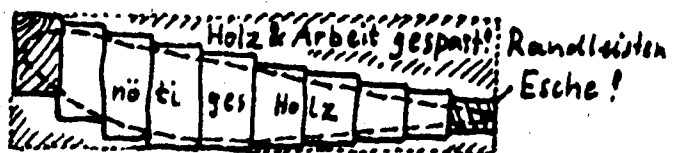
Für große Repeller besonders gut: Aus vielen Leisten zusammengeleimte Bohle (blockverleimt, Güte B4!). Extra edel: Hierbei für die äußersten Leisten Hartholz (z.B. Esche) nehmen, so sind die bei Hagelschlag usw. am stärksten angegriffenen Kanten verstärkt! (Foto Selbstbau s. S. 21 )

**„Blockverleimte“ Bohle:**



Leisten immer „Rücken an Rücken“ gedreht, also Maserung entgegengesetzt = Verzug hebt sich auf!

**Bei Selbstbau möglich:**



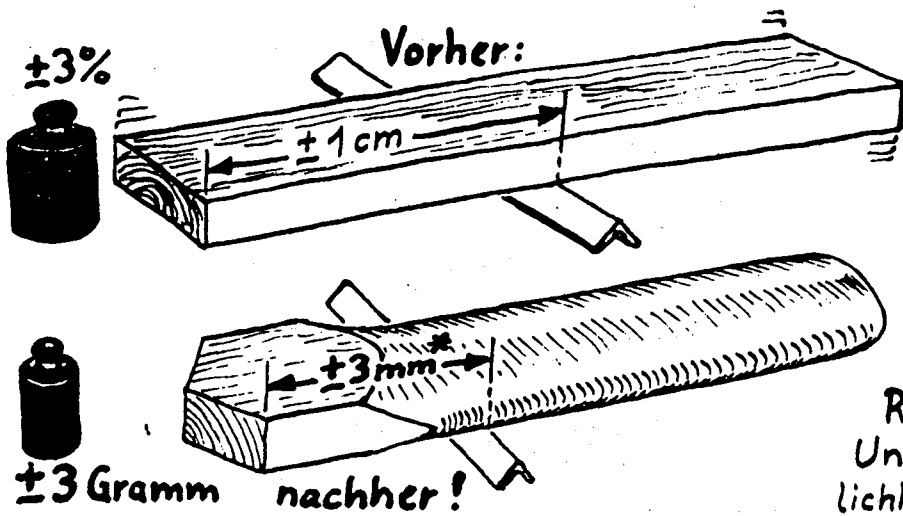
Leisten passend zusägen, außen Hartholz: stabiler, spart Holz und Arbeit!

# 12 Bau des 3-Flügel - Repellers

Dieser Repeller läuft besonders leise und ohne Vibrationen, weil er als Dreiflügler keinen Massenträgheitsmomenten - Ausgleich braucht. Maße für 2,5 m Ø, für andere Größen alle Maße im gleichen Verhältnis umrechnen!

Wichtig ist bei allen Schritten, daß die Flügel genau gleich werden, gleich schwer sind und gleiche Schwerpunktlage haben. Eine Bohle, die an einem Ende viel Kernholz, am anderen viel Splintholz (leicht!) hat, hat verschieden schwere Hälften. Das muß bei allen drei Bohlen ähnlich sein, damit nachher Gleichgewicht erreichbar ist.

Ausgangsmaß: 3 Bohlen 124 cm lang, 150 mm breit, 40 mm dick (wenn gehobelt, reicht 38 mm Dicke). Gleichheit prüfen!



**Vergleiche Gewicht und Schwerpunkt** der Bohlen und der Flügel nach jedem Arbeitsschritt. Falls Grenzen s.o. eingehalten, ist Genauigkeit s.u. leicht erreichbar. So kriegt der Repeller später keine Unwucht. (Ausgleich-Möglichkeit beim Verleimen s.S.16)

Bei allen drei Bohlen die Seite der Maserung als Luvseite nehmen, die sich (falls es passiert) hohl verzieht, schadet dann am wenigsten. Keinesfalls eine Bohle andersherum als die anderen!



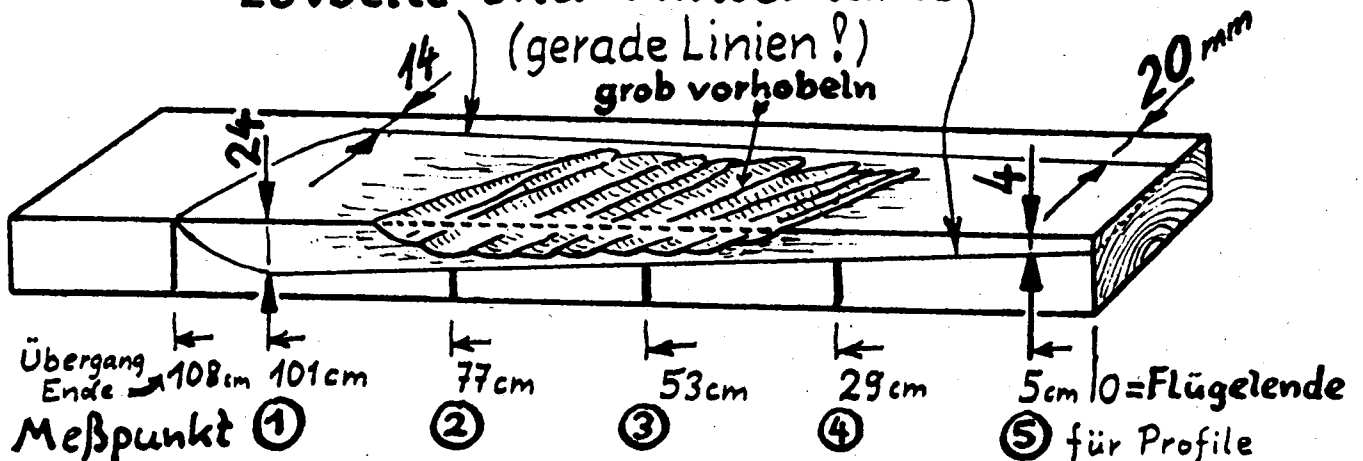
← Kern

**Bohle möglichst so nehmen, daß Kernseite auf der Leeseite\*<sup>1)</sup> liegt, auf jeden Fall immer alle 3 Bohlen gleich!**

\*<sup>1)</sup>falls Bohle extrem trocken, Kern auf der Luvseite!

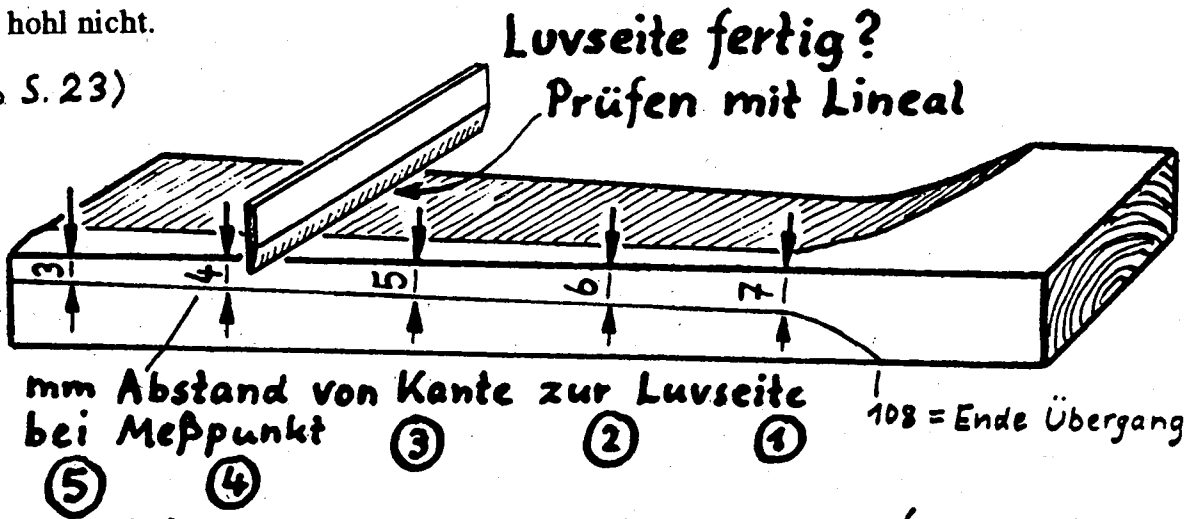
Die Profile sind so ausgelegt, daß alle anzuzeichnenden Linien (Luvseite, Hinterkante, Profilenasen - Linie) gerade sind.

**Luvseite und Hinterkante anzeichnen:**



Beim Vorhobeln genug Abstand von den Linien halten (besonders: Luvseite!), Feinarbeit bis an die Linien heran, Fläche quer zum Flügel muß eben werden! Ballig (= vorgewölbt) schadet, minimal hohl nicht.

(Photo S. 23)

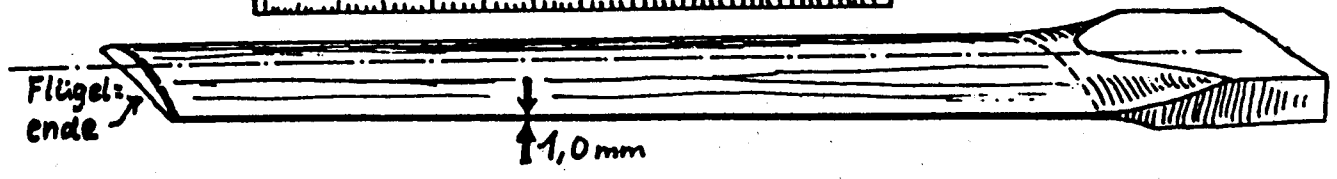
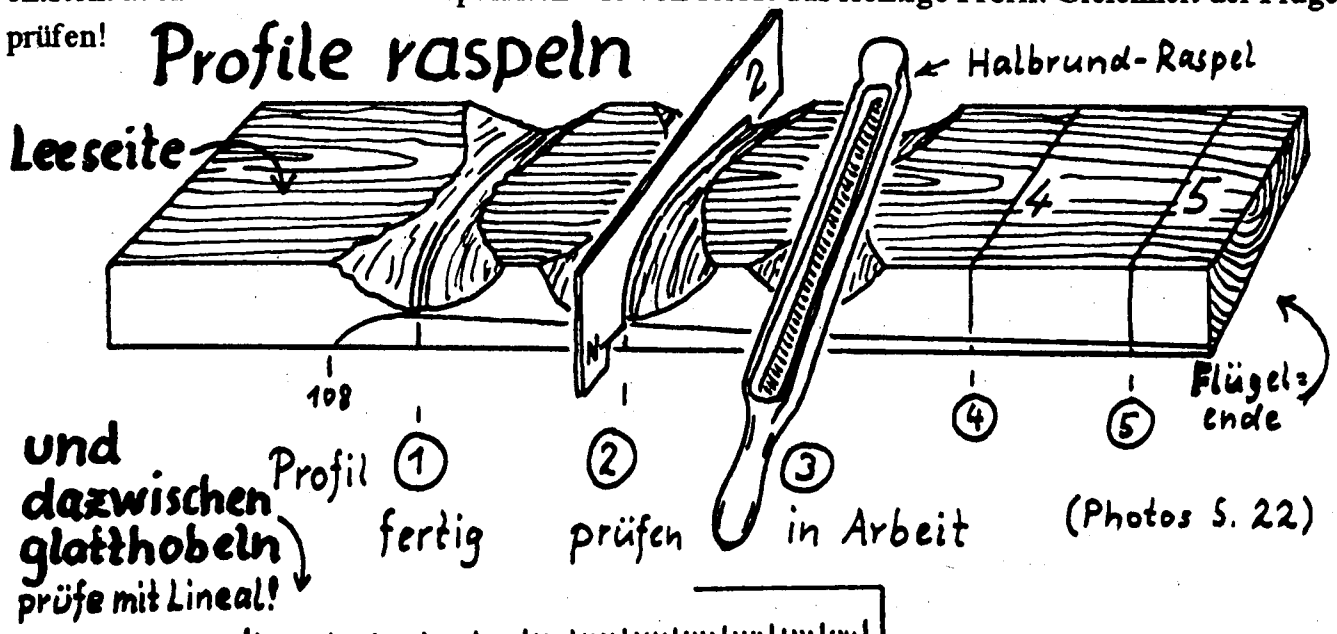


### Profilnasen-Linie anzeichnen (gerade Linie?)

Die Meßpunkte sind die Stellen, an denen die Profilschablonen angelegt werden. Der Bereich jenseits der 108 - cm - Marke (in der Mitte der Breitseiten 106,5 cm!) darf nicht bearbeitet werden, die Flächen müssen zum Verleimen glatt bleiben. Zwischen Profil 1 (bei 101 cm) und der 108 - (bzw. 106,5) - cm - Marke das Profil in einem sanften Übergang auslaufen lassen, keinesfalls mit einer Ecke oder Kerbe (gibt Bruchstelle)! Gleichheit prüfen!

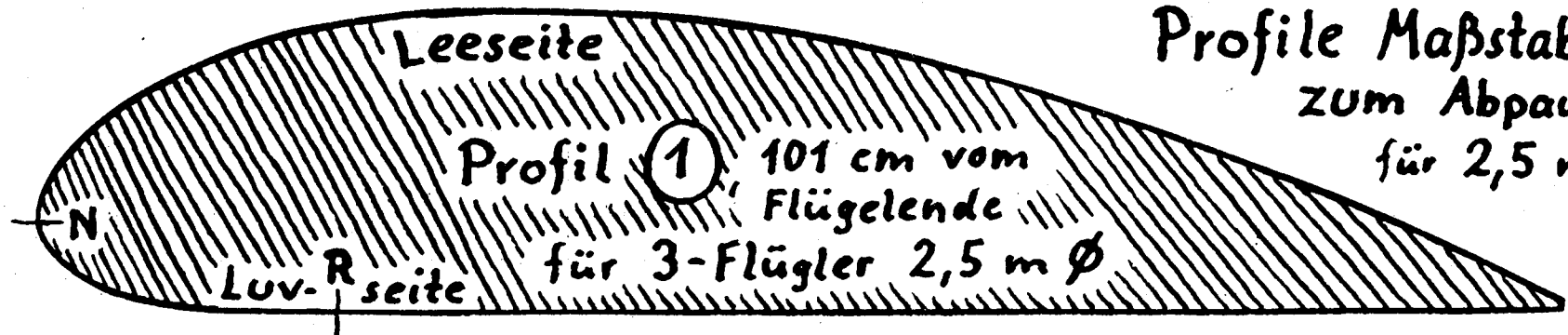
Profilschablonen herstellen (s. S. 14), Flügelblatt umdrehen, beim Bearbeiten der Leeseite aufpassen, daß das Profil weder längs noch quer zum Flügel Dellen oder Stufen kriegt (böser aerodynamischer Fehler). Nach dem Raspeln an den Meßpunkten geht alles mit dem Hobel (gerade Linien) bis auf bei Profil 1, wo der Übergang im Weg ist. Hobelst Du längs zum Flügelblatt, entsteht auch zwischen den Meßpunkten wie von selbst das richtige Profil. Gleichheit der Flügel prüfen!

### Profile raspeln

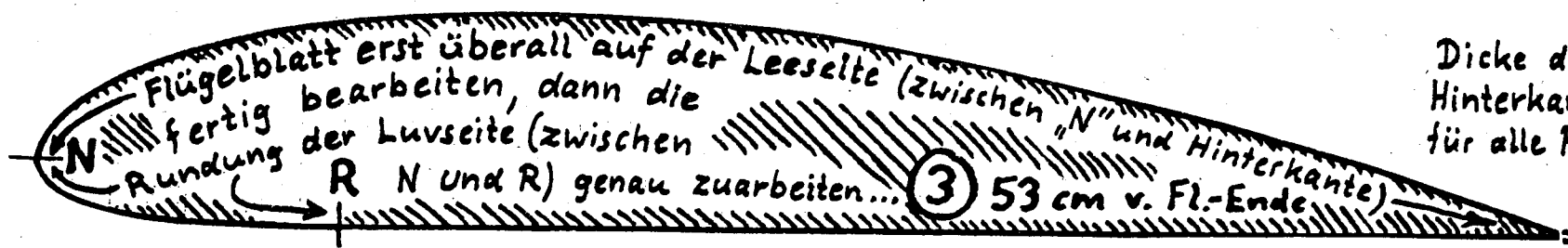


Am fertigen Flügel muß die Hinterkante genau 1 mm dick sein: Dicker macht zu viel Krach, dünner ist zu zerbrechlich.

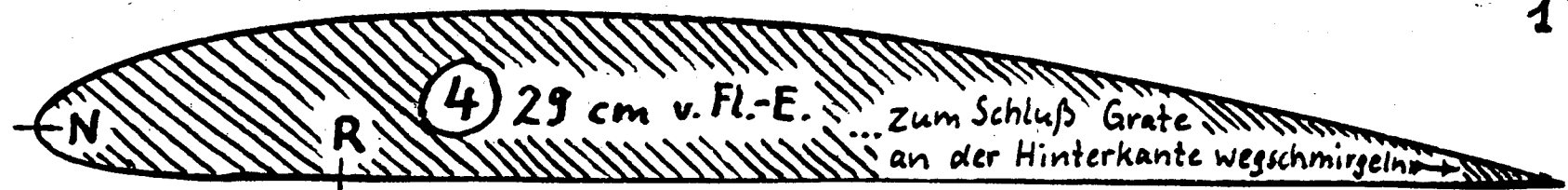
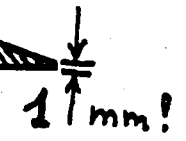
Profile Maßstab 1:1  
zum Abpausen  
für 2,5 m  $\phi$ .

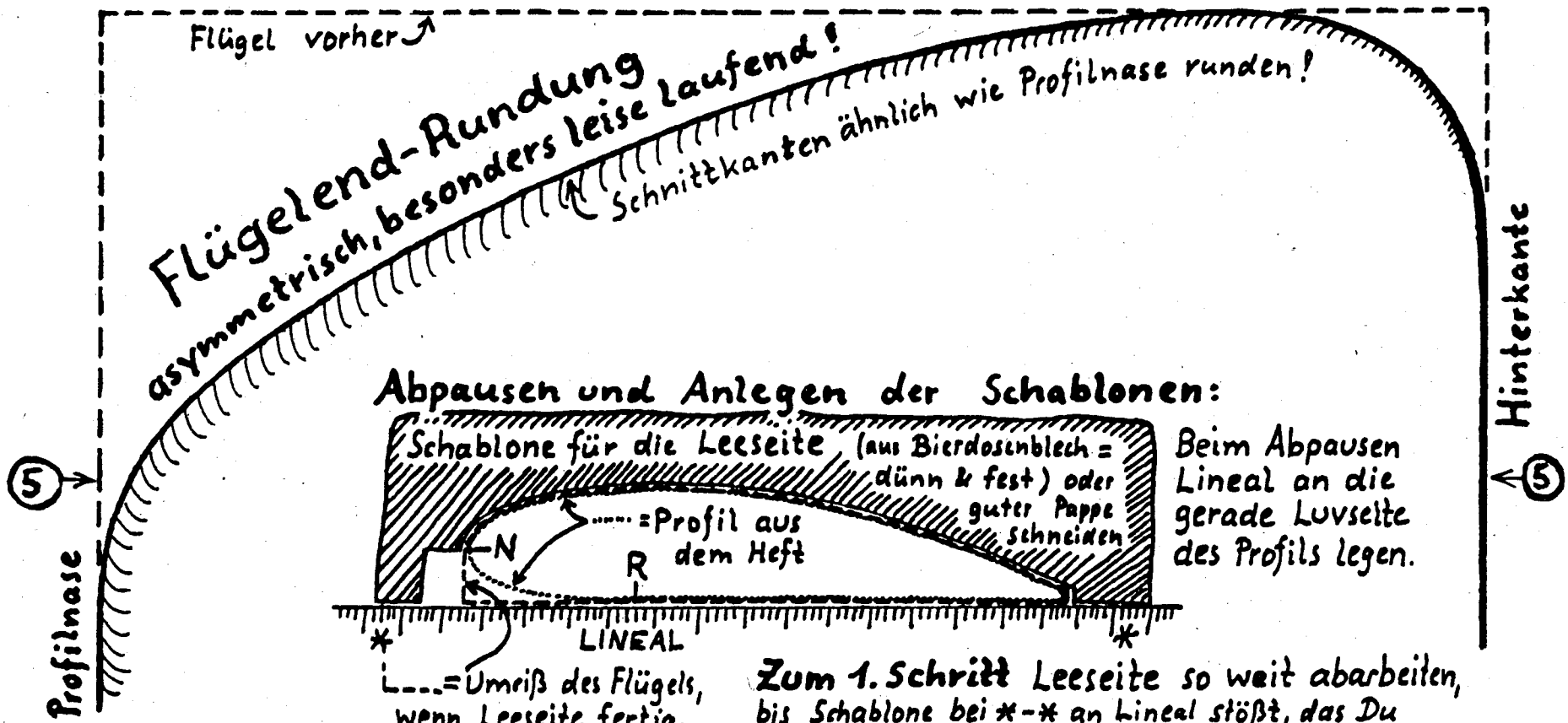


Für größeren Repeller- $\phi$   
maßstäblich vergrößern,  
z. B. mit „Stufenlos“-Kopier-  
gerät. z. B.: 3 m  $\phi$  =  
120% von 2,5 m  $\phi$ .

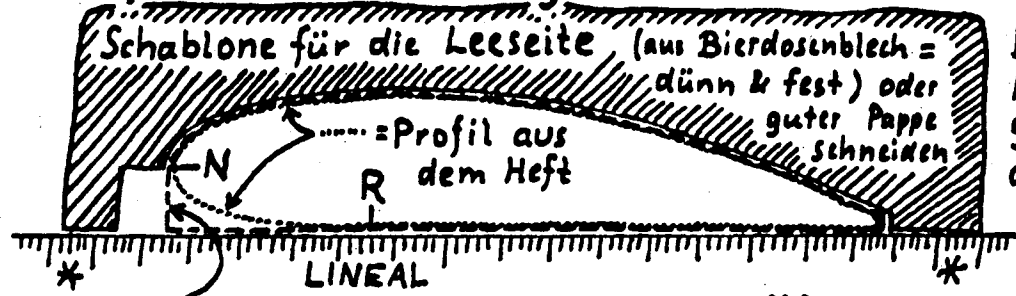


Dicke der  
Hinterkante:  
für alle Profile





**Abpausen und Anlegen der Schablonen:**

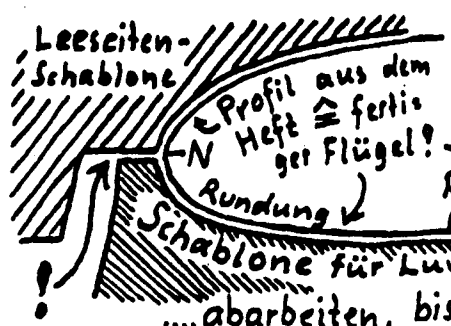


Beim Abpausen Lineal an die gerade Luvseite des Profils legen.

L--- = Umriss des Flügels, wenn Leeseite fertig.

**Zum 1. Schritt** Leeseite so weit abarbeiten, bis Schablone bei \*-\* an Lineal stößt, das Du gegen die glatte Luvseite des Flügels hältst.

⑤ = Hier war Meßpunkt 5.



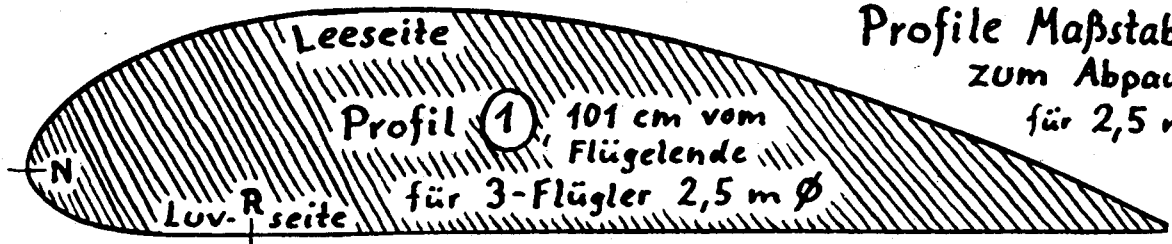
**Im 2. Schritt** Schablone für die Luvseiten-Rundung ausschneiden. An die glatte Luvseite halten und Rundung zwischen N und R so weit...

...abarbeiten, bis Schablone bei N an die Leeseiten-Schablone stößt.

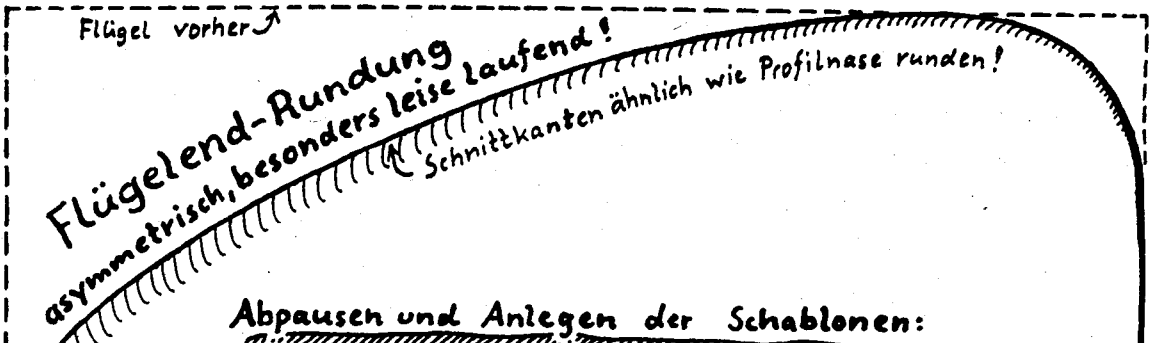
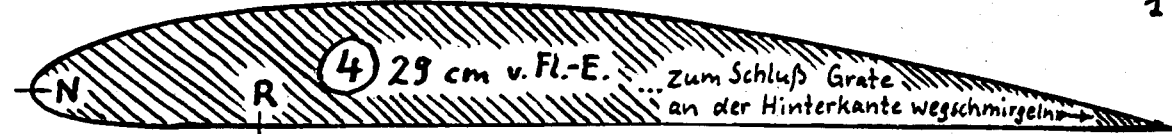
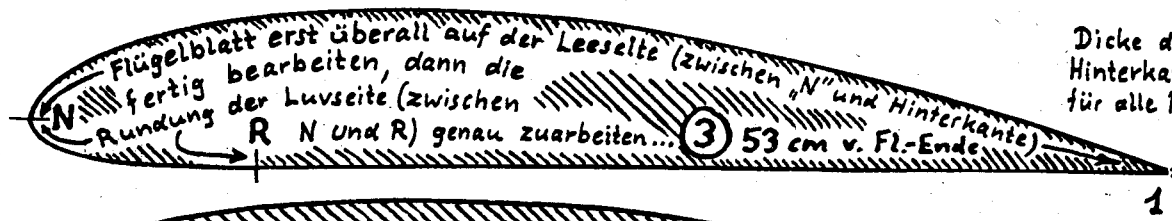
**3. Schritt: Hinterkante nacharbeiten: → Flügelform fertig!**

Flügelspitzen runden, Feinarbeit S.16.

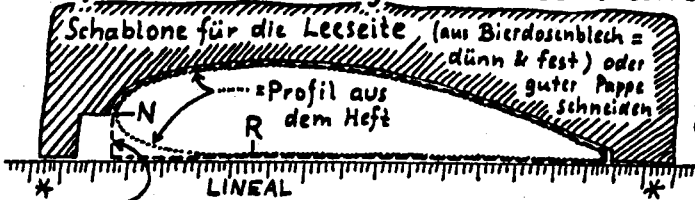
# Profile Maßstab 1:1 zum Abpausen für 2,5 m $\phi$ .



Für größeren Repeller- $\phi$  maßstäblich vergrößern, z. B. mit „Stufenlos“-Kopiergerät. z. B.: 3 m  $\phi$  = 120% von 2,5 m  $\phi$ .



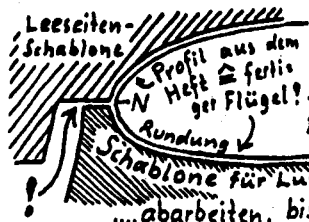
## Abpausen und Anlegen der Schablonen:



Beim Abpausen Lineal an die gerade Luvseite des Profils legen.

L... = Umriß des Flügels, wenn Leeseite fertig.

Zum 1. Schritt Leeseite so weit abarbeiten, bis Schablone bei \*-\* an Lineal stößt, das Du gegen die glatte Luvseite des Flügels hältst.



Im 2. Schritt Schablone für die Luvseiten-rundung ausschneiden. An die glatte Luvseite halten und Rundung zwischen N und R so weit...

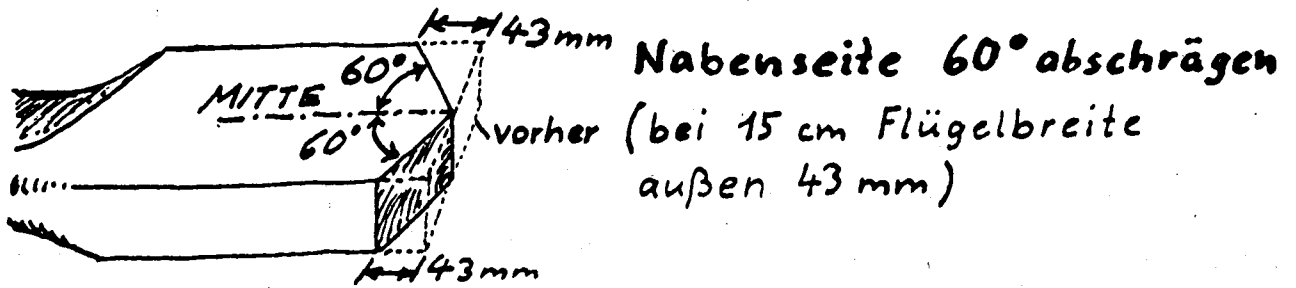
## 3. Schritt: Hinterkante nacharbeiten: → Flügel form fertig!

Flügelspitzen runden, Feinarbeit S. 16.

⑤ = Hier war Meßpunkt 5.

Jetzt vorsichtig die Luvseiten - Rundung an den Meßpunkten raspeln, dazwischen mit fein eingestelltem Hobel längs zum Flügel hobeln. Feine Form schmirgeln!

Flügelende nach Schablone formen, entstehende Kanten (dem Repellerprofil entsprechend) abrunden. Nabenseite zusägen, Gleichgewicht prüfen.



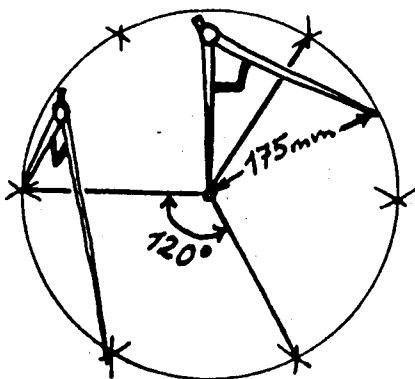
Alle bearbeiteten Flächen, wo noch nötig, schmirgeln: Kleinste noch fühlbare Hobelstriche stören das Profil. Endgültiges Herstellen der Gleichheit: Notfalls beim zu schweren Flügel das Profil großflächig dünner schmirgeln, aber unauffällig, d. h. die Profilform muß bleiben, keine Dellen! Schlankeres Profil nahe der Nabe stört die Aerodynamik kaum, nahe den Flügelspitzen stören schon kleinere Änderungen!

Bei ungleicher Schwerpunktlage ist die letzte "Schummel - Möglichkeit", den Flügel weiter herausstehend oder dichter zum Mittelpunkt geschoben einzuleimen, aber die Durchlüftung der Nabe (s. Zeichnung S. 16 ) muß bleiben. Sonst läßt durch feine Ritzen eindringendes Wasser den Repeller von innen vergammeln!

Verleime die Flügel nur mit Leim Güte B4 (= garantiert unterwasserfester Bootsleim). Leim Klasse B3 wird auch als "wasserfest" verkauft, löst sich aber schon nach 12 Std. Dauerregen auf!

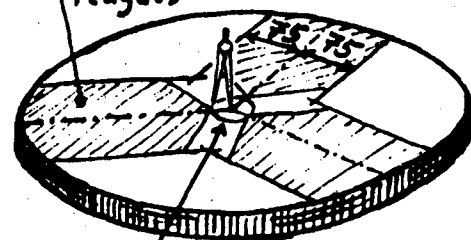
Die Sperrholzscheiben für die Nabe säge nur aus absolut wasserfestem Boots- oder Betonbausperrholz (Großbaustellen - Abfall), mind. 20 mm stark. Mit Zirkel anzeichnen, ebenso die 120° - Teilung, kleines Mittelpunktsloch bohren, Flügelposition aufzeichnen.

Scheiben-Ø und



3 Mittellinien der Flügel in genau 120° zueinander anzeichnen

Flügel-Umriss parallel zu den Mittellinien anzeichnen, Position des Flügels

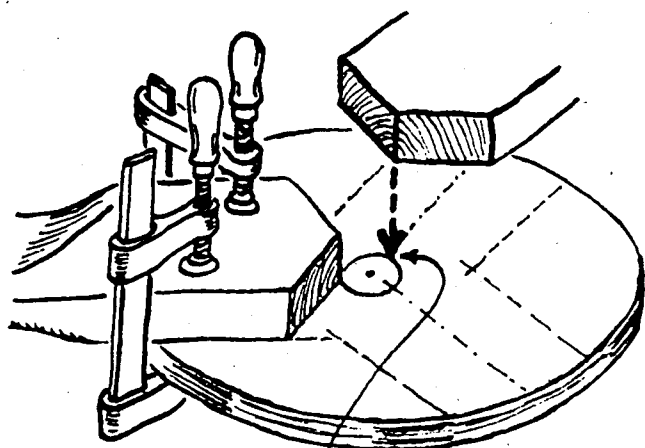


Mittelkreis 2 cm Ø bleibt frei! (Durchlüftung)

Flügel mit 1 cm Abstand von der Mitte (Lüftung!) an die 1. Scheibe ohne Leim festzwingen, Ausrichtung prüfen (Abstand der Flügelspitzen voneinander messen), mit Holzschrauben fixieren. Schrauben dabei so setzen, daß die Schraubenlöcher später für die durchgehenden Schrauben dienen können (s. Zeichnung S. 17 ). Das Ganze auf die 2. Scheibe leimen. Unbedingt Abfallbretter zwischen Zwinde und Scheibe bzw. Flügel legen, sonst gibt es nur eine punktweise Verleimung, außerdem die Flügel unterstützen, "Gefahr im Verzuge"!

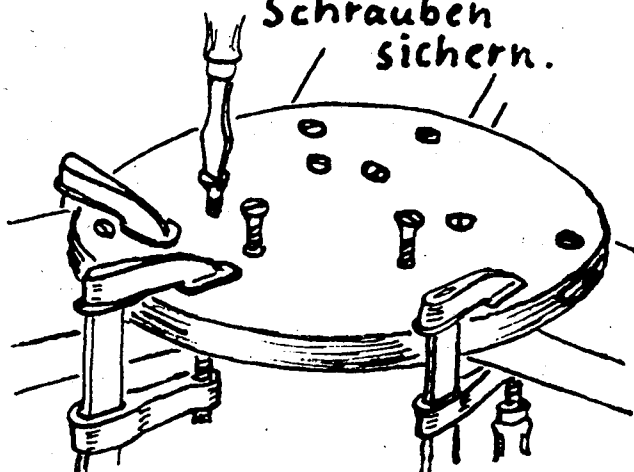
Wenn ausgehärtet, 1. Scheibe abschrauben und ebenfalls aufleimen, Flügel dabei unterstützen. Außerdem die Zentrierscheiben zum Befestigen am Radlager (s. S. 24) aufleimen. Verleimungen der Flügel mit dünnen, durchgehenden Schrauben (M 6) mit großen U - Scheiben (!) sichern. Bohrungen für dicke Schrauben schwächen das Holz unnötig. Bedenke immer, wie das Holz bei Überlastung spalten würde: Nie 2 Schrauben in einer Linie der Flügel - Maserung und am Nabende des Flügels nicht zu weit seitlich. Schrauben und Bohrungen gut mit Leinölfirnis einstreichen, sie rosten dann nicht im Repeller.

### Flügel festzwingen,

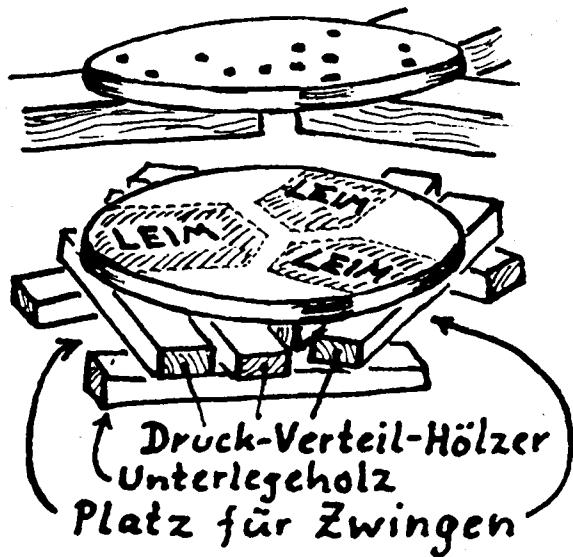


1 cm Luft zum Mittelpunkt!

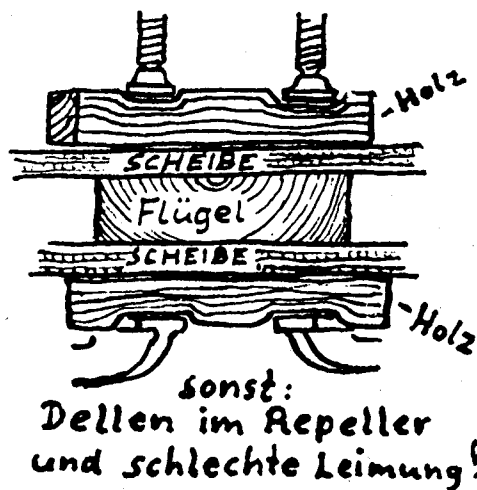
### Repeller umdrehen, Ausrichtung prüfen, mit Schrauben sichern.



### Fixierte Flügel auf 2. Scheibe leimen:



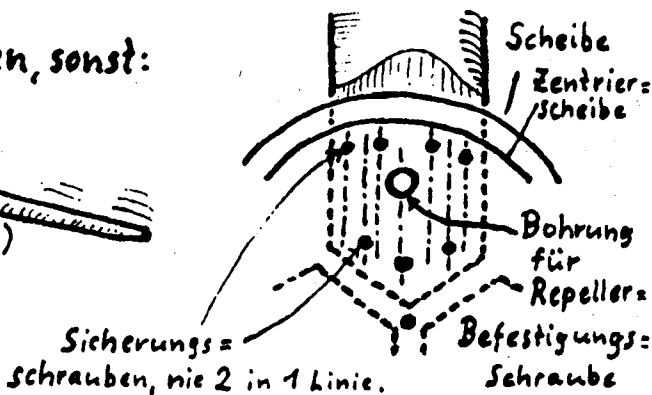
### Zwingen-Druck verteilen!



### Flügelenden unterstützen, sonst:



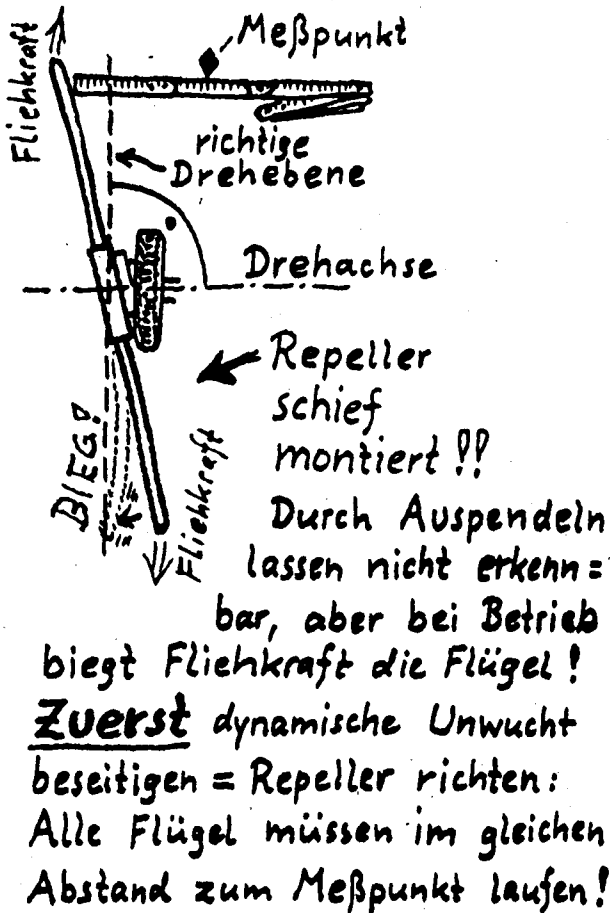
Folge: nach dem Leimen verzogen!



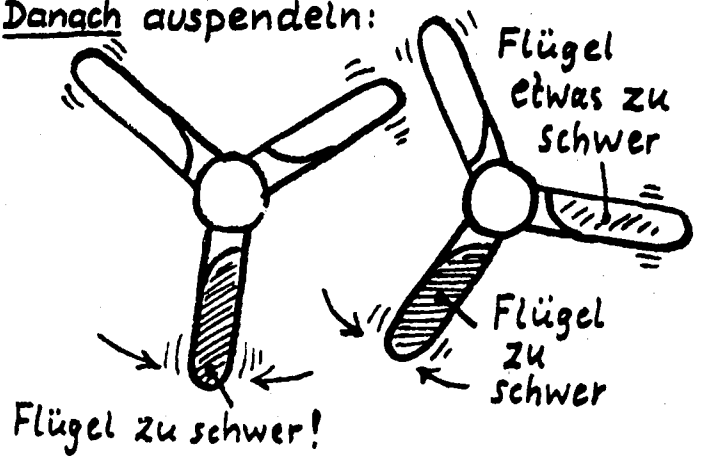


# 3) Repeller „dynamisch“ und „statisch“ auswuchten!

Vor dem Fertigschleifen und Lackieren Repeller probeweise an der Felge montieren, damit wir das Gleichgewicht und dynamische Unwucht kontrollieren können. Dafür Radlager leichtgängig machen: öffnen, altes Fett 'raus, Nähmaschinenöl 'rein, wieder zusammenbauen. Gleichgewicht durch Schmirgeln und evtl. zusätzliche Lackschichten herstellen, nur notfalls durch Ausgleichgewichte (Schrauben mit Unterlegscheiben in den Sperrholzscheiben stets auf beiden Seiten, sonst trotz genauer Ausrichtung dynamische Unwucht!)



Danach auspendeln:



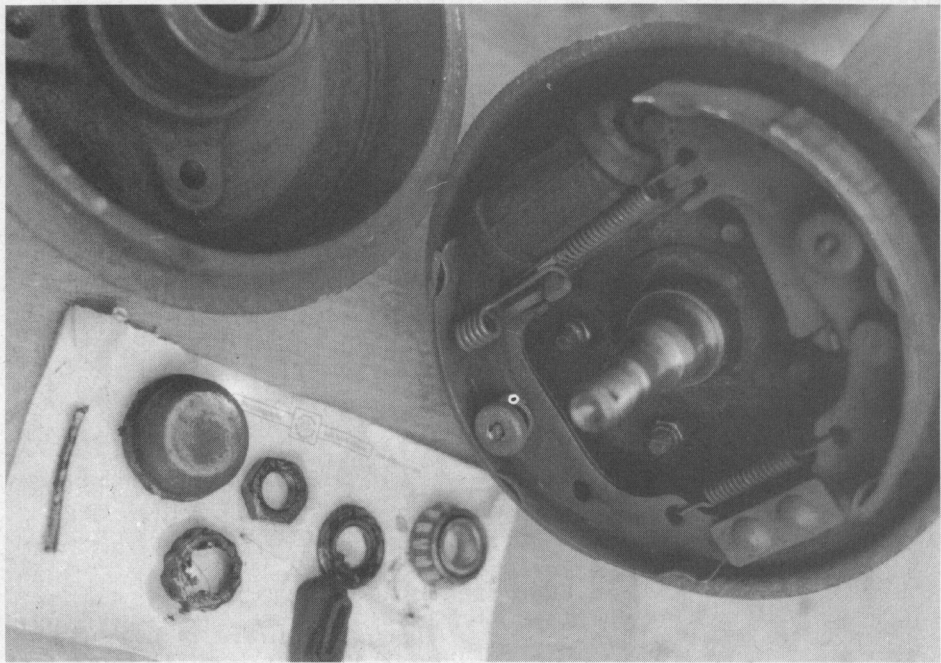
Pendelt der Repeller von selbst in eine bestimmte Stellung? Große Unwucht. Anstoßen: wie bleibt er stehen? Markieren. In anderer Drehrichtung anstoßen; ebenso? Noch eine kleine Unwucht. Wie viel? Wäsche = klammern an leichte Flügel klemmen und probieren, ob Gleichgewicht.

Dreht sich der Repeller, trotz der schön zur Felge passenden Sperrholzscheiben, nicht genau in einer Ebene (dynamische Unwucht!) hilft ein Gummistreifen zwischen Sperrholzscheibe und Felge. Vor der Endmontage Radlager wieder neu fetten und sorgfältig einstellen.

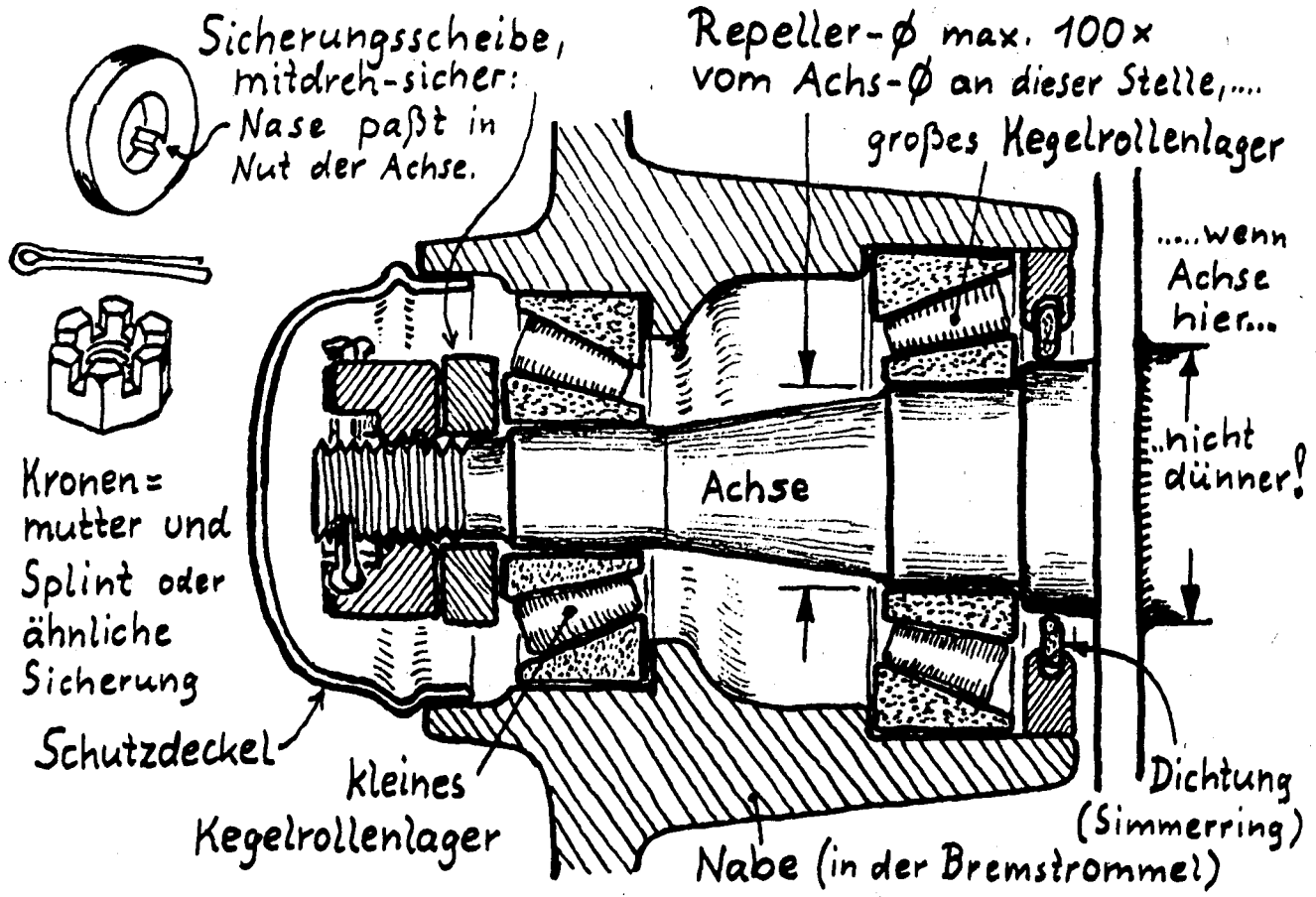
Erst oben auf dem Mast schraube die Felge endgültig fest an die Bremstrommel, dann den Repeller an die Felge.

## Auseinander- und Zusammenbau des Radlagers:

Zum Öffnen Schutzkappe abhebeln, Sicherungssplint rausziehen, Mutter(n) abschrauben, an der Bremstrommel ziehen (oder beidseitig gleichmäßig hebeln), Bremstrommel zieht das kleine Lager von der Achse. Großes Lager bleibt, je nach Aufbau, auf der Achse oder in der Bremstrommel. Lagerteile gut säubern, sehr sauber halten, mit Heizöl o.ä. leichtgängig machen, mit Kugellagerfett für den Betrieb schmieren. Montage umgekehrt, Sicherungsscheibe keinesfalls vergessen! Festziehen, bis kein fühlbares Spiel mehr, aber noch ganz leichtgängig. Achtung! Auf die Bremsbeläge darf nie Öl oder Fett kommen, geht nicht mehr raus, ölige Bremsbeläge bremsen nicht mehr!



Links oben: Bremstrommel, unten v.li.: Splint, Schutzkappe, Mutter u. Sicherungskrone (hier getrennte Teile), Sich.-Scheibe, kl. Lager. Rechts: Achse mit Bremse.



Sicherungsscheibe,  
mitdreh-sicher:  
Nase paßt in  
Nut der Achse.

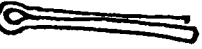
Repeller- $\phi$  max. 100x  
vom Achs- $\phi$  an dieser Stelle,...  
großes Kegelrollenlager

...wenn  
Achse  
hier...

...nicht  
dünner!

Dichtung  
(Simmerring)

Nabe (in der Bremstrommel)



Kronen=  
mutter und  
Splint oder  
ähnliche  
Sicherung

Schutzdeckel

kleines  
Kegelrollenlager

Achse

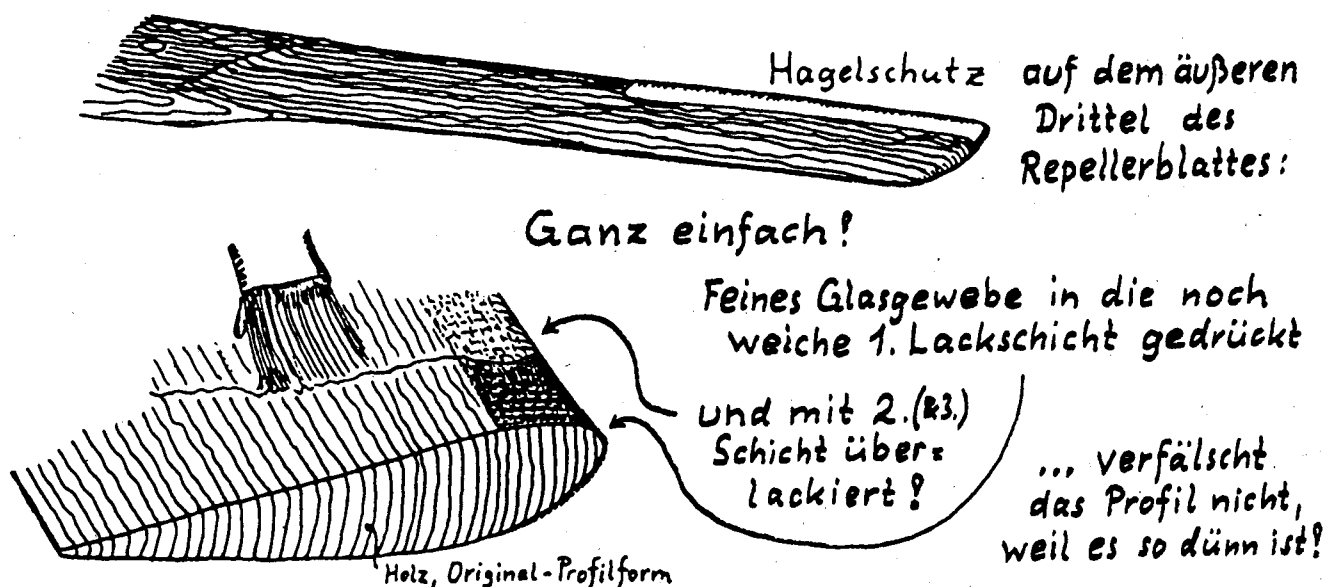
# Repeller schmirgeln, Hagelschutz, Lack:

Schmirgele zunächst mit 50er, dann mit 80er, und zuletzt mindestens mit 120er Sandpapier, um eine möglichst glasartig glatte Oberfläche zu erreichen.

Dabei stets das Gleichgewicht prüfen.

Ist fertig geschmirgelt und auch die Randbögen aalglatt, kann das Holz imprägniert werden, aber bitte nicht mit irgendwelcher Chemie, sondern tränke das Holz mit Leinölfirnis und wische den Überschuß, der nicht aufgesaugt wurde, rechtzeitig ab. Nach mindestens einer Woche Wartezeit kann Bootslack drauf. Trage jede Lackschicht dünn auf, eine dicke Schicht würde rau und kaum haltbar. Zwischendurch immer mindestens 3 Tage warten, dann ganz fein schmirgeln, damit die folgende Schicht absolut glatt wird.

Beim Lackieren müssen wir den Hagelschutz anbringen:



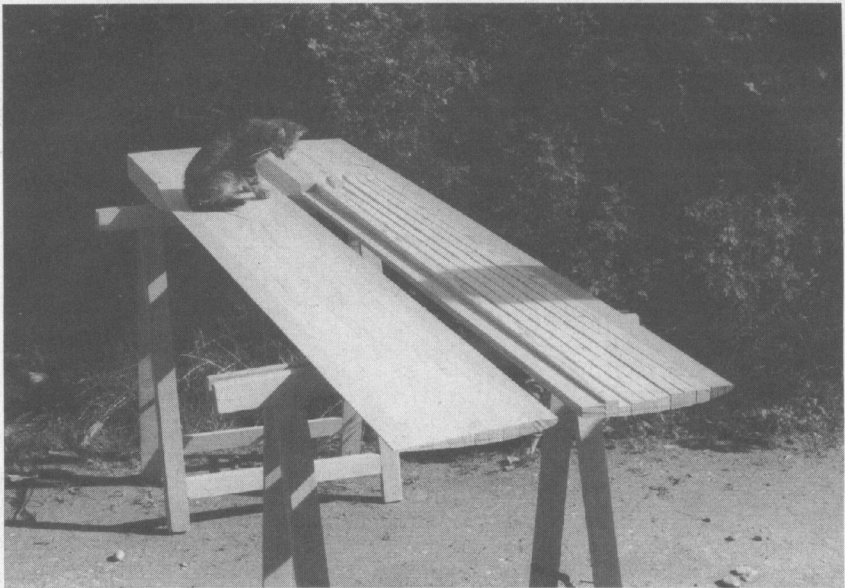
Der Repeller läuft schnell, bei Windstärke 7 können die Flügelspitzen mit 200 bis 300 km/h die Luft durchschneiden. Treffen sie mit dem Wahnsinnstempo gegen Hagelkörner, sind die Vorderkanten bald ramponiert. Auf die Dauer würde sogar Regen schaden.

Drücke in die klebrige 1. Lackschicht eine Lage feines Glasgewebe. Es muß sehr glatt gewebt sein, etwa wie Bettlaken. Gib't's im Flugmodellbau - Bedarf. Trocknen lassen. Die 2. Lackschicht durchtränkt und festigt alles. Gut trocknen lassen, evtl. vorstehende Fasern abschmirgeln, 3. Lackschicht drauf. Das ist Öko-er, viel leichter zu verarbeiten und besser reparierbar als Methoden mit Kupferfolie oder ekelchemostinkendem Glasfaser - Kunstharz!

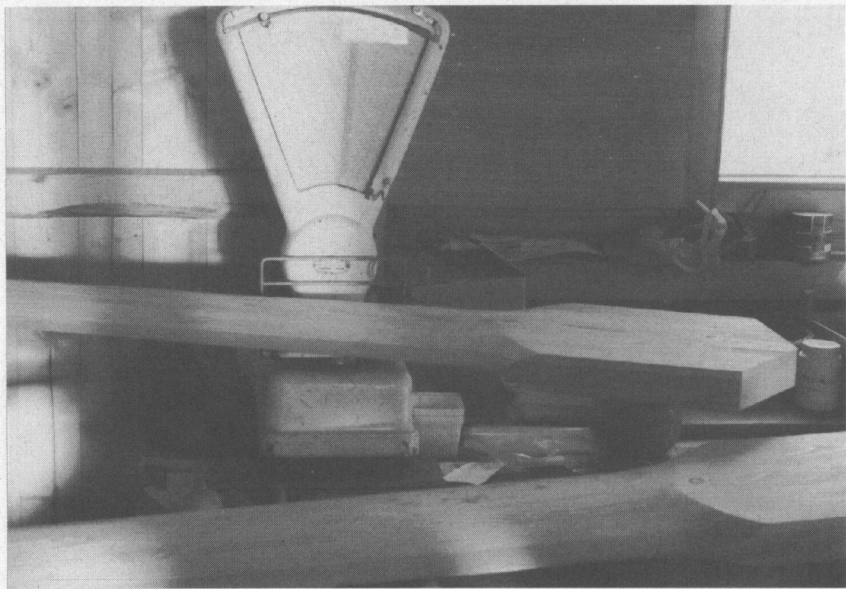
Lackiere in einem trockenen, möglichst auch warmen und staubfreien Raum mit einem Haarpinsel oder sehr weichen, flachen Borstenpinsel. Auch das Firnissen und Lackieren kann das Gleichgewicht durcheinanderbringen, zur Korrektur stellenweise eine zusätzliche Lackschicht aufbringen.


Lack auf Ölbasis ist wesentlich besser als Kunstharz- oder PU - Lacke, er geht beim Arbeiten des Holzes mit und neigt nicht zum Aufplatzen, was z.B. bei Fensterrahmen die typischen Verwitterungs- und Gammelecken entstehen läßt.

Bei Unwettergefahr sollten wir das Windrad lieber stilllegen, dann brauchen wir nur alle 1 - 2 Jahre Lackschäden auszubessern.



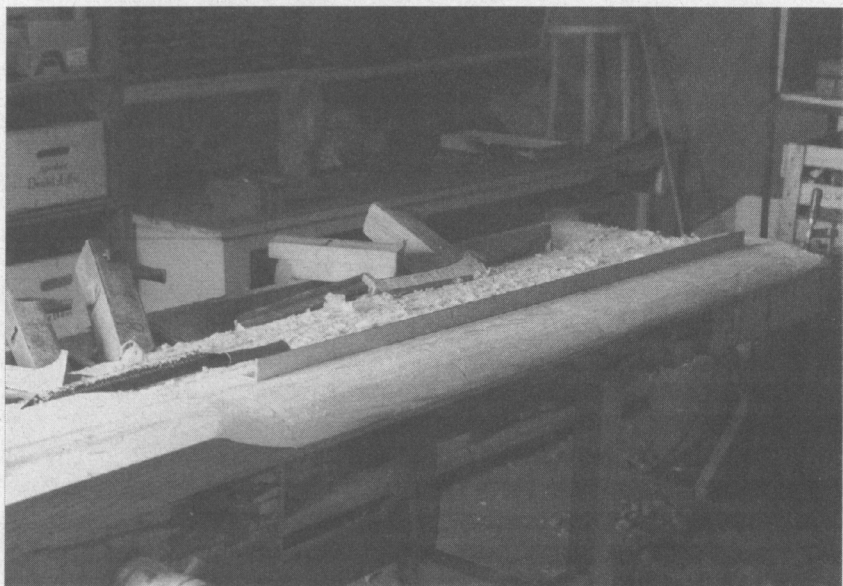
Flügel aus selbstgemachtem Blockleimholz: rechts roh, links fertig



Zwischen allen Arbeitsgängen Schwerpunkt <sup>↑</sup> hier auf -Eisen- suchen und wiegen!



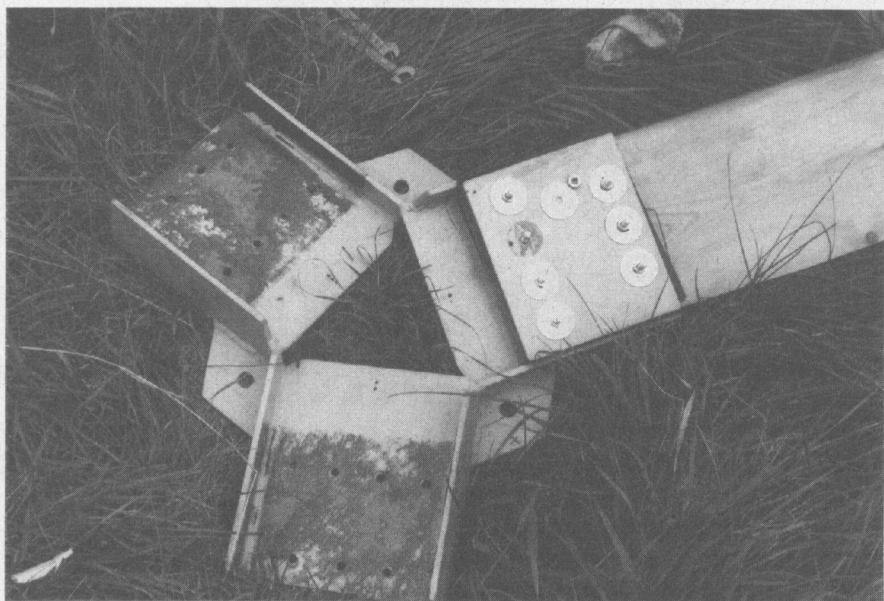
*Nach grober Vorarbeit Raspeln der Leeseitenprofile an den 5 Meßpunkten*



*Leeseite zwischen den Meßpunkten geradehobeln, prüfen mit Lineal*



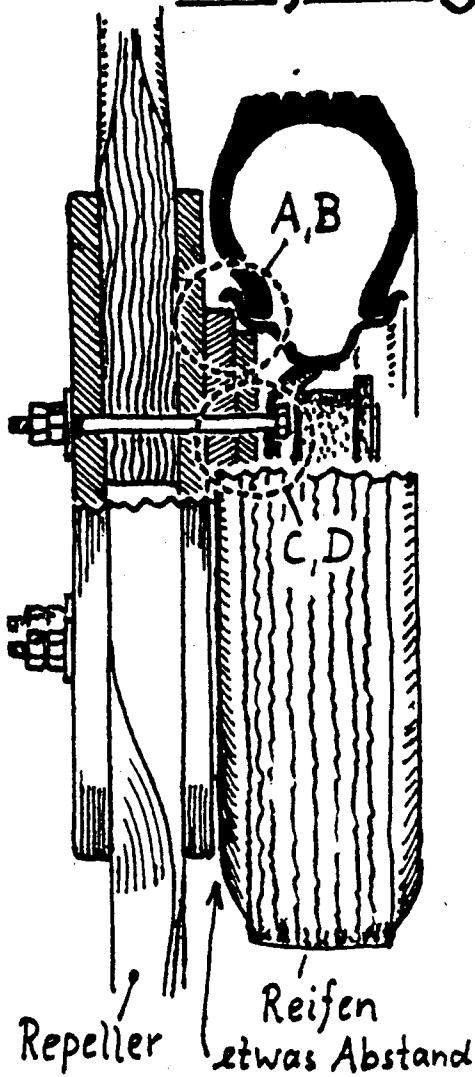
*Luvseiten-Schrägstellung mit Schrupphobel und Doppelhobel herstellen*



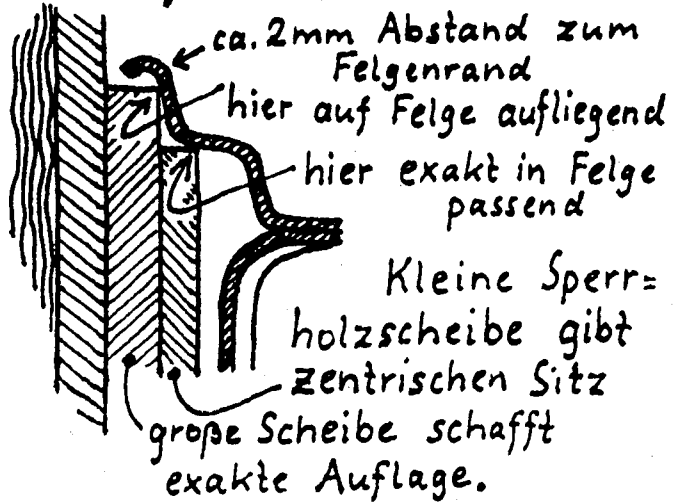
*Variante für Metallbauer: Eiserne Nabe mit 5° Anstellwinkel für Flügel mit unbearbeiteter Luvseite ergibt sehr einfache, zerlegbare Repeller.*

# Befestigung des Repellers

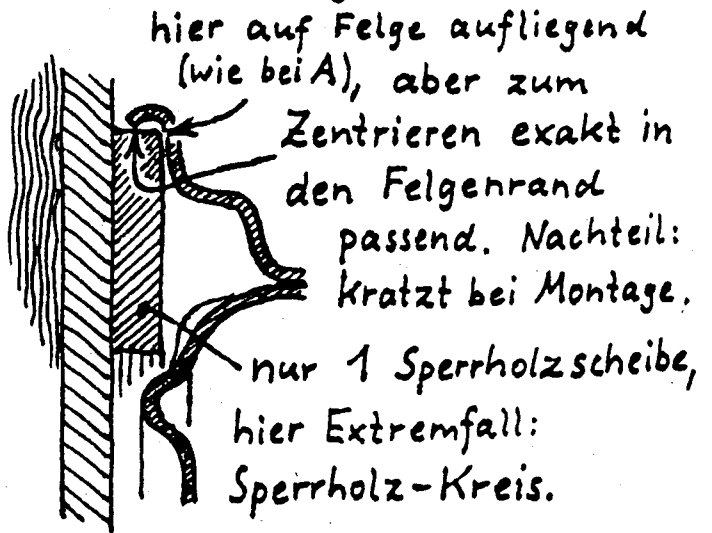
24



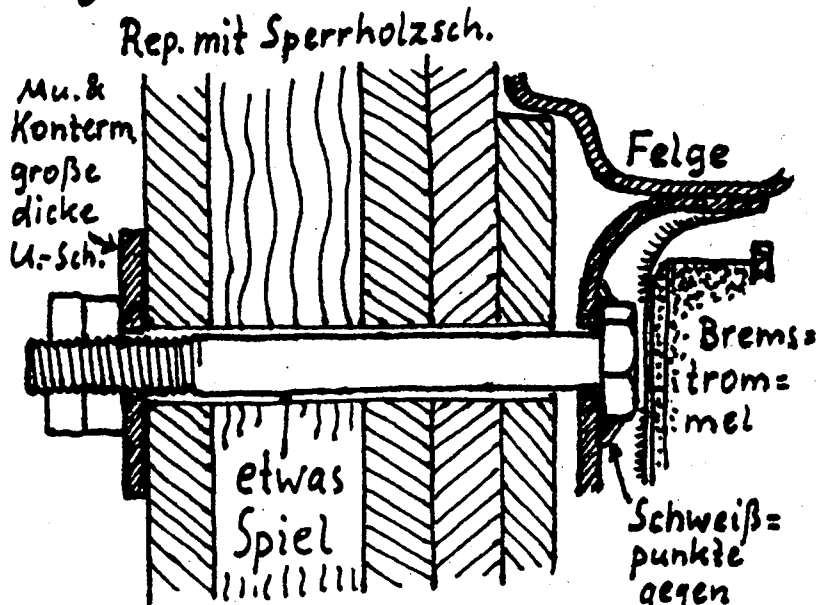
**A: ideal, wenn genug Platz:**



**B: wenn zu wenig Platz:**

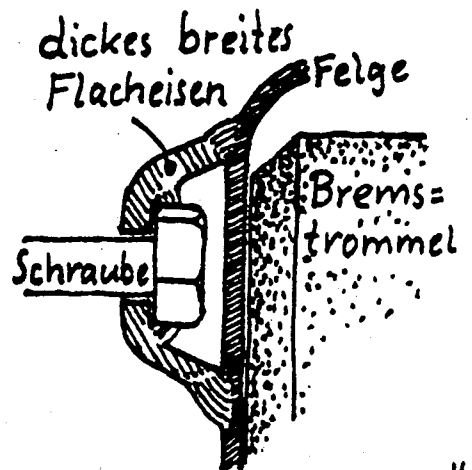


**C: gut & einfach, wenn Platz:**



Schraube durch Felge durchgehend.

**D: Notlösung:**



„Schrauben-Halter“ supersorgfältig an Felge geschweißt.



Der Repeller muß genau mittig sitzen (sonst Ungleichgewicht) und so aufliegen, daß die Felge genau in einer Ebene um die Drehachse stehen (sonst dynamische Unwucht!). Er soll beim Anschrauben "von selbst" in die richtige Position kommen, Ausrichten erst bei der Montage oben auf dem Mast wäre zu mühsam. Zum Reifen soll der Repeller mind. 1/2 cm Abstand haben, sonst sammelt sich Wasser dazwischen (gammelt...).

Die Felge sitzt zentrisch auf der Bremstrommel. Der Teil der Felge, der den Reifen trägt, ist damit auch zentrisch und in einer Ebene zur Drehachse. Also sitzt der Repeller richtig, wenn er genau dort an der Felge anliegt. Dafür sägen wir 2 kreisrunde Scheiben aus Betonbau - Sperrholz, die zur Felge passen (s. Zeichn. A), leimen und schrauben sie mittig auf den Repeller.

Viele Felgen sind aber über der Bremstrommel so stark gewölbt, daß die kleine innen unter dem Reifensitz anliegende Sperrholzscheibe keinen Platz hätte. Da müssen wir mit nur einer Scheibe auskommen (s. Zeichn. B), die außen am Reifensitz aufliegt zum Ausrichten in der Drehebene und genau in den Felgenrand paßt zum Zentrieren. Nachteile: Der Felgenrand ist nicht so genau gearbeitet wie der Reifensitz und die Kante kratzt an der Sperrholzscheibe. Zum Schutz beschlage den Scheibenrand mit einem Streifen verzinktem Blech (wie ein hölzernes Wagenrad).

Die Befestigungsschrauben zentrieren den Repeller nicht, sie halten ihn "nur" fest: sie sind für die Sicherheit extem wichtig, dürfen keinesfalls zu schwach sein. Für Repeller 2,5m  $\varnothing$  3 Stck. M12, für Repeller 4m  $\varnothing$  mind. M16, auf jeden Fall Güte 8G (=8.8) mit glattem Schaft! Je weiter außen die Befestigungspunkte, umso sicherer die Verbindung.

Meistens hat die Felge an passenden Stellen Ausbuchtungen, so daß der Schraubenkopf zwischen Felge und Bremstrommel reichlich Platz hat (Zeich. C). Hier Felge durchbohren, Schrauben durchstecken, Kopf z.B. mit 3 Schweißpunkten gegen Mitdrehen sichern. Nicht ringsrum schweißen! Schweißnaht schwächt Material der Felge, Schraube könnte samt dem Stück Felge herausreißen!

Hat die Felge keine passenden Ausbuchtungen, biege aus breitem Flacheisen (z.B. 5x40...6x50, stabiler als Schraube!) passende Halter, Loch durch, Schraube durch, Kopf sichern (s.o.!) und Halter auf die Felge schweißen. Die Breite des Flacheisens ermöglicht je zwei längere Nähte, die die Kraft auf die Felge verteilen. Bei guter Ausführung reißt der Halter nicht ab. Sonst wäre es supergefährlich!

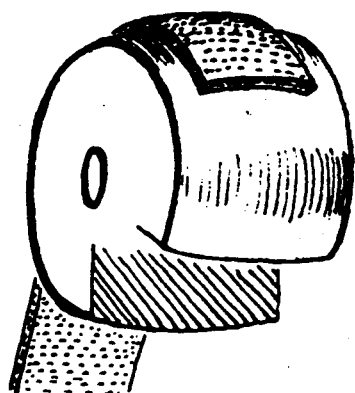
Die Schrauben sollen etwas Spiel in den Bohrungen im Repeller haben, sonst läßt er sich nur mühsamst montieren. Bei Endmontage Repellerschrauben und Bohrlöcher mit Leinölfirnis dick einpinseln gegen Vergammeln. Auf den Repeller dicke, sehr große Unterlegscheiben legen (mind. 4 cm  $\varnothing$ ), Muttern festziehen und mit Kontermuttern sichern!

## Bau des Getriebes

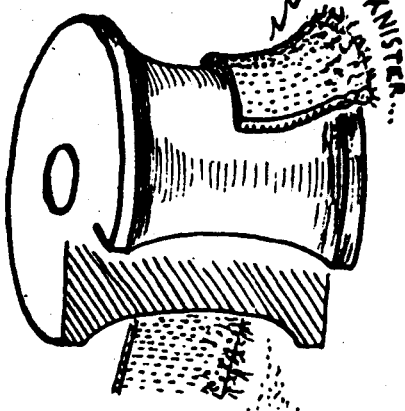
Bei Windrädern dieser Größe kommt man (außer mit superteuren Spezialgeneratoren) ohne Übersetzung nicht aus. Ein Übersetzungsgetriebe muß aber leise laufen, dauerhaft und wetterfest, leicht zu finden oder leicht zu bauen sein - vor allem bei Schwachwind - besonders leichtgängig sein. Nach Jahren von Experimenten erwies sich der altbewährte Flachriemenantrieb besonders in dieser trickreich einfachen Ausführung als beste Lösung. Einzige Probleme: Festfrieren bei Windstille und Eisregen, Blockieren bei Windstille und viel Schnee, Rauhreif macht nichts. Lösung: Windrad kurz von Hand drehen und alles ist wieder gut, ca. 2x im Jahr nötig.

Flachriemen laufen immer auf die dickste Stelle der Riemenscheibe, also muß die Riemen-

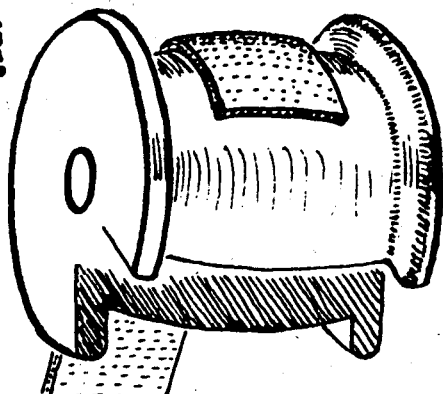
scheibe ballig wie ein Faß sein. Bei sehr verschieden großen Riemenscheiben wie bei der Übersetzung hier reicht es, wenn die große Riemenscheibe ballig ist. Die kleine kann zylindrisch sein. Ein Blick auf den Schrott: Jeder aufgepumpte Autoreifen hat eine ballig gewölbte Lauffläche! Da liegt also schon die große Riemenscheibe fertig herum.



**Ballig (wie Faß):**  
Riemen läuft stets zur dicksten Stelle, also zur Mitte. Aber: Völlig schlaffer Riemen kann abrutschen.



**Hohl (wie Felge):**  
Riemen läuft zum Rand, klettert daran hoch, Riemenrand zerfetzt oder Riemen läuft ab.

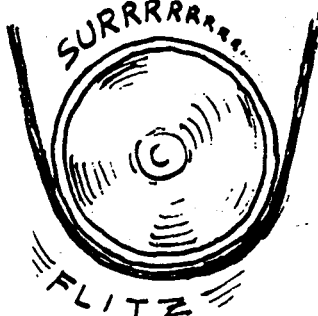
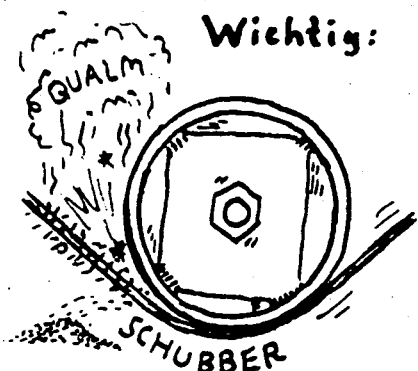


**Ballig mit Randscheiben:** Schlaffer Riemen kann nicht abrutschen. Riemen läuft bei Betrieb zur Mitte, Riemen kann nicht über den Rand klettern.

**Flachriemenscheiben** müssen „ballig“ sein, aber nicht zu stark, sonst liegt der Riemenrand nicht auf und überträgt keine Kraft.

Räder von französischen Autos sind oft besonders günstig, sie haben 3 - Loch - Felgen, passend zu 3-Flügel-Repellern. Raddurchmesser bis ca. 1/5 vom Repeller - Ø. Achse stark genug für den Repeller! Für große Repeller reichen große PKW-Räder nicht, z. B. mußte ich für das 4m Ø-Windrad die Achse von einem landwirtschaftlichen Anhänger nehmen (war Vierkantstahl 4 x 4cm massiv). Richtwert: Achs - Ø mindestens 1/100 Repeller - Ø, s.S. 19.

Die kleine Riemenscheibe allerdings müssen wir selbst machen. Nicht schwierig, denn sie braucht nicht einmal exakt rund zu sein. Die Genauigkeit von alten Wasserrohren reicht. Mit Glück finden wir eine LiMa-Keilriemenscheibe und ein Stück Rohr, was darauf paßt. Zusammenschweißen, fertig. Sonst machen wir sie ganz selber.



Je weiter der Riemen die Scheibe umschlingt, umso mehr Berührfläche, umso mehr Kraft ohne Durchrutschen übertragbar oder umso schlaffer darf der Riemen sein!

**SCHLECHTE ..... GUTE KRAFTÜBERTRAGUNG**

Natürlich überträgt der Riemen umso mehr Kraft, je weiter er die Scheibe umschlingt!

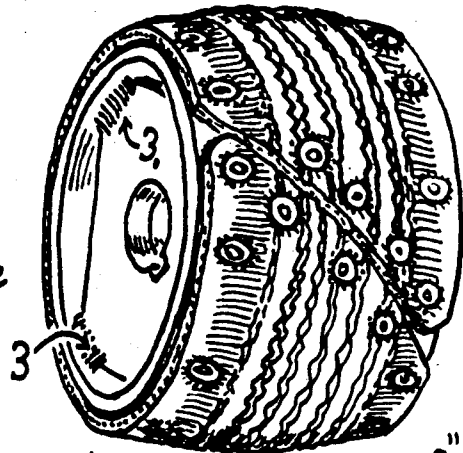
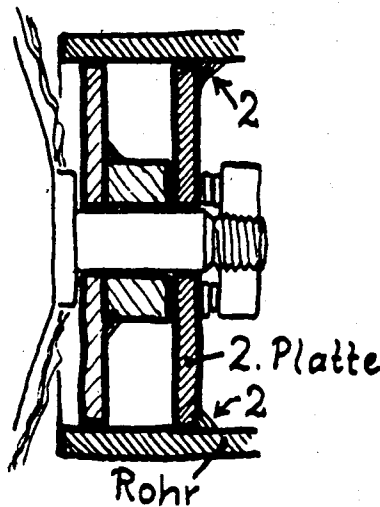
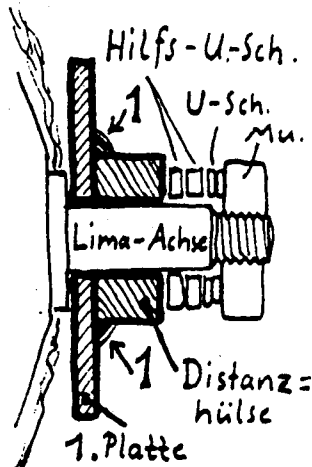
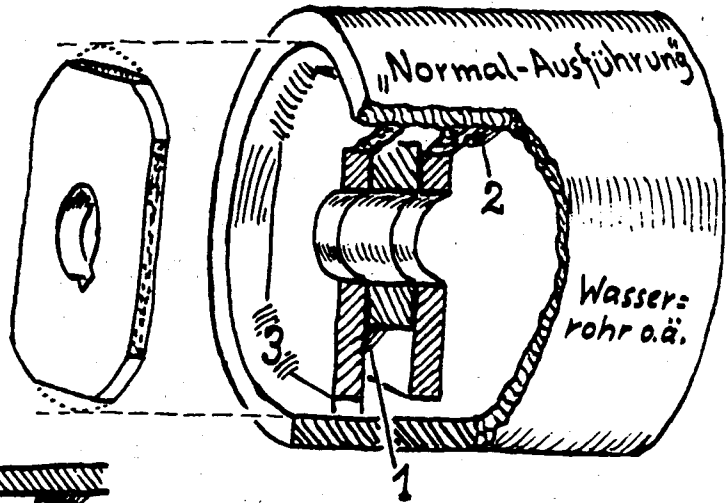
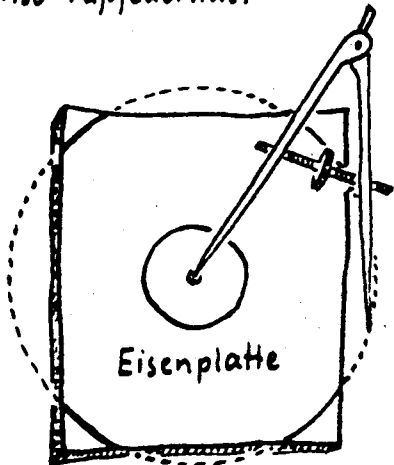
Material: Stück Rohr, Länge 1 cm über Reifen-Laufflächen-Breite. 1 Eisenplatte mind. 8 mm dick, besser 2 Platten 4 - 6 mm dick. Distanzhülse(n) mit Nut für Paßfeder von früherer LiMa - Riemenscheiben - Befestigung.

### Bau der kleinen Riemenscheibe:

Lima-Achs- $\phi$  u. Rohr-Innen- $\phi$  exakt anzeichnen, Achsloch bohren & genau passend feilen, ebenso Paßfedernut.

Ecken absägen/feilen, stramm passend ins Rohr.

So zusammensetzen (1,2,3 = Schweiß-Reihenfolge. Distanzhülse möglichst lang, aber Platten müssen noch voll auf dem glatten Stück Achse sitzen!)



Abdeckung? Lima unbedingt z.B. mit nasser Pappe gegen hereinfliegende Funken schützen!

„Höchstlast-Ausführung“ mit Gummiauflage -

1. Platte u. Distanzhülse auf Lima-Achse, Mutter fest!, Naht 1 stückweise schweißen. Hilfs-U-Sch. weg, 2. Platte drauf, Mutter fest, Rohr draufstecken, prüfen, ob nicht eiert, Heftpunkte bei 2, nochmal prüfen, Nähte 2. Mutter ab, alles von Lima abziehen, möglichst nichts verwackeln, statt Limaachse Schraube durch, Heftpunkte bei 3. Wieder auf Lima, Lauf prüfen, evtl. nachbessern, Nähte 3 schweißen. Eiern um ca. 1mm macht nichts.

- falls Riemen bei Vollast rutscht, von altem Fahrrad- oder Schubkarrenreifen Streifen ums Rohr, mit „Popnieten“ fest. Nieten nicht vorstehend, Fuge schräg. Oder Stück ganz großen Kühlerschlauch (Rarität) draufschieben.

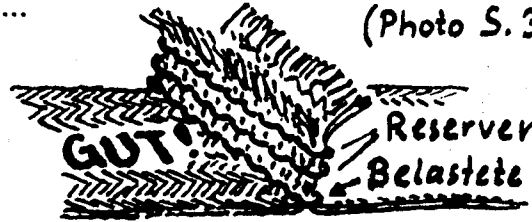
Als Treibriemen dient kein uralt - steifer Transmissionsriemen, sondern ein superleicht biegsamer und dennoch äußerst zugfester Auto - Sicherheitsgurt, aus wetterfestem Kunstfasergewebe, überall im Schrott zu finden. Die Verbindungsnaht nähen wir sorgfältig mit Kunstfaser - Nähgarn und die auf den ersten Blick schlechtere Art ist die wesentlich bessere: hier zerrt zwar alle Last an einer Naht, aber die können wir beliebig kräftig nähen und die Fäden laufen nie auf der Riemenscheibe. Sollte sie dennoch reißen, sind noch die Reservenähte da. Der Riemen wird zwar vielleicht 1 cm lockerer, aber das Windrad läuft weiter....

(Photo S. 32)



Nähte wetzen durch!

Stufe stoppt beim Anlauf!

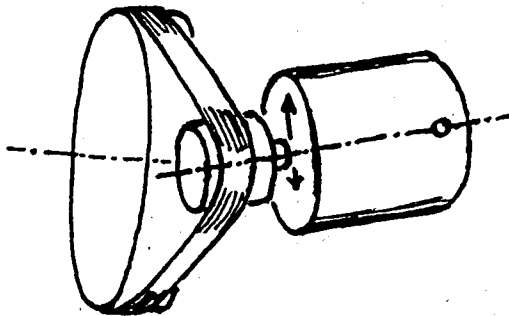


Reservenähte Belastete Naht

Läuft ohne Stocken!

Beim Flachriemenantrieb sehr wichtig: Beide Achsen genau parallel zueinander einstellbar, sonst läuft der Riemen immer zum Rand der Riemenscheibe und leicht ab, Riemen spannen nützt nichts. Daher schraube den Generator in 2 um 90° versetzten Langlöchern fest:

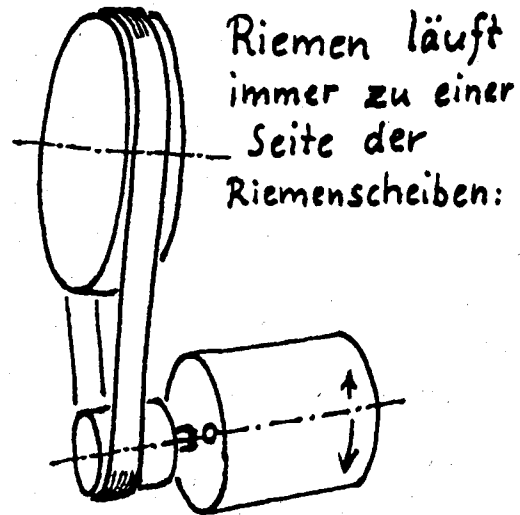
**Von unten gesehen:**



Riemen läuft je nach Drehrichtung zum einen oder anderen Rand der Riemenscheiben:

Ausrichten quer zum Riemenzug nötig, Einstellmöglichkeit zweckmäßig auf der Riemen-seite.

**von der Seite gesehen:**



Ausrichten längs zum Riemenzug nötig, Einstellmöglichkeit auf der riemenabgewandten Seite, weil stabiler und weniger störend für die Riemen-spannung.

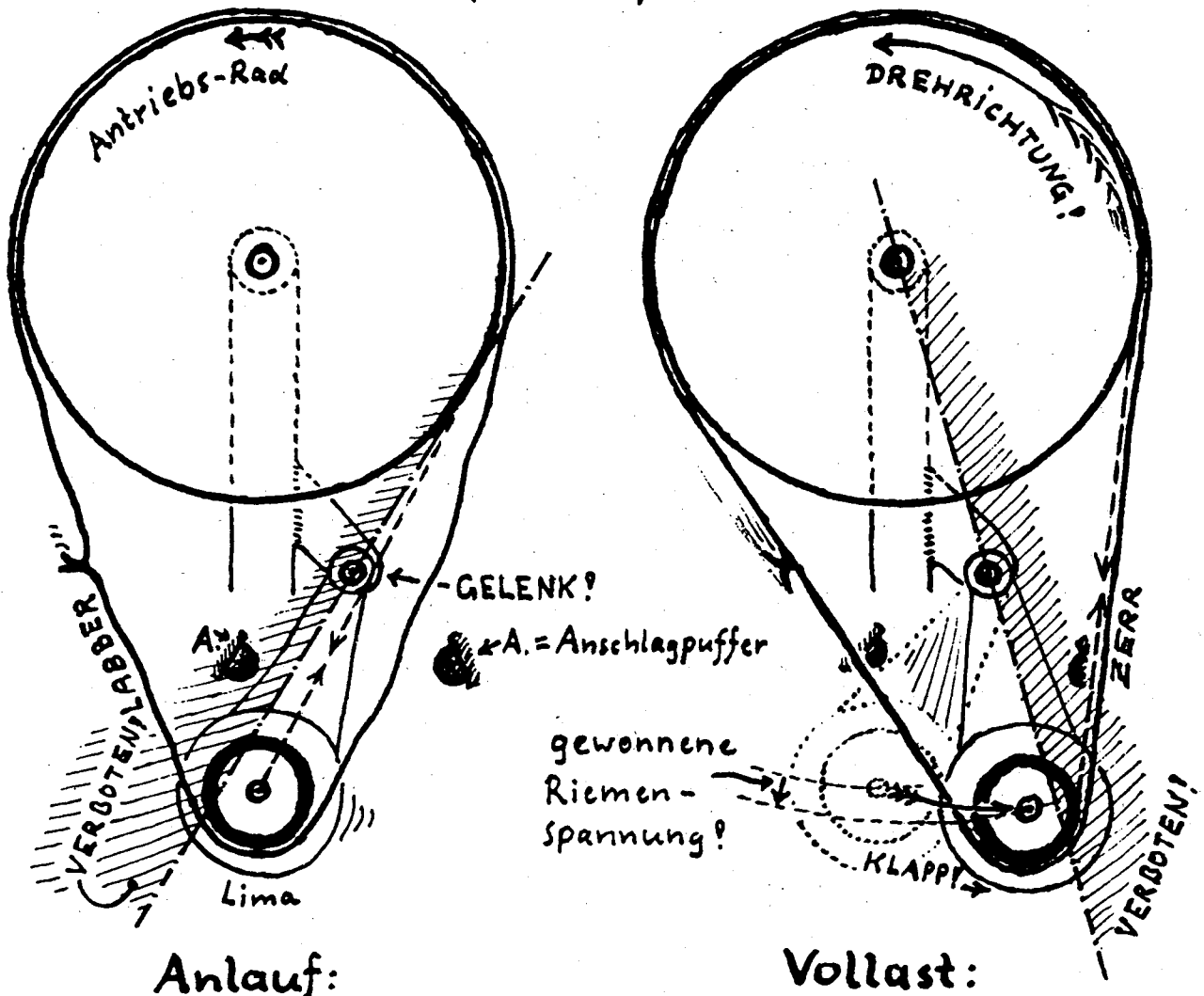
**Parallel- Ausrichten der Riemenscheiben!**

Ein Autosicherheitsgurt als Flachriemen ist zwar so ziemlich der leichtgängigste mögliche Treibriemen, aber wenn er so stramm gespannt ist, daß er bei Vollast nicht durchrutscht, ist die Reibung doch so hoch, daß das Windrad bei zum Ladebeginn ausreichendem Schwachwind nicht anläuft. Darum baue an Standorten mit eher schwachem Wind auf jeden Fall eine Riemen-spann-Automatik. Die funktioniert so (s. Zeichnung): Die LiMa ist pendelnd aufgehängt und kann zwischen den beiden verbotenen Bereichen hin- und herschwenken.

# So funktioniert die Riemen-Spann-o-matik:

29

(Photo S.32)



## Anlauf:

LiMa spannt den Riemen nur durch Eigengewicht. Riemenzug zieht zwischen Radlaufläche und LiMa-Achse, weil LiMa noch unmagnetisiert, also ganz leichtgängig ist.

Anschlagpuffer so, daß LiMa-Achse nicht über die Verbindungslinie Radlaufläche-Gelenk schwenken kann, sonst klappt der Riemenzug die LiMa falschrum!

## Vollast:

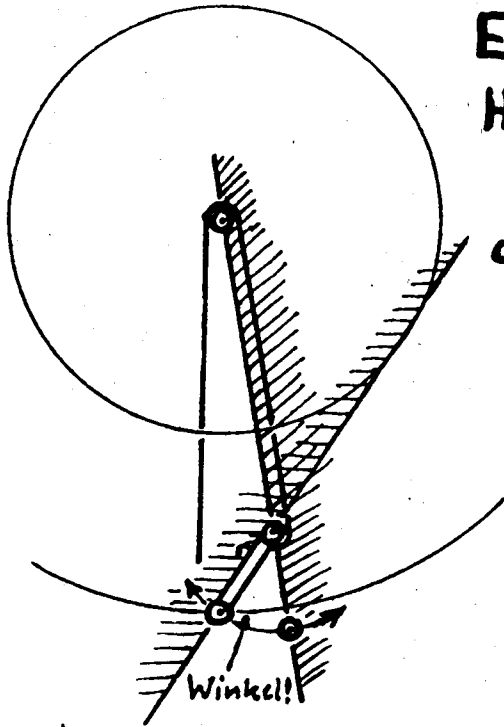
Riemenzug zieht zwischen Radlaufläche und LiMa-Riemenscheibenufläche, weil LiMa arbeitet, also schwer läuft. Dadurch klappt LiMa so, daß sich die Linie Radnabe-Gelenk-LiMa-Achse streckt, also der Riemen spannt. Hier Anschlagpuffer, weiter darf die LiMa nicht. Riemen würde da wieder lockerer!

Machst Du Dir die Funktion klar, merkst Du: auf dem ersten Stück des Schwenkens von Pos. Anlauf zu Pos. Last wird der Riemen am meisten gespannt, also muß hier das Eigengewicht der LiMa mithelfen. Aber die LiMa muß auch durch ihr Eigengewicht aus der Stellung Vollast heraus wieder zurückfallen, sonst bleibt der Riemen stramm, auch wenn das Windrad stillsteht.

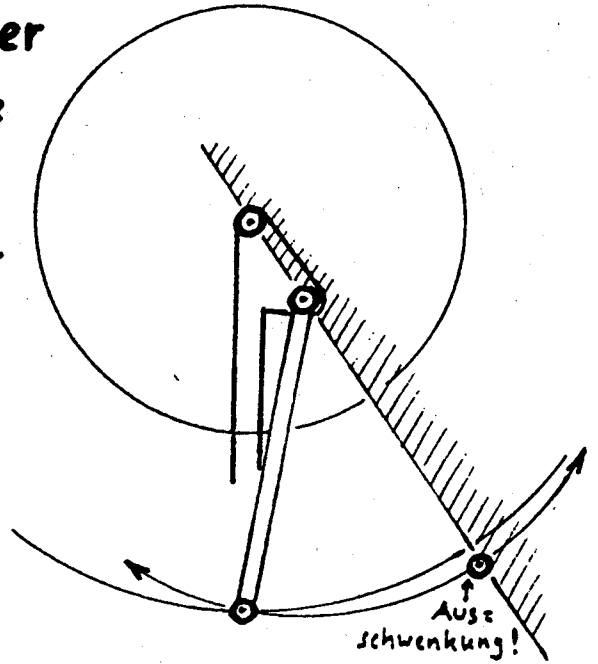
Setzt Du das Pendelgelenk zu nahe an die LiMa, kann ihr Eigengewicht gut mitarbeiten, aber die Riemenspannbewegung beginnt in ungünstig großem Winkel zum Radius um die Radachse, also reicht die Kraft zum Spannen nicht aus.

Setzt Du das Pendelgelenk zu nahe an die Rad - Achse, ist der Bewegungswinkel zwar sehr günstig, aber die LiMa muß für gleichen Spann - Effekt sehr weit ausschwenken (gegen ihr Eigengewicht!), erreicht also nur schwer Stellung Vollast, d.h. Riemen rutscht bei hoher Last durch.

# Einfluß der Hebel-Länge und Lage des Gelenks.



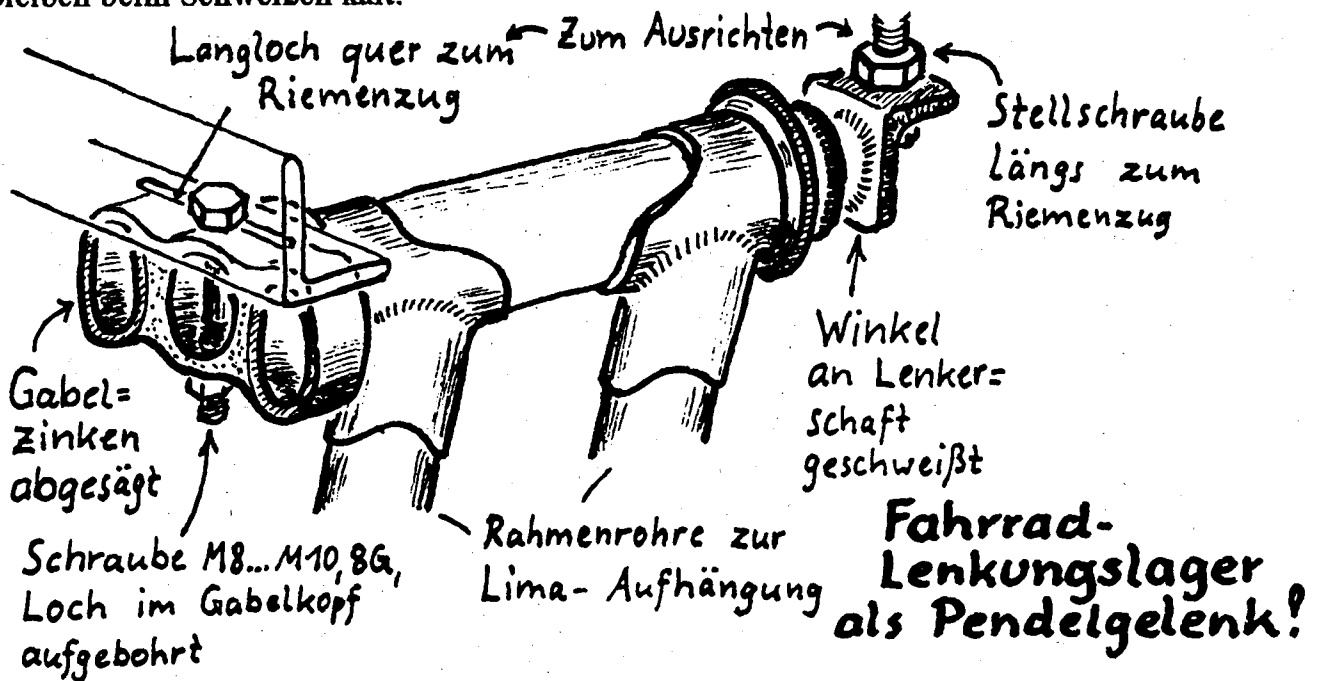
extrem kurzer Hebel



extrem langer Hebel bei gleichem Riemen-Spann-Effekt

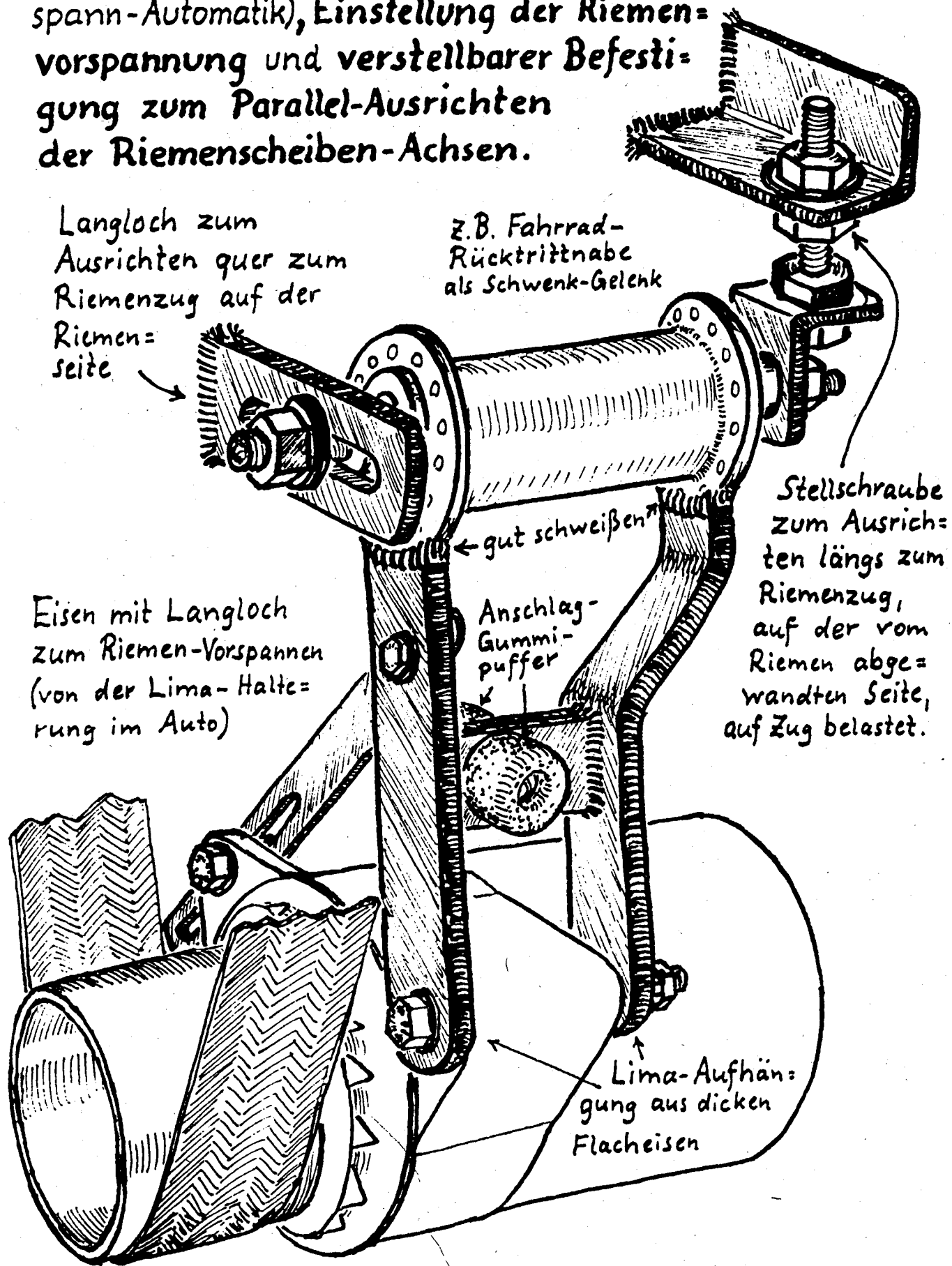
Pendelgelenk etwa in der Mitte zwischen Rad - Achse und LiMa ist günstig, etwas näher an der LiMa geht auch. Liegt das Gelenk innerhalb des Umfangs vom Rad (also hinterm Rad), gibt es keinen verbotenen Bereich bei der Anlaufstellung, aber die Verbindung Gelenk - LiMa ist schwieriger zu bauen ( um die Ecke herum). Liegt das Gelenk außerhalb des Radumfangs, läßt sich die LiMa - Aufhängung einfacher und stabiler bauen. Ein Beispiel: (S.31)

Für größere Windräder oder wenn das Pendelgelenk hinterm Autorad liegt, läßt sich ein altes Fahrradlenkungs-lager gut als Pendelgelenk einbauen: hierbei sind alle Lagerteile auswechselbar und bleiben beim Schweißen kalt.



Besonders einfach zu montieren ist eine alte Fahrrad-Rücktrittnabe als Gelenk. Der Stahl der Nabenhülse ist nicht zum Verschweißen mit Baustahl gedacht (Rißgefahr), geht aber mit einfachem E-Schweißgerät und etwas Sorgfalt. Damit die Lagerflächen möglichst wenig ausglühen, Aufhängung außen an die Speichenflansche schweißen, vorher Innenteil und Lager raus!

# Lima - Aufhängung mit Pendelgelenk (Riemen- spann-Automatik), Einstellung der Riemen- vorspannung und verstellbarer Befesti- gung zum Parallel-Ausrichten der Riemenscheiben-Achsen.



Langloch zum Ausrichten quer zum Riemenzug auf der Riemen-seite

z.B. Fahrrad-Rücktrittnabe als Schwenk-Gelenk

Stellschraube zum Ausrichten längs zum Riemenzug, auf der vom Riemen abgewandten Seite, auf Zug belastet.

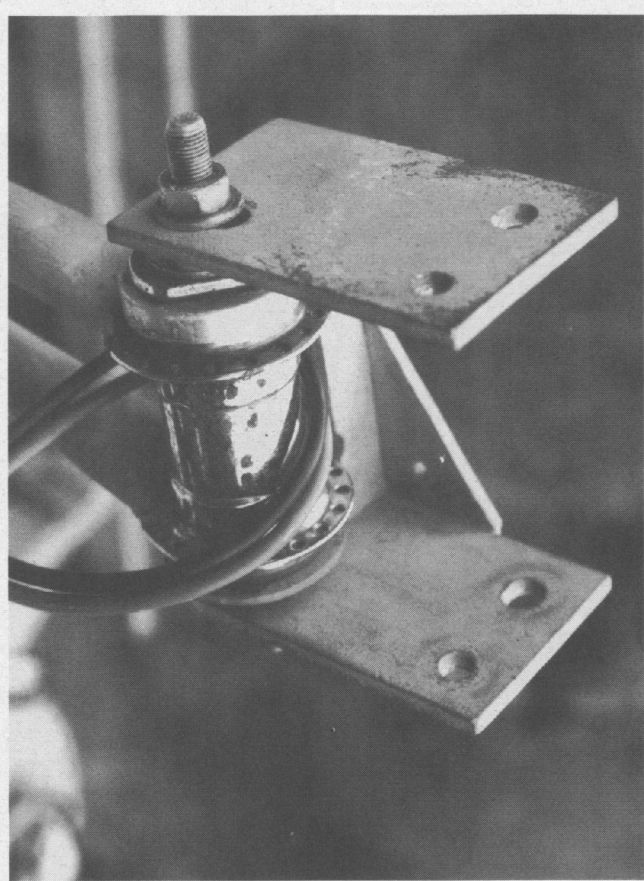
Eisen mit Langloch zum Riemen-Vorspannen (von der Lima-Halterung im Auto)

Anschlag-Gummi-puffer

← gut schweißen

Lima-Aufhängung aus dicken Flacheisen

Beim Bau der LiMa - Aufhängung mit Pendelgelenk achte sorgfältig darauf, daß LiMa - Achse und Gelenk - Achse genau parallel laufen, sonst läuft später der Treibriemen immer schief!

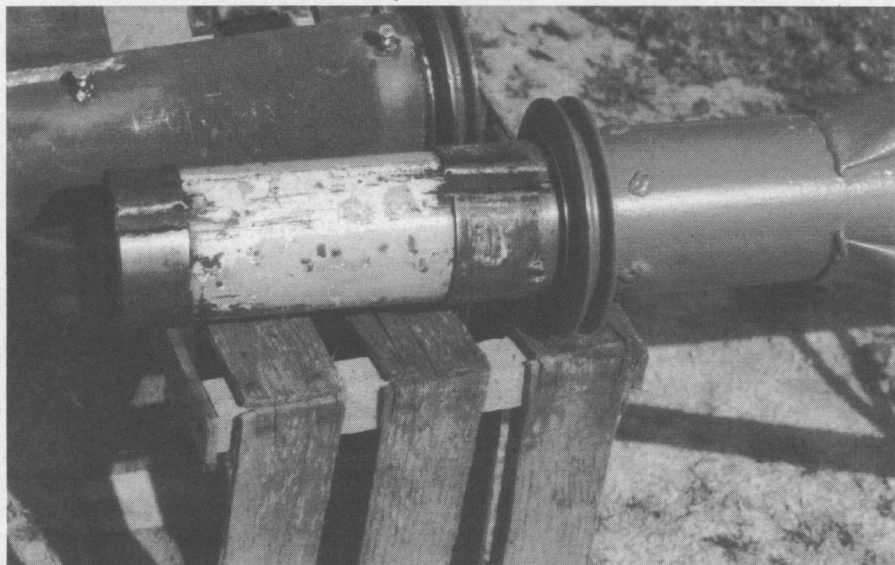


Riemengetriebe: Autorad und vernähter Sicherheitsgurt. Fahrradnabe als Pendelgelenk, Langlöcher zum Ausrichten.



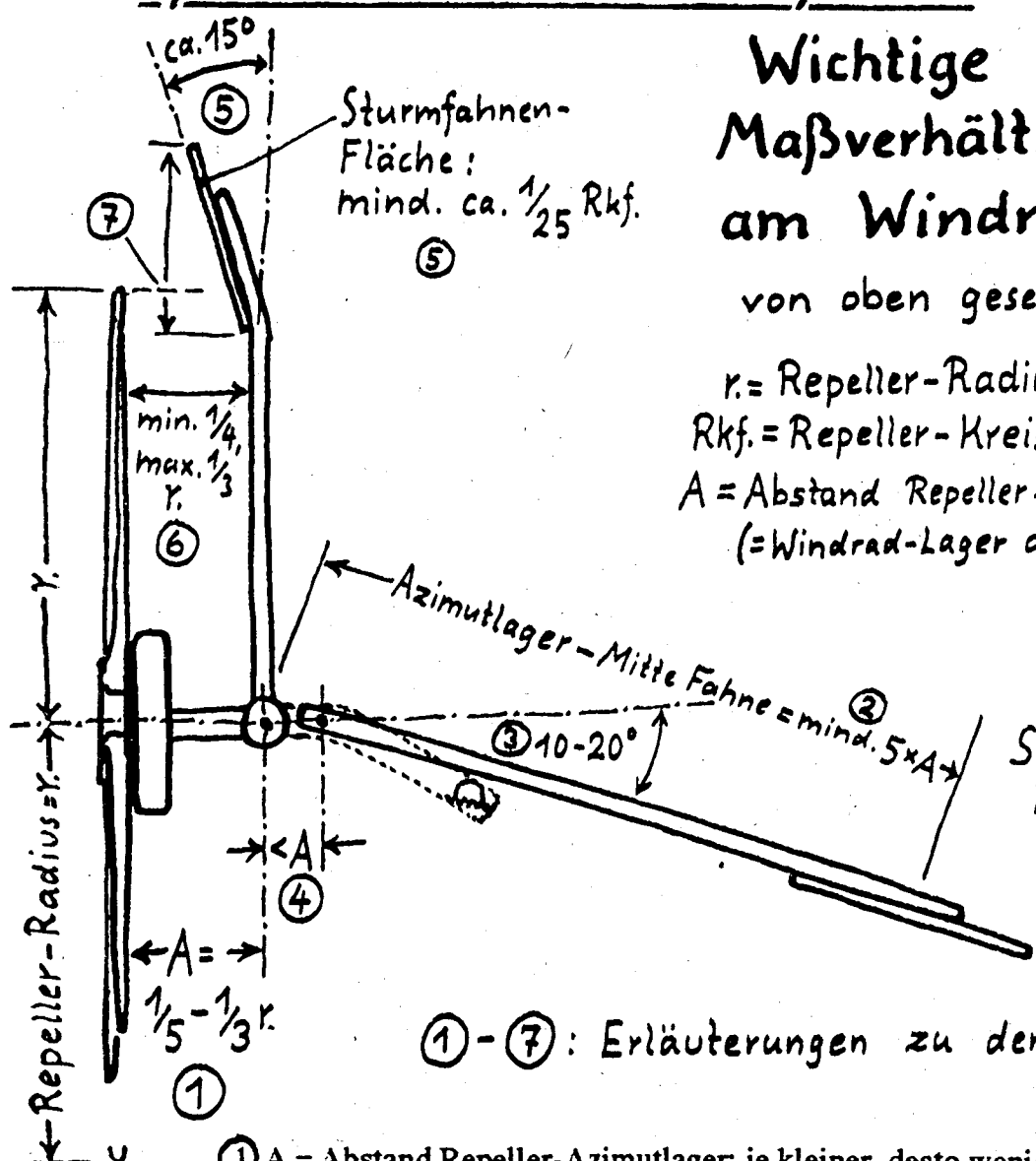


Aus dem vorhandenen Schrott wurde hier der Rahmen (S.43) so. Links Bremszug (S.44), Sturm- und Steuerfahne (S.98) mit Dämpfer u. Seilzug (S.37).



Azimet-Lager (S.40) mit Führungslager-Ringen aus Rohr-Resten, Riemenscheiben als Drucklager-Ringe, zuschraubbaren Schmier-Löchern.

# Die Mechanik: Steuerung, Rahmen, Lager, Bremse für die Bauart mit Seitenfahne.



**Wichtige Maßverhältnisse am Windrad, von oben gesehen.**

$r =$  Repeller-Radius  
 $Rkf. =$  Repeller-Kreisfläche  
 $A =$  Abstand Repeller-Azimuthlager (=Windrad-Lager auf dem Mast)

① - ⑦: Erläuterungen zu den Maßen, s.u.

①  $A =$  Abstand Repeller-Azimuthlager: je kleiner, desto weniger Kraft ist zum Steuern nötig (kleinere Fahne und kürzerer Holm sind möglich).

Aber: Repeller nahe am Mastrohr gibt "Flapp-Flapp" - Laufgeräusche.

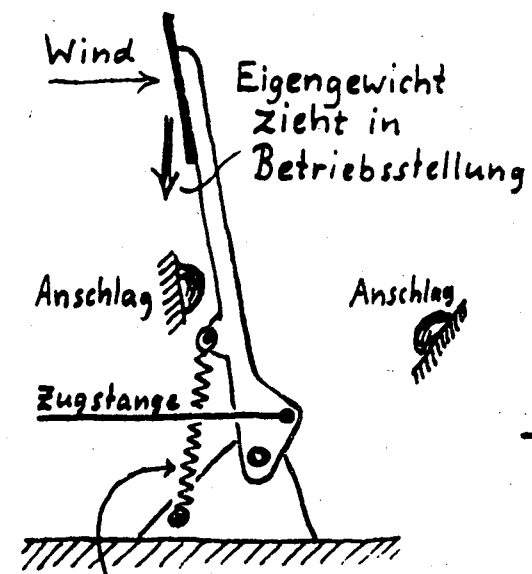
- ② Fahnenholm länger: steuert besser.
- ③ Schrägstellung für Gegenkraft zur Sturmfahne. Kürzerer Fahnenholm verlangt größeren Winkel.
- ④ Schwenklager weiter weg von Azimuthlager spart Fahnenholmlänge, beweglicher Teil leichter. Nachteil: Hebelkraft zum Ziehen der Trommelbremse schwächer, Aus-dem-Wind-drehen unzuverlässiger. Daher kleiner als  $A$ !
- ⑤ Nicht schräg gestellte Sturmfahne schlecht, aber möglich, muß dann größer sein.
- ⑥ Mindestabstand: sonst Windstau vor der Sturmfahne in der Repellerströmung (Flapp-Geräusche). Höchstabstand: Sonst Aus-dem-Wind-drehen unzuverlässig.
- ⑦ Sturmfahne ca.  $\frac{1}{3}$  im Repeller-Windschatten: ungebremst laufender Repeller (z.B. Riemen ab, elektrischer Defekt) läßt Wind fast unvermindert durch, Sturmfahne wirkt dann schon bei starkem Wind.

# Steuerung und Sturmsicherung

Eine einfache Methode ist eine starre Seitenfahne (die das Windrad bei Sturm aus dem Wind dreht) und eine schwenkbare Steuerfahne (die dann seitlich wegklappt). Prinzipiell ist Aus-dem-Wind-drehen nicht ideal, weil dabei starke Kreiselkräfte am Repeller entstehen. Doch Radlager und übrige Konstruktion halten es problemlos aus, die Methode hat sich viele Jahre gut bewährt.

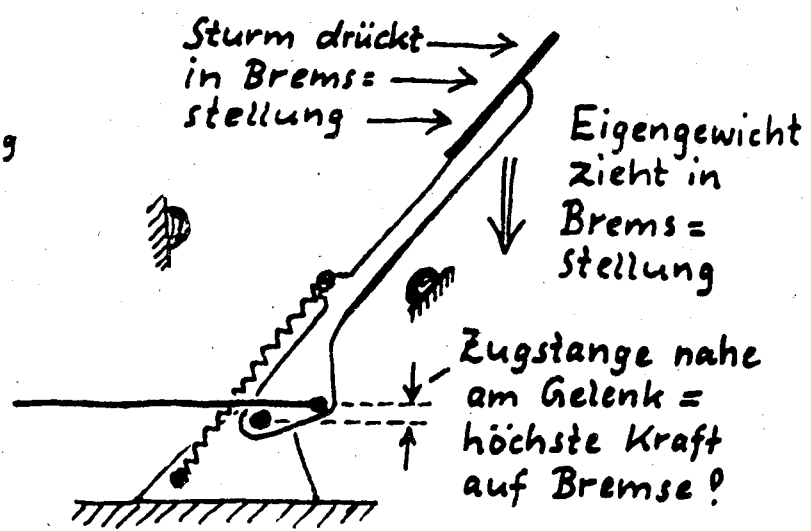
Andere Methoden wären die "Helikopter - Sicherung" (Klappen des Windrades nach oben). Hierbei entstehen aber auch Kreiselkräfte, und in hochgeklappter Stellung kann der Treibriemen zu leicht ablaufen!

Eine gute Möglichkeit ohne Kreiselkräfte wäre eine starre Steuerfahne und eine bewegliche Sturm-fahne, die das Windrad aber nicht aus dem Wind dreht, sondern die hier vorhandene starke Autoradbremse betätigt und so das Windrad stilllegt. Prinzipskizze hier, Nachbauplan erst, wenn ich genügend Erfahrung damit habe.



Rückstellfeder zieht in günstigem Winkel, also stark in Betriebsstellung.

"Überkipp-Mechanik"?



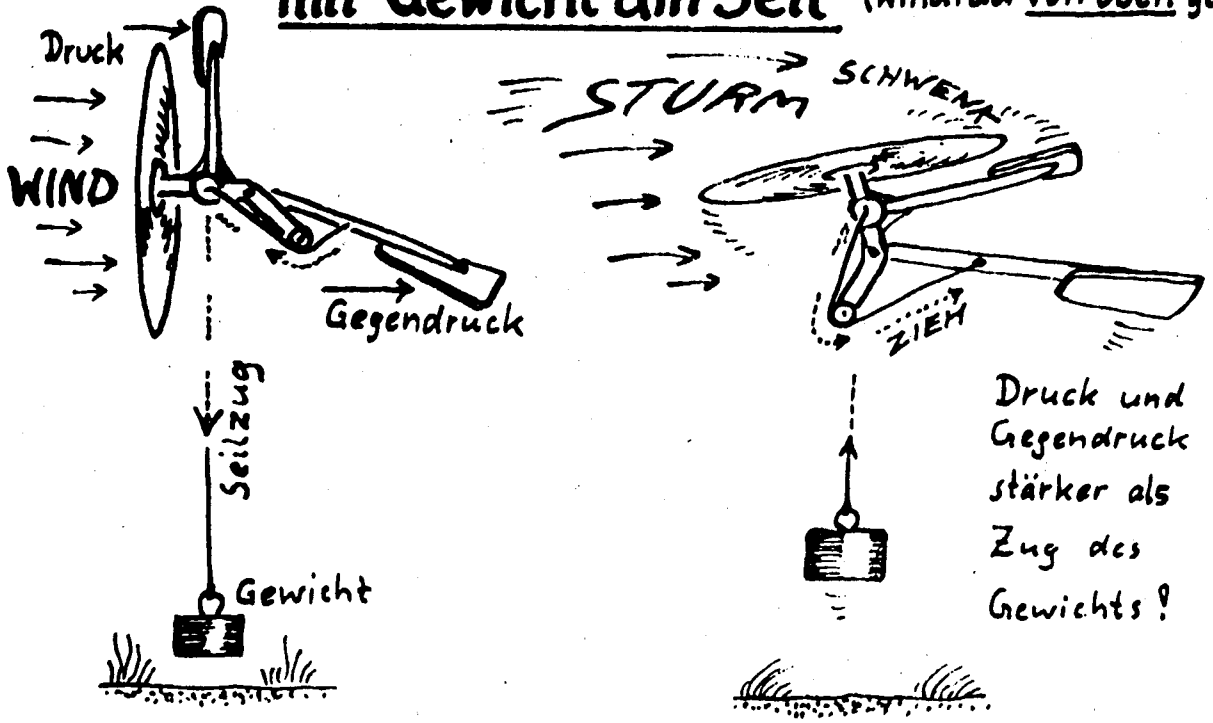
Rückstellfeder stramm, aber ungünstiger Winkel, wirkt kaum. So spannen, daß erst bei wenig Wind wieder in Betriebsstellung zurückklappt, nicht schon bei "Windlöchern" im Sturm.

## Nach oben stehende Sturm-fahne zieht Bremse.

Die einfachste Bauart der Seitenfahnen - Sturmsicherung ist hier so: Sturm-fahne (Seitenfahne) starr über den Repeller - Drehkreis herausstehend. Steuerfahne über ein Zugseil in den Wind gehalten, das über Rollen nach unten führt, wo Gewichte dranhängen. Gewichte so dosieren, daß Sturm sie hochziehen kann. Autoradbremse mit der Steuerfahne verbinden, daß bei Sturm das Windrad zusätzlich festgebremst wird. (Zeichnung S.44).

Schwachpunkt dieser Seilzugmechanik ist, daß sie versagt, wenn das Seil blockiert ist. Früher habe ich gelegentlich Bowdenzüge verwendet und darin blockierte Seile erlebt, daher lieber die Mechanik mit Rückstellfeder statt Zugseil aufgebaut (s. Einband und S. 71). Die funktioniert immer, auch wenn das Seil blockiert, hat aber andere Schwachpunkte: Rückstellfeder muß mühsam einjustiert werden, ist aber durch Gewichtskraft (schräge Schwenkachse) ersetzbar. Bremsseil kann als Schlaufe runterhängen und muß von Repeller und Riemen ferngehalten werden.

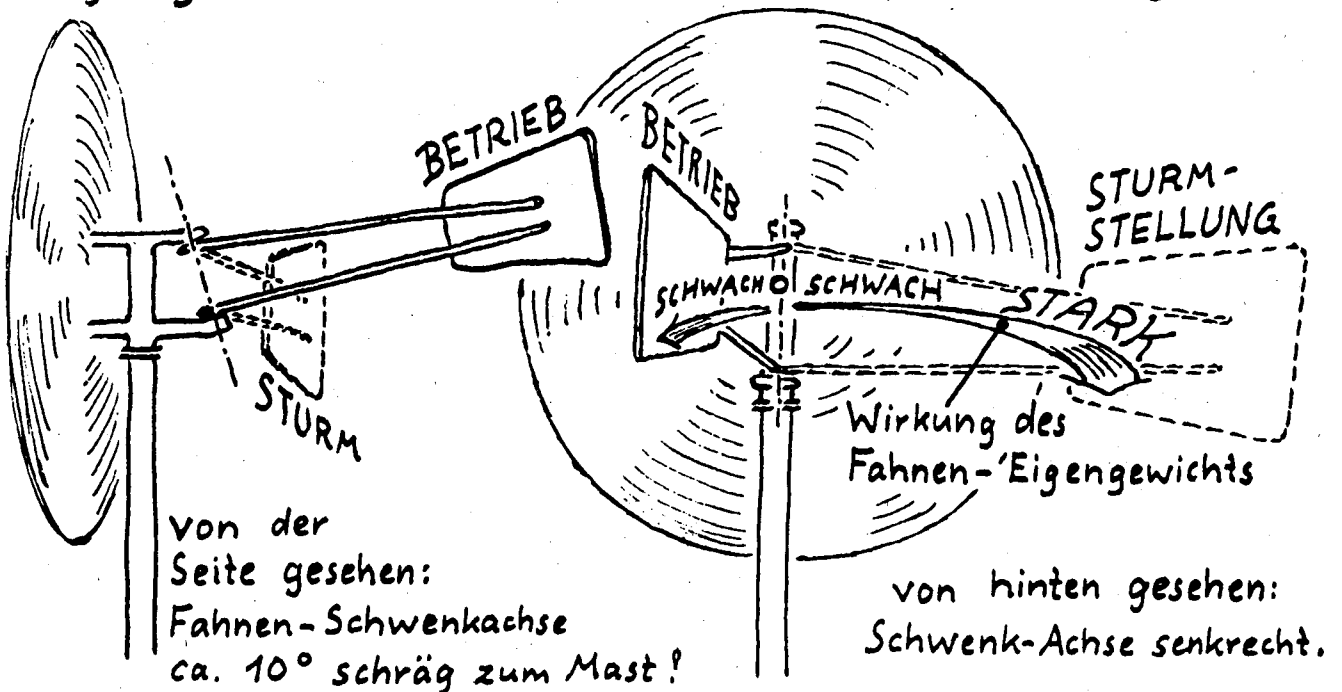
# Funktion der Seitenfahnen-Sturmsicherung mit Gewicht am Seil (Windrad von oben gesehen)



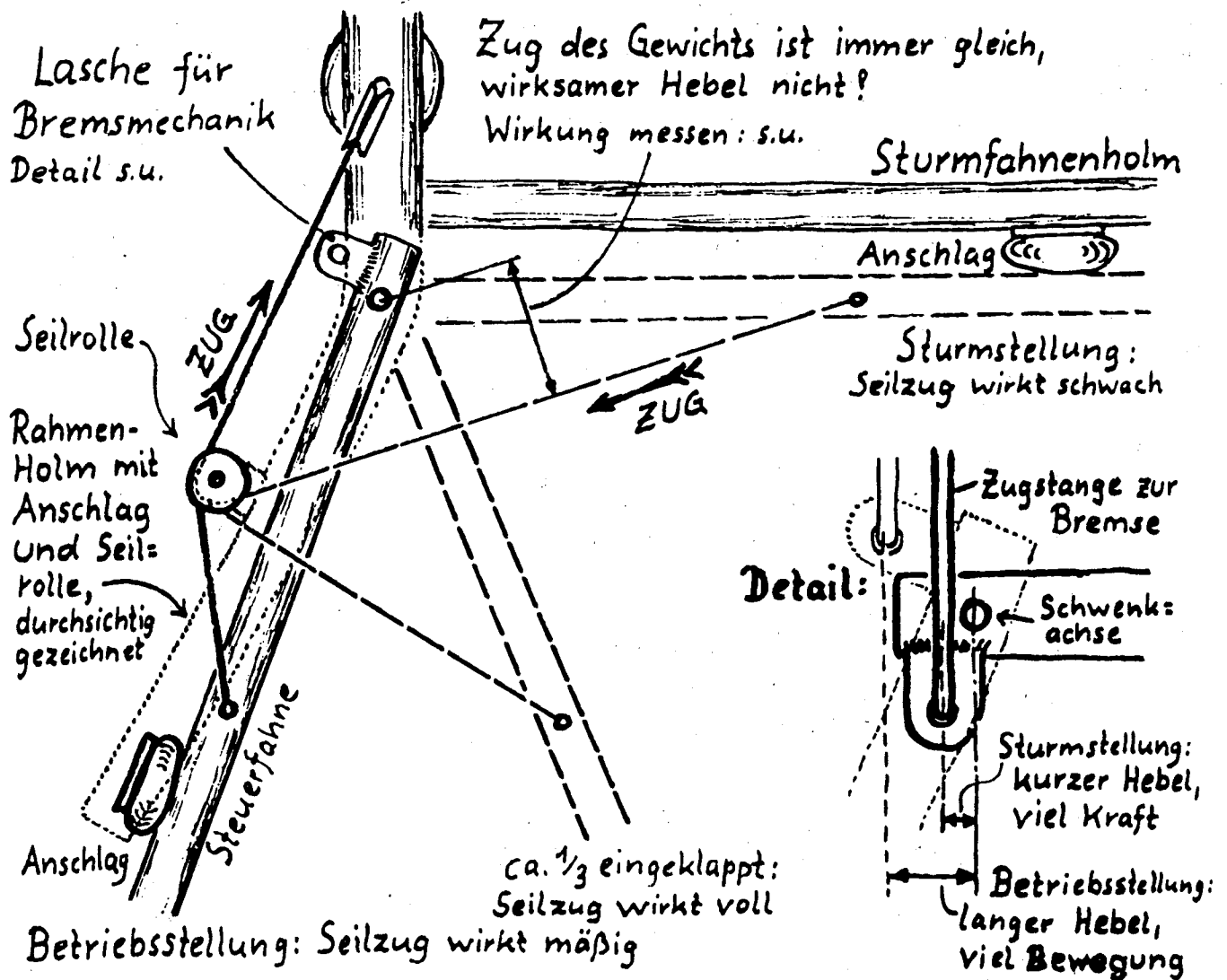
Feinheiten:

- Seil so führen, daß Zug bei Betriebsstellung mittel, in ca. 1/3 eingeklappter Stellung stark (günstigster Zugwinkel), in Sturmstellung schwach (ungünstiger Zugwinkel). Zusätzlich
- Schwenkachse der Steuerfahne schräg stellen, so daß ihr Eigengewicht die Fahne in Sturmstellung zieht. Sinn: Bei starken Windböen soll das Windrad nur etwas aus dem Wind drehen (verringerte Angriffsfläche), aber wieder voll in den Wind zurückschwenken. Nur Sturm soll es schaffen, den Punkt mit stärkstem Seilzug zu überwinden, damit das Windrad weggeschwenkt wird und bleibt, bis der Sturm nachläßt.

**Steuerfahnen-Schwenkachse schräg: Eigengewicht wirkt in Richtung Sturmstellung.**



- Zum Stilllegen von Hand Gewicht vom Seil abhängen: Steuerfahne klappt durch Eigengewicht in Sturmstellung und zieht die Bremse.
- Steht die Schwenkachse der Steuerfahne senkrecht, Gewichtskraft durch Zugfeder ersetzen.
- Sturmflahne etwas abwinkeln, damit der Wind Sturm- und Steuerflahne auch in Sturmstellung noch zusammendrückt und dadurch die Bremse angezogen hält. Das Eigengewicht der Steuerflahne an der schrägen Schwenkachse hilft auch dabei.
- Steuerflahne etwas schräg stehend in Betriebsstellung, damit sie die Gegenkraft der Seitenflahne ausgleicht, sonst läuft das Windrad immer schief im Wind (falsche Anströmung, Leistungsverlust, Geräusche, Bild S.42)
- In beiden Endstellungen ein weicher Anschlagpuffer (evtl. von Autofederungen, sonst Tennisball), besonders gut und bei größeren Windrädern wichtig: ein Autostoßdämpfer zwischen den Fahnen gegen zu schnelle Schwenkbewegung, er mindert Kreiselkräfte erheblich und vermeidet harten Anschlag.

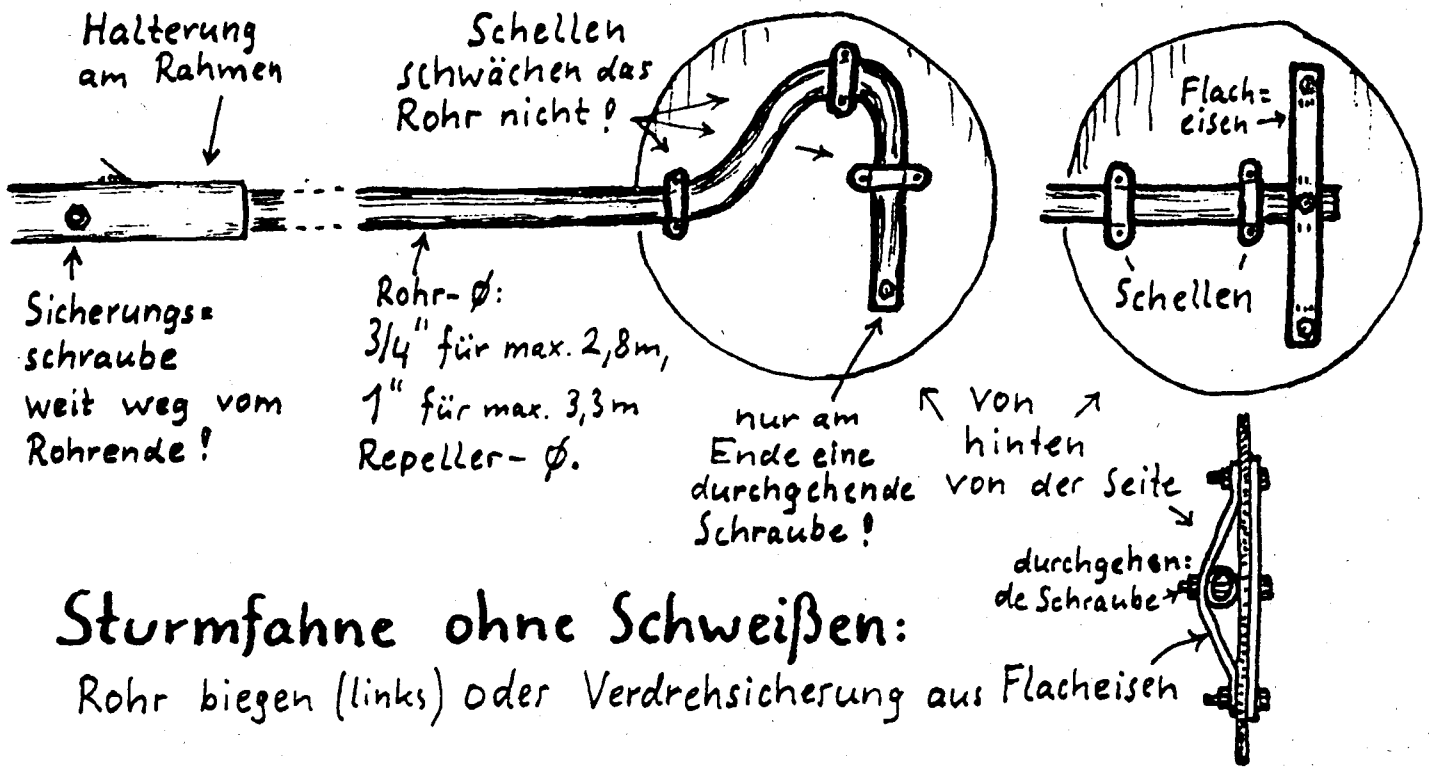


## Seilführung und Hebelwirkungen an der Sturmsicherung.

Zugkraft an Maßzeichnung ablesen: von der Linie, in der das Seil von Rolle zur Fahne läuft, miß im rechten Winkel den Abstand zum Gelenk. Maß am längsten = volle Kraft des Gewichts wirkt an der Steuerflahne. Maß kürzer: Kraft entsprechend verringert (aha, Hebelgesetze...)

# Bau-Beispiel für bis ca. 2,8 m Windrad- $\phi$ (größerer $\phi$ $\rightarrow$ stärkere Teile):

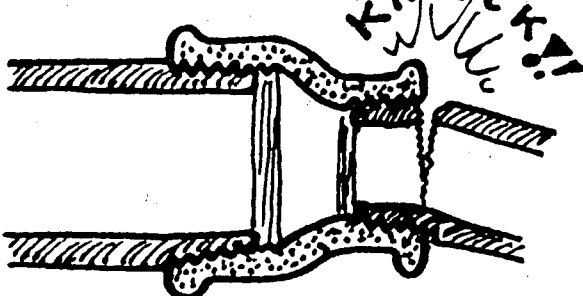
Sturmfahnen - Halterung am Rahmen 1"-Rohr, mind. 30 cm seitlich rausstehend. Sturmfahnen-Holm 3/4"-Rohr, reingesteckt, weit weg von Steckverbindung. Schraube quer durch.



## Sturmfahne ohne Schweißen:

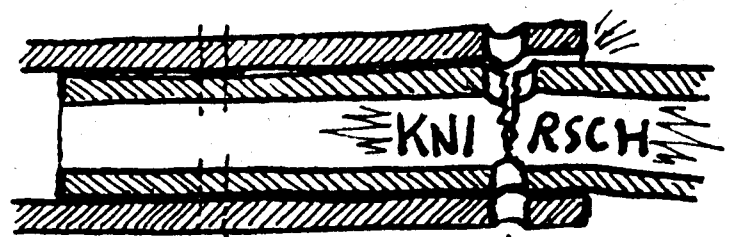
Rohr biegen (links) oder Verdrehsicherung aus Flacheisen

### Rohr-Gewinde:



Ganz schlimm! Gewinde ist Kerbe in höchstbelasteter Zone!

### Gesteckt mit Sicherungsschraube:



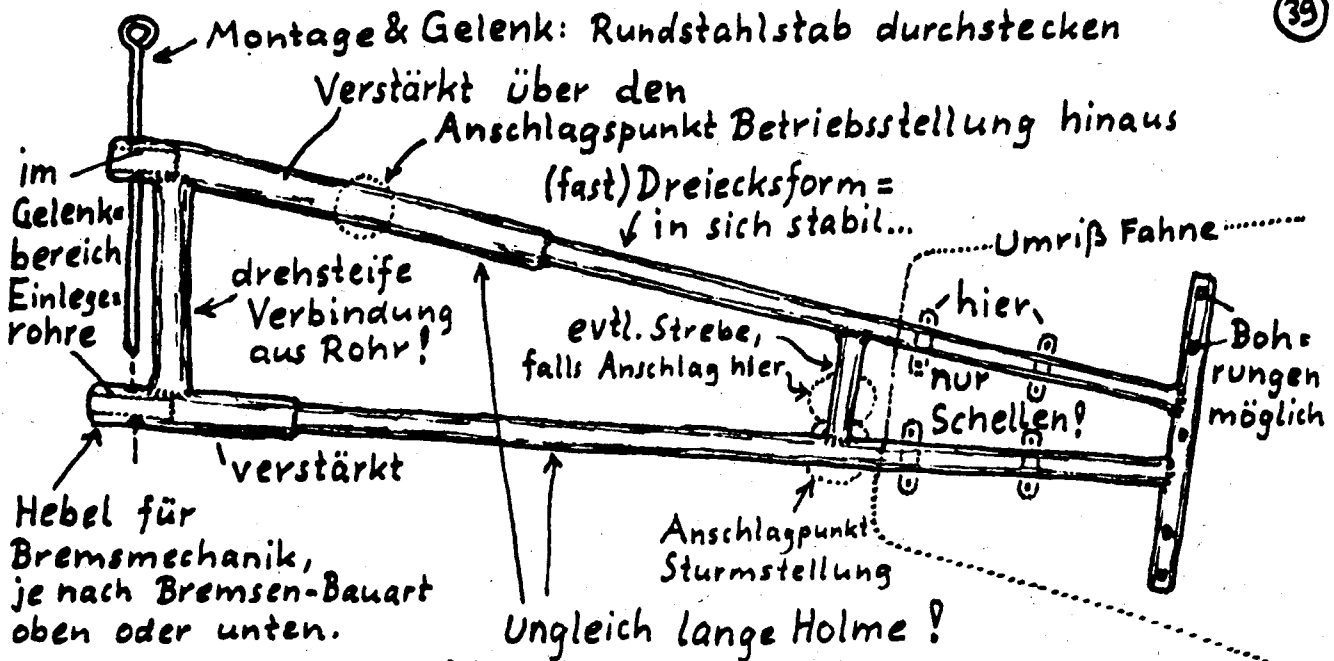
hier harmlos, ehe das dicke Rohr bricht, biegt das dünne.

**FALSCH!** Loch in belasteter Zone!

Anschlagsrohr am Rahmen: 1" weit über die Gelenkbohrung hinaus ins obere Rahmenrohr (1 1/4") gesteckt, anschweißen. Steuerfahnen-Holm trapezförmig aus zwei Rohren 1/2", oberes Rohr vom Schwenkgelenk bis ca. 30 cm über Anschlagpunkt Betriebsstellung hinaus aus 3/4"-Rohr gegen Knickgefahr bei hartem Anschlag. Unten kurzes Stück 3/4"-Rohr am Gelenk. Bei den Gelenkbohrungen Einlegerohre 1/2", sonst zu schneller Verschleiß.

Gelenk: Rundeisen 10-12 mm  $\phi$  von oben durchgesteckt. Anschlagpuffer: Tennisbälle in Sicherheitsgurtstücke eingenäht.

Material für die Fahnen: Dünnes, wasserfestes Sperrholz (Betonbauabfall) besser als Blech, dröhnt und scheppert nicht so. Fahnenholme in belasteten Bereichen nicht anbohren, hier Fahne mit Schellen befestigen.

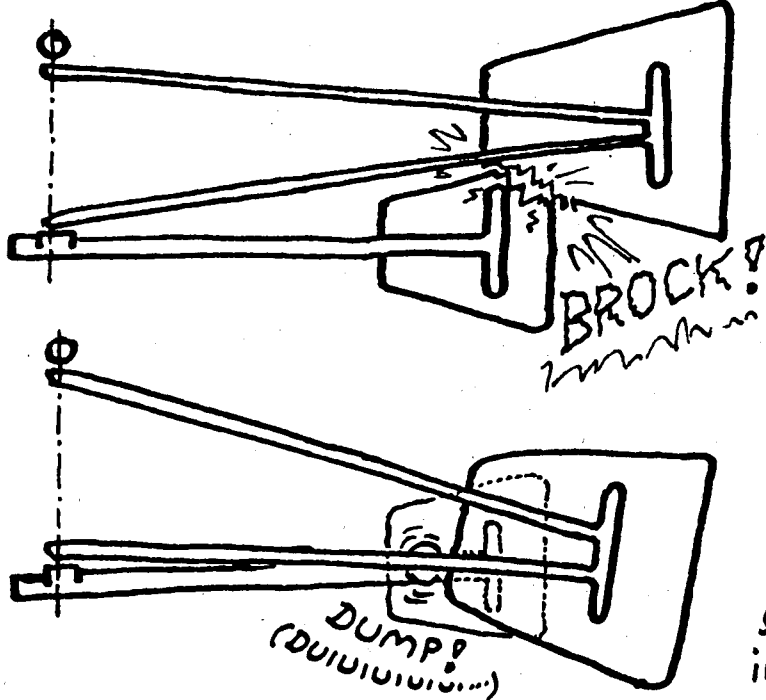


**Steuerfahnen - Konstruktion aus Wasserrohr 1/2",**  
 verstärkte Teile aus Rohr 3/4". Einlegerohre = stramm reingekloppelte  
 Rohrstücke 1/2", gegen ausleiernde Gelenk-Bohrungen. Stab in Steuer-  
 fahne drehbar, im Rahmen nicht (fixieren)! Sonst Verschleiß am nicht  
 auswechselbaren Teil. **Passend für Rahmenform s. S.43 mit**  
**unten reingesteckter Sturmflanze.**

(Für Windrad-Ø über ca. 2,8 m: 3/4"- und 1"-Rohr nehmen.)

Form des Steuerfahnen - Holmes so, daß in Sturmstellung Holm gegen Holm schlägt, nie Fahne gegen Fahne (Bruchgefahr!).

**Anschlag in Sturmstellung: nie Fahne gegen Fahne!**



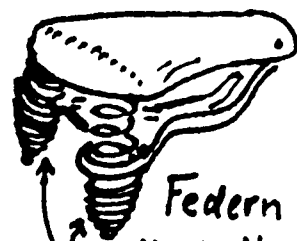
**Gefahr!**  
 Bei Bruch kommt Steuerfahne in den Repeller-Drehkreis: Total-Selbstzerstörung!

**Anschlag Holm an Holm: sicher!**  
 Gummipuffer dämpft. Steuerfahne mit ungleich langen Holmen steht wegen schräger Schwenkachse in Betriebsstellung gerade.

Verwendest Du statt der Gewichtskraft durch schräge Schwenkachse Zugfedern (z.B. von alten Fahrradsätteln oder Bettgestellen), Drahtseil durch alle Federn fädeln, sonst bei Federbruch Folgeschäden! Elegant als Feder: alter Türschließer (leider selten im Schrott). Hat zusätzlich eingebauten Dämpfer!



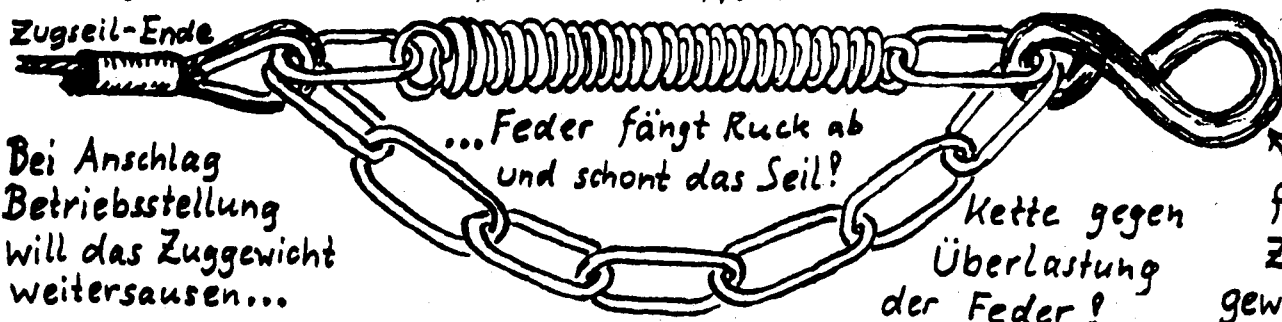
↑ Sicherheits-Seil, durch alle Federn gefädelt und an Steuer- und Sturmflanze fest, in Betriebsstellung noch nicht ganz stramm: Kein Unfall bei Federbruch!



Federn von alten Tourenrad-sätteln: gut!

Für große Windräder: „Ruck-Dämpfer“?

Zugseil-Ende



Bei Anschlag Betriebsstellung will das Zuggewicht weitersausen...

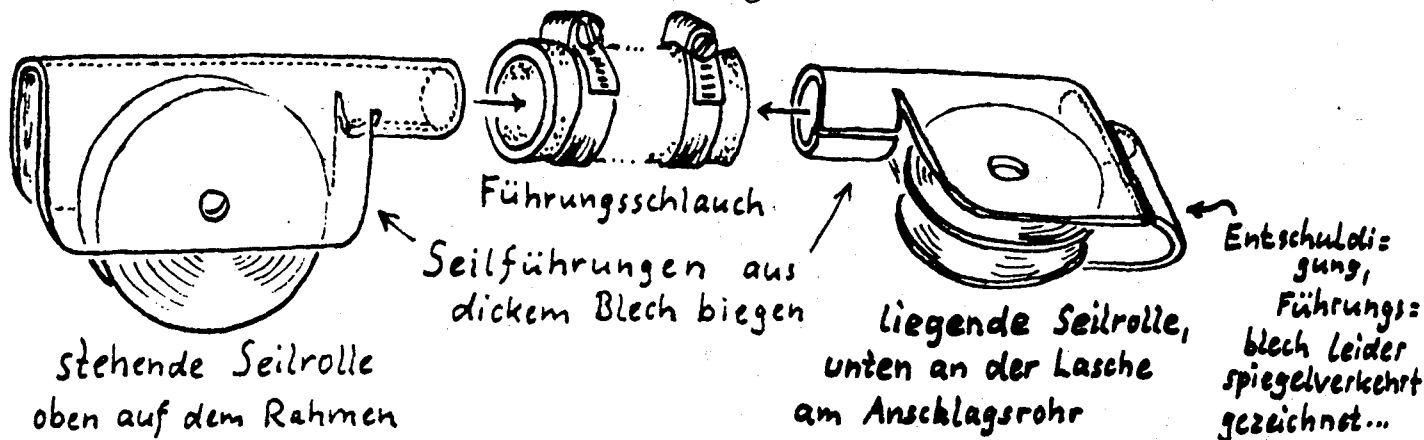
...Feder fängt Ruck ab und schont das Seil!

Kette gegen Überlastung der Feder!

Öse fürs Zuggewicht

Auf keinen Fall darf ein Teil (z.B. losgehauene Steuerflanze oder gerissene Feder) in den Repellerdrehkreis kommen: Sofortige Selbstzerstörung des Windrades mit bösen Folgen!

Besonders gutes Zugseil: Niro-Seil z.B. vom Seglerbedarf.



stehende Seilrolle oben auf dem Rahmen

Führungsschlauch  
Seilführungen aus dickem Blech biegen

liegende Seilrolle, unten an der Lasche am Anschlagrohr

Entschuldigung, Führungsblech leider spiegelverkehrt gezeichnet...

Seilführung: Nie im Bowdenzug (wenn festfriert oder-rostet, Sturmsicherung unwirksam!) sondern über Rolle. Seil durch Führungsbleche am Ablaufen hindern. Damit evtl. gerissenes Seil nicht in den Repellerdrehkreis oder Riemen kommt, Führungsschlauch zwischen den Seilrollen.

## Das Azimutlager (=Drehlager des Windrades auf dem Mast)

Zwei ineinandergesteckte dicke Rohre als Gleitlager haben sich bestens bewährt und durch die Rohre können wir bequem Kabel und Bremsseil runterführen. Kugellager o.ä. sind zu leichtgängig! Weil der Wind nahe am Boden nie konstante Richtung hat, würde sich das Windrad dauernd hin- und herdrehen, der Repeller oft im Lauf abgebremst werden und die entstehenden Kreiselmomente alle Teile unnötig belasten. Mit Gleitlager stellt es sich in die momentane Hauptwindrichtung und läuft dann ruhig und fleißig drauflos.

Bei Windrädern um 2,5m Ø kommen wir noch mit einfach ineinandergesteckten Rohren aus,

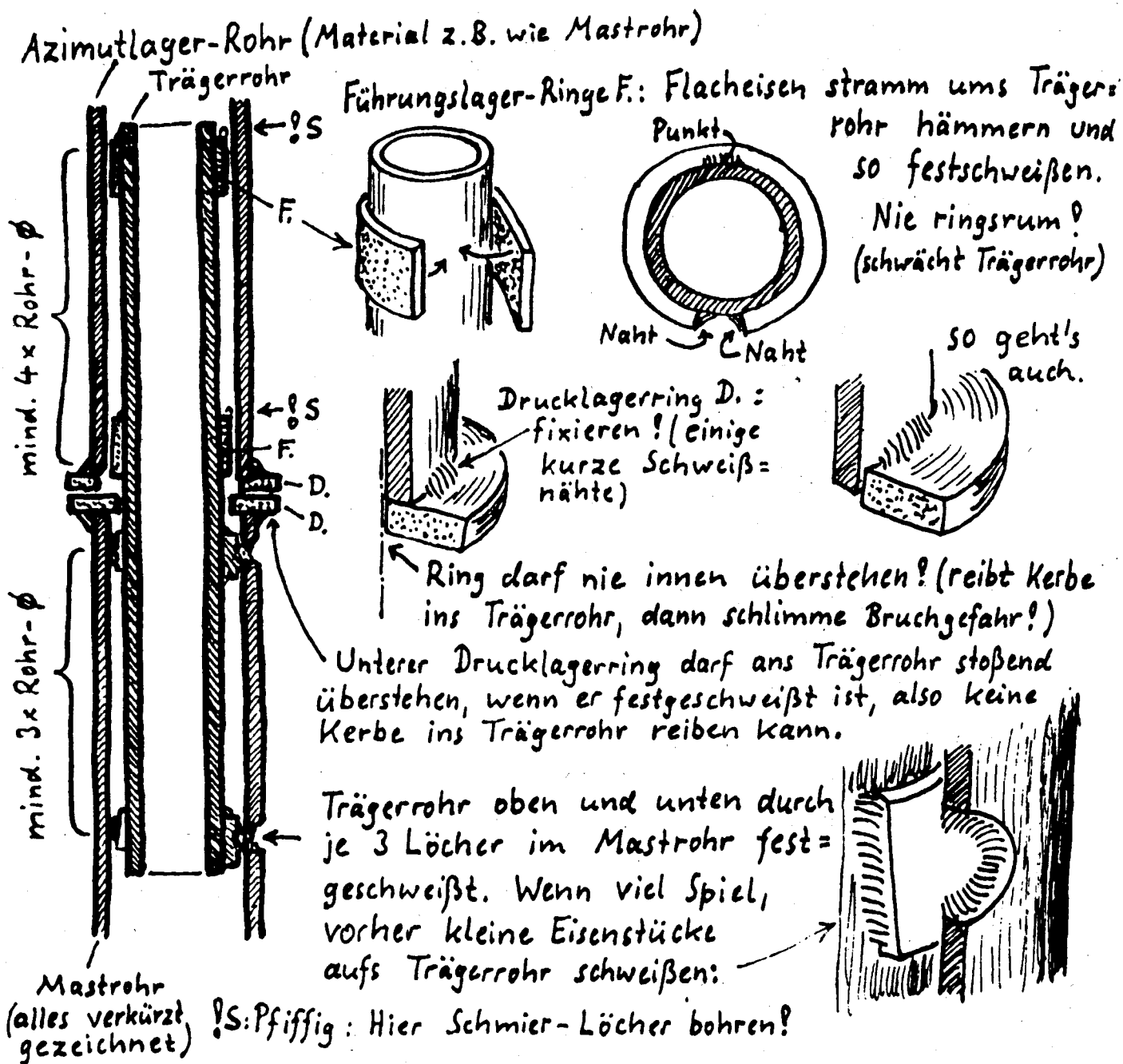


die aber recht genau passen müssen. Sonst sitzt das Windrad ständig schief auf dem Trägerrohr, so daß die Unterkante des Azimutlager - Rohres beim Hin- und Herdrehen eine Kerbe ins Trägerrohr wetzen kann. Sehr gefährlich! Dasselbe kann passieren, wenn die auf Druck aufeinanderreibenden Flächen von Mastrohr und Lagerrohr zu klein sind und nach innen Grate bilden.

Besser (und leichter zu finden!): zwei mit etwas Spiel ineinanderpassende Rohre, z.B. 2" und 2 1/2". Ans Trägerrohr Führungsringe als Reibfläche schweißen z.B. Rohrabschnitte, Flach- oder Bandeisenreste, evtl. überfeilen. So bleibt das Trägerrohr vor jeglicher Reibung geschützt.

Bei großen, schweren Windrädern ist ein breiteres Drucklager unentbehrlich. Mit Glück finden wir irgendwelche passenden Rohrflansche, Flanschringe von Elektroboilern o.ä. als Drucklagering. Sonst müssen wir mühsam Löcher in Eisenplatten meißeln oder schneidbrennern. Die Platten müssen außen nicht rund sein, innen darf die obere keinesfalls überstehen. Zwei außen auf die Rohre passende und festgeschweißte Ringe tun's auch.

Wichtig: Trägerrohr nicht schwächen, also nie ringsherum schweißen, Kerben machen o.ä., Trägerrohr - Innenkanten vorm Zusammenbau sorgfältig runden (besonders am unteren Ende, das ins Mastrohr soll), sonst scheuern sich Kabel und Bremsseil daran kaputt.



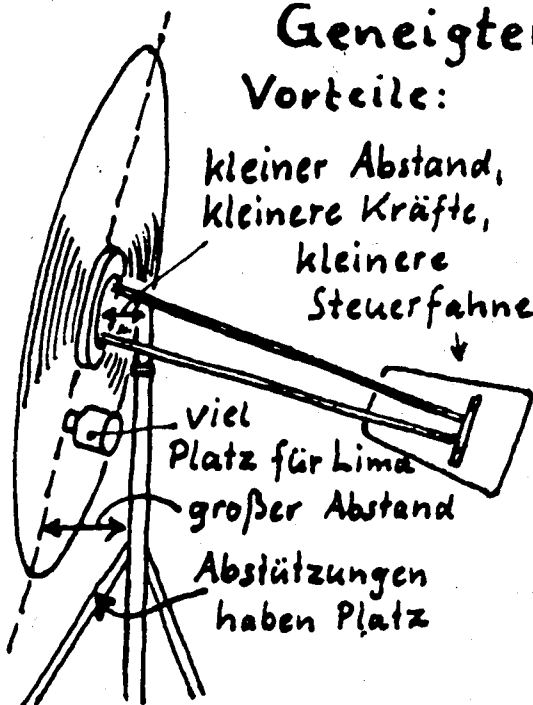
# Der Rahmen

Konstruktionstrick: Geneigter Repeller - Drehkreis setzt Repeller näher ans Azimutlager (kleinere, kürzere Steuerfahne, also weniger Kräfte, weniger klobige Konstruktion möglich), ohne daß der Repeller zu nahe am Mastrohr vorbeisaust. Außerdem mehr Platz im LiMa - Bereich, mehr Platz für Mastrohrabstützungen. Jedoch Drehkreis nicht zu schräg neigen! Ca. 5° schadet noch nicht, je schräger, umso falscher werden die Flügel angeströmt, d.h. Leistung geht verloren, Krach entsteht, ebenso wie wenn das Windrad schief in den Wind gesteuert wird. Natürlich lassen sich Rahmen, Steuer- und Sturmflanze auch ohne Schweißen, nur geschraubt und genietet oder sogar weitgehend aus Holz bauen. Weil Autoachse und die Lagerung auf dem Mast (sog. "Azimutlager") sowieso aus Eisen sind, macht es tatsächlich am wenigsten Mühe, den Rahmen aus weiterem Schrott - Eisen zusammenzuschweißen. Das geht sogar mit Windkraftstrom (s.S.68)!

## Geneigter Repeller-Drehkreis.

Vorteile:

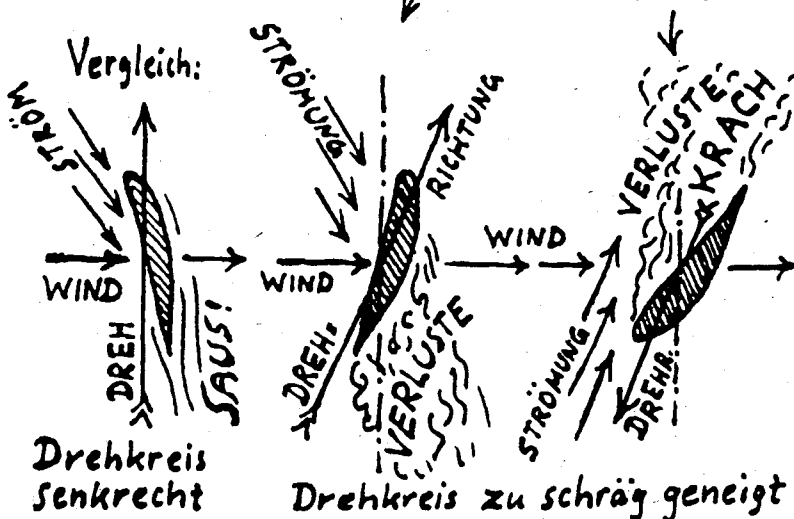
kleiner Abstand,  
kleinere Kräfte,  
kleinere  
Steuerfahne



viel  
Platz für LiMa  
großer Abstand  
Abstützungen  
haben Platz

Problem: schraffierte Bereiche im Drehkreis (s.links) schlecht angeströmt!

auf der einen Seite  
wie bei Anlauf  
auf der anderen  
wie bei  
Überdrehzahl



Drehkreis  
senkrecht

Drehkreis zu schräg geneigt

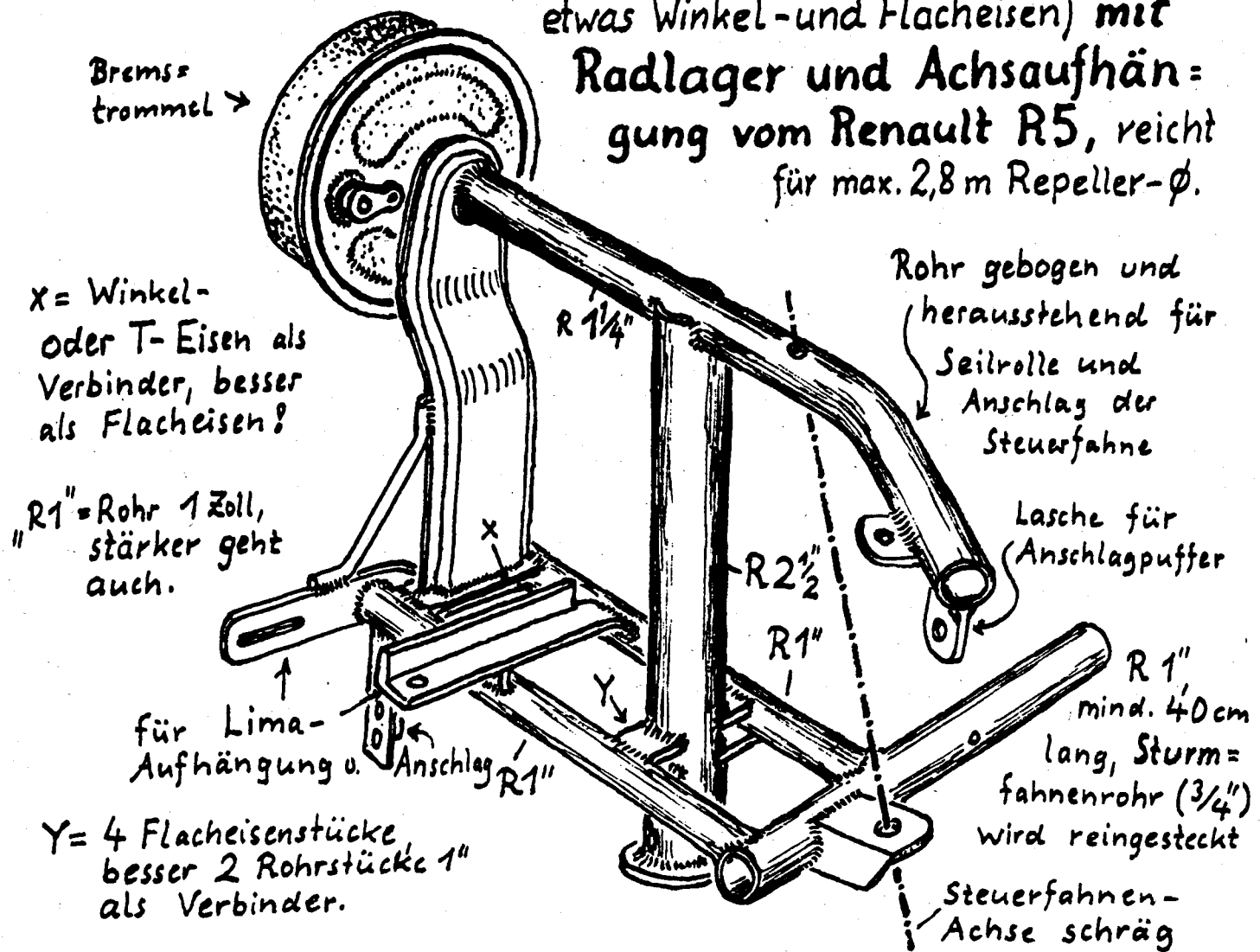
Wir haben die Freiheit, vorhandene Schrotteile gerade so zu verwerten, wie es damit einfach und praktisch ist. Besonders stabil und auch häufiger im Schrott als z.B. Flach- und Winkeleisen sind Rohre. Nutze aus, daß Wasserrohre oft ineinandersteckbar sind (1/2" sehr stramm in 3/4", 3/4" oft stramm in 1", 1" mit Spiel in 1 1/4").

Nur Radlager und Azimutlager (s.S.40) werden fest verbunden, für die anderen Teile (LiMa - Aufhängung s.S.31, Steuer- und Sturmflanze s.S.38) kriegt der Rahmen Halterungen, damit man sie einzeln hochhieven und erst oben auf dem Mast anbauen kann. Sonst wird das Windrad zum Hochhieven zu schwer! Wie die Teile zueinander stehen müssen, zeigt die Zeichnung "Maßverhältnisse".

Gezeichnetes Beispiel mit Materialhinweisen für max. 2,8 m Repeller - Ø (größere Windräder = stärkeres Material!):

Das Radlager vom R5 hat ein ovales Stahl - Hohlprofil als Achsaufhängung quer zur Radachse, das läuft jetzt fast parallel zum Azimutlager - Rohr. Für dieses reicht 2 1/2" - Rohr, als

# Bau-Beispiel: Rahmen aus Schrott (Rohre, Bau-Rundeisen, etwas Winkel- und Flacheisen) mit Radlager und Achsaufhängung vom Renault R5, reicht für max. 2,8 m Repeller- $\phi$ .

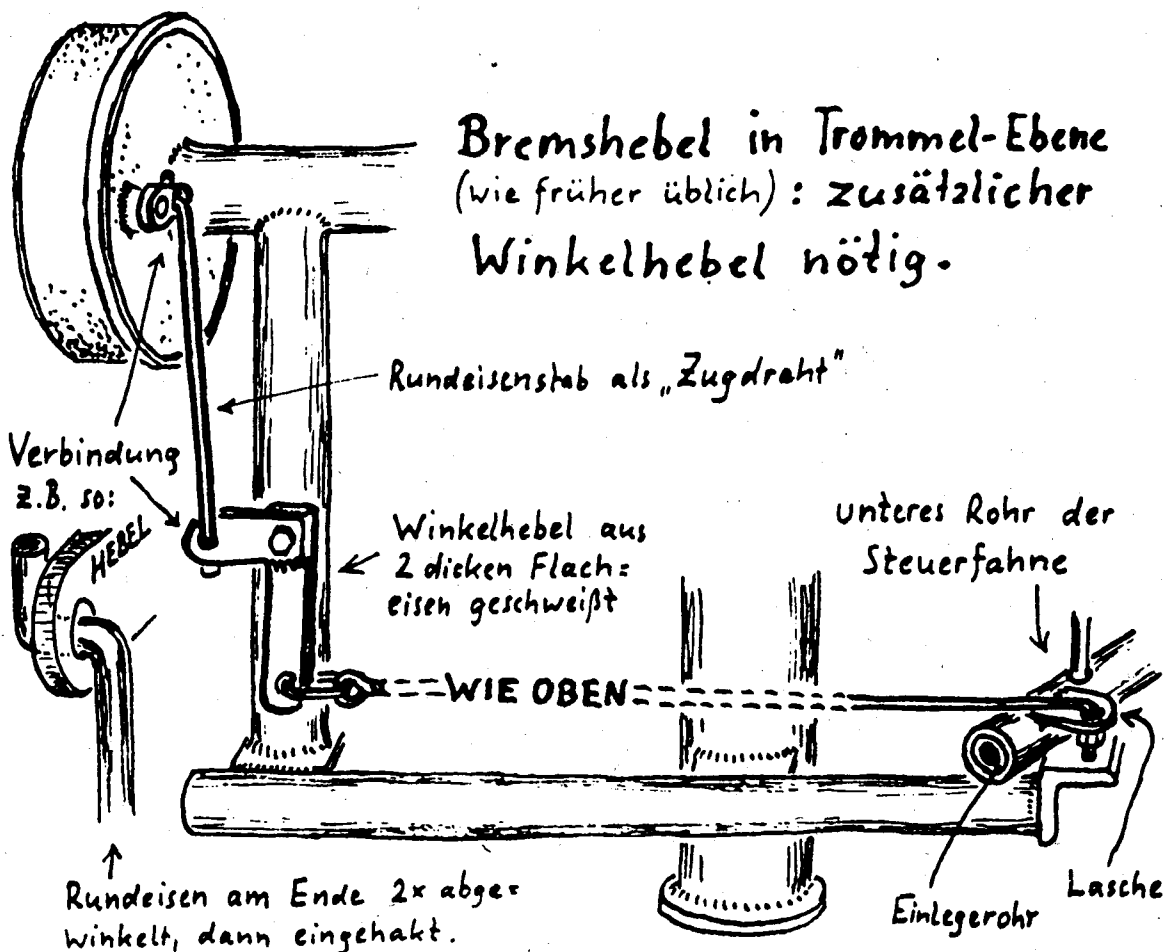
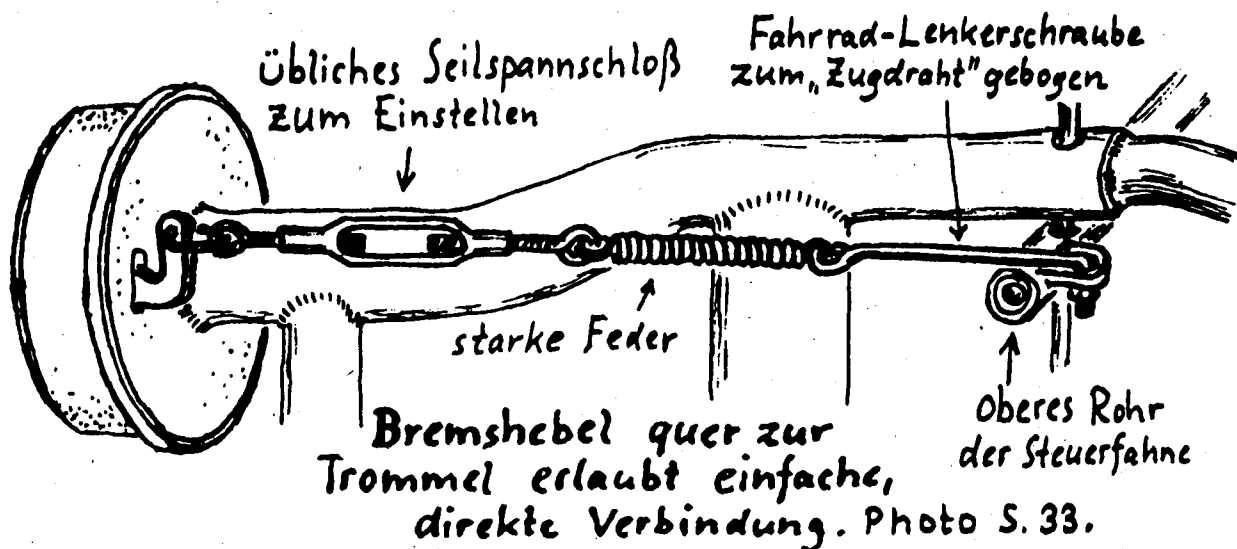


darin drehendes Träger - Rohr (Mastspitze) reicht dickwandiges 2" - Rohr mit Führungsringen gerade eben. Verbunden oben mit 1 1/4" - Rohr, etwas gebogen und nach hinten rausstehend mit Anschlag für die Steuerfahne und Halter für Seilrolle. Sonst hinter der Bohrung fürs Schwenkgelenk mit gebogenem 1" - Rohr verlängern, tief ins 1 1/4" - Rohr reingesteckt. Verbunden unten mit 2 Rohren 3/4" - 1", an diesem hinten quer ein 1" - Rohr, in das der Sturmflaggenholm gesteckt wird. Verbindungsstücke aus Rohr, Flach-, Winkel- oder T-Eisen, Laschen für LiMa - Aufhängung und - Anschlag aus Flach- und Winkeleisen, untere Bohrung fürs Schwenkgelenk in Winkel- oder T-Eisen. Nicht mitgezeichnet: Halterungen für Bremsmechanik, Seilrollen u.ä.

## Betätigung der Trommelbremse (Zeichnung: b.w.)

Die Bremse im Radlager wird von der Steuerfahne betätigt (s. Zeichnung "Seilverlauf"). Sie soll zu ziehen beginnen, wenn die Steuerfahne ca. 2/3 eingeklappt ist, nicht erst fast bei Anschlag Sturmstellung, daher Lasche an der Steuerfahne so setzen, daß in Sturmstellung der Zugdraht fast an den Gelenkstab stößt = wenig Bewegung am Zugdraht, aber höchste Kraft. Im mittleren Bereich der Einklappbewegung wird der Zugdraht schneller, aber mit weniger Kraft gezogen. Wichtig: eine starke Zugfeder im Zugdraht, die etwas nachgibt, sobald die Bremse voll gezogen ist. Sonst würde der Zugdraht reißen oder die Bremse erst bei Anschlag in Sturmstellung ziehen.

44



Bei einigen Autos (z.B. Ford Fiesta) läuft der Bremszug quer zur Bremstrommel; für uns ideal, Bremshebel und Steuerfahne direkt mit Zugdrahtfeder und Einstellschraube verbinden! Bei anderen Autos läuft der Bremszug in Ebene der Bremstrommel (s. Zeichnung "Rahmen" S.43), da brauchen wir einen Umlenkhebel. Vermeide Bowdenzüge in Hüllen, rosten fest! Je nach Verlauf der Bremsmechanik kommt die Lasche ans obere oder untere Rohr der Steuerfahne.

## Kabel und Bremsseil durch den Mast führen:

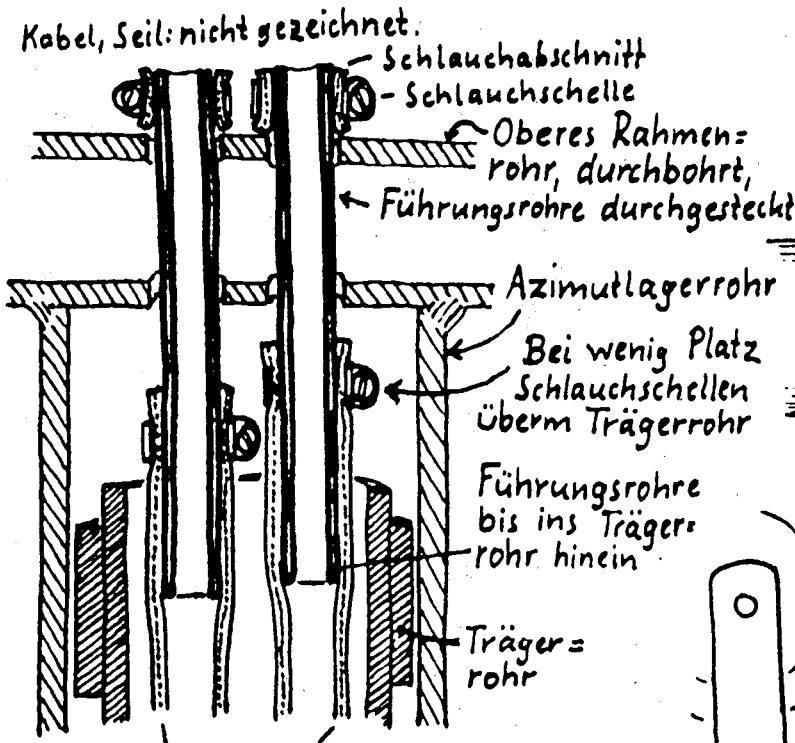
Weil sich das Windrad kaum jemals viele Umdrehungen nur in eine Richtung um den Mast dreht, hat es sich bewährt, Kabel und Bremsseil einfach durchs Mastrohr herunterhängen zu lassen. Wenn nötig, wird das Kabel unten lösbar angeschlossen und, sollten sich Kabel und Brems-

seil zu sehr umeinandergewickelt haben, "entzwirnt". Nur bei extrem schwierigen Windverhältnissen oder wenn das Windrad monatelang unbeobachtet läuft, wird ein elektrischer Schleifkontakt sinnvoll sein. Nachteile: Kontaktflächen können oxidieren, Wackelkontakt kann LiMa gefährden!

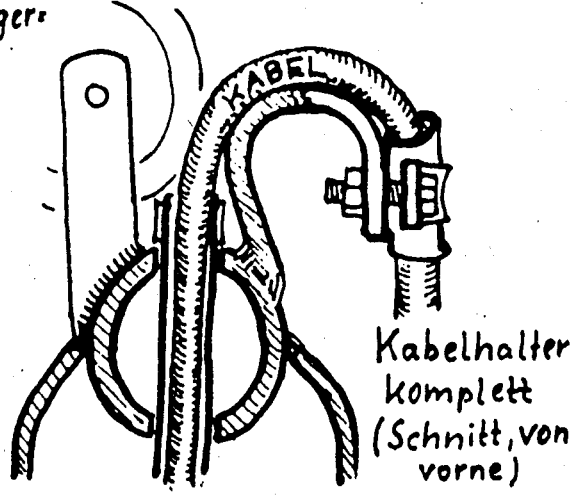
Da sich Kabel und Bremsseil umeinander wickeln, muß das Bremsseil in einer Hülle laufen. Bowdenzughüllen sind unbrauchbar, das Seil rostet oder friert darin fest, weil eben doch Wasser reinkommt. Ein alter Gartenschlauch als Hülle hat sich gut bewährt. Ebenso fürs Kabel, damit seine Isolierung nicht am Mastrohr durchscheuert. Besonders wichtig im Bereich des Trägerrohres und unten am Mastrohr.

In die oberen Enden der Schläuche kommen dünne Rohre (z.B. Druckluftrohr oder Kupferrohr 12 mm Ø). Kabel und Seil samt Schläuchen (an dünnen Drähten) von unten nach oben durch Mast und Windradrahmen ziehen. Wenn Schlauch-Röhrchen durchgefummelt, Schlauchabschnitt und Schlauchschelle drauf.

Das Bremsseil läuft über die Seilrolle. Das Kabel gegen Rausziehen nach unten befestigen: extra gut erst über ein U-förmig gebogenes Flacheisen, das schon viel Zug abfängt, dann mit einem Kabelklemmer sichern. Übrigens brauchen wir nur ein durchgehendes Plus-Kabel, weil Minus über Windradrahmen und Mastrohr laufen kann. Dann jedoch Minus-Kabel von der LiMa bis an den Rahmen nahe ans Drucklager legen, damit kein Strom über das Schwenkgelenk der Aufhängung läuft (Kugellager gehen kaputt). Weiteres Kabel vom Mastrohr dicht unter dem Drucklager nach unten für möglichst geringen elektrischen Widerstand.



Kabel- und Bremsseilschlauch, Befestigung im Windradrahmen. (Schnitt, von der Seite)



# Details: Kabel- und Bremsseilführung oben am Windradrahmen.

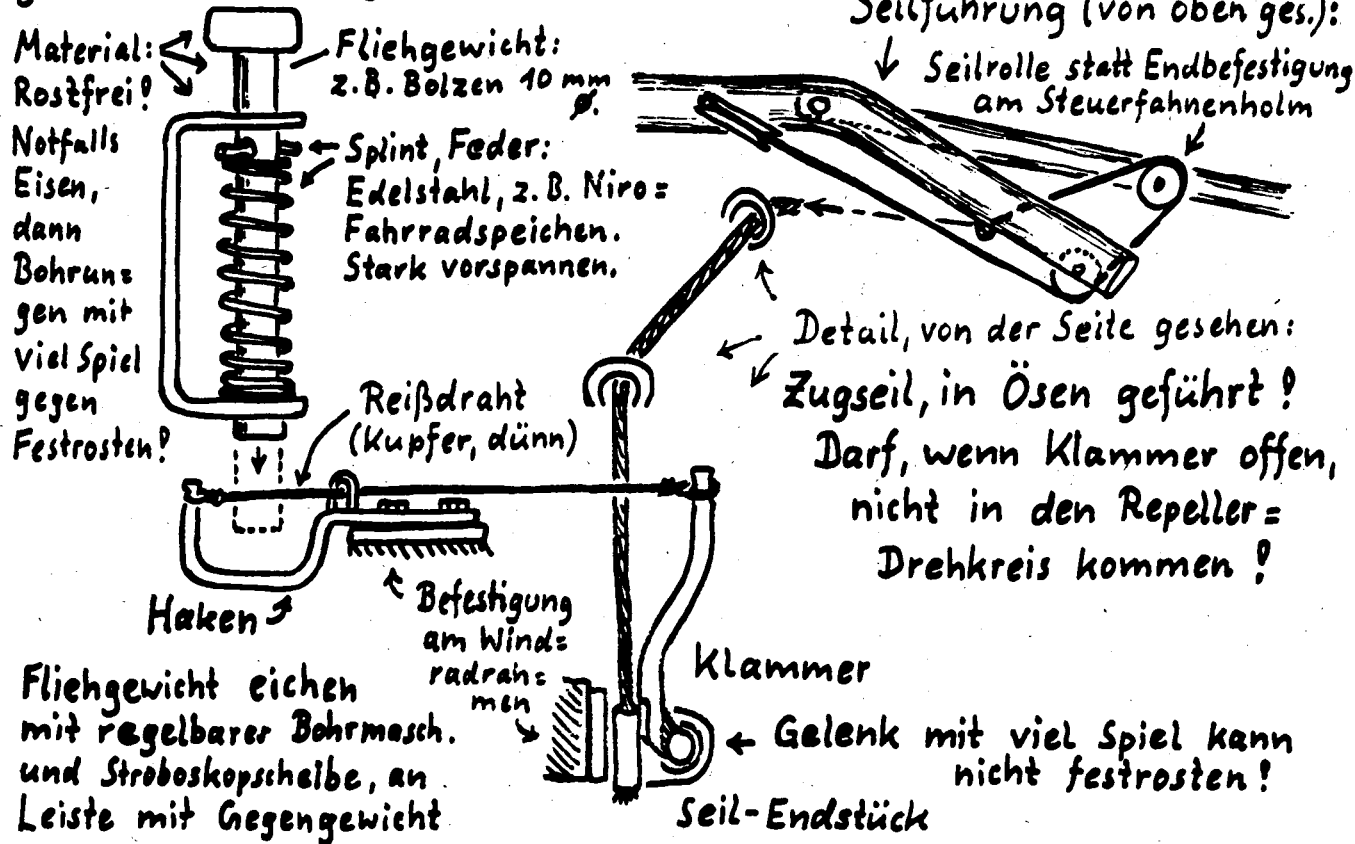
# Super-Sicher: Zusätzliche Fliehkraft-Drehzahlsicherung!



Die Teile: Klammer für Seilende, Haken mit Zerreißdraht, Fliehgewicht.

Überdrehzahl schleudert das Fliehwegicht nach außen, Draht wird zer-  
 rissen, Klammer öffnet sich und gibt das Zugseilende frei: Steuerfahne  
 geht in Sturmstellung und zieht die Bremse.

Seilführung (von oben ges.):



Material:  
 Rostfrei?  
 Notfalls  
 Eisen,  
 dann  
 Bohrunge  
 mit Viel Spiel  
 gegen  
 Festrosten?

Fliehwegicht:  
 z.B. Bolzen 10 mm  
 Splint, Feder:  
 Edelstahl, z.B. Niro:  
 Fahrradspächen.  
 Stark vorspannen.

Seilrolle statt Endbefestigung  
 am Steuerfahnenholm

Detail, von der Seite gesehen:  
 Zugseil, in Ösen geführt?  
 Darf, wenn Klammer offen,  
 nicht in den Repeller =  
 Drehkreis kommen?

Fliehwegicht eichen  
 mit regelbarer Bohrmasch.  
 und Stroboskopscheibe, an  
 Leiste mit Gegengewicht

Klammer  
 Gelenk mit viel Spiel kann  
 nicht festrosten?  
 Seil-Endstück

Befestigung  
 am Winds-  
 radrah-  
 men

Haken

Reißdraht  
 (Kupfer, dünn)

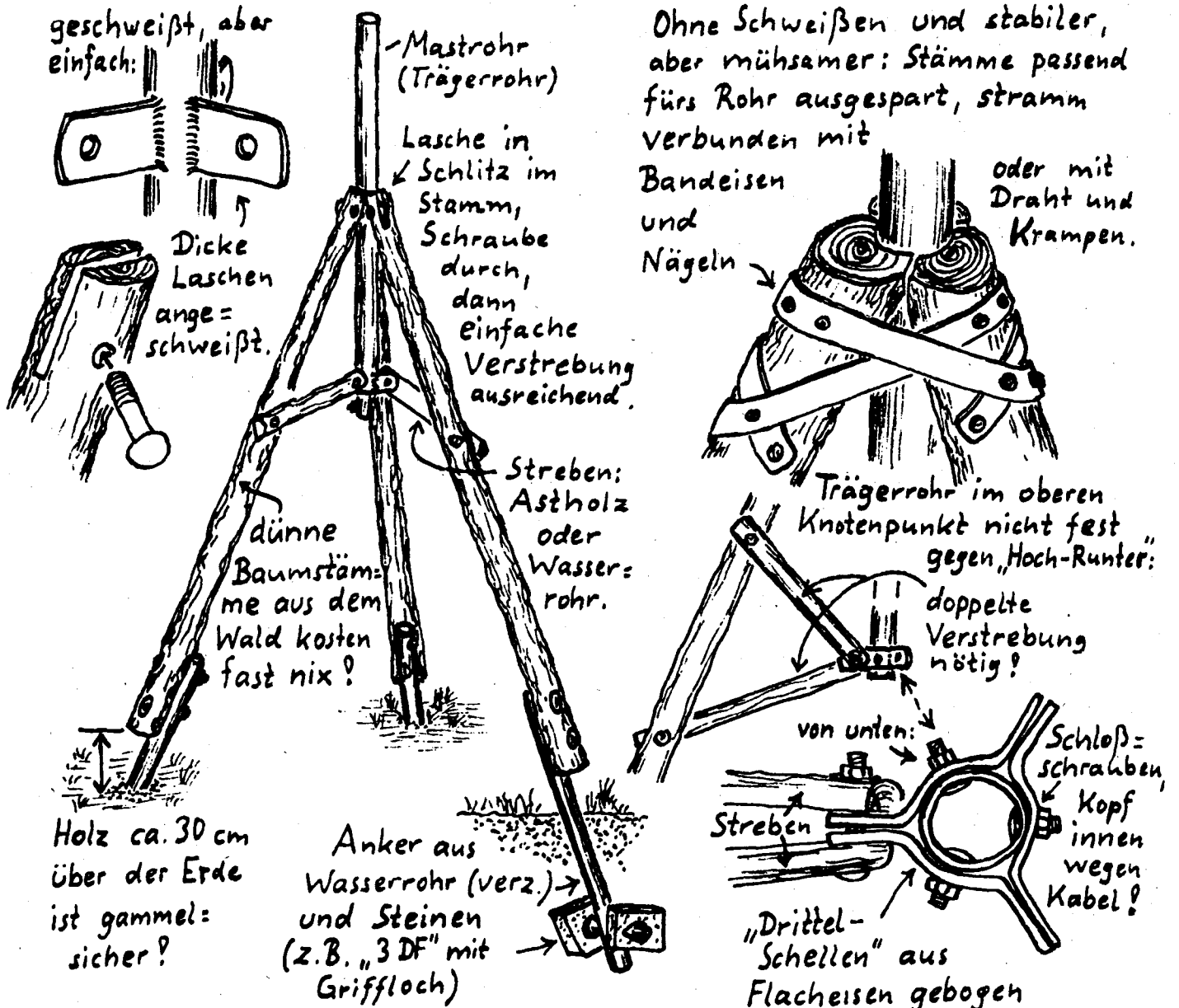
# Der Windrad-Mast:

Ein Dreibeinmast ist in sich stabil und braucht keine bombastischen Fundamente (vergleiche: Photo-Stativ). Dickes Wasserrohr (verzinkt) oder alte Eisenträger (vom Bauschutt) als Erdanker mit Querstab und 2 Mauersteinen versehen sind verrottungsfest, superstabil und bei evtl. Demontage wiederverwertbar. Betonfundamente bleiben übler Bauschutt! (S. 2, Photo S. 48)

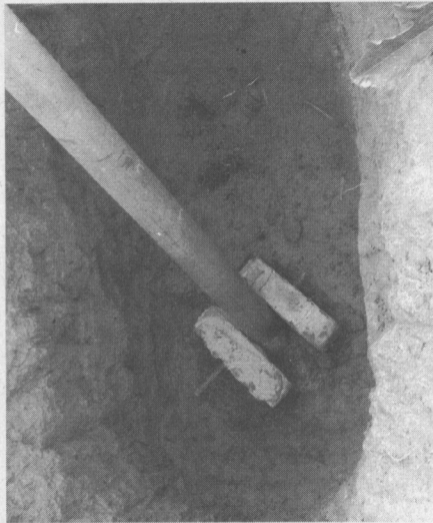
Ein mit Seilen abgespannter Einzelmast wird erst halbwegs stabil, wenn alle Seile stramm angezogen sind: die Seile versuchen, sich gegenseitig die Verankerungen aus der Erde zu reißen. Die Erdanker sind viel stärker belastet als beim Dreibeinmast. In der hier sinnvollen Höhe wird der Mast stark in sich schwingen, wenn er nicht zusätzlich auf halber oder 2/3 Höhe abgespannt ist. Viel Aufwand, wenig Effekt. (S. 70)

Da wir mit dem Windrad aus dem Windschatten (z.B. des Hauses) raus müssen (20% weniger Wind = halbe Leistung!) und weil es für freistehende Masten evtl. Grenzen der Genehmigungsfreiheit gibt, ist Aufstellen auf dem Hausdach oft ein sinnvoller Trick. Der Dachstuhl muß an der Stelle oft nur wenig oder gar nicht verstärkt werden. Auf Gummi (z.B. alter Autoreifen) gelagert ist das Windrad im Haus praktisch nicht zu hören!

Merke: Besser ein höherer Mast als ein größeres Windrad!







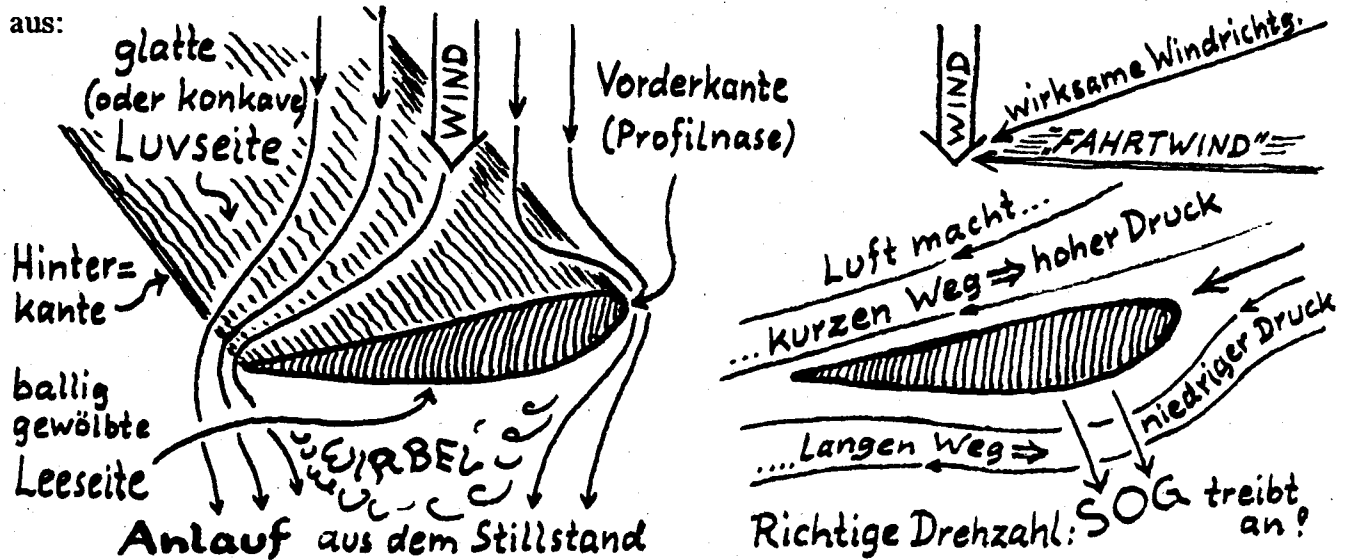
*Mast aus Wasserrohr-Schrott fürs 4-m-Windrad. So einfach sind die Anker?*

# „Fachkunde“ zu besonderen Bauteilen

## Wie funktioniert der Repeller?

Repeller, nicht Propeller!

Beide sehen auf den ersten Blick zum Verwechseln gleich aus, sind jedoch in Bau und Wirkungsweise ganz verschieden. Weil aber immer wieder Leute fragen, ob man nicht auch einen alten Flugzeugpropeller fürs Windrad nehmen könnte, machen wir den Unterschied schon im Namen deutlich. Ein aerodynamisch geformtes Profil, wie hier verwendet wird, sieht etwa so aus:



Läuft ein Repeller aus dem Stillstand an, kann der Wind ihn nur sehr schlecht antreiben: Die Luvseite steht fast quer zum Wind und an der Leeseite entsteht kaum wirksamer Sog, weil die Anströmrichtung noch falsch ist. Deshalb kommt er nur mühsam in Bewegung. Er muß praktisch ungebremst loslaufen können (kein kraftfressendes Getriebe, Lichtmaschine nicht magnetisiert), sonst läuft er erst bei starkem Wind an.

Sowie der Repeller aber schneller wird, verbessert sich die Anströmrichtung immer mehr, und plötzlich setzt der "aerodynamische Effekt" ein: Der Repeller saust leise zischend in abenteuerlichem Tempo los, weil der richtige Sog auf der Leeseite entsteht. Er kann jetzt ein Vielfaches der Anlaufkraft abgeben, also leicht eine magnetisierte Lichtmaschine treiben. Hat sich die aerodynamische Strömung gebildet und läuft der Repeller mit der vorgesehenen Schnelllaufzahl, wirkt der ganze Drehkreis für den Wind als Angriffsfläche, die Flügel laufen so schnell, daß sie für den Wind "überall" zu sein scheinen.

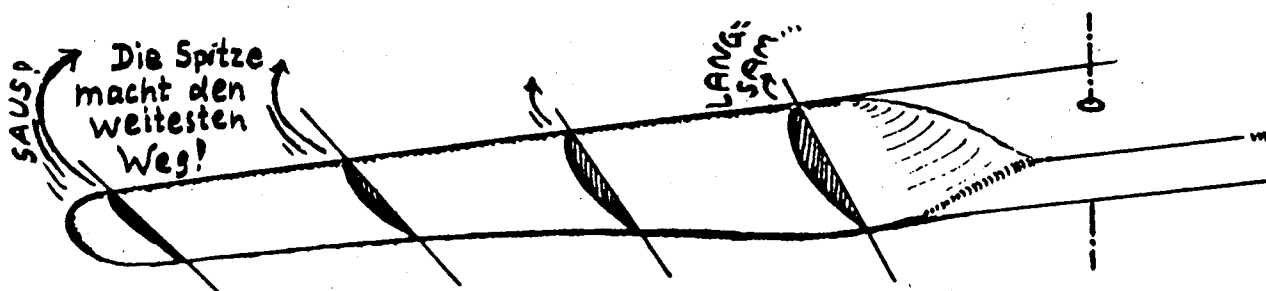
Wenn der Repeller so schnell durch die Luft saust, kriegt er auch ihren Widerstand "zu spüren". Der muß möglichst klein sein, rauhe Oberflächen, Fehler im Profil, breite Hinterkante usw. verursachen Widerstand und bringen Krach statt Kraft.

"Schnelläufigkeit":

Das Flügelende läuft schneller als die Windgeschwindigkeit um, die Schnelllaufzahl (bei unserem 3 - Flüglern  $\lambda = 5$ ) nennt das Verhältnis, um wieviel schneller die Flügelspitze als der Wind laufen muß, damit die Strömung am Profil ideal ist. Muß der Repeller (z.B. weil die LiMa nicht paßt) langsamer oder wesentlich schneller laufen, gibt er nur wenig Leistung ab, stattdessen viel Lärm.

Die Profilform muß auch zur Schnelläufigkeit passen! Ein Profil, das schnell die Luft durchschneidet, ist dünn und schmal, eins, das langsam und kraftvoll laufen soll, dicker und breiter. Schon mit einem "Pi-mal-Daumen"-Profil kann ein Repeller recht gut laufen, aber an den Stellen, die nicht strömungsgerecht sind, gibt es Wirbel, die Geräusche machen und Leistung schlucken. Besonders bewährte Profile sind für die Fliegerei untersucht worden und in "Profilkatalogen" zu finden. Profile mit ebener Luvseite sind einfach herzustellen, also für uns günstig.

Jedes Repellerblatt hat in sich schneller und langsamer laufende Stellen:



Ein richtig edler Repeller hat daher eine "Verwindung", also ist der Anstellwinkel an der Nabe groß und das Profil dick, an den Spitzen klein und dünnes Profil. Für die Stabilität ist das auch gut: Leichte Flügelspitzen verursachen wenig Fliehkraft, und an der Nabe, wo sich die Kräfte konzentrieren, soll der Repeller dick sein. Auf keinen Fall umgekehrt!

So ein Repeller läuft wunderbar leise bei hoher Leistung und läuft auch leicht an, weil der nabenahe schräge Bereich schon aus dem Stillstand heraus viel Kraft gibt. Ein "vielseitiges" Profil sorgt dafür, daß der Repeller auch bei böigem Wind stets noch richtig angestömt wird.

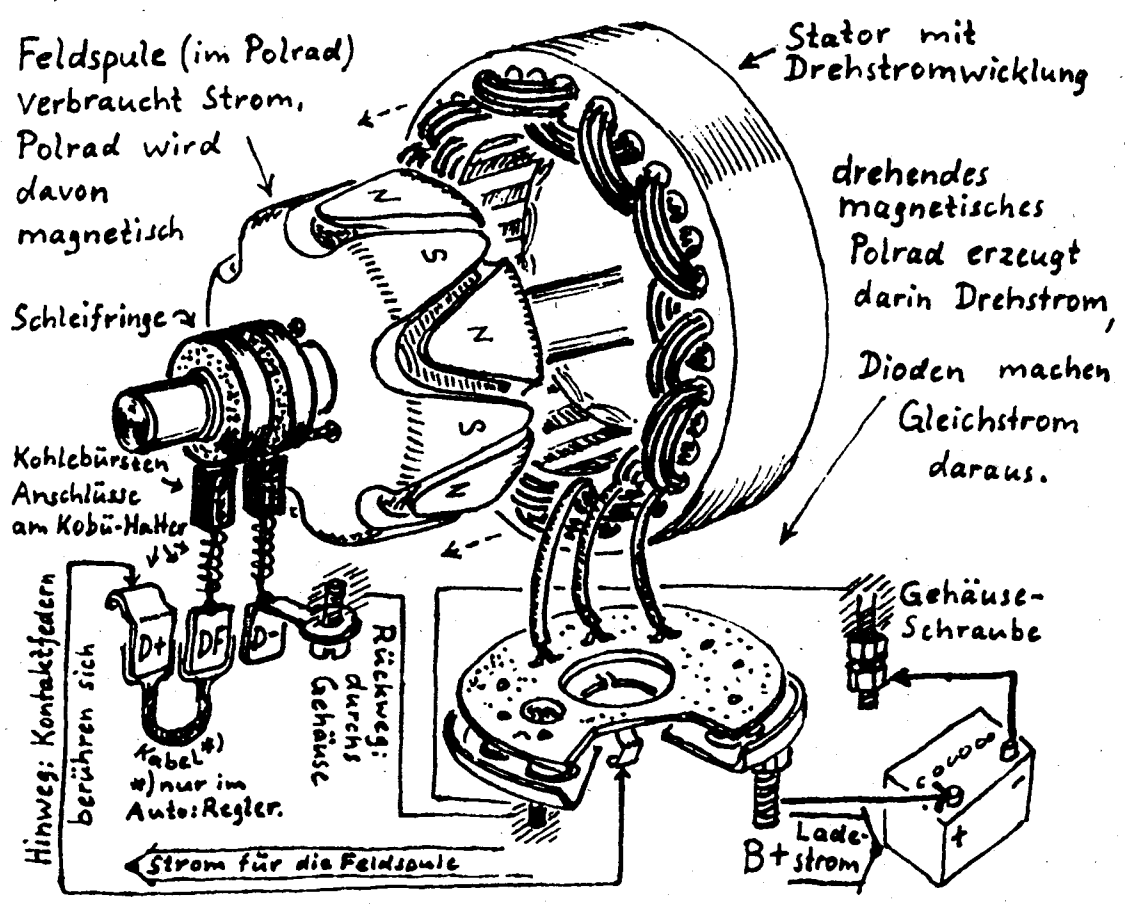
Das freistehende Windrad kann bestenfalls 2/3 der Windleistung in mechanische Leistung umsetzen; dazu muß der Wind auf 1/3 seiner vorherigen Geschwindigkeit vom Windrad abgebremst werden. Mehr geht nicht, sonst würde der hinterm Windrad fast stillstehende Wind wie eine Mauer den nachkommenden Wind stoppen.

Die Leistung wächst mit dem Durchmesser hoch 2 (weil für den Wind die ganze Drehkreisfläche Angriffsfläche ist) und mit der Windgeschwindigkeit hoch 3. Merke: 10% mehr Wind gibt 33% mehr Leistung.

# Wie funktioniert eine Auto-Lichtmaschine?

Beim Fahrraddynamo dreht sich in der Mitte ein Dauermagnet, um den Magneten herum sitzen Spulen, in denen das drehende Magnetfeld Strom erzeugt. Die Kraft des Dauermagneten ist immer da, wir spüren sie deutlich, wenn wir mit der Hand langsam am Rädchen drehen. (Genau erklärt im Heft "Wirkkraft?- Ganz einfach")

Drehstrom - LiMas (und die selteneren Wechselstrom - LiMas) funktionieren im Prinzip genauso. In der Mitte dreht sich kein Dauermagnet, sondern ein Elektromagnet (das "Polrad" auf dem Läufer). Deshalb läßt sich der Läufer einer nicht arbeitenden LiMa ganz leicht drehen. Damit die LiMa Strom erzeugen kann, muß die Spule des Elektromagneten (die "Feldspule") Strom kriegen. Dann läßt sich der Läufer ziemlich schwer drehen und das starke Magnetfeld erzeugt in der Wicklung des Stators Drehstrom (bei Wechselstrom - LiMas Wechselstrom). Zum Batterieladen und für die Feldspule ist aber Gleichstrom nötig. Darum fließt der Strom, bevor er aus der LiMa herauskommt, noch durch Gleichrichter - Dioden. Dabei wird ein Teil abgezweckt zum Versorgen der Feldspule, der Rest geht in die Batterie.



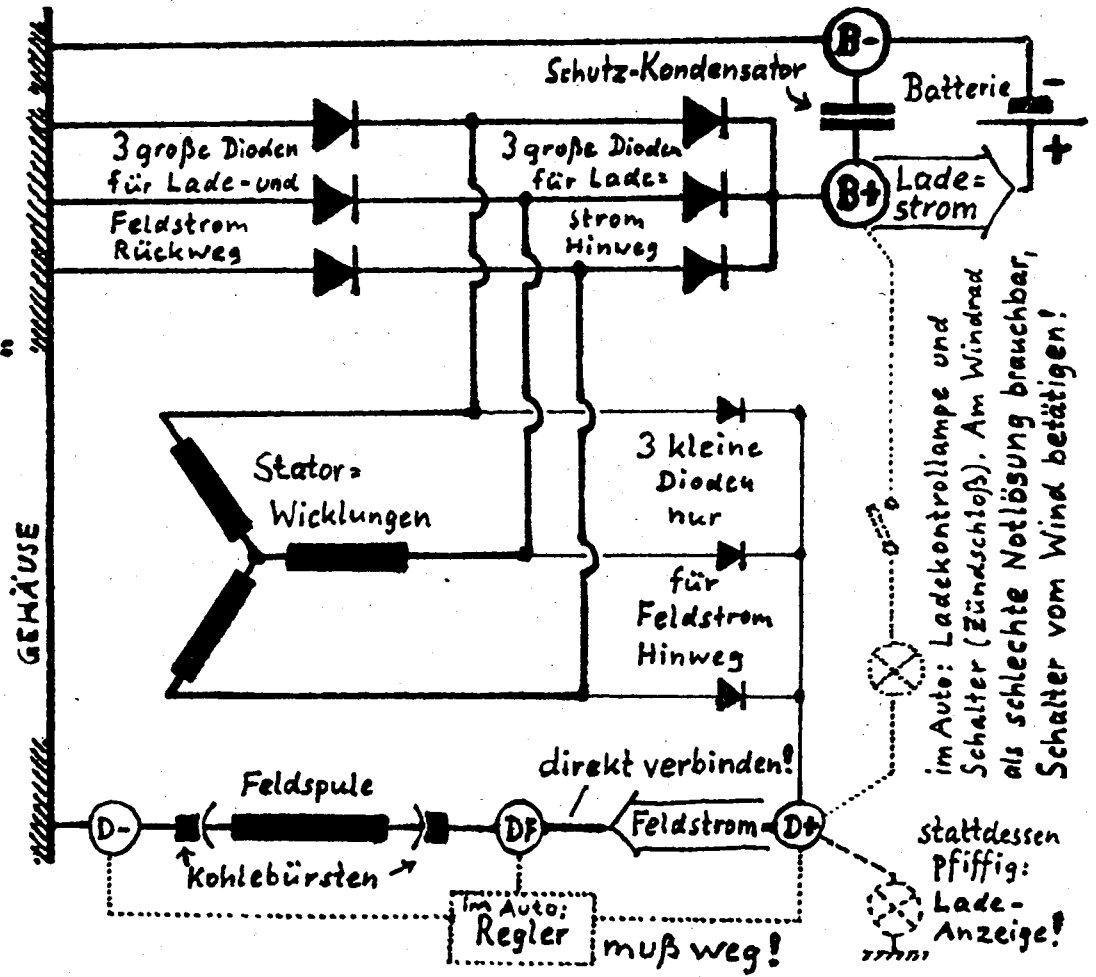
## Die wesentlichen Teile einer Drehstrom-LiMa.

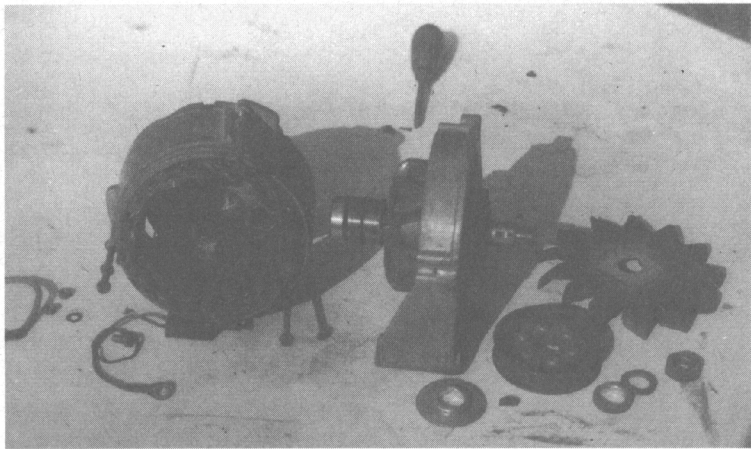
Jetzt kommt die Tücke: Woher kriegt der E - Magnet den ersten Strom, damit die LiMa überhaupt anfangen kann, Strom zu erzeugen? Im Auto aus der Batterie (über Ladekontrollampe und Zündschloß). Im Windrad wäre das Mist, dann würde bei Flaute die LiMa dauernd Strom fressen. Doch da kann uns der Erdmagnetismus helfen. Außerdem bleibt vom letzten Mal Stromerzeugen ein kleiner Restmagnetismus im Eisen der LiMa zurück, so wenig, daß wir ihn nicht fühlen beim Drehen am Läufer. Aber dieser Restmagnetismus reicht schon, um ganz wenig Elektrizität im Stator zu erzeugen. Doch leider kommt die nicht raus (außer wenn wir die LiMa ganz fürchterlich schnell drehen), denn die Gleichrichterdioden lassen nicht alles durch. In einer Richtung, in der

nie Strom fließen soll, lassen sie gar nichts durch, doch auch in der anderen Richtung lassen sie erst durch, was mehr als 0,7 Volt pro Diode ist (wie ein Staudamm, über den nur fließt, was höher als der Staudamm ist).

Original=  
Schaltung  
einer  
Drehstrom=  
LiMa.

Photo:  
LiMa,  
geöffnet  
(Bosch, ältere Bauart)

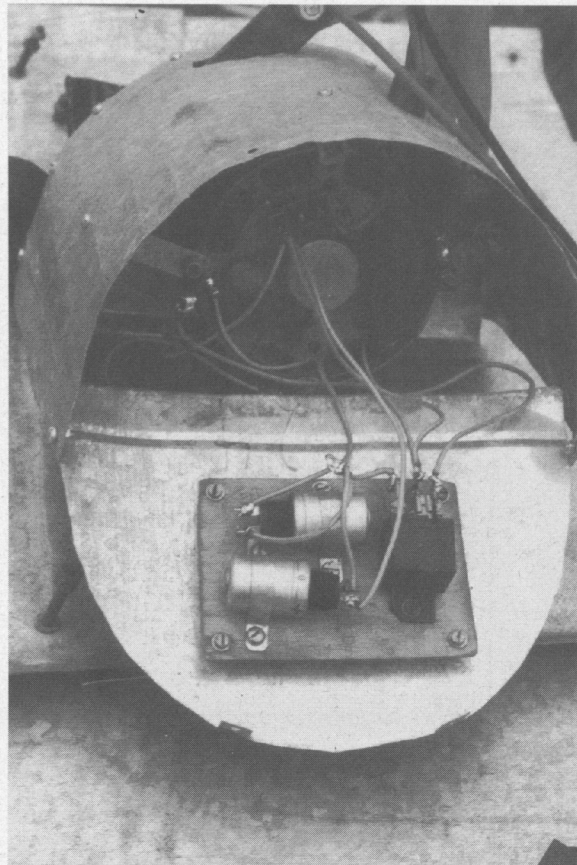
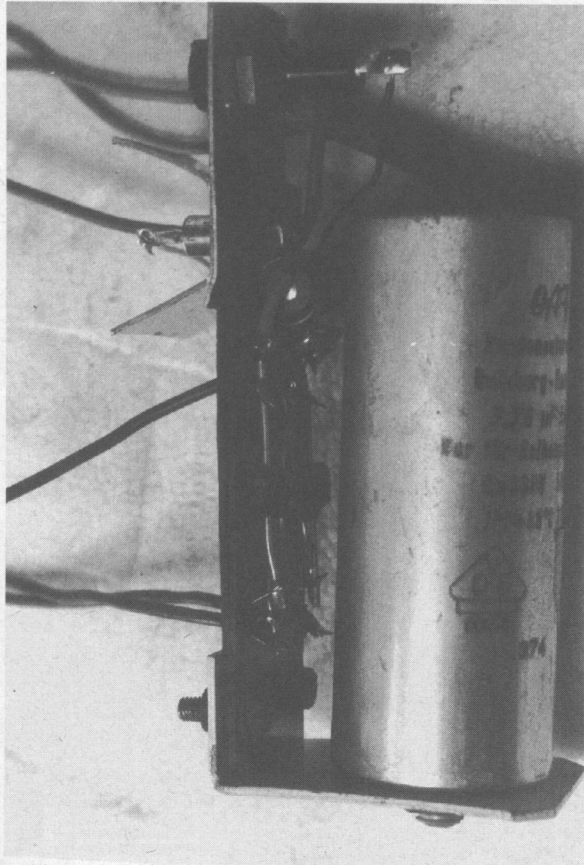




hinteres Gehäuseteil mit Sta-  
tor und Kohlebürstenhalter

vord. Gehäuseteil  
mit Läufer

Lüfterrad, Riemen-  
scheibe, Paßfeder usw.



Selbsterregungs-Schaltung mit Schottky-Dioden,  
dazu Schutzkondensator, da dieser an der Lima fehlte.

Lima mit Abdeckhaube und Rombach-Schaltung.  
Kl. schwarzer werksmäßiger Schutz-Kond. ist an der Lima.

**LiMas haben große Öffnungen für die Kühl - Luft. Dringt Regen ein, verrosten innen die Eisen-  
Teile! Darum für LiMa (und Zusatzschaltung) eine unten offene Abdeckhaube basteln. Nur z.B.  
bei Drehstrommotoren mit geschlossenem Gehäuse als Generator ist keine Abdeckung nötig.**

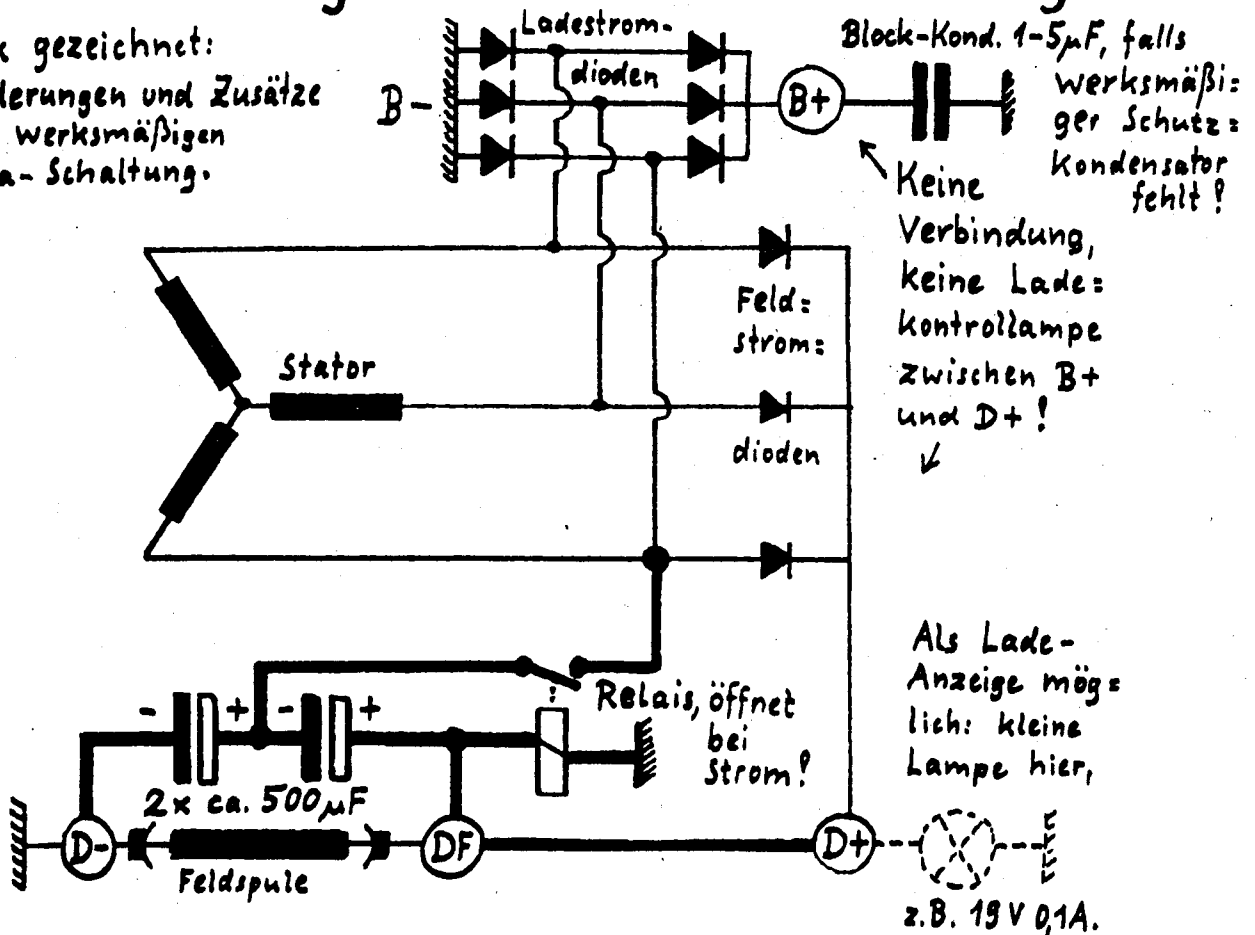


Wenn es gelingt, Strom an den Dioden vorbei herauszuholen, in Gleichstrom zu verwandeln und damit die Feldspule zu versorgen, würde sich die LiMa ohne Hilfsstrom von außen selbst magnetisieren, d.h. sie wäre "selbsterregend".

Und das gelingt z.B. so: Bei der "Rombach - Schaltung" (weil von Peter Rombach entwickelt), wird Wechselstrom aus der LiMa an den Diolen vorbei abgezapft und in Kondensatoren geleitet. Die wirken wie kleine Batterien: Drehen wir am Polrad, nehmen sie das kleinste bißchen Strom auf und geben es wieder ab, ohne "Staudamm - Effekt". Dadurch, daß nun Strom zwischen den Kondensatoren und der Spule hin- und herfließt, entsteht Magnetismus (jeder Strom, der fließt und nicht am Staudamm hängenbleibt, erzeugt Magnetismus!), dadurch erzeugt die LiMa sofort mehr Strom, mehr Magnetismus entsteht, und in Sekundenbruchteilen hat sie sich voll magnetisiert.

### Lima selbsterregend durch „Rombach-Schaltung“:

dick gezeichnet:  
Änderungen und Zusätze  
zur werksmäßigen  
Lima-Schaltung.



Wichtig ist, daß wir jetzt die Kondensatoren wegschalten, sonst fließt beim Laden auch starker Strom zwischen den Kondensatoren und der Spule hin- und her, der nach der Selbsterregung völlig nutzlos ist und erhebliche Verluste macht. Dazu dient das Relais, es öffnet den Kontakt, wenn die LiMa magnetisiert ist und volle Spannung abgibt. Wird die LiMa nur noch so langsam gedreht, daß der Strom nicht zur Versorgung der Feldspule ausreicht, bricht das Magnetfeld in der LiMa zusammen. Aber das Relais schließt dann den Kontakt zu den Kondensatoren, so daß die LiMa sich wieder magnetisieren kann, wenn sie schneller getrieben wird.

Die Teile für diese Schaltung finden wir leicht im Schrott. Die LiMa selbst bleibt original, nur müssen wir an einem beliebigen Anschluß, wo die Statorspulen mit den Dioden verbunden sind, ein Kabel anlöten. Bei Bosch - LiMas älterer Bauart und bei den meisten französischen LiMas ist das leicht (Diodenplatte oder Plastikabdeckung abschrauben). Andere LiMas muß man aufschrau-

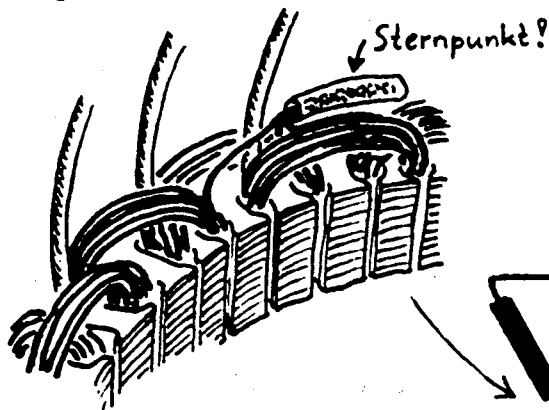
ben. Beim Aufschrauben stets vorher die Kohlebürsten ausbauen (können sonst brechen!), nie hämmern oder die Gehäusehälften einseitig auseinanderhebeln, sondern gleichmäßig auf beiden Seiten hebeln. Kugellager würden sonst schadhaf!

Weitere Möglichkeiten: Den Strom für die Feldspule nicht über die eingebauten Dioden gleichrichten. Es sind Silizium - Dioden, die brennen zwar nur selten durch, aber haben den "Staudamm - Effekt" von 0,7V. Es gibt inzwischen auch recht robuste Spezial - Dioden, "Schottky - Dioden", die haben nur 0,2 - 0,3V "Staudamm - Effekt". Type SB 5-60 hält 5 Amp. und 60V aus und kostet unter 3 DM im Elektronik - Fachhandel. Ein Gleichrichter daraus läßt schon unter der Ladebeginn - Drehzahl den vom Restmagnetismus erzeugten Strom durch und macht die LiMa dadurch selbsterregend. Sehr wichtig hierbei: Die elektrische Verbindung von der Minus - Kohlebürste der Feldspule zum Gehäuse unterbrechen! Sonst fließt der Ladestrom auch den bequemen Weg über die Schottky - Dioden und überlastet sie sofort!

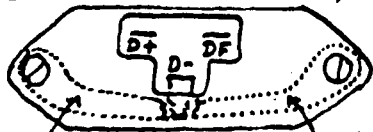
### "2-Stufen-LiMa" für Schwach- und Starkwind!

Wirkungsweise: Statt, wie original, über einen Vollbrücken - Gleichrichter, kriegt die Feldspule jetzt nur über einen Einweg - Gleichrichter Strom, verbraucht also weniger, dadurch läuft die LiMa deutlich leichter, leistet aber auch weniger. Der Wirkungsgrad ist besser als beim Original, die Ladebeginn - Drehzahl fast unverändert: Schaltung für Schwachwind.

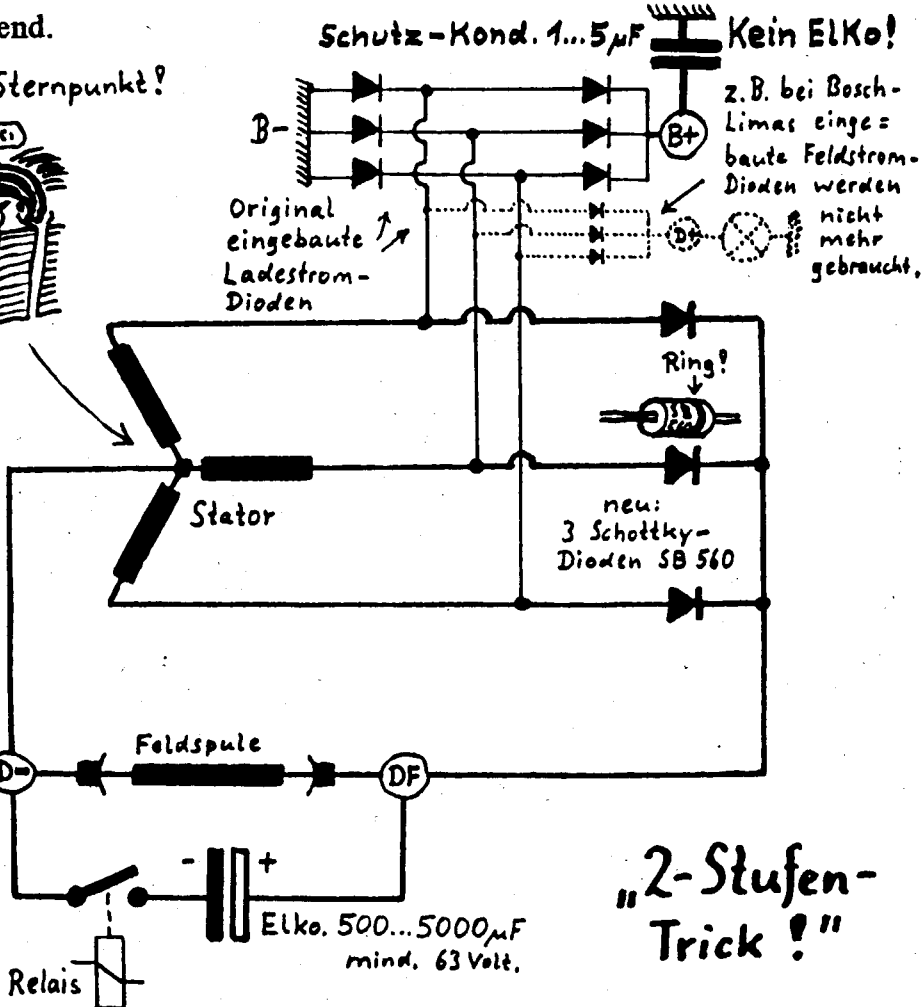
Bei höherer Drehzahl wird der Kondensator zugeschaltet: Er glättet die Strompulse aus dem Einweg - Gleichrichter, so kriegt die Feldspule Strom ähnlich wie aus dem Original - Brückengleichrichter, aber hat mieseren Wirkungsgrad. Die LiMa hat jetzt nahezu volle Leistung und läuft entsprechend schwerer. Gut bei starkem Wind. Der miesere Wirkungsgrad macht nichts, denn der Repeller ist dann sowieso unterfordert. Verwendest Du Schottky - Dioden, wird die LiMa gleichzeitig selbsterregend.



Bei Bosch (neuere Limas)



diese Blech-Verbindungen entfernen. Sonst: Kabel der "D-" - Kohlebürste vom Halter löslöten, verlängern und isoliert nach außen führen! **Unbedingt** Verbindung von "D-" zum Gehäuse trennen!

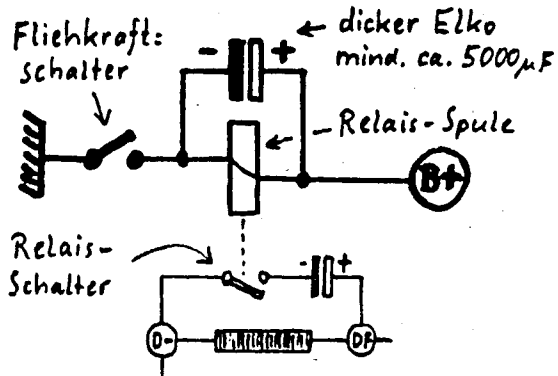
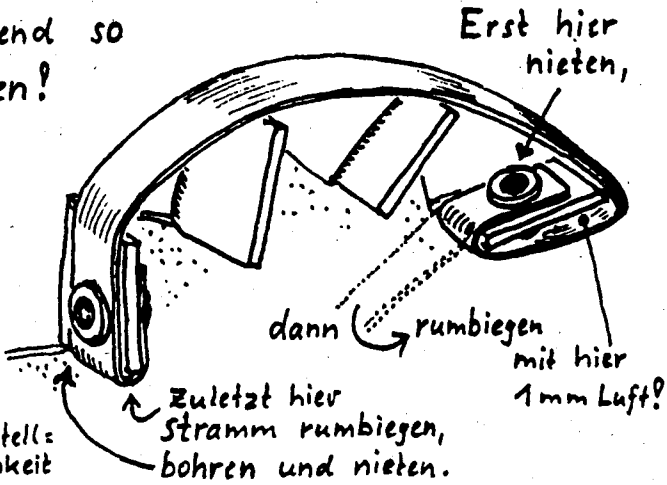
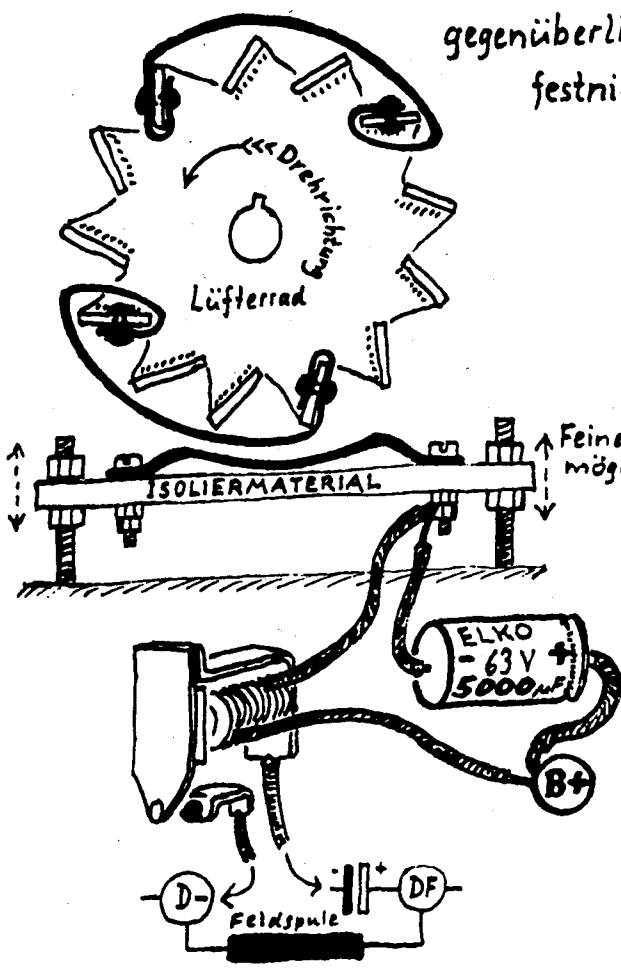


"2-Stufen-Trick!"

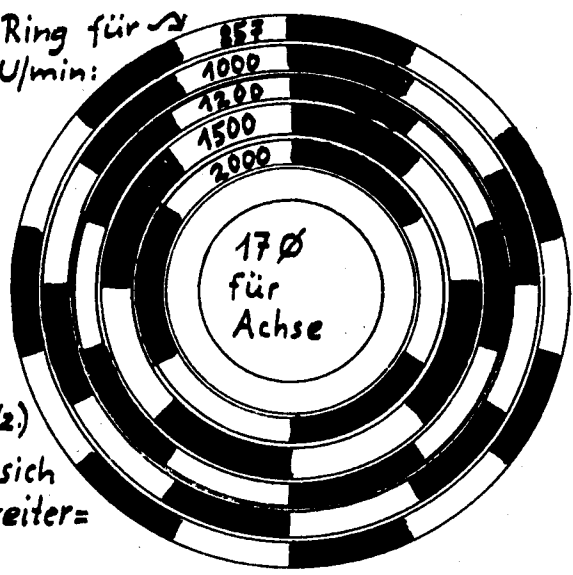
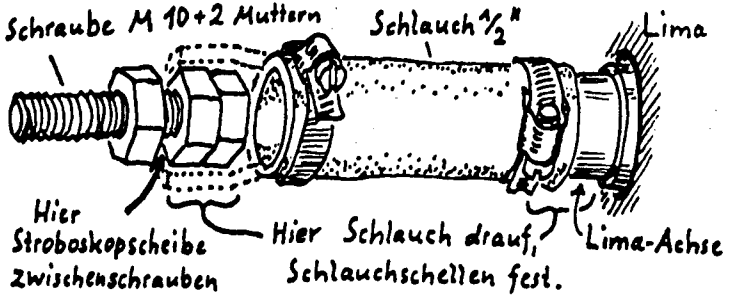
Als Umschaltautomatik baue ich Niro - Blechstreifen ans Lüfterrad (Zeichnung). Nieten mit dünnem Schaft und großem Flachkopf, besser große Unterlegscheiben, sonst Bruchgefahr der Streifen am Niet. Bei hoher Drehzahl beulen sich die Streifen nach außen, schleifen am Gegenkontaktblech, das Relais kriegt Strom (geglättet mit dem ELKo, damit es nicht rattert) und schaltet den Kondensator zu.

### Fliehkraft-Schalter :

Am Lüfterrad 2 Blechstreifen gegenüberliegend so festnieten?

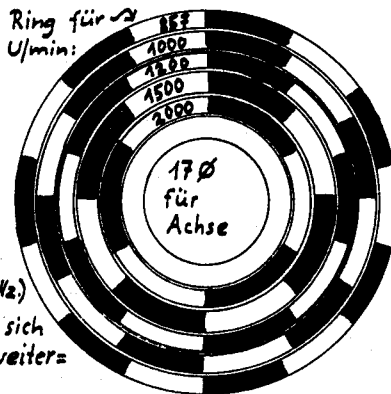
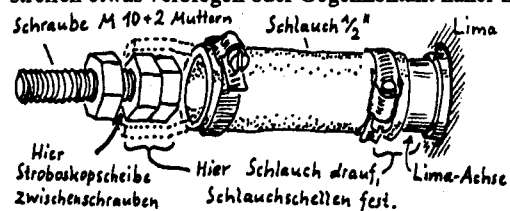


Zum Justieren z.B. diese Stroboskopscheibe hier abpausen, auf's Lüfterrad kleben, mit Atomstrom - Licht beleuchten und mit regelbarer Bohrmaschine antreiben. Justiermöglichkeit: Blechstreifen etwas verbiegen oder Gegenkontakt näher heran oder weiter weg stellen.



Kupplung zum Drehzahlmessen  
 Stroboskop-Scheibe: Atom-Licht (am besten Neonröhre) hat 100 Lichtblitze pro Sekunde (50Hz)  
 Ist die Drehzahl der Scheibe so hoch, daß sich ein Ring zwischen 2 Blitzen genau 1 Feld weiterdreht, scheint dieser Ring stillzustehen.

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# Besonderheiten bei einigen LiMas :

Manche (meist ältere französische) LiMas haben nicht die drei kleinen eingebauten Dioden nur für den Feldstrom - Hinweg (s. Schaltplan S.51), es gibt auch nicht die Klemme "D+", nur "EXC" ( entspricht "DF" bei Bosch). Für Rombach - Schaltung (und für Notlösung mit Lade - Kontrollampe und Schalter) müssen wir 3 gewöhnliche, ausreichend belastbare Dioden direkt an die Stator - Anschlüsse schalten. Beim "2 - Stufen - Trick" macht's nichts, wenn diese Dioden fehlen, wir schließen ja statt dessen Schottky - Dioden an.

Vor allem bei Auslands - LiMas sind die Statorwicklungen manchmal nicht in Sternschaltung, sondern zur Dreieckschaltung zusammengeschlossen. Kennzeichen: Das nirgends angeschlossene Kabelende, wo 3 Drähte zusammen laufen (s. Zeichnung S.54 "Sternpunkt") fehlt, stattdessen laufen jeweils 2 Drähte zusammen zu den 3 Dioden - Anschlußstellen. Hier geht der "2 - Stufen - Trick" nicht. Interessant: Du kannst die Wicklungen in Sternschaltung zusammenschalten. Effekt: Nur noch ca. 60% der Leistung, aber auch ebensoviel niedrigere Ladebeginn - Drehzahl, jetzt "2 - Stufen - Trick" möglich. Ideale Schwachwind - LiMa.

## Wo bleibt der Regler ?

Wichtig bei allen LiMas: Der im Auto verwendete Regler kann am Windrad viel Schaden anrichten! Er schaltet die Feldspule ab, sobald die Spannung an der LiMa 14V überschreitet. Folge: Bei Sturmböen läuft die LiMa plötzlich ganz leicht, das Windrad fängt an, fürchterlich zu rasen! Der Regler muß raus, Direktverbindung zur Feldspule (Kabel zwischen "D+" und "DF") rein.

Damit die Batterie jetzt aber nicht überladen werden und dadurch kaputt gehen kann, beobachte sie entweder regelmäßig oder baue eine Überlade - Schutzschaltung an, die Strom verbrät (oder auf eine zusätzliche leere Batterie schaltet), wenn die Batterie zu voll wird. Wichtig: s.S.66!

## Die alt-bewährte Gleichstrom-LiMa...

Auto - Gleichstrom - LiMas funktionieren genau wie ein als Generator benutzter Auto - Kühlergebläsemotor (genaue Erklärung im Heft "Windkraft?- Ganz einfach!"), nur daß statt Dauermagneten Feldspulen drin sind.

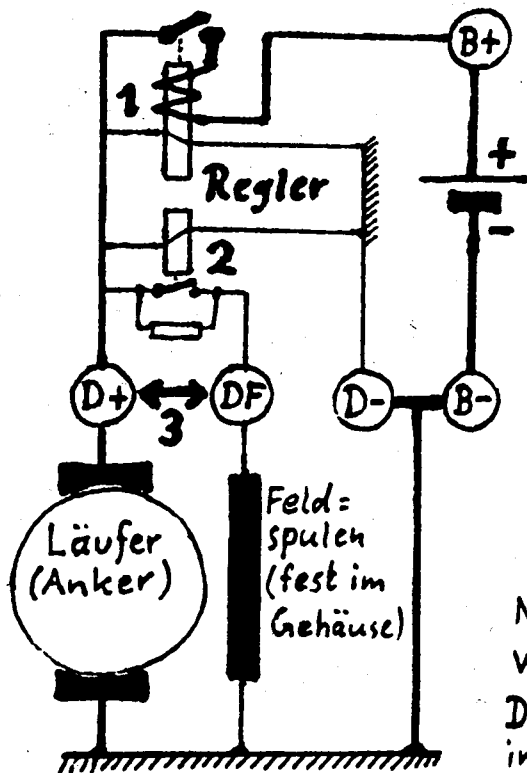
Gleichstrom - LiMas haben keine Dioden, der drehende "Kommutator" schaltet die Wicklung stets so an die Kohlebürsten, daß Gleichstrom rauskommt. Nachteil: Hier geht nicht der Feldstrom, sondern der Ladestrom über die Kohlebürsten und belastet sie viel höher als bei Drehstrom - LiMas. Wichtiges Verschleißteil, Ersatz bereithalten!

Vorteile: Bei Drehstrom - LiMas frißt der Spannungsverlust an den Dioden 10% des Wirkungsgrades! Hier keine Verluste durch "Staudamm - Effekt" an Dioden, keine Dioden, die durchbrennen können. Mechanischer Aufbau meist solider als bei Drehstrom - LiMas.

Anschlußweise: Läufer und Feldspule parallel schalten (sog. Hauptschlußschaltung"), d.h. "D+" und "DF" verbinden. Aber nicht direkt an die Batterie schalten, sonst läuft die LiMa als starker Motor mit Batteriestrom! Die Verbindung DF/D+ zur Batterie darf nur eingeschaltet werden, wenn die LiMa Strom erzeugt. Dazu ist das Rückstromrelais (Schaltplan: Relais 1, erkennbar am ganz dicken Draht) des Original - Reglers nötig. Fast keine Verluste!

Im Original - Regler ist auch ein 2. Relais ( Nr. 2 im Schaltplan), das die Feldspule bei über

14V abschaltet. Darf (ebenso wie bei Drehstrom - LiMas) am Windrad keinesfalls sein, sonst könnte das Windrad bei Sturm ungebremst losrasen. Relaisschalter überbrücken durch direktes Kabel zwischen "D+" und "DF" (Nr. 3 im Schaltplan)!



### Beschaltung der Gleichstrom-LiMa:

Relais 1: Dünner Draht: Zieht bei ca. 13V an, Ladestrom fließt von D+ zur Batterie durch den dicken Draht, damit das Relais auch bei ca. 11V noch angezogen bleibt.

Fließt Strom von der Batterie in die LiMa, fließt er falschrum durch den dicken Draht, Wirkung der beiden Wicklungen von Relais 1 hebt sich auf, Relais öffnet.

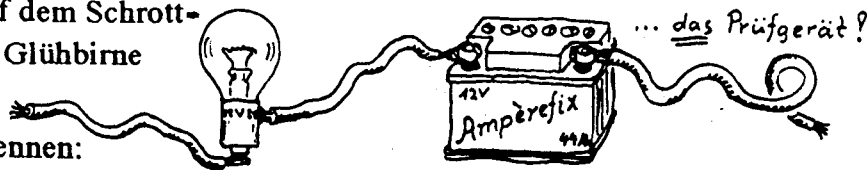
Relais 2: Trennt bei über 14V Direktverbindung D+ -DF, darf am Windrad nicht passieren.

Notlösung, falls Regler weg: D+ und DF direkt verbinden (3), dicke Diode von D+ zur Batterie. Dioden-Verluste nur halb so hoch wie die in Drehstrom-LiMas.

## LiMas aussuchen & prüfen

LiMas, die geeignet erscheinen, auf dem Schrottplatz grob prüfen (mit Batterie und Glühbirne möglich, s.S. 58 Punkt 1-4).

Besonders geeignete LiMas erkennen:



Die Ladebeginn-Drehzahl ist wichtig fürs Übersetzungsverhältnis, aber auf dem Schrottplatz schwer zu messen (regelbare Bohrmaschine und Stroboskopscheibe (s.S. ) sind nötig), aber Bosch-LiMas haben eine Kennziffer für den Drehzahlbereich. Die 3. Zahl nennt die Drehzahl, bei der 2/3 Vollast erreicht werden, z.B. bei einer 14 V 35 A 20 - LiMa bei 2000 U/min, bei einer ...V...A 28 - LiMa bei 2800 U/min. Ladebeginn ist bei ca. 2/5 dieser Drehzahl, d.h. bei 20-er-LiMas bei 800 U/min, bei 28-er - LiMas bei gut 1100 U/min.

Je weniger Strom die Feldspule verbraucht, desto schwächerer Wind ist nutzbar. Viele französische LiMas verbrauchen bei gleicher Leistung wie Bosch - LiMas deutlich weniger Feldstrom, z.B. braucht Ducellier 35 A nur 1,7 A Feldstrom, Bosch 35 A frißt 2,6 A Feldstrom! Mit Ampèremeter zu messen. Grobvergleich mit Batterie und Glühbirne: Minus an Gehäuse, Plus (über Glühbirne) an "DF" (franz. "EXC") oder (bei LiMas mit elektron. Regler) an "D+". Birne dunkler = weniger Feldstrom.

Bei LiMas gleicher Leistung hat die mit dem dickeren Stator - Blechpaket meist den besseren Wirkungsgrad. Gründe: Mehr Eisen leitet das Magnetfeld besser, weniger Magnetismus geht verloren, schwächere Feldspule reicht aus. Und: Nur in dem Teil des Wickeldrahtes, der in den Nuten läuft, wird Strom erzeugt. Die Bögen von einer Nut zur anderen machen nur Verluste (Widerstand). Bei dickeren Statorn sind die Nuten länger, die Bögen aber gleich wie bei dünnen.

## LiMas prüfen: Grobe Prüfung für Dreh- und Wechselstrom-LiMas, sinngemäß auch für Gleichstrom-LiMas.

1. Alle Kabel abkoppeln!
2. Fließt Feldstrom? Batterie direkt an die Feldspule schließen,  $\ominus$  an Masse, bzw. "D-",  $\oplus$  an "DF" bzw. EXC". An der Achse drehen. Muß schwerer gehen. Geht's ganz leicht, ist kein Feld da, Kohlebürsten prüfen. Bei LiMas vom Schrott: häufigster Fehler: 1 Kohlebürste ist so kurz, daß Wackelkontakt  $\rightarrow$  evtl. Schleifring verbraten.
3. Wenn Feldstrom fließt, erzeugt die LiMa Strom? Batterie direkt an der Feldspule lassen, Glühbirne mind. 21W direkt zwischen B+ und Masse schließen. LiMa schnell und kräftig von Hand drehen, z.B. Bindfaden auf die Riemenscheibe wickeln und kräftig abziehen. Birne brennt? Wohl in Ordnung. Aber: Genaue Prüfung, denn die LiMa kann zwar noch Strom erzeugen, aber mit Riesen-Verlusten!

## Genauere Prüfung, nur für Drehstrom- und Wechselstromlimas:

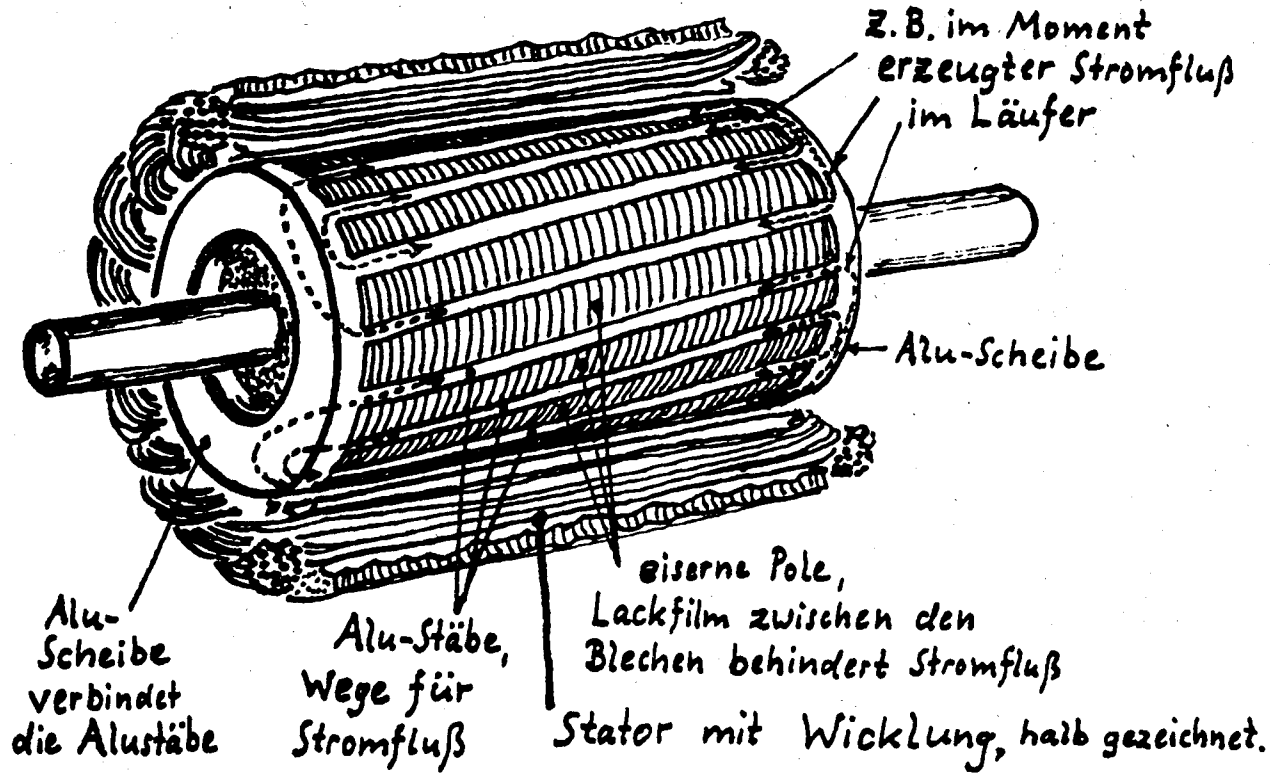
4. Polrad-Drehgefühl-Probe. Wie Punkt 2, aber langsam an der Riemenscheibe drehen. Muß bei Wechselstrom-LiMas stark ruckweise gehen, bei Drehstrom-LiMas darf's nicht rucken, sondern muß sich anfühlen, als wär' die LiMa voll Sirup, es darf höchstens leicht pulsieren. Ruckweise? Fehler! Möglich:
  - eine oder zwei Dioden durchgebrannt.
  - Wicklungs-, Masse- oder grober Windungsschluß (S.\*), Wicklung berührt Gehäuse
  - Statorspulen falsch zusammengeschaltet (1 Phase falschrum, s. S.\*).
 Das Rucken kommt, weil die LiMa zwar Strom erzeugt, aber der Strom von 1 Phase kurzgeschlossen oder fehlgeleitet wird und Verlust macht. Immer, wenn diese Phase dran ist, kommt der Ruck! Im praktischen Betrieb macht diese LiMa viel zu wenig Ladestrom und wird heiß, mit Selbsterregungs - Schaltungen (S.53) erregt sie sich oft gar nicht oder bei sehr hoher Drehzahl.
5. Polrad durchgebrannt? Feldstrom messen. Soll: 2-CV-LiMa = 1,6A, Bosch 14V 35A = 2,6A, - 55A = 3,3A. Geringe Abweichung macht nix, falls deutlich höher, ist das Polrad mind. zum Teil durchgebrannt. Damit kann die LiMa zwar noch Strom erzeugen, aber mit miesem Wirkungsgrad, das Polrad frißt zu viel.
6. Dioden-Grobprüfung: Mit Batterie und Birne.  $\oplus$  an "B+",  $\ominus$  an Statoranschluß. Brennt: Diode(n) nach "B+" kaputt.  $\oplus$  an Statoranschluß,  $\ominus$  an Gehäuse. Brennt: Diode(n) nach "B-" (Gehäuse) kaputt. Nur bei Schaltung mit Extra - Dioden für Feldstrom:  $\oplus$  an "D+" (Feldstromdioden),  $\ominus$  an Statoranschluß. Brennt: Felddiode(n) kaputt.
7. Achtung: Masseschluß des Stators täuscht kaputte Ladestromdioden (nach "B-") vor, in dem Fall Stator ablöten und extra prüfen. Statorprüfung s.S.\*. Zum genauen Prüfen der Statorwicklungen und Dioden Statoranschlüsse von den Dioden ablöten.
8. Dioden genau prüfen: Mindestens einen Anschluß ablöten oder abklemmen, dann mit 24V oder 36V Gleichspannung und schwacher Glühbirne (höchstens 2W) oder besser einem Galvanometer prüfen. Darf nur in einer Richtung Strom durchlassen, in der anderen Richtung kein bißchen!

\*) im Heft: „Windkraft? Ja bitte!“

# Mit einem einfachen Asynchronmotor Strom erzeugen?

Hokus-Pokus, weil der ja keine Feldspule hat? Doch, es geht, auch wenn manche Elektriker das nicht wissen. Der gewöhnliche Asynchronmotor hat nämlich sehr wohl eine Feldspule, die nur nirgends angeschlossen ist, sondern in sich kurzgeschlossen. Daher der Name "Kurzschlußläufer". Der Aufbau des Asym ähnelt einer Auto-LiMa, nur daß im Polrad dicke Adern aus Aluminium sind, an den Seiten miteinander vergossen. Das ist die Feldspule.

## Gewöhnlicher Kurzschlußläufer-Asynchronmotor



Beim Gebrauch als Motor schicken wir Drehstrom in die Statorwicklungen. Dann erzeugt das vom Stator kommende Magnetfeld Strom im Polrad. Der macht das Polrad magnetisch. Und weil das Magnetfeld im Stator immer ganz schnell ringsherum wandert, jagt es auch das Polrad immer ringsherum, weil die Magnetfelder sich abstoßen bzw. anziehen.

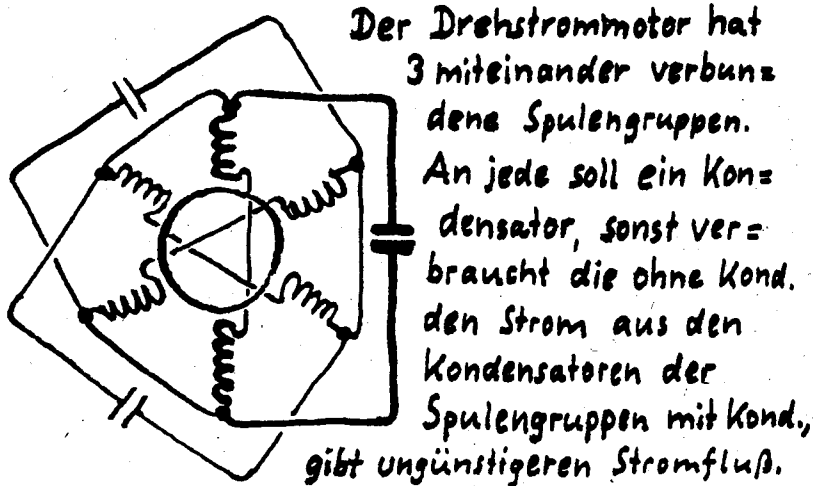
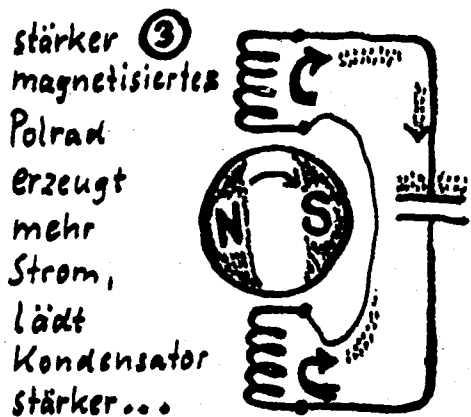
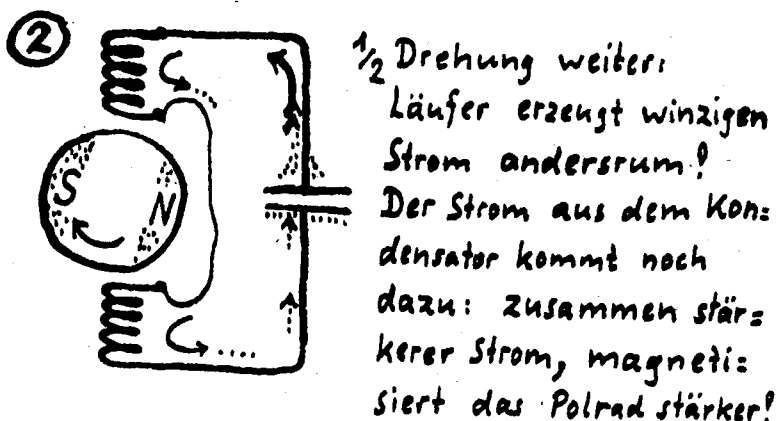
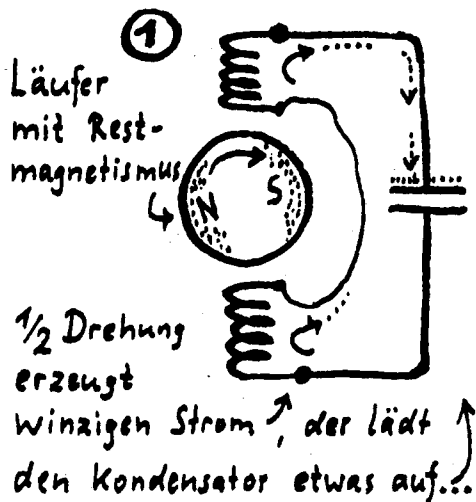
Wollen wir Strom erzeugen, wäre es das einfachste, den Motor am Netz laufen zu lassen, aber dabei schneller anzutreiben, als das Stromnetz es schafft. Dann scheucht das Magnetfeld des Polrades den Strom in den Statorspulen sozusagen "stärker" als das Stromnetz ihn liefert. Der Stromzähler läuft rückwärts (falls er keine Rücklaufsperr hat).

Das Stromerzeugen auf diese Weise klappt aber nur in einem ganz engen Drehzahlbereich wenig über der "Synchrodrehzahl" der Asynchronmaschine. Drehen wir zu schnell, kommt das Magnetfeld sozusagen "nicht mit" und die Stromerzeugung bricht zusammen. Drehen wir zu langsam, verbraucht die Asym Strom. Da die Windraddrehzahl in einem riesigen Bereich schwankt, ist die Regelung äußerst schwierig: Bei großen Industriewindrädern wird es mit Rotorblattverstellung, evtl. Getriebeverstellung und elektronischer Hochleistungs-Umformertechnik gemacht. Für unsere Zwecke viel zu aufwendig! (S.65)



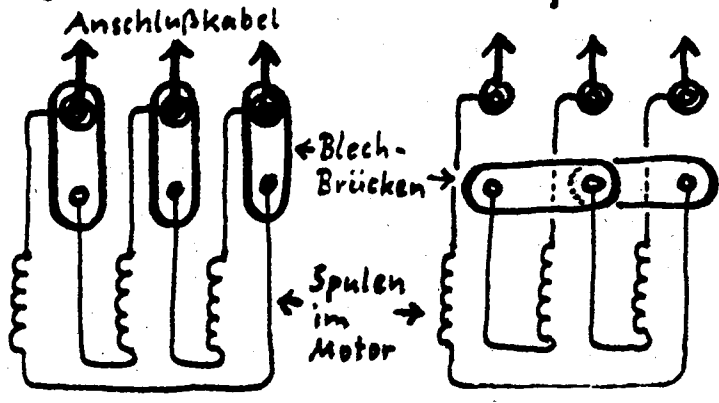
Wir können den Strom nur brauchen, wenn es egal ist, wie seine Frequenz schwankt, also im "Inselbetrieb" ohne Verbindung zum Stromnetz. Aber wie wird dann das Polrad magnetisch? Wie bei der LiMa helfen uns Restmagnetismus und Kondensatoren. Wir schalten drei gleiche Metallpapierkondensatoren (MP-Kondensatoren, z.B. aus alten Waschmaschinen) im Stern oder Dreieck an die Statorspulen des Asym (hier ebenfalls Stern- oder Dreiecksschaltung möglich).

## Selbsterregung mit Kondensatoren, hier nur 1 Phase eines 2-poligen Drehstrommotors betrachtet:



Drehen wir, erzeugt der Restmagnetismus minimal Strom, der in die Kondensatoren fließt, von dort zurück in die Statorspulen, fließender Strom verstärkt das Magnetfeld usw., schon erregt sich der Asym selbst, je größer die Kondensatoren, bei um so niedrigerer Drehzahl. Aber der zwischen Kondensatoren und Statorspulen fließende Strom macht Verluste. Daher nie zu große Kondensatoren! Weitere Variationsmöglichkeiten: Die gleichen Kondensatoren wirken in Dreieckschaltung geschaltet in voller Größe, weil jeder Kondensator mit beiden Anschlüssen direkt an die Spulen geschlossen ist. In Sternschaltung wirken sie kleiner (also höhere Selbsterregungs-Drehzahl, weniger Verluste), weil bei jedem Kondensator ein Ende nur mit dem Umweg über die anderen Kondensatoren angeschlossen ist. Bei den Spulen bewirkt Sternschaltung niedrigere Selbsterregungs-Drehzahl, weil die um  $\sqrt{3}$  höhere Spannung herauskommt, denn zum Strom aus der einen Spule kommt noch ein Teil des aus der anderen Spule hinzu, bevor der Strom am Anschluß ist. Sternschaltung bewirkt auch höhere Spannungsabgabe bei gleicher Drehzahl als in Dreieckschaltung. (s. S. 63)

# Drehstrommotor-Anschluß: (Photo S. 62) Typenschild:

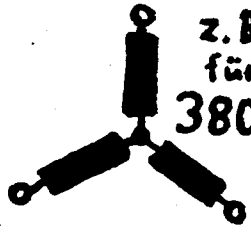


= Dreieck-Schaltung

Stern-Sch.



z.B. für 220 V.



z.B. für 380 V.

„D-Mot.“, 220/380 V,  
 $\Delta$ ,  $\Delta$  und Anschluß  
 wie links: sicher ein  
 Drehstrommotor. Gut!

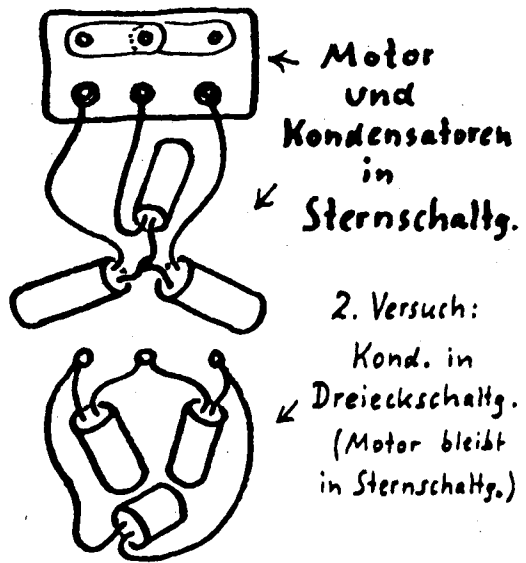
„E-Mot.“, 220 V~,  
 1-Ph., Hinweis auf  
 Hilfskondensator: „C=12µF“,  
 nur 2, 3 oder 4 Anschlüsse:  
 nur selten innen wie ein  
 Drehstrommotor gewickelt,  
 meistens nicht (nur 1 oder  
 2 Spulengruppen); schlecht.

Prüfen auf dem Schrottplatz: Selbsterregung geht in Sternschaltung fast immer, in Dreieckschaltung manchmal nicht. Für den 1. Versuch je kW - Motorleistung ca. 20µF Kondensatorgröße in Sternschaltung. Motor in Sternschaltung anschließen. Kondensatoren etwa gleich, ca. 25% Unterschied für Test harmlos.

Schnur um Achse wickeln, dran ziehen, evtl. mehrere Versuche, langsamer, schneller, ganz schnell. Selbsterregung spürbar (geht viel schwerer) und hörbar (Motor surrt). Meistens klappt es gleich. Evtl. ist die Kondensator - Größe falsch: andere nehmen oder anders schalten (4 Möglichkeiten), mit zu kleinen oder viel zu großen Kondensatoren geht's nicht.

Wenn trotzdem nichts passiert, anderen Motor suchen: einfache Motoren nehmen! Motoren mit 2 verschiedenen Drehzahlen gehen fast nie, und wenn, dann nur die höhere Drehzahl. Offenbar stören die Wicklungen sich gegenseitig bei Generatorbetrieb. Oft gehen ganz kleine Motoren auch nicht.

## Anschlußweise für 1. Versuch:



Motor und Kondensatoren in Sternschaltg.

2. Versuch: Kond. in Dreieckschaltg. (Motor bleibt in Sternschaltg.)

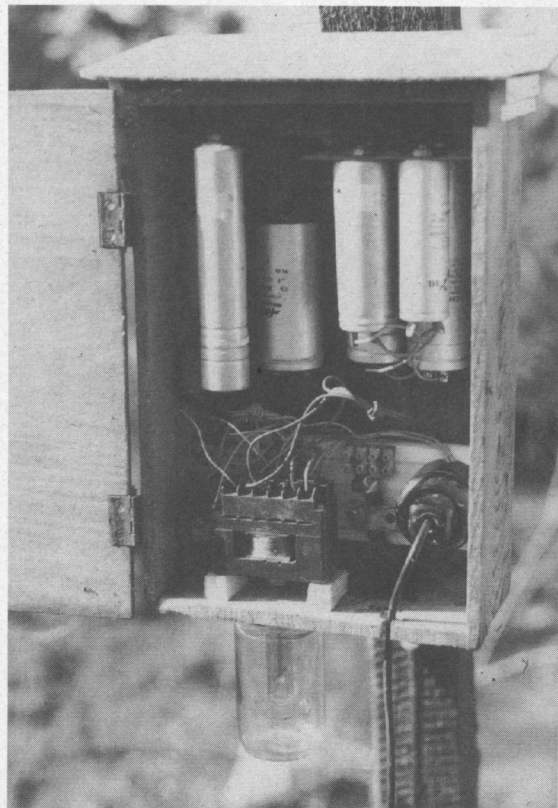
## Aufdruck auf den Kondensatoren:

„MP“ = Metall-Papier: gut, selbst-reparierend!  
 „340V ~ DB“ ← = Dauerbetrieb. Gut.  
 „260V ~ AB 15%“ ← = Aussetzender Betrieb, darf nur 15% der Zeit eingeschaltet sein, sonst aus! Wird sonst überlastet.  
 „400V =“ ← = Stromart. „~“ = für Wechselstrom geeignet. Gut. Nur für Starthilfe gut, im Dauerbetrieb nur mit viel niedrigerer Spannung!  
 Höchst Betriebs- spannung. Ausreichend? „=“ = Nur für Gleichstrom? An Wechselstrom Explosionsgefahr!  
 „ELKO“ = Elektrolyt-Kondensator. Nur für Gleichstrom! Polung beachten, sonst... WUMME!

(Motor in Dreieckschaltung: geht oft nur schlecht als Generator.)



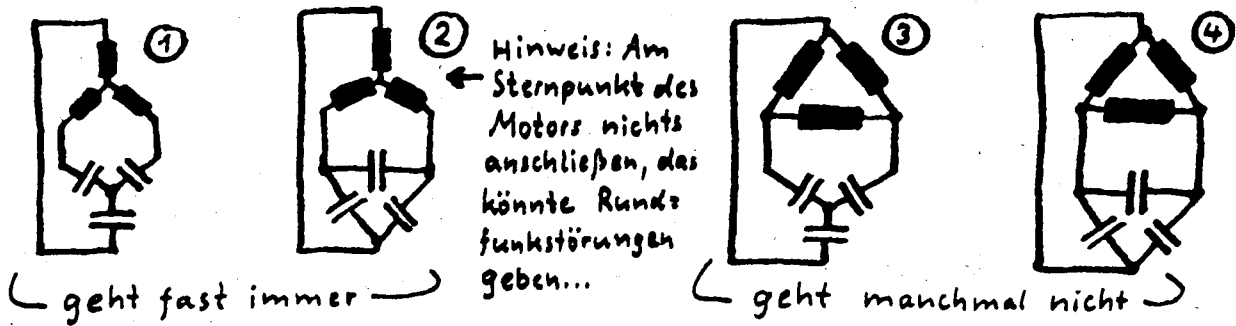
Drehstrom-Motoranschluss (in Sternschaltung, s.S. 61),  
 Typenschild: 0,45 kW Leistung bei 720 U/min, wenn  
 langsamer, weniger Leistung (s.S. 63).



Schaltkasten mit Erregerkondensatoren  
 (s.S. 60/61), Starthilfekond. und Schaltschütz (S. 64),  
 Glühbirne (im Glas) vom „Klick-klack-Trick“ (S. 64).

**Achtung, die Kondensatoren stehen unter Hochspannung! Nur "MP" - Kondensatoren (s.o.) sind sicher, einfache Kondensatoren nur für 1. Versuche brauchbar, ElKo's für Wechselstrom unbrauchbar (können explodieren!). Höchstspannung, Stromart und Betriebsart auf dem Typenschild beachten! Elko's sind nur für Gleichstrom gut! (s. S. 61)**

# Anschlußweise und Effekt (gleicher Motor, gleiche Kond., gleiche Drehzahl)



( geht fast immer )

( geht manchmal nicht )

Spannung:  $\frac{1}{1}$

Spannung:  $\frac{1}{1}$

Spannung:  $\frac{1}{\sqrt{3}}$

$\frac{1}{\sqrt{3}}$

Selbsterregungsdrehzahl:

mittel

niedrig

Selbsterregungsdrehzahl:

hoch

mittel

Kondensatoran:

wirken kleiner, mit weniger Spannung belastet

wirken voll, mit voller Spannung belastet

(wird bei größeren Kond. niedriger)

Kondensatoren: wie 1.,

wie 2.,

belastet mit weniger als

belastet mit

(Schaltung bei niedrigerer Drehzahl auch für niedrigere Spannung geeignet)

$\frac{1}{\sqrt{3}}$  Spannung.

$\frac{1}{\sqrt{3}}$  Spannung.

Richtige Kondensator - Größe feststellen: Könnte man auch berechnen. Ich habe es immer mit Versuchen gemacht. Fest steht die Drehzahl, ab der das Windrad zu laden beginnen soll, Übersetzung so, daß der Asym dabei nicht unter  $\frac{1}{3}$  Synchrondrehzahl läuft, sonst mieser Wirkungsgrad.

Es gibt Motoren mit diesen Synchrondrehzahlen:

3000	1500	1000	750	600	500 U/min	darunter
(2-poliger -	4-poliger -	6-poliger -	8-poliger -	10-poliger -	12-poliger Motor)	(mehr)
↑ Häufig →		selten	sehr selten ...			superselten

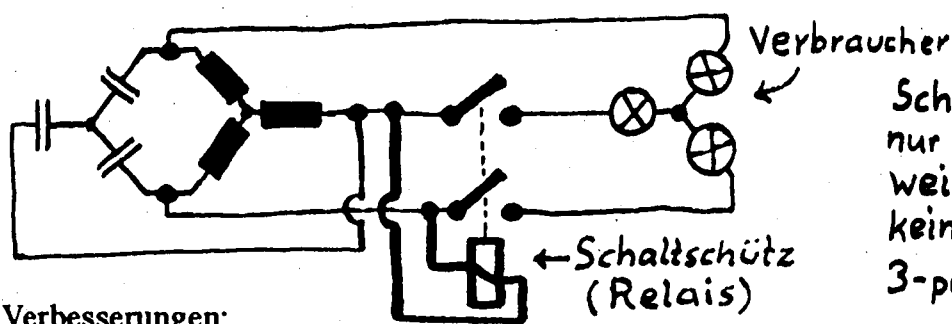
Bei der erzeugt er, als Generator verwendet, genau 50 Hz (wie das Atomstromnetz) und unter Last die Spannung wie auf dem Typenschild (ohne Last deutlich mehr!). Auf dem Typenschild steht die Drehzahl bei Vollast als Motor. Synchrondrehzahl ist die nächsthöhere in der Reihe hier: z.B. für 1380 U/min. 1500 U/min. synchron.

Wenn bestimmte Mindestspannung wichtig ist, die Mindestdrehzahl berechnen: z.B. Mindestspannung 110V = ca.  $\frac{1}{2}$  von 220V  $\Rightarrow$  Mindestdrehzahl ca.  $\frac{1}{2}$  Synchrondrehzahl bei Dreieckschaltung oder knapp  $\frac{1}{3}$  Synchrondrehzahl bei Sternschaltung. Bei Betrieb weit unter Synchrondrehzahl ist die Leistung auch entsprechend niedriger, Leistung = Magnetfeld x Drehzahl! Darum in dem Fall Motor mit laut Typenschild viel zu großer Leistung als Generator nehmen.

Mit der ermittelten Mindestdrehzahl drehen und die kleinstmöglichen Kondensatoren wählen, bei denen sich der Motor noch erregt (= magnetisiert), denn größere Kondensatoren machen mehr Verluste (deshalb funktioniert ein Asym mit übergroßen Kondensatoren auch nicht als Generator!) Die Magnetisierung bricht erst bei deutlich niedrigerer Drehzahl zusammen.

Zuschalten der Last: Zum Selbsterregen darf kein Verbraucher eingeschlossen sein, der würde den winzigen, vom Restmagnetismus erzeugten Strom gleich verbrauchen und die Kondensatoren würden nicht geladen. Erst wenn der Asym magnetisiert ist, Last zuschalten. Geht automa-

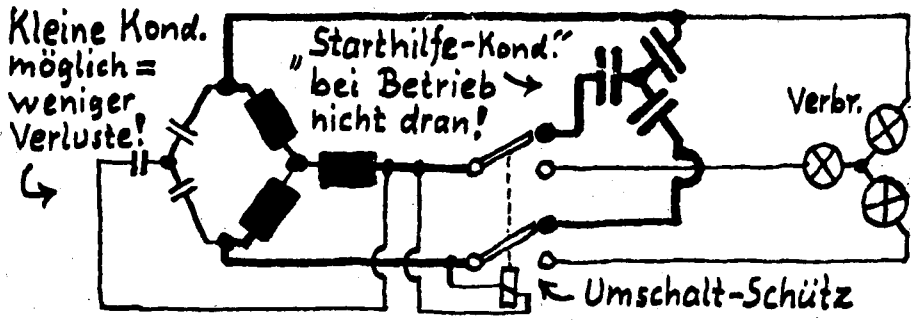
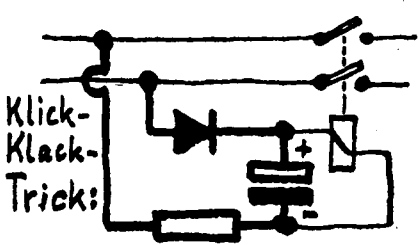
tisch mit einem Schaltschütz (= Starkstromrelais), zu finden in manchen Waschmaschinen, Motorschutzschaltern und elektrischen Schalttafeln auf dem Schrottplatz. Spannung der Relaispule beachten! Ihr winziger Verbrauch schadet nicht. So anschließen (Minimum):



Schaltschütz braucht nur 2-polig zu sein, weil durch nur 1 Draht kein Strom abfließen kann: 3-poliges Schütz nicht nötig!

Verbesserungen:

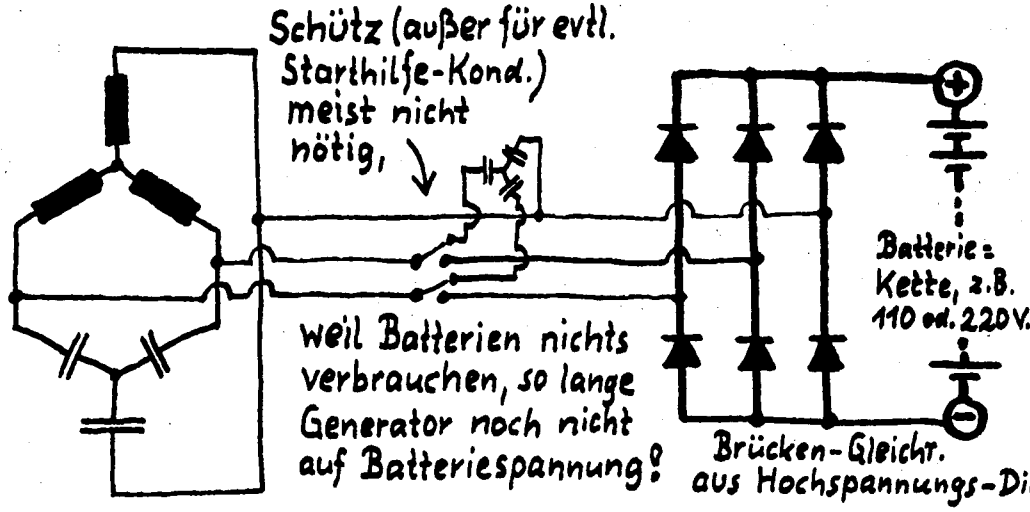
Damit das Relais bei niedriger Frequenz nicht rattert (Kontakte verbraten!) Gleichstrom machen mit hochspannungsfester Diode, Widerstand (z.B. kleine Glühbirne) vorschalten, da Relaispule Gleichstrom viel leichter durchläßt (brennt sonst durch!). Kondensator (ElKo 100µF) parallel zur Relaispule macht aus den Stromstößen gleichmäßigen Strom: "klick...klack" statt "ratatata".



Umschaltendes Schütz verwenden, 2 Kondensatorengruppen anschließen: zum Selbsterregen beide angeschlossen, danach eine weggeschaltet. Die, die dranbleibt, so klein wählen, daß der Generator bei Mindestdrehzahl gerade noch magnetisiert bleibt. So sind unter Last viel kleinere Kondensatoren möglich, deutlich besserer Wirkungsgrad!

Verbraucher: Durch eine schlechte Stromverwertung können wir uns viele Verluste einhandeln! Grundregel: Alle 3 Phasen immer möglichst gleichmäßig belasten.

Bei Verwendung direkt als Hochspannung z.B. zum Heizen (eigentlich schade um den edlen Strom) oder zum Laden einer Hochspannungsbatterie (über Brückengleichrichter) ist der Wirkungsgrad gut. Runtertransformieren auf z.B. 12 oder 24V bringt Riesen-Verluste, weil Trafos mit schwankender Frequenz kaum fertig werden. Hierfür sind Autolichtmaschinen viel besser!



Schütz (außer für evtl. Starthilfe-Kond.) meist nicht nötig, weil Batterien nichts verbrauchen, so lange Generator noch nicht auf Batteriespannung?

Beachte bei Berechnung der Generator-Mindestspannung: Zwischen ⊕ und ⊖ kommt  $\sqrt{3}$ -fach höhere Spannung raus als zwischen den Generator-Anschlüssen!

Brücken-Gleichr. aus Hochspannungs-Dioden.

# Wohin mit dem Strom ???

65

Die Speicherung des gewonnenen Stromes bleibt der heikelste Punkt: 1. geben Batterien bei weitem nicht das ab, was man hineinpumpt, 2. ist die Batterie - Herstellung äußerst umweltschädlich. Kaufen wir Batterien, fragt sich, wie viele Jahre das Windrad nun Atomstrom sparen muß, um den Umweltschaden vom Batterie - Herstellen und "Entsorgen" wieder wett zu machen. Also nehmen wir lieber höhere Batterie - Verluste in Kauf und holen bzw. tauschen die Batterien gratis bei der Schadstoffsammlung. s. S. 2.

Schön wäre es, den Strom direkt zu nutzen und gar nicht erst in Batterien verloren gehen zu lassen. Doch die Möglichkeiten sind bescheiden:

Wenn Du ein Gelände mit Riesen - Gefälle hättest, könntest Du ja mit dem Windrad Wasser in irgend einen großen Behälter vom Schrott pumpen und bei Strombedarf genau die nötige Menge durch eine kleine Turbine rauschen lassen, - für 99,99% der Windradbastler bleibt das Illusion.

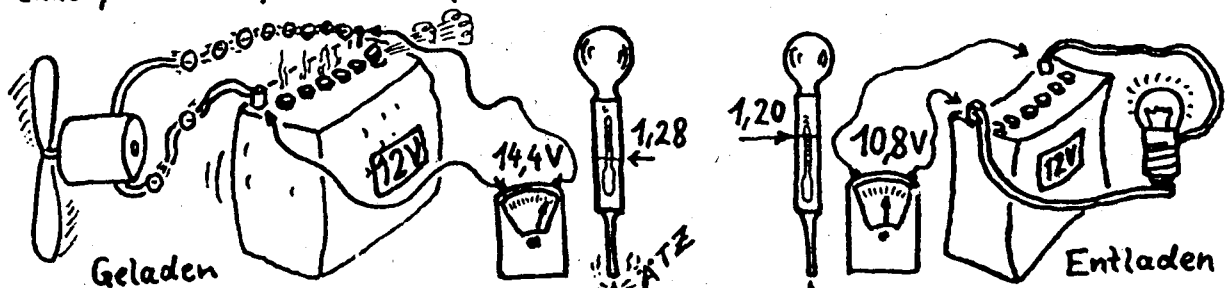
Vom Atomstrom - Netz wollen wir Selbstversorger sowieso nichts wissen, aber mit einem 220/380 -V-Generator wäre es möglich, ins Netz einzuspeisen. Doch das Stromnetz hat genau 50 Hz Frequenz, den ein Drehstrom - Asynchron - Motor als Generator nur in einem kleinen Drehzahlbereich halten kann. Ohne sehr aufwendige Regeltechnik geht es nicht. Am realistischsten wäre ein elektronischer Drehstrom - Drehstrom - Wandler statt mechanische Regelung am Windrad. Offiziell muß das Einspeisen genehmigt werden, aber illegal geht's auch, selbst wenn Dein Atomstromzähler nichts anzeigt. Er hat nämlich eine Rücklaufsperr! Baue einen eigenen Zähler ans Windrad, dann kannst Du ablesen, was es ins Netz geschickt hat, wieviel Du also guten Gewissens aus dem Netz wieder rausholen kannst. Offiziell lädst Du natürlich Batterien mit dem Windrad. Stelle Dir daher einfach eine alte Schrottbatterie hin, damit es so aussieht, als ob. Ansonsten kannst Du auf die Weise das Batterieproblem umgehen.

Mit Elektrolyse kann man auch Wasserstoff und Sauerstoff herstellen und daraus bei Bedarf Knallgas machen und verbrennen - saubere, aber gefährliche Energiespeicherung, für echte Nutzung viel Sicherheitstechnik nötig.

Der einzige wirklich einfache Weg, ohne Batterien auszukommen, ist leider nur, den Strom zu verheizen. So einfach, daß ich nichts weiter darüber zu schreiben brauche. Jeder Elektriker weiß Bescheid. Aber wohin mit dem Strom im Sommer? Also doch Batterien...

## Batterien richtig behandeln:

Kontrolliere den Ladezustand mit Voltmeter oder Säureprüfer. Nicht höher laden, nicht tiefer entladen, nicht entladen stehenlassen! (Werte für 12-V-Bleiakku)



Die gewöhnliche Autobatterie, ein 12-V-Bleiakku, ist leer bei 10,8 Volt, voll bei 14,4 Volt. Höher laden und tiefer entladen schadet der Batterie schon nach kurzer Zeit. Steht eine Batterie unter 10,8 Volt entladen länger herum, ist sie meist völlig ruiniert! Dauernder Ladestrom von

mehr als 1/10 der Ampèrestundenzahl, die draufsteht, schadet ebenfalls. Kurzzeitig macht's nichts (also eine 96-Ah-Batterie max. mit ca. 9A laden).

Dementsprechend schlieÙe genügend Batterien ans Windrad, aber nicht zu viele, denn jede Batterie hat eine Selbstentladung und bei zu vielen Batterien friÙt die Selbstentladung einen Großteil des Stromes auf. Außerdem schadet auch zu schwacher Ladestrom: Die Batterie muß ab und zu mal blubbern, sonst sinkt die vom Laden konzentrierte Säure nach unten, oben bleibt die zu dünne Säure stehen, in der die Platten von oben her sulfatieren. Hast Du einige Wochen kaum Wind, schwenke die Batterien gelegentlich etwas hin und her, um die Säure zu durchmischen.

Was beim Aufladen blubbert, ist Knallgas, hochexplosiv! Vermeide jeden Funken bei Batterien, die geladen werden. Der Batterieladeplatz muß gut belüftet und sollte zum Wohnraum abgeschottet sein. Ein alter Kühlschrank als dichter Batterieschrank mit Luftrohr nach draußen hat sich bewährt.

PKW - Batterien vom Schrott halten meist nicht länger als noch 1 Jahr, dagegen waren LKW - Batterien mit der Bezeichnung "rüttelfest" meistens noch jahrelang äußerst zuverlässig. Offenbar zerfallen deren Platten nicht so leicht. Wirklich als Dauerbatterien gebaut sind solche von Notstromversorgungen für Krankenhäuser, Militär, Telefonanlagen usw. Meistens sind es einzelne, durchsichtige 2 - Volt - Zellen. Wenn Du so etwas findest, nimm es auf jeden Fall mit. Ausführliche Hinweise zum Aussuchen und Verbessern von Schrottbatterien im Windheft 2.

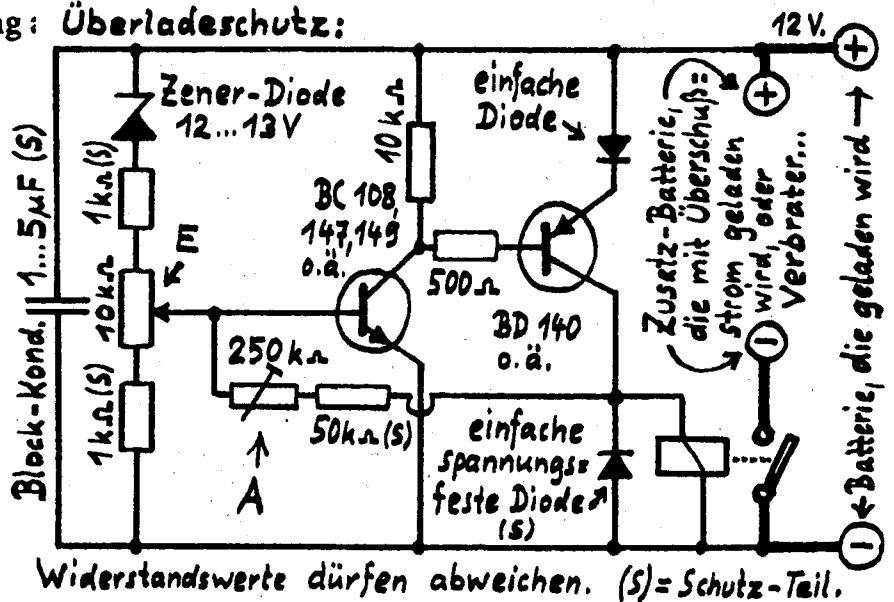
Eine geeignete (!) Überladeschutzschaltung gibt auch ohne Beobachten die Sicherheit, daß die Batterie nicht überladen wird. Der Regler an der LiMa muß ja weg, damit das Windrad bei vollen Batterien sicher bleibt und keine Überdrehzahl kriegt. Gegen zu tiefes Entladen sichert diese Schaltung. Richtet man sich danach, wann das Licht dunkler wird, ist es meistens schon zu spät...

Vorsicht bei handelsüblichen Laderegul- und Schutzschaltungen! Die Sorte, die die Batterie vom Stromerzeuger trennt, sobald die Batterie voll ist (üblich und harmlos bei Solarzellen) zerstört jede LiMa im Nu! Die LiMa darf nie ohne angeschlossene Batterie laufen, sonst brennt sie durch! Verwende nur Schaltungen, die parallel zur Batterie angeschlossen werden, wo also die Ladestromkabel vom Windrad zur Batterie immer direkt angeschlossen bleiben.

Dann achte auf den "Ruhestromverbrauch": Manche Schaltungen verbraten ständig merklich Strom, auch bei fast leerer Batterie! Willst Du, statt Überschuß - Strom zu verheizen, damit eine Reservebatterie laden, sollte die Schaltung mit einem Relais statt mit Halbleitern arbeiten: Am Halbleiter (Transistor etc.) "Staudamm - Effekt": 0,7V werden verheizt!

Hier meine Selbstbau - Schaltung: Überladeschutz:

Ganz einfache Bauteile!  
Ruhestromverbrauch ca. 0,01W!  
Fernlicht-Abblendlicht-Relais für die Last, schaltet problemlos bis 25 Ampère zu!  
E = Einschaltspannung einstellbar, z. B. 14,4 Volt  
A = Abschaltspannung einstellbar, z. B. 1/2 Volt weniger.



Widerstandswerte dürfen abweichen. (S) = Schutz-Teil.

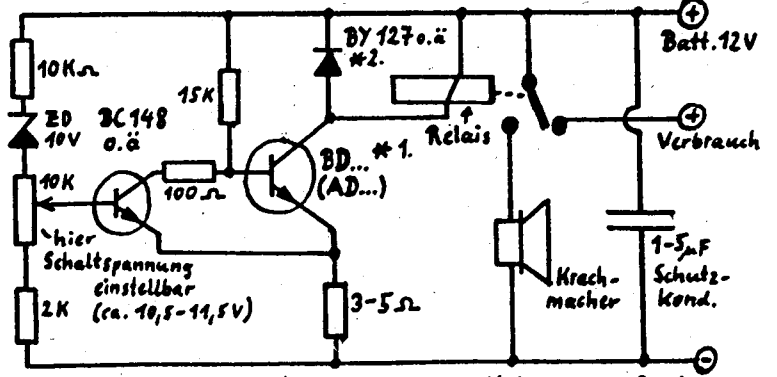


### Tiefentladeschutz:

Wenn Batterie leer, schaltet das Relais die Verbraucher ab und evtl. ein Warngerät (z. B. aus altem Quarz-Wecker) zu. Ruhestrom = verbrauch wenige Milliwatt!

Achtung: So stromsparende Schaltungen reagieren auch schon auf „Kriechstrom“ (durch Dreck und Luftfeuchte). Zum Schutz dagegen fertige Schaltung mit Lack einpinseln!

Ruhestromverbrauch wenige Milliwatt?

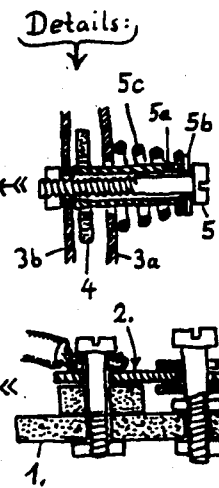
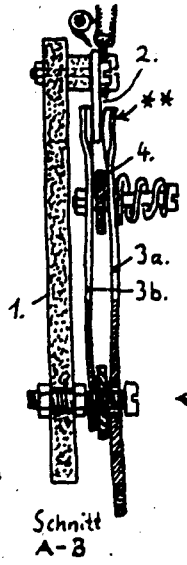
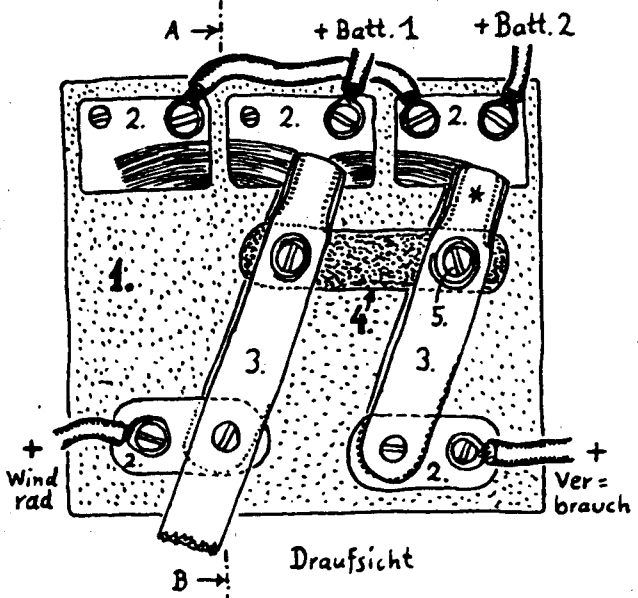


- \* 1. Stärke des Transistors entsprechend Verbrauch des Relais, bei kleinen Relais reicht eine sehr starke C-Type.
- \* 2. Schutzdiode gegen Spannungsspitzen vom Relais

Eine Batterie gleichzeitig zu laden und zu entladen ist ungünstig, denn Lade- und Entladestrom schwanken je nach Wind und Verbrauch so, daß die Batterie dauernd im Wechsel voller und leerer wird. Das kehrt jedesmal den chemischen Vorgang in der Batterie um, und jede Umkehrung verschleißt die Batterie.

Daher sind 2 Batterien (oder Batteriegruppen) und ein mechanischer Umschalter gut, so gebaut, daß immer eine Gruppe nur entladen und eine nur geladen wird und daß niemals keine Batterie angeschlossen ist (superwichtig, sonst brennt die LiMa ruckzuck durch!). Statt von Hand umzuschalten, kann einer kleiner Elektromotor es machen, der Strom von der Überlade- und der Tiefentladeschutzschaltung kriegt. Achtung bei Batteriegruppen: Ist von parallelgeschalteten Batterien eine kaputtgegangen, entlädt sie auch die intakten Batterien!

ca. 1/3 - 1/4 tatsächlicher Größe. Hohe Stromstärke verlangt große berührende Blechflächen?



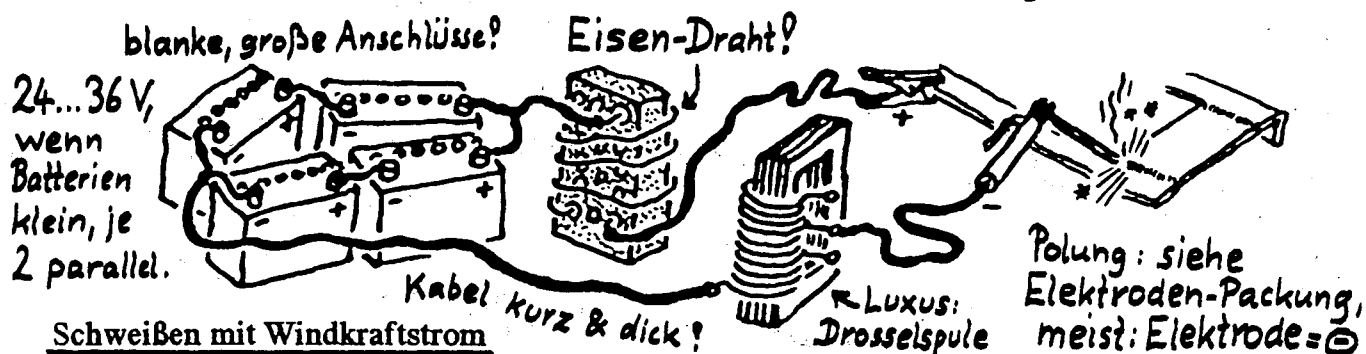
1. Grundplatte, Isoliermaterial (Pertinax od. ölgetränktes Holz)
  2. Kontaktbleche (ca. 1mm Messing)
  3. Kontaktfinger, einer verlängert als Schalterhebel  
3a. oberer -, 3b. unterer Kf.
  4. Verbindungsstange (Isoliermaterial, z.B. Plastikzylinder)
  5. Schraube mit  
a. Distanzröhrchen (alte Antenne)  
b. evtl. Unterlegscheibe  
c. Druckfeder, drückt die Kontaktfinger auf die Kontaktbleche.
- \* Kontaktfinger breiter als die Lücke zwischen den K-blechen?  
\*\* Kontaktfinger-Kanten hochgebogen?

## Was man mit dem Windradstrom alles kann...

12 Volt aus den Batterien sind vielseitig verwendbar. Das Wichtigste dürfte Licht sein. Die Stromausnutzung ist dank der hohen Temperatur des dicken Glühfadens besser als bei 220 - V - Glühlampen. Eine einfache 21W - Auto - Blinkerbirne leuchtet fast so hell wie eine 40W - Birne für 220V, eine 20W - Halogenbirne aus dem Elektroladen noch viel heller: Energiesparlicht ohne den gesundheitlichen Elektromog aus Energiesparlampen und Wechselstromnetz!

In Batteriegeräte wie Radio oder Recorder ohne 12V - Anschluß stecke Besenstiele mit Kabeln dran ins Batteriefach, führe die Kabel raus und schließe sie an den Windstrom an, von dem Du vorher in Dioden soviel verbrätst, daß gut die Spannungen der Batterien, die früher im Radio waren, rauskommen. Beispiel: drin waren  $6 \times 1,5V = 9V$ . 12V Windstrom erst durch 4 Dioden in Reihe (je  $0,7V$  Staudammeffekt =  $2,8V$ ) schicken, bleiben  $9,2V$  übrig; paßt prima! Und die Dioden schützen vor falsch gepoltem Anschließen.

Inzwischen gibt es alle nur erdenklichen Haushaltsgeräte auch in 12 - Volt - Ausführungen im Campingbedarf, weil man heute statt mit Rucksack und Zelt mit rollenden Haushalten unterwegs sein muß (!?!). Natürlich ist auch viel unnützer Schnickschnack dabei, oder furchtbar gierige Stromfresser, wie Kühlschränke mit 12V - Heizspiralen. Motorgeräte können wir oft umbauen, indem wir Autoelektrik einbauen. Sogar windstrombetriebene Waschmaschinen sind so möglich, wenn das Wasser statt elektrisch mit Sonnenkollektoren, Feuer oder Gas geheizt wird.



Schweißen mit Windkraftstrom ist keine Zauberei, die Batterien sammeln mit der Zeit die "kleinen Mengen" Strom vom Windrad, können ihn aber "auf einen Schlag" abgeben: der höchste zulässige Strom, der auf einmal entnommen werden darf, steht auf der Batterie, z.B. 12V 110Ah 450A. Doch darunter leidet die Batterie, lieber nur bis  $1/4$  dieses Stromes belasten, bei kleinen Batterien besser zwei parallel schalten. Wir brauchen 24 - 36 Volt. Ich habe auch schon mit 3 superschrottigen PKW-Batterien prima geschweißt.

Wichtig: dicke Kabel (wie "Starthilfe - Kabel" von Nachbar's Autozubehör), gute, großflächige Anschlüsse und der "automatische Schweißstromregler": nicht zu dicker Eisendraht (Zaundraht um Ziegelstein wickeln), Eisendraht läßt kalt (geringe Last) Strom leicht durch, wird er heiß (Überlast), steigt sein Widerstand rapide und begrenzt den Strom. Für Elektroden 2 - 2,5 mm Ø, ca. 3 - 5 m Draht 2 mm Ø, wahlweise einen oder zwei parallel. Günstig sind Abgriffe zum Stromstärke - wählen.

Das Schweißen geht sauberer als mit üblichen Atomstrom - Schweißtrafos! Superedel ist noch eine zusätzliche Drosselspule (aus dickem Schrott - Trafo). Aus Baukalk soll man Elektrodenumhüllungen selbst machen können. Wenn das gelingt, wären wir völlig "kommerz - unabhängig"!

Für 12 Volt muß Du dicke Kabel legen, je länger der Weg und je höher die Leistung, umso wichtiger. Denn hier sind die Ströme hoch und der Widerstand dünner Kabel verursacht große Verluste!

1 mm<sup>2</sup> Kupferkabel hat ca. 18 Ω Widerstand pro km.

Für Dauerbetrieb: ca. 5% Verlust möglichst nicht überschreiten!

**Faustformel:**

$$\% \text{ Verlust bei } 12 \text{ Volt} = \frac{\text{Länge (m)} \cdot \text{Strom (Amp.)}}{\text{Querschnitt (mm}^2\text{)} \cdot 6}$$

Für 5% Verlust erlaubte Kabellänge (Hin- und Rückweg beachten):

für Strom bei	1mm <sup>2</sup>	2,5"-11-	6"-11-	Querschn.
2 Amp.	16	40	100	} ca. Meter
5 "	6	16	40	
10 "	3	8	20	

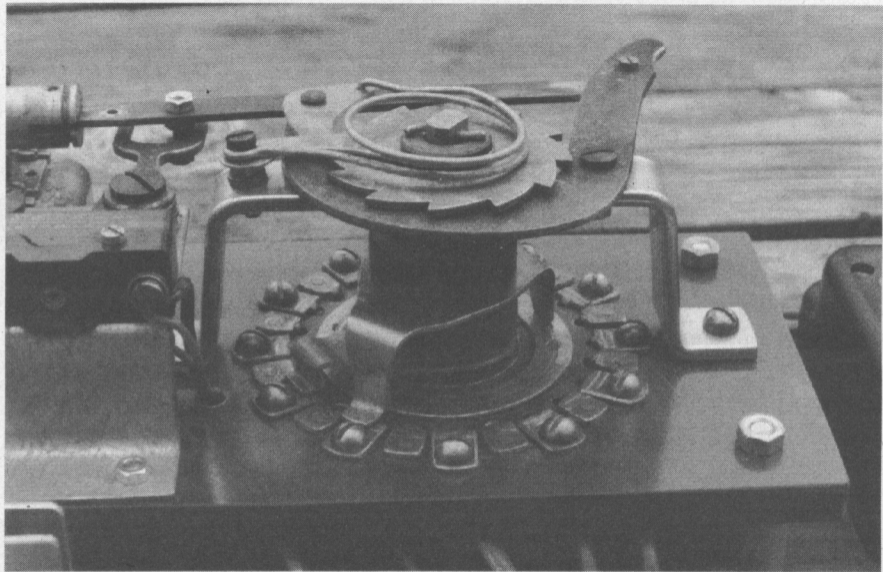
Manches handliche 220V - Gerät ist schwer umzubauen oder die Mühe lohnt nicht, weil wir es nur selten benutzen (z.B. Elektrowerkzeuge). Hier kann ein Umformer von 12 auf 220V sinnvoll sein, während er für den alltäglichen Bedarf viel zu viel Verluste macht. Grundregel: Was irgend geht, direkt als 12V - Strom verbrauchen.

Laden wir eine Batteriekette von 110 oder 220V, können wir den Hochspannungs - Gleichstrom in allen 110 - bzw. 220V - Geräten direkt verbrauchen, die auch für Gleichstrom geeignet sind: Glühbirnen, Motorgeräte mit Allstrommotoren (hat Kohlebürsten), wie Bohrmaschine, Staubsauger usw. ohne elektronische Regler! Heizgeräte ohne Wechselstrom - E - Motor, also Fön älterer Bauart, Heizsonne, Bügeleisen oder Warmwasserboiler gingen auch, aber wie gesagt, schade um den Strom! Typenschild beachten: manchmal steht "220V~ " drauf, obwohl sie auch für Gleichstrom gehen. Im Zweifelsfall Elektriker fragen!

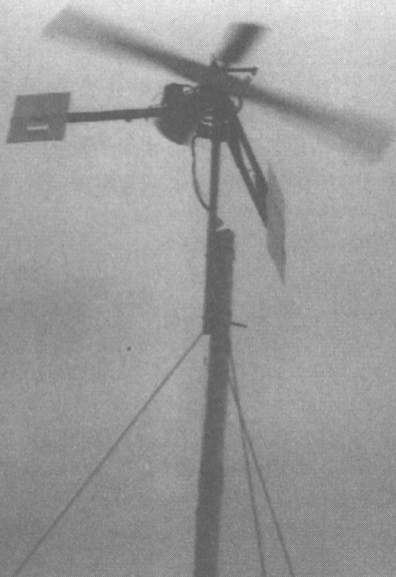
An 220V - Gleichstrom gehen nicht (oder sogar kaputt!): Alles mit Trafo's, Umformern und Wechselstrommotoren (die leise laufenden ohne Kohlebürsten): Energiesparlampen, Neonröhren, Kühlschrank, Heizlüfter usw.

Das 220V - Gleichstromnetz ist ebenfalls frei vom Elektrosmog der üblichen Stromnetze. Vorteilhaft ist auch, daß wir in einem Haus die vorhandenen Kabel ohne nennenswerte Stromverluste weiterverwenden können.

Wollen wir 12V aus der Batterie - Kette holen, darf immer nur so viel aus jeder Batterie verbraucht werden, daß alle immer etwa gleichmäßig geladen bleiben, sonst blubbern alle Batterien vor Überladung, während eine leer ist. Entweder Dioden zum Verbrauchsstrom, oder motorbetriebener Umschalter, der, wenn die Batterie z.B. 0,5 Volt leerer ist, auf die nächste umschaltet. Strom für den Motor über die Tiefentladeschaltung(anders eingestellt).



*Selbstgebauter motorbetriebener Umschalter für 12 V aus 120-V-Kette.*



Dies ist ein früheres Getriebe - Windrad von uns (von 1982), zwar nicht ideal, aber mit interessanten Details:

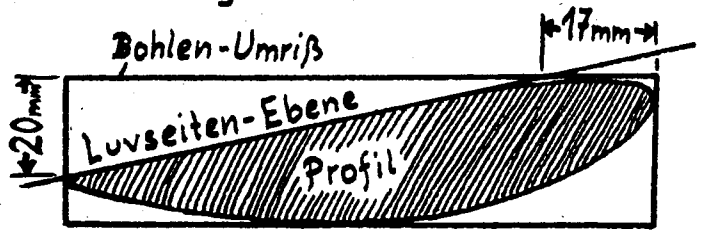
- Repeller: äußerst einfacher Zweiflügler, zwar schlechtere Laufeigenschaften, aber halb so viel Arbeit wie an einem Dreiflügler bei gleichem Leistungs- und Drehzahlbereich. Daher kurzer Bauplan hier:

Bohle: 2,7 m lang, 15 cm breit, 32 mm dick (gehobelt 29 mm)

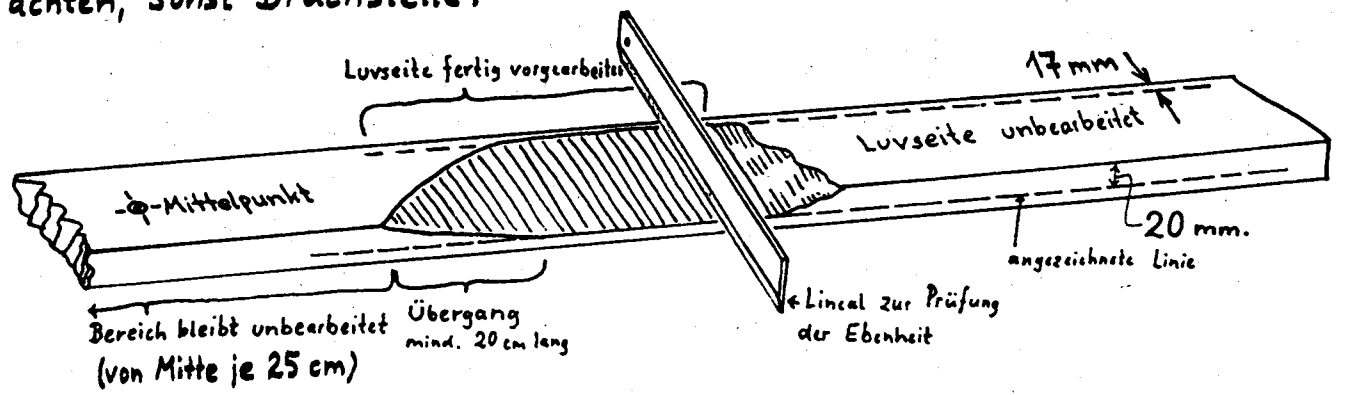
Profil 3 vom 3-Flügler nehmen (s.S.14), wird auf ganzer Länge gleich!

Unbedingt auf langen Übergang achten, sonst Bruchstelle!

Profil liegt so in der Bohle:



(zu dick gezeichnet, damit erkennbar)

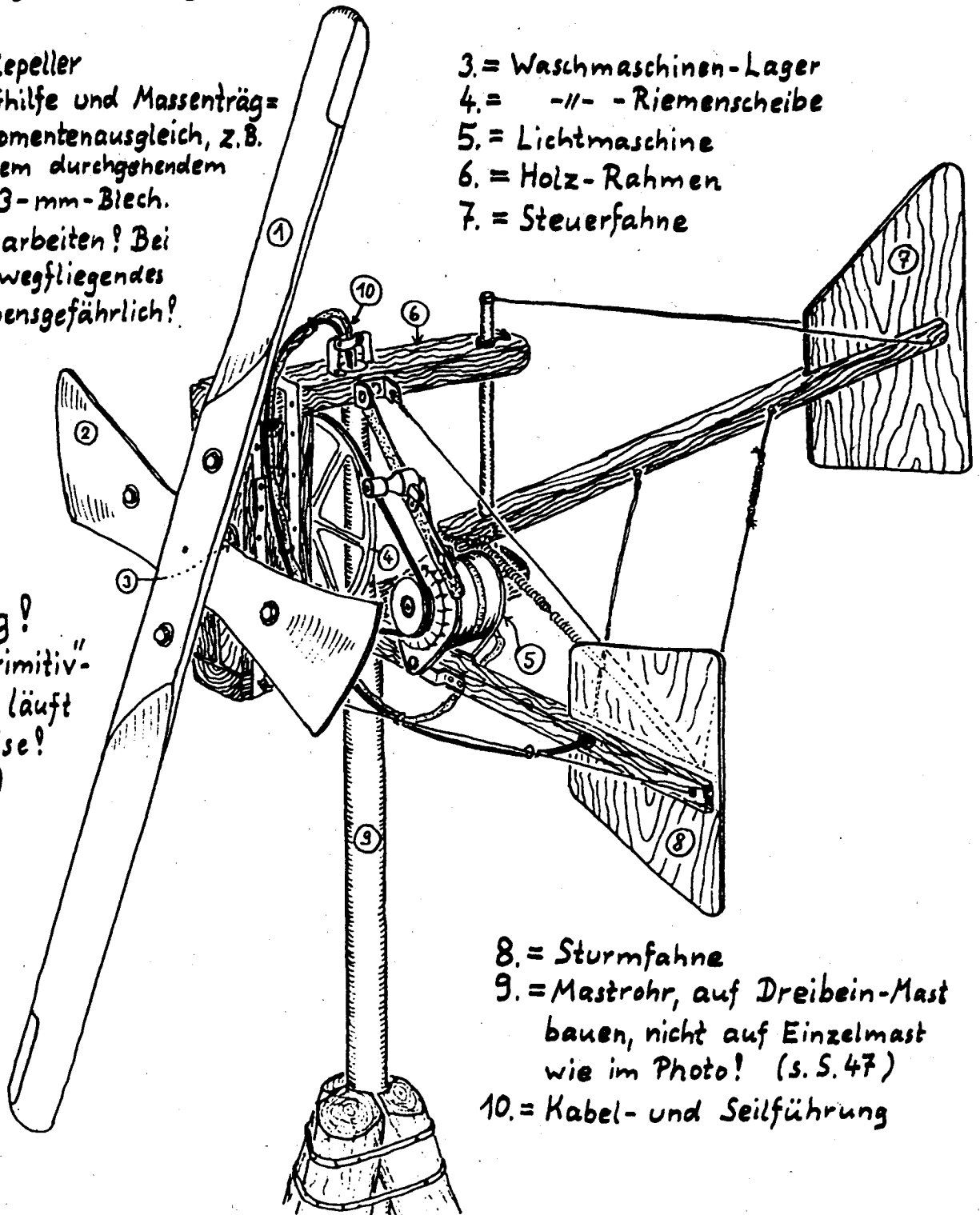


- Quer zum Repeller kurze, schwere Flügel, als Anlaufhilfe auch beim Flachriemengetriebe ratsam. Als Massenträgheitsmomenten - Ausgleich gegen Erschütterungen sehr wichtig.
- Lager und Riemenscheibe aus alter Waschmaschine: Sehr gute Repeller - Befestigungsmöglichkeit, stabil und wasserdicht, trotzdem nur Notlösung: Schwergängiger Keilriemen, Windrad lädt deshalb erst ab 5,5 m/sek, außerdem keine Bremse.
- Rahmen und Steuerfahne aus Holz, empfehlenswerte Tricks für Holz statt Eisen! (Details für's Autoradlager - Windrad passend s. Zeichnung b.w.).
- Sturmsicherung mit Seitenfahne, aber nicht durch Gewicht am Seil, sondern mit Zugfeder im Wind gehalten: Seil beeinträchtigt Sturmsicherung nicht (Vor- und Nachteile s.S. 35 ). Konstruktionsdetails empfehlenswert für Holzbau!
- Seilführung im Bowdenzug schlecht! Seilrollen nehmen.

1. = Holz-Repeller  
 2. = Anlaufhilfe und Massenträgheitsmomentenausgleich, z.B. aus einem durchgehendem Stück 3-mm-Blech. Solide arbeiten! Bei Bruch wegfliegendes Teil lebensgefährlich!

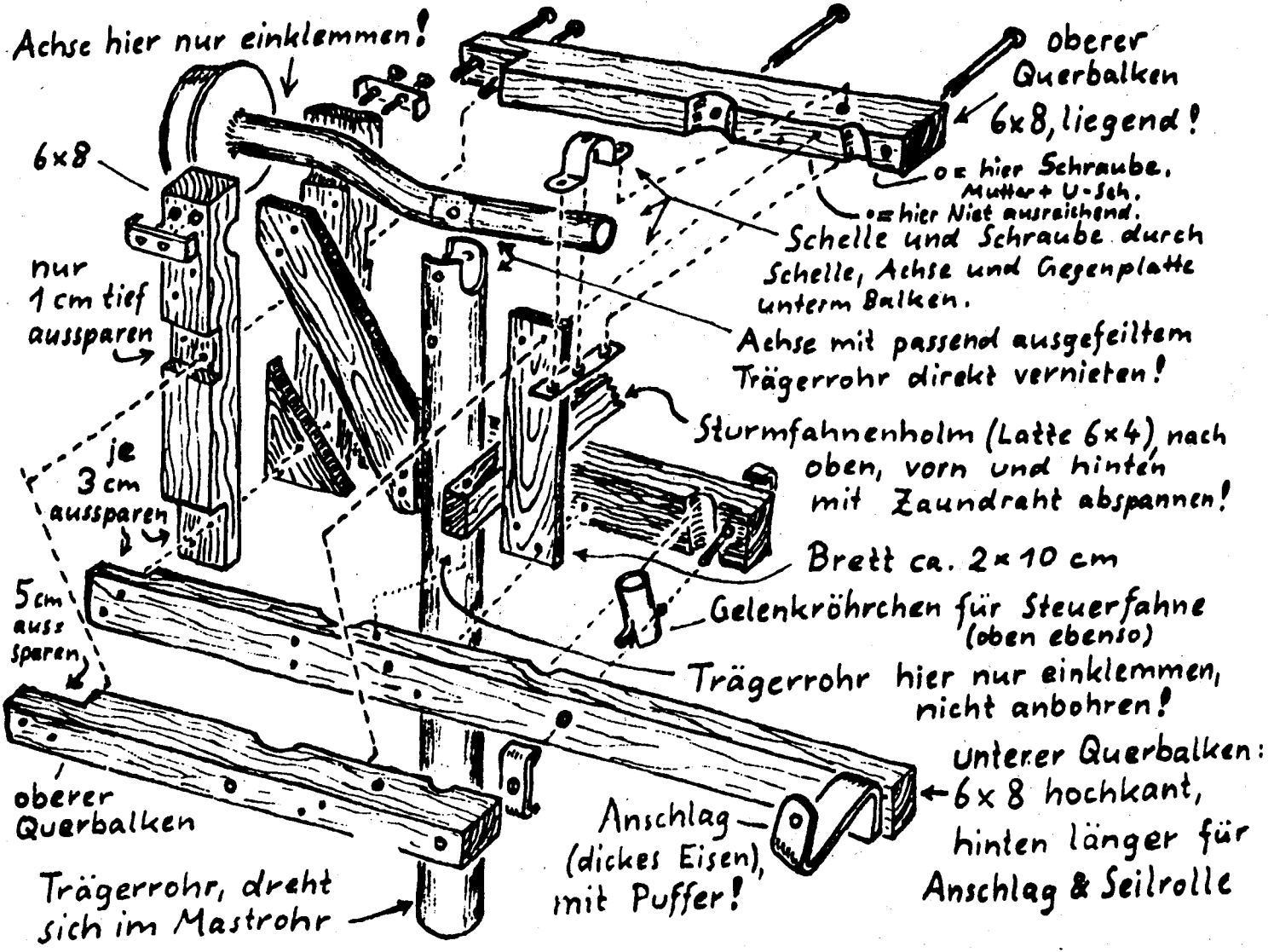
3. = Waschmaschinen-Lager  
 4. = -//- - Riemenscheibe  
 5. = Lichtmaschine  
 6. = Holz-Rahmen  
 7. = Steuerfahne

Achtung!  
 Dieser „Primitiv“-Repeller läuft nicht leise!  
 (s. S. 9)



8. = Sturmfahne  
 9. = Mastrohr, auf Dreibein-Mast bauen, nicht auf Einzelmast wie im Photo! (s. S. 47)  
 10. = Kabel- und Seilführung

# Rahmen aus (gutem!) Bauholz für bis 3m Rep.-φ



Niet: z.B. passend abgesägter großer Nagel (5x140, 6x180 o.ä.) & große Unterlegscheiben.

**Achtung:** Auto-Achse und Trägerrohr in höchstbelasteten Zonen nicht anbohren, nur einklemmen.

### Steuerfahnenlager:





## Nützliche Adressen:

73

Ich schreibe die "Einfälle" - Hefte nicht, damit sie irgendwo verstauben, sondern um möglichst vielen Selbstbauern zu helfen. Manche Bastler wünschen sich auch persönliche Hilfe, die ich natürlich nicht allen geben kann. Gemeinsam geht's besser: Wer ein Windrad gebaut hat, schreibe mir bitte ebenso, wie wer Hilfe dabei sucht, damit ich Windradbauer miteinander in Verbindung bringen kann. Gelegentlich kann ich auch gute Bauteile (z.B. große LKW - LiMas) oder ein ganzes Windrad aus meinem Bastelbestand oder von einem anderen Bastler weitervermitteln: Christian Kutzt, Dammstraße 44 Hof, 24103 Kiel - kein Telefon.

Kleine Dauermagnet - Generatoren baut in professioneller Kleinstserien - Qualität: Peter Rombach, An der Kesselschmiede 7, 52223 Stolberg, Tel.: 02402/24216. Für ein Windrad dieser Bauart im Schwachwindgebiet besonders interessant, extrem niedertourig. Auf der Rückseite des Generators ist statt des (im Freien nicht nötigen) Lüfterrades eine AutoliMa als Starkwindgenerator ankuppelbar. Repellerflügel, evtl. auch den nach diesem Bauplan, will künftig bauen:

*Jugendwerkstatt Spinnereistr. 1-5, z.Hd. Mstr. Hötgen, 52222 Stolberg, 02402/26417.*

Individuell und sehr pfiffig bastelt Wolfgang Schwarz, Am Bubengarten 4, 57489 Drolshagen - Schlade auch an größeren Dauermagnet - Generatoren.

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Wer diese Hefte kauft, aber nichts danach baut, vergrößert den Müllberg !!

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ISBN 3 - 924038 - 46 - 5

Einzelpreis 6,- DM

Hinweis: Unsere Baupläne sind gründlich erprobt und haben sich bewährt. Für sorgfältige Ausführung und Gebrauch ist jeder selbst verantwortlich, wir lehnen jede Haftung ab.

**120 Watt Wind Generator - HA5 4PR. Jemmett Engineering UK 1994.**

120 WATT WIND GENERATOR

This manual gives full details of how to construct a small high performance wind generator for 12 volt battery charging.

The wind generator starts to charge at 11-12 mph wind speed and gives its rated output of 120 watts at approximately 25 mph wind speed.

No voltage regulator is required for this size of generator and the output current/voltage varies according to the state of charge of the battery. The rated output of the generator is 8 amps at 15 volts, and the maximum 10 amps at 16 volts (160 watts).

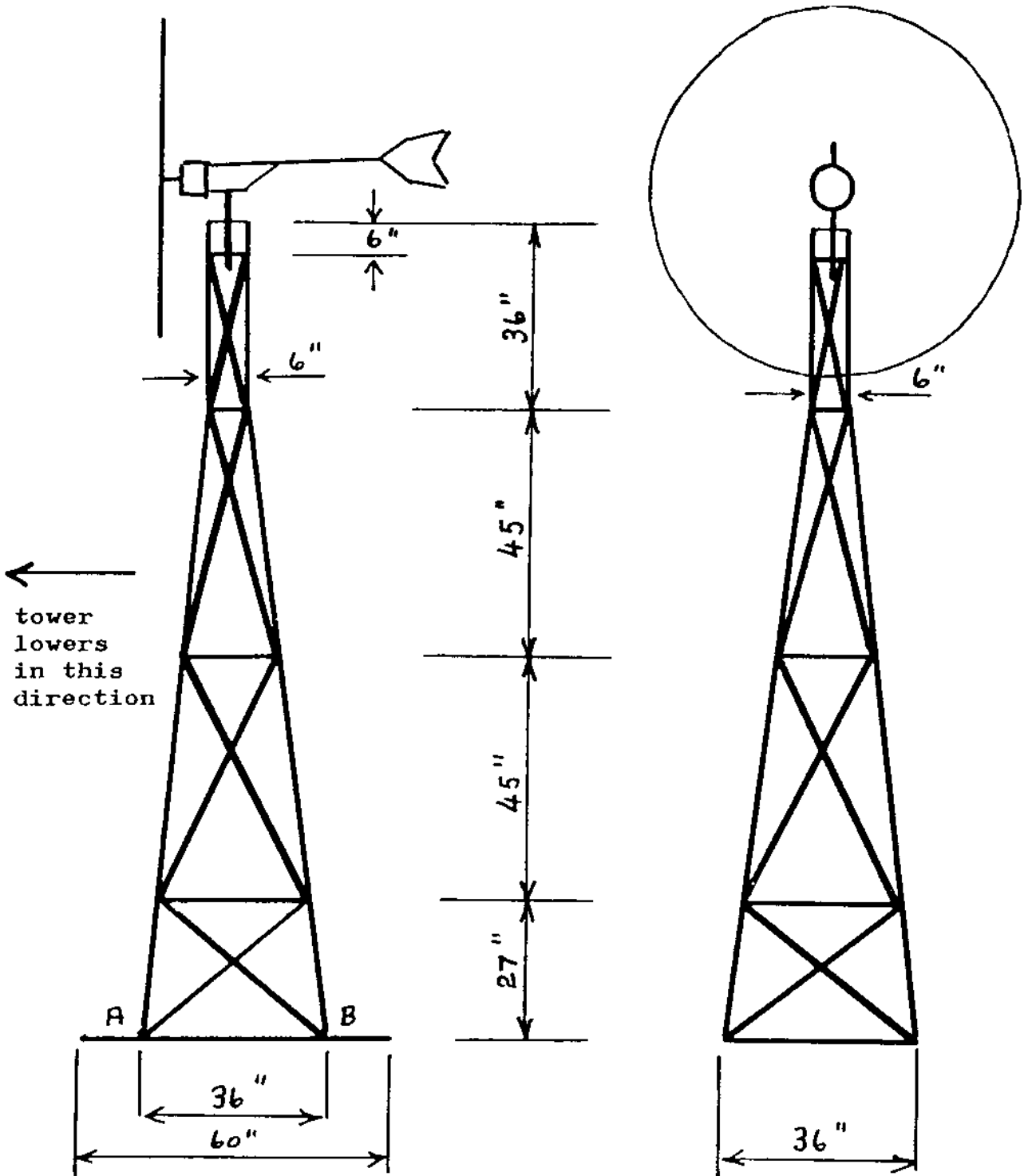
The design uses a Lucas 11AC car alternator which is modified to run at low rpm. It is driven directly by a high speed 5 foot diameter two bladed propeller.

The construction can be divided into five parts :-

1. Rewinding the alternator.
2. Building the wind generator frame.
3. Building the propeller.
4. Building the tower.
5. Building the control box.

The performance of wind generators depends largely upon the propeller and alternator being correctly matched, and these items must be very carefully constructed. Probably the most difficult job is rewinding the alternator and so this is described in great detail.

FIG. 9 - TOWER



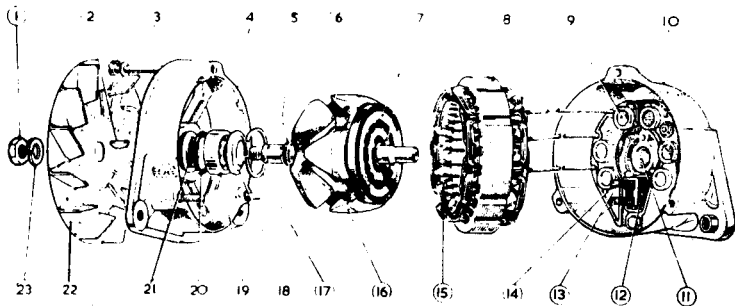
NOTES:

1. All the tower is made of 1" x 1" mild steel angle welded together.
2. The tower is hinged at A on 5/16" (8mm) bolts and has locking 5/16" bolts at B.
3. The windgenerator bearing shaft tube is held on the tower by two U bolt clamps 6 inches apart.

PARTS LIST

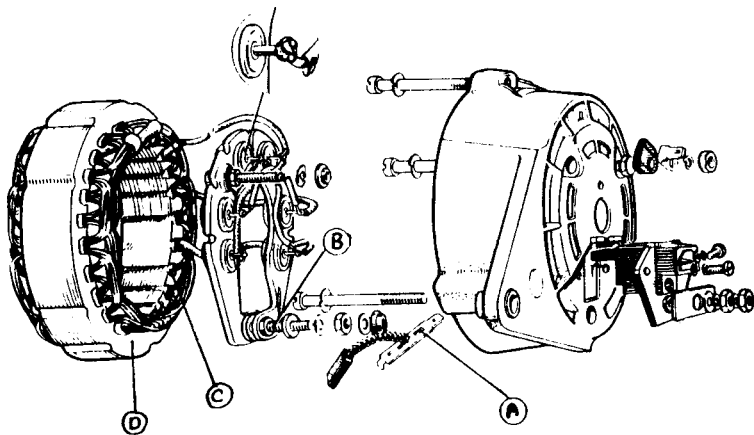
<u>Alternator</u>	Lucas 11AC car alternator (see text)	1 off
	Enamelled copper wire 21 swg	1 lb reel
	Polyurethane varnish (clear)	small tin
	Resistor 1.5 or 1.8 ohms 20 watt rating	1 off
<u>Generator</u>	$\frac{3}{4}$ " diameter mild steel tubing	7 $\frac{1}{2}$ ft
<u>Frame</u>	1" x $\frac{1}{8}$ " mild steel strip	2 ft
	20 swg mild steel sheet (or 18 swg alum.)	3 sq.ft
	$\frac{1}{8}$ " gauge mild steel sheet	24 sq. in
	2" diameter, $\frac{3}{4}$ " bore steel washer	1 off
	$\frac{5}{16}$ " diameter 2" bolts with nuts	3 off
	$\frac{1}{4}$ " diameter 1" bolts with nuts	4 off +
	$\frac{1}{4}$ " diameter 2" bolt with nut	1 off
<u>Bearings &amp; Slip Rings &amp; Brushes</u>	Plastic bearing material, Nylon, Acetal, etc	
	2" diameter x 1"	1 off
	$\frac{1}{2}$ " " x 3"	1 off
	1" " x 1"	1 off
	$\frac{1}{4}$ " diameter copper tube (water pipe)	2 in
	Car alternator/dynamo/starter motor brushes and brush holder	2 off
	Grub screw	1 off
	10 amp rating red & black wire	as req.
<u>Propeller</u>	65" x 3 $\frac{1}{2}$ " x 1" wood (see text)	1 off
	Polyurethane varnish or epoxy paint.	small tin
	Mild steel strip 2" x $\frac{1}{4}$ "	8 in.
	$\frac{3}{8}$ " bolts 2" long with nuts & washers.	2 off
	Balance washers.	as req.
<u>Control Box</u>	Aluminium/steel box 8" x 6" x 3" (approx.)	1 off
	0-10 amp ammeter	1 off
	10 amp, 50 volt rating stud recifier diode	1 off
	18 swg aluminium sheet	8 sq.in
	Wood block (see text)	1 off
	Press button 1-2 amp rating	1 off
	10 amp wire	as req.
	$\frac{2}{4}$ BA screws	as req.
	Rubber grommet $\frac{1}{4}$ " bore	1 off
	Insulated terminals, red & black (10 amp)	2 off
<u>Tower</u>	1" x 1" mild steel angle (see text)	as req.
	$\frac{5}{16}$ " diameter bolts 1" long with nuts	4 off
<u>Miscellaneous</u>	20 amp 2 core cable	as req.
	Primer paint (grey or red oxide)	as req.
	Enamel paint (e.g. Humbrol)	as req.
	Epoxy glue	small pack

**FIG. 1 - LUCAS 11AC CAR ALTERNATOR**



**Fig. 1. Alternator model 11AC, dismantled**

- |  |                           |                        |                               |
|--|---------------------------|------------------------|-------------------------------|
| 1. Shaft nut                                 | 6. Rotor (field winding)  | 12. Brush box moulding | 18. Bearing retaining plate   |
| 2. Key                                       | 7. Slip rings             | 13. Brushes            | 19. Ball bearing              |
| 3. Through fixing bolts (3)                  | 8. Stator laminations     | 14. Diode heat sink    | 20. 'O' ring oil seal         |
| 4. Drive end bracket                         | 9. Silicon diodes (6)     | 15. Stator winding     | 21. 'O' ring retaining washer |
| 5. Jump ring shroud<br>(earlier models only) | 10. Slip-ring end bracket | 16. Rotor              | 22. Fan                       |
|  | 11. Needle roller bearing | 17. Circlip            | 23. Shaft washer              |



**Slip-ring end, showing heat sinks withdrawn**

- |                                    |               |
|------------------------------------|---------------|
| A. Terminal blade retaining tongue | C. Slot wedge |
| B. Output terminal                 | D. Stator     |

## REWINDING THE ALTERNATOR

The Lucas 11 AC car alternator is normally rated at 43 amps output and starts to charge at 1000 rpm.

It has a larger than average rotor and stator which makes it ideal for modifying for low speed operation.

For wind generators the alternator must start to charge at 500 rpm or less.

This is achieved by increasing the number of turns on the stator by a factor of three.

The output current however is then reduced by a factor of three giving a new maximum output of 12.3 amps.

### 1. Remove Stator from Alternator (see Fig. 1)

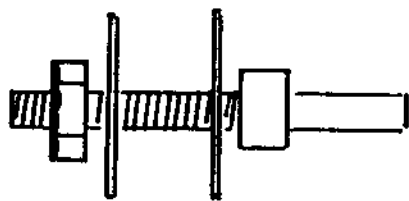
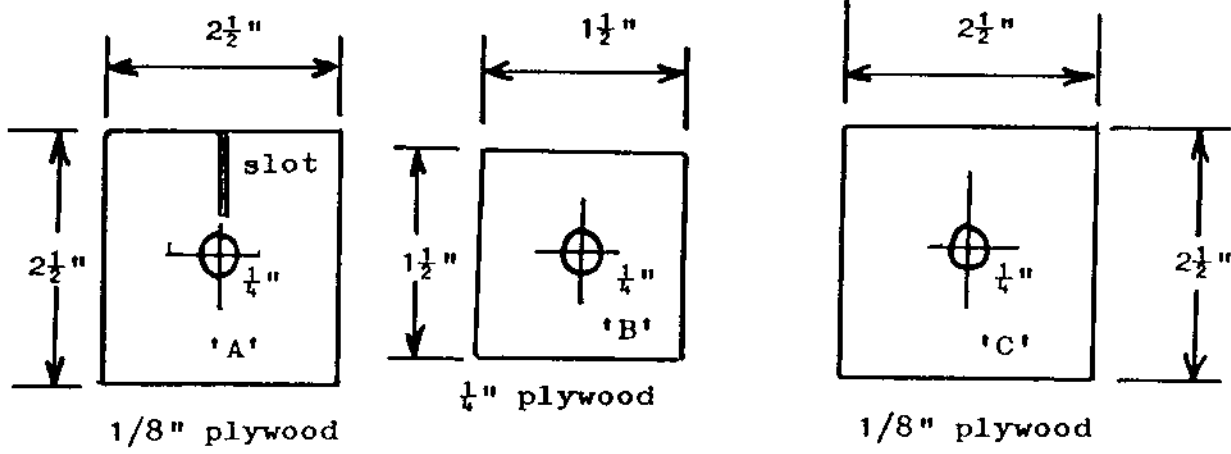
- (a) Unscrew the three fixing bolts and split the alternator by removing the drive end bracket. (item 4)
- (b) Lift the stator assembly (item 8) out of the end bracket (item 10) as far as possible. (It will be still attached by 3 wires)
- (c) Remove the three bolts/nuts holding the diode heat sink (item 14) in the end bracket.  
Then lift out the stator and diode heat sink assembly from the end bracket.
- (d) Note where the three wires are attached to the diode assembly.  
Then using as little heat as possible unsolder the three wires.

### 2. Remove Winding from Stator

- (a) Slide out the fibre slot wedges from the slot entrances using a small screwdriver.  
Avoid damaging them as they are used again.  
If they are very tight, soak the stator in a strong solvent (e.g. Cellulose Thinners) to loosen the varnish.
- (b) Carefully unwind the winding, taking care not to damage the insulation in the slots.
- (c) Blow dust out of slots and clean with methylated spirits.
- (d) Check that the insulation in each of the 24 slots is undamaged. (If one is damaged, a new piece of insulation should be made from thin postcard)

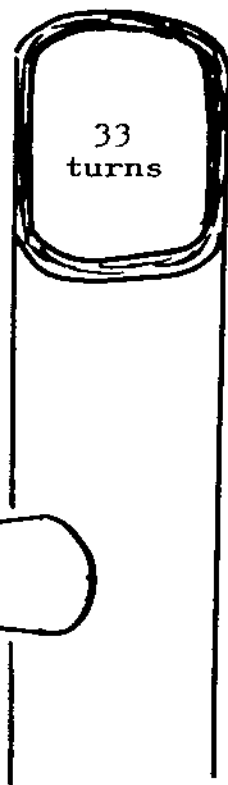
FIG. 2 - COIL WINDING JIG

Not to scale

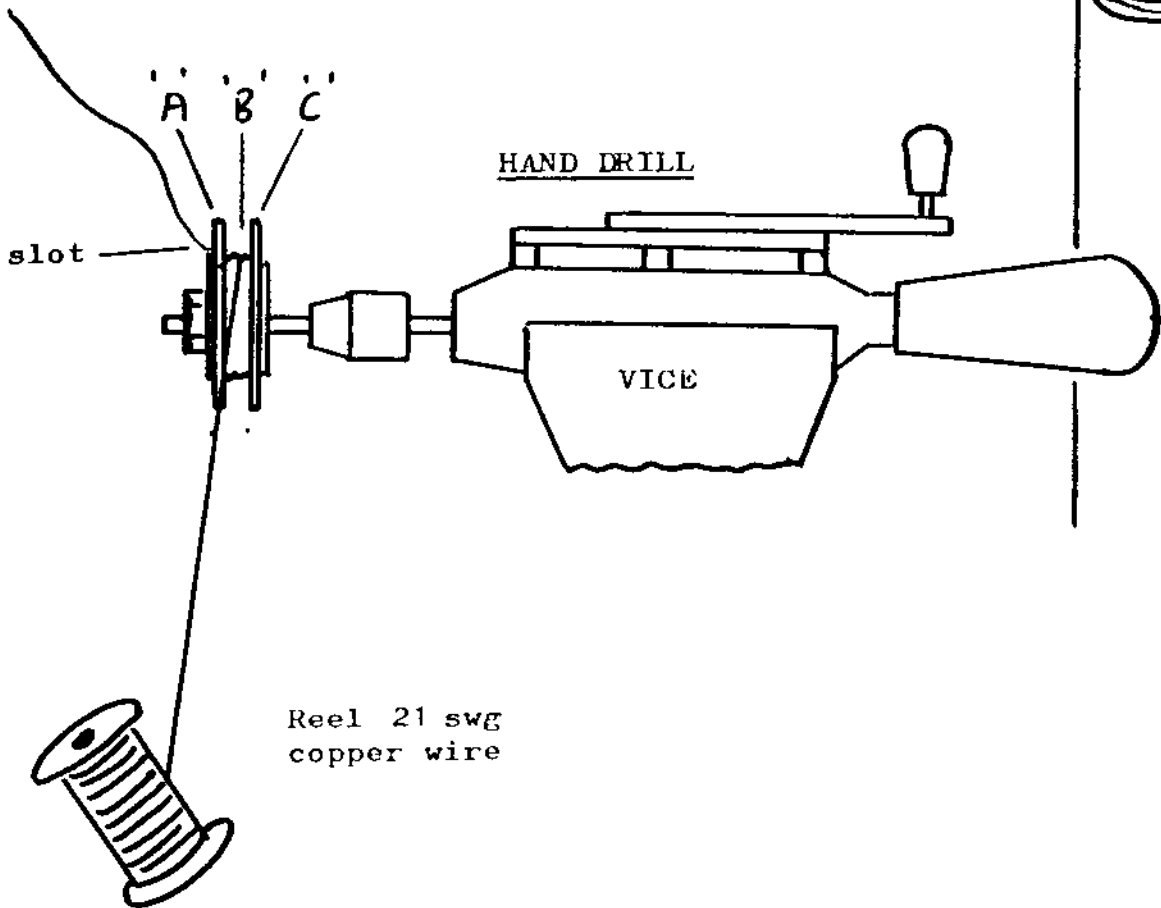


1/4" DIA. WHEEL ARBOUR

FINISHED COIL



33 turns





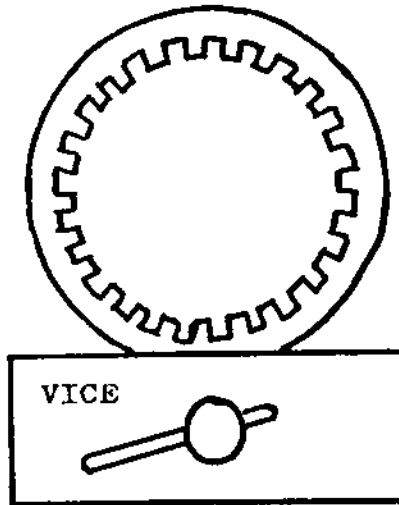
### 3. Make Coil Winder (See Fig. 2)

- (a) Cut three plywood sheets 'A', 'B' and 'C' to the dimensions shown.
- (b) Cut a slot with a small hacksaw in 'A' as shown.
- (c) Drill  $\frac{1}{4}$ " holes in the centre of each sheet and assemble the three sheets onto the wheel arbour to make a coil former.
- (d) Fix the wheel arbour into the chuck of a hand drill and clamp the drill in a vice as shown.

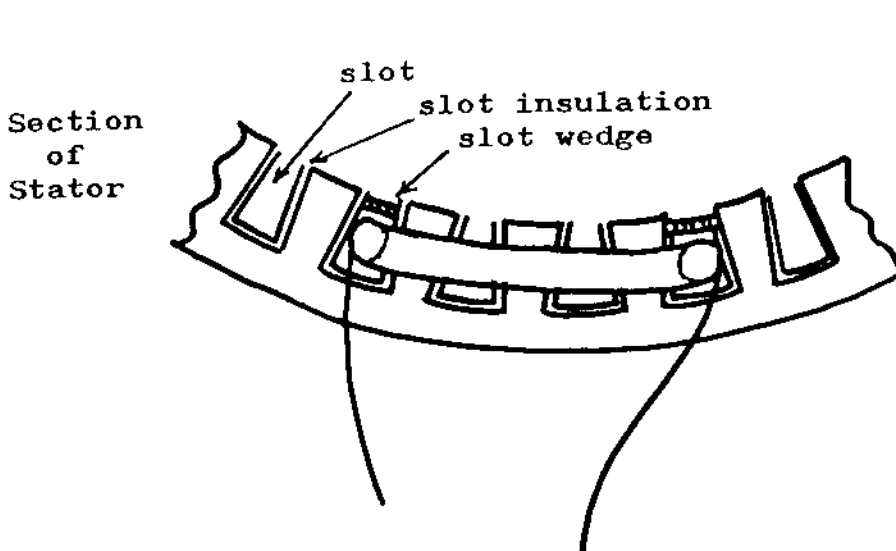
Turn the drill handle one revolution and measure how many times the chuck turns, e.g. 3.2

Then for 33 turns on coil =  $33/3.2 = 10.3$  handle turns.

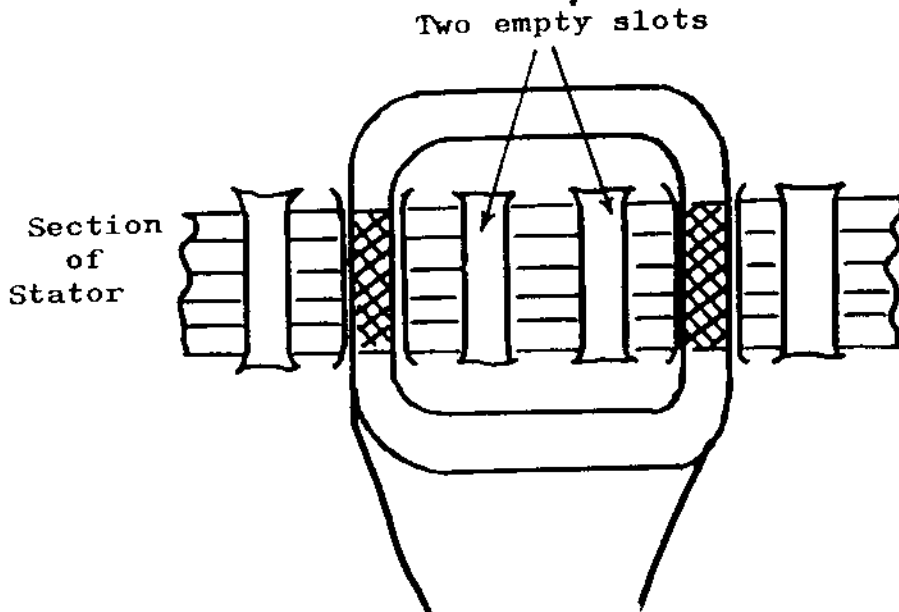
FIG. 3 - FITTING FIRST COIL INTO STATOR SLOTS



Hold the stator  
in a vice to fit  
the coils.



First Coil Fitted  
(side view)



First coil Fitted  
(plan view)

#### 4. Rewind Stator (See Figs. 3, 4 & 5)

The new winding consists of 12 identical coils which are fitted to the stator in two banks of coils, 6 odd number coils, and 6 overlapping even number coils.

The 12 coils are wired to form a three phase winding with 4 coils connected in series in each phase.

The start of each phase is joined together thus forming a "Star" connected 3 phase winding.

(a) Wind one coil of 33 turns of 21 swg enamelled copper wire on the winding jig.

Leave 6" ends and twist these lightly together to stop the coil unwinding when it is removed from the coil former.

(b) Hold the stator in a vice and fit the first (odd number) coil.

This should be four slots wide and leave two empty slots in the middle.

Gently slide first one side of the coil and then the other side into the slot a few turns at a time, taking care not to scratch or kink the wire.

Fit two slot wedges to hold the coil in place.

(c) If the coil shape is satisfactory, wind the remaining 11 coils the same. If not, adjust the size of former 'B' and wind another trial coil.

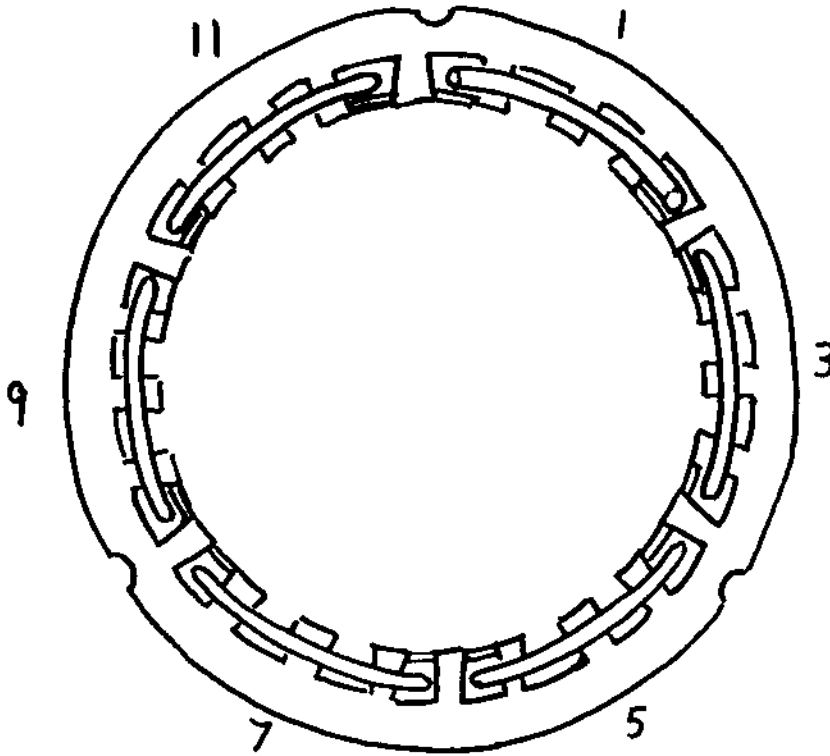
(d) Fit the remaining 5 odd number coils, i.e. 3, 5, 7, 9 & 11. (see Fig. 4)

(e) Fit the 6 even number coils to the stator. i.e coils 2, 4, 6, 8, 10 & 12.

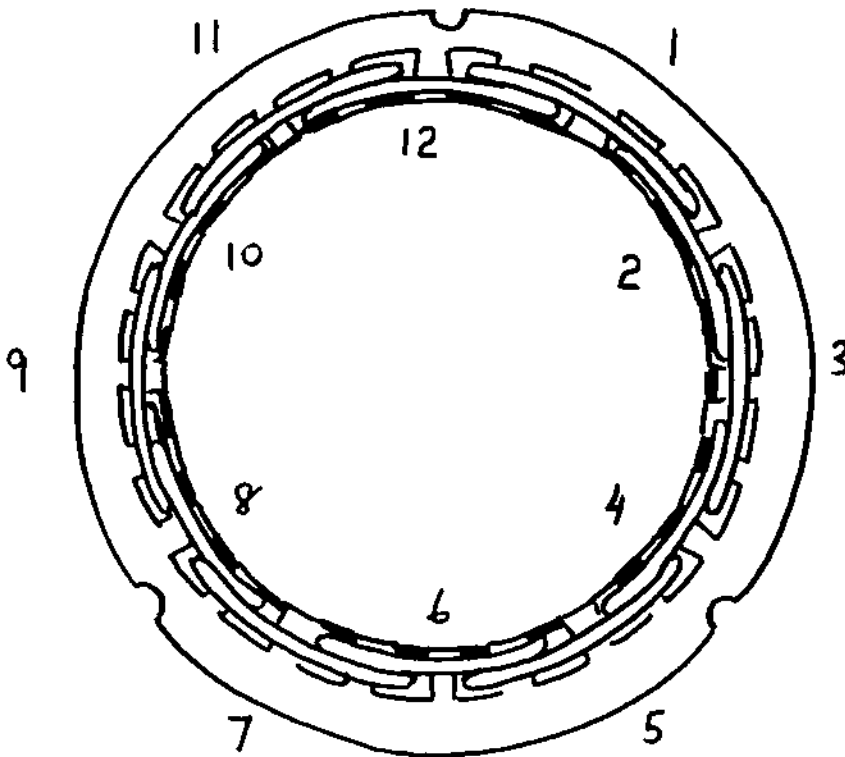
These overlap over the top of the odd number coils.

All 12 coils should now be fitted to the stator filling every slot.

FIG. 4 - STATOR WINDING

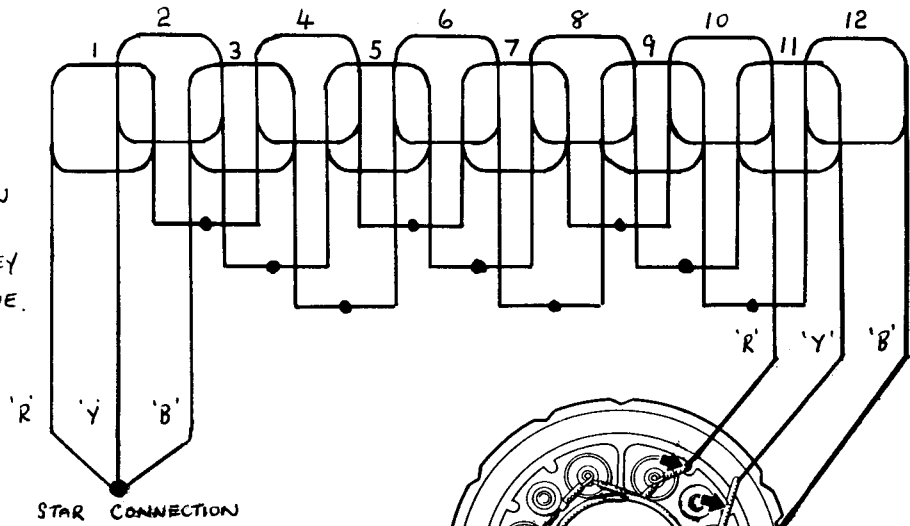


6 Coils  
Fitted  
to Stator

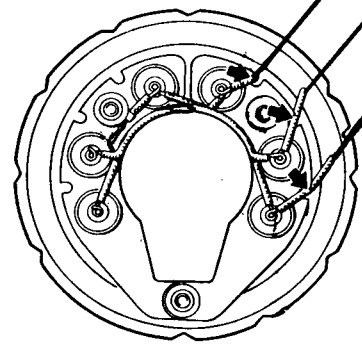


12 Coils  
Fitted  
to Stator

FOR CLARITY  
THE 'ODD' AND  
'EVEN' NUMBER  
COILS ARE SHOWN  
OFFSET.  
IN PRACTICE THEY  
ARE ALL IN LINE.



STAR CONNECTION



Heat sink cable securing points

FIG. 5 - STATOR WIRING DIAGRAM

## 5. Connecting the Coils (See Fig. 5)

Since all the coils are identical and the stator is symmetrical, it does not matter where you start connecting the coils together providing that you keep to the same numbering system once you have started. The winding will always start and finish at the same part of the stator.

### (a) Star Connection

Join the beginning of coils 1, 2 & 3 together with a soldered joint. This is called the "Star" connection and is the start of the winding.

### (b) Phase 'R'

Join the four Phase 'R' coils together in series with three soldered joints. i.e. coils 1, 4, 7 & 10.

### (c) Phase 'Y'

Join the four Phase 'Y' coils together in series with three soldered joints. i.e. coils 2, 5, 8 & 11.

### (d) Phase 'B'

Join the four Phase 'B' coils together in series with three soldered joints. i.e. coils 3, 6, 9 & 12.

(e) Fit a short piece of insulating sleaving over each solder joint and then fold the joint neatly against an adjacent coil.

(f) Fit insulating sleaving on the three output wires from coils 10, 11 & 12.

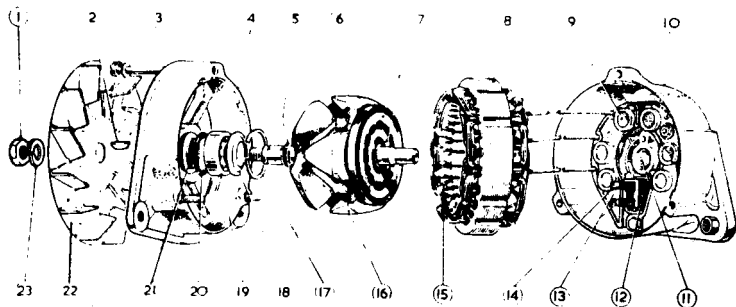
(These wires should still be about 6 inches long)

Note:

### To join enamelled copper wire

- (a) Burn off enamel with match.
- (b) Clean to bright copper with fine sand paper.
- (c) Twist together.
- (d) Solder (with fluxed multicore solder)
- (e) Trim off surplus wire.

**FIG. 1 - LUCAS 11AC CAR ALTERNATOR**



**Fig. 1. Alternator model 11AC, dismantled**

- |  |                           |                        |                               |
|--|---------------------------|------------------------|-------------------------------|
| 1. Shaft nut                                 | 6. Rotor (field winding)  | 12. Brush box moulding | 18. Bearing retaining plate   |
| 2. Key                                       | 7. Slip rings             | 13. Brushes            | 19. Ball bearing              |
| 3. Through fixing bolts (3)                  | 8. Stator laminations     | 14. Diode heat sink    | 20. 'O' ring oil seal         |
| 4. Drive end bracket                         | 9. Silicon diodes (6)     | 15. Stator winding     | 21. 'O' ring retaining washer |
| 5. Jump ring shroud<br>(earlier models only) | 10. Slip-ring end bracket | 16. Rotor              | 22. Fan                       |
|  | 11. Needle roller bearing | 17. Circlip            | 23. Shaft washer              |

## 6. Test the Stator Winding

- (a) Check that no wire is trapped against the metal of the stator.
- (b) Use a battery and bulb to check that the windings are continuous between each of the three output wires.  
If you have a test meter, the resistance between any two of the three output wires should be approximately  $1\frac{1}{2}$  ohms.
- (c) Carefully try fitting the stator into the drive end bracket (item 4, Fig.1)  
Check that the coils do not touch the rotor, or the inside of the case. Adjust the coils if necessary.

## 7. Varnish and bake the winding

To improve the mechanical strength and insulation it is necessary to varnish and bake the winding.

Polyurethane varnish (any colour) should be used.

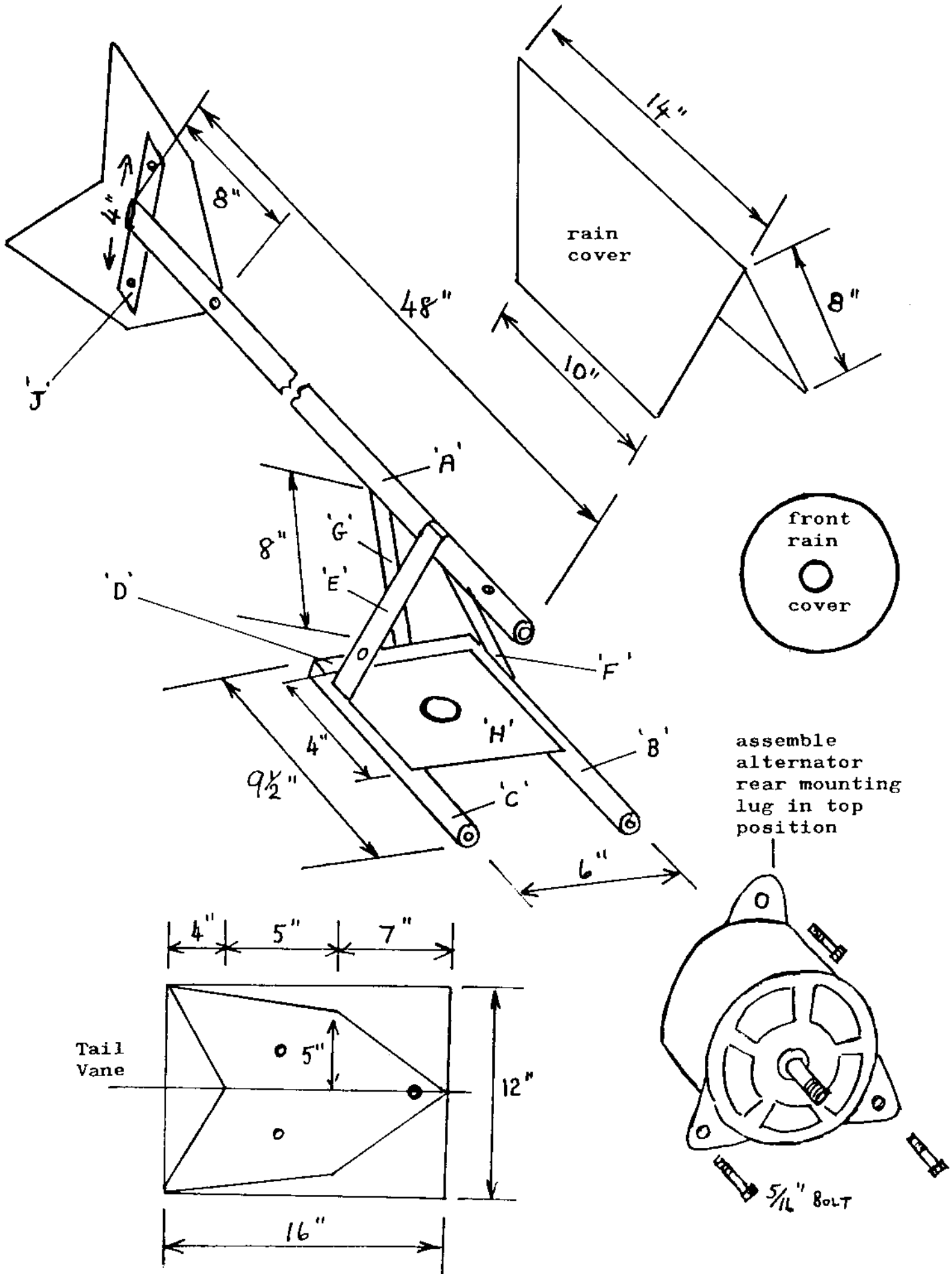
- (a) Dry the stator in a low oven ( $50-100^{\circ}\text{C}$ ) for 1 hour.
- (b) Remove the stator from the oven and while still warm liberally varnish the winding, brushing into all the slots.
- (c) Allow the surplus varnish to drain off.
- (d) Support the stator above a drip tray and then bake in a low oven ( $50-100^{\circ}\text{C}$ ) for 4-5 hours.
- (e) After baking when the stator has completely cooled, check with a battery and bulb (or test meter) that there is no connection between the output wires and the metal of the stator.  
Finally scrape any surplus drips of varnish off the stator with a knife, but do not scratch the winding itself.

## 8. Re-assemble the alternator (See Figs. 1 & 5 )

- (a) Reduce the lengths of the three stator output wires to 3-4 inches and then resolder them back onto the diode assembly.
- (b) Refit the diode assembly/heat sink back into the end bracket (item 10).
- (c) Position the stator in the end bracket and align the grooves for the screws.
- (d) Refit the drive end bracket (in position shown Fig. 6 )  
Fit the three screws, tighten and check that the rotor shaft turns freely.



FIG. 6 - FRAME CONSTRUCTION



## FRAME CONSTRUCTION (see Fig. 6)

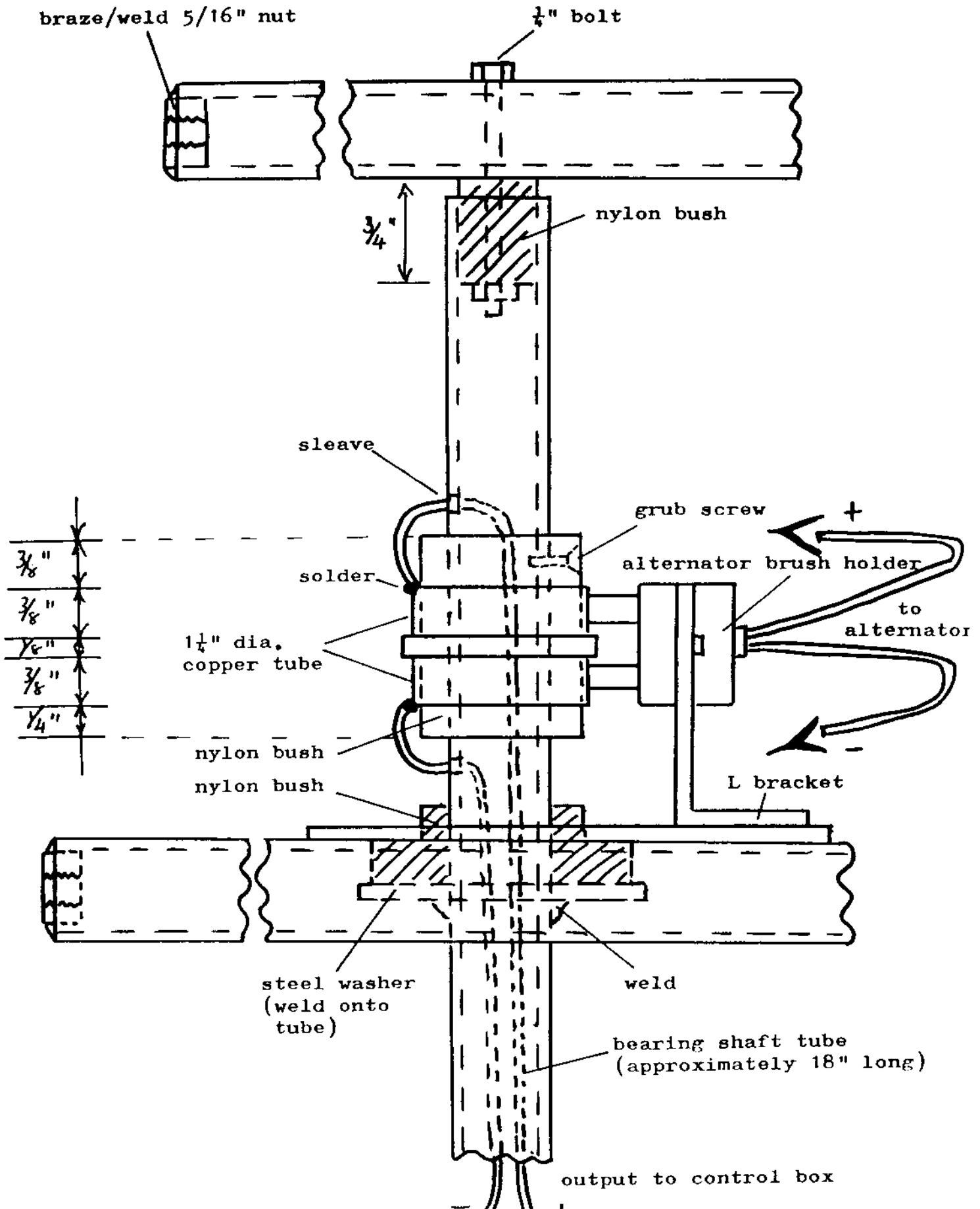
The construction of the frame is not critical and although tubing is shown, one inch angle could also be used. The prototype was arc welded together with the three mounting nuts brazed into the tube ends.

1. Cut tubes A, B and C to length.
2. Braze or weld  $5/16$ " (8mm) nuts into the ends of each tube.
3. Bolt the three tubes onto the alternator, ensure that they are square. Then weld cross member D (1" angle), side members E & F (1" strip) and tail support G ( $\frac{3}{4}$ " tube) into position.

Remove the alternator from the frame.

4. Drill a  $1\frac{1}{4}$ " diameter hole in the centre of the bearing support plate H ( $1/8$ " gauge) and then weld into position.
5. Drill a  $\frac{1}{4}$ " diameter hole directly above it in tube A.
6. Drill two  $\frac{1}{4}$ " holes in vane support J (1" strip) and then weld onto the end of tube A.
7. Drill a  $\frac{1}{4}$ " hole through tube A for front vane support.
8. Cut out the tail vane and rain cover from steel or aluminium sheet. Also the alternator front rain cover.
9. Hold the vane in position, drill three  $\frac{1}{4}$ " holes and then bolt into position.
10. Hold the rain cover in position, drill  $\frac{1}{4}$ " mounting holes through E & F and then bolt on. Remove until final assembly.
11. Paint the frame with primer and then top coat with enamel.

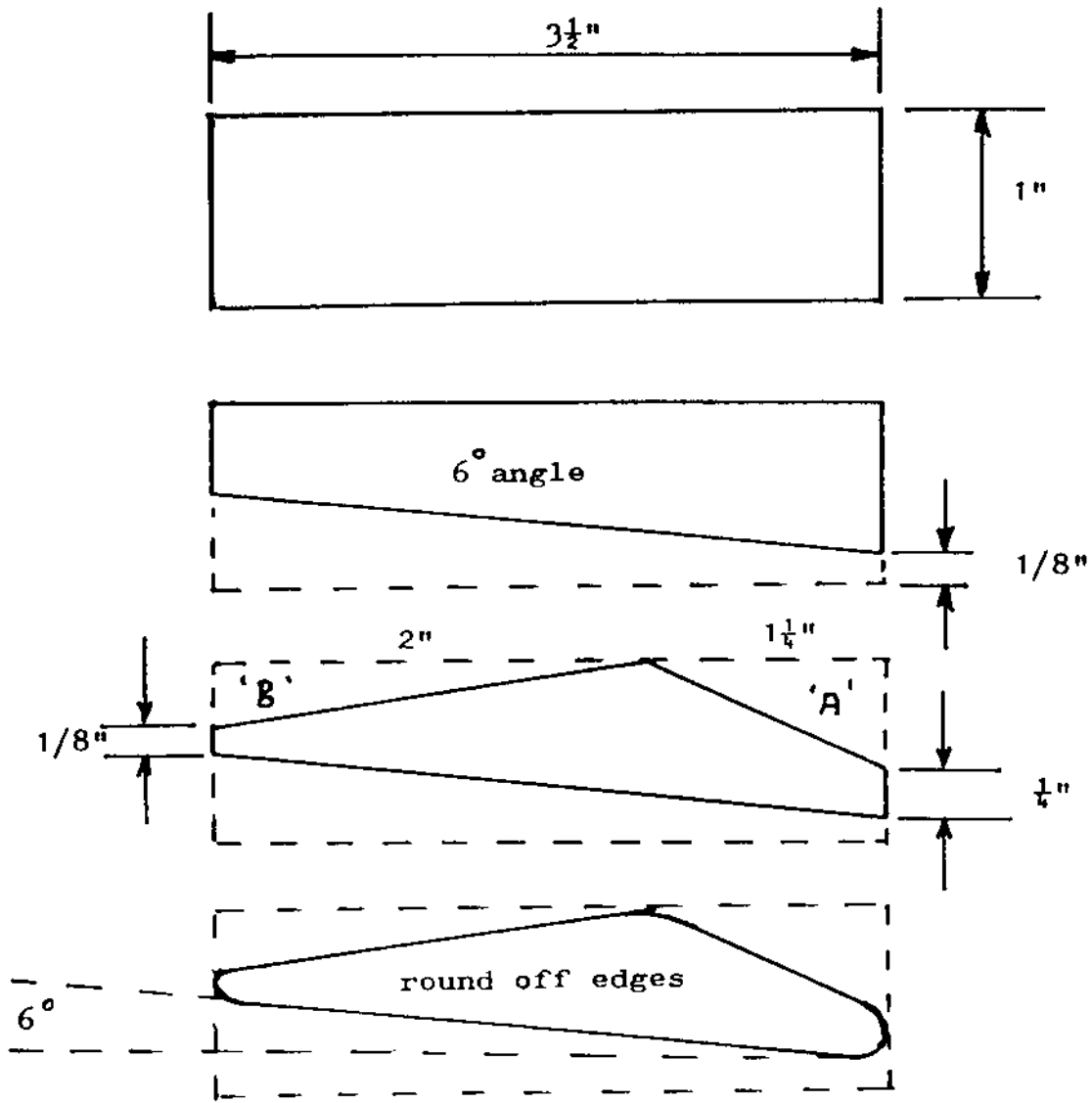
**FIG. 7 - BEARINGS AND SLIP RING/BRUSH ASSEMBLY**



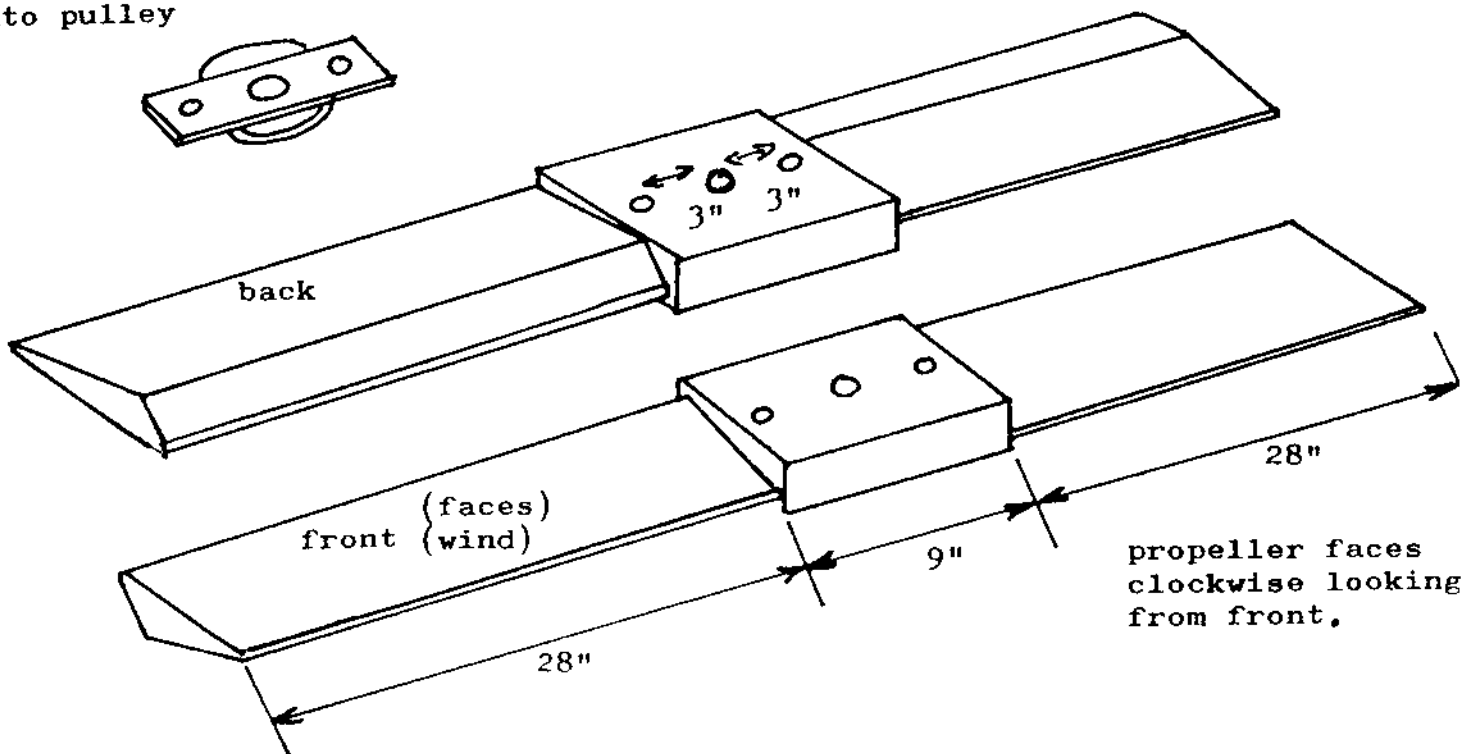
BEARINGS AND SLIP RINGS/BRUSHES ASSEMBLY (see Fig. 7)

1. Machine a nylon bush so that it is a sliding fit inside the bearing shaft tube.  
Drill a  $\frac{1}{4}$ " hole in it and then mount it with a 2" bolt onto the top frame tube.
2. Machine a second 2" diameter nylon bush with  $1\frac{1}{4}$ " shoulder (To push fit it into the hole in the support plate.)  
Machine a  $\frac{3}{4}$ " hole for the bearing shaft tube.
3. Weld a 2" diameter steel washer onto the bearing shaft tube to support the nylon bush.
4. Machine a third nylon bush to push fit onto the shaft for the slip rings. Glue two slip rings made from  $1\frac{1}{4}$ " dia. copper water pipe onto the bush.  
Drill two  $\frac{1}{4}$ " holes above and below the slip rings and then solder a red and black wire onto the slip rings and bring them through the holes down the centre of the tube.  
Finally, mount an 11AC alternator brush holder on an L bracket.  
(OR/ Two car dynamo brush holders can be used if slip rings  $7/8$ " wide made.)

**FIG. 8 - PROPELLER CONSTRUCTION**



weld  $8" \times 2" \times \frac{1}{4}"$  strip onto pulley



## THE PROPELLER

The whole performance of a wind generator depends upon the propeller running at the correct rpm over the required wind speed range with sufficient power to drive the generator. Small high speed wind generators require a propeller with a tip speed ratio of approximately 8:1 (i.e. the tip of the propeller travels 8 times faster than the wind speed). This type of propeller has thin parallel sided blades with a fixed pitch of 6 degrees.

The traditional (and still best) material for small propellers is wood.

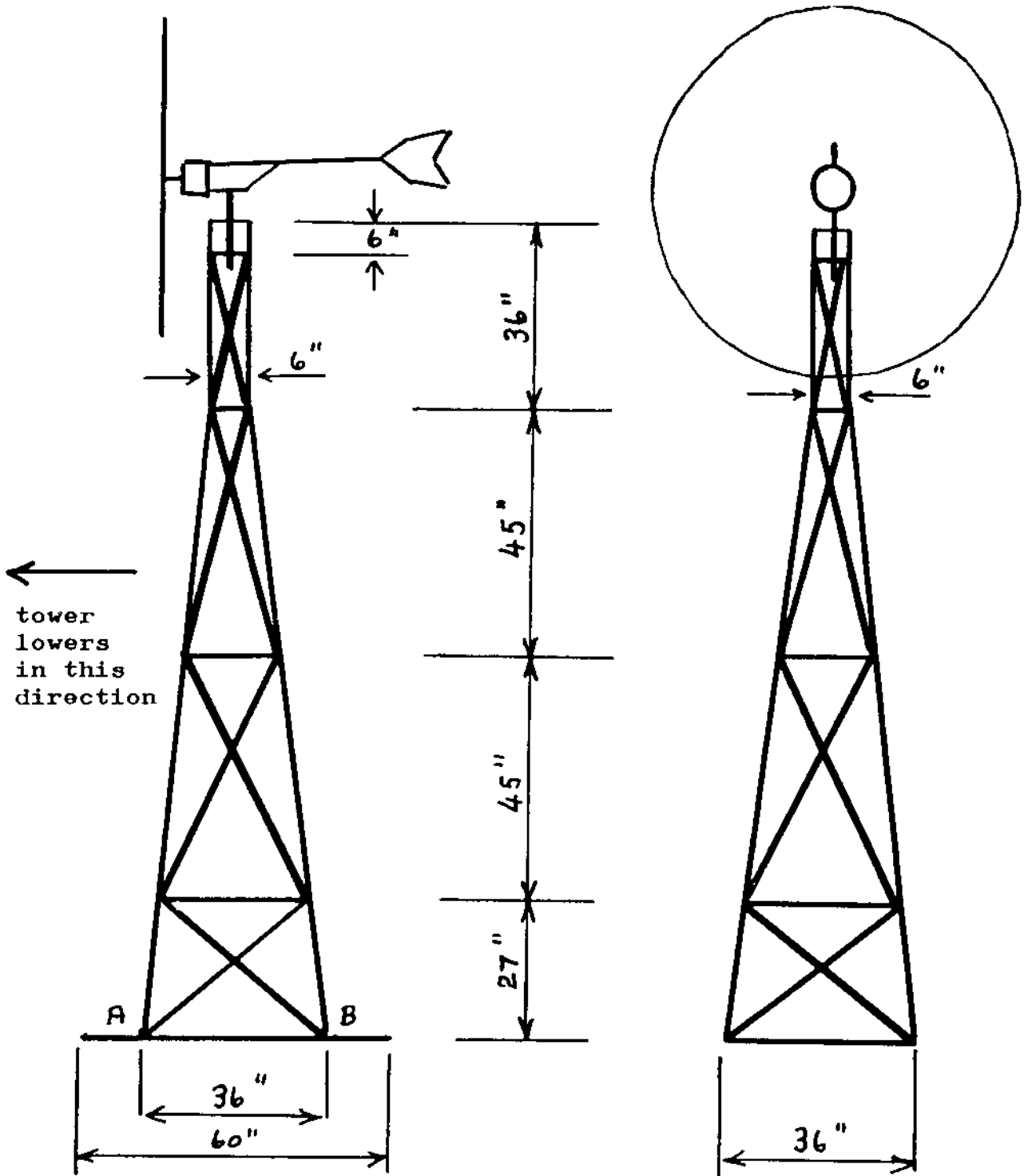
This should be of the highest quality, straight grained and free from any warping, knots or cracks.

Recommended woods include :-  
Sitka spruce  
Beech  
Mahogany

### Construction (see Fig. 8)

1. Cut a piece of wood accurately to 65" x 3½" x 1".
2. Using a fine tooth saw, or bandsaw, or plane, accurately cut a 6 degree angle for 28" from the tip of each blade. Blend a smooth bend at the end of the cut.
3. Cut the front of the aerofoil of each blade (section 'A') to give a leading edge ¼" thick.
4. Cut the back of the aerofoil of each blade (section 'B') to give a trailing edge 1/8" thick.
5. Drill a ½" centre hole in the propeller and two 3/8" mounting holes at 3" radius.
6. Sand the propeller smooth. Round off leading & trailing edges.
7. Weld a piece of mild steel 8" x 2" x ¼" onto the alternator pulley after first drilling two 3/8" holes and a centre hole large enough to tighten the pulley nut through.
8. Paint the propeller with either 3 coats of polyurethane varnish or two coats of epoxy paint.
9. Mount the propeller on the pulley assembly and then on the alternator shaft for balancing. Add balance washers as required. Secure either on one mounting bolt or with wood screws at the root of the blade

FIG. 9 - TOWER



NOTES:

1. All the tower is made of 1" x 1" mild steel angle welded together.
2. The tower is hinged at A on 5/16" (8mm) bolts and has locking 5/16" bolts at B.
3. The windgenerator bearing shaft tube is held on the tower by two U bolt clamps 6 inches apart.

## THE TOWER (see Fig.9)

The tower should be at least 10 feet high and 20 or 30 feet high on less advantageous sites.

There are many ways to build a tower but as a guide to constructors Fig.9 shows the one used for the prototype.

This is 14 feet high and constructed entirely of 1" x 1" mild steel angle.

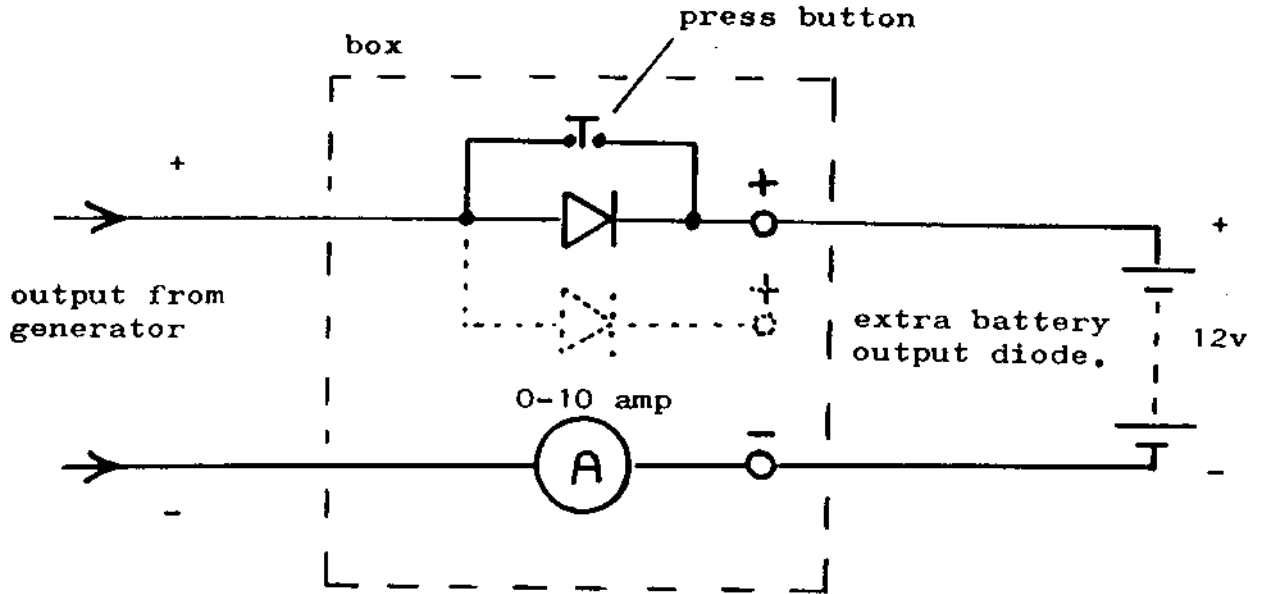
This design has the advantage that it is hinged on two legs and so can easily be lowered for windgenerator maintenance.

It is arc welded together but could be bolted if further cross bracing was added.

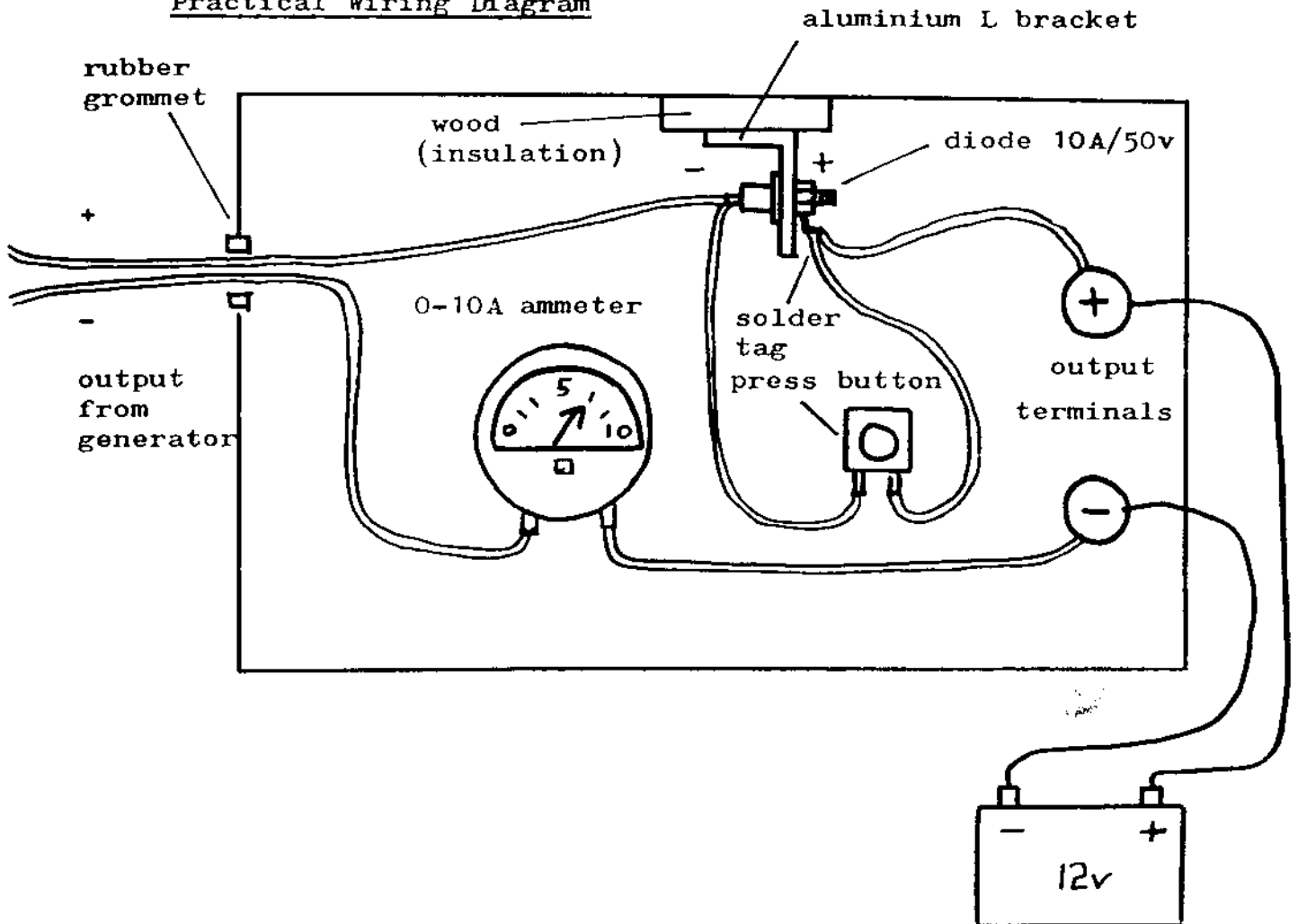


FIG. 10 - CONTROL BOX

Circuit Diagram



Practical Wiring Diagram



## THE CONTROL BOX (see Fig. 10)

The control box contains two important parts :-

The diode This is to stop current flowing from the storage battery to the alternator field coil when the generator is not charging.

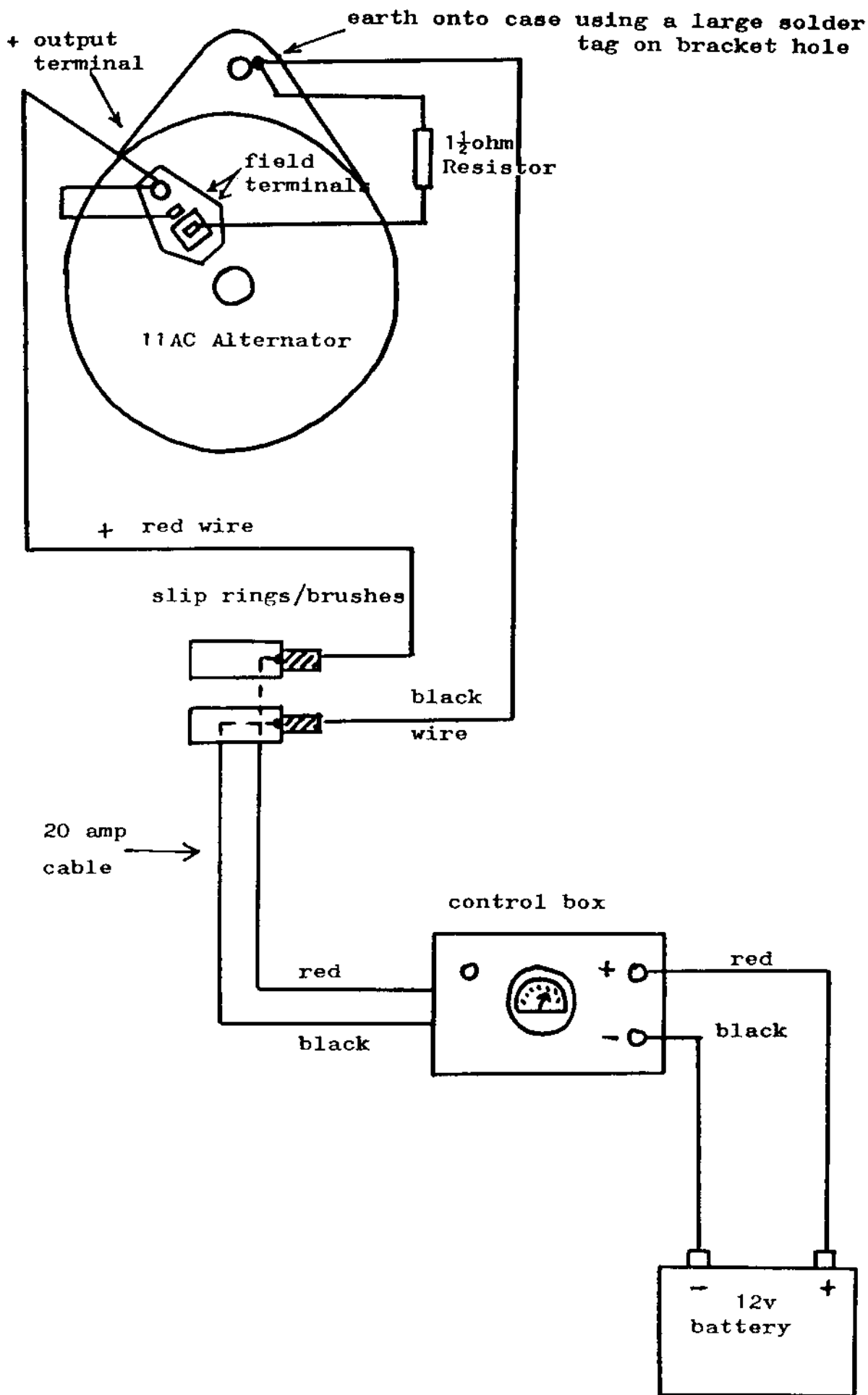
The Press Button This is to initially polarise the alternator field and manually excite the alternator at low wind speeds.

### Construction

1. Mount the ammeter, press button and two output terminals on the top of the box.
2. Make an aluminium L bracket (8 square inches approx. area) Drill a  $\frac{1}{4}$ " hole and mount the diode with a solder tag. Mount the L bracket in the box on an insulating block (e.g. wood)
3. Drill a  $\frac{3}{8}$ " hole in the end of the box, fit a rubber grommet, and bring the two output wires through from the generator.
4. Wire up the components as shown in the diagram.

Note: If two or more storage batteries are connected in parallel, an extra diode should be used for each positive output. The negatives are connected together.

FIG. 11 - WIRING DIAGRAM



### FINAL WIRING (see Fig. 11)

1. Connect two wires to the alternator positive output and take one to a field terminal and the other to the top slip ring brush terminal.
2. Connect two wires to the alternator case, and take one wire to the bottom brush terminal and the other to the 1.5 ohm resistor whose other end is connected to the remaining field terminal.

### TESTING THE WIND GENERATOR

CAUTION: HIGH SPEED PROPELLERS CAN CAUSE SERIOUS INJURY AND MUST BE TREATED WITH RESPECT.

1. Fit the propeller to the generator and check that it :-
  - (a) Turns true.
  - (b) Balances.
2. Connect a length of 20 or 30 amp cable from the generator output down the tower to the control box.
3. Connect a 12 volt car battery to the output terminals of the control box.  
Check that when the press button is operated, that the ammeter gives a small negative reading.
4. Tie a length of string to the tail. (To turn the wind generator out of the wind and so stop it if required)
5. Bolt the wind generator into position on top of the tower and raise the tower to its upright position.
6. The propeller will start to turn slowly and gradually pick up speed until it reaches about 200 rpm. From 200 rpm (with a whistling sound) it will accelerate rapidly to normal running speed, typically 400-800 rpm.
7. The alternator will charge from 450-500 rpm (11-12 mph), but not self excite the field until 600-650 rpm (15-16 mph). However once excited it can drop to 375-400 rpm (9 mph) before losing the field excitation.

In practice on a typical breezy day it rarely loses its excitation, as a gust of wind catches it before it can slow down below 400 rpm.

The field excitation can be started manually at any time by pressing the button for 1-2 seconds.

### OPERATING THE WIND GENERATOR

Before leaving the wind generator unattended ensure that the tower is firmly attached to the ground.

Very little maintenance is required, mainly checking that the brushes and cleaning the slip rings. The propeller should also be periodically checked for damage (from bird strikes).

The wind generator can safely be left in winds up to 45-50 mph, but in strong gales it must be closed down. This is best done by turning the tail 90° to stop the propeller and then tying a loop of cord around the blade and lashing it to the tower.

## BATTERIES

A battery capacity of 100 Ah is recommended.

If the battery is disconnected from the control box while the generator is free to run, a shorting link should be connected across the output terminals.

This is to keep the generator on load and stop excessive voltage occurring which could burn out the field coil.

If more than one battery is used, an extra diode is required for each one.

This is to separate the charges and ensure that the batteries charge equally.

Fig.12 - CAR ALTERNATOR EXCITER UNIT

Car alternators have insufficient residue magnetism to self excite the field coil at low rpm. This useful electronic unit produces a small pulse of current at regular intervals. The pulse of current is just sufficient to make the alternator self excite, providing that it is running fast enough to charge a battery.

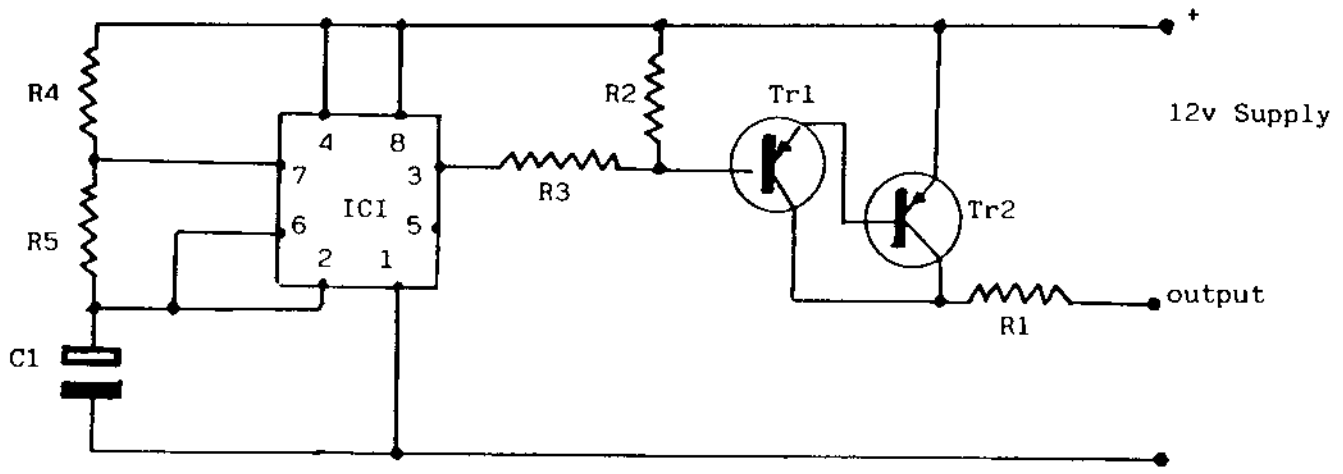
Automatic Exciter Unit

Although the alternator will always excite in a fresh breeze, there are times when the wind is not quite strong enough to excite the alternator but when it could charge.

This problem can be overcome by fitting an electronic automatic alternator exciter unit in the control box. This unit gives a short pulse of current ever 20 seconds or so to ensure that the alternator will excite if it is going fast enough.

Battery consumption is negligible.

Circuit Diagram



- ICI 555 Timer C-MOS
- Tr1 BC143 Transistor (PNP)
- Tr2 BC143 Transistor (PNP)
- C1 100mfd 25v Elect. Capacitor

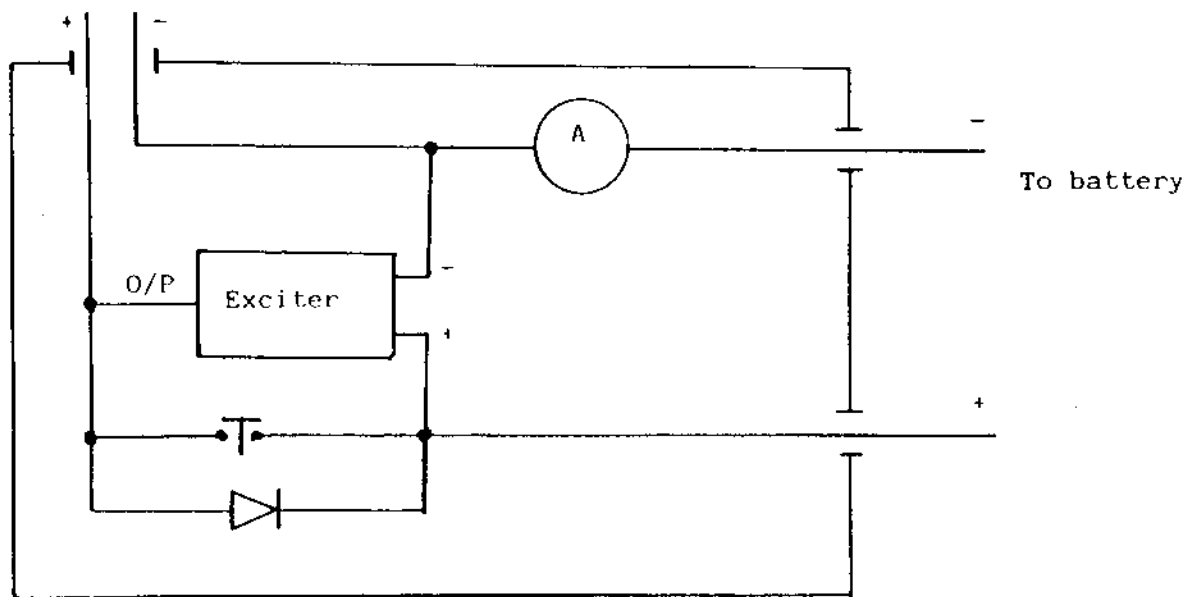
- R1 18 ohms 1W
- R2 1.5k ohms ¼W
- R3 1.5k ohms ¼W
- R4 220k ohms ¼W
- R5 2.7k ohms ¼W

Specification

- Supply voltage 9-15 volts
- Pulse current 0.6 amp (approx.)
- Pulse length 0.5 second (approx.)
- Frequency 3 pulses per minute (approx.)
- Average current consumption 12 mA (approx.)

### Control Box Wiring

From Alternator





## APPENDIX

### Lucas 11AC car alternator

This large 43 amp car alternator was fitted to several medium size British cars including models of the Ford Zephyr & Zodiac and Austin A60 & Oxford.

The best place to find them at a reasonable price is at scrapyards and secondhand auto spares dealers.

### Other Alternators

The Lucas 10AC is a 35 amp alternator very similar in appearance to the 11AC. It can be used but will give 20-25% less output i.e. about 100 watts.

The ordinary Lucas 15/16/17ACR alternators are much more difficult to rewind and give even lower output.

### Wind Generator Control

To keep the cost as low as possible and the construction as simple as possible no control systems have been used on this 120 watt wind generator design.

However several useful additions may be fitted to the Wind Generator to improve the overall performance :-

### Parking Brake

This is used to close down the generator during gales and also to stop it for routine maintenance.

A simple brake can be made by fitting a 6 inch diameter vee pulley behind the propeller and then mounting a brake lever pivoted about its centre on the frame under the alternator. Fit a bicycle brake pad on the brake lever end under the pulley. Fit a fork at the other end of the brake lever to straddle the bearing shaft tube. Spring load the brake to the off position. Finally fit a larger diameter tube onto the bearing tube with a flange to engage the brake fork. By pulling down the outer tube with a piece of cord the brake can be operated.

### Air Brake

In very strong winds the propeller will just run faster and faster until there is a risk of it breaking.

One effective method of stopping this happening is to fit a centrifugal air brake which is designed to operate at typically 1000 rpm. It has a dual action and brakes the propeller by causing drag with its paddle blades and also upsets the air flow to the propeller.

Air brakes are tricky to construct and must be built to close tolerances.

# LOW COST WIND GENERATOR BATTERY CHARGER

Design by C. John Dakin

**Small wind powered generators are useful devices for people dependent on battery power, such as caravanners and yachtsmen. Commercial products are expensive. The smallest models cost over £250. A generator giving up to 30 watts output can be made using a permanent magnet radiator fan motor, DC converter, described here, costing less than £15, and an 800mm diameter wooden propeller.**

## CIRCUIT DESCRIPTION

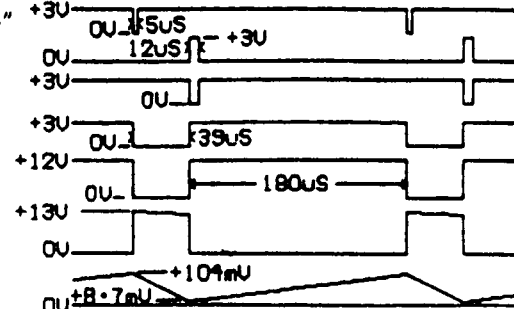
The DC-DC converter is necessary because the voltage output of the motor when used as a generator is much less than 12 v, the commonest battery voltage.

As shown by the circuit diagram in **Fig.2** the converter uses an inductor, L1 and a power MOSFET switch, T2. Each time T2 switches off, the current which has built up in L1 during the 180  $\mu$ s T1 was on, is steered into the battery, B1, by D2. The current in L1 is sensed by R11, a 10 m $\Omega$  resistor, and two voltage comparators, IC1b and IC1c. When the input voltage  $V_1$  is 3V, IC1b detects the current rises to 10.4A, and IC1c detects it when it falls to 0.9A. Both current levels are defined by the voltages from R1e, R3 and R4, and are proportional to  $V_1$ .

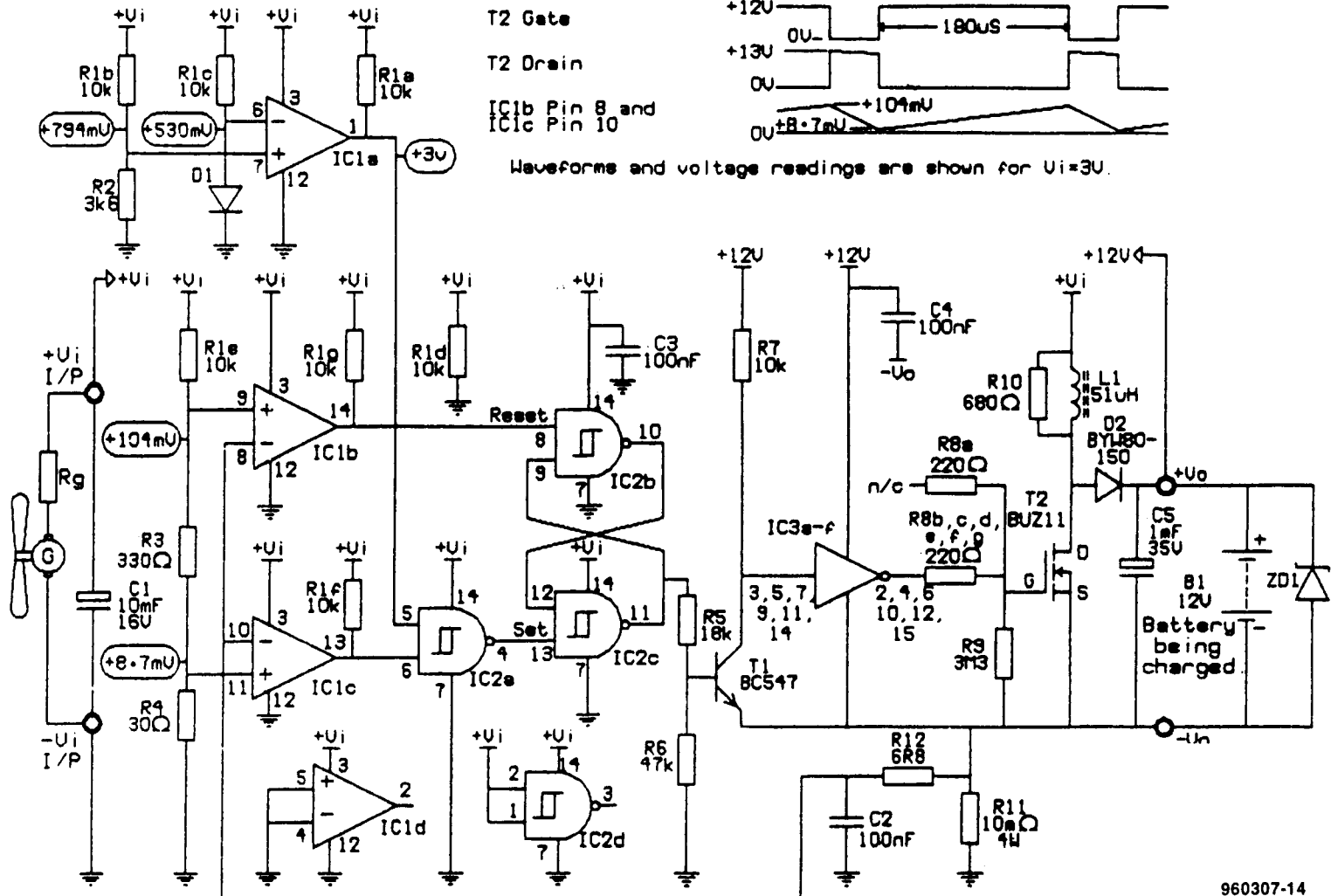
The converter looks like a resistor,  $R_{in}$ , of 0.57 $\Omega$  to the generator. The outputs of IC1b and IC1c reset and set respectively the bistable formed by the two NAND gates IC2b and IC2c. The set pulse is via a third NAND gate IC2a, the second input to which is held high by IC1a, a third voltage comparator, as long as  $V_1$  is more than 2V. Setting the bistable switches T1 on and the collected falls from +12V to 0V. T1's output drives the six inverters of IC3. IC3 drives the gate of T2 which has an input capacitance of 2nF, from 0V to +12V in 2 $\mu$ s.

When  $V_1$  is rising from 0V to 2v, IC1a's output stays low as pin 6 is above pin 7. IC1b's and IC1c's outputs stay high as there is no current through R11. The bistable is forced to the reset state by R5 and R6 holding pin 9 of IC1b low. When  $V_1$  is less than 2V T1, IC3, C5 and D2 draw only leakage current from the +12V rail.

IC1b Pin 14. "Reset" +3V  
 IC1c Pin 13  
 IC2a Pin 4. "Set" +3V  
 IC2c Pin 11  
 T2 Gate +12V  
 T2 Drain +13V  
 IC1b Pin 8 and IC1c Pin 10  
 +104mV  
 +8.7mV



Waveforms and voltage readings are shown for  $U_i = 3V$ .



960307-14

Fig. 2. Circuit diagram of the wind-powered battery charger.

## COMPONENTS LIST

### Resistors:

R1a-g	10k $\Omega$ SIL array
R2	3k $\Omega$ 6
R3	330 $\Omega$
R4	30 $\Omega$
R5	18k $\Omega$
R6	47k $\Omega$
R7	10k $\Omega$
R8a-g	220 $\Omega$ SIL array
R9	3M $\Omega$ 3
R10	680 $\Omega$
R11	0.01 $\Omega$ (Farnell 148-724)
R12	6 $\Omega$ 8

(all single resistors metal film)

### Capacitors:

C1	10mF 16V
C2,C3,C4	100nF
C5	1mF 50V

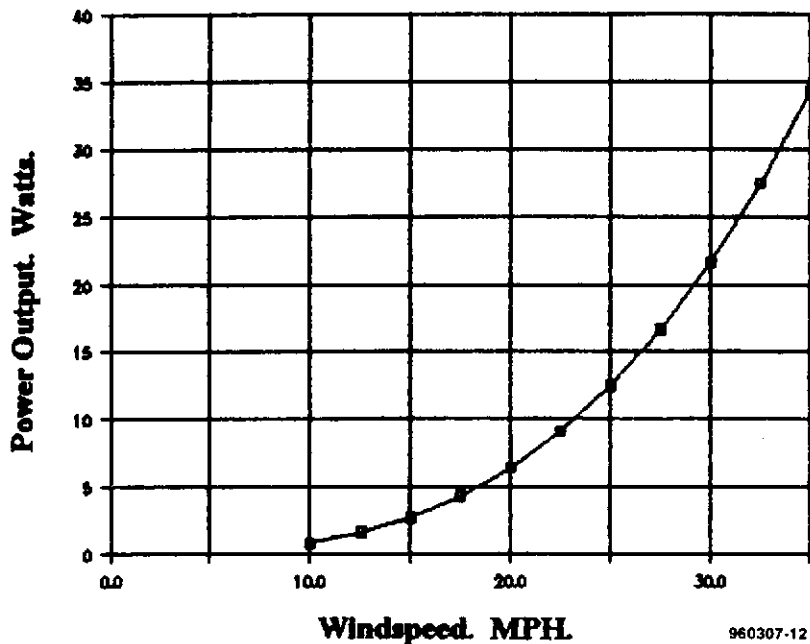
### Inductor:

L1 3C8 core, former, clip, ec wire 14SWG (2mm). Maplin order codes: JR81C, JR82D, JR83E, BL16S.

### Semiconductors:

T1	BC547
T2	BUZ11
D1	1N4148
D2	BYW80-150
IC1	LM339
IC2	HCF4093
IC3	HCF4049
ZD1	BZY93C16





960307-12

Fig. 1b. Power output of the combined generator and converter against wind speed.

The inductor in the circuit consists of 16 turns of 2mm dia. enamelled copper wire wound on an ETD39 Ferroxcube core. A 0.6 mm air gap is put in the magnetic circuit of the core using a piece of cardboard or other non metallic material. Each end of the winding is connected to two pins of the former. See the pcb layout for the correct pins.

ZD1, a BZY93C16, 16V 20W zener should be fitted if B1 may be disconnected at any time. ZD1 will then limit the peak voltage at the drain of T2 to 17V. ZD1 requires a suitable heatsink.

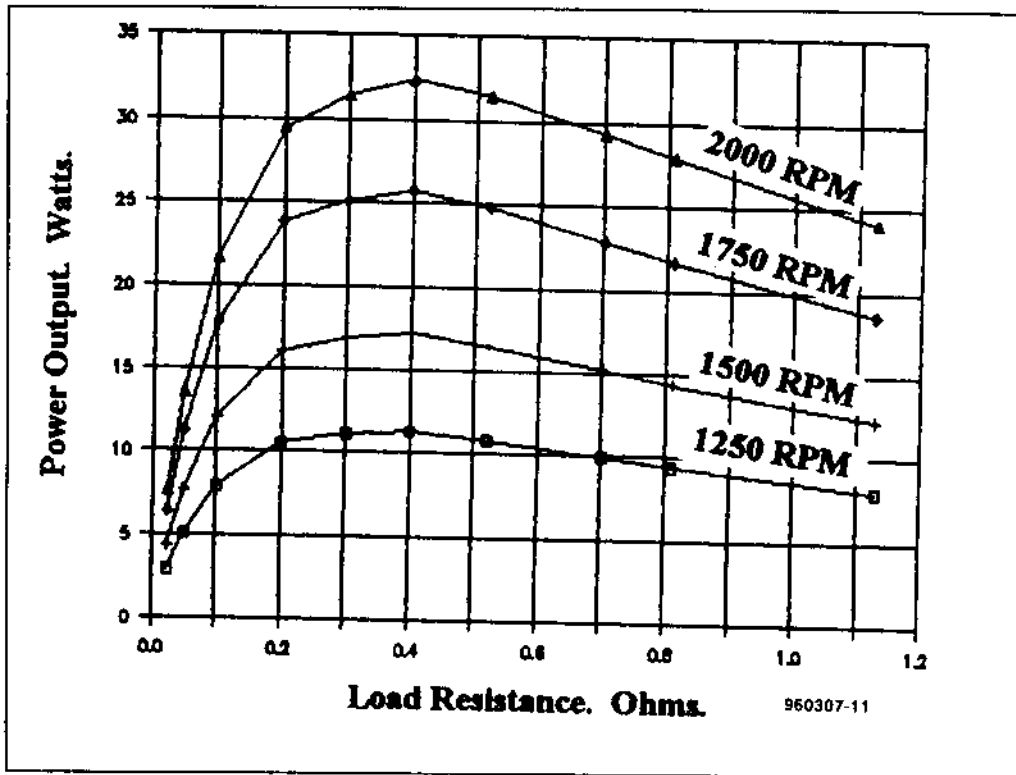


Fig. 1a. Typical 12V car radiator fan motor power output power.

Fig. 1a shows the power output of a typical car fan motor when used as a generator. The output is maximum with a load of about  $0.4\Omega$ . This equals the output resistance of the generator,  $R_g$ . Because the converter losses increase as  $R_{in}$  decreases,  $R_{in}$  is set higher than  $R_g$  for the best efficiency of the combined generator and converter. The resistance of the connecting cable between the generator and the converter must be kept as low as possible.

References: *Scrapyard Windmill Realities - Building Windmills with recycled parts* by Hugh Piggot Published by the Centre of Alternative Technology - Powys Wales - also available through Jemmett Engineering.

Pcb for above design available through Jemmett Engineering and Elektor Electronics Publishing - Readers Services - Dorchester UK.





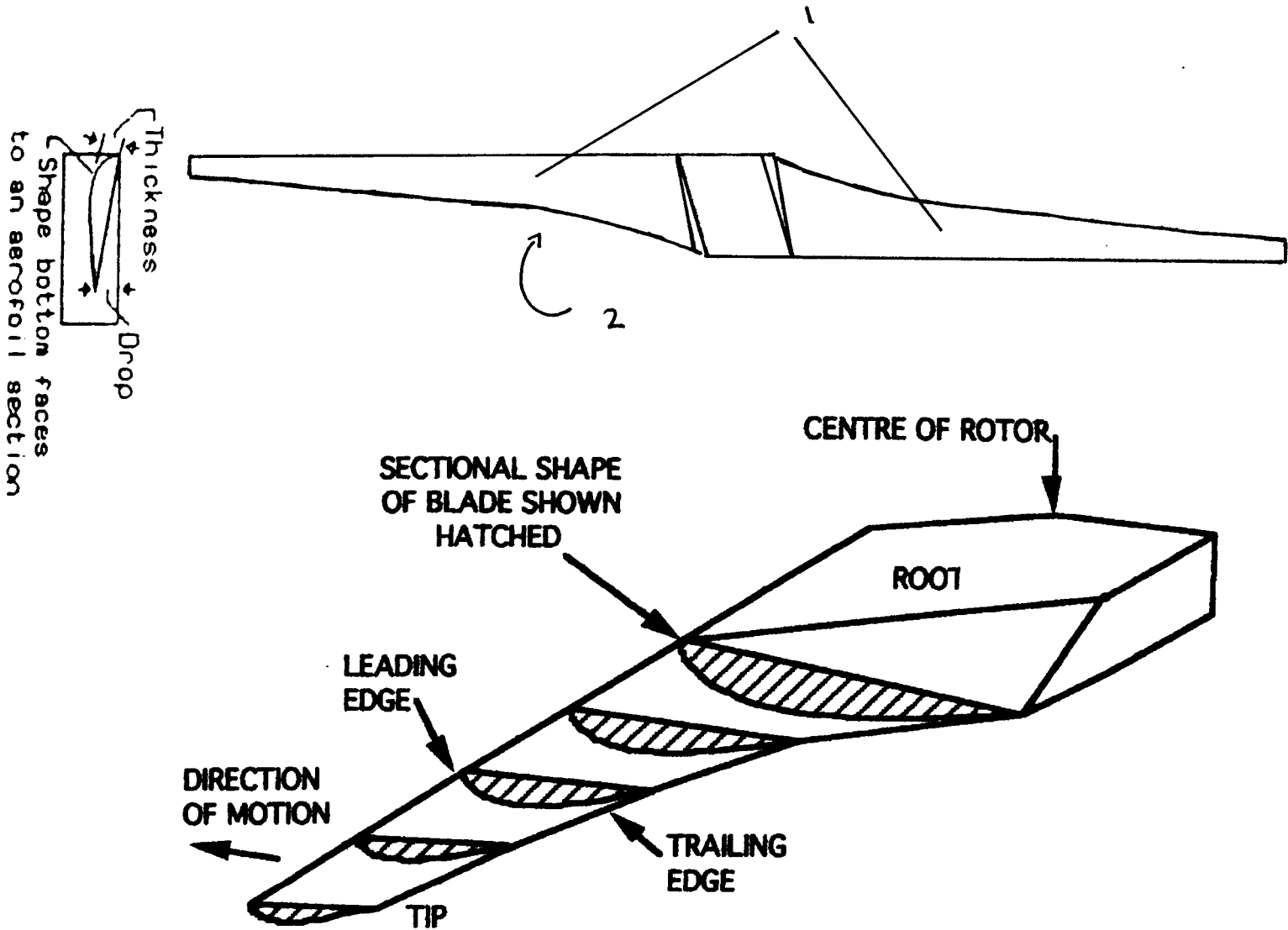
## Corrections to rotor-drawing:

Please note that the above drawing is “backwards” - and can be easily misunderstood by an inexperienced experimenter. A more correct view is shown below.

It should be noted that the finished rotor should face the wind and thereafter turn in a clockwise direction as viewed by an observer facing the rotor with the wind blowing on the observer’s back.

1: Front or top “flat”-side - facing the wind direction.

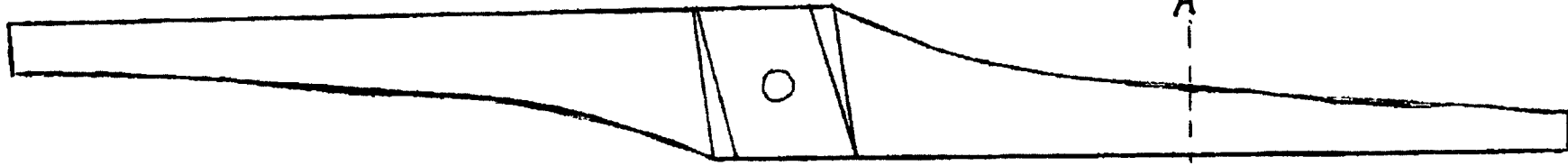
2: Rear or lee curved-side on the opposite side from the wind direction



The twisted shape of the blade

The windward face of the blade is flat, like the underside of an aircraft wing. The blade angle needs to be coarser at the root than it is at the tip. Figure shows a series of sectional views of the blade, to indicate how they change in size and angle between the tip and the root of the blade. The angle of the blade changes because the ratio of blade-speed to windspeed becomes less as we approach the centre. This affects the angle of the actual air velocity striking the blade at each station.

A-A



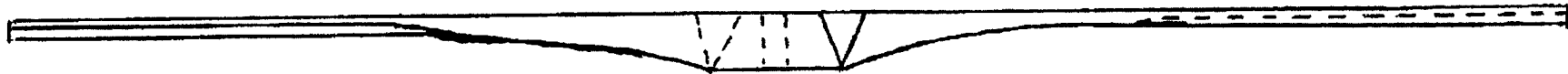
A



B

A

A



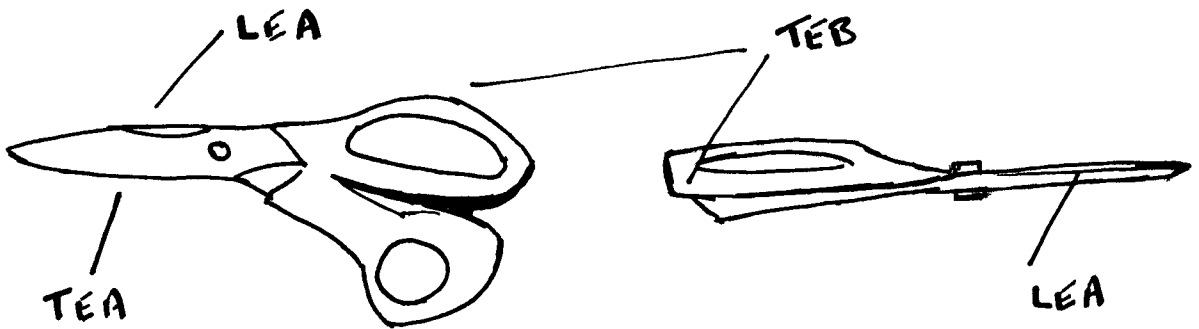
B

## Visualization of Small Wind Turbine Blades

1: Find a pair of kitchen or dressmaker's scissors - such as shown below. Notice that the handles are at about an angle of 20-25 degrees below the horizontal angle of the cutting blades - down to the right.

2: Hold the scissors up in an edgewise position - at arm's length in front of your face as shown. We are looking directly and flat-on "down" at the scissors and at what we will now call the - **Top or Upper Side**.

Note that the top blade-edge is horizontal and is on your left. This upper side edge of the scissor blades - we will now call the - **Leading Edge A** - this is the blade edge that first meets the air - when the blade [or rotor] rotates in a normal and clockwise direction. The bottom or lower scissor blade is now called the **Trailing Edge A**. The trailing edge is the rear edge where the air-stream leaves the blade. We will also call the lower handle of the scissors - **Leading Edge B** and the upper handle **Trailing Edge B**.



3: Now rotate the blades away from you. You will now see that the scissor blades are now flat at a horizontal angle - while the handles are at about an angle of 15-20 degrees up to the right.

4: Now move your body round to the other side of the flat scissors - so that one is now looking directly at the scissors from what was formerly "the rear or far side". One will of course notice that the handles are now on the left - with the **Trailing Edge B** - directly facing you on the left and the **Leading Edge A** - directly facing you on the right.

[And of course **Leading Edge B** - is on the left-hand rear side and **Trailing Edge A** likewise on the right-hand far side]

5: It is important to also visualize - that the before-mentioned and flat **Upper Side** - is the side of the blades or **Wind Turbine Rotor** - that first meets the wind "head-on" and is normally more-or-less formed in a flat angled shape - going from the **Leading Edge** to the **Trailing Edge**. The opposite or underneath side of this "flat-angled shape is formed as an aerodynamic curve - like the top of an aeroplane wing.

6: In the scissor situation example mentioned above under 4: - The thickest aerodynamic section of blade **B** - will therefore be on the left-hand underneath far side - while the thickest aerodynamic section of blade **A** - will be on the right-hand near side.

## THE PROPELLER

The whole performance of a wind generator depends upon the propeller running at the correct rpm over the required wind speed range with sufficient power to drive the generator. Small high speed wind generators require a propeller with a tip speed ratio of approximately 8:1 (i.e. the tip of the propeller travels 8 times faster than the wind speed). This type of propeller has thin parallel sided blades with a fixed pitch of 6 degrees.

The traditional (and still best) material for small propellers is wood.

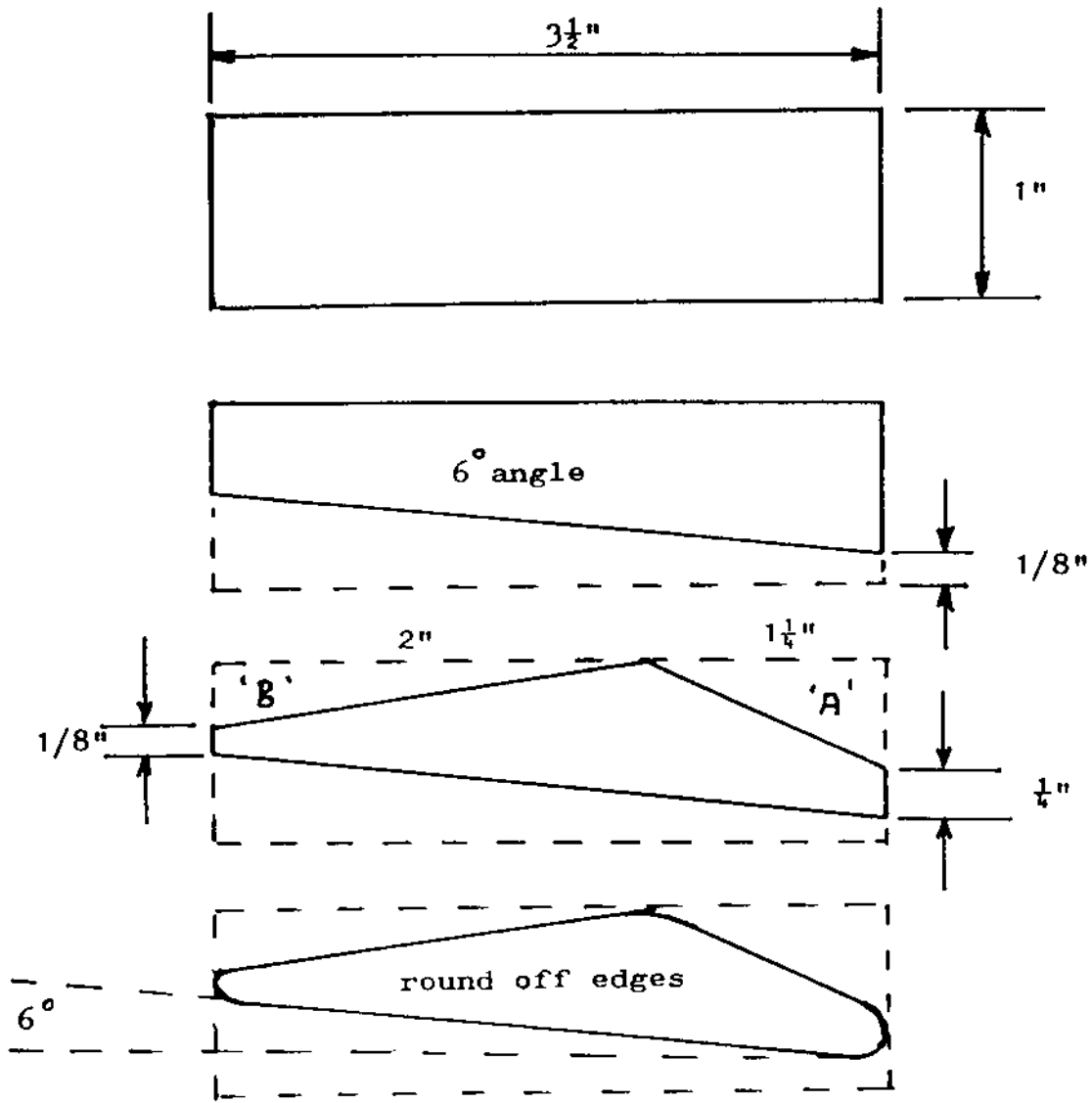
This should be of the highest quality, straight grained and free from any warping, knots or cracks.

Recommended woods include :-  
Sitka spruce  
Beech  
Mahogany

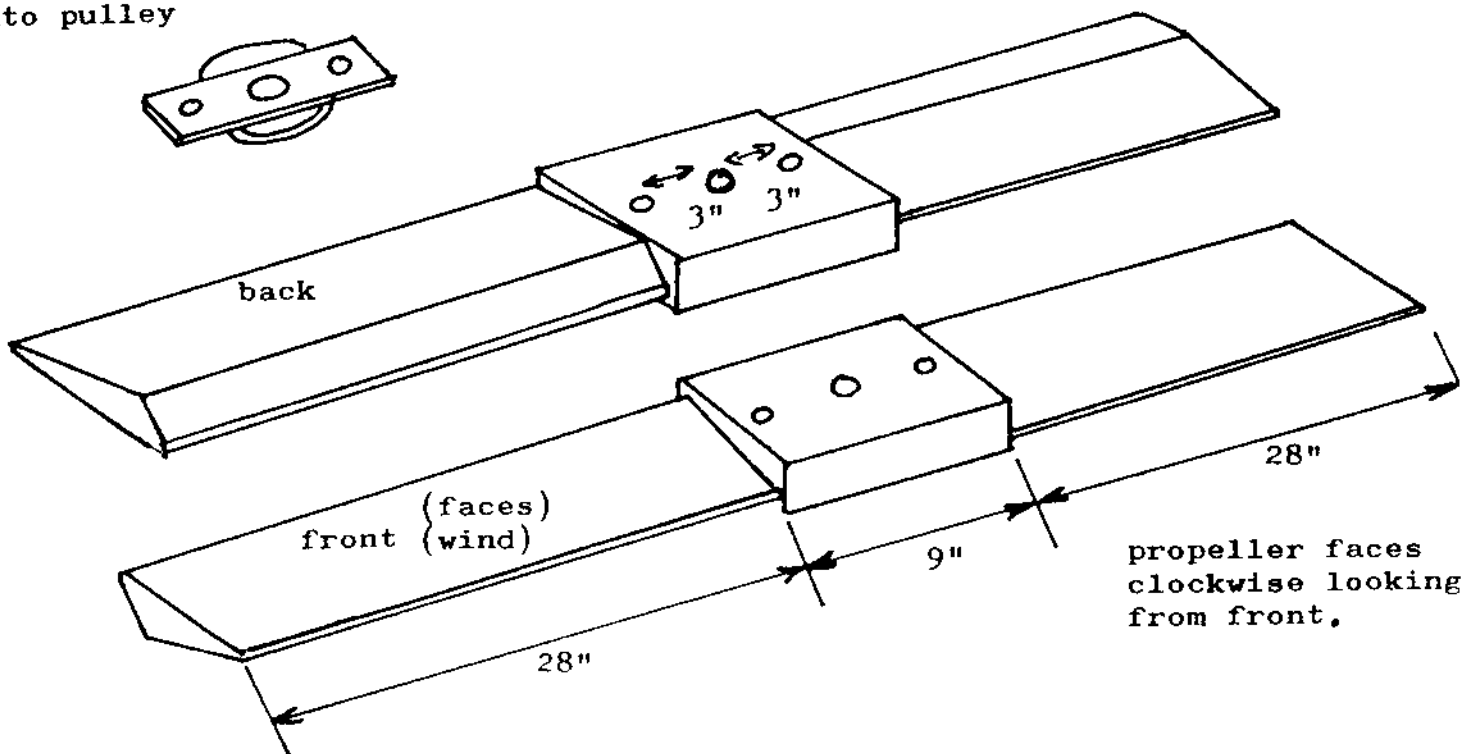
### Construction (see Fig. 8)

1. Cut a piece of wood accurately to 65" x 3½" x 1".
2. Using a fine tooth saw, or bandsaw, or plane, accurately cut a 6 degree angle for 28" from the tip of each blade. Blend a smooth bend at the end of the cut.
3. Cut the front of the aerofoil of each blade (section 'A') to give a leading edge ¼" thick.
4. Cut the back of the aerofoil of each blade (section 'B') to give a trailing edge 1/8" thick.
5. Drill a ½" centre hole in the propeller and two 3/8" mounting holes at 3" radius.
6. Sand the propeller smooth. Round off leading & trailing edges.
7. Weld a piece of mild steel 8" x 2" x ¼" onto the alternator pulley after first drilling two 3/8" holes and a centre hole large enough to tighten the pulley nut through.
8. Paint the propeller with either 3 coats of polyurethane varnish or two coats of epoxy paint.
9. Mount the propeller on the pulley assembly and then on the alternator shaft for balancing. Add balance washers as required. Secure either on one mounting bolt or with wood screws at the root of the blade

**FIG. 8 - PROPELLER CONSTRUCTION**



weld  $8" \times 2" \times \frac{1}{4}"$  strip onto pulley



## BLADE CARVING

Friends:

It has been our objective to conduct research into "construction and ease of visualisation in rotor-blade-construction". It is our impression that many "blade-designs" are rather difficult to visualize [if not to say very difficult, confusing and indeed perhaps too complicated] - and it is therefore advisable to "take your time and have a simple model for reference".

Please take time to carefully several time read-through the following notes. It is indeed complicated - but only once. Please consult the relevant above mentioned drawing.

[In this respect it should be noted that Hugh Piggott has recently done much to improve the visualization process prior to marking-out of the individual blades on his latest three-bladed models. See downloads and links - [www.scoraigwind.co.uk](http://www.scoraigwind.co.uk) - & - [www.otherpower.com](http://www.otherpower.com) ].

It has also been our objective to experiment with glued-strips. Finally it is our intention to further experiment with longer - straight-sided blades as shown on the specially-available CD-3 in several different files. However the necessity for our now lengthwise-sawn beech logs to be more fully dry has meant a postponement of this task.

**01:** 190 cms lengths of 2.5 cms x 10 cms "battens" - were cut into 190 x 3 x 2.5 cm strips - using an old baby-size Black & Decker circular-saw. These strips were then glued with a good BOSTIK waterproof and "flexible" wood-glue. We decided that we would not use more expensive epoxy-glue as these were solely for prototype experimental carving.

**02:** The strips were glued and clamped with many large screw-clamps and laid-out on the floor on a sheet of plastic.

**03:** The glue has a drying time of 30 minutes - but because of the cold and damp and with our workshop temperature of about 5-7 degrees - the glue was still not quite dry the next morning - however the actual "plank" looked good and strong. Although because of the different internal "stresses" in the individual strips [and possibly the cold temperature] there were now considerable height differences between the individual strips - both on the top and the bottom - in spite of being very tightly clamped with heavy-duty wooden-formwork concrete construction screw-clamps. This means that future glued work must be very heavily top-loaded to prevent possible "spring-effects".

**04:** Because the glue had not completely hardened - it was a hard job to first scrap off as much as possible of the excess glue in between the different "strip-height differences" - before we were prepared to use the hand-held electric plane so as not to mess-up either the cutting edge of the plane nor to clog-up the flexible-plastic air-suction tubing from the machine-plane to the industrial-type workshop vacuum-cleaner.

Non-mechanical tools such as a Stanley hand-plane, a drawknife a spokeshave and a Stanley SURFORM "rasp-shaper" have been used with success and indeed - all these are needed. As well as the Bosch machine plane, a Holtz-Her belt sander and a Black and Decker orbital sander.

**05:** It is recommended to make the strip-height 3 cms - as the "finished-plank" - prior to the carving has to be 1" - inch [2,54 cms] - so there as adequate and sufficient reserve-excess wood to remove.

**06:** An minor but very unfortunate incorrect small-cut with the circular saw on one edge of the wooden plank required a repair with the inserting, gluing and clamping of a small repair-strip of wood - 5 mm x 2,5 cms x 20 cms. It is advisable to use either a table-saw or a hand-held jig-saw - such as a Scintilla/Bosch orbital jig-saw for edge-cutting. Even though the cuts are perhaps not as straight as with a circular saw, any irregularities can be smoothed out either with the spokeshave or a sander. AND one is always in complete "view" of the actual cutting situation.

**07:** We have noticed and we consider - that in constructing blades from drawings - there is always a great possibility of MISTAKING the correct direction of rotation and therefore - ??? - which blade is carved in which direction.

We have decided that to avoid this possibility it is advisable to first construct the ultra-simple blade - shown on CD-1 in the file "Low-cost Windmills" - in the section Jemmett 120 W. Windmill. This simple 65" x 3½" x 1" - two bladed rotor with only three straight angles on each blade. However as shown in the drawing and to be very correct - it does first need a calculation of 3.5" [inches] x tangent 6 degrees and then a reconversion back into fractions of inches => about 3/8" inch and add 1/4" inch to find the correct angle height on the plank trailing edge.

**08:** This model with a 65" diameter [just over 165 cms] rotor and with plain straight-sided shape with a width of 3½" and start thickness of 1" - is highly suited for not only experimenting but as a visualisation model. As the measurements for this blade are hereafter given in inches - the following figures are given as a rough reminder:

1" = 25.4 mm  
1/8" = 3.175 mm  
1/4" = 6.35 mm  
½" = 12.7 mm  
5/8" = 15.88 mm

**09:** The 9" center section was measured from the ends and the temporary "center position" marked. This center section was marked-up and squared and the two lines each at 4½" from the exact center were also squared and drawn across the surface. A further middle line was drawn through the center-point lengthwise through this "box". There are now four rectangles in this upper surface 9" x 3½" box. These measurements are repeated on the reverse side and each of the three upper lines joined with the three reverse-side lines around the 1" plank-edges.

**10:** On each flat side in this center box there are now 4 small rectangles each  $4\frac{1}{2}$ " x  $1\frac{3}{4}$ " wide. On the upper left-side rectangle draw an arrow pointing-up and write "WIND". Now in the lower right-hand side draw another arrow pointing-down and again write "WIND".

**11:** Along the drawn center line from left to right now write - "FRONT" or "TOP".  
[This is the side that the wind will first meet - as seen by a person standing in front facing the blade - with his own back to the wind. The Blade rotates in a clockwise direction].

**12:** Turn the plank lengthwise over and write along the rear center line "BACK"

**NB:** The top and bottom surface-lettering of the words "FRONT" and "BACK" must be written in the same plane and of course on opposite sides of the plank.

**13:** Position or turn the plank "BACK" [rear-side] - so that the lettering "BACK" is now upside-down. Measure  $1\frac{1}{4}$ " [one and one quarter of an inch] UP from the bottom of the lower left edge of the left-hand side lower rectangle and then project and draw the line - out to the left-hand edge of the plank. This is now written on the surface with a pencil as line "A"  
This line will mark the highest point of the left-side rear or "BACK" aerofoil-shape.

**14:** Repeat the process by measuring  $1\frac{1}{4}$ " DOWN and out to the right from the upper right edge of the top right-hand rectangle of the same "BACK" -side and written in as line "B".  
These two lines "A" and "B" will mark the highest points of the aerofoil shape

**15:** Now turn the plank over and towards you 270 degrees - so it is now on edge on the work-bench. The side and lettering marked "FRONT" is now facing you [with the lettering "FRONT" the right way up]. Starting from the "squared box lines" on the upper top left-hand side marked "WIND" - measure  $\frac{1}{8}$ " DOWN - out and away from you and across the 1" edge. Make a mark "C" and thereafter further measure and mark again  $\frac{1}{4}$ " - "D". Thereafter project these two parallel lines [ $\frac{1}{4}$ " apart out to the left edge or tip.

**16:** Rotate the plank on the work-bench 180 degrees away from you - on edge [BACK is now facing you - and again upside down]. Repeat the same procedure. Across from the "FRONT" original lower right-hand rectangle edge [and in this present position - now towards you] mark "E" and "F". These two parallel lines must be projected out to the right-hand edge of the plank. These 4 lines "C" "D" and "E" "F" - are the "leading edges" of the blades.

**17:** Now measure  $\frac{5}{8}$ " towards you from the edge of the FRONT lower left-hand rectangle "G". Thereafter measure a further  $\frac{1}{4}$ " - "H". Project these two parallel lines out to the left-hand tip.

**18:** Rotate the plank 180 degrees away from you - so that FRONT is now facing you. Repeat the same process and measure  $\frac{5}{8}$ " across from the edge of the right-hand upper rectangle. Project these lines out to the right-hand tip - "I" and "J".  
These 4 lines "G" "H" and "I" "J" are the "trailing edges" of the blades.



**19:** Go out to the squared tip-ends and join-up the different projected lines. It will now be seen that they form an aerofoil shape. Looking at the plank with the FRONT facing you - with the lettering the right-side up - it will be seen that - the "left" flat side [facing the wind] slopes DOWN from the FRONT upper left-hand side rectangle. And the "right" flat side [- of course also facing the wind] slopes UP from the FRONT upper right-hand side rectangle.

**20:** Now go through all these measurements a second and third time to check and control.

**21:** Place the plank on top of another plank to avoid excess vibration especially at the tip end while working with tools. Use a screw-clamp placed with the center "BACK" section uppermost and fasten them both to the work-bench.

**22:** Using a draw-knife and plane carefully remove away as much of the wood as possible from the visible 1 1/4" pencil-lines "A" and "B" down to the pencil line on the edges "D" and "F".

**NB:** PLEASE BE VERY CAREFUL - AND CHECK THAT YOU DO NOT REMOVE TOO MUCH WOOD - OR MISTAKE THE DIFFERENT PARALLEL LINES !!!.

**23:** Then repeat the process from other side of the still visible pencil lines "A" and "B" - down to the lines "H" and "J".

**24:** Use a fine-set spokeshave during the later stages of this work. For cutting along the sides of the large center rectangle the use of a hacksaw and a loose hacksaw blade and a rasp are recommended. At first we used a fine-toothed saw - however this was perhaps too big and clumsy for this purpose and a hacksaw or hacksaw blade is preferable.

**25:** Turn the plank over so that the "FRONT" side is now on top and fasten as previously described. Using the draw-knife, plane and spokeshave - carefully remove the wood across the whole width of each blade from "C" across to "G" on the left-hand side and from "E" across to "I" on the right-hand side.

**NB:** DURING THESE STAGES - DO NOT REMOVE ALL WOOD RIGHT DOWN TO THE DRAWN LINES.

**26:** As all the sections on this blade design are flat and straight - it is a very easy task to use a good belt-sander and orbital sander to remove much of the last uneven areas down to the lines.

**27:** The blade sections will need a final sanding and finish with a wooden block and fine sand paper and also rounding and smoothing of the leading and trailing edges [between lines "C" "D" and "E" "F" and likewise between lines "G" "H" and "I" "J" in addition to a smoothing-over of lines "A" and "B"].

**28:** Likewise the necessary shaft measurements, drilling, fixing and balancing etc will of course still be necessary before the blade is finished.

However as mentioned above - the purpose of the whole operation was the following:

**A:** Visualization of shape - etc.

**B:** Experimentation with glued strip wood for blades.

Results from this process have been highly favourable - without however - actual wind testing for performance or reliability etc.

However we have noticed that even though problems with imperfections in the wood are avoided by the use of glued wooden strips, two areas have been encountered where the over-energetic use of the draw-knife near knots and other potential weak areas and faults - rather than using the belt-sander - has resulted in a couple of small imperfections. In future only "near-perfect and good" wooden strips should be used in any gluing process.

However in reality this is no problem and the present encountering of this problem can perhaps only have resulted from lack of necessary concentration during the strip-assembly prior to gluing process.

The time taken for this last Second-Stage process - has been about 1 hour for the measuring [and checking and then re-checking] and then about 1½ hours for the wood carving process.

With a more systemised approach - even at this present stage - it should be possible to produce a finished "simplified-design" two-meter two-bladed rotor in about 3½ - 4 hours or at a rate of at least about 2 units per day.

## Appendix B AIRFOIL DATA

Following is a discussion of the method by which you can lay out an exact airfoil shape according to some numbers which are presented in this section of the book. A graph is presented which shows the lift coefficient performance for each of the airfoils listed. This graph will help you in Blade Angle computations. Other airfoils are available, some better than those listed here, many less suitable. Check the bibliography in this book for sources of further airfoil information.

### HOW TO LAY OUT AN AIRFOIL

The numbers presented for each type of airfoil are percentages of the airfoil's chord length. When you have determined chord lengths, you can calculate dimensions from which to develop the exact airfoil shape much as you would plot a graph.

#### EXAMPLE

A few of these numbers for the Clark Y airfoil are:

Station	Upper	Lower
0	3.50	3.50
1.25	5.45	1.93
2.5	6.50	1.47
5.0	7.90	.93

and so on . . . .

For simplicity let's assume a chord length of 10 inches. Then you multiply each number in the box by the chord length. Remember that these are percentages before multiplying by chord length, -that is, 3.50 percent is really 0.035, and 1.25 percent is really 0.0125. Move the decimal point two places to the left. You may run into some source of airfoil numbers listed as the real multiplier number rather than as a percentage. In this case, use the numbers as they are. Then, multiply:

Station	Upper	Lower
0 x 10 = 0	0.35 x 10 = .35	0.35 x 10 = .35
.0125 x 10 = .125	.0545 x 10 = .545	-----ETC

SELECTED AIRFOIL ORDINATES

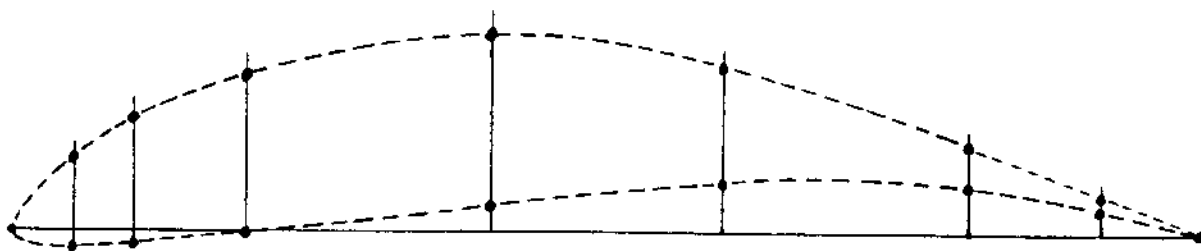
STA	CLARK Y		St. CYR 234		NACA 0012		NACA 0015		NACA 4412	
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER
0	3.5	3.5	6.42	6.42	0	0	0	0	0	0
1.25	5.45	1.93	9.55	3.75	1.89	-1.89	2.37	-2.37	2.44	-1.43
2.5	6.5	1.47	11.0	2.7	2.62	-2.62	3.27	-3.27	3.39	-1.95
5.0	7.9	.93	12.7	1.4	3.56	-3.56	4.44	-4.44	4.73	-2.49
7.5	8.85	.63	13.8	.85	4.2	-4.2	5.25	-5.25	5.76	-2.74
10	9.6	.42	14.6	.5	4.68	-4.68	5.85	-5.85	6.59	-2.86
20	11.36	.03	16.2	.2	5.74	-5.74	7.17	-7.17	8.8	-2.74
30	11.7	0	16.55	.65	6.0	-6.0	7.5	-7.5	9.76	-2.26
40	11.4	0	16.1	1.1	5.8	-5.8	7.25	-7.25	9.8	-1.8
50	10.52	0	15.2	1.35	5.29	-5.29	6.62	-6.62	9.19	-1.4
60	9.15	0	13.3	1.9	4.56	-4.56	5.7	-5.7	8.14	-1.0
70	7.35	0	10.8	1.35	3.66	-3.66	4.58	-4.58	6.69	-.65
80	5.22	0	7.75	1.05	2.62	-2.62	3.28	-3.28	4.89	-.39
90	2.8	0	4.0	.5	1.45	-1.45	1.81	-1.81	2.71	-.22
100	0	0	0	0	0	0	0	0	0	0
LR = 1.5					LR = 1.58		LR = 2.48		LR = 1.58	

STA	FX 60-126		FX 72-MS-150B	
	UPPER	LOWER	UPPER	LOWER
0	0	0	0	0
1.7	2.77	-1.37	3.05	-1.23
2.65	3.44	-1.8	4.01	-1.24
5.16	4.81	-2.48	6.15	-1.14
6.69	5.46	-2.76	7.26	-1.03
10.33	6.59	-3.26	9.43	-.72
19.56	8.33	-3.75	13.32	.13
30.86	9.13	-3.39	16.05	1.16
40.24	9.04	-2.55	16.86	2.09
50.0	8.43	-1.42	16.16	3.27
59.75	7.4	-.3	14.21	4.25
69.13	6.08	.55	11.55	4.64
80.43	4.05	1.07	7.5	4.07
91.57	1.78	.85	3.23	2.21
100	0	0	0	0

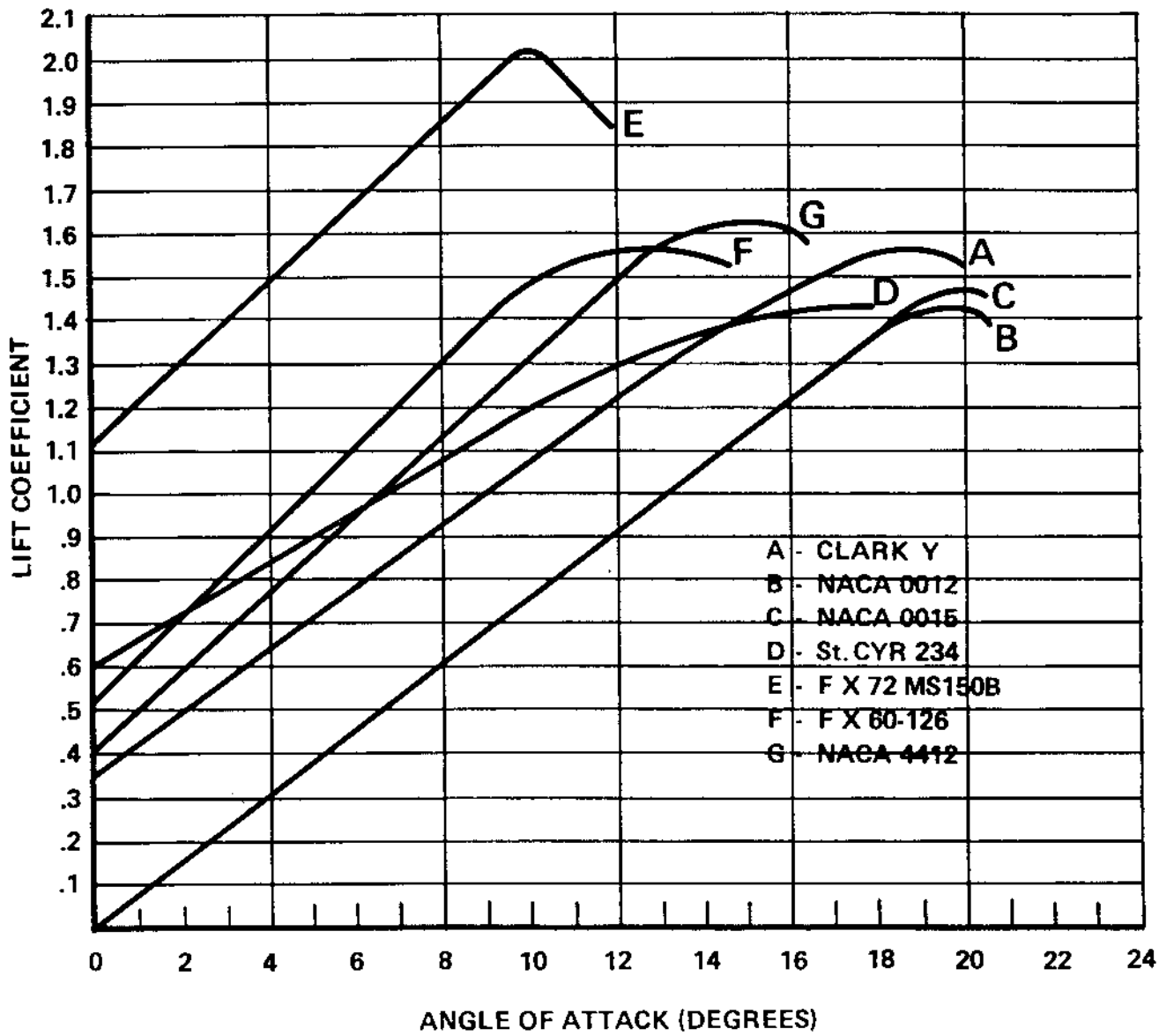
Now you simply plot the airfoil on a large sheet of graph paper. Start on a straight horizontal line. Always measure from Station = 0 to the right to each next station point, then measure up or down to the upper or lower points. Measure up from this line by the upper value. Make a dot at this point. Then, at the same station, measure from the horizontal line to the lower value. If the lower value has a minus (-) sign, measure below the line. If not, the lower value is measured above the line. Some sources of airfoil information will have different station values for the upper point than for the lower value. For these airfoils, you will have to compute the different additional station values. Keep them separate.

By making all the dots for the upper and lower values, you will generate a series of dot targets which, when connected with a curved line, will form the airfoil shape.

The "LR" value is the leading edge radius. Again, it's a percentage of the chord. For the Clark Y, LR = 1.5%, or 0.015. For a 10 inch chord, leading edge radius =  $10 \times .015 = .15$  inches. Use this value to shape the curve at the leading edge with a compass or draftsman's circle guide. Some airfoils will not show the leading edge radius value. This is really a reference number. You can draw the curve without it.



EXAMPLE FX 72-MS-150B

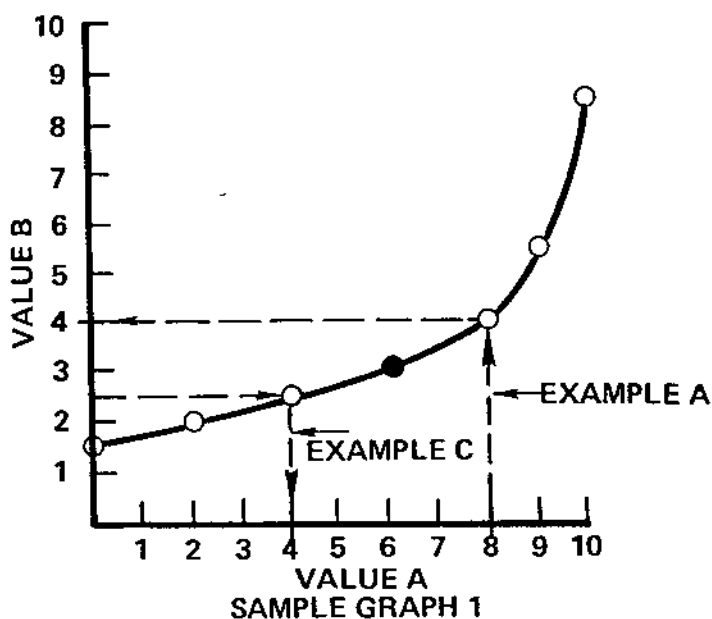


AIRFOIL LIFT AND ANGLE OF ATTACK DATA

# Appendix C HOW TO READ A GRAPH

Graphs are used to simplify calculations. I have presented many graphs in this manual so that computations which are normally difficult will be made easily. So that all users of this text have graph reading ability, this page is presented.

CONDITION 1 - You know VALUE A and you want to find VALUE B on Sample Graph 1.



## EXAMPLE A

If VALUE A equals 8, start on the horizontal line at 8 and look (or draw a line) vertically up to the curve. Next, look (or draw a line) horizontally to the scale at the left. Notice that the answer VALUE B equals 4.

NOTE - You may have more than one curve which applies to your problem. You select the curve which applies, or add a curve which does.

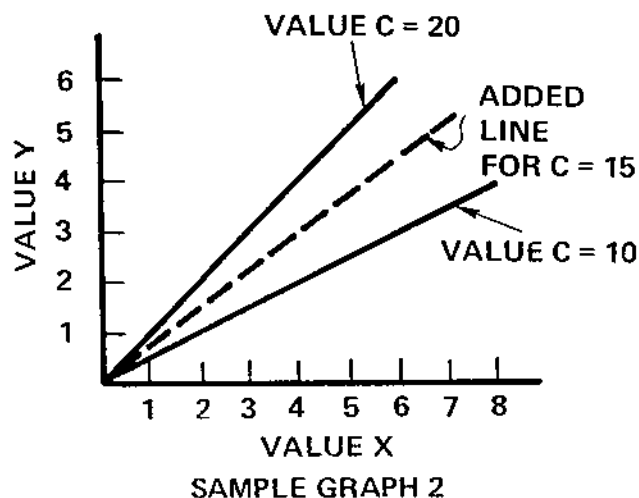
## EXAMPLE B

Look at Sample Graph 2. Suppose that VALUE C in your problem equals 15, which is half-way between the line for C=10, and C=20. Simply add a line roughly half-way between the two and proceed as above.

CONDITION 2 - Refer to Sample Graph 1. You know VALUE B, and need VALUE A.

## EXAMPLE C

Start at VALUE B (B=2.5 in this example). Look to the right to the curve, then down. Notice that the answer is VALUE A = 4.



# Appendix D

## DETAILED WINDMILL PERFORMANCE

1 - Power = Force x Velocity

2 - Force = Pressure x Area

3 - Pressure =  $\rho \times V^3 / 2$

where  $\rho$  = Mass density of air = 0.0024 slugs / foot<sup>3</sup>  
at sea level

$V$  = wind speed measured in feet per second

4 - Power = .0012 x  $V^3$  x A

where  $A$  = windmill frontal area measured in square feet

$V$  = wind speed measured in feet per second

This is the theoretical power available in a wind of speed =  $V$ , acting across a windmill of frontal area =  $A$ . Power units here are foot-pounds per second.

5 - One Horsepower = 550 foot-pounds per second

6 = Horse Power = .0012 x  $V^3$  x A / 550 = 0.0000022 x  $V^3$  x A

Again, this is theoretical horsepower.

7 - The mathematical horsepower which a windmill can extract from the above value is 59.3% of the total. However, no windmill is perfect, and the actual maximum horsepower available from a windmill will be more like 10% to 40% of the total. For calculations,  $E$  will be efficiency factor.

8 - Actual Horsepower available from a wind = 0.0000022 x  $(k V)^3$   
x A x E

where  $V$  = wind speed

$k$  = a constant to adjust  $V$

if  $V$  is measured in miles per hour,  $K = 1.47$

if  $V$  is measured in feet per second,  $K = 1.0$

$A$  - frontal area of the windmill measured in square feet

$E$  = the efficiency factor

9 - For calculation of electrical power: One horsepower = 746 watts

10 - Actual watts available from a wind = 0.0016 x  $(k V)^3$  x A x E



# Appendix E

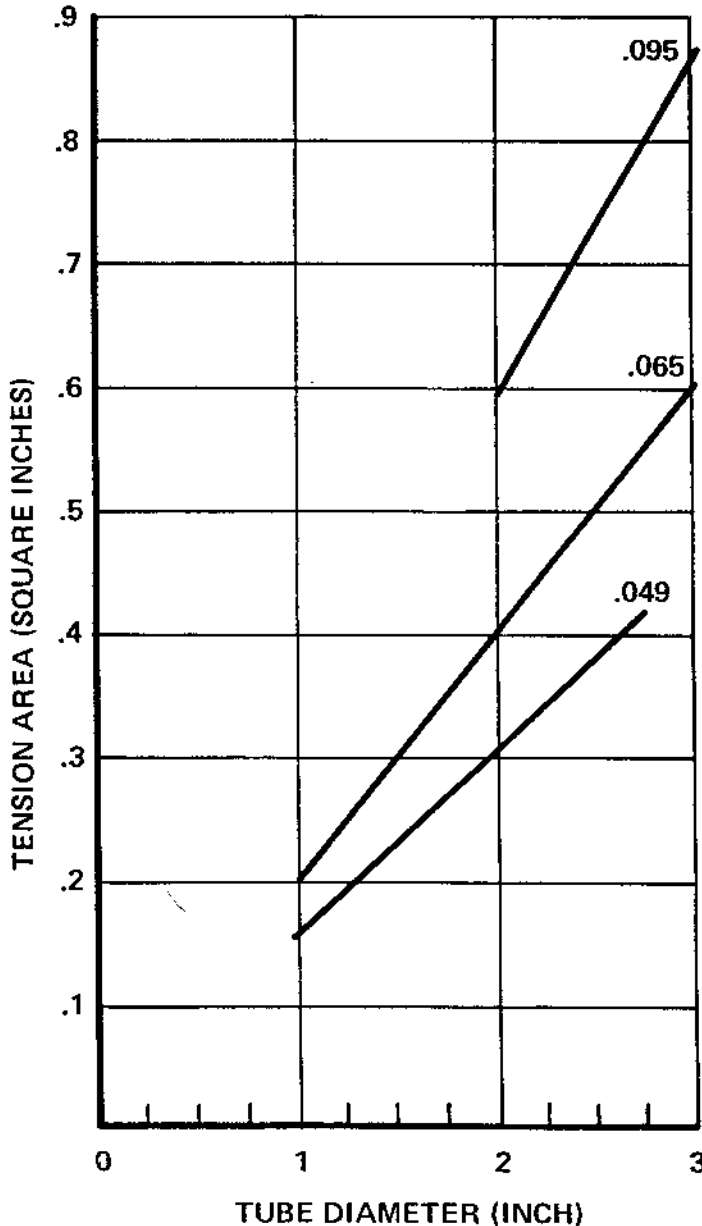
## STRENGTH OF CONSTRUCTION MATERIALS

### TUBE TENSILE STRENGTH

To compute tube tensile strength, measured in pounds of force, multiply tension area from Graph A below times the tensile strength factor for the metal alloy of the tube. See next page for tensile strength factors.

#### EXAMPLE

A 2-inch diameter by .065 inch wall thickness tube of Aluminum alloy 2024 T-4 is selected. Calculate the tensile strength. From Graph A, note that tension area equals .39. Tensile strength factor for this alloy is 60,000. Then Tensile Strength =  $.39 \times 60,000 = 23,400$  pounds.



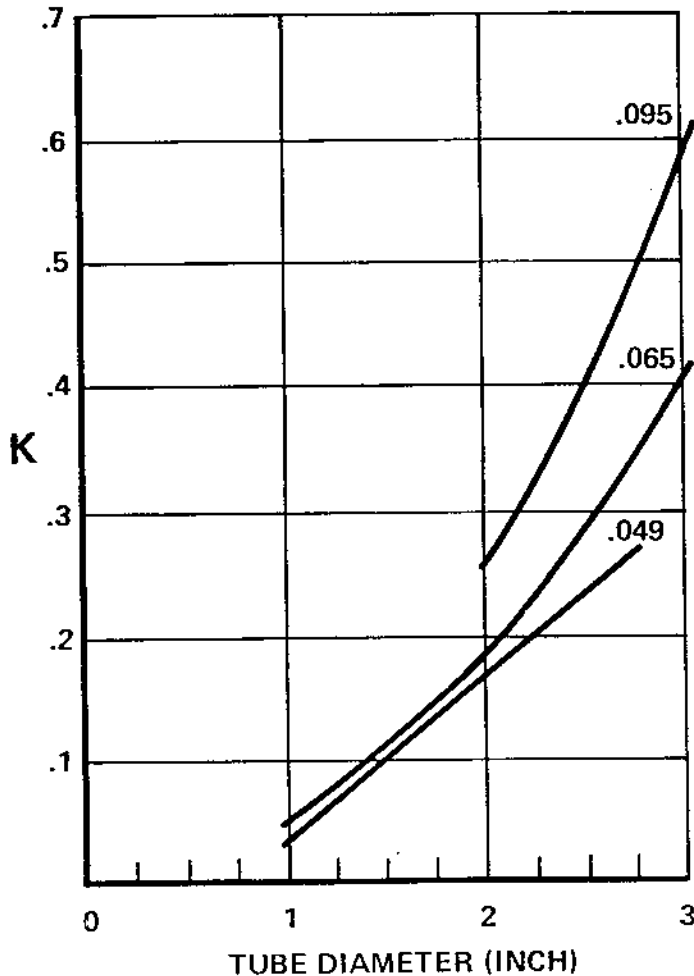
GRAPH A TENSION AREA FOR TUBE DIAMETERS AND THREE WALL THICKNESS VALUES

## TUBE BENDING STRENGTH

To compute approximate tube bending strength, measured in inch-pounds, multiply K-value from Graph B below times the tensile strength factor.

### EXAMPLE

A 2-inch diameter by .065 inch wall thickness tube of Aluminum alloy 2024 T-4 is selected. Calculate the bending strength. From Graph B, note that  $K = 0.19$ . Tensile strength factor for this alloy equals 60,000. Then Bending Strength =  $0.19 \times 60,000 = 11,400$  inch-pounds.



### TENSILE STRENGTH FACTORS

Alloy	Tensile Strength Factor
Aluminum	
2024 T-4	60,000
6061 T-6	42,000
7075 T-6	75,000
Steel	
4130	
4130	90,000

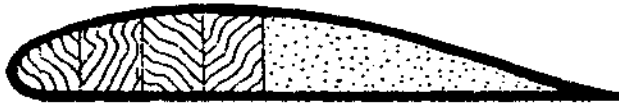
GRAPH B K VALUE FOR TUBE DIAMETERS AND THREE WALL THICKNESS VALUES

## TENSILE STRENGTH OF WOOD BLADES

Wood blades - as discussed earlier in this manual - are laminated and carved from quality materials like aircraft grade spruce. The Tensile Strength Factor for wood varies between 7000 to about 12,000 pounds per square inch. This value depends on the type of wood used, and the moisture content. Wood strength increases rapidly as the material dries out. For average wood used in the 10% to 15% moisture content range, a safe check of blade strength can be made with a tensile strength factor of 8,000. You need to know the tensile area of the blade. Then multiply this area times the strength factor to compute blade tensile strength.

### EXAMPLE

The blade sketched has a tensile area for the structural wood forward portion (you can disregard any strength value in the balsa or foam trailing edge in this example) of approximately 12 square inches. Blade strength =  $12 \times 8,000 = 96,000$  pounds. This is the maximum centrifugal tension load this blade can withstand.



## CABLE STRENGTH

Cables are used for tower guy wires, windmill bracing, and so on. Data presented is for 7 x 19 flexible aircraft stranded cable - available in surplus outlets, or the source listed in the Bibliography of this book.

CABLE DIAMETER (inches)	BREAKING TENSILE STRENGTH (pounds)
1/16	400
3/32	750
1/8	2,000
3/16	4,200
1/4	7,000

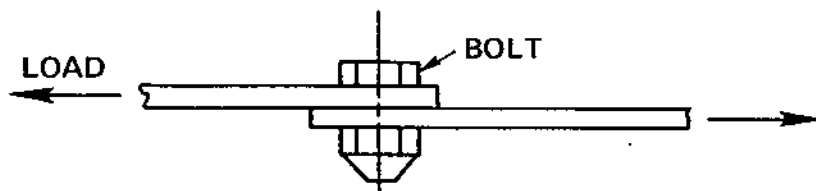
## BOLT STRENGTH

Data presented are for aircraft quality (AN) bolts.

BOLT DIAMETER (inches)	SINGLE SHEAR STRENGTH (pounds)	TENSILE STRENGTH (pounds)
3/16	2,100	2,200
1/4	3,600	4,000
5/16	5,700	6,500
3/8	8,200	10,100
7/16	11,200	13,600
1/2	14,700	18,500

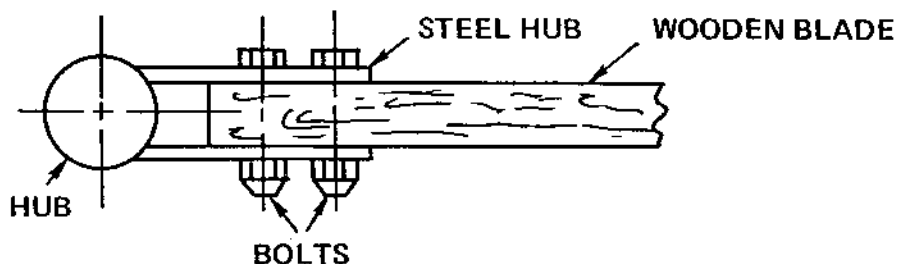
### EXAMPLE 1

Two strips of steel are to be bolted together. The maximum tensile load in the strips is 8,000 pounds. The bolt will take this load in single shear. The minimum size bolt for this load is one 3/8 inch aircraft quality bolt, or two 5/16 inch bolts. Hardware store bolts will have to be larger in diameter.



### EXAMPLE 2

A wooden blade is to be bolted to a steel hub. The centrifugal force is equal to 20,000 pounds. The bolts are loaded in shear as illustrated below.



Notice in the sketch that the blade load ends up in two hub parts, which means that half of the load goes into each side of the blade. Thus 10,000 pounds is loaded at two different places along the attachment bolt - called double shear. Two 5/16 inch bolts could handle this load. In the case of wood blade attachment, lots of smaller bolts are recommended.

## CONSTRUCTION OF ROTOR.

- A: 1.45 meters [145 cms.] plastic roof gutter - eg. "Plastmo nr. 12" - [145 mm. inside diameter, with smooth inside and outside finish - 2.5 mm. thick walls].
- B: Hand tools, drill, jig or fret or pad saw, adhesive, clamps, sandpaper, scraper, etc.
- C: Thin pliable cardboard, sissors, pencil, ruler, felt-tipped pen, tape, etc.

The 145 cms. length of plastic roof guttering is cut into two lengths. One piece of about 20 cms. and another of about 123 cms. [Any end junction-collar is cut off as close as possible].

A cardboard pattern is made from the drawing. The center-line must also be clearly marked. A tiny hole is pricked in the center-line as a mark for the future shaft. The cardboard pattern is placed inside the guttering, - **with the indicated lettering facing upwards.** - This ensures that the rotor shall have the desired direction of rotation. The center-line must be completely true with regard to the lengthwise axis of the guttering. If necessary the pattern can be pressed down inside the guttering with the assistance of a wooden straight edge and a couple of screw clamps.

Using a felt-tipped pen, the pattern is carefully transferred to the inside of the guttering. The rotor is sawn-out with a jig-saw, etc. and possible jagged or rough edges are filed clean.

To reinforce the rotor, - the short 20 cms. piece is marked in the middle and placed at the exact center on the **rearside** of the rotor. A 5 mm. hole is drilled through both pieces and they are then assembled together with a 5 mm. bolt, a nut and washer.

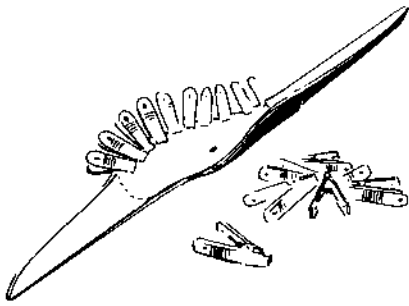
The rough shape of the rotor is then drawn on the inside of the shorter piece. They are disassembled and the shorter piece is cut out, and filed clean. The ends are rounded as indicated by the dotted lines shown on the pattern drawing. Sandpaper the edges of the junction between the two pieces to ensure that the joint will be as smooth as possible.

The two facing sides that are to be joined together - are cleaned for dirt or dust and then further prepared, as specified in the advisory accompanying instructions where or when the guttering was purchased, - such as, - "Instructions for joining plastic guttering". After the adhesive has been applied, - the 5 mm. bolt is replaced in the center hole and tightened. As many glue clamps as possible are placed around the edges of the reinforcing unit, - as shown.

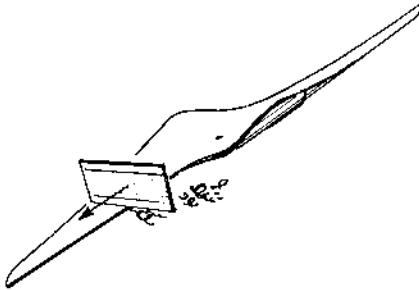
When the adhesive is completely dry - the rotor is roughly balanced by removing material from the blade center area - **on the side that meets the wind - [the leading edge]**. Balance is found by allowing the rotor to come to a level rest, by placing a rounded object - such as a vertically hand-held fountain-pen in the 5 mm. center hole. After the rotor is roughly in balance, - the edges are carefully and gently sandpapered, - at first with coarse sandpaper, then followed by finer - **using a wooden backing block**. Fine balance adjustments are also made.

The edge that meets the wind under rotation - the leading edge - **is rounded**.

The edge where the wind slips the blade - the trailing edge - **is sharpened** - by removing material from **the inside of the guttering**. This final treatment can be done by using a fine, thin and sharp-edged steel cabinet-scraper. During these final finishing processes - the rotor must be constantly checked to maintain correct balance.

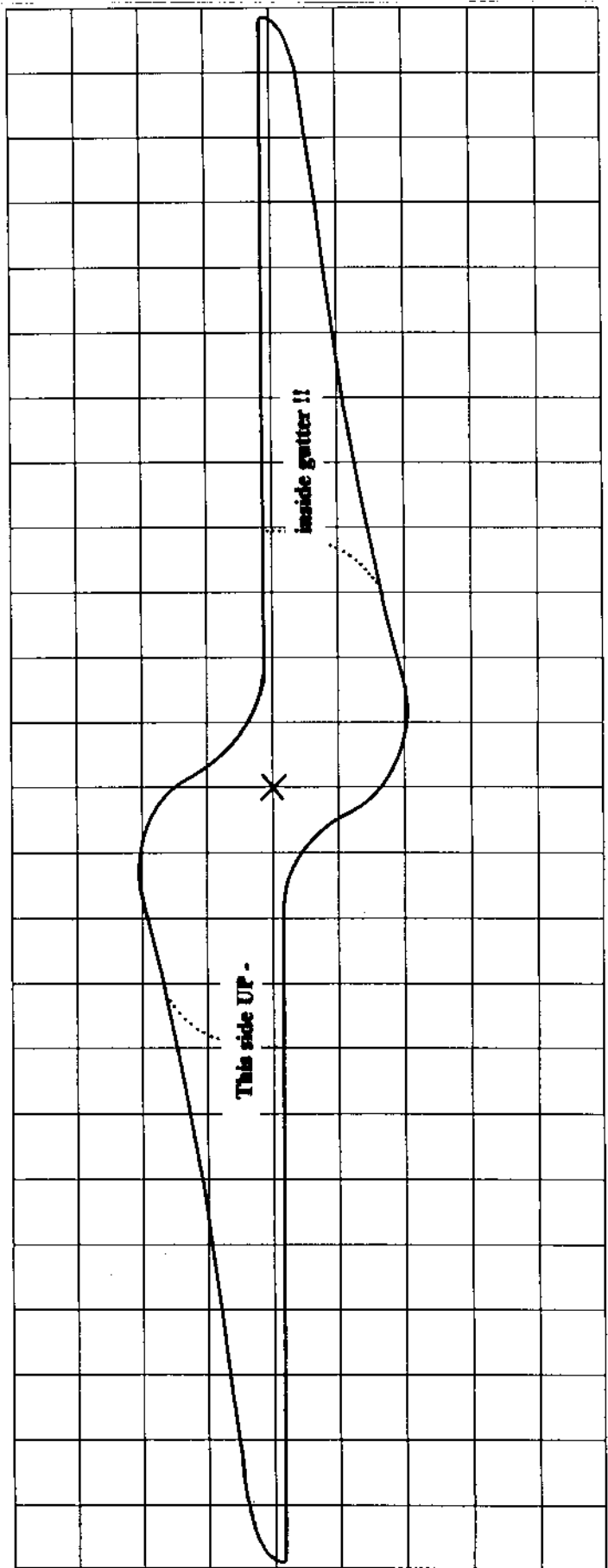


**Gluing & application of clamps.**



**Final finishing process.**

**Specifications:**  
 145 cms. Plastic roof gutter.  
 145 mm. Inside diameter.  
 2.5 mm. Wall thickness.  
 120 cms. Rotor diameter.

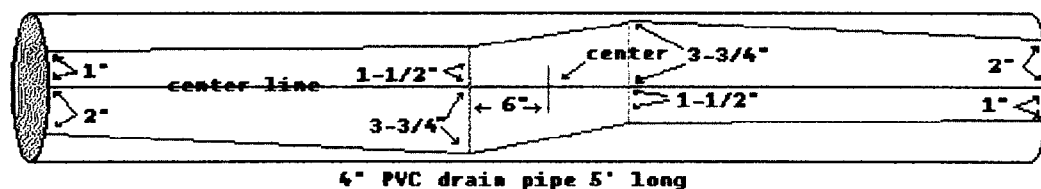


**Balancing of rotor.**

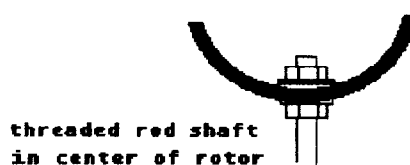
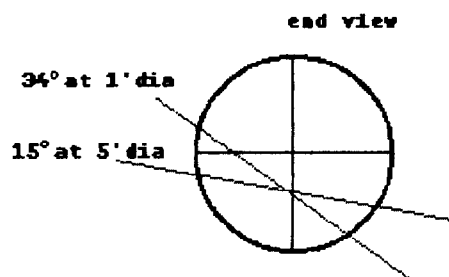
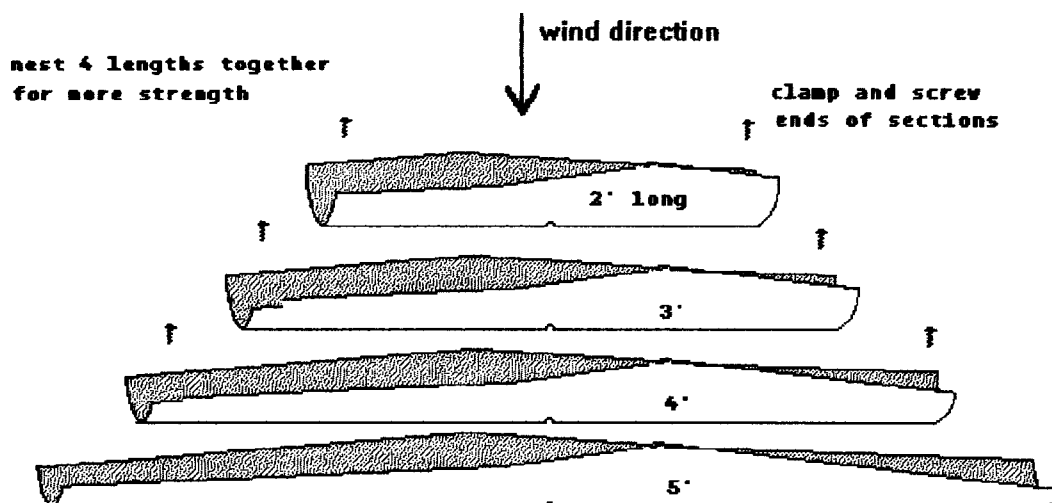
**WARNING:** PVC is a fickle type of plastic. Sometimes you can bend it and beat it and it seems like it will not break. Other time a slight tap can break it. So if you use PVC to make a tower or rotors, Remember the tower can break and fall and the rotor can break and be thrown hundreds of feet and could hurt someone. In fact, my first rotor (made from schedule 80 pipe) was thrown about 300 feet perpendicular to a 50 mph gust.

Use string taped at measurements to mark out red lines

Cut on the red lines



4" PVC drain pipe 5' long



threaded red shaft  
in center of rotor

Find a straight center line down the length of the pipe. If there are words down the length, line up on them. Measure the distances from the blue center line and tape the ends of a stretched string to them. Draw a line along the taught string and cut along the line ( the red line in diagram ) with a jig saw. Drill a hole in the center and balance the blade by removing a little material from the heavy end. You can sand and file the rotor edges to make it look nice.

The rotor looks pretty unusual and it doesn't look like it will work. The end view is cupped quite a bit and at first it looks like it will have a lot of drag. Of the rotors I have made like this, I am surprised at how well they work and I am guessing the efficiency is around 25 to 50%.

This rotor design seems strong enough until the wind reaches about 40 mph. I have had this rotor break before, so I now use 4 pipe thicknesses of reducing length. 5 foot 4 foot 3 foot and finally 2 foot on the inside. I then use small screws to hold each length together. If you use an over speed brake of some kind, you may not need to nest sections together for extra strength.

### Experimental

Other pipe sizes can work for a smaller rotor. My first trial was with a 2" schedule 40 pipe 2 feet long. Note the end view in the diagram and use a drawing like it to figure your blade angel. An angle closer to 34 degrees at the tips will give you a slower rotor design. Consider using other pipe materials also.

Make a longer rotor. If you do Please let me know how it works.

You should paint the rotor when it's finished. This will keep UV light off the surface. Some PVC will deteriorate in sunlight. I paint mine with silver spray paint. It looks like a "store bought" aluminum rotor.

Table 8.1 Tube Sizes and Rotor Diameters

Windmill rotor diameter	Tube nominal bore suggested	Tube actual overall diameter
1 metre	'inch and a half'	48.3 mm
2 metres	'two inch'	60.3 mm
3 metres	'four inch'	114.3 mm
5 metres	'six inch'	165.1 mm

Fabricating from Steel Pipe

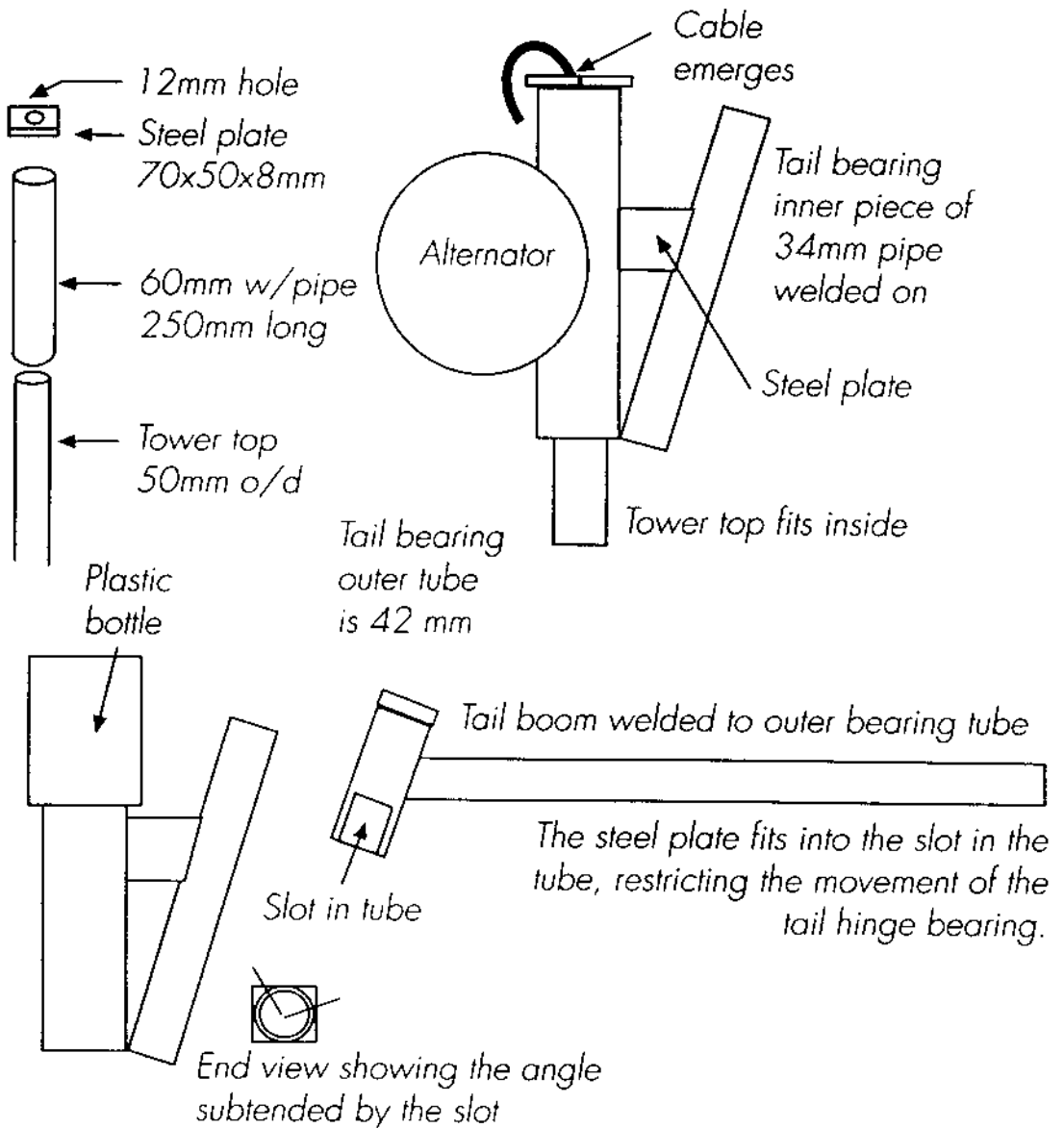


Fig. 8.3 Fabricating a yaw bearing and tail-hinge from steel pipe.



## How to carve a set of rotor blades

Here is a detailed, step-by-step description of the process for carving a set of blades for a three bladed rotor with diameter of 2.3 metres, and tip speed ratio of around 5.5. You can adapt the technique for any other tip speed ratio by adjusting the dimensions.

### Tools

You will need the following: a hand saw (and optionally jigsaw or bandsaw), wood chisel (and mallet), plane, spokeshave, draw knife (recommended, if you can find one), callipers, compasses, square, tape measure, ruler, pencil, spirit level, drill.

Keep your tools very sharp, using an oilstone. The angle of the edge of the tool is quite critical. Always start by honing the tool, and then work up to the edge. Go easy on the edge itself, or you will actually make it blunter. Finish by removing any rag from the edge, using swift, light longitudinal strokes, or stropping the edge on leather or wood.

Always work with the grain of the wood, to prevent it splintering. Grip the workpiece firmly to a bench with a G clamp. If a tool judders or sticks, try sliding it sideways as you cut. A slicing motion like this gives more control.

### Materials

3 pieces of wood, 150 mm by 50 mm, by 1150 mm long.

2 plywood discs, 12 mm thick, 300 mm in diameter, exterior or marine grade.

—Table 4.1 Summary of Finished Dimensions—

Station	Width	'Drop' (step 3)	Thickness
1	145	50	25
2	131	33	20
3	117	17	18
4	104	10	15
5	90	5	11

Mounting bolts to suit your hub.

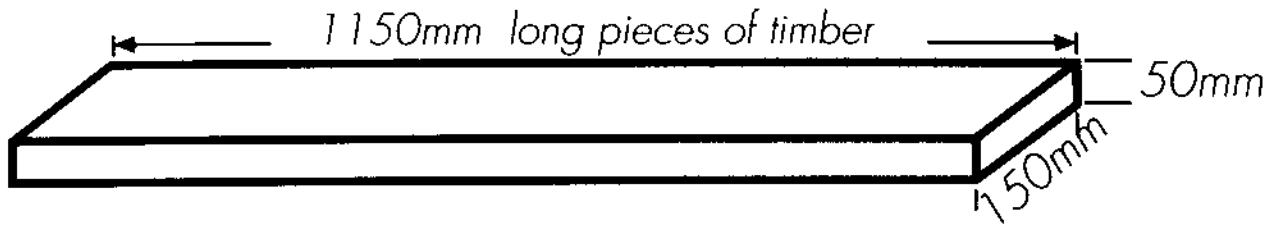
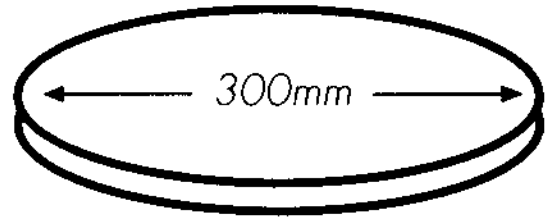
48 galvanised woodscrews, size 40x4 mm countersunk.

If you have access to a thicknesser machine, you should start by passing the three pieces of wood through, to remove any warp and give a smooth straight finish. Do not worry if you lose a few millimeters off the overall dimensions, provided that all three are identical.

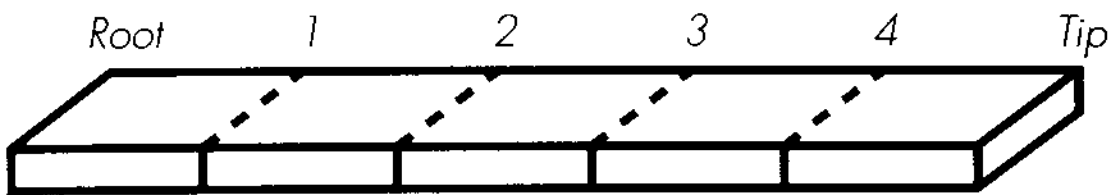
# Carving the Blades

Fig. 4.1 The raw materials:

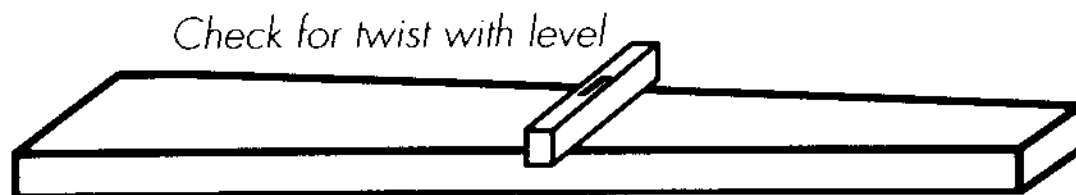
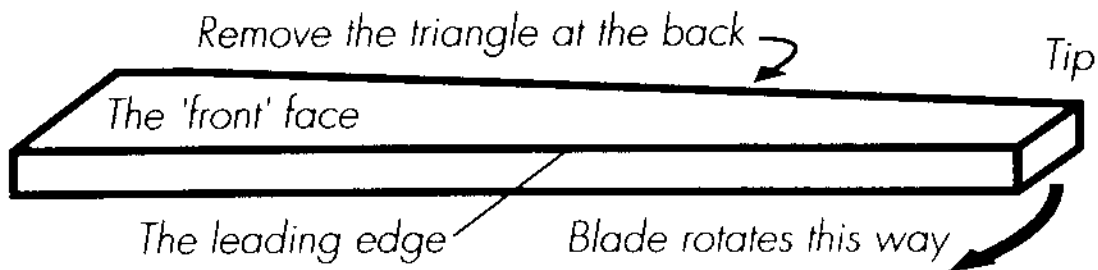
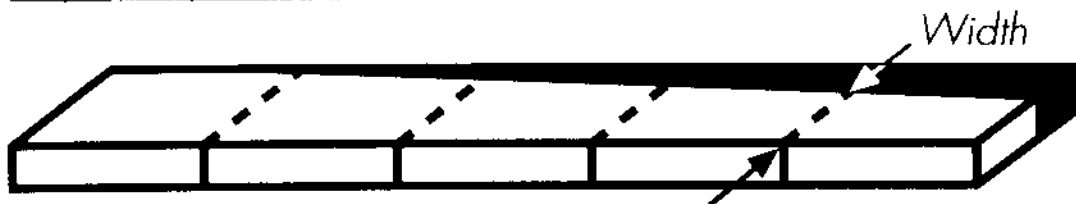
2 Plywood disks



Step 1. Marking out the stations:



Step 2. Tapering the blade:



### Step 1. The stations

Mark out the stations on the pieces of wood (Fig. 4.1), equally spaced at intervals of 230 mm. Draw a line right around the piece, using a square. The left hand end is the root of the blade, which will be at the centre of the rotor. The fifth station is the tip.

### Step 2. Taper the blade

Measure the widths in millimetres (Table 4.1) from the edge which is nearest to you, and mark dots. Join the dots with a line. If there are any knots in the piece, turn the wood over so that they are in the triangular piece at the back which you will remove. You can use a bandsaw, or cross-cut the waste and split it out in sections using a chisel. Plane the newly cut surface smooth, straight and square.

Try to visualise the shape of the finished blade (Fig. 4.1). The tip moves clockwise, viewed from upwind, so the leading edge is the one nearest to you. The front (or windward) face is uppermost now. It should be perfectly flat (untwisted) at this stage. If not, then plane it flat. Check for twist with a spirit level, laid across the piece at each station in turn.

### Step 3. Carving the twist

The next view (Fig. 4.2) shows the piece turned around, so that the leading edge is at the back, and the tip is on the left. At each station, draw a vertical line on the newly cut face, square to the front face.

Mark a point on each line, a certain distance down from the front face. We call this distance the 'drop' (Table 4.1). It determines the setting angle at that station. Join the dots to draw the line of the trailing edge of the blade. Carve away all the wood above the trailing edge (pencil line). The windward face should end up so flat that when you lay a ruler edge across the blade between the leading and trailing edges, it will not rock.

At the root, the pencil line must rise again to the uncut face in a steep ramp 100 mm long. The root is to be left uncut, for assembly between the hub disks. (Note: with larger blades, it is easiest to use a bandsaw to remove much of this deep 'scoop' near the root — see the above photograph).

### Step 4. Carving the thickness

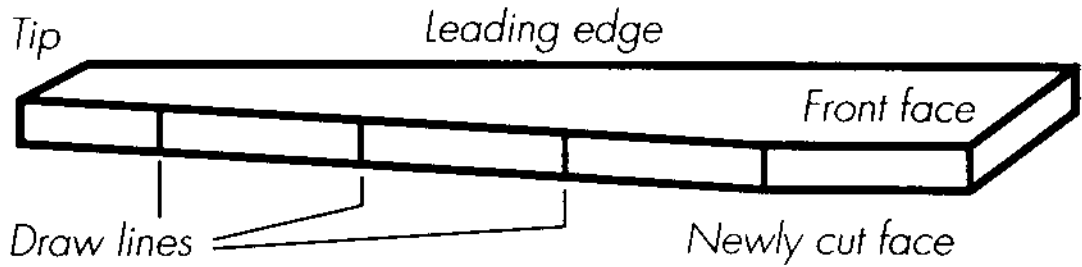
You now have a slightly tapered piece of wood, with a twisted face hollowed out of the 'front'. The next step is to remove wood from the back of the piece, so that it is the correct thickness at each station (see Table 4.1).

Lay the piece of wood with leading edge uppermost. At each station, make a mark at the correct (thickness) distance from the leading edge. Join the dots with a line. Turn it over and do the same relative to the trailing edge. Now you have two lines (Fig. 4.3) to guide you as you cut off the waste wood. Support the piece so that the front face is underneath, and cut away the waste until you get close to the lines you have drawn. When you get close, it is

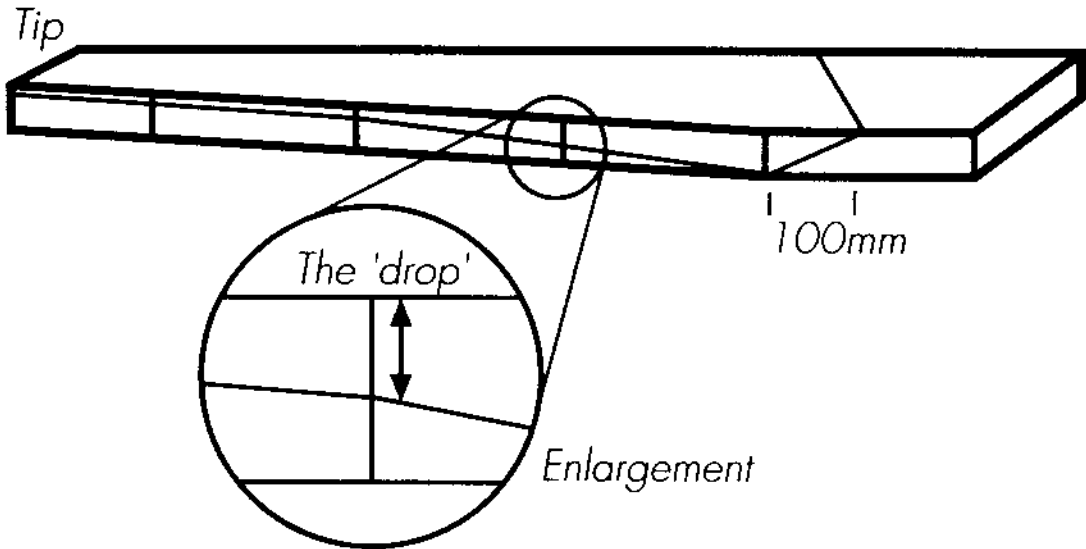
# Carving the Twist

Fig. 4.2

(A)

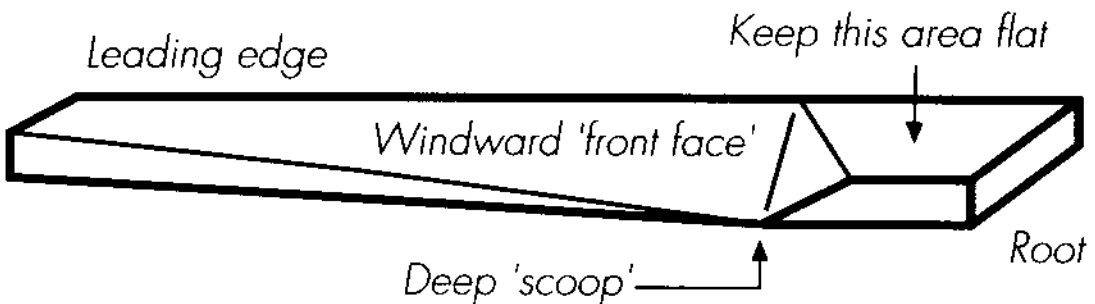


(B)

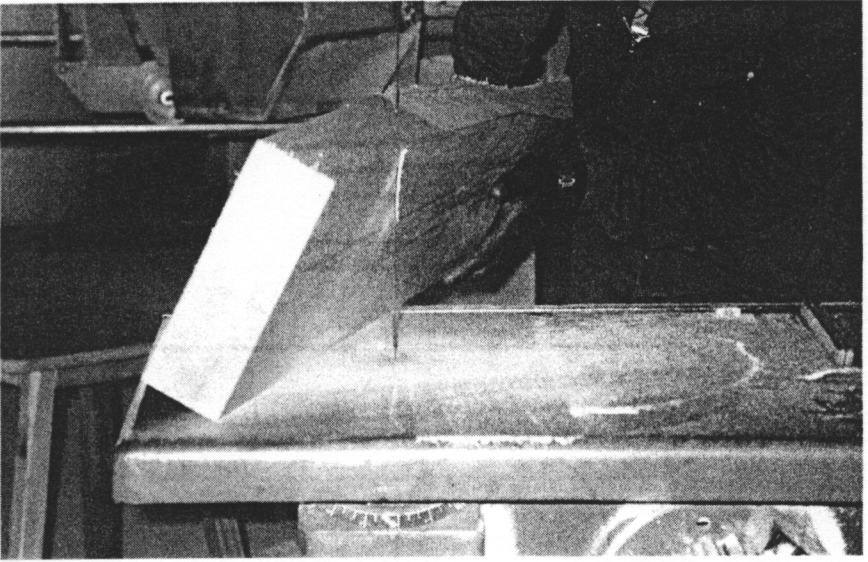


(C)

The end result of this step looks like this:



## Cutting out a Rotor Blade



necessary to use callipers (Fig. 4.4) to check the actual thickness at each station. Measure how many more millimetres need to be removed, write it in pencil on the workpiece at each station, and resume shaving the piece down until the thickness is correct to within 0.5 mm.

(Note: If you do not have callipers, it is easy to make a good pair [Fig. 4.4] using two pieces of sheet aluminium, or even plywood, bolted together.)

At the root, be sure to leave an area untouched (just as you did with the front face) for sandwiching between the hub disks.

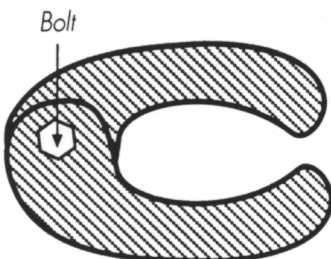
### Step 5. Smoothing out the section

You should now have a tapered, twisted blade, of the correct thickness. The cross section is just a crude parallelogram shape (shown bold in Fig. 4.5), which is not very aerodynamic. The final stage of carving your blade is to give it a streamlined airfoil 'section'.

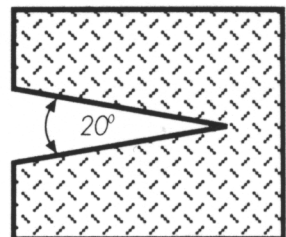
Start by feathering off the trailing edge. Plane off wood from the

## Two Tools You Can Make Yourself

Fig. 4.4



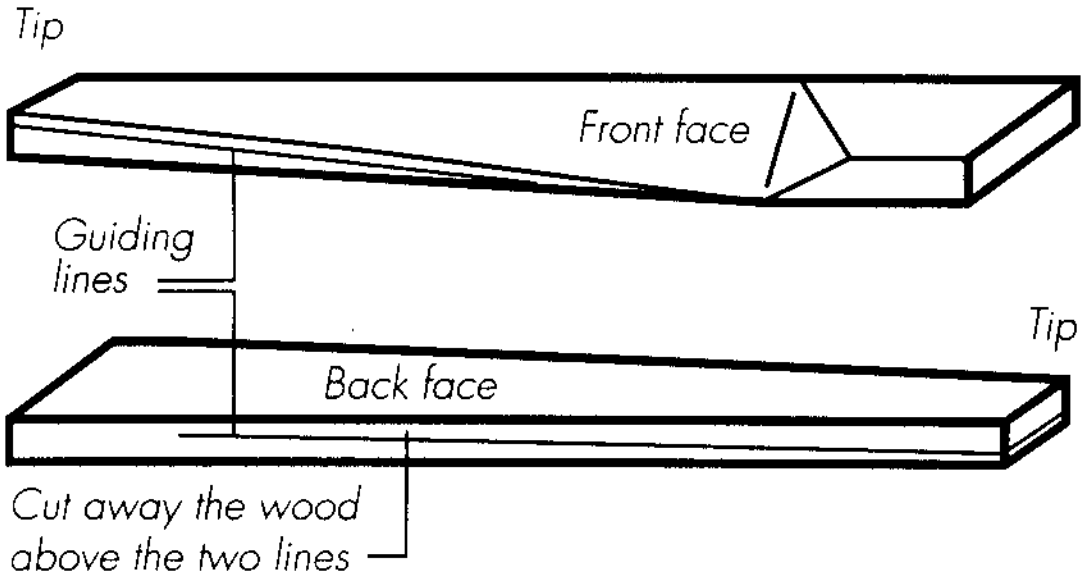
Callipers



Trailing edge template

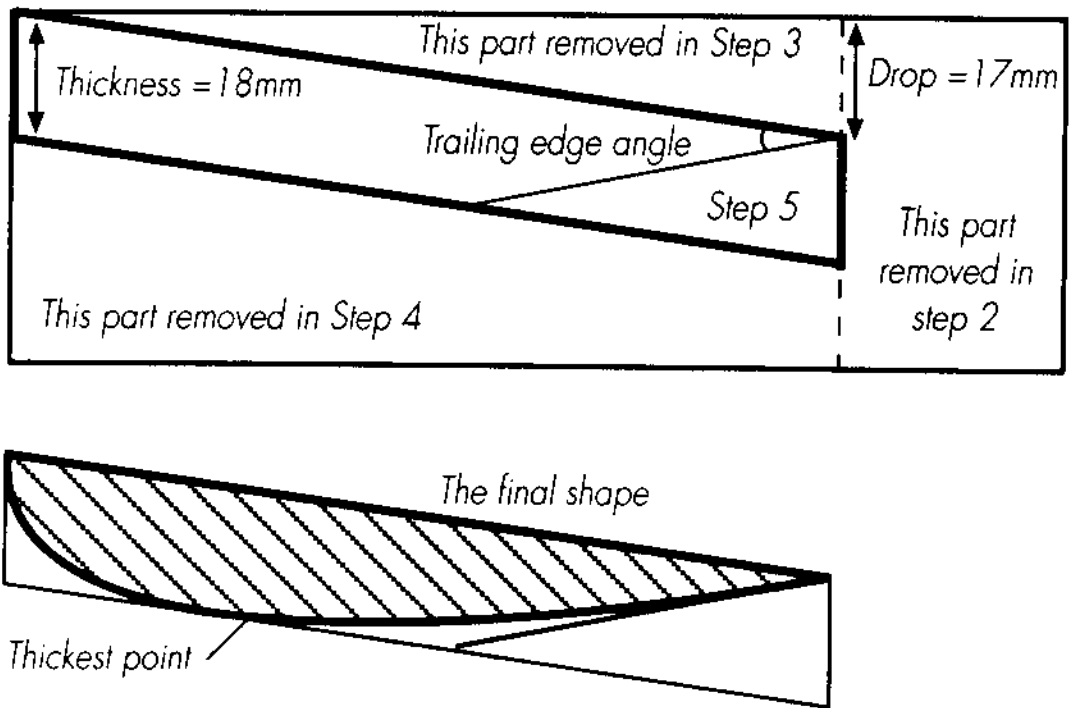
# Carving the Thickness

Fig. 4.3



# A Cross Section of the Blade

Fig. 4.5



back (not the windward face) until you have a sharp edge, less than a millimetre wide, bevelled at the  $20^\circ$  angle shown. Set the work up with light shining onto the trailing edge, so you can easily see how wide it is. The finished edge should be under 1 mm wide.

Note: It may be helpful to make an angle template (Fig. 4.4), which you can fit over the trailing edge, to check that you have got it right, and adjust it accordingly. Again, this can be made from plywood or aluminium sheet material.

Finally, the section needs rounding off into a smooth 'wing shape'. Take care not to reduce the overall thickness. The thickest part should be at about 35% of the width back from the leading edge. Draw a line along the back of the blade at this thickest point, and avoid cutting the line.

Round the back of the blade off by continually removing the corners, running your fingers over the surface of the back of the blade or watching the way the light casts shadows as it rakes across the wood. Use sandpaper if you must, but a really sharp spokeshave, set very fine, is lovely to use.

#### Step 6. Assembling the rotor blades

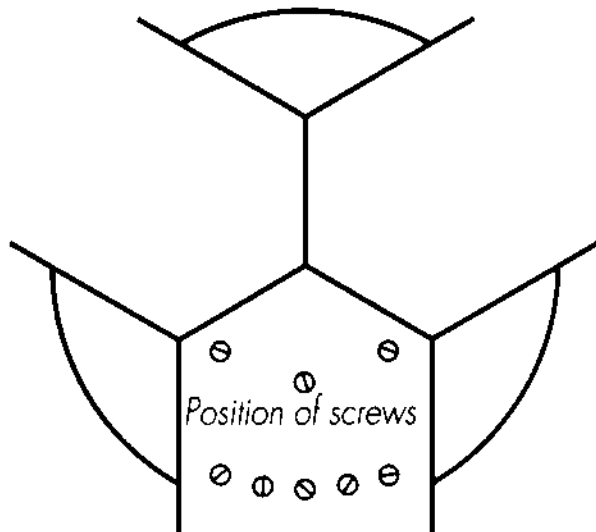
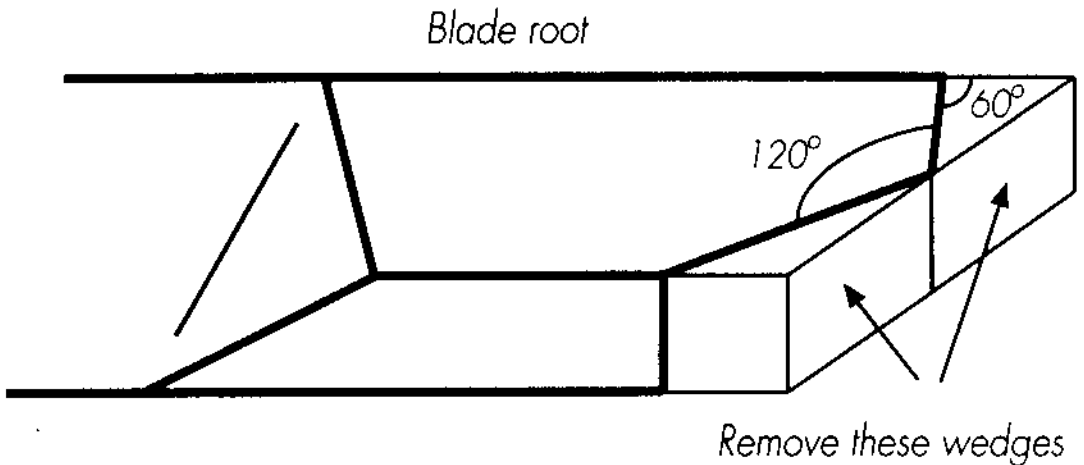
Ensure that the thickness is the same all over each blade root. Reduce the large ones if necessary. The exact thickness does not matter as long as they are all the same.

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## Assembling the Hub

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Fig. 4.6



Each blade root must be cut to a point (Fig. 4.6) to fit snugly at the hub. Measure the exact centre of each blade root, and draw lines out to the edges, at an angle of  $60^\circ$  to each edge. Mark them front and back, then cut along the lines.

The blades can now be laid out with all three roots fitting together. They will be supported in this position by the two plywood disks, one on each side. Make a pencil mark on each blade, 152 mm from the root (front and back), to help you to centre the plywood disks.

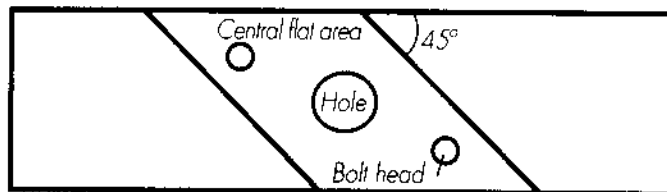
Drill and countersink holes in each disk for the screws (Fig. 4.6). I suggest 8 screws on each side of each blade. They must not obstruct the holes which you will need to drill, for bolting the rotor to the windmill. Check that the blades are equally spaced. Measuring the distance from tip to tip and adjusting them until equal is the easiest way to ensure a  $120^\circ$  angle between the blades. Check also that the tips are all the same height above the bench on which the plywood sits. This will ensure that they 'track' properly

### Two Bladed Rotor

Fig. 4.7



Close-up view:



(follow each other through space). If the blades do not track within 5 mm, there will be some 'dynamic' imbalance.

Drilling the bolt holes is best done with a drill press if possible. In any case take care to drill the holes square to the rotor.

While dismantling the hub for painting, take care to mark each blade for re-assembly. Use a drill to make a number of shallow dimples in each blade (one, two or none), and mark the disks to match.

#### *More hints on wooden blade construction*

The above procedure does not cover all shapes and sizes of blade. Here are some more hints:

Two bladed rotors can be built from a single piece of wood (Fig. 4.7). This saves work in constructing a hub. It is simple and strong.

The central portion of the piece of timber can be left full-size. Bolt the rotor to the generator pulley, then drill a large hole through the centre of the rotor, to accommodate a socket spanner when fitting the pulley to the shaft. The shaft nut must be locked with thread sealant to prevent it from working loose.



## Fins at the root

A glance at the blade designs in chapter four shows that it is desirable to have a wide section and a coarse setting angle at the root of the blade. If you cut such a blade from a single piece of

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## Two Bladed Rotors

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*Some two bladed rotors carved from wood.*

timber, it would be very wide and thick, and there would be a lot of waste. A simple solution is to use offcuts from the outer parts of the blade, glued on as supplements to the inner part. Build up the trailing edge with a fin to increase the chord width. Build up the windward face with another fin to increase the setting angle.

## Painting and balancing the blades

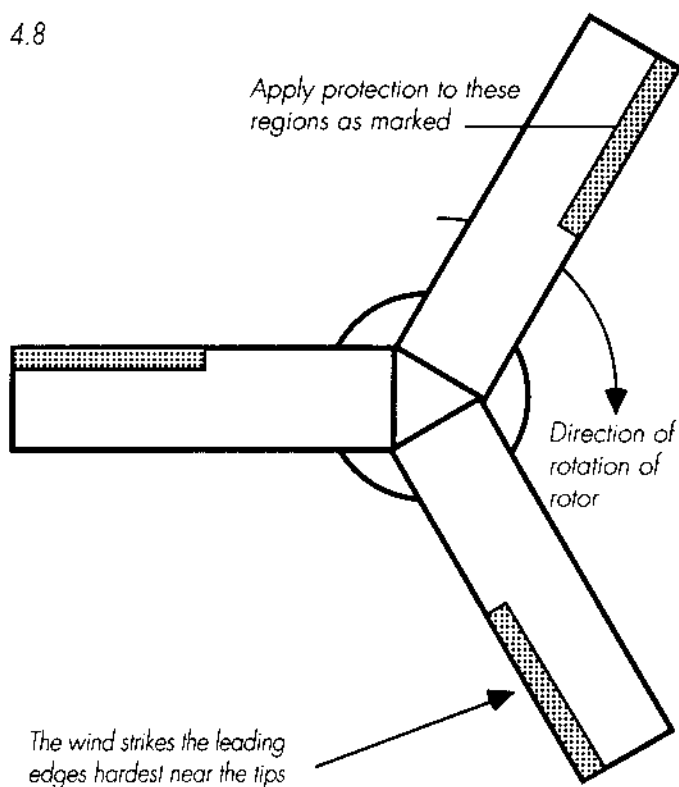
High tip speeds cause rapid erosion of the blade material. The leading edges of the blades need special treatment (Fig. 4.8), either with epoxy resin or 'leading edge tape'. Leading edge tape is sold for the propellers of microlight aircraft (see the Resource Guide for suppliers). It is easy to apply and to replace, and it offers very effective protection for a period of time. Apply the tape after painting.

If you are using epoxy resin, you should first plane off about 3 mm from the leading edges and rebuild them with a paste, mixed from epoxy resin and aluminium powder (or a similar filler). Polyester resin pastes such as 'Plastic Padding' are not so durable as epoxy. Apply the resin before painting.

The ideal protective surface would be a resilient (rubbery) finish. Good adhesive strength is also required. Silicone rubber can make a good on-site repair, but it is hard to produce a smooth finish.

## Leading Edge Protection

Fig. 4.8



### Painting

Prime the wood carefully, and apply plenty of coats of gloss paint. Sand it well before the final coat. Household gloss paint may seem crude, but it has advantages over epoxy paints and varnishes.

Epoxy paint is completely watertight, which is not always an advantage. Water within an epoxy coating cannot escape, whereas other paints will breathe. If the blade is damaged, for example by fastenings biting into the wood near the root, then water will enter, and be centrifuged out to the tip, where it will collect, and swell the wood, until it bursts. Varnish degrades much faster than paint in ultra-violet light. (Varnished wood does look lovely though, for a while.)

### Balancing

It is essential to balance the blades carefully. The aim is to ensure that the centre of gravity of the assembled rotor is exactly at the centre of rotation, i.e. the centre of the shaft. This is known as 'static balancing'. Dynamic balancing is not necessary, provided that you ensure that the tips of the blades 'track' each other. Rotor blades are axially thin, so static balancing is quite sufficient.

Balancing should be done indoors, in a large open space, free of draughts.

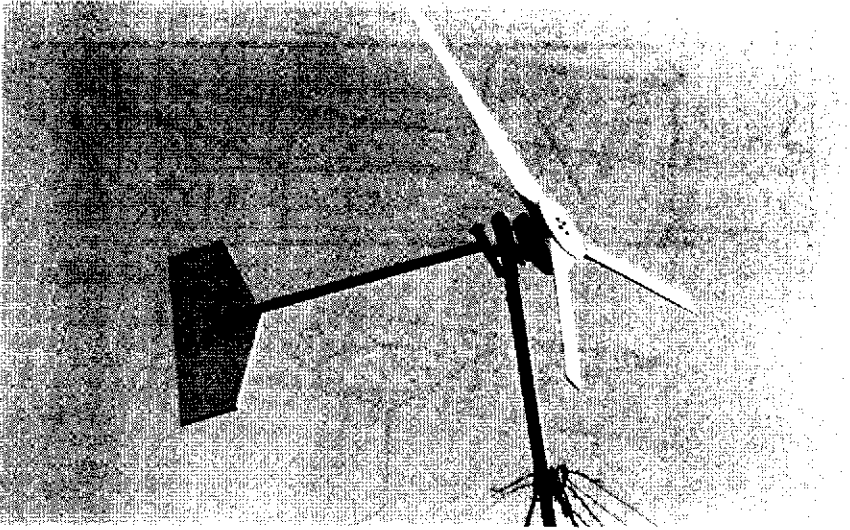
Pieces of lead flashing (from the scrapyards) make ideal balance weights. If very heavy weights are required, they can be shaped (from steel or lead), and tucked into the recesses between the three blades.

Here is one method of checking the static balance. The blade is poised on a sharp spike (Fig. 4.9), perhaps made from a 100 mm

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## The Finished Rotor

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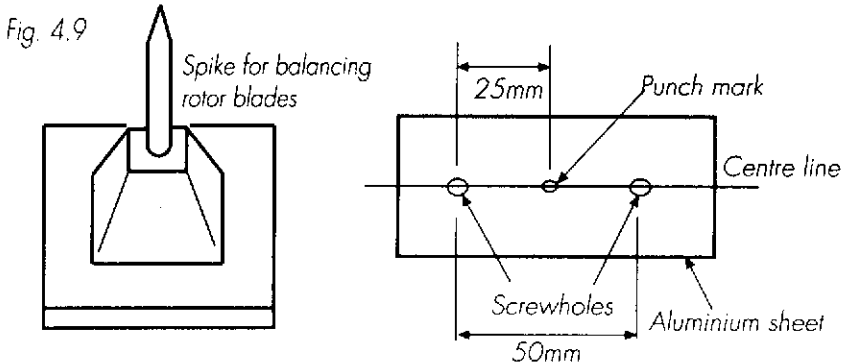
A 2.3m diameter rotor as described in the instructions.

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## A Jig for Balancing the Rotor

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nail or similar, driven into a wooden support, and sharpened with a grinder. The spike engages with a punch mark at the exact centre of the rotor.

Make a jig from a small piece of aluminium sheet (Fig. 4.9) with a punch mark at the centre, between two screw holes. Position the holes precisely, at (say) a 25 mm radius from the mark. Make two corresponding holes in the back of the rotor hub, on an exact line through the centre of rotation. Screw on the jig, with the punch mark at the exact centre of the rotor.

Engage the spike with the punch mark and sit the whole thing on its stand. It will be unstable. Set the rotor level, using a spirit level. Lift off the spirit level gently, and observe in which direction the rotor falls. Add weights to the opposite side, until the rotor is capable of balancing momentarily on the spike, with no preferred direction to fall in. You need to place the spirit level both 'north-south' and 'east-west'.

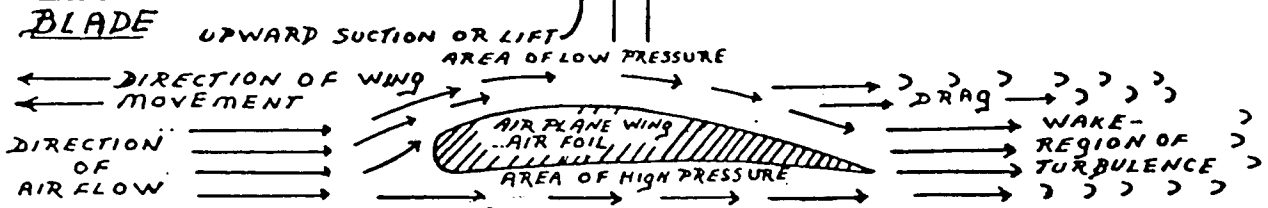
Making the rotor is perhaps the most satisfying part of building a windmill, and it is a feasible task for anyone with simple tools, patience and enthusiasm.

- THE AIR FOIL - ROTOR BLADE - I  
- PRINCIPLES I

①

AIR PLANE WING AIR FOIL

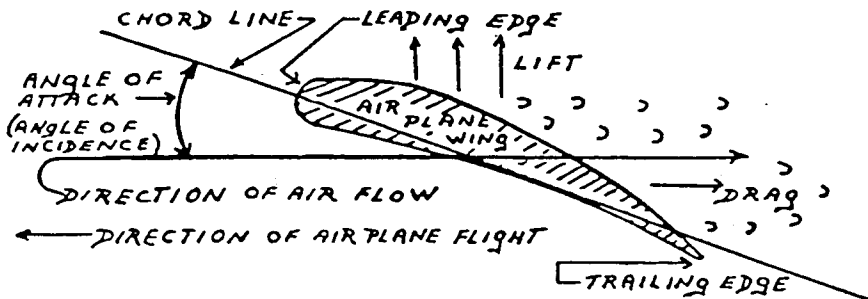
PRINCIPLES ADAPTED TO ROTOR



NOTE- AIR FOIL "SPLITS" AIR FLOW - PART THAT PASSES BENEATH WING TRAVELS THE SHORTEST DISTANCE, A STRAIGHT LINE. PART THAT PASSES OVER TOP TRAVELS A LONGER DISTANCE, A CURVED LINE, WHICH CAUSES AIR FLOW TO "STRETCH" OR THIN OUT WHICH CREATES THE VACUUM THAT CAUSES UPWARD SUCTION OR "LIFT". WAKE TURBULENCE FOLLOWING THE DOWNWARD CURVE, BEHIND THE TANGENT (HIGHEST) POINT, "PULLS BACK" OR IMPEDES THE FOREWARD MOTION. PROBLEM- TO MAXIMISE LIFT AND, AT THE SAME TIME, MINIMISE DRAG. WIND MACHINE USES LIFT TO TURN HIGH SPEED ROTOR BLADES.

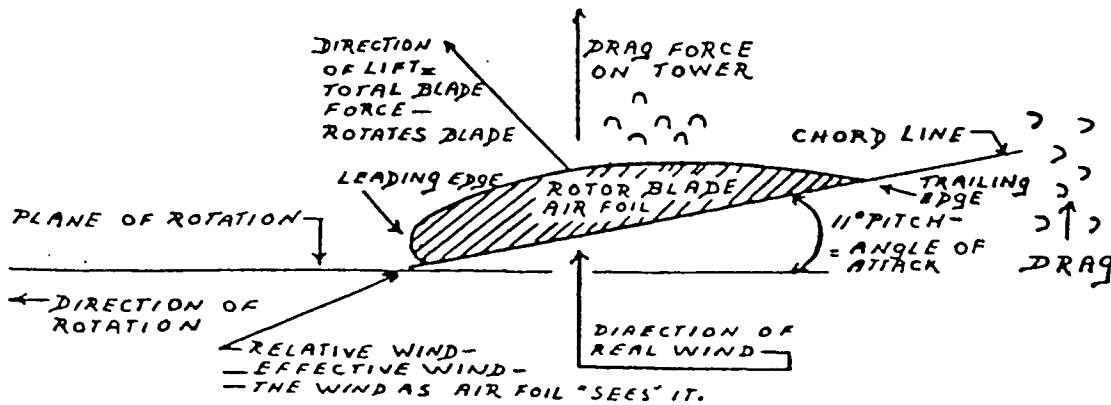
②

AIR PLANE WING - AIR FOIL - PRINCIPLE



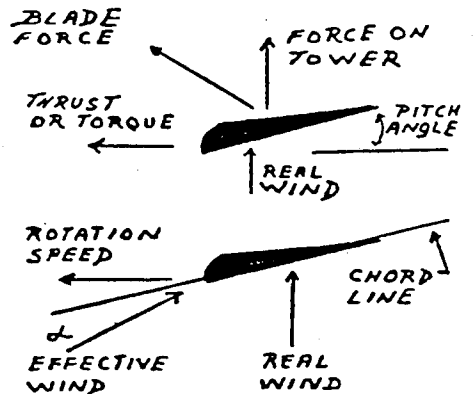
③

SAME PRINCIPLE - APPLIED TO ROTOR BLADE -

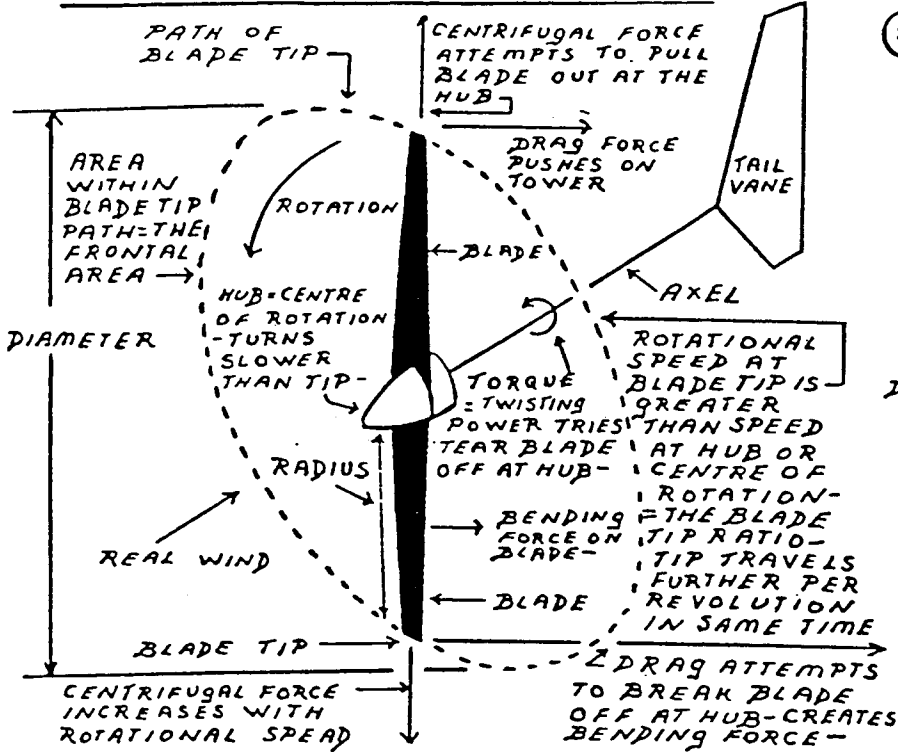


④

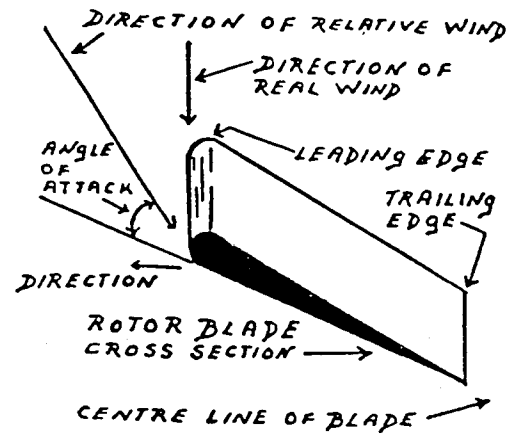
ESSENTIAL ROTOR BLADE RELATIONSHIPS



① FURTHER ROTOR BLADE RELATIONSHIPS



② THE SAME ROTOR BLADE IN CROSS SECTION



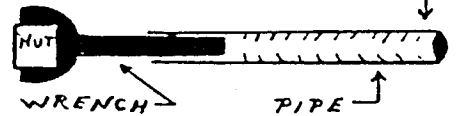
NOTE

- THE SMALLER THE ANGLE OF ATTACK (PITCH), THE FASTER THE ROTOR WILL TEND TO TURN - INCREASING THE ANGLE OF ATTACK SLOWS THE ROTOR DOWN - AS CHANGING THE SET OF A SAIL - I.E. THE POSITION OF THE SAIL - CHANGES THE SPEED OF A SAILING VESSEL - MAXIMUM ANGLE = 15°

④ PRINCIPLE OF TORQUE

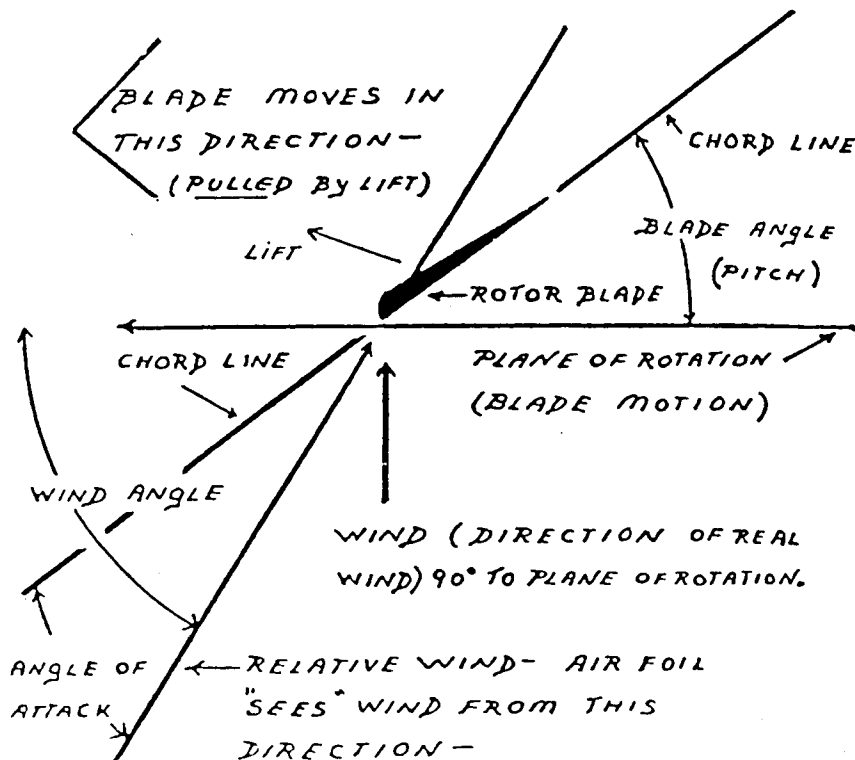
= TWISTING POWER

DOWNWARD FORCE REMAINS CONSTANT



- WRENCH EXERTS TWISTING FORCE ON NUT - EXTEND LENGTH OF WRENCH BY ADDING PIPE - AND TWISTING POWER, OR TORQUE, IS INCREASED -

③ ROTOR BLADE - PRINCIPLES APPLIED



NOTES

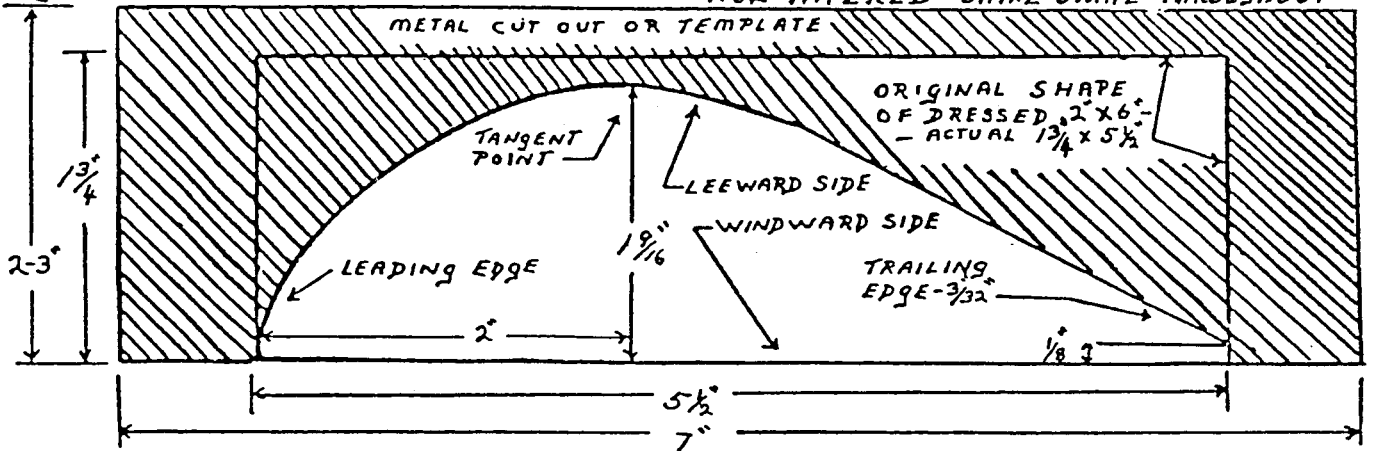
- THE AIR FOIL ROTOR BLADE - III  
 - NON TAPERED - 11°-15° PITCH -  
 - BLADES ANGLED BY WEDGES - I

(A) WEDGES -

- 7" WEDGES - INSIDE THE HUB  
 ON EACH SIDE OF THE ROTOR BLADE -  
 - INSIDE THE HUB - ANGLE THE BLADES AT EITHER 11° OR 15° - OR ANY  
 OTHER ANGLE DESIRED - BLADES CAN THEN BE CUT IN RADIAL LENGTHS -  
 - IE - 7 FOOT DIAMETER ROTOR BLADES CAN BE CUT IN 3 FOOT 6 INCH LENGTHS -  
 AND THEN JOINED AND ANGLED AT THE CENTRE HUB - THIS MAKES 3-BLADE  
 ROTORS POSSIBLE - IT IS BY FAR THE BEST METHOD -

(B) - BLADES - BLADES CAN THEREFORE BE MADE FROM 2" X 6" DRESSED  
 LUMBER (1 3/4" X 5 1/2") - FIR - USING MILLED SIDE OF PLANK  
 AS WINDWARD SIDE OF BLADE - ONLY  
 CURVED LEEWARD HAS TO BE SHAPED -  
 - NON TAPERED - SAME SHAPE THROUGHOUT -

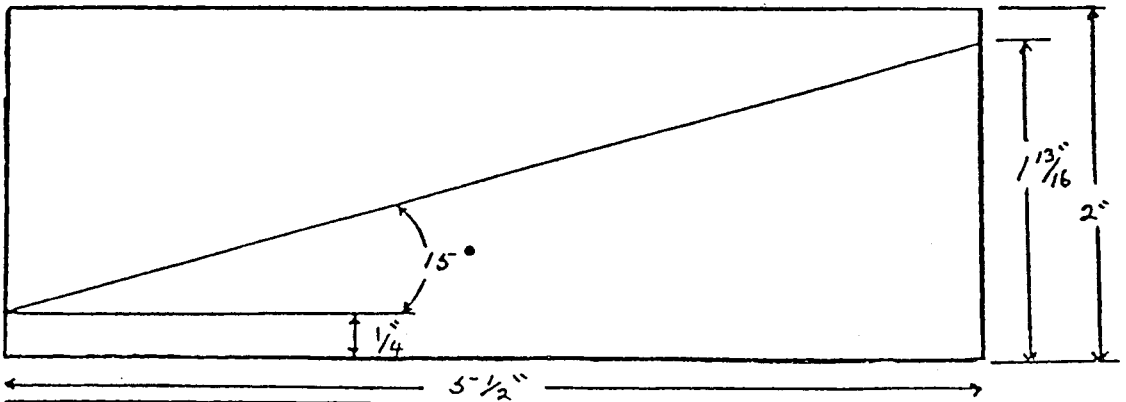
① END VIEW - ACTUAL SIZE -



② END VIEW - 15° WEDGE ACTUAL SIZE -

- FROM UNDRESSED 2" X 6" -

- ONE ON EACH  
 SIDE OF (HUB  
 END OF) ROTOR  
 BLADE - ANGLES  
 BLADE TO 15°  
 PITCH - ALL  
 WEDGES ARE  
 7" LONG



③ END VIEW

- 11° WEDGE  
 ONE ON EACH  
 SIDE OF HUB  
 END - ANGLES  
 ROTOR BLADE  
 PITCH TO 11°

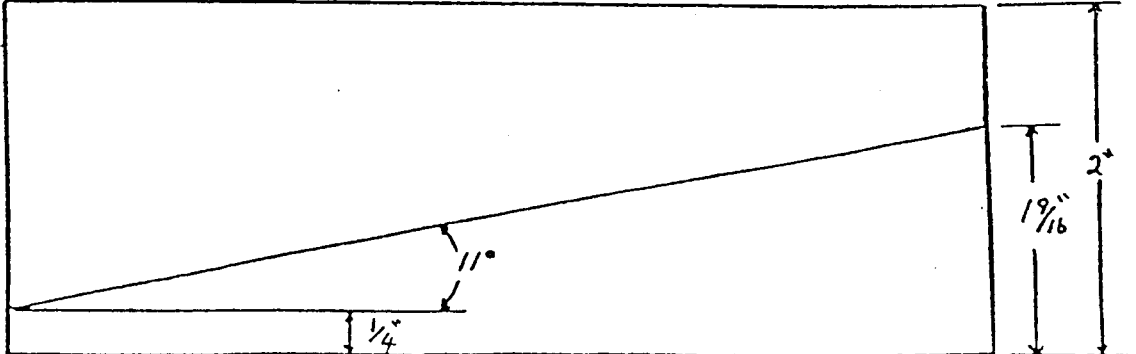


PLATE NO. 39

This blade is to be cut from a dressed piece of Douglas Fir, 2" X 6".

The flat bottom side is not touched. It remains as the flat surface of the original 2" X 6".

The curved back side is shaped with a draw knife, plane etc. Check the shape constantly with the metal template cut out.

Use the wedges to set the blades into the hub at the desired angle.

The strength of the airfoil is largely determined by its thickness at the tangent point. In this case it is 1 9/16".

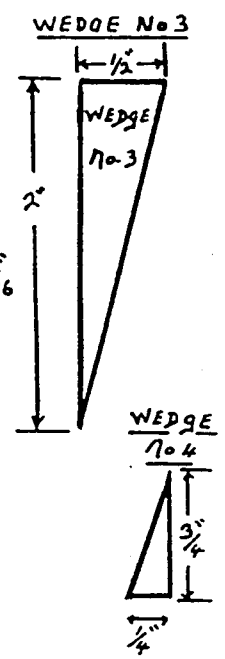
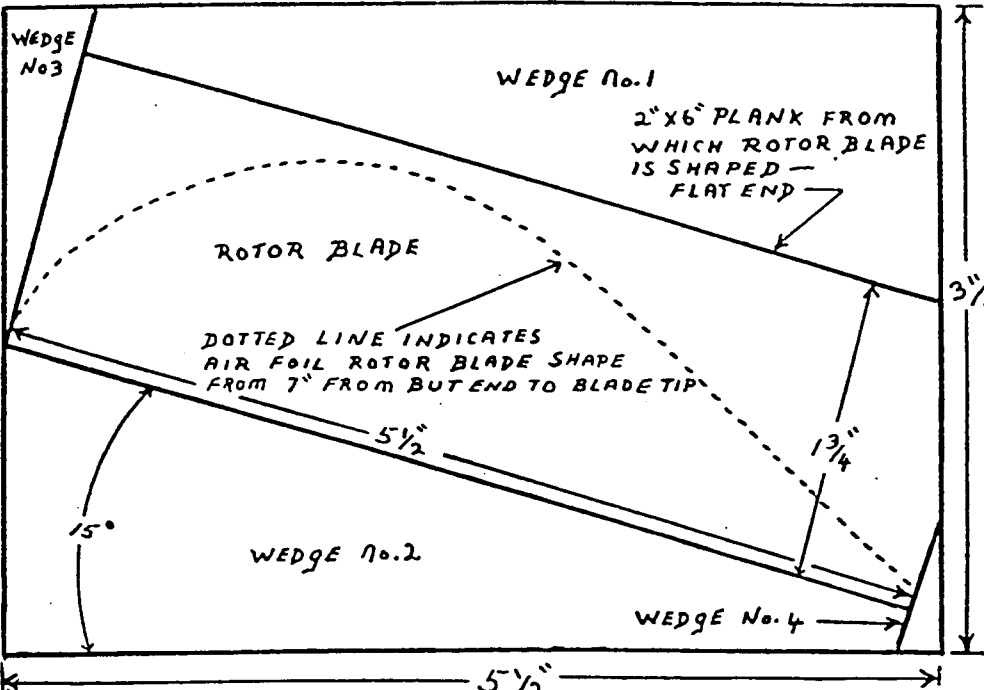
Length to width ratio should 10:1, so the length of 5' 6" wide blade = 10 X 5.5 (inches) = 55" - 4 feet 6 inches or a diameter of 2 X 4' 6" = 9 feet plus 10" for the hub = 9' 10" or 10 feet. (Read both sections on airfoils very carefully).

PLATE No. 40

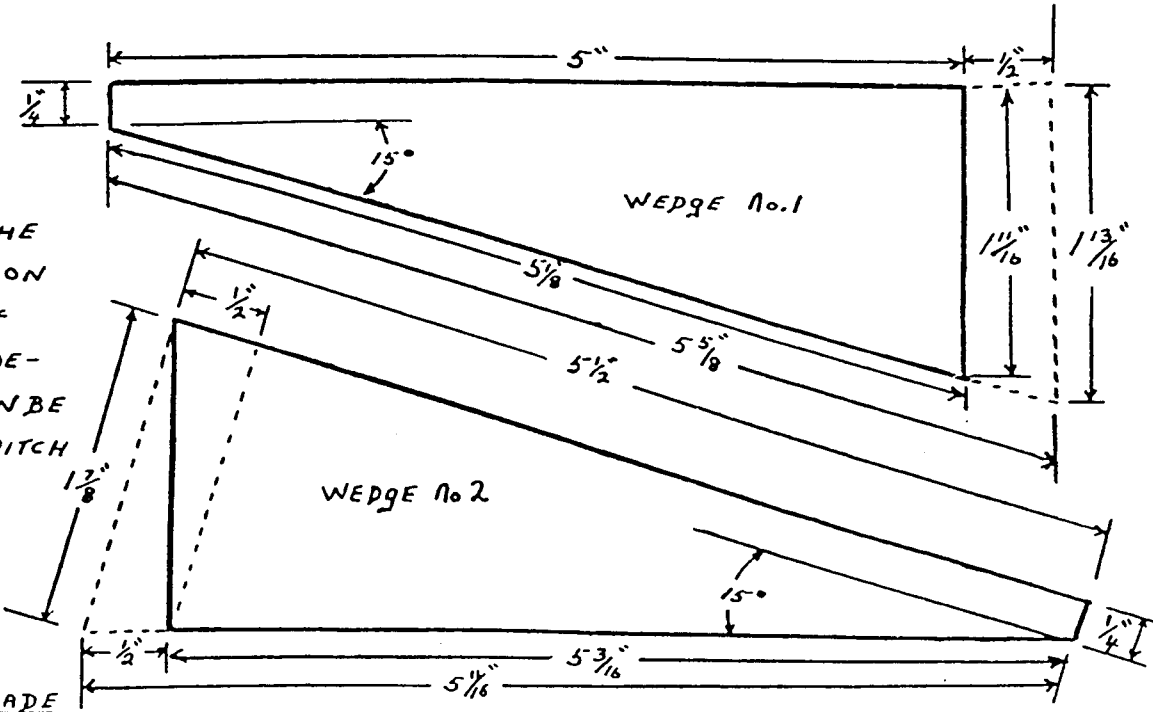
-THE AIR FOIL-ROTOR BLADE-IV  
 -NON TAPERED- 11°-15° PITCH-  
 -BLADES ANGLED BY WEDGES II  
 -METHOD OF ANGLING BLADES-

-NOTE-USE SAME CUT-OUTS  
 TEMPLATES-AS IN  
 PLATE No-37- ONLY CURVED  
 SIDES ARE SHAPED-NO TAPER-

①  
 (HUB)  
 END  
 VIEW  
 OF BLADE  
 END AND  
 WEDGES  
 WEDGES  
 GLUED TO  
 2" X 6"  
 PLANK-  
 -ACTUAL  
 SIZE



②  
 (HUB) END  
 VIEW OF  
 WEDGES -  
 EACH WEDGE  
 IS 7" LONG  
 TO COVER THE  
 "FLAT AREA" ON  
 HUB END OF  
 ROTOR BLADE -  
 WEDGES CAN BE  
 MADE TO PITCH  
 11° OR 15° -  
 -ACTUAL  
 SIZE-



③  
 SIDE VIEW  
 OF ROTOR BLADE  
 SHOWING POSITION  
 OF WEDGES  
 AXLE

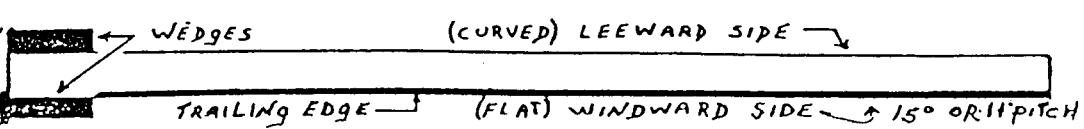


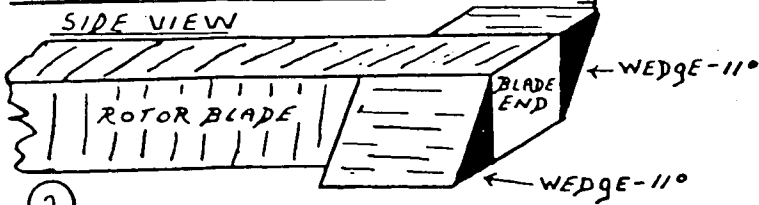
PLATE NO. 40

Shows the blade in plate no. 39 with the 7" wedges glued onto its butt, (root), end. Note that this blade is of the same shape from end to end. There is no taper or twist.

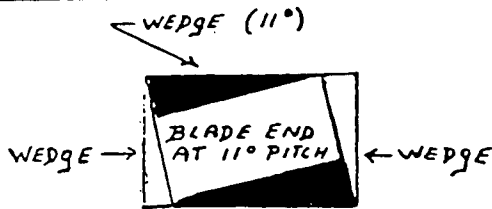
PLATE No. 41

- THE AIR FOIL - ROTOR BLADE V  
- NONTAPERED - 11°-15° PITCH -  
- 3-BLADE HUB CONSTRUCTION.

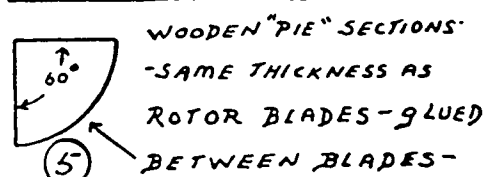
① THE ROTOR BLADE WITH WEDGES



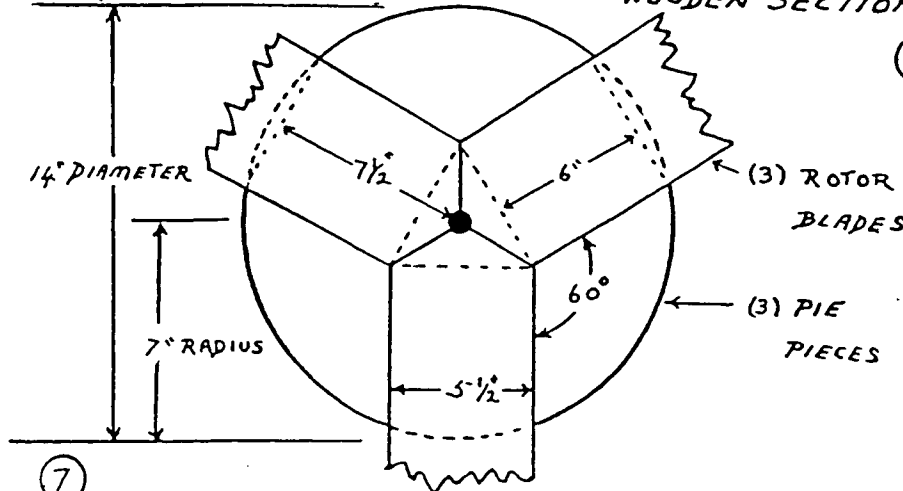
② END VIEW - BLADE AND WEDGES



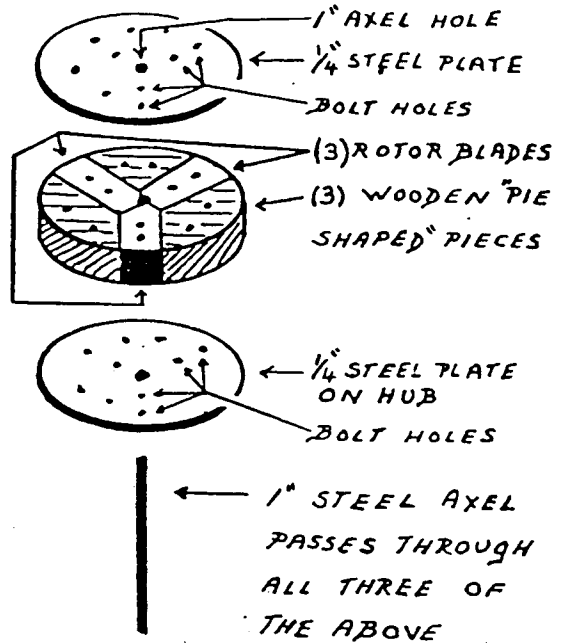
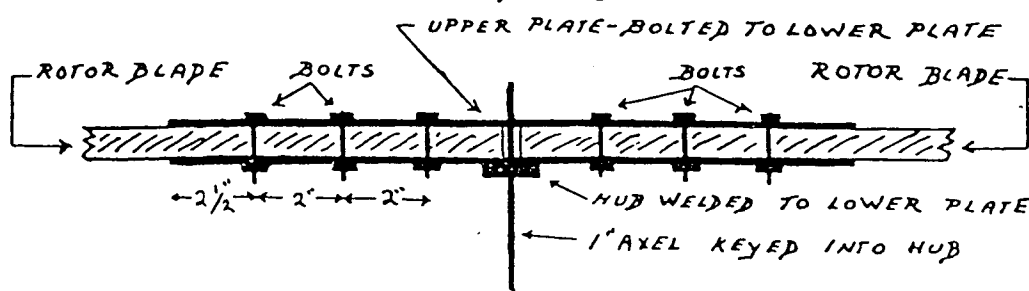
③ THE PIE PIECE



⑤ THE UPPER PLATE - AND BLADES



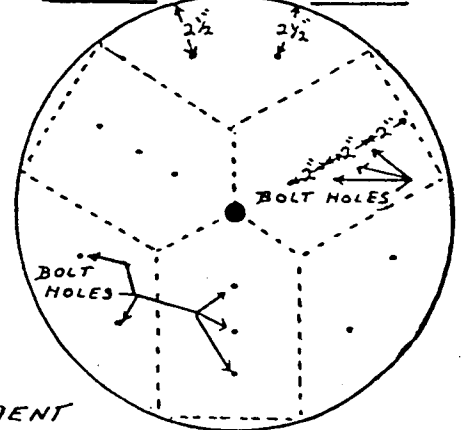
⑦ SIDE VIEW - SHOWING 3/16" BOLT PLACEMENT



④ ASSEMBLY

SECTIONS. IT IS ATTACHED BY MEANS OF THE HUB TO THE LOWER PLATE. THE UPPER PLATE IS BOLTED THROUGH THE WOODEN SECTIONS TO THE LOWER PLATE.

⑥ UPPER AND LOWER PLATE - BOLT HOLES -



- BOLT HOLES - 2 1/2"  
FROM OUTER RIM  
- 2" APART -  
- 3 BOLTS IN EACH BLADE  
- 2 BOLTS IN EACH PIE PIECE.



PLATE No. 42

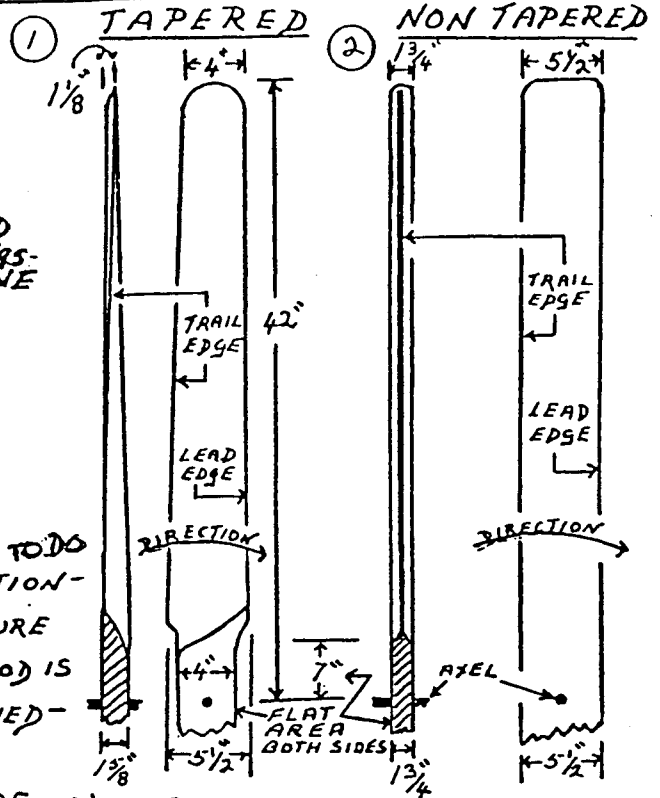
- THE AIR FOIL - ROTOR BLADE - VI  
- COMPARE - NON TAPERED - TAPERED -  
- CONSTRUCTION - 7 FOOT ROTOR -

NOTES

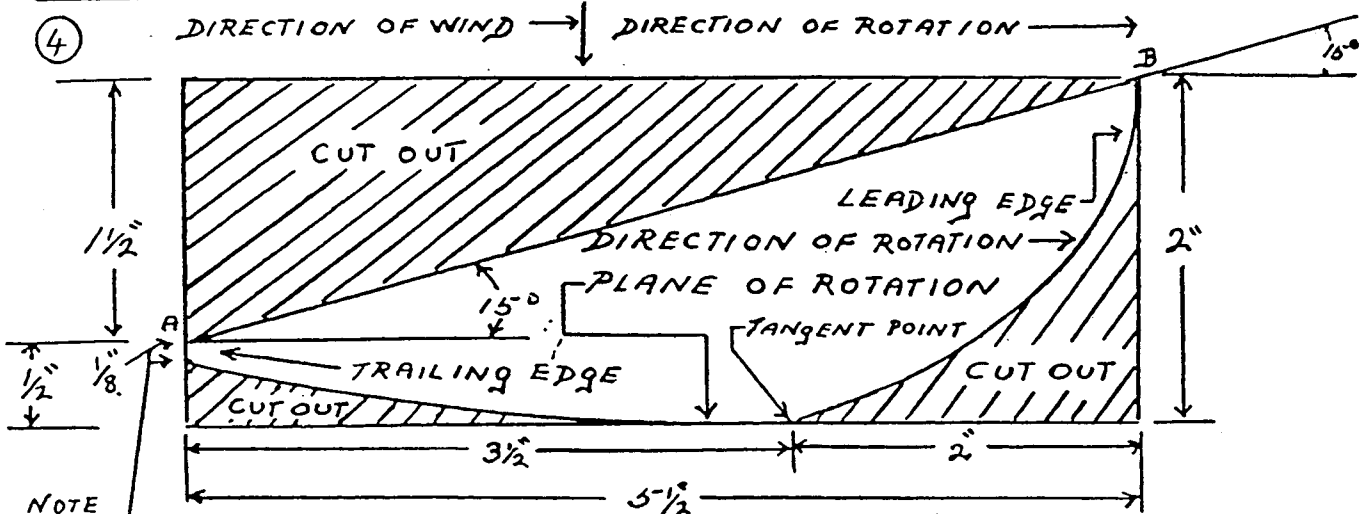
- 7-FOOT ROTOR - (PROPELLER) BLADES - FOR ELECTRICAL GENERATION -  
 - FROM 7 FOOT PIECES OF 1" X 6" FIR - OR SPRUCE WOOD -  
 - AIR FOIL SHAPES ARE INSPIRED BY THE SHAPE OF AIR PLANE WINGS -  
 - NOT BY THE SHAPE OF AIR PLANE PROPELLERS -

- PITCH - = 15° = THE ANGLE OF THE BLADE TO THE PLANE OF ROTATION - THE ANGLE OF THE BLADE FROM A POSITION FLAT AGAINST THE WIND -

- TAPER - IS NO LONGER CONSIDERED NECESSARY IN THE DESIGN OF ROTORS - ALSO TAPER IS HARD TO DO WOOD SELECTION - BY GRAIN FORMATION -



CROSS SECTION OF NON TAPERED BLADE - 7" ACTUAL SIZE -



NOTE TRAILING EDGE = 1/8" (THROUGHOUT) -

- UPPER (WINDWARD) SIDE - A-B - IS FLAT THROUGHOUT - AT 15° TO THE PLANE OF ROTATION - NOTE THAT POINT "A" IS 1/2" ABOVE (2" X 6") PLANK BOTTOM - LINE RUNS DIAGONALLY TO UPPER CORNER "B" = 15°
- BOTTOM SIDE CURVES CAN BE JUDGED BY THE EYE OR (BETTER) - MEASURED BY THE ILLUSTRATED GALVANIZED IRON CUT-OUTS.

PLATE NO. 42

Note the difficulty in shaping tapered and twisted blades, especially if you have to make two, three or four blades, and they all have to be exactly the same. There is no scientific proof that such an effort is worthwhile, (fig. 1 and 2).

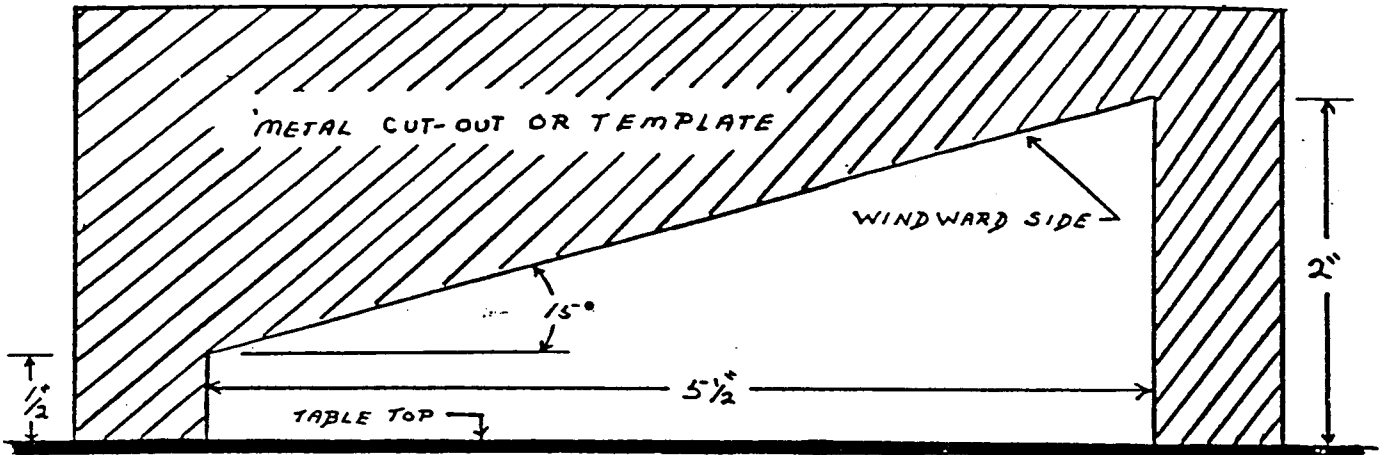
Fig. 4 is a cross section of a two blade rotor, cut from a single piece, and illustrates the difficulty of such a task.

15° PITCH - NON TAPERED

METAL CUT-OUTS - (GALVANIZED IRON) - TO MAKE 7' WOODEN ROTOR BLADES -  
 7' DIAMETER - BOTH BLADES FROM A SINGLE 7' PIECE - NO WEDGES -

① FIRST - MAKE THE FLAT (WINDWARD) SIDE -

- MAKE THE CUT - WITH RIP SAW, PLANE AND RASP - THEN  
 CHECK EXACTNESS AT ALL POINTS WITH CUT-OUT - WITH BLADE ON TABLE TOP -  
CUT-OUT FOR WINDWARD SIDE - ACTUAL SIZE -



② SECOND - MAKE THE LEEWARD SIDE - SHAPE THE CURVES WITH

DRAW KNIFE, RASP AND PLANE BY EYE JUDGEMENT THEN CHECK CURVES  
 WITH CUT-OUT - BY PLACING (FINISHED) WINDWARD SIDE ON WORK TABLE.  
CUT-OUT FOR LEEWARD SIDE - ACTUAL SIZE

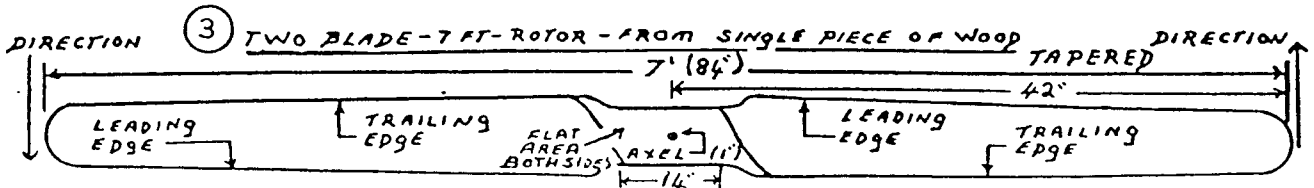
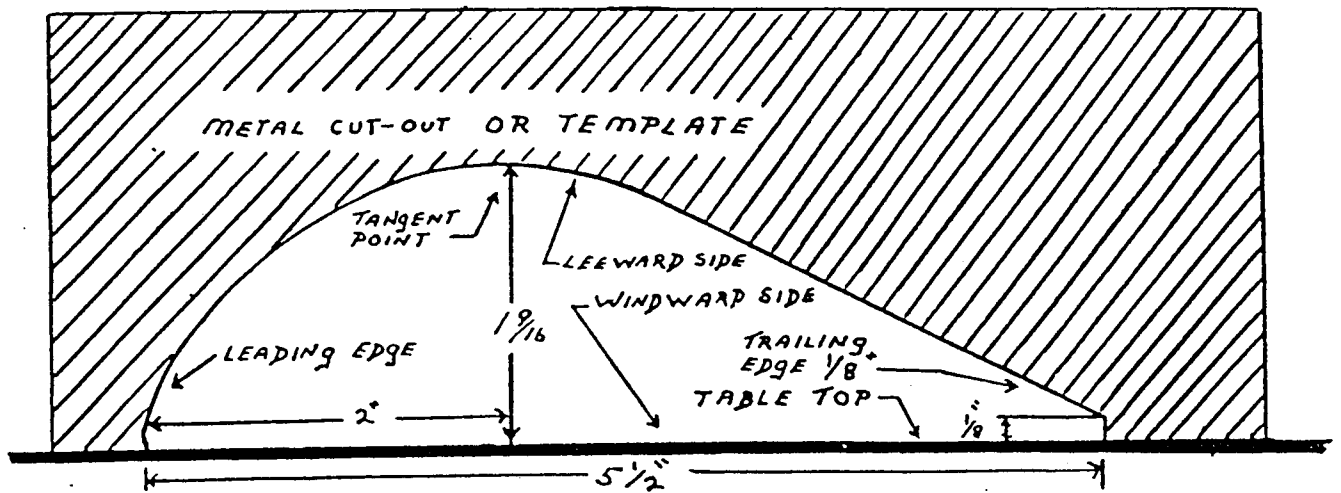


PLATE NO. 43

Shows the templates necessary for making the blade illustrated in plate no. 42, that is the two blade, 15° pitch rotor cut from a single piece, a blade that has no need for wedges.

Make the two flat windward sides first as shown in fig. 1.

Then make the two curved back sides as shown in fig. 2.

In both cases, the thick dark lines at the bottom of the drawing, indicate the table top, along which the templates will slide to assure the accuracy of the shaping.

The 15° pitch is faster starting, but does not have the top rotational speed, (maximum R.P.M.), of the 11° pitched blade.

Fig. 3 shows the finished product, except in this case the blade is tapered, which is not advised.

PLATE No. 4 1/4

-THE AIR FOIL- ROTOR BLADE- VIII

- TEMPLATES - 7'-14'- SINGLE PIECE -

- 11° PITCH - NON TAPERED -

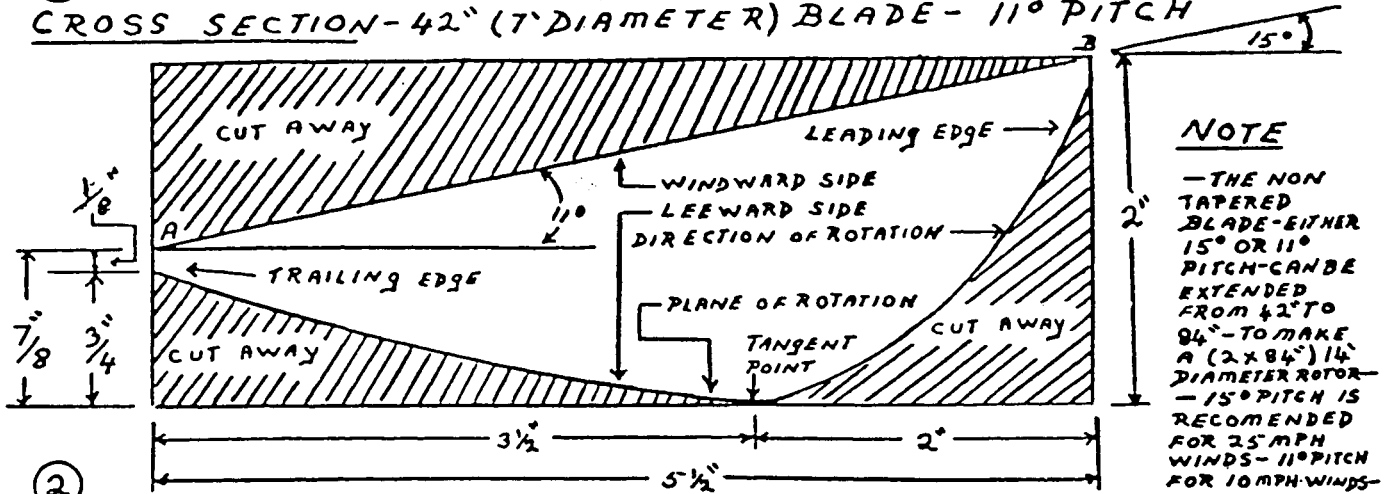
- SAME METHOD AS PLATE No. 41 -

- DIFFERENT PITCH -

- 7'-10'-14'- DIAMETER -

①

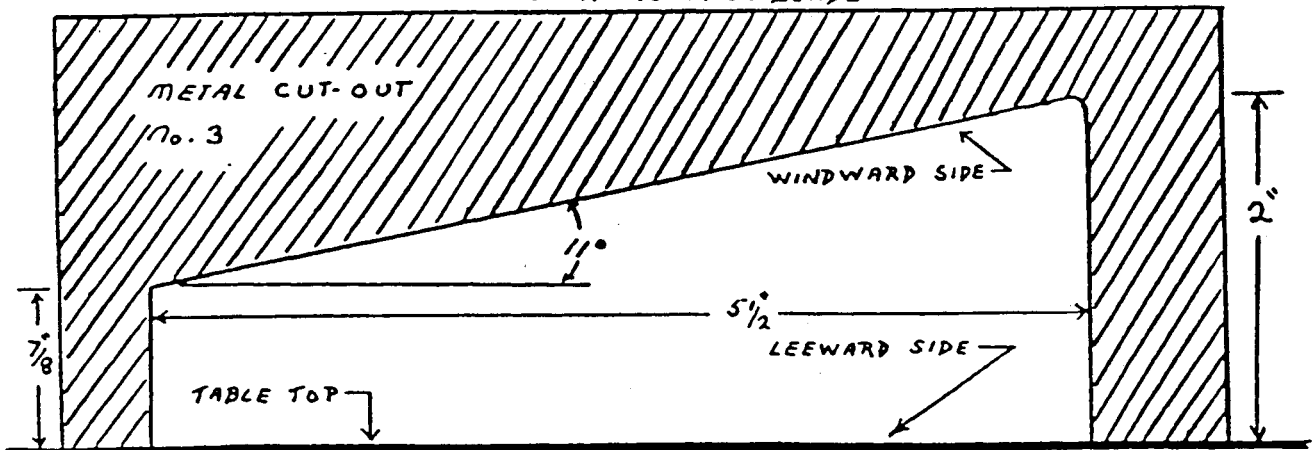
CROSS SECTION - 42" (7' DIAMETER) BLADE - 11° PITCH



②

STEP No. 1 - MAKE WINDWARD SIDE CUT-OUT - ACTUAL SIZE

- SAME INSTRUCTIONS AS WITH 15° PITCH BLADE -



③

STEP No. 2 - MAKE LEEWARD SIDE CUT-OUT - ACTUAL SIZE

- SAME INSTRUCTIONS AS WITH 15° PITCH BLADE -

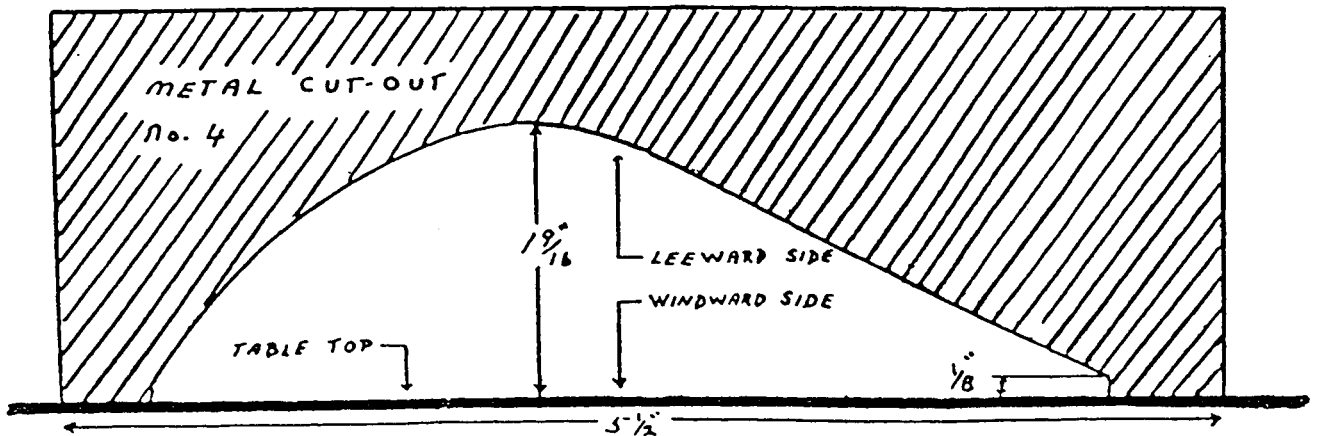


PLATE NO. 44

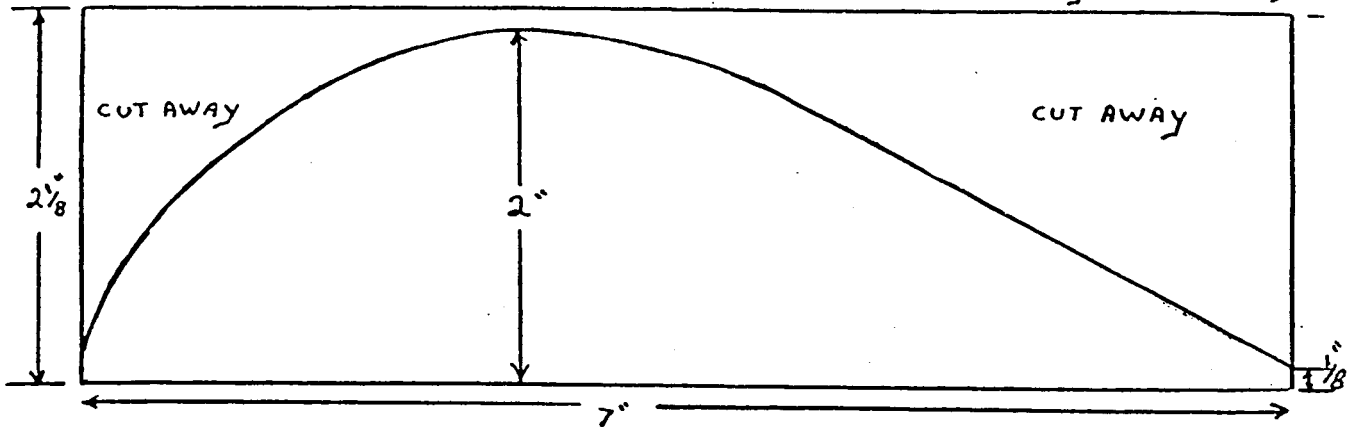
Shows the same two blade, single piece rotor construction as in plate no. 42 and 43, except that this blade has an 11° pitch.

This 11° pitch is a faster moving (rotating), airfoil, but somewhat slower in starting.

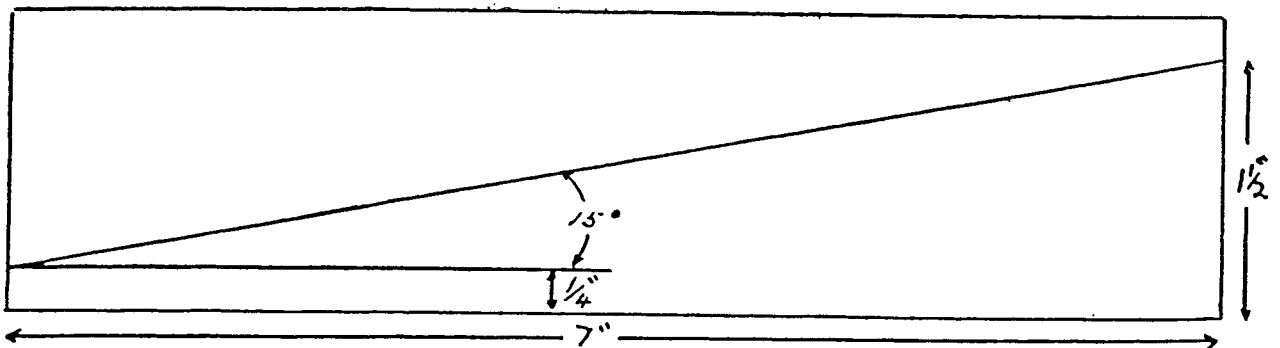
PLATE No. 45

- AIR FOIL - ROTOR BLADE - IX
- LARGER ROTOR BLADE
- MORE STRENGTH - LONGER BLADES - STRONGER WINDS -

① END VIEW - ROTOR BLADE - FROM LAMINATED 1" X 8" DRESSED PLANKS -  
ACTUAL SIZE - USE SAME METAL TEMPLATES AS PREVIOUSLY DESCRIBED -



② END VIEW - WEDGE - 15° - 10" LONG - USE TWO - AS IN  
ACTUAL SIZE PLATE IV - TO ANGLE BLADE 15° -



③ END VIEW - WEDGE - 11° - 10" LONG - USE TWO - AS IN  
ACTUAL SIZE PLATE IV - TO ANGLE BLADE 11°

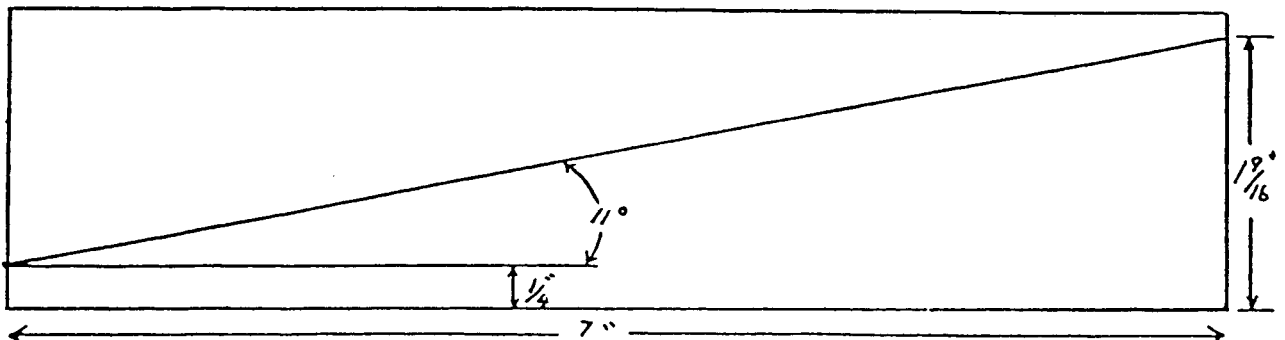


PLATE NO. 45

The wider 7" blade is designed for blade lengths of 6' to 7' 6", or maximum diameters of 14'.

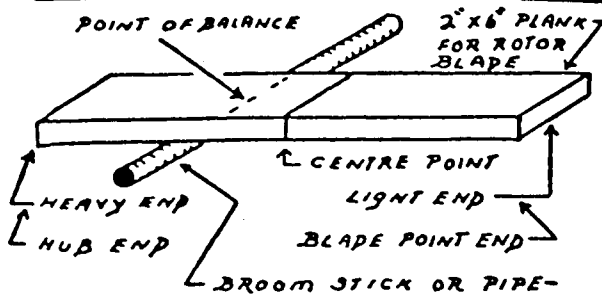
As the main strength is in the (2") tangent, the 6" butt end, (which is not shaped), can be reduced to a width of 6" so that it gets a better and stronger grip in the 12" (diameter), hub.

See notes on plates 43 and 44 (this section), for discussions on 11° and 15° pitches.

PLATE No. 46

- AIR FOIL - ROTOR BLADE - X  
 - TAPERED - I  
 - TWO BLADE - SINGLE PIECE - I  
 - CONSTRUCTION -

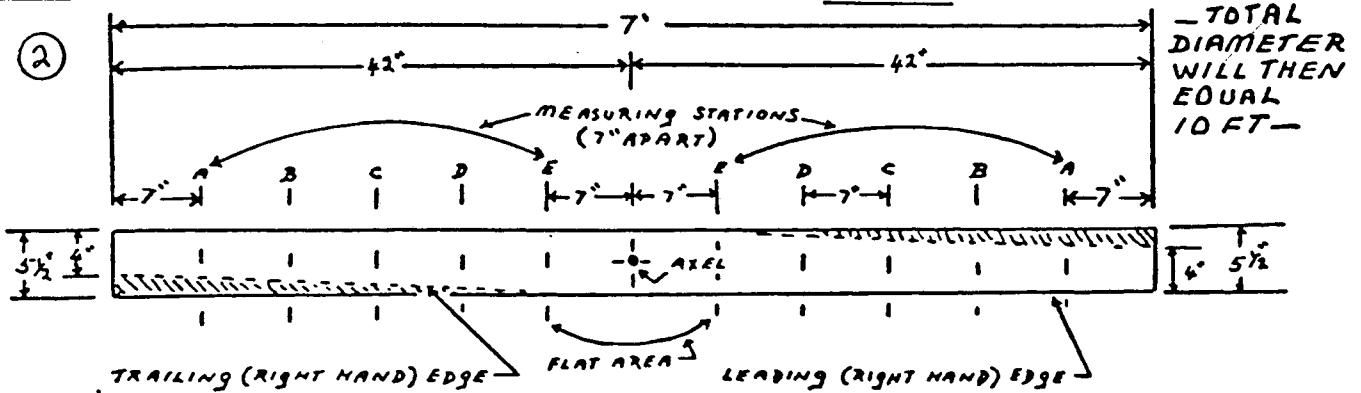
① SELECT HEAVY END FOR HUB - STEP I



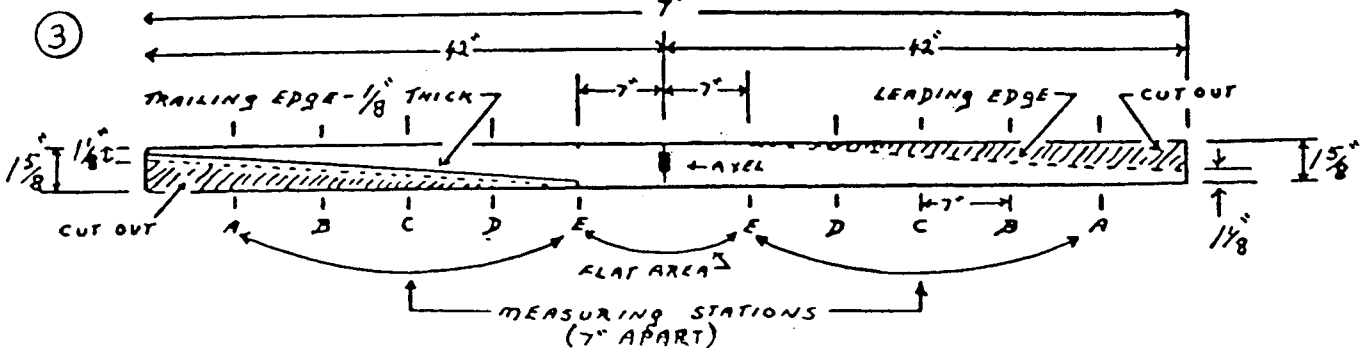
NOTE - PLACE BROOM STICK OR PIPE UNDER UNCUT PLANK TO SELECT HEAVY END FOR HUB.  
 - TEETER-TOTTER PRINCIPLE.

NOTE - ROTOR BLADE LENGTH CAN BE EXTENDED FROM 42" TO 60" BY INCREASING THE DISTANCE BETWEEN THE STATIONS FROM 7" TO 10" AND THE FLAT AREA FROM 7" TO 10"

TOP VIEW - SAW CUTS - 7 FT - TAPERED ROTOR BLADES - STEP II



SIDE VIEW - SAW CUTS - (RIGHT HAND SIDE) - 7 FT - TAPERED ROTOR BLADES - STEP III



④ FINISHING - STEP IV

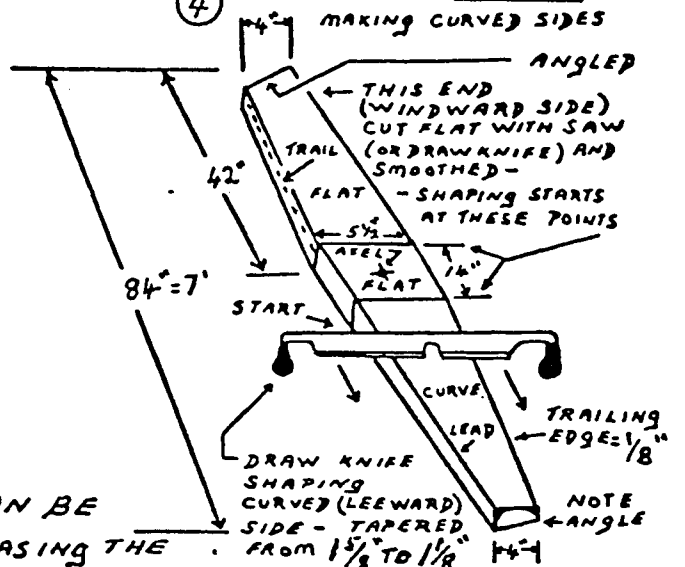


PLATE NO. 46

The butt end weight calculation in fig. 1 applies to all rotor blades.

The shaping methods in fig. 2, 3 and 4, apply only to tapered and twisted blades and only to the two blade single piece rotors, illustrated in plates 42, 43 and 44.

The flat centre section which fits into the hub, however, applies to all blades.

PLATE No. 47

TWO BLADE-SINGLE PIECE MEASUREMENTS

42" OR 60" ROTOR BLADE - TAPERED - MEASUREMENTS - CURVED SHAPES -

- IF STATION MEASUREMENTS ARE INCREASED FROM 7" TO 10" - ALL OTHER MEASUREMENTS REMAIN THE SAME -

- TOP VIEW - SHOWS TAPER FROM TRAILING EDGE SIDE ONLY

- SIDE VIEW - SHOWS PLANK THICKNESS - L-M = 1 5/8" - TAPERED TO 1/8" AT TIP SHOWN AT "N"

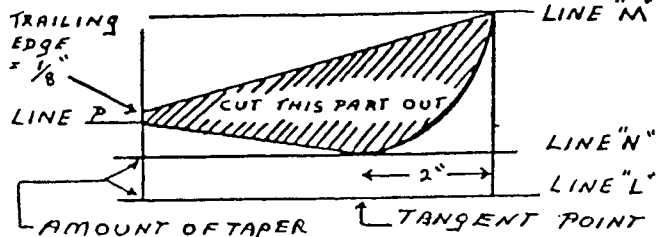
- TAPER IS SHOWN BY LINE "L-N" GETTING CLOSER TO LINE "M"

- AT TIP - DISTANCE FROM LINE "N" TO BOTTOM OF TRAILING EDGE "P" = N-P = 4/16"

NOTE - TO DOUBLE THE LENGTH OF BLADE FROM 42" TO 84" (TOTAL DIAMETER = 14 FT) - JUST DOUBLE ALL OF THESE MEASUREMENTS - EG. MAKE THE DISTANCE BETWEEN THE STATIONS = 14" ETC.

- TRAILING EDGE REMAINS AT 1/8" - EASE SECTION CAN BE 7" OR 8" ACROSS - TO FIT INTO HUB

METHOD OF CONSTRUCTING METAL TEMPLATES FOR EACH MEASURING STATION - "A" TO "E"



AIR FOIL ROTOR BLADE XI

TAPER-II

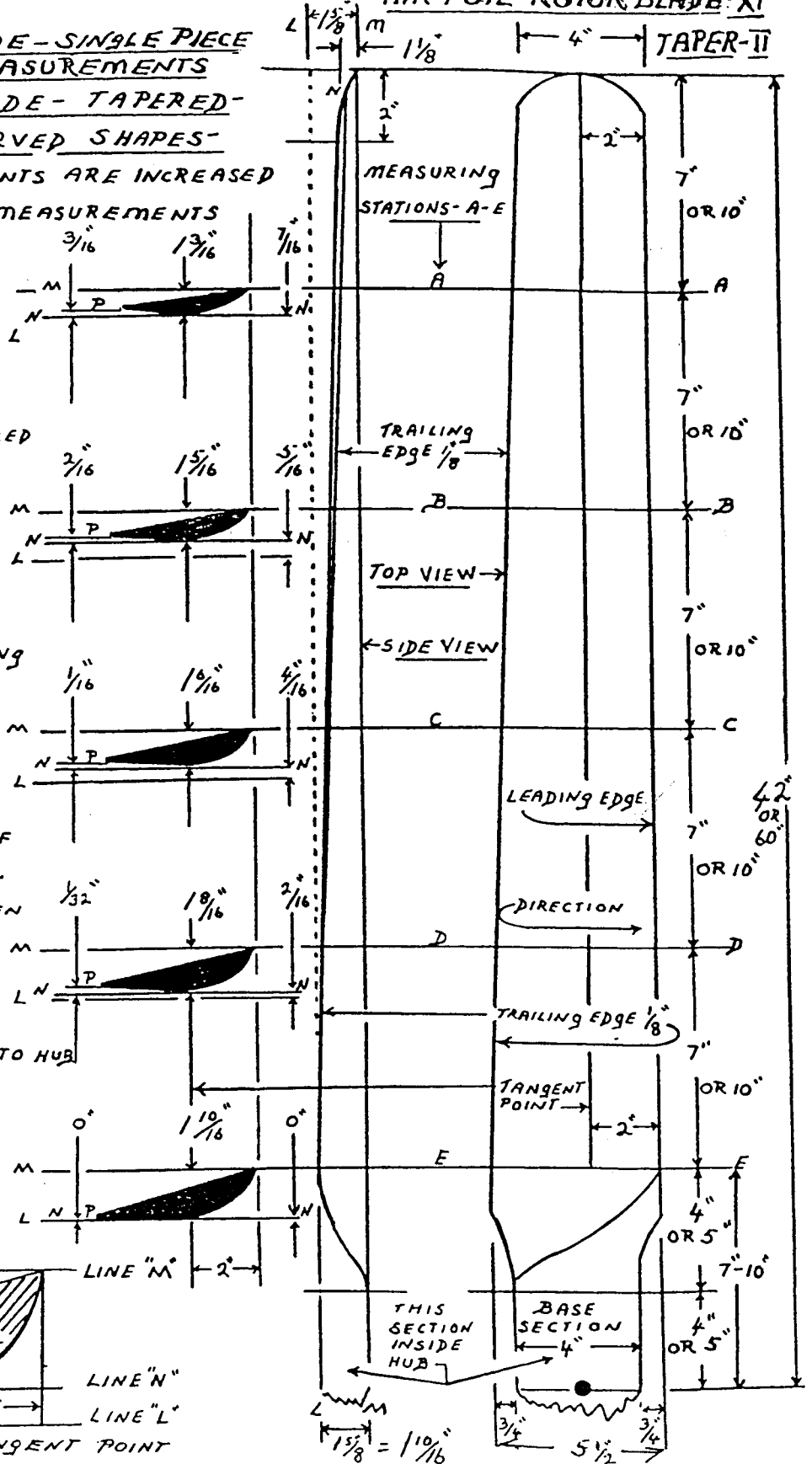
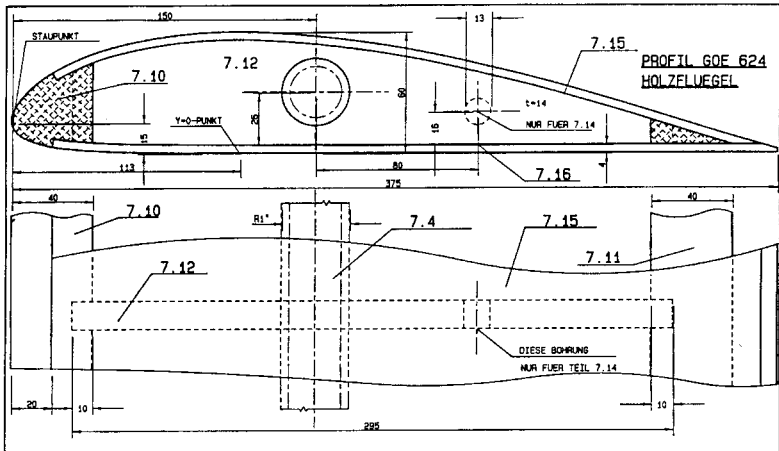


PLATE NO. 47

This is the standard tapered twisted blade that has been used for many years. The original was made of metal and shaped by machine. It is not worth the effort required for its construction. The only reason it is included is to provide a "yard stock" or basis of comparison.

To make a seven foot or seven foot six inch blade, you simply double the distance between the "stations" and keep everything else the same. The "root", or butt end, that fits into the hub, should have its width extended to no more than 6".



KUES	ALLGEMEIN- TEILNENNUNG ODER 7-LEBENS- ZEICHEN	ÜBERFLÄCHEN- N. ODER IBO LÄSSE NEHME !	MASSTAB: 1 : 1
	BREMNER CAD/CAM-LABOR IM SCHULZENTRUM IM HOLTZER FELD		WERKSTOFF: Holz
DATEI	NAMM	BENENNUNG:	
REV.		HOLZFLUEGEL	
PROJEKT	KUKATE 5	ZEICHNUNGSNR. k79spnc	

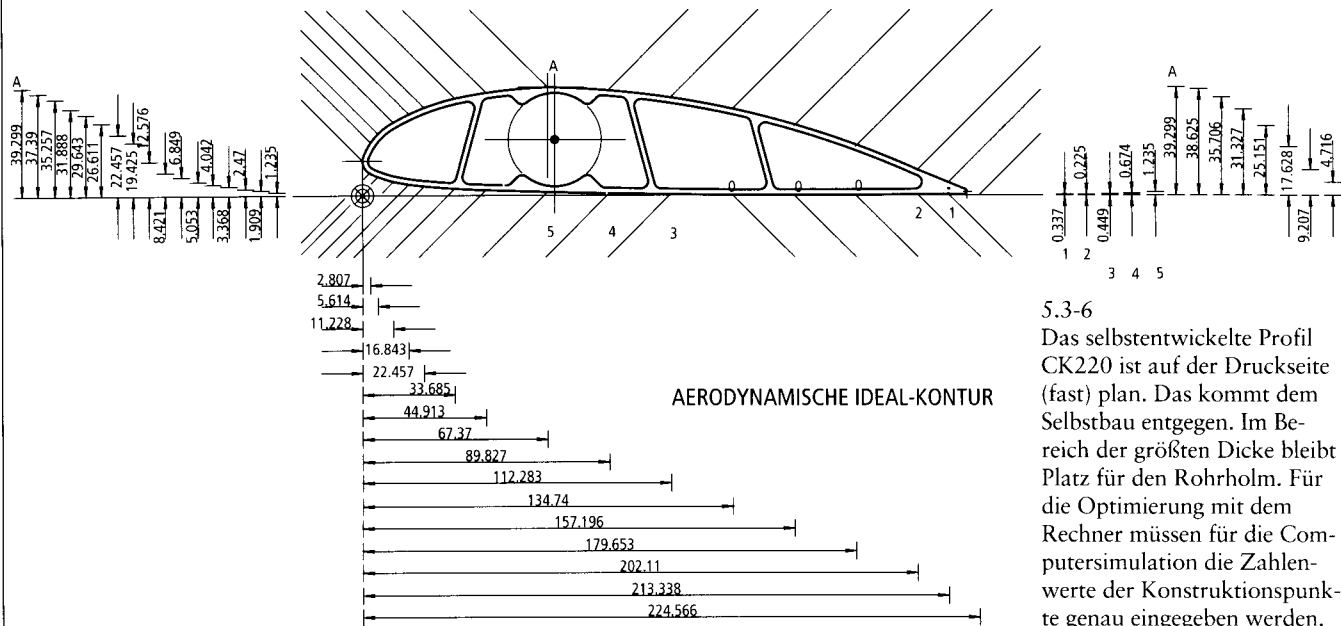
x-Koordinate(T)	Y oben	Y unten	x-Koordinate (T)	Y oben	Y unten	x-Koordinate (T)	Y oben	Y unten
0	4	4	0	8,8	8,8	0	15,0	15,0
1,25	7,15	2,25	0	15,73	4,95	0	26,8	8,4
2,5	8,5	1,65	5,5	18,7	3,63	9,375	31,9	6,2
5	10,4	0,95	11	22,88	2,09	18,75	39,0	3,6
7,5	11,75	0,6	16,5	25,85	1,32	28,125	44,1	2,3
10	12,85	0,4	22	28,27	0,88	37,5	48,2	1,5
15	14,35	0,15	33	31,57	0,33	56,25	53,8	0,6
20	15,3	0,05	44	33,66	0,11	75	57,4	0,2
30	16	0	66	35,2	0	112,5	60,0	0,0
40	15,4	0	88	33,88	0	150	57,8	0,0
50	14,05	0	110	30,91	0	187,5	52,7	0,0
60	12	0	132	26,4	0	225	45,0	0,0
70	9,5	0	154	20,9	0	262,5	35,6	0,0
80	6,6	0	176	14,52	0	300	24,8	0,0
90	3,55	0	198	7,81	0	337,5	13,3	0,0
95	2	0	209	4,4	0	356,25	7,5	0,0
100	0,5	0	220	1,1	0	375	1,9	0,0

Profilkoordinaten GÖ 624 T = 100

Profil GÖ 624 für T=220 mm

Profil GÖ 624 für T=375 mm





### 5.3-6

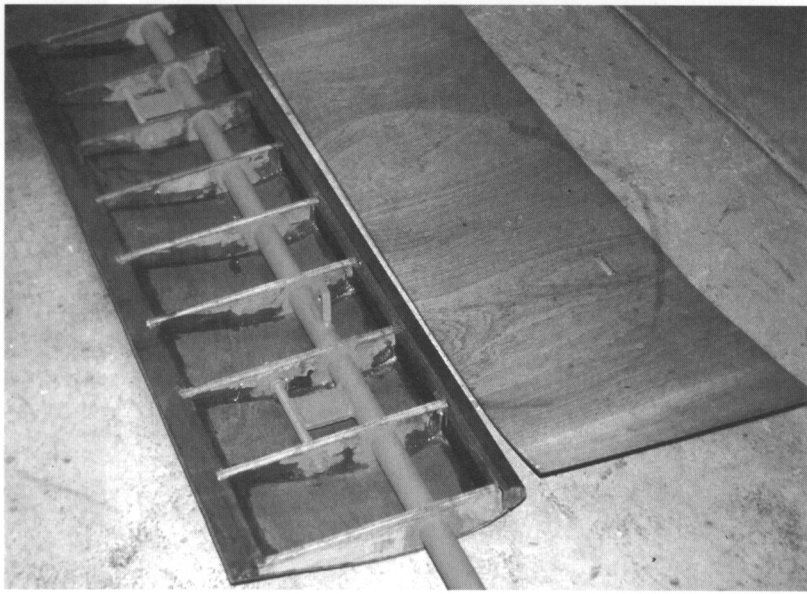
Das selbstentwickelte Profil CK220 ist auf der Druckseite (fast) plan. Das kommt dem Selbstbau entgegen. Im Bereich der größten Dicke bleibt Platz für den Rohrholm. Für die Optimierung mit dem Rechner müssen für die Computersimulation die Zahlenwerte der Konstruktionspunkte genau eingegeben werden.



7.4-6

Holzflügel einer 7 m-Anlage in traditioneller Flugzeugbauweise gefertigt, nur sehr viel stabiler: Nasenholm, Hauptholm, Endholm, Spanten und Beplankung. Alles - bis auf den Hauptholm aus Stahl - massiv oder aus nassfest verleimtem Bootsbausperrholz.

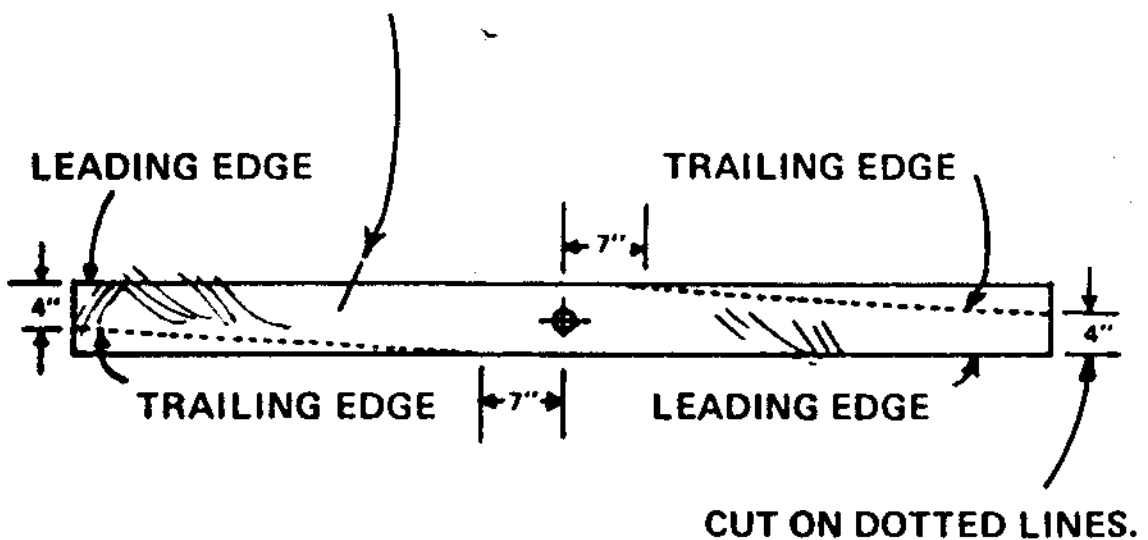
Die nassfeste Verleimung der Beplankung aus Bootsbausperholz und der passende Anstrich sind für eine lange Haltbarkeit von Holzflügeln unabdingbar.



**I decided to use an alternator because I thought it would put out at lower rpm's than a generator and because it was modern and had diodes in it. But I'm beginning to think that there is no problem using a regular DC car generator. In fact, there are some definite advantages: they are cheaper, they *don't* have diodes in them, and you can use a cutout relay to take the battery out of the circuit when the wind stops. With an alternator, you have to rig up some kind of wind- or centrifugal-force-activated switch to accomplish this.**

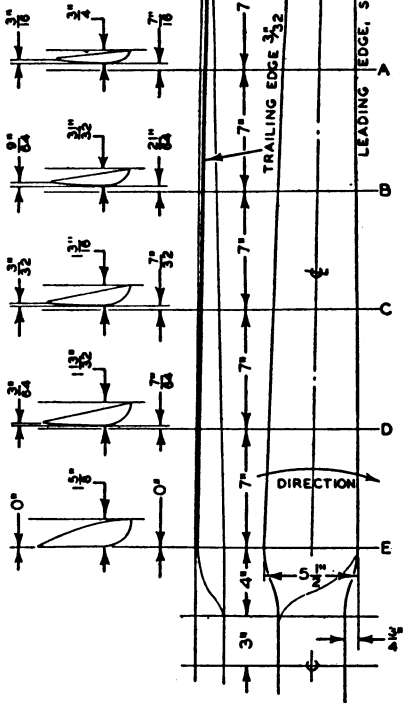
Now, about the propeller. This is really the heart of the thing... and if nothing else, the main point of this article is that a wooden propeller of this type is *easy* to build with almost no woodworking skill and very little money. The plan I used is from the LeJay Manual and I've included step-by-step instructions which I hope anyone can follow to make a prop, using a good piece of wood, a drawknife, a rasp and some sandpaper. If you've never seen a high-speed prop going in the wind, by all means try building this one. Mount it on an old generator or something and set it up in the wind. Don't hold it in your hands! I almost lost my head that way. It'll blow your mind when you get a feeling of the power that this thing produces!

7' X 2" X 6" (REDWOOD, STRAIGHT-  
GRAINED FIR, OR SPRUCE)



### STEP 1

CROSS-SECTIONS  
OF BLADES AT THE  
STATIONS

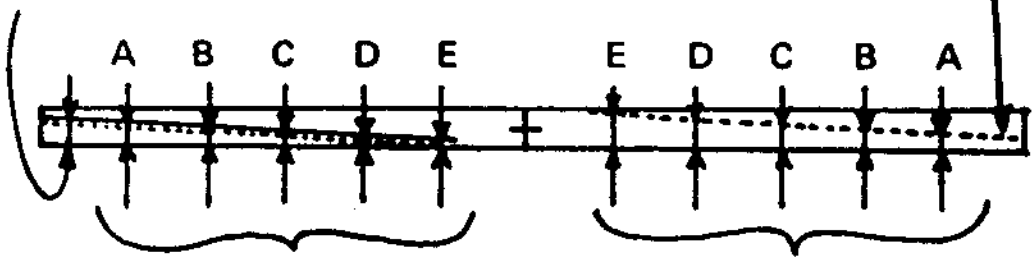


PROPELLOR PLAN  
MAKE PATTERNS FULL  
SIZE  
THIS IS A 7FT. PROP.

**DRAW DOTTED LINES ON EDGES (FIGURE FOR STEP 2 SHOWS RIGHT-HAND EDGE OF FIGURE IN STEP 1).**

**TRAILING EDGE  
(3/32" THICK)**

**LEADING EDGE**

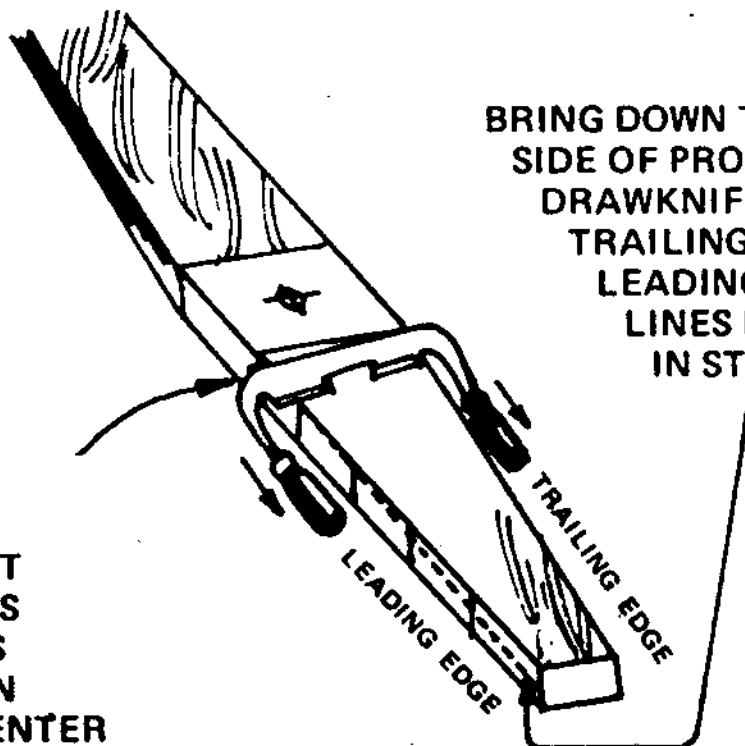


**DIMENSIONS ARE  
"X" + "Z" FOR  
EACH STATION**

**DIMENSIONS ARE  
"Y" + "Z" FOR  
EACH STATION**

## **STEP 2**

**HOLD  
DOWN  
WITH VICE OR  
C-CLAMPS**

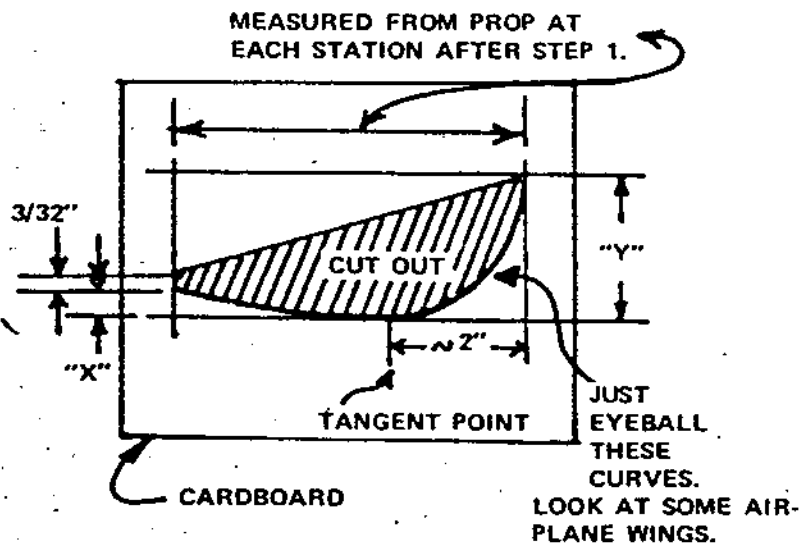


**BRING DOWN TO FLAT  
SIDE OF PROP WITH  
DRAWKNIFE. WATCH  
TRAILING AND  
LEADING EDGE  
LINES DRAWN  
IN STEP 2.**

**FLAT SIDE  
BEGINS TO  
CURVE A BIT  
AT STA. E AS  
IT BECOMES  
FLAT AGAIN  
TOWARD CENTER**

## **STEP 3**

DRAW CROSS SECTIONS FOR EACH STATION  
 FULL SIZE ON CARDBOARD AND CUT OUT  
 WITH RAZOR TO MAKE TEMPLATE



STEP 4

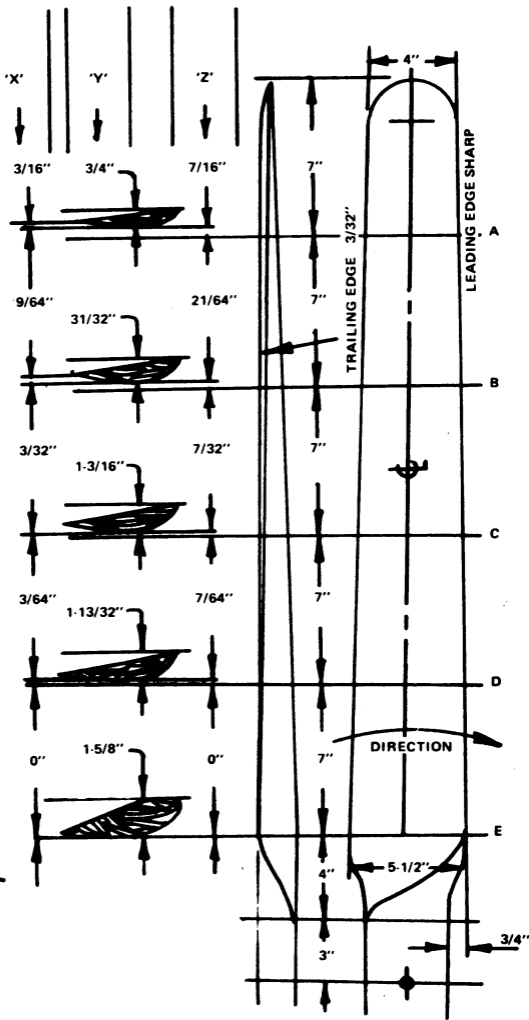
## GENERAL CONSTRUCTION TIPS

Start at tips bringing wood down on airfoil side of prop with drawknife (or rasp when it starts getting close) until template for station A will fit on prop in the right place (7" from tip)—then go to template B until it fits (7" from A)—and so on toward the center. The flat side made in Step 3 is your reference for positioning the templates.

Sand well, varnish (several coats), and balance both horizontally and vertically. Balancing can easily be accomplished by adding small weights to the edge (vert. balance) and front (horiz. balance).

**NOTE:** This prop can be made 10 feet long by extending the distance between stations from 7" to 10", making the 3" x 4" sections both 5". All other dimensions, the same. ☺

DIMENSIONS FOR CROSS SECTIONS AT EACH STATION







HOW TO SHAPE THE PROPELLER

WITH THE USE OF PATTERNS'

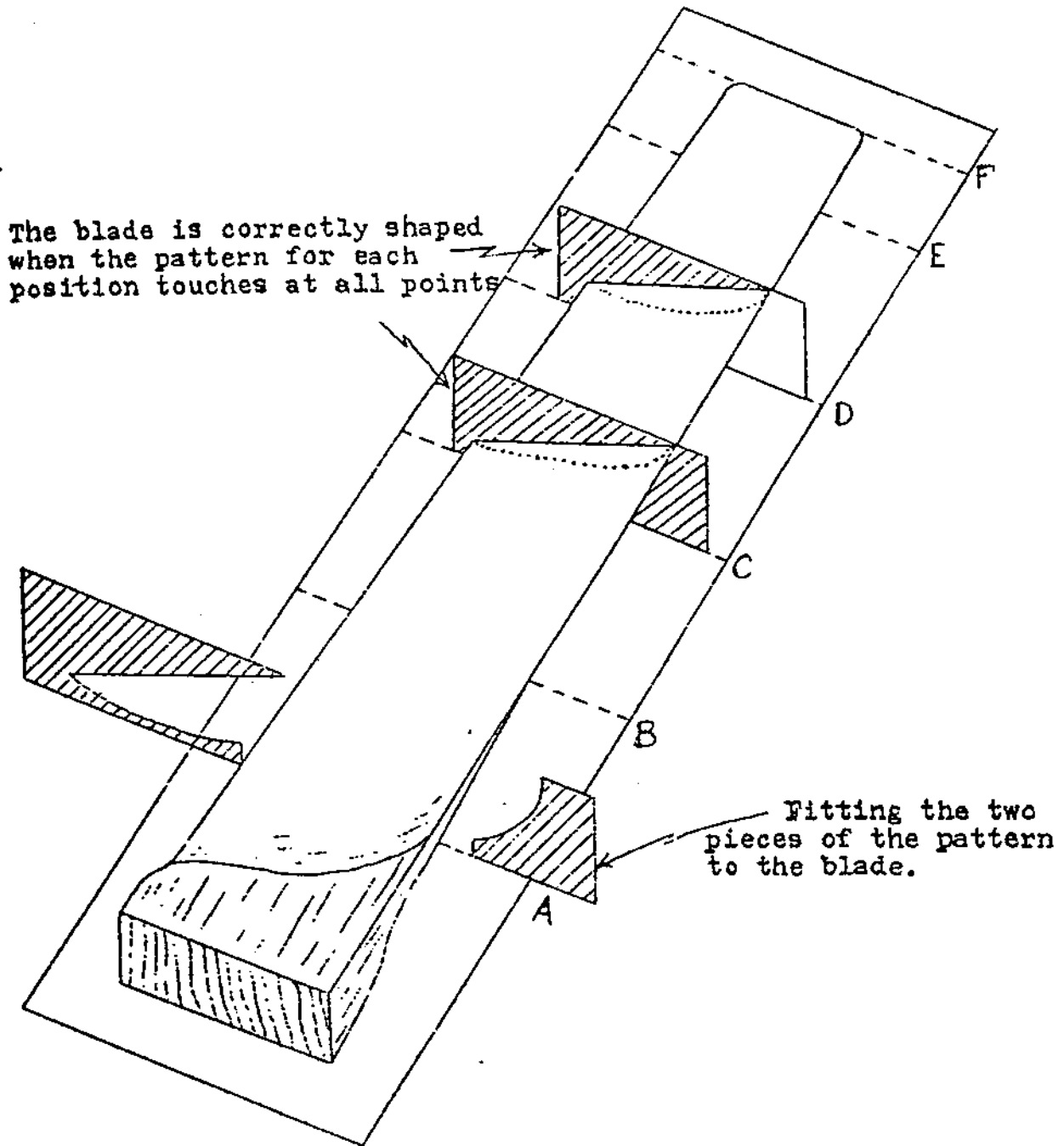


FIG. 2

Shape it with a spoke shave or a rasp or a surform.....Best wood? Redwood or straight-grained fir. Willow? Sitka spruce.



FULL SIZE PATTERNS FOR EACH POSITION

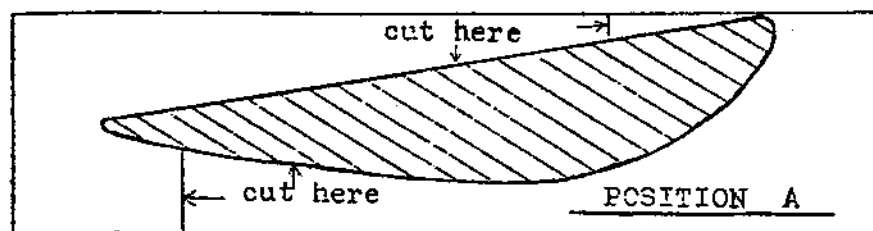
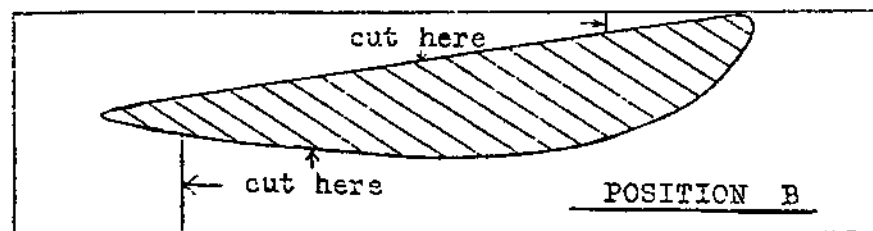
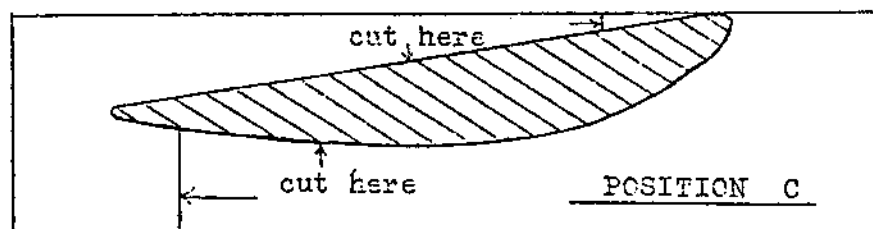
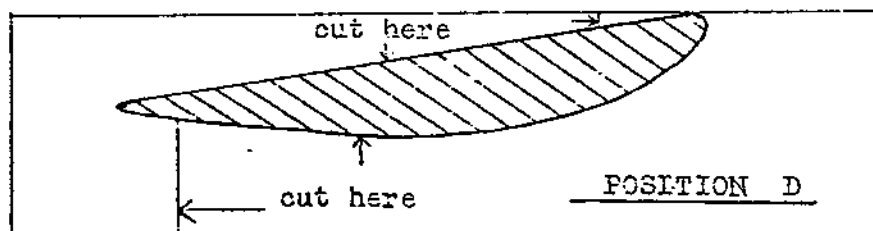
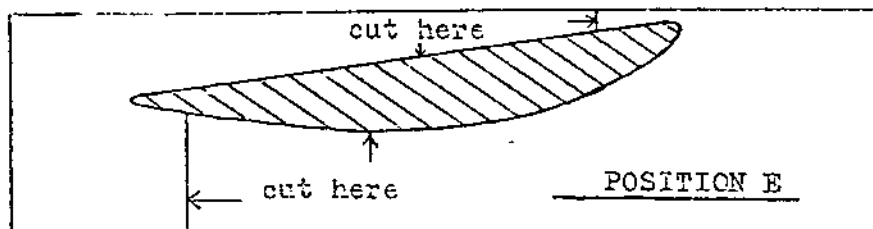
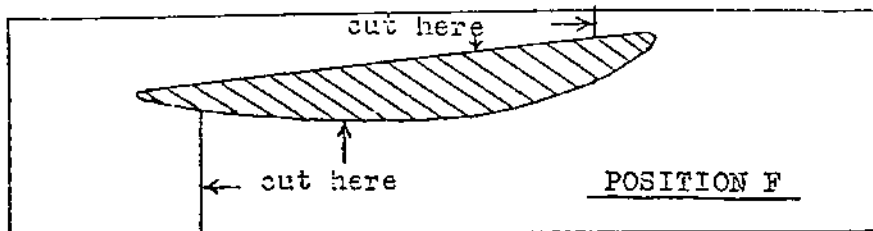


FIG. 3

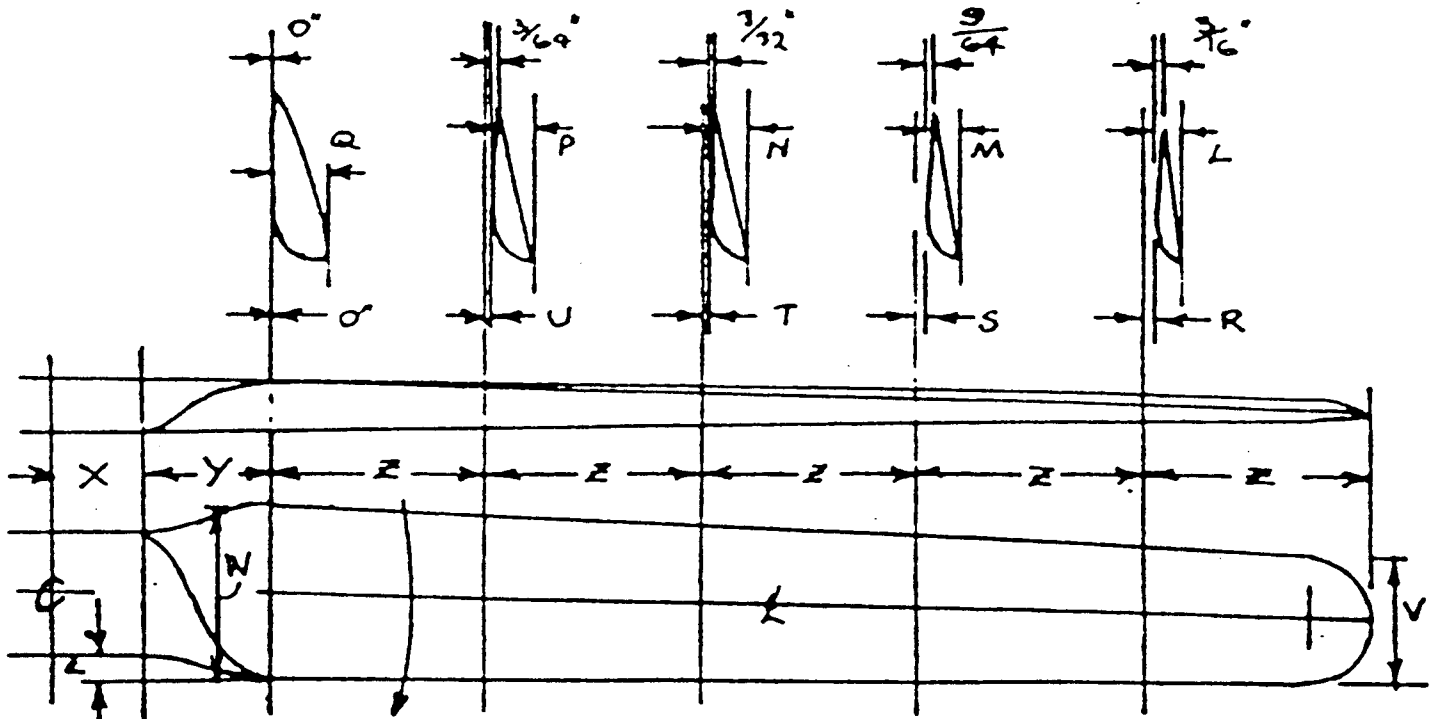
PROP DETAIL 3.



Blades are carved out of the plank by means of plane, saw, spokeshave and sand paper. The blades should be protected by sealing against moisture with about five coats of enamel or

varnish, and rubbing with wet and dry emery paper between each coat. The tips also have to be protected by means of metal foil or a standard metal tip designed for aircraft propellers.

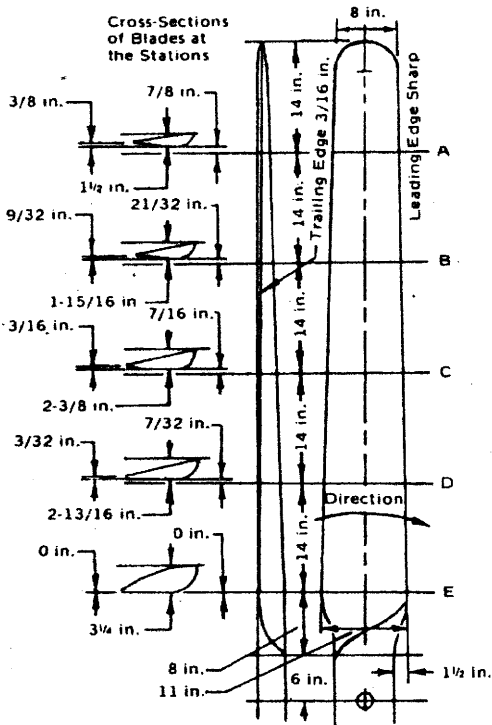
Lecjay design wooden propeller blades for diameters from 6ft to 10ft.



	Z	Y	X	W	V	U	T	S	R	Q	P	N	M	L
6ft. dia. prbp	6"	3½"	2½"	4½"	2¾"	¼"	⅛"	3/16"	¼"	¾"	2 1/32"	9/16"	15/32"	3/8"
7ft. - ..	7"	4"	3"	5½"	4"	7/64"	7/32"	2 1/64"	7/16"	15/8"	1 13/32"	1 3/16"	3 1/32"	3/4"
8ft. - ..	8"	4"	4"	5½"	4"	7/64"	7/32"	2 1/64"	7/16"	15/8"	1 13/32"	1 3/16"	3 1/32"	3/4"
10ft. - ..	10"	5"	5"	5½"	4"	7/64"	7/32"	2 1/64"	7/16"	15/8"	1 13/32"	1 3/16"	3 1/32"	3/4"



Cross-Sections of Blades at the Stations



# Der Rotor

Diesem Bauteil ist besondere Aufmerksamkeit zu schenken. Hier muß mit allergrößter Sorgfalt gearbeitet werden - lieber zweimal zuviel nachmessen und wiegen als einmal zu wenig!

Mit der sorgfältigen *Auswahl des Holzes* wird schon festgelegt, wie gut der Rotor am Ende gelingt und wie lange er halten wird. Gönnen Sie sich bei der Auswahl viel Zeit, Geduld und Ruhe. Das Holz muß fest und zäh sein und darf möglichst wenig arbeiten. Das Wichtigste ist ein absolut gleichmässiger Wuchs; die Holzfaser sollte die ganze Bohle durchziehen, einerseits, damit der Rotor später nicht bei hohen Belastungen bricht, und andererseits, damit die Gewichtsverteilung innerhalb der Bohle möglichst gleichmäßig bleibt. Die Jahresringe sollten möglichst schmal und gleichmäßig sein und senkrecht in der Bohle stehen. Wegen der sehr hohen Drehzahlen sollte das Holz obendrein möglichst leicht sein, damit die Fliehkräfte an den Flügeln nicht zu groß werden.

Harthölzer wie Buche oder Eiche eignen sich nicht, da sie zu schwer und zu spröde sind. Eschenholz wäre eine sehr gute Wahl, aber leider ist eine gut abgelagerte Eschenbohle hier schlecht zu bekommen und nicht billig.

Brauchbare Ergebnisse lassen sich auch mit dreifach (wetterfest-) verleimtem Kiefern- oder Fichtenholz erzielen. Nach meiner Erfahrung können dafür sogar gesunde und trockene Fußbodendielen aus Abbruchhäusern verwendet werden, da dieses Holz mit Sicherheit gut abgelagert ist und sich kaum mehr verzieht. Sie müssen auf die richtige Dicke gehobelt und wasserfest verleimt werden.

Sehr gute Erfahrungen habe ich mit einem leider nicht heimischen Holz gemacht. Es heißt Niangon und wird von einigen Firmen unserer Gegend zur Herstellung von Fensterrahmen verwendet. Es ist der heimischen Esche sehr ähnlich.

Der Rotor hat später einen Durchmesser von 2,2 Meter, die Bohle sollte jedoch vorerst auf 2,4 Meter geschnitten werden, damit das Blatt beim Bearbeiten mittels kräftiger Schraubzwingen an beiden Enden auf der Arbeitsplatte gehalten werden kann. Wenn Sie die Bohle auf die Maße 15 cm \* 240 cm \* 4 cm abgerichtet haben, sollten Sie eine Zentrierbohrung von 4 mm Ø in der Mitte anbringen und das erste Mal den Rotor auf die Gewichtsverteilung kontrollieren. Ein langer, schlanker und polierter Schraubendreher, wie ein Nagel durch ein Brett gesteckt, leistet beim Auswiegen wertvolle Hilfe.

Nun werden die beiden Rotorspitzen wie in der Zeichnung (Abb. 32) angegeben verjüngt. Vergessen Sie nicht, nach jedem Arbeitsgang, den Rotor auszuwiegen und auszugleichen!!! Die Profilschablonen sind im Maßstab 1 : 1 gezeichnet. Sie sollten die Schablonen (Abb. 32) jeweils zweimal auf starken Kar-

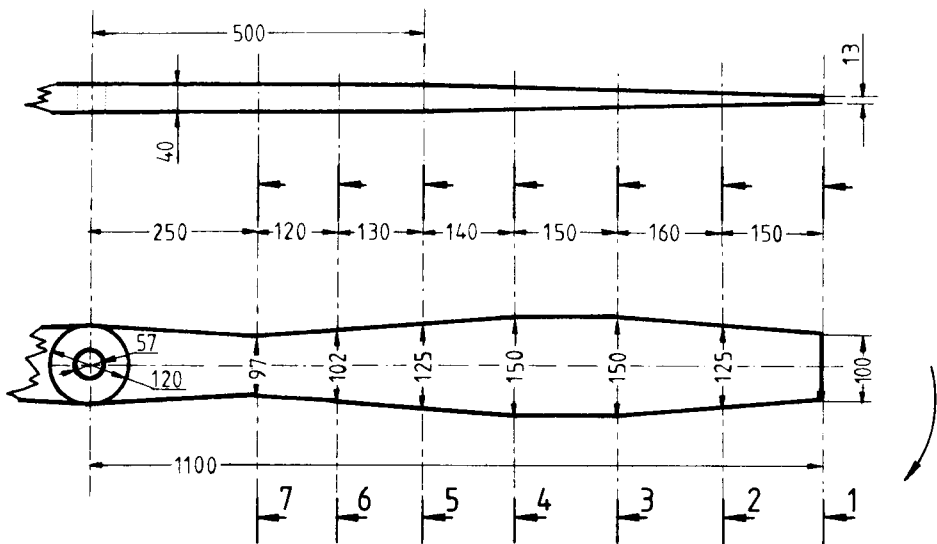


Abb. 32: Abmessungen und Profilschnitte des Flügels (Alle Maße in mm)

ton übertragen und durchnummerieren. Die beiden Schablonensätze werden einmal für die Vorder- und einmal für die Rückseite benötigt. Die Vorderseite (zum Wind gerichtet) hat das glatte Profil. Die Drehrichtung des Rotors ist in der Ansicht von vorn im Uhrzeigersinn.

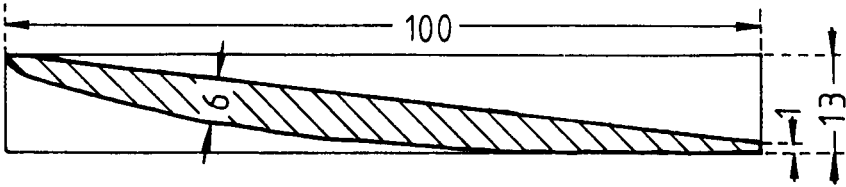
Arbeiten Sie die Profile sehr genau heraus und messen Sie immer wieder nach. Etwas zuviel Abgehobeltes läßt sich nicht ersetzen! Sind alle Profile auf den Rotor übertragen, müssen vor allen weiteren Arbeiten die beiden überstehenden Spitzen gekürzt werden, so daß der Rotor jetzt den endgültige Radius von 110 cm erhält.

Ist der Rotor komplett fertig gehobelt und geraspelt, muß geschliffen werden - beginnend mit einer 80 er Körnung, dann 120 er und 180 er, bis schließlich mit der 240 er Körnung das Holz fast glänzt und keine Schleifspuren mehr zu sehen sind.

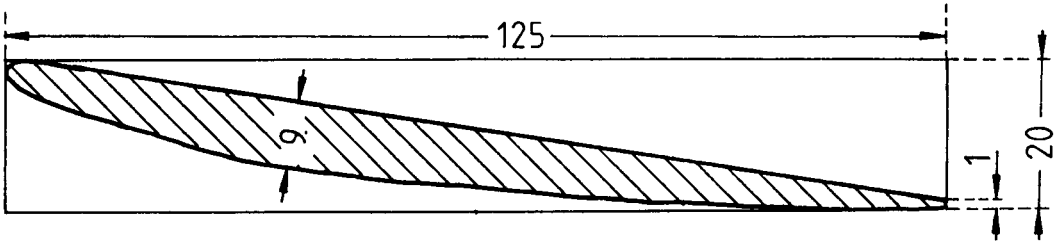
Sie können den Rotor jetzt schon sehr vorsichtig testen, wenn Sie ihn auf einen Schraubendreher stecken und sich in den Wind stellen. Aber es ist größte Vorsicht geboten. Wenn er erst einmal zu schnell dreht, läßt er sich nicht mehr so leicht bremsen und Sie können sich bei diesem Versuch unter Umständen schwer verletzen!!!



SCHNITT 1



SCHNITT 2



SCHNITT 3

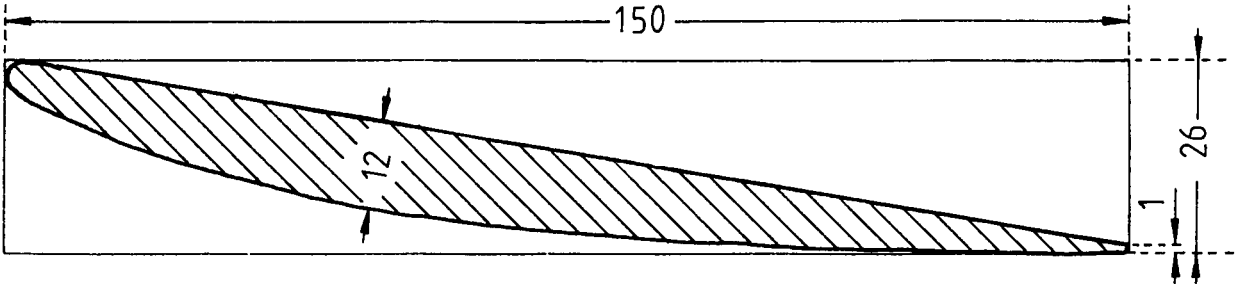
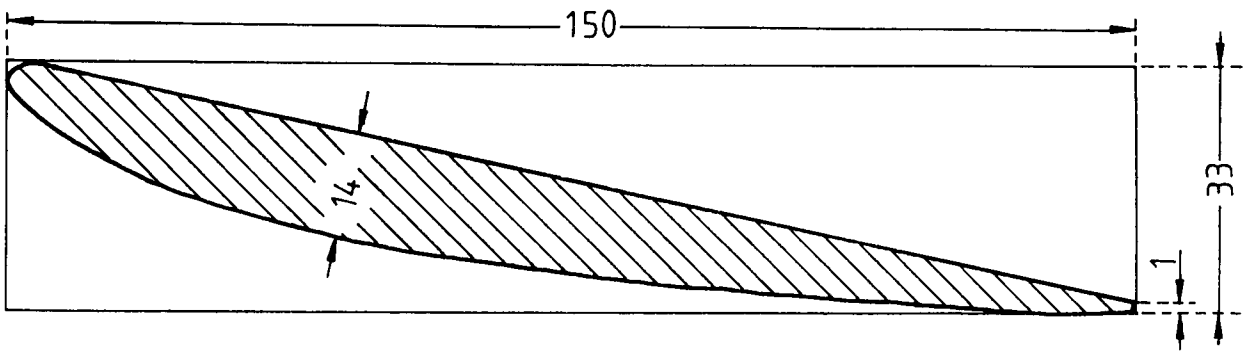


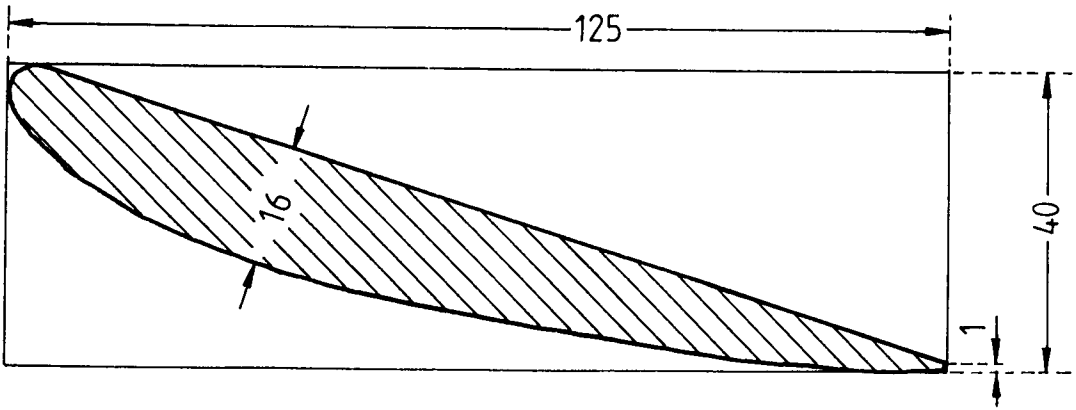
Abb. 32 a: Das Profil des Flügels (Maßstab 1 : 1)

Abb. 32 b: Das Profil des Flügels (Maßstab 1 : 1)

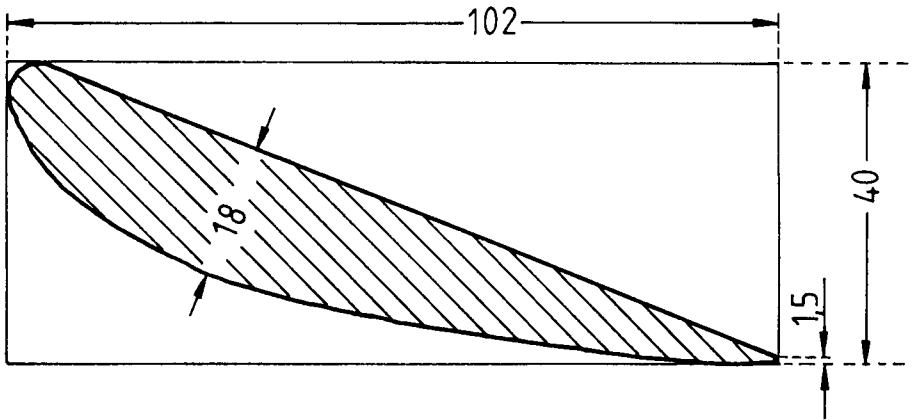
SCHNITT 4



SCHNITT 5



## SCHNITT 6



## SCHNITT 7

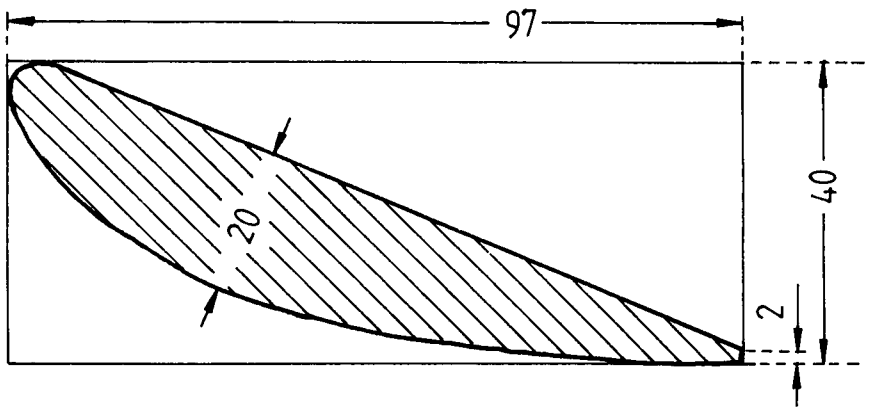


Abb. 32 c: Das Profil des Flügels (Maßstab 1 : 1)

Wenn alles zu Ihrer Zufriedenheit ausgewuchtet und ausgewogen ist, wird die dickere Kante (Hagelschlagkante) mit Glasfasergewebe und Polyesterharz beschichtet (Abb. 33). Die Profilschablonen berücksichtigen eine Glasfaserauflage von  $3 \times 0,2$  mm. Um eine gute Verbindung zwischen Holz und Polyester zu erreichen, werden die betreffenden Flächen mit der Grundierung »G4« gründlich vorbehandelt (Bezugsquellen im Anhang). Die Grundierung bleibt etwa 2 Tage lang klebrig. In dieser Zeit sollte die Polyesterbeschichtung beendet sein. Die drei Lagen Gewebe für jeden Flügel müssen schon zugeschnitten sein, bevor das Polyester angerührt wird. Denn ist das Polyester erst einmal angerührt,

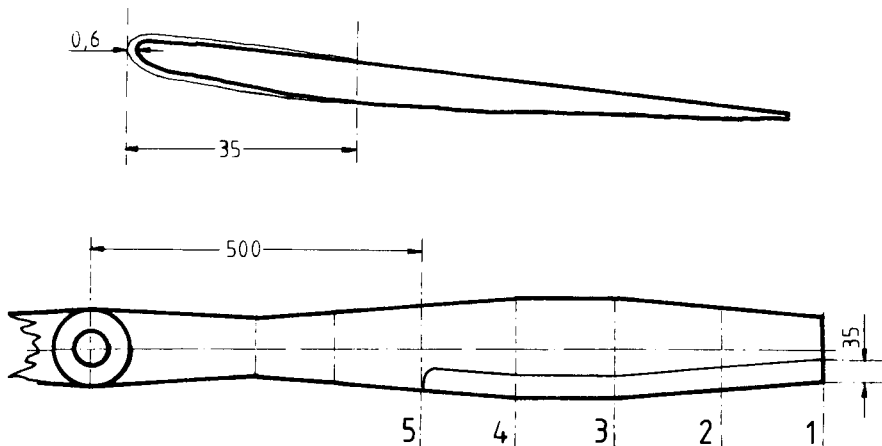


Abb. 33:

Im eingezeichneten Bereich (1 - 5) wird die vordere Flügelkante mit glasfaserverstärktem Kunststoff beschichtet. Maße in mm

muß alles sehr schnell gehen und doch zugleich sehr exakt und sauber gearbeitet werden. Auf gar keinen Fall dürfen zwischen den Lagen Blasen eingeschlossen sein! Es ist ganz sinnvoll, diese Arbeit in mehreren Schritten auszuführen und nur jeweils kleinere Mengen Polyester anzurühren.

*Und noch ein sehr wichtiger Hinweis:*

*Polyester bzw. die Dämpfe, die bei der Verarbeitung entstehen, sind sehr giftig und können Reizungen an Haut, Augen und Lunge verursachen!!! Arbeiten Sie nach Möglichkeit im Freien.*

The key to making wooden propellers like this is to make cardboard templates of the right shape to fit the blade at 7-inch intervals or stations along the 7-foot blade, or at 10-inch stations along the 10-foot blade. The hole in the cardboard should be the exact shape of the blade, and to fit it you snip the template in two, and fit it over the blade at each station. Whittle away at each station till you have an exact fit, then shape the blade between the stations by eye.

## **Fiberglassing a Prop**

If a wood prop is basically sound and airworthy, it can be made stiffer, stronger and more resistant to erosion by sheathing the blades in fiberglass. It is NOT a means of salvaging a split, damaged or otherwise unsafe prop.

The resin used can be either polyester or epoxy, but it must be laminating resin, not casting resin. To get fresh resin and hardener, it is a good idea to go an aircraft supply house that sells a lot of it, such as Aircraft Spruce and Specialty Company in Fullerton, CA. Resin from a local marine or paint store may have been sitting on the shelf for a long time.

The glass cloth should be bidirectional and about .011 inch thick (about 8 oz. cloth). The selvage edge should be trimmed off.

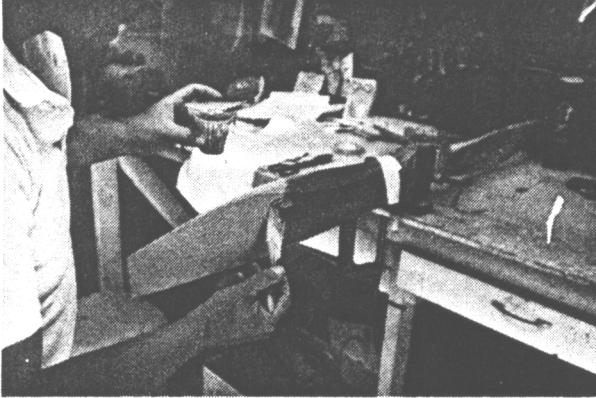
Mask off the center of the prop and sand the prop down to bare wood. Do it by hand or with an oscillating sander. Don't use a belt or disc sander, as they will leave an uneven surface that will increase drag.

Mount the prop in a vise, with the jaws covered with wood blocks. Lay the cloth over the leading edge with the weave at a 45 degree angle and trim it to within about an inch. (Fig. 11-18) Set the cloth aside and brush a layer of resin on one blade. (Fig. 11-19) Give the resin a few minutes to set up and then lay the cloth over the leading edge. Smooth the cloth with the palms, working out all of the wrinkles and bubbles (Fig. 11-20).

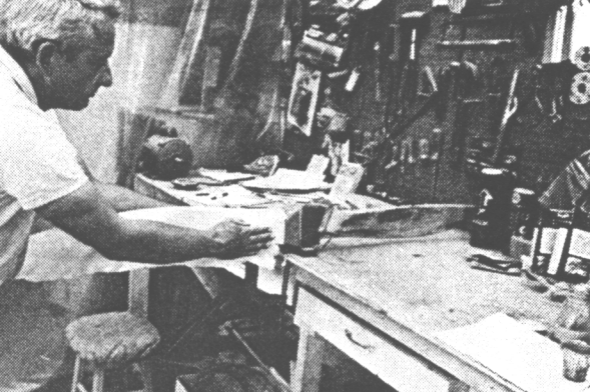
Trim the cloth within about 1/4 inch all around the edge. (Fig. 11-21) Brush on a light layer of resin and work it into the cloth with the brush. Don't use a squeegee, as this will keep moving the cloth around. Brush on enough resin to fill the weave of the cloth. (Fig. 11-22) When the resin is no longer tacky, trim off the excess cloth with a razor blade (Fig. 11-23).

Let the resin cure overnight at room temperature. Don't attempt to speed the cure by using heat, as this can weaken the fiberglass. Grind or sand off any bumps or threads. Then brush on a layer of Featherfill (available at some auto stores or Aircraft Spruce). This will fill the weave of the cloth and is ready for sanding in about an hour or so. Sand it lightly, taking care not to sand into the glass cloth. (Fig. 11-24) Use another layer if necessary. Let the Featherfill cure overnight. Spray on a coat of automotive Hot Rod gray primer. This is necessary to allow the paint to adhere to the fiberglass. For a finish coat, use a urethane paint.

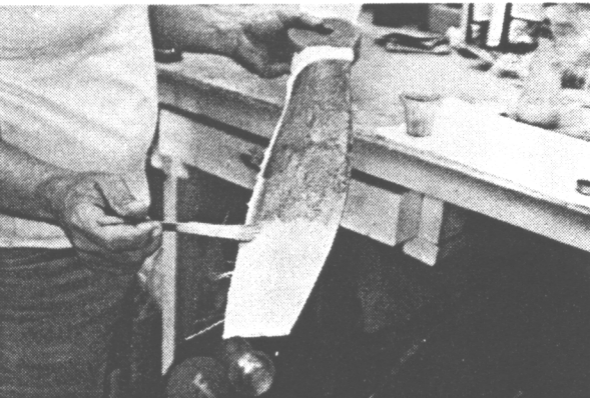


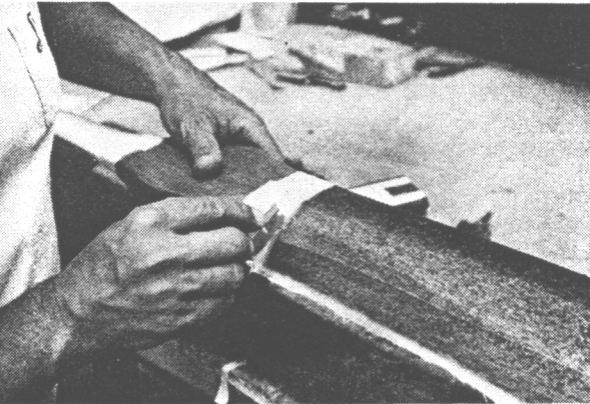




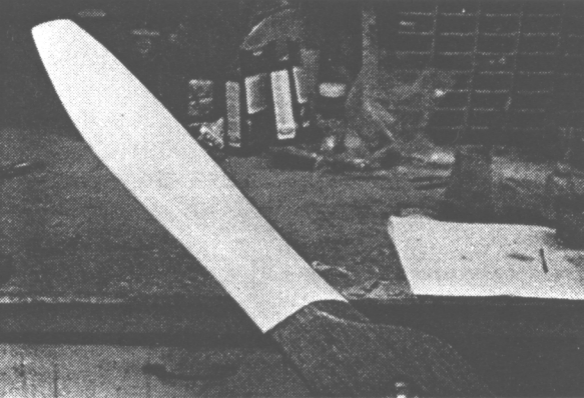












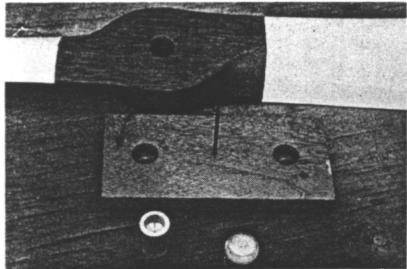


Fig. 11-14. Components needed to balance a prop: a stand (consisting of a piece of wood and a nail), a machined bushing, and a small bubble level with its suction cup removed.

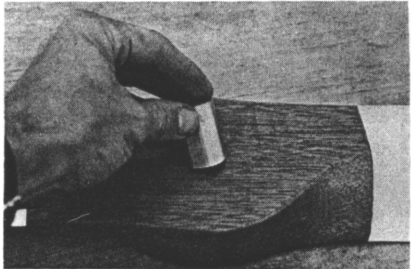


Fig. 11-15. The bushing should fit snugly in the center hole.

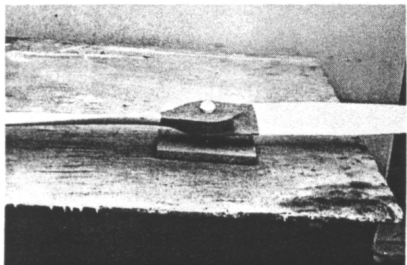


Fig. 11-16. Put the bushing in the prop. Place both on the nail and put the bubble level on the prop.

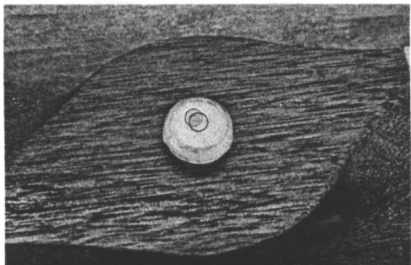


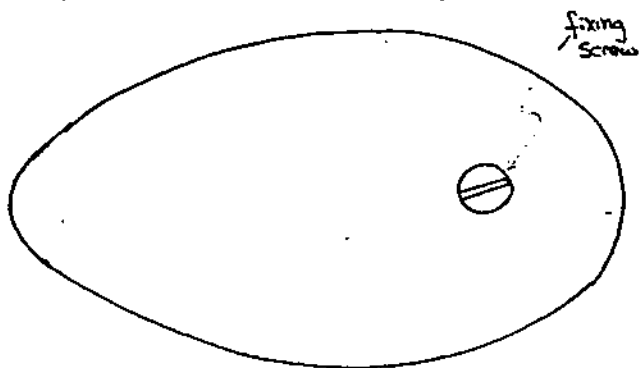
Fig. 11-17. Apply small amounts of spray paint (for weight), or varnish, as needed until the bubble is centered. (This prop needs more paint on the trailing edge of the left blade to center bubble.)

# PROPELLOR FINISHING.

Choice of Wood: Close grain is best to give the prop. rigidity and stiffness. The wood used should be well seasoned and dried out for at least 2 weeks before using. This is important as the blades may lose their balance by uneven drying out.

Balancing the Propellor. A unbalanced propellor will soon destroy itself.

Method: place the prop. on a free turning shaft indoors where there are no air currents. The prop. is rotated and allowed to come to rest. The heavier blade will determine the point of rest. A properly balanced prop will come to rest at varying points on repeated testing.



Choose a piece of sheet metal of a weight that would logically balance your propellor. Shape it elliptically and drill an  $\frac{1}{8}$ " hole at the larger end.

Now take a  $\frac{1}{2}$ " wood screw and the balancer and hang them from a piece of light thread on the lightest end of the prop. move the weight along the blade until the prop. is fairly well balanced. Then screw the weight to the blade in that position. Fine adjustment is then made by rotating the shape about the fixing screw. Great care and patience should be taken to thorough balance any propellor. The balance should be rechecked at least once a year.

Note: Sealing against moisture must be well done. Five coats of enamel or varnish rubbing down well with wet and dry emery paper between coats is what is needed.



# Wind Generator Blade Balancing

Mick Sagrillo

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**M**any different ways of balancing wind generator blades and rotors have been used over the years. Some methods work, although often on a hit or miss basis. There is more to rotor balancing than just screwing lead onto the blades. An unbalanced rotor will cause unnecessary vibration and stresses resulting in premature wear on the generator's bearings, governor, blades and tower. A properly balanced rotor will give the wind generator long life and its owners years of problem free power.

## Ancient History

An old way of balancing is to mount the blades on their governor and then hang the entire assembly from a wire attached to the ceiling. The wire passes through the generator shaft hole in the governor and acts as a fulcrum or balance point. The entire rotor is then hung horizontally a few feet from the floor. The wire must pass exactly through the center hole of the governor. The point where the wire passes through the rotor becomes the fulcrum about which the rotor teeters. Weights are added to the lighter of the two blades (for a 3 blade rotor) until the entire rotor is horizontal. The primary problem with this system is that the fulcrum is below the rotor's center of gravity. This is because the assembly is supported from beneath by the wire. Balance is best achieved when the fulcrum point is above the center of gravity of the entire rotor/blade assembly. It is virtually impossible to balance the rotor accurately by hanging it from a wire.

## Better But Not Perfect

Another old timers method involves mounting the entire rotor on the generator shaft. The generator can be on the tower or preferably on a stub tower on the ground. The rotor is lightly spun and allowed to come to rest. The heaviest blade will always come to rest in the bottom position. On a three blade rotor, weights are added to the lighter of the two and the rotor is spun again. When the blades come to rest randomly, the rotor is considered balanced. This method is tedious and time consuming but with patience a somewhat balanced rotor can be achieved.

## Two Blade Balancing

Individual blades can be balanced, one against the other or against a known weight, on a fulcrum. This only works with a two blade system and then only if the governor or hub that the blades are attached to is perfectly balanced. If the governor is not well balanced, the case with most two blade Windchargers, or the rotor has three or four blades, this method doesn't work well.

## Balancing with a Fulcrum

A common but ineffective way of balancing blades with a fulcrum is to find the center of gravity of the heaviest blade and transfer this dimension to the lighter blades. These blades are placed, one at a time, on the fulcrum at the marked point & balanced with weights.

## Fulcrum Balancing Problems

One major problem with fulcrum balancing is the assumption that the blades are identical in gross weight and in weight distribution or density along their length. We have received blades from manufacturers that have varied by as much as six ounces from the heaviest to the lightest. And these have been considered quality blades. One of our customers bought blades from a well know supplier that varied by three pounds! Even if you've individually balanced all three blades, the rotor assembly will still not be properly balanced if the blades don't all weigh the same. As an exaggerated example, let's say that you used two 2 X 4's and one 2

X 6 instead of blades. Obviously, the 2 X 6 is going to be the heaviest of the three. If you find the center of balance of the 2 X 6, transfer this center distance to the two 2 X 4's, then balance the two 2 X 4's on your fulcrum, all three will have the same center of balance. You'd have plenty of problems if you tried to use these three pieces of wood to drive your wind generator.

## Wood Density

One of the reasons for the large discrepancies in blades is wood density. Trees vary in density, as do parts of individual trees. Ideally, the densest wood should be at the butt of the blade. The butt is the blade end closest to the governor. I know that our blade carver takes these things into consideration. But someone who is buying just one set of blades to finish for his own generator is really stuck with whatever the manufacturer sends. Blade manufacturers sell their wares either prepaid or C.O.D. Once a customer has paid for the blades, he has to be content with what's been shipped.

## Blades and Rotor Together

The blades should not be individually balanced using the fulcrum method. Here at Lake Michigan Wind & Sun, we do not balance individual blades. We treat the entire rotor (the blades and governor) as a single unit. The first step in system balancing is to break down all structures to fundamental units. The entire rotor assembly is a fundamental, rotating unit. In theory, the rotor can be balanced by balancing individual blades, then mounting them onto what is supposed to be a balanced governor. In practice, all sorts of assumptions come into play that are givens in theory. These assumptions are not even considered when someone is screwing weights to blades, and therefore become variables. And variables can become vibrations.

The way we balance rotors at Lake Michigan Wind & Sun is very similar to the way tires were balanced before computerized spin balancing. We bubble balance.

Our balancer (photo 1) consists of a shaft machined to fit the center hole of the governor, in this case a Jacobs or DWS blade-activated governor. Different shafts are machined to fit different styles of governors. The shaft is bored out nearly to the top end. A pivot rod is machined to a point which fits inside the bored shaft. An

Photo1 by Mick Sagrillo

Photo 2

Photo 3

Photo 4

Photo 2: Bubble balancer, bored shaft & pivot rod in place.

Photo 3: Blades and hub on the balancing rig.

Photo 4: Bubble balancer at the hub's center.

Photo 5: Governor spring mounting brackets. An ideal place to add weights.

Photo 6: A weight sandwiched between the bracket and the blade.

All photos by Mick Sagrillo.

Photo 5

Photo 6

inexpensive bubble balance, available from any local tool shop, completes the hardware required.

The assembled balancer is shown in photo 2. The governor is placed on the bored shaft and the blades are then mounted onto the governor. At this point, the blades, governor hub, and governor spider are numbered. This is done so the rotor can always be reassembled in exactly the same way that it was balanced. If this is overlooked, the balancing is for naught. It's a good idea to place sawhorses under the first two blades that are mounted onto the governor to keep from placing undue stress on the pivot rod. Once the third blade is installed the sawhorses can be removed because the rotor will, more or less, maintain its own balance.

The rotor mounted on the balancer is shown in photo 3. The primary advantage to this system is that the pivot point of the rod (the fulcrum) is above the center of gravity of the governor and blades, see figure 1.

This makes balancing very accurate as well as very easy. The bubble balancer is placed directly over the center of the top of the bored shaft that is sticking out of the governor (see photo 4).

#### **The Balancing**

To balance a Jacobs or DWS blade mounted on a blade-activated governor, place gram weights on the eyebolt brackets of the two lighter blades until the bubble balance reads level (see photo 5). The eyebolt brackets are there to tension the governor springs. They provide a convenient place to attach weights along the blade's center of gravity.

#### **Adding The Weights**

Once the rotor is balanced, weigh the gram weights on a beam balance. Measure out the same weight of lead for casting. Add several grams extra to compensate for the mounting bolt holes which must be drilled in the weight. Melt the lead, pour it into a

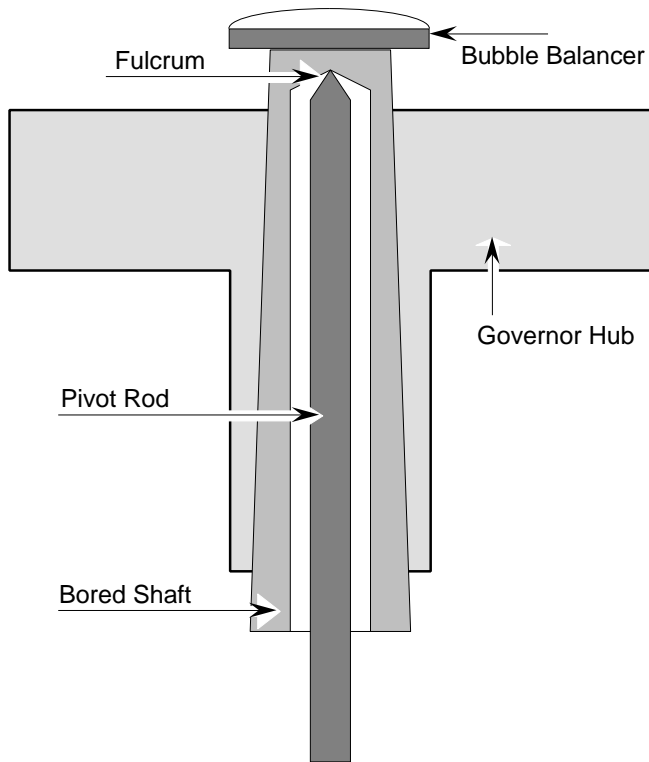


Figure 1- the balancing rig.

mold and set aside to cool. Drill the bolt holes and mount the weight to the blade by sandwiching it between the eyebolt bracket and the blade (see photo 6).

This way, the weight cannot work its way loose from the blade. Now, recheck the balance of the rotor to see how good a job has been done. If you've removed too much or too little lead during the drilling of the bolt holes, make corrections if possible. If not, then do it over. A perfectly balanced rotor is one of the most critical parts of your wind generator. Once you're satisfied with the balancing, move on to finishing the blades, and taping the leading edges.

**Finishing Up**

Before you balance the rotor, prime and finish sand the blades and mount all the hardware. Don't apply the finish coats of paint before balancing for two reasons. First, several ounces of paint spread more or less evenly over the entire surface will not affect the balance of the rotor. Second, it's very important to attach the weights to the blade before painting so the finished blade is completely protected by the final coats of paint. Then there are no breaks in the paint's skin for moisture to enter. Moisture entering the wood will not only affect balance, but also eventually cause rot.

**Inner Workings- Centers**

Problems often arise because of where the weights are placed on the blades. As can be seen from the cross section of a blade in

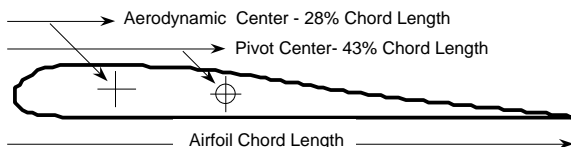


Figure 2- Airfoil Centers & Chord Length

figure 2, the thickest part of the blade is near the leading edge of the blade. This is called the aerodynamic center. Also shown in figure 2 is the pivot center. The pivot center is where the blade is attached to the rotor.

The aerodynamic center is where most people would probably attach weights because it's the thickest and presents the least danger of the screws going all the way through the blade.

**The Aerodynamic Center vs. the Pivot Center**

In the Modified Clark Y Airfoil used on Jacobs and DWS wind generators, the aerodynamic center is 28% of the chord length measured from the leading edge of the blade. The chord length is the distance from the leading edge to the trailing edge of the airfoil. In the case of a Jacobs or DWS blade used on a blade-activated governor, the hole bored into the blade's butt for the governor blade shaft is the pivot center. The pivot center of the blade is 43% of the chord length from the leading edge. The three blade shafts of the blade-activated governor are 120° apart. The center of gravity of the blade lies along a line that passes through the pivot center of the blade (Figure 3).

Therefore, the center of gravity of each blade is 120° apart. By placing lead weights beneath the eyebolt brackets, you add weight along the center of gravity of the blades. Since each blade's center of gravity remains the same (120° apart), the rotor will balance nicely. If you add weights along the blade's aerodynamic center, then the center of gravity is shifted forward, towards the leading edge. This means that the centers of gravity for the three blades are no longer 120° apart (figure 4 on the next page).

While a rotor assembly whose blades are weighted along the aerodynamic center will balance as a unit on the bubble balancer, it may vibrate in actual use. Care must be taken to locate weights along the center of gravity of the blades (the pivot center if a pivot is used) and not along the aerodynamic center.

**Weights On or Within the Airfoil?**

Never add weights on the outside of the airfoil. The airfoil of the rotor is a most important part of the entire wind system. The last thing you want to do after painstakingly preparing and finishing a set of blades is bolt some globs of lead to the outside of the airfoil. This creates all sorts of turbulence which will adversely affect the airfoil's performance.

However, some rotors do not have governor hardware attached to them (like the Jacobs or DWS blades) and therefore lack convenient mounting points for weights. There is a method of attaching weights that does not compromise the airfoil. This technique involves countersinking the weights into the blades. We use this method quite often with different airfoils and it works well.

**Countersinking Weights INTO the Airfoil**

In this technique, weights are placed along the center of gravity line of each blade requiring additional weight. Countersink the weights into the blade with a Forstner bit. A Forstner bit drills a perfectly clean hole in wood and leaves a flat bottom in a blind hole (the hole

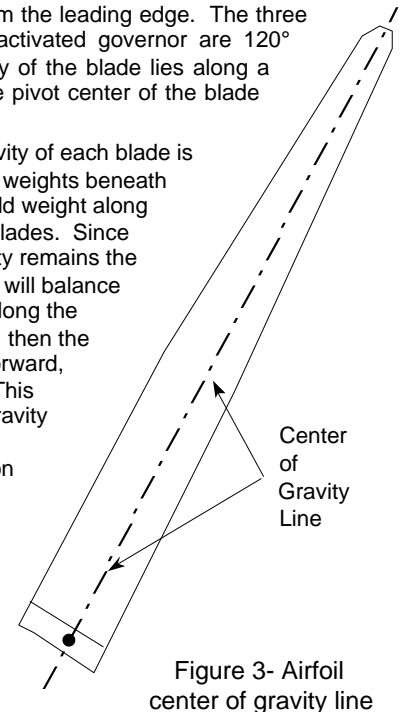


Figure 3- Airfoil center of gravity line

## Wind Power

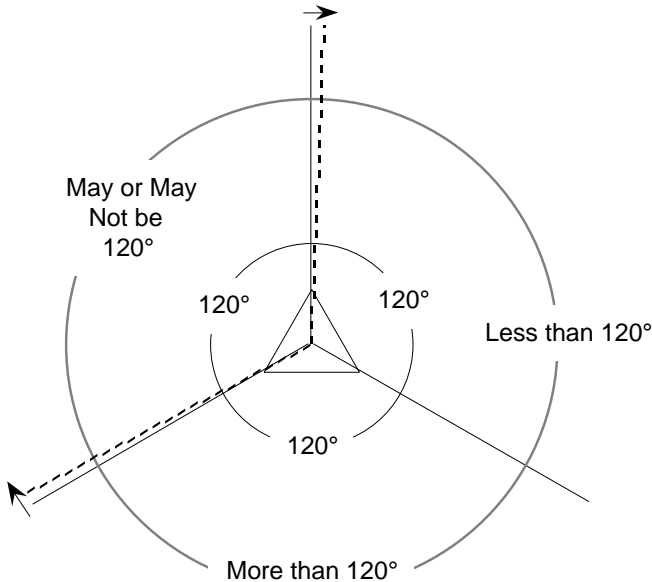


Figure 4- Symmetry of the entire blade/rotor system.

doesn't go all the way through the wood). You'll find an example of a blind hole on chair legs. These blind holes are drilled into the legs and accept crossrails. The best results are achieved with a drill press. I use a 7/8" Forstner bit, although most any size will work. After determining how much weight is needed to balance a blade, the lead is melted and poured into a form. The form I use is a short piece of heavy wall tubing that has been bored to exactly 7/8" to match the holes. The weights are never more than 3/8" high. If more weight is needed for the blade, more holes should be drilled and the lead made into several weights, one weight for each hole. The holes are about 1/2" deep for a weight that is 3/8" high. Epoxy is applied to the bottom of the weight and the weight is pressed into the hole. The hole is then sealed with automotive body putty, such as Bondo or fiberglass. I have found that the 1/8" of body putty or fiberglass that covers the lead weight nearly equals the weight of the wood removed from the hole. No allowances for the additional weight of the body putty or fiberglass are needed. Once the body putty or fiberglass has hardened, it can be sanded to match the contour of the blade. If you have done a good job, it will be very difficult to find the weights once the finish coats of paint have been applied. You have now balanced the blades without destroying the integrity of the airfoil.

### The Bottom Line

As you can see, rotor balancing requires looking at the entire rotor assembly as a unit. Balancing individual blades is approximate at best. If you take time and consideration with the balancing process, you'll have a happy and long lived wind plant.

### Access

If anyone has any comments on these ideas or any other ideas concerning rotor balancing, I would appreciate hearing from them. Feedback can be sent to: Mick Sagrillo, Lake Michigan Wind & Sun, E 3971 Bluebird Rd., Forestville, WI 54213, (414) 837-2267.

*Lake Michigan Wind & Sun rebuilds, buys, and sells wind*

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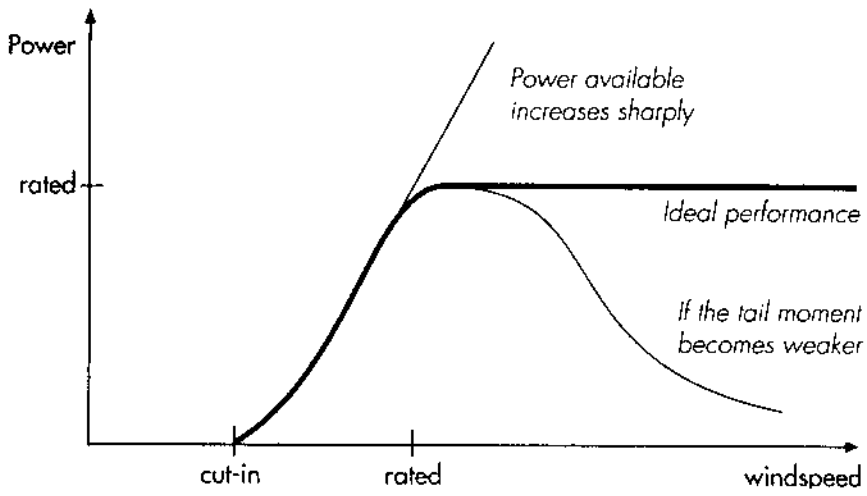
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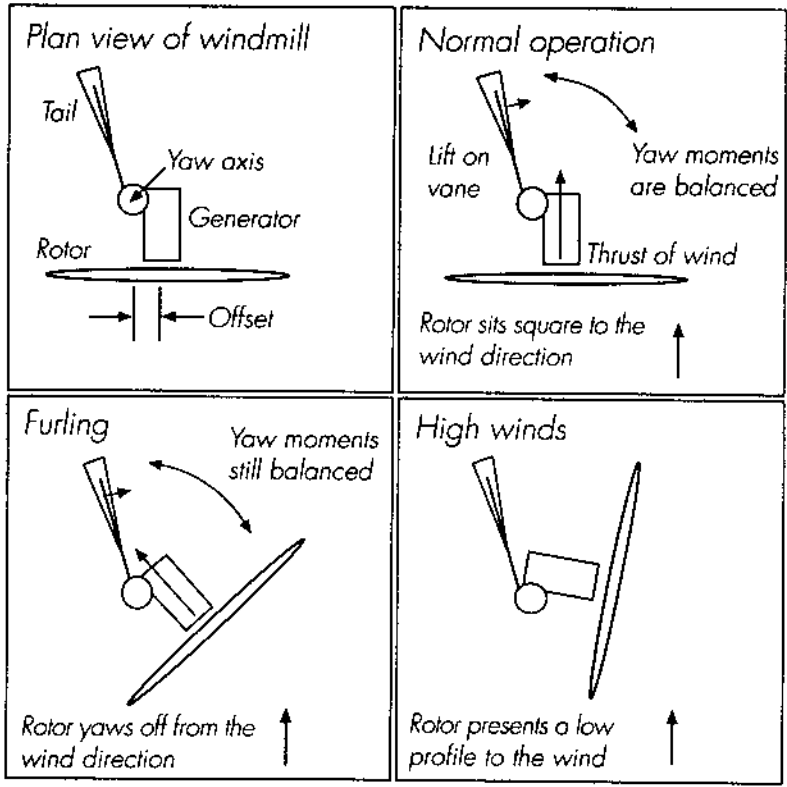
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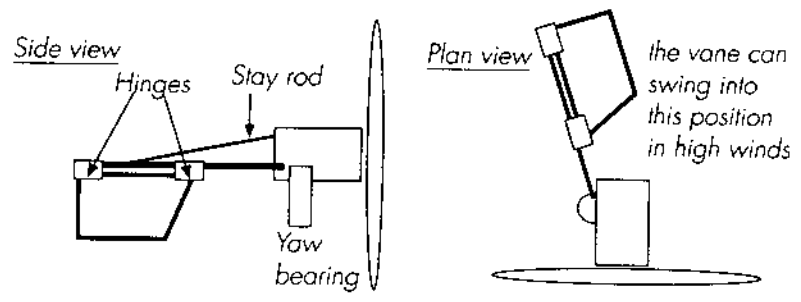
# Graph of Power versus Windspeed



## Yaw Governing System



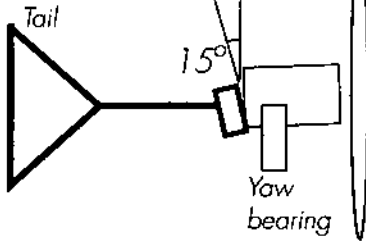
## Hinged Vane System



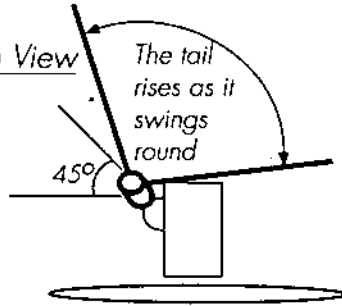
## Gravity Operated Furling Tail

Tail bearing is angled 15 degrees away from vertical

Side View

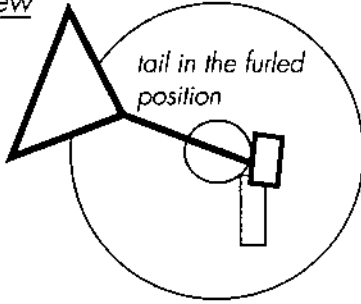


Plan View



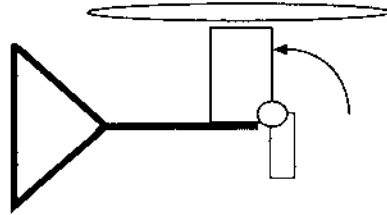
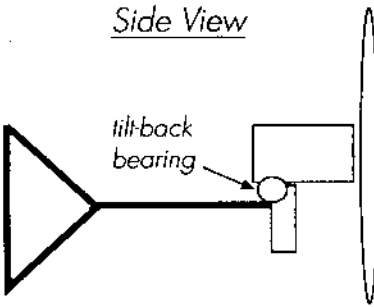
Seen from above, the axis of the tail hinge should make an angle of 45 degrees to the rotor plane.

Rear View



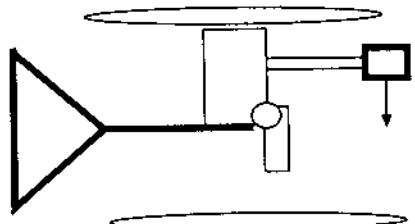
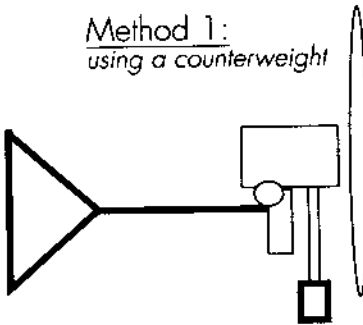
## Tilt-Back Governing System

Side View

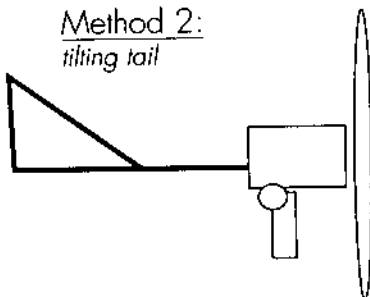


## Tilt-Back Governors without Springs

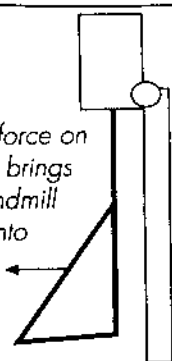
Method 1:  
using a counterweight



Method 2:  
tilting tail



Wind force on the tail brings the windmill back into action



## Laminations for Alternators

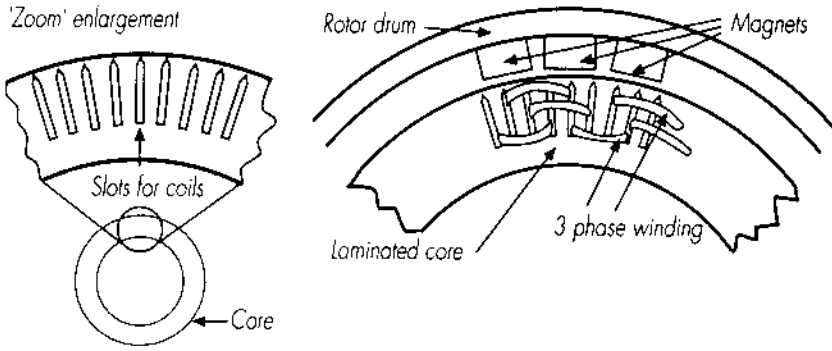


Fig. 5.21 The best shape of laminations for 'case driven' alternators.

Some windmill manufacturers in Holland use induction motor bodies as the basis for their alternators. They use many poles and wind the stator with many more coils than an induction motor. The main difficulty with this arrangement is that the magnet blocks are subject to high centrifugal forces, combined with frequent, large changes in temperature. These conditions are quite demanding for the glue.

The other radial field arrangement is to put the rotor on the outside. Two big advantages of this 'case driven' arrangement are that the centrifugal forces press the magnets against the rotor, rather than pulling them off; and that you can use the brake drum or even the wheel of a vehicle as a rotor. Car wheel bearings are cheap, and substantial enough to support rotor blades bolted to the hub.

To build the stator for such a machine, we need to find a laminated core, onto which we can fit the output coils. The outside of this core must come close to the magnet faces, leaving only a small air gap for the flux to jump across. A wide air gap means lower flux density, but where the flux comes from ferrite magnets there is only a small loss of performance if the gap is about one millimetre. The advantage of a wide gap is that there is less danger of the rotor and stator making contact due to slack bearings or distortion, as often happens in the real world.

Figure 5.21 shows the best kind of laminations to use for such a machine, but they are hard to find these days. Most motors

## An Alternative Approach

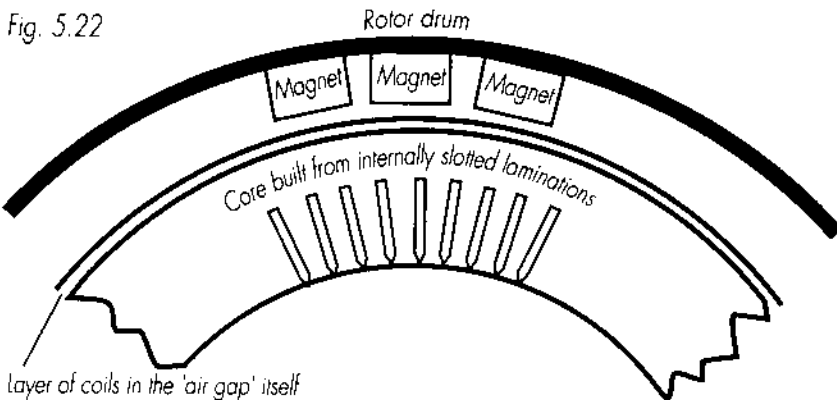


Fig. 5.22

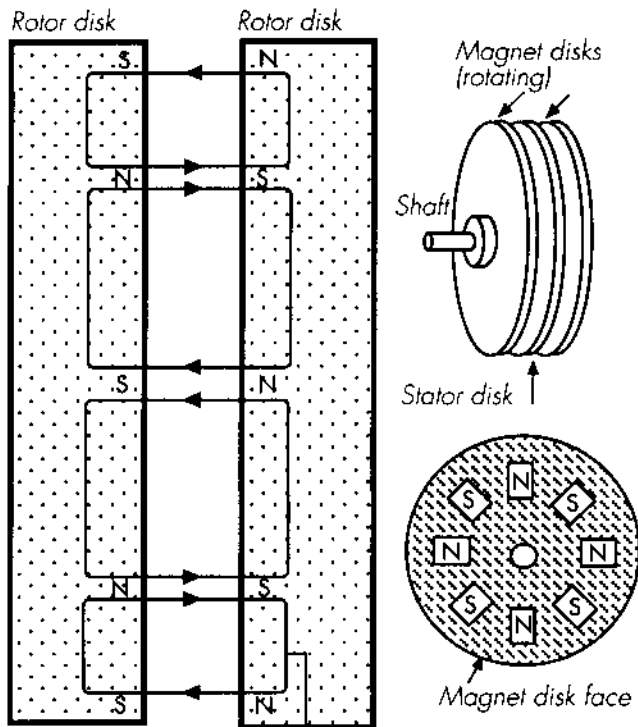
obtainable as scrap are induction motors, with slots on the inside of the core. However, there are specialist suppliers of laminations, or complete stators, for DIY permanent magnet alternators of this sort (see the Resource Guide).

Figure 5.22 shows an alternative approach, using the laminations from a common induction motor. For example, a brake drum with a 254 mm (10 inches) bore from a van with twin-wheel rear axle (e.g. Ford Transit) can be used with magnet blocks 20 mm thick glued around the inside, as shown above, and 203 mm (8 inch) laminations from an electric motor. The resultant air gap (about 5 mm) is large enough that you can glue coils to the surface of the stack of laminations, 'in the air gap' as it were. There are detailed plans for doing this, available from the author (see the Resource Guide).

This arrangement is less powerful than an alternator with externally slotted laminations would be, because there is less space available for windings and because more of the flux from the magnets 'leaks' from one pole to the next without cutting any wires, but the arrangement is very efficient for low power outputs (in light winds). The iron losses are less than with the externally slotted laminations, there is no cogging, and starting is easier.

## An 'Air Gap' Alternator

Fig. 5.23



Side view of the rotating disks showing the magnetic circuit crossing the air gap twice each way.



## Axial field machines

'Axial field' means that the flux lines crossing the air gap are parallel to the axis of the shaft, jumping from one disk to another (Fig. 5.20, page 87). The commonest type of axial field permanent magnet alternator is the 'air gap' alternator, as used (for example) in 'Rutland' windmills.

Figure 5.23 depicts the magnet disks of an air gap alternator, seen from the edge. There are two disks, with several poles (8 or more) each, facing each other. The north pole on one disk faces the south pole on the other (and vice versa). Flux passes across the gap in both directions. Large loudspeaker magnet rings are often used, magnetised with many poles using a special jig. Or the self-builder

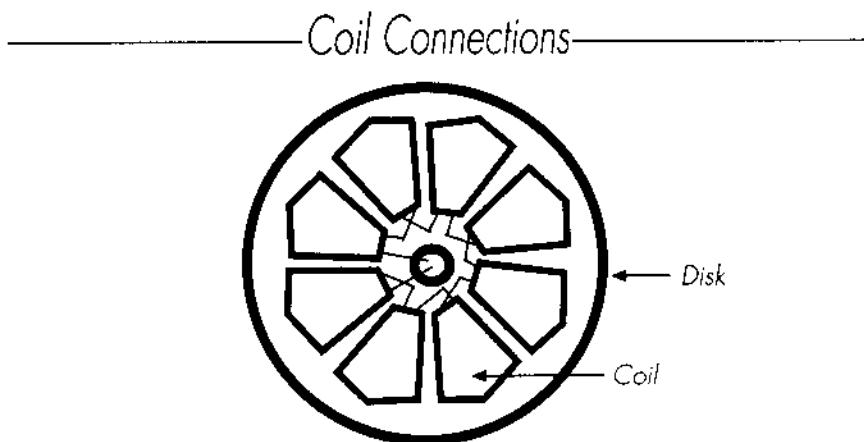


Fig. 5.24 Series connection of coils in a single phase stator disk of the 'air gap' type. Every second coil has its connections reversed.

can glue pre-magnetised ceramic blocks to the faces of steel disks. One advantage of the latter arrangement is that the magnet blocks act like the blades of a fan, helping air to circulate past the stator and cool it.

The stator disk sits in the gap between the two magnet disks. It consists of a set of coils embedded in resin (a polyester resin, as used for fibreglass construction, will serve). In the single phase version, there is one coil on the stator for each pole on a magnet disk. The coils can be connected in series to produce higher voltage, but every second coil needs its connections reversed, because the flux direction alternates (Fig. 5.24).

It also is possible to build a three phase version. There are three coils for every four poles (e.g. six coils for eight poles). Every third coil is connected in series to make a phase group (no need to reverse any this time). Join the starts of all three phase groups together, and use the three finishes as output to the rectifier. (See also Fig. 5.11, 'star grouping'.)

Even with the 'air gap alternator' there is a choice between mounting the rotor on the shaft or on the case (Fig. 5.25). Axial field machines are usually 'case driven', but this is not the best arrangement, because the stator disk is only supported at the centre, where it is easily warped or cracked. The shaft-drive configuration is more robust.

Fig. 5.25 'Air Gap' Alternators

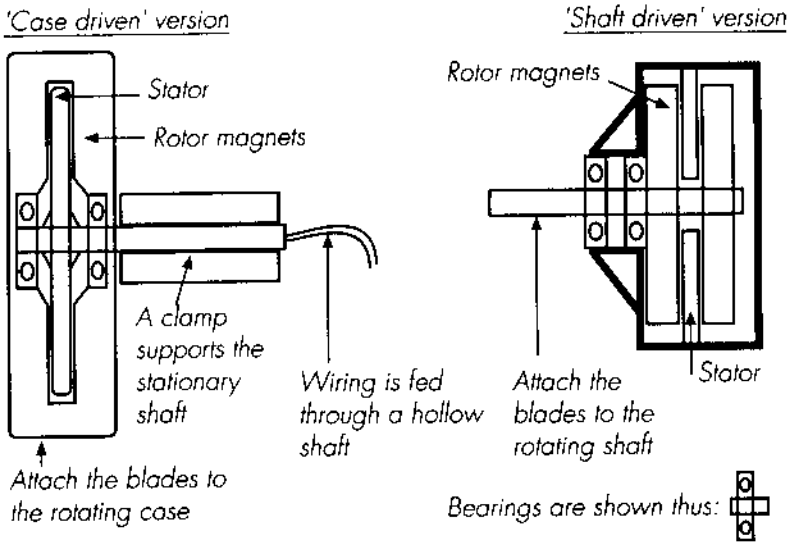


Fig. 5.25 Drive arrangements for 'air gap' alternators. Sectional views of the two types.

The 'air gap' alternator has no laminations in it, so:

- There are no iron losses;
- There is no 'cogging' and minimal starting torque required;
- You can build one without needing laminations.

However the thin stator disk is difficult to cool, so it can be burned out easily.

### Design hints

There are plenty of 'windmill plans' available (see the Resource Guide), but for those who want to design their own alternator, using available bits or personal brainwaves, here are some hints.

### Air gap diameter

The best shape for a low speed alternator is 'fat'. The circle described by the air gap should be large. By increasing the diameter, you increase the speed at which magnets pass coils. This improves the efficiency for a given weight of magnets and coils, at a given rpm.

The limit on making the alternator 'fat' comes when the rotor cannot be made sufficiently rigid to prevent contact with the stator. Magnetic forces, gyro forces, and slack bearings all contribute to this risk. The operating frequency also limits the diameter.

### The number of poles

If the air gap diameter is large, then there is room for plenty of poles. Your choice of the number of poles is fairly arbitrary, because a few wide poles will push very little more flux through the coils than many narrow ones will. For each alternator there will be an optimum, depending on the following factors:

- Frequency depends on the number of poles. Higher frequency (more poles) is helpful if you want to use transformers, but also leads to higher iron loss;
- Copper loss depends on the width of the coils and is less if the poles are smaller;
- Some flux fails to pass through the stator but jumps to the next-door pole. The amount of flux which leaks in this way is more where there are many poles and a wide air gap;
- The magnetic circuit needs to be more heavily built in order to carry more flux without saturating, if the pole faces are large.

### The shape of the coil

The coil should be shaped so that as each pole passes the coil, most of the flux will link through it. The thickness of the coil will depend on the space available. For example, the coils in an 'air gap alternator' will be the same thickness as the stator disk. Coils in a laminated core must be designed to fit the slots, with due allowance for insulating liners. If the coils overlap (as in most three phase windings) you must provide enough slack for this.

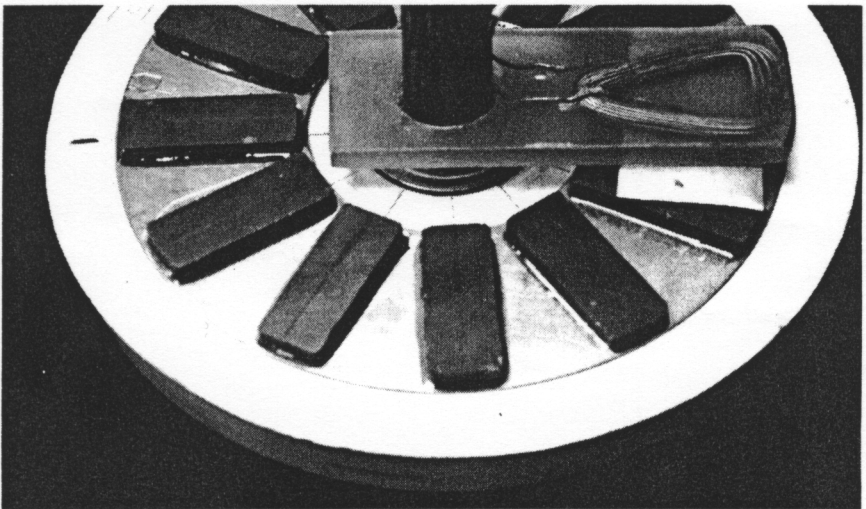
### The number of turns

This needs to be chosen so as to give you the desired voltage at the desired rpm. The voltage/speed performance is not always easy to predict, especially where the design has not been used before.

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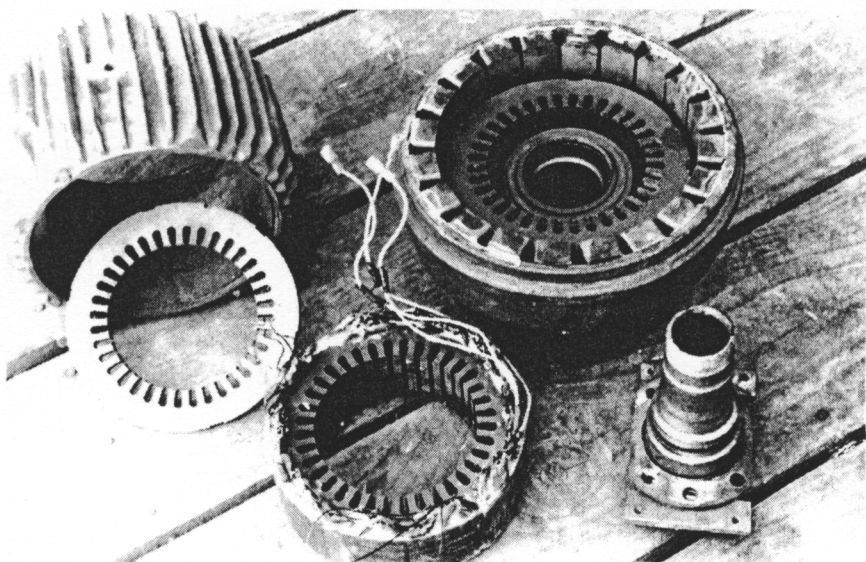
## *An Axial Field Alternator*

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*Magnet rotor and a single test coil for an axial field alternator.*

---



*Bits of a DIY brake drum alternator.*

---

The Appendix gives a 'rule of thumb' formula for the number of coil turns which produce 12 volt cut-in at a given rpm. Divide these turns among the coils in parallel grouping.

If the cut-in speed turns out to be too low, or the voltage is too high, you can reconnect the coils in delta or parallel. But it is better to use a replacement winding with fewer turns. Delta or in parallel windings may suffer from parasitic or 'harmonic' currents which circulate between one coil and another.

### Thickness of wire

Use the thickest wire you can comfortably fit into the available space, so as to minimise the copper loss. If the thick wire is too stiff you can use two or more thinner wires bundled together.

Unlike cables, winding wires do not have a specified current which they can carry without overheating. This is because the cooling depends entirely on the geometry of the winding. Where the stator has a large surface area and good ventilation, it will be able to dissipate more heat before reaching the temperature where the insulation is damaged.

Use the formula for predicting copper loss in wires (see Appendix) to estimate what fraction of the power is lost in the windings. Check that the efficiency is acceptable (above 50%, say). You can also check how much current the stator can handle, by passing this current through it in a bench test, and measuring the temperature rise. On a windmill, the cooling will often be better.

### In conclusion

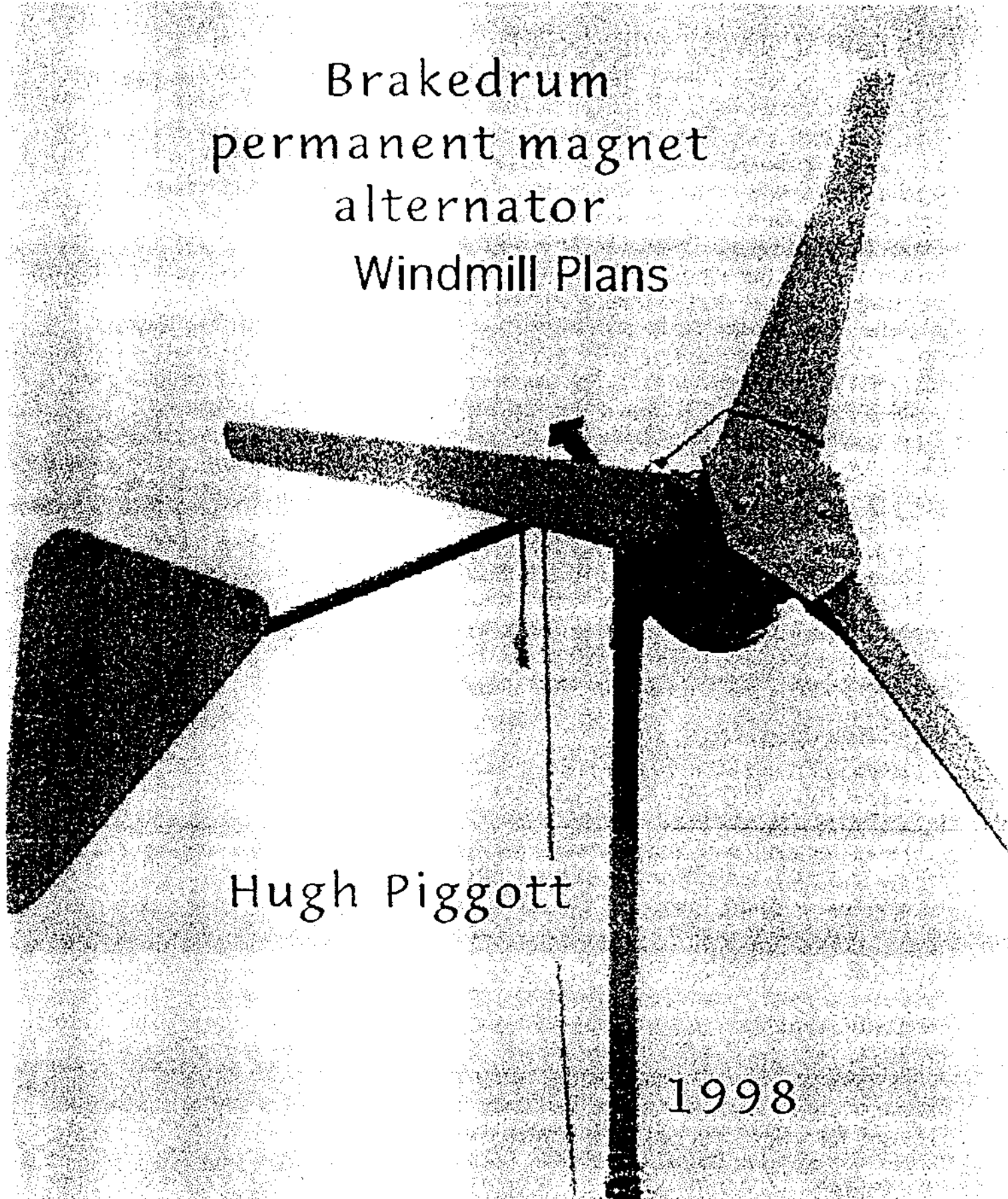
The generator is the heart of the wind turbine, and the hardest part to get right. Given a good generator, you are more than half way there. You can make blades according to the details in previous chapters. You will also need good controls, as described in the next two chapters, to get the best from your generator.

Brakedrum PM-Alternator Windmill Plans. UK 1998  
Hugh Piggott 1998.

Brakedrum  
permanent magnet  
alternator  
Windmill Plans

Hugh Piggott

1998



# Brakedrum Windmill Plans

First devised in 1993, revised October 1999

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## PREFACE TO THE YEAR 2000 EDITION

This new edition of *Brakedrum Windmill Plans* is completely reformatted and contains many minor corrections as well as some significant new information.

For the first time since its initial release in 1993, this edition has been completely re-typeset from scratch. The previous editions were looking rather worn; they were maintained using “cut and paste” of the old fashioned variety that literally used scissors and glue! All of the diagrams have been redone, some improved significantly from the largely hand drawn figures in the previous editions.

The formatting also features a consistent method of giving measurements in both metric and North American units. Metric units always appear first, then equivalent North American units are given in square brackets following. In some cases British terminology that is unfamiliar to North American readers is also “translated” using square brackets as well.

Numerous minor corrections and clarifications have been made, based on questions asked by readers and found during proof reading. No doubt these will be of great benefit to people building these plans.

New information has been added regarding modifications for using the Ford 3/4 ton pickup truck, a common truck in North America. This information was furnished to me by Mr. Bob Budd, who has been teaching workshops on how to build wind turbines based on this design for several years.

In addition, a new section gives a mathematical model that can be easily programmed into any spreadsheet application. This model allows the ambitious windmill builder to modify design parameters of the alternator to suit individual needs. For example, one can determine the likely effect of changing the number of magnets and coils or turns of wire per coil in the alternator in order to obtain a desired output at a given speed.

### A NOTE ON MEASUREMENTS AND CONVERSIONS

In some cases, North American conversions are rounded to the nearest commonly available size that will work properly. For example, M10 threaded rod is 10mm in diameter, but the near-equivalent 3/8<sup>th</sup> inch threaded rod is used as the equivalent even though technically 3/8<sup>th</sup> inches is only 9.6mm. In other cases where imprecise measurements are being described the discrepancy may be even greater. For example, when describing shaving off wood for a blade, I may say ‘shave off about 1mm [1/16”]’. Even though 1/16<sup>th</sup> inch is quite a bit more than 1mm, it is still used because it’s a commonly used measurement meaning “a little bit”.

The one case where North American units are used directly in the text is when specifying pipe. This is because water pipe is commonly specified via its “nominal bore” size which is given in imperial units. For example, a pipe might be specified as “1.5 inch nominal bore”. The outer dimension for such a pipe would be 48mm [nearly 2”]. We will specify both the nominal bore size as well as giving inner and outer dimensions in both metric and North American units.

### ACKNOWLEDGEMENTS

Thanks to Elliot Bayly of World Power Technologies, and Gordon Proven of Proven Wind Turbines, for inspiration. Steve Wade of Wind and Sun Ltd. (UK), and Michael Eavis of Glastonbury Festival for motivation to produce the first machine. Robert Budd of [www.windmill.on.ca](http://www.windmill.on.ca) for building a North American version. Steve Pendergrast of PicoTurbine.com for tireless diligence retyping the whole thing, and helping to clarify it.

## FOREWORD, BY PAUL GIPE

Hugh Piggott's plans for turning a used brakedrum into a windmill is a welcome addition to the literature on small wind turbines. *Brakedrum Windmill Plans* is especially valuable because plans for building your own wind turbine have not kept pace with the technology. Most plans date from the 1970s—or even earlier.

Better yet, the plans in this booklet are for a wind turbine that really works from someone who lives with and depends on wind energy. The brakedrum windmill is a proven design that Hugh has operated at a remote, windswept headland in northwest Scotland since 1993. His site on the Scoraig Peninsula is so windy in fact that several commercial wind turbines failed within a few years (some, unfortunately, much sooner). Hugh's prototype of the brakedrum windmill in these plans has operated so reliably that he substantially increased its output within a few years after installation. And it continues to run to this day.

The beauty of these plans can be found in Hugh's use of conveniently handy scrap yard parts. The design is based on rear brake drums used by Ford trucks widely available in both Britain (the transit van) and North America (the F250 and F350).

Another plus is Hugh's elimination of slip rings and yaw bearings. Slip rings often bedevil the design of commercial wind turbines as well as home built machines. They're not necessary and seldom found on many wind turbines built in Europe. Hugh wisely avoided them, instead substituting a simple pendant cable. This greatly simplifies this design as does Hugh's use of pipe-on-pipe for a simple and hardy yaw system that allows the turbine to respond to changes in wind direction.

Hugh's brakedrum windmill also incorporates the durable "inside out" alternator design found in the popular—and successful—small wind turbines built by Bergey Windpower and World Power Technologies. With this alternator configuration there's no need to build a complicated hub that attaches the blades awkwardly to a small diameter shaft as in some other designs. Instead a simple plywood sandwich holds the blades tightly to the rotor and this assembly is mounted directly to the generator housing: the brake drum. In wind turbines it doesn't get more straightforward than this.

And like all reliable commercial wind turbines today these plans use "self-furling" to protect the product of your labor in high winds. Hugh's an expert on this technique to limit the speed of the wind turbine's rotor and the simple design found in these plans would be helpful to not a few commercial wind turbine companies who haven't quite mastered the art.

*Brakedrum Windmill Plans* includes detailed instructions for building the entire wind turbine, from carving your own blades for a 2.1 meter [7 foot] diameter rotor to building your own permanent-magnet, direct-drive alternator capable of generating real power. By following these plans you will construct a genuine wind turbine—not just a toy—that can reliably churn out 300 to 400 watts.

*Brakedrum Windmill Plans* is a great companion to Hugh's *Windpower Workshop*. Both are a valuable addition to any windmillers' library.

Paul Gipe  
Tehachapi, 1999



## MATERIALS YOU WILL NEED

Quantity	Item Description/Size	Notes
1	The rear hub from a Ford Transit double wheel van or Ford 3/4 ton truck.	Similar hubs may work, see section DISMANTLING THE BACK AXLE.
20	Block magnets, 64 x 32 x 20mm [2.5" x 1.25" x 0.75"]	See section SUPPLIERS.
1	Laminated core from a 5 horsepower electric motor, 203mm [8.0"] in diameter.	This is the part made from a stack of thin sheets of steel.
800g [1.75 pounds]	Enamel coated copper magnet wire, 0.75mm [20 AWG] thickness.	See section SUPPLIERS.
About 500g [1 pound]	Epoxy or similar resin.	See section SUPPLIERS.
Several sheets	Glass fibre surfacing tissue, or thin fabric.	
2	Single phase bridge rectifiers, rated at least 30 amps and PIV of at least 100 volts.	See section SUPPLIERS.
1	Piece of aluminum scrap, approximately 200 x 200mm [8" x 8"] to be used as a heat sink	for the rectifiers. Any shape will do. An old saucepan may work nicely.
1	Mild steel, flat 90 x 90 x 10mm [4" x 4" x 3/8"]	Used for mounting.
5	Mild steel, flat 125 x 25 x 6mm [5" x 5" x 1/4"]	For stator mounting lugs and horizontals.
1	Steel tube 6000 x 48mm overall x 4mm thick [20' x 2" black pipe or similar]	Pole for mounting.
1	Steel tube 250 x 60 mm overall x 4 mm thick [10" x 2.5"]	Used as a bearing.
1	Steel tube 150 x 43 mm overall x 4 mm thick [6" x 1.75"]	Tail bearing.
1	Steel tube 1,000 x 34 overall x 4mm thick [3' x 1.5"]	For tail.
1	Threaded rod plus nuts, 500 mm x 10mm diameter [20" long x 3/8" diameter]	
40	Wood screws, 50mm [2"] long	
3	Wood 1,000 x 100 x 50 mm [two by four, 40" long]	Must be knot-free, for blades. See section MAKING THE PROPELLER.
3	Wood 750 x 100 x 50 mm [two by four, 30" long]	Must be knot-free, for blades. See section MAKING THE PROPELLER.
2	Plywood, 300mm diameter disc by 12mm thick [1' diameter disc by 1/2" thick]	Marine or pressure treated plywood is required.
About 1/2 liter [1 pint]	Primer and gloss paint for wood parts.	
About 1/2 liter [1 pint]	Hammerite [Rust-oleum] or similar paint for steel parts.	

## TOOLS YOU WILL NEED

TOOL	Comments/Notes
Socket spanners [wrenches], hammer, chisel, screw driver, pliers	
Wire brush, rags, petrol [gasoline]	
To clean auto parts.	
Hacksaw with good quality, new, blades	Sandvik blades recommended.
Angle grinder, electric drill and sharp bits	Cobalt bits recommended.
Pieces of 1mm [1/16"] aluminum sheet.	For shims between magnets during assembly. Thickness is approximate.
Scraps of plywood	For coil-former and cheek pieces. See section COIL WINDING MACHINE.
Former for clamping coils, made from 75 x 50mm [3" x 2"] timber.	See section HOW I DID IT.
G clamps [C clamps]	
Knife, soldering iron, multicore solder, tape	
Electric welder and steel welding rods, size 2.5 or 3 mm	
Wood working tools: saw, plane, spokeshave	To carve blades.

## WHY DO IT?

I have been making windmills from scrap materials for twenty years. It cuts the cost and I like recycling. The biggest headache has always been to find a suitable generator. A generator for a windmill has to work at low speed, be efficient (not wasteful of power), and also be reliable and affordable. A tough spec.

Vehicle dynamos [DC generators] and alternators were the obvious first choice, but they need rather high speed (RPM) and are inefficient. I learned to rewind Lucas alternators, so they would work at low RPM, but the efficiency went from bad to worse, so most of the energy caught from the wind was wasted heating up the alternator.

The best bet turned out to be dynamos from buses or jeeps. A low speed 24 volt dynamo can be simply converted to a very low speed 12 volt dynamo, and these heavy old machines are rugged, efficient, and cheap. I have described how to make them into windmills in my booklet "Scrapyard Windpower Realities", first published in 1982, updated in 1992, but now out of print.

There are many successful windmills in operation based on these dynamos, but I have become painfully aware of the shortcomings. The worst thing is the performance in light winds. Here is the reason why:

All generators require magnetism: they work by dragging coils of wire through a magnetic field. Vehicle dynamos and alternators use electromagnets, and these need about 40 watts of power AT ALL TIMES. So the first 40 watts of power you generate is used up energising the field coils, and only when the wind is stronger do you see an actual "profit" in terms of charging the battery.

Old dynamos are also harder and harder to obtain in good condition, and there are maintenance problems with the brushes.

The best type of generator for a small wind turbine is a purpose-built permanent magnet alternator (PMA). This requires no field coils to energise, and has no brushes to cause problems. There are scrap permanent magnet machines which can be useful, such as computer tape drive motors, washing machine motors, servos, etc., but I have found no reliable source. (See Suppliers at the end of the booklet for some sources.)

Buying permanent magnet machinery new is expensive, and I prefer to recycle, so I started making alternators built on wheel bearings. My first attempt is detailed in "Scrapyard Windpower". It was a rather laborious, welded fabrication of steel discs. Magnets glued on the faces of the steel discs (see figure 1) rotated past coils set in a stationary disc sandwiched between, as in the design used by Marlec for their Rutland wind turbines. It worked very reliably, but I felt that it had been too much hassle to justify building another.

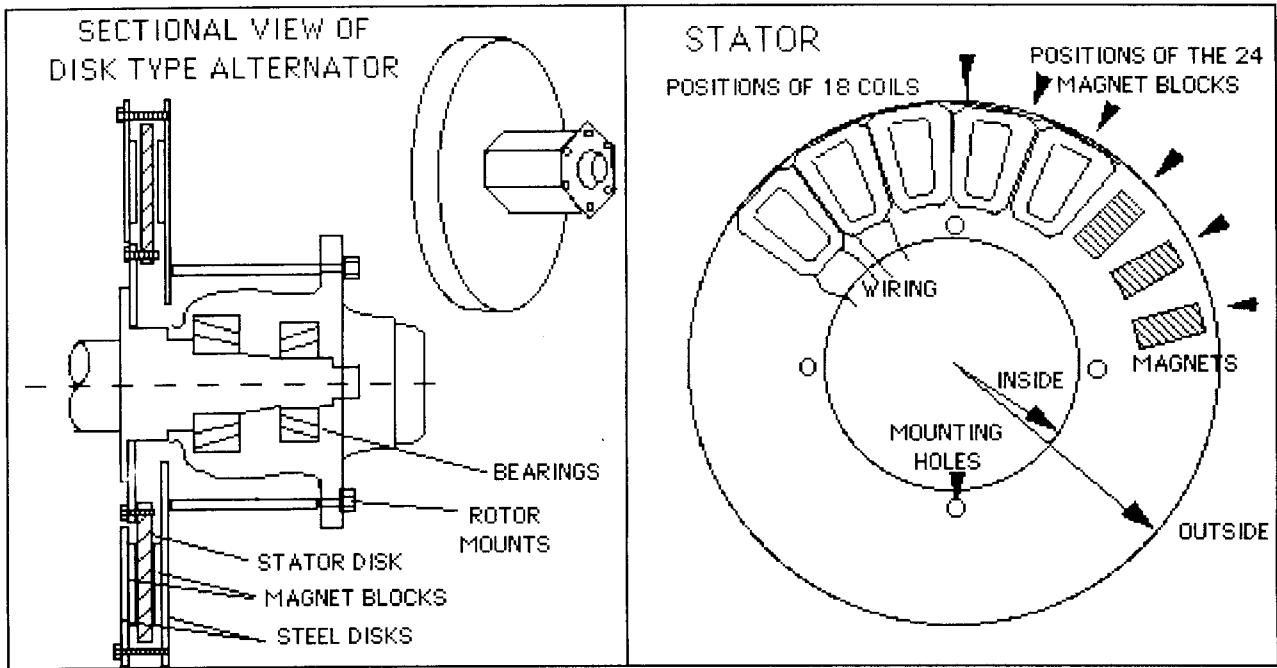


Figure 1

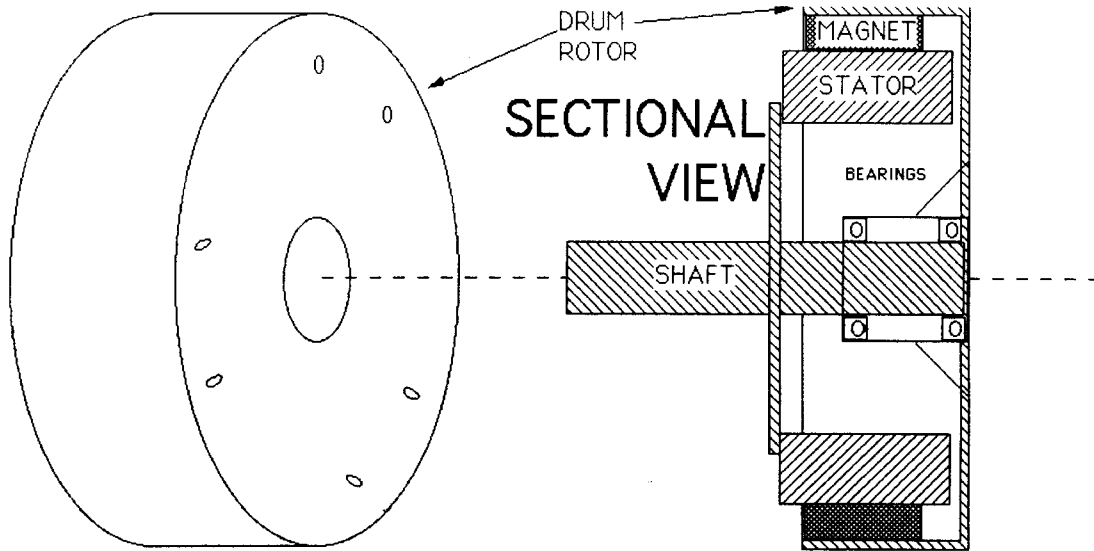
But over the years, quite a few people have built these, using the plans in 'Scrapyard' and I hope to produce a new set of plans for an axial design some day.

Small American wind turbines such as the Whisper and Bergey machines use a different geometry for their PMA. The magnets are glued to the inner surface of a cylinder (steel tube) which rotates. The coils which produce the output are wound on a stationary core of laminated iron material, with slots in its outer surface for the coils to fit into (see figure 2). The stationary part with the coils is called the stator. It seemed to me that a much simpler wheel-hub PMA could be built using a brake drum rather than steel discs, and following this American style. Long wheel base Ford Transit vans and 3/4 ton trucks have big brake drums on the back axle, and excellent bearings.

## HOW I DID IT

Finding suitable magnets was not a problem. Hawnt Electronics in Birmingham gave the best quote, although I could have got smaller quantities from Magnet Applications at twice the unit price. Nowadays I would recommend CER-MAG in the U.K. (but see Suppliers at the end for other international sources). The internal diameter of the brake drum is 254 mm [10"]. The length is 64 mm [2.5"]. I chose magnet blocks 64 mm x 32 mm with thickness 20 mm [2.5" x 1.25" with thickness 0.8"]. The magnets are magnetized through the thickness, with poles on the large faces. Twenty magnets can be fitted around the inner face of the drum, bringing the internal bore down to about 212 mm [8.35"].

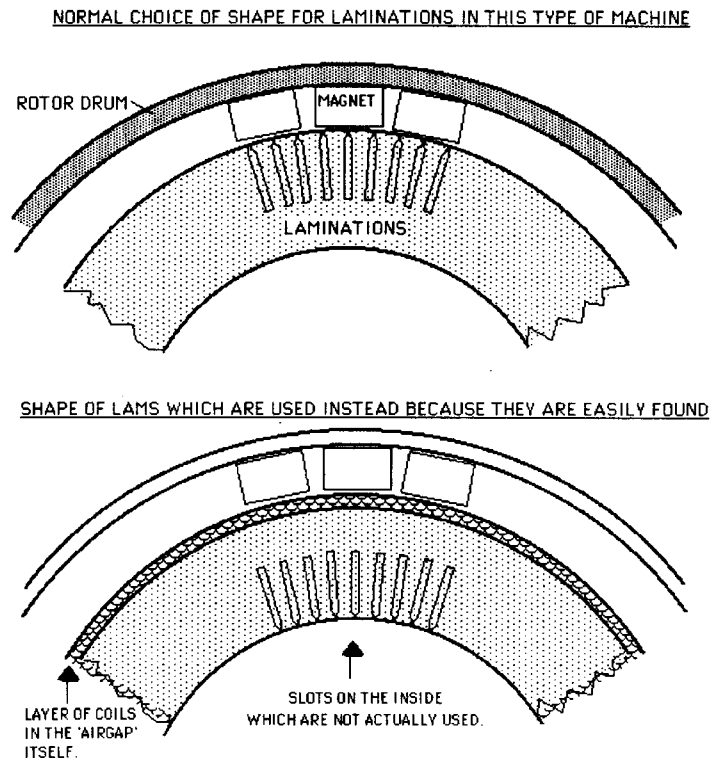
The big problem was finding laminate material for the core of the stator, to carry the coils. The core has to be made from thin laminates of soft iron stacked into a solid block. You can see them in transformer cores, or dynamo armatures. If you use solid iron, the changing magnetic fields would set up wasteful eddy currents in the iron, but the lacquer between the laminates prevents this. I wanted a core that fitted close up to the magnets, with only a small air gap, and slots to carry the coils, as in the American design. A small air gap allows the maximum magnetic field strength. But the diameter of the laminated material I needed was much bigger than standard sizes in scrap dynamos, and to have it purpose made would have added over a hundred pounds [about US \$160] to the cost of each alternator.



**AMERICAN STYLE PMA BASED ON A ROTATING CYLINDER**

**Figure 2**

For a while I almost abandoned the whole idea. I could see no way to make the stator at low cost. Then Gordon Proven of Proven Wind Turbines encouraged me to try a different tack.

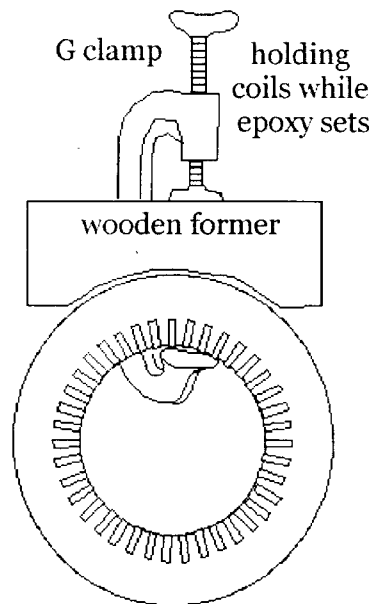


**Figure 3**

The way I did it in the end was using laminates from a very ordinary big 3 phase, 5 horse power electric motor. The laminates are the “wrong way out”, with slots on the inner bore, and an almost smooth outer surface, diameter 203mm [8”]. Rather than placing the coils in the slots, I glued them on the outer face of the laminated core, in the 4.5mm [3/16”] gap between core and magnet faces. This gap is a rather large one for the magnetic field, and the field is weakened. Much of it also “leaks” straight from one magnet to its neighbor, to avoid jumping the gap. But the laminates were cheap (from a scrap motor). and the resulting alternator does work.

In fact the alternator was quite a success. For its weight, it is not as efficient as an alternator with the right sort of laminations and a smaller air gap, but it does have some advantages. For one thing, this sort of lamination is much easier to find. Also, the alternator starts up more easily in light winds than it would if the air gap were narrow. Machines with small air gaps have much higher magnetic drag, which holds the windmill back from starting up in light winds.

I glued the coils to the outside of the laminations with epoxy resin. I need a very thin layer of coils, so I used a G-clamp [C-clamp] to press them down onto the laminations. The wooden former shown is easily made by carving a hollow in the wood with an internal radius of 104mm [4.1”].



**Figure 4**

From past experience, the commonest problem with permanent magnet alternators is that the magnets start to rub the stator, so I allowed plenty of clearance, around 2mm [1/16”]. So only just over half of the air gap is filled with coils. You could get more power by making the coils thicker, but at the cost of lower reliability. I have never had a problem with the magnets hitting this stator, even when the bearings were quite slack.

The resulting windmill has been one of the best I ever built, and I immediately set to work and prepared plans so others could do the same. I actually built it for the low wind speeds of the Glastonbury Festival site in 1993, where it proved to be as good as the Marlec fm 1800 wind turbine in low winds.

After the Festival, I put it up on a hilltop site near my home, powering a neighbor’s house. Here it had the chance to prove itself as a high wind speed survivor. The furling tail system protects it against over speed. At first we set the tail up to limit the output to 300 watts, but after a couple of trouble free years I added more weight to it, so my neighbor gets 500 watts (well actually rather less, as nearly half is lost in the cable to the house).

Here is some data for the alternator (connected 'star' ['Y'] for 24 volts):

Internal resistance:	4 ohms
Cut-in RPM:	200 RPM
320 RPM Output:	3 amps @ 30 volts = 90 watts
600 RPM Output:	9 amps @ 42 volts = 378 watts

See section PERFORMANCE at the end of the booklet for more details.

The technically minded reader will have suspected that there will be quite some heat generated in the windings when the alternator is putting out 9 amps. In fact the loss will be about 360 watts, so the alternator is only about 50% efficient at this point.

This is not wonderful efficiency, but the important thing is to be efficient in light winds, when power is scarce (and this alternator certainly is that). In higher winds, there is often power to spare, and also plenty of cooling to prevent the windings from burning out!

To milk the best output from the alternator, you should ideally load it with only a small current and use higher voltage in higher winds. The Marlec 1800 wind turbine has a special controller which does this (part of the reason why this windmill is so expensive). One solution would be to use star ['Y'] connection in low winds, and change to delta in high winds. Resistive loads (heaters, lights) will work with better efficiency from the alternator than battery loads because the voltage will vary.

But this is not the crucial issue, and in fact you will have a very good windmill even if you ignore the above considerations.

## GENERAL NOTES

I should be very surprised if anyone follows these plans exactly, although this course of action would certainly give good results. In practice, it is most likely that:

- The parts which are obtained will vary slightly in size and shape from those suggested,
- Individuals will have their own ideas for simpler or better ways to suit their own skills and resources.

For example, I have made much use of electric welding, but for some it will be easier to bolt pieces of steel together and so avoid welding.

## BLADES

I prefer to make blades from wood, but they can also be made from glass fibre and resin, or even from metal. Metal blades will tend to suffer from fatigue, and this danger should be recognised. Gordon Proven has a very interesting technique for making blades from polypropylene sheets, but I am not qualified to describe this properly.

I have used a 3-bladed propeller for this windmill, because they run more smoothly than 2 bladers and faster than 4 or more blades would. You could use a larger, 2-bladed propeller instead. The pitch of the blades would need to be finer (flatter) in this case. You could increase the diameter from 2.1m [7'] to 2.7m [9'] using a higher tip speed ratio (see my book "Windpower Workshop").

## SPEEDING

The alternator can be run through a belt drive to obtain higher speed, and so more power, from the same machine, if this is considered worthwhile. Belt drive or other gearing is not only more work to make, but will introduce friction, which may make starting difficult in light winds.

The windmill described here cuts in at a very low wind speed, for battery charging applications, where a reliable, slow charge is most desirable. It is at its most efficient when it cuts in, but is fairly inefficient by the time it delivers 300 watts, directly driven by a propeller, and wired as described here, for low speed cut-in.

Higher outputs could be obtained with good efficiency by running it at higher speed, and either rewiring the coils in parallel groups, or operating at a higher voltage. There is a trade-off between speed and power which you can use: more speed allows the alternator to handle more power, but also brings more problems with noise, wear, fatigue and vibration. A better approach to getting more power would be to use a larger brakedrum or fabricate something with larger diameter. It's all up to you, but I am available to give advice on the phone or in answer to letter, email, or FAX inquiries.

## GETTING PARTS

There is a list of suppliers included (see section SUPPLIERS), to help you find the parts you need. If you find cheaper sources (I am sure they exist) perhaps you would let me know, and I shall pass the information on to others. If there is anything you really cannot get hold of (laminations may be a problem) then I may be able to help out. The Ford 3/4 ton truck brakedrum can be used with different dimensions for magnets and laminations. See section MODIFICATIONS FOR FORD 3/4 TON TRUCK.

## DISMANTLING THE BACK AXLE

What you need is a big brake drum from a Ford transit long wheel base van or similar. There is a Bedford with the same size brake drum, and there will probably be other makes. Front wheel hubs usually have disc brakes these days and so are not suitable for this design of alternator. You need "fully floating" bearings on the hub, i.e. the hub must be supported by two bearing races, even after the half shaft is removed. In the case of the transit, there are two tapered-roller bearings.

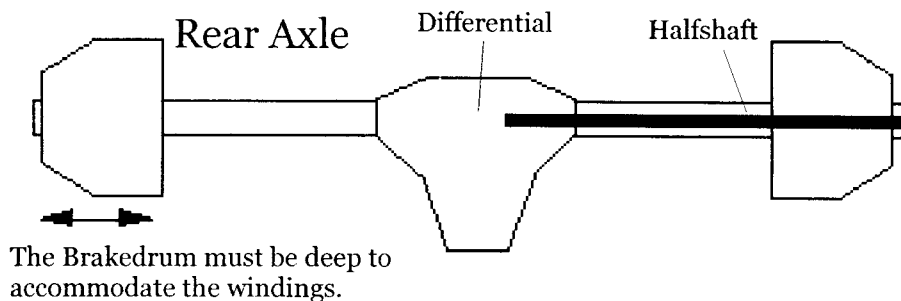


Figure 5

The first step is to remove the half shaft, which carries the drive from the gearbox out to the hub. This is done by removing the six small nuts near the centre of the hub, and simply pulling the circular flange which is actually the end of the shaft.

Next you need to remove the outer bearing race, which is retained by two large thin nuts. The outer nut (which has been revealed by removing the half shaft) is locked by a tab bent outward from a washer behind the nut. Knock this tab backwards with a screwdriver or punch, driven by a hammer, so that the nut can turn. The nut is undone (anticlockwise) by placing a chisel against a corner, and driving it around with a hammer. Lift out the washer, and remove the second nut in the same way. Now the bearing race is free to come out, but it may not wish to. The easiest way I know to persuade it is to refit the half shaft back-to-front (sticking out, not in) and tighten two or three nuts. Pulling and waggling the shaft should release the bearing. When it comes out, keep it clean. It will need to be washed in petrol and repacked with grease (in moderation) before refitting.

Section through hub showing tapered roller bearings

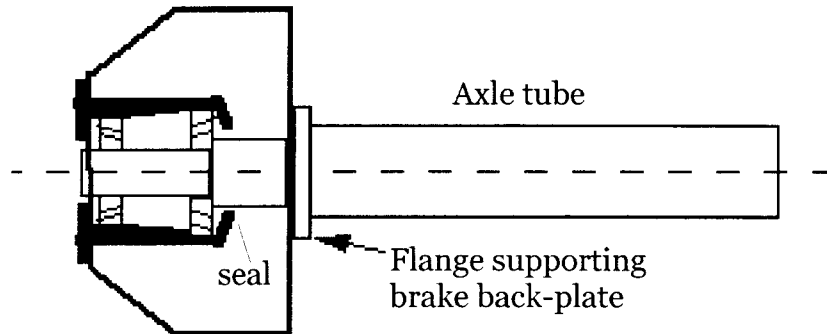


Figure 6

Now the whole hub and brakedrum can be removed from the axle, but it may still be retained by the brake shoes and the seals. Ensure that the handbrake cable is released. Keep waggling and pulling the half shaft. Some hammer blows may also be needed to release the brakes.

The brake parts can be removed as a whole by undoing the four nuts which retain the brake back plate to the axle. These may need penetrating oil, or even some heating, as they will probably be corroded. A piece of pipe on the end of the socket wrench will give you more leverage (and you may also bend your wrench!). Again, some hammer blows may help to crack the rust and let in the easing oil. Having removed the brake parts, knock out the screws which held them with a hammer.

The seal on the inner end of the hub can be removed from the hub using a hammer and screwdriver to prise it out. Maybe there is a more sophisticated method but this does work ok. Take care not to damage the inner bearing race. The purpose of this seal was to keep the oil (which comes from the gearbox to lubricate the bearings) out of the brakes. The seal causes a lot of friction, and you do not need it.

You can saw off the axle tube wherever you want, using a sharp hacksaw blade, in a few minutes. It is not that hard to do! Take it slowly, use the full length of the blade, and pay attention to keeping it square. I cut it off quite close to the brake back plate, but if you plan to bolt the windmill together rather than weld it you can leave the flat bracket (which normally meets the leaf springs) attached to the end you are using. For a small fee, the scrap merchant will probably cut it off with oxy-acetylene at the point of sale, and this would save you from transporting the incredibly heavy axle home at all.

## DISMANTLING THE ELECTRIC MOTOR

Induction motors are the commonest motor in the world and you can easily find one in a scrapyards or similar location. I have only done two of these, but in spite of some differences in age and general appearance, they had exactly the same kind of laminates in the core, so I think it is commonly used. You need a big (3 phase probably) motor, and the body is usually of cast iron/white metal, with fins. The quickest way to see the laminates is to remove the cover on the terminal box where the wires enter, and perhaps the whole box. You can then estimate the radius from the axis of the shaft to the outer face of the core. This radius should be about 102mm [4"].

Start by taking off the cover from the fan at the back, and remove the fan from the shaft. It may be held in place by a roll pin which can be driven out with a punch or a nail with the tip sawn off. Then remove the screws holding on both the ends. The ends should come away, bringing the rotor from inside, and leaving only the motor body. Now you can see the copper windings, fitted to the core within the body. You need to remove the outer frame from the core, or vice versa. The core is retained in the outer frame by a locking pin which is not easy to locate, so the simplest method I know is to destroy the outer frame (the bit with the cooling ribs on it). If you have an angle grinder, cut the frame from



one end to the other, at the thinnest place, which is where the wiring comes through. Having split the frame, it may spring open or it may need to be levered open until it releases the core, or snaps. The casting is not strong.

To remove the copper windings from the core, first shear off the ends of the coils with a sharp wood chisel, working tangentially (around the circle rather than inwards, or the coils will move into the gap and jam up). When the ends are neatly cut off, you can punch out the copper wires from the slots with a piece of 6mm [1/4"] rod, leaving the laminates ready for use.

Exploded view of motor

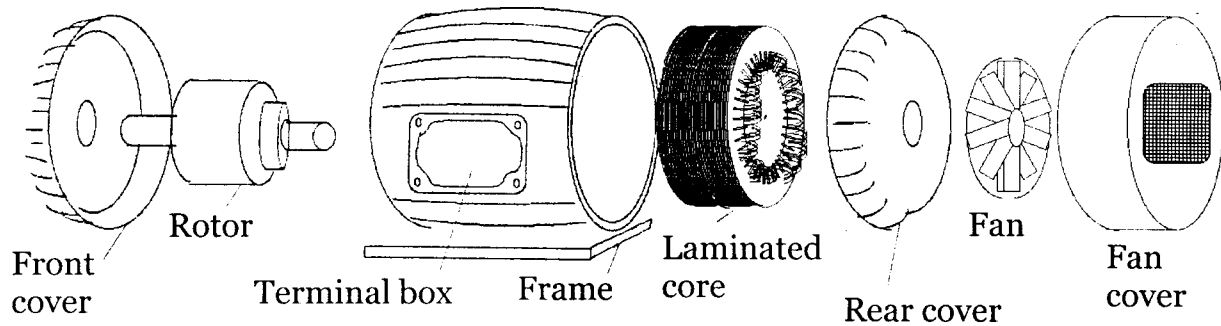


Figure 7

## FITTING THE MAGNETS TO THE BRAKE DRUM

The hub and brakedrum will need to be cleaned up thoroughly, to remove all grease and grime, especially from the inner face where the shoes rubbed and the magnets are to be fitted. A rotary wire brush in a drill chuck is good. Beware of asbestos dust from the brakes: this should not be inhaled.

Place the blocks around the inner face of the drum evenly and note the space between blocks. It should be around 1mm [about 1/16" to 1/32"]. You will need shims of some non-magnetic material to place between the blocks as you lay them or they will slip together (they are attracted). Aluminum sheet is ideal, it can easily be obtained as aluminum flashing material at any hardware store.

If you want to shape the magnets, this can be done with an angle grinder, using a stone-cutting disc. The magnets are flat and the drum curved, so they do not fit perfectly, but shaping is not essential.

The magnets must be clean (no magnetic debris attached). Sticky tape is good at removing rubbish, as is plasticine.

The magnets must be fitted alternating first with north inside, then with south inside, and north against the drum. (Of course, it does not matter which is north as such). The blocks will naturally stack with north against south. As you take them off the stack, TURN EVERY SECOND ONE OVER. As you place it on the drum it should be attracted sideways to its neighbor and should not be repelled. When the inner face of the drum is coated with resin the magnets slip around fairly easily and they will slide together. Hence the need for the shims. You actually only need about 4 shims because after a while you can start robbing shims which you used earlier and re-use them. Once there are magnets on each side of any given magnet, it will no longer tend to shift. When you get to the end you can adjust the spacing so it is as even as you can get it. Performance will not be adversely affected by any error which you can easily see.

The epoxy resin I use is intended for boat building in wood (SP Systems 106). You mix it at the rate of five of resin to one of hardener, and it takes plenty of time to set (maybe an hour you can safely work in). Avoid mixing a large amount in a pot, or it may heat up and set too fast (going "exothermal"). It helps to add powder to the mix before applying it, to thicken it, otherwise it will dribble away. "Colloidal silica" is a good powder, but again, do not inhale this. There are other thickeners which will do just as well, such as microballoons, or aluminum powder. Iron "weight-

ing powder” or “magnetite sand” could possibly be used with epoxy to make a core without laminations. But this is not relevant to the job at hand.

Clean resin from the fingers at once with a dry rag or paper. It can be removed from the skin with solvents such as meths, but this tends to carry it into the skin as well, and can cause an allergic reaction. Resin is nasty stuff, do not touch it if possible, or better yet wear impervious gloves.

## WINDING THE COILS

You will need about 800 grams [1.75 pounds] of enamel coated copper wire. The enamel prevents the wires from shorting out, and must not be damaged. I used 0.80mm [about 20 AWG] wire, because that is what I had, and it gave good results. I used 24 turns per coil. A smaller number of turns of thicker wire, or a larger number of turns of thinner wire would give more current or more voltage per coil respectively. Power output (volts x current) is not affected by the size of wire chosen, but the RPM speed at which it will charge a given battery voltage will be affected.

More power can be obtained by making the coils physically bigger (wider) and using more turns of wire. This is possible to do, since there is good clearance between the magnets and the coils. But if the magnets do touch the coils then you have problems, so I suggest you keep the coil size close to the 2.5mm [a bit under 1/8”] which I used.

See figure 8 which shows the coil winding machine and former. You need to build something like this. The tricky bit is getting the crankshaft (made of M10 [3/8”] threaded rod or similar) to drive the coil former and cheek pieces. Nuts are required on the shaft, which can be tightened against the pieces of ply. You start winding the coils by twisting the end of the wire around the retaining nut and passing it into the notch in the front cheek piece. Hold the wire in one hand, keeping a gentle tension on while you crank the machine with your other hand. The coil should be wound neatly in layers to get tight packing.

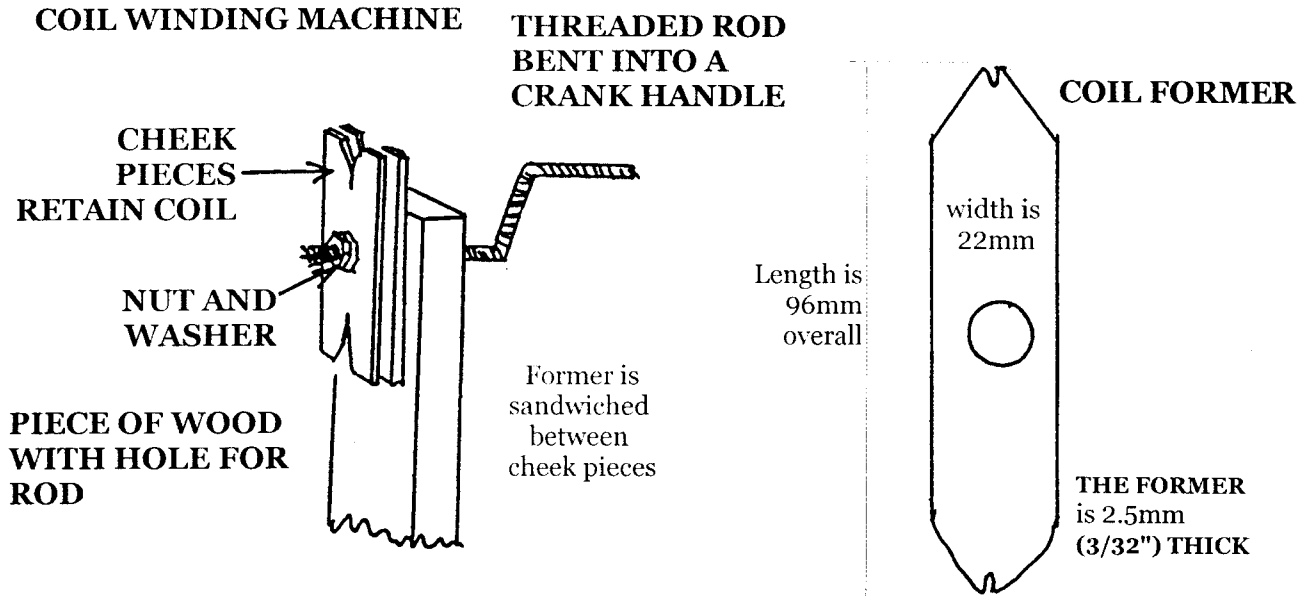
Before removing from the coil former, the coil has to be tied up. You can simply put a loop of wire around each end, but because the coil is wide and thin, it tends to be distorted this way. I suggest as follows:

Either:

- 1) Use a hot glue gun to solidify the ends of the coils, leaving enough flexibility to shape them later, or
- 2) What I did was this:
  - a) Wind 12 turns
  - b) Pass short pieces of wire inside the ends of the coil
  - c) Cross them over outside the ends of the coils
  - d) Wind the next 12 turns
  - e) Twist the ends of the short pieces together outside the coil, so that it grips the coil in a figure eight.

The core should be as thick as the magnet blocks are long, 64mm [2.5”]. Simply split off as many laminates as you need to make 64mm [2.5”] thickness, from the core which you extracted from the electric motor. The core must be coated in a thin layer of resin and surfacing tissue or something to prevent sharp edges which might damage the enamel on the wires.

When you have wound six coils, you can glue them to the core. Mark the core in five places for accurate positioning of the coils around the circumference (five equal intervals of 72 degrees, easily found by dividing the 635mm [25”] circumference into 5 equal 127mm [5”] arcs). Place the coils in two heaps of three on the core, overlapping as shown in figure 9. The ends of the coils need to be manipulated to pass each other without causing bumps which would foul the magnets.



**Figure 8**

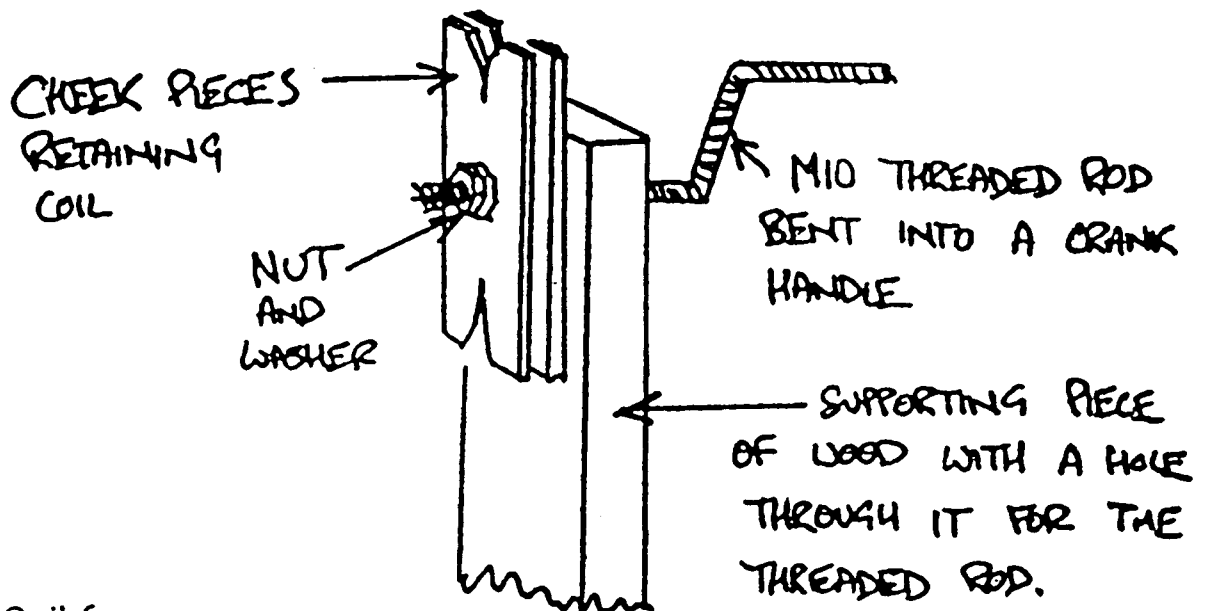
When you are happy with the shape of the coils, mix some (thickened) resin and tip it onto the coil groups. Lay on some surfacing tissue, and press down the wooden former. The inner radius of the curve on the former should be 104mm [4 1/16"]. The surface of the former needs to be greased to prevent it sticking to the job., Or maybe you could use polyethene. Anyway, as the clamps tighten the former down onto the coils, resin squirts out the ends. This should be encouraged to soak into the end windings in such a way as to set them solid. But ensure that you can still see which end of the coil is which when you come to connect them up. You need to be able to see whether the coil runs clockwise from one end to the other (see below). Now wash your hands.

## **CONNECTING UP THE COILS**

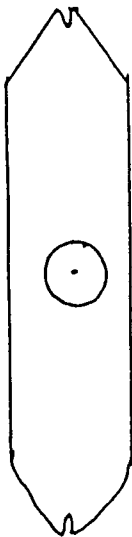
When I talk about the start and the finish of a coil, it does not matter which is which, provided you always follow the same rule. For example, looking at the coil from the outside (it is hard to look at it from the core side anyway!) the wire runs clockwise from the starting tail to the finishing tail. This rule defines the start and the finish. You can say anti-clockwise instead, provided you apply the same rule to all thirty coils.

The coils fall into three kinds according to the timing or "phase" of the AC power produced. There are ten of each kind. You will need to take every third coil, and connect them in series (finish of one to start of the next) as show in figure 9:

# COIL WINDING MACHINE

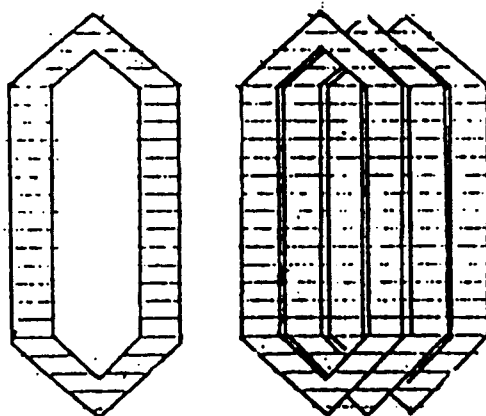
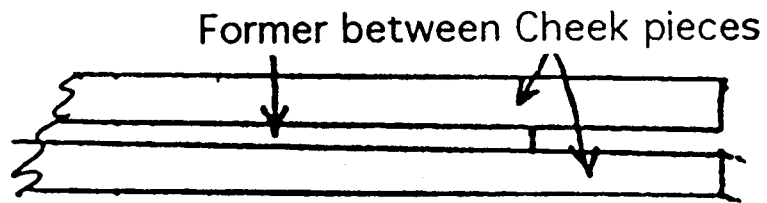


Coil former  
(actual size)



Thickness = 2.5mm

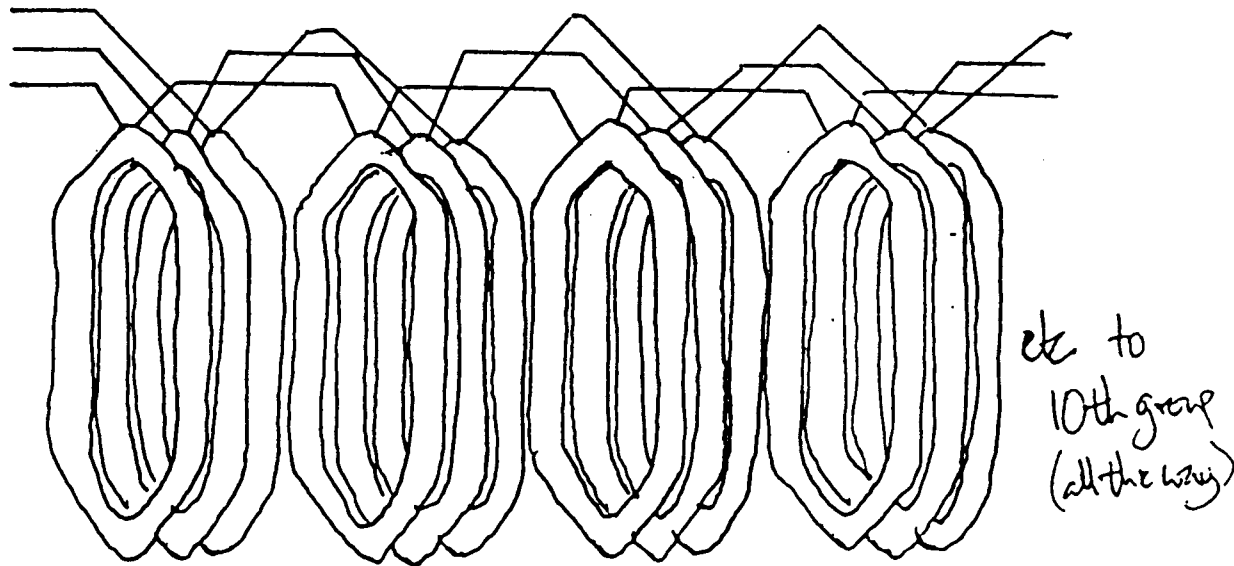
The former is attached to one cheek piece, which in turn is locked to the shaft.



The coils are overlapped in groups of 3 like this.

There are ten groups of three coils each, in all.  
 Glue them to the core in pairs. (six coils at a time).  
 This makes five gluing sessions.  
 Use a G-clamp and a wooden former as shown  
 Others have succeeded in gluing all thirty coils at once,  
 using a band around the whole thing.

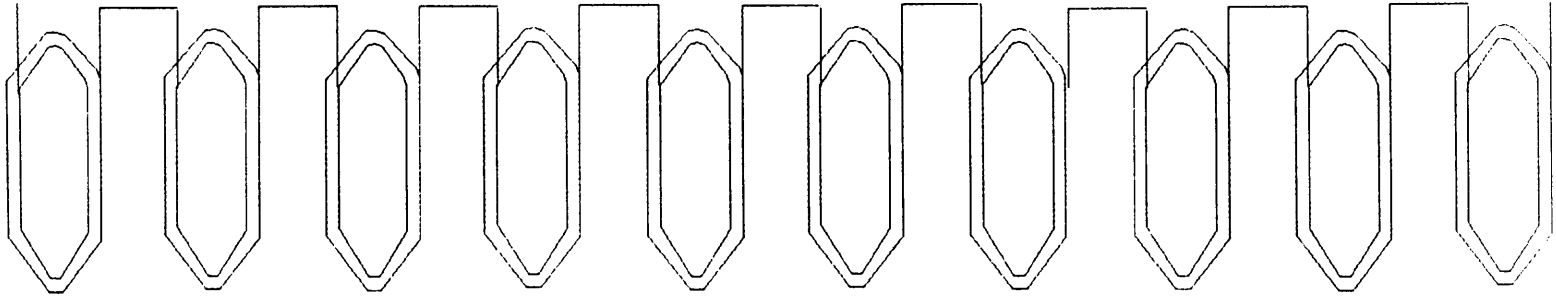
The coils fall into three kinds according to the timing or "phase" of the AC power produced. There are ten of each kind. You will need to use take every third coil, and connect them in series (finish of one to start of the next) as shown below:



The tails of the coils must be meticulously cleaned with a sharp knife to remove ALL the enamel coating, then twisted together tightly and soldered with a hot soldering iron, and resin core solder. Insulate the joins with tape (self amalgamating tape is best) or heat-shrink sleeving.

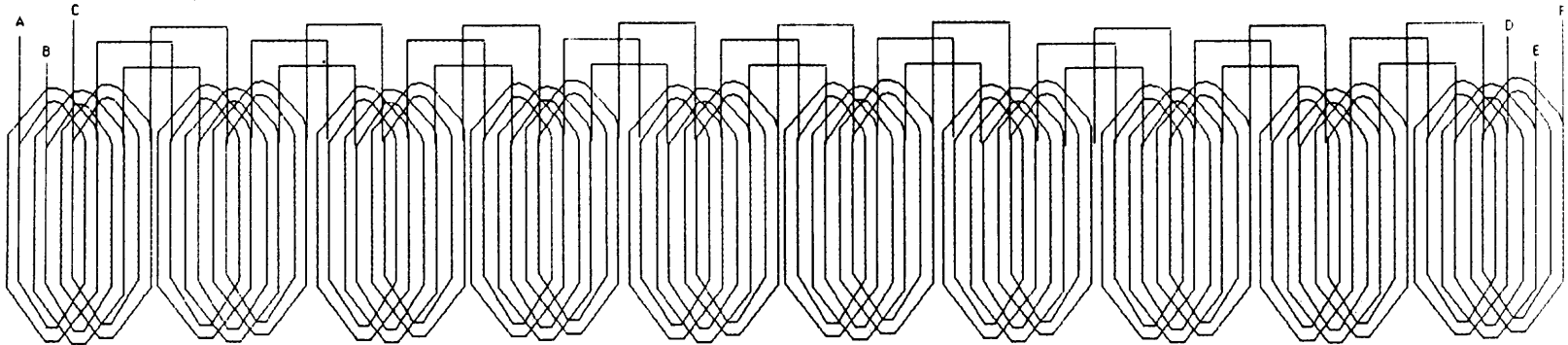
## COIL CONNECTIONS

HERE ARE ALL THE COILS IN ONE PHASE, SHOWING HOW YOU CONNECT THEM TOGETHER - FINISH OF ONE COIL GOES TO START OF NEXT COIL - IN SERIES



HERE IS HOW YOU SHOULD CONNECT THE COILS FOR ALL THREE PHASES - JUST THE SAME, BUT THE COILS THEMSELVES OVERLAP

IN THE FIRST EXAMPLE, THE COILS ARE HEAPED UP IN GROUPS OF THREE, SO YOU CAN GLUE THEM ON IN STAGES AS DESCRIBED - THE STARTS ARE LABELLED A,B,C AND THE FINISHES D,E,F

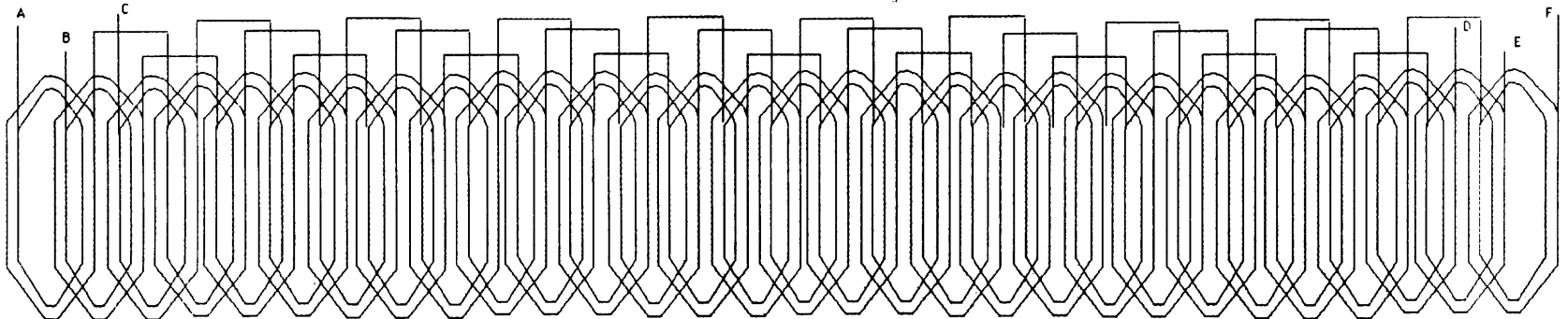


FOR DELTA CONNECTION (12 VOLTS) CONNECT A TO B, C TO D, AND E TO F.

FOR STAR CONNECTION (24 VOLTS) CONNECT B TO D AND TO F (NEUTRAL POINT).

IN BOTH CASES, CONNECT A, C AND E TO THE RECTIFIER.

IN THE SECOND EXAMPLE, THE COILS ARE ARRANGED EVENLY, AND WOULD NEED TO BE GLUED UP ALL AT ONCE (SOME PREFER TO DO IT THIS WAY)



FOR DELTA CONNECTION (12 VOLTS) CONNECT A TO F, B TO D, AND C TO E.

FOR STAR CONNECTION (24 VOLTS) CONNECT D TO E AND TO F (NEUTRAL POINT).

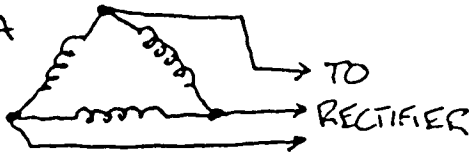
IN BOTH CASES, CONNECT A, B AND C TO THE RECTIFIER.

The tails of the coils must be meticulously cleaned with a sharp knife to remove ALL the enamel coating, then twisted together tightly and soldered with a hot soldering iron, and resin core solder. Insulate the joins with tape (self-amalgamating tape is best), heat-shrink sleeving, or “liquid electrical tape”.

You can crank the alternator around and measure the voltage from a set of coils using a multimeter. At 60 RPM (one revolution per second), a set of ten coils produces around 3.5 volts AC. This tells us that at 180 RPM it will produce 10.5 volts AC. The DC rectified voltage will be about 30 to 40 percent higher than the AC voltage depending on current draw, so the turbine would “cut in” at about 180 RPM for a 12 volt battery charging application.

Check the outputs of each group of coils: they should be the same voltages at the same speeds, or you have got some coils reversed. This will leave you with six ends: the starts and finishes of the three series groups of coils. To make a 12 volt machine, these three groups of coils should be connected in “delta” (start of one goes to finish of the next and so on), whereas a 24 volt machine can be produced by connecting them in ‘star’ [‘Y’] (one tail from each coil group goes to a neutral connection, and the free tails go to the rectifier). In figure 10, each coil group is shown as a single coil for simplicity.

DELTA  
(12V)

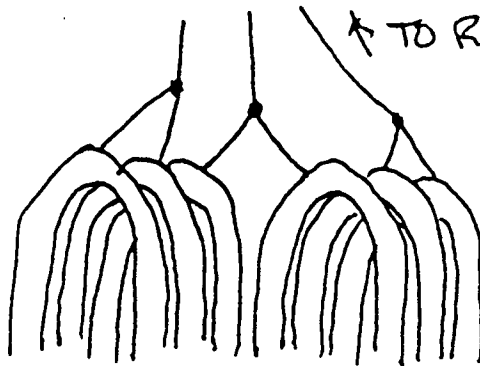


STAR  
(24V)



Just to make life more confusing, the second group of coils, which is made up of all the coils in the middle of the overlapping heaps of three, must be reversed. In other words the start of this group and the finish must be reversed. The actual wiring diagram which results from all this is shown next:

### CONNECTING THE SIX ENDS OF THE GROUPS



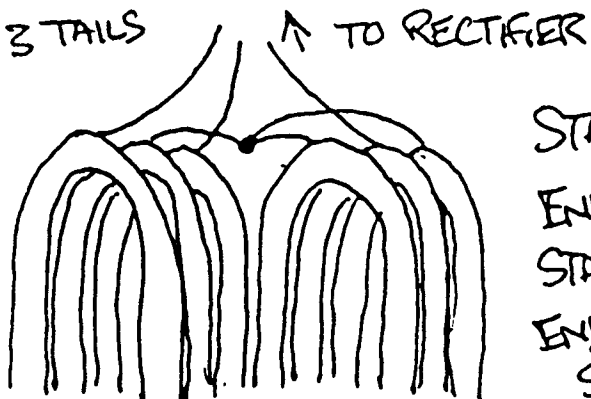
DELTA CONNECTION (12VOLT)

END OF GROUP ① TO END OF ②

END OF GROUP ③ TO START OF ①

START OF GROUP ② TO START OF ③

3 TAILS



STAR CONNECTION (24 VOLT)

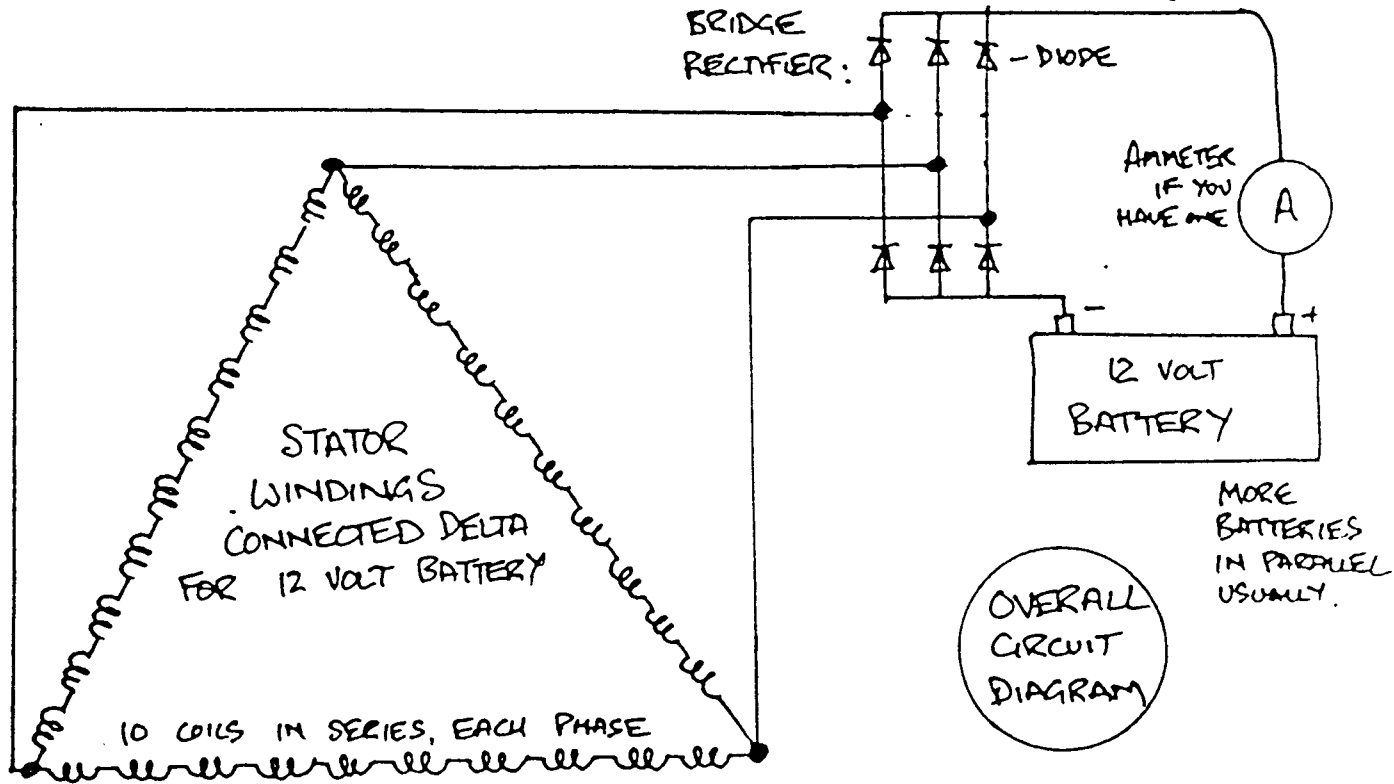
ENDS OF GROUPS ① AND ③ TO OUTPUT

START OF GROUP ② TO OUTPUT

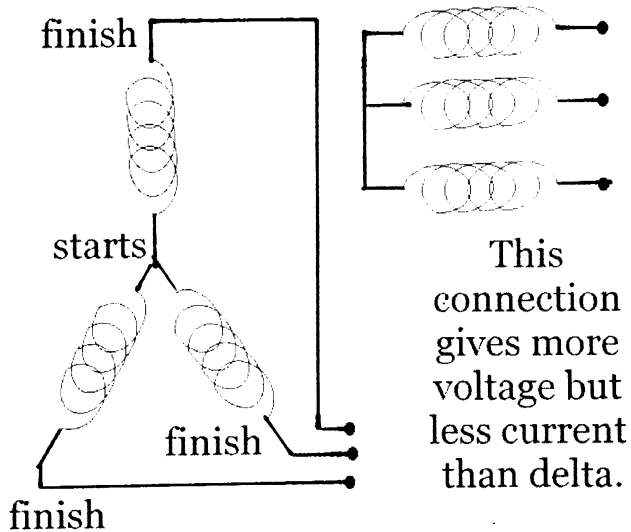
END OF GROUP ② JOINS

STARTS OF GROUPS ① AND ③



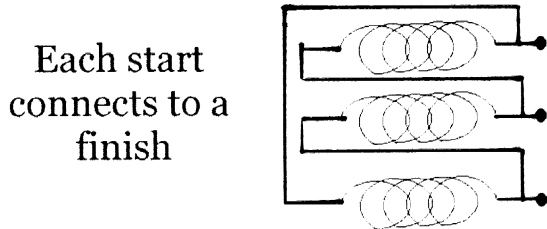


### Star connection

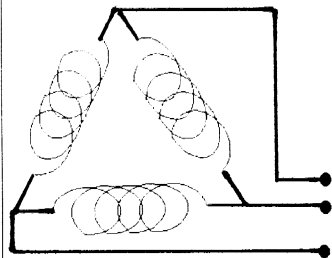


This connection gives more voltage but less current than delta.

### Delta connection



Each start connects to a finish



This connection gives less voltage but more current compared to star connection.

Figure 10

If you want to glue in the coils in heaps of 3, as I have done, rather than all 30 coils at once evenly spaced, then there is a complication. The middle coil of the heap is too close in its timing or 'phase angle' to the others in the heap. This needs to be corrected by reversing the start and finish of this middle phase. Follow the instructions for coil connection in figure 9, which uses letters for the wire tails.

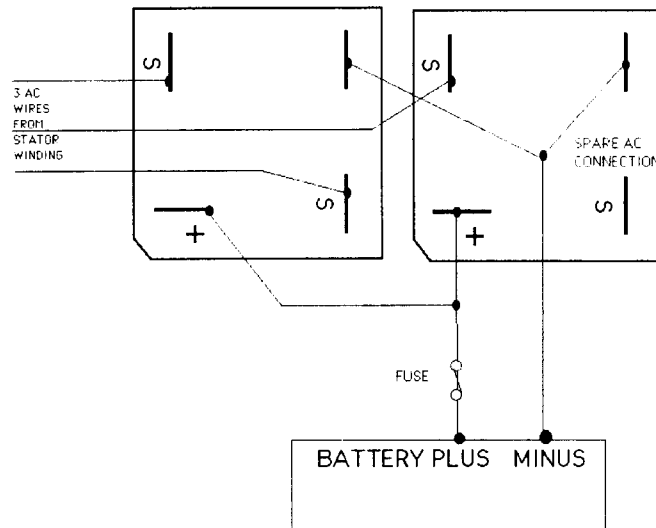
## **WIRING TO THE BATTERY**

The tails which go to the output should be flexible cable leading to the bridge rectifier, probably through some sort of connectors and a cable to the house. I find that the blade and receptacle type of crimp connectors are very handy for this sort of situation. The wiring is simply fed through the centre of the yaw bearing and goes down inside the tower, exiting near the base of the tower. I normally support the pole such that its bottom opening is clear, which allows easy checking for twisting. You could also drill a hole.

Some readers will no doubt be horrified that there are no slip rings used in this design. In my experience there are few sites where you will experience problems with a cable hanging down the middle. I have had more problems with brushes and slip rings (few enough but some) than I have with free hanging cables in the tower centre. There are some turbulent sites and some very free yawing machines where I have had problems but they are few and do not justify the hassle of fitting slip rings as standard. Slip rings have to be of very good quality or it is not worth doing them.

You can connect wiring to the rectifiers with these same crimp-on receptacle connectors (or solder them). The rectifiers are square blocks which must be bolted to a piece of aluminum to dissipate the heat they produce. There are four terminals on each. One terminal is at right angles to the other three. This is connected to a battery (+). The one diagonally opposite to it is connected to battery (-). The remaining connectors take the AC wires from the windmill. Since we have three wires (3 phases) we need two rectifier blocks, and there is one spare AC terminal: useful if damage occurs due to lightning or suchlike. It does not matter which AC wire goes to which AC terminal. See figure 11.

## CONNECTING THE BRIDGE RECTIFIERS



**Figure 11**

## MODIFICATIONS FOR FORD 3/4 TON TRUCK

The following table lists modifications to make when using a Ford 3/4 ton truck instead of a Ford van.

Item	UK Version	North American Version
Vehicle	Transit Van, long wheel base version	Ford 3/4 ton truck, E or F, 250 or 350
Internal brakedrum diameter	254mm [10"]	306mm [12"]
Number of magnets	20	16
Magnet length	64mm [2.5"]	76mm [3"]
Magnet width	32mm [1.25"]	51mm [2"]
Magnet thickness	20mm [3/4"]	25mm [1"]
Air gap diameter	212mm [8 5/16"]	251mm [9 7/8"]
Lamination diameter	204mm [8"]	245mm [9 5/8"]
Lamination stack thickness	64mm [2.5"]	76mm [3"]
Coil former leg length	76mm [3"]	76mm [3"]
Coil former overall length	96mm [3.75"]	90mm [3.5"]
Coil former width	22mm [7/8"]	33mm [1 9/32"]
Coil former thickness	2.5mm [3/32"]	2.5mm [3/32"]
Number of coils per phase	10	8
Phases	3	3
Total number of coils	30	24
Wire size	0.8mm diameter [20 AWG]	0.7mm diameter [21 AWG]
Wire turns per coil	24	36
Nominal voltage, delta	12V	21V (usable at 12V)
Nominal voltage, star ['Y']	24V	36V
Propeller diameter	2.1m [7']	2.8m [9' 2"]

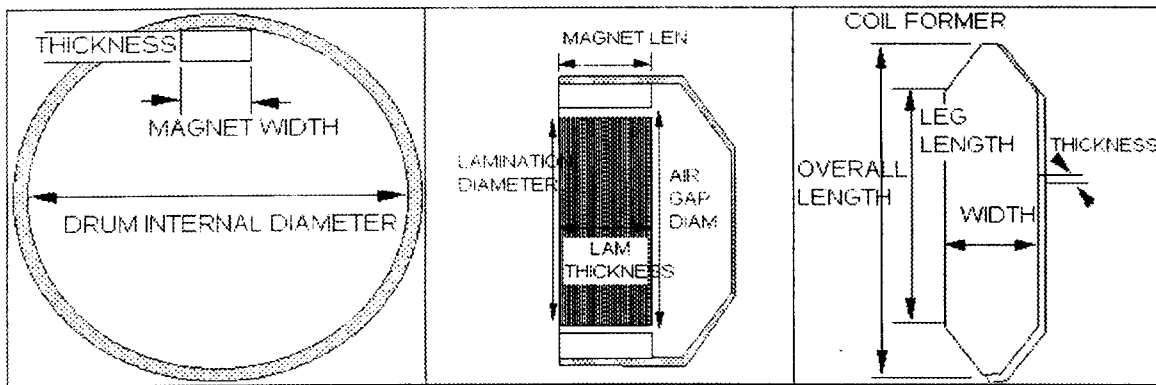


Figure 12

## MATHEMATICAL MODEL OF BRAKEDRUM ALTERNATOR

The following mathematical formulas will help those of you who wish to modify the parameters given above. It should be kept in mind that these models are only approximations of what you will find in practice. You can easily program these formulas into a spreadsheet. A downloadable spreadsheet containing these formulas is available from PicoTurbine.com (see section SUPPLIERS at the end).

### INPUT VARIABLES

These are things you need to know in advance which will affect the performance:

Description	Variable Name
Number of magnets in the rotor (must be an even number)	N
Length of each magnet, in mm	L
Width of each magnet, in mm	W
Battery voltage (system voltage)	VBAT
Turns of wire per coil	T
Speed of rotation, in RPM	RPM

### ASSUMPTIONS

1. I assume that the stator winding is 2.5mm thick, in a total gap of around 4mm.
2. The magnets need to be 20-25mm thick, and at least 32 mm wide.
3. I assume there are 3 coils for every 2 magnets, and coils are in 3 phases.
4. Coils are connected in star ['Y'] rather than delta grouping.
5. Common sense needs to prevail when playing with these numbers. For example, if magnets become too wide they will not physically fit around the brakedrum unless they are curved, etc.

### OUTPUT VARIABLES AND FORMULAS

Description	Variable and Formula
DC voltage output, open circuit, in volts	$VALT = N^2 * L * W * T * RPM / 150000000$
Internal resistance of alternator, in ohms	$R = (L+W) * N * T^2 / W / 8640$
Total current produced, in amperes	$I = (VALT - VBAT) / R$
Total power generated, in watts	$P = VBAT * I$ (watts)
Power lost in windings, in watts	$LOSS = I^2 * R$
Wire diameter, in mm	$DWIRE = 0.7 * (W / T)^{0.5}$

Notes:

- 1) You need to add your cable resistance to internal resistance  $R$  for a true picture of resistive losses. This affects the current output as well.
- 2) Your spreadsheet will give negative values of current,  $I$ , at low speeds. This should be treated as zero current. If you wish, you can use the IF operator of your spreadsheet to set to zero. For Microsoft Excel, for example, the statement would look like this assuming you have named the cells VALT,VBAT, and R:  
$$\text{IF}(\text{VALT}-\text{VBAT}<0, 0, (\text{VALT}-\text{VBAT})/R)$$

## MAKING THE PROPELLER

Whilst I am aware that many people are apprehensive about carving their own propeller out of wood, I still strongly advocate that you try this method, as it yields much better results than bent pieces of metal. Making molded fibreglass blades is a tricky operation and very laborious for a one off job. If you do not feel you can successfully make blades yourself, you could purchase the blades from a wind turbine blade supplier. See section SUPPLIERS at the end of this booklet for some sources.

You will need some sharp tools: a plane, a spokeshave [plane-like tool with handles on each side], chisel, saw and ideally, a drawknife, which is great fun for ripping out great hunks of wood. Sharpen the edges with an oilstone, at the correct angle (work up towards the edge rather than back from it). And remove any rag [loose threads of steel at the edges] which may result, by stropping the edge to and fro until it breaks off.

I usually clamp the wood onto a bench with a G-clamp [C-clamp], or clamp it to a waste piece of wood, which in turn is firmly gripped in a vice. This allows me to turn it around to the best working angle with ease, and hold it rock steady. If it vibrates, and the tools judder, try cutting slightly crabwise, angling the blade diagonally to the direction of motion. Obviously you will need to cut with the grain for best results. Power tools may be useful but they create a lot of dust, and it is difficult not to cut too much off at once.

Reasonably knot free (“clear” is the technical term), straight grain wood is necessary for a satisfactory job: if you buy it new, then Oregon pine is a good choice but very expensive. Old bed frames can be a good source of propeller wood or even old building timber or church pews. In what follows I assume you are using 100mm x 50mm (“two by four”) timber, but you can piece the same shapes together with any starting size once you understand the principle.

You need a total of over 5 meters [16.5'] of 100mm x 50mm [“two by four”] timber, cut into six pieces, 3 at 1000mm [39"], 3 at 750mm [30"]. Each blade is then built up by gluing two pieces together, overlapping as shown in figure 13:

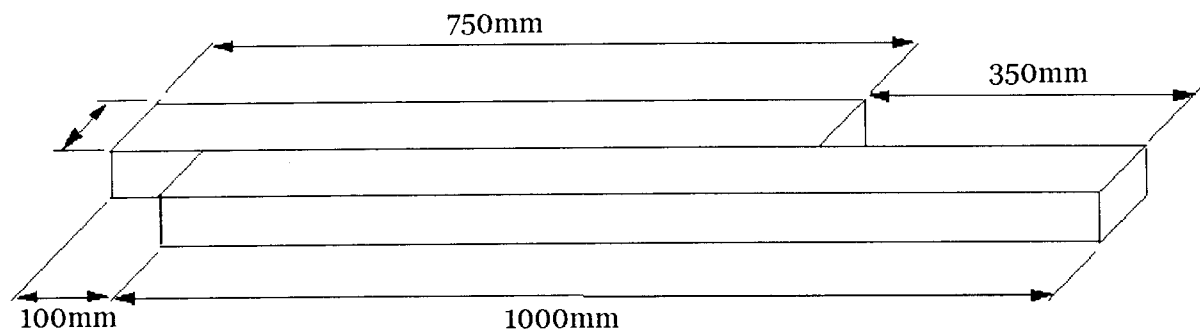


Figure 13

If you do not have enough wood, you may be able to work out a way of producing the final shape by cutting what you have into triangles. Use the same epoxy as for the alternator job. Other glues may be ok, but epoxy is definitely very suitable. Clamp the pieces together very firmly while the glue sets.

Each of the operations which follow will start by marking the correct measurements onto the work piece at each of a series of "stations". There are 7 stations including the tip, spaced equally at 150mm intervals from the centre of the propeller. Mark the stations on the work piece now, using a square to draw a line right around the piece as shown in figure 14. (Note that the actual centre of the propeller assembly is beyond the wood of this one blade. Measure stations from the tip.)

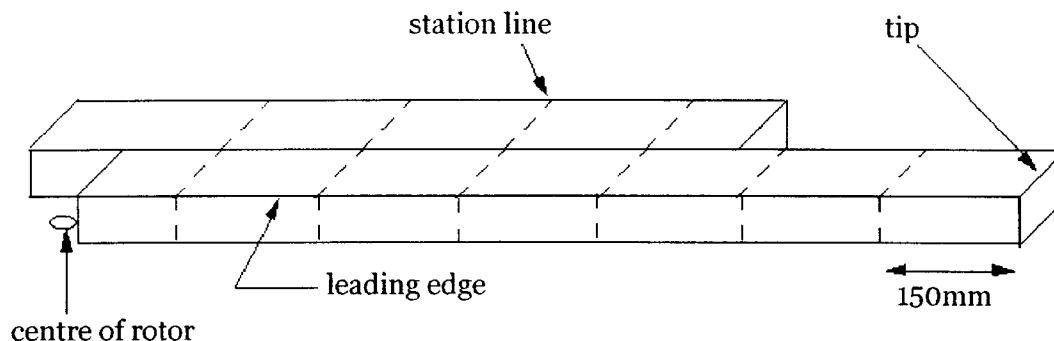


Figure 14

Next you will need to produce the correct taper: i.e. get the blade "chord width" right at each station. In all that follows, the leading edge remains untouched, as a sort of reference line. Measure the width from the leading edge at each station, join the dots with a line, and cut away the surplus wood, as shown in figure 15:

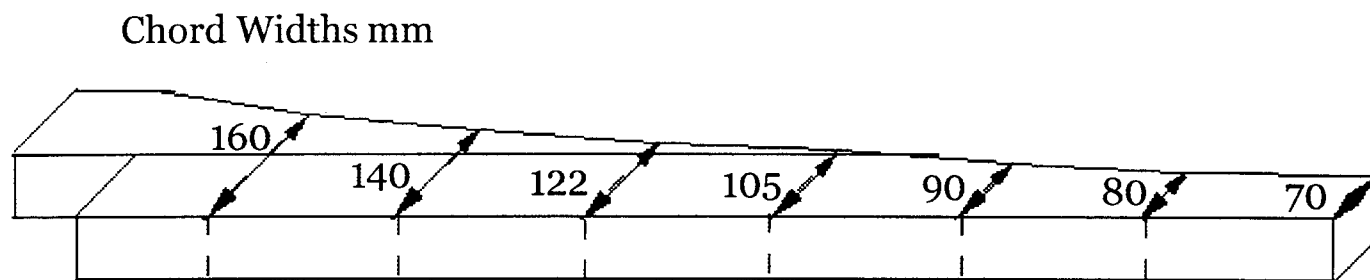
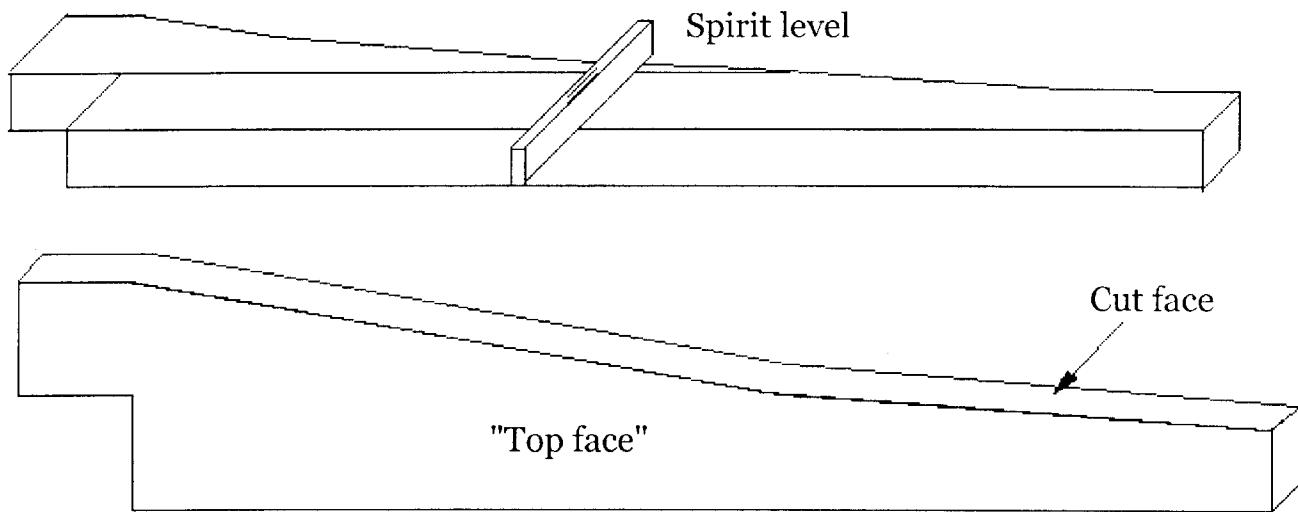


Figure 15

Turn the blade on edge, and work down to the line to an accuracy of plus or minus 1mm [about 1/32"], and keep the cut face square to the "top" of the wood (see figure 16). Where there is more than 10mm [3/8"] of wood to remove, it may be easiest to cut through the waste across the grain with a saw and then chop out chunks with a chisel, along the grain. Or you can use a band saw if you have access to one.

The next job is to put the correct angle on the blade, so it will catch the wind and run at the right speed. This is variously known as the weather angle, setting angle, or pitch of the blade. The angle is measured relative to the "top face" of the piece of wood: the one shown facing you in the above figures.

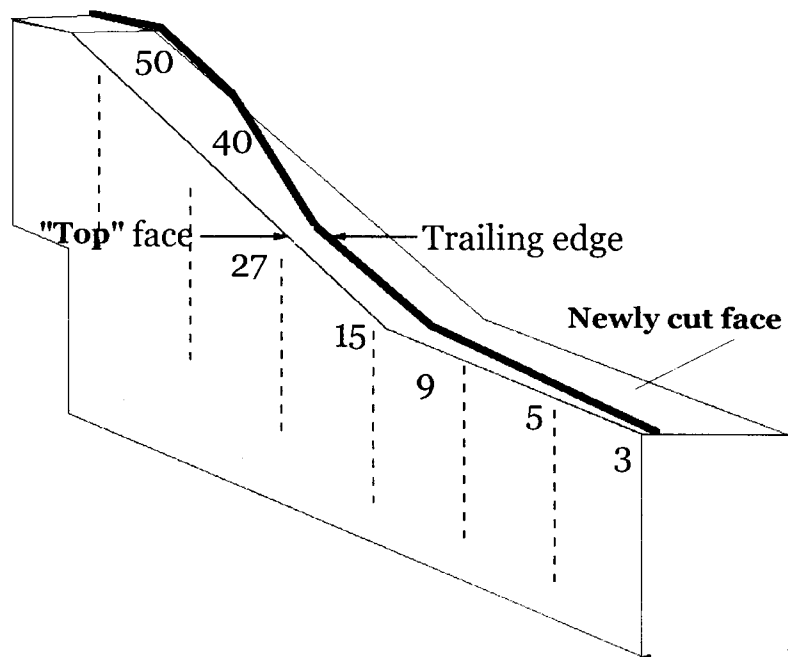


**Figure 16**

Before going any further, check for warp on this face, as this will affect the angle produced. You can check for warp by laying the work piece on a level surface, with the top face horizontal. Place a spirit level *across* this top face at each station in turn. At each station the bubble should sit at the middle of the glass. If there is a tilt at some of the stations then you will need to compensate, either by planing the top surface carefully level, or by measuring the error and compensating for it in what follows.

Turn the wood up on edge again. Draw your square lines at each station on the newly cut face, as shown in figure 16.

Now we need to draw a line to mark the position of the trailing edge of the blade on the newly cut face. At each station, measure the prescribed amount (see figure 17 below) from the “top face” along the newly drawn lines on the cut face. Mark a dot on each line at the correct distance from the top face. Join the dots, to produce the trailing edge line of the blade, as shown in figure 17:



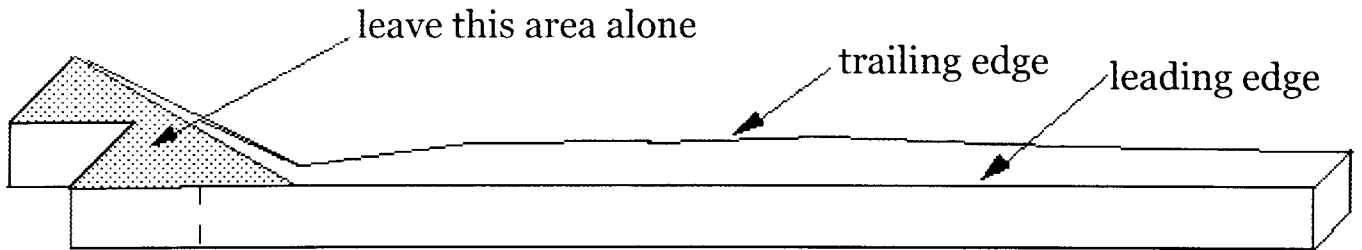
**Figure 17**

The trailing edge line is shown in bold in figure 17. This line is all that will remain of the face of the wood when you



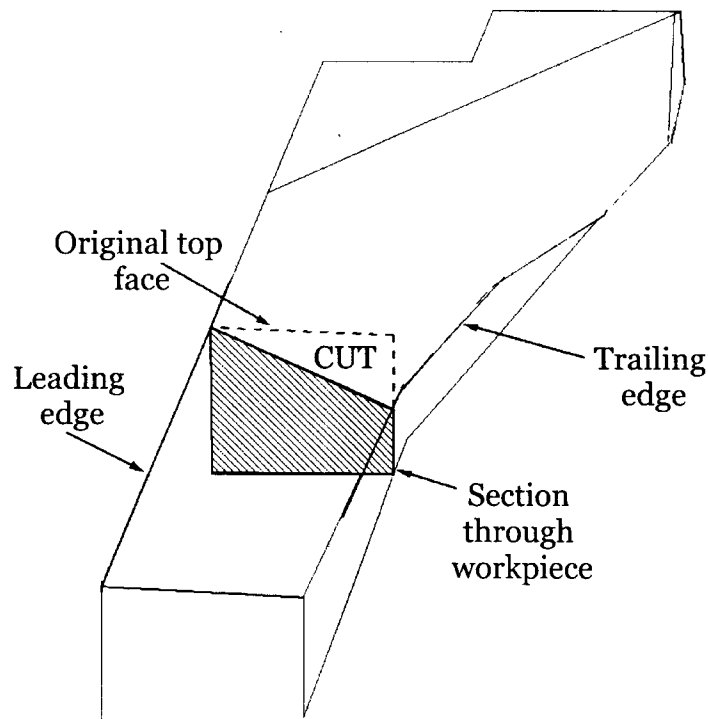
have finished the job. Now it is time to tackle the windward face (front) of the propeller blade. For simplicity, I recommend a flat front face, although some people cut them concave. When I say flat, I mean that the line between leading and trailing edges is straight. The face itself is not flat, but twisted, due to the strange curve of the trailing edge.

First mark the top face as shown in figure 18, which shows (hatched) the part of the top face which should be left alone:



**Figure 18**

Now you have to cut away all the wood above a line between the leading and trailing edges, to produce the flat, twisted, front face referred to above. Figure 19 is a *cross-sectional* view of the fourth station, to show the part of the wood which must be removed (marked "CUT").



**Figure 19**

Having cut the front face, the next step is to make the blade the correct *thickness*. The thickness is related to the chord width (see figure 15). Near the root, the thickness should be about 15% of the chord width. It drops to about 12% of the chord width at the tip. The actual thicknesses I recommend are shown in this table:

Station:	1	2	3	4	5	6	7
Thickness:	50mm	20mm	18mm	16mm	14mm	12mm	9mm

You must measure these thicknesses from the front face, in a way similar to marking out the trailing edge in figure 5. Do it at both the leading and trailing edges, and make two lines running the length of the blade, on opposing faces as shown in figure 20:

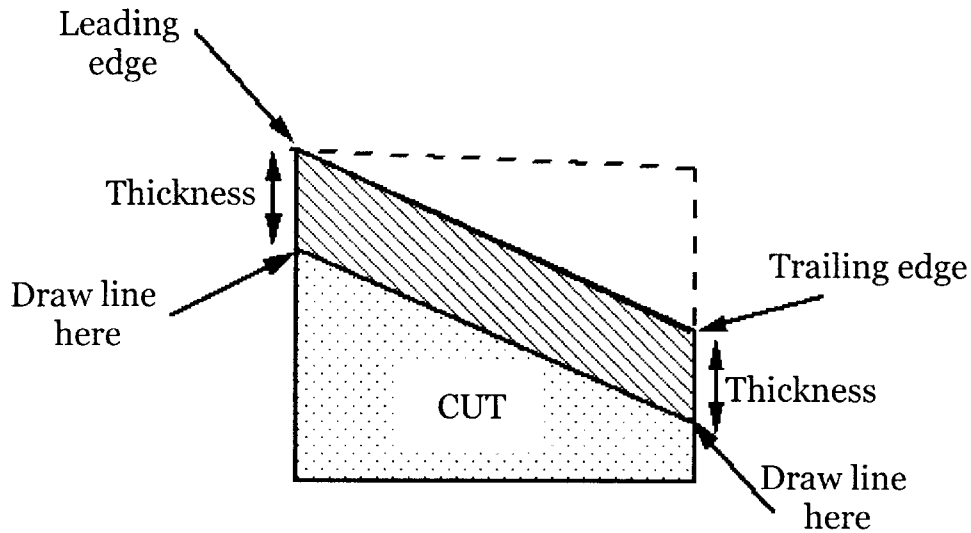


Figure 20

Turn the work piece upside down, with the front face downward. Now cut away the portion marked "CUT", working down to the two lines you have just drawn. It may be helpful to use calipers for accurate measurement of the remaining thickness, especially near the tip where precision is required.

You will be left with a blade which is the correct width and thickness, but has a crude rectangular/parallelogram cross-section. This now needs to be made into an aerodynamic shape. I normally leave the front face flat, but the back face (away from the wind) has to be convex (bulbous), and the trailing edge needs to be sharp, for minimum drag.

Shave wood away from one side of the most recently cut face to sharpen the trailing edge. The correct angle for the trailing edge is obtained by cutting away about 40% of the back face into a bevel down to the trailing edge as in figure 21:

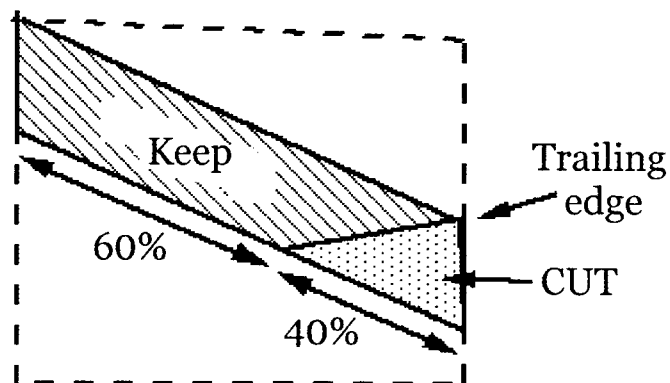


Figure 21

Finally you need to round off the sharp corners on the back of the blade, to produce a smoothly curved airfoil shape. I do this by eye really. Draw a line on the back face about 25% of the width back from the leading edge, and leave this line untouched, or you will lose your thickness. Figure 22 shows the general idea:

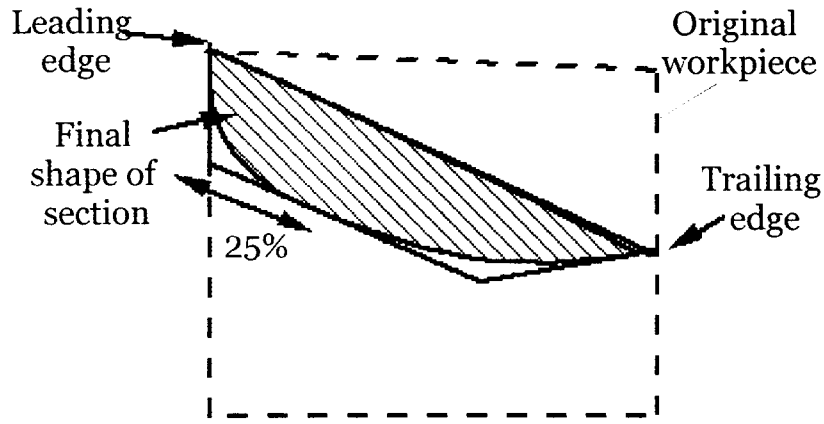


Figure 22

There is usually some debate about the best shape of the leading edge. I tend to keep it rather too sharp for some people's taste; maybe it should be more bulbous. In any case the wind generally wears this bit out of all recognition after a couple of years.

You should now have three lovely propeller blades. Normally I remove the leading edge with a plane to a depth of about 3mm [1/8"] and rebuild it with a mixture of epoxy and powder, to provide a tough setting paste. This has to be applied with a butter knife, and filed off when hard to make the original shape again.

I do recommend painting the blades thoroughly. I use Woolworth's non drip gloss on primer, and coat them thickly, sanding smooth with waterproof abrasive paper after the fourth coat. Painting should follow the next bit: assembling the whole rotor at the hub.

The way the blades fit together is shown in figure 23. The centre of the prop is 50mm [2"] back from the line of each leading edge, and 50mm [2"] from the end of the longer piece of wood, in the original construction (see figure 14). Position the blades so that these centre points coincide, and the angle between any two leading edges is 120 degrees. The easiest way is to measure the distances between tips and make them all the same. Fitting them together will require the removal of some wood (a triangle at the root) from the pieces you glued on the sides (see figure 13). I leave this until last, because these pieces are useful for clamping up during the carving phase of operations.

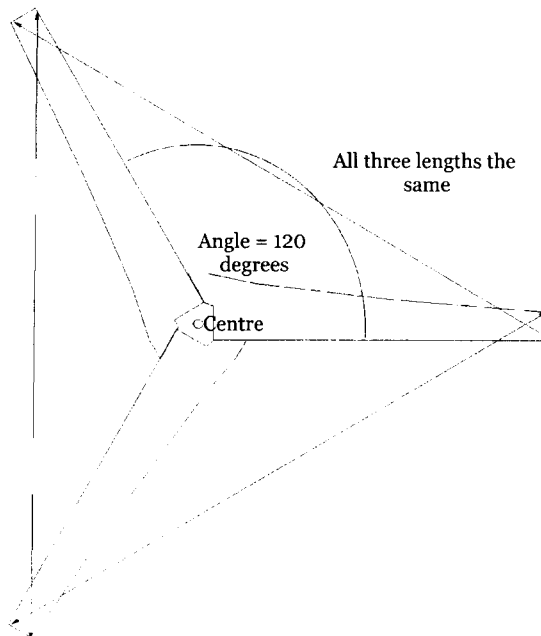
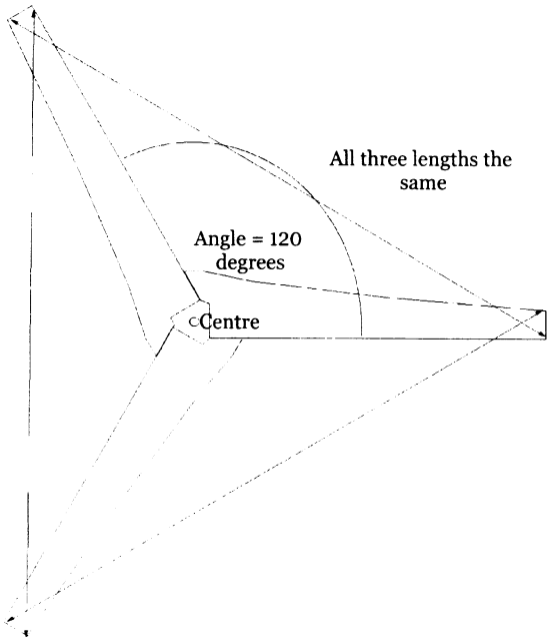
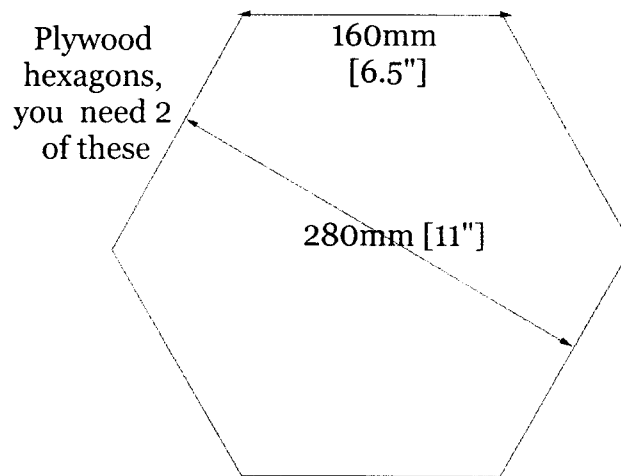


Figure 23



When you have the blades all fitting snugly as described, cut two hexagons out of sturdy plywood (minimum 9mm [3/8"] better 12mm [1/2"]) as shown in figure 24:



**Figure 24**

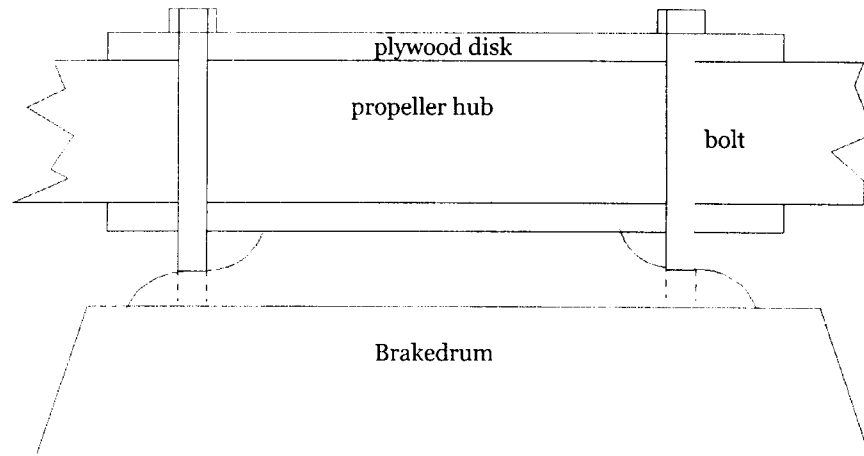
Sandwich the centre of the propeller between these two hexagons and fasten the whole together with a pattern of 50mm [2"] wood screws. I used 36 screws in all. Obviously you need to position the blades carefully before you start driving in screws.

If you will never need to take the propeller apart again (for easy transport or painting for instance) then it may be an idea to use epoxy as well as screws in the assembly of the hub.

The propeller is now complete, but it still needs to be balanced and fitted to the brakedrum alternator. Balancing is just a matter of making sure that the centre of gravity of the propeller assembly lies exactly on the centre of the shaft of the alternator. First find the centre of gravity of the propeller as follows:

Mount a sharp "knife-edge" about 300mm [1'] long horizontally in the jaws of a vice or similar. Balance the back of the propeller hub on this knife-edge. Sit the propeller dead level, and release it gently. If it tips, move it in the opposite direction a fraction and try again. Finally you should reach the point where it can hardly decide which way to tip. Press down firmly and slide it to and fro on the knife-edge to mark this position. Rotate through 60 degrees or so and repeat the process. Rotate a second time and cut a third line on the underside of the hub. When you have three lines, all passing below the centre of gravity of the propeller, turn it over and check that all three scratches meet at one point. This is the centre you need to use. It may not be the exact geometrical centre of the propeller, due to differences in density or whatever, but it is the centre you must use. If you do not like it, you can move the centre by attaching weights (e.g. pieces of lead screwed on), and repeating the process. The back of the hub will get a bit messy and you will find the line hard to interpret after a while.

Having found the centre, you can interface this with the mounting to the alternator. I mounted the prototype propeller by drilling and tapping two M10 [3/8"] holes in the front of the hub. One was in a hole previously used by a small screw which holds the brakedrum to the hub. The other hole I put exactly opposite. Precision is necessary for correct balance of the propeller. The holes are not flush with the surface of the alternator but I filled the gap with nuts and washers. See figure 25.



**Figure 25**

When drilling the two 10mm [3/8"] holes in the propeller hub assembly, use the centre of gravity as the mid-point between holes. This will ensure correct balance.

The studs for securing the half-shaft need to be removed or ground off. I tried drilling them out at one point, but found them very hard indeed. You can seal the front end bearing against entry of moisture, using silicone sealant or mastic. Put a bead of sealant around the hexagonal face where the propeller sits on the alternator before applying the propeller. When the propeller is correctly attached, the tips should follow each other exactly through space, as the blades rotate. If you find that the tips are more than 3mm [1/8"] in front or behind each other, then it will be worth shimming the propeller slightly to correct the tracking.

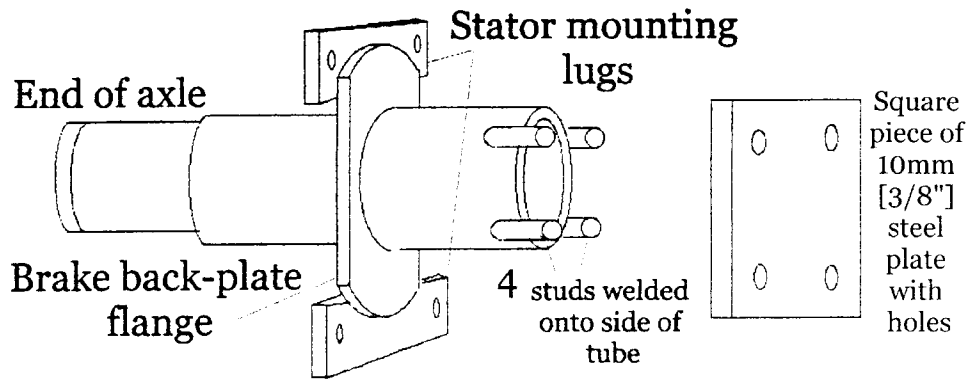
## **PUTTING IT ALL TOGETHER**

We now have an alternator and a propeller attached to it. It only remains to explain how I mounted it on a pole as a workable wind turbine. The mounting which is described in what follows has the following functions:

1. Holding the alternator up securely on the tower top,
2. Keeping it facing the breeze, and
3. Protecting it from overload when the wind is too strong (the mounting allows the turbine to turn away from the wind).

I built this mounting from scrap steel, using an electric arc welder. It is no doubt possible to achieve a satisfactory result without welding, but it will look awkward, with bolts and pieces sticking out, and it will probably be more work. Provided the important dimensions are the same, then a successful result can be achieved.

My first step was to cut through the axle tube with a hacksaw. I recommend the use of *new* Sandvik (or similar high quality) hacksaw blades, and this will be found to take only ten minutes or so work. If you are going to bolt it together, you may wish to leave the bracket on the axle tube, which took the leaf spring suspension. I cut through closer to the wheel end (in fact about 30mm [2.5"] from the back of the brake back-plate flange). To connect the alternator to the mounting, I welded four pieces of M10 [3/8"] stud to the axle tube, such that they project beyond it thus:



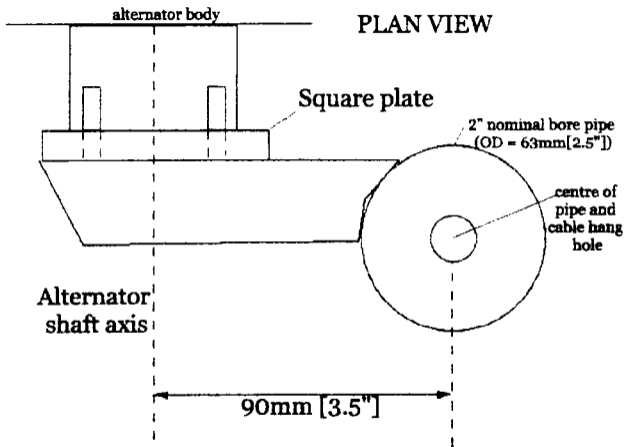
**Figure 26**

Actually, to be honest, before I welded them I found a piece of square 10mm [3/8"] plate with four holes in exactly the right places, and I used these holes to support the studs while welding. Lovely coincidences like this happen sometimes, but I expect you will need to drill your own holes in a piece of plate or piece(s) of heavy steel angle. Or you could simply weld the tube itself onto the mounting.

The tower is a piece of 1.5 inch nominal bore water pipe (48.3mm [1 29/32"] overall diameter). This is the standard size for scaffold tubing, and although it is rather smaller than Marlec use for their wind turbines, it is strong enough, as I have used it for years on machines this size. It does need to be well guyed (or otherwise supported) at a point just below the propeller tips, so as to be stiff enough.

The bearing which supports the wind turbine and allows it to rotate and face the wind is simple in the extreme. I have used car front wheel bearings, which are very good, but lots of hassle. They tend to corrode up anyway unless you do a very good job of stopping the rain from running in. For this job, I just used a piece of 2 inch nominal bore (60.3mm [2 3/8"] outer diameter) steel water pipe, which can be a fairly neat fit over the smaller pipe. I cut a 250mm [10"] length of the 2" nominal bore pipe, and welded a small piece of plate over the end. I drilled a 12mm [7/16"] hole in the centre of the plate, for the flexible cable from the windmill to the ground (it goes down through the entire supporting tube, and out through another hole drilled near the base). When well greased, this slips quite nicely on the top of the smaller tube. Both tube ends have to be cut accurately square.

The piece of square plate to which the alternator bolts is in turn attached to this 2" nominal bore steel pipe, at around the mid-point. It is set up such that the face of the plate is approximately tangential to the tube, and the centre of the alternator is 90mm [3 3/8"] away from the centre line of the tower. These dimensions are important, and are shown in figure 27:

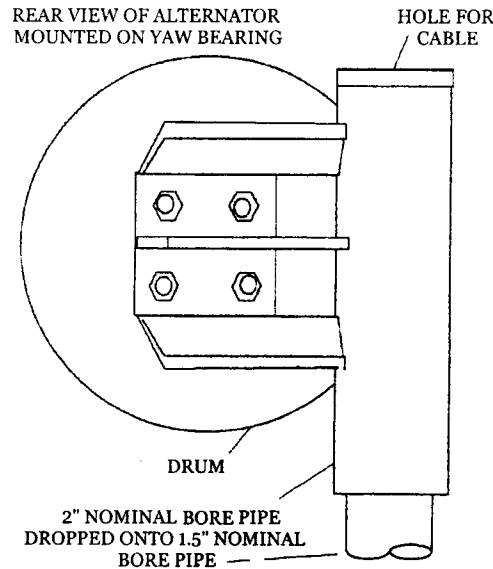


**Figure 27**



The square plate is connected to the pipe by three pieces of steel about 100 x 25 x 10mm [4" x 1" x 3/8"] in size, running horizontally. Care must be taken so they do not interfere with the operation of the spanner [wrench] which you use to secure the nuts on the ends of the alternator mounting studs. Figure 28 shows what they look like from behind.

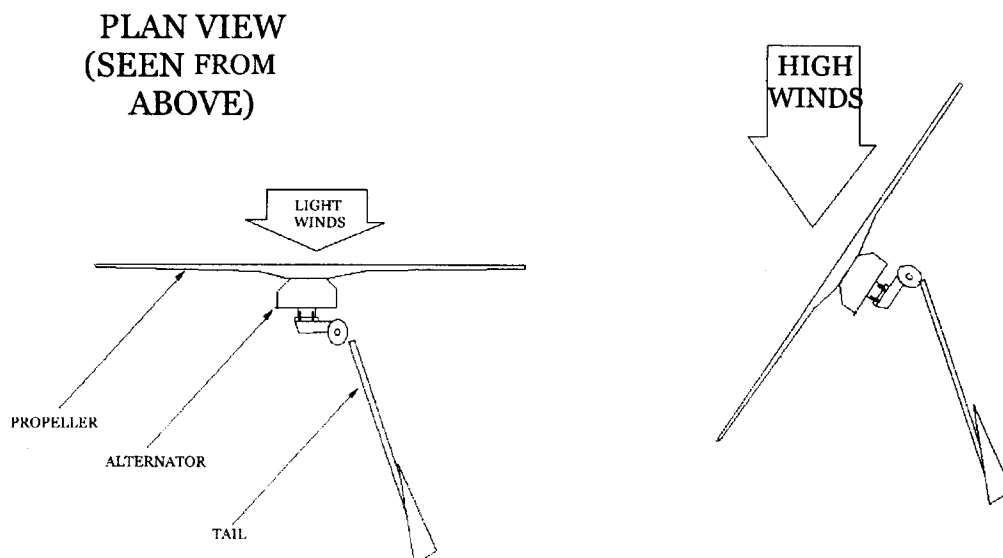
The alternator axis should be about 90mm away from the centre axis of the tower tube, so that wind pressure on the propeller will try to turn it away from the wind. If it is less, then this action will not be sufficiently positive. If it is more than 90mm [3 3/8"] then you will need a bigger tail.



**Figure 28**

Now we have a windmill which is supported and can rotate to face the wind. We need a tail to make it face the wind. We also need to allow it to face away when the wind gets too strong. This will prevent over speed, with consequent erosion damage to the blades, overheating of the alternator, and vibration fatigue of the whole structure.

The tail must be designed to hold the windmill into the wind until the wind pressure exceeds a certain limit. After that, the tail must yield, allowing the windmill to turn away from the wind. The action needs to be proportional, so that we continue to generate power, but do not expose the windmill to undue stress. Figure 29 shows what is intended.



**Figure 29**

I have a great deal of experience in the design of these tails, and the tail on this windmill, while it is not the absolutely optimal system for best energy production in all wind speeds, is simple and reliable, and will keep the machine working without falling apart.

The tail is a piece of plywood (aluminum sheet always fatigues) bolted onto a steel boom. I used a triangle of plywood, but the shape is not very critical provided it is large enough: at least 0.25 square meters (2.5 square feet). The overall length of the tail is 1250mm [just over 4 feet]. Another important feature of the tail is its *moment of weight*. This is the combined weight of the tail and boom, multiplied by the distance from its centre of gravity to the root where it attaches to the windmill. In this case, the weight was 4.4 kg [9.7 pounds], and the distance was 0.6m [2'], giving a moment of weight of 2.6 kg-m [19 foot-pounds]. (Engineers use a different unit of force, the Newton, but kg-m will do us fine.) I suggest you use the same moment of weight, plus or minus 10%. However, please recall that I increased the moment of weight in 1994 to 3.6 kg-m [26 foot-pounds], as mentioned in the section HOW I DID IT.

The moment of weight is what makes the tail hard to hold up from the root. We can use this moment of weight to control the whole windmill, by mounting the tail on an inclined hinge, so that it falls down into place, but can be lifted away by strong winds to allow the windmill to yaw out of the wind.

Here is how you construct the included hinge. Once again, a simple bearing is used: a piece of 1-1/4 inch nominal bore water pipe (outer diameter 42.4mm [1 21/32"]) fits neatly over a piece of 1 inch nominal bore pipe [(outer diameter 33.7mm [1 11/32"])]. We start by attaching the smaller pipe (1 inch nominal bore) to the main windmill mount at the correct angle, and this is hard to describe.

Cut a piece of one inch pipe about 150mm [6"] long. It is to be welded to the small plate on the top of the 2 inch pipe used as a main bearing for the windmill, such that:

- It does not obstruct the hole for the cable exit.
- It is angled 27 degrees from the vertical.
- View from ABOVE, it makes an angle of 45 degrees to the windmill proper.

See figure 30.

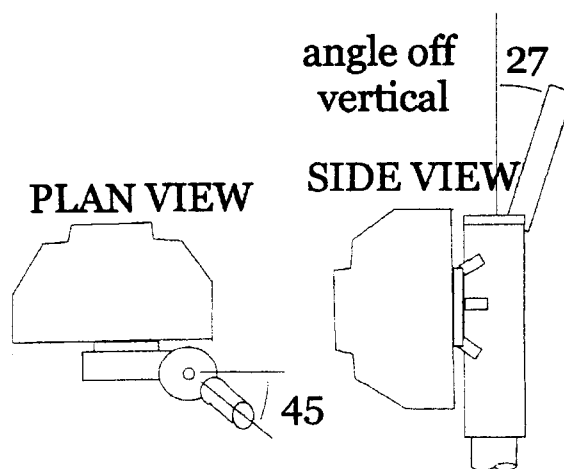
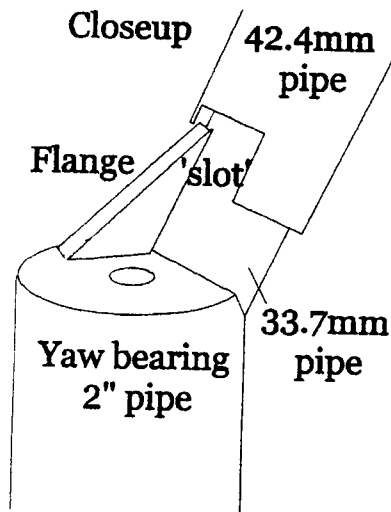


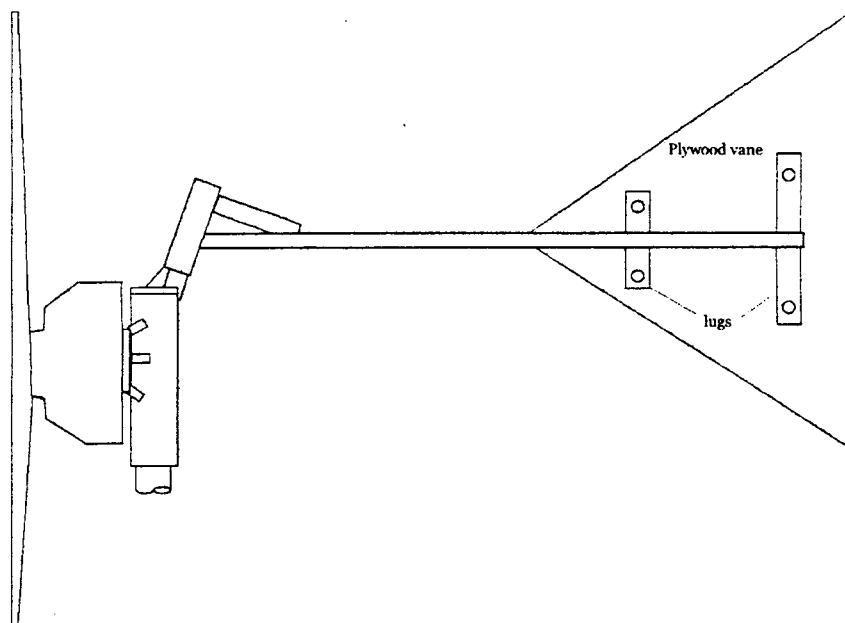
Figure 30

Now we cut a shorter, 125mm [5"] piece of the larger size pipe (1-1/4 inch nominal bore). Weld a small piece of plate across the top so it can be dropped onto the 1 inch pipe just described. We need to limit the range of movement of this outer pipe to about 100 degrees. This is done by welding a flange to the smaller pipe, and cutting a slot in the large pipe, so it can only rotate by that much, as shown in figure 31.



**Figure 31**

When all this is set up, you can weld the tail boom (could be another piece of the 1 inch pipe: I used a patent shelving support material) onto the larger, outer pipe so that it hangs horizontally outward when the outer pipe is rotated fully anticlockwise.



**Figure 32**

Conditions when you tack weld the tail boom on should be as follows:

- Boom is horizontal.
- Outer pipe is fully anticlockwise rotated
- Tail boom as seen from ABOVE should be almost square to propeller but cocked 10 degrees into the wind as shown in figure 29.

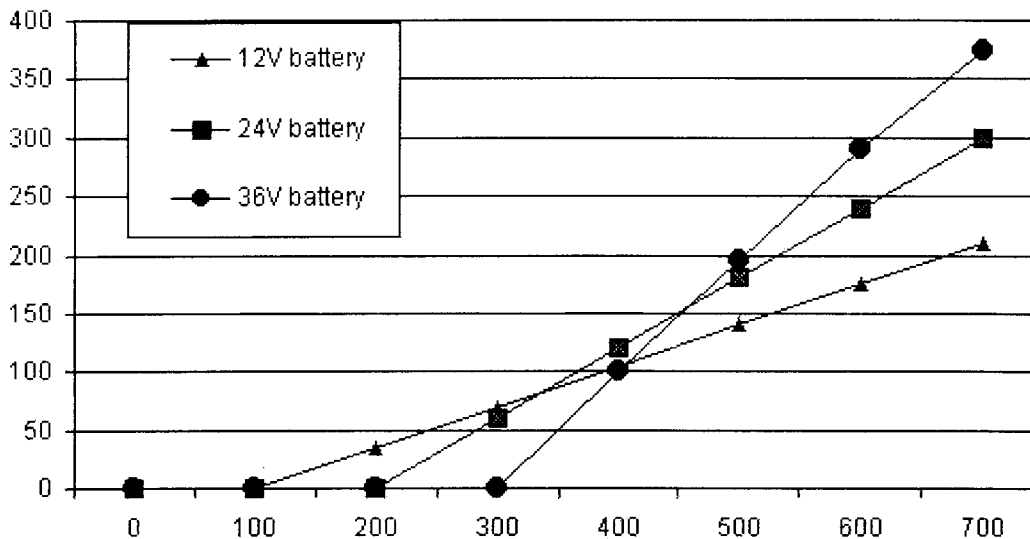
This is a highly stressed point if there is vibration, and good welding is essential at the tail root. Next fix the plywood support brackets (pieces of steel with holes in) such that the ply is neatly vertical on the horizontal boom. When you swing the tail around it should fall back into position under the action of its own weight. Check that it cannot swing as far as to hit the propeller blades, when at the top of its swing.

To increase the output in high winds, add weight to the tail. To make it turn away sooner, make the tail lighter.

When you have finished, paint all the steel work with Hamerite [Rust-oleum] or similar metal paint, and the ply with suitable paint for wood.

I hope that covers everything. If not, please give me a ring, and I shall try to explain some more.

## PERFORMANCE CHART



This chart shows the pros and cons of different battery voltages for a given alternator winding. It is approximately based on performance of the star connected, 24 turns per coil winding given in this booklet. External cable voltage drop is ignored.

Connected to a 12 volt battery, the cut in RPM is lower, but the maximum power output is also lower. 24 volt operation does not start until the speed reaches 200 RPM, but after that, the power output soon exceeds the 12 volt performance curve. The higher the battery voltage, the less power you will lose in heating of the stator, too.

You could also change performance by altering the number of turns per coil. Volts increase with turns, so by rewinding with 100 turns (instead of 24), for instance, you could get 100 volts output, with the same wattage as the 24 volt graph above. This might be useful for long cable runs and for powering heaters, but it could also be lethal, so take care!

# SUPPLIERS

## U.K. Suppliers

Epoxy resin SP 106 Colloidal silica powder	Blake Marine Paints Ask for Loretta (01703) 636373 She will tell you your nearest supplier.
Polyester Resin Surface tissue Aluminum powder	Glasplies 2, Crowland St. Southport Lancs. PR9 7RL (01704) 540626 Ask for the free information pack as well.
Enameled copper wire 250g 0.71mm product code YN83E crimp receptacles product code JH82D	Maplin Electronics plc Freepost, PO Box 3, Rayleigh, Essex, SS6 2BR (01702) 554 000
Enameled copper wire 500g 0.8mm product code 146-530 Bridge rectifiers product code 234-136	Farnell Components Canal Rd, Leeds, W. Yorkshire LS12 2TU (0113) 263 3411
Windpower courses, 2-4 days Twice each year. Meet me there!	Centre for Alternative Technology Machynlleth, Powys, Wales, SY20 9AZ (01654) 703743
Rectifiers for GPB 2.50 each Book: Windpower Workshop by Hugh Piggott Book: It's a Breeze by Hugh Piggott	Scoraig Wind Electric Scoraig, Dundonnell Ross shire, IV23 2RE (01854) 633 286
Magnet Blocks, cut to size	CERMAG LTD. 94, Holywell RD, Sheffield, S4 8AS (0114) 244 6136 or (01462) 896896
Magnet Blocks	UNIMAG, (01709) 829783

## USA Suppliers

Enamel coated magnet wire 20 AWG, 1 pound product code 2700MG20 Silicone rectifier product code 11TB251	Electronix Express 1 (800) 972-2225 www.elexp.com
Rectifiers, cables	Digi-Key 1 (800) 344-4539 www.digikey.com Amazing searchable web catalog!
Rectifiers, product code MDA990-3	Jameco 1 (800) 831-4242 www.jameco.com
Magnets	Master Magnetics 1 (888) 293-9399 www.magnetsource.com
Magnets	Magnet Sales and Manufacturing 1 (800) 421-6692 www.magnetsales.com

Magnets	Other numbers to try: 1 (800) 747-7543 1 (800) 345-4082 1 (800) 525-3536
Magnets	All Electronics Corp. www.allelectronics.com
Book: Windpower Workshop, by Hugh Piggott Book: It's a Breeze!, by Hugh Piggott Video: Hugh Piggott's Windmill Workshop Spreadsheet: Brakedrum Alternator Calculator	PicoTurbine.com www.picoturbine.com FAX: (973) 208-2478
Servo motors which can be used as permanent magnet generators for windmills	Surplus Center 1025 W O St. Lincoln, NE 68528-1322 (402) 474-5167
Carved Wooden Blades	Lake Michigan Wind and Sun (414) 837-7534 email: lmwands@aol.com
Blades, small wind turbine alternators	World Power Technologies (218) 722-1492 www.worldpowertech.com

### Canadian Workshop

Courses on building a wind turbine from recycled parts based on the designs in this booklet are given by Mr. Bob Budd, RR#2, Goderich, Ontario Canada. Tel: 519-524-6729 or email to ramdesign@odyssey.on.ca, web site: <http://www.windmill.on.ca>

### Magnets from China

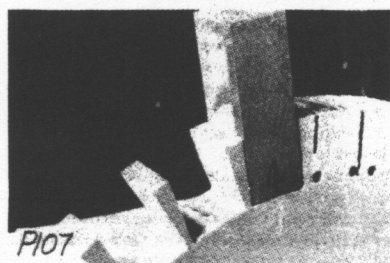
Magnets	Pro-Perfect (Xiamen) Magnetics Co. Ltd. PO Box 0915, Xiamen, Fujian, P.R. China Tel: (86582) 5035370, Fax: (86592) 5063572 Email: sales@chinamagnet.com <a href="http://www.chinamagnet.com/">http://www.chinamagnet.com/</a>
Magnets	Zhejiang Dongyang Magnetic Enterprise Group Co. Tel: (0574) 7292002, Fax:: (0574) 7323103 Email: industri@pub.nb.zj.cninfo.net

# The Homebuilt Dynamo

*This rather arcane book offers complete (to say the least), copiously illustrated instructions for making your own small, slow-speed generator — a type that is very difficult to find, let alone at a reasonable price. Slow-revving generators are suitable for powering by domestic-scale wind or hydro turbines, or, as in this case, the author's exercise bicycle. (One good workout provides enough battery-stored electricity for his modest daily needs.)*

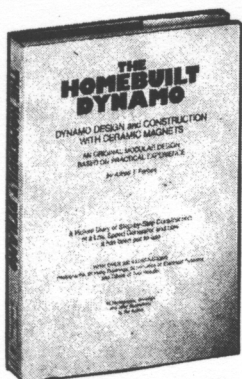
*It's hard to imagine a better set of directions for making anything. To me, however, the book is most valuable as an apprenticeship in how to imbue an idea with sufficient intellectual energy and information to make it flicker into being as irrefutable proof-of-concept hardware, a skill not taught in schools or textbooks. The author teaches by revealing how he arrived at his design and fabrication decisions. The patiently explained underlying physics includes worked-out calculations for larger models. Logic and cleverness are balanced by a discussion of his blind alleys and mistakes. Inadvertently, perhaps, it's a rarely seen, intimate and accessible revelation of a designer's thought process.* —J. Baldwin

•  
[P107] Each of the 32 Rotor Magnets used in the Magnet Rotor are now individually numbered from 1 to 32. They are still in their unmagnetized condition and, as each slot is cut in the Magnet Rotor, it, too, is given a corresponding number. Each magnet must fit snugly into its own slot and there may be slight imperfections in the cut sides or bottoms of the slots — and it is far better to discover and smooth out such imperfections (with a file) at this point rather than later on when the magnets have been magnetized, the epoxy glue mixed, and any delay would be very aggravating to say the least. It is hard enough to deal with the magnets after they are magnetized — they tend to slap together or jump apart in the most annoying fashion — without any added difficulty in matching magnet to slot and correcting any slot imperfections when you are glueing them into place! After all slots and magnets are numbered for fit and placement, set the magnets aside in a safe place for now.



**P106:** Cutting slots in rotor disk.

**P107:** Fitting each magnet to its individual slot.



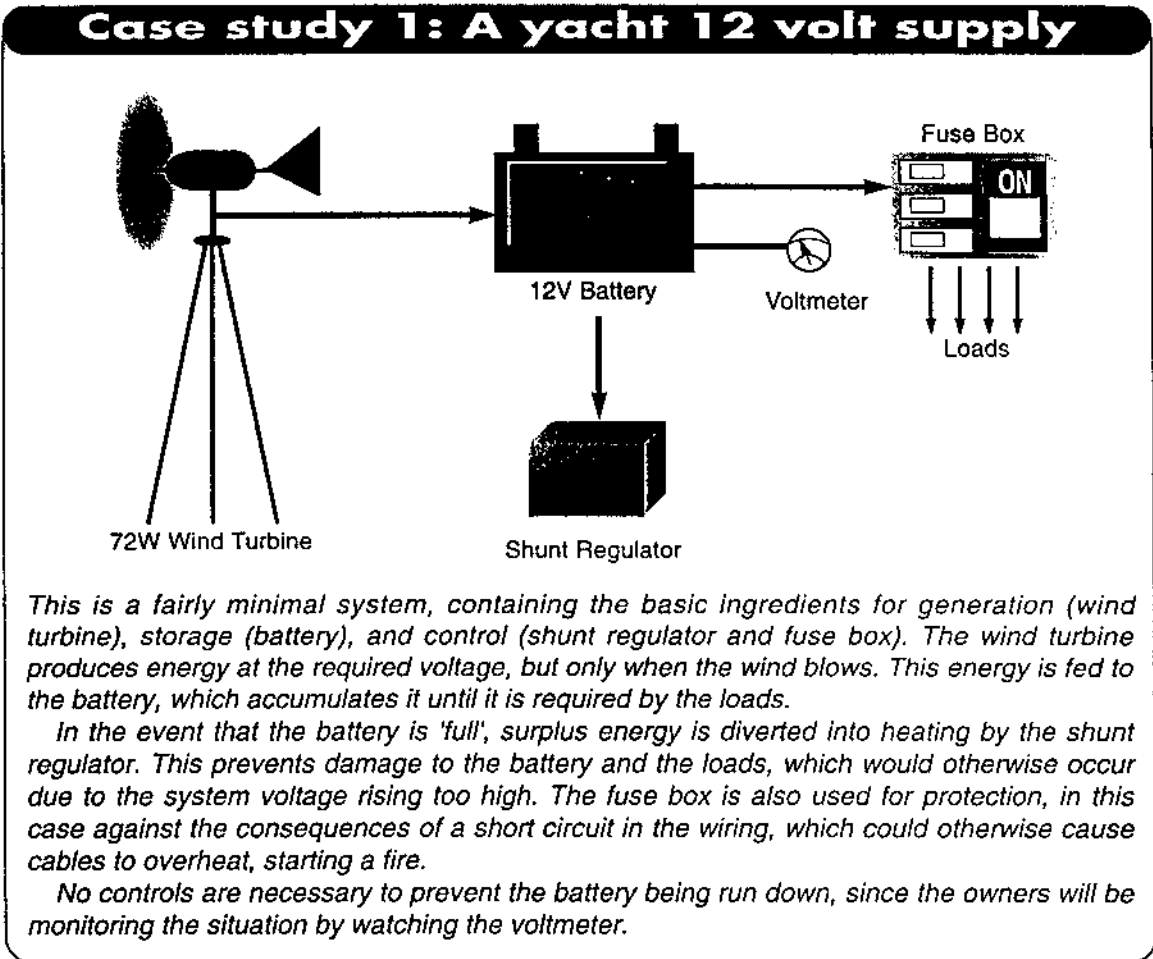
## The Homebuilt Dynamo

Alfred T. Forbes, 1987; 182 pp.

**\$50** (\$65 postpaid) from Todd-Forbes Publishing, P. O. Box 3919, Auckland, New Zealand

WE. Winter 1991

**Case study 1: A yacht 12 volt supply** Here, mains power is not available, since the boat is kept on a mooring when not in use. The only engine on board is the outboard motor, which has no electrical output. At weekends, electricity is needed for lighting and small appliances, such as the bilge pump, winch and TV. These can all be conveniently run from a 12 volt battery, which is charged from a very small wind turbine during the week.



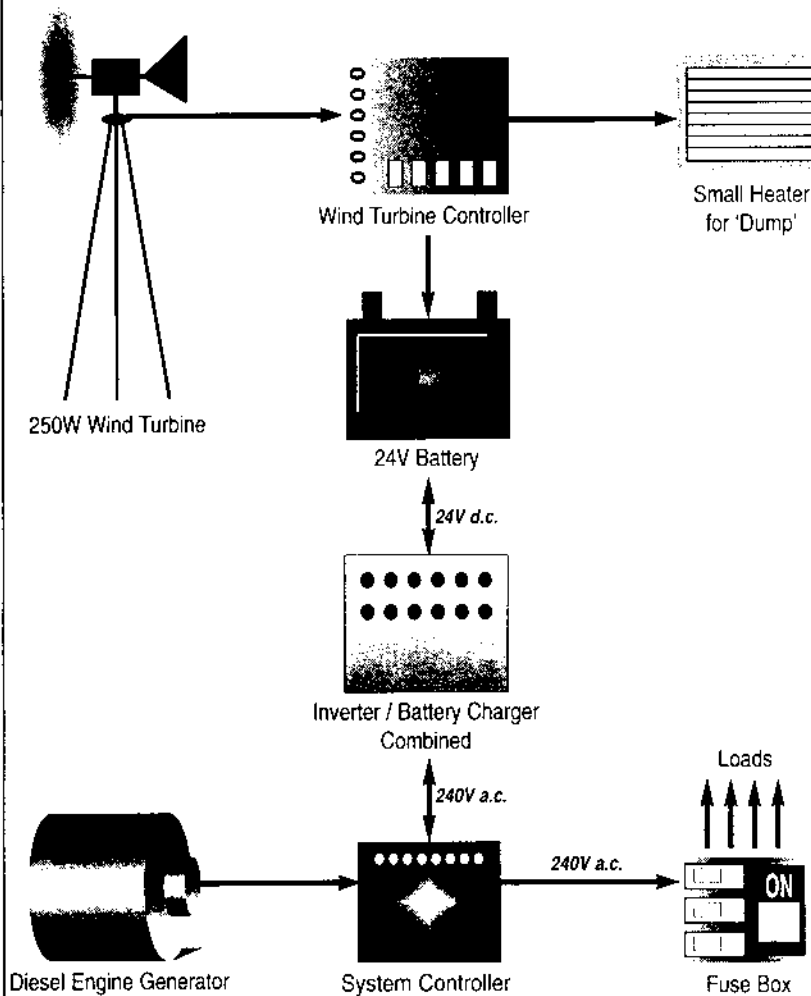
**Case study 1: A yacht 12 volt supply** The loads are mostly quite modest. The cabin is quite small, and 12 volt lighting is very efficient, so 20 watt bulbs are bright enough. Halogen spot lamps can be used to create a very cosy atmosphere, with very bright pools of light where needed.

The electric winch uses a lot of power, but since it is only used for a brief period of time, the energy consumption per week is very small.



**Case study 2: A holiday cottage** All normal electrical equipment will be needed (within reason), since the cottage will be rented out to all comers. The guests cannot be expected to understand the system, so it must be completely automatic in operation (a 'turnkey' system). To give security of supply under all conditions it may be necessary to use a back-up engine-driven generator from time to time.

## Case study 2: A holiday cottage



The holiday cottage system is much more complicated, in order to make life simple for the occupants. Again, energy from the wind turbine is accumulated in a battery, and surplus energy is diverted to heat. Since this is a larger system, a small heater is used, which is separate from the controller as such. The biggest difference is that light and power circuits in the cottage are fed with mains-voltage, so that conventional appliances can be plugged in. The inverter converts the electricity from 12 volts to mains-voltage.

To provide fully automatic operation, a second, 'system', controller is needed, which monitors battery condition and power consumption. If more power is required than either the battery or the inverter can provide, then the controller will start up a diesel generator. When the diesel is running, it provides all the electricity for the cottage. At the same time, the inverter (a special kind of inverter) is used as a battery charger, converting mains voltage to 12 volts, to recharge the battery. In this way, the diesel is always kept well loaded when it runs, and best use is made of the fuel consumed.

**Case study 2: A holiday cottage** We need to keep energy use to a minimum, since it would be very expensive to provide the amount used by a typical household on the mains (about 20 kWh per head per week). With a little attention to energy conservation this can be cut right down.

- No electric heaters are provided, as there is good insulation and an efficient wood fired heating system.
- Compact fluorescent lights are used in place of normal 'incandescent' light bulbs. These lamps cost more to buy, but only use a fraction of the power to give the same light level.

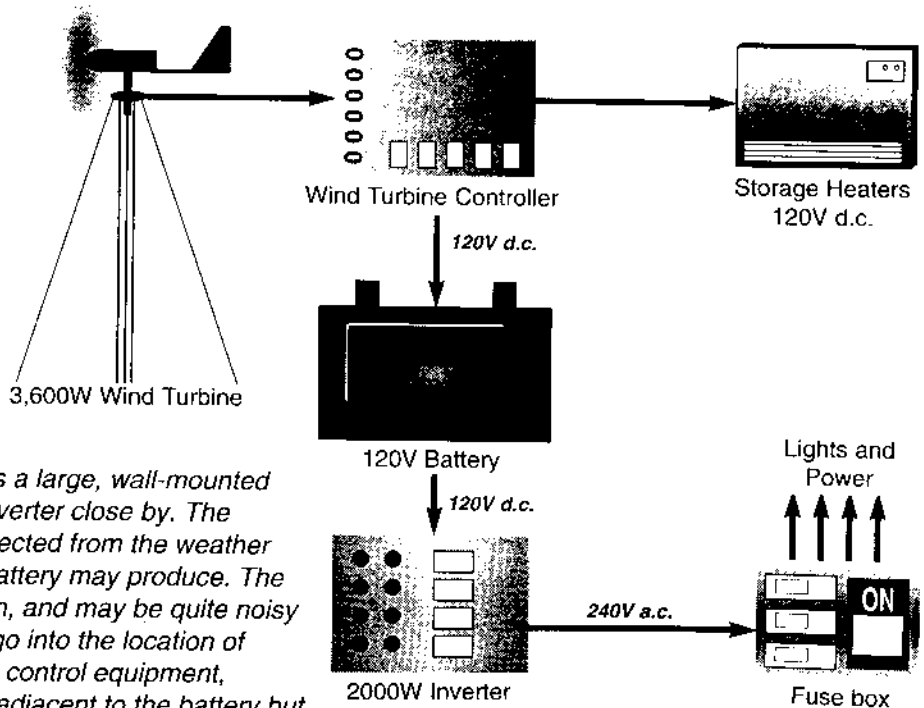
**Case study 3: A primary school** Again, it is beyond the reach of the national grid. Access is difficult, so it is planned to reduce the amount of heating fuel needed for the building by using the wind for heating. There is also a requirement for electric lighting and power for computers, photocopier and vacuum cleaner.

Electric heaters use much more power than light and power applications. It is not realistic to use battery power to run heaters. A much cheaper option is to put power into storage heaters directly from the wind turbine, when there is surplus power, beyond what the battery needs. A relatively large wind turbine is needed to produce a useful amount of heat, and this has the added advantage that plentiful power will be available in relatively light winds for charging the battery. So, no back-up generator is needed.

### Case study 3: A primary school

The primary school has a relatively simple system. The wind turbine is much larger again (3,600W is 3.6kW) and provides much more energy than is needed for lighting and power. The controller dumps about 80% of the incoming energy into the storage heaters over the course of the year. However, it never diverts any energy to heat unless the battery is receiving its optimum charging current already. This ensures that the battery is always kept well charged, even in periods of relatively low windspeed, and no back-up generator is needed.

In case studies 2 and 3, the controller is a large, wall-mounted box in a shed near the battery, with the inverter close by. The controller and the inverter need to be protected from the weather and from the corrosive fumes which the battery may produce. The inverter especially needs ample ventilation, and may be quite noisy in operation, so careful thought needs to go into the location of these items. A control cubicle housing the control equipment, inverter and fuse-box is normally erected adjacent to the battery but not in the same compartment. This must be of sound construction in areas of high windspeed, because entry of rain or snow will cause serious damage to the electronics.



**Case study 3: A primary school** Here, we have two different classes of load. The heaters use 3kW, but they do not run from the battery, so we can ignore them in our calculation of storage capacity. The other loads all run from the battery through the inverter.

The fluorescent tubes which the Education Authority uses for classroom lighting are not compatible with a 'semi-sine wave' inverter, which causes buzzing and flickering. Proper sine wave is needed. This could be provided by filtering the semi-sine wave with a 'sine wave filter' but it is found that the filter would draw 300 watts of power on its own. Although this sort of energy loss would be tolerable on a system with such a large wind turbine it is decided to use the latest 'state-of-the-art' sine wave inverter for the job, giving both high efficiency and pure sine wave.

**Case study 1: Weekend use of 12 volt power in a yacht**

Load Name	Power (watts)	Hours per week	Energy kWh/week
4 Interior lights @ 20W each	80	10	0.8
Lights (navigation)	60	4	0.24
Bilge pump	50	2	0.1
Portable T.V.	50	4	0.2
Electric winch	700	1/6	0.117
Total			1.457
+ 30% to cover losses			0.437
<b>Total</b>			<b>1.894</b>

Battery voltage: 12V

Capacity: 200 amp-hours, giving  $12V \times 200 / 1000V = 2.4$  kWh

Of this capacity only 80% should be used, giving 1 week's supply.

## LOAD TABLES FOR THE CASE STUDIES

**Case study 2: Holiday cottage turnkey system**

Load Name	Power (watts)	Hours per week	Energy kWh/week
5 Compact fluorescent lamps @ 20W each	100	40	4
T.V. (20" colour)	100	40	4
Vacuum cleaner	800	1	0.8
Washing machine	2,000	1	2.0
Total			10.8
+ 30% to cover losses			3.24
<b>Total</b>			<b>14.04</b>

Battery voltage: 24V

Capacity: 416 amp-hours, giving about 10 kWh

In this case the presence of the diesel engine generator makes battery capacity less critically important. The battery would last about 4 days (80%=8kWh).

**Case study 3: Remote primary school building (battery/inverter powered loads only)**

Load Name	Power (watts)	Hours per week	Energy kWh/week
5 Fluorescent tube lights	500	40	20
Computer systems	200	15	0.3
Water heater	2000	1	2
Vacuum cleaner	1000	2	2
Photocopier	1200	1.5	1.8
Total			26.1
+ 30% to cover losses			7.83
<b>Total</b>			<b>33.93</b>

Battery voltage: 120V

Battery capacity: 450 amp-hours, giving 54 kWh

80% of 54 = 43.2 kWh which is nine days supply.

## Wind turbine outputs

Average Windspeed	Wind turbine rotor diameter			
	1m	2m	3m	5m
3m/s	0.5	2.5	6	16
4m/s	1.5	6	15	40
5m/s	3	12	25	75
6m/s	4	17	40	110

(energy outputs quoted in kWh/week)

## Effect of 'Roughness' on windspeed

### Roughness

category	at 10m	or	20m height
0	6.9m/s		7.5m/s
1	5.5m/s		6.2m/s
2	4.7m/s		5.5m/s
3	3.5m/s		4.5m/s

Where there is a change in roughness, windspeed will change only gradually. So for example, even though they are not actually located on open water, sites near the sea will be windier than similar inland sites.

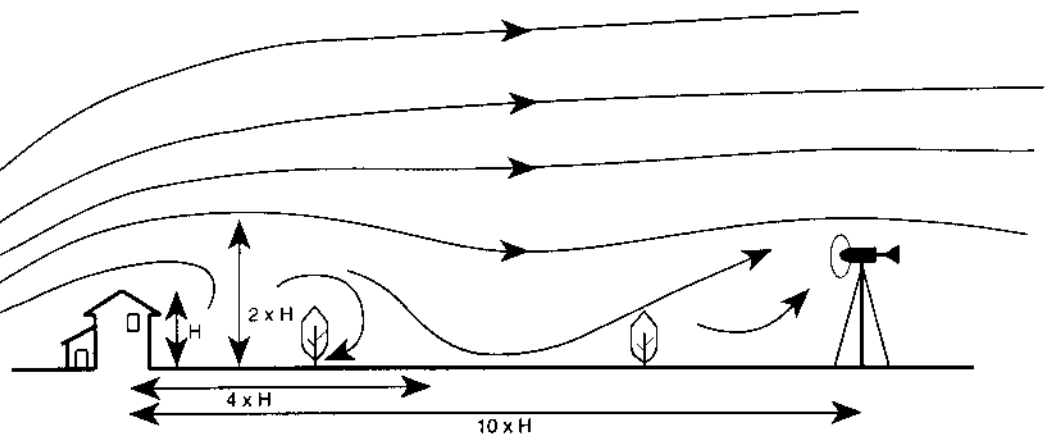
## Cable length and power loss

Wind turbine		Copper cable size							
Volts	watts	1.5mm <sup>2</sup>	2.5mm <sup>2</sup>	4mm <sup>2</sup>	6mm <sup>2</sup>	10mm <sup>2</sup>	16mm <sup>2</sup>	25mm <sup>2</sup>	
12 or 24	60 250	22m	36m	58m	86m	144m	230m	360m	
12 or 24	250 1000	<b>Do not use these sizes</b>			11m	21m	35m	55m	86m

Maximum length of cable in metres for 20% power loss at full power output (average losses will actually be less).

## Windflow over an obstacle

The zone of turbulence actually rises as the flow progresses downstream. If the obstacle is a building, then it should not block the prevailing wind. If you have a block of trees near the site, then you may find better wind above the trees than away from them.



## How this applies to the case studies

**Case study 1: A yacht 12 volt supply** The yacht is to be moored in an anchorage. Although it is by the sea, it is among a cluster of other boats and the south side of the harbour faces a large town. We can estimate the average windspeed at about 5m/s at mast head height. Referring to the table on page 13 we see that a wind turbine with a diameter of 1 metre might therefore give us around 3kWh/week. This is well above our projected energy consumption. There are plenty of machines to choose from around this size, but the question is: can we hoist one up to the mast top? There will be much less power available at deck level.

**Case study 2: A holiday cottage** Our holiday cottage is high in the hills but far from the coast, and the free ETSU service predicts a windspeed of 4.5 m/s at our 10 metre tower height. Allowing for the shelter effect of a plantation of trees 100 metres to the north, we decide to say 4 m/s. The table on page 13 shows that a 3 metre diameter machine would provide about 15 kWh/week, which would meet the full demand, in theory. However, the budget will not stretch that far, and since there has to be a diesel generator in the system anyway, we opt for a machine of about 2 metre rotor diameter, giving an estimated 6 kWh/week. This should save a lot of diesel fuel, and will probably keep the house going alone in winter, when there are fewer visitors and the wind is strong.

**Case study 3: A primary school** The school is in a windy place, beside the sea on the west coast, so the prevailing wind comes in over the water. We can estimate an average windspeed of 6.5 m/s at our 20 metre tower height. To provide serious heating input to the building, a 5 metre diameter machine has been chosen. The table shows this will give about 130kWh in an average week, which is almost 1kW average power (there are 168 hours in a week)! In the winter, when heat is needed most, the figure should be well above this. Even in summer time we can be practically sure of the 26kWh we have estimated we need for light and power. After all, the days are brighter in summer, and the school can do without lights altogether if the weather is exceptionally calm.

# Circuit for Two Windmills

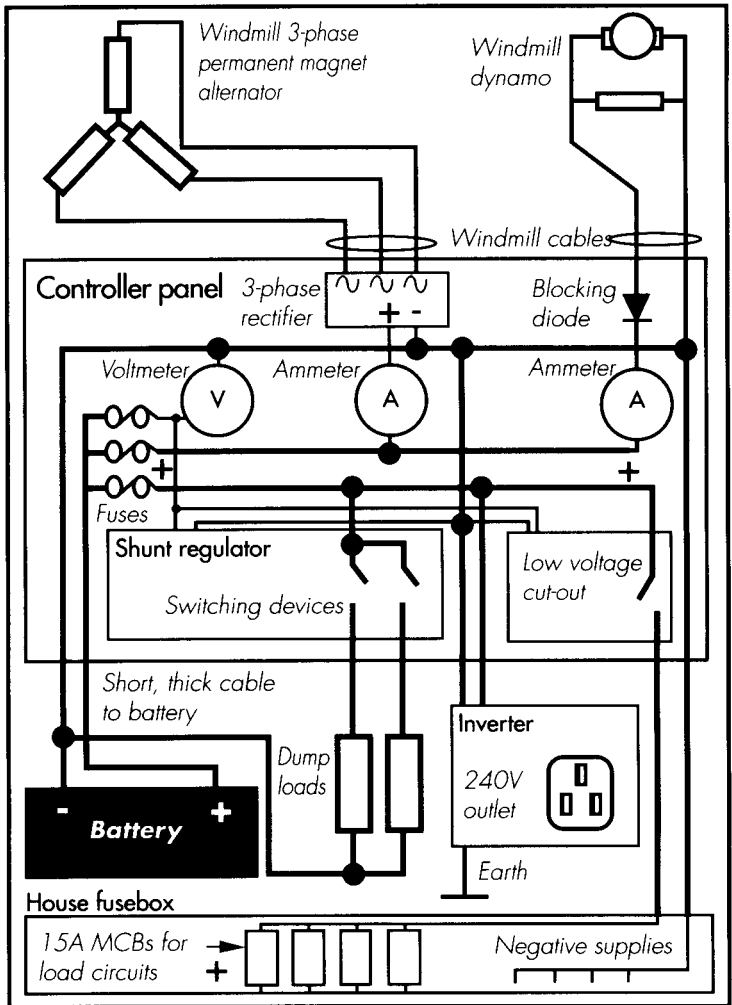


Fig 7.4 Overall systems circuit for a system with two windmills.

## Wind and Water Generators

Wind generators and water generators are essentially the same units fitted with different propellers (impellers, turbines, vanes). Wind generators in particular are making a tremendous impact on the cruising scene. The rest of this section focuses on them, although almost all the information is equally applicable to towed water generators.

### How They Work

A wind generator is a simple device that uses a propeller, or turbine, to convert wind energy to a rotating force that is used to spin a generating device. There are a couple of interesting relationships that hold in this conversion process: All other things being equal, (1) *a doubling of the propeller diameter produces a theoretical fourfold increase in generator output*, and (2) *a doubling of the wind speed produces a theoretical eightfold increase in output*.

In practical terms, at wind speeds of less than 5 knots the wind has insufficient energy to produce output from any wind generator. At 5 knots the more efficient generators will begin to trickle-charge a battery, whereas less efficient designs may not "kick-in" until the wind speed has picked up to as high as 7 knots. This "kick-in" speed is of some importance for sailors, particularly in areas of generally light winds. Once the kick-in speed is reached, the output of the various devices on the market picks up slowly at first, and then rises with ever increasing rapidity as the wind speed rises. Above 10 knots or so, for any given wind speed output is broadly determined by blade diameter. The wind itself, in conjunction with an appropriately sized propeller, contains sufficient energy to meet the electrical needs of just about any cruising sailor.

**Two basic types.** The propeller may be used to spin either a custom-built alternator or a DC electric motor. The differences need not concern us here except to note that although both types produce alternating current (AC) in the output windings, in the alternator-type this output is rectified to DC with diodes (see Chapter 2, Alternators), while in the DC-motor type the output is rectified to DC using a commutator and brushes (see Chapter 6).

Until recently the alternator types all had small propellers (turbines), a relatively low output, and were made in Europe (e.g., the Ampair 100, the LVM, and the Rutland Windcharger), while the DC-motor types had large propellers, higher outputs, and were made in the USA (e.g., the Neptune Supreme, Fourwinds, WindBugger, and RedWing). This neat classification is breaking down. There are at least two DC-motor manufacturers (Fourwinds and Windstream) with downsized propellers, and a correspondingly reduced output, and there are now available alternator type with outputs exceeding the larger DC-motor types (the Wind Baron Neo Plus and several models from Southwest Windpower).

A few models will double up as water generators (the Ampair, Neptune Supreme, RedWing, and Fourwinds II and III). In this configuration the propeller is removed so that a towed impeller can be used to spin the generator. Typically a boat moving at near hull speed will generate more than enough electricity to keep up with the entire DC demand—a very useful capability, especially on transoceanic downwind runs when apparent wind speeds tend to be light and wind generators, as a result, are ineffective.

### Pros and Cons

The alternator types need no brushes to generate electricity, and so in this sense are "maintenance-free," whereas the DC-motor types need brushes to pick up the current from the commutator. The commutator and brushes require periodic maintenance. In addition, a poor contact between the brushes and commutator can create annoying radio frequency interference (RFI—see below).

The lower-output wind generators are almost silent. Of more significance is the fact that they can be used in any wind speed without damage, which means that they can be left operating when a boat is unattended. Their biggest drawback is that, except in sustained strong winds, they simply do not have the capacity to keep up with the demands of an electrically-loaded boat, particularly one with DC refrigeration.

In the past some of the higher-output wind generators, which do have this capacity, have been quite noisy. In addition, in strong winds the centrifugal forces developed by the large propellers (from 54 to 60 inches in diameter) have also caused some units to self-destruct! Improving blade design, materials, and manufacturing tolerances, combined with methods to regulate the top speed of these generators, have eliminated these problems with some, but not all, generators. But even where there are no limits on the wind speed that can be tolerated, the high output can, in itself, be a problem: when a boat is left unattended with little or no load to absorb the generator output, the batteries can be seriously overcharged (particularly gel-cells) unless some means is found to regulate the generator. These two issues of speed control (*governing*) and voltage regulation need a closer look.

**Speed control.** Five different approaches are used to keep the speed of large wind generators under control. The first is simply to tie off the blades when the wind pipes up (the RedWing)—in strong winds and rough seas this can be a nerve-wracking operation! The second, adopted by the WindBugger, is to have a centrifugally activated friction brake inside the generator housing. This brake, however, is not powerful enough to handle sustained wind speeds much above 35 knots. In these conditions the generator once again has to be tied off.

The third, in use on the Fourwinds II and on the Neptune Supreme, is an optional centrifugally-operated air brake that is effective in sustained heavy winds. It is possible, from a mechanical point of view (though perhaps not from an electrical one—see below), to leave a

generator with an air brake in operation on an unattended boat for extended periods.

The fourth, used on the Wind Baron Neo Plus, the larger LVM's and Southwest Windpower models, and the Windstream, is a *furling* or *tilt-back* mechanism that progressively turns the machine out of the wind as the wind speed picks up (Figure 5-26).

The fifth is to design the blades in such a way that they flutter and stall out at higher wind speeds (Southwest Windpower). It is very effective but can also be exceedingly noisy.

**Voltage regulation.** With an effective governor, any wind generator can be kept going in just about any wind condition. However, the boat's DC system may not be able to handle the output! To take an extreme example, one of the high-output generators in a sustained wind of 25 knots or more will produce up to 400 amp-hours a day at 12 volts. Without a heavy load on the DC system, this will eventually cook even the largest battery bank. There are times when some form of regulation is needed.

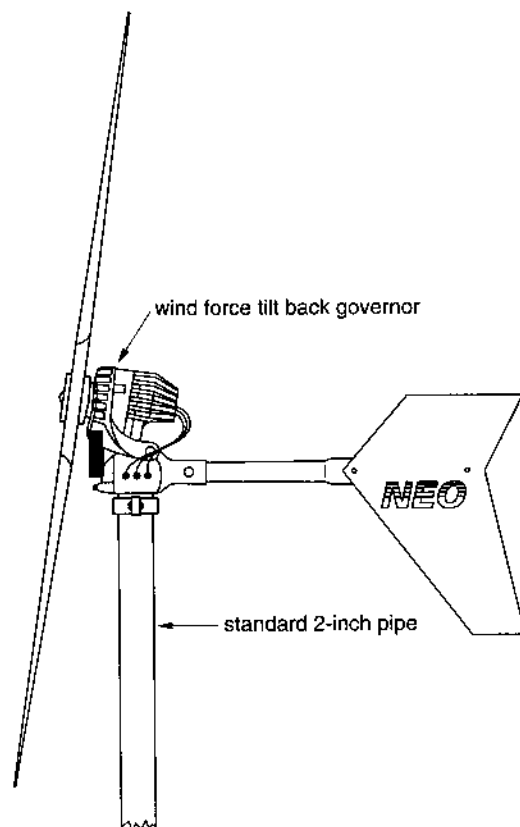
A conventional alternator is regulated by varying the field current to the field coil, altering its magnetism (Chapter 2). All wind generators, however, have *permanent magnets with a*

*fixed level of magnetism*, so this option is not available for controlling output.

Three methods are used to regulate a wind generator's output:

1. Monitor the battery voltage and shut the generator down *manually* when the battery is charged (WindBugger, RedWing). This approach is entirely dependent on the operator, and *cannot be used if a wind generator is to be left unattended* for even a few hours—our WindBugger was caught in a 50-knot squall while we were ashore; the resulting high output melted down the brush holders.
2. Use a device that senses battery voltage and open-circuits the generator (i.e., disconnects it from the battery) when the battery voltage reaches a certain level. But unless the generator has a governor, *releasing the load can allow the generator to speed up uncontrollably and dangerously*. The Windstream uses this method with a blade design and furling tail that keep the maximum speed below damaging levels; the Neptune Supreme also uses it but in this case the manufacturer recommends the optional air brake to control blade speed.
3. Dissipate the wind generator's unwanted output as heat, which can be done through transistors mounted on a heat sink (a *shunt* regulator—Ampair, LVM, Windcharger, and Fourwinds II and III), or by diverting the generator's output to another load (a *dummy* load) as the battery comes up to charge (a *charge-divert* regulator; the output is normally fed to a fixed resistor, but it could be switched into a hot water tank and put to useful work—Wind Baron Neo Plus).

Figure 5-26. Tilt-back mechanism for controlling (governing) maximum speed on a wind generator. Note that as the unit tips back, the blades will be spinning in a more horizontal plane. There must be adequate clearance from all rigging. (Wind Baron)



**Shunt regulation.** Shunt regulation is generally of the constant-voltage type: The wind generator output is cut back progressively as battery voltage rises, rather than simply being chopped off when a set voltage is reached. Normally regulators are set to around 14.4 volts, which means generator output starts to taper off around 13 volts—too low for effective fast charging, or equalizing, of deep-cycle batteries. Shunt regulators therefore should have a disabling switch (Figure 5-27) so that at times the full generator output can be maintained until the batteries come up to 14.0 volts or higher. Note, however, that anytime a wind generator is used with the regulator disabled, the battery voltage must be monitored since it is quite possible to do some serious, and permanent, damage through overcharging.

When a shunt regulator dissipates excess



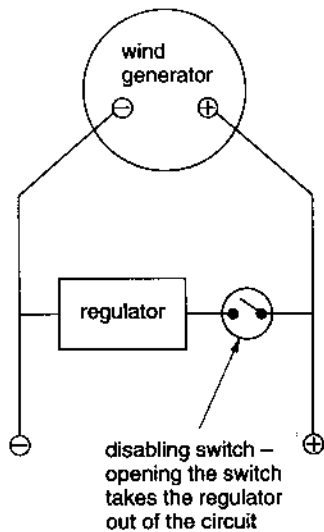


Figure 5-27. Shunt regulation circuit.

charging current it creates heat—sometimes quite a bit of heat. A regulator must be in a cool place with good airflow (Figure 5-28). Shunt regulators generally have a fairly low amperage rating, sufficient only to handle the loads of the wind generator in question. If the wind generator output is teed into the ship's battery-charging circuits, the engine-driven alternator can feed back through the shunt regulator, burning it up and causing a severe fire risk. A protective diode sized to handle the wind generator's full output must therefore be installed between the shunt regulator and the ship's battery-charging circuit (Figure 5-29).

This diode may be built into the regulator, in which case the regulator's set-point will be compensated for the diode-induced voltage drop on the charging circuit (Chapters 1 and 2), but if a diode has to be added it will cause a voltage drop of around 0.6 volt. Now the regulator will start to cut in when the battery voltage is around 12.4 volts and limit output at the battery to 13.8 volts. If the regular charging circuit also incorporates diodes for split charging, there will be an *additional* 0.6-volt drop (Figure 5-30A), producing a cut-in voltage at the battery of 11.8 and a final voltage of 13.2—much too low to be of any use. In other words, the wind generator must be hooked in *downstream* from any alternator split-charging diodes, and if the wind generator regulator is adjustable its setting must be raised to compensate for the total voltage drop on the charging circuit. To charge two batteries independently, a wind generator will need its own pair of split-charging diodes to avoid paralleling the batteries through its charging line (Figure 5-30B).

Note that the Fourwinds shunt regulator is

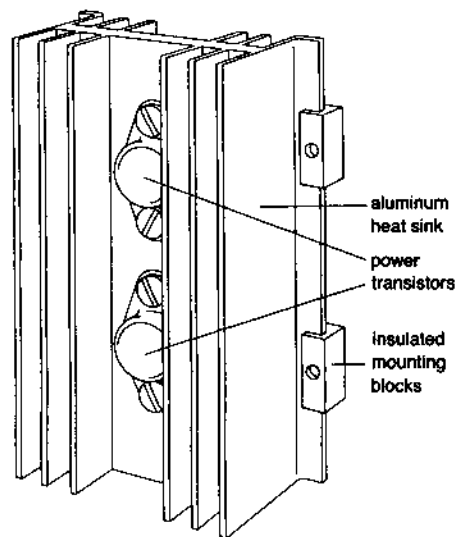


Figure 5-28. Shunt regulator. The regulator is a solid-state device sensitive to battery voltage. As the voltage approaches a preset limit (for example, 14.0 volts for a 12-volt battery), the regulator allows current to be diverted increasingly from the battery to be dissipated as heat through the heat sink. (Jim Sollers)

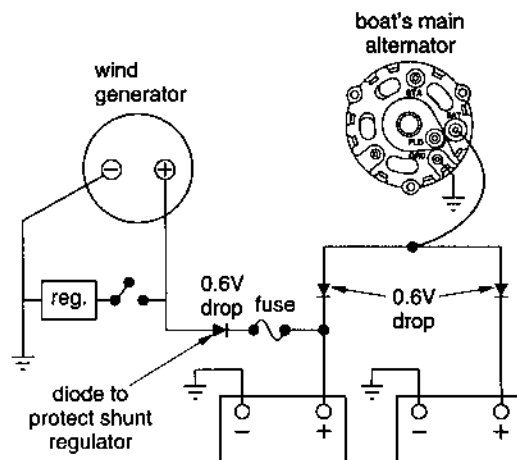
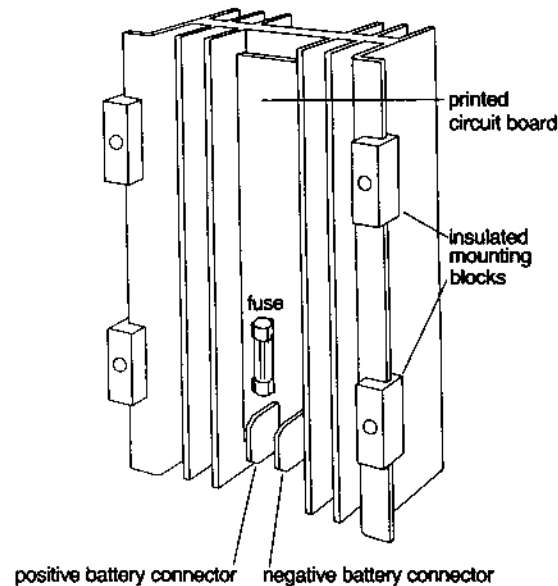
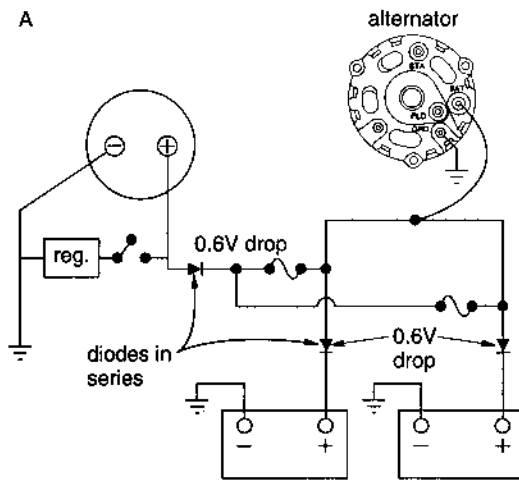


Figure 5-29. Wiring schematic for a wind generator charging a single battery, using a shunt regulator.

Figure 5-30A. Charging two batteries—incorrect installation. This approach produces excessive voltage drop.



currently the most sophisticated available with a two-step charging program, allowing settings either for bulk charging and float charging or else for bulk charging and equalization of liquid-electrolyte batteries.

**Charge divert regulation.** The principle is the same as that for shunt regulation. Excess wind generator output is fed to a resistor and dissipated as heat. With a larger wind generator a lot of heat can be created! The resistor must be placed in a location with good airflow, particularly if the generator is to be left in operation when the boat is unattended.

The Wind Baron Neo Plus regulator is mounted on the negative side of the batteries, where it can interact adversely with any other regulator set to a higher voltage. If, for example, the wind generator regulator is set to hold the wind generator output to 14.0 volts, but an alternator has a bulk-charge voltage setting of 14.4 volts, once the battery voltage is above 14.0 volts, the wind generator regulator will divert the alternator's output to its resistive load instead of charging the batteries! *The solution to this conflict is to disable the wind generator regulator when the alternator is on line* (and also when equalizing wet-type deep-cycle batteries). Wind Baron provide a couple of leads to do this. These can be wired either to a manually operated switch (mounted next to the engine ignition switch) or to an oil pressure switch on the engine (in which case the wind generator regulator will be disabled automatically whenever the engine is running).

**Making choices.** Making sense of these many factors to effect an informed choice between wind generators is not easy. First one must assess the boat's power needs, the type of cruising that will be engaged in, and the available winds in the

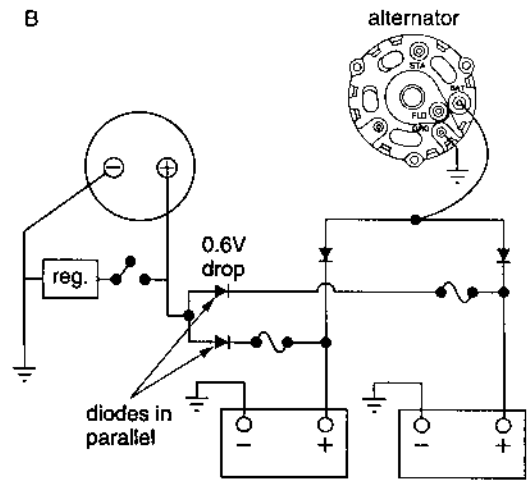


Figure 5-30B. Charging two batteries—correct installation.

cruising grounds. For example, someone intending to do transoceanic passages would probably benefit from a water generation option, while another person intending to cruise the Gulf of Maine in the summertime, where winds are characteristically below 10 knots much of the time, might consider solar panels a better investment!

In making a choice the tendency is to go for the higher-output wind generators on the assumption that more must be better. Although this is often so, it is not necessarily the case. If a boat is used on weekends and for an annual vacation but is kept on a mooring for the rest of the year, the primary function of a wind generator is likely to be to keep up with the loads on the mooring—the bilge pump, perhaps a 12-volt refrigeration unit (although this may be more than a small generator can handle), and a float charge on the batteries—rather than the load when cruising. A lower-output wind generator that will safely run continuously—the Ampair, LVM, Rutland Windcharger, Windstream, or Fourwinds III—may prove a better investment than one of the high-output units. The low-output unit will be essentially maintenance-free, quiet, and unobtrusive. It will continue to produce electricity in storm conditions on ocean passages after many of the higher-output types have been shut down. To be sure, over a weekend's cruising it will not keep up with the load and the batteries will slowly be discharged, but then they can be replenished during the week. On longer vacations the engine-driven alternator will be needed to supplement the wind generator.

At the other end of the scale from a boat used only infrequently is a boat used for extended cruising in, for example, the Caribbean. Fan and refrigeration loads will be high and one of the

## Comparing Wind Generators

There are no industry-wide standards for comparing wind generator outputs. Some specifications are borderline fraudulent, others just hopelessly optimistic.

Certain of the alternator types have stator coils that will overheat at higher levels of output. To protect the coils from burning up, a temperature-sensitive switch is added (a *winding protection thermostat*). As the wind pipes up, or in a particularly hot environment, the switch may be off more than it is on, crippling output. Beware a product description in which the small print reads "typical performance, cold windings," or "voltage limiter inoperative" or something similar—Figure 5-31!

As with battery chargers *it is essential to know at what voltage the rated amperage is attained*. Most companies use the output at 12.0 volts for rating purposes, although this is too low for battery charging! For any given wind speed, a much better basis for comparison would be the output (amps) at 14.0 volts (for a 12-volt system). In any event, when making comparisons, use the same voltage.

What is less obvious is that *the kick-in speed is also affected by battery voltage*—the higher the voltage, the higher the kick-in speed. When making comparisons between generators, *be sure the kick-in speed is at 12.0 volts*. At this voltage some wind generators will get going in 5 knots of wind, while others will need 7 or 8, severely affecting their utility in most popular

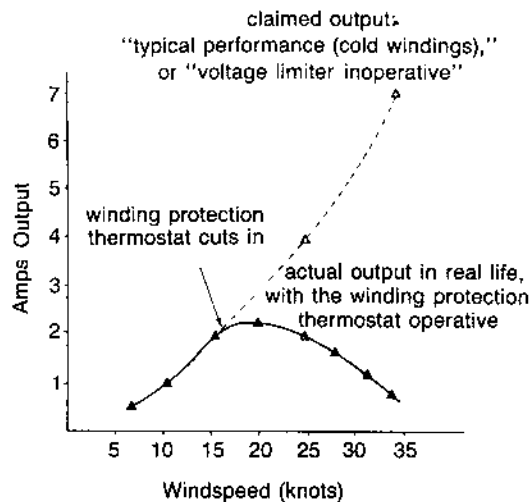


Figure 5-31. Performance curve of a wind generator with a "winding protection thermostat."

*cruising grounds*. It is also important to remember that even in the trade wind belt (e.g., the Caribbean) most boats spend most of the time anchored in relatively protected anchorages where wind speeds much above 10 knots are uncommon. As a result, *so far as output is concerned the two key indices are the kick-in speed at 12.0 volts and the output at 14.0 volts given a wind speed of 10 knots*.

Table 5-5. Wind Generator Comparisons

Machine	Type diam.	Prop. (inches)	Weight (pounds)	Governor option	Regulator option	Water option	Output (amps) at 10 knots	Warranty period (years)
Fourwinds II	DC-M	60	22	yes	yes	yes	5.6	3
Fourwinds III	DC-M	40	20	NA	yes	yes	4.0	3
Neptune Supreme	DC-M	60	25	yes	yes	yes	4.5	1
WindBugger	DC-M	54	38	no	no	no	4.0	1
RedWing	DC-M	60	35	no	no	yes	2.0	1
Windstream	DC-M	42	20	yes	yes	no	1.0	1
Ampair	Alt	36	20	NA	yes	yes	1.2	3
LVM 3	Alt	33	15	NA	yes	no	1.0	1
LVM 5	Alt	60	30	yes	yes	no	3.0	1
Rutland Windcharger	Alt	36	28	NA	yes	no	1.3	1
Wind Baron Neo Plus	Alt	60	20	NA	yes	no	5.0	2
Southwest Windpower "Air Marine"	Alt	45	11	NA	Incl.	no	2.0	3

Notes:

All figures are based on manufacturers' specifications. When it comes to output ratings some are more optimistic than others!

DC-M = DC-motor

Alt = alternator

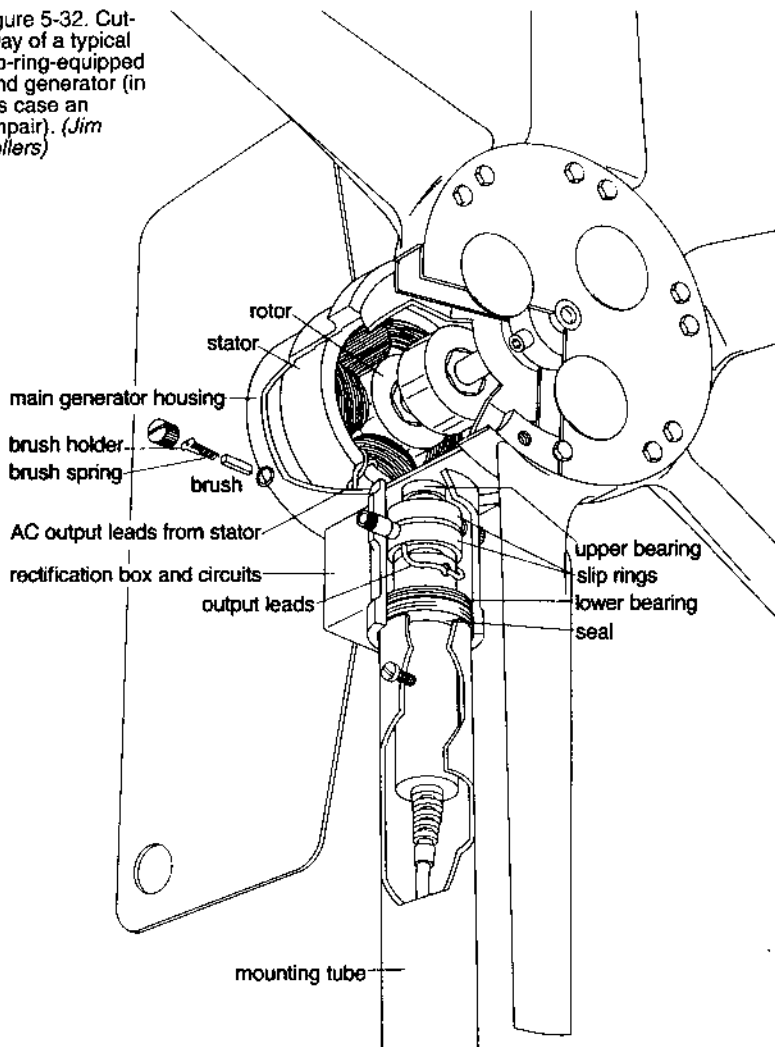
NA = Not Applicable (does not need overspeed control)

Incl. = included

Output (amps) = the manufacturer's given output at 10 knots windspeed. (Rating methods vary widely—there are no industry standards. This column can be taken only as a very rough guide, it is inherently unfair to those manufacturers who rate their products conservatively.)

At the time of writing (1994) the Wind Baron Neo Plus is a new model, untested in the marine field.

Figure 5-32. Cut-away of a typical slip-ring-equipped wind generator (in this case an Ampair). (Jim Sollers)



higher-output wind generators will be a far more valuable investment than a small generator. Factors determining which generator is chosen will likely include the reputation of the manufacturer, the ability to leave the generator operating in any wind speed, the availability of a voltage regulator if the unit is to be left operating unattended, and, of course, price.

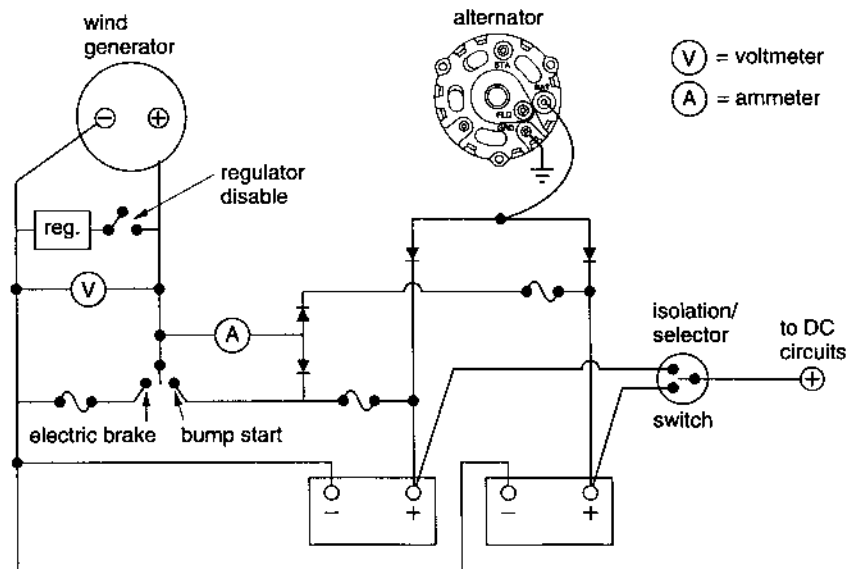
Either way, on any boat that does not have an AC generator running 24 hours a day, a wind generator can transform a cruising lifestyle. There is no other device on the market that can come close to generating as much power without having to run an engine. In many instances a wind generator can almost completely free a sailboat from any need to run its engine, with major savings on fuel and maintenance bills, not to mention the reduction in noise and elimination of exhaust fumes.

### Installation and Maintenance

Although some wind generators are mounted in a fixed alignment, this severely limits their effectiveness. Much to be preferred is a wind-seeking capability, produced by hanging the generator in the rigging, or by placing it on a pole-mounted bearing assembly into which are built brushes and slip rings (Figure 5-32). The brushes, rotating with the generator, receive its output, feeding this output to the fixed slip rings (or vice versa), which transmit the output to the batteries. (Note, however, that sometimes a generator is mounted on a bearing assembly with-

Figure 5-33. Wind generator schematic with shunt regulation, extended to include electric braking, a "bump-start," and volt and amp meters. Notes:

1. The electric brake functions by shorting out the generator output. This must be done using a *momentary-type* switch, that cannot accidentally be left "on" (see the text).  
 2. The "bump-start" switch can be used only with DC-motor-type wind generators. It allows battery current to be used to get the generator spinning in marginal wind conditions. It too must be a *momentary-type* switch. 3. *It must never be possible to operate an electric brake and a bump-start device at the same time, since this would put a dead short across the battery!*



out slip rings. In this case, when the generator turns, it twists its output cable. Statistically speaking, the cable should unwind itself, but in some instances it will need to be unwound manually from time to time.)

Clearly any generator must be mounted high enough, or in a sufficiently out-of-the-way location, to avoid being a hazard to people moving around on deck. But on the other hand, unless it has a remotely operated brake (as do some models of the Fourwinds II and the Air Marine), it has to be accessible enough for the operator to be able to shut it down (by turning it out of the wind) and tie off the blades, sometimes in rough conditions when the unit will be swinging wildly from side to side. These contradictory requirements are not easy to balance. Inevitably there are times, particularly with the larger generators, when shutting a machine down can be quite hazardous. (Wind generators can be braked electrically by shorting the output leads, locking the generator magnetically—Figure 5-33. The problem with electric braking is that when it is done at high speeds and levels of output, it tends to burn up the generator, and in any case still may not stop it.)

Wiring a generator is simplicity itself. Almost all are attached directly to a battery so that when the boat is unattended, and the battery isolation switch is turned “off,” the generator can still be left “on line.” In any event, the wiring must be such that *whenever the battery is isolated from the ship’s circuits, the wind generator is also isolated* (Figure 5-33). If a wind generator is left connected to the DC circuits without a battery to absorb its output, *it can drive up the voltage to a level that will destroy most of the electrical equipment on board!* Wire should be sized for a maximum 3% voltage drop at full rated output (Chapter 3).

The DC-motor types require a diode in the positive cable to prevent a reverse drain from the batteries when the generator is not running (this diode may already be present with some regulators); the alternator types already have this diode in the rectification circuit. All models must be fused in the positive cable close to the batteries. *This fuse is an essential safety device: It prevents a short in the generator circuit from putting a dead short across the battery and so melting down the wind generator wiring.*

The problem with such a fuse is that if it blows, it will open-circuit the generator, which may, in high winds, then self-destruct. To avoid this situation the fuse rating must be at least as high as the *maximum possible output from the generator*, which, in the case of the larger generators, may be 25 amps or more. A 40-amp fuse will, in most instances, serve the purpose of ulti-

mate wiring protection without threatening the generator.

It is desirable, but by no means necessary, to install an ammeter to monitor performance. Battery voltage can be measured with existing meters.

**Maintenance.** Given the wide variety of wind generators available, it is possible to make only a few general points on maintenance. Brushes and brush springs are the most obvious point of failure (Figure 5-34). Alternator types will have brushes only on the slip rings, and none at all if no slip rings are present. DC-motor-type generators will have brushes to collect the output from the commutator, as well as slip ring brushes if they are fitted. Some larger generators have four brushes on the commutator.

Check brushes and brush springs periodically for wear, corrosion, and loss of tension. If brushes or springs are defective, inspect the commutator or slip rings for burning or pitting (see page 216).

Check the shaft bearing occasionally by gripping the blades and attempting to move the shaft up and down and side to side. Any play indicates the need for bearing replacement, which will require generator disassembly. See below for one or two precautions to observe when taking the unit apart.

Check all external fasteners periodically. Most wind generators are subject to a certain amount of vibration, and fasteners will sometimes work loose. Add a drop of Loctite thread-sealing compound when replacing them.

To cure excessive vibration, if the turbine blades can be detached individually take them off in *opposite pairs*, weigh them on a postal scale, and correct any differences. Be sure to mark them so that they can be replaced as matched pairs. After reinstallation, check the alignment as shown in Figure 5-35.

Fiber-reinforced plastic blades are UV-degradable in sunlight. If the surface becomes crazed and powdery, sand them lightly and paint with a two-part polyurethane paint.

The leading edge of unprotected spruce blades will wear down just from the impact of bugs, rain, etc. The blades must be kept smooth for maximum efficiency and noise reduction; recoat the blades with epoxy or two-part polyurethane.

Many generators have aluminum housings with stainless steel fasteners, shafts, and bearings. Add salt spray and this is a recipe for corrosion. Rinse the housings from time to time with fresh water. Watch closely for any signs of galvanic interaction. If present, remove the relevant fastener or part, apply a corrosion inhibitor (such as Tefgel, Duralac or a teflon-based grease), and

Figure 5-34. Wind generator components—alternator type.

**(Top)** This rotor has two permanent magnets; each has a set of stator coils. One set of coils can be seen on the right in the generator housing; the other set is in the other half of the housing, which has been removed. **(Below left)** Looking into the base of the same generator. The output shaft and slip rings (see above) have been removed to expose the brushes. **(Below right)** A complete wind generator kit.

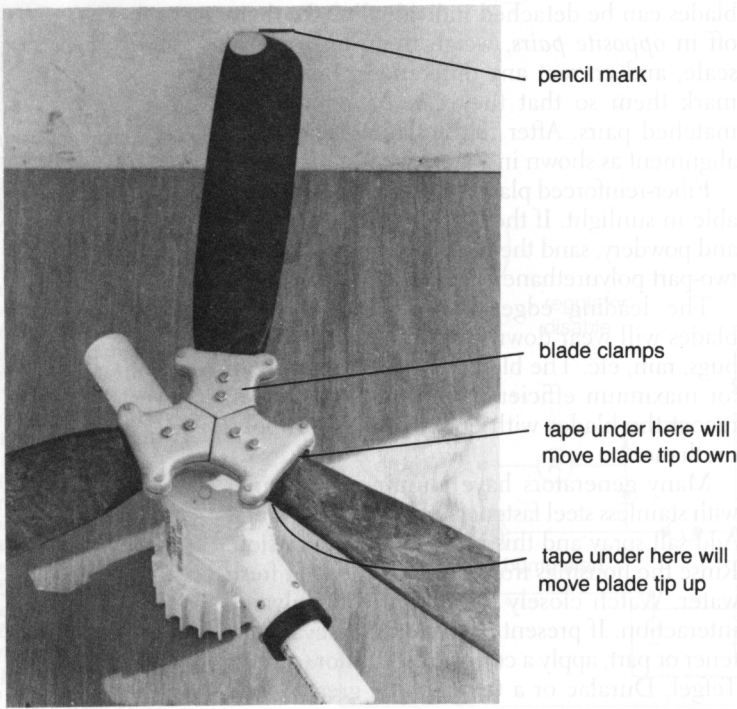
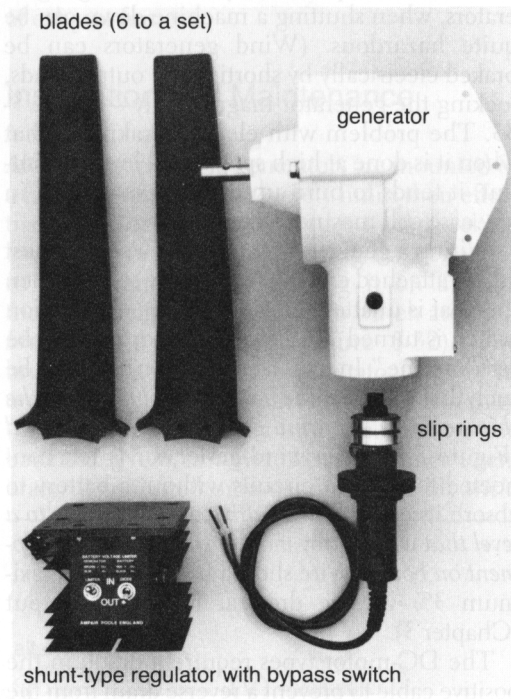
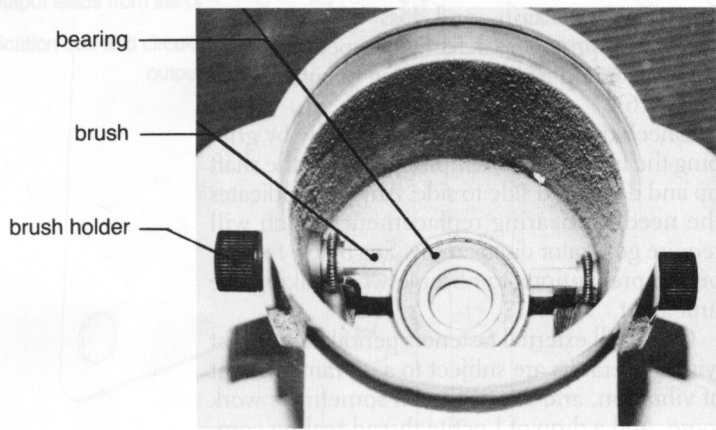
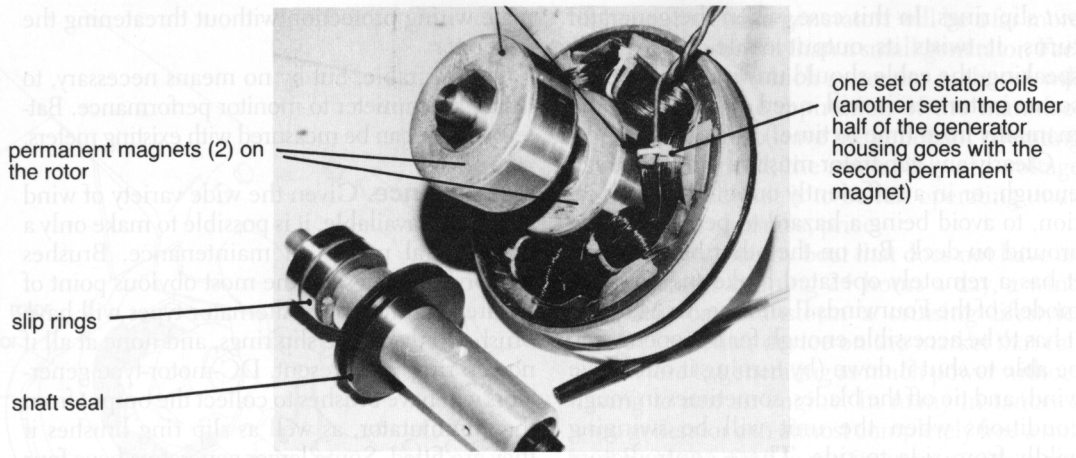


Figure 5-35. **(Left)** To check wind generator blade alignment, place the generator, blades up, on a flat surface with one blade tip just touching a wall. Draw a pencil mark on the wall at the blade tip and slowly rotate the blades, checking the alignment of each as it passes the mark. If blades are out of alignment, adjust them by putting pieces of tape, or some other shim material, under the blade clamp.

replace. Pay particular attention to the pivot points on any air-brake, furling, or tilt-back mechanism, making sure that these are free and lubricated.

## Troubleshooting and Repair

**Radio frequency interference.** A poor contact between a brush and a slip ring or commutator can create arcing that generates *radio frequency interference* (RFI). The frequency will vary with the wind generator speed, but is most likely to interfere with ham radio operations, sometimes on boats a good distance away. The DC-motor type of wind generator is the worst offender. Solutions are to keep brushes in good condition and commutators and slip rings clean. If problems persist, capacitors should be wired across the output leads of the wind generator as close to the brush holders as possible. Bill Owra, manufacturer of the Fourwinds, suggests three in parallel, rated at 7.5 microfarads, 0.01 microfarads, and 0.001 microfarads (available from electronics stores; some are polarity sensitive, and must be installed the right way around, while others are not).

**Erratic output.** If the generator has brushes (DC-motor type, or any wind-seeking generator with slip rings), check the brushes for adequate spring tension and the slip rings and/or commutator for a clean mating surface. Otherwise look for loose or corroded connections (see the various voltage and resistance tests in the next paragraph).

### No output from the generator:

1. Check all fuses and switches (there may be a fuse inside any voltage regulator).
2. With the generator spinning in a wind usually high enough to produce output, check the voltage across the output leads *as close to the generator as possible*. It should be a little above battery voltage (normally around 0.5 volts higher—a good digital multimeter is needed), in which case the wind generator is working. If it is high (it may run to 40 volts or more), the charging circuit is open at some point; check the fuses and switches once again. Open-circuited wind generators can give quite a shock at high speeds; *be careful*.
3. Check the continuity of all wiring with an ohmmeter (see Chapter 3). Be sure to disconnect the generator from the batteries first and immobilize its blades; any output is likely to damage the ohmmeter.
4. With the generator still disconnected from the

battery, let the blades spin and check the open-circuit voltage. It should be well above battery voltage.

5. If there is no output, disconnect any voltage regulator and try again.
6. Still no output: Check all brushes and brush springs for possible sticking.
7. Still no output: If a rectifier is fitted (alternator types), test the diodes as outlined on page 73. On DC-motor types inspect the commutator (see page 216).
8. Finally, as a crude test disconnect the output leads from the batteries, short them together, and try spinning the propeller blades by hand. If everything is working, they should be noticeably more difficult to turn than normal. If not, there is likely some internal fault in the generator; check the stator (alternator types) or armature (DC-motor types).

**Generator hard to turn.** The output leads may be shorted (see above), but otherwise there is a mechanical problem. Most likely are (1) corroded bearings from the failure of a shaft seal—both bearings and seals need replacing; (2) friction from a bent shaft—it may be possible to remove it and straighten it; or (3) magnets coming loose and binding (the generator will probably be “squeaking”). Many magnets are simply glued in place; moisture in the marine environment can cause corrosion under the glue bond, causing the bond to give way. If no other damage has been done, after you’ve cleaned the seating surfaces you can glue the magnets back in place with an epoxy glue (MarineTex, often found on boats, will do), *making sure that each magnet goes back in the same place from which it came, and the same way around* (don’t let them get mixed up or turned around!). Handle magnets with care (they will shatter if dropped), and clamp them gently while the glue sets (they are brittle and easily cracked).











If there is evidence of moisture inside a wind generator, it is a good idea to flush the various coils with mineral spirits, blow them dry (with an air compressor if available, but otherwise with the exhaust from a vacuum cleaner or even a bicycle pump) and then bake the unit in an oven at no more than 200°F (93°C) for several hours.

## Troubleshooting Chart 5-2.

### Wind Generator Output Problems.

**Symptom:** Generator provides no battery charging when battery voltage is below the preset cutoff level of the voltage regulator (if one is fitted).

**Note:** Many of the following tests involve checking the voltage on an open-circuited generator. An open-circuited (i.e., disconnected from its battery) wind generator can produce up to 100 volts and give a severe shock. Be careful.

Disconnect the generator leads at the battery and check for voltage with the generator spinning. Is voltage present? 	 Generator is OK.
Disconnect the output leads at the generator and check for voltage at the generator output terminals with the generator spinning. Is voltage present? 	 Generator is OK. The fault is in its circuit. Check all fuses, switches, breakers and terminals. Bypass any diode or voltage regulator to see if this is the problem.
Inspect all brushes and brush springs for wear, corrosion, loss of tension, or sticking. Replace as necessary and spin again. Is voltage present? 	 Generator is OK.
<i>DC-motor-type generators:</i> Inspect the commutator for burning and pitting (page 216); <i>Alternator-type generators:</i> Test the rectifying diodes (page 73); repair as necessary and spin again. Is voltage present? 	 Generator is OK.
Short together the output leads from the generator and turn the generator by hand. Is there more resistance to turning than normal? 	 The generator is probably OK. Go back to the beginning.
The generator is probably defective: Check its stator or armature (see Chapters 2 and 6).	

**Disassembly.** It is impossible to be specific, but these are a few points to watch for:

1. It is frequently crucial to align housing halves to within plus or minus 1 degree. Before separating any housings, mark the two halves for an exact realignment. A line scribed across the joint works best.
2. The permanent magnets used in wind generators are powerful and hold housings together with a strong magnetic force. Some housings have threads for the addition of jacking screws to aid in separation; others must be levered apart carefully with screwdrivers. When replacing them, keep fingers well out of the way: The magnets may grab the housings and pull them together uncontrollably.
3. The magnets will attract any metal particles or flakes lying around. *Work in a scrupulously clean environment and check the magnets before reassembling.* It is particularly important to keep the air gap between the magnets and the stator (armature) clean.
4. Whenever a unit is opened, pay special attention to any shaft seals where the drive shaft exits the housing. Some units rely solely on "sealed" bearings and have no additional shaft seals. These bearings do not always keep out salt water for long and may need replacing.
5. Various armature and stator tests can be carried out as outlined in the sections on universal motors (Chapter 6) and alternators (Chapter 2).
6. Any glued-in-place magnets should be given a tug to make sure they are still firmly bonded.



# How to get it up and down, without getting into trouble!

I was recently asked by Ralph, a member of the A.T.A. to rig up some information on methods of pulling down and putting up wind generators. While Ralph who is the proud owner of a couple of the smaller Dunlites, probably knows more about these machines than most of us his knowledge does not include methods of handling the larger 2 kW machines.

In particular Ralph wanted to know how the late Tony Stevenson of Survival Technology used to handle the 2 kW units. After some digging around this is what I came up with.

When you are 60, 80 or even 100 feet up in the air accidentally dropping a 2 kW wind generator is not a good idea, It could give someone a very sore toe, not to mention what it would do to the generator.

They are so heavy that there is no way you can lift them yourself, so you need an arrangement that can do the lifting for you.

Here is the simplest way of lifting this heavy bit of machinery down from the heights. This method was reportedly used by one of the Dunlite technical people a few years ago. (Incidentally for people who don't know Dunlite no longer manufacture Wind Generators or supply complete spares for those they did).

Upon arriving at this particular dead, wind generator, the Dunlite guy after glancing up at the tower said "right, we'd better pull it down". The fact that the guy had no lifting gear, no poles or gallow, arrangement didn't seem to worry him. Instead he disappeared in a puff of dust



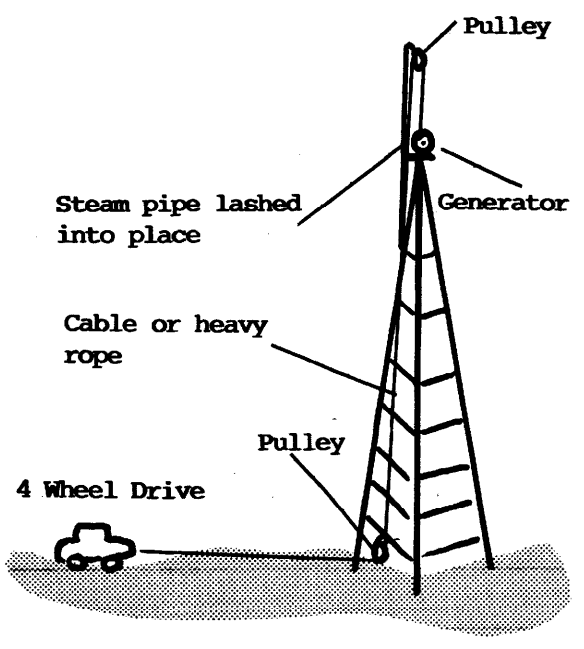


Figure 1. Basic lifting arrangement.

off to the closest town. He soon returned brandishing a 10 foot length of 2" steam pipe.

Next he dug around and came up with a coil of rope and a few pulleys. He climbed the tower and lashed the steam pipe securely onto the tower so that about 5 feet of pipe extended above the top of the tower. He then hooked one pulley over the top of the steam pipe. He hooked the other pulley onto the bottom of the tower. The rope was attached to the front of the car and run through the bottom and top pulley and secured to the wind generator.

The tail and propellers should be removed prior to removing the actual generator. After unbolting the pant for removal the car at ground level moves a little away from the tower to lift the pant free from the rest of the wind generator. Next the vehicle slowly drives back to the tower, lowering the generator pants. A 4-wheel drive is best for this or it is a bit hard on the clutch of a two-wheel drive vehicle.

Without too much trouble you can build a set of gallows which makes it easier and safer to work with these heavy

wind machines. With the approach previously described very nasty things would happen if the bottom of the steam pipe clipped off the cross beam of the tower. Also because of the position of the pipe, the top pulley is not directly above the resting position of the generator. This means when you are installing a generator you must leave it over, away from the pulley, to get it into position.

To solve these problems a set of gallows can be built. They basically consist of the 10 foot pipe plus an arm at the top with a hook for the pulley. This brings the pulley position out to be directly above the generator. A small metal tab is welded into place half way along the length of the pipe. This has a hole drilled into it and is used to fix the pipe securely to the tower cap at the top of the tower. The final feature of the gallows is at the base of the pipe where a number of approaches can be used to improve the fixing of the pipes base to the cross bar. This could include the use of a scaffolding clamp or adding a bar which runs at a right angle to the main pipe making it easier to secure to the cross bar.

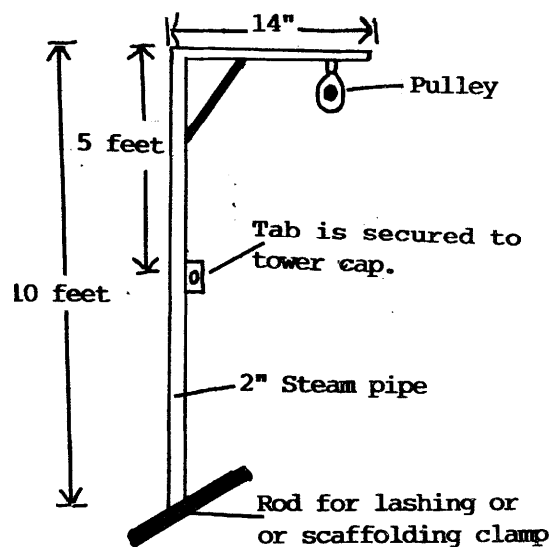


Figure 2. Heavy duty Gallows.

Whenever handling a 1 kilowatt or large machine it is important to use the pulley at the bottom of the tower. If you don't you will probably bend your steam pipe and might end up dropping your beloved generator. With large generators it is also better to use a steel cable. The cable needs to be more than double the height of the tower so that when the equipment is lowered, there is enough cable for the run from the car up to the top of the tower and back down to the bottom.

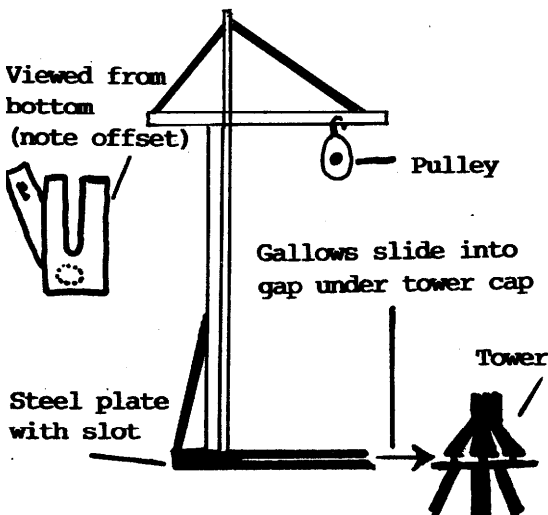


Figure 3. Light duty (750 w) gallows

There is another set of gallows which you can use for smaller wind generators, (up to 750 watt Dunlite size). Its small and easy to use, but don't make the mistake of trying to use it on something too big.

If you have a look at the top of a 750 watt Dunlite tower you notice at the top of the tower is the tower cap. It is a cast metal thing bolted to the three steel angle legs. The top of the tower cap is flat and has four bolts which poke up from this flat face.

The base of the wind generator turntable assembly is fixed to these bolts. However, they are not bolted tightly together and there is a gap of about 1cm,

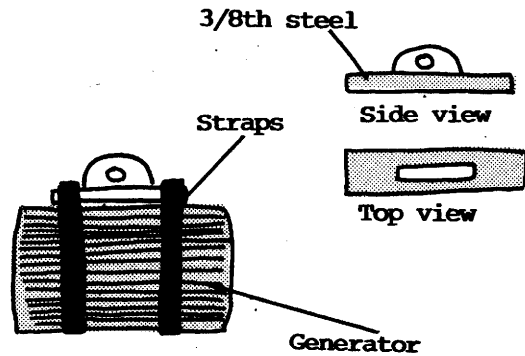


Figure 4. 2KW. Generator lifter.

By sliding a metal plate (complete with a pole and gallows attached) into this gap you instantly have the gear to erect or pull down one of the smaller wind generators.

If you are planning to do some work up a wind generator tower, don't forget safety. Falling from a 60 foot tower, the ground feels mighty hard, If possible use a safety harness, otherwise, lash yourself securely into place before you start work. Also take a bag for tools as it is important to have your tools readily accessible.

Good luck.



Hanging safely from the tower thanks to the safety harnesses

CHAPTER

3

# TOWERS

If you want to generate electricity from the wind, you must consider using a tower; maybe the reasons are not so obvious, but they are simple -- increased height ( above ground level ) means more wind ( i. e., more usable energy ) and less turbulence. Scramblin' up and down ( or around the top of ) a tower will make things more adventurous, but this has nothing to do with the importance of more wind/ less turbulence. If you're into wind-generators, you'd best get used to the idea of climbing towers.

## Turbulence and windspeed vs. Height

You can't see the wind ( only its effect on things ) but, for a moment, let's pretend that you can. What do you see? Probably the first thing that you'd notice is that it moves more slowly at ground level. Know why? Even if the ground is level and fairly smooth, it will provide friction ( or a resisting surface ) to the free agent of moving air, and therefore, slow it down. This slow-moving air will, in turn, provide friction for the air above it, and slow it down. This goes on and on; if the wind was constant in both direction and speed, we might be able to see barely distinguishable boundaries between the layers of faster- and slower-moving air. Normal wind will, however, fluctuate in speed and direction, so these boundaries will be constantly changing, and this has a name: Turbulence. If you were standing in the midst of it, you would not fully appreciate its effect; in most instances, it isn't going to be the old "sock you around, throw you to the ground" kind of thing. To an aeroturbine, however, any disruption of a flow of air will steal power it might otherwise use. With some types of aeroturbine, turbulence is more than power-robbing; it can cause some potentially destructive stresses on the machine's components.

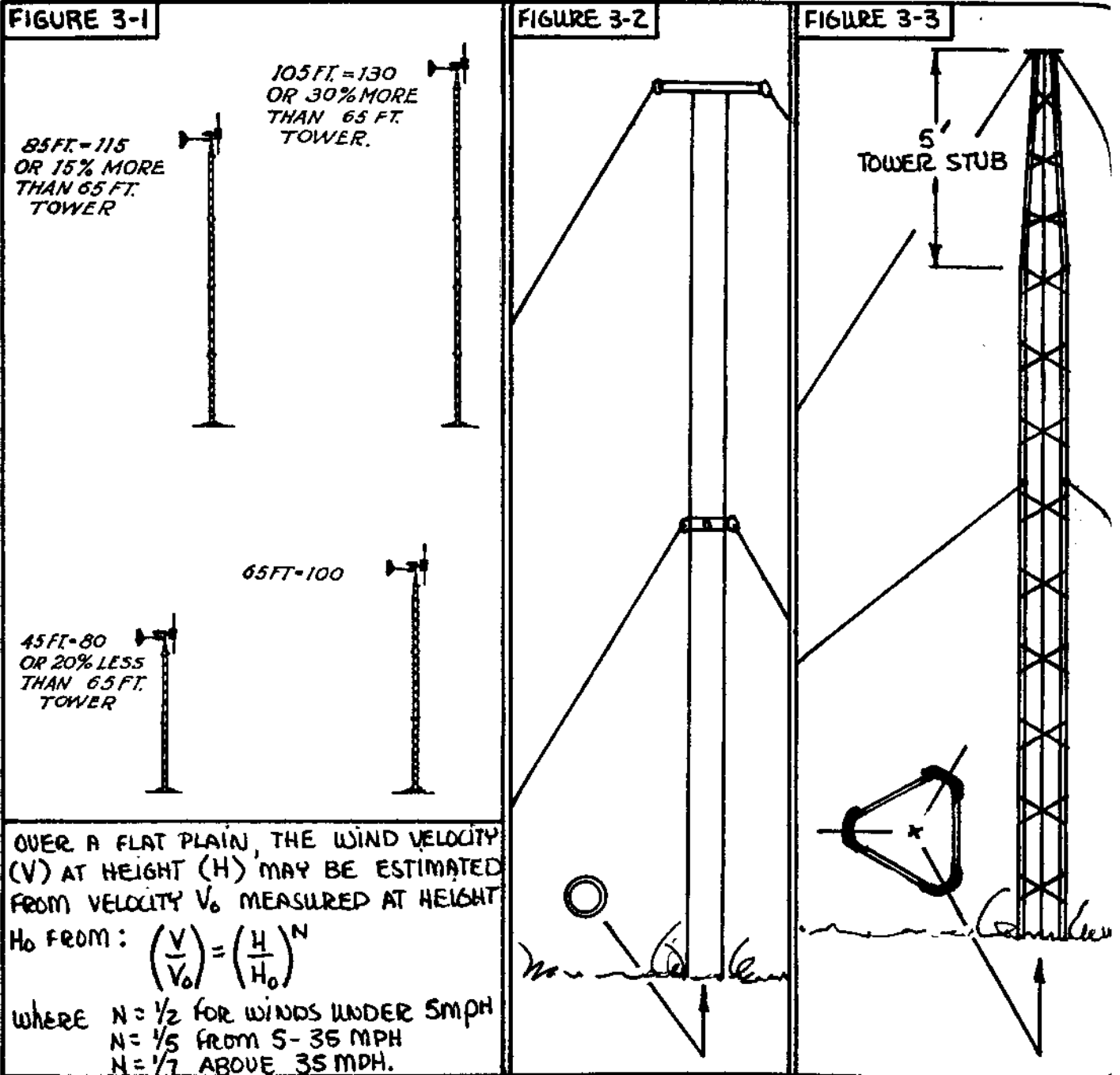
Turbulence will be more pronounced with rougher terrain, the more obstructions there are rising above ground, the higher the windspeed, and the more gusty it might be, so it's not something to be ignored or considered insignificant. Rudimentary observations will show detectable differences in windspeed at even ten-foot intervals of height above ground. A formula has been developed ( see Fig. 3-1 ) to aid in figuring out what the windspeed would be, say, at 45 feet above the ground, for a given windspeed at ground level; this applies to a flat, level plain, but it can be somewhat of an indicator in obstruction-ridden or rough ground conditions, too. In the wind-energy field, thirty feet of tower is considered to be the minimum required over a level plain.

If you play with the windspeed vs. height formula, you'll probably want a height that will have the top of the tower snaggin' satellites; a look at the cost for such a venture will quickly bring you out of the heavens ( or clouds ) and much closer to earth. Knowing that it will be somewhere between the two may not be of much value, so let's look at some relationships between where the tower goes and how high it should be.

Determining Tower Site and Height

The aeroturbine, and its tower, should be located as close to the batteries as possible; this cuts down on the need for a lot of electric wire and the resultant  $I^2R$  losses ( power that is robbed by the resistance of the electrical wire ). For the same reason, the batteries should be located as close as possible to the motors, lights, appliances, etc., that use this power. Sometimes this cannot be avoided, but with long runs of electrical wire the only way to decrease the losses ( for any given voltage ) is to go to a larger size of wire and this will cost more.

The tower should be located in an area where it can be raised from a horizontal position to a vertical one. This may seem almost too simple a statement to make, but people do make boats



( or whatever ) in houses and find, when removing the finished product, that it won't fit through the door or any windows. If you build the tower from the ground up ( this takes a hearty breed of folk ), this does not represent much of a problem.

The tower should rise 15 feet above all obstructions within 400 feet. This is a tuff one to get around and if it's just not possible for your situation, then give strong consideration to placing it where the aeroturbine will at least have an unobstructed view ( or access ) to the prevailing winds in your area. Climatological stations usually keep a record of wind directions; this information is available to the public, so consult it before installing any wind-power system. Be aware, however, that this information results from a few minutes of readings a few times a day ( for most stations ) and depends on how high the instruments are mounted, what kind of instruments are used, how long it's been since they were calibrated, and where they're located on the property ( it's a well-known fact that different readings may be obtained at the same site at points that may only differ by small distances ). Data collection for the last 35 years leaves much to be desired where application to wind-electric systems is concerned.

A higher tower is going to cost more money; a lot depends on the type of tower used, but another relationship seems to exist which makes it something other than a direct, proportional increase. My own guesstimations seem to indicate that the price goes up with the multiple of the increase factor; i. e., a 40-foot tower will cost four times what a 20-footer will cost ( and a 60-footer, six times the cost of the 20-foot tower, etc. ). This is not surprising when one considers that a free-standing tower ( legs cemented in the earth ) must be more spread apart at the base with the increased height, and a guyed tower ( such as the Wincharger-type tower -- see Types of Towers section ) must use more, and longer lengths of guy wire. This is not intended as a rule of thumb, but it certainly isn't a direct proportion, so check it out.

The importance of these "general rules of thumb" depends very much on the situation. Understanding the intricacy of the relationships will help you make a final decision. As tower height increases, greater windspeeds will be experienced and less turbulence encountered. But longer lengths of expensive electrical wire will be needed, the power losses in the wire will increase, the cost of the tower materials will go up, etc. Therefore, for your situation, thresholds exist, beyond which additional height ( in terms of the cost/benefit ratio ) will be unproductive.

On the other hand, don't get too bogged down in trying to apply this information to your situation. Some of the factors here weigh more heavily than others, and some apply more to squeezing out a few extra watts than just getting wattage, period. They're not so much determinants of whether you can make use of wind energy as they are factors which will help optimize what you can get. Just don't altogether ignore them!

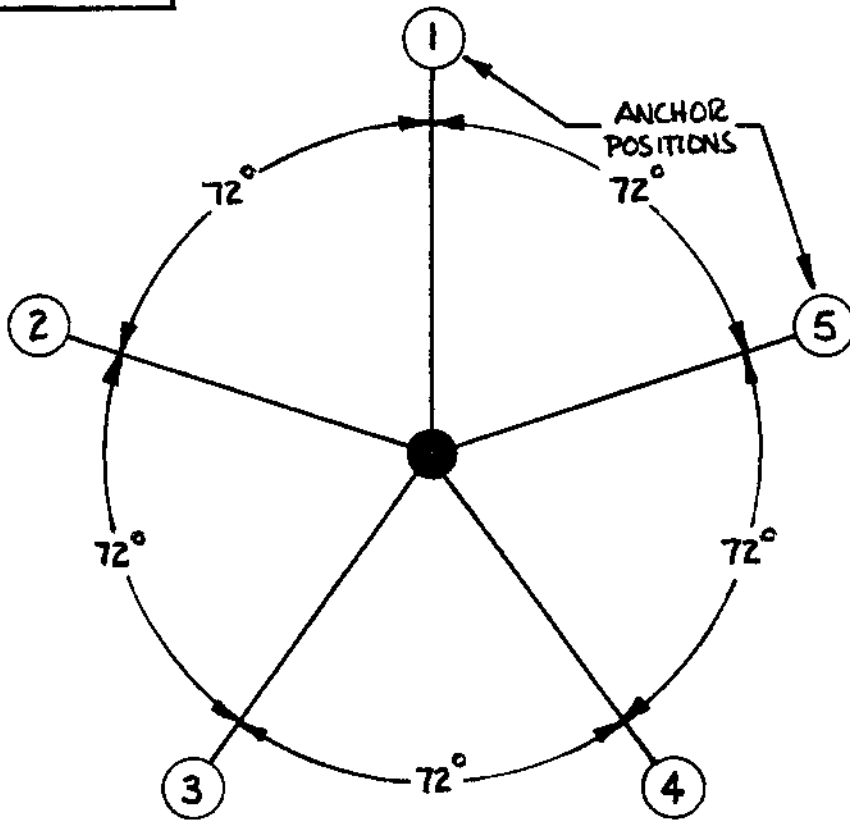
### Types of Towers

Most towers fall ( a figure of speech ) into one of four groupings -- single-leg, three-leg, four-leg, or octahedron-segment -- and are usually made from one of three materials: wood, angle iron, or pipe. Let's look at them in terms of cost, type and amount of material used, weight, rigidity, ease of construction, tools required, and methods of securing them.

The single-leg tower ( see Fig. 3-2 ) is inexpensive, simple to build, and easy to raise. The most basic material to use here is a telephone pole, but a long section of well-casing pipe is a strong

second. A fancier single-leg tower ( see Fig. 3-3 ) was used with Winchargers of the pre-REA (Rural Electrification Administration ) days; it consisted of three 20-foot parallel angle-iron sections which formed an equilateral triangle of 12" sides. These sections were bolted together to give the desired height. At least three guy wires ( spaced  $120^{\circ}$  apart ) will hold a tower like this, but for wind machines, nothing less than 5 wires ( spaced  $72^{\circ}$  apart ) should be used (see Fig. 3-4 ). In this instance, should one of the guy wires break ( they are all too easy to snag ), the tower ( and whatever is on top ) will not be lost; for anything less than 5 wires, it's bye-bye tower and wind machine. More guy wires are required with increased height, but the same anchors can be used if they have been properly distanced from the tower. ( A rule of thumb: Anchors for the guy wires should be located at a distance from the tower base of not less than one-half the height of the tower; i.e., a 50-foot tower will have anchors located not less than 25 feet from the base of the tower -- see Fig. 3-5 ).

FIGURE 3-4

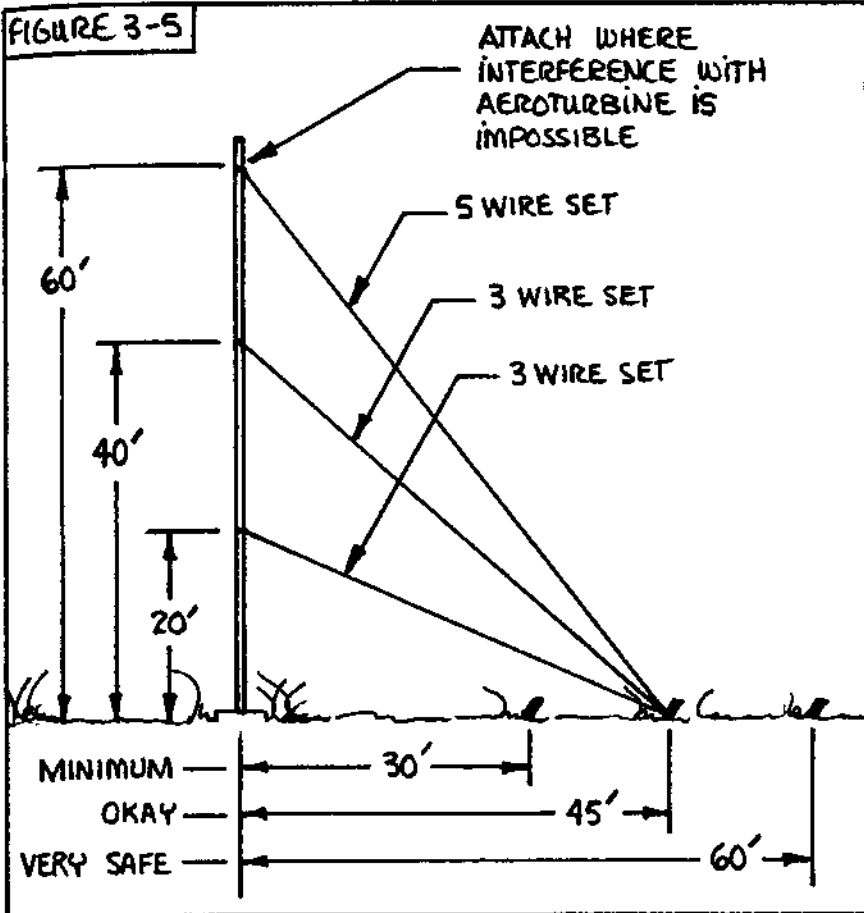


NOTE:  
FOR 3-WIRE SETS, USE ANCHORS 1, 3, AND 4.

(1) GUYWIRES SHOULD BE SPACED  $72^{\circ}$  APART. ONE WAY OF INSURING THIS ANGLE IS TO CUT TWO LENGTHS OF STRING — ONE 17- FEET LONG AND THE OTHER 20 FEET LONG — AND GET 5 SMALL STAKES. MEASURE 17 FEET OUT FROM THE TOWER BASE AND DRIVE A STAKE. ATTACH THE 20-FOOT LENGTH OF STRING TO THIS STAKE. IN EITHER DIRECTION, A POINT THAT IS 17 FEET FROM THE TOWER BASE AND 20 FEET FROM THIS STAKE IS ALSO  $72^{\circ}$  SEPARATED. NEAT, HUH? DRIVE A STAKE IN AT EACH POINT AND REPEAT FOR THE OTHER POINTS, MARKING THEIR POSITIONS WITH STAKES. WHEN INSTALLING THE GUYWIRE ANCHORS, MERELY LINE UP WITH THESE STAKES.

(Author's note: When I say "should not be" or "should be," I am generally referring to the fact that it is physically possible to cheat and I do not wish to be insistent in what I say. I occasionally indulge in cheating ( not doing something like it should be even though I know better ); but in these cases, I deserve ( as will you, if you fudge ) whatever happens in consequence. In situations involving wind machines and towers, I have formed what might be called, for lack of a better name or description, Hackleman's Laws. One of them applies here and goes something like this: Should an object of value -- a house, a car, or a favorite rosebush -- be the only thing within a distance to the tower's base of less than the height of that tower, the guy wire that will fail, fray, or be accidentally snagged and broken shall be that one, in the case of less than 5 used, which is

FIGURE 3-5



(1) THE TOP SET OF WIRES WILL ALWAYS BE A 5-WIRE SET, IRRESPECTIVE OF THE TOWER'S HEIGHT. THREE-WIRE SETS SHOULD BE USED AT 20-FOOT INTERVALS FOR TOWERS HIGHER THAN 20 FEET. THE 3-WIRE SETS MAY USE THE SAME ANCHORS AS THOSE INSTALLED FOR THE 5-WIRE SETS.

(2) IF  $h$  EQUALS THE HEIGHT AT WHICH A SET OF GUYWIRES IS ATTACHED AND  $y$  EQUALS THE DISTANCE FROM THE TOWER BASE TO THE ANCHORS, THEN THE LENGTH OF EACH OF THESE GUYWIRES WILL BE EQUAL TO:

$$\sqrt{h^2 + y^2}$$

(3) THE 5-WIRE SET OF GUYWIRES SHOULD BE A DOUBLE STRAND OF NUMBER 9 WIRE. THE 3-WIRE SETS MAY BE A SINGLE STRAND OF NUMBER 9 WIRE.

(4) ANCHORS FOR GUYWIRES DO NOT HAVE TO BE LOCATED EQUALLY-DISTANT FROM THE TOWER. JUST INSURE THAT THE CLOSEST ANCHOR IS NOT LESS THAN ONE-HALF THE TOWER'S HEIGHT.

(5) UNLESS SOME MEANS IS AVAILABLE WHEREBY ALL OF THE TOWER'S GUYWIRES CAN BE TENSIONED DURING INSTALLATION, TURNBUCKLES OF SUITABLE RATING SHOULD BE USED. LOCATE THEM NEAR THE ANCHORS.

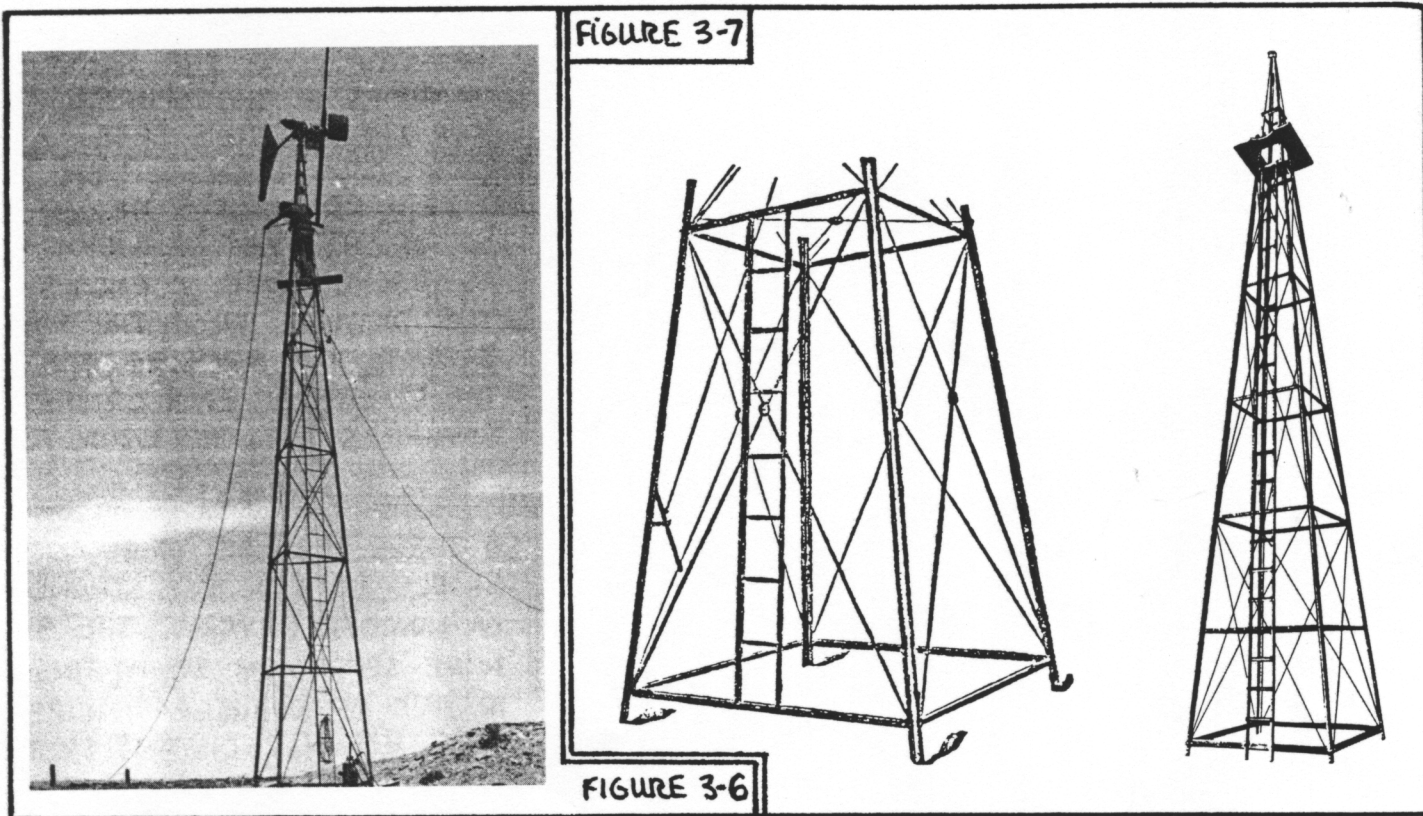
directly opposite in direction ( from the tower ) of the said object of value. End of valued object. End of tower. End of wind machine. End of Law. End of author's note. )

I have seen single-leg towers that were not guyed, but cemented like free-standing towers generally are. Much deeper holes were made, more cement was used, and in one instance where well-drilling pipe was used, the pipe was filled with cement to increase its rigidity. It was neat lookin', not having unsightly guy wires all over the place. The only problem was that it swayed; in winds of 15 mph, it was discernable. I've yet to see one in high winds, but then, I really wouldn't care to -- I don't like to see wind machines rip apart or fall down. And that's what's going to happen to machines mounted on an unguyed, single-leg tower . . . eventually.

The three- and four-leg towers ( see Figs. 3-6 and 3-7 ) are the most commonly-seen towers; they find frequent use for water-pumping windmills and wind-electric machines. Wooden towers up to 30 feet were common, but this type of tower is most frequently made of angle iron. These towers are, by far, the most expensive; the 4-leg uses more material and will therefore weigh and cost more than a 3-leg of similar height. They are very strong. In some sections of the country ( particularly the Midwest ) they are found in abundance, and can be purchased for a fraction of



the material cost or the cost of a new one of the same size. This is one of those diminishing resources, though, with the price of steel going up and more people buying/using them. You can buy new ones, but a look at the pricetags would gag most folks; they range from \$400-\$1200 depending on the height. The wide spacing of the legs makes this type of tower very stable when in an upright position; if the legs are cemented into the ground, it's hard to find a more rigid structure.



The octahedron-module tower is a relative newcomer; it stems from the principles of the geodesic dome and the inherent strength of the triangle ( see Fig. 3-8 ). The first time I saw one of these up close, it was very obvious how neatly this type of tower took the advantages of the 3- or 4-leg towers ( rigidity, strength, cemented-leg securing ) and the advantages of the single-leg tower ( low cost, lightweight, simple, easy to construct, use of less -- and less expensive -- materials, etc. ) without their disadvantages. Wasn't too long before I tried building one (without any plans) and, while I did get one together, it was not without having done some real muscle-strainin' and metal-bendin'; that was solely due to my miscalculations. Octahedrons don't draw so well on paper and it's difficult to believe what you're seein' when you're lookin' at one, much less tryin' to see one in your head. ( To keep sane, you build them out of straws -- see Fig. 3-9. If the sales clerk at the counter asks you what you're buying all them straws fer, she'll never believe you if you say "an octahedron-module tower"; so just tell her you heard that there was going to be a straw shortage and you thought you'd better stock up on 'em. ) I'd advise the purchase of a set of plans from Windworks for building these towers (their address is given in the Bibliography, and other special considerations in the use of this type of tower are given in the Octahedron-Module Tower section of this chapter ); we used these plans when we built the next two towers, and the stuff went together like tinker-toys.

EMT ( Electrical Metallic Tubing, or electrical conduit ) is used in the construction of the octahedron-module tower; if someone figures out a way to build one using wood or angle iron, I'd be fascinated to hear it.



Fig. 3-9

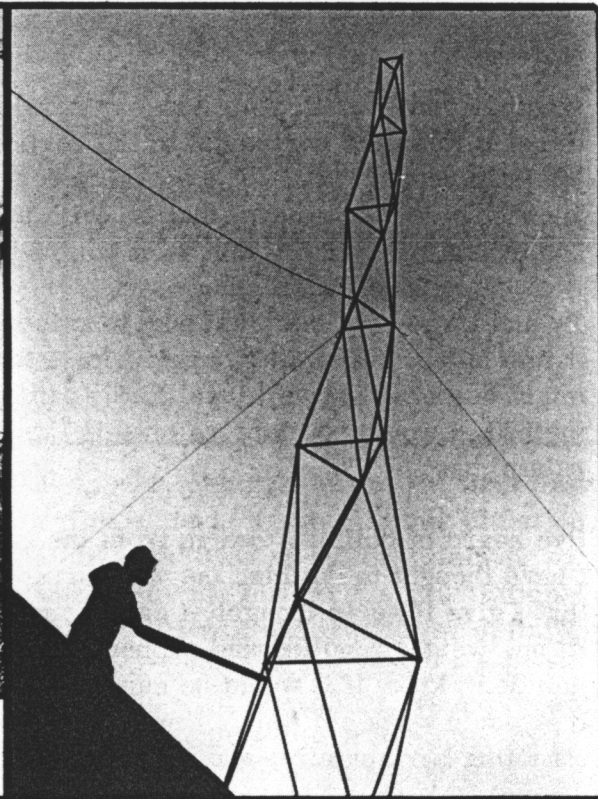


Fig. 3-8

Building vs. Buying a tower

This is a sticky question -- lots of if's and but's and completely situational. Now that I am aware of the octahedron-module tower, I wouldn't look for another type of tower; I'd rather build one becuz it's fun, I can do it right out in the back yard, and build one as high as I'd want. If someone walked up to our door and said, "I have a 60-foot tower a few miles from here that I can bring over, do you want it? for \$200?" I'd probably do it. But I wouldn't pay \$50 for one if it was 500 miles away. Why? Well, the cost/benefit ratio just wouldn't be that good. I'd have to get myself out there, take it down, disassemble and load it, transport it back here, re-assemble it, and raise it. Even if it cost less than the \$150, that would make the two deals 'equal (monetarily), the time and energy spent for the latter would shoot it down.

But then we're not talkin' 'bout history, just current events (you!), and maybe you would spend the time and the money. With that bein' the case, here's some things I've learned which may be of some value to your getting a tower:

I'd advise lookin' for one in your immediate area. If you do spot one and find that it's for sale, consider what work is going to be involved in getting it down ( if it's up ), disassembled ( unless you can transport it whole ), assembled, and back up. You're only going to be finding three- or four-leg towers so weight is a factor -- they're gonna be heavy! Don't be in such a hurry to get a tower that you commit yourself to money you can't really afford to put out, or energy you don't have to expend. Look over the section on lowering towers ( in this chapter ). Can you do it?

If you can't find a tower locally, or you can't afford what's being asked for them ( in money, time, and energy ), then get some information on the octahedron- module tower. If you don't like the way it looks ( too progressive, or sumthin' ) or aren't able to build a tower for yourself, look at the single-leg tower idea. Still no good? Well, then check outlying areas and further and further out from your place. Or check with the utilities; maybe they have some old towers around. ( I'm runnin' out of ideas, folks. ) Or . . .

## Tower-Raising Techniques

Whether you've built your own sky scraper or bought one, in some manner you're going to have to get it from the horizontal to the vertical. Raising a tower is much akin to welding; 90% of the job is in preparation. The actual task is inversely proportional to the amount of ingenuity and knowledge that you have; that is, with foresight and meaningful preparation, raising it is a trifle. I'm oversimplifying it, but -- if you're breaking your back, you're doing sumthin' wrong.

By and large, the simplest way to raise a tower might be to rent a crane or a helicopter and pull it into place. The latter might appeal to the jet set, but not to me! As for the crane . . . well, I might use one if it were real handy and didn't cost much, but having raised towers by the "gin-pole" method, I would not deprive myself ( or anyone else ) of the fun and excitement of holding a "tower-raisin' bee"!

I've heard of building towers from the ground up, but have never participated in doing it this way. I have thought to do this, but was turned off to this approach primarily for safety reasons; now that I give it some thought, I can see ways of getting around that but I can think of other problems -- fit up, weight handling and support, and minimized rigidity ( becuz of the incompleteness ) -- and just don't know if it would be easier. I don't feel enterprising enuff to work with it further to see if it would work out well. I'm sure I could do it; I'm just not certain it would be better than constructing horizontally, and lifting it to the vertical.

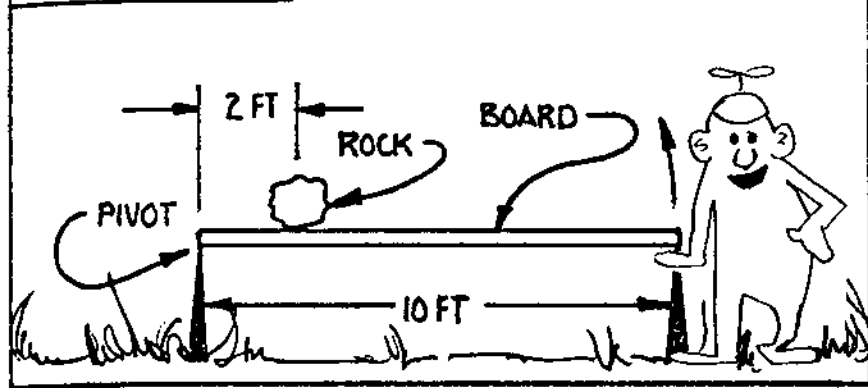
## Tower Physics

There are a few basics to tower raising that ought to be explained at this point just to make it a little easier to talk about other things as we go along. Anytime that someone is trying to tell someone else about sumthin', there are three things that generally come into conflict -- how much to tell 'em, how to tell 'em, and in what order. Assumptions as to what you know are always difficult to deal with becuz of the extremely diversified backgrounds of the recipients of the information. So, while I'll try to optimize these factors, I have no intention of getting sidetracked and writing a physics or math book. Examples will be given as to their application in tower raising ( or lowering ) but, if you find them to be just so much "greek" to you, be prepared to break out the books on the basics. At any rate, if you do find yourself bogging down, just continue on and see how the stuff is further applied. As much as possible, try to picture in your mind what is happening, why or how it's happening, and when (don't let my casualness on the subject lead you to believe it's not important); this is the cornerstone of tower raising, wind machine raising, and many other things. Take the time to study it. If you don't, then you'll just be playin' Follow the Leader -- knowing what, but not why!

The most essential element of "tower physics" is the lever, or the principle of its use. We use it in everyday life. It allows us to use a small amount of foot pressure to stop several tons of vehicle -- many times over -- whenever we drive a car. It allows us to free a rusty nut on a lawnmower ( when our fingers could not do it alone ). How? By giving a torque capability. A force exerted at a distance. A mechanical advantage. Different words, but the same meaning. Let's examine this in a few examples to make their meaning clearer.

A board rests between two supports ( see Problem 1 ); it's 10 feet long and there's a 100 pound rock resting on it, two feet from one end. The man in the drawing wants to lift one end of the board.

**PROBLEM 1-A**



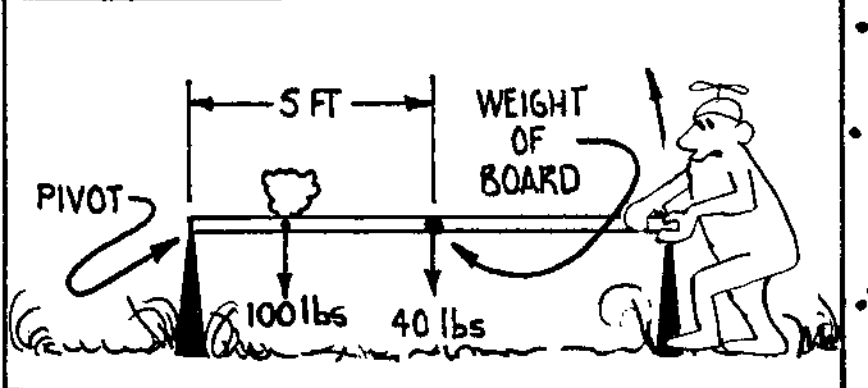
- STONE WEIGHS 100 lbs
  - FORCE OF STONE = 100 lbs x 2 FT.  
= 200 FT-lbs
  - 200 FT-lbs = x lbs (FOR MAN) x 10 FT.  
or x lbs = 200 FT-lbs ÷ 10 FT.  
= 20 lbs
- or the MAN feels like he's lifting only 20 lbs.

How much force does he have to exert, and how heavy will it appear to him? We might first draw attention to the fact that a subtle distinction exists between "force" and "weight" in this situation, so I'll define them as I will use them in the text. Weight can be classified as either referring to mass ( which is universal and applies to a body outside as well as inside the earth's gravitational field ) or as a force ( applied within the earth's gravitational field ); I will use this latter definition in the examples. Force, on the other hand, will refer ( in the examples ) to the work or energy expended in picking up objects or equalizing their "effect." Forces will, therefore, be expressed in "ft-lbs" ( foot-pounds ) and weight in "lbs" ( pounds ). Don't get confused with this right off; the distinctions will become clearer immediately.

For the situation in the first example, the weight of the stone is 100 lbs. It will produce a rotational force of 200 ft-lbs becuz of its position relative to the lever's pivot ( or fulcrum ); I arrived at the value of force by multiplying its weight by the distance to the pivot ( which is 2 feet ), thus giving us 200 ft-lbs. Don't let it bug you that we are multiplying feet by pounds and coming up with ft-lbs; it really isn't the same as oranges multiplied by apples. The man must overcome the 200 ft-lbs of force exerted by the stone if he is to lift the board from his end. He is, however, 10 feet from the pivot so the weight that he feels will be the 200 ft-lbs divided by 10 feet, or 20 pounds. A simple ( and equivalent ) experiment will confirm to you that this is indeed what he ( or you ) will feel, so do it if there is doubt in your mind. At any rate, this demonstrates the principle of the lever -- lifting 100 pounds and yet feeling only 20 lbs ( this saves the ole back, too ).

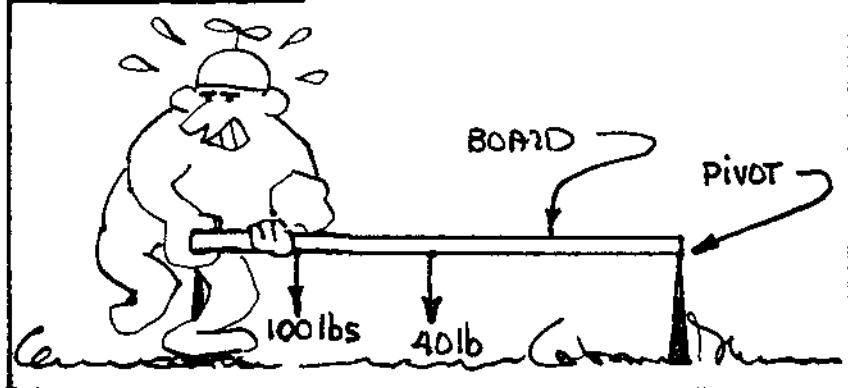
We left something out of this experiment, though; the board must weigh something! If this was a physics book, they'd probably say sumthin' like "assume the weight of the board to be negligible." In the real, live world, however, there are no such things as "infinitely strong, zero-mass" boards,

**PROBLEM 1-B**

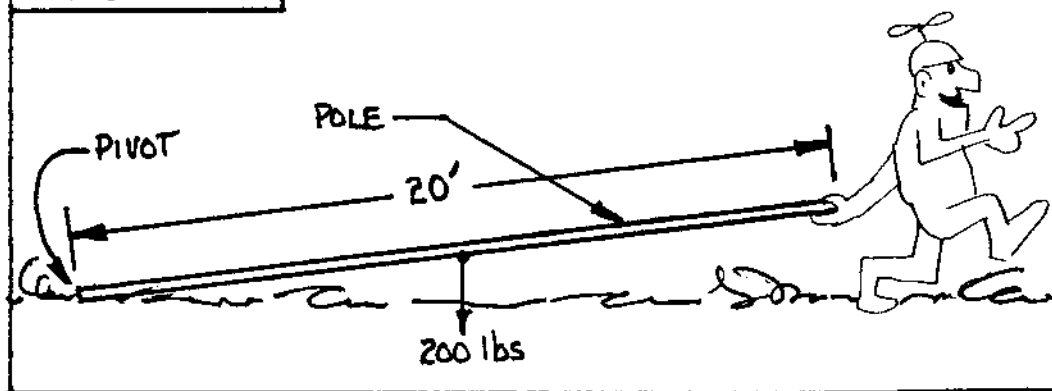


- FORCE OF STONE = 200 FT-lbs
- FORCE OF BOARD = 40 lbs x 5 FT.  
= 200 FT-lbs
- FORCE OF STONE AND BOARD  
= 200 FT-lbs + 200 FT-lbs  
= 400 FT-lbs
- x lbs = 400 FT-lbs ÷ 10 FEET  
= 40 lbs MAN MUST LIFT.

so let's include it and say that it's 40 lbs. How do we figure it in? Well, the board's density can be assumed to be equal throughout its length ( this is not an unreasonable assumption -- if we cut the board in half, we would expect each of the 5-foot sections to weigh 20 lbs ). With further experimenting we'd find that we can represent all of the board's weight at one point -- in the middle, or five feet from either end ( see Problem 1B ). With this fact, we can then proceed to calculate the force exerted by its weight. It will be 200 ft-lbs ( 40 pounds multiplied by 5 feet -- the distance to the pivot ). Divide that by the distance the man is from the pivot ( still 10 feet ), and you have another 20 lbs that he will feel ( in addition to the 20 lbs from the stone ), making a total of 40 lbs of weight.

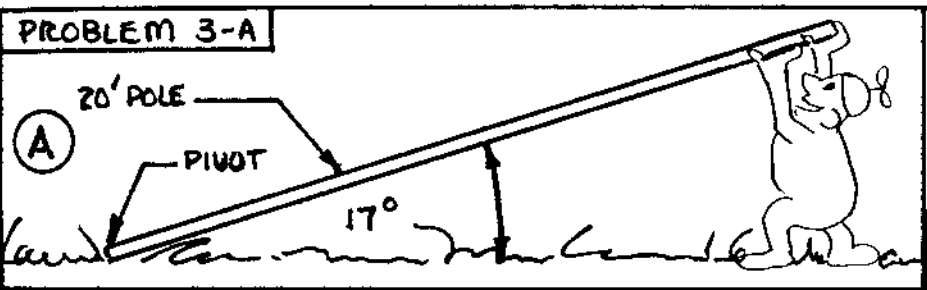
<p><b>PROBLEM 1-C</b></p> 	<ul style="list-style-type: none"> <li>• FORCE OF STONE = 100 lbs x 8 FT. = 800 FT-lbs</li> <li>• FORCE OF BOARD = 40 lbs x 5 FT. = 200 FT-lbs</li> <li>• TOTAL FORCE (BOARD &amp; STONE) = 1000 FT-lbs !</li> <li>• POUNDS MAN MUST LIFT = <math>\frac{1000 \text{ FT-lbs}}{10 \text{ FT.}}</math> = 100 lbs</li> </ul>
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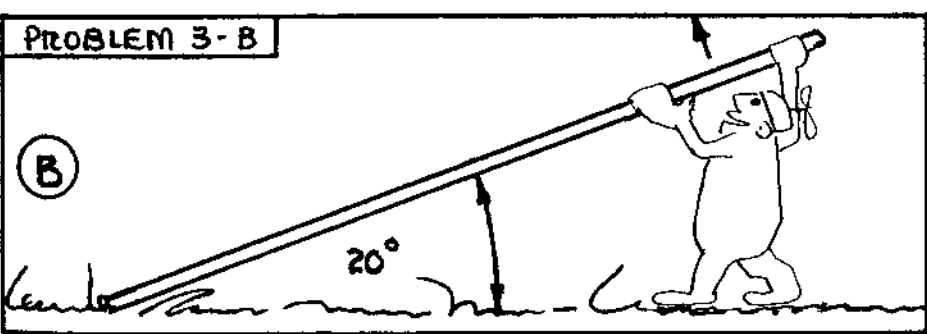
If the man went to the other end of the board, would he still only exert 400 ft-lbs of force, or feel just 40 lbs. of weight? Nope -- it's a whole different situation. Look at Problem 1C. The other end of the board is now the pivot ( and the fulcrum for the lever ), so we'll have to compute the forces relative to that end. The board still weighs the same ( 40 lbs ) and the force that it exerts is the same ( 200 ft-lbs ) becuz it's still 5 feet from the pivot. The stone still weighs 100 lbs but now it's 8 feet from the pivot, not just two; the force that it exerts will, therefore, be 800 ft-lbs ( 8 ft multiplied by 100 lbs ). Stone and board now exert a whoppin' 1000 ft-lbs! How much force does the man have to exert? The same amount -- 1000 ft-lbs! But becuz he's 10 feet from the pivot, he only feels 100 lbs when he expends the energy of lifting it ( or holding it just about the support ). This example is intended to explain the differences between forces ( moving about a pivot ) and weights, and how the lever works for you ( and where it doesn't ). There's a lot of difference between 20 lbs felt on one side of the board and 100 lbs felt on the other. Understanding why there is a difference is the important thing; if you find yourself in a daze, study the diagrams or put on your beeny-copter and try a similar experiment yourself. If you're still with me, let's go on.

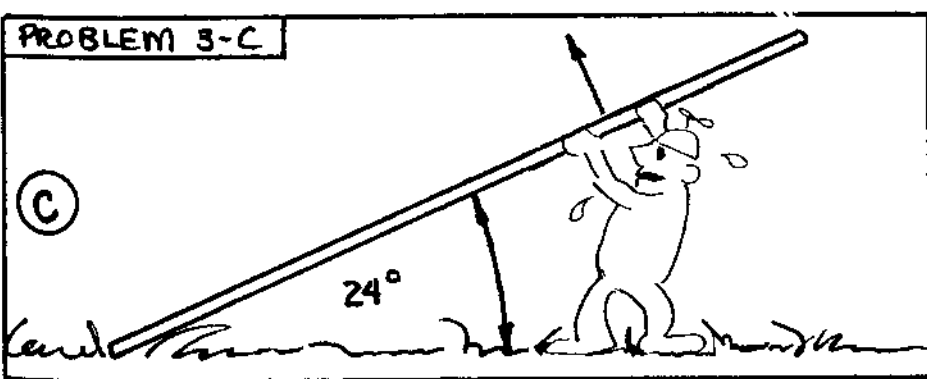
<p><b>PROBLEM 2</b></p> 	<p>FORCE OF POLE = = 200 lbs x 10 FT = 2000 FT-lbs</p> <p>WEIGHT FELT BY MAN = <math>\frac{2000 \text{ FT-lbs}}{20 \text{ FT}}</math> = 100 lbs</p>
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Now it just so happens that this man is wanting to put a birdhouse on a pole in his back yard. The pole is 20 ft. long and weighs 200 lbs, and the newly-made birdhouse weighs 40 lbs. Not one for doing a lot of figurin', he decides to just go ahead and do it. He tries to pick up the 200-lb pole. Mercy, but it is heavy! So, he just grabs one end and drags it around the house and into the back yard. Believe it or not, he's makin' good use of the lever again (see Problem 2 ). We can represent the pole's weight as being located all at the center, so it exerts 2000 ft-lbs of force ( 200 lbs times 10 feet ); he's 20 feet away from the pivot, though ( that's the end that's draggin' ), so he only feels 100 lbs ( 2000 ft-lbs divided by 20 feet ).

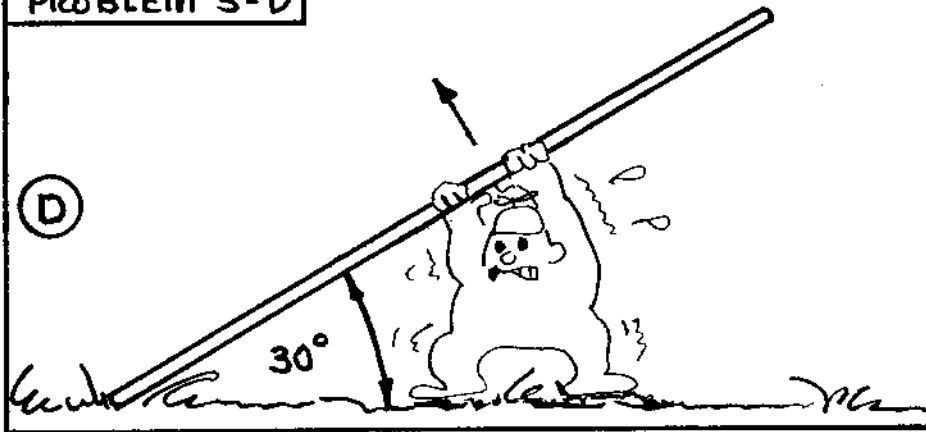
He finds a convenient place for the base of the pole, attaches some wires to the top ( to be used to hold it in place once it's vertical ), and proceeds to push up on what will be the top ( or birdhouse ) end of the pole, and begins walking down the pole, lifting as he goes. It starts up all right, but pretty soon it's just too heavy, so he backs off and sets it back down on the grass. What happened? Well . . . he began to lose all that leverage ( see Problem 3 ). When he started, he was feeling only 100 lbs ( the same as when he dragged it around the house ). But when he moved up the pole one foot, it was more like 106 lbs ( 2000 ft-lbs divided by 19 feet ). At two feet, it was up to 112 lbs ( 200 ft-lbs divided by 18 feet ). At three feet, it was 118 lbs; at four, it was 125 lbs. ( By now the strongest of most of us would have quit, but being an ex-weight lifter, he perseveres.) At 5 feet, he's up to 134 lbs. At 6 feet, it's up to 143 lbs. Can he continue? Yep, he makes it to 7 feet, and 154 lbs! That's it. He can't go on. And the tower is only at 27 degrees -- less than one-third of the way up!

<p><b>PROBLEM 3-A</b></p> 	<p>OUR MAN STARTS PUSHING UP ON THE POLE. HE IS 20' FROM THE PIVOT SO HE ONLY HAS TO LIFT ABOUT 100 LBS. NOTE THE 17° ANGLE.</p>
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<p><b>PROBLEM 3-B</b></p> 	<p>HERE, HE'S MOVED UP 3 FT AND THE ANGLE IS UP TO 20°. BUT HE'S LOSING THE EFFECT OF THE LEVER — NOW HE HAS TO PUSH AGAINST 110 LBS. NOT TOO BAD . . . YET!</p>
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<p><b>PROBLEM 3-C</b></p> 	<p>HERE HE'S MOVED UP ANOTHER 2½' ( 5½ FT ALTOGETHER ) AND THE ANGLE HAS INCREASED TO 24°. BUT THE WEIGHT HAS INCREASED, TOO . . . HE NOW HAS TO PUSH AGAINST 126 LBS!</p>
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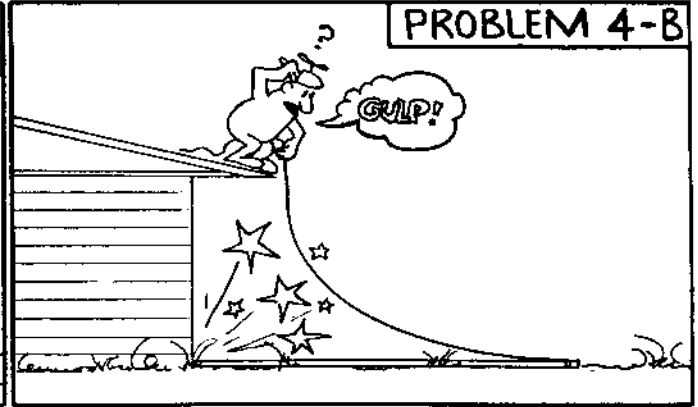
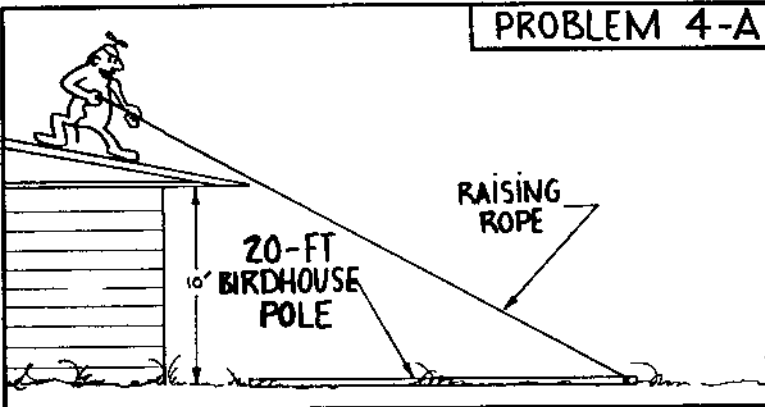
**PROBLEM 3-D**



AT THIS POINT, HE'S MOVED UP THE POLE, 8 1/2 FT. AND THE ANGLE IS UP TO 30° — ONE THIRD OF THE WAY UP. HOW MUCH DOES HE FEEL AS THOUGH HE'S LIFTING? WOULD YOU BELIEVE 151 LBS? THAT'S RIGHT. ABOUT TIME TO TRY ANOTHER WAY TO DO IT!

Okay, I fudged a bit -- he's not holding 154 lbs at 7 feet, only 137 lbs. What's wrong with the figures? Well, the pole still weighs 200 lbs, but part of that weight starts pushing down on the base of the pole. I mean, when the pole's fully upright, all of its weight is pushing straight down. And that doesn't happen all at once, just sort of gradual-like. So, even at an angle of 27°, some of the weight pushes down (along the pole) and that's less that has to be lifted. So I left out the calculation correction on the portion of the weight that's shifted to push the pole in the ground. That takes knowin' trigonometry (we'll do a bit of that later on). At any rate, I think the point has been made. The man started out with 100 lbs of weight and only made it 7 feet before it was up to 137 lbs and very little gain was made in getting the tower up.

Our man is not defeated, however; he has an idea. (See Problem 4.) He is raising the pole near his house (so that he can get the birdhouse on top after he got it up), so he ties a rope to the top of the pole, and climbs up on the roof with the other end, figurin' to pull the pole up thataway. Not a bad idea, considering that he won't be losing leverage. Or will he? Let's watch.

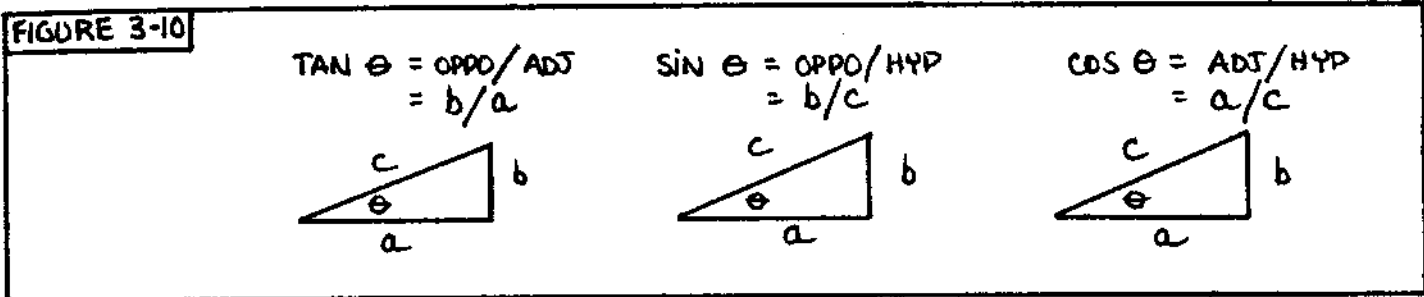


He starts pulling on the rope. Hmmmm, it doesn't want to move. He pulls harder. Suddenly, the pole slides along the ground and slams into the house. Why'd it do that? Well, he wasn't pulling straight up on the end of the pole, like he'd been pushing -- he's got an angle now. And the effect of that angle is that a portion of the pulling that he was doing was, indeed, lifting, but a portion of it was also pulling the pole toward him. And with nothin' to stop it, it slid (in the direction of the pull) until it hit the house. Well, that's simple enuff to fix. He climbs back down, repositions the pole, and attaches a wire to the bottom of the pole and hooks it onto a water sprinkler back near the top of the pole (he would've used a stake in the ground at the bottom of the pole, but his wife is fussy about tearin' up the lawn). While he's down there he decides to attach two of the wires that are attached at the top of the pole to some other water sprinklers that are to the sides of the pole; in this way, he insures that the pole won't fall to either side as he pulls it up into place.

He's smart about it, too; he chooses some water sprinklers that are in line with the bottom of the pole and perpendicular to the axis of the tower, knowing that this will keep them at a constant tension thru the whole pole raisin'.

Now, it's back up on the roof again. He starts pulling on the rope. The pole doesn't budge. He pulls harder. Still nothing. Wow, that's a lot more than the 100 lbs that lifted it from below! Wanna know how much more?

(Author's Note: Okay, here's where the trig comes in. If you don't know that's short for trigonometry, then we're off to a bad start. If you groan, then you're remembering those drowsy classes that you had to take when you were in high school or college; it really isn't all that bad. You'll find it easy and fun to work with once you have somethin' to apply it to ( which may have been sorely lacking when you took the course ). There are three functions that we have to work with -- sine, cosine, and tangent. If you can multiply, divide, and are able to look up some figures in the trig tables ( found in most math books ), you're in. I'm going to go through one example here in the text, but you need the tables if it's going to mean anything to you, so get 'em. The rest of the problems will be worked on the assumption that you know ( or can quickly learn ) trig; Fig. 3-10 shows the relationship of angles to the three functions aforementioned. Good luck. End of Note.)



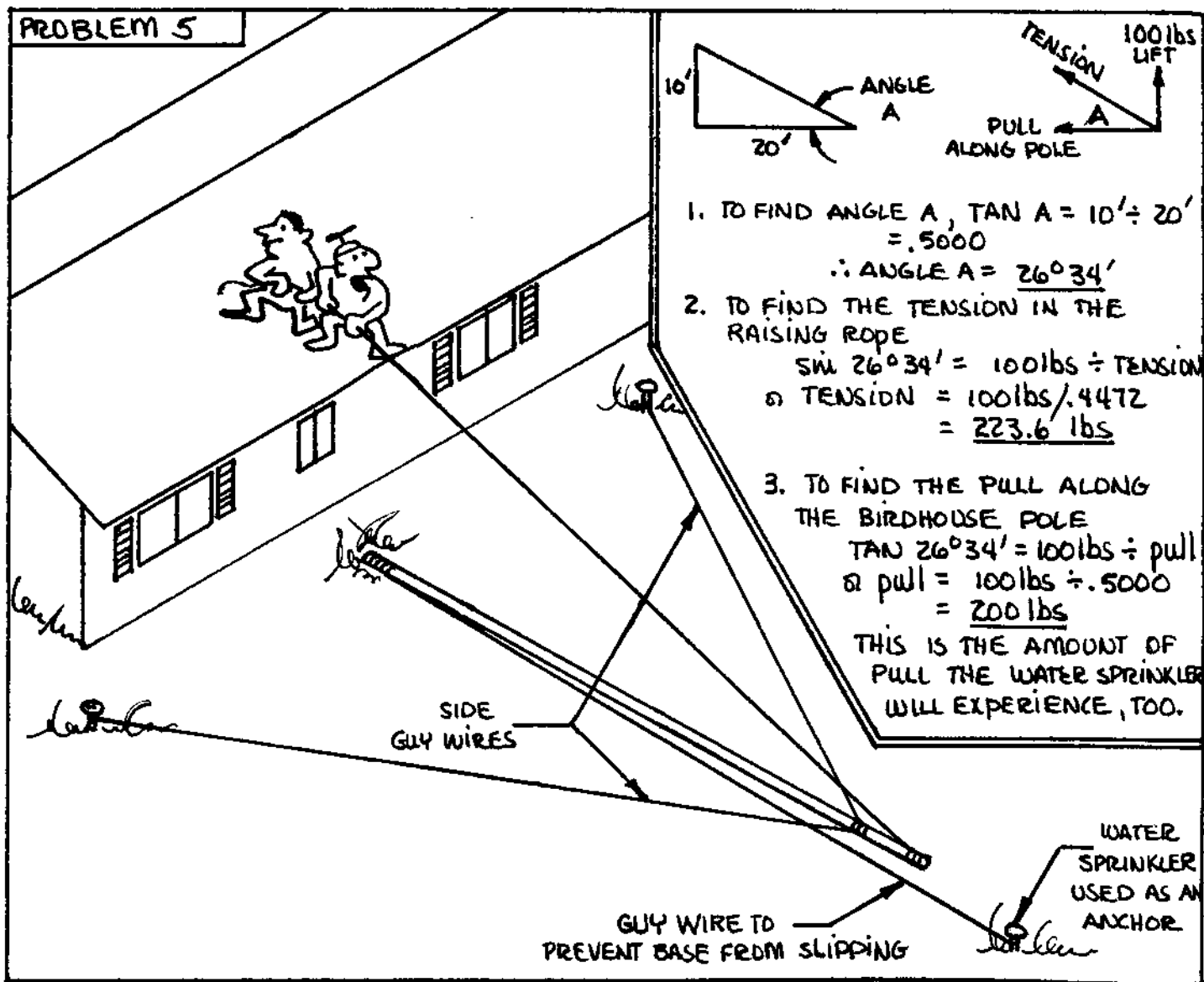
The first thing that we want to do for this situation ( see Problem 5 ) is to find the angle that the rope makes with the tower. We know that the roof is 10 feet high and the pole is 20 feet long; that's all that we need to know to find the angle ( other than knowing that one of the angles is 90° ). The appropriate function here is the tangent. So: the tangent of the angle is equal to the roof height ( 10 feet ) divided by the pole length ( 20 feet ), or the tangent of the angle equals .5000, right?

Now, look in the trig tables under the column marked "tangent" until you see .5000 ( or sumthin' close to it ). Then read across the table until you find the number of "minutes" ( there are 60 of these to a degree ). Then look up at the top of this column, and you'll see the number of degrees. Together they form the angle we're looking for. That wasn't so bad, was it? We don't have to have this kind of accuracy for what we're doing but you will want to write down the number of minutes just so that you can find that exact place again. Or, write down the value for the sine and the cosine ( found under the column heading bearing those names ) becuz we will use one of them ( if not both ) when we continue the problem.

This angle can be otherwise obtained; if the situation were accurately drawn ( to scale ), a protractor would quickly establish this angle well within the ballpark figures we can use. Determining the actual angle is, however, not the goal of this exercise, but merely the means to finding the force required on the rope to lift the top of the pole. Trig tables would still be required. An individual who knows trig well also knows that it is a matter of ratios; with such knowledge, trig tables are not an absolute necessity to the solution of such problems as I am presenting. Shortcuts are much aliking the situation with food consumption: You can't know what's enuff, until you've had too much. So run it out with trig, okay?



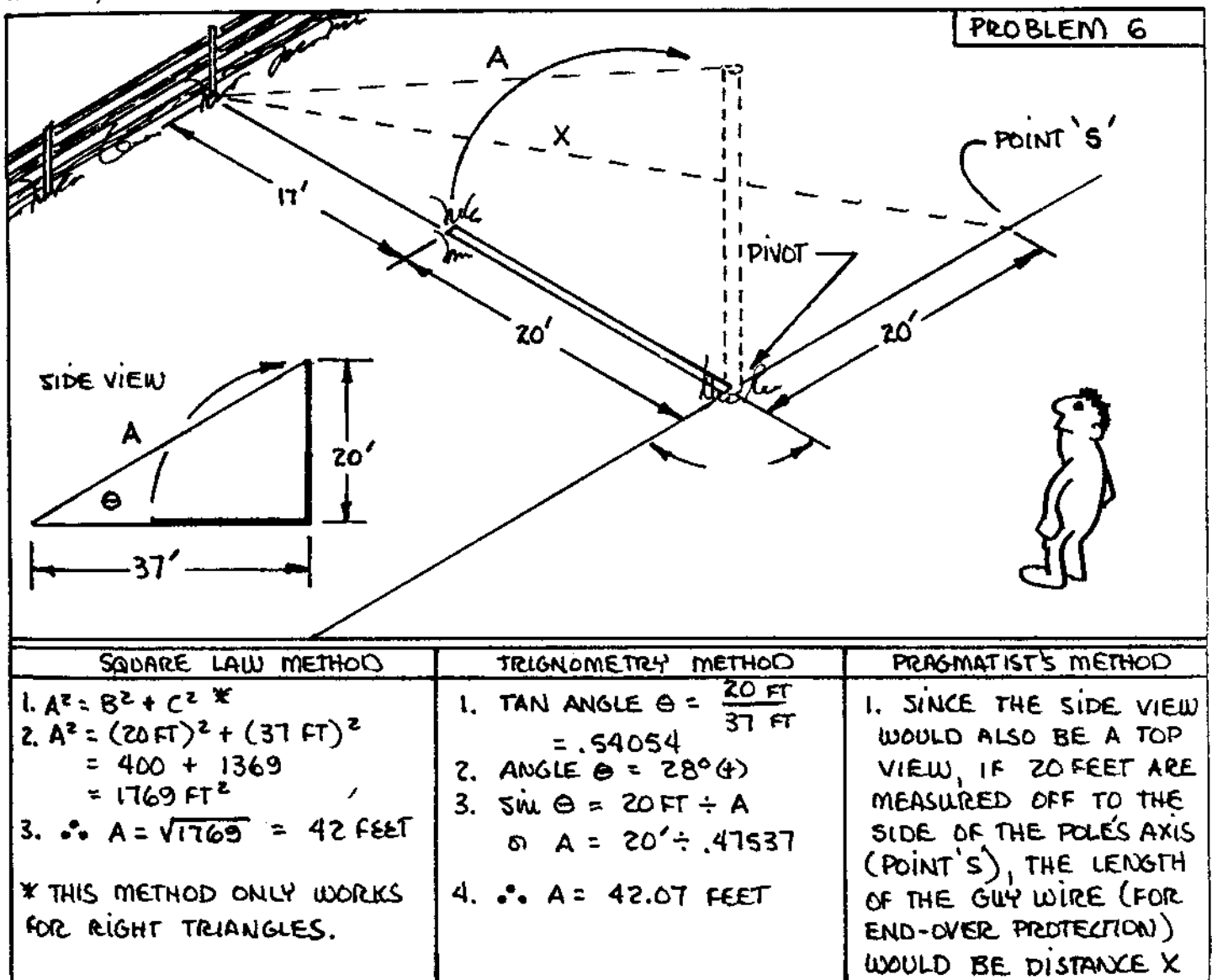
Back to Problem 5: In this case, the angle whose tangent is .5000 is  $26^{\circ}34'$ . That's our angle. So now what happens? Remember that we are trying to find out how many pounds of pull on the rope will lift the pole. And we know that if the pole was pushed ( or pulled ) straight up, it would take 100 pounds to do it. So . . . we make another little triangle and we find that we can take the sine function ( of the angle  $26^{\circ}34'$  ) and it will equal the lift ( 100 lbs ) divided by the unknown pull of the rope. It's not really all that abstract; we can substitute an X for this unknown pull ( shades of algebra ) and solve for the X. This means that X equals the lift ( 100 lbs ) divided by the sine of the angle. If you didn't write this down when you found the angle in the first place, find  $26^{\circ}34'$  and look across, reading the figure in the column marked "sine." This is .44724, but if you're running a pencil calculator, round it off to .45 and divide it into 100. My Heathkit calculator got 223.6 lbs for the 5-digit number and 222.2 for the 2-digit one. Close enuff for wind energy work.



Well, how do you like that? To lift the pole, our man is going to have to pull with a mighty 220 lbs ( plus ) on that rope! No wonder he couldn't get it to budge! And if you're wondering where all those pounds of pull are going, figure out how much pull the pole gets in the direction of the house ( along the ground ). It isn't that hard; it turns out to be the 100 lbs divided by the tangent of the angle ( which we found to be .5000, right?). That comes to 200 lbs! Sure hope the sprinkler

that's keepin' the pole from sliding into the house is well secured! If you're wondering how you can get 100 lbs of lift and 200 lbs of pull ( along the pole ) from only 220 lbs of pull on the rope, chalk it up to the craziness of the math; it's the only kind where 220 can be equivalent to 300!

(Author's Note: If I am giving you the impression that knowing trig, algebra, or angles is necessary to raising poles ( or towers ), then I am losing you somewhere. Nothing could be further from the truth. There are people who've raised towers that might not be able to explain why they do it the way they do ( as I have ) but they certainly have raised towers! The reason is simple -- they've got the principle of the thing. I really don't care to convince you to do the math -- you will or you won't. I do want you to be able to picture in your mind why certain things will work and other's will not. The man who's raisin' the pole for his birdhouse is comin' up against a mess of problems -- like those you might encounter if you were trying to raise sumthin' similar -- and I'm tryin' to think of every wrong way it can be done. While I'd know better, maybe you wouldn't. I'm really not into sayin', "this is the right way -- do it!" Becuz that's not liberating knowledge. End of note.)



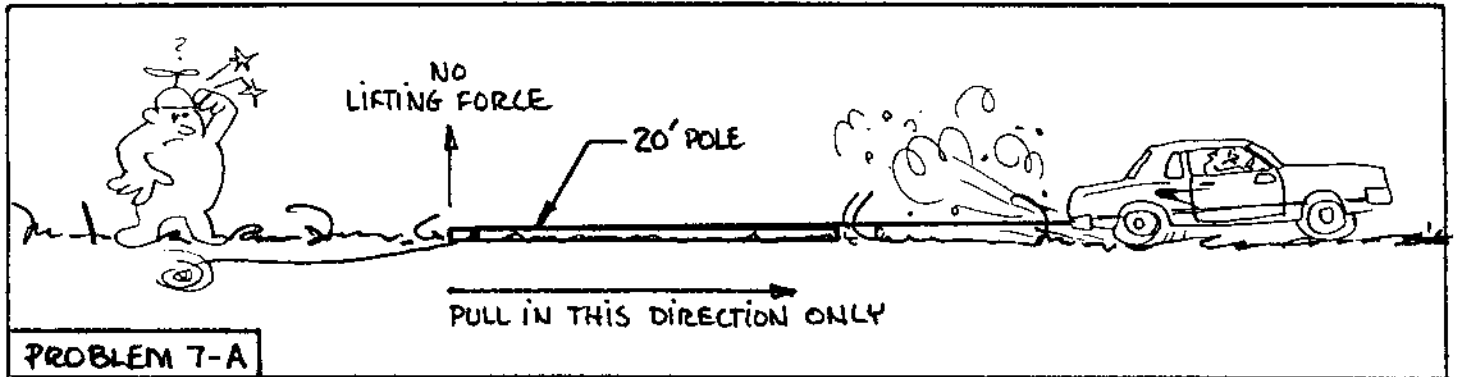
Well, our man is a bit chagrined; with the largest amount of energy he exerts, it will not budge. Finally, he calls over a neighbor friend, and together they try it. Well, it moves a little bit but then, it falls right back. His neighbor suggests that they attach the rope to a car and pull it up that

way. Now, there's an idea. A car can exert a lot of force, right? Well, maybe. Let's see how they do it.

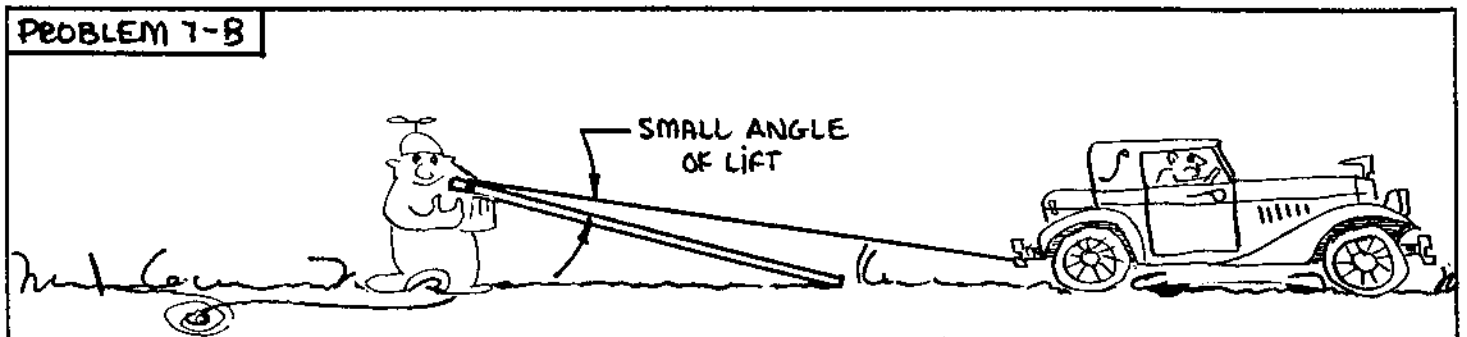
His neighbor has a light, imported pickup with a stick shift, so he brings it over, driving onto the lawn. The man's wife is watching the whole thing by now ( she wasn't too happy about the roof shakin' that was going on when the two of them were trying to lift it that way ), so the neighbor takes care not to rip up the lawn as he drives over to the pole. Our man has been busy re-arranging the guy wires for a pull from another direction, and he attaches the wire hooked onto the bottom of the pole to another anchor -- a nearby fencepost. But again, he's using his head. He knows from before ( with the roof-top effort ) that once the pole was upright, it wouldn't fall over in the direction of the pull becuz the edge of the roof would be there to keep it from doing this. The situation is different now, so he attaches a wire to the top of the pole and ties the other end to the fencepost. How long does the wire have to be?

Well, there are three ways of determining this ( see Problem 6). The first two involve trig and the third simulates the condition on the ground. Our man that doesn't like to work with the figures just marches off 20 feet to the side of the base of the pole ( this represents its height ) and then measures the distance from this point to the place where the wire will be secured -- the fence post. Yep, it turns out to be real close to 42 feet ( give or take six inches ) which is found by the "square law of triangles" and normal 3-function trig. The man measures off 42 feet of guy wire, attaching one end to the top of the tower and the other to the fencepost.

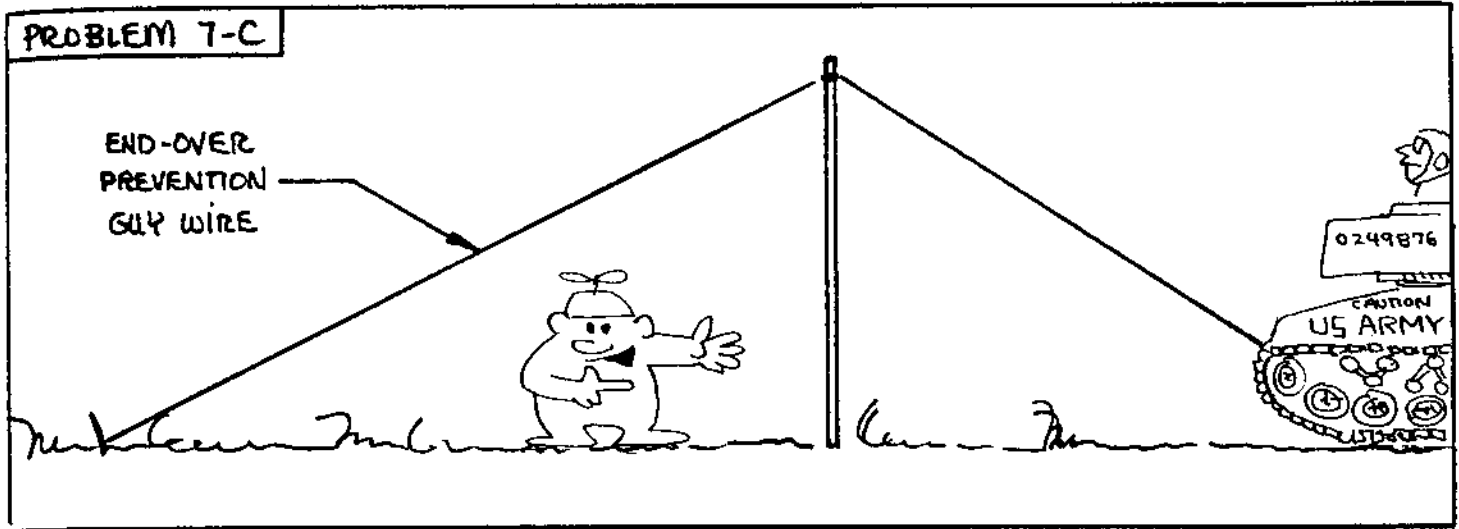
Everything seems to be in order, so the neighbor attaches the rope to the top of the tower and the other end to the bumper, starts the engine and eases forward until the rope is taut. Then he gives



it a little more gas. Nothing happens! A little more gas -- still nothing happens. The wife is screaming at him to stop. What's that? The wheels are spinning! What's wrong? Well, it's a scheme that looks as though it might work, but it won't. Why? Becuz there's no lift angle! ( See Problem 7. ) All of the pull is directed along the axis of the tower. If there was a few tons of tower instead of a meager 200 pounds of pole, only one of five things could happen ( none of which



will raise the tower or the pole! ). The line will break. Or the tower ( or pole ) will go sliding along the ground in the direction of the pull ( if the base is not secured, or if the wire securing it breaks ). Or the clutch will burn out in the truck. Or the tower will collapse like an accordion ( in which case, it wasn't worth raising anyway! ). Or the scene will be one of active immobility and the rear wheels of the vehicle will slowly dig into the terrain.

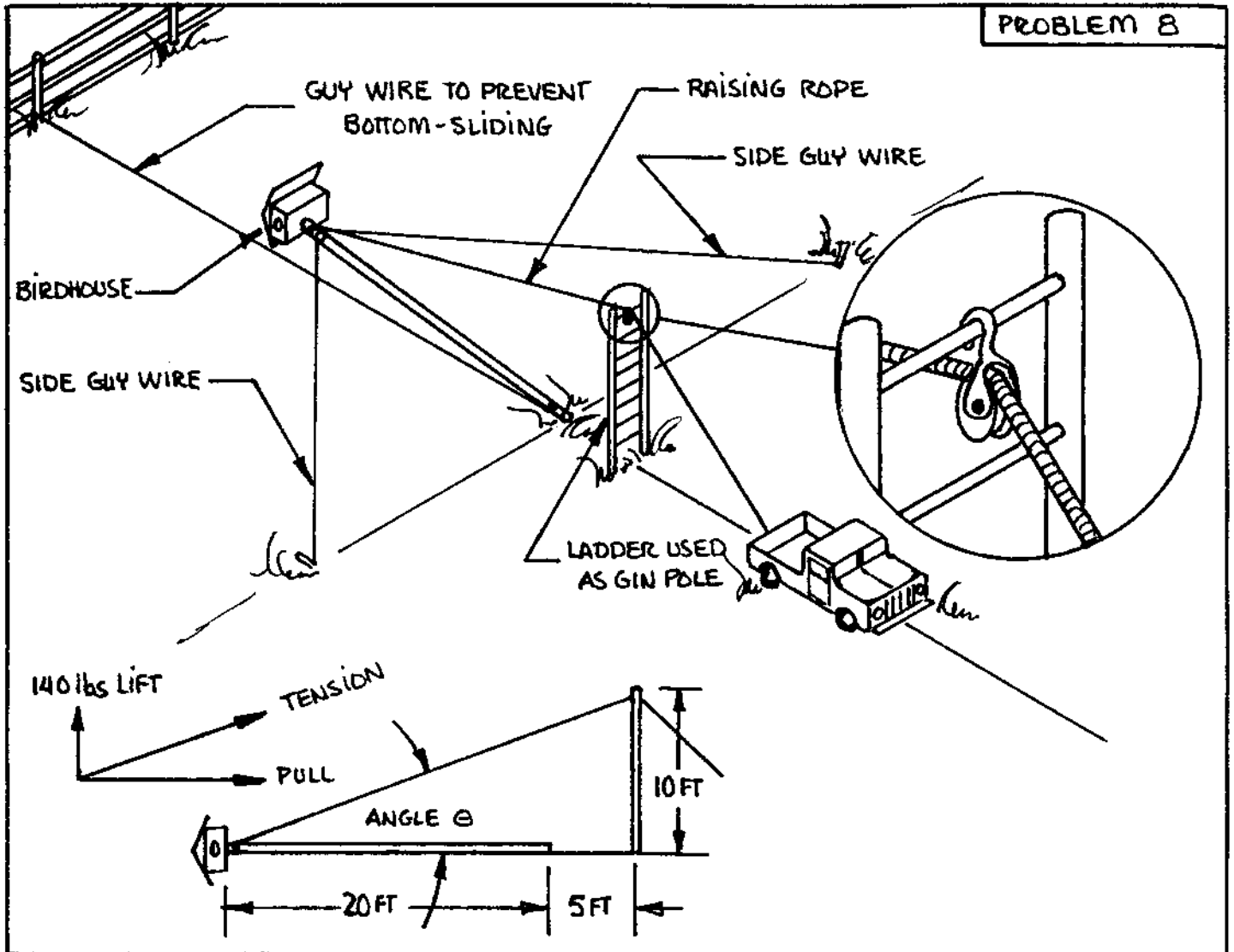


The neighbor, meanwhile, has been calming down our man's wife while he's over looking at the situation, sees the problems, and yells at the neighbor to try again. He picks up the top of the pole as his neighbor gives the vehicle power and, sure enuff, it starts to go up. Up and up it moves until, finally, it's straight up and down. Even the wife is quiet as the three admire the finally-raised pole. Then the wife drops the bomb. "How are you going to get the birdhouse up there?" The husband is looking a wee bit red. Whoops! When they were raising the pole near the house, he'd planned to use their 10-foot ladder to reach the top ( by putting it on the roof and laying it against the pole ). But he's not by the roof any more. He suddenly has an idea, though; they can bring the pole back down, bolt on the birdhouse, and raise pole and birdhouse together. The neighbor backs off the truck and the pole swings back until it touches the ground again, while hubby goes and gets his pride-and-joy -- a cast-iron birdhouse weighing 40 pounds. He bolts it onto the pole. When he tries to lift the end of the pole, though, he finds that he can't. Why? Well, remember that it takes 100 pounds worth of lifting to move just the pole; with the birdhouse attached right at the end, he feels the full 40 pounds of that, too. With two of them trying it, they can hold it up, but then there's nobody to drive the truck ( the wife can only drive an automatic ) and she's not hearin' the idea that she help lift it while the neighbor drives, so it's thinkin' time again.

What's the next best thing to raising the pole to provide a lift angle? Why, givin' the raising rope an angle ( just like on the roof, remember? ). The only problem here is that the roof ain't handy any more. But, thinks our man, we can "simulate" the roof being there by standing the ladder up between the pole and the truck and draping the raising rope over that. And if a pulley is attached to the ladder near the top end, the rope would freely travel over it during the raisin'. He explains the idea to the neighbor and wife and they set about doin' it.

The pulley and guy wires ( not shown ) are attached to the ladder ( see Problem 8 ) and the raisin' rope is strung thru the ladder and over the pulley. The ladder is raised to a vertical position and its guy wires are secured ( thereby holding the ladder in this position ) to water sprinklers in the immediate vicinity ( the yard is well plumbed ). Back into the truck goes the neighbor, firing the engine up and easin' out the clutch to take up the slack in the rope. He then gives it a little more oil-juice and . . . up she goes! What a pretty sight!

Okay, let's examine a few of the incidentals to this most recent try. With the birdhouse attached, what's the tension in the rope at the beginning of the pull ( no tower angle ) and what's the lift angle? Introduced a few terms, didn't I? Let's see what they mean before we work out the problems.



1. TO FIND ANGLE Θ, LET  $\tan \text{ANGLE } \Theta = 10\text{ FT} \div 25\text{ FT} = .4000 \therefore \text{ANGLE } \Theta = 20^{\circ}19'$
2. TO FIND TENSION IN THE RAISING ROPE, LET  $\sin 20^{\circ}19' = 140\text{ lbs} \div \text{TENSION}$   
OR  $\text{TENSION} = 140\text{ lbs} \div \sin \Theta = 140\text{ lbs} \div .34721 = 403.2\text{ lbs}$
3. TO FIND THE PULL ALONG THE POLE (TENDING TO PULL IT TOWARD THE TRUCK)  
LET  $\tan 20^{\circ}19' = 140\text{ lbs} \div \text{pull}$  OR the pull =  $140\text{ lbs} \div \tan 20^{\circ}19'$   
which =  $140\text{ lbs} \div .4000 = 350\text{ lbs}$  OF PULL ALONG THE POLE.

Tension in the raising rope is the same as the number of pounds that it feels like it's lifting. The tower angle is defined as that angle which the tower ( or pole ) makes with the ground; when it's lyin' there, it has no angle ( or it's zero ). When it's raised, it will increase its angle with the ground until it's fully upright, at which time the tower angle will be  $90^{\circ}$ . The lift angle is defined as that angle which the raising rope ( or cable ) makes with the tower that it's attached to. When the man was pushing straight up on the end of the pole ( or if he'd been pulling straight up on it ), the lift angle was  $90^{\circ}$ . Remember that this was the only situation where the tension on the rope

would have been equal to the required pounds of lift. When he tried it from the roof, the tension in the raising rope was much larger because the lift angle was less than  $90^\circ$  (in fact, it was  $26^\circ 34'$ ). And when they tried to raise the pole (with the truck) while it was lying flat on the ground, there was a zero lift angle, and the wheels just spun. By these examples, it should be clear that a large lift angle is desirable; it simply reduces the amount of force that must be exerted to do the job, and it considerably lessens the amount of tension in the raising rope (or cable). If the lift angle cannot be large initially (and in many cases, it cannot), the next most desirable thing is to have the lift angle increase as quickly as possible during the raise.

In our example, the ladder serves as a "gin pole" -- a device that is frequently used in home-style tower raisings; more information on its use will be discussed in the next section. I have in this example, however, placed it 5 feet from the base of the pole and this is not altogether necessary; for the pole (or any single-leg tower), the gin pole may be located right at the base of the tower. For the more commonly-raised 3-leg, 4-leg, or octahedron towers, the width of the base must be taken into consideration for the placement of the gin-pole (to prevent interference) and I only did it for the example so that I'd have an opportunity of making you aware of that circumstance at this point. On with it!

Problem 8 details the computation of the lift angle and the tension in the rope. I hope that you have been doing the problems all along; if you have, that you'll have the gist of the thing by now and my workin' them out will serve as a check for yours. If you keep gettin' an answer that's different from

**PROBLEM 9**

20 FT POLE

GIN POLE

X FT

ANGLE B

ANGLE C

ANGLE A

ANGLE D

140 lbs

TENSION

40 FT RAISING ROPE

GIVEN AS  $55^\circ$

FINDING THE TENSION IN THE RAISING ROPE REQUIRES THE USE OF TRIG. FINDING THE ANGLES, HOWEVER, ONLY REQUIRES THE USE OF A PROTRACTOR IF THE SET-UP IS DRAWN "TO-SCALE".

IN ORDER TO FIND THE LIFT ANGLE (ANGLE 'C') BY THE TRIG METHOD, WE MUST FIRST FIND ANGLE 'D'. TO FIND THIS ANGLE WE MUST FIND THE VALUE OF 'X'.

$$\sin \text{ANGLE 'A'} = X \div 20 \text{ FT}$$

$$\text{THEN 'X'} = (\sin 45^\circ)(20')$$

$$= (.707)(20)$$

$$\therefore \text{'X'} = 14.14 \text{ FT}$$

NOW WE CAN FIND ANGLE 'D'

$$\sin \text{ANGLE 'D'} = 14.14 \text{ FT} \div 40'$$

$$= .3535$$

$$\therefore \text{ANGLE 'D'} = 19^\circ 28'$$

NOTICE THAT ANGLE 'B' IS EQUAL TO  $90^\circ$  MINUS ANGLE A

$$\text{OR ANGLE B} = 90^\circ - 55^\circ$$

$$= 35^\circ$$

THEREFORE, ANGLE C

$$= 90^\circ - 35^\circ - 19^\circ 28' = 35^\circ 32'$$

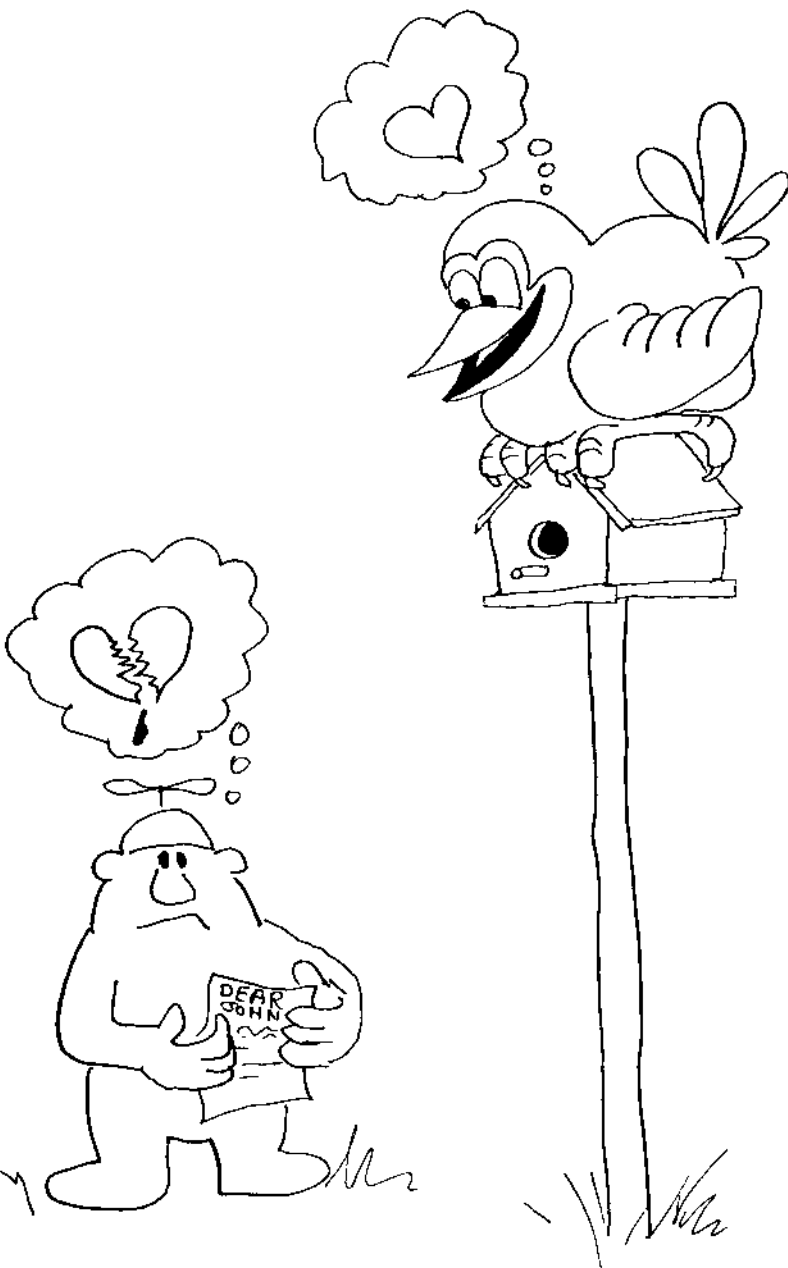
TENSION IN THE RAISING ROPE CAN BE EASILY FOUND. LET:

$$\sin \text{ANGLE D} = 140 \text{ lb} \div \text{TENSION}$$

$$\text{OR TENSION} = 140 \text{ lbs} \div \sin 19^\circ 28'$$

$$= 140 \text{ lbs} \div .3535$$

$$= 396 \text{ lbs}$$



### The Gin Pole

As indicated in the last section, the purpose of a gin pole is to give a lifting force to a pull such as that exerted by a truck on a raising rope ( or cable ). The taller the gin pole, the more angle it will give to the raising cable, and hence, the greater the lift angle. If the gin pole were infinitely high, the raising cable would be almost straight up ( like it's being lifted by a helicopter ) and all of the pull would be a lifting force ( a hypothetical extreme ).

In reality, a gin pole need not be over 20 feet high; I've seen drawings which depict the raising of a 130-foot tower with a gin pole only 20-feet high, so you'll be quite safe with that as a maximum. I don't know what the minimum height of a gin pole could be and still work satisfactorily, but I wouldn't use anything less than 15 feet.

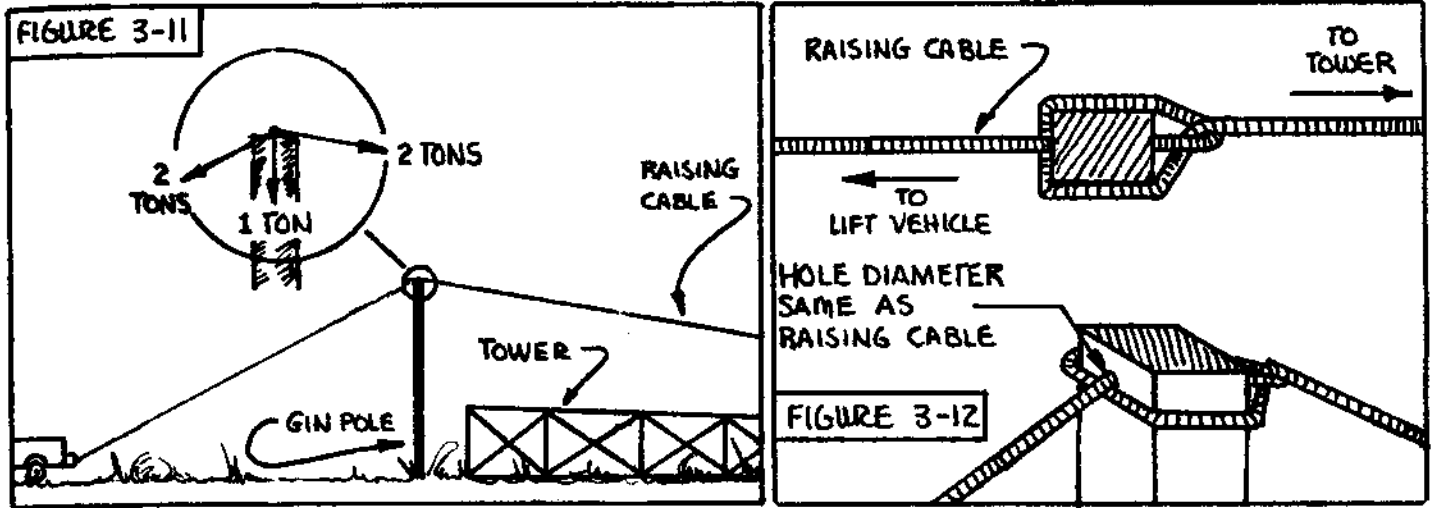
What you use for a gin pole requires some careful consideration; its greatest requirement is that it not bend or break when subjected to compressive forces ( which work mostly through its axis -- see Fig. 3-11 ). I've used a 20-foot section of Wincharger tower ( for a 54-foot, 3-leg tower ) and it worked fine. I wouldn't hesitate to use a telephone pole, or a 4 x 4 beam, or maybe even a 3-inch diameter pipe, but I'd think twice about anything else that comes to mind.

mine, check over what I did; maybe I've made a mistake! Be sure to let me know if you do find an error on my part, or just can't get yours to agree!

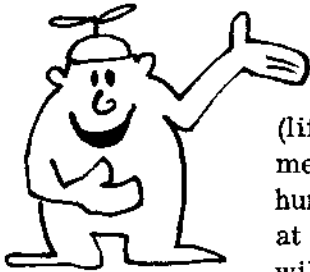
We've just gotta throw in one more problem, so let's say that the tank runs out of gas just when the tower reaches an angle of  $45^\circ$ . The neighbor leaves the tank in gear and puts on the emergency brake ( these prevent the forces exerted by the pole from pulling the vehicle backward ) and runs off to get some gas. So, while he's doin' that, let's look at what the lift angle is, and how much tension is on the rope at this angle ( see Problem 9 ).

Once the truck is gassed ( you'd be gassed, too, if someone filled you up with high octane ), the raising commences again and continues until the tower is upright. Guy wires are secured all around, the ladder-type type gin pole is removed, and the vehicle is removed from the yard. Everything's hunky-dory, right? Well, sorta, anyway. The wife ran off with the neighbor man and our man watches the big bird that decided to take roots in ( or, rather, on ) his birdhouse. Sorry, I can't think of a moral to this story!

When you've found a likely candidate for the gin pole, you must make one of those decisions that I'll be throwing at you occasionally: To secure the tower-raising cable to the gin pole ( Fig. 3-12 ), or to run the cable through a pulley that's secured to the gin pole ( Fig. 3-13 ). I have worked with the second method only, so I cannot personally vouch for the other, but I have seen it in drawings and see no reason why it wouldn't work.



It's important to understand the implications of doing it one way or the other, however, and to understand what will happen to the gin pole once the tower has been raised to the point where the raising cable will "clear" the gin pole ( see Fig. 3-14 ), beyond which it is no longer required. The tower angle that must be achieved to reach this point depends on many factors -- the tower length, the gin pole height, the distance between the tower base and the base of the gin pole, etc. -- but the effect is still the same. Use of the tethered method or pulleyed method depends on a number of factors, some of which we have not yet discussed, so the decision cannot be made at this point. Keep the following relationships in mind, though, as you are provided with that information.



1. With the tethered method, the gin pole will be "raised" with the tower (lifted into the air by the raising line -- see Fig. 3-15 ); you won't want to use this method if you have selected a heavy gin pole, unless you like the idea of a few hundred pounds of gin pole dangling from the raising line twenty feet up in the air at the end of the tower raising. If you're using the pulleyed method, the gin pole will just slide along the raising cable, but here again, you will have to take some precautions, ( like securing a line to it ) or it may come whizzing down the line and collide with the truck. This is a real no-no if you're raising a light tower and you're using people to raise it instead of a truck.
2. Either method will require the use of guy wires to keep the gin pole from toppling over to either side during the raise. The placement of these guy wires is not significant in the case of the pulleyed method; the gin pole will not need to move ( and, in fact, should be secured to prevent it from doing so ), so the wires can be hooked as shown in Fig. 3-16 ( at least three will be required just to keep it from falling over before the actual tower-raising begins ). The tethered method, however, requires that the top of gin pole be permitted free movement ( in the direction of the pull ) during the raise; the wires used to prevent side-fall must be located directly to the sides of the gin pole ( somewhere along a line which is drawn through the base and perpendicular to the tower axis -- see Fig. 3-17 ) if they are to remain snug ( and not loosen or tighten further ) during the raise. Obviously, the



FIGURE 3-13

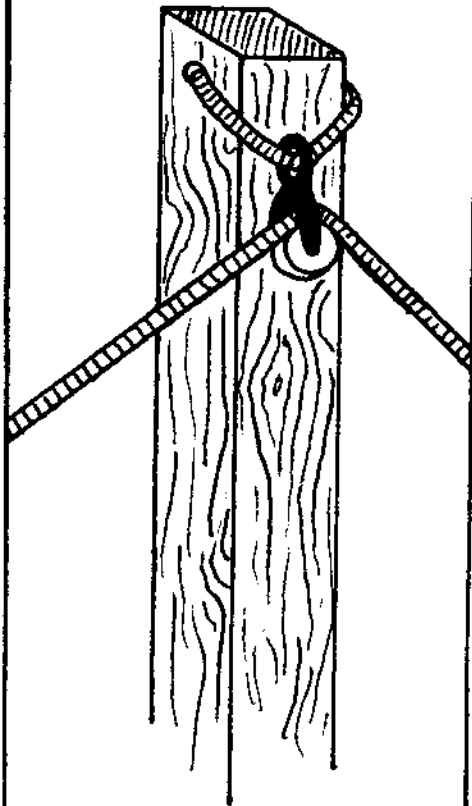


FIGURE 3-14

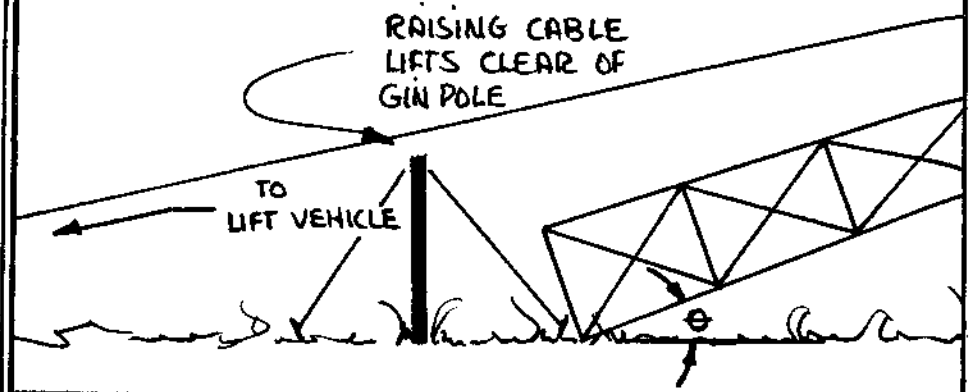


FIGURE 3-15

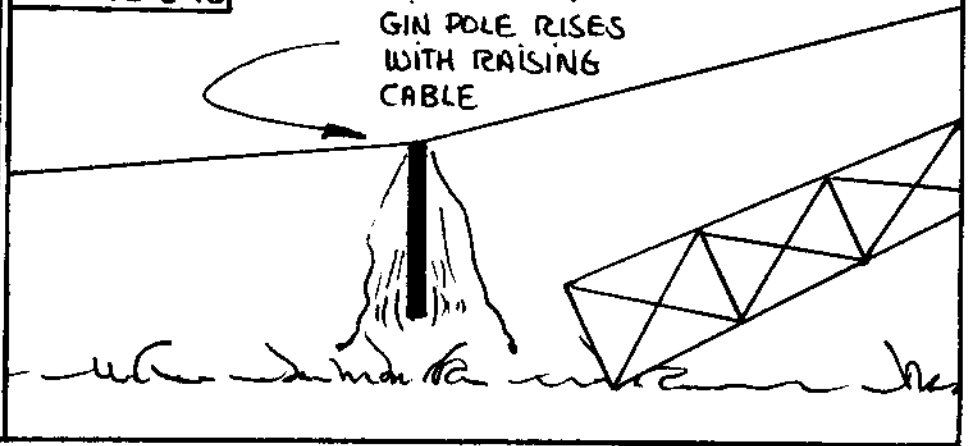


FIGURE 3-16

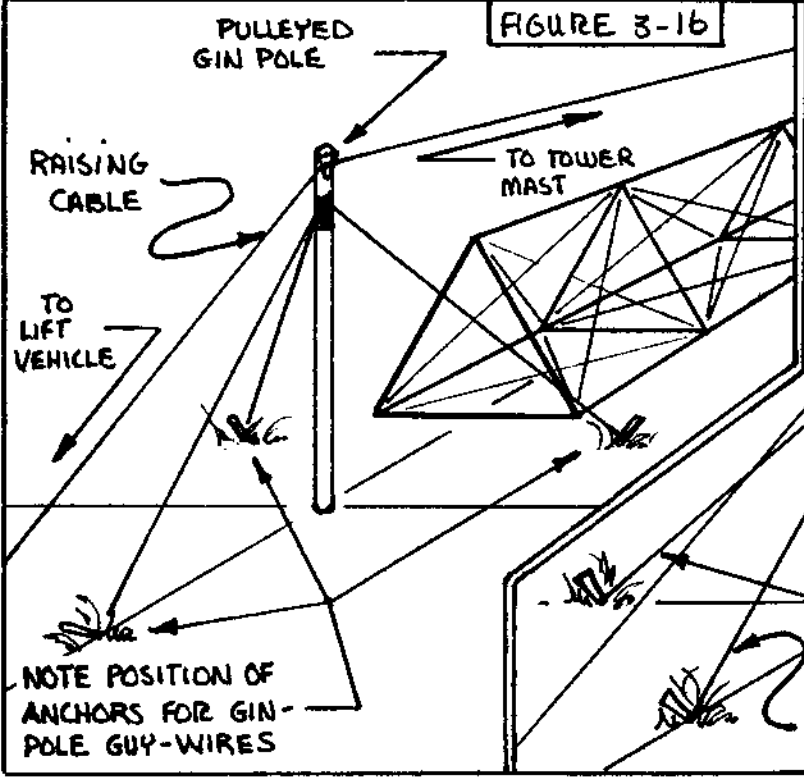
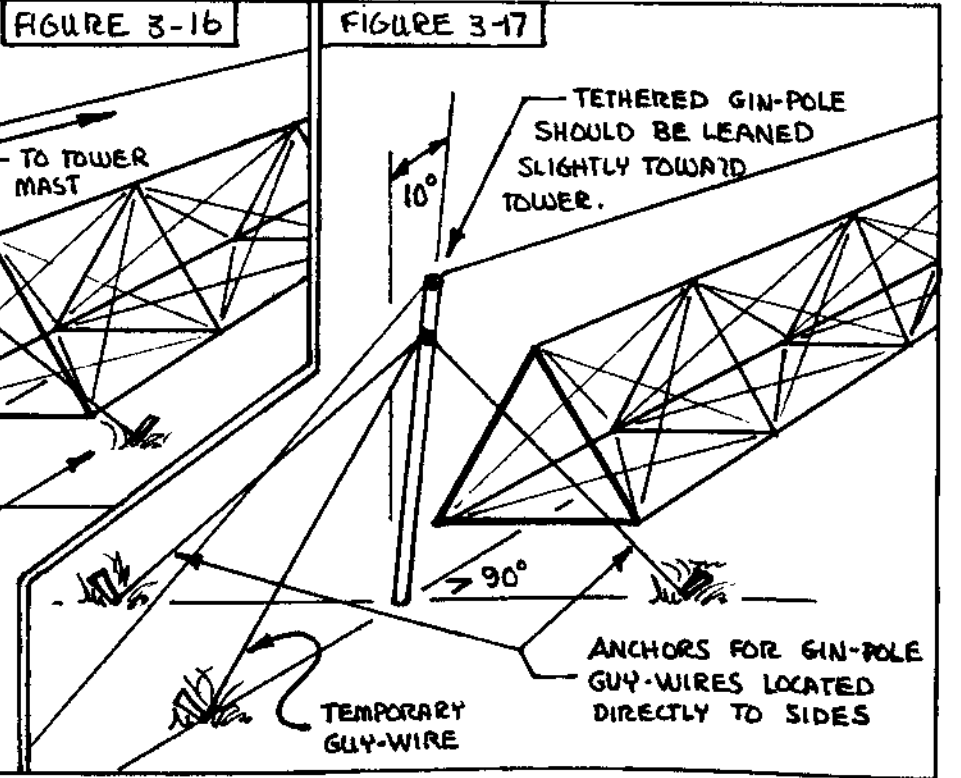


FIGURE 3-17



gin pole will not stay upright with just two wires, so a third, temporary guy wire can be used to keep it upright ( if it's leaned as shown ) until the raising commences.

3. If a pulley is used, care should be exercised in securing it to the gin pole to insure that it is not going to slip or break under the compressive forces previously mentioned. As indicated in Fig. 3-11, the compressive forces are very large so don't get too casual when you make this tie-up.

The base of the gin pole should be placed on a hard and level surface so that it does not dig in or canter to the side during its use in the tower-raising. If you've got soft ground, you might place a piece of 2 x 6 under it to help the situation. Insure that all tie-ups are tight before the raise; the gin pole may only be used for the first one-third of the raise, but its proper performance is a critical factor.

Negligence here will unquestionably snap the raising cable or create enuff slack that a crashed tower is the very least that can happen!

### The Raising Cable

One of the more important components of the tower-raising equipment is the raising cable itself; it must be strong enuff to do the job and then some ( if you want any kind of safety factor ). How strong it needs to be depends on the height of the tower and its weight. If you're buying cable for the job, it won't be too difficult to get that info ( unless you're getting it surplus ), but if you've got a piece of sumthin' lyin' around the place that turns out to be long enuff to be used, you may not know what it is rated to pull or lift. Whatever the situation, it might be helpful to understand that the maximum tension the cable will experience ( during the lift ) will occur at the beginning, or start, of lift. This is a very neat safety item ( unless you are lowering a tower ), becuz you can assume that whatever cable is used will do the job. Then, before the raise starts ( or just as it starts ) you give it the "acid test." If it's going to break, it should break immediately and you will drop the tower a few feet at the most. Mind you, I am not recommending this method. If it does break, you're going to have some highly dangerous cable whipping around for a few seconds. I mention it here primarily to indicate that you shouldn't get into a frame of mind of trusting even brand new cable; it only takes one small kink, or nick, to create the possibility of breakage, and under the stress conditions of raisin' a tower, it must be considered a certainty. A closer look at some of the drawings in this chapter should tell you one thing -- tension in the raising cable will be decreasing very rapidly as you lift a tower ( becuz, if you remember, the lift angle is increasing ) so, if it doesn't break within the first few feet, the possibility of its breaking will be decreasing very rapidly thereafter.

Cable is rated in two ways: what it will lift ( in lbs or tons ) with a steady pull and what it will lift rapidly ( like if it were snapped ). This means that a specific cable may be able to lift several tons normally ( if done slowly ) but will break, if snapped, while it is lifting only one-fourth of a ton. This has other meanings when a cable is used for tower raising, so let's deviate a moment, and discuss them.

If you have a tower that weighs 2 tons, do not assume that you need only find a cable that will lift two tons. With the kind of lift angle most of us will have initially, the tension on the raisin' cable initially will be many times the weight of the tower. It is a rule of thumb that a lifting force of one-half the tower's weight is required at the top, but this is the situation if it's pushed from beneath or pulled from above. Becuz this can't be done when using a gin pole, a minimum of 4 times this force is rule of thumb for the cable at the low lift angle. That means, therefore, that

the cable should have a minimum rating of twice the weight of the tower. A safety factor of two is considered rule of thumb, so it should be rated in pull 4 times the weight of the tower. For the lift angle that will result with a 20-foot gin pole and 60-foot tower, this is probably sufficient; for a tower twice that length ( 120-footer ) this will be doubled again.

I've already indicated that the normal situation will be that the maximum tension exerted on the raising cable will occur at the start of raise; if you check out some of the drawings, you'll see that it will only be toward the end of the raise that the tension will be small enough in the cable for it to be able to sustain ( that means survive ) a sudden snap, or jerk, on the cable. This can easily occur if something slips a little, or if the person operating the truck pops the clutch. It can help ease a troubled mind to say the probability of breakage decreases as the tower angle increases, but bear in mind that "probability" is a description of a finite number of things doing something a certain percentage of the time of a whole bunch of times that it's done. This is very much of a mind thing, and has little to do with real events ( as losers at casino tables will vividly attest ) so don't let it fool ya!

With this in mind ( especially if you have a cable of unknown ratings ), you can perform a little experiment. When you're ready to lift the tower, take the slack out of the cable and then pop the clutch on the truck. This will probably kill the engine on the vehicle, but the tower should jump up a little and hold ( or just fall back into place ). If it doesn't break, chances are real good that the cable will be able to take a steady pull. Now run a second test. Pull on the raising cable until the tower has lifted a foot and then block the wheels on the lift vehicle so that the tower can't go back all the way down. Then pop the clutch. This will cause the tower to raise up a smidgen and then bounce up and down a bit. If it can do this, it will probably survive a snap during the raise. If it does break, it still might be useful for a raise ( becuz the steady pull didn't break it and you know the snap rating is of a lower value ) but I'd have to be desperate before I would use it. At any rate, now is the time to be thinkin' 'bout who you're gonna get to operate the lift vehicle -- they should be a real smoothie on the clutch and not someone likely to get rough on it when excited or pressured.

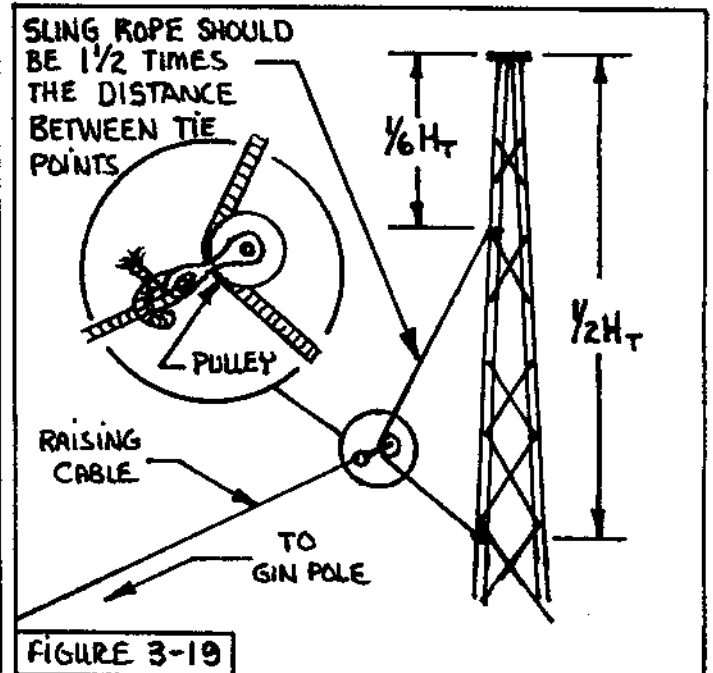
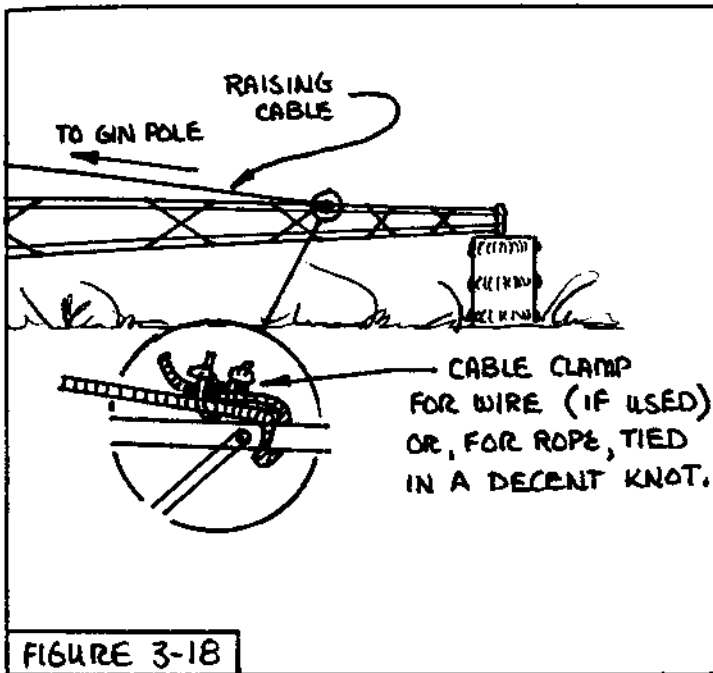
Steel cable is not the only thing that can be used for the raising cable; I'm certain that a sturdy hemp, nylon, or whatever would do nicely. These are generally rated in steady pull; they may indeed have a snap rating but I've never seen one so indicated, so watch out! Without any tensile strength specifications, I'd use one-half inch ( maybe ) or larger, but I'd sure inspect it well for rot or fraying, and would assuredly give it the "snap" test previously described. I admit my ignorance about rope, and hesitate to provide tables of "ratings" for various kinds and sizes. It doesn't make sense to provide someone ( who is also ignorant on the subject ) with a false sense of security about such things; it does make sense for you to find it out for yourself or to protect yourself ( by allowing for it ) if you can't find out. Enough said.

If the info is of any use, we used a 5/16-inch steel cable ( with a hemp center ) on Jim's 54-foot tower ( a three-leg monstrosity which must have weighed 2 tons ). We got the cable at a nearby surplus place ( 450 feet for, I think, \$80 ) and we experienced no difficulty with it and had no indication that it was under any severe stress.

### Securing the Cable to the Tower

There are two methods of securing the raising cable to the tower: Direct ( see Fig. 3-18 ) and using a pulleyed sling ( see Fig. 3-19 ). The pulleyed-sling method seems to be intended for use

with towers over 60 feet in height; the only time that I've used this method was to raise a 40-foot Wincharger-type tower which had a Wincharger attached to it at the time, and the sling did not "come into effect" ( a pulleyed sling is a physics trick which is supposed to fool the raising cable, making it appear as though a shorter tower is being raised ). If you use the pulleyed sling for your very tall tower, connect the top of the sling within ten feet of the top of the tower and the bottom of the sling within 30 feet of the top; the raising cable attaches to a pulley which is allowed free travel along the sling. If you are making a direct connection to the tower, the raising cable should be secured at a point about one-sixth of the height of the tower down from the top of the tower ( i.e., for a 60-foot tower, that would be 10 feet from the top ). For steel cable, use cable clamps to connect the wire to the tower; for rope, tie a decent knot ( or get someone to do it that can especially if you are using nylon rope ), or you'll risk it coming undone during the raise or not being able to get it undone after the raise!

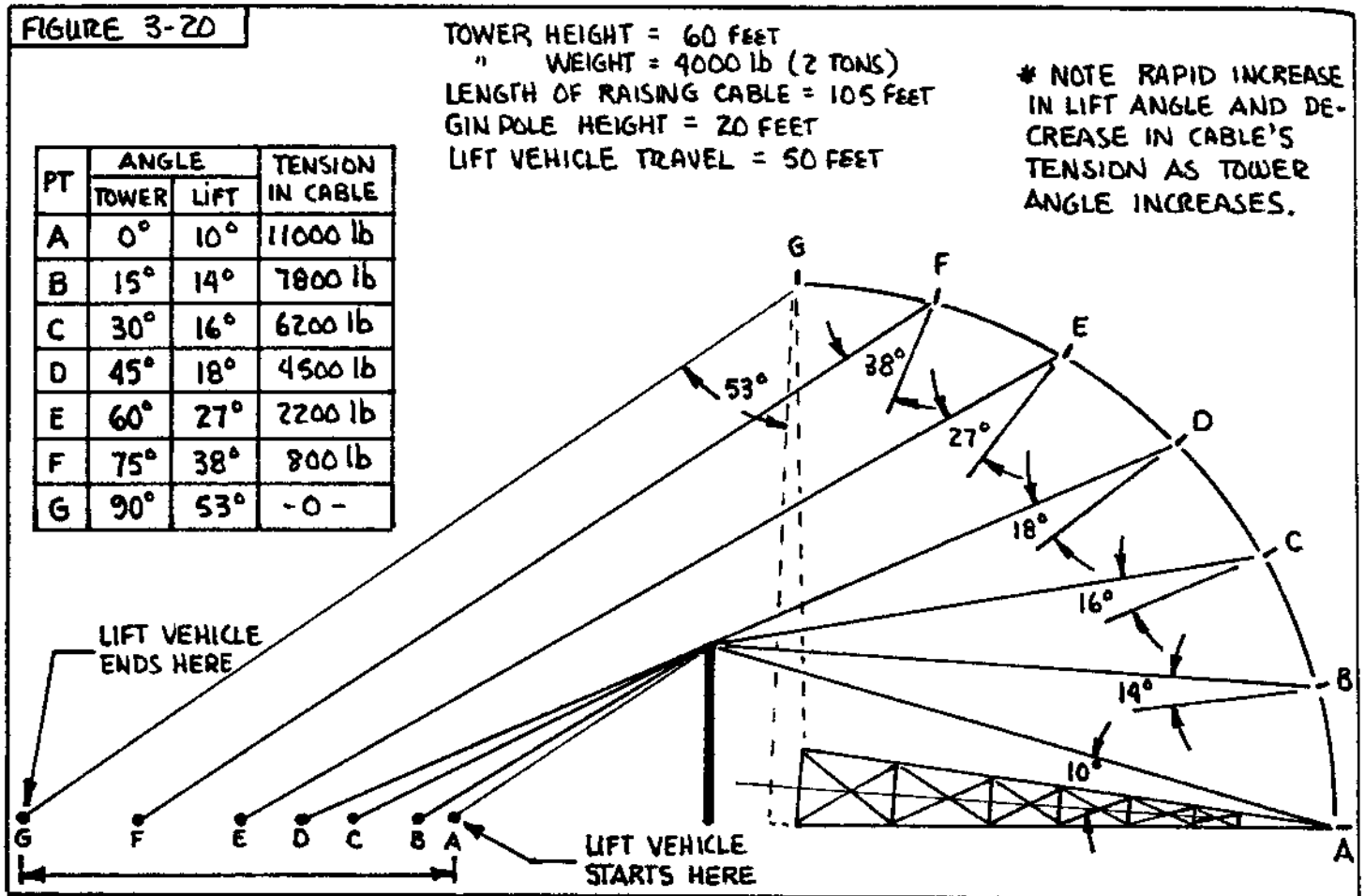


### Raising Cable Length

Next question for the raising cable is: How long? Well . . . that depends ( wouldn't ya know it! ) on the tower's height, the amount of room you have for the vehicle to move around in, what obstacles might interfere with the raising cable's movements, and whether or not you are going to use a pulley-type mechanical advantage during the lift. Okay, that's a lot of "depends" so let's go thru some basic relationships.

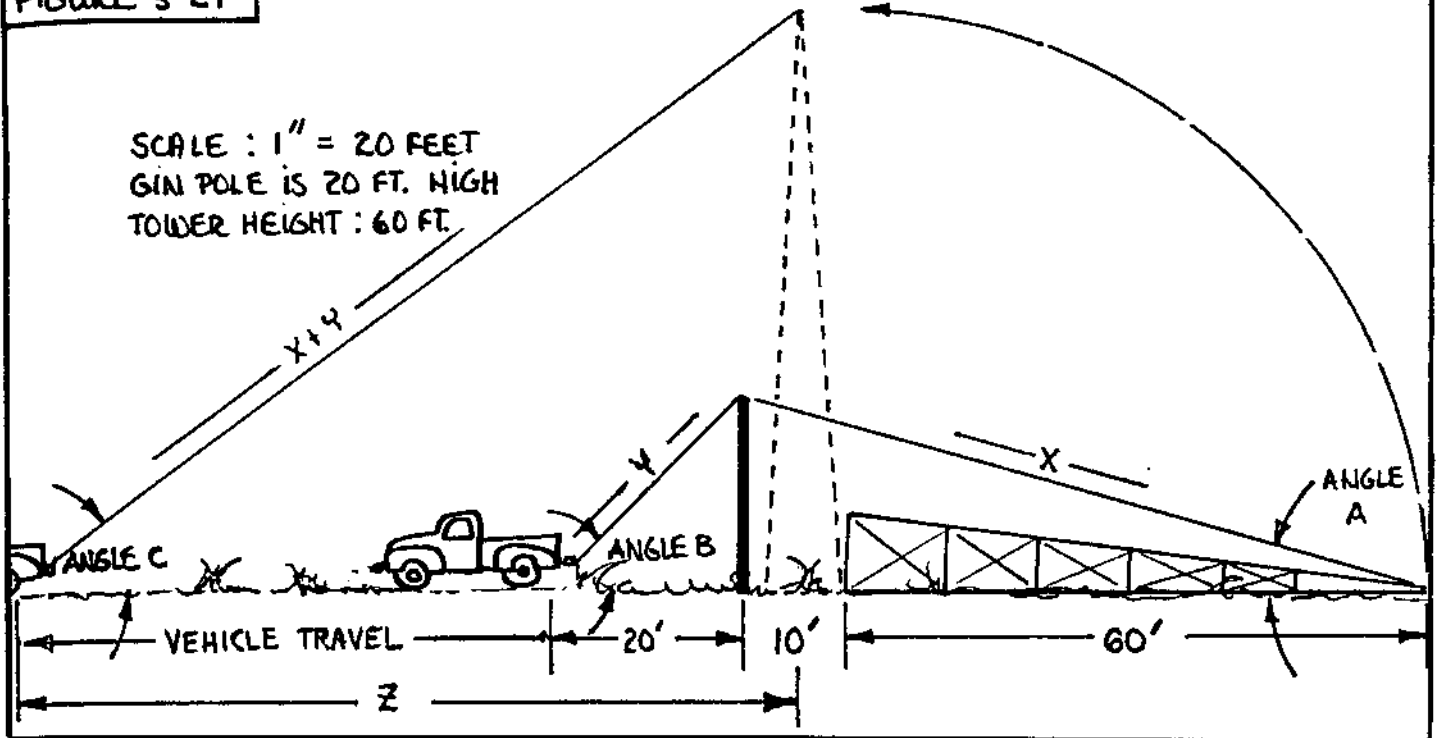
1. The lift vehicle should be as far away from the tower ( initially ) as possible. While this will have no relative importance at the beginning of the raise, it will allow for a rapid increase in the lift angle as the tower goes up ( see Fig. 3-20 ) and you should by now know the importance of a large lift angle. A compromise is in order here; increased distance between tower and lift vehicle ( which defines any vehicle being used to exert the pull on the raising cable ) will make for a direct increase in the length ( and expense ) of the raising cable.
2. The raising cable must be allowed free movement during the raise. Here's another one of those mental images that you're going to have to conjure up; if your vehicle goes between a few trees, it might clear but will the raising cable ( as it rises ) also clear? Are there power lines or telephone wires in the way? The best way

to check for these possibilities ( if they exist at all ) is to determine the total distance that the truck will travel during the raise ( from start to finish ), put yourself at the point where the truck will begin initially, and walk along the route for that distance, looking back and up ( to where the top of an imaginary tower will be at the end of the raise ). It's no fun to get a tower up most of the way to find that something will interfere with the cable; by the same token, it's lousy to go thru some of the extra effort to compensate for an obstacle which looks as though it will interfere when it really wouldn't. Either way, it is worth the effort to check it out.



3. The lift vehicle must be able to move through a distance sufficient to allow the tower to come full upright. A seemingly obvious point, but how do you determine this? Fig. 3-21 shows one way ( with only a few small guestimations ) whereby you can come close enuff to determining what distance your vehicle will travel in your situation.
4. There are several ways in which a lift vehicle can be relieved of having to exert the full force ( or raising-cable tension ) required to raise the tower; one that should come to mind is to use two vehicles. If each vehicle is separately tied to the tower ( by a raising cable ) this unnecessarily complicates the situation; as well, the actual raising will probably be quite jerky ( and the strain on the cable more severe ) because the vehicles would have a hard time of pulling exactly equal with one another through the entire lift. A simpler arrangement that accounts for this problem is shown in Fig. 3-22; any momentary slackening of the pull from either vehicle will be instantly taken up by the other.

FIGURE 3-21

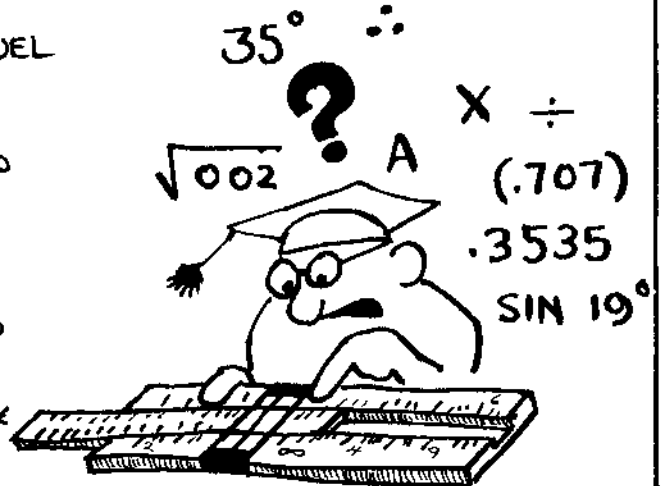


▷ RULER METHOD OF FINDING VEHICLE TRAVEL

1. DRAW THE SET-UP TO SCALE.
2. MEASURE X AND Y AND ADD ; THIS IS THE RAISING CABLE LENGTH.
3. PLACE ONE END OF THE RULER AT THE TOWER MAST (WHERE IT WILL BE WHEN UPRIGHT) AND SWING THE OTHER END UNTIL THIS MEASURED DISTANCE INTERSECTS A POINT ON THE GROUND LINE. THEN MEASURE THE DISTANCE FROM THIS POINT TO THE POINT WHERE THE VEHICLE STARTED. MULTIPLY THIS NUMBER OF INCHES TIMES THE SCALE USED; THIS IS THE DISTANCE THE LIFT VEHICLE WILL TRAVEL DURING THE RAISE.

▷ TRIG. METHOD OF FINDING VEHICLE TRAVEL

1. TAN. ANGLE A =  $20' / 70' = .2857$
2. ANGLE A  $\approx 16^\circ$
3.  $\sin 16^\circ = 20' / X$  or  $X = 20 / \sin 16^\circ$
4.  $X = 20 / .2756 = 72.5'$  ←
5. TAN ANGLE B =  $20' / 20' = 1$  or
6. ANGLE B =  $45^\circ$
7.  $\sin 45^\circ = 20' / y$  or  $y = 20' / \sin 45^\circ$
8.  $y = 20' / .707 = 28.3'$  ←
9.  $x + y = 72.5' + 28.3' = 101 \text{ FEET} *$
10.  $\sin \text{ ANGLE C} = 60' / 101' = .5940$
11. ANGLE C  $\approx 36.5^\circ$
12.  $\tan 36.5^\circ = 60' / Z$  or  $Z = 60' / \tan 36.5^\circ$
13.  $Z = 60' / .7400 = 81.1 \text{ FEET}$
14. VEHICLE TRAVEL =  $Z - 20' - 5' **$
15. VEHICLE TRAVEL =  $81.1' - 25' = \underline{\underline{56.1 \text{ FEET}}}$



\* LENGTH OF RAISING CABLE  
\*\* DISTANCE FROM GINI POLE TO CENTER OF TOWER BASE (WHEN TOWER IN RAISED POSITION)

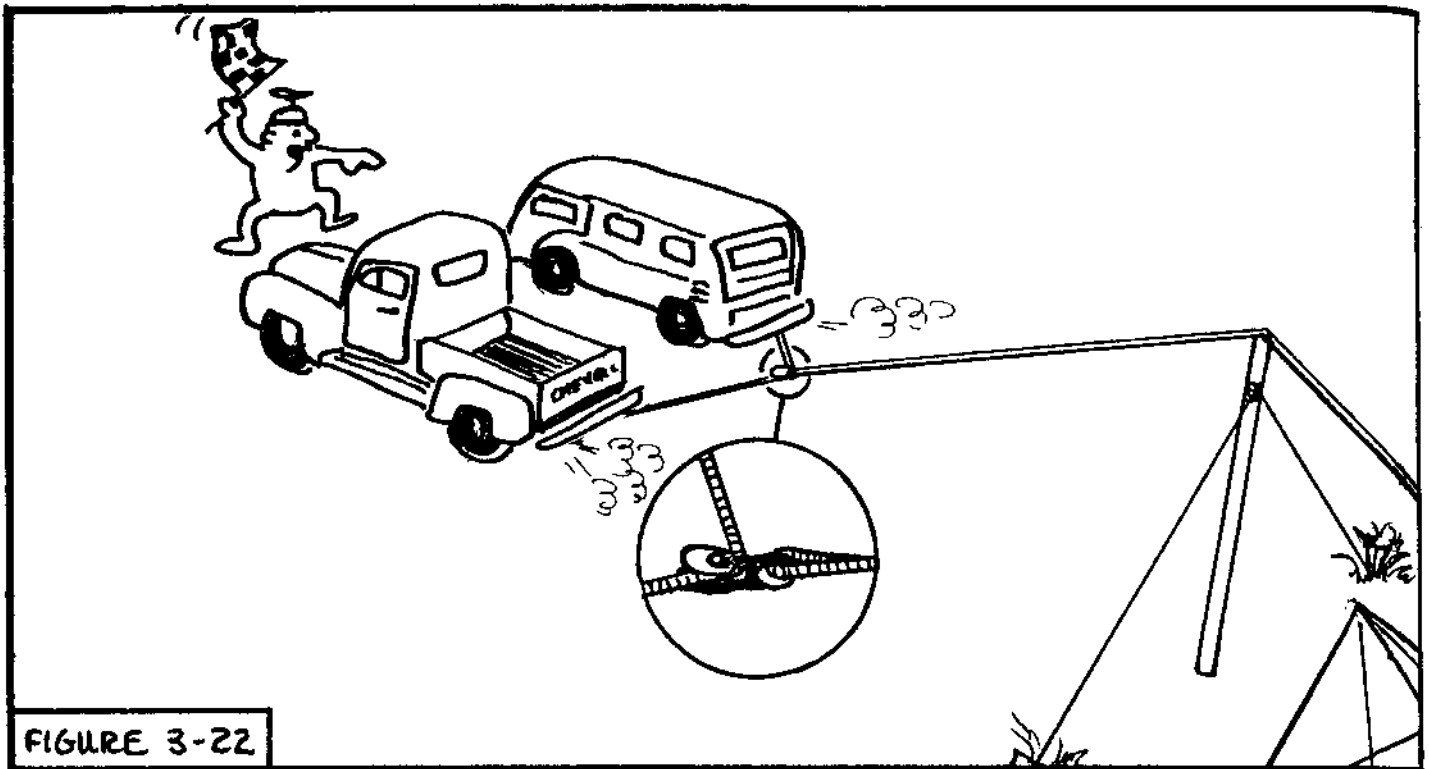


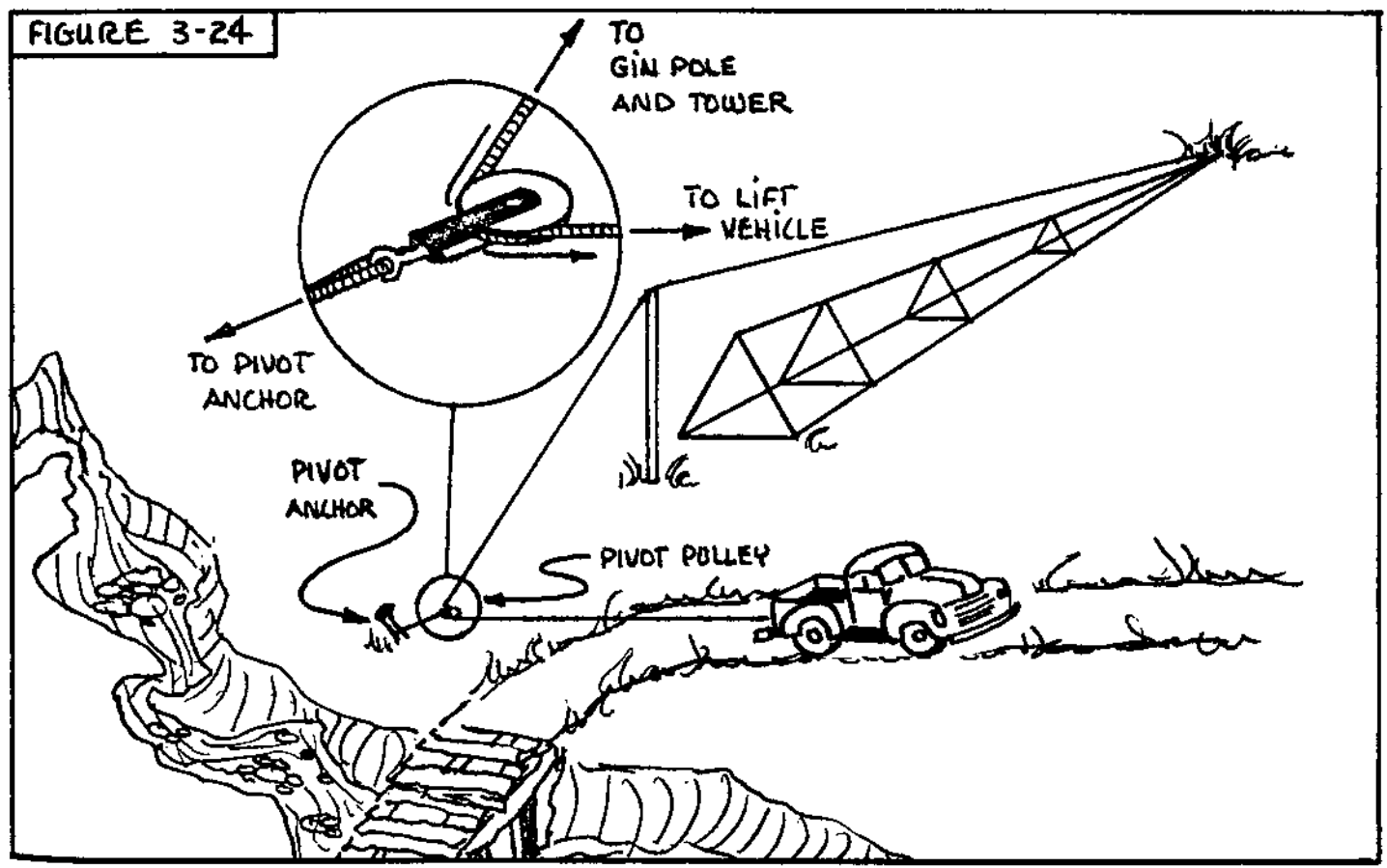
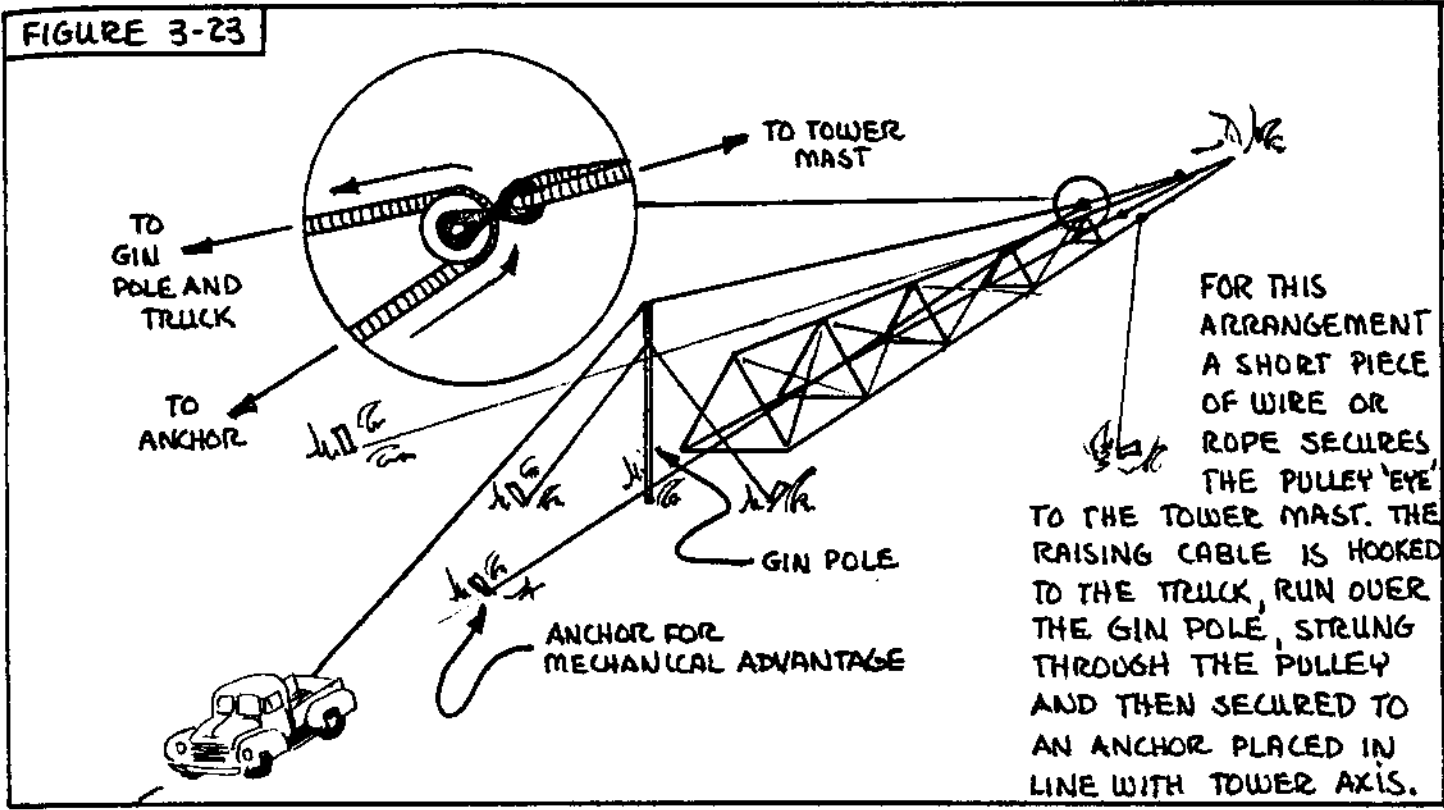
FIGURE 3-22

If you have only one vehicle available for use as a lift vehicle and it's not a truck or tractor but rather a VW bus, small car, horse, or a buncha friends, then consider using some kind of "mechanical advantage" along the lines of a block-and-tackle. Fig. 3-23 illustrates the use of the simplest mechanical advantage ( of two times ); this cuts the pulling force required by the lift vehicle in half ( provided the two lines are parallel ). You won't be getting something for nothing, though; you have to have a very strong anchor at hand such as a large tree or tree stump or a stationary vehicle able to take at least one-half the required lifting force. As well, for each factor of mechanical advantage used, the distance the lift vehicle will travel is increased -- by that same factor. So . . . for a mechanical advantage of two ( times ), the vehicle must travel twice as far as it would travel if no mechanical advantage was used; for an advantage of three, three times as far, etc. This means the raising cable will also have to be longer -- that's right, you guessed it -- by the same factor.

If you use a mechanical advantage, be sure to hook it up the right way. In raising Jim's 54-footer, we tried to use a mechanical advantage of two but we got in too much of a hurry and hooked it up backwards ( this gave us a mechanical disadvantage of two ) and almost burned the clutch in his truck trying to lift the tower. It just wouldn't lift. We figured it out, re-arranged the lines, and proceeded uneventfully.

5. If lift vehicle travel is severely restricted, or obstacles abound in the intended direction of pull, consider using a pivot anchor ( see Fig. 3-24 ). It will have to be very secure as it will generally experience forces that could be ( depending on the angle ) as much as twice the raising-cable tension. We used this method in raising Jim's 54-footer ( in addition to using a mechanical advantage of two ) and it worked admirably. A truck was used as the pivot anchor; it was braked, blocked, and staked to the ground so thoroughly that I thought it would probably be left anchored as a monument to the tower's raising. There is one disadvantage, though, in using

a pivot anchor; it does not allow the lift angle to increase as quickly as a non-pivoted pull would. This is, however, of little concern if it's a situation where the tower can't otherwise be raised, so it's just an observational note.





This is a lot of "if's" to figure out, so get out some paper; there's no sense in strugglin' with it in your head. Get a ruler, protractor, and graph paper and make a series of drawings; this will help make the situation clearer and the decisions more sound. One of the drawings should be a map which shows the tower site, the position of the tower, and the surrounding area; note all trees, houses, garden plots, ditches, fences, or anything that would represent an obstacle to a vehicle, or the raising cable. All of the drawings should be "to scale"; for an accurate representation of these items in the map, use a long tape measure ( or a consistent stride in walking off distances ) to find the distance to each of these objects from some reference, say the tower base. ( Sighting along a properly-used protractor will give bearings which will make the maps even more accurate. ) Do a good job on this map; it will be used for plotting out the varied possibilities for raising the tower, among other things. Then make a drawing for: configurations for using the mechanical advantage, ways to route the raising cable, places to plant the various anchors, placement of the pivot anchor ( where applicable ), etc. Make more than one drawing if it's starting to get cluttered. So far, you've made top views; now you'll want to make some side-view drawings of the way it will look before the raise and after. If you draw them to scale ( like letting one inch equal ten feet ), then you'll get a very close approximation of the lengths of certain guy wires or the raising cable, and can avoid having to brush up on trigonometry to mathematically arrive at the lengths. Tricky, huh? This will quickly let you know if a certain power line is going to represent a problem if it's done this way or that, and it will let you know the best way to use what you've got. All of these drawings are extremely helpful, so don't underrate the idea of making them. When it comes time to start making decisions, it's always helpful to have other people informed of what's going on becuz the suggestions, comments, questions, answers, etc., will be most welcome. Unless one person is going to do all the setup, it will be a master plan that all can work from when the time comes. And finally, when all is readied and the magic day arrives, it can be used in the pre-lift pow-wow ( for all of those folks involved in the tower-raising ), letting everyone know who will be where!

### Guy Wire Supports

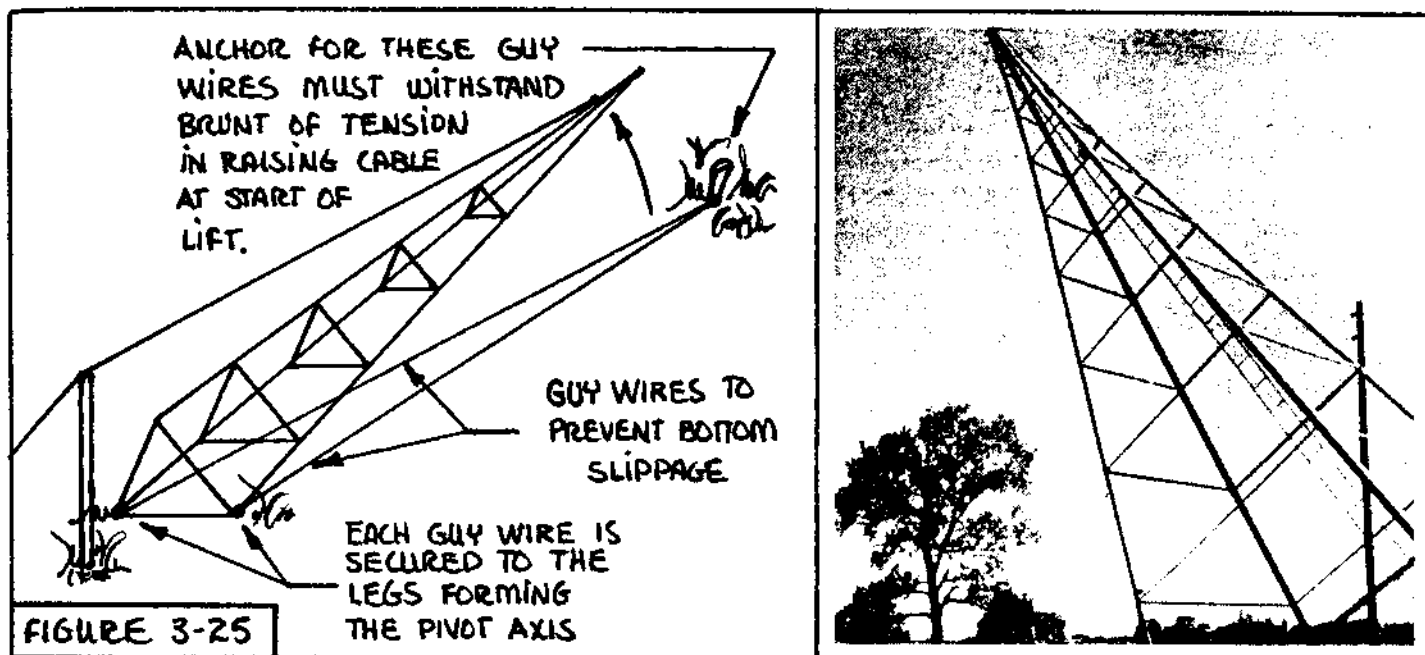
When a tower is being raised, there are a number of different ways that it can go. If you want it to go only one way ( like up! ), then you're going to have to know where it might otherwise want to go, and how to prevent it from going these different ways.

As you start the raise, the bottom of the tower will tend to slide along the ground in the direction of the lift vehicle or the direction of pull (remember the man whose birdhouse pole crashed into the house? ); I refer to this occurrence as bottom-slippage. Then, as the tower goes up a way, it might try to fall on one side or the other; this event is described by the term side-fall. Finally, when the tower is almost all the way up, it will pass thru a point ( which I refer to as teeter ) after which it will "fall" into the upright position. When this happens, it might just keep on going ( in the direction of the pull ) and fall over in that direction; I refer to this as end-over. Preventing this, and the other possibilities for a "downer" ( a term which describes both the feelings of the owner and the wreckage resulting from a fallen tower ) is the subject of the following sections.

### Bottom-Slippage

As previously indicated, the bottom of the tower will tend to slide in the direction of the pull; this will occur with any tower that is raised by the gin pole method and is due, primarily, to the relatively small lift angle, the absence of tower angle, and the high proportion of the pull which is exerted along the tower axis. This effect will disappear as the tower comes full upright becuz its own weight will then "push" the tower into the ground.

The simplest means of preventing this occurrence is to anchor the bottom of the tower. While this can be simply done at the base by driving stakes into the ground, this does not afford much protection. Why? As the tower is raised, it will pivot about one or two legs and it is easy for the pivoting action to cause the bottom of the tower to ride up and over the stakes. A far more effective means of anchoring the bottom is to attach wires to the two legs which will provide the pivot ( see Fig. 3-25 ); for a single-leg tower, only one leg is available and, therefore, only one wire is attached. The other end of these wires may then be secured to an anchor located along the tower axis and in the direction of the top of the tower ( as it lies horizontally ). These anchors and wires must be very strong, as together they must be able to withstand the brunt of the tension on the raising cable at lift-off, so use the same size and kind of cable used for the raising cable itself.



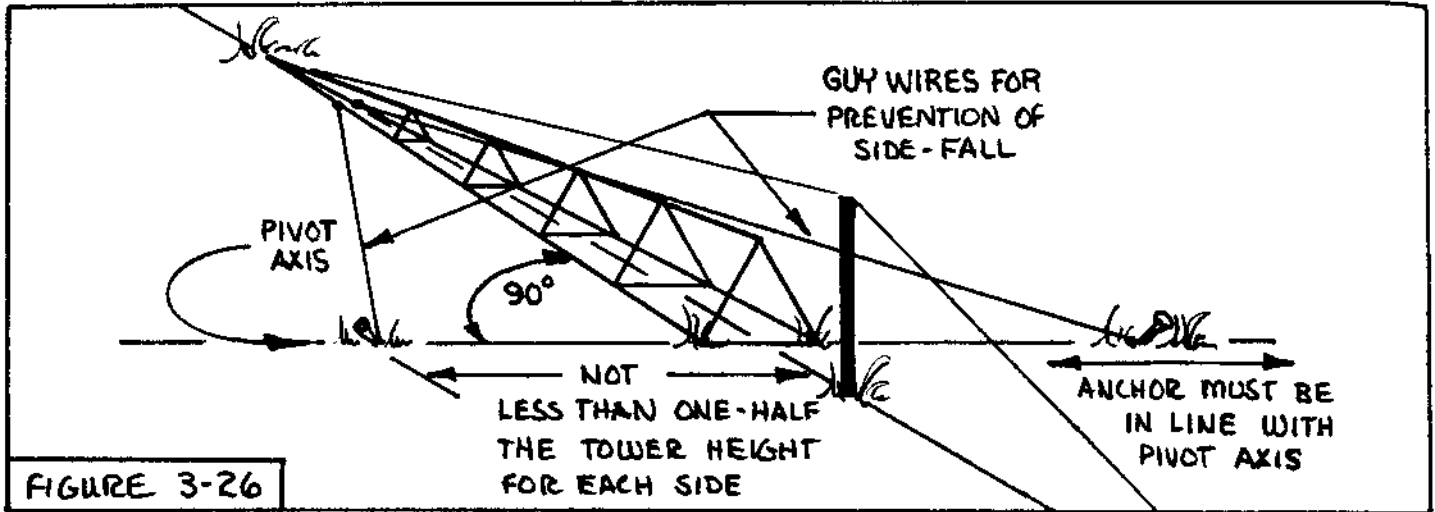
### Side-Fall

During the raise, a tower can fall to either side (perpendicular to the pull ). While it is more likely to occur with a narrow-base tower ( one that has no base width -- like a single-leg tower ), it can occur with any tower. This is due to soft ground under the base , a change in the direction of the pull ( or a pull that isn't perfectly aligned to begin with ), and the effect of wind. It is prevented from happening by attaching guy wires to each side of the tower and securing them to anchors in the ground ( also located to the sides of the tower ); in this manner, a guy wire on one side prevents it from falling to the opposite side and vice versa.

If you don't want to be changing tension on them during the raise, you must locate them along a line drawn through the pivot axis of the tower and perpendicular to the tower axis ( and direction of pull ). This sounds a lot more complicated than it really is ( see Fig. 3-26 ). They should be located at a distance from the base of the tower of not less than one-half of the tower height, but they may be located at a much greater distance if you happen to have sumthin' out there that will do the job ( like a fencepost or a dead tractor ) and it is along that line drawn through the pivot axis of the tower. Don't fudge! If it isn't in line, don't use it!

The guy wires used to prevent side-fall must be able to withstand at least two hundred pounds of pull ( such as that exerted by two men ) but a safety factor of 500 lbs is recommended. These

wires should be attached to the tower at a point about one-fourth of its height from the top. As the wires will be "following" the tower as it is raised, they should be positioned so that they are not interfered with during this movement. When we raised Jim's 40-footer, we could not position one of the side guy wires to clear an anchor line for a nearby utility pole; consequently, we had to pause during the raise to secure a temporary guy wire, remove the existing guy wire ( see photo ), get it around the utility line that was causing the interference, re-tie the guy wire, and remove the



back-up wire. Becuz we'd forgotten to tie the back-up wire to the tower before we started the raise, I ended up having to climb the tower. This didn't bother me ( I didn't feel like I was defying death or anything ), but I think it might bother others, so plan ahead or you'll have to lower the tower to do it!

### End-Over

When a tower is nearly upright, it will reach a point that I call teeter ( for lack of ever having heard another word to describe the same event ). This is the position where the center of gravity of the tower is directly above the pivot axis of the tower; at this precise point, it "balances". If it's a single-leg tower, it will occur when the tower is fully upright ( like you'd balance a pencil ). If you have a 3-leg, 4-leg, or octahedron tower ( which can be thought of as having 3 legs ), it will occur before the tower reaches vertical position. After it has reached this point, it will ( if completely freed ) just "fall" into the upright position. If you need some proof of this, try this little experiment:

Get a drinking glass ( preferably one made of plastic, or sumthin' unbreakable ) and put it on a level surface. Use one finger and slowly begin pulling it to one side until it's just balanced, and let go. Only three things can happen. The thing will stay balanced, or it will fall over on its side, or it will "fall" into an upright position, rocking back and forth until it comes to a vertical rest. When you balanced the glass, it was at teeter. And if you let it go and it fell into an upright position, it rocked over to the opposite side just a bit ( but not enuff to fall, probably ). Well, a tower will do the same thing as the drinking glass did but when it rocks over to the opposite side, there is a very high probability that it is going to keep on going, falling over on its side in the direction of the pull. Unlike the drinking glass, which will rarely fall to the other side, the tower has the weight of the raisin' cable on that side, and that and gravity are all that it needs to get past the teeter point on that side.

Well, it's easily prevented. Just add in another guy wire, attaching one end near the top of the tower and the other end to an anchor ( which can be the same one that's used to prevent bottom-

slippage ). Like the guy wires used to prevent side-fall, it needs to be able to hold onto a few hundred pounds, but figure 500 lbs and play it safe. Its length is determined by one of the three methods described in Problem 6.

In raising both of Jim's towers, we used a truck as an anchor for the guy wires used to prevent bottom-slippage and end-over ( see photos). In addition, we used a "Power-Pull" ( a small, hand-cranked, portable winch ) to ease the towers into their final, upright positions as they approached "teeter." ( We were sure that we couldn't stand to see them fall into place and hear the end-over prevention wire twang as it went taut.) Consider doing this to ease the tower into vertical position.

### Additional Notes

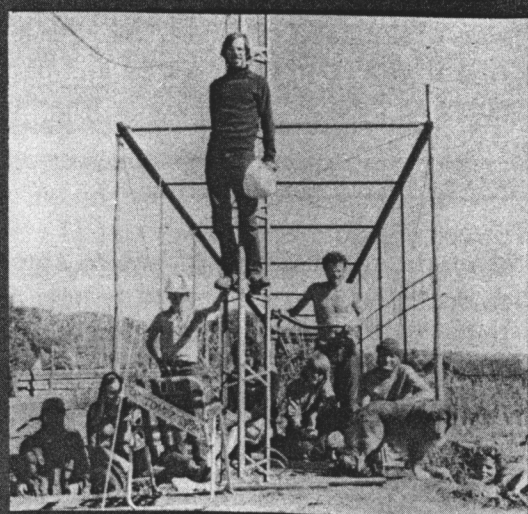
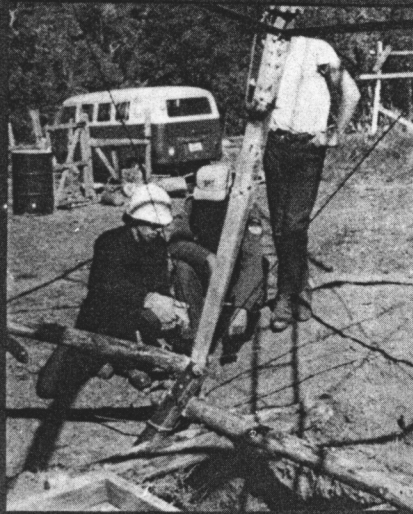
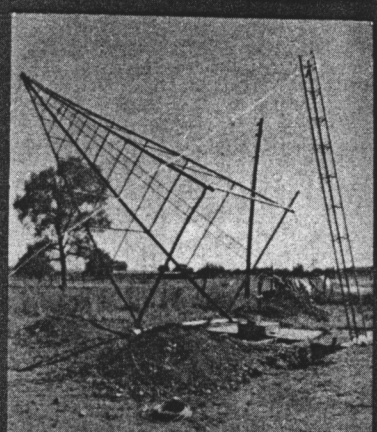
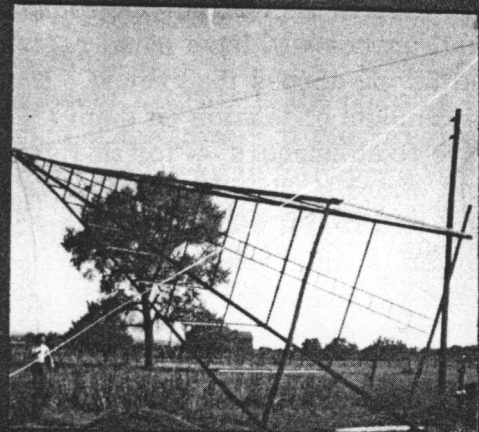
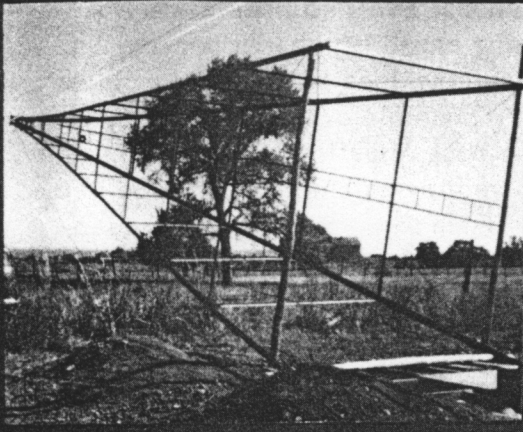
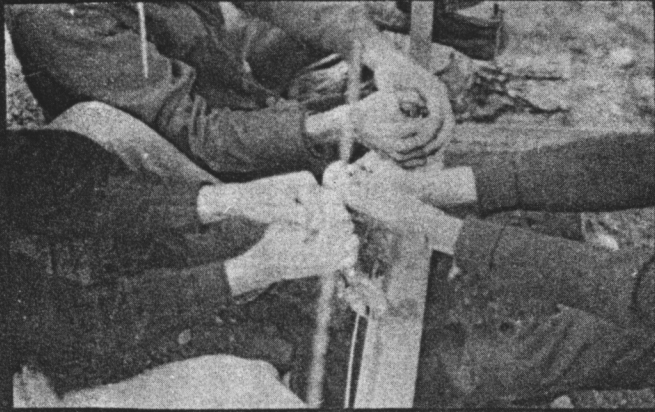
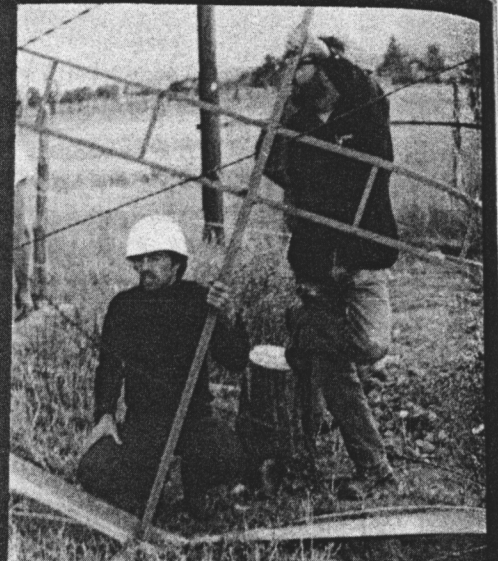
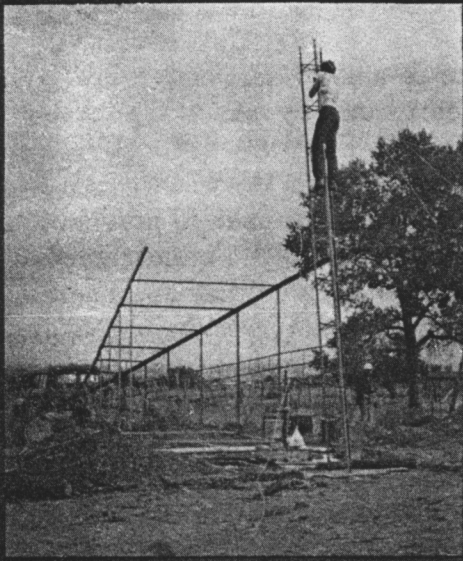
Guy wires will be running hither-and-yon by the time you're ready to lift the tower into place, so learn well what they do and where they go or your mind will be tripping over them like your feet probably will. It may take a bit of mental gymnastics to see what will be happening, but its worth should not be underestimated; working with a few tons of tower can be hair-raising. Knowing that you've taken care of 99% of the "things that can go wrong" is immensely helpful in preventing ulcers and cardiac arrest during the actual lift. In raising the first of the two towers at Jim's place, we had one of those 1% things occur -- the legs buckled ( the tower was missing a few vital pieces at the base and their absence went unnoticed ). We had gotten it up to a tower angle of about 45° when this happened, but we merely stopped the raise, looked over the situation, and then lowered it back down to repair the damage. Panic or "do something!" reactions to these little mishaps can have grave results.

Guy wires and anchors are used to prevent any ( or all ) of these events from happenin' to you during the raise. I've seen drawings where people were used instead of the anchors, but I don't hold to the idea of this alternative to the affixed-in-ground anchor. First off, it's askin' for trouble; even a simple, small anchor will have more restraining capability than a person, and will hold while a person goes skittering across the ground. If everything goes right, most of these guy wires will have only a small amount of tension on them ( so it's possible to use a person ), but that's why you want to use the fixed anchors -- for that going-wrong situation. The fixed anchor will keep the tower precisely where it should be ( and thus preventing an unwanted tension in the guy wire ), whereas a person will find it difficult to know how much force to exert ( without a reference ) and, once the tower is out of position, the forces required to get it back grow much greater very quickly. And the person on the other side is holding tight so you'd have to fight that. Geesus, that's a nightmare! No thanks!

As far as I'm concerned, you only start the raise when everything that can be accounted for, is. So that leaves only the freakish kinds of thing that can happen. If what you have provisioned for won't take care of those, there's nothin' you can do . . . so don't try. That's what kills, folks. And if you've got guy wires and people all over the place, the odds are real good that somebody's going to be under that tower when it comes down. Towers are expendable -- people aren't!

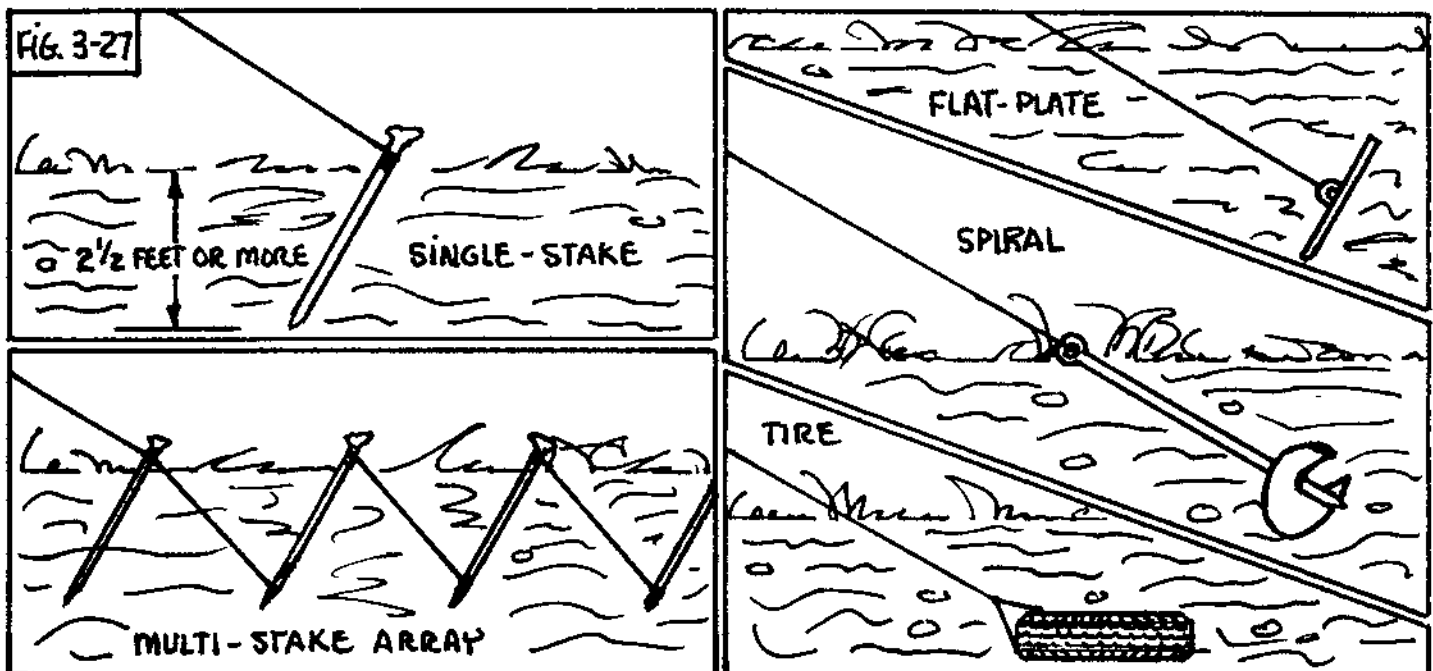
### Pre-Raise Preparation

It might seem like it's time to start talking about actually raising the tower, but there's still a lot to do. Some of this you may have already done, but it's included here as a checklist of sorts for those that haven't even gotten a tower yet. I've probably forgotten a few things, so don't substitute it for your own head. The Pre-Raise is divided into three sections -- anchors, final tower preparation, and the raising equipment itself.



## Anchors

Once the tower has been procured and the site for it selected, extensive thought should be given to the manner in which it will be secured for the years to come. If it's a single-leg tower that you will be using, you have little option; the tower should be secured with guy wires in the manner described for single-leg towers ( as shown in Fig. 3-4 ). The type of anchor to use will vary depending on various aspects of your situation and the soil condition, so I have included drawings of the types that I am familiar with ( see Fig. 3-27 ). The single-stake type is recommended for use in the raising process only; it is sufficient for the guy wires used to prevent side-fall or end-over. It may be used successfully, as well, for temporarily securing a tower which is awaiting final cementing of its legs ( after which these guy wires would be removed ); it is not recommended for permanent guy-wire anchoring. The multi-stake type can be used for a permanent guy-wire anchor but only if the soil conditions are such that the ground is very hard as they will eventually loosen if not. If you don't want to worry or constantly recheck guy wires using this anchor, don't install it. The Wincharger manual recommends the spiral-type anchor when making permanent guy-wire installations, but I would refrain from using it if soft ground represents your situation. The flat-plate type is suitable for most permanent guy-wire anchoring, but insured that a proper depth is reached if installing this type. The auto-tire type is included becuz of its possibility for use in this situation; but I would recommend its use only where the soil is aliking desert sand conditions ( this is derived from an old trick for winching a vehicle out of sand in the desert ).



For the 3-leg, 4-leg, and octahedron towers, the legs may be cemented and guy wires altogether not used ( I'll include some information here on how to do this ), but for the most part you're going to have to do some research in this area. Cement is neat stuff, but in the hands of amateurs it comes out just like that -- amateurish! Know what you're doing! If you don't, study up on it extensively, or get someone that does know ( or has done it before ) to do it. Check 'em out thoroughly; you may be enlisting the aid of another amateur. A few poured patios is not a good indication that they know what they're doing. I've never cemented tower legs before ( although I will be doing three towers in the near future ) so I can't give you any specific advice beyond what's included here; I just don't hold any expertise in the area at present.

◁ CALCULATIONS ▷

(1) WIND EFFECT ON WINDPLANT  
 THRUST =  $.001 A_p V^2$   
 =  $(.001)(113 \text{ FT}^2)(88 \text{ FT/SEC})^2$   
 =  $(.113)(7744)$   
 = 875 lbs for FORCE A

(2) WIND EFFECT ON TOWER  
 DRAG =  $.00125 A_f V^2$   
 =  $(.00125)(25 \text{ FT}^2)(88 \text{ FT/SEC})^2$   
 =  $(.031)(7744)$   
 = 242 lbs for FORCE B

(3) LEVER ARM FOR FORCE A  
 = 875 lbs x 60 FT  
 = 52,500 FT-lbs

(4) LEVER ARM FOR FORCE B  
 = 242 lbs x 30 FT  
 = 7260 FT-lbs

(5) COMBINED A AND B LEVERS  
 = 52,500 + 7260  
 = 59,760 FT-lbs

(6) AS FORCE C ACTS ON THE TWO LEGS WHICH OPPOSE THE PIVOT LEGS, THIS MEANS THAT  
FORCE C =  $59,760 \div 10 \text{ FEET}$   
 = 5,976 lbs OF LIFT

(7) WEIGHT OF TOWER & WINDPLANT  
 = 4000 lbs + 500 lbs  
 = 4500 lbs

(8) AS THE TWO TOWER LEGS SUPPORT THIS WEIGHT EQUALLY  
FORCE D =  $4500 \text{ lbs} \div 2$   
 = 2250 lbs

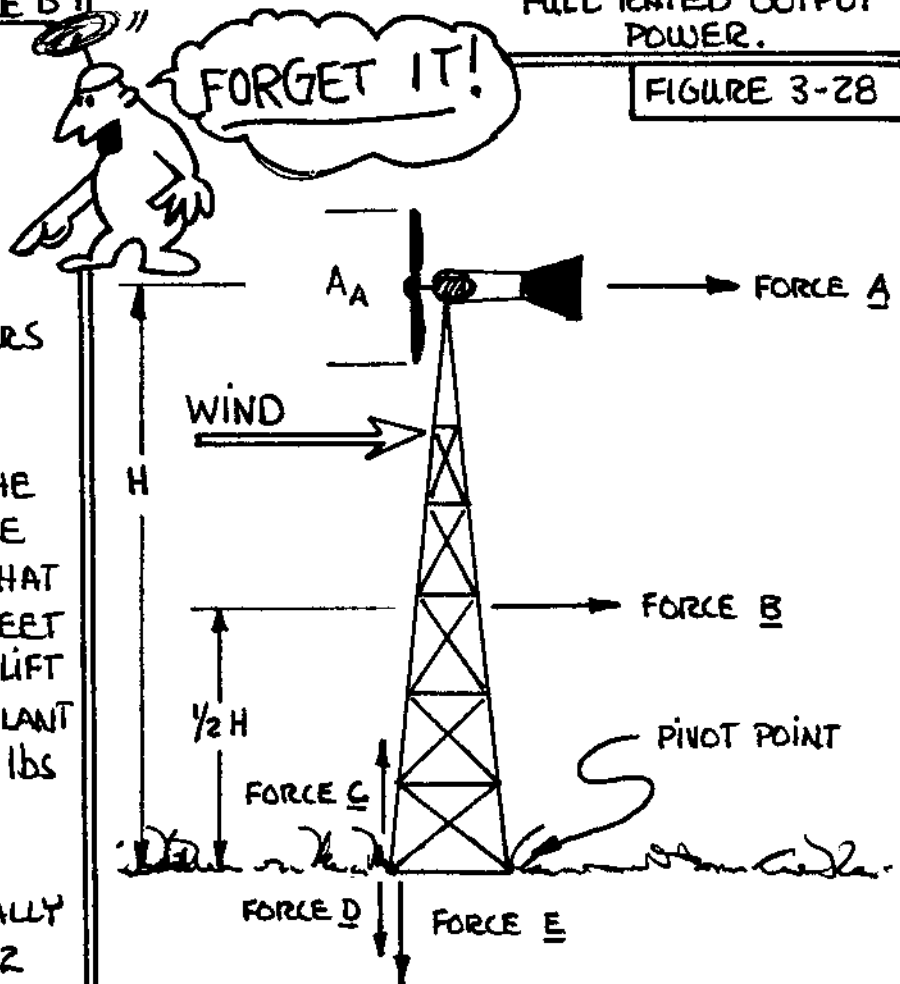
(9) FORCE C MINUS FORCE D =  $5976 \text{ lbs} - 2250 \text{ lbs} = 3726 \text{ lbs}$  UPWARD

(10) FORCE E REPRESENTS THE RESISTIVE FORCE (DOWNWARD) BY THE CEMENTED LEGS. THIS IS A COMBINATION OF THE CEMENT'S WEIGHT AND THE SHEAR RESISTANCE OF THE SOIL. IF THE TWO LEGS EACH HAVE, SAY, 200 lbs OF CEMENT, THE SHEAR RESISTANCE MUST HOLD 3726 lbs. MINUS 400 lbs, OR 3326 lbs. PER LEG, THIS IS 1663 lbs OF FORCE TO RESIST.

• KNOWN PARAMETERS FOR EXAMPLE •

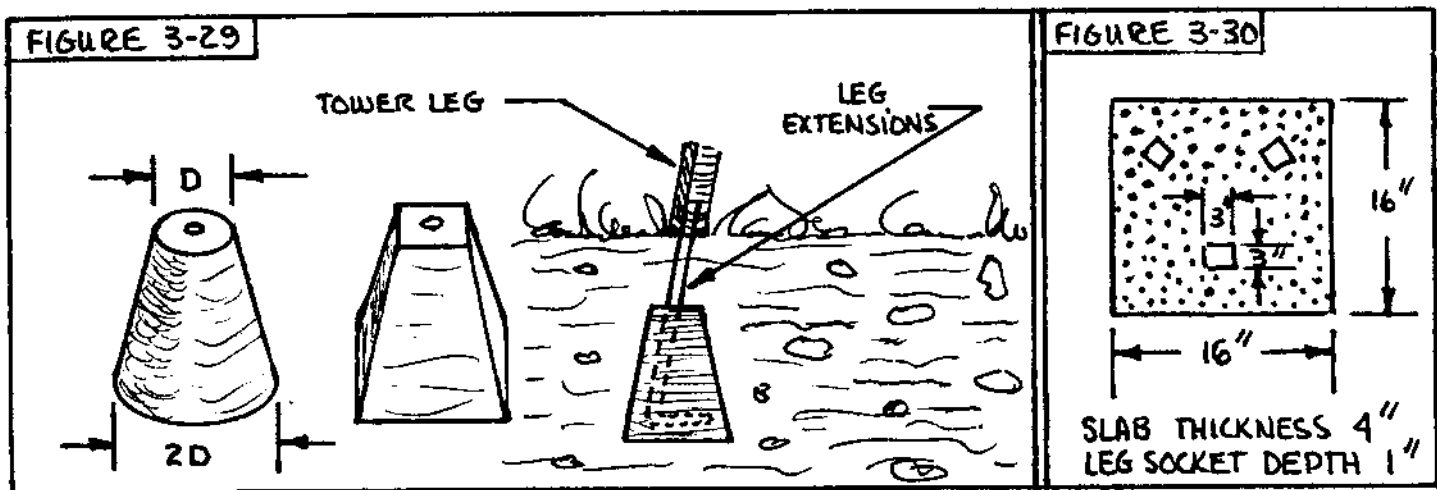
- WINDSPEED : 60MPH (88FT/SEC)
- WINDPLANT : PROP DIAMETER - 12FT  
PROP AREA = 113 FT<sup>2</sup>  
WEIGHT - 500lbs
- TOWER : HEIGHT - 60FT  
WEIGHT - 4000lbs  
BASE - 10 FT SQUARE  
PROJECTED AREA - 25 FT<sup>2</sup>
- SITUATION : WINDPLANT DELIVERING FULL RATED OUTPUT POWER.

FIGURE 3-28



For a 60-foot tower, cemented legs should be at least 5 feet in the ground; a 30-footer might be able to get away with 4 feet. For higher than 60-feet, check with tower manufacturers and find out what they recommend. Lighter towers will need more rigid ( or deeper ) anchors becuz their weight does not tend to help keep the tower from blowing over. Narrower-based towers will require stronger securing becuz they have more of a tendency to topple than the wide-base ones. ( Make sense?) Wind machines provide so much surface area to the wind in normal operation that the wind will try to push the top of the tower back. And, in turn, becuz the tower is secured to the earth, this is further translated into trying to topple the tower ( about the pivot of the base ). Fig. 3-28 illustrates these forces and one way they can be calculated ( for worst conditions). Remember that the tower is just one big lever ( and remember how effective levers are ) and you're on the right track. These forces are not constant, so they'll "work" on a poor cement job until there's enuff "give" to break it up.

I recommend a fluted-type hole for tower-leg anchoring ( see Fig. 3-29 ), but it's a hand-shaping job becuz mechanical or post-hole-type diggers can't make it for you. It not only makes the mold for the cement, but it will provide a wedge that is difficult to get out of the ground once it's buried.



Throwing rocks ( or, in general, adding weights ) on top of the anchor is no good; weight alone will not hold the anchor in place. What you do want is a high shear-type resistance, and that's mostly going to be a soil condition. Adding the cement does give a weight factor ( which helps ), but the idea behind it is to provide a large, underground form or shape to the anchor. Building codes deal with this type of anchoring for houses and the like, or the industrial installation of street-lamps, traffic signals, and large display signs, so there are many sources for this specific installation. Check 'em out if you find the information I'm providing still doesn't give you a clear picture of what to do, but keep in mind that the type of anchor depends on the application so it may not be a clear-cut straight-across-the-board way of doing it for a tower.

Once you've decided on the way to secure the tower ( for a free-standing anchorage -- this means no guy wires used ), the next question is: When do you do it? You could cement some leg stubs in position, raise the tower, bolt its legs to these stubs. Or you can just dig the holes and then raise the tower so that it's positioned above the holes, and attach the leg stubs, cementing them in place. Having raised towers that used both methods, I find myself in favor of the latter method. It does take some extra preparation; you have to do something to prevent the tower from falling into the holes during or after the raise ( see photos ). Pre-cemented leg stubs, though, are one helluva mate-up problem, especially for a large tower; you have to use some kind of large jack to move the tower around until you can throw the bolts through the holes ( see photos ). So both require preparation, but with the noncemented way there's no real problem with getting the precise align-

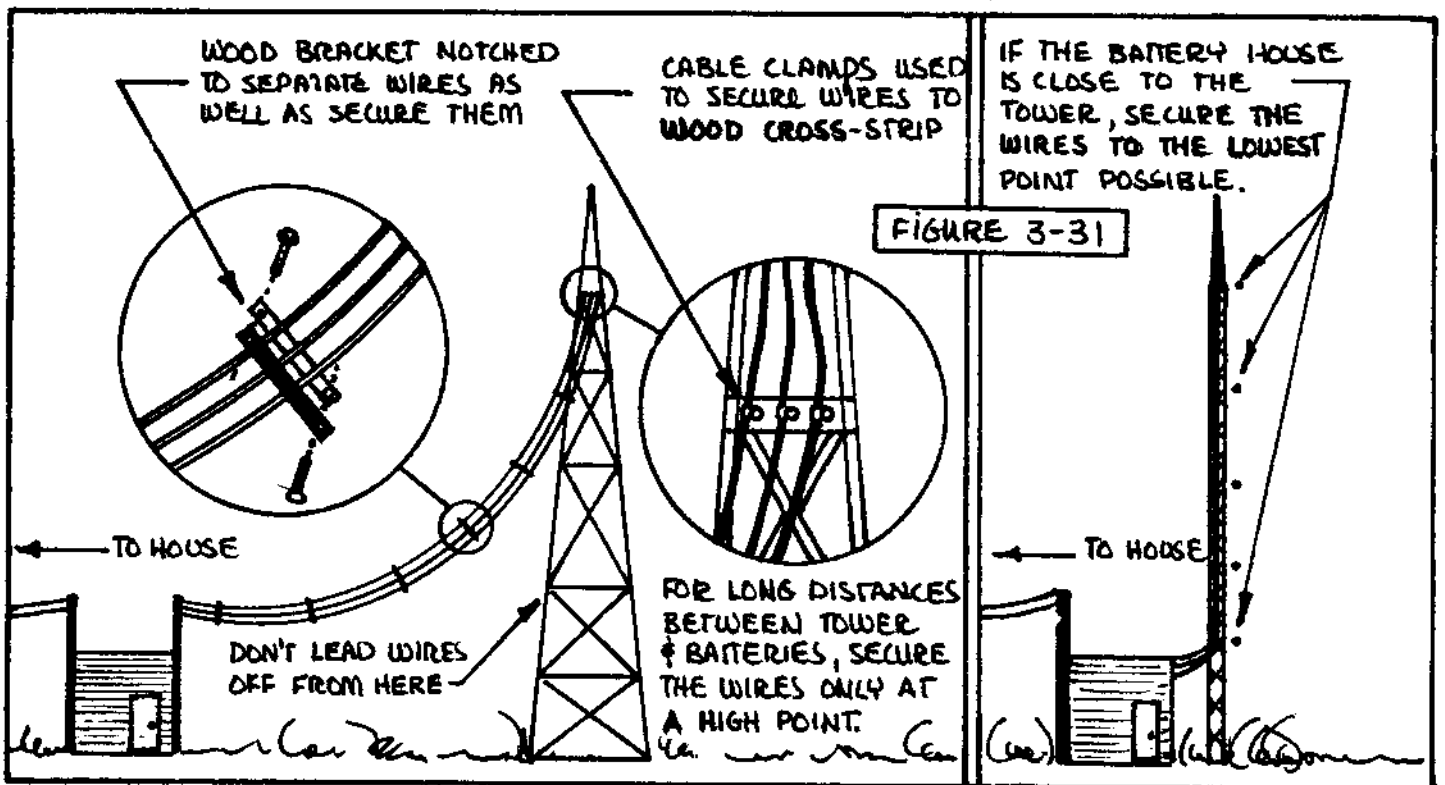


ment required of the other ( the tower base can have shifted slightly from the intended or attempted positioning without the need to get it back ).

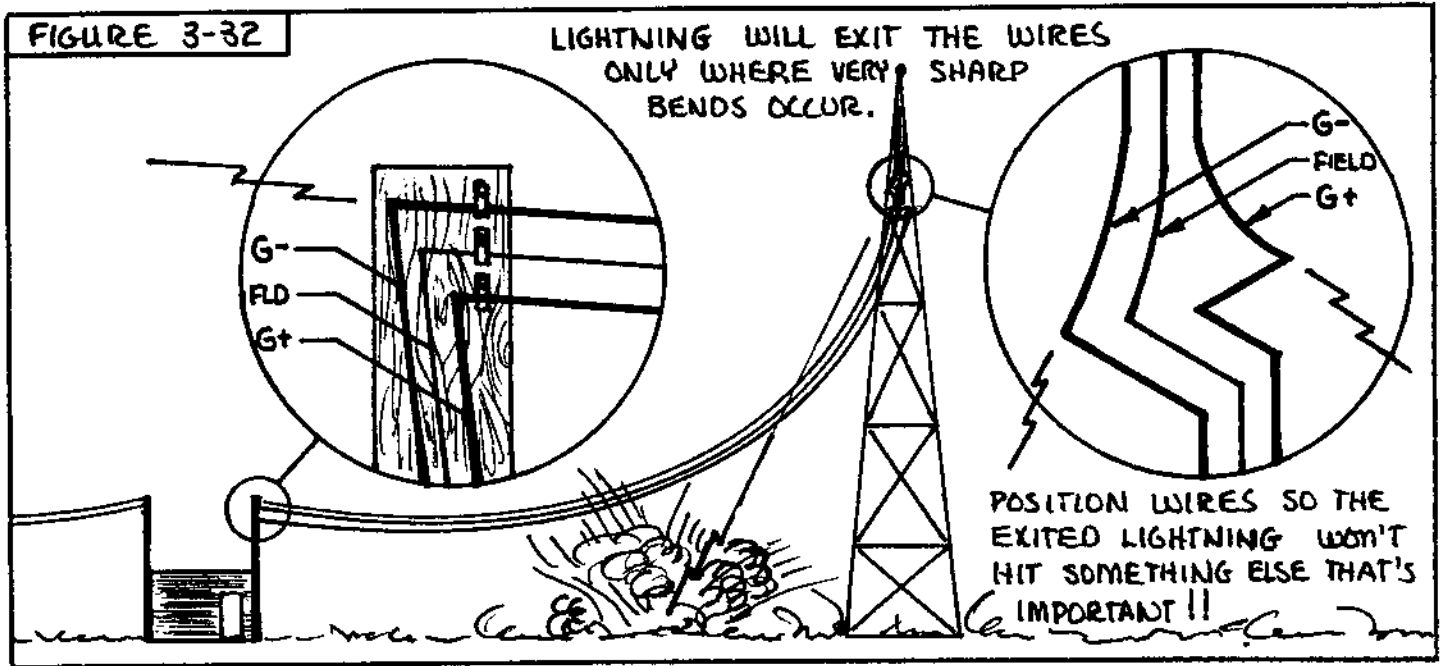
The single-leg tower, by the way, should have some kind of base support; this can be a cemented block ( as called out in the Wincharger manual -- see Fig. 3-30 ) but, as the weight of the tower and wind machine, and guy-wire pressure will prevent the bottom from scooting out from under the tower, the socket holes are not necessary in firm soil conditions. To prevent the tower from sinking into the earth, however, a cement slab or some kind of flat, hard surface should be used. We inserted a few 2 x 6's under ours and it's working admirably.

### Tower Paraphernalia

To get power from the wind machine down to the batteries requires the usage of electrical wires ( unless you've got an inside line on Tesla's work ) and the time to install them on the tower is before you raise it. It can be done afterward, but it's difficult and time-consuming. Fig. 3-31 illustrates some of the ways the wires might be secured to the tower as well as ways to hang the wires when hooking up to a nearby structure ( housing the batteries ).



Lightning protection is a necessity for towered wind machines; these will protect the machine, the control box, and the fire hazard that comes from a direct or close hit by a bolt or static buildup during an electrical storm. You can buy lightning arresters ( check with surplus places that deal with electronics stuff or ham equipment or contact the local utility office for more info on where they may be obtained ) or you can use an old trick that was developed to reroute the lightning; this takes advantage of the fact that lightning doesn't take corners so well ( understandable, since it's traveling so fast ) and involves zig-zagging the power wires a bit ( see Fig. 3-32 ). Better check with the codes in your area, though, as I'm certain an inspector of your system wouldn't be too thrilled by this old-timey substitute. The other standard procedure here is to ground both the tower and control box; the tower may be well grounded as is, but the control box should be grounded to a



water pipe or a copper grounding rod driven about 8 feet into the ground. The whole idea in lightning protection is to provide an easy, non-resistive path for the lightning to ground. If it doesn't have it, it'll take what path it can find, and it ain't particular about it. It's super-high-voltage stuff, so it can go through just about anything, and the hotter that item is gonna get if it cannot dissipate the heat caused by the flow of current. Melting guy wires and blown fuses are not funny in this situation becuz high winds generally accompany such storms. Don't shrug off doing something about it!

In some areas you may have to install a red warning light on the tower, especially with very high towers. This is a bummer for wind-electric system installations becuz of the power this light consumes, but at least consider it ( if the codes don't outright demand it ). Neither you nor some low-flyin' pilot is going to like his flyin' into your unlighted tower. If you need, or decide, to use this warning light, install it before you raise the tower becuz it's a hazard as soon as it gets up there and will be difficult to install afterwards. You should probably arrange to have it sense light conditions ( or their absence ) and switch on and off automatically. It's a bummer to have a crash becuz you forgot to turn it on, or in having drained batteries becuz you ran it during the day, too.

While the tower is still on the ground, get the tower stub ready to receive the wind machine you're going to install. This means installing the slip-ring assembly, lubricating the lolly-shaft bearings, and attaching all components necessary to lock the wind machine in place. While you're at it, install the wind machine-raising gin pole or ( if it will get in the way of the tower raising ) as much of its support assembly as you can at the moment. Being on top of a tower is fun for mountain-climbing people like myself, but this may not represent your attitude and, if not, you're going to have to think ahead on such things. It's real easy to get carried away with puttin' up your first tower, so write it down and do it before the beast goes up.

Most 3-leg and 4-leg towers have ladders on them so the top is easy to get to, but if yours doesn't ( or it's a home-brew job or an octahedron tower ), better think about installing one beforehand. A commercially-made ladder might be adaptable, or you can build one yourself; for our octahedron towers, I have built one using EMT ( electrical metallic tubing, or conduit ). While ours is welded together, bolting one together is not out of the question. Make it well, though; 40 feet up in the air

is no place to lose a rung! Most towers are not equipped with a service platform near the top, but if you've got a mind to, most any tower could have one built. These come in real handy if you're anticipating working on the machine alot and it sure beats grappling with a safety belt all the time. Make sure it's well below the bottom reach of the propeller! Some of the folks we talked to on our expedition lost some good friends up on those towers during installations and removal of the wind machines or while servicing the things. Seems like a real silly way to go!

While it's still down, you might think to use a little WD-40 ( or some other rust inhibitive ) on all of the tower bolts. This'll help 20 years from now when you're movin' away or just wanting to move the tower and have to disassemble it. Never know when you might have to get some of the bolts undone to add something. There are some pretty amazing rust penetrants on the market, but a little foresight will keep you from having to do it later while the monster is upright. Vaseline might also work ( you'll be needing to have it around for the battery terminals, anyway ).

Painting the tower is another thing worth considering before it's raised. The question is: Is it rustic or just rusty? Rust isn't some kind of disease that covers ferrous materials; it's the rapid oxidation of the metal itself and that fancy terminology means "eroding away" or "being eaten up." After so many years, there won't be any left. For massive, thick metal towers, this is a lot of years, but for thin angle iron, or the EMT that's generally used for octahedrons, it is a reality not wisely ignored. If you do paint it, think about the sight pollution a psychedelic tower is going to produce and try to merge it into the background. If it's galvanized, you must use a paint that's exclusively made for galvanized metal, or it'll weather off in a few years' time. Of course, if it's galvanized, that's a rust inhibitive, so it's not necessary to paint it except wherever the galvanizing has been damaged ( where the tubing was crushed ) or burned off ( by welding ).

There may be some other things that you'll want to do to ( or with ) your tower before it's raised; if you think of any, write them down somewhere or you'll surely forget them until after it's up. Once you start thinking about raising a tower, it'd be a good idea to carry around a small notepad for such tidbits, or a loose-leaf binder which can also hold the drawings you made, and the like.

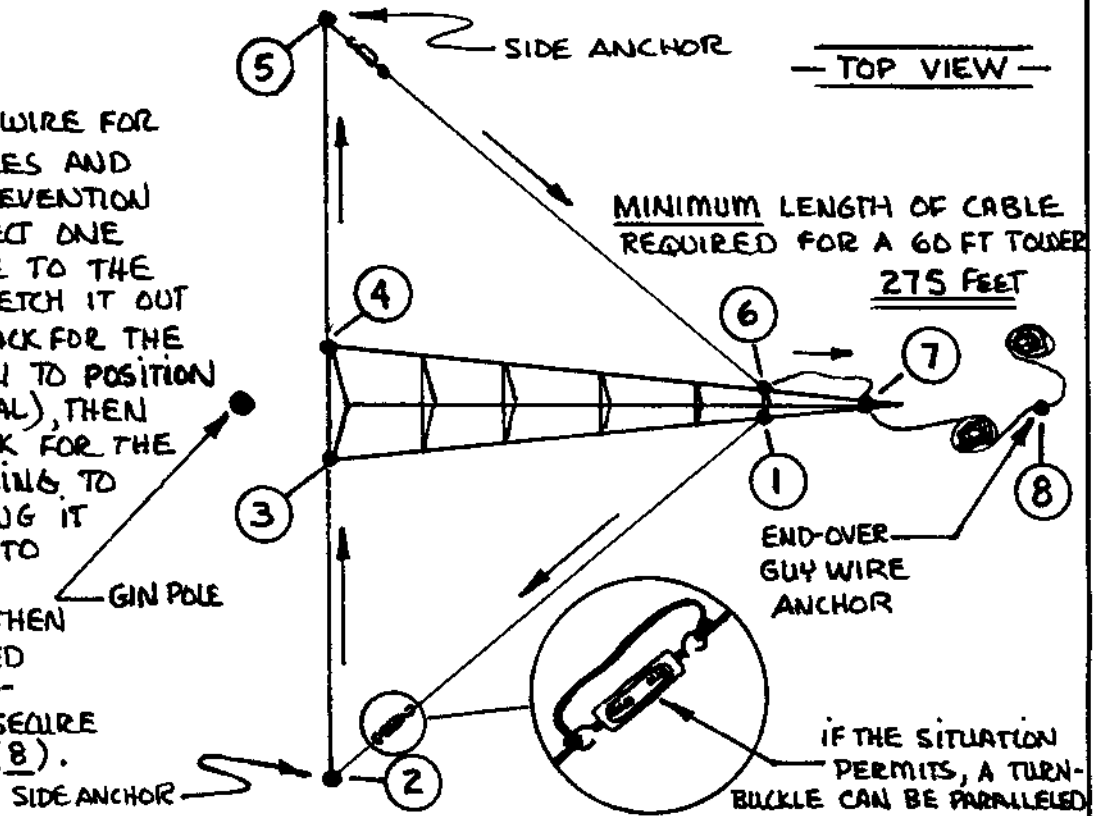
### Setting Up for the Raise

Setting up for the raise should probably be done the day before you intend to actually raise the tower; what you want to avoid is doing the setting up and raising on the same day. If you're doing a good job of setup, you're going to take more time than you might allow ( you know, little problems here and there, a cable clamp you need to get from the store, etc. ) so give yourself all the time that's necessary. If you've got some pressure ( like a whole bunch of people show up ), then you'll get hurried, you'll get mad becuz you're hurried, and get mad becuz you're mad. Tower raising is exciting stuff for the local inhabitants, so they'll come even if you didn't advertise or send out "invites" ( somehow the word just gets around ). But it's not a show and they didn't pay for tickets, so don't feel like you owe them anything, or can't say "No, I'm not going to raise it -- it just isn't ready," becuz you can and should.

Fig. 3-33 illustrates one way whereby a single, long guy wire can be used to prevent side-fall (both sides) and end-over. If you have purchased a very long length of wire for the raising cable, cut alength for the raising line that you will need and use the remainder for the guy wires needed to prevent bottom-slippage. If you still have a lot left over, then use this same wire for side-fall and end-over prevention ( there is, after all, nothing wrong with using wire that's rated heavier than required ) and a way to use one long, continuous wire for bottom-slippage, end-over, and side-fall prevention is illustrated in Fig. 3-34. If you make the overlap ( between the cable clamps

FIGURE 3-33

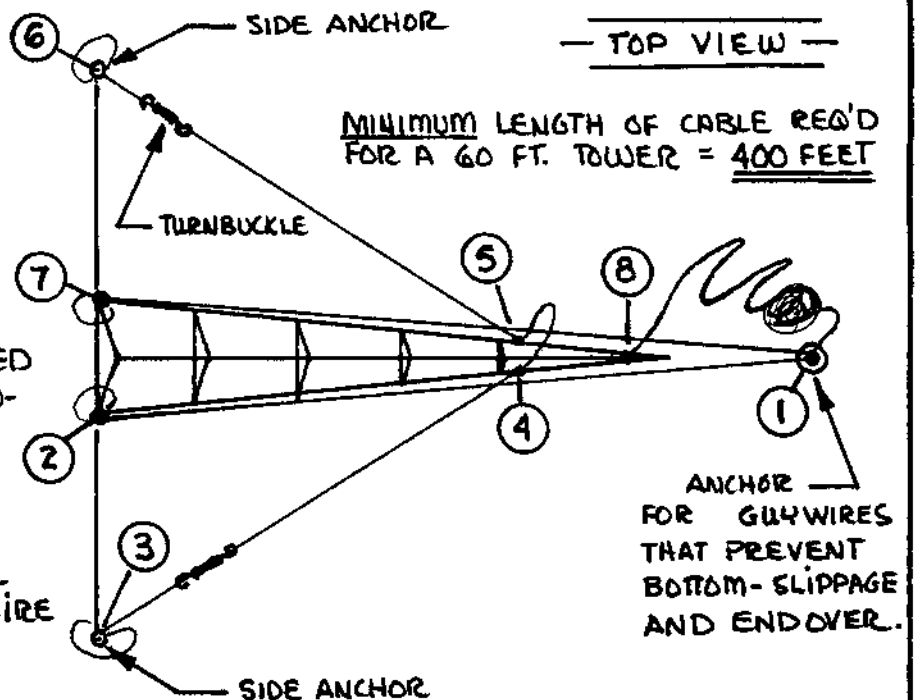
TO USE ONE, LONG WIRE FOR BOTH SIDE GUY WIRES AND THE END-OVER PREVENTION WIRE, FIRST CONNECT ONE END OF THE WIRE TO THE TOWER AT 1, STRETCH IT OUT TO 2 (LEAVING SLACK FOR THE TURNBUCKLE), THEN TO POSITION 3 AND 4 (OPTIONAL), THEN TO 5. LEAVE SLACK FOR THE TURNBUCKLE IN GOING TO 6. AFTER SECURING IT HERE, LOOP IT UP TO 7 AND SECURE IT THERE AS WELL. THEN LEAVE THE REQUIRED SLACK FOR THE END-OVER WIRE AND SECURE IT TO ITS ANCHOR (8).



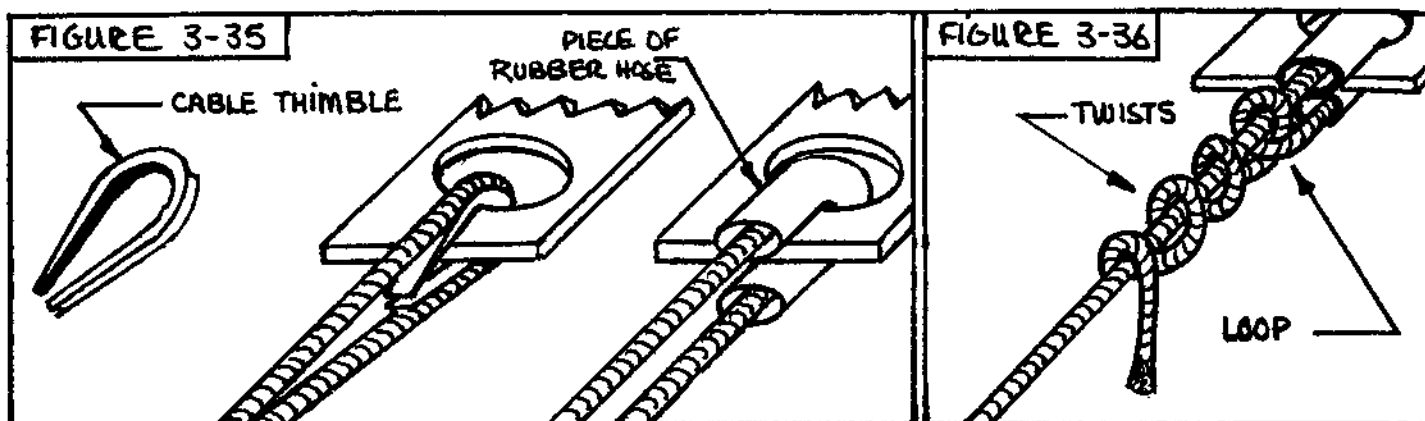
at each junction ) a couple of feet in length, then you'll be able to tighten or loosen these cable clamps to adjust tension for the specific situation. It requires more cable clamps ( for this option ) becuz you can just install one cable clamp at each of the junctions, but I recommend it; the versatility of the situation makes it just the same as using individual wires for each situation ( which involves cutting up the wire just for the tower raising ) without having to cut up the wire ( which means you have a handy piece of wire which can be used for all kinds of things around the place ).

FIGURE 3-34

IF A LONG, STRONG WIRE IS AVAILABLE (MEETING THE REQUIREMENTS FOR BOTTOM-SLIPPAGE PREVENTION), IT MAY BE RIGGED AS SHOWN TO SERVE ALL TOWER GUY WIRE NEEDS (AS IN FIG. 33). ONCE IT HAS BEEN ROUTED TO POSITION 7, IT IS RETURNED TO POSITION 1, AND THEN PROCEEDS TO POSITION 8. POSITIONS 2 AND 7 ARE NOT OPTIONAL IN THIS SET-UP. AT EACH POSITION, THE WIRE (OR ROPE) MUST BE CLAMPED (OR KNOTTED) TO PREVENT THE WIRE FROM SLIDING THROUGH THAT PARTICULAR JUNCTION



While you're at it, you might install a wire which will substitute for the raising cable once the tower is upright. You can just secure the raising cable, but if you pull it off the truck that it was secured to for the lift, then the tower is unprotected until you get it secured to something else. Either way, then, use the backup wire and, if you wish, just secure it and remove the raising cable entirely. I don't mind leaving guy wires out in the elements, but I sure don't like leaving steel cable or real nice rope out; it doesn't last long that way.



Securing guy wires or the raise cable to the tower, truck, or anchors should be done in such a way as to insure that they will not fray while in use. Fig. 3-35 shows two ways this can be done to protect the cable ( for future usage ). The idea here is to keep from having to bend the wire sharply or have it rest against a sharp edge of metal which can nick, fray, or cut it when it's subjected to some tension or other stress. Cloth works nicely for most situations but "cable thimbles" will work best especially when you are routing wires through holes where the cloth is unlikely to fit. You can bend them open a bit with pliers, but be sure to close them after you've hooked them through a hole and inserted the wire. If you're terminating a wire at that point ( tying it in a knot and twisting it ), insure that once you're done, the wire can't slip off the thimble. If you don't have thimbles, file or sand any rough edges and insert a piece of rubber or nylon rubber hose to keep the wire from touching any sharp, or sharply countoured, edges of metal.

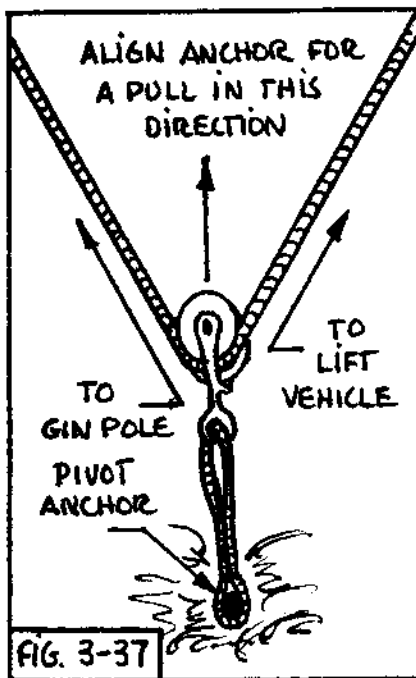
If you are using metal or heavy wood stakes as anchors, drive them into the ground about 3 feet and angle them away from the tower, so that there's no chance the wire ( especially if it will angle upward during the raise ) will slip off the end. This can be done by flattening the pipe or wood on its outermost end ( which occurs anyway, most of the time, just by the process of pounding it into the ground ) or driving another stake behind the first to jam the wire against the stake it's wrapped around, or tied to. Be careful, though, that you don't crush the wire, becuz this will fatigue it and it'll break under stress. Guy wires that are terminated should be tied first, then twisted ( as illustrated in Fig. 3-36 ); if you just twist it, it will unravel under tension.

If the method chosen to secure the raising cable to the gin pole will prevent the raising cable from rising completely clear of the gin pole once a certain tower angle has been achieved, then you must release the guy wires that are holding it in place when you reach that point. If you have few people involved in the raise, then merely stop the raise and release the wires. If you have the people available, have them stand by all of the guy wires involved, and release them at that point in the raise. If you're using the tethered method ( of securing the raising cable to the gin pole ), the gin pole will then rise with the raising cable as the tower angle increases. If you're using the pulleyed method of securing the raising cable to the gin pole, then it will be free to slide down the raising cable as the tower angle increases. Be certain, in this latter instance, that you instruct the individuals releasing the guy wires to hang onto them, and slowly let the gin pole slide along the raising cable until it's near the lift vehicle or pivot anchor ( if used ); otherwise, it will really zing along the cable and crash for certain.

Only in the instance where the raising cable is pulleyed to the gin pole must you concern yourself with insuring that the gin pole is placed where it will not interfere with the base of the tower when it is raised. I've never raised a tower where this was not the case, but I have always placed the gin pole far enuff away to prevent this from happening under any circumstance. To get the maximum benefit from the gin pole, you should place it as close to the tower as possible, but in no case should it be closer than 5 feet. For a pulleyed gin pole, it should be the width of the base away from the pivot legs.

When you position the gin pole, make certain that it is perfectly in line ( or as perfectly as you can get it ) with the tower axis. Place the base of it on a board ( or some other hard surface if soft ground is present ). Secure the guy wires attached to it only after someone has confirmed that it is perfectly vertical ( a bubble-type level can be used here ). If it is out of alignment with the tower axis or is less than vertical, this will cause some severe side pressure on the gin pole during the raise, and one of its side guy wires might break.

If you're using a pivot ( like that described in Fig. 3-24 ), be sure that the anchor you choose and



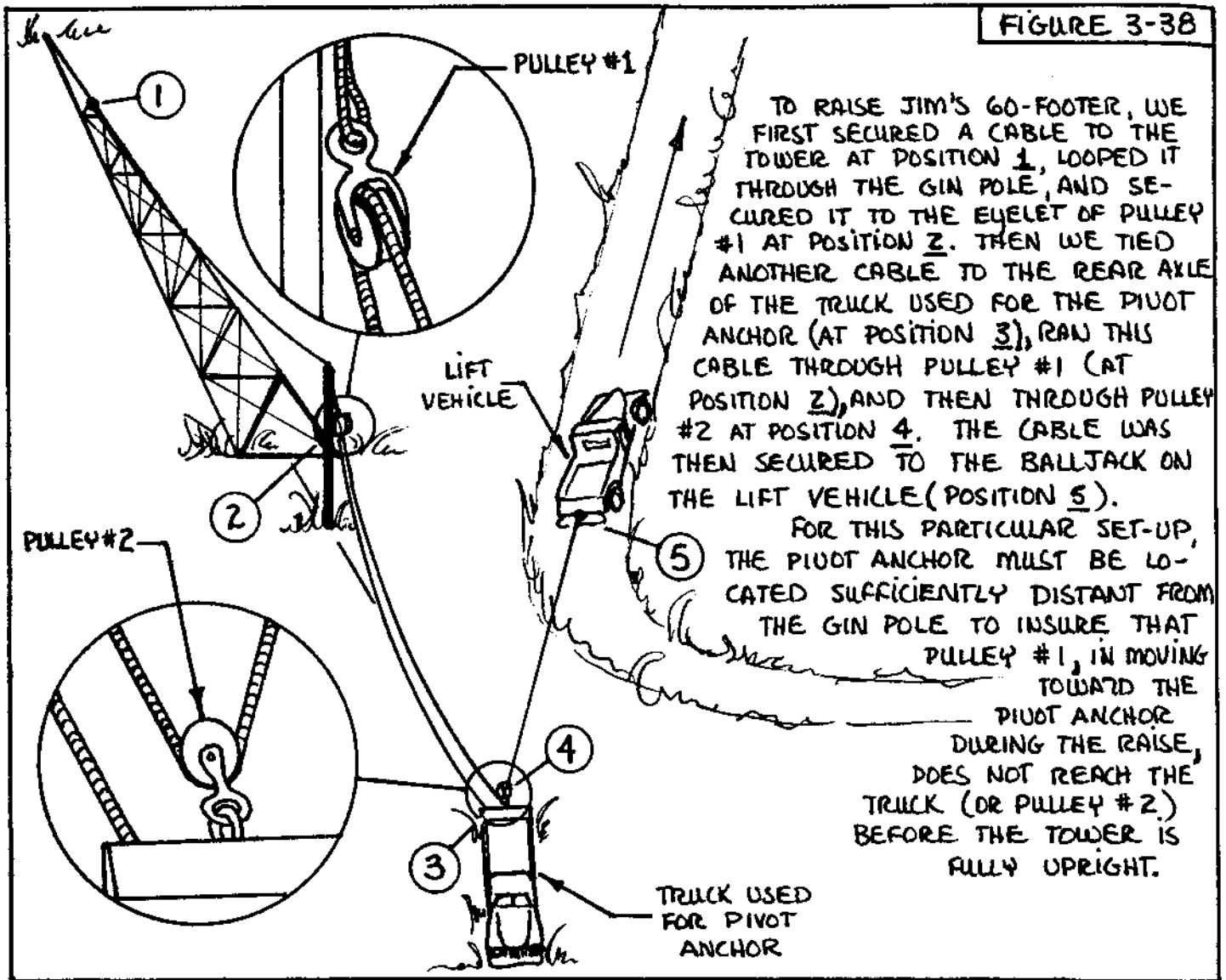
install is also directly in line with the tower axis ( for the same reasons indicated above for the gin pole ). Make sure that the pulley to be used is well-lubricated and large enuff to take the tons of force exerted on the raising cable and tower. Secure it with the same strength of cable used for the raising cable, and don't hesitate to take many turns around the pulley's "eye" to "beef-up" the connection. If you're using a vehicle for the pivot anchor, be certain to orient the vehicle so that it "splits the angle" between the tower-axis line and the actual direction of pull ( see Fig. 3-37 ). If you're driving an anchor into the ground ( or installing one of the anchors depicted in Fig. 3-27 ), this will mean slanting the anchor in such a way to account for the apparent, bisected-angle direction of pull.

If you're installing a pulleyed-mechanical advantage, be certain to draw it out first and work from the drawings; an advantage of two is complicated enuff whereas three or above are outright confusing, even if you are working with a drawing. Use pulleys that will stand the strain, and connect them to the tower, anchor, and vehicle with raising cable-strength wire. Lay them out neatly so they will not become tangled, twisted, or snagged when you're ready to tension them. Fig. 3-38 describes the combination of mechanical advantage and pivot anchor that we used to raise Jim' 54-footer.

### The Lift Vehicle

I have made casual mention of the lift vehicle requirements elsewhere, but there are a number of points I haven't covered; hence, it gets its own section. Whatever type of vehicle it might be -- tractor, truck, sedan, space-hippy van, or motorcycle -- it should have a manual transmission. I have no doubt that an automatic might make for a very smooth raising, but there's good reason for having a stick shift. If you know anything about the automatic transmission, then you should know that, should the engine die if it's in drive, low, or reverse, it will still move freely. If an engine dies in any gear of a stick shift ( and if the clutch is out ), the vehicle is prevented from moving becuz the engine is still directly ( mechanically ) connected to the wheels. You can simulate an automatic transmission effect in a stick-shift vehicle by simply pushing in on the clutch ( whether it's in gear or not ), and then the vehicle is free to move. Unfortunately, you can't simulate a

FIGURE 3-38



TO RAISE JIM'S 60-FOOTER, WE FIRST SECURED A CABLE TO THE TOWER AT POSITION 1, LOOPED IT THROUGH THE GIN POLE, AND SECURED IT TO THE EYELET OF PULLEY #1 AT POSITION 2. THEN WE TIED ANOTHER CABLE TO THE REAR AXLE OF THE TRUCK USED FOR THE PIVOT ANCHOR (AT POSITION 3), RAN THIS CABLE THROUGH PULLEY #1 (AT POSITION 2), AND THEN THROUGH PULLEY #2 AT POSITION 4. THE CABLE WAS THEN SECURED TO THE BALLJACK ON THE LIFT VEHICLE (POSITION 5).

FOR THIS PARTICULAR SET-UP, THE PIVOT ANCHOR MUST BE LOCATED SUFFICIENTLY DISTANT FROM THE GIN POLE TO INSURE THAT PULLEY #1, IN MOVING TOWARD THE PIVOT ANCHOR DURING THE RAISE, DOES NOT REACH THE TRUCK (OR PULLEY #2) BEFORE THE TOWER IS FULLY UPRIGHT.

stick shift with an automatic transmission becuz the transmission gear shafts must be rotating a certain number of rpm before the automatic clutch engages. If the engine dies in an automatic-transmission'd vehicle that's lifting the tower, all hell's going to break loose becuz the vehicle is free to roll back. Becuz most automatic transmission-equipped vehicles are also using power brakes, they are most ineffective unless the engine is running -- jamming on those dead brakes is no fun. Dig?

Even if you are using a stick shift, give serious thought to having someone follow the lift vehicle during the raise, blocking the wheels to prevent rollback should the raising have to be stopped suddenly. Jim's son and a neighbor friend did this when we raised the 54-footer, becuz the brakes in the vehicle were not all that good and the engine wasn't much better. A couple of big logs were used, and the boys just slid them along the ground behind the rear wheels as the vehicle advanced. With this procedure, if the engine died or Jim ( who was driving the vehicle ) was given the word to stop momentarily, the logs would have prevented a rollback of more than a few feet. Other blocks were laid on the running boards, so that the boys could block the front wheels as well if the pause was longer than momentary ( like if a situation had to be carefully looked over, a guy wire adjusted ). This might sound a little bit dangerous for anyone handling the blocks, but we carefully instructed the boys to keep their hands and feet away from the wheels of the vehicle. We had them

move alongside the vehicle ( instead of behind it ), and used long-enuff logs so they were nowhere near the wheels. If you have no option but to use an automatic-transmission'd vehicle, this is an absolute must.

When securing the raising line to the lift vehicle, get it tied up to the frame or the axle. Some vehicles are equipped with a ball-jack on the back, for pulling trailers, boats, etc. This might do, but inspect it well to see that the bumper has been reinforced and secured with additional support members which attach to the frame. If in doubt, tie up to the axle. Anything but reinforced bumpers will be no good for this job.

As it is essential that the driver know what is going on, you might consider setting up the lift vehicle so that it raises the tower by driving in reverse. This is a no-no for an obstruction-riddled path the lift vehicle might have to travel or maneuver through, but if it's fairly clear, it can be a very positive way to do it. As most vehicles have a lower gear in reverse ( compared to the lowest gear forward ), this also means that more torque can be applied to the situation. I do know that it will also create a situation where the drive wheels are less likely to spin, but I'm not sure how much difference results from driving it this way, or if it is really of any consequence. But these are all fringe benefits to the advantage afforded to having the driver clearly see the tower and what's happenin' around it. If a good winch exists on the front bumper, this will be a good place to hook up the raising cable. Of course, if you've got a winch, you might just use that, right? Just remember that if you use a winch, it doesn't really matter that it might be rated to handle 8000 lbs; you're still going to have to secure the vehicle.

### Pre-Raising Pow-Wow

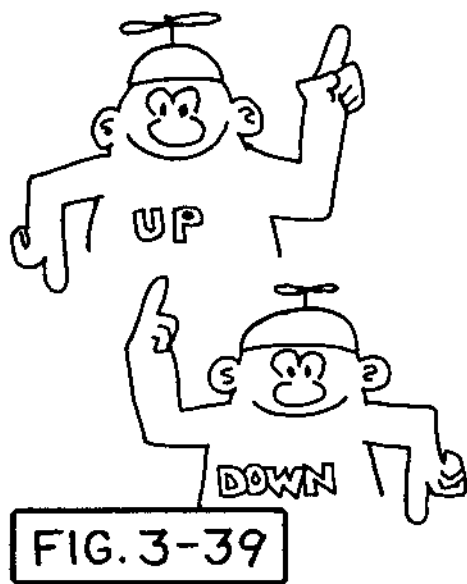
Either the day before, or the day you're planning to raise the tower, you'll want to hold a little get-together, and go over the whole thing. I call it the pre-lift pow-wow. You should call together anybody that will be involved in the raising -- and I do mean everybody! If everyone knows what everybody else is supposed to be doing, then things are going to run a lot smoother, especially if some little thing goes wrong. At the very least, you should pass this book around or offer it to all involved, becuz maybe they may be doing it next. Go over the drawings. Explain what can happen, and when. Explain the jobs that need to be done, and ( if you haven't already filled these positions ) determine who will do what. And where. And when. If you've built a little tower that's a model of the one to be raised, go through all the motions with it. Talk about what everyone should do if this wire breaks, or that anchor pulls out, or the raising cable snaps when the tower is partway up. ( If you tell them anything else but "Get the hell outta there," then you've just flunked the course. ) Walk around the tower site. Point out the various guy wires. Show 'em which way the truck is going to go, and how far it will move. Show which wires are going to raise which way. Show 'em where to stand and what to look at and what to watch out for. If you can't do this, you've got some rereading and studying to do. Or find somebody that can do this. It's helpful, but not absolutely essential, that everybody knows what's happenin'. The next best thing is to have most of them know what's happenin'. But at the very least, one person should know what's happenin'!!

Pow-wow is a good process to go through -- you'd be amazed at how much feedback it will give you, how well you'll learn it yourself, and how many potential problems might be suddenly "in the light." What you don't or can't understand brings fear; maybe everybody will still be this way after they've been told, but they'll operate much more automatically when sumthin' happens that "wasn't on the menu."

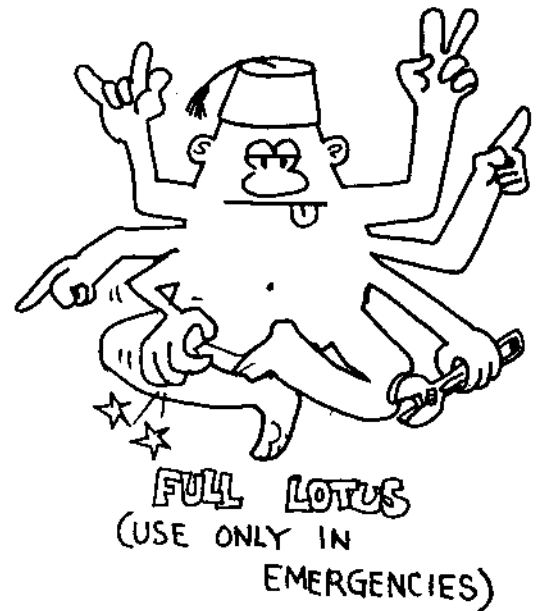
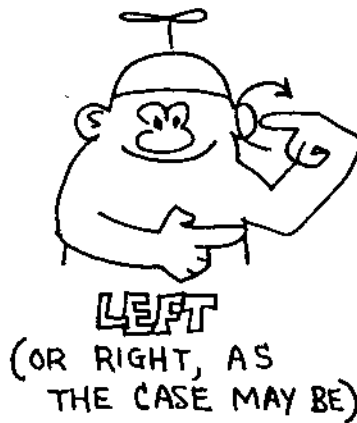


Work out hand signals for the raise; shouts can go unheard or be misunderstood when you've got the noise from a revved-up engine. It is essential that the driver of the lift vehicle be able to see the tower or someone who can. Whatever hand signals are worked up, make them simple and universal ( see Fig. 3-39 for some examples ) and practice them so they become natural; otherwise, someone is going to be yelling STOP when their hand is raised and signalling GO. Walkie-talkies are handy little things for events like this, and quite good for the small distances between the folks involved.

# OFFICIAL TOWER-RAISING HAND SIGNALS



and **BODY ENGLISH**



Where the people go depends on the situation. I don't think that I would risk a large tower-raising without at least 4 people. I'd put one near the top of the tower to remove the barrel ( or whatever ) that I had the top of the tower restin' on; I'd want that out of there once the tower had lifted from it just in case the tower came back down ( so the tower would have a flat landing ). I'd put someone by the gin pole; it's one of the more dangerous spots to be, but one of the more important, too. From here, the base of the tower and gin pole can be watched for slippage, the top of the gin pole can be watched for anything that might come loose, and the movements of both gin pole and tower keenly observed. Another person would be in the lift vehicle. And I'd have at least one person manning the block for the wheels on the lift vehicle. If this was all of the folks available, I'd get the person near the top of the tower to help with wheel-blocking once the tower was goin' up.

If I had gathered more people, though, or a few of those that showed up to watch were game for the idea, I'd put them to work, too. I'd get someone on each of the guy wires that presented side-fall, to just stand there and feel the tension in those wires as the tower went up. They're going to tension and slacken a bit, anyway, but they could let us know if some kind of stress was buildin' up, before it'd pop them, or pull the anchors. I'd have two people standin' clear of anything until the tower angle was such that the gin pole guy wires had to be released. They could run in and cut or loosen them at a signal, or shout, and get the gin pole safely down and along the raising cable -- and then get back outta there. I'd put someone else on blockin' the wheels and keep whoever is up near the top of the tower there, so he'd be able to say when the end-over prevention wire was startin'

to get tight. And maybe, I'd stick another person over there by the driver, just to help relay any chitchat that was goin' on to and from him. And I'd be darned sure to get somebody to take movies or pictures of the whole thing . . . just for posterity and all that.

Of course, you can double up some of the jobs, but the idea of people running over, under and around the tower doesn't appeal to me; it's sumthin' like people roulette. Besides, it's too distracting. You'll want to be puttin' all of your attention to what's happenin' with the tower. So plan it to be quiet . . . and let the tower do all the moving.

While you're doing the sightseeing tour with the folks that are involved, clean up any debris in the immediate vicinity of the tower that might interfere with people movin' around. You don't need an obstacle course when you're trying to move quickly ( like when it's rainin' towers and wires! ) If you're going to have a lot of people participating in the event, or just if they're watchin', you might try marking out the perimeter of the tower's reach. Grab a sack full of flour ( make it white flour -- it's not much good for human consumption anyway ) and make a trail of it around the tower. If you get a string or rope that's equal in length to the tower's height and attach it to the base of the tower, then you can use this to mark off a very concise boundary. This'll let folks know what's safe and what ain't. You can also instruct the curious and watchful members of the audience that this is as close as they can get -- period!

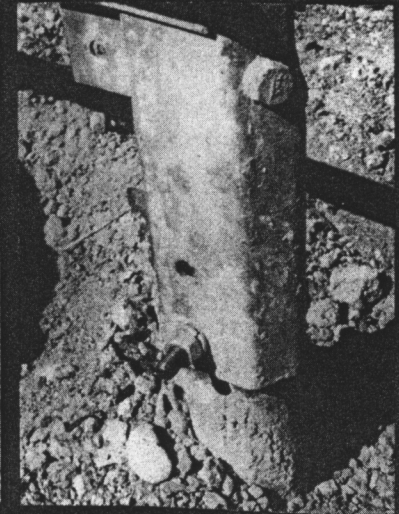
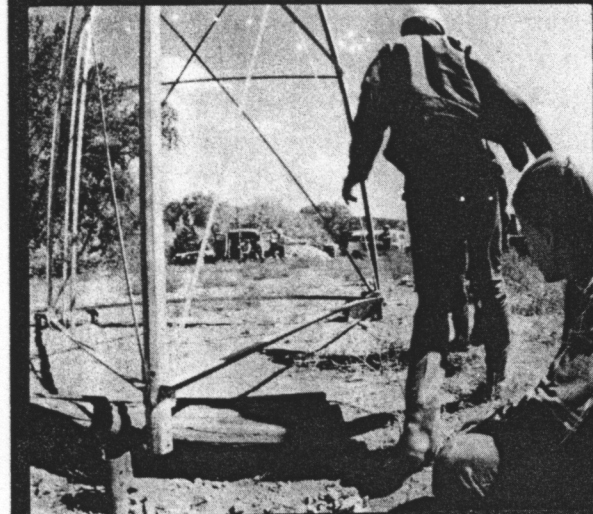
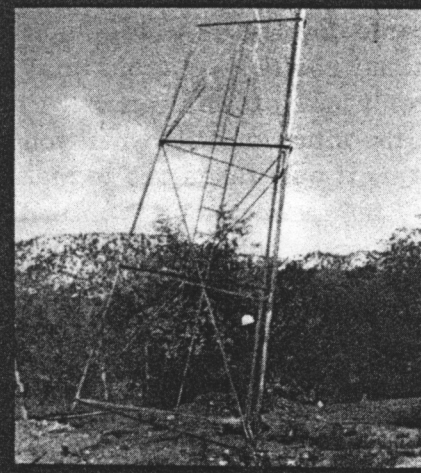
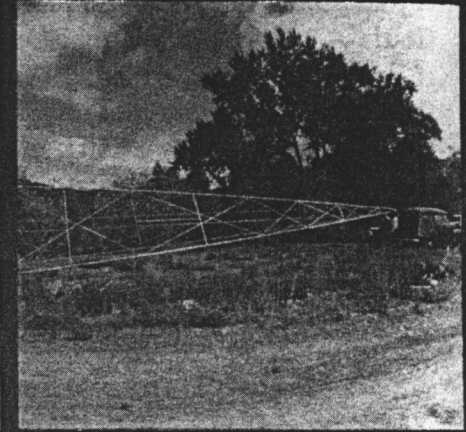
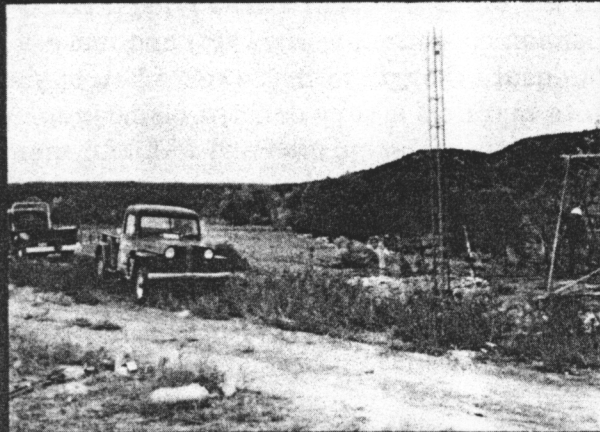
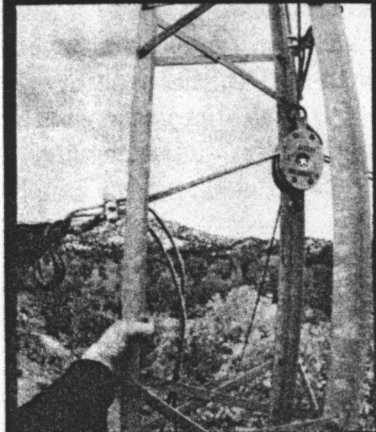
(Author's Note: I don't mean to sound negative, telling you to mark off a danger zone; it'll sound funny when you've done the thing and are wondering what all the extra precautions were for. If I were raising a tower tomorrow, I wouldn't do half the stuff I'm telling you to do. But then I try to be responsible for my actions. And I want to be responsible here, too. When all the writing is done, and the book's published, and folks are buying it and raising towers from the information I've supplied, I'll know that it wasn't for a lack of something I didn't emphasize enuff that somebody got hurt, or that a tower came down when it was supposed to be going up. I was sorely tempted at points to say, "You don't really need to do this" or "You can get away with doing it so-and-so," but I didn't. I haven't lost a tower yet, but I'm still afraid I'm going to. That, friends, keeps me in touch with the situation; it's when you start thinkin' you've really got it "wired" that you begin to make mistakes -- it only takes one to make it go bad.

### Doing It

So now you're ready to do it. You've already checked and rechecked the wires, the cables, the anchors, the people involved, and still you walk around and keep lookin' for things that might not be just right. Everyone's in their position, the lift vehicle's engine is idling, and everything that needs to be said has been said.

So do it!

Take a breath or two, and move into it slowly. Give the GO signal. The lift vehicle should first take up the slack. When it's done that, check the angles. Is the raising line right down the center of the tower? Not quite? Back up the lift vehicle and re-orient. Okay now? Yep! Take up the slack again. Do you have to give the cable the "acid test"? All right, give it a little power. The top of the tower should lift about a foot. You can pop the clutch here, or just run over and grab onto the top of the tower and pull it down. Give it a strong jerk. Bounce it up and down a little -- it should be able to take this easily. Everything all right. Get everybody positioned.



Let the clutch out on the vehicle. Slowly. Rev the engine a little until she starts to take the load. Don't let it rev up too much; you don't want to be riding the clutch. You want to let it all the way out and just give it enuff gas to keep from killing the engine. And she'll start movin': the vehicle, forward; the tower, up. And up, and up, and up. The base of the tower will move a bit, taking up the slack, tensioning the wires. The gin pole is creaking and groaning under the compressive forces. The pulley is catchin' and then lettin' the wire slide through it. Lots of tension everywhere: vehicle, tower, wires, and people. The tower will seem to float up, like in a dream. Can this really be happenin'? Yep, it's going up. Watch it, though, you've got a raisin' cable that's just about to clear that gin pole. A little more. That's it. Now . . . HOLD IT! Logs sliding under the rear wheels. The tower's swaying a bit with the change in motion. Wipe a brow and let it die down. Call in the folks that are going to free the gin pole's guy wires. Check with the folks checkin' on the strain in the side guy wires. One a wee bit tight? How's the other one doin'? Okay. The one that's tight isn't all that bad, but maybe you'd better let the turnbuckle out a bit, anyway. Okay, things look good. A glance at the audience -- they're just standin' there in complete awe. Maybe a quick chat with the driver of the vehicle or, if that's you, a quick chat with the gin pole watcher. A little slower with the vehicle? Okay. Back to the station. Ease out on the clutch, a little gas, get the clutch all the way out, and she's movin' again. Up and up and up. Reachin' for the sky. A bird flyin' overhead gives you the eye -- what's all this insanity? Keep your mind tuned to it. She's nearly up now. And you get the signal from the person standin' to the side -- the end-over prevention wire is straightening out. Watch 'em both. Give the SLOW signal. Steady. Suddenly, it's tight. Give the STOP signal. The tower sways now in the wind. Back up the lift vehicle a bit. Nope, the tower isn't comin' back down. Sure enuff, she's past teeter. Okay, let out the end-over guy wire a bit. Or let the Power-Pull out until she's on all legs ( unless it's a single leg ). Now . . . ain't that a beautiful sight? Give somebody a hug and chug some carrot juice. That's it. You've done it! You! And some friends!

### Post-Raise

Don't wait too long before you finish the job! You've only got 4 guy wires on that tower, and it takes only one wire snagged and pulled to bring down a lot of work. If you've got a single-leg tower, get that fifth wire on NOW! You can shift the wires that you used for the raise, but you must substitute a wire for each wire that you remove from an anchor, and reposition according to Fig. 3-4 and Fig. 3-5. Don't have people climbin' on the tower when you're doing this, becuz you can goof and disconnect a vital wire -- there's no sense in compounding mistakes.

If you're going to cement the tower legs, either start working on it, or prepare everything for a wait until you do; in this latter instance, this only involves placing the guy wires so they are in no danger of being snagged or pulled out. Insofar as they're "temporary" wires, they often get treated like that, and the care and attention rendered them is not nearly what permanent ones receive. To keep people from falling over or running into the wires, tie tassles of cloth on each wire around eye-level.

### Cementing Legs

When you're ready to cement in the legs, the first thing that you'll want to do is to level the tower. This can be done several ways, but blocking up the base will prove more work than using the guy wires as "adjusters." Tensioning and loosening guy wires is going to allow for a finer adjustment to the readings afforded by the bubble-type level than blocks inserted under crosspieces. Turnbuckles will really help here. If the tower is really out of kilter, you may have to loosen the guy wire from its anchor and readjust it. If you need more slack, remember to turn the turnbuckle all the way in before you re-tie the wire; this will allow for further slackening. If you want it

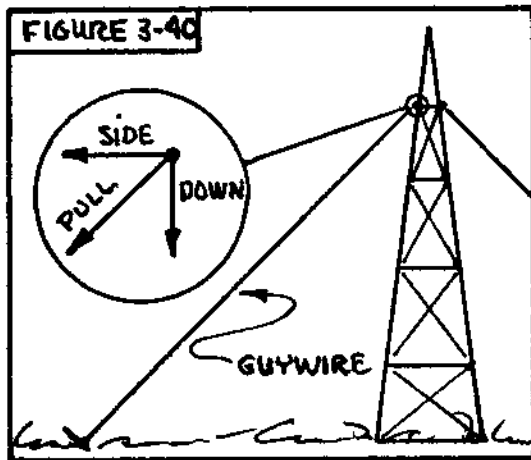
tensioned more, untie it, turn the turnbuckle all the way out, and re-tie; this will allow further tightening. Whenever you release a guy wire, know what you're doing. If there is any possibility of the tower being in danger of falling for lack of that guy wire, install another wire and secure it before you do any untying of the guy wire needing coarse adjustment. You should keep checking the bubble on the level, checking it in two directions each time ( like north-south, and east-west ); this will let you know which wires need tensioning or loosening. If your guy wires are fairly tight to begin with, you will probably have to tighten one wire and loosen another for each adjustment you make. Be certain that you loosen one before you tighten the other, though! Turnbuckles allow for some pretty good torque, and guy wires can pop.

Assume that you have dug the appropriate holes, leveled the tower, and attached some extensions to the tower legs ( the ones which will be then encapsulated in the cement ). You are now ready to cement the legs. By some rough approximation, you should be able to figure out how much you'll need; if not, get someone that can look at it. If you have a truck bring in the cement, they'll need to know how much -- be ready to tell 'em how many "yards" you need ( this is cubic yards, which is cubic feet divided by 9 ). If you live near a cement company that does a lot of business, you might check with them at the end of the day. They may have cement in their trucks that they want to get rid of, and you can get it free just for the asking! Make sure you have everything ready so they make a fast dropoff, and you'll have established yourself as a good dump for any stuff they have left over. There will be a limit to the amount of cement you need unless you're into monoliths, so be thinkin' about other folks you can turn on to the deal. If you are remote enuff to make trucking in the cement unfeasible, or if you can't afford the cost and want to mix it yourself, know what you're doing.

I would postpone any work on cementing legs if you've got damp weather or high winds; the former will keep the cement too wet to cure; and the latter will shake the tower enuff to keep the cement from firmly grasping the legs. Guy wires can be tensioned hard to keep the tower more secure during the few days' curing time for the cement, but they cannot be tensioned enuff to take out all the movement. So check the precipitation and wind forecast!

When the cement has dried, bury the remainder of the leg extensions until the ground is level or slightly bulged upward at the legs of the tower. For lightning protection, this might be a good time to drive in a ground stake. Even if you have the leg extension buried in cement that goes down five or six feet, that part of the leg which is encapsulated will not be grounded, just in the ground. Drive some pipe or rod in and connect it with some heavy wire ( #4 or larger ) to one of the tower base bolts. All done? Get up on the tower and shake it good ( throw your weight around a little bit ) and have someone look at what's happenin' there at the base while you're doin' it. If the legs move up and down a bit, you've goofed it. If the top of the tower shakes a bit, but there's no vertical motion at the base legs, that's normal. Go ahead and remove the guy wires. If it did move down there, you must add more cement, dig deeper, or keep the guy wires attached. Don't remove them and call it okay -- it won't take long for the action of the wind ( once a machine is installed ) to work the legs loose even more. Then you're going to shake a wind machine to pieces or bring it all down in a real "blow."

If you have previously installed the leg extensions and cemented them, you now get to go through the fun of trying to bolt all of the legs to their respective extension stubs. If this is your situation, hopefully you watched the bottom-slippage wires as the tower started to go up. You made certain that you allowed for enuff stretch in these wires, and the legs did not move past the stubs too far. The stubs aren't broken off, crushed, or otherwise mangled and no longer capable of mating up to the legs. In our case, we backed the tower off about a foot to allow for stretch in the wires, and



placed a log under the legs right near the end, securing it solidly to the legs. This formed the pivot for the base of the tower during the raise. Additionally, this helped to keep the legs from burying themselves with the tower's weight and the raising motion; it further insured that the ends of the tower legs were not likewise mangled. While we had a jack that would easily lift the tower -- a component of the force they exert not only keeps the tower from going sidewise, but also pushes it into the ground. (See Fig. 3-40.) If something slips during the raise and the legs do bury themselves, you may have to loosen all the guy wires a bit before you try to jack it up to where the legs will bolt to the extension stubs. Watch out for the ole fingers when you're trying to push a

bolt through each; one of them might become a permanent part of the tower. Ugh!

If you have installed a single-leg tower, install good anchors if you have not already done so. If the ones that you have installed don't seem adequate after you've tried them, make up some others. Just make sure that you have the 5 wires close to  $72^\circ$  apart. Install large, strong turnbuckles so that you have the capacity to tighten them after a while, as the tower will settle a bit despite the basecap. The wire attachments will work out any slack in time. You may have to untie the wires, open up the turnbuckle, and re-tie them if they have more slack than the turnbuckle can adjust out. If the wires have been properly spaced, you will not necessarily need to install a temporary wire when you untie the main wire. Just don't have the machine running when you do, or pick a non-windy day for the adjustments.

If you have temporary wires to be cemented, or have installed a guyed tower, make up a schedule to check the guy wires frequently (especially at first). Keep to it! It only takes a few moments, and will relieve any worry in the middle of the night when a full-fledged gale comes up.

### Tower Safety

For whatever reason you climb a tower, don't be without a safety belt. And when you stop to observe, adjust, or whatever, attach it. It can be a simple thing -- just some rope, and a ring, and a snap hook. Or it can be a webbed belt, with a pouch or loops for tools. Don't just wrap it around you. Put it through three or four of the belt loops on your jeans, so it can't slip up and off. A lot of things could happen to render someone unconscious and the strongest arms or legs are of no help at all. I could truly bore anyone with all of the strange little things that have happened to me, with and without a safety belt attached. Most of them were pretty stupid -- and you don't get any kind of credit for the things you can't foresee (or even the things you can). Once gravity takes hold, your time is measured in split-seconds.

Static electricity can build up on top of a tower, especially where there are parts of it that are insulated from the rest; if you grab hold of it, you can get a small shock. It's not much -- no more than what you'd get by touching a doorknob after walking across a rug. But the effect of the shock is to make you let go; that's a purely automatic reaction. And that's what'll get ya! So beware.

If you wear a helmet, you'll prevent a few bumps you might otherwise acquire in running into the blade tips. They have a sneaky habit of turning around and pointing straight down after you've looked to see if they're oriented safely. Sometimes the bottom of the wind machine will swing

around on ya, too. I don't like helmets so I have the bumps to prove I don't wear one. I do wear a cap or a bandanna ( tied like a scarf) whenever I'm working on a tower, though; it keeps my long hair from catching in things and covering my eyes. Can't always spare the hand to push it back and out of the way!

Other than falling bodies, the next most dangerous thing is falling tools or parts of wind machines; that is truly uncalled for, but it happens. It's really handy to have someone at the base of the tower to talk with when you're workin' on the machine, but you don't need to reward them with a 3-pound crescent wrench traveling 35 MPH! If your pockets are bulging, you're settin' up for droppin' sumthin'! Figure out another way to secure them, or make two trips. One thing you can do is hook a piece of line to your belt. When you get topside, let it go, and just haul things up and down as necessary. If you make it twice as tall as the tower ( or the height at which you are working ), then you can drape it over sumthin', and have the person at the base of the tower haul things up or lower them down. Or tie little pieces of string to the tools so if they're dropped, they only drop a foot or two, and you can retrieve them. Or attach a pouch or box to the tower at the place you're workin', and store 'em in there. If you have parts of the wind machine to remove in order to get at other parts underneath, take along a few extra lengths of line, and tie them to the tail of the machine or the tower. Then tie them to the thing you're removing before you take it off. That way if you slip, you don't end up mangling the nosecone, the governor, a blade, or a tail cover and your friend, to boot. Get line that is appropriate for the thing that's supposed to dangle from it; hawsers aren't necessary for nosecones, and kite string is absurd for props.

If you do drop something, yell "HEADS UP." I've always thought of this as something really absurd to say, but for some reason it's easier to remember -- and it's understood. Of course a person below is not supposed to look up, just cover the ole head and tuck away to make the least target for whatever's comin' down. Helmets are a must for those standing at the base of the tower while someone is workin' on top, but they won't be of much use for anything over 5 pounds. So instruct such a helper to stand clear of the tower base until you need something attached, and then have 'em get back out of there. There is nothing which requires that person to be right at the base, anyway.

You may find it helpful to wear gloves in climbing up and down towers, especially if it snowed the night before and you've got sub-zero weather; if ya don't wear 'em, you'll leave a lot of skin on the metal. This will also protect you from any residual static charges that build up on the tower or some of its components. When you take them off up there, be sure to secure them well somewhere. They really like to fly off, and it can make for a painful or uncomfortable trip back down. If it's cold on the ground and there's wind aloft, get a jacket on; that wind will be working along with the cold to produce a chill factor which will freeze you all too fast. If you haven't got anybody to come and get you, they might just leave you for the spring thaw!

One final note: I've seen folks carryin' things up towers with only one hand used to climb the tower. There is no mistaking it when someone is doing this. It isn't easy, and it looks jumpy and awkward from the ground. The trick is to shift the body weight in until it's close to the ladder, then let go of the one rung and grab the next before the body falls out to the point where the next rung is no longer reachable. Yep, it does work, and you can do it, but you deserve whatever happens. Tower rung roulette, they call it, and there are no missers in the club -- only fools! If you see someone doin' that, just back away from the tower a bit to give the body plenty of landing room.

### Tower Lowering

Unless you build your own tower, or someone just drives up and delivers one to you, chances are

real good that you're going to have to lower a tower before you get a chance to raise one. And that is unfortunate. Why? Well, becuz it's harder to lower one than it is to raise one. Okay, maybe you do have gravity in your favor. But, consider the situation with the bottom-slippage guy wires and the raising-cable tension. These will both be minimum when you start to lower a tower, but they will rapidly approach maximum toward the end. You don't get to subject anything to the acid test until it's too late. As well, the vehicle can only provide a braking force to the raising-cable tension, and it's hard for it to keep from sliding along. If ya jam blocks under the wheels, it makes it a wee bit difficult to get them out (you'd have to back up). And you don't know if the gin pole is strong enuff, etc. Once that tower has started down, you're committed to it. And that's not a fun place to be.

If you haven't got the experience, then you haven't got it, so you might as well just do it. Make sure you study the material on raising towers well -- most of it will apply, only in reverse. You'll need the same guy wires, and they must be located identically. Allow for plenty of cable length when you lower the tower; this is no place to come up short. You must use a gin pole! Otherwise, you'll lose control in the last 10 or 20 feet and you'll surely damage the tower somewhat, if not completely. Make certain that the area you're lowering the tower into is clear of obstructions; if it does fall, you'll want it to impact on as level a surface as possible. This will distribute the impact and lessen the likelihood of extensive damage. If it hits a tractor or something solid like that, about midsection, it'll bend it in half just as pretty as can be. If there is a wind machine on the tower you want to lower, and you've never lowered either before, don't try them both at this point unless you're in the junk salvage business. Take the wind machine off first, and then lower the tower.

I have never lowered a large tower, like the ones we raised with Jim on his homestead. I imagine that the most difficult part is to get the raising cable onto the gin pole, once the tower is down to where it's necessary. One thing is for sure, though -- count on it not lining up to one that you've rigged up. You will have to stop the lowering at that point, so be ready for it. You'll want to rig up the gin pole so you can tell when you've reached that point. You'll either have to climb the gin pole and get the raising cable secured to it ( tethered or pulleyed method ), or you'll have to relocate the gin pole so that it is directly under the raising cable at that point. The raising cable must unquestionably come to rest on it and not slip off. The only thing you're going to have to do is get a pulley on the raising line before you begin the lowering ( unless you have one that opens up ). Think it out.

The safest way to transport a tower any distance is to disassemble it and transport it in pieces. This will seem a lot more work than required if it's only a short distance from where it's at to where you want it to be, but I think that transporting it whole might not really be any savings at all, energy-wise. If it's a long tower and you insist on transporting it whole, you might rig some wheels out there at one end; this might, however, not be very legal and it'd be too much like the ole, long-ladder type fire engines they used to have ( the ones with the driver in the back as well ) and tiz a bit more than I would tackle. Nope, I'd stick to the ole WD-40 and a couple of good wrenches and take the thing apart; if you do this, draw out the sections and cross-pieces and use some kind of coding to identify the pieces. Mark the actual tower pieces, too. Save dem bolts and nuts and lockwashers and washers!

#### Notes on the Octahedron-module Tower

If you want to build an octahedron-module tower or, at least, check out the possibility of using this type of tower, get the Windworks plans. They are extremely well done and easy to under-



stand. I take issue in this section with the limitations imposed by the plans but you will need those plans to understand fully what I'm talkin' about here.

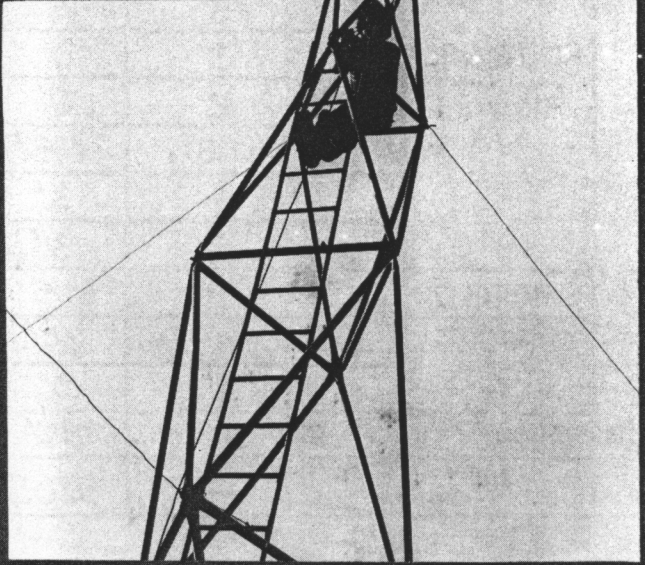
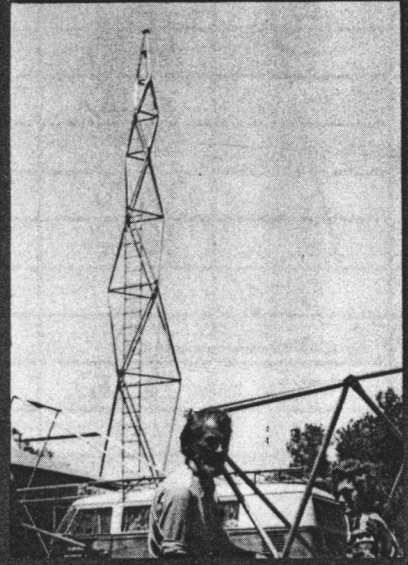
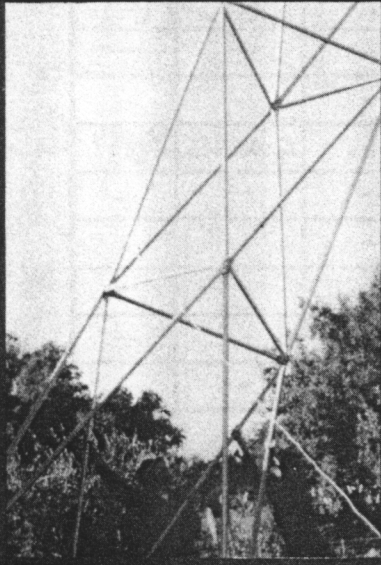
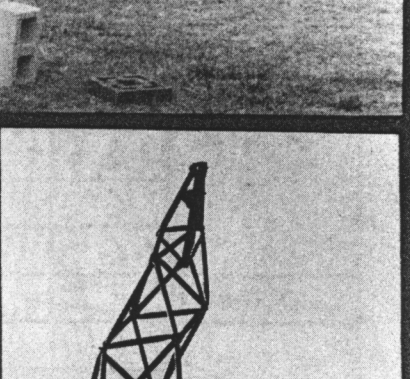
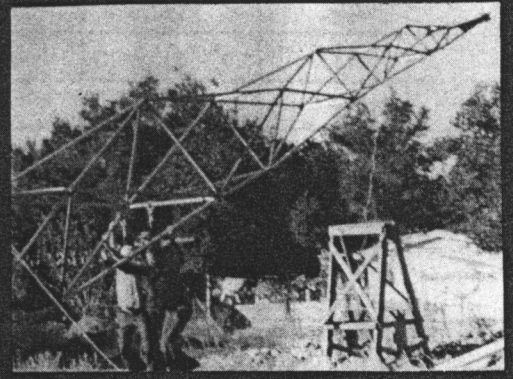
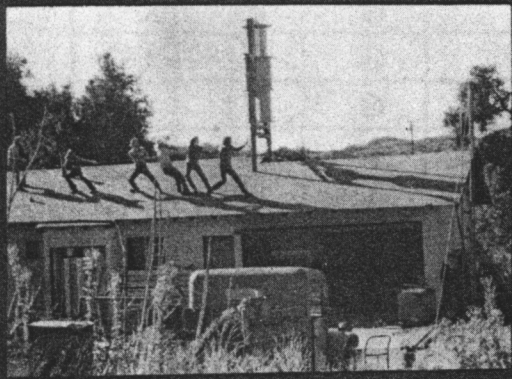
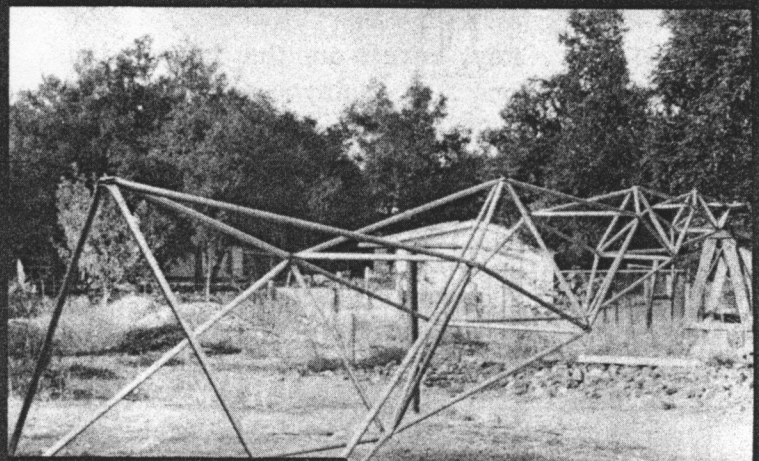
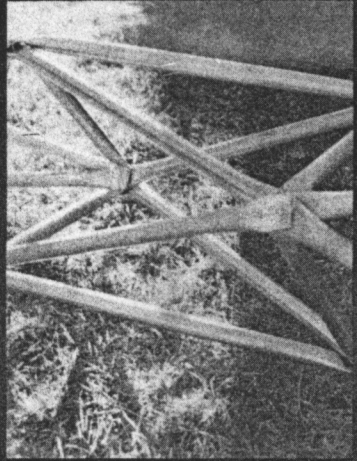
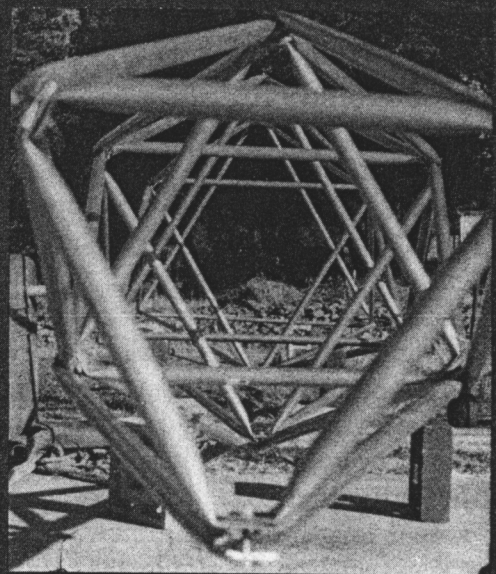
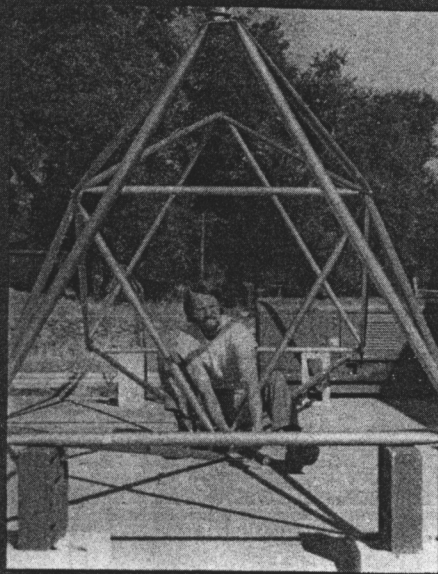
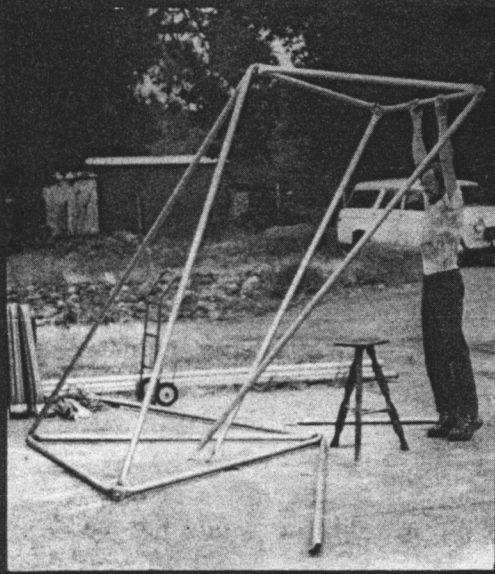
Windworks says that structural strength and esthetics were the criteria in the final design for the tower. Their plans do not tell you precisely how to build a tower higher than 30 feet but the necessary info is there if you can understand a few basic relationships. I totalled up the material waste and came up with a figure close to 10%; that's not too bad, but I tend to optimize materials use and let esthetics slip a bit. And I wanted a taller tower, so I changed some things. If you study their plans and look at my recommendations, you can design and construct a tower which is at the approximate height you want it to be, and it'll be easy on your pocketbook.

Windworks wanted their octahedron-module tower to look like the Eiffel Tower. This makes a very sound structural design, but it cost them convenience and some material waste. One of the first things that you will notice (when you look at the plans) is that they specify some rather unusual lengths for the vertical and horizontal struts; some of 'em are called out to the nearest 1/32nd of an inch! Okay, you gotta get each set of vertical or horizontal struts the same length but you don't really need to get a weird length. Second thing you'll notice is that the lengths of both horizontal and vertical struts decreases as you get closer to the top of the tower. These pieces get smaller at a progressively slower rate as they approach the top of the tower -- this gives the Eiffel Tower effect and you'll want to follow this pattern to preserve structural strength.

When I modified their design to optimize material use and shoot for a taller tower, I forgot about tower height and esthetics. If you design the tower my way, you may end up with a height of 53 feet, but you'll probably use the same amount of material as someone who tries to design the tower to a nice round 50 feet. EMT comes in 10 foot lengths; if you want to optimize material use, you must remain painfully aware of the fact that you're gonna have lots of material left over if you don't plan it out. You'll need six of any specified length for vertical struts and three for horizontal. Let's look at an example. You need six 8-foot lengths. Six times eight is 48. Can you get these sections out of five 10-foot sections (50 feet). No, of course not! You'll use six 10-foot sections and you'll have six 2-foot sections left over. Okay, maybe you can use them elsewhere. But nowhere do you have a need for six vertical struts of this length. And you'd need only three at a time for the horizontal. Sure, you can cut a bit off three of them, then use them for a horizontal triangle at a higher point on the tower. But you've just introduced waste. Comprene? Well, maybe you can use them for the bottom support struts (not shown).

Designing your own tower is fun. Get out a piece of paper. Lay out some columns as I've done. Start with the vertical struts and select a length. Specify the number of pieces of tubing required (how many 10-foot sections used). Describe what is left over. Identify it with a letter so that you can easily show the transfer of this remainder (or a portion thereof) to another position as you proceed. Decrease the length of vertical and horizontal struts at approximately the same rate as the Windworks plans. Fill in the slots for the horizontal struts as you go along. Don't forget that you can further cut a remainder piece (or, in other words, a 10-foot section can be cut three times). Don't forget that you need six vertical braces and three horizontal braces at the bottom of the tower.

There's nothing sacred about the number of modules in the tower. Windworks has six. You can have more. Don't decrease the number of modules if you're going higher, though. And don't stay with six if you're going to go even 10 feet higher. Don't let the vertical struts get too much longer than they specify or they'll not be as strong.

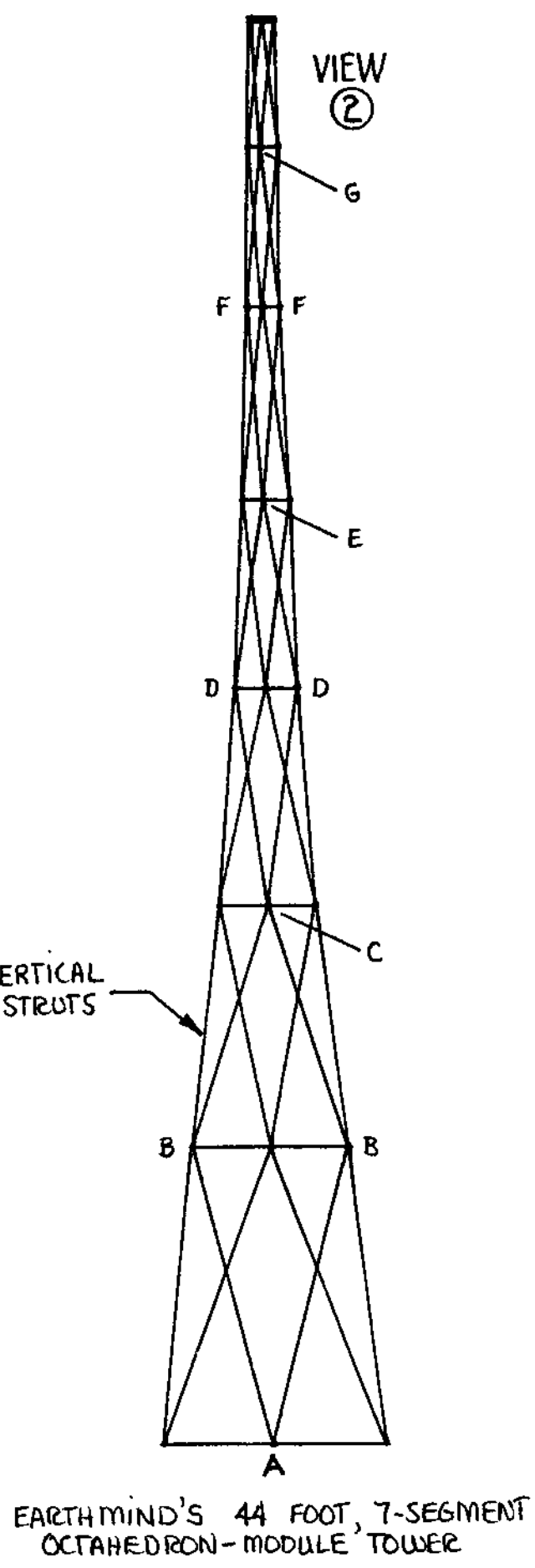
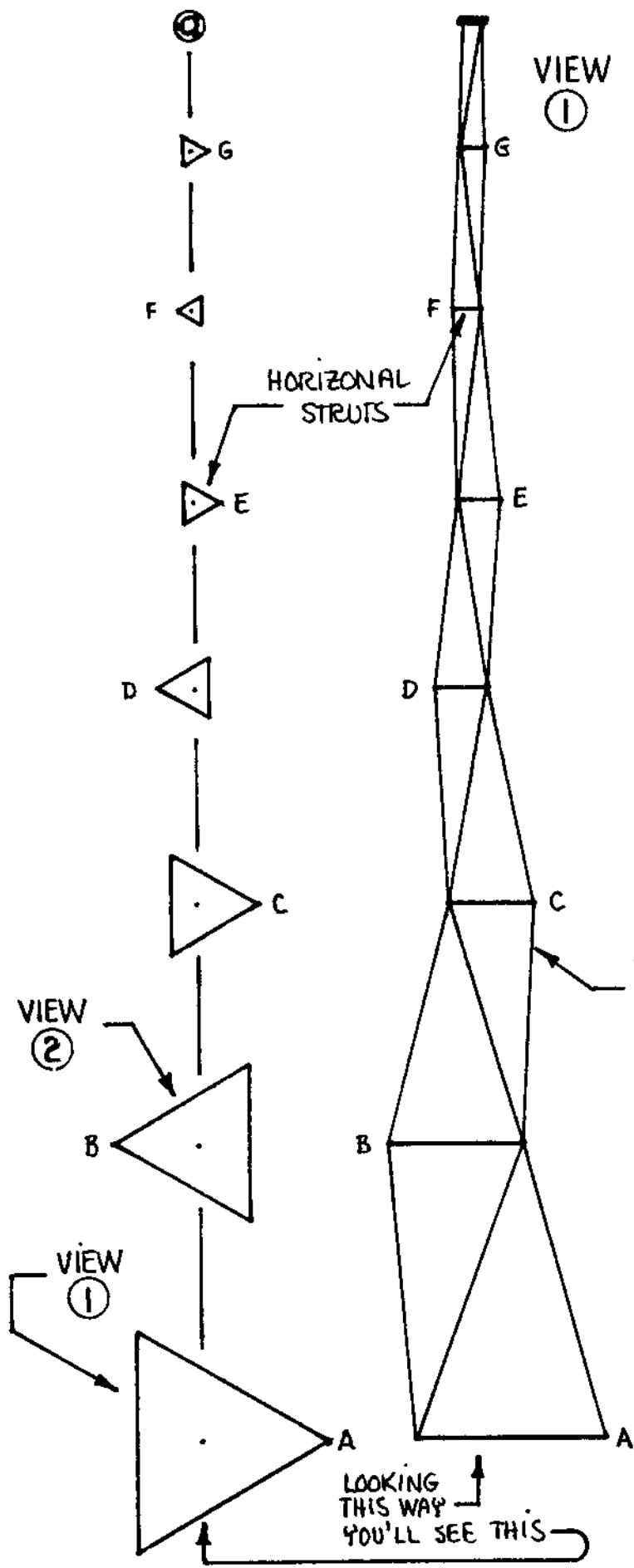


If you're shooting for a tower that's higher than 45 feet, I strongly recommend using a larger size EMT. I've used all the way up to 1-3/4 inch; It's harder to work with but you'll have a tower that's strong enuff to support a Jacobs. I doubt that the Windworks unit ( which uses 1-inch EMT) will support a Jacobs wind machine. Larger diameter tubing is going to cost more, but if you've got a heavy wind machine, use it.

Before you commit yourself by cutting up that precious EMT, build a model of the tower you' ve designed. If it's ungainly, try again. Build one out of straws stapled together or lengths of wood ( like bamboo skewers ) glued together. The things are difficult to draw. You have to know trig to do this. One last point: if you have, say, 8-foot vertical struts in the base module this will not give you 8-feet of height to the horizontal triangle! It will be something less, becuz it is not literally vertical. At the base of the tower, the actual height gained will be about 3/4 of the actual length of the vertical strut. As you get closer to the top of the tower, the actual height gained will be closer to the actual length of the struts.

EXAMPLE : Okay, here's one that I worked out. Understand that there is nothing sacred about this particular one . . . I played around with the scraps and shifted the lengths of horizontal and vertical struts. This particular design had three 3-foot and one 6-inch piece of EMT left over; that's less than 2.5% waste and the leftovers are large enuff to use for other things. Realize, in working with the table below, that the leftovers are coded and used instead of a 10-foot section wherever possible. You need more info than this to build a sound tower. GET THE PLANS !

	QTY OF STRUTS	LENGTH OF STRUTS	TOTAL FEET	SOURCE OF MATERIALS		LEFTOVER SCRAPS		CODE
				# OF 10 FT. SECTIONS	SCRAPS	QTY	LENGTH	
VERTICAL STRUTS	6	10'	60'	6	-	-	-	-
	6	8'	48'	6	-	6	2'	(A)
	6	7'	42'	6	-	6	3'	(B)
	6	6'	36'	6	-	6	4'	(C)
	6	6'	36'	6	-	6	4'	(D)
	6	5'	30'	3	-	-	-	-
	6	4'	24'	-	(C)	-	-	-
SUBTOTAL ①			276'	33	-	-	-	-
HORIZONTAL STRUTS	3	7'	21'	3	-	3	3'	(E)
	3	5'	15'	2	-	1	5'	(F)
	3	3'	9'	-	1/2 (B)	-	-	-
	3	2'	6'	-	1/2 (A)	-	-	-
	3	1.5'	4.5'	-	(F)	1	6 INCHES	(G)
	3	1	3'	-	1/4 (A)	-	-	-
	3	1	3'	-	1/4 (A)	-	-	-
SUBTOTAL ②			61.5'	5	-	-	-	-
SUPPORT STRUTS	6	4' (V)	24'	-	(D)	-	-	-
	3	3'	9'	-	1/2 (B)	-	-	-
SUBTOTAL ③			33'	0	-	-	-	-
TOTAL ①,②,③			370.5'	38	-	-	-	-



EARTHMIND'S 44 FOOT, 7-SEGMENT OCTAHEDRON-MODULE TOWER

# INSTALLING the WIND MACHINE

When it comes time to put the wind machine on the tower, there are only two ways to do it -- before the tower is raised and after it's raised. In terms of the work that's involved, the installation appears to be simpler by just attaching the wind machine and then raising tower and wind machine simultaneously, but keep in mind that this will make the raising a lot more dangerous ( at the least ) and somewhat more involved in preparation. The only time that I raised a wind machine and tower at the same time, it went smoothly and without event; I attribute that to both my knowledge and understanding of the precise way that it should be done ( and a lot of ways it shouldn't ), and the experience of having raised towers ( without wind machines ) three times before the attempt; besides, neither the tower nor the machine were particularly heavy. If you have not raised a tower and wind machine before, I would recommend that you not raise them together the first time around. I have included a section, however, on special considerations for this method at the end of the chapter; believing you shouldn't do this does not translate to "I'm not going to tell you how."

Lowering a wind machine is essentially a reflection of raising one but, as most folks will raise one before they lower one, I'll describe the raising process thru most of the chapter. The last section -- Wind Machine Lowering -- will point out special problems of consideration for this process wherever it differs from raising a windplant.

If the tower is raised first, and the wind machine raised second, the method is fairly well restricted to the use of a machine-raising gin pole ( not the same as the tower-raising gin pole ). Again, the proverbial helicopter or crane could do the job, but if you're doing it that way, you don't need to know anything ( unless you don't trust the pilot or crane operator ). If neither of these methods is available to you, then the first thing that needs to happen is to understand what the gin pole is, where it goes, what it does, and how. Let's get to it.

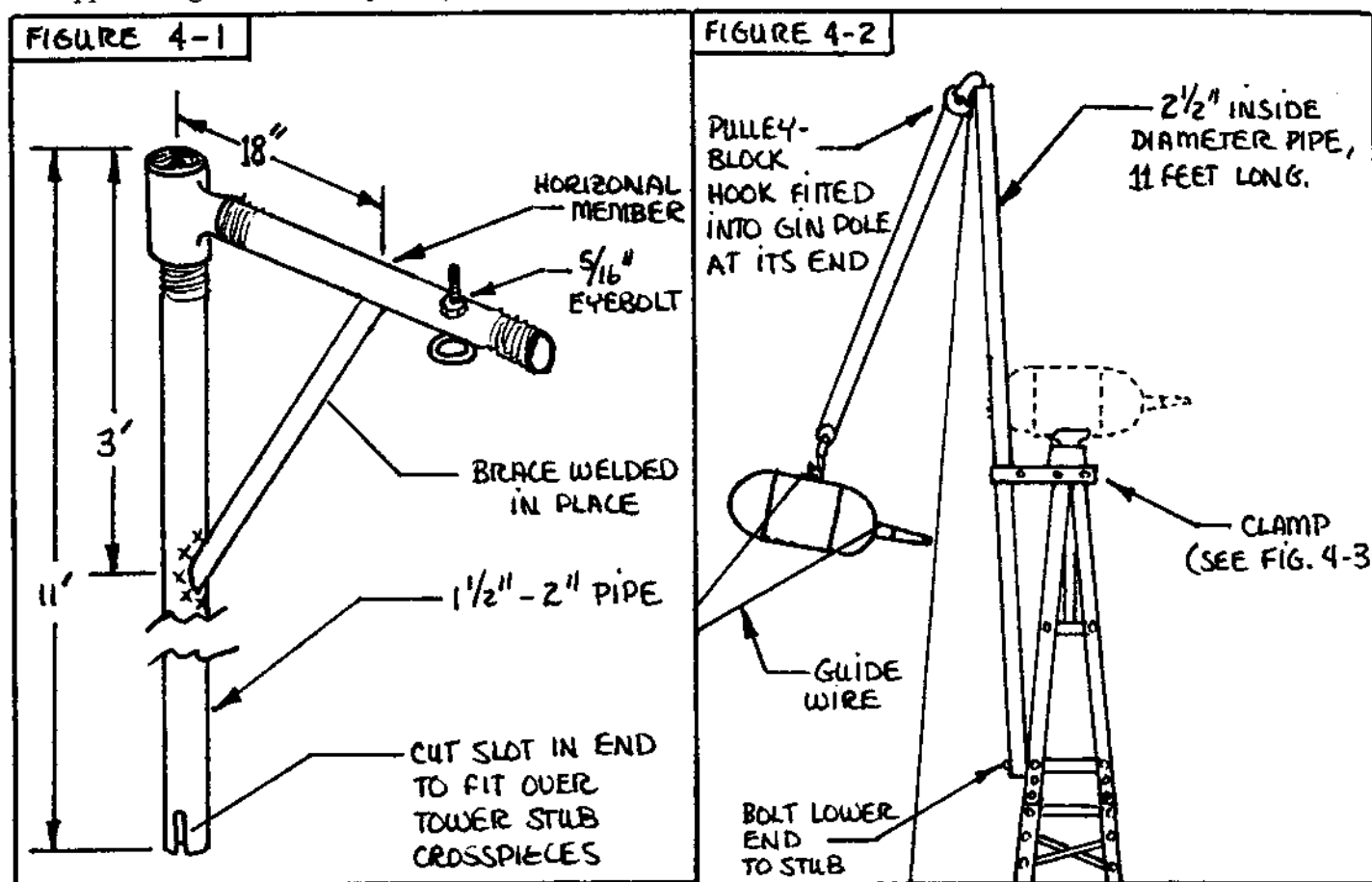
## The Machine-Raising Gin Pole

Quite simply, the gin pole used to raise wind machines to the top of the tower is a miniature crane; the only difference between it and the big guys is that it doesn't move around, it attaches to the tower, and it's something that you can put together yourself. If selected well, installed correctly, and operated within its limitations, it is reliable, strong, and safe.

Fig. 4-1 depicts the type and size of gin pole recommended for the installation of a wind machine like the large Winchargers of the pre-REA period. The latter is made of one and one-half inch to two inch water pipe, and measures 9 to 11 feet in length. A T-connector can be used to attach the horizontal member of this gin pole ( don't use a 90° elbow as it is not strong enough ), but a preferred attachment is by welding. A brace must be added for strengthening the horizontal member and, by virtue of its position, must be welded. If you are doing this yourself, I recommend using an arc

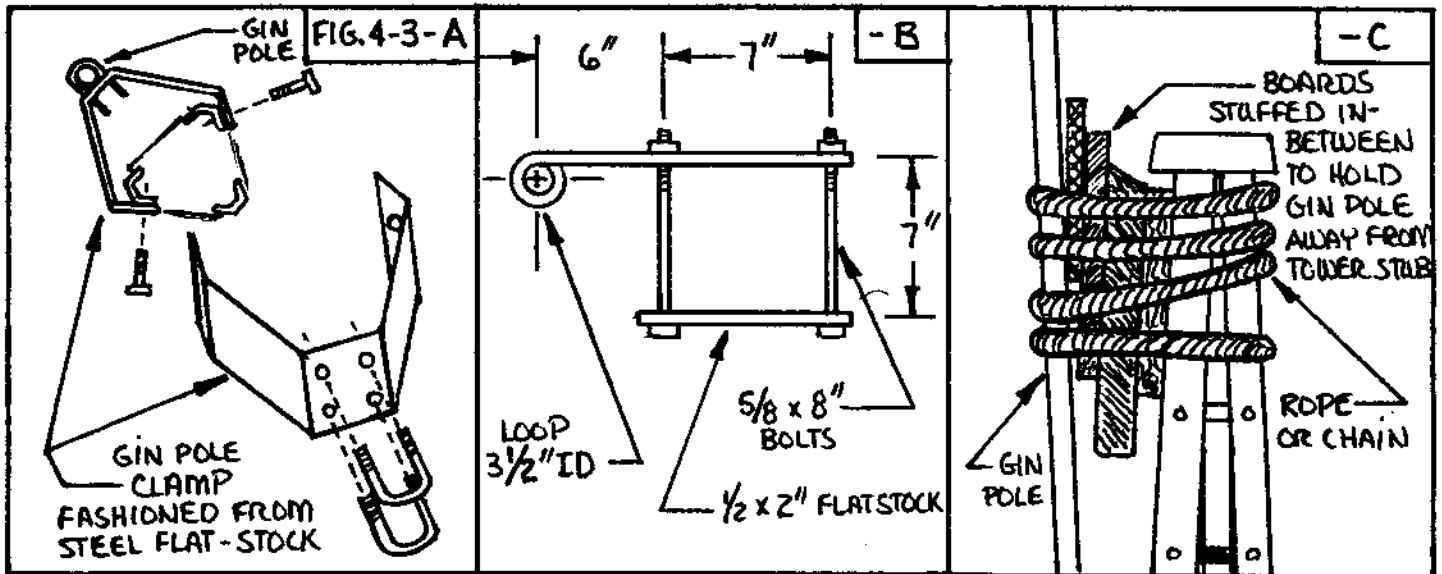
welder rather than a gas-welding outfit as the weld will be stronger with the former and the metal surrounding the weld will not be as weakened by the application of so much heat. So, if you don't have an arc outfit, take it to a place that does. An eyebolt ( mounted as shown ) will provide the greatest versatility for any kind of pulley used, but insure that it is large and that it is mounted as close to the brace as possible.

The Wincharger type of gin pole is suitable for the installation of any wind machine up to 150 lbs of weight. For larger wind machines, a Jacobs-type gin pole is recommended ( see Fig. 4-2 ). This is an 11-foot-long, straight pipe, with a 2-1/2" inside diameter and should be of the seamless variety of pipe ( not water pipe ). When installed, a gin pole thus fashioned is incredibly strong and able to lift 500-600 lbs with no indication of unusual stress. ( I admit my ignorance of what its upper weight limit truly is. )



Both gin poles attach to the tower at two points and will rise above the wind machine for about half of their length ( see Fig. 4-2 ). The bottom of the gin pole is best secured by slotting it to slip over a cross-brace that is part of the tower itself. It must also be secured at a point below the wind machine mount but as far up the pole as possible. The greater the distance between these points, the more secure the gin pole will be during a wind machine-raising becuz it will have less of a tendency to shift or angle over to one side or the other as the force and direction of pull shift. By virtue of the shape of the tower, it is nigh impossible to secure the gin pole directly beneath the wind machine position without using some kind of "stand-off." Without it, once you've gotten the wind machine up near the top, you won't be able to mount it becuz the gin pole is in the way. It helps in this situation to visualize the clearance from wind machine to gin pole as though the wind machine is already in place. Fig. 4-3 illustrates three types of stand-off that can be used. The first is designed for a three-leg tower and is characteristically used for a wind machine of the Wincharger type ( and weight ). The second is the type used for a four-leg tower and for a class

of wind machine like that of the Jacobs wind machine ( and its weight ). The third is a "gotta-be-desperate" method that I have used with some success a number of times. The latter is by far the most dangerous and the most difficult to use; while it makes for a faster setup, it will cost time and energy during the wind machine installation becuz it's not as stable. Use it if you are crazy, desperate, and fully paid up on your life insurance.



#### Machine-Lifting Physics

As previously indicated, the gin pole used for raising wind machines is essentially a small crane. To prevent unusual stress on it or on the top of the tower to which it is attached, there are a few general rules-of-thumb that should be followed:

1. When securing the lower end of the gin pole, notch or slit the gin pole so that it fits over the crossmember; this will serve to prevent this end from moving inward or outward or from rotating. If crossmembers are not available to support the lower end of the gin pole, then bolt a sturdy piece of angle iron horizontally at the desired position. The situation may be that you have angled pieces of metal that are in the vicinity of this position but they don't appear strong enough; you can, however, remove them and use the same bolt-holes for securing the angle iron. If no such convenience is present, then drill some holes and use quarter-inch bolts or larger. Here's one of those things that you'll want to do while the tower is still on the ground, so write it down as one of the items in the tower's pre-raise preparation list.

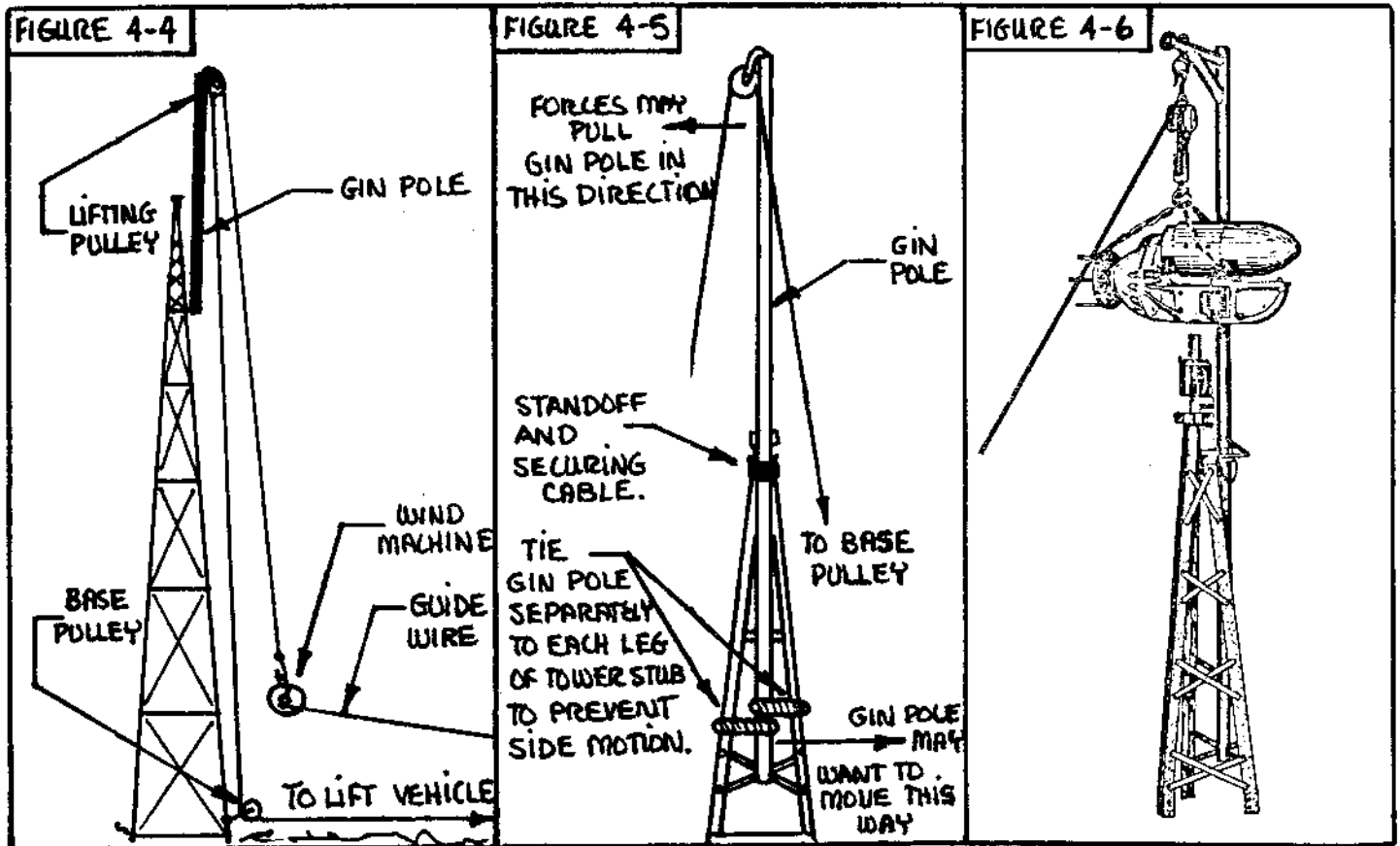
The angle iron that is used should not protrude more than about six inches from either side of the tower. This will prevent any collision of the wind machine during the raising with the angle iron piece. They're all tied together, folks. We used a similar piece of angle iron on an installation job and secured it only with some chain. This was quite safe for the raising becuz the wind machine was brought up on the gin pole side and swung around to be bolted on to the lolly shaft. A year later, however, we brought the machine back down for some work but, in this case, we removed it ( along with the tail and governor ) to the side of the gin pole. The obvious interference wasn't noticed until the wind machine was being lowered and it took a few seconds for the vehicle to get stopped, and we almost banged the angle iron crosspiece out of position. If it had moved a bit, the gin pole would have shifted to the side. This would have lowered the wind machine a bit more, pressing down onto the angle iron more, shifting the gin pole further: a very vicious cycle. The extra length of angle iron ( about 18" ) had made a handy footrest for tower work. In lowering the

wind machine we could have had both -- a 6" footrest and a noninterfering member -- by cutting off the excess 12". 'Tis what happens when you take siestas with the ole head.

2. Fig. 4-4 illustrates another little point of consideration when using a machine-raising gin pole -- you shouldn't apply pull to the side of the gin pole any more than you have to. The pull should be nearly straight down. The best way to insure that the pull remains downward during the raise is to install and use another pulley at the base of the tower. By using this "base pulley," the movement of the vehicle will not affect the direction of pull at the "lifting pulley" ( attached to the gin pole ). It should be secured to the tower ( not just hooked to it ) to prevent the possibility of its release, should the raising cable be slackened at any time during the raise. ( The rope or cable used for this purpose should be of equal rating to the one used for the wind machine raising. )

3. The bottom attachment of the gin pole to the tower should also include some means of preventing any side movements of the lower end of the gin pole ( toward one leg or the other ). In the highest probability, the wind machine will be raised to the side of the gin pole and not behind it, or on the side of the tower opposite its installation. Consequently, the bottom of the gin pole will tend to move in a direction opposing this stress ( see Fig. 4-5 ). Cable, rope, or chain should be used to prevent this, but it must be secured somewhat in the manner shown if it is to be effectual.

4. With either the Wincharger or Jacobs-type raising pole, a cable, rope, or chain should be used to further secure it to the tower. If the third method is used for gin pole stand-off, this is a necessity. For the latter, it will be many wraps as a minimum, and for the former two, that will be a sufficient maximum. I've seen so much poor quality metal used for all kinds of clamps, etc., that I tend to overdo the number of ways it should be secured. It only takes a little more time and longer lengths of cable, rope, or chain, but it sure beats the idea of giving ceremonial last rites to your wind machine.

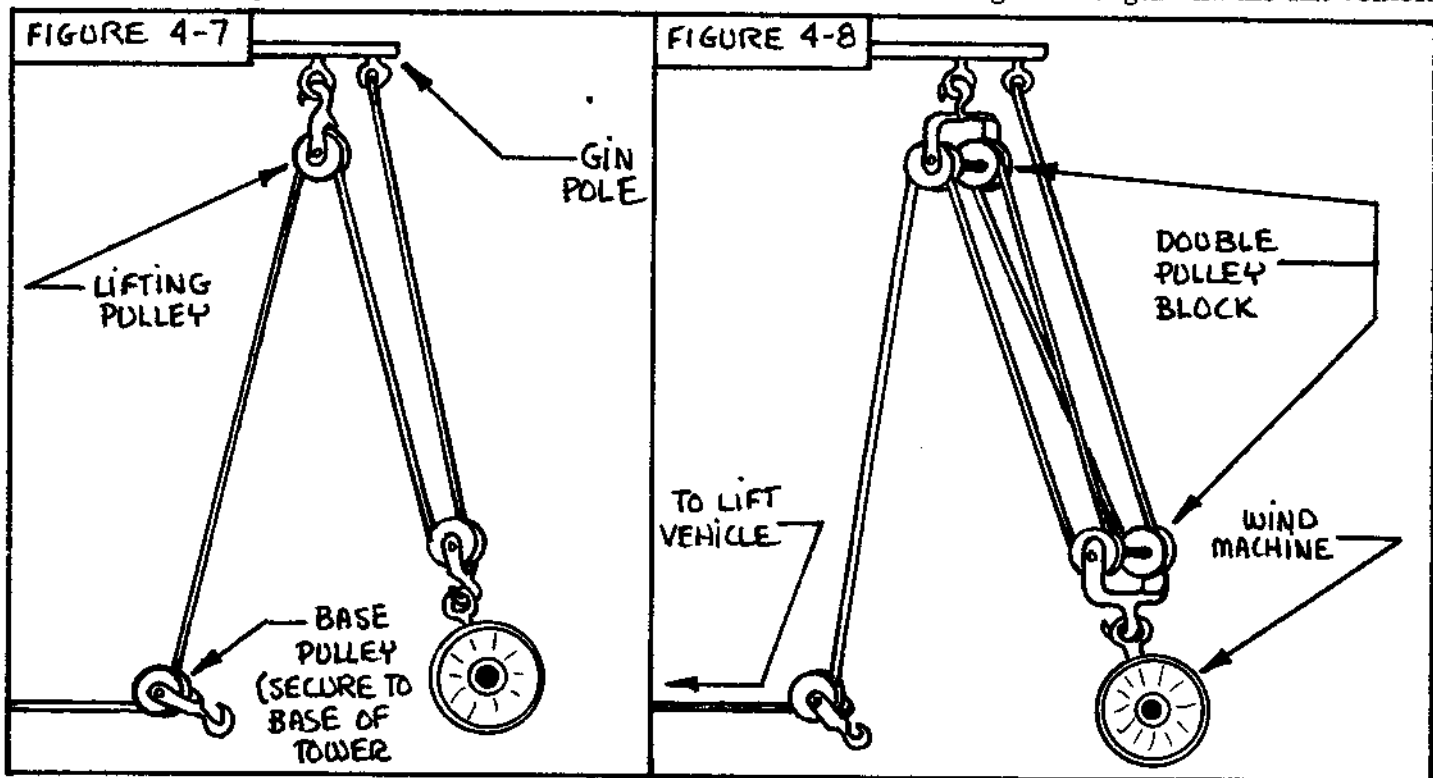


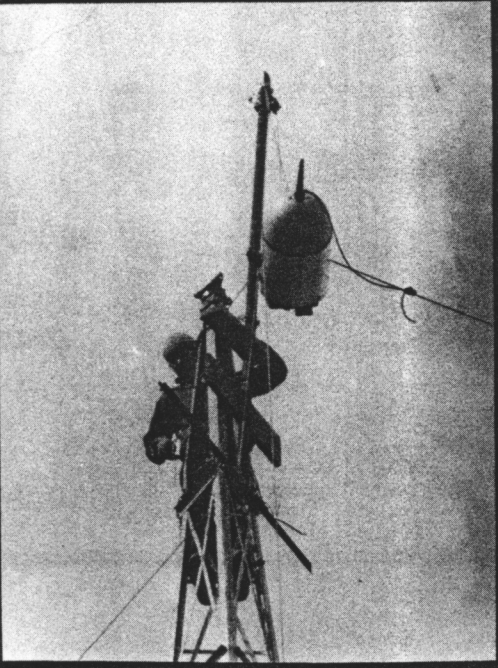
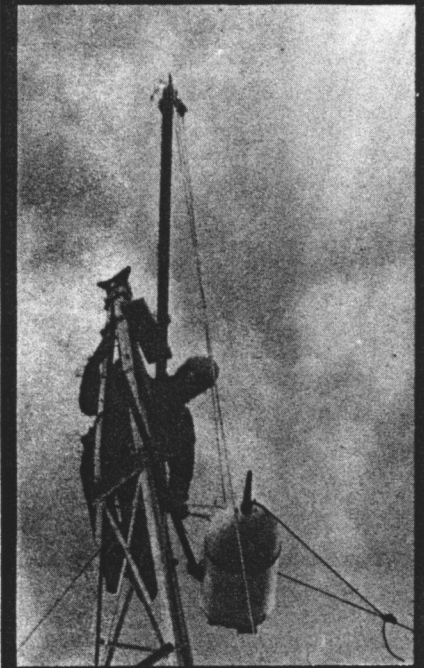
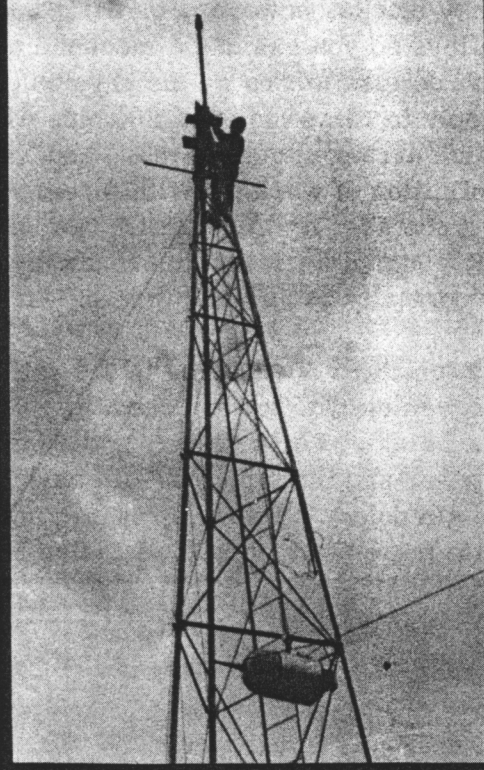
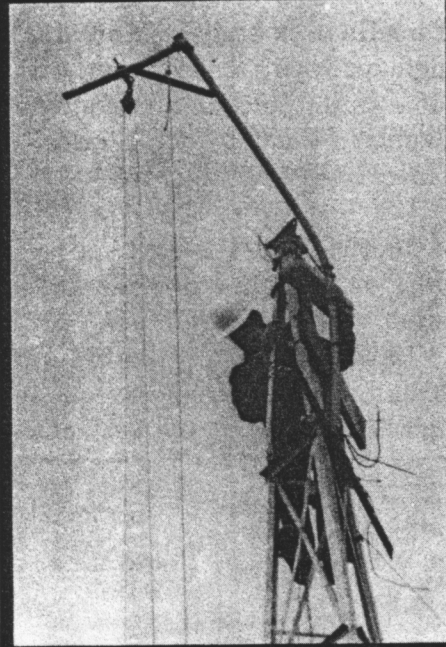
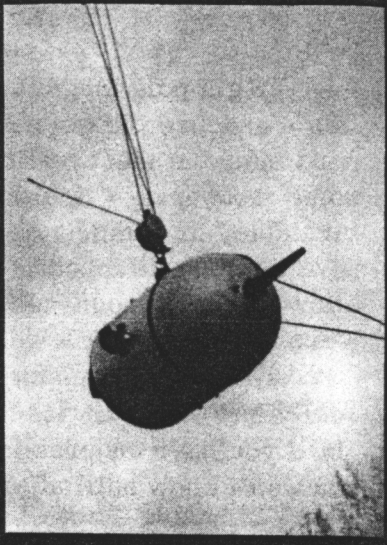
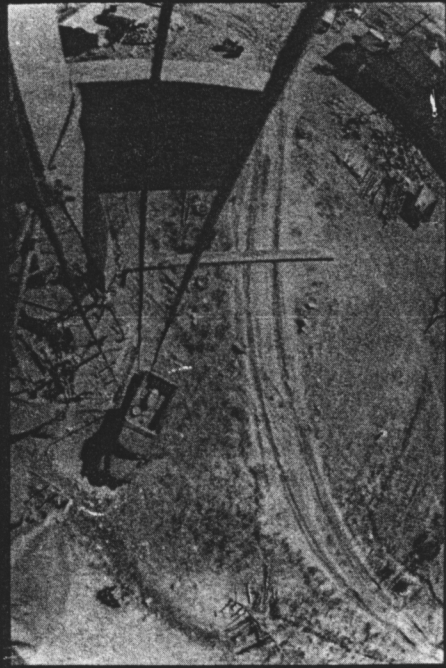


5. The gin pole length varies for different wind machines and the types of tower, but the idea is this -- secure the gin pole in such a fashion that it allows 18-24 inches more than the distance the wind machine must be lifted up to clear the lolly-shaft, turntable, or saddle ( see Fig. 4-6 ). Do some measuring ( in either case ) of the width of the wind machine, the length of the lolly-shaft, turntable, or saddle, etc. If you're wondering why the extra 18-24 inches, remember that you will have a pulley attached to the gin pole ( through which the raising cable will be strung ) and must allow for any amount of "swing" that might occur during installation or removal. The straight (Jacobs-type) gin pole will need maximum allowance becuz the pulley attached to it will not be directly above the mount for the wind machine. You won't want the gin pole any higher than it really has to be but 'tis better to be that way than to come up short. You'll know almost immediately if you have underestimated in the case of lowering a wind machine; but if you're raising one, you won't know until after you've gotten it all the way up there.

6. If you have three single-pulley blocks, however, then consider using a mechanical advantage ( or consider getting this many pulleys so you can use a mechanical advantage ). A mechanical advantage is a lever arm; you won't do less work ( by the physics definition of the word ), but the amount of force that you have to apply to raise the wind machine will be reduced by one-half, one-fourth, or more ( depending on which arrangement you use ) and that spells less struggle, strain, and sweat ( which is a layman's definition of work ). With three single-pulleys, the best you will be able to do is one-half the force ( see Fig. 4-7 ), but with two double-pulley blocks and a single-pulley block ( for the base pulley ), you can work up a mechanical advantage whereby you'll only have to exert one-fourth the force normally required to lift the wind machine ( see Fig. 4-8 ).

The only disadvantage with using mechanical advantages in the pulley arrangements is that you will need a longer cable and the lift vehicle ( if you still need it ) must travel further in order to raise the wind machine to the same height. Let's illustrate the meaning here in an example. Supposing that you have a 54-foot tower and the top of the gin pole is 6' above the top of the tower ( making it 60 feet to the top of the gin pole ). If you don't use a mechanical advantage ( Fig. 4-4 ), the cable will only need to be a little more than twice the tower's height in length and the lift vehicle





must travel out about 60 feet to get the wind machine all the way up there. For a mechanical advantage like that shown in Fig. 4-7, the cable will need to be a little more than 3 times the tower's height in length, and the lift vehicle will have to travel out about 120 feet to get the wind machine to the top. For a mechanical advantage like that shown in Fig. 4-8, the cable will need to be a little more than 5 times the tower's height in length, and the lift vehicle will need to travel 240 feet in order to raise the wind machine to the top. So you're not gettin' sumthin' for nothin'! The extra cable costs more and you'll need a longer path for the vehicle to travel ( although you could stop, tie off the line, bring back the vehicle, and start off again ). Another alternative here is to lift the wind machine by people power ( Armstrong method ). This would be hard to do if a mechanical advantage is not being used becuz you must lift the full weight of the windplant ( let's say it's 240 lbs ). If you're using the mechanical advantage in Fig. 4-7, that's reduced to 120 lbs, and if it's like Fig. 4-8, it's reduced to 60 lbs.

### The Raising Cable

The raising cable must have a rating which will handle the weight of wind machine that is to be installed. If possible, it should have a snap rating ( referring to the weight it will hold if the cable is suddenly tensioned ) but it is not necessary if you can insure a strong, smooth pull. I've only used rope once to lower a wind machine ( it was about three-eighths-inch nylon ), but certainly prefer using my five-sixteenths steel cable with its hemp center. When raising a wind machine, it is easy to give the raising cable a little test without having to worry about what happens if it is not strong enuff, but this is impossible to do if you're lowering a wind machine without lousy consequences. More on that in the section dealing with lowering wind machines . . .

The raising cable will be secured to the top of the gin pole or to the wind machine, depending on whether or not a mechanical advantage is used. If it is attached to the wind machine, this will be at the ring-bolt or to a sling that supports the wind machine (See Fig. 4-6). If it's to the top of the gin pole, secure it to the eyebolt ( along with the pulley's hook ). Some pulleys have a hook underneath the pulley block which is attached to the center of the pulley, and this can be used also.

Wherever it's hooked, it should be secured with cable clamps if it's steel cable, or a strong and appropriate knot if it's rope. Keep the connections neat and prevent any dangling ends from any possible interference with the cable as it goes through the pulleys, or whatever, during the raise. Wherever a pulley is used, don't just use the hook! Secure a piece of line in addition to the hook around the same point to prevent the pulley from inadvertently slipping off when the cable is slackened. Always route the wire ( or rope ) over the pulleys in a neat manner ( don't let 'em get all twisted ); they should not cross but once at any point. If this is done on the ground, insure that the assembly is attached so they are not twisted during the installation. Think about where it is that it might turn ( as the wind machine comes off ) and you can compensate for situations where it might get messed up during the raise.

### Guide Wires

Becuz of the gin pole's position, you should use a long rope ( or wire ) to hold the wind machine away from the tower once it is on the way up. If you are raising the wind machine without a tail, props, or hub, then one long rope will do it, and it should be secured directly to the wind machine,

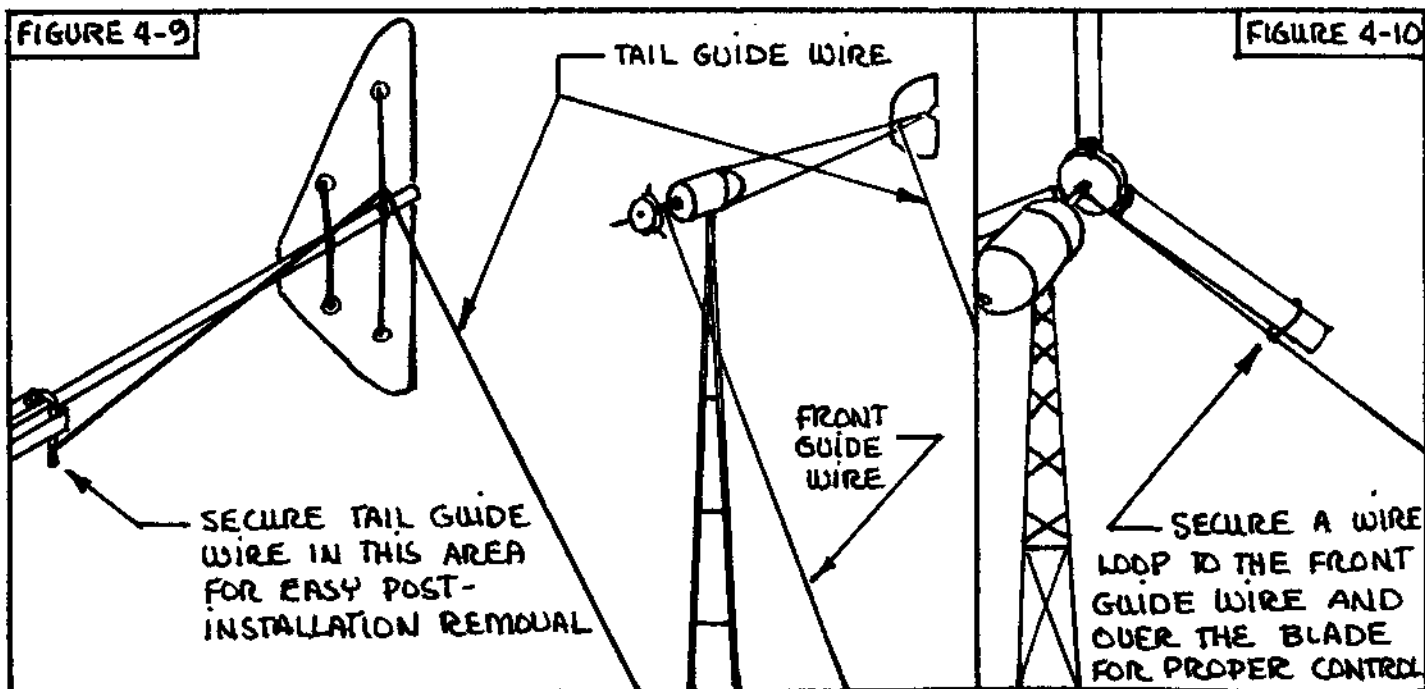
With the gin pole installed, the Jacobs is readied for the raise. After a long look down, it's pulled out of the truck and the lift begins. After no more than a 20 foot raise, the inadequate gin pole bent and we thanked our last-minute decision to install a back-up wire. With a new gin pole attached, Jim pulled away and we got it up there. The author got some assistance from Ken in the bolt-up.

not to the pulley block to which the raising cable is attached.

The guide wire should be at least one and one-half times as long as the tower height. This will insure that the person pulling on the guide wire can get as far away from the tower base as may be necessary to hold the wind machine away from the tower without exerting tremendous amounts of downward force ( and buckets of sweat ) to do it. Of course, this person will be pulled toward the tower as the wind machine goes up ( this is natural ),but that individual can keep the brakes on sufficiently to do the job. The guide rope will only have to sustain, at the very most, a hundred pounds or so.

If you are raising the tail and governor at the same time, but not the props, then you should use two long wires for the wind machine, one attached to the front and the other near the tail. For the latter, tie it in such a way that you can get it off once the wind machine is installed; after all, the end of the tail may be a long way from the tower and you can't very well go scootin' out there to undo it. Fig. 4-9 shows just one of many ways this can be done. The reason for the two wires is so that it is easier to keep the assembly from turning one way or the other and jamming up on the tower ( or marring your perfect paint job ). On a perfectly windless day you can probably get away with only one line, but if you've got wind ( or want to prepare for that eventuality ), then run the two wires so that you can maintain perfect control.

Most folks who install propellers on the wind machine before it's raised are in too much of a hurry, as far as I'm concerned. There is simply too much hazard involved and, for most wind machines, the props are no manner of difficulty to attach once the wind machine is up there. ( Usually it has been part of the design criteria for that wind machine. ) However, this condition might not exist and for that reason I indicate the way to do it. The rope for the front of the wind machine should be well secured to the prop shaft or hub, and then the line should be secured to the tip of one of the props LOOSELY ( see Fig. 4-10). Extra precautions are in effect here. Number one: use the two long guide wires ( as in Fig. 4-9 ); this will prevent overstressing the blade by exerting bending forces toward the front or rear of the wind machine. Number two: the person or persons involved in pulling on this guide wire during the raise must always insure that they are pulling only directly out on the prop ( they should have a perfect side-view of the wind machine from their position ).

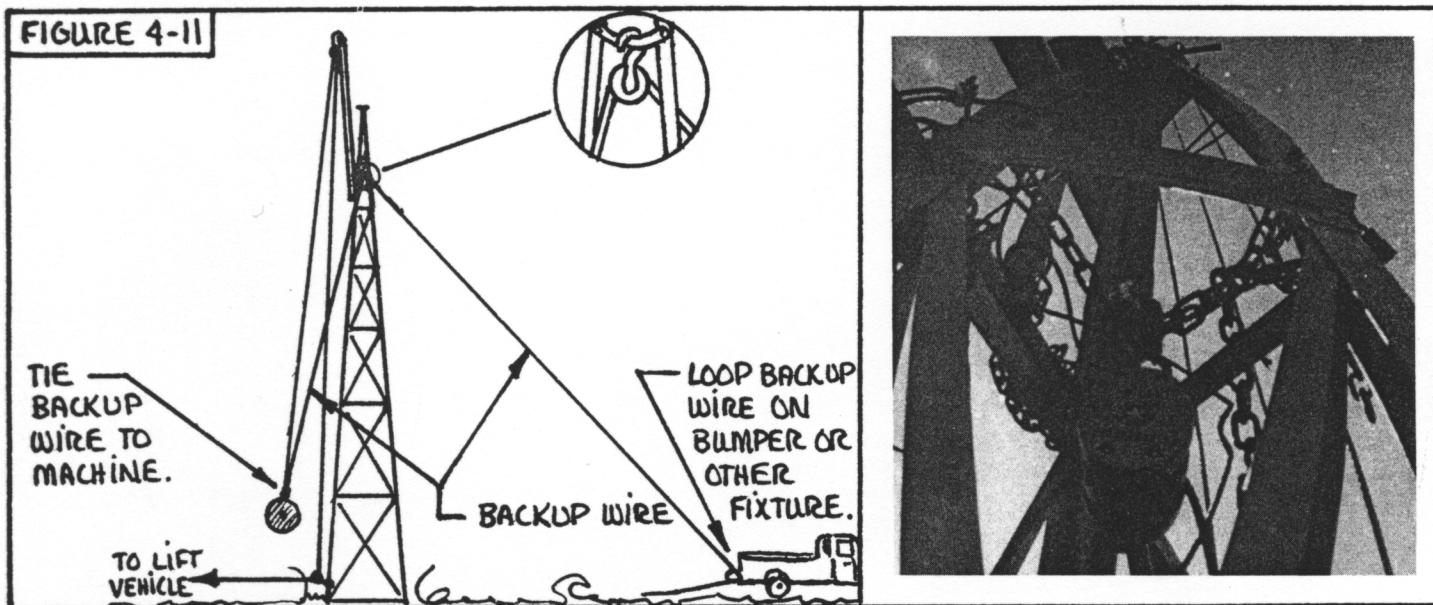


Understand that the guide wire attached to the governor or prop shaft is not attached to the blade tip at all; it is merely strung thru the loop around the blade. The purpose of doing it this way is to insure that the prop doesn't start spinning during the raise.

### Backup Wire

Using a backup or safety wire for the raising cable is purely optional. I've only done this once, and it saved the day, as the gin pole started to bend over when the wind machine was a quarter of the way up; it would have doubled over and probably snapped, otherwise. We were using the wrong gin pole for the job and knew it. That had a lot to do with our decision to install the backup wire in the first place.

If you want to get maximum use out of the backup wire, then secure the pulley used for it as close to the top of the tower as possible ( see Fig. 4-11 and accompanying photo ). If you secure it to the gin pole, then you're only protected against cable breakage and not against the gin pole bending, slipping, or breaking. We secured one end of this wire directly to the ring-bolt on the Jacobs that we were installing, looped it over a well-secured pulley block near the top of the tower, and down to a truck. We looped the wire around a bumper support so that we could take up the slack as the wind machine went up. In this way, the most that the wind machine could fall was a few feet.



After the machine reaches the height of the backup pulley, the backup wire will need to be slacked off so the raising cable can pull the wind machine up the rest of the way. The backup wire can remain attached to the wind machine but, of course, the wind machine will fall a distance before all the slack is taken up and the backup wire may not be able to sustain the shock of sudden tension. One can be fairly assured, however, that if the wind machine can make it 90% of the way, chances are better than ever that it will make it the remainder of the distance.

### Personnel

The number of persons required to raise a wind machine is the same here as it is for a tower-raising. I'd put the minimum at 3 -- one in the lift vehicle, one at the top of the tower, and one holding the guide wire. If you have two guide wires ( tail to be raised with the wind machine ), then add one person. If you are insane enough to raise the props with the wind machine, add one other; this person can help to hold the guide wire for the front of the wind machine to eyeball its progress. If it might get windy, add two more people -- to help with the guide wires and to stand

close to the lift vehicle so that messages can be relayed very clearly and quickly. If the wind is over 10mph ( and I'm talking about gusts ), invite them in for coffee and then send them home. If you're still go ( it's a calm day ), and you're running a backup wire for the raising cable, you'll need someone to take up the slack in this cable ( around an inch ) and hang onto it if the main raising cable setup goes haywire. If you've got people to spare, then get someone in there to take pictures and maybe get a cassette recorder on the set. This last thing may sound corny, but I would give a lot at this point to have a recording of the raises that I've been involved in.

### Final Setup Check

When you're actually ready to raise a wind machine, go back through all the points mentioned in the chapter thus far, and write down all of the applicable ones. As in the case for tower-raising, don't substitute this information for your own head. I'll probably think of sumthin' I should have said when the book's out and it's too late. When you've set up all the equipment -- pulleys, raising cable, backup cable ( if used ), guide wires, vehicle positions, etc. -- then you should go over the setup and procedure with someone who's not familiar with it and let him/her doublecheck it.

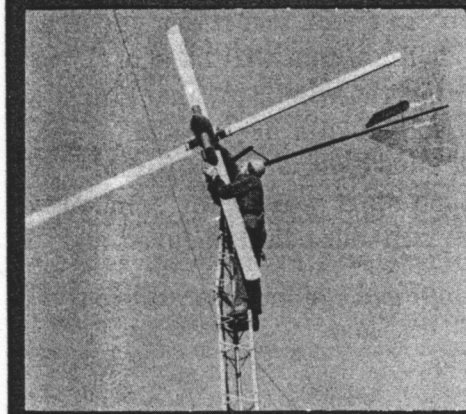
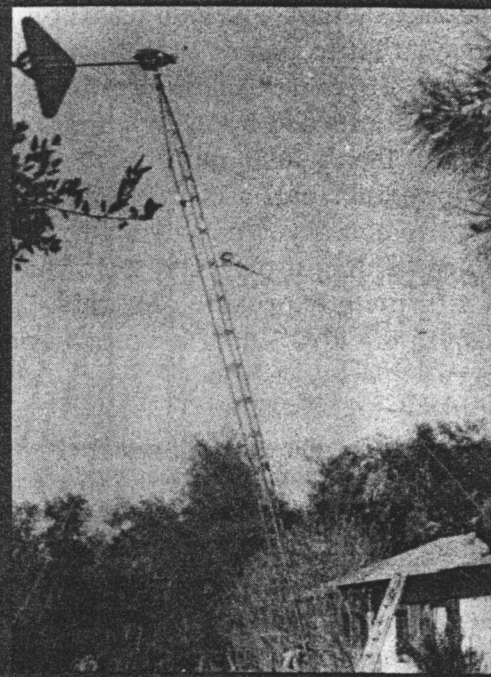
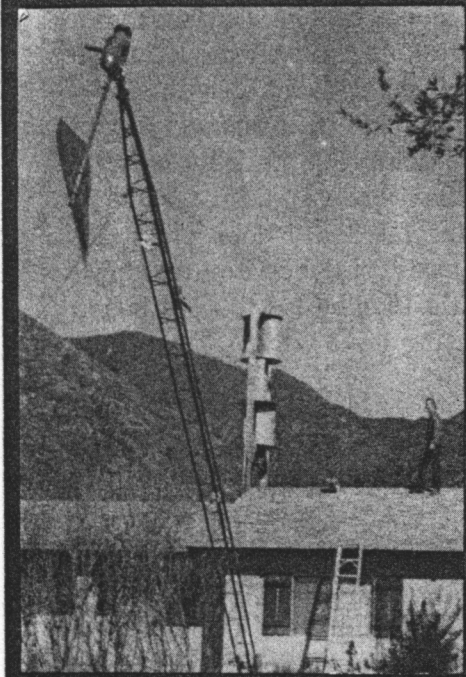
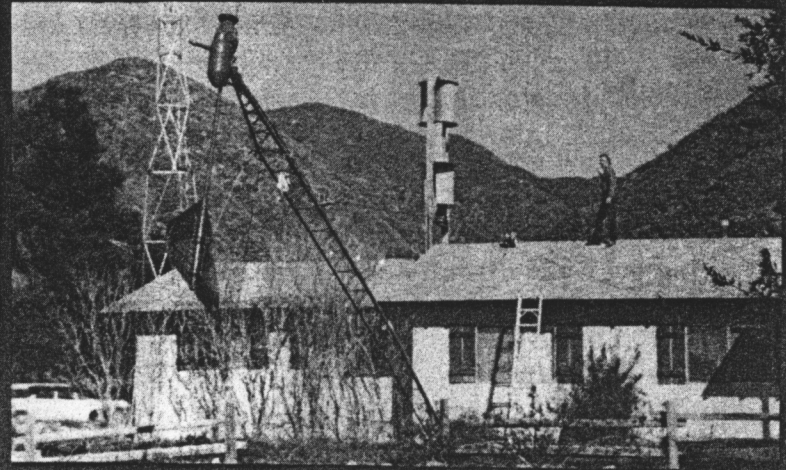
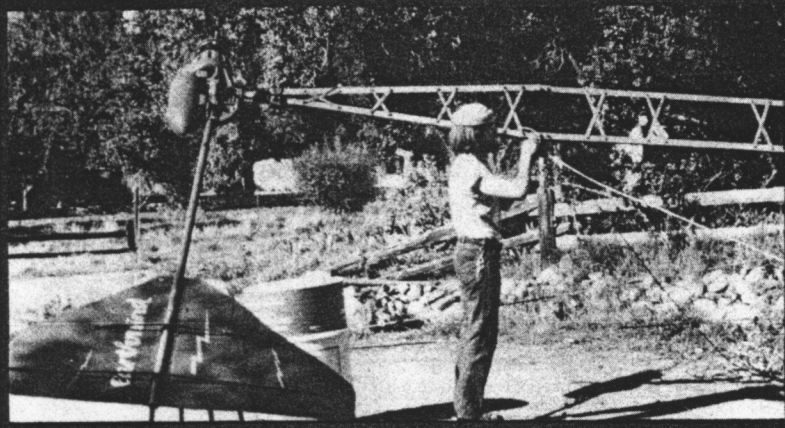
A pre-machine-raising pow-wow is just as necessary as the tower-raising one previously suggested. The danger zone is still quite wide; even though the area that might be impacted by a falling wind machine is small, a snapped and loose cable can strike out like a rattlesnake, so keep spectators back at a safe distance.

### Doing it

Shades of tower-raising! Do it!

When you've completed the "acid test" for the raising cable, give the GO signal again. Easy does it. The rope tensions and she starts doin' the anti-grav thing again. Up and up and up. The tail is swinging toward the tower so give the signal or yell to the guideline tenders for the tail to hold it a bit. They shouldn't have to actually pull out on it becuz they're allowin' it to slip through their fingers or movin' forward as the thing rises. If the machine is out from the tower more than a few feet, have them both slack off a bit. No sudden pulling here or the other end will surely swing inward. Watch the pulleys carefully. A simple kink in the rop or cable can jam up easy and rip a pulley loose or cause a cable or rope to snap. Everything flows like honey right now, though, so keep her going. Higher and higher into the sky. Guide-wire tenders movin' in now as the wind machine gets higher. Still taking up the slack on the backup wire. A shout from the top of the tower. The wind machine is almost up to the point where the backup wire's pulley is secured. Give the signal for SLOW. And another shout from above. It's there. Give the STOP signal. Check with the top-o'-the-tower watch and have the folks tending the backup wire ready to give up slack as the wind machine raises. But no more than necessary. It may not be much of a backup at this point, but it is sumthin'. And that's better than bare-fistin' it any day. Everything understood? Fine! Run over and talk to the driver. A nice and slow lift cuz the backup wire tenders have to match the raise now. And back to it!

The author balances the tower on his ear while adjusting some side guy wires in preparation for the raising of a restored, 32 volt, 1500 watt Wincharger at Earthmind. The farmhouse roof served as the gin pole and Jim Davis located his winch-equipped Toyota on the other side of the house. Nessie guided the machine's tail until it was high enuff, and up it went! Governor and blades were installed later and the author checks blade-tracking, gives it a lube job, and watches ( cautiously ) as the tail is let out ( to the operating position ). Then it's a quick scramble down the tower as it revs up.



The top-o'-the-tower tender takes it from here. A GO SLOW signal and it's rising again. Now it's up above the top of the tower. Dead slow at this point. A STOP signal from the tower tender. He looks the situation over. Nope, it won't quite clear. Raise it a mite -- maybe a foot or so. She inches upward. The STOP signal again. Nope, an inch or two higher. Steady back-up of the lift vehicle. Okay, STOP. That's it. Set emergency brake on the vehicle and block the wheels if it seems necessary. Kill the engine on the vehicle and keep it in gear ( if it's a stick shift ), or Park if it's an automatic.

At this point, a break is in order, unless everyone is primed and ready. There might be a need for two people up there for the bolt-up, so figure out who's going to do it. Get rigged up with the necessary stuff -- tools, good-and-strong safety belts, bolts, nuts, lock washers, etc. -- for bolting it up. Put 'em where they are easy to get out ( back pockets are better than front pockets, incidentally ).

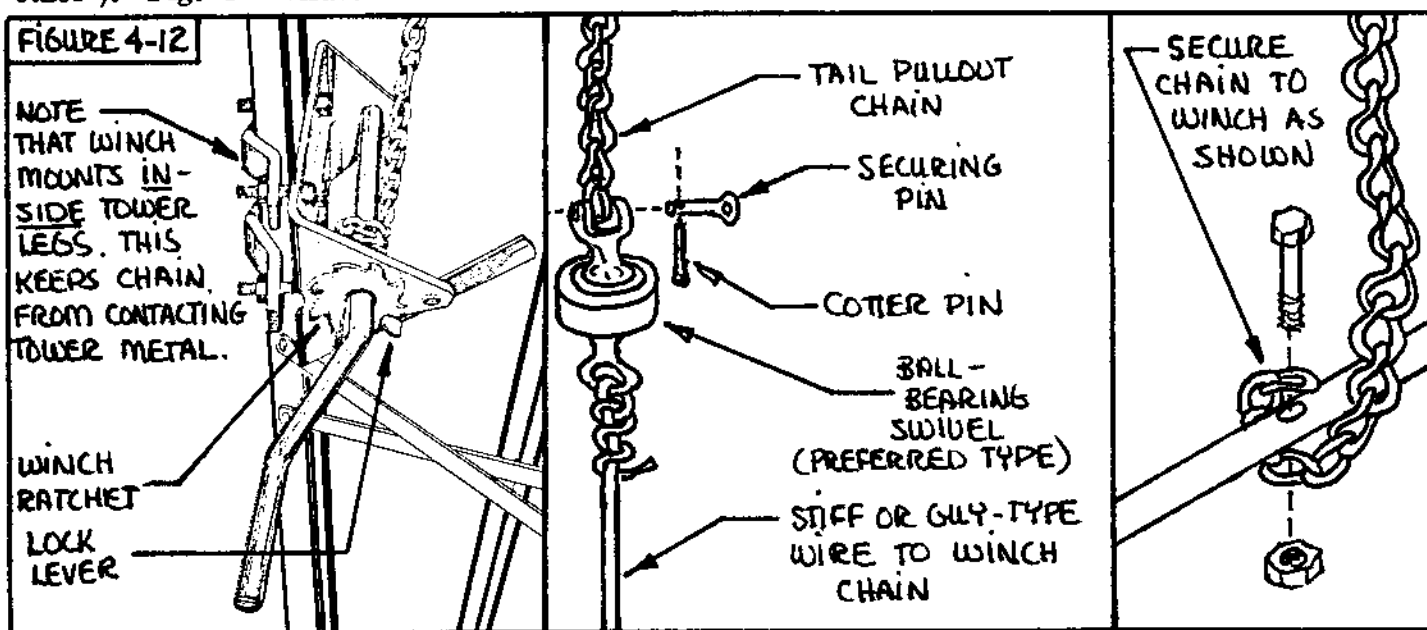
The long climb up. At the top, a shifting around until the two people can work together and not be in each other's way. Get both safety belts secured and checked. Check the amount of slack afforded by the wind machine's position. How much can it be moved to one side or the other? Will it swing over and directly above the saddle ( or to the top of the tower )? Don't expect this to be very much. The wind machine will be very close to the gin pole, and there won't be much rope to play with. Yell down to slacken off on the raising cable a bit so that the wind machine will start moving down on the top of the tower. If the saddle and lolly-shaft are attached to the wind machine, you'll have to guide them into the recess for the lolly-shaft. It's a wee bit more tricky sometimes than just lowering a wind machine down onto the saddle and bolting-up, but not impossible. If you're using a large mechanical advantage, then you may have to shake the blocks a bit and, in general, jerk the wind machine around a bit to insure that the raising cable isn't hung up. If ya don't do this, and they are hung up, the lift vehicle may give a tremendous amount of slack before they suddenly let go and fall the distance afforded by the accumulated slack. It can crush fingers, arms, and heads, or it'll at least scare the dickens out of you. If the vehicle is perceptively moving but the wind machine is not lowering, call a HALT and have them back up a bit to take the tension and work at those cables a bit to see if you can free any binding. When it does start moving down, push on it sideways until you're holding it over the top of the tower and keep coming down. This is exhausting work. Jim has a favorite expression for this. "It's like trying to install or remove a V-8 engine 50 to 60 feet up in the air." It'll have you sweating in no time. Take lots of breaks. No place to get in a hurry!

You may have to jockey the wind machine up and down several times during the last few inches until you can get a bolt started and on its way. Keep the fingers away from between tower and wind machine as it can suddenly slip on you and catch you a good one. When you do get a few bolts home, get the rest of them in there. Get 'em turned down tight before you release the raising cable connections or the pulley blocks. When that's done, the guide lines for the tail and the governor can be removed. If you have the props attached, keep the retaining wires for both of them attached until you can get the pull-out chain in operation. Without electrical wires attached to the wind machine, there will be no "load" condition to hold the prop in check and it can get to a very high RPM before you have a chance to sneeze. If the wind is turbulent, this will be a real chore because the guide lines will find it difficult to keep it pointed out of the wind. At that point, however, two mistakes have already been made -- raising the wind machine with props, and raising it on a windy day -- so whatever happens next is deserved. If I have gotten myself into this jam, I'd straddle the wind machine, get my safety belt on tight, and start yelling for someone to please hurry ( although probably not in that vernacular ) and get the pull-out chain secured and operating.



## Installing the Pull-out Chain

Most wind machines are provided with some means of automatic feathering -- spoilers, governors, furling, etc. -- whose aim it is to slow the wind machine in high wind conditions or once the prop ( or whatever ) has reached a certain RPM. In addition, most wind machine are provided with a means whereby the aeroturbine's revolutions are manually stopped. This may be the only system installed ( no automatics at all ) and it can also be a means to completely shut the windplant down ( instead of just the limiting effect of automatic devices ). The good wind machine designs incorporate both; in this manner, the windplant provides for unattended operation with a capability of complete shutdown for maintenance or repair work ( as required ). Some existing wind machines have electrical shutdown devices, but most have a mechanical affair which is cranked by hand at the base of the tower. Whether it applies a mechanical brake or pulls the tail around ( so the windplant is side-facing the wind ) doesn't really matter; what is important is that some means is required to connect the crank at the bottom with the appropriate device at the top. This is a long wire with a short section of chain at the lower end ( for winding onto the crank ) and a swivel at the upper end so that the activated device at the upper end will do the job without twisting the wire excessively ( which will occur if the windplant revolves into the wind more in one direction than the other ). Fig. 4-12 illustrates these connections.



The swivel at the upper end is attached to another wire or chain that then connects to the brake or tail pull-out; it usually travels up through the center of the lolly-shaft so that the windplant is still free to turn. The Wincharger and Jacobs pull-out arrangements are somewhat similar ( see Tail-Furling in CHAPTER 2 ) but you must know -- for these and other wind machines -- whether the tail is pulled into place ( like the Jacobs ) or pulled out of place ( like the Wincharger ). This and the tower height determine the length of pull-out chain used. Once established, the wire should be connected to the swivel. Be sure to lubricate the swivel with some heavy grease before you do this. If you can afford it, get a ball-bearing swivel as the ElCheapos don't work at all under tension.

The lower end of the pull-out or brake wire should be connected to some chain. The winch used here will have a small diameter spool; if wire is secured there directly, it will not take very long before the wire will be frayed and weakened by the tight turns it must take going onto the spool and the straightening that occurs when the wire is unspooled. I guess if you used stainless steel aircraft cable, it would do the job without being fatigued; but then you run into a problem in

trying to cut it to length ( you wouldn't believe what it does to wire cutters ! ). So chain is wound up on the spool instead.

To find the length of chain required for the crank is not all that difficult. First, route the pull-out wire down and into the vicinity of the pull-out crank. Pull it tight, give an excess of 9-15 inches, and cut off the excess. Loop the wire into the hole in the crank spool or attach it to a pin located there. Now rotate the crank clockwise ( when viewed from the handle end ).

When the pull-out wire is just tight, notice how many turns of wire have been made on the spool. Now, crank the handle around ( in the same direction ), making sure that the turns are going onto the spool side by side and neatly. As the wire is spooled in, watch the tail swing out and behind the wind machine ( for the Jacobs-type ) or out of this position and into a side-facing position ( for the Wincharger-type ). When it's straight behind or side-faced ( respectively ), mark the wire at a point where it is just starting to go onto the spool ( a small piece of masking tape works well if wound tightly ). Now, unwind the crank until the tail is back in its original position. Mark the wire where it just starts to come off the spool ( at about the same number of winds you turned it before the tail began to move ) and take the wire the rest of the way off the spool. The distance between the two markings ( of tape ) is the amount of wire that must be spooled to bring the tail from side-facing to operating position and/or vice versa. The top piece of tape marks the approximate point where the chain must be attached.

Get some good chain. Requirements are that it be able to sustain several hundred pounds of force. Get closed-link chain, and not the S-link variety. Don't get it so large that it won't clear the space between the spool and the crank-n-spool supporting frame. Once you find some, get one and one-half times the length you found between the two pieces of tape markings on the pull-out wire. It will take more chain than wire to make the same number of turns on the crank spool and a little extra won't hurt all that much. The stuff isn't exactly cheap, so I'm providing a way to keep the cost low without sacrificing utility. Once you're ready to attach the chain, you have to determine where to cut the pull-out wire. Generally this can be done right at the upper tape marking. You'll want it a bit higher than that in reality but by the time you tie the wire onto the chain, it will have shortened all the more. If the distance between the two tape markings was more than three feet, you might move up the pull-out wire about 3 inches for every extra foot and cut it there. Just do some visualization here and what you're tryin' to do will become more obvious. You'll want the chain to make a few turns on the crank before it starts to move the tail of the wind machine, but extra won't hurt provided that the spool is wide enuff to take the required number of turns to bring the tail full around. Loop the wire through one of the links and just twist it a bit until you check the amount of chain left over ( below the crank ). It should be anywhere from 6-12 inches. Okay?

Now tie the pull-out wire to the chain (like that shown in Fig. 3-36 of Chapter 3). Cut off the excess or twist it neatly around the wire until there is none sticking out more than a few inches. Don't want to get it caught on anything!

Because of the tremendous lever-arm of the crank, it would be wise to mount a sign at the base of the tower as to which way the crank should be turned to furl the windplant or to bring it into operation. Someone familiar with the cranking procedure for the Jacobs must reverse this process if a Wincharger is in use. Never know when you might have to tell a stranger to furl the windmachine (becuz you are otherwise occupied) and mistakes can be disasterous. We will be operating wind-plants of both types here so we plan to install these signs just so that we don't get confused. If it's dark, raining, and so windy that you must furl the windmachine, it can get done backwards very easily. I recall a conversation with a gentleman at one time where he commented that there were only three things that he couldn't remember. The first was the names of people. The second was the names of places. And he couldn't remember the third one! Have I made my point?

The pull-out crank, wire, chain, pulleys, swivel, and all connections associated with this function should be checked periodically for fraying, loose hardware, and rust. The swivel and chain should be lubricated with grease whenever necessary. Check the little ratchet-arm on the crank for wear. This is the only thing that keeps the windmachine furled or open and it will eventually wear out.

If the crank at the bottom of the tower is used to operate a brake on the windmachine, much of the above procedure applies but you will find that it will take less turns of the crank to engage or disengage the brake mechanism. The mechanical-brake assembly at the top will need close attention as it doesn't take much rust or dirt to muck-up the movement of the parts in the assembly, especially for releasing the brake. If it doesn't completely release, a slackened cable will be the first sign but it may not always evidence itself thusly. A partially-released brake will very quickly be worn by the propeller's rotation. As well, sufficient friction here will generate enough heat to ignite any residual grease, so keep surfaces and hardware in the vicinity of the brake clean and free of grease.

### Installing the Governor and Props

If you raised the wind machine without props (and a governor, if applicable), then it's sumthin' you're gonna have to do. If you have a tail to install, do it immediately after you've installed the governor and props. This way you can control the wind machine a lot better; it will not be constantly trying to orient itself to the breeze. If you have installed the tail, make certain that you have installed the pull-out chain or brake cable and that the tail is furled or the brake set tight. Never install, remove, or work on the windplant if you can't stop the machine.

The gin pole will help bring up the governor and the props, too. You shouldn't have to struggle too much to get it attached with someone holding the raising cable from below, but you will have to lean out a ways to do it. Some governors will mount before the props are attached and some after. If yours is the latter, watch out for the blades! Even with the windplant furled, the blades of the prop can (and will) swing around freely (particularly in gusty winds where the wind direction is changing faster than the tail can follow). It doesn't take much of a movement on the blades to draw blood if you get wopped one. Sometimes the blade will move backwards and that sharp, trailing edge can slice you good. If it's moving and hits you with the rounded, leading edge, it generally won't cut but it compensates neatly by just knocking you out (if that's any consolation). Even without wind, the windplant will respond to any pressure that you exert on various parts of it and swing away from you at just the wrong time, so prepare for it and make your movements sure and thoughtful.

Just a word here on something I have observed before. Never tie a blade tip to the tower in an attempt to keep the windplant from tracking or the blade from revolving. If there is no wind at all, it looks functional. But even in a slight breeze, the blades will revolve as the windplant tracks and it will slip out of the rope or it will just try to do these things and bend or break a blade. If you've ever tried to push a tail sideways when the wind is blowing, you will understand quickly the amount of force it is capable of applying and the absurdity of such an effort will find no place in your actions. After all, the tail keeps the windplant oriented into the wind and that's no easy thing. The area directly behind the propeller is very calm even in high winds and yet this small movement of air is sufficient to keep the wind machine well oriented and, generally, very responsive to fluctuating wind direction. Take heed!

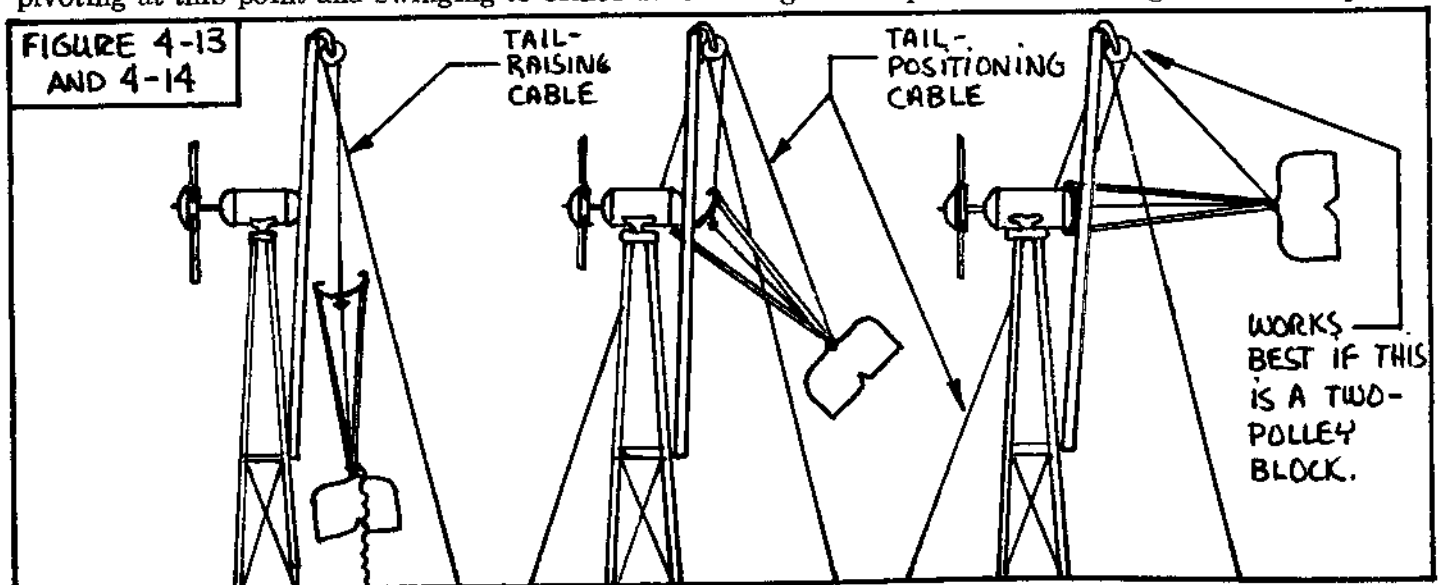
When the prop is ready to be attached to the windplant, you must decide whether to raise it assembled (if possible) or in pieces. If you have a one piece, two-blade prop and the governor installs

later, there isn't any decision to make. If you have a hub on which 3 or 4 blades are installed, then you might possibly raise governor and blades together, or the governor first and each blade separately. Doing it on the ground is easier for assembly, but the idea of having a combination of the weight and cumbersome size of this fragile assembly being raised 60 feet and then attached is a bit too scary for me. If you do it (wind or not), attach guide lines similar to those used in the windplant raising and take it slow and easy. Aerodynamic surfaces don't like dings and dents.

If you take the slower one-at-a-time method of attaching the props, the gin pole will come in handy for raising them up there. Insure that the person down below is holding onto a guide line cuz it's easy for the blade to swing and collide with the tower. Attach whatever is used for a raising cable in such a fashion that you can install the blade without having to remove the raising cable to do so. In this way you account for that "whoops" that is bound to occur with at least one of the blades that you're installing. Some of the Wincharger and Jacobs blade-and-governor assemblies had a piece of tubing inside the blade which slipped over a piece of stock-rod sticking out of the governor. If this represents your situation, then you'll want to rub a light oil over the shaft before you try to install the blade. A gentle twisting movement will work the blade onto the shaft, but you may have to have someone located further down the tower (at about that point where the blade tip is) pushing up on it. The whole assembly will need to be prevented from moving to install the next blade and, unquestionably, the windplant will be trying to swing around one way or the other. It's a skillful and patient individual that gets these things on with a minimum of effort and time. Tighten all bolts immediately as each prop goes on, and install the air-brake if the windplant uses this type of governor.

#### Afixing the Tail

If the tail was not installed on the windmachine before the windplant was raised to the top of the tower, prepare to experience the fun of installing it afterward. The gin pole will be absolutely necessary to doing this, so leave it up there. Attach the cable (that is used to raise it to the top of the tower) as you would have for the guide wire (see Fig. 4-13). You might also attach a short piece of rope to the end of the tail that will mount on the wind machine, just for a little easier handling once you've got it up there. This is a two person operation -- make one a strong-arm and the other one with some brains (to figure out the best way to do it). Using only muscles with this job is the wrong way altogether becuz it is truly difficult to apply enuff force to counteract the tremendous lever-arm of the tail. By using a method similar to the one in Fig. 4-14, the attachment is just a matter of adjusting raising cable tension once the end of the tail assembly (that secures to the windplant) is at the attachment point. The strong-arm helps to prevent the tail assembly from pivoting at this point and swinging to either side during mate-up. Use the lift angle afforded by



the gin-pole and raising cable and adjustments to the shorter piece of rope (which can be looped thru the eyebolt on the gin pole) to do the work and it will just be a matter of concentration rather than a weight-lifting contest. Don't expect it to be a fifteen minute job.

Once the tail is installed, attach the pull-out line and route it through the pulleys and holes to the position of the swivel. If you're trying to get the wire (or a chain located here) up through the center of the lolly-shaft, you may need to lower some wire through it from above and then tie it up and pull it back through. A piece of baling wire will work wonders here (if you're not the farmy type, try a coat hanger). If you find that you are getting nowhere while working on a tower, you're no longer tuned into it, so stop, lean back (with the safety-belt attached, of course), and think about it. This is no place to get hurried!

### Blade-Tracking

The remaining thing to check is the blade-tracking. (This is different than windplant-tracking.) This is easiest done using a ruler or small stick at a position on the tower directly at the level of the blade tip. Do this on a non-windy day and preferably with someone at a higher point on the tower holding on to the tail to insure that the windplant does not change its orientation during the check. Secure the measuring device tightly to the tower (with the hand) and move the stick or ruler out until it just touches the blade. Pull it back a slight amount so that it will not scratch the blades. Give the blade a slight push to get the prop to rotate and bring the next blade into position (this movement may cause the windplant to turn if it's not being held -- if this happens, it'll screw up the test). All blades should be the same distance from the tower.

If there is any possibility that the blades are warped, take this into account by measuring the distances to the blade (from the tower) at points in line with the blade's tip and at its mid-point. Always correct for the middle of the blade first. If the blade is slightly bent near the tip, this will tend to straighten out and align itself with the rest of the blade when the centrifugal forces become significant. So . . . the distance to the blades should be the same at the midpoint of the blades even if they are not quite the same at the tips.

If the blades are not the same distance from the tower and it's only a two-blade prop, you're going to need to put a shim between the blade and the blade-mounting plate on the windplant. Insert the shim between the blade and mounting-plate on that side which has the blade that is closest to the tower. The shim can be a thin washer or piece of sheet metal or shim-stock. How thick it must be depends on how far the blades differ in distance from the tower. Try something, tighten it down, and re-do the test (at the tip and midpoint of the blade). Mark which blade was closer to the tower to begin with. If it's still closer than the other blade, you need to add more shim. If it is now the one which is further out, you need to insert a smaller shim in place of the one you installed. Keep it up until the blades are equidistant from the tower. That's it.

Make the same kind of measurements for a 4-blade propeller as you would for the 2-blade unit. If you find differing distances to the blades from the tower, then you should mark the blades before you attempt any adjustment. It will be important to keep track of which one is at what distance becuz in adjusting for one blade, you may change the distance of any or all of the other blades in the process. As well, with a governor assembly like the four-blade Wincharger, there are two sets of blades attached to the windmachine (see Fig. 2-5 ); one set attaches to the governor mechanism on arms that will move and allow the propellers to change pitch when governing is activated. The other set of blades attaches to a fixed plate which is located rearward (or closest to the wind machine); these blades do not change pitch as the governing mechanism activates. The only significance to this

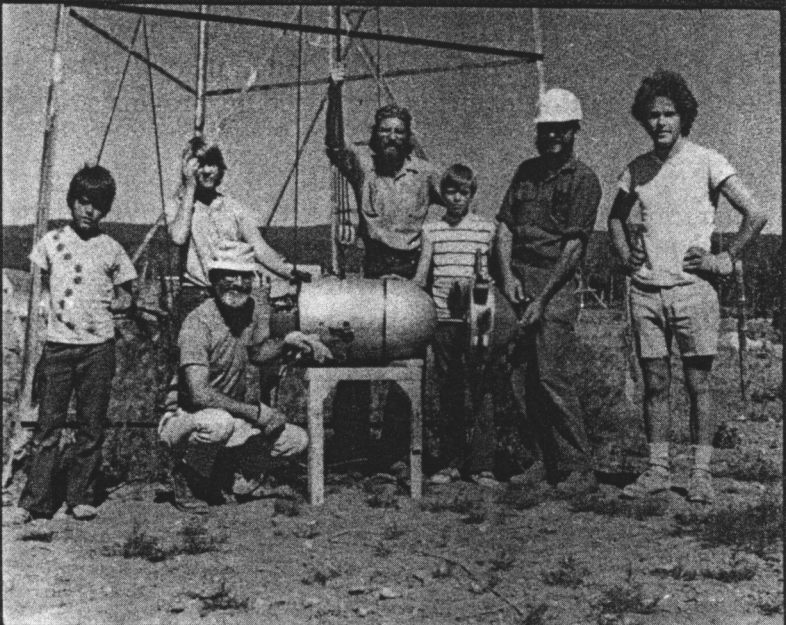
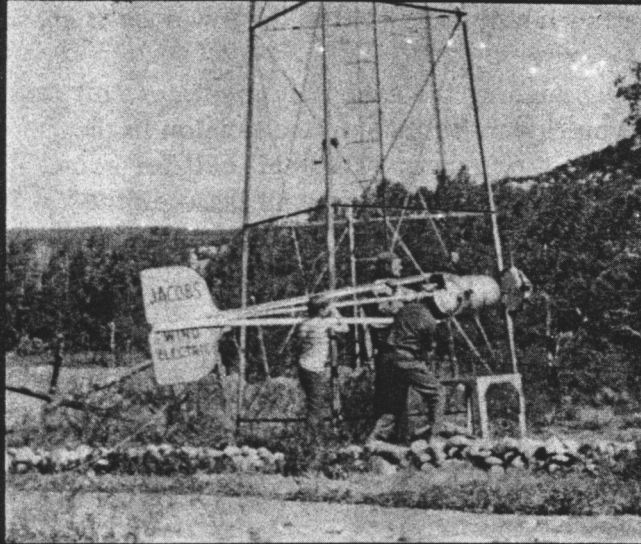
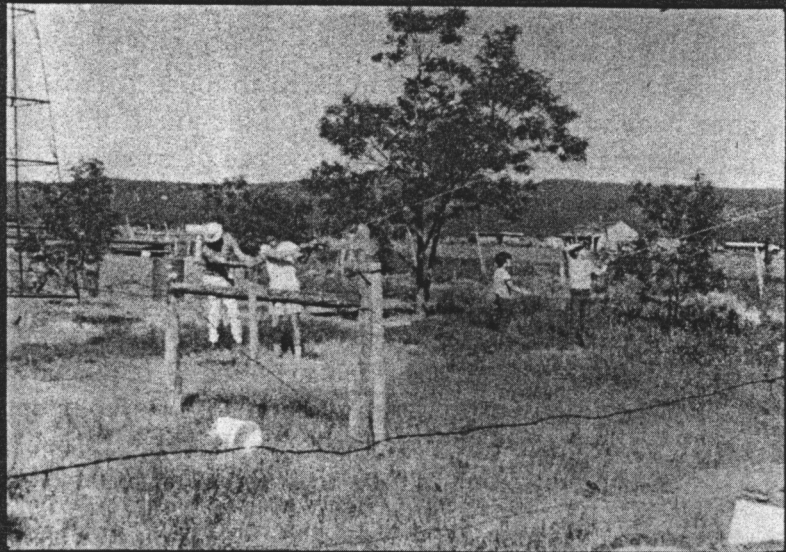
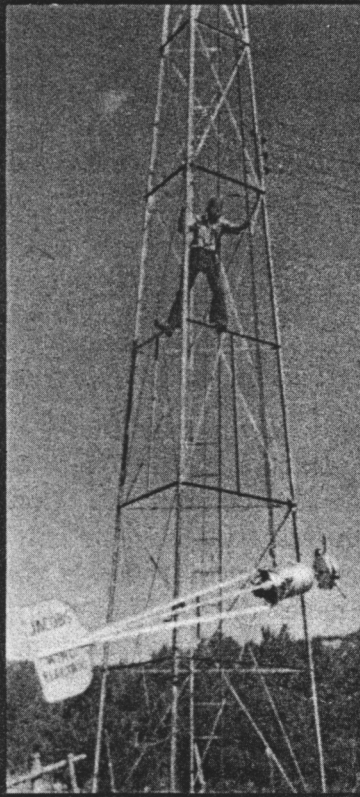
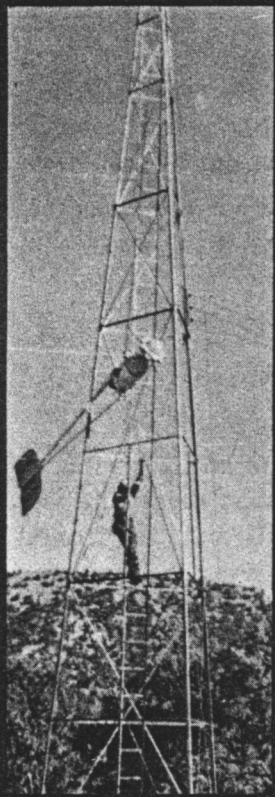
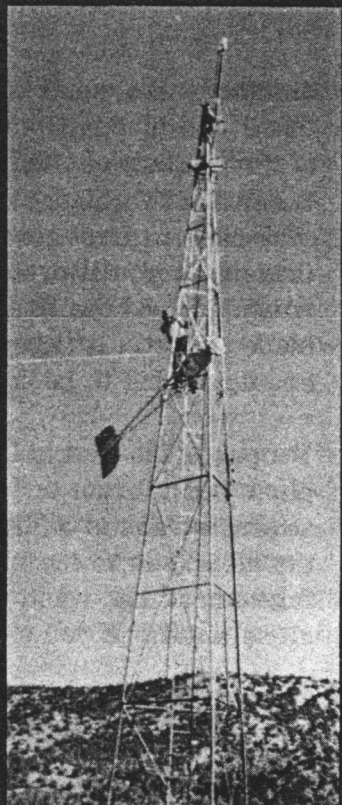
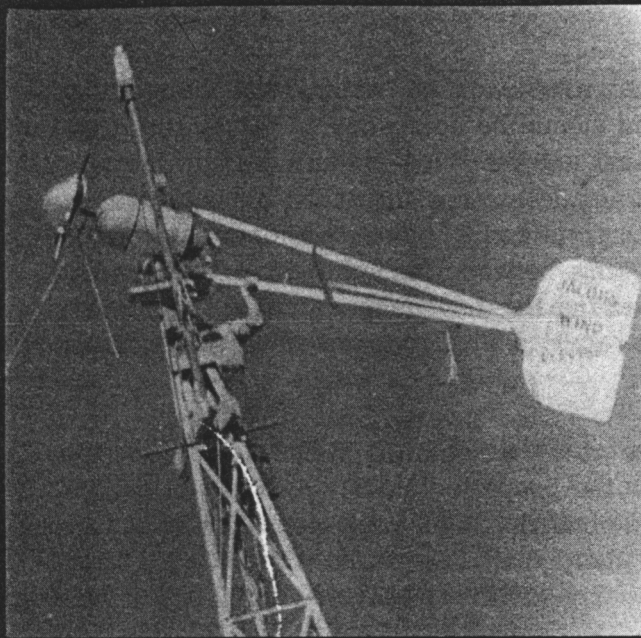
design is that any wind machine with this or a similar design of blade-mounting will require special attention when blade-tracking adjustments are made. For purposes of clarity in the following discussion on these adjustments, I shall refer to the blades mounted on the fixed and immobile portion of the governor as the fixed-blades and the governor assembly portion as the fixed-blade mount. The other blades will be referred to as the feathering-blades and the portion of the governor assembly to which they attach will be referred to as the feathering-blade mount. To further facilitate communication, let's label the blades A, B, C, and D. There are a number of out-of-track situations that might be experienced and I'll run through several of them to give you a feel for what might have to be done.

1. Let's begin with this oddity. You find, after careful measurement, that two of the blades are further away from the tower than the other two. It's the same situation when you check at the blade midpoints. It just so happens that two of the blades, say A and C, are equal in distance from the tower and the same goes for blades B and D, but the distance to A and C is different than the distance from B and D. Weird, huh? Not really. Look up and you'll find that A and C belong to one set (like they're both feathering blades) and blades B and D belong to the other (fixed blades). What do you do? Well, check to be sure that you have tightened both the governing mount and the fixed-blade mount to the propeller-and-governor mounting plate on the windplant. If you can see daylight in the cracks between all of these plates, chances are good that it wasn't machined right or that it's part of the design. As long as one blade in a set is not out-of-track (more or less distant from the tower than the other in the same set), there's nothing to worry about. It will not upset the action of the blades in operation.

2. What about this one? After some measuring at the blade tip and the midpoints you find that blade B is farther away from the tower than blades A and C (which are the same distance) and that blade D is closer to the tower than blades A and C. You're gonna need a shim here. But, you have to get the answer to a question first: are all the blades attached to one governing unit or are they attached, like in the Wincharger, to separate portions of a governor. If the former is the case, then simply insert a shim between the governor assembly and the governor and propeller-mounting plate on the windplant on that side where blade D is attached. If the answer to this question is the former--the blades are attached to a two piece governor assembly (with fixed and feathering blades)--you must then answer another question. (Hang in there--this all sounds a lot more complicated than it really is.) Are the blades that are out-of-track the feathering-blades or the fixed-blades? If the answer is the former -- the feathering-blades -- then you will place the shim between the feathering-blade mount and the fixed-blade mount on the side where blade D mounts. If these blades are the fixed-blades, on the other hand, you will place the shim between the hub mounting plate on the windplant and the fixed-blade mount. In this instance, you will have to loosen the feathering-blade mount to, in turn, loosen the fixed-blade mount and put the shim in. Make sense? Tighten down the assembly and again check the tracking. If blade D is still closer to the tower than blade B, you must add more shim, and vice-versa. Check each time to see that you are not causing the distances to blades A and C to change by whatever you do. Repeat until it is right and you're finished.

3. Supposing that you did your measuring at blade-tip and blade-midpoint and found that, say, blades A and B were closer to the tower than blades C and D. This can be a tuffy if none of the

Jim's Jacobs needed its commutator turned down; an attempt to do it with the EM tool (with the unit on the tower) failed, so we brought it down. Insofar as the Jacobs wind machine is balanced with the governor and tail attached, we left them on during the lowering. After attaching the twin guide wires to the Jacobs, we lifted it clear of the saddle and the author walked it down. Posing for the post-lowering (R to L): Ken, Jim and Clayton DeKorne, the author, Charles, and some neighbor helpers.



distances are equal but, for a moment, suppose that they are -- blades A and B are the same distance and blades C and D are the same distance . This should be compensated for by the insertion of a shim between the hub-mounting plate on the windplant and the fixed-blade mount halfway between the two blades A and B. If the distances are not equal between any of the blades, then you may have to first get the fixed-blades equidistant and the feathering-blades equidistant next. For this case, you'll probably end up with several shims -- one between the hub-mounting plate on the windplant and the fixed-blade mount and another between the fixed-blade mount and the feathering-blade mount. It'll be a time consuming event, so give a rest period in there somewhere or you'll end up saying to heck with it and not doing it right.

Proper blade-tracking is essential to good performance of the windplant. Without it, the windplant will vibrate and abnormally wear the bearings for the propeller shaft. As well, it can cause severe stresses on the propeller assembly in high wind conditions. If you're wondering how close the distances to the blades should be with one another, then go by this rule of thumb. With careful measuring, when you can no longer detect any differences with a standard ruler, it will be close enough. If you can note the differences, you're not yet there.

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### Removing the Wind Machine

Bringing a wind machine down from a tower is far more exciting than puttin' one up, at least to the person that's gotta be up there to loose it from the tower stub. Extra precautions are in order here becuz there is little room for the small mistakes that a raising can 'absorb!' The entire procedure is essentially the reverse of wind machine installation, but here's a few additional notes.

First, if the wind machine has the blades on it, I strongly recommend that they be removed. Fasten lowering wires to 'em before you detach 'em. Attach a guide wire to them so that friends on the ground can help keep 'em away from the tower as they come down. Consider removing the governor and tail. If the wind machine is balanced with 'em attached (the unit will stay horizontal when lifted clear of the stub or mount), it's your option. My preference is removing them, but I have done it the other way. ( See photos. ) If you've never done this sort of thing before, your first consideration should be to remove as much weight from the wind machine as possible.

Attach the main lowering cable and guide lines as indicated in the text for wind machine installation. I recommend installing the back-up wire; insofar as the pulley for the backup wire is installed in the tower (as previously indicated), it won't have much effect until the wind machine is lowered below the pulley position, but it could prevent an otherwise lenthly fall, hitting the tower as it goes.

For most wind machines, it will not be a matter of simply pushing the assembly sideways (off its mounting position) and lowering it. At the very least, you'll want to take up the tension in the lowering cable and, in most cases, you'll have to lift it a foot or more. This will call for some precision teamwork and it will be absolutely necessary to have good line-of-sight between the vehicle driver or winch operator and whoever is tending the top of the tower. Some good relay work or clearly understandable hand signals (like those shown in Fig. 3-39) will facilitate communication over possible engine noise. Be sure that no guy wires, electrical wires, or other obstructions will interfere with the lowering. You'll have much better control of the wind machine if you lower it on the windward side of the tower, but refrain if the wind is truly a nuisance.

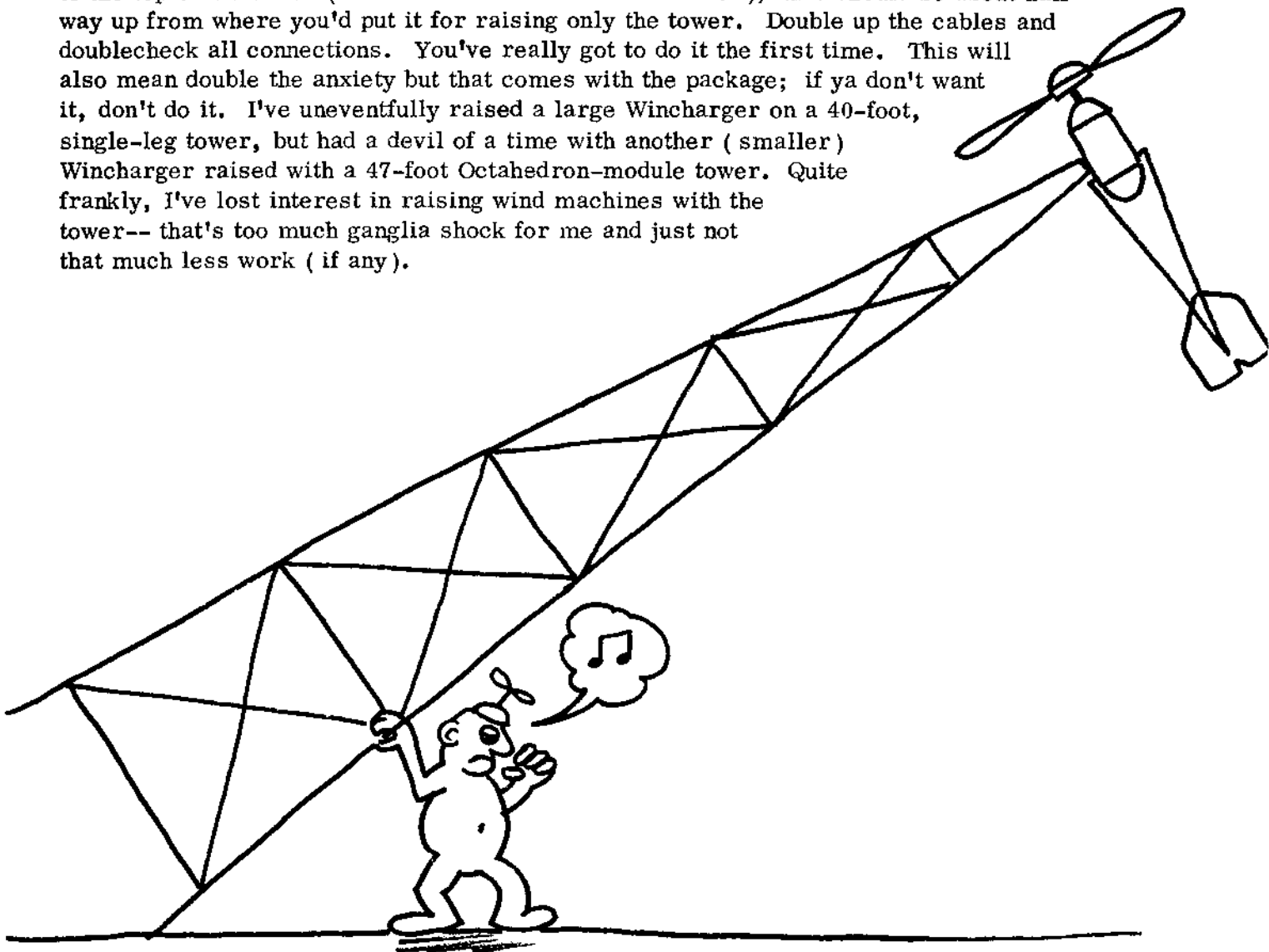


## Raising the Wind Machine and Tower Simultaneously

This procedure is not recommended for someone that has no experience with raising towers or wind machines; the special allowances required should provide sufficient reason for this statement. The first effect of raising tower and machine together is the tremendous increase of cable tension over that required to raise only the tower. An example: If you have a 60-foot tower that weighs 2000 lbs ( one ton ) and a wind machine that weighs 250 lbs and you attempt to raise them together, you're going to need 25% more lifting force than you would with just the tower to raise. And if the tension is initially 4000 lbs, another 1000 lbs is a lot !

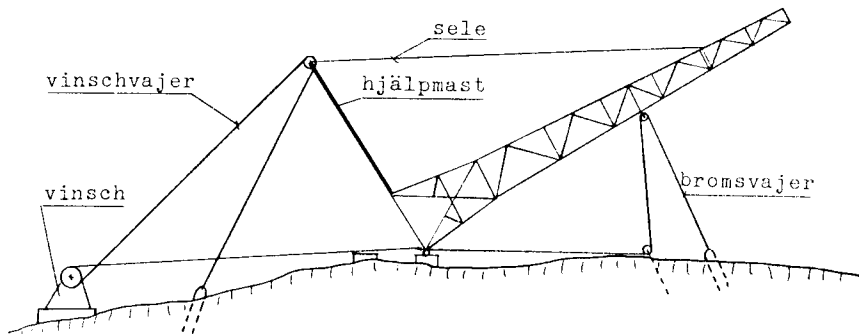
Second thing: To mount the wind machine, you'll need to raise the top of the tower off the ground a bit ( see photos ). Whatever you use for a standoff is critical becuz , when you start the raise, there might not be enuff pull to raise the thing more than a few feet and it's going to settle back down on the standoff. If it's not wide or strong enuff, the wind machine will miss or crush it and that's very rough on the wind machine. Unless you have unlimited lifting capacity, you're going to have a real problem lowering the tower back down ( should you have to ) before the raising is completed.

Okay, I'll get off the negative aspects. Irrespective of the way you've attached the raising cable to the tower ( pulleyed-sling or direct ), you'll want to move this entire attachment closer to the top of the tower ( to relieve internal tower stresses ); this should be about half-way up from where you'd put it for raising only the tower. Double up the cables and doublecheck all connections. You've really got to do it the first time. This will also mean double the anxiety but that comes with the package; if ya don't want it, don't do it. I've uneventfully raised a large Wincharger on a 40-foot, single-leg tower, but had a devil of a time with another ( smaller ) Wincharger raised with a 47-foot Octahedron-module tower. Quite frankly, I've lost interest in raising wind machines with the tower-- that's too much ganglia shock for me and just not that much less work ( if any ).



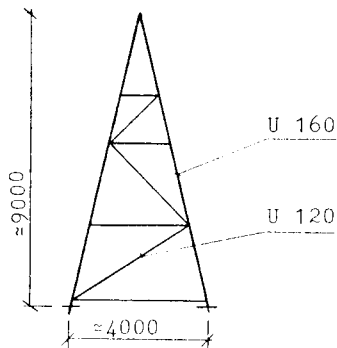
## 5 KOMPLETTERANDE KONSTRUKTIONER

**5.1 Hjälpmast.** För att kunna resa och fälla masten har en permanent hjälpmast monterats i roten av huvudmasten. Hjälpmasten är en A-bock med ett linshjul i toppen. Den är nedtill ledat infäst i huvudmasten och upptar den resande kraften via ställinor. Två av huvudmastens hörnstolpar anknyter till fundamentet via ett gångjärn. Hjälpmastens funktion framgår av fig. 8.



**Fig. 8** Hjälpmastens funktion.

Hjälpmastens geometri framgår av fig. 9.



**Fig. 9** Hjälpmastens geometri.

Hjälpmasten har dimensionerats som böjd och tryckt stång enligt RIL 90. Resdonen har kapacitet för lyftning av vindkraftaggregat på 900 kg under gynnsamma vindförhållanden.



# CHEAP TOWERS

John Dailey

©1996 John Dailey

In the spring of 1990, we put up a Windseeker II to evaluate the feasibility of wind power. Here on our homestead in the foothills of the Alaska Range, we get frequent blows lasting a day or two, and then calm for a week or so. We constructed a 50 foot tower from a 20 foot utility pole and three lengths of 2 inch pipe (see HP 28 page 26). After two years of operation with our Windseeker II, we felt that our local wind regime merited a larger machine.

After a false start with a machine that was not really designed for our rugged mountain winds, we took the plunge and bought an 850 watt Bergey. This Bergey was selected to withstand the rigors of our 80+ mph Chinook winds and has lived up to its sterling reputation. This bigger machine needed a stronger tower, and after reading Mr. Wind's great articles on tower height (see Mick Sagrillo's Econ 101 and 102, HP 37 and 38), we realized an extra 10 feet would greatly increase our output.

This is one person's solution, and not appropriate for all. Be sure it is right for you and that you have access to the appropriate materials and tools. If you have any doubts, consult qualified persons.

Any tower type, whether free-standing, guyed lattice, or guyed pole, must allow the owner/operator access to the wind machine for periodic maintenance. Generally, pole towers are lowered, not climbed, and the machine is then serviced on the ground.

These towers can be built from a variety of locally available materials. In our neighborhood, there is an abundant surplus of old 20 foot utility poles from the abandoned Anchorage to Fairbanks telegraph line, so one of these poles was the starting point for us. Our pole is about nine inches at the base. Use your imagination to take advantage of the materials available to you locally, but be careful to get it right; you don't want to wait for a nasty blow to realize that you underbuilt. By then, it's too late to do anything but wring your hands and stay out of the way as your tower and expensive machine come crashing down.

#### **A Note about Safety**

Although towers that lower your genny to the ground for service are in many ways safer than towers you must climb, remember that falling bolts, forgotten tools, etc.

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Above: The Dailey homestead in the foothills of the Alaska Range, showing the Bergey 850.

can still dent your head when falling 60 feet. So, unless you are tougher than Wyl-E-Coyote, WEAR A HARDHAT! During the critical raising and lowering phases, remove all pets and kids from the area: you'll have enough to worry about. (See safety sidebar.)

#### You Can Build It!

The design of this tower is simple: a 20 foot utility pole is permanently guyed and serves as a fixed gin pole. A 60 foot wooden pole hinges at 1 foot up from the base of the gin pole. The pole swings from a horizontal access position up to vertical and is then clamped with a heavy nylon strap with a ratcheting binder to the top of the fixed utility pole. Additional guys run from the top of the tall pole down to the same ground anchors that secure the utility pole guys. All guy wires are 3/16 inch. A chain saw winch (rush right out and buy one of these gems, if you're a homesteader and don't already have one...), or tractor, pickup truck, etc., can pull the main pole and attached generator up or down. The winching cable should also be a minimum of 3/16 inch.

After you have selected a good wind site, lay out your tower location and where you will locate the three guy anchors. The minimum guy radius is 50% of the tower height if you have a small field, but 75% is better. The wider the guy radii, the more horizontal the supporting guy wires are, and the less is the downward, buckling force on the tower during strong winds. Bergey recommends a simple method to eliminate plotting angles for the tower foundations (see guy sidebar).

Once you have laid out the positions for the guy anchors and the tower, the next step is to secure the guy anchors so that they cannot pull out. Our soil has good shear strength so we were able to use auger type

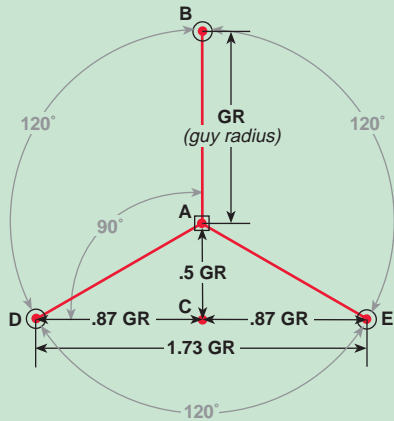
anchors (excavated and re-buried). No concrete deadmen were required. Evaluate your own situation, though, and make sure that they will not pull out. A small backhoe is very valuable here, although (we can only imagine that) a strong back will get the job done, too...

To install the permanent utility pole, excavate and pour one foot below grade an approximately 2 by 2 by 1 foot thick concrete pad with some rebar incorporated. The base of the utility pole will be anchored laterally as it is buried a little. Tamp the soil in around the pole above the pad. If you have very rocky, well-drained soil like ours, you will not even need the concrete pad, but pour the pad if you need to. You do not want the tower settling later and slacking your guy wires. Plumb this permanent gin pole, and tighten the guy turnbuckles.

Fabricate a hinge bracket and bolt it to the base of the utility pole, about a foot above grade. We used two pieces of 1/4 by 14 by 18 inch plate steel with a piece of plate welded across the outside bottom to keep them parallel. This hinge bracket should be bolted through the permanent gin-pole in three places with 1/2 inch bolts.

For the tower pole, you need to find a long, straight, strong pole. You can sometimes find these poles where there is crowded tree growth. These trees seem to reach tall and straight towards the sun, with little bend or taper. We used a peeled Sitka Spruce pole. Select a strong straight pole from the appropriate local species and peel it, but don't worry about treating the wood. (*ed. note: We can't overemphasize the need to choose a strong spar. Some tree species may not be up to this task, and others could have weakness because of large knots or other flaws. Also, do not try to use heavy wind machines with this design. The Bergey weighs 86 lb. If*

**120° Guy Anchor Positioning**  
*excerpted from BWC installation manual*



- AB = GR (guy radius)
  - AC = 0.5 GR
  - DC = 0.87 GR
  - CE = 0.87 GR
  - DE = BE = BD = 1.73 GR
  - $\angle ACD = \angle ACE = 90^\circ$
  - $\angle BAD = \angle BAE = \angle DAE = 120^\circ$
- = Tower Base
  - = Guy Anchor
  - = Measure Point
  - = Guy Cable

To Eliminate the need to plot angles in laying out the tower foundations we can resolve the equilateral triangle into two perpendicular lines as shown in figure ?

The three anchors are at points B, D, and E, the tower's base pad is point A, and point C is a reference point. The distance A-B (from point A to point B) is the guy radius (GR). For normal installations, GR is approximately 60% of the tower height. The distance D-E is one side of the equilateral triangle and is equal to  $GR \times 1.73$ . One half of D-E is C-E, where point C is the center of D-E. C-B, and thus C-A, are perpendicular to D-E. The length of C-A is equal to 1/2 of GR.

These relationships make it easy to lay out the anchor points and base pad with only a tape measure. You will need a 30 meter (100 feet) tape measure, a hammer, and five stakes. Starting at the center point A, measure out a distance equal to GR and stake it. This will be point B. Put another stake at point C by measuring a distance equal to 1/2 GR along the line connecting points A and B. Now estimate a perpendicular line through point C to find and stake points D and E. Points D and E can be checked and adjusted by making sure that distances A-D and A-E are equal to GR. A final check can be made by confirming that distances B-D, D-E, and E-B are equal.

Right: Detail of the stub tower assembly and the Bergey 850.

Below: Top of the gin pole showing nylon strap, guy attachment, and fairlead pulley.



**Test Your Work**

Before mounting your precious generator, try raising and lowering the pole. Mount a small fairlead (a pulley/guide to protect the cable and ease its travel) on top of the 20 foot utility pole. The winch cable will travel over the fairlead, around a pulley block attached to the tower pole, and back to the top of the gin pole (see diagram). This doubling back of the winch lead cuts the speed at which the pole is lowered in half and also halves the necessary pulling force. Do not drill thru the tower pole to mount the pulley block, as that could weaken it at a very critical spot. We temporarily attached the pulley block to the tower pole with a heavy nylon strap. When lowering the tower, be sure not to let the winch freewheel out. Your pole could quickly get away from you.

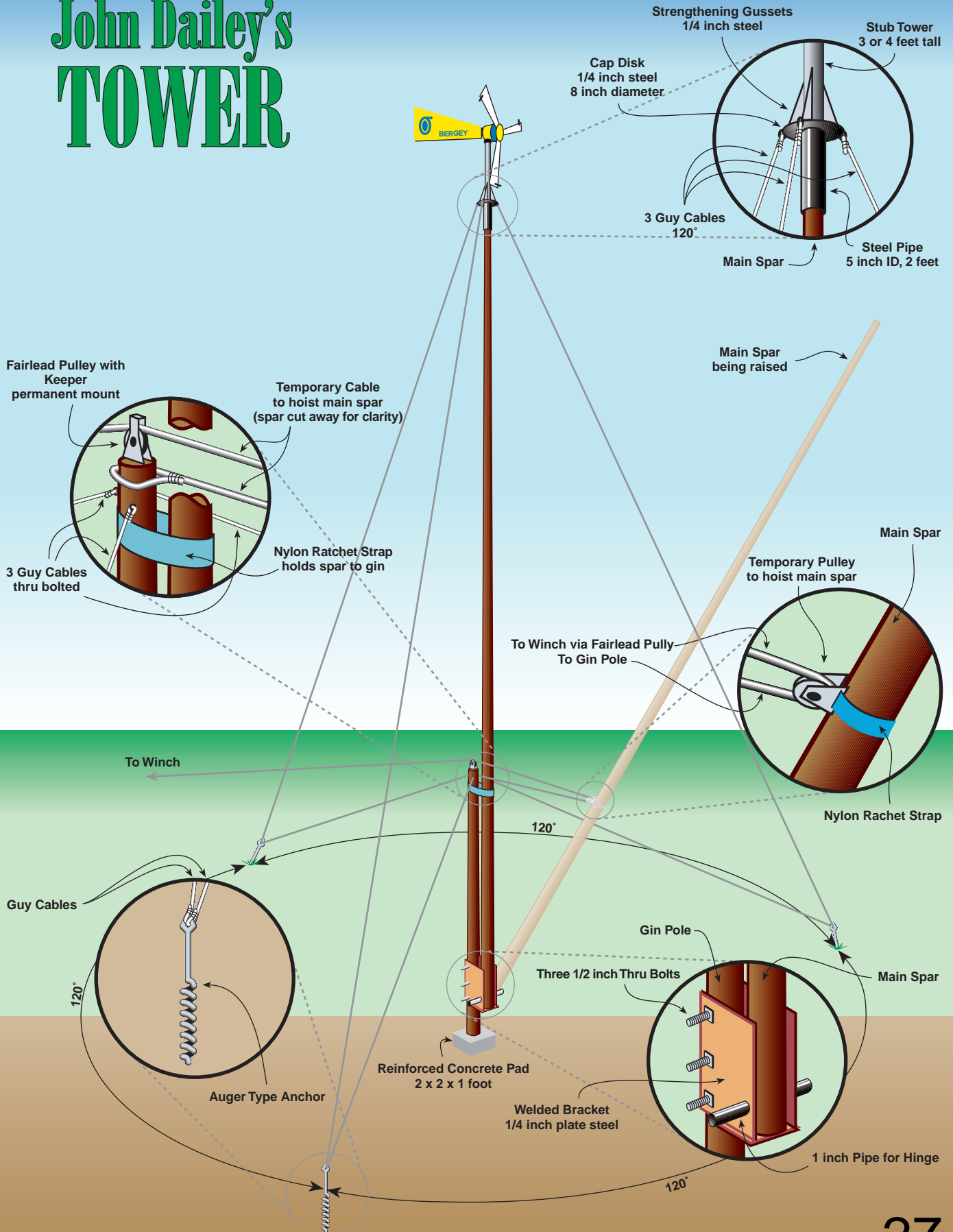


Above: Base detail showing 1/4 inch plate steel bracket, the shaved spar sides, and 1 inch pipe hinge.

Right: Detail of auger type guy anchor.



# John Dailey's TOWER



## Tower Safety

*excerpted from BWC installation manual*

The primary concern at any installation should be for the safety of the individuals involved. Tower work is inherently dangerous, and there is always the potential for injury. If everyone is careful and remains aware of the dangers, however, there should be little risk. The following rules should be observed *ed. note: Many of these rules apply only to scalable towers, but we thought they were all worth mentioning.*

1. Persons not directly involved in the installation should stay clear of the work area.
2. All persons on or in the vicinity of the tower should wear OSHA approved hard hats.
3. Tower work should be done by or under the strict supervision of trained personnel.
4. Never construct a tower near utility lines. If any portion of the tower or equipment comes into contact with them, serious injury or death may result.
5. Anyone working on the tower should use a lineman's belt and a tool belt.
6. Never carry tools or parts in your hands while climbing the tower. The use of a hoistable tool bucket is recommended.
7. Keep the number of tower trips and the amount of work to be done on the tower at a minimum.
8. Never stand or work directly below someone who is working on the tower.
9. Never work on the tower if alone at the site.
10. Never climb the tower unless the machine is furled and the alternator shorted.
11. Stay clear of the tower in the presence or the possibility of thunderstorms, high winds, tower icing, or severe weather of any kind.



Above: The Dailey home showing off the rest of the RE system.

i.d. pipe slip-fit snugly over the top of our pole. If it is not very snug, a thru-bolt will make sure that it will stay. We welded an 8 inch disk of 1/4 inch steel to make a cap on the top. Three links of chain at 120° intervals were then welded to the cap to provide attachment points for the tower (upper) guy wires. The 3 or 4 foot long stub is then welded onto the cap disk, with strengthening gussets if needed. To get the stub tower plumb, it helps to have a transit because there is very little reference when you are looking up. Do this when the tower is raised without the generator, and adjust accordingly.

Mount the wind generator and bring the power wires down the pole. Make sure to provide strain relief for the wires as they are quite heavy. We ran the power wires directly from the stub tower over to our house, down the wall, and into the basement. A better solution may be to cable-tie the wires to a guy wire.

Winch up the tower pole with the generator and use a 2 inch trucker's load-binding ratchet strap to bind the tower pole to the top of the fixed gin pole.

We added an extra upper guy cable way out from the normal guy directly to the south, where the snot-kicker winds always come from. We recommend it if you, too, have a prevailing wind. It provides added security when things get wild.

When the wind is howling, we're warm and snug inside, and enjoying all that electricity all night long!

### Access

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Photos by Kate Salisbury

Bergey Wind Company, 2001 Priestley Ave., Norman, OK 73069 • 405-364-4212 • fax: 405-364-2078.



As you begin to raise the pole, you are lifting considerable weight compounded by the steep angle of pull when the pole is horizontal. This will be made even greater when you add the weight of the generator. A safe way to test your winching system and the bending strength of the main spar is to suspend a weight that is 1 1/2 to 2 times the weight of the wind machine from the top of the pole to simulate the wind generator. Slowly start winching the tower up. If the winch is not up to it or the pole breaks, you will find this out safely, not as your generator comes crashing down.

### Final Installation

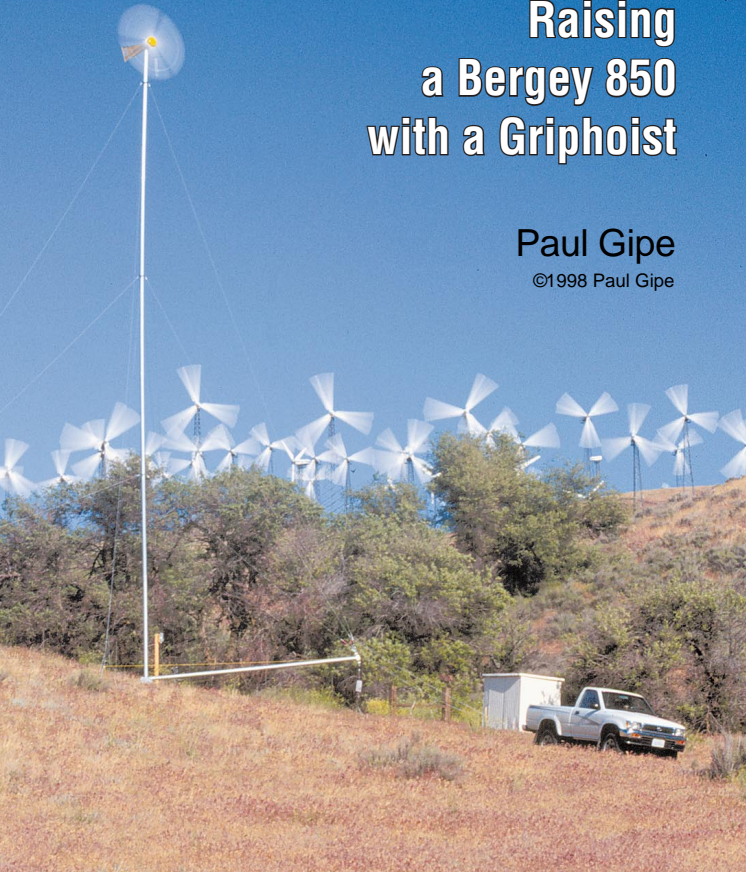
To mount the generator, build a stub tower to fit down over the top of your pole. The exact dimensions needed to mount your generator will be given by the manufacturer. We found that a 2 foot section of 5 inch

# Get a Grip!

## Raising a Bergey 850 with a Griphoist

Paul Gipe

©1998 Paul Gipe



Above: A Bergey 850 installed on a 64 foot NRG tower. One of the world's largest wind farms is right next door.

**M**any users of small wind turbines opt for guyed, tilt-up towers because of their simplicity and lower costs. And everyone who has chosen a guyed tower to support their small wind turbine has had to face a difficult question: How do I raise it? Next to servicing a wind turbine atop a tower, there is no more dangerous aspect of using wind energy than raising and lowering a wind turbine and its tower.

The most common technique here in the United States is to raise the tilt-up towers with a truck or tractor. I've never been a fan of this approach and I've long wondered if there is a better way. The griphoist, a simple hand winch, may be the answer. While no system is foolproof, using a griphoist can reduce the chance of accidents when raising and lowering a tower.

For me, this question came to a head when my wife Nancy Nies and I decided to install a Bergey 850 (BWC 850) on a nearly inaccessible site in southern California's Tehachapi Mountains. Ed Wulf, a local pioneer of off-grid living, provided the site so that we could experiment with small wind turbines.

Because of the difficult access and our desire not to bulldoze any roads, we chose NRG's lightweight, guyed, tilt-up tower system that uses thin-walled steel tubing. These lightweight towers are easily transportable and don't require concrete anchors. Today they are widely used in the wind industry as meteorological (met) masts. The BWC 850 was designed specifically for NRG's 4.5 inch (114 mm) diameter mast.

Considering our site and our inexperience, we chose the 64 foot (19.5 m) tower. We thought that NRG's 44 foot (13 m) tower probably was too short to clear nearby trees, and we felt that their 84 and 104 foot (26 and 32 m) towers were more than we wanted to handle in our first project.

The quest to find a griphoist suitable for raising the Bergey 850 on NRG's tilt-up tower began when I saw Niels Ansø use one to lower a Whisper 1500 at the Folkecenter for Renewable Energy in Denmark. It seemed like an ideal way to raise and lower small wind



Right: Author Paul Gipe begins to install one of the five screw anchors.





Above: The screw anchors can be driven by hand.

turbines on hinged towers. So when I began planning to install our own BWC 850, I naturally thought of using one myself.

"It's a good way to raise a windmill," says Scoraig Wind Electric's Hugh Piggott. It gives you "plenty of time to check things." Zephyr North's Jim Salmon agrees. Salmon, a Canadian meteorologist, uses a griphoist to raise 164 foot (50 m) NRG anemometer towers in Canada. "They are easier to control" than either electric winches or vehicles, he says, "and in some cases much safer."

**Griphoists**

A griphoist is a compact portable winch which passes the hoisting cable through the body of the device rather than wrapping the cable around a spool. The griphoist is operated manually by using one of two short levers protruding from the top of the hoist. One lever is used to pull cable through the hoist, the other to pay out cable in controlled increments. A griphoist also includes a detachable handle that fits over either one of the hoist levers. The

length of the handle is governed by the rated load of the hoist, and special shear pins are built in to prevent overload.

With the help of Hugh Piggott, Niels Ansø, Jim Salmon, and NRG's Dave Blittersdorf, I was able to track down this hoisting tool that I'd seen used in Denmark. To Hugh this tool is a tirfor. To Niels it's a wire talje (hoist). Jim calls it a griphoist.

It's all of the above, and more. Tractel, the manufacturer, officially calls this hand winch a griphoist-tirfor-greifzug product. Griphoist



Above: NRG tower sections slip fit together and seat firmly when the tower is raised.

pretty much says it all in English. But the tool was originally sold as a tirfor, which in French says much the same thing. "Tir" comes from the French for pull, but it can also mean heave as in the maritime expression "heave ho." "For" is probably a shortened form of fort, French for strong or powerful. Greifzug is the German equivalent "greif" for taking hold or gripping, and "zug" for pulling.

This tool, whatever you call it, was patented by Simon Faure in 1945. Tractel began manufacturing them in 1948. Today, Tractel claims 70% of the griphoist market worldwide with plants in France, Luxembourg, Germany, Canada, and Brazil. Griphoists are used throughout the world for a variety of applications that include raising wind turbines and met masts. Griphoists are also used in the United States, mostly in industry. However, most folks here still raise tilt-up towers using a truck or tractor.

**Risky Business**

Using a vehicle for tower raising is just too risky for me. I've used a truck with block and tackle to salvage wind machines back in the 70s and I had one or two near misses that I've never forgotten. And I've installed Bergey 1000s on guyed towers in Pennsylvania using a truck and gin pole. It was always, shall we say, exciting. The NRG tower looks like a long strand of steel spaghetti. Raising it with the jerky motions common to a vehicle-driven lift seems like a recipe for disaster.

Below: Unreeling the guy cables. All attachments to the guy bracket are swaged, simplifying assembly.





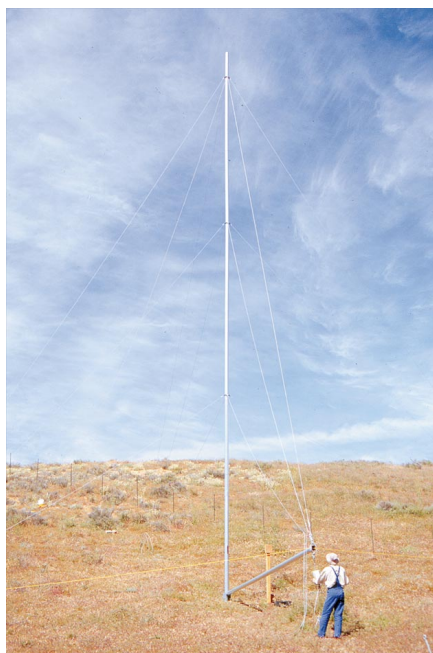
Above: The gin pole bracket showing the hoisting cable (left), nylon rope for steadying, and three lifting guys to tower (right).

Properly using a vehicle for raising a tilt-up, guyed tower also demands a large crew. Altogether, I'd need half a dozen people. Mick Sagrillo recommends two on the truck and one for each anchor. Also, our site is remote. Crew members would have had to hike in or be trucked in. Once there, they'd be there all day. We'd have to feed and entertain them while I was readying everything. Then if there were any glitches, I'd be in the awkward position of either forging ahead and taking some chances I'd rather not take or asking everyone to come back another day.

As it turned out, my fears were justified. There was indeed a glitch. When we went to connect NRG's prefabricated lifting cables to the gin pole, one was too short. These measured lifting cables are one of the three key elements in NRG's tower system. The other two key features are the use of hand-driven screw anchors instead of concrete, and tower sections that slip together without bolts. Without the correct lifting cable, we had to postpone the tower raising one week while NRG air freighted a new set of top guy

cables. Since there were just the two of us there that day, we were under no pressure to continue so we spent the rest of the day frolicking among the wildflowers.

Another facet of the communal approach to tower raising is often overlooked: you can quickly wear out your credit with friends and family. Communal tower raising is like Amish barn raising, bringing people together for a common purpose. But barns last indefinitely. You put it up and it stays up. Not so with a wind turbine. Whether we like it or not, small wind turbines do need repairs



Above: Raising the tower the first time, without the wind turbine, using the griphoist.

and we have to bring them down before we can haul them off to the local windmill doctor. Some turbines are up and down a lot. Gathering six people together every time you want to raise or lower your turbine would get old quickly. Since our purpose was experimentation, we wanted a system that would allow us to raise and lower the turbine as needed, with as few people as possible. A hand winch seemed like the best solution.

Now, I haven't raised a tower or installed a wind turbine in fifteen years. I am basically a paper pusher—keyboard pusher is more descriptive—and my tool skills are a bit rusty. I lost my spud wrench in the mud at the base of an 80 foot (24.5 m) Rohn SSV tower in 1983 and I haven't seen a spud wrench since. So, I wanted to take my time to ponder my next move. I didn't want a bunch of our friends standing around twiddling their thumbs and asking, "Hey, are we going to install this windmill or not?"

Electric winches are usually used here in the States to install the NRG towers for met masts. Installers typically power the winch with a truck battery. I didn't want our new truck in harm's way during my first attempt at raising an NRG tower. Of course, we could have lugged a battery up there to power the winch. But that didn't seem like a great idea either. Battery, winch motor, cables, connectors—seems like a lot of places for something to go wrong. With an 1100 pound (449 kg) load on the winch line, and a \$2,000 BWC 850 at the end of a 64 foot

Below: Using the Super Pull-All to lower the tower. The cable passes through the body of the griphoist.



(19.5 m) fishing pole, I didn't want any surprises. By comparison, the hand operated griphoist seemed like such a simple, straightforward, and safe way to raise a tower.

**Winches and Come-alongs**

Before I got the terminology straight, I made the mistake of calling a griphoist a "come-along." This is a lightweight tool found in North American hardware stores that uses a small spool for coiling a short length of wire rope, often only ten feet long. Ranchers, for example, use come-alongs to tighten fencing, and for that they don't need much cable.

It's the spool or drum that sets come-alongs as well as winches in general apart from griphoists. Technically, griphoists are not winches. Winches use a drum to spool the hoisting cable, like the large drum on a crane. Griphoists, in contrast, pull the hoisting cable directly through the body of the hoist, without rolling it up on a drum. Tractel likens the locking cams inside the griphoist to the way we take in a rope "hand over hand." To

use a griphoist, you move a lever forward and back. This pulls the cable through the tool. The hoisting cable for a griphoist can be any length since there is no need to spool the cable on a drum. Capstan winches can also use cables of any length, but they pass the cable over a drum.

Like come-alongs, griphoists can "float" between the load and the anchor for the hoist. Electric winches and hand-cranked mechanical winches are all intended to be



Above: Tightening wire rope clips. Remember, "Never saddle a dead horse."

the griphoist had safety keepers. You can never predict what may happen when you're raising a load; often there are some jerky movements despite your best efforts. Safety keepers or latches keep the hooks engaged when there's unintended slack in the cable. NRG's Blittersdorf as well as our local Tractel reps offered to replace the stamped metal hooks with hooks using keepers, but I wanted to test the griphoist right out of the box, so we sent it back.



Above: Adjusting cable tension. The NRG tower system doesn't use turnbuckles which allows for quick adjustments under less than ideal site conditions.

Next we ordered the Super Pull-All, the Pull-All's bigger brother. It's a real tool. At 8.3 pounds (3.8 kg), the Super Pull-All weighs twice as much as the Pull-All. It has twice the working load (1,500 pounds / 680 kg), and it comes with safety keepers on both forged hooks. At \$390, The Super Pull-All isn't cheap, but good tools never are. It's shipped with 10 meters (32.8 ft) of 1/4 inch (6 mm) wire rope and two wire rope slings. You can order a longer cable if you need it.

Tractel also makes three other sizes. For example the T-508 griphoist is suitable for raising the BWC 850 on NRG's 84 foot (26 m) tower, and the T-516 is suitable for raising the BWC 850 on NRG's 104 foot (32 m) tower. If it included safety keepers, the inexpensive Pull-All would be ideal for raising the BWC 850 on NRG's 44 foot (13 m) tower.

**Using the Griphoist**

To use NRG's tower system, the

mounted to something solid, like a boat deck or the frame of a sport-utility vehicle. Griphoists are also portable. You can lug them into places you wouldn't want to haul an electric winch and battery or where you can't drive your 4x4. All in all, the griphoist sounded good, but then I'd never actually used one before. After consulting with Dave Blittersdorf at NRG about the hoisting loads, I ordered Tractel's Pull-All.

**Tractel's Pull-All**

You could call the Pull-All an entry-level griphoist. It was inexpensive and it would have done the job except for one serious drawback: neither the hook on the hoisting cable nor the hook on the body of

Below: The tower almost down. The forward lever on the griphoist is used to pay out cable.



## Wind Towers



Above: Raising the tower again, this time with the Bergey 850, takes some effort. Going slow allows time for double checking.

hoist or the hoisting tackle must be anchored directly below the gin pole when the tower is fully upright. The twenty foot long gin pole is comprised of two ten-foot sections. If the hoisting anchor is farther than the length of the gin pole from the tower base, the sections could come apart, endangering the lift. NRG provides a safety cable to prevent this from happening, but no one wants to tempt fate.

The 44 foot (13 m) tower, which uses a 20 foot (6 m) guy radius, uses the forward guy anchor to secure the hoisting tackle or winch. Because the guy radius is larger on NRG's taller towers, they require a separate lifting anchor. So our 64 foot (20 m) tower, with its 35 foot (11

m) guy radius, uses a separate lifting anchor 20 feet (6 m) from the base of the tower. There are five anchors altogether, one for each of four guy cables, and one gin pole or lifting anchor. We attached the griphoist to the lifting anchor with one of the wire rope slings.

When raising a tower with a gin pole, one of the first challenges is raising the gin pole itself. We attached the hoisting cable to the top of the gin pole with a shackle. With the sling, the hoisting cable was just long enough to thread through the griphoist while the gin pole was still horizontal. Nylon ropes from the top of the gin pole to the side anchors kept it from tipping either way. We first used the griphoist to raise the gin pole upright. That was a piece of

Below: Not quite up yet. Using the griphoist allows for taking in or paying out cable as needed.



Above: Checking the tower for plumb. The turbine will only yaw properly on a plumb tower.

cake. Then we slowly raised the tower, inch by inch. While I operated the griphoist, Nancy kept tension in the rear guy cable with a tag line, standing well clear of the fall zone.

The griphoist pulls a few inches of cable on each stroke of the rear hoist lever, both on the back stroke and on the forward stroke. Because it's a simple mechanical device, you can actually feel the tension in the cable. This gives the operator a tactile sense of the load. When the loads are high, the lever is harder to move than when the loads are light. The loads in tower raising are greatest when the tower is just off the ground and least as the tower nears the vertical. Operating the griphoist takes the most effort when the tower first begins leaving the ground.

### Griphoist ratings

<i>Griphoist Model</i>	<i>Capacity lbs (kg)</i>	<i>Cable Dia. in (mm)</i>	<i>Weight lbs (kg)</i>	<i>Cable Length ft (m)</i>	<i>Price \$</i>
Pull All	700 (318)	3/16 (4.75)	3.9 (1.8)	32.8 (10)	115
Super Pull All	1500 (680)	1/4 (6.3)	8.3 (3.8)	32.8 (10)	390
T-508	2000 (907)	5/16 (8.3)	14.5 (6.6)	32.8 (10)	495
T-516	4000 (1814)	7/16 (11.5)	30 (13.5)	32.8 (10)	679
T-532	8000 (3629)	5/8 (16.3)	51 (24)	32.8 (10)	1170

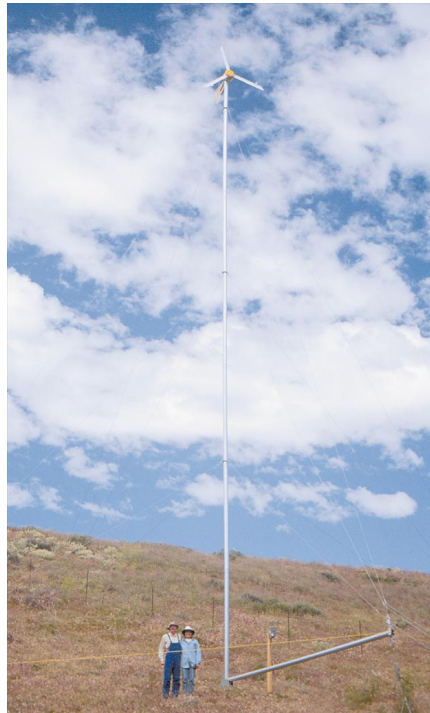
We spent a whole day on the initial tower raising. It took a lot of time because our site is far from ideal. In fact, it's on the side of a hill! I've never tightened and loosened wire rope clips so many times in my life. After we practiced plumbing the tower, we lowered it. It was easy to use the griphoist to let the tower down. The griphoist has two levers, one for pulling in cable, and one for letting it out. You simply use the forward lever to operate the hoist in reverse to pay out cable.

On the next visit, we mounted the turbine on the tower and repeated the raising sequence. The eighty pound turbine increased the weight of the lift by 60 percent, and I could clearly feel it in the griphoist. It took a lot more muscle than raising the tower alone. Rather than grumbling about the frequent adjustments to the guy cables, I found myself using the adjustments as an opportunity for a short breather. "Ah, I think those cables need adjusting," I found myself saying.

We raised the tower in less than one hour. It took another hour to plumb the tower and tighten the guy cables in a stiff wind. Though it wasn't a stroll in the park, physically operating the griphoist during the early part of the lift wasn't very difficult. It became much easier once the tower reached about 45 degrees. After the tower was upright and the Bergey began whirring, Nancy said, "I thought there was going to be a lot more to it than that. It was a lot simpler than I thought." That was the whole idea.

### Adjusting Cable Tension

Unlike traditional towers with anchors at exact positions relative to the tower, the NRG system was designed for quick installation under field conditions. The guy cables are tensioned by hand. As the tower is raised and lowered, the guy cables may need adjusting. This system can't use pre-formed wire grips or



Above: The new American Gothic. The griphoist allowed us to slowly and safely raise our BWC 850 on a difficult hillside site.

turnbuckles unless the anchors and tower are all perfectly aligned. Because of the frequent and sometimes large adjustment necessary in guy cable tension, we used wire rope clips. Pre-formed wire grips require so much unwrapping and rewrapping that they lose their effectiveness in this sort of application.

In our case, the anchor eyes were at different elevations and slightly out of perfect alignment. This was due to the slope of our site and because I screwed some anchors down closer to the ground than others. These misalignments cause tension in the cables to vary during the lift. The thin-walled tubing used on the NRG towers easily buckles. So it's necessary to adjust cable tension as the tower is being raised and lowered. If everything was perfect this wouldn't be necessary. But our site was far from perfect.

### Tower Height

Since I've been such a stickler about adequate tower height in my books, I was concerned that the 64 foot tower wouldn't clear nearby obstructions. But I didn't want to work with a taller tower either, at least until I gained some experience with the NRG tower system. Fortunately, the 64 foot tower was sufficiently tall and gives us about twenty to thirty feet of clearance above some nearby willows—our only trees. It also gave us sufficient clearance from the hilltops overlooking the site.

### Turbine Thrust

After the installation, we returned to the site to check on the turbine, which is a good idea. One of the wire rope clips had slipped and the tower was no longer vertical. A stiff wind was blowing and the tower was pulling against the top cable that had slackened.

In the NRG system, the guy cables are tightened by hand. Let's just say that I wouldn't want to try this with a BWC 1500 in a strong wind. Nor would you ever want to make the mistake of not using the friction of pulling through the guy anchor eye to help hold the cable after loosening the wire rope clips. While it was never in danger of getting away from me, I was immediately conscious that I had to really lean into tensioning the cable and not make any mistakes. As it was, the thrust on the turbine was too great for me to get the tower top back to vertical. I got it to where I was comfortable with it and we left well enough alone as we were planning to lower the tower a few days later.

### Lowering the BWC 850 with the Griphoist

Because we would be traveling for an extended period, we didn't want to leave the turbine unattended and thought it best to lower the tower. Though we've raised and lowered the tower only twice, we are quickly

becoming proficient. The lowering went smoothly. As I developed a sense of how the tower behaves, I found it necessary to adjust the guy cables much less often. The down side is that there were fewer breaks from operating the griphoist lever. The cable moves only a few inches with each stroke of the lever. So, to lower the tower you need to operate the lever quite a few strokes. As an office type, I am not accustomed to all that activity and my shoulder muscles were sore for a few days afterward. But lowering the tower was uneventful, which is the way we like it.

### Griphoists for the Rest of Us

While little has been written about griphoists, it's surprising the number of people who have used or are now using them. Bergey Windpower, for example, has been using griphoists for remote installations since 1993, when they used one to raise a 10 KW Excel on an offshore platform. Though you won't find any mention of griphoists in Bergey's installation manual for the 850, they recommend griphoists to their overseas clients, says Pieter Huebner, Bergey's field technician. When a heavy-duty drum winch isn't available, Huebner prefers the griphoist to raising a turbine with a vehicle. The griphoist "is much safer and gives much better control," he says. It "eliminates the possibility of miscommunication" between the vehicle driver and the tower crew.

The experience of Scoraig Wind Electric's Hugh Piggott mirrors that of Huebner. A griphoist is "hard to beat for erecting tilt-up towers, because it is slow and fail-safe," says Piggott. "Unlike using a truck or other vehicle to raise a tower, the operator of the winch has full control of the operation, and there's no dependence on hand signals or risk of missed cues." If you have to buy any tool for your off-grid wind system, Piggott recommends buying a griphoist. After using one myself, I agree.

Paul Gipe is the author of *Wind Power for Home & Business* (Chelsea Green Publishing, 1993), and *Wind Energy Comes of Age* (John Wiley & Sons, 1995). Gipe introduces griphoists in his new book *Wind Energy Basics: A Guide to Small and Micro Wind Systems* scheduled for release in early 1999 by Chelsea Green Publishing.

Disclaimer: I paid for all the components mentioned in this article and I have no affiliation with the manufacturers. In the mid 1980s I did some work for NRG. In the early 1980s I was a Bergey dealer. —Paul Gipe

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### Access

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sales@bergey.com • Web: [www.bergey.com](http://www.bergey.com)

NRG Systems Inc., 110 Commerce St., PO Box 509, Hinesburg, VT 05461 • 802-482-2255  
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## RECIPROCATING WIRE POWER TRANSMISSION FOR SMALL WATER WHEELS

A reciprocating wire can transmit power from a water wheel to a point up to 0.8km (1/2 mile) away where it is usually used to pump well water. These devices have been used for many years by the Amish people of Pennsylvania. If they are properly installed, they give long, trouble-free service.

The Amish people use this method to transmit mechanical power from small water wheels to the barnyard, where the reciprocating motion is used to pump well water for home and farm use. The water wheel is typically a small undershot wheel (with the water flowing under the wheel) one or two feet in diameter. The wheel shaft is fitted with a crank, which is attached to a triangular frame which pivots on a pole (see Figure 2). A wire is used to connect this frame to another identical unit located over the well. Counterweights keep the wire tight.

### Tools and Materials

Wire - galvanized smooth fence wire

Water wheel with eccentric crank to give a motion slightly less than largest stroke of farmyard pump

Galvanized pipe for triangle frames:  
2cm (3/4") by 10 meters long (32.8')

Welding or brazing equipment to make frames

Concrete for counterweight

2 Poles: 12 to 25cm (6" to 10") in diameter

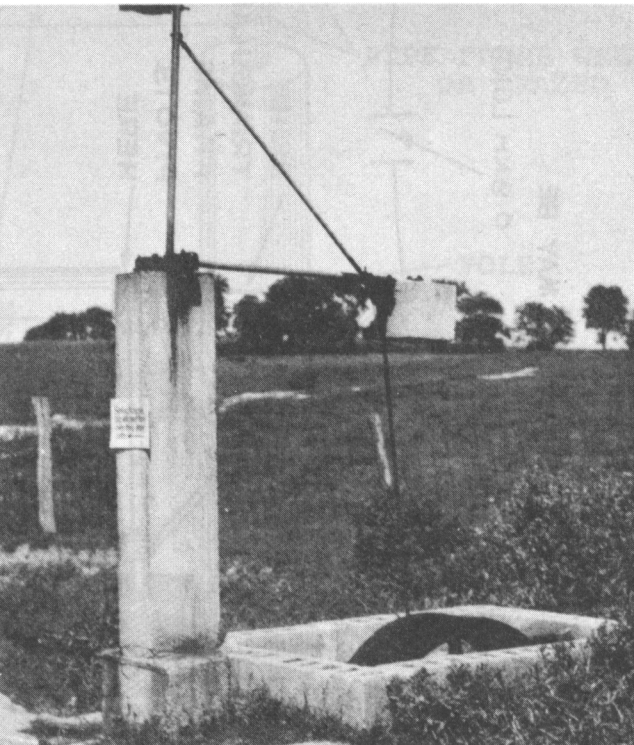
As the water wheel turns, the crank tips the triangular frame back and forth. This action pulls the wire back and forth. One typical complete back and forth cycle, takes 3 to 5 seconds. Sometimes power for several transmission wires comes from one larger water wheel.



NEW ARROWS  
→

Dairy Barn  
American Dairy  
1911





Vertical  
to 40 ft  
to 100 ft  
to 150 ft

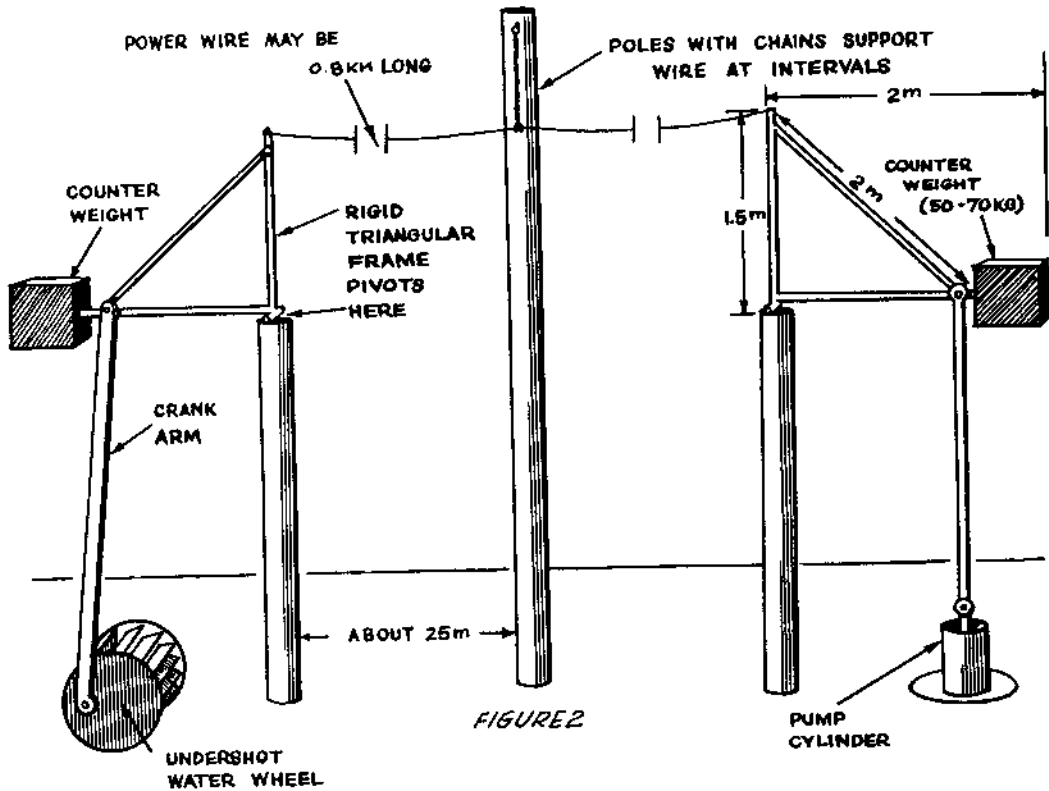


FIGURE 2

Turns can be made in order to follow hedgerows by mounting a small triangular frame horizontally at the top of a pole as shown in Figure 4.

Water Wheel

Figures 5, 6 and 7 show how to build and install a small water wheel made from wood and bamboo.

Source:

New Holland, Pennsylvania VITA Chapter.

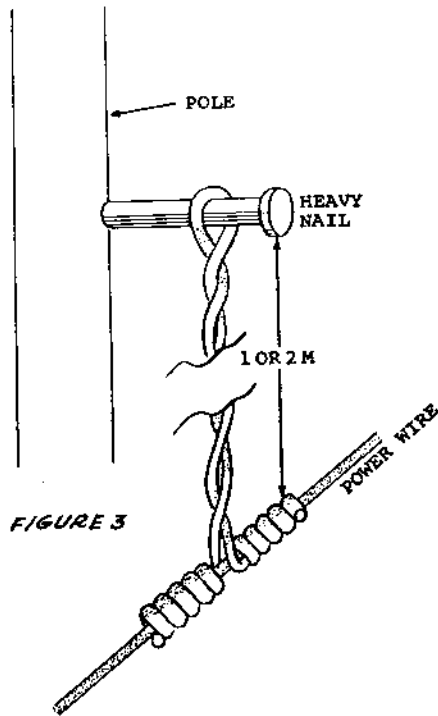


FIGURE 3

The wire is mounted up on poles to keep it overhead and out of the way. If the distance from stream to courtyard is far, extra poles will be needed to help support the wire. Amish folks use a loop of wire covered with a small piece of garden hose attached to the top of the pole. The reciprocating wire slides back and forth through this loop. If this is not possible, try making the pole 1-2 meters higher than the power wire. Drive a heavy nail near the pole top and attach a chain or wire from it to the power wire as shown in Figure 3.

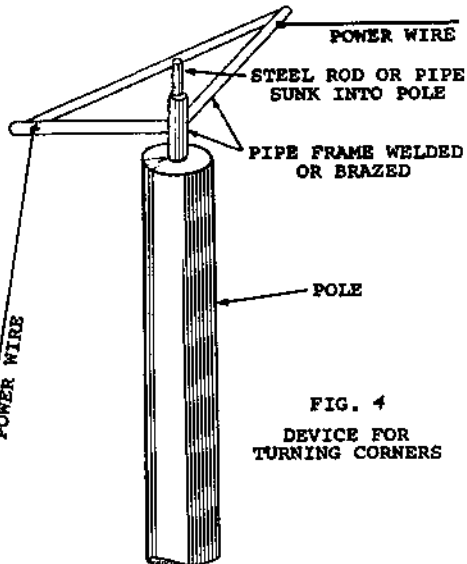
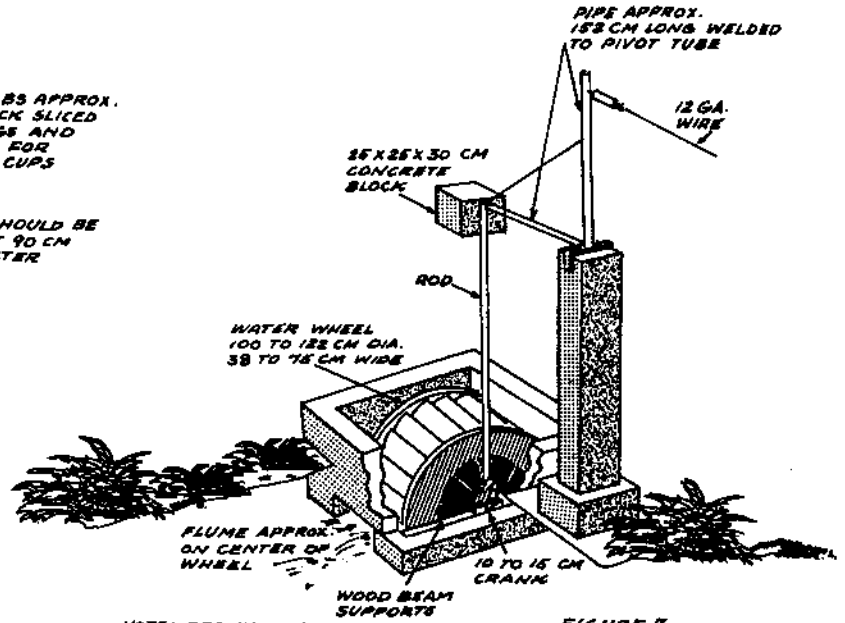
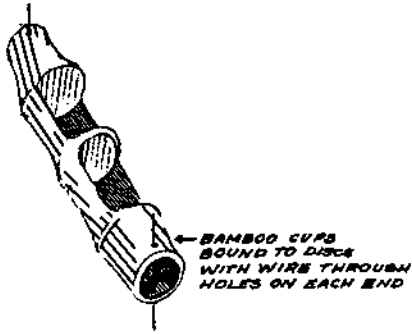
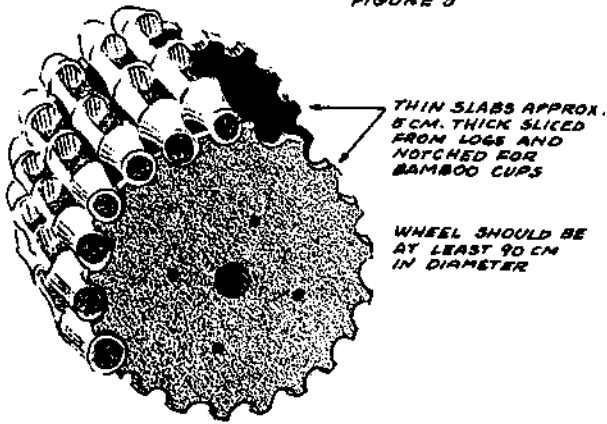


FIG. 4  
DEVICE FOR  
TURNING CORNERS

FIGURE 5



NOTE: CRANK CAN BE ADDED TO OTHER END OF SHAFT AT 90° ANGLE TO FIRST CRANK TO ATTACH MORE POWER TRANSMITTING WIRES

FIGURE 7

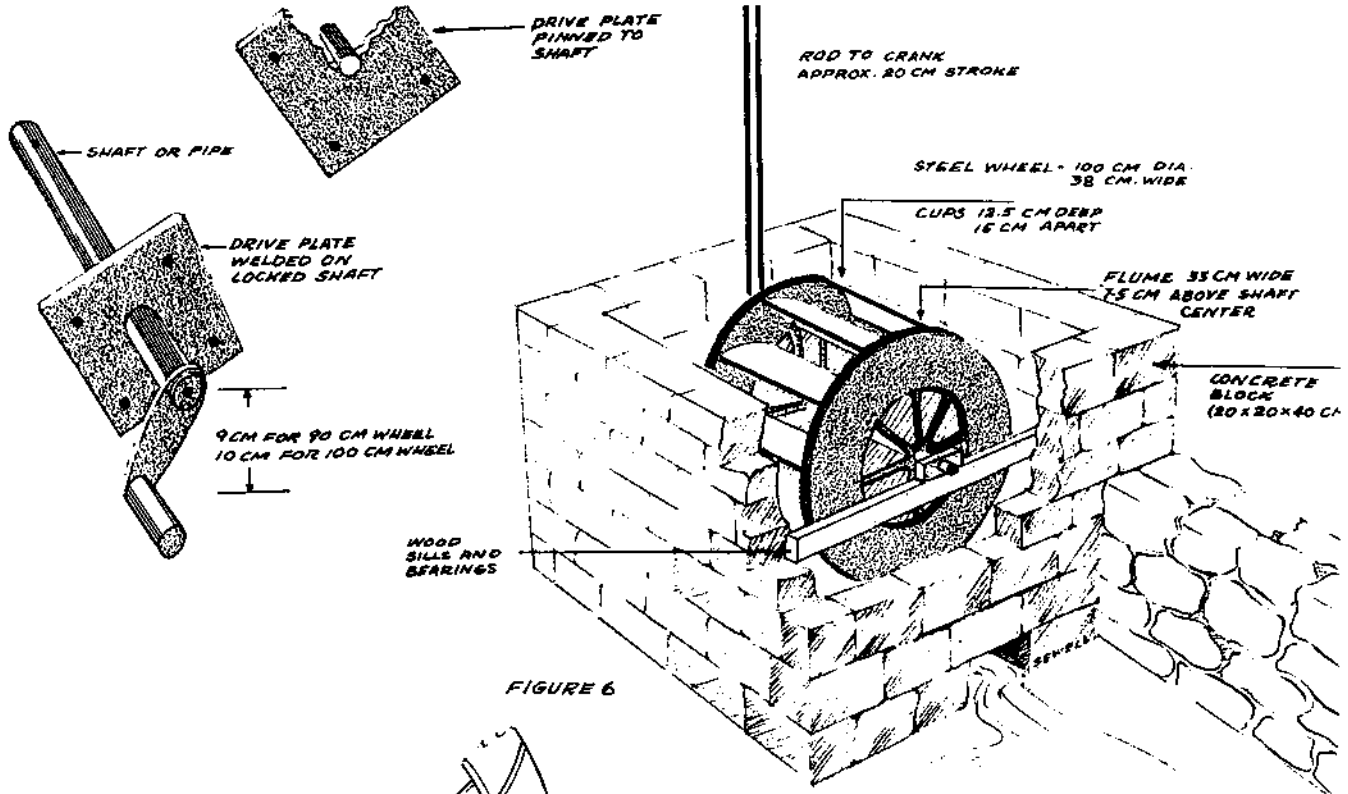
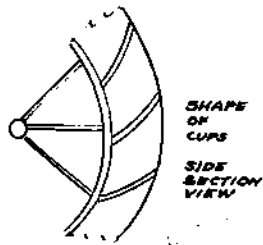


FIGURE 6



## Power for Water Pumping

The power required to pump water is proportional to the flow rate and to the pressure against which the pump is working. This pressure is usually expressed in terms of the "head," which has two contributions: (1) the height that the water must be pumped from groundwater level, and (2) an extra contribution, called the "friction head," due to friction in the pipes retarding the flow of water. A fairly accurate value for the power required can be calculated using the formula:

$$\text{Power} = 0.00025 \times \frac{G}{E_p} \times (WH + FH),$$

where

$G$  = water flow rate in gallons per minute;

$E_p$  = mechanical efficiency of the water pump;

$WH$  = water head—the vertical height in feet from groundwater level to tank inlet; and

$FH$  = friction head in feet.

This formula gives you the power in units of horsepower; to get the answer in watts, multiply by 746.

This equation is meant to work with the average flow rate and to give you the average power required by the pump. One simple way to establish an average flow rate is to estimate your need for water, expressed in gallons, and divide this need by the number of hours you expect the wind to produce usable power during the same time period. Do this on a daily, weekly or monthly basis—depending on the results of your wind survey. To get the flow rate in gallons per minute, then, use the formula:

$$G = \frac{\text{Gallons Needed}}{60 \times \text{hours of wind}}$$

Friction losses depend on the pipe length  $L$  (in feet), the pipe diameter  $D$  (in inches), the number  $N$  of pipe joints and corners, and the flow rate  $G$ . The formula for friction head  $FH$  is:

$$FH = \frac{L \times G^2}{1000 \times D^5} + 2.3 \times N.$$

The pipe length  $L$  includes all pipes down in the well, across the pasture, and up the hill or into the tank. If pipe diameter changes along the way, as it usually does, this formula must be used separately for each different length of pipe, and the results added together to get the total friction head.

**Example:** Suppose the depth of water in a well is 100 feet below the ground level. A 3-inch pipe brings this water to the surface. The water passes through one elbow joint and into a 1-inch diameter pipe running 200 feet along the ground, then through a second elbow joint and up 14 feet before passing through a third elbow and into the tank. Suppose the farmer needs 2700 gallons of water per day and there are an average of 6 hours of usable wind per day. How many watts of wind power must be supplied to a water pump with 75 percent efficiency?

**Solution:** The average flow rate needed is

$$G = \frac{2700}{60 \times 6} = 7.5 \text{ gallons/min.}$$

The friction head in the 3-inch pipe is

$$\begin{aligned} FH &= \frac{100 \times 7.5^2}{1000 \times 3^5} + (2.3 \times 1) \\ &= 2.3 \text{ feet.} \end{aligned}$$

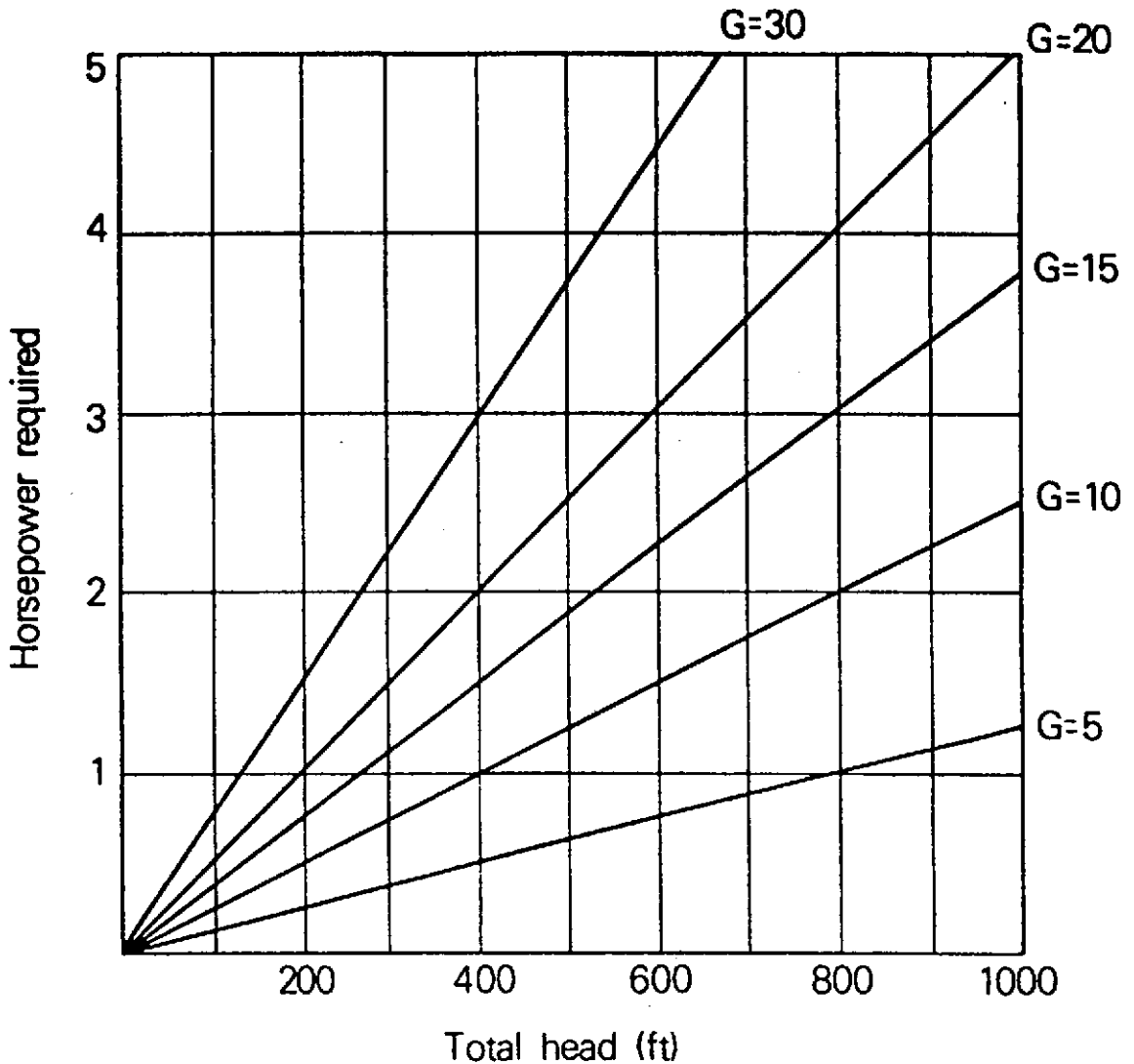
The friction head in the 1-inch pipe is

$$\begin{aligned} FH &= \frac{214 \times 7.5^2}{1000 \times 1^5} + (2.3 \times 2) \\ &= 16.6 \text{ feet.} \end{aligned}$$

The total friction head is the sum of these two contributions or  $FH = 18.9$  feet. Then the pump power required is

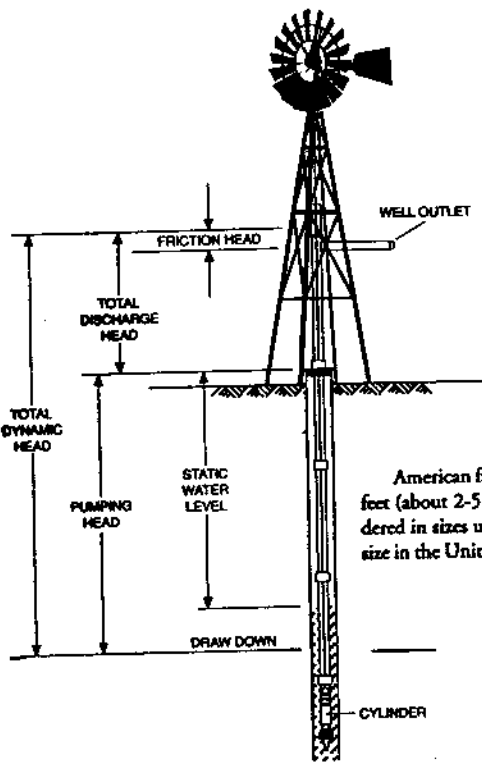
$$\begin{aligned} \text{Power} &= 0.00025 \times \frac{7.5}{0.75} \times (114 + 18.9) \\ &= 0.33 \text{ hp.} \end{aligned}$$

To get the answer, you just multiply by 746, so the power requirement is 246 watts.

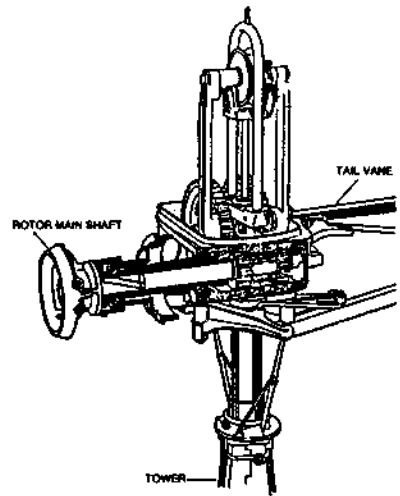


Pump power needed to lift water at a flow rate  $G$ , in gallons per minute. To get the wind power needed to drive the pump, divide by the pump efficiency—about 70 percent.

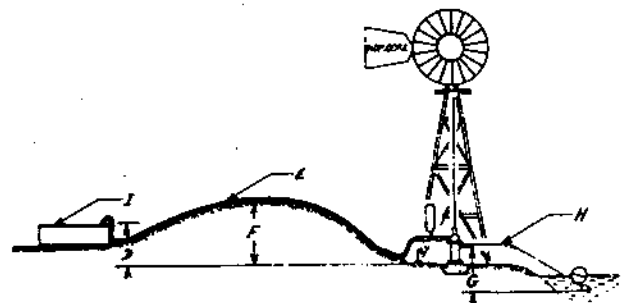
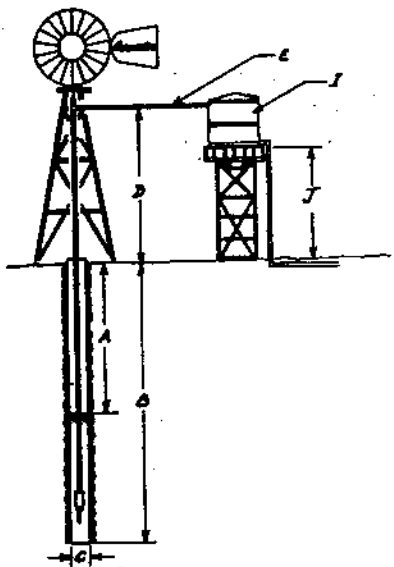
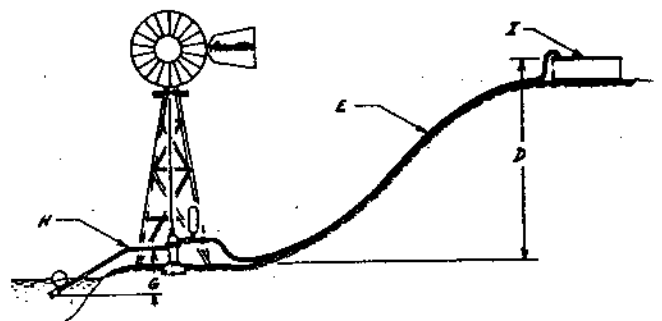
## CHOOSING A WINDMILL



American farm windmills are available in sizes ranging from 6 feet to 16 feet (about 2.5 meters) in diameter. Australia's Southern Cross can be ordered in sizes up 25 feet (about 8 meters) in diameter. The most common size in the United States is the 8-foot mill.



Most farm windmills are back-geared, that is, the rotor turns several revolutions per pump stroke. (Aeromotor Co.)



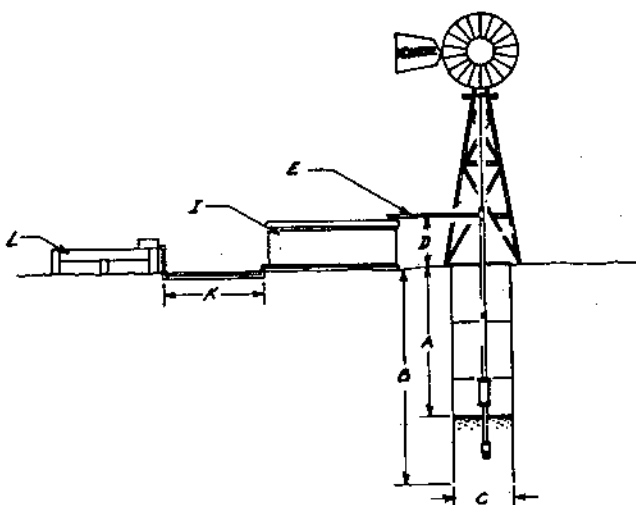
### CHOOSING THE CORRECT WINDMILL

Use this pamphlet as a guide of your proposed installation.

1. What size tower is required to place your Aeromotor windmill at least 20 feet above all surrounding obstructions . . . . .
2. What quantity of water is required per day . . . . .
3. What quantity of water is the bore, well or soak expected to yield per day . . . . .
4. Are the average wind conditions, light, moderate or strong . . . . .
5. Which of the sample pumping installations is similar to your proposed system . . . . .
6. Are there any piping, pump rod, or pumps already on the job (Give particulars regarding sizes and types) . . . . .

#### INFORMATION FROM SAMPLE PUMPING INSTALLATIONS

- A. What is the depth from ground level to the low water mark . . . . .
- B. What is the total depth of the bore or well . . . . .
- C. What is the outside diameter of the bore casing or the size of the well . . . . .
- D. How high is the point of delivery above the ground level at the mill base . . . . .
- E. What is the length of the delivery pipeline . . . . .
- F. The vertical height of any rise or depression in the delivery pipeline from the ground level at the mill base, is . . . . .
- G. What is the height of suction (note: it is not recommended for suction to exceed 18') . . . . .
- H. How long is the suction pipeline . . . . .
- I. What type and capacity storage tank do you require . . . . .
- J. How high do you want your tankstand . . . . .
- K. What is the length of the pipeline from the tank to the trough . . . . .
- L. What size and type of trough do you require . . . . .



# PUMPING WITH WINDMILLS



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*IF YOU HAVE WATER TO LIFT, WRITE YOUR REQUIREMENTS,  
WHEN WE WILL GIVE YOU THE BENEFIT OF  
OUR LONG EXPERIENCE.*

The information in this article comes from a 1930's book produced by the Alston Windmill Company. The book is made up of number booklets and leaflets produced by Alston over the years. It includes a range of fascinating information about windmills and associated equipment. This article is made up of extracts from the book. If you would like a look at the original book we have a copy in the ATA library. If you would like to contact Alston, their address is:

#### **Alston Windmills**

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#### **Development of the Windmill**

The origin of the windmill is lost in the oblivion of the past; as early as the 12th century, the use of Windmills in Europe is recorded. For centuries the windmill was the most important source of mechanical energy, but was of primitive construction, and being built as a

fixture, was adapted to work when the wind blew from one direction only. The first improvement seems to have been in mounting the mill on a movable base, to be turned to face the wind, by means of a long pole or lever projecting from the back of the mill; the sails of the wheel, formed of four arms with a skeleton frame, were covered with canvas. The later improvements, at the beginning of the last century, were of more importance, and consisted of making the top portion to revolve by means of a small tail wheel, so that it faced the wind automatically; and making the sails of narrow slats resembling Venetian blinds, set in a framework actuated by weighted levers which opened by centrifugal force as the speed of the mill increased. These mills were used throughout Germany and Holland for grinding and draining purposes, also in France and Great Britain, the largest windmills being found in Norfolk, where the wings described a circuit of 100 feet diameter. At the best, these were



cumbersome and costly structures,

With the advance of science the windmill received the attention of engineers in different countries. America, with her vast tract of new territory, opened up a demand for small pumping plants for lifting water or stock ranches, to meet which, a light mill made of slats of timber of circular form, with self-regulating device of umbrella principle, came greatly into use.

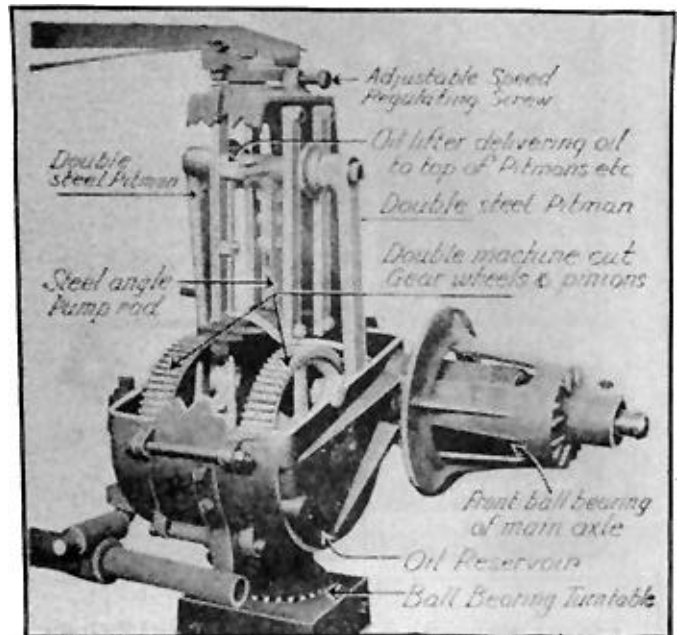
Being made mostly of wood, they soon showed their weak points, and



**Camels transporting windmills in central Australia.**

something more substantial was demanded. The advent of the iron age brought a solution of the difficulty, and the more modern iron or steel mill came into existence, and has come to stay. Our own country has been particularly fortunate in this respect. Over 100 years ago Mr. James Alston patented the all-steel wind-wheel of circular form, the sails of which

were curved in shape, giving great driving power. This was found so vast an improvement that it was copied by different makers throughout the world, and today is the standard form of windmill sail with nearly every maker.



### How They Work

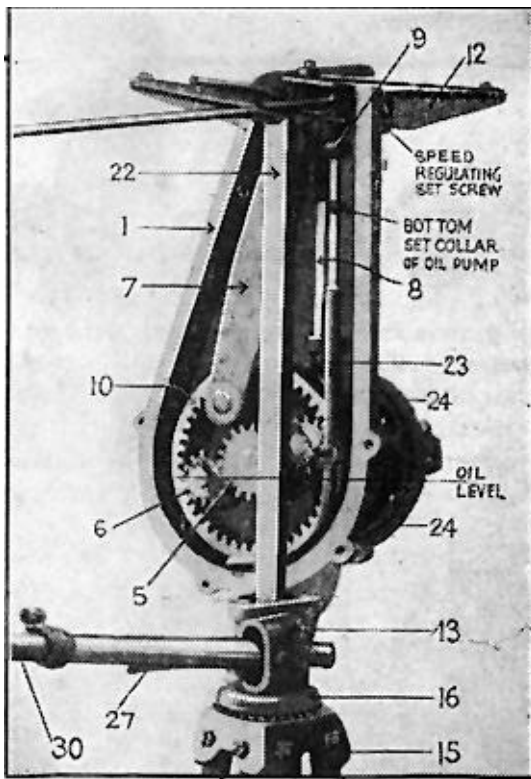
#### Enclosed Double-Geared Self-Oiling Mill

The product of over 60 years' experience, manufactured in six sizes, 6, 7, 8, 10, 12, and 14 ft. diameter Windwheels, designed or operating Pumps against total heads up to 400 ft.

The whole of the Working Parts are enclosed in a Case, protecting them from dust and weather, also ensuring safety when inspecting the Mill while it is running. Every working part is automatically lubricated. The Gears are simply covered with oil as they revolve in the Oil Bath, and a Tubular Oil Lifter supplies a continuous stream of oil to the top of the Pitmans and Rollers.

Wheels, two Pinions, and two Pitmans. The Spindles are steel, and the Gear Wheels and Pinions are machine-cut from the solid, ensuring silent and smooth running. All Working Parts can be removed without disturbing the case.





### Planetary Geared Windmill

The Enclosed Self-Oiling Planetary Geared Mill is manufactured by us in the following sizes:-

5ft, 6ft, 7ft, 8ft, 10ft, 12ft, and 14ft. diameter Windwheels.

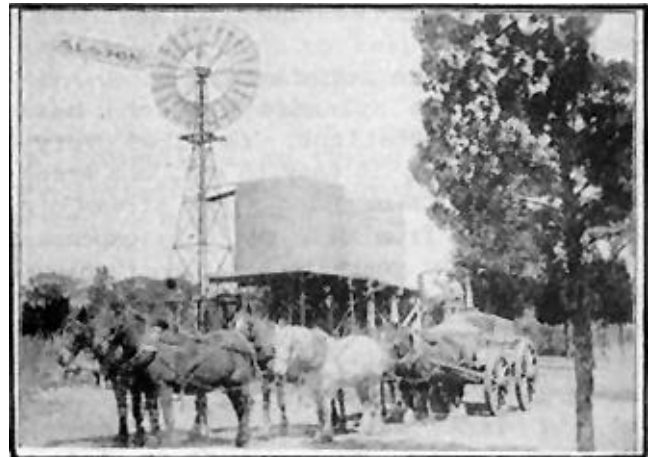
The principle of the invention will be readily understood from the illustration. It consists of a Spokeless Wheel or Annular Rack (10) which does not revolve, being securely locked in the Main Body Casting (1). The three Pinions (5-6-6) revolve inside the Annular Rack (10). The Windwheel Centre (24) is keyed to the Main Axle (26) and the Pinion (5) is keyed to the opposite end of same; the Main Axle (26) revolves freely in the Carrier (3) whilst the Carrier revolves on its Bearing in the Main Body Casting (1). The two Pinions (6-6) revolve on the two projecting pins of the Carrier Casting (3) and mesh with teeth of the pinion (5) and with the teeth of the Annular Rack (10), causing the Carrier (3) to revolve in the same direction as the Windwheel, thus conveying the power of the Windwheel to operate the Steel Angle Pump Rod (22) through the Pitman (7).

The true vertical travel of the top of the Pitman (7) is maintained by the vertical Guide Casting (9) and the vertical Guide Rod (8).

### Enclosed Self-Oiling Type Patent Gearless Windmills

Automatic Lubrication from Oil Reservoir is obtained by means of an Oil Conveyor No. 11 attached to the Main Axle. At each revolution of the windwheel, the Oil Conveyor is rotated, maintaining a constant flow of oil to all Bearings whilst the Mill is in operation.

The Windwheel Centre No. 9 is a very substantial one-piece Casting of immense strength designed to carry the weight of the Windwheel without overhanging the Main Axle and the Main Axle Bearing. By referring to the illustration the advantage of supporting the Main Axle at the extreme end of same immediately under the centre of the Windwheel will be readily appreciated. Our method of Keying the Windwheel Centre Casting No. 9 to the Main Axle No. 1 (Double Keying in the larger sizes) effectively secures the Windwheel to the Main Axle, yet permits its easy removal if required.



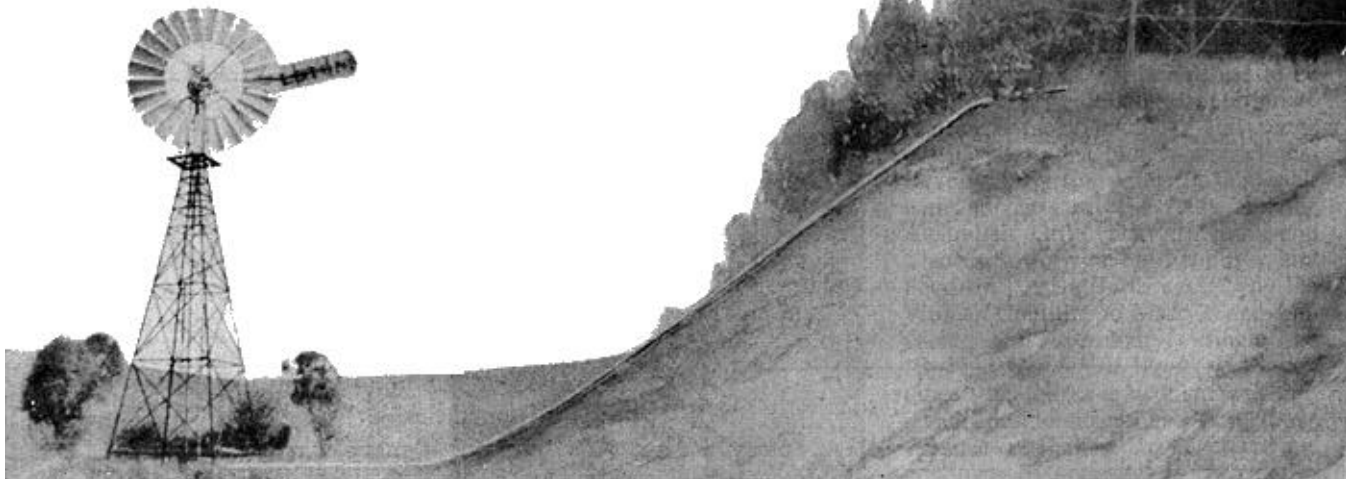
### Testimonials

S. CADWELL, Manager, Woolloomanata, Lara, Vic.

Re 20 ft. Gearless Mill: I have pleasure in supplying particulars below. Mill Pumps from dam into storage tanks a distance of about half a mile, steady rise all the way. Above tanks supply water for the following:- Garden, about 4 acres, consisting of Lawn, Fruit Orchard, Vegetables and Flowers, also water for

**A TYPICAL WINDMILL FORCE PUMP INSTALLATION**

A 12ft. Enclosed Self-Oiling Double Geared Windmill on a 30ft. steel tower pumping from a well to a 3,000 gallon tank. The tank is approximately 100ft. higher than the windmill.



cows, Horses and about 500 Sheep. Mill is running continuously for about 8 months of the year, balance as required. Attention required: About two hours during each year.

Mill gives entire satisfaction.

This is a splendid Mill and has exceeded expectations, requires very little attention, is easy to oil, and even with a light breeze pumps a good stream of water. Apart from oil, the only expense during the five years it has been running has been 2/- for a Retention Valve Leather and Packing.

GEORGE DE PURY, Yeringberg, Victoria:

The 20ft. Gearless Mill with 40 ft. Tower you supplied me in December, 1925, is working perfectly. It is delivering the water into a tank a mile and a half distant, and the lift is about 300 ft.

The Mill is giving me entire satisfaction. I had a steam pump doing this work for many years, but it entailed a lot of labour and time, now the water is coming up without any expense and it is very rare that there is not enough wind to keep me sufficiently supplied, as it requires only a slight breeze to turn the

Mill. I only wish I had put your Mill in many years ago,

MR. H. J. RIX, Officer, Victoria:

Re the 8 ft. Gearless Mill that I got from you. I think it was during the War that I got it. There was a 30 ft. Tower with it. As regards the work it has done, it had to keep the clay hole pumped, which was very heavy work in the Winter. It did that all the number of years till 18 months back when electricity was installed. I then moved it up to my dairy farm and erected it to pump from the dam for my herd's water supply. It is a pleasure to see it at work, it is one continuous flow the whole time it is pumping. I have used oil, petrol and motor pumps, but nothing so cheap or less trouble than your Gearless.

The A.T.A. will be putting the information above into practice as we have bought a 10 ft. diameter Alston Windmill. Over future months, we will be reconditioning the unit and eventually erecting it. Anyone interested in seeing how we do this is welcome to get in touch. We will report on the experience in a future issue of Soft Technology.

## Estimates of Water Pumping Capacity of Farm Windmills

Table 12-3 is adapted from Aermotor's table of standard pumping capacities and pumping heads for winds 15-20 mph when the windmill is set for the maximum stroke. The common 8-foot windmill, when matched with a well cylinder 2 inches in diameter, will pump about 3 gallons per minute from a well about 140 feet deep in winds 15-20 mph. According to Aermotor, the pumping capacity remains the same for the same size well cylinders among rotors 8-16 ft in diameter. By varying the pump's stroke—its vertical travel—Aermotor uses the increased power from the larger diameter rotors to increase the height through which the water can be lifted. A 12-foot farm windmill will pump water at the same flow rate as the 8-foot rotor, but will lift the water through more than twice the total dynamic head.

**Table 12-3**  
American Farm Windmill Pumping Capacity  
(15-20 mph wind speed)

Pump Cylinder Diameter (inches)	Flow (gallons/minute)	Flow (liters/minute)	Maximum Total Pumping Head in Feet for Wind Wheel Diameter (feet)				
			8	10	12	14	16
2	3	12	140	215	320	460	750
2.5	5	20	95	140	210	300	490
3	8	30	70	100	155	220	360
3.5	11	40	50	75	115	160	265
4	14	52	40	60	85	125	200
4.5	18	66	30	45	70	100	160
5	22	82	25	40	55	80	130

Adapted from Aermotor Co.

The traditional farm windmill, because the blades are not true airfoils, is much less efficient than modern wind turbines. The overall operating efficiency of farm windmills is only 4-8 percent. Assuming an overall operating efficiency of 5 percent and a Rayleigh speed distribution, Wyatt's formula is,

$$\text{daily or monthly volume in m}^3 = \frac{0.4 \times D^2 \times S^3}{H}$$

where  $D$  is the rotor diameter in meters,  $S$  is the average daily or monthly wind speed in m/s, and  $H$  is the total pumping head in meters. Table F-1 summarizes the calculations for an 8-foot diameter farm windmill. For a site with an average wind speed of 11 mph (5 m/s) at a hub height of 40-50 feet (12-15 meters), an 8-foot mill will pump about 2600 gallons (10 cubic meters) per day from a well approximately 100 feet (30 meters) deep.

The following tables estimate the amount of water a traditional American windmill of a given diameter will pump daily from a given depth within different wind regimes. The tables assume that the overall efficiency of the windmill is 5% in a Rayleigh wind speed distribution. Actual performance may vary depending on the windmill and whether it's properly matched to the well pump.

To use the tables, first find the total dynamic head in the left most column. Then find the average annual wind speed at hub height. For example, if the total pumping head is about 100 feet (30 meters) at a site with an 11 mph (5 m/s) average wind speed, a farm windmill with an 8-foot windwheel will pump about 2600 gallons (10 m<sup>3</sup>) per day.

**Table F-1**  
Approximate Daily Output, American Farm Windmill  
8-foot (2.4-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head (m) (ft)		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)	4 (9)	5 (11)	6 (13)	7 (16)					
10	30	6	1,700	15	4,000	30	7,900	51	13,600	82	21,600
20	70	3	800	8	2,000	15	3,900	26	6,800	41	10,800
30	100	2	600	5	1,300	10	2,600	17	4,500	27	7,200
40	130	2	400	4	1,000	7	2,000	13	3,400	20	5,400

Source: Center for International Development, Research Triangle Institute. Assumes overall efficiency of 5 percent.

**Table F-2**  
Approximate Daily Output, American Farm Windmill  
10-foot (3.05-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head (m) (ft)		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)	4 (9)	5 (11)	6 (13)	7 (16)					
10	30	10	2700	24	6300	47	12,300	80	21,200	128	33,700
20	70	5	1300	12	3100	23	6100	40	10,600	64	16,800
30	100	3	900	8	2100	16	4100	27	7100	43	11,200
40	130	3	700	6	1600	12	3100	20	5300	32	8400

Source: Center for International Development, Research Triangle Institute.

**Table F-3**  
Approximate Daily Output, American Farm Windmill  
12-foot (3.7-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head (m) (ft)		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)	4 (9)	5 (11)	6 (13)	7 (16)					
10	30	14	3800	34	9100	67	17,700	116	30,600	184	48,500
20	70	7	1900	17	4500	33	8800	58	15,300	92	24,300
30	100	5	1300	11	3000	22	5900	39	10,200	61	16,200
40	130	4	1000	9	2300	17	4400	29	7600	46	12,100

Source: Center for International Development, Research Triangle Institute.

**Table F-4**  
Approximate Daily Output, American Farm Windmill  
14-foot (4.3-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head (m) (ft)		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)	4 (9)	5 (11)	6 (13)	7 (16)					
10	30	20	5200	47	12,300	91	24,100	158	41,600	250	66,000
20	70	10	2600	23	6200	46	12,000	79	20,800	125	33,000
30	100	7	1700	16	4100	30	8000	53	13,900	83	22,000
40	130	5	1300	12	3100	23	6000	39	10,400	63	16,500

Source: Center for International Development, Research Triangle Institute.

**Table F-5**  
Approximate Daily Output, American Farm Windmill  
16-foot (4.9-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head (m) (ft)		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)	4 (9)	5 (11)	6 (13)	7 (16)					
10	30	26	6800	61	16,100	119	31,400	206	54,300	327	86,300
20	70	13	3400	30	8000	60	15,700	103	27,200	163	43,100
30	100	9	2300	20	5400	40	10,500	69	18,100	109	28,800
40	130	6	1700	15	4000	30	7900	51	13,600	82	21,600

Source: Center for International Development, Research Triangle Institute.

### F. Estimates of Water Pumping Capacity of Farm Windmills

The following tables estimate the amount of water a traditional American windmill of a given diameter will pump daily from a given depth within different wind regimes. The tables assume that the overall efficiency of the windmill is 5% in a Rayleigh wind speed distribution. Actual performance may vary depending on the windmill and whether it's properly matched to the well pump.

To use the tables, first find the total dynamic head in the left most column. Then find the average annual wind speed at hub height. For example, if the total pumping head is about 100 feet (30 meters) at a site with an 11 mph (5 m/s) average wind speed, a farm windmill with an 8-foot windwheel will pump about 2600 gallons (10 m<sup>3</sup>) per day.

**Table F-1**

#### *Approximate Daily Output, American Farm Windmill*

8-foot (2.4-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)		4 (9)		5 (11)		6 (13)		7 (16)	
(m)	(ft)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)
10	30	6	1700	15	4000	30	7900	51	13,600	82	21,600
20	70	3	800	8	2000	15	3900	26	6800	41	10,800
30	100	2	600	5	1300	10	2600	17	4500	27	7200
40	130	2	400	4	1000	7	2000	13	3400	20	5400

Source: Center for International Development, Research Triangle Institute.

**Table F-2**

#### *Approximate Daily Output, American Farm Windmill*

10-foot (3.05-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)		4 (9)		5 (11)		6 (13)		7 (16)	
(m)	(ft)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)
10	30	10	2700	24	6300	47	12,300	80	21,200	128	33,700
20	70	5	1300	12	3100	23	6100	40	10,600	64	16,800
30	100	3	900	8	2100	16	4100	27	7100	43	11,200
40	130	3	700	6	1600	12	3100	20	5300	32	8400

Source: Center for International Development, Research Triangle Institute.

Table F-3

*Approximate Daily Output, American Farm Windmill*

12-foot (3.7-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)		4 (9)		5 (11)		6 (13)		7 (16)	
(m)	(ft)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)
10	30	14	3800	34	9100	67	17,700	116	30,600	184	48,500
20	70	7	1900	17	4500	33	8800	58	15,300	92	24,300
30	100	5	1300	11	3000	22	5900	39	10,200	61	16,200
40	130	4	1000	9	2300	17	4400	29	7600	46	12,100

Source: Center for International Development, Research Triangle Institute.

Table F-4

*Approximate Daily Output, American Farm Windmill*

14-foot (4.3-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)		4 (9)		5 (11)		6 (13)		7 (16)	
(m)	(ft)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)
10	30	20	5200	47	12,300	91	24,100	158	41,600	250	66,000
20	70	10	2600	23	6200	46	12,000	79	20,800	125	33,000
30	100	7	1700	16	4100	30	8000	53	13,900	83	22,000
40	130	5	1300	12	3100	23	6000	39	10,400	63	16,500

Source: Center for International Development, Research Triangle Institute.

Table F-5

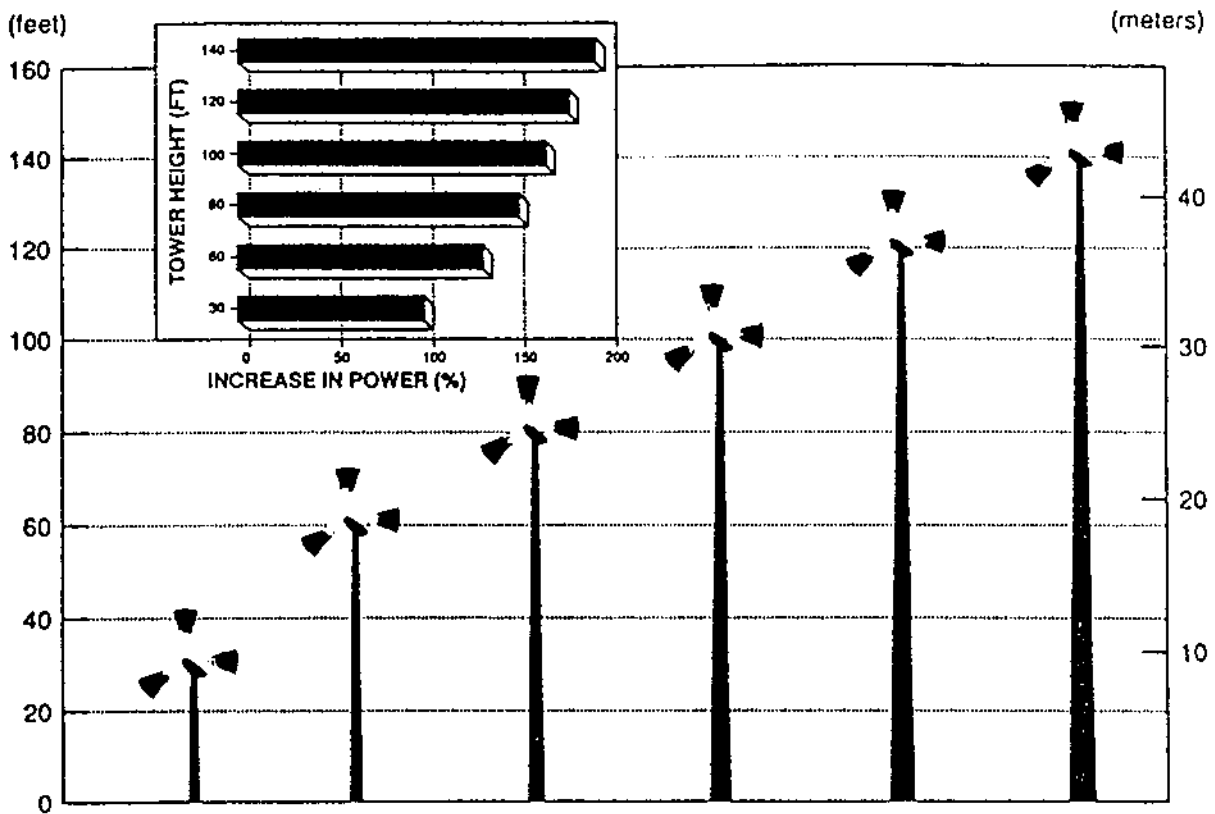
*Approximate Daily Output, American Farm Windmill*

16-foot (4.9-meter) Diameter Rotor, in cubic meters/day and gallons/day

Pumping Head		Average Annual Wind Speed, m/s (approximate mph)									
		3 (7)		4 (9)		5 (11)		6 (13)		7 (16)	
(m)	(ft)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)	(m <sup>3</sup> )	(gals.)
10	30	26	6800	61	16,100	119	31,400	206	54,300	327	86,300
20	70	13	3400	30	8000	60	15,700	103	27,200	163	43,100
30	100	9	2300	20	5400	40	10,500	69	18,100	109	28,800
40	130	6	1700	15	4000	30	7900	51	13,600	82	21,600

Source: Center for International Development, Research Triangle Institute.

## INCREASE IN POWER WITH HEIGHT ABOVE 30 FT (10 M)



*Figure 3-6. The power available to a wind machine increases with height. The power available at 80 feet (24 meters) above the ground is 150% of that at 30 feet.*

**Table 3-5**

### *Increase in Wind Power Density with Height*

Above 30 ft (10 m)\*

Height		Surface Roughness Exponent ( $\alpha$ )			
		1/10 (0.10)	1/7 (0.14)	1/5 (0.20)	1/4 (0.25)
30	9	1.00	1.00	1.00	1.00
60	18	1.23	1.35	1.52	1.68
80	24	1.34	1.52	1.80	2.09
100	30	1.44	1.68	2.06	2.47
120	37	1.52	1.81	2.30	2.83
140	43	1.59	1.94	2.52	3.18
150	46	1.62	1.99	2.63	3.34
160	49	1.65	2.05	2.73	3.51

\*30 feet is approximately equivalent to a 10-meter anemometer mast.

**Table 3-3**

*Changes in Wind Speed with Height*

Site	Speed at Height (m/s)		Speed Increase	Approx. $\alpha$
	9.1 m (30 ft)	45.7 m (150 ft)		
San Gorgonio Pass	6.2	7.7	1.24	0.13
Livingston, Montana	6.8	8.4	1.24	0.13
Clayton, New Mexico	5.4	7.3	1.35	0.18
Minot, North Dakota	6.5	8.4	1.29	0.16
Amarillo, Texas	6.3	8.1	1.29	0.16

Source: Battelle, PNL

**Table 3-4**

*Increase in Wind Speed with Height*

Above 30 ft (10 m)\*

Height		Surface Roughness Exponent ( $\alpha$ )			
		1/10	1/7	1/5	1/4
(ft)	(m)	(0.10)	(0.14)	(0.20)	(0.25)
30	9	1.00	1.00	1.00	1.00
60	18	1.07	1.10	1.15	1.19
80	24	1.10	1.15	1.22	1.28
100	30	1.13	1.19	1.27	1.35
120	37	1.15	1.22	1.32	1.41
140	43	1.17	1.25	1.36	1.47
150	46	1.17	1.26	1.38	1.50
160	49	1.18	1.27	1.40	1.52

\*30 feet is approximately equivalent to a 10-meter anemometer mast.

**Table 3-6**

*Changes in Power Density with Height*

Site	Power Density at Height (W/m <sup>2</sup> )		
	9.1 m (30 ft)	45.7 m (150 ft)	Power Increase
San Gorgonio Pass	351	712	2.03
Livingston, Montana	457	794	1.74
Clayton, New Mexico	162	334	2.06
Minot, North Dakota	271	533	1.97
Amarillo, Texas	228	464	2.04

Source: Battelle, PNL

# Letters to Home Power

We Print 'em Unedited.  
Selected & Entered by  
Kathleen Jarschke-Schultze

## Homebrew Anemometer

Dear Richard and the HP Crew, I enjoy seeing more information in HP about wind energy systems. I think your idea of installing a small wind generator to check a site's wind energy potential (#21, P. 78) is really good. After living with a small wind system for thirteen years, I've got a couple ideas to share.

My first wind machine was a homemade unit. If you want a good, reliable, efficient unit homemade is definitely NOT the way to go. But if you want a good, hands on education in wind energy, the homebrew will really give you that. Just don't expect it to perform like a factory model and be prepared to give the project plenty of time.

Another possibility for low cost site analysis is a homemade anemometer. I made one by attaching three sheet metal cones to a hub which is mounted on a small permanent magnet generator. Most any PM motor will work for the generator, though its best to use a slow speed unit. Remember too that it will be spinning day and night so one with ball bearings will probably last longer. Surplus Center and Fair Radio Sales Co. are two good sources of PM motors and Fair also has a good selection of meters.

The output from the generator is connected through a series resistor to a milliammeter. If you use two different resistors and a switch you can have a high and low range. Ours reads 0-25 on low and 0-70 on high. You'll need to make your own dial for your meter, so one with a removable face is handy. Just flip it over and mark on it the wind speed scales you want. Determine the proper resistors by experimentation.

I calibrated our unit by clamping it on the front bumper of our car, high enough above the hood to be in "clean" air. Note your readings as you drive at different speeds (this is a two person task). Do your calibration run before marking the meter as described above. Another way to calibrate would be to mount your unit next to a factory made one and note the readings. This would really be preferable to the car method. I calibrated ours using the car method though (did it on our way to church on a calm Sunday morning) and the readings correlate very closely with what is reported by the National Weather Service in our area.

If you're looking for one more reason to buy a Fluke 80 series digital multimeter the anemometer project is it. By

putting the Fluke in parallel with the milliammeter and switching to the min/max/avg. recording mode you now have some of the functions of a full blown recording anemometer. It will tell you the minimum windspeed, the peak gust, and calculate the average windspeed over the entire day. You'll need to make a conversion chart to convert your Fluke numbers to windspeed. I also made a cardboard face that lays over the Fluke's face so one can read windspeed directly from the bar graph.

Hope this might be helpful to someone. Below is a

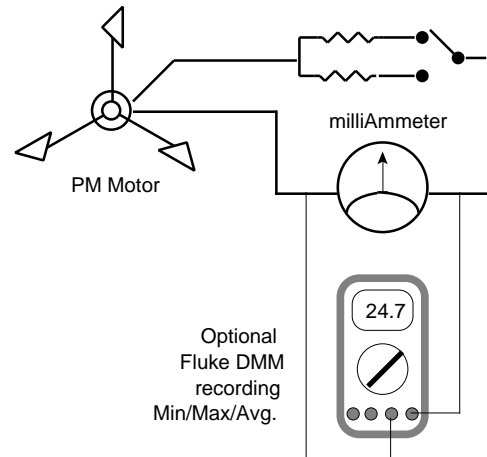


diagram to show what the setup looks like.

Fair Radio Sales, POB 1105, Lima, OH 45802 Tel. (419) 223-2196

Surplus Center, POB 82209, Lincoln, NE 68501 Tel. 1 (800) 228-3407

P.S. Thanks for the "Time Machine" in #21. Exactly what I was looking for. How did you know? I plan to build several. Just need more time for all these HP inspired projects.

Bruce Johnson, 7605 N. Post Rd., Spencer, OK 73084

*Hi, Bruce. Thanks for the flowers and the easy to build anemometer. I built one like you described and used old panty hose containers for the anemometer cups. Only problem was that the plastic used to make these egg-shaped containers is photosensitive and they fell apart in about a year. Bob-O and I buy a lot of parts from Fair Radio Sales. They have great stuff, excellent service and bargain basement prices. Glad you liked the Time Machine. Feedback from readers on this circuit has been hot and heavy. We're glad to be of service. Richard.*

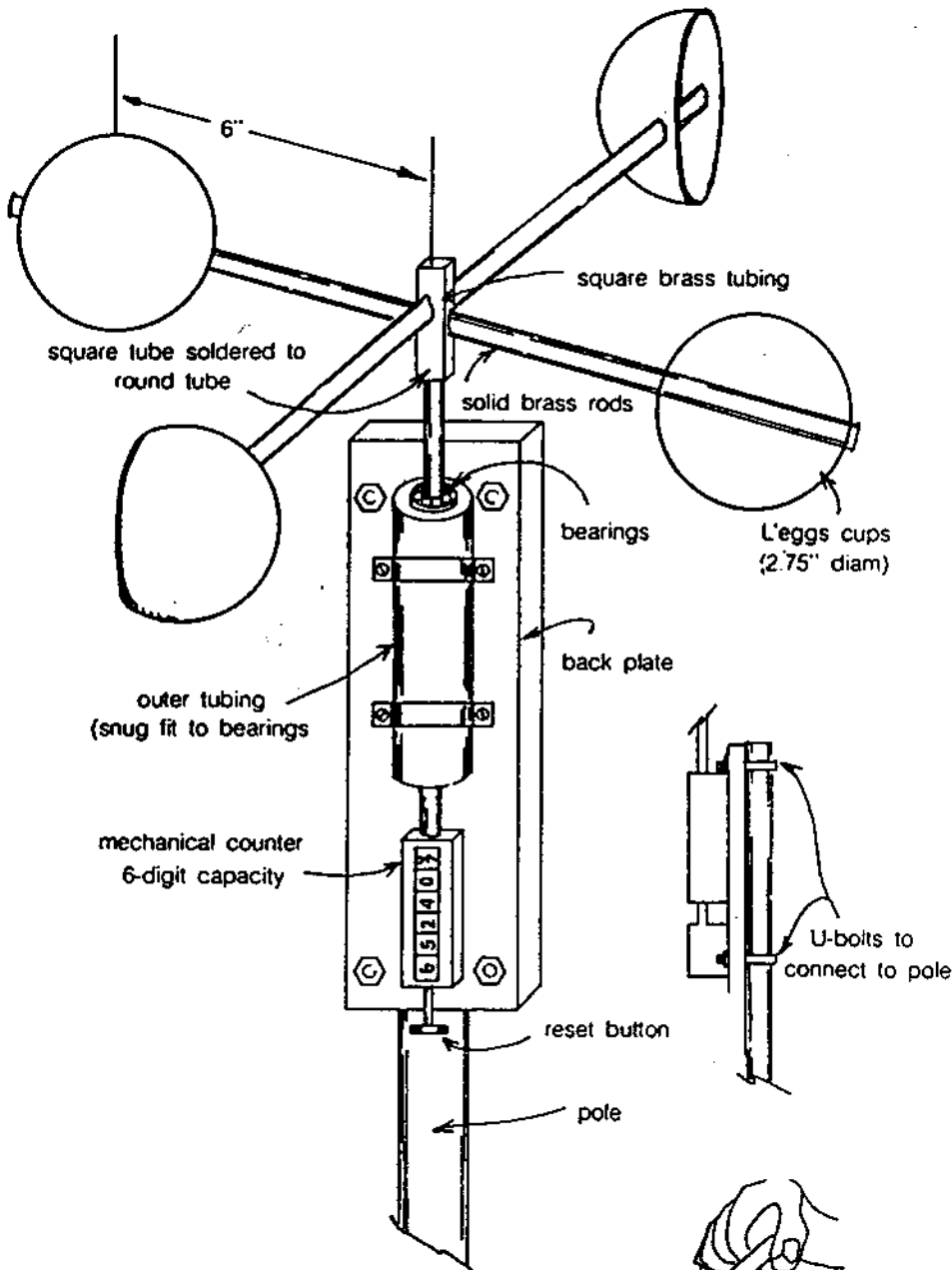
## Outback Bucks

Dear Home Power, I am interested in receiving copies of your design newsletter about the OOZIE backwoods electric vehicle project. Please let me know about any costs involved.

You may be interested in the incentive which New South Wales State Energy Authority provides for remote power



A do-it-yourself cup anemometer for measuring average wind speeds.



calibration data

angle	mph
90	0
85	5.8
80	8.2
75	10.1
70	11.8
65	13.4
60	14.9
55	16.4
50	18.0
45	19.6
40	21.4
35	23.4
30	25.8
25	28.7
20	32.5

A do-it-yourself, hand-held wind gauge with calibration data (based on C.L. Strong, *Scientific American*, October 1971).

stand away to minimize air disturbance

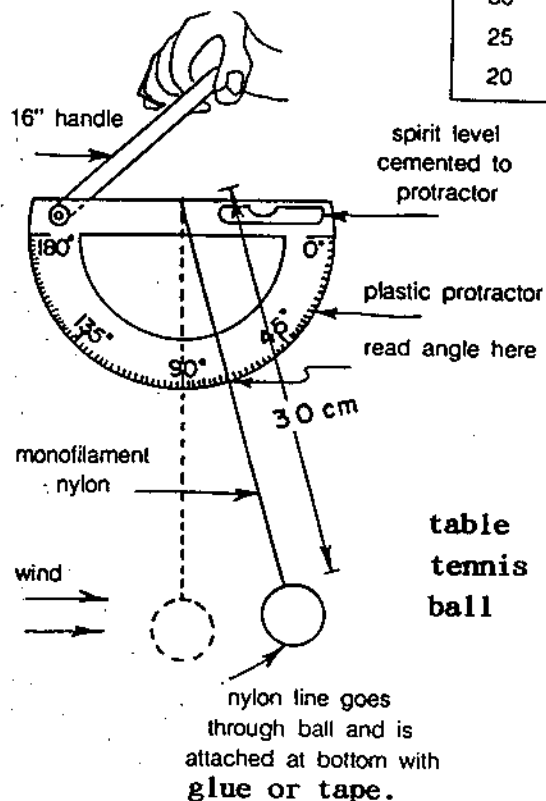


table tennis ball

nylon line goes through ball and is attached at bottom with glue or tape.

Wind- stärke	Bezeichnung	Windgeschwindigkeiten			
		m/sec.	Knoten	km/h	Meilen/h
0	Windstille	0,1 bis 0,3	0,2 bis 0,6	0,4 bis 1,1	0,2 bis 0,7
1	leichter Zug	0,4 bis 1,5	0,9 bis 3,2	1,4 bis 5,4	0,9 bis 3,4
2	sanfte Brise	2,0 bis 3,5	4,3 bis 7,5	7,2 bis 12,6	4,5 bis 7,8
3	leichte Brise	4,0 bis 5,5	8,5 bis 11,7	14,4 bis 19,8	8,9 bis 12,3
4	mäßige Brise	6,0 bis 8,0	12,8 bis 17,1	21,6 bis 28,8	13,4 bis 17,9
5	mäßiger Wind	8,5 bis 11,0	18,1 bis 23,4	30,6 bis 39,6	19,0 bis 24,6
6	starker Wind	11,5 bis 14,0	24,5 bis 29,8	41,4 bis 50,4	25,7 bis 31,3
7	sehr starker Wind	14,5 bis 17,0	30,9 bis 36,2	52,2 bis 61,2	32,4 bis 38,0
8	stürmischer Wind	17,5 bis 20,5	37,3 bis 43,7	63,0 bis 73,8	39,1 bis 45,9
9	Sturm	21,0 bis 24,5	44,8 bis 52,2	75,6 bis 88,2	47,0 bis 54,8
10	heftiger Sturm	25,5 bis 28,5	54,4 bis 60,7	91,8 bis 102,6	57,0 bis 63,8
11	orkanartiger Sturm	29,0 bis 32,5	61,8 bis 69,3	104,4 bis 117,0	64,9 bis 72,7
12	Orkan / Hurrikan	33,0 bis 34,0	70,3 bis 72,5	118,8 bis 122,4	73,8 bis 76,1

Einteilung der Windgeschwindigkeiten - Umrechnungstabelle

**WIND SPEEDS & DESCRIPTION.**

Description	Speed knots	Mean speed knots	Beaufort force	MPH	km/h	m/s	Weather forecast
Calm	< 1	0	0	0.5	1.0	0.2	Calm
Light air	1-3	2	1	2.3	3.7	1	Light
Light breeze	4-6	5	2	5.7	9.3	2.6	-
Gentle breeze	7-10	9	3	10.4	16.7	4.6	-
Moderate breeze	11-16	13	4	15.0	24.0	6.7	Moderate
Fresh breeze	17-21	19	5	22.0	35.2	9.8	Fresh
Strong breeze	22-27	24	6	27.6	44.5	12.4	Strong
Near gale	28-33	30	7	34.5	55.6	15.4	-
Gale	34-40	37	8	42.6	68.6	19.0	Gale
Strong gale	41-47	44	9	50.6	81.5	22.7	Severe gale
Storm	48-55	52	10	60.0	96.4	26.8	-
Violent Storm	56-63	60	11	69.0	111.2	31.0	-
Hurricane	64-71	68	12	78.3	126.0	35.0	-

**RELATIONSHIP BETWEEN GRIGGS-PUTNAM INDEX [G] & ANNUAL MEAN WIND SPEED [V] - IN m/sec.**

G	V [m/sec]	MPH	W/sq.m. ‡	Batelle Class <sup>a</sup>
0	< 3	< 7	< 50	0
1	3 - 4	7 - 9	50 - 80	0 - 1
2	4 - 5	9 - 11	80 - 125	1 - 2
3	5 - 6	11 - 13	125 - 250	2 - 4
4	6 - 7	13 - 16	250 - 400	4 - 6
5	7 - 8	16 - 18	400 - 600	6 - 7
6	8 - 11	18 - 25	600 - 1600	7 - 9
7	> 11	> 25	> 1600	9 - 10

**See also:**  
**A:** A Handbook on the use of Trees for Wind Power Potential. E.W.Hewson, Wade N.T.I.S. USA 1979  
**B:** Siting Handbook for Small Wind-energy Conversion Systems. [ PNL-2521 Rev. 1. ] Nat. Tech. Info. Service USA Dept. of Commerce Springfield VA 22161 USA  
**C:** Wind-Atlas computer-program. RISØ National Laboratory Roskilde Denmark  
**‡** Measured at standard height of 10 m. [ at 50 m. height => a: wind speed + 26 % b: energy + 100 % ].

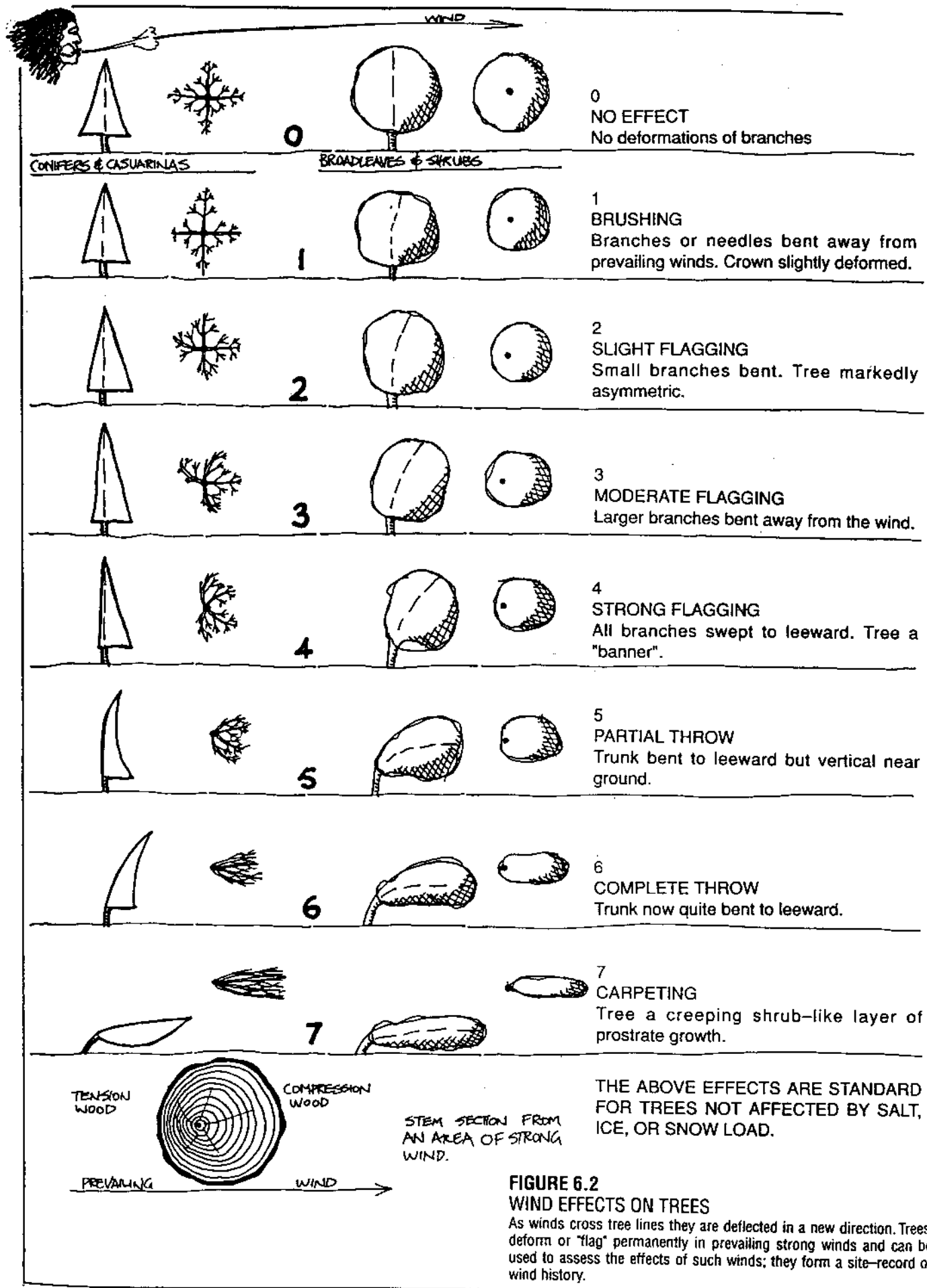
**APPROXIMATE WIND SPEED ENERGY EFFECTS:**

A: < 2.5 m/s => Slight effects, no damage to crops or structures.  
 B: 4.5 - 6.5 m/s => Damage to very susceptible species.  
 C: 9.5 - 12.5 m/s => Mechanical damage to crops, some damage to structures.  
 D: 15.5 - 35.0 m/s => Severe structural & crop damage. Damage to some wind-mill types & models. [ Most useful wind-turbine electrical energy is produced in wind-sectors B. and C. - However an Australian model can produce useful electricity at app. 2.5 m/sec. ].

**REDUCTION OF WIND VELOCITY IN FORESTS:**

Penetration in meters:	30 m.	Remaining velocity in % :	60 - 80 %
	60 m.		50 %
	120 m.		15 %
	300 - 1,500 m.		Negligible wind.

GRIGGS AND PUTNAM INDEX



THE ABOVE EFFECTS ARE STANDARD FOR TREES NOT AFFECTED BY SALT, ICE, OR SNOW LOAD.

**FIGURE 6.2**  
**WIND EFFECTS ON TREES**

As winds cross tree lines they are deflected in a new direction. Trees deform or "flag" permanently in prevailing strong winds and can be used to assess the effects of such winds; they form a site-record of wind history.

# Site Analysis for Wind Generators

## Part 1: Average Wind Speed

Mick Sagrillo

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**Y**ou've decided that it's time to consider a wind electric system. It sure seems windy in your area, at least part of the time anyway. And you could really use the power!

But how can you tell if a wind generator will really do well at your site? How do you know if you have enough wind, and where the wind is? And if it turns out that you do have a good resource, where's the best place to put the tower?

### Tools

The common response to the above questions is that you must monitor the wind speed at your site for a year or two to find out if a wind generator will work for you. For a residential-sized system, this is nonsense! PV installers don't record available sunlight forever, so why do it for wind? Actually, PV installers have a couple of tools at hand to help them site PV arrays. We can do the same for wind generators.

In order to correctly site and size a wind electric system, it is helpful to have the following information about your location:

- average annual wind speed
- prevailing wind directions
- vegetation and buildings at the site
- surface roughness
- the type of energy storage

What we need to do is quantify your resource in general terms first. Once that is done, we can fine tune your resource for your specific site. So, let's analyze each of these tools and see how to use them.

### Options

Because it is so easy to address, let's consider the type of energy storage first. If utility electricity is available to you, by all means, consider a utility tie-in system. By using the grid, you eliminate the need for a very expensive and time consuming component: the

batteries. In a grid intertie system, the utility stores your electricity in the form of a credit whenever the wind is blowing. When the wind is still, you reclaim that credited power. In this case, your primary concern is producing enough electricity over extended periods of time to offset your consumption of utility-generated power. Daily or weekly production is irrelevant.

If yours is a remote system utilizing batteries rather than the utility grid, then you can actually do with less wind than the minimum cost-effective grid intertie system. Any renewable source of energy is more cost effective than running, maintaining, and fueling a gas or diesel generator for several decades.

In the case of a utility intertie system, a ten mph average annual wind speed is usually considered the cut-off. Below ten mph, the wind generator cannot be justified on a purely economic basis compared to purchased utility power. With a stand-alone system, wind generators are certainly cost effective in the nine mph and even the eight mph average wind speed ranges. These numbers refer to wind speeds at the height of the blades, referred to as hub height. The big question is, how do you get these numbers for your site?

### You What???

Determining your exact average annual wind speed is difficult, expensive, and time-consuming. But, Mick, you say, you just told us that monitoring the wind for a year or so was nonsense. What gives?

While it is necessary to have an idea of your average annual wind speed, you do not need an exact measurement. We're not prospecting for a wind farm here. Therefore, monitoring wind speed at hub height for several years is unnecessary.

So how do we get this elusive number called average wind speed. We guess. Don't laugh! It's done all of the time, and fairly accurately, I might add. What we need to do is get a ballpark idea of the average annual wind speed for your area. I'll explain how it was done at my site, and we can work backwards from there.

### Conventional Wisdom

When we moved to our homestead in Wisconsin, we investigated the use of a wind generator because it always "seemed" so windy. Conventional wisdom said to check the airport and weather bureau data for our area. We found that the average annual wind speed at the Green Bay airport, 35 miles away, was barely nine mph, hardly worth considering due to the cost of electricity we were buying from the utility.

After replanting the same peas in our first garden four times (they kept blowing out of the ground), we asked

the neighbors what they thought. A few could remember wind generators in the area in the '30s and '40s, but they had all disappeared when the REA strung power lines through the area after World War II. That winter, our most frequent visitors were the county snow plows. Our corner of the country was plowed three and four times a day for the school buses and milk haulers (we live in dairy country). We quickly learned that leaving the homestead for a few hours could very well mean half a day of snow shoveling to get the car back home again.

After a few years of battling the wind and its effects, we decided to monitor our average wind speed. While the Green Bay airport and National Weather Bureau could still only muster a paltry nine mph annual average, our site turned up a surprising 13 mph at 100 feet after a year's monitoring. As we suspected, we did indeed have a respectable resource. So much for conventional wisdom!

#### **Lessons Missed**

We actually had positive indications from several sources around us, but failed to see their value. The first was our intuition. While gut feelings are hardly scientific, it's pretty hard to discount the breeze that blows your laundry all over the township every time you use the clothesline.

Our second indication was the problem of continuously drifting snow. Crews work full time in our area to keep the roads open. Other areas of the country experience similar problems with dust, dirt, sand, and dried bits of vegetation constantly "sandblasting" the neighborhood.

Our third indication was the collective experience of various old timers and the locals. Living in the area, they have spent considerable time with environmental factors that newcomers like us may have discounted or never experienced.

Our fourth indication was the vegetation in the area. We'll get back to this one in a bit.

We made the same mistake most folks do when first investigating wind energy: attributing the final word on average wind speed for our site to professionally collected data at a less than ideal location.

#### **Assumption is the Mother of all Screw-Ups**

Our problem occurred when we unquestionably accepted the value given to airport and weather data, considering their location versus ours. We discovered that weather bureaus monitor wind speeds at or slightly above street level, where people live. They do not monitor wind speeds at 80 or 100 feet, where wind generators live. And as we saw in Tower Economics 101 (*HP#37*) jumping from street level to 80 feet

substantially increases the average wind speed and, therefore, the power available in that wind.

Similarly, airport data has limited value. Because airplanes traditionally had problems taking off and landing in windy locations, airports were sited in rather sheltered locations. Virtually all airports are sheltered.

Most of the time the "professionals" really don't get it right. Without exception, all airports and weather bureaus I have visited have located their anemometers on the tops of buildings, next to trees, or in low spots on the terrain. In other words, their sampling equipment is either sheltered, or severely influenced by turbulence, or both. This helps to explain, for example, why the measured average wind speed at my site is greater than that recorded for the Green Bay airport. Taken at face value, professionally recorded wind speeds make a lousy yardstick for determining wind generator installations.

#### **Making it Useful**

Does this mean that we should discount airport or weather bureau averages? Not at all. What it does mean is that their average wind speeds are in all likelihood very low baseline numbers, really just a starting point for our consideration. Virtually all wind generator sites I have seen have higher wind speeds by at least a mile per hour or two when compared to the nearest airport or weather bureau. Many times the disparity is three or four miles per hour, as we found at our site.

Consider the location, topography, surrounding vegetation and buildings, and the monitoring height of the recording station equipment (airport or weather bureau). By comparing these to your location, you can get a feel for the potential differences between the sites. Then by using the graphs in "Tower Economics 101" (*HP#37*), you can make an educated guess as to your average annual wind speed at hub height.

You may be in for a surprise when you call or visit your nearest wind recording station asking about the physical location of the monitoring equipment. Believe it or not, a very common reply is, "We're not really sure where it is." This response doesn't do much to build confidence in their numbers!

#### **Shear Factor**

Another way of using nearby airport or weather bureau figures is to extrapolate their numbers to your location using a concept known as "shear factor". Based on their numbers and the topographical difference or similarity between your site and theirs, you can theoretically estimate your wind speed at any proposed height. I'll use our site again to explain how it's done.

**Surface Friction Coefficient**

from *The Wind Power Book* by Jack Park

Description of Terrain	$\alpha$
Smooth, hard ground; lake or ocean	0.10
Short grass on untilled ground	0.14
Level country with foot-high grass, occasional tree	0.16
Tall row crops, hedges, a few trees	0.20
Many trees and occasional buildings	0.22 – 0.24
Wooded country; small towns and suburbs	0.28 – 0.30
Urban areas, with tall buildings	0.40

**Table 1**

## How windy is it?

**Table 2**

**Height Correction Factor, H**

from *The Wind Power Book* by Jack Park

Height feet	Surface Friction Coefficient, $\alpha$								
	0.100	0.140	0.160	0.200	0.220	0.240	0.280	0.300	0.400
10	0.895	0.857	0.839	0.802	0.785	0.768	0.735	0.719	0.644
15	0.933	0.908	0.895	0.870	0.858	0.846	0.823	0.812	0.757
20	0.960	0.945	0.937	0.922	0.914	0.907	0.892	0.885	0.850
25	0.981	0.975	0.971	0.964	0.960	0.957	0.950	0.948	0.929
30	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
35	1.016	1.022	1.025	1.031	1.034	1.037	1.044	1.047	1.063
40	1.029	1.041	1.047	1.059	1.065	1.071	1.083	1.090	1.121
45	1.041	1.058	1.067	1.084	1.098	1.102	1.120	1.129	1.176
50	1.052	1.074	1.085	1.107	1.118	1.130	1.153	1.165	1.226
55	1.062	1.089	1.102	1.128	1.142	1.156	1.184	1.199	1.274
60	1.072	1.102	1.117	1.148	1.164	1.180	1.214	1.231	1.319
65	1.080	1.114	1.132	1.167	1.185	1.203	1.241	1.261	1.362
70	1.088	1.126	1.145	1.184	1.204	1.255	1.267	1.289	1.403
75	1.096	1.137	1.158	1.201	1.223	1.245	1.292	1.316	1.442
80	1.103	1.147	1.170	1.216	1.240	1.265	1.316	1.342	1.480
85	1.110	1.157	1.181	1.231	1.257	1.283	1.338	1.366	1.516
90	1.116	1.166	1.192	1.245	1.273	1.301	1.360	1.390	1.551
95	1.122	1.175	1.203	1.259	1.288	1.318	1.380	1.413	1.585
100	1.128	1.184	1.212	1.272	1.303	1.335	1.400	1.435	1.618
105	1.133	1.192	1.222	1.284	1.317	1.350	1.420	1.456	1.650
110	1.139	1.199	1.231	1.296	1.330	1.365	1.438	1.476	1.681
115	1.144	1.207	1.240	1.308	1.343	1.380	1.456	1.496	1.711
120	1.149	1.214	1.248	1.319	1.356	1.394	1.474	1.515	1.741
125	1.154	1.221	1.257	1.330	1.368	1.408	1.491	1.534	1.769

Let's be daring and assume that the recording station knows the whereabouts of their anemometer, and that it is on the standard 30 foot tower it's supposed to be on. You visit their location and find that the anemometer is in a very well-exposed site, far from the influence of any trees or buildings. The recording station tells you that the average wind speed at the site for a 35 year period of time is 9.0 mph. What does this translate to at your site?

The first thing you do is estimate the similarity of your site to theirs and assign your site a surface friction coefficient from Table 1.

Assuming that their site is wide open and your site is like ours, a farm with the usual buildings and trees plus a nearby wooded area, you might choose a surface friction coefficient of 0.24. We have a 100 foot tower that we would like to use to mount the wind generator. At 100 feet, we will easily pass the "30 feet above anything within 500 feet" rule (see Tower Economics 101). What kind of average wind speed can we expect at this height?

If we look across the 100 foot row in Table 2 to the column labeled 0.240, we find a correction factor of 1.335. Multiplying 1.335 by the recording station's figure of 9.0 mph means that we can expect an average annual wind speed of 12.0 mph at our site. While this is still below the actual measured average wind speed of 13.0 mph at our site, it's a lot closer than 9.0 mph!

The one caveat in using this technique is the assumption that the recording station's anemometer is not surrounded by trees and buildings. If it is, the shear factor technique of estimating wind speeds does not work very well.

**Flagging**

Another useful tool to help determine the potential of a wind site is to observe the area's vegetation. Trees, especially conifers or evergreens, are often influenced by winds. Strong winds can permanently deform the trees. This deformity in trees is known as

“flagging”. Flagging is usually more pronounced for single, isolated trees with some height.

Pictured here is a pine tree in my yard with an obvious wind swept deformity. The upper part of the tree is swept back and away from the solar shower next to it. On the upwind side of the tree, the branches are noticeably stunted. On the downwind side, they’re long and horizontal. The flagging was caused by persistent winds from, more or less, one direction.

Ecologists have been using flagging in trees for decades to ballpark the average wind speed for an area. (Vegetables don’t lie!) Pick up any ecology book and you will find a diagram similar to the one bottom right on the page that quantifies an area’s wind speed as a function of tree deformity.

Note that you can get an idea of the average wind speed by the amount of flagging. Comparing the picture to the diagrams, we could categorize my pine tree as Class III, an 11 to 13 mph average wind speed. The monitoring done at my site certainly bears this out.

If you do not have any conifers in your area, look around at the deciduous trees. They may also show evidence of flagging. Look around especially for single trees, or trees on the outskirts of a grove. Unless they have grown considerably above the common tree line, trees in a forest will not show flagging because the collective body of trees tends to reduce the wind speed over the area.

While the presence of flagging positively indicates a wind resource, you should not conclude that the absence of flagging in your area precludes any suitable average wind speeds. Other factors that you are not aware of may be affecting the interaction of the wind with the trees.

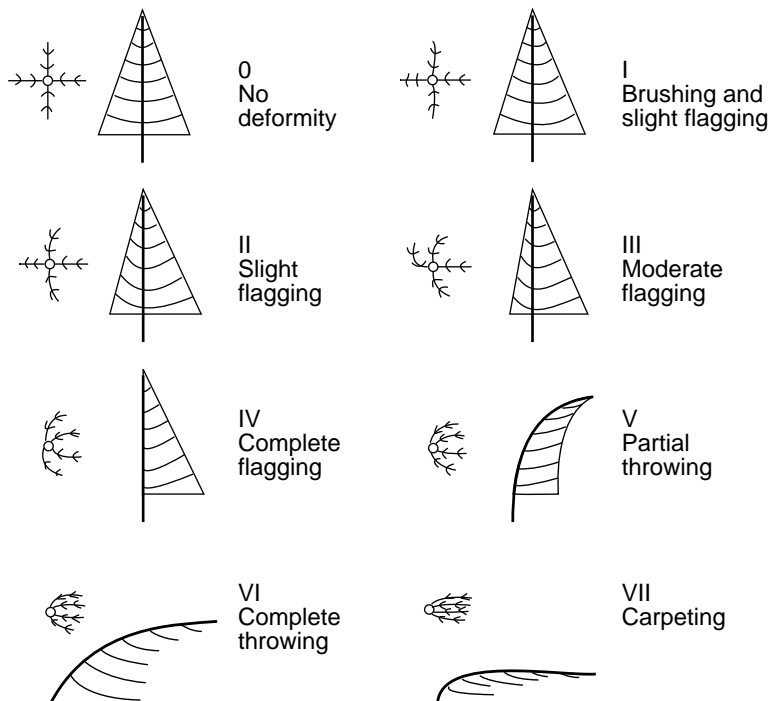
**Tools Revisited**

So far, the tools that we have available to us for approximating our wind resource are:

- The various experiences of your area’s neighbors, especially the old timers
- Any flagging that might be observed in the surrounding areas
- Local wind generated problems (snow drifting, severe soil erosion, tumbleweeds)
- The average wind speed established by the nearest airport or weather bureau, which can be used as our baseline
- The average wind speed for your site as determined by the shear factor
- Your gut feelings based on all of the above



Above: Moderate flagging on a tree tells you how much wind is blowin’ through.



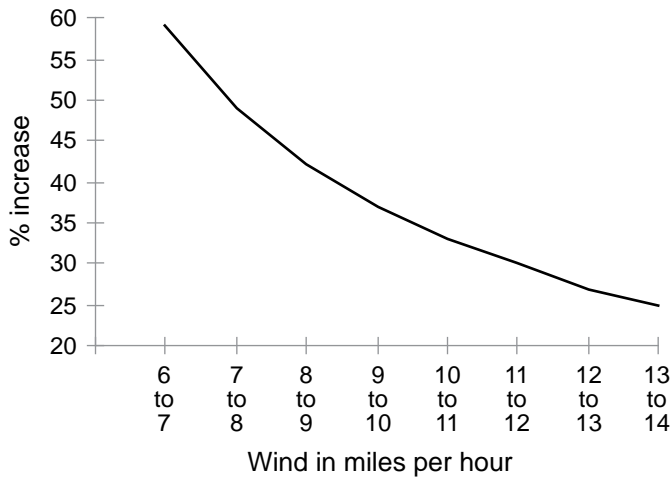
**Griggs-Putnam Index of Deformity**

from *Wind Power for Home & Business* by Paul Gipe

Index	I	II	III	IV	V	VI	VII
Wind Speed (mph)	7-9	9-11	11-13	13-16	15-18	16-21	22+



**Power Increase vs. 1 mph Wind Speed Increase**



Remember from "Tower Economics 101" that even small increases in wind speed can yield substantial increases in power to the wind generator because velocity is cubed in the power equation. This is especially true at lower average annual wind speeds, as depicted in the graph above.

**The Bottom Line**

So what is the bottom line number for an acceptable average wind speed? Because there seems to be such

a disparity between monitoring stations (airports and weather bureaus) and actual wind generator installations, we can actually fudge a little here. For a utility intertie system with a good exposure compared to the monitoring station site, an average wind speed of eight mph at the recording station or at ground level at your site is acceptable. Remember, our economic cut-off point (if you're doing this to make money) is ten mph at hub height when we're competing with cheap utility power.

For a battery charging wind system in which the monitoring station has nearly identical topographical exposure to your site, an annual average wind speed as low as seven mph at the recording station or at ground level at your site is acceptable. If the monitoring site is very sheltered compared to your site, this number could drop to about six mph. However, I wouldn't consider any site with average wind speeds less than these.

Next time we'll take a look at maximizing the usefulness of your site.

**Access**

Mick Sagrillo gets blown around a lot at Lake Michigan Wind & Sun, E 3971 Bluebird Rd., Forestville, WI 54213 • 414-837-2267



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# Site Analysis for Wind Generators

## Part 2: Your Site

Mick Sagrillo

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In our last episode (HP#40), we outlined some ways of estimating the wind resource in your area. We also developed a method to determine the average wind speed at hub height for your proposed wind generator. The question before us now is: where on your property is the best place to put your wind generator tower?

The answer to this one is easy. Put the tower where it's windiest! It is actually windier in some places on your property than on others. In this article, we will show you how to analyze your specific location so that you can maximize your wind resource.

### Tools

The purpose of examining any potential renewable energy (RE) site is to optimize the RE resource, and therefore, the power output of the proposed RE generator. To accomplish this, you will need to gather some information about your site, such as:

- Location of vegetation and buildings
- Prevailing wind direction/directions
- System voltage (battery charging systems only)
- Surface roughness or topography.

From this information, we will develop a series of rules or guidelines that will help you qualify the resource at your site.

### Vegetation and Buildings

Since any site analysis requires a specific location, we'll use our homestead as an example. Figure 1 illustrates the layout of the buildings and most trees on our property. Also noted are the compass points, and a distance scale. The numbers indicate the approximate heights of the trees and buildings.

The terrain in our area is somewhat rolling and relatively open, but spotted with buildings, overgrown fencerows, groves of trees, and the occasional woodlot (several

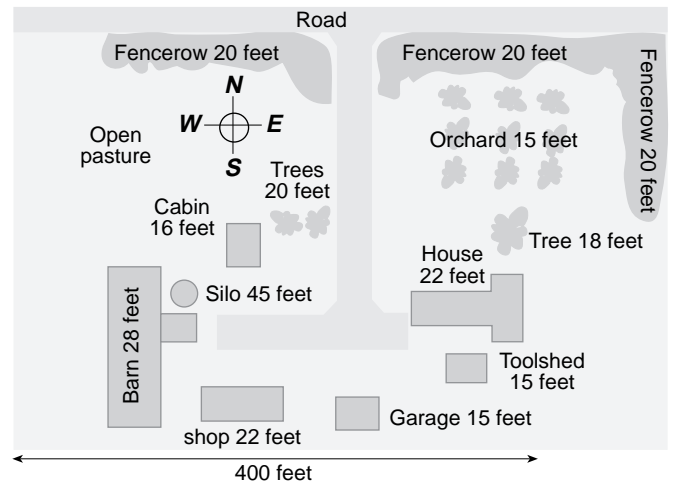


Figure 1

hundred acres). While we live in farm country with some forested areas, this site need not be rural, strictly speaking. It could very well be a small town, suburban development area, or the edge of a larger city.

### Tower Height

Remember from "Tower Economics 101" (HP#37) that our arch enemy is turbulence. It robs us of our fuel, the wind, and puts unnecessary wear and tear on the wind generator. Therefore, rule #1 is: minimize turbulence as much as possible. We'll return to turbulence later.

Another important consideration is that the wind generator must be at least 30 feet above anything within 500 feet — a *minimum* requirement. Let's call this rule #2. For anything larger than about 1 kiloWatt (kW), the "30 foot" above rule must include the blades as well.

As an example, let's assume that we will install a large wind system, say a high voltage 10 kW wind generator with a 24 foot rotor diameter. If we add the radius of the rotor (12 feet) to the 45 foot silo and the "30 foot above rule", we find that the minimum tower height for this location is 87 feet. Since an 87 foot tower is not readily available, we'll opt for the next closest size, 90 feet. Notice that we went up in height rather than skimp with an 80 foot tower. This is the minimum tower height for this location given a 10 kW wind generator.

We have the wind generator, system voltage, and tower height selected. Our next question is where do we put it to best utilize our wind resource.

### Prevailing Winds

To answer this question, we need to know the seasonal wind patterns for this proposed site. This should be fairly obvious for your location if you have lived there for a least a year. If you are new to the area, ask your neighbors.

At our place, the wind blows quite regularly during the fall, winter, and spring. Summer winds are restricted to frequent thunderstorms. While brief, these storms are usually accompanied by high winds for several hours.

Winter is dominated by winds out of the north and northwest. Fall and spring bring winds from the south and southwest. While the winds from a summer storm come from any direction, they arise most frequently out of the west. We can see a pattern developing here (Figure 2).

The best place for the tower which optimizes our prevailing wind directions is west of the barn. We now have rule #3: after you determine the direction of the prevailing winds, site the wind generator upwind of any buildings or trees.

But Mick, you say, the wind sometimes blows from the northeast, east, and southeast. At those times, the tower and generator are downwind of the trees and buildings and in the zone of turbulence. Won't we have problems when the winds are from these directions?

Unless we install a movable tower (something no one has perfected yet), the answer is yes. Because the wind blows from any compass direction some of the time, we have to compromise. Since we are interested in where the wind blows most of the time, we have to accept that occasionally the tower is in a less than ideal location. This brings us to rule #4: in a site analysis, tower placement minimizes those compromised locations, thereby maximizing our wind resource.

### Wire Restrictions

Since we know the rotor size and building height, we can easily determine the minimum tower height at this location. The distance of the wind generator to its controller is of little concern because it is a high voltage system. We can locate the tower almost anywhere on the property without worrying too much about wire size.

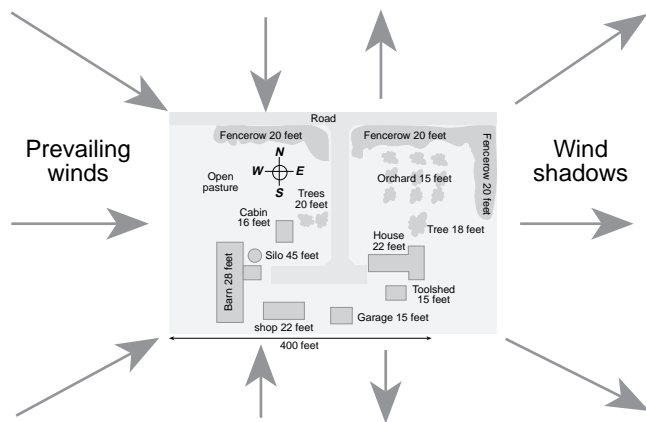


Figure 2

In a wind system, your wire run includes the distance from the tower to the controller plus the tower height, and back again. Because wire runs in a wind system can add up fast, higher voltage systems are preferable. Why is this, you ask. The power that a wind generator produces is a function of volts multiplied by amps. Thus, voltage and current are inversely related. If the voltage doubles, the current carried by your wires is cut in half, for a given amount of power.

The power lost in a wire run is a function of the wire's resistance (a function of the length and diameter) multiplied by the square of the amps that the wire carries. For a given wire gauge, doubling the voltage means that the wind generator can be located four times the distance and still have the same power loss! With wind generators, higher system voltages are easier to work with and more cost effective than lower system voltages. Which brings us to rule #5: raising system voltage gives you considerable flexibility in where you can put the tower.

### Low Voltage Dilemma

Now, let's muddy the waters by lowering the voltage. Rule #3 would favor the location west of the barn. A tower near the house would be downwind of buildings and trees. It would see a lot of turbulence and reduce our power output. "Tower Economics 103" (HP#39) diagrammed the zone of turbulence behind such obstructions.

But let's suppose that we already have a low voltage system in the house, and upgrading to a higher voltage is not an option. The distance from the proposed tower site west of the barn to the house is 400 feet. Add the 90 foot tower height, and we have a low voltage dilemma. We cannot run 12 Volts for nearly 500 feet. Now what do we do, Mick?

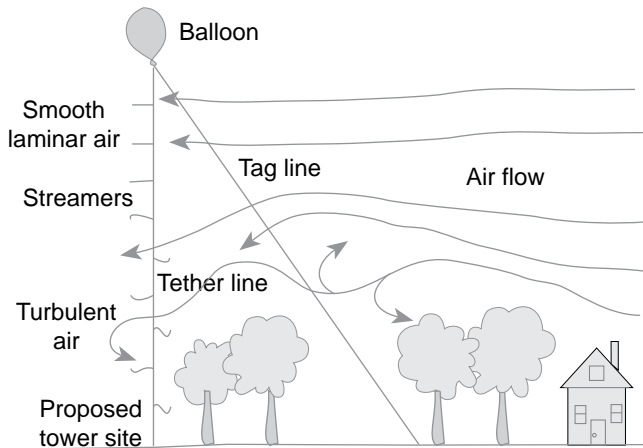
We can opt to move the tower closer to the house. If we place the tower within 30 or so feet of the house, we reduce the wire run to under 150 feet. This will require some gonzo wiring, but is acceptable cost-wise. But now the only place for the tower is downwind of the buildings, which puts us into a zone of turbulence (see Figure 2).

Installing a wind generator tower is not like plopping PVs on the ground somewhere. It is a considerable project, involving concrete. We want to get it right the first time (concrete is not very forgiving). Therefore we must determine the extent of the turbulent zone at our proposed tower site.

### Mr Wizard!

Now comes the fun! You will need a "giant weather balloon", the kind available from scientific mail order

## Wind



**Figure 3**

Adapted from *Wind Power for the Homeowner* by Don Marier

stores. (Admit it; you always wanted one of these as a kid. Now, you have an excuse to buy one!) Take it down to your local FTD florist, the folks who sell helium filled anniversary and birthday balloons. Have them fill it with helium. You might want to do this outside. Few florists have enough room (especially florists specializing in cacti) or doors wide enough to accommodate six foot weather balloons.

Once you get the damn thing home in one piece, it's time to conduct our experiment. Whatever you do, don't let the balloon go or it's back to the florist. Get someone to help (Mr. Wizard always has an assistant) rather than attempt this alone. Tie the balloon to a nylon cord about 100–120 feet long. This is your tether line. The other end of this cord should be securely fastened to a stake driven into the ground. Place the stake where you want the tower to be. Tie a second nylon cord, about 200 feet long, to the balloon. This is your tag line.

As your helper lets out the tether line with the balloon, tie streamers made of four feet long pieces of yarn or crepe paper every ten feet along this line. Keep the tag line from getting tangled up in the tether line and streamers. Tie the tag line off in the upwind direction once the balloon is in the air. Get the balloon to fly directly over your proposed wind site, as in Figure 3.

Why, you ask, are we doing all of this? Elementary, my friend. We are trying to determine the boundary layer where turbulence ends and smooth flowing laminar air begins. The streamers in the turbulent zone will ruffle in the wind, whipping around in all directions. Once you cross the boundary layer and reach the undisturbed air, the streamers straighten out and only blow downwind of the tag line. Count off the streamers to determine the height of the smooth flowing air. This is the minimum height for your wind generator tower.

Do this experiment over a period of days, with winds coming from different directions and at various speeds. This way you will have a good sample for determining the turbulent zone around the proposed wind site. You'll need to relocate the tag line from day to day as the wind shifts directions. When not in use, bring the weather balloon down so that a shifting wind does not blow it into a balloon-eating tree. If you live in a town or populated area, this technique is especially good to use to qualify your wind resource. By the way, this experiment is sure to bring every kid in the neighborhood to your yard.

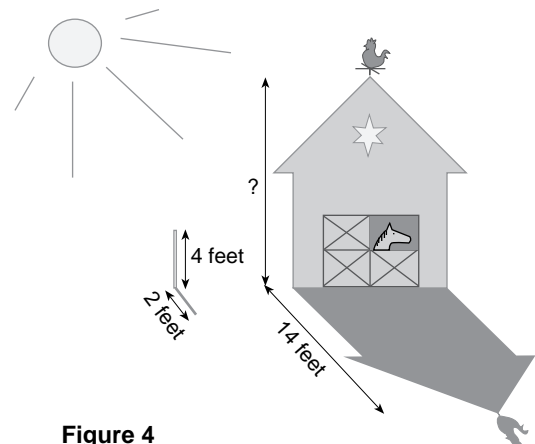
You may discover that the boundary layer raises in height at higher wind speeds or when the wind comes over a building from a particular direction. Since you want to stay clear of the turbulent winds, you will need to determine the upper limits of the boundary for most wind conditions.

If you actually do the above exercise, you will empirically discover rule #6: rougher surfaces produce gustier winds, especially at higher wind speeds. The solution? It's rule #7: if you must be downwind of obstructions, raise your tower height to get out of the turbulent zone and into the laminar flow of air. Don't forget that the blades need to be completely above the boundary layer as well.

### Estimating Heights

Let's assume that we are upwind of all obstructions again. We know that we still need to get the wind generator 30 feet above the downwind obstructions. But we don't know how tall the neighboring buildings and trees are. How can you determine their heights without risking your neck with a tape measure in hand?

One way is what I call the "shadow method". Suppose we want to know how tall our barn is. On a sunny day, drive a stake into the ground and measure the height of the stake above ground. Let's say it's four feet tall. Then measure its shadow. Let's say that the shadow



**Figure 4**

extends two feet. Next, measure the shadow that is cast by the barn. Let's say it's 14 feet. (See Figure 4)

Using the formula, we can determine the height of the barn without climbing.

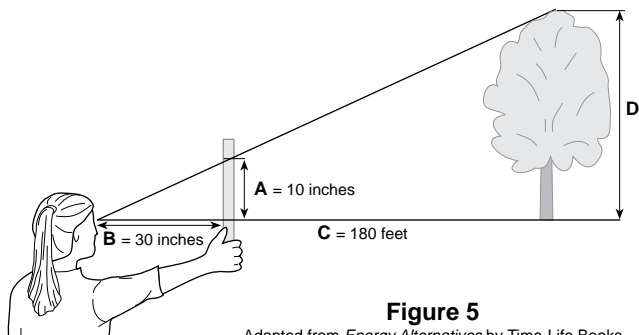
$$\frac{\text{Stake height}}{\text{Stake shadow length}} \times \text{Barn shadow length} = \text{Barn height}$$

$$\frac{4 \text{ feet}}{2 \text{ feet}} \times 14 \text{ feet} = 28 \text{ feet}$$

Piece of cake! The barn is 28 feet tall.

But what happens if the sun doesn't shine in your area? Another way of determining heights is called the triangulation method (see Figure 5 below).

Let's say that we need to know the height of a nearby tree. With a 12 inch ruler in hand, stand far enough away from the tree so that when you hold the ruler in your outstretched hand and site past it to the tree, the tree is slightly smaller than the ruler. With ruler still in hand, record the height of the tree in inches (distance A, say, 10 inches). Then measure the distance in inches between the ruler and your eye (distance B, say, 30 inches). Finally, measure the distance, in feet, between the place where you were standing and the tree (distance C, say 180 feet). Now use the following formula to determine the height of the tree (distance D).



**Figure 5**

Adapted from *Energy Alternatives* by Time-Life Books

$$D = C \times \frac{A}{B} \quad \text{or} \quad D = 180 \text{ feet} \times \frac{10 \text{ inches}}{30 \text{ inches}} = 60 \text{ feet}$$

Simply and safely, our tree is 60 feet tall!

### Trees, Trees, Trees

Let's assume that we have not just one tree, but an entire forest of trees. We have done the above exercises, and we know that the forest canopy is about 60 feet tall. Is a wind generator still practical?

Sure, but we need to get the generator at least 30 feet above the top of the tree line. In this case, we need to know the approximate age of the trees, their species, and the height that these particular types of trees will reach at this location. Why? Because of rule #8: trees grow, towers don't!

If the forest is made up of maples and ash, and the canopy is 60 feet high, you can be fairly confident that these trees are mature and will not grow much taller. You would be safe with a 90–100 foot tower. If the 60 footers are Douglas fir trees and you install a 90 foot tower, you can be assured that in not too many years the wind generator will be engulfed by branches. In most areas, Doug fir will be more than 90 feet tall. Your time and investment will have been wasted.

### And More Trees!

Let's complicate the situation a little. Assume that you own ten acres of cleared land in a national forest made up of oaks or aspen trees. Either species will mature at around 40 feet in your area. Your house is only 18 feet tall and situated smack dab in the middle of the ten acres. That puts you at least 500 feet away from the trees. Since you are 500 feet away from the nearest obstacle except the house, you can get by with a 48 foot tower. Right?

Not in this case. While it may seem that you are an adequate distance away from the trees, you are essentially in a sheltered hole! The tree canopy is the effective ground level as far as the wind is concerned. A 48 foot tower at this location would be analogous to an eight foot tower on open ground.

The minimum tower height in this instance would be 70 feet (40 foot trees plus the "30 foot rule"). If you wanted to install a 1 kW wind generator with a ten foot rotor, a safer bet would be to include the radius of the rotor (or length of a blade) at five feet, to this height. This would put the tower height at 75 feet. Since there are no other obstacles above the forest canopy, prevailing wind direction is of little concern to us.

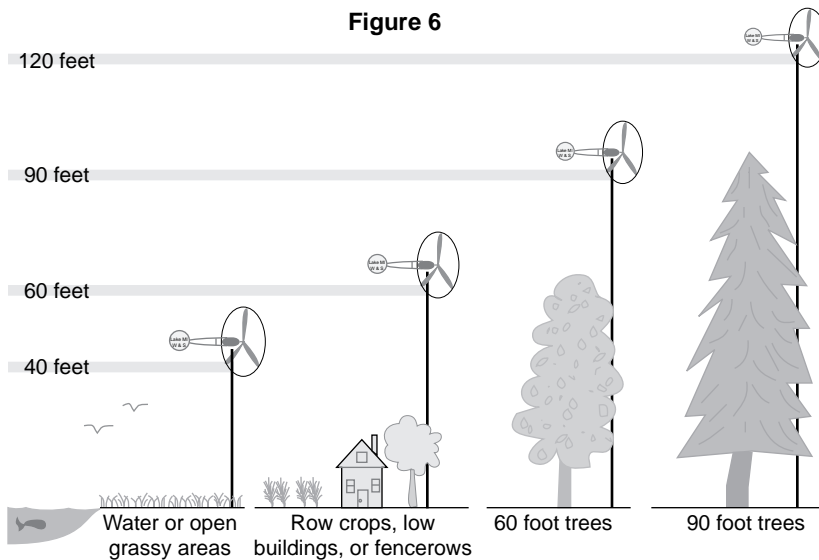
One final note about trees: avoid putting towers amidst a dense group of trees. It complicates the installation and jeopardizes the safety of the installer or service people climbing the tower. You don't want tree branches rubbing on the tower. It's not safe for the tower or the trees.

### To Tree or Not to Tree

Folks who live around tall trees may feel discriminated against when it comes to tower height. They're right. But that's the price one pays for living in a tall neighborhood. Figure 6 graphically represents what I am talking about.

If we assume a given location with a given wind speed at any point in time, Figure 6 depicts how tall your tower must be at a minimum to compensate for the surrounding vegetation. Does this mean that you should cut down all of your trees? Hardly! Just ask anybody in Kansas about the value of shade. Does this

Figure 6



mean that a wind system in an area with tall trees is impractical? Not at all. No matter where you live, you still have to install the wind generator on a tower. So what we are discussing is the incremental cost increase of an additional 30 feet of tower compared to the cost of the entire system. ("Tower Economics 102" in *HP#38* discusses this subject in detail.)

### Low Voltage Options

Since many *Home Power* readers already have low voltage systems, and a goodly number also probably live near tall trees, let's revisit this issue.

Going back to rule #5, I recommend increasing system voltage first. Resistance to change aside, this will always be the cheapest option. In addition, systems need not be restricted in total power output. A 12 Volt system, for example, is limited to a power output from a few hundred watts to about 1.5 kW. Due to the amount of current that must be generated, building 12 Volt wind equipment larger than this capacity is just not practical. Because of this, 12 Volt systems larger than 1.5 kW are not even commercially available.

There are, however, a few tricks that are available to low voltage system users facing extremely long wire runs. Many of the newer wind generators utilize permanent magnet alternators. These alternator's produce something called three phase wild ac, which is rectified to DC with diodes in the system's controller before travelling to the battery bank. A three phase wind system utilizes three wires to transmit current down the tower to the controller. A DC system only uses two wires, positive and negative.

The advantage of three phase ac is that the current produced by the alternator is split up and transported equally by its three wires. By contrast, all the current

produced by a DC generator is transported down a single wire. Three phase alternators can use lighter gauge wire for a given wind generator capacity at a given distance. Therefore, three phase permanent magnet wind generators offer greater flexibility in siting — they allow longer distances from the battery.

### High Voltage Transmission

One final trick that can be used for low voltage systems is to actually install a high voltage wind generator, but then step the voltage down at the batteries. With a three phase ac alternator, the solution is simple: use a three phase step-down transformer before the rectifiers. These transformers are relatively inexpensive when compared to cost of enormous wires.

Transformers are only about 85% efficient, so some power is lost in the process. The efficiency can be boosted somewhat by adding capacitors to the system. While a 15% loss of efficiency may be considered extreme by some, it is a small price to pay when the option is a much-compromised tower location tethered to welding cable-sized wires.

There is no such thing as a DC transformer for systems utilizing a DC wind generator. However, a linear current booster (LCB) performs essentially the same function as an ac step-down transformer. An LCB is a high speed switching device that will allow the user to transmit high voltage DC, reducing the voltage at the battery bank. LCBs are also about 85% efficient. They are, however, more expensive than transformers.

While neither the transformer nor the LCB is a cheap option, they do allow the user to cut down on the size wire needed. In many cases, these devices more than pay for themselves in money and aggravation when compared to the cost of heavy-duty wires. But their big advantage is that they allow the user to site their wind system at the most ideal location rather than compromise with less than ideal tower placement. We have customers using these devices that have sited their wind generators as far as 2000 feet from their battery bank.

### Sounds of Silence Broken

You may be thinking, why not virtually eliminate the wire run by just mounting the tower right on top of their house. Don't even consider this idea for several reasons. First of all, few roofs have the structural beefiness to support the loads presented by a wind generator and tower, let alone when the wind is trying to blow them over.

Second, even if your roof was strong enough or the tower was short enough or the generator was light enough, there is another serious drawback to this idea. Any rotating electrical generating device produce a harmonic that we can perceive by touch as a vibration. That harmonic vibration is transmitted down the tower. Touch one sometime and you will feel what I mean.

If the tower were attached anywhere to a building, the building itself would begin to resonate, similar to a guitar's sounding box. This resonance would vibrate the building, doing who knows what kind of structural damage over time. In addition, the resonance would develop into sound inside the building. Unless you are deaf and don't mind things walking off horizontal surfaces or jumping off walls whenever the wind is blowing, this is a pretty bad idea.

### Recap

Proper siting of a wind generator tower is actually easier than initially meets the eye, if you remember the following guidelines:

1. Minimize turbulence.
2. Install the tower at least 30 feet above anything within 500 feet.
3. Note your prevailing winds and stay upwind of any obstacles.
4. Minimize compromises in location, voltage, and tower height.
5. Consider higher voltages.
6. Rougher surfaces produce gustier winds.
7. If downwind of obstacles, compensate with a taller tower.
8. Trees grow, tower don't.
9. Never attach the tower to your house.

You now have the tools to properly site your wind generator. Take the time to ask questions and do it right. You will be rewarded with a system that takes the best advantage of one of Nature's greatest and most powerful gifts: the wind.

### Access

Mick Sagrillo flies his balloons at Lake Michigan Wind & Sun, E 3971 Bluebird Rd., Forestville, WI 54213 • 414-837-2267

Giant weather balloons:

American Scientific and Surplus, 3605 Howard St., Skokie, IL 60076 • 708-982-0870

Edmund Scientific, C911 Edscorp Building, Barrington, NJ 08007 • 609-547-8880



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# Appendix 2 Metric conversion charts

Imperial measurements are expressed below in yards, feet and inches rather than in decimals for convenience if converting with rulers or measuring tapes which do not include decimal readings.

## Metric prefixes and abbreviations

The metre is used as an example below. The same prefixes apply to litres (l or lit) and grams (g). The abbreviation lit is used for litre when unqualified to avoid confusion with the numeral 1.

millimetre (mm)	0.001	one thousandth metre
centimetre (cm)	0.01	one hundredth metre
decimetre (dm)	0.1	one tenth metre
metre (m)	1	one metre
decametre (dam)	10	ten metres
hectometre (hm)	100	one hundred metres
kilometre (km)	1000	one thousand metres

## Length (linear measure)

Conversion from inches is only taken up to 40 in the chart below, see next chart for continuation.

### Fractions of 1 inch in millimetres

Thirty-seconds, sixteenths, eighths, quarters and one half

<i>in</i>	<i>mm</i>
1/32	0.8
1/16	1.6
3/32	2.4
1/8	3.2
5/32	4.0
3/16	4.8
7/32	5.6
1/4	6.3
9/32	7.1
5/16	7.9
11/32	8.7
3/8	9.5
13/32	10.3
7/16	11.1
15/32	11.9
1/2	12.7
17/32	13.5
9/16	14.3
19/32	15.1
5/8	15.9
21/32	16.7
11/16	17.5
23/32	18.3
3/4	19.0
25/32	19.8
13/16	20.6
27/32	21.4
7/8	22.2
29/32	23.0
15/16	23.8
31/32	24.6
1 inch	25.4

Twelfths, sixths and thirds

<i>in</i>	<i>mm</i>
1/12	2.1
1/6	4.2
1/4	6.3
1/3	8.5
5/12	10.6
1/2	12.7
7/12	14.8
2/3	16.9
3/4	19.0
5/6	21.2
11/12	23.3
1 inch	25.4

## Note

Find the Imperial figure you wish to convert in the **heavy** type central column and read off the metric equivalent in the right-hand column and vice versa.

For example:

10 inches = 254 millimetres and 10mm = 0.39in.

### Inches/millimetres

<i>in</i>	<i>mm</i>
0.04	1
0.08	2
0.12	3
0.16	4
0.20	5
0.24	6
0.28	7
0.31	8
0.35	9
0.39	10
0.43	11
0.47	12
0.51	13
0.55	14
0.59	15
0.63	16
0.67	17
0.71	18
0.75	19
0.79	20
0.83	21
0.87	22
0.91	23
0.94	24
0.98	25
1.02	26
1.06	27
1.10	28
1.14	29
1.18	30
1.22	31
1.26	32
1.30	33
1.34	34
1.38	35
1.42	36
1.46	37
1.50	38
1.54	39
1.57	40
1.97	50
2.36	60
2.76	70
3.15	80
3.54	90
3.94	100
7.87	200
11.81	300
15.75	400
19.68	500
23.62	600
27.56	700
31.50	800
35.43	900
39.37	1000

### Feet/metres

<i>ft</i>	<i>in</i>	<i>m</i>
3	3	1
6	7	2
9	10	3
13	1	4
16	5	5
19	8	6
23	0	7
26	3	8
29	6	9
32	10	10
65	7	20
98	5	30
131	3	40
164	0	50
196	10	60
229	8	70
262	6	80
295	3	90
328	1	100

### Yards/metres

<i>yd</i>	<i>ft</i>	<i>in</i>	<i>m</i>
1	0	3	1
2	0	7	2
3	0	10	3
4	1	1	4
5	1	5	5
6	1	8	6
7	2	0	7
8	2	3	8
9	2	6	9
10	2	10	10
20	2	7	20
30	2	5	30
40	2	3	40
50	2	0	50
60	1	10	60
70	1	8	70
80	1	6	80
90	1	3	90
100	1	1	100

## Quick conversion factors – length

Terms are set out in full in the left-hand column except where clarification is necessary.

1 inch (in)	= 25.4mm/2.54cm
1 foot (ft)/12in	= 304.8mm/30.48cm/0.3048m
1 yard (yd)/3ft	= 914.4mm/91.44cm/0.9144m
1 mile (mi)/1760yd	= 1609.344m/1.609km
1 millimetre (mm)	= 0.0394in
1 centimetre (cm)/10mm	= 0.394in
1 metre (m)/100cm	= 39.37in/3.281ft/1.094yd
1 kilometre (km)/1000m	= 1093.6yd/0.6214mi

## Quick conversion factors – area

1 square inch (sq in)	= 645.16sq mm/ 6.4516sq cm
1 square foot (sq ft)/144sq in	= 929.03sq cm
1 square yard (sq yd)/9sq ft	= 8361.3sq cm/ 0.8361sq m
1 acre (ac)/4840sq yd	= 4046.9sq m/0.4047ha
1 square mile (sq mi)640ac	= 259ha
1 square centimetre (sq cm)/	
100 square millimetre (sq mm)	= 0.155sq in
1 square metre (sq m)/	
10,000sq cm	= 10.764sq ft/1.196sq yd
1 are (a)/100sq m	= 119.60sq yd/0.0247ac
1 hectare (ha)/100a	= 2.471ac/0.00386sq mi

## Quick conversion factors – volume

1 cubic inch (cu in)	= 16.3871cu cm
1 cubic foot (cu ft)/	
1728cu in	= 28.3168cu dm/0.0283cu m
1 cubic yard (cu yd)/	
27cu ft	= 0.7646cu m
1 cubic centimetre (cu cm)/	
1000 cubic millimetres (cu mm)	= 0.0610cu in
1 cubic decimetre (cu dm)/	
1000cu cm	= 61.024cu in/0.0353cu ft
1 cubic metre (cu m)/	
1000cu dm	= 35.3146cu ft/1.308cu yd
1 cu cm	= 1 millilitre (ml)
1 cu dm	= 1 litre (lit) See <b>Capacity</b>



# Useful equations and Conversion Factors

1. Areas of a rectangle = Length x width  
 Areas of a circle =  $\pi \times (\text{radius})^2$   
 Surface area of a cylinder  
     =  $2\pi \times \text{radius} \times \text{height} + 2\pi \times (\text{radius})^2$   
 Surface area of a sphere =  $4\pi (\text{radius})^2$
2. Volumes of a rectangular tank  
     = Length x Width x Height  
 Volumes of a cylinder =  $\pi \times (\text{radius})^2 \times \text{Height}$   
 Volumes of a sphere =  $\frac{4}{3}\pi \times (\text{radius})^3$
3. Retention time =  $\frac{\text{Volume of Tank}}{\text{Rate of flow of liquid or gas}}$
4. 1 inch = 2.54 cms.                      1 m. = 3.28 feet  
 1 foot = 0.305 m.                        1 sq. ft. = 0.093 sq. m.  
 1 sq. m. = 10.76 sq. ft.                1 cu. ft. = 28 litres = 0.028 m<sup>3</sup>.
5. 1 gallon = 4.55 litres                1 litre = 0.22 gallons  
 1 m<sup>3</sup> = 220 gallons
6. 1 gallon occupies 0.161 cu. ft.    1,000 litres in 1 cu. m.  
 1 cu. ft. = 6.23 gallons
7. 1 gallon of water weighs 10 lbs.  
 1 litre of water weighs 1 kg.
8. 1lb. = 0.454 kg.                        1 kg. = 0.221 lb.  
 2240lb. = 1 ton = 1.02 tonnes    1000kg. = 1 tonne = 0.984 tonne
9. 1 part per million = 1 milligram/litre = 1 gm/m<sup>3</sup>  
 1% = 10,000 ppm = 10,000 mgm/litre = 10 gm/litre
10. 1 cu. ft./lb. = 0.062 m<sup>3</sup>/kg.        1 m<sup>3</sup>/kg. = 16.1 cu. ft./lb.
11. 1 lb./cu. ft. = 16.2 kg./m<sup>3</sup>.       1 kg./m<sup>3</sup>. = 0.062lb./cu. ft.
12. 1 acre = 4,840 sq. yards = 0.405 hectares  
 1 hectare = 10,000 sq. metres = 2.47 acres
13. T °F =  $\frac{5}{9} (T - 32) ^\circ\text{C}$         T °C =  $\frac{9}{5} T + 32 ^\circ\text{F}$
14. Pressure: 1 in. of water = 0.25 m. bar  
                   1 lb/sq. in. (psi) = 68.95 m.bar  
                   1 atmosphere = 1.013 m.bar
15. 1 British Thermal Unit = 0.252 Kcals.  
     1 BTU = 1,055 Joules                1 Kcal = 3.97 BTU  
     1 Joule =  $9.5 \times 10^{-4}$  BTU        1 Kcal = 4.19 kJ.
16. 100,000 BTU = 1 Therm = 29.3 kilowatt hours
17. 1 BTU/cu. ft. = 0.038 J/cm<sup>3</sup> (or Mega Joules/m<sup>3</sup>)  
     1 J/cm<sup>3</sup> = 27.0 BTU/cu. ft.
18. 1 BTU/lb. = 2320 J/kg.            1J/kg. =  $4.29 \times 10^{-3}$  BTU/lb.
19. 1 BTU/hr. = 0.0011 mJ/hr.
20. Heat transfer coefficient:  
     1 BTU/ft.<sup>2</sup>/°F/hr. = 20.44 kJ/m<sup>2</sup>/°C/hr.

## TABLE OF CONVERSION FACTORS

Because different conventions historically have been used to measure various quantities, the following tables have been compiled to sort out the different units. This first table identifies the units typically used for describing a particular quantity. For example, speed might be measured in "miles/hour".

Most quantities can also be described in terms of the following three basic dimensions:

length	L
mass	M
time	T

For example, speed is given in terms of length divided by time, which can be written as "L/T". This description, called "dimensional analysis", is useful in

determining whether an equation is correct. The product of the dimensions on each side of the equal sign must match. For example:

$$\begin{aligned} \text{Distance} &= \text{Speed} \times \text{Time} \\ L &= L/T \times T \end{aligned}$$

The dimension on the left side of the equal sign is length, L. On the right side of the equal sign, the product of L/T times T is L, which matches the left side of the equation.

The second table is a Conversion Table, showing how to convert from one set of units to another. It might be necessary to take the reciprocal of the conversion factor or to make more than one conversion to get the desired results.

### Measured Quantities and Their Common Units

Length(L)	Area(L <sup>2</sup> )	Volume(L <sup>3</sup> )
mile(mi.)	sq. mile(mi <sup>2</sup> )	gallon(gal.)
yard(yd.)	sq. yard(yd <sup>2</sup> )	quart(qt.)
foot(ft.)	sq. foot(ft <sup>2</sup> )	pint(pt.)
inch(in.)	sq. inch(in <sup>2</sup> )	ounce(oz.)
fathom(fath.)	acre	cu. foot(ft <sup>3</sup> )
kilometer(km.)	sq. kilometer(km <sup>2</sup> )	cu. yard(yd <sup>3</sup> )
meter(m.)	sq. meter(m <sup>2</sup> )	cu. inch(in <sup>3</sup> )
centimeter(cm.)	sq. centimeter(cm <sup>2</sup> )	liter(l)
micron(μ)		cu. centimeter(cm <sup>3</sup> )
angstrom(Å)		acre-foot
		cord(cd)
		cord-foot
		barrel(bbl.)
<b>Mass(M)</b>	<b>Speed(L/T)</b>	<b>Flow Rate(L<sup>3</sup>/T)</b>
pound(lb.)	feet/minute (ft./min.)	cu. feet/min.
ton(short)	feet/sec.	cu. meter/min.
ton(long)	mile/hour	liters/sec.
ton(metric)	mile/min.	gallons/min.
gram(g.)	kilometer/hr.	gallons/sec.
kilogram(kg.)	kilometer/min. kilometer/sec.	
<b>Pressure(M/L<sup>2</sup>)</b>	<b>Energy(ML<sup>2</sup>/T<sup>2</sup>)</b>	<b>Power(ML<sup>2</sup>/T<sup>3</sup>)</b>
atmosphere(atm.)	British thermal unit(Btu.)	Btu./min.
pounds/sq. inch(psi)	calories(cal.)	Btu./hour
inches of mercury	foot-pound	watt
cm. of mercury	joule	joule/sec.
feet of water	kilowatt-hour (kw-hr.)	cal./min.
	horsepower-hour (hp.-hr.)	horsepower(hp.)
<b>Time(T)</b>	<b>Energy Density(M/T<sup>2</sup>)</b>	<b>Power Density(M/T<sup>3</sup>)</b>
year(yr)	calories/sq. cm.	cal./sq. cm./min.
month	Btu./sq. foot	Btu./sq. foot/hr
day	langley	langley/min.
hour(hr.)	watt/hr./sq. foot	watt/sq. cm.
minute(min.)		
second(sec.)		

### Table of Conversion Factors

MULTIPLY	BY	TO OBTAIN:
Acres	43560	Sq. feet
"	0.004047	Sq. kilometers
"	4047	Sq. meters
"	0.0015625	Sq. miles
"	4840	Sq. yards
Acre-feet	43560	Cu. feet
"	1233.5	Cu. meters
"	1613.3	Cu. yards
Angstroms(Å)	1 × 10 <sup>-8</sup>	Centimeters
"	3.937 × 10 <sup>-9</sup>	Inches
"	0.0001	Microns
Atmospheres(atm.)	76	Cm. of Hg(0°C)
"	1033.3	Cm. of H <sub>2</sub> O(4°C)
"	33.8995	Ft. of H <sub>2</sub> O(39.2°F)
"	29.92	In. of Hg(32°F)
"	14.696	Pounds/sq. inch(psi)
Barrels(petroleum, U.S.)(bbl.)	5.6146	Cu. feet
"	35	Gallons(Imperial)
"	42	Gallons(U.S.)
"	158.98	Liters
British Thermal Unit(Btu)	251.99	Calories, gm
"	777.649	Foot-pounds
"	0.00039275	Horsepower-hours
"	1054.35	Joules
"	0.000292875	Kilowatt-hours
"	1054.35	Watt-seconds
Btu/hr.	4.2	Calories/min.
"	777.65	Foot-pounds/hr.
"	0.0003927	Horsepower
"	0.000292875	Kilowatts
"	0.292875	Watts(or joule/sec.)
Btu/lb.	7.25 × 10 <sup>-4</sup>	Cal/gram
Btu/sq. ft.	0.271246	Calories/sq. cm. (or langleys)
"	0.292875	Watt-hour/sq. foot
Btu/sq. ft./hour	3.15 × 10 <sup>-7</sup>	Kilowatts/sq. meter
"	4.51 × 10 <sup>-3</sup>	Cal./sq. cm./min(or langleys/min)
"	3.15 × 10 <sup>-6</sup>	Watts/sq. cm.
Calories(cal.)	0.003968	Btu.
"	3.08596	Foot-pounds

Conversion Factors—Continued

"	1.55857 × 10 <sup>-6</sup>	Horsepower-hours	Furlong	220	Yards
"	4.184	Joules (or watt-sec)	Gallons(U.S., dry)	1.163647	Gallons(U.S., liq.)
"	1.1622 × 10 <sup>-6</sup>	Kilowatt-hours	Gallons(U.S., liq.)	3785.4	Cu. centimeters
Calories, food unit (Cal.)	1000	Calories	"	0.13368	Cu. feet
Calories/min.	0.003968	Btu/min.	"	231	Cu. inches
"	0.06973	Watts	"	0.0037854	Cu. meters
Calories/sq. cm.	3.68669	Btu/sq. ft.	"	3.7854	Liters
"	1.0797	Watt-hr/sq. foot	"	8	Pints(U.S., liq.)
Cal./sq. cm./min.	796320.	Btu/sq. foot/hr.	"	4	Quarts(U.S., liq.)
"	251.04	Watts/sq. cm.	Gallons/min.	2.228 × 10 <sup>-3</sup>	Cu. feet/sec.
Candle power (spherical)	12.566	Lumens	"	0.06308	Liters/sec.
Centimeters(cm.)	0.032808	Feet	Grams	0.035274	Ounces(avdp.)
"	0.3937	Inches	"	0.002205	Pounds(avdp.)
"	0.01	Meters	Grams-cm.	9.3011 × 10 <sup>-8</sup>	Btu.
"	10.000	Microns	Grams/meter <sup>2</sup>	3.98	Short ton/acre
Cm. of Hg(0°C)	0.0131579	Atmospheres	"	8.92	lbs./acre
"	0.44605	Ft. of H <sub>2</sub> O(4°C)	Horsepower	42.4356	Btu./min.
"	0.19337	Pounds/sq. inch	"	550	Foot-pounds/sec.
Cm. of H <sub>2</sub> O(4°C)	0.0009678	Atmospheres	"	745.7	Watts
"	0.01422	Pounds/sq. inch	Horsepower-hrs.	2546.14	Btu.
Cm./sec.	0.032808	Feet/sec.	"	641616	Calories
"	0.022369	Miles/hr.	"	1.98 × 10 <sup>6</sup>	Foot-pounds
Cords	8	Cord-feet	"	0.7457	Kilowatt-hours
"	128(or 4×4×8)	Cu. feet	Inches	2.54	Centimeters
Cu. centimeters	3.5314667	Cu. feet	"	0.83333	Feet
"	0.06102	Cu. inches	In. of Hg(32°F)	0.03342	Atmospheres
"	1 × 10 <sup>-4</sup>	Cu. meters	"	1.133	Feet of H <sub>2</sub> O
"	0.001	Liters	"	0.4912	Pounds/sq. inch
"	0.0338	Ounces(U.S. fluid)	In. of Water(4°C)	0.002458	Atmospheres
Cu. feet(ft. <sup>3</sup> )	0.02831685	Cu. meters	"	0.07355	In. of Mercury(32°F)
"	7.4805	Gallons(U.S., liq.)	"	0.03613	Pounds/sq. inch
"	28.31685	Liters	Joules	0.0009485	Btu.
"	29.922	Quarts(U.S., liq.)	"	0.73756	Foot-pounds
Cu. ft. of H <sub>2</sub> O (60°F)	62.366	Pounds of H <sub>2</sub> O	"	0.0002778	Watt-hours
Cu. feet/min.	471.947	Cu. cm./sec.	"	1	Watt-sec.
Cu. inches(in. <sup>3</sup> )	16.387	Cu. cm.	Kilo calories/gram	1378.54	Btu/lb
"	0.0005787	Cu. feet	Kilograms	2.2046	Pounds(avdp.)
"	0.004329	Gallons(U.S., liq.)	Kilograms/hectare	.893	lbs/acre
"	0.5541	Ounces(U.S., fluid)	Kilograms/hectare	.0004465	Short ton/acre
Cu. meters	1 × 10 <sup>6</sup>	Cu. centimeters	Kilometers	1000	Meters
"	35.314667	Cu. feet	"	0.62137	Miles(statute)
"	264.172	Gallons(U.S., liq.)	Kilometer/hr.	54.68	Feet/min.
"	1000	Liters	Kilowatts	3414.43	Btu./hr.
Cu. yard	27	Cu. feet	"	737.56	Foot-pounds/sec.
"	0.76455	Cu. meters	"	1.34102	Horsepower
"	201.97	Gallons(U.S., liq.)	Kilowatt-hours	3414.43	Btu.
Cubits	18	Inches	"	1.34102	Horsepower-hours
Fathoms	6	Feet	Knots	51.44	Centimeter/sec.
"	1.8288	Meters	"	1	Mile(nautical)/hr.
Feet(ft.)	30.48	Centimeters	"	1.15078	Miles(Statute)/hr.
"	12	Inches	Langleys	1	Calories/sq. cm.
"	0.00018939	Miles(statute)	Liters	1000	Cu. centimeters
Feet of H <sub>2</sub> O(4°C)	0.029499	Atmospheres	"	0.0353	Cu. feet
"	2.2419	Cm. of Hg(0°C)	"	0.2642	Gallons(U.S., liq.)
"	0.433515	Pounds/sq. inch	"	1.0567	Quarts(U.S., liq.)
Feet/min.	0.508	Centimeters/second	Lbs./acre	.0005	Short ton/acre
"	0.018288	Kilometers/hr.	Liters/min.	0.0353	Cu. feet/min.
"	0.0113636	Miles/hr.	"	0.2642	Gallons(U.S., liq.)/min.
Foot-candles	1	Lumens/sq. foot	Lumens	0.079577	Candle power(spherical)
Foot-pounds	0.001285	Btu.	Lumens(at 5550Å)	0.0014706	Watts
"	0.324048	Calories	Meters	3.2808	Feet
"	5.0505 × 10 <sup>-7</sup>	Horsepower-hours	"	39.37	Inches
"	3.76616 × 10 <sup>-7</sup>	Kilowatt-hours	"	1.0936	Yards
			Meters/sec.	2.24	Miles/hr.
			Micron	10000	Angstroms
			"	0.0001	Centimeters
			Miles(statute)	5280	Feet

*Conversion Factors—Continued*

"	1.6093	Kilometers
"	1760	Yards
Miles/hour	44.704	Centimeter/sec.
"	88	Feet/min.
"	1.6093	Kilometer/hr.
"	0.447	Meters/second
Milliliter	1	Cu. centimeter
Millimeter	0.1	Centimeter
Ounces(avdp.)	0.0625	Pounds(avdp.)
Ounces(U.S., liq.)	29.57	Cu. centimeters
"	1.8047	Cu. inches
"	0.0625(or 1/16)	Pint(U.S., liq.)
Pints(U.S., liq.)	473.18	Cu. centimeters
"	28.875	Cu. inches
"	0.5	Quarts(U.S., liq.)
Pounds(avdp.)	0.45359	Kilograms
"	16	Ounces(avdp.)
Pounds of water	0.01602	Cu. feet of water
"	0.1198	Gallons(U.S., liq.)
Pounds/acre	0.0005	Short ton/acre
Pounds/sq. inch	0.06805	Atmospheres
"	5.1715	Cm. of mercury(0°C)
"	27.6807	In. of water(39.2°F)
Quarts(U.S., liq.)	0.25	Gallons(U.S., liq.)
"	0.9463	Liters
"	32	Ounces(U.S., liq.)
"	2	Pints(U.S., liq.)
Radians	57.30	Degrees
Sq. centimeters	0.0010764	Sq. feet
"	0.1550	Sq. inches
Sq. feet	2.2957 × 10 <sup>-5</sup>	Acres
"	0.09290	Sq. meters
Sq. inches	6.4516	Sq. centimeters
"	0.006944	Sq. feet
Sq. kilometers	247.1	Acres
"	1.0764 × 10 <sup>7</sup>	Sq. feet
"	0.3861	Sq. miles
Sq. meters	10.7639	Sq. feet
"	1.196	Sq. yards
Sq. miles	640	Acres
"	2.788 × 10 <sup>7</sup>	Sq. feet
"	2.590	Sq. kilometers
Sq. yards	9(or 3×3)	Sq. feet
"	0.83613	Sq. meters
Tons, long	1016	Kilograms
"	2240	Pounds(avdp.)
Tons(metric)	1000	Kilograms
"	2204.6	Pounds(avdp.)
Tons, metric/hectare	0.446	Short ton/acre
Tons(short)	907.2	Kilograms
"	2000	Pounds(avdp.)
Watts	3.4144	Btu./hr.
"	0.05691	Btu./min.
"	14.34	Calories/min.
"	0.001341	Horsepower
"	1	Joule/sec.
Watts/sq. cm.	3172	Btu./sq. foot/hr.
Watt-hours	3.4144	Btu.
"	860.4	Calories
"	0.001341	Horsepower-hours
Yards	3	Feet
"	0.9144	Meters

*Average Power Outputs in Watts*

Average windspeed:	3 m/s 7 mph	4.5m/s 10 mph	6 m/s 13 mph
Blade diameter 1m	4	13	30
Blade diameter 2m	15	51	121
Blade diameter 3m	34	115	272
Blade diameter 4m	60	204	483

# Windpower equations

(These equations are in a form suitable for use in a computer programme.)

\* means 'multiply by', / means 'divide by', and ^ means 'to the power of' the first thing (only) that follows the symbol.

Variable	Symbol	Units	Notes or Equation
Pi	Pi	none	$\bar{\pi} = 3.14$ (geometrical constant)
Density of air	rho	kg/m <sup>3</sup>	rho = 1.2 (temperature dependent)
Power coeff.	Cp	none	Cp < 0.6, say 0.15
Windspeed	V	m/s	try 10m/s (= 22mph)
Diameter	D	metres	$D = (P / (Cp * rho / 2 * \bar{\pi} / 4 * V^3))^{0.5}$
Power	P	watts	$P = Cp * rho / 2 * \bar{\pi} / 4 * D^2 * V^3$
Mean windspeed	Vm	m/s	Vm = around 5 m/s usually
Mean power	Pm	watts	$Pm = 0.14 * D^2 * Vm^3$ (approx.)
Tip speed ratio	tsr	none	$tsr = rpm \times \pi \times D / 60 / V$
Shaft speed	rpm	rpm	$rpm = 60 \times V \times tsr / (\pi \times D)$
<b>Blade Design</b>			
Radius (station)	Rs	metres	distance from central axis
No. of blades	B	none	An integer (3 is best)
Lift coeff.	Cl	none	Cl = 0.8 say (alpha dependent)
Angle of attack	alpha	degrees	alpha = 4 say (chosen for best lift/drag)
Setting angle	beta	degrees	$\beta = ATAN[D/3/Rs/tsr] * 57.3 * \alpha$
<i>(NOTE: 'ATAN( )' is a software function giving 'the angle whose tangent is' in radians.)</i>			
Chord width	Cw	m	$Cw = 1.4 * D^2 / Rs * COS[\beta / 57.3]^2 / tsr^2 / B / Cl$
<b>Tail Vane side force</b>			
Area of vane	Avane	m <sup>2</sup>	$Avane > D^2 / 40$
Side force	Fside	kg	$Fside = Avane * V^2 / 16$
Rotor thrust	Frotor	kg	$Frotor = D^2 * V^2 / 24$
<b>Copper loss in wires/cables</b>			
Copper diam.	Wdiam	mm	Wdiam = diameter of wire
Copper area	Warea	mm <sup>2</sup>	$Warea = Wdiam^2 * 0.785$
Twin cable len.	Tcl	m	if investigating cable
Single wire len.	Swl	m	$Swl = Tcl^2$ [or Swl = length of wire in coils]
Single wire res.	Swr	ohms	$Swr = Swl / Warea / 50$
<i>(NOTE: Resistance is at copper temp. = 40 deg.C, increasing by factor of .004/deg.C.)</i>			
Current	I	amps	I = current through coil or cable
Volt drop	Vdrop	volts	$Vdrop = Swr * I$
Power lost	Ploss	watts	$Ploss = Vdrop * I$

Variable	Symbol	Units	Notes or Equation
<b>Alternators</b>			
No. of poles	$N_p$	even no	$N_p = 120 \cdot f / \text{rpm}$
Frequency	$f$	Hz	$f = N_p \cdot \text{rpm} / 120$
Length of airgap	$l_{\text{gap}}$	m	length parallel to axis
Diam. of airgap	$D_{\text{gap}}$	m	$D_{\text{gap}} = \text{radius from shaft axis} \cdot 2$
Area of air gap	$A_{\text{gap}}$	$\text{m}^2$	$A_{\text{gap}} = l_{\text{gap}} \cdot \pi \cdot D_{\text{gap}}$
Cut-in speed	$C_{\text{rpm}}$	rpm	$C_{\text{rpm}} = 12 \text{ volt cut-in speed}$
No. of coils		$N_{\text{coils}}$	$N_{\text{coils}} = \text{no. of coils in series}$
Turns/coil		$N_{\text{turns}}$	$N_{\text{turns}} = 1200 / A_{\text{gap}} / C_{\text{rpm}} / N_{\text{coils}}$
<i>(Note this is only approximate. Increase by 50% for very large airgaps)</i>			

### Variables:

<b>A</b>	Cross-sectional area of copper wire in cable (in square millimetres)
<b>AP</b>	Average power (watts)
<b>AV</b>	Average windspeed (m/s)
<b>CP</b>	Power coefficient (measure of efficiency - cannot exceed 0.6 and should exceed 0.1)
<b>D</b>	Rotor diameter (metres)
<b>DP</b>	Power loss (watts)
<b>DV</b>	Volt drop (volts)
<b>E</b>	Energy (kWh)
<b>I</b>	Electric current (amps)
<b>L</b>	Length of a twin copper cable one way (metres)
<b>P</b>	Power (watts)
<b>P (VW)</b>	Power output of wind turbine at windspeed VW (watts)
<b>RPM</b>	Rotational speed (rpm)
<b>T</b>	Time (hours)
<b>V</b>	System voltage (volts)
<b>VT</b>	Tip speed (m/s)
<b>VW</b>	Windspeed (m/s)
<b>x</b>	multiplication symbol
<b>/</b>	divide by what follows

### Cables:

Volt drop  $DV = L \times I / (30 \times A)$       Where  $I = P / V$   
Power loss  $DP = DV \times I = L \times P / (30 \times A)$

Energy:  $E = P \times T / 1000 = V \times I \times T / 1000$   
 $= V \times \text{amp-hours} / 1000$

Tip speed:  $VT = \text{RPM} \times D / 19.1$

Power coeff.  $CP = P / (0.48 \times D^2 \times VW^3)$

### Algorithm for finding average power:

For  $VW = 1$  to 20

$AP = AP + 1.57 \times (VW / AV^2) \times \text{EXP}(-0.79 \times (VW / AV)^2) \times P(VW)$

Next  $VW$

(EXP is the exponential function; your computer should understand.)

# Conversions: length

Use of the table: the number of inches to be converted, which is made up by the number of inches at the head of a column and the fraction at the side of a line, is converted to the number in the position where line and column meet. For example, 1 1/64 in = 1 in + 1/64 in = 25.797 mm

## Inches and fractions of an inch to Millimetres

1 in = 25.4 mm

in →	0	1	2	3	4	5	6	7	8	9	10	11	← in
↓	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	↓
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	254.000	279.400	0
1/64	0.397	25.797	51.197	76.597	101.997	127.397	152.797	178.197	203.597	228.997	254.397	279.797	1/64
1/32	0.794	26.194	51.594	76.994	102.394	127.794	153.194	178.594	203.994	229.394	254.794	280.194	1/32
3/64	1.191	26.591	51.991	77.391	102.791	128.191	153.591	178.991	204.391	229.791	255.191	280.591	3/64
1/16	1.588	26.988	52.388	77.788	103.188	128.588	153.988	179.388	204.788	230.188	255.588	280.988	1/16
5/64	1.984	27.384	52.784	78.184	103.584	128.984	154.384	179.784	205.184	230.584	255.984	281.384	5/64
3/32	2.381	27.781	53.181	78.581	103.981	129.381	154.781	180.181	205.581	230.981	256.381	281.781	3/32
7/64	2.778	28.178	53.578	78.978	104.378	129.778	155.178	180.578	205.978	231.378	256.778	282.178	7/64
1/8	3.175	28.575	53.975	79.375	104.775	130.175	155.575	180.975	206.375	231.775	257.175	282.575	1/8
9/64	3.572	28.972	54.372	79.772	105.172	130.572	155.972	181.372	206.772	232.172	257.572	282.972	9/64
5/32	3.969	29.369	54.769	80.169	105.569	130.969	156.369	181.769	207.169	232.569	257.969	283.369	5/32
11/64	4.366	29.766	55.166	80.566	105.966	131.366	156.766	182.166	207.566	232.966	258.366	283.766	11/64
3/16	4.762	30.162	55.562	80.962	106.362	131.762	157.162	182.562	207.962	233.362	258.762	284.162	3/16
13/64	5.159	30.559	55.959	81.359	106.759	132.159	157.559	182.959	208.359	233.759	259.159	284.559	13/64
7/32	5.556	30.956	56.356	81.756	107.156	132.556	157.956	183.356	208.756	234.156	259.556	284.956	7/32
15/64	5.953	31.353	56.753	82.153	107.553	132.953	158.353	183.753	209.153	234.553	259.953	285.353	15/64
1/4	6.350	31.750	57.150	82.550	107.950	133.350	158.750	184.150	209.550	234.950	260.350	285.750	1/4
17/64	6.747	32.147	57.547	82.947	108.347	133.747	159.147	184.547	209.947	235.347	260.747	286.147	17/64
9/32	7.144	32.544	57.944	83.344	108.744	134.144	159.544	184.944	210.344	235.744	261.144	286.544	9/32
19/64	7.541	32.941	58.341	83.741	109.141	134.541	159.941	185.341	210.741	236.141	261.541	286.941	19/64
5/16	7.938	33.338	58.738	84.138	109.538	134.938	160.338	185.738	211.138	236.538	261.938	287.338	5/16
21/64	8.334	33.734	59.134	84.534	109.934	135.334	160.734	186.134	211.534	236.934	262.334	287.734	21/64
11/32	8.731	34.131	59.531	84.931	110.331	135.731	161.131	186.531	211.931	237.331	262.731	288.131	11/32
23/64	9.128	34.528	59.928	85.328	110.728	136.128	161.528	186.928	212.328	237.728	263.128	288.528	23/64
3/8	9.525	34.925	60.325	85.725	111.125	136.525	161.925	187.325	212.725	238.125	263.525	288.925	3/8
25/64	9.922	35.322	60.722	86.122	111.522	136.922	162.322	187.722	213.122	238.522	263.922	289.322	25/64
13/32	10.319	35.719	61.119	86.519	111.919	137.319	162.719	188.119	213.519	238.919	264.319	289.719	13/32
27/64	10.716	36.116	61.516	86.916	112.316	137.716	163.116	188.516	213.916	239.316	264.716	290.116	27/64
7/16	11.112	36.512	61.912	87.312	112.712	138.112	163.512	188.912	214.312	239.712	265.112	290.512	7/16
29/64	11.509	36.909	62.309	87.709	113.109	138.509	163.909	189.309	214.709	240.109	265.509	290.909	29/64
15/32	11.906	37.306	62.706	88.106	113.506	138.906	164.306	189.706	215.106	240.506	265.906	291.306	15/32
31/64	12.303	37.703	63.103	88.503	113.903	139.303	164.703	190.103	215.503	240.903	266.303	291.703	31/64
1/2	12.700	38.100	63.500	88.900	114.300	139.700	165.100	190.500	215.900	241.300	266.700	292.100	1/2
33/64	13.097	38.497	63.897	89.297	114.697	140.097	165.497	190.897	216.297	241.697	267.097	292.497	33/64
17/32	13.494	38.894	64.294	89.694	115.094	140.494	165.894	191.294	216.694	242.094	267.494	292.894	17/32
35/64	13.891	39.291	64.691	90.091	115.491	140.891	166.291	191.691	217.091	242.491	267.891	293.291	35/64
9/16	14.288	39.688	65.088	90.488	115.888	141.288	166.688	192.088	217.488	242.888	268.288	293.688	9/16
37/64	14.684	40.084	65.484	90.884	116.284	141.684	167.084	192.484	217.884	243.284	268.684	294.084	37/64
19/32	15.081	40.481	65.881	91.281	116.681	142.081	167.481	192.881	218.281	243.681	269.081	294.481	19/32
39/64	15.478	40.878	66.278	91.678	117.078	142.478	167.878	193.278	218.678	244.078	269.478	294.878	39/64
5/8	15.875	41.275	66.675	92.075	117.475	142.875	168.275	193.675	219.075	244.475	269.875	295.275	5/8
41/64	16.272	41.672	67.072	92.472	117.872	143.272	168.672	194.072	219.472	244.872	270.272	295.672	41/64
21/32	16.669	42.069	67.469	92.869	118.269	143.669	169.069	194.469	219.869	245.269	270.669	296.069	21/32
43/64	17.066	42.466	67.866	93.266	118.666	144.066	169.466	194.866	220.266	245.666	271.066	296.466	43/64
11/16	17.462	42.862	68.262	93.662	119.062	144.462	169.862	195.262	220.662	246.062	271.462	296.862	11/16
45/64	17.859	43.259	68.659	94.059	119.459	144.859	170.259	195.659	221.059	246.459	271.859	297.259	45/64
23/32	18.256	43.656	69.056	94.456	119.856	145.256	170.656	196.056	221.456	246.856	272.256	297.656	23/32
47/64	18.653	44.053	69.453	94.853	120.253	145.653	171.053	196.453	221.853	247.253	272.653	298.053	47/64
3/4	19.050	44.450	69.850	95.250	120.650	146.050	171.450	196.850	222.250	247.650	273.050	298.450	3/4
49/64	19.447	44.847	70.247	95.647	121.047	146.447	171.847	197.247	222.647	248.047	273.447	298.847	49/64
25/32	19.844	45.244	70.644	96.044	121.444	146.844	172.244	197.644	223.044	248.444	273.844	299.244	25/32
51/64	20.241	45.641	71.041	96.441	121.841	147.241	172.641	198.041	223.441	248.841	274.241	299.641	51/64
13/16	20.638	46.038	71.438	96.838	122.238	147.638	173.038	198.438	223.838	249.238	274.638	300.038	13/16
53/64	21.034	46.434	71.834	97.234	122.634	148.034	173.434	198.834	224.234	249.634	275.034	300.434	53/64
27/32	21.431	46.831	72.231	97.631	123.031	148.431	173.831	199.231	224.631	250.031	275.431	300.831	27/32
55/64	21.828	47.228	72.628	98.028	123.428	148.828	174.228	199.628	225.028	250.428	275.828	301.228	55/64
7/8	22.225	47.625	73.025	98.425	123.825	149.225	174.625	200.025	225.425	250.825	276.225	301.625	7/8
57/64	22.622	48.022	73.422	98.822	124.222	149.622	175.022	200.422	225.822	251.222	276.622	302.022	57/64
29/32	23.019	48.419	73.819	99.219	124.619	150.019	175.419	200.819	226.219	251.619	277.019	302.419	29/32
59/64	23.416	48.816	74.216	99.616	125.016	150.416	175.816	201.216	226.616	252.016	277.416	302.816	59/64
15/16	23.812	49.212	74.612	100.012	125.412	150.812	176.212	201.612	227.012	252.412	277.812	303.212	15/16
61/64	24.209	49.609	75.009	100.409	125.809	151.209	176.609	202.009	227.409	252.809	278.209	303.609	61/64
31/32	24.606	50.006	75.406	100.806	126.206	151.606	177.006	202.406	227.806	253.206	278.606	304.006	31/32
63/64	25.003	50.403	75.803	101.203	126.603	152.003	177.403	202.803	228.203	253.603	279.003	304.403	63/64









## How to Build a Post Windmill

Väderkvarner: Anne & Scott MacGregor. DK. 1984. 91-510-4205-3.

### Material required:

- A: 2 sheets of thin cardboard.
- B: 1 sheet of medium-thick cardboard.
- C: 1 piece of thick cardboard - 20 cms. x 20 cms. [200 x 200 mm.].
- D: 48 matches or wooden toothpicks - about 42 mm. long.
- E: 2 new sharp pencils.
- F: 3 cotton-reels - 32 mm. diameter.
- G: Paper clips, staples, 4 thin flat split-pins as used for fastening large envelopes, tape or duct tape, tracing or carbon paper, glue, etc.

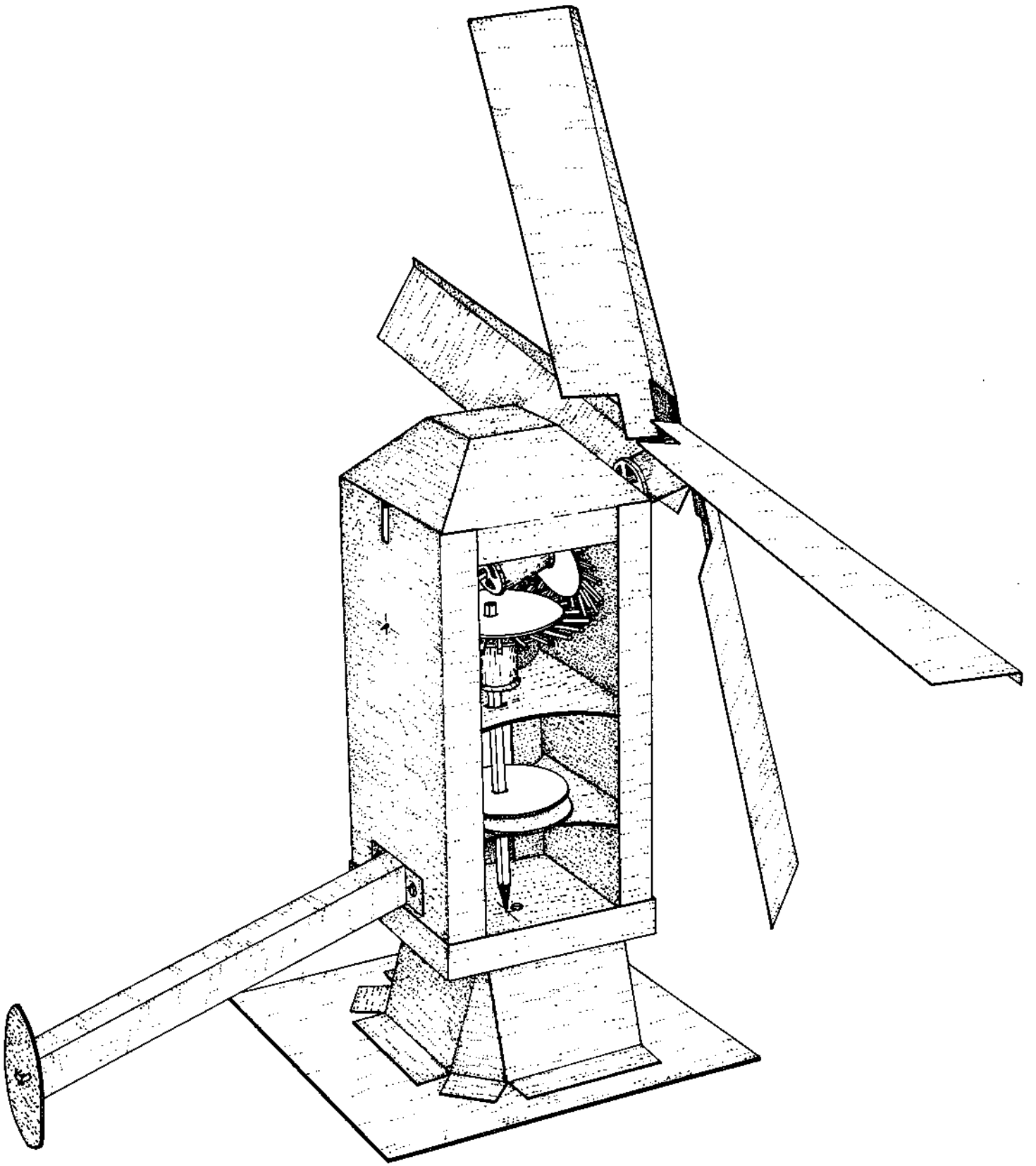
### Tools required:

Sissors, hobby or modelling knife, compass, sharp pencil, ballpoint pen, ruler, etc.

Cut out along the thick lines. Score and bend along the striped lines, as shown.

Use paper clips or staples to hold the different components together during glueing. Score carefully and with caution, along the straight striped lines using a ruler and the back of a knife blade, or with a sharp pencil or ballpoint pen, - before bending.

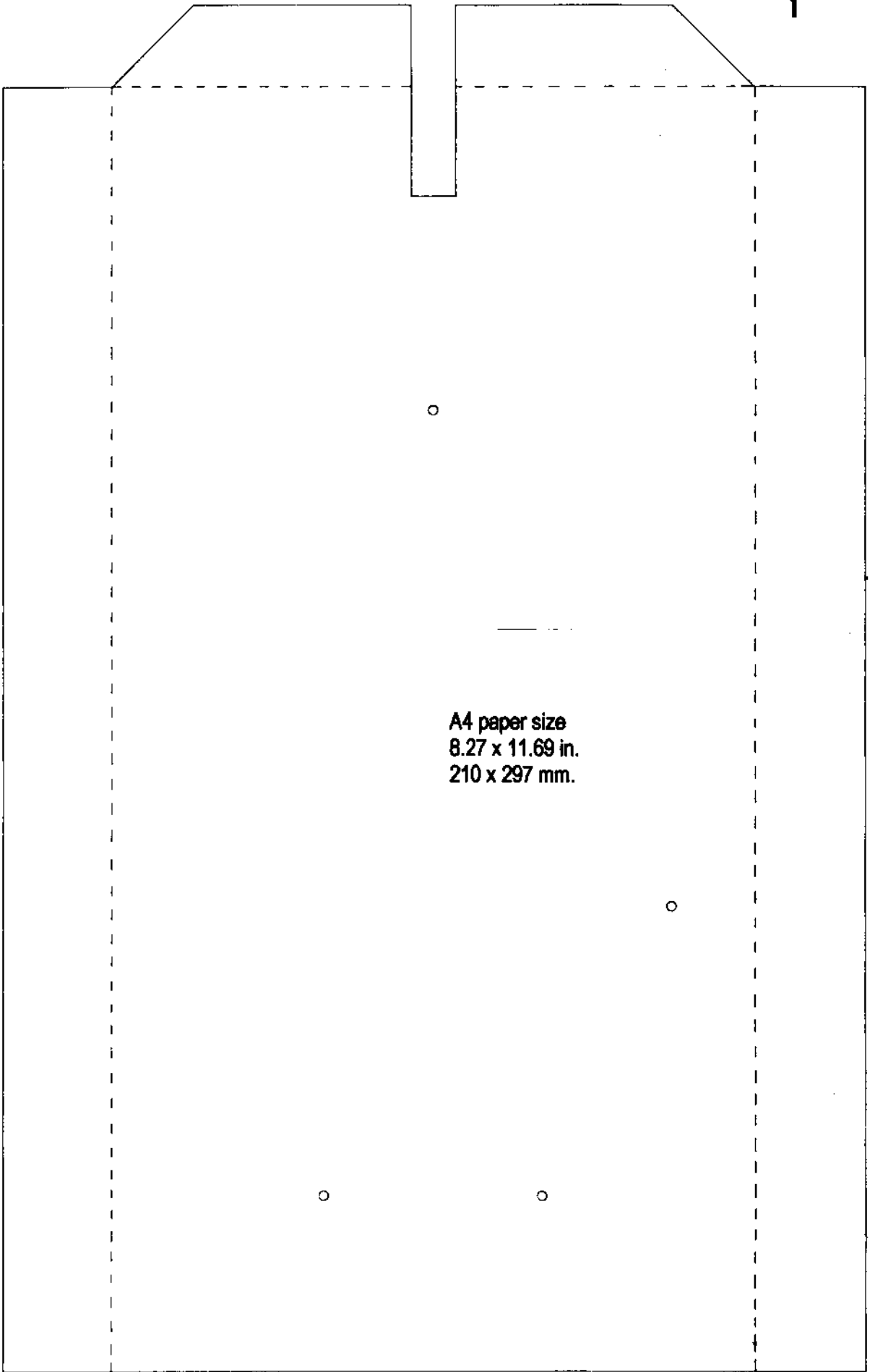
- 1: Trace or copy the **windmill tower** wall pattern drawing onto a sheet of thin cardboard, - cut out **2 tower walls**. Bend as illustrated and make two holes with a sharp pencil in the rear tower wall for the main rotor shaft - [**windshaft**] and for the **tailpole**.
- 2: Trace or copy the **bottom floor** pattern onto a sheet of thin cardboard, cut out and make the bottom hole with a sharp pencil.
- 3: Bend up the floor side flaps, - assemble and glue them to the walls. Ensure that the wall side flaps are bent inwards as illustrated.
- 4: Trace or copy the **floor** pattern onto a sheet of thin cardboard and cut out **2 floors**. Bend down the flaps and make a **9 mm.** hole for the mill-stone shaft. This hole must be large enough for a pencil to rotate freely.
- 5: Position both floors and glue all **4 flaps** on the walls, as illustrated.
- 6: Trace or copy the **cog or peg gear wheel** pattern and cut out **4 circles** from a sheet of medium-thick cardboard. Make a hole in the exact center of each circle, by pressing a pencil through the middle.
- 7: To construct the **2 peg gear wheels**, **24 matches** are carefully glued onto each wheel as shown. The matches must project **15 mm.** from the circumference of the circles.
- 8: Carefully glue the **2** remaining circles on top of the **2 sets** of glued matches.
- 9: Carefully glue **2 cotton reels** onto one side of each assembled peg wheel. Use the thick striped line for guidance so that the reels will be placed in the exact center of the wheel.
- 10: Push **2 sharp pencils** through the center holes in both peg wheels. Ensure that the pencils fit tightly inside the cotton reels, by wrapping tape or duct tape around the pencil.  
**Note that:** The illustration should show the exact position and measurements of the pencils and peg gear wheels representing the two drive shafts.
- 11: Using the drawing of the gear wheel - trace or copy **2 circles** from medium-thick



cardboard, - for the **millstones**. Make a **9 mm**. hole in **1 circle** - so that a pencil can freely rotate inside the hole. This **bed** millstone is then glued to the floor, as shown.

- 12:** Make a tight hole in the second millstone - [**the runner**], - with a pencil. Position the assembled upright shaft - [**B**]. Ensure that the runner does not touch the bed millstone.
- 13:** Position the windshaft and main peg gear **brake wheel A**, - so that the brake wheel and the upright millstone shaft with the peg gear **wallower wheel B** - inter-mesh. If these units are assembled correctly, they should easily rotate when the windshaft is turned.
- 14:** Trace or copy the drawing for the **rotor hub** and cut out from a sheet of medium-thick cardboard.
- 15:** Trace or copy the **rotor blades** from a sheet of thin cardboard. Cut out **4 blades** and bend as illustrated.
- 16:** Glue **2 blades** onto the rotor hub.
- 17:** Then glue the other **2 blades** onto the rotor hub, so that they cover the first 2 blades as shown.
- 18:** Turn the assembled blades over and carefully glue a **cotton reel** on the rear side, in the exact center of the hub, in order to provide extra strength.
- 19:** Trace or copy the drawing of the **roundhouse** and cut out from a sheet of medium-thick cardboard. Make a hole with the tip of a sharp pencil. Bend and glue the **2 angled flaps** - inside, as shown.
- 20:** Glue the roundhouse to thick cardboard.
- 21:** Trace or copy the **roof** drawing and cut from a sheet of medium-thick cardboard. Cut, bend and glue the corners as illustrated.
- 22:** Trace or copy the drawing of the **tailpole** and cut out from thin cardboard. Make holes as shown. Bend the end flaps and glue together the flaps marked with **X**.
- 23:** Place the tower on the roundhouse and fasten with an envelope flat split-pin, as shown at **A**.
- 24:** Fasten the tailpole to the tower with **2** envelope flat split-pins as shown at **B**.
- 25:** Trace or copy a **circle** from the gear wheel drawing onto medium-thick cardboard. Cut out, - make a small hole in the center and fasten with an envelope flat split-pin at **C**.
- 26:** Position the rotor blades on the main rotor windshaft as shown at **D**, and fasten by wrapping carefully with tape.
- 27:** Place in position and fasten the roof, as shown at **E**.

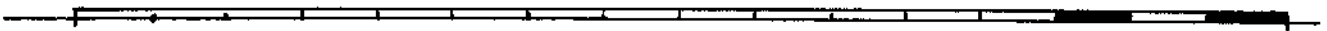
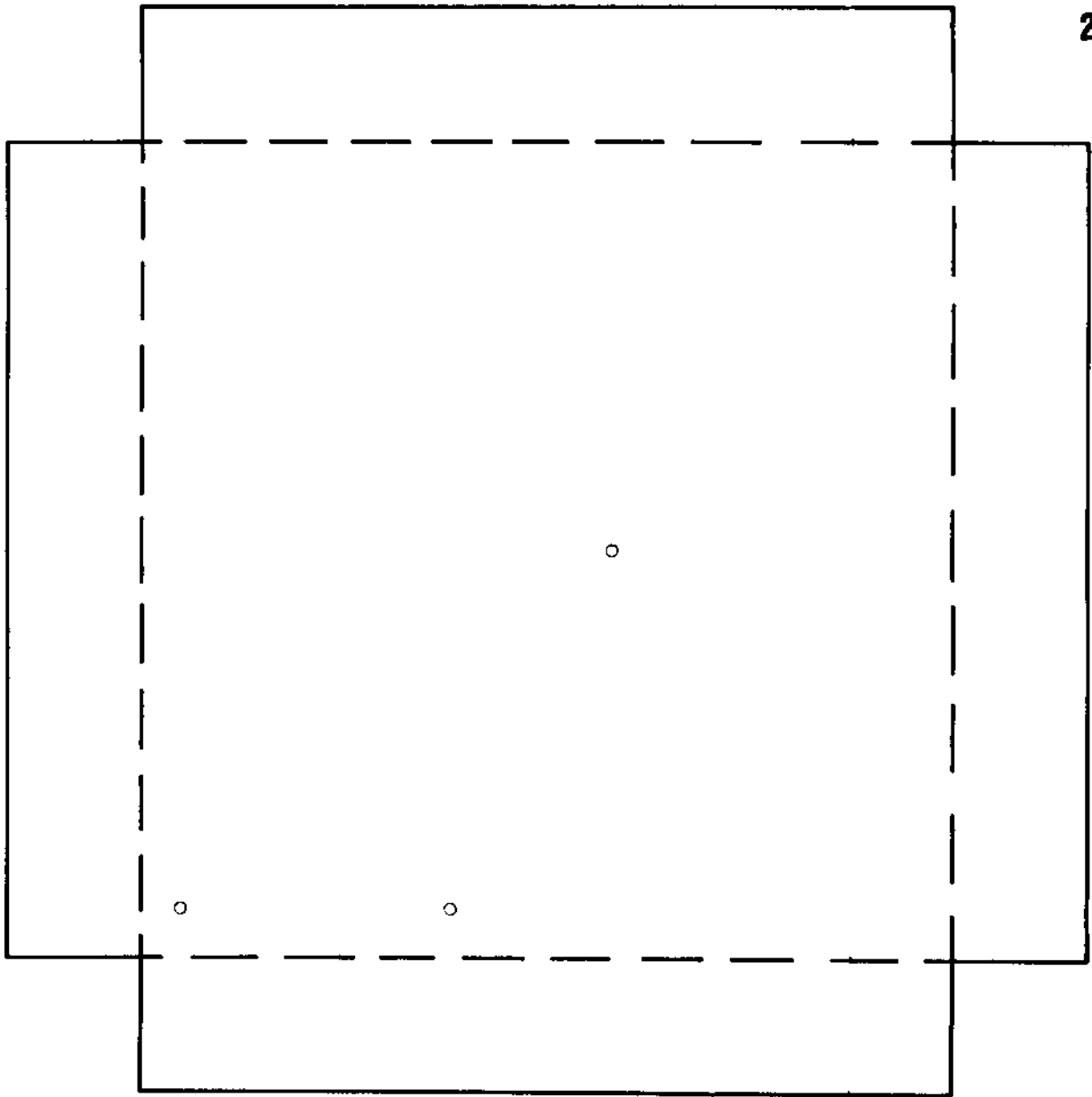
The Post Windmill is now finished. The windmill is turned to face the wind with the help of the tailpole so that the rotor blades may catch the wind. Try and blow an air stream on the blades with the help of an electric fan. Or even better take the model outside and let the wind turn the rotor blades - as the wind does on a full-size windmill.



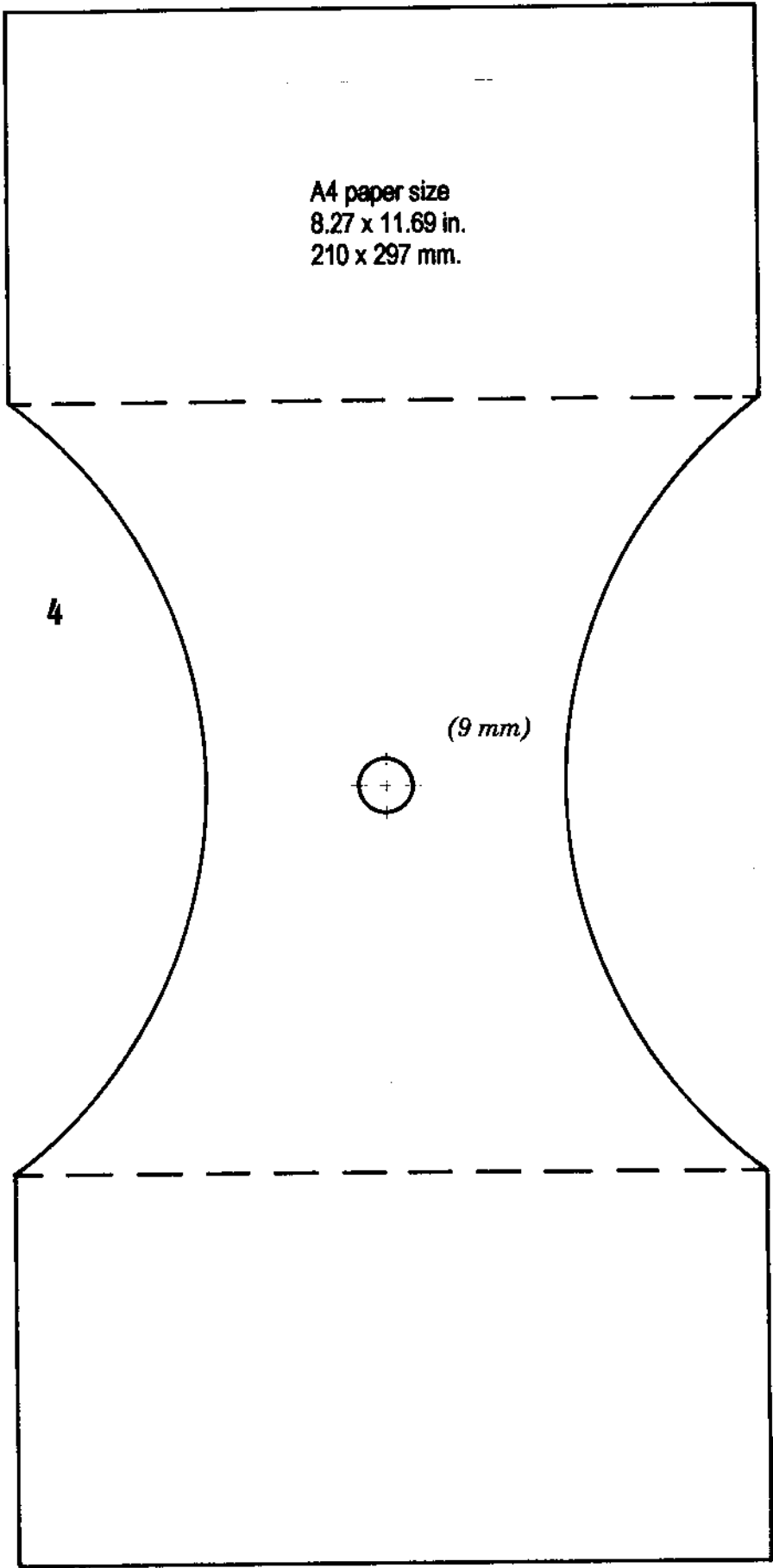
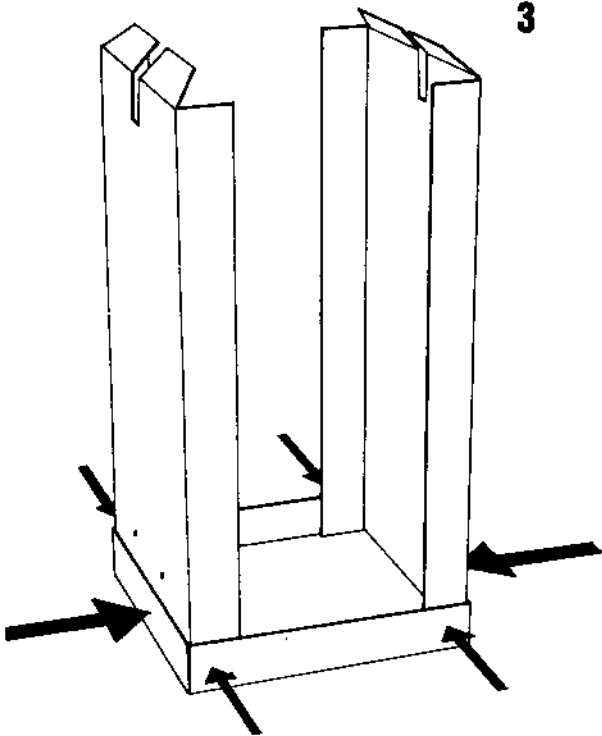
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8.27 x 11.69 in.  
210 x 297 mm.

A4 paper size  
8.27 x 11.69 in.  
210 x 297 mm.

2



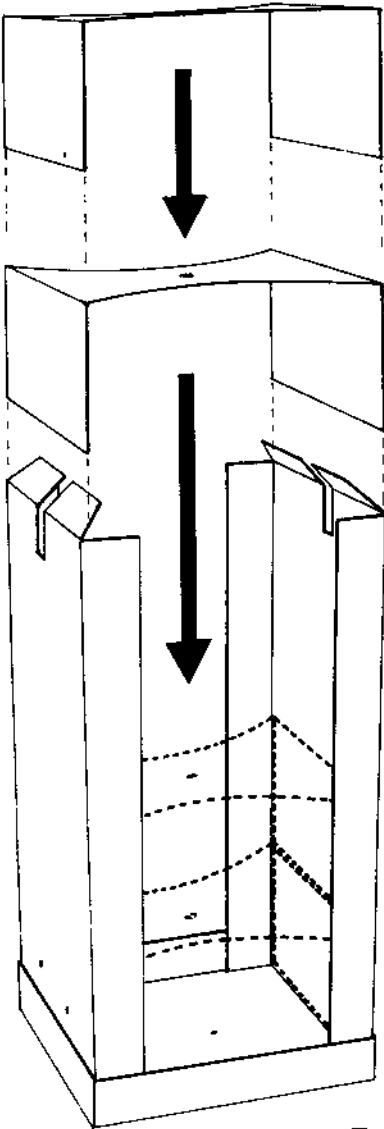
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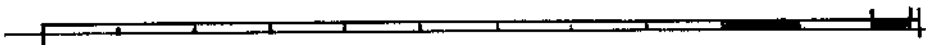
A4 paper size  
8.27 x 11.69 in.  
210 x 297 mm.

4

(9 mm)



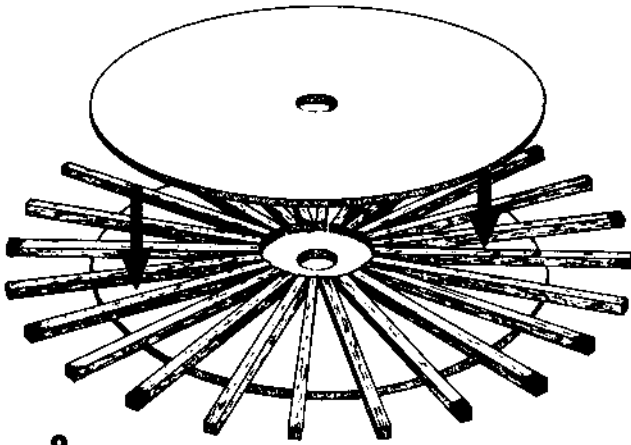
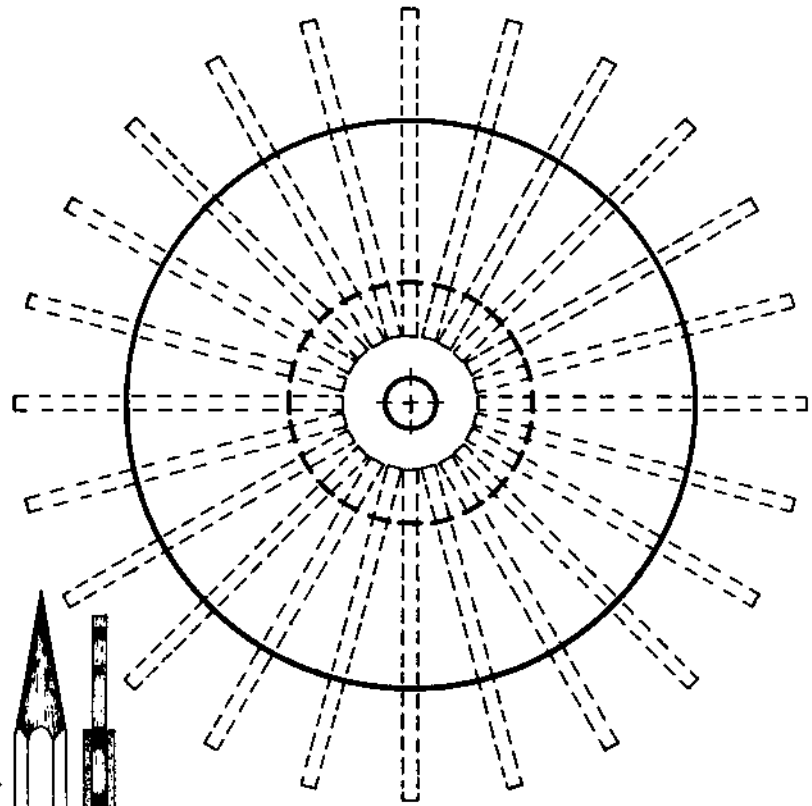
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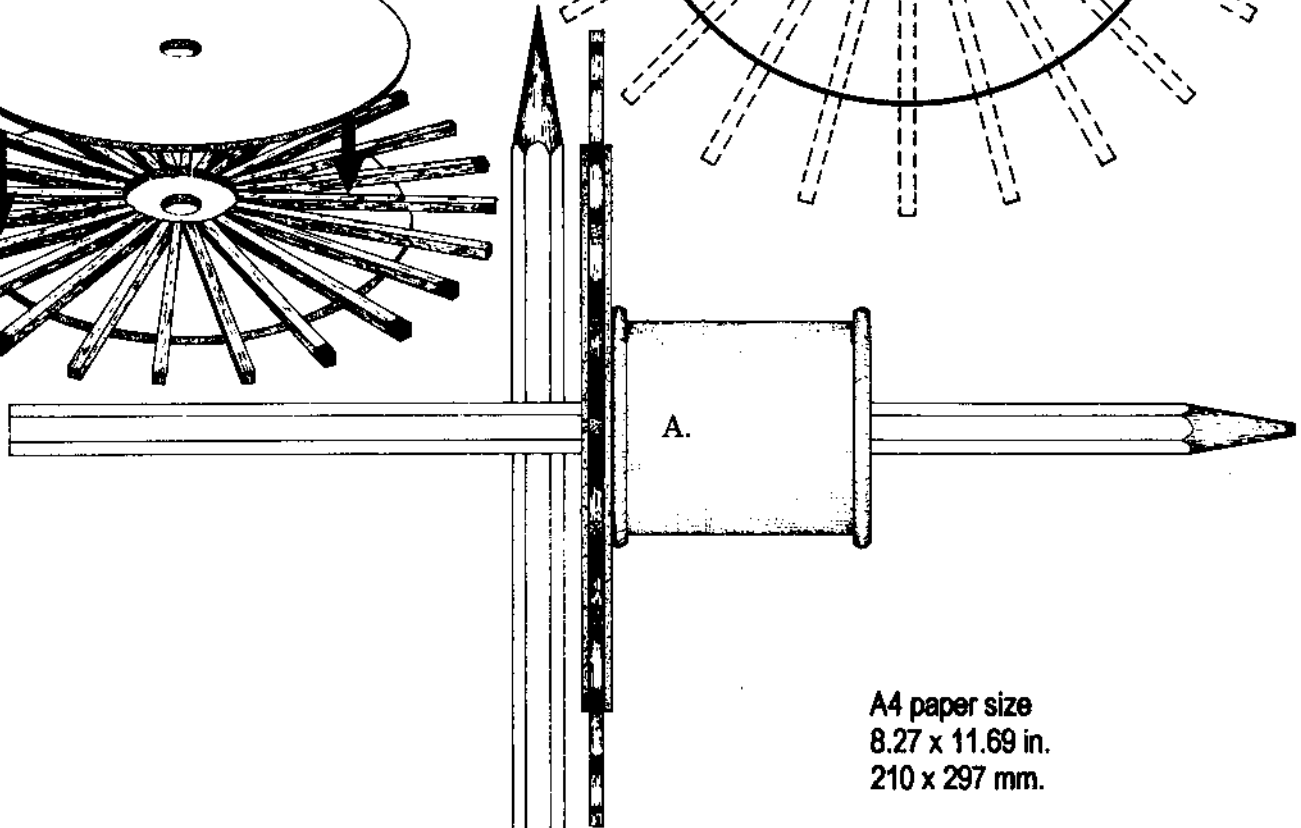


6  
7

**NB: Check the circle diagram carefully with a compass. Verify that the circle is true, to avoid possible error as a result of any copy or reproduction process.**

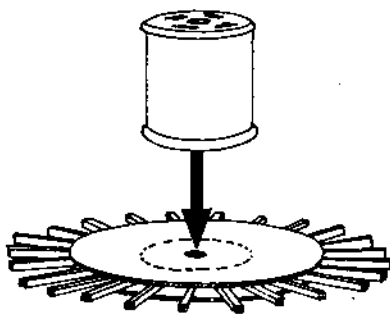


8

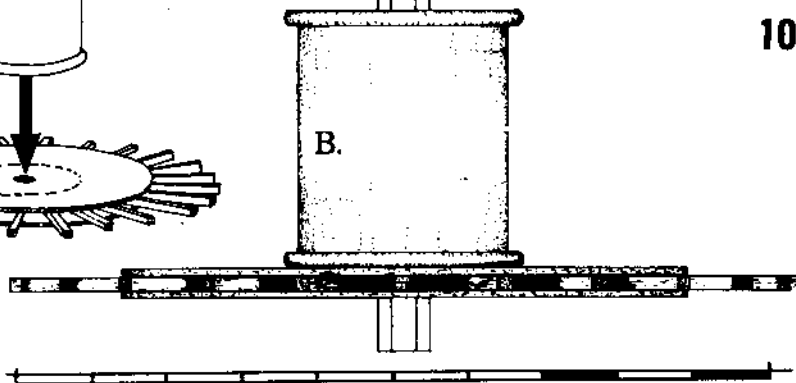


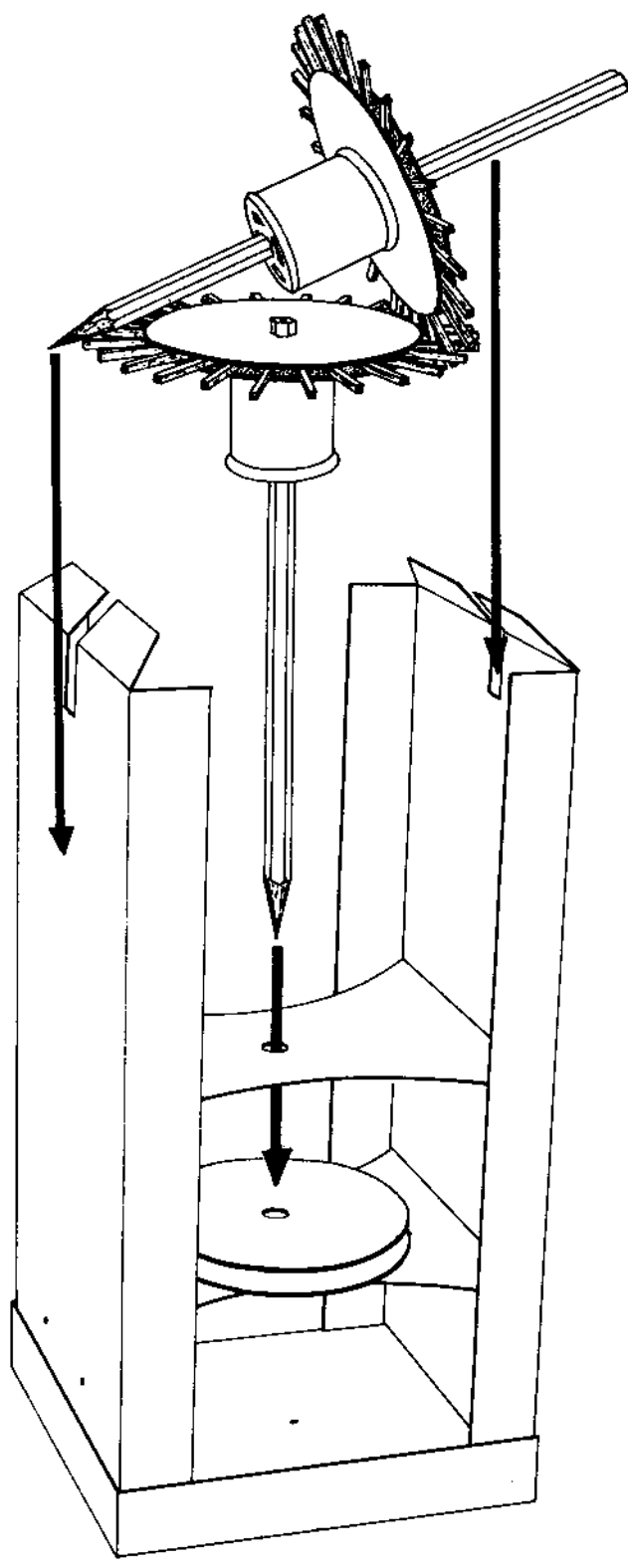
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210 x 297 mm.

9

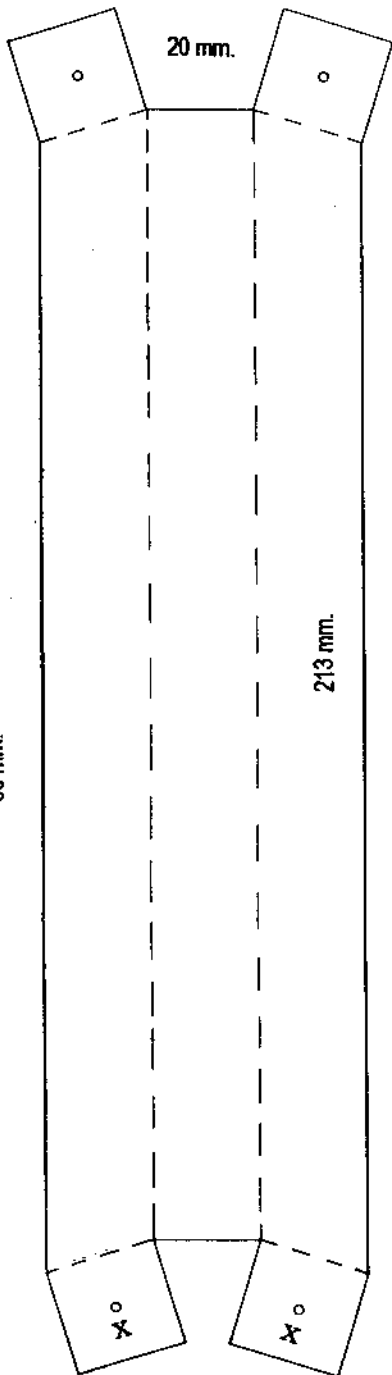
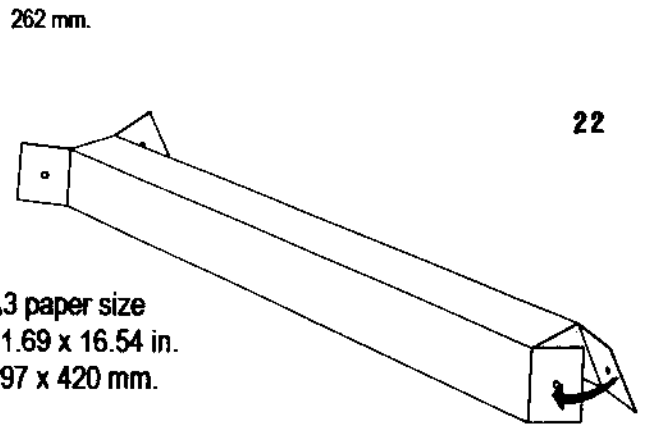
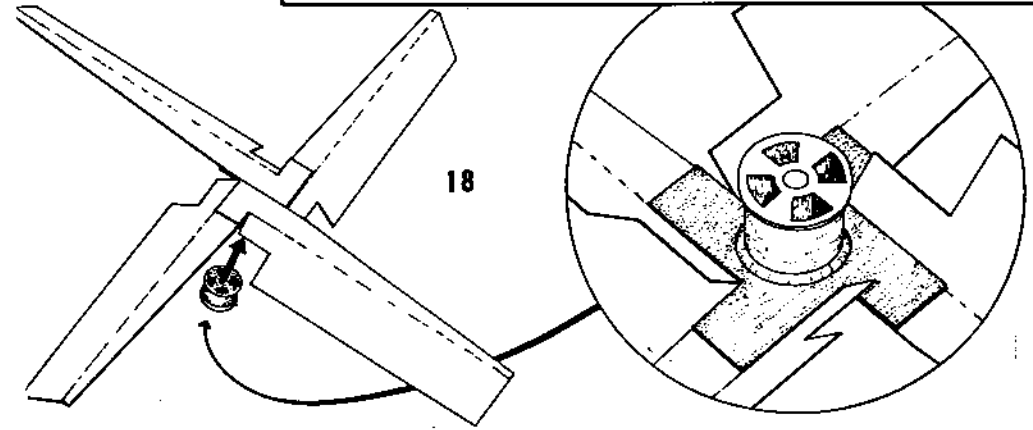
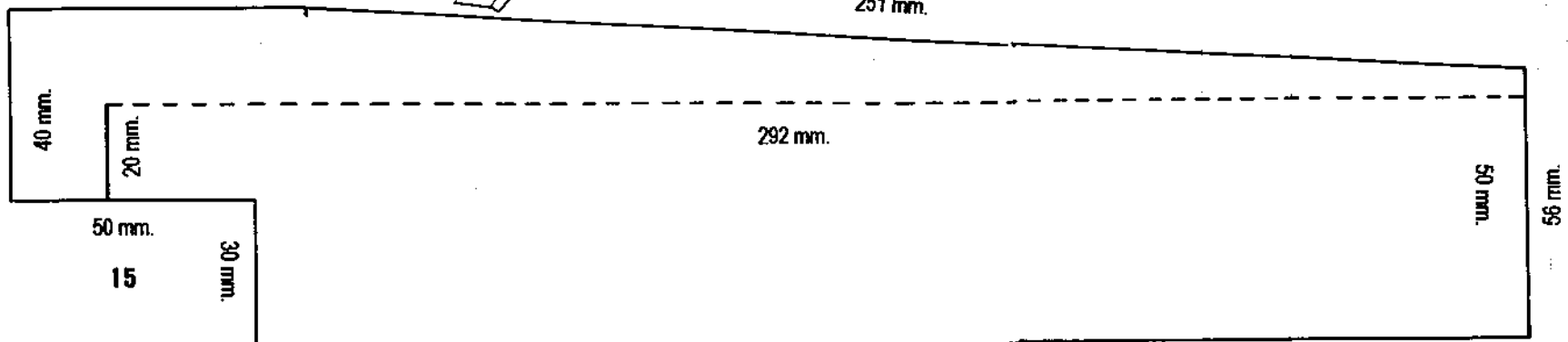
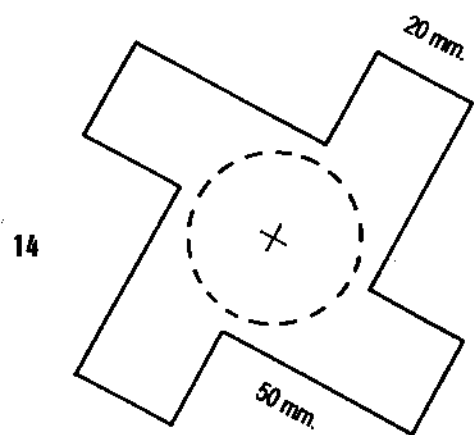
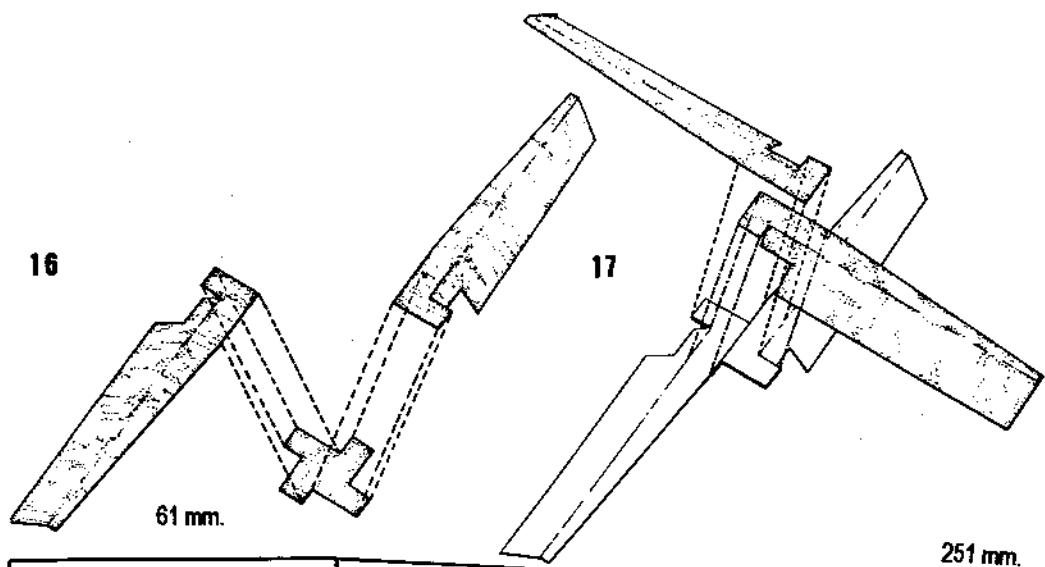


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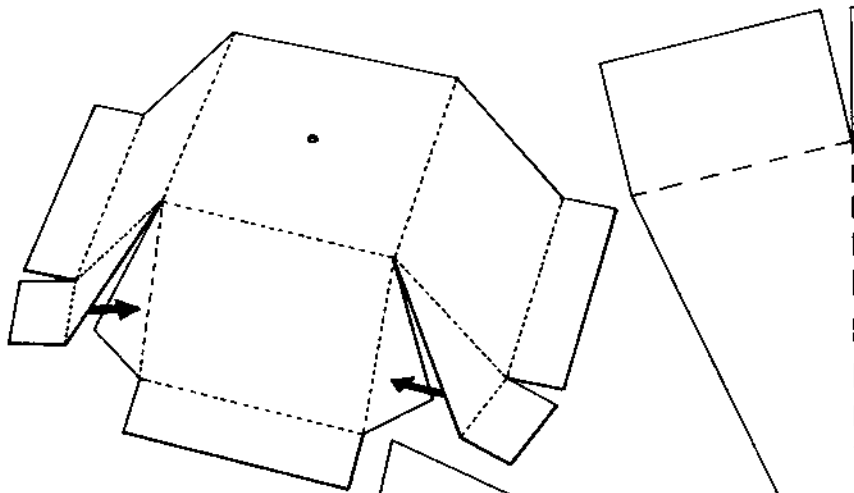


- 11
- 12
- 13



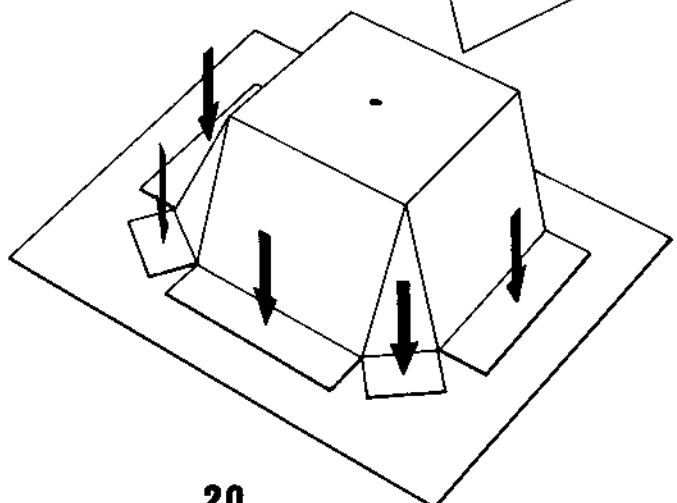
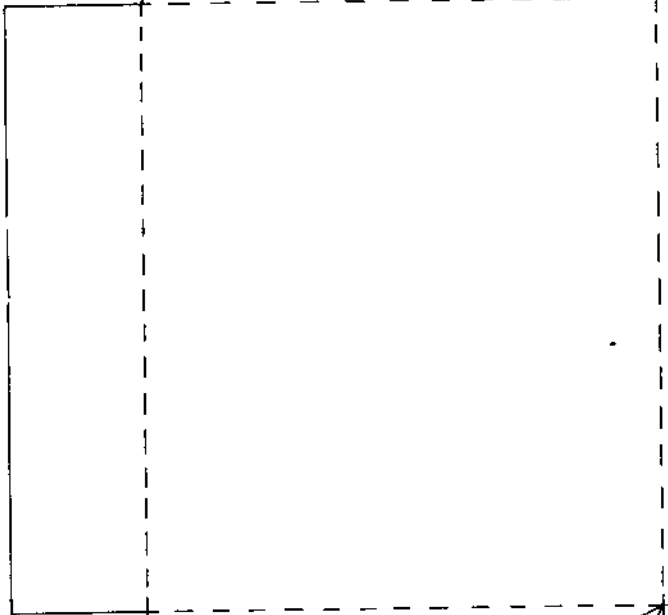
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297 x 420 mm.

380 mm. / 15 in.

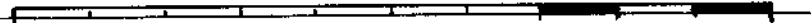


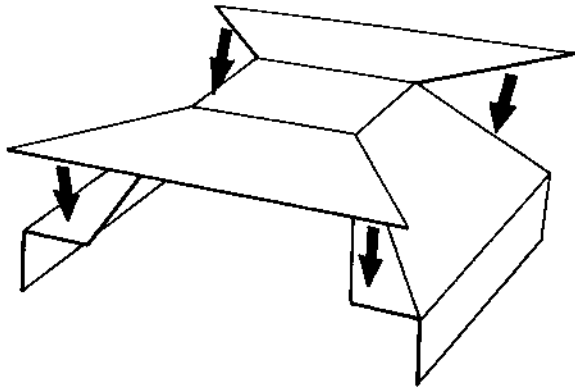
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210 x 297 mm.



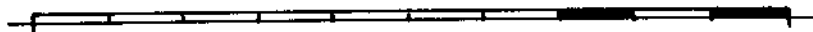
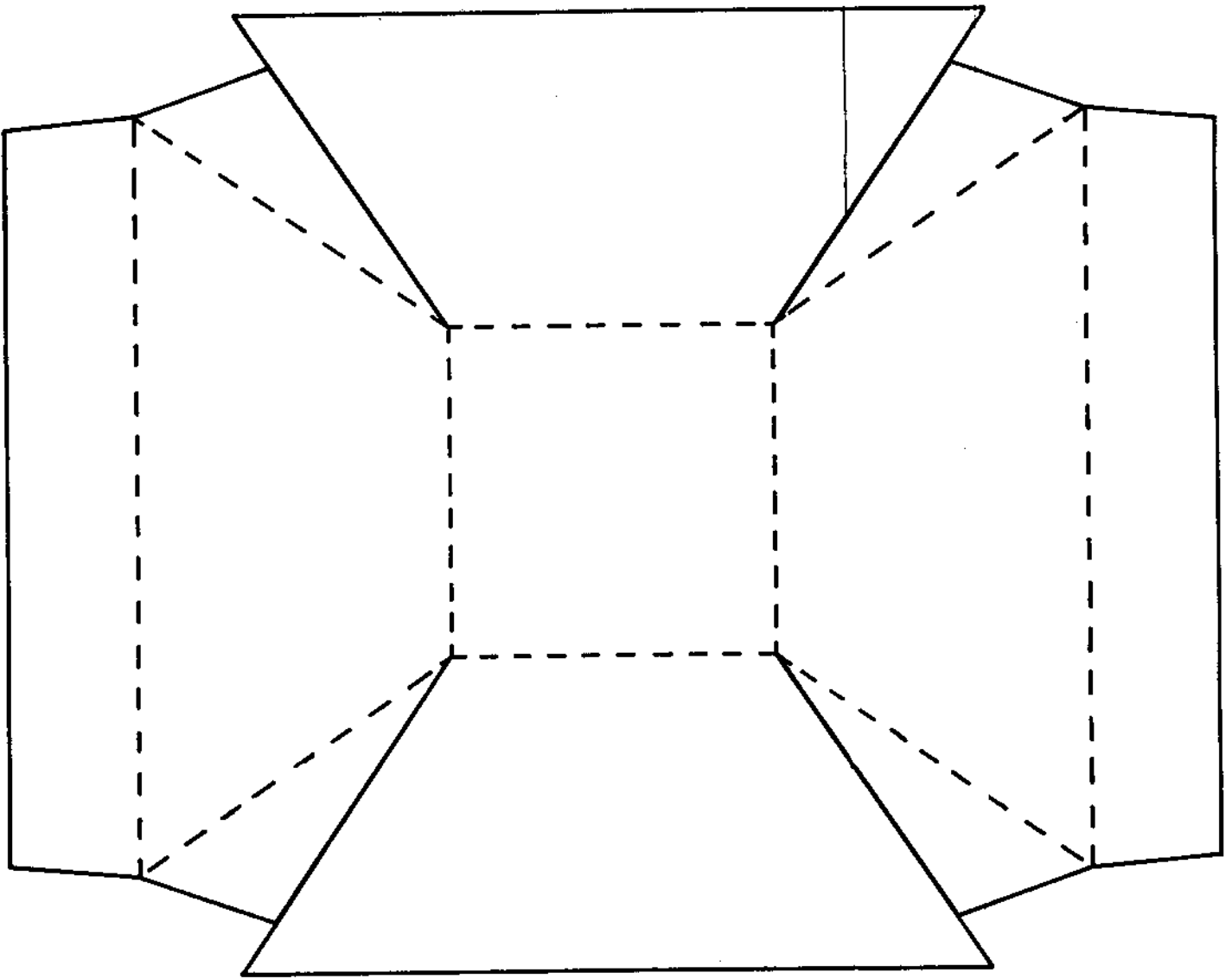
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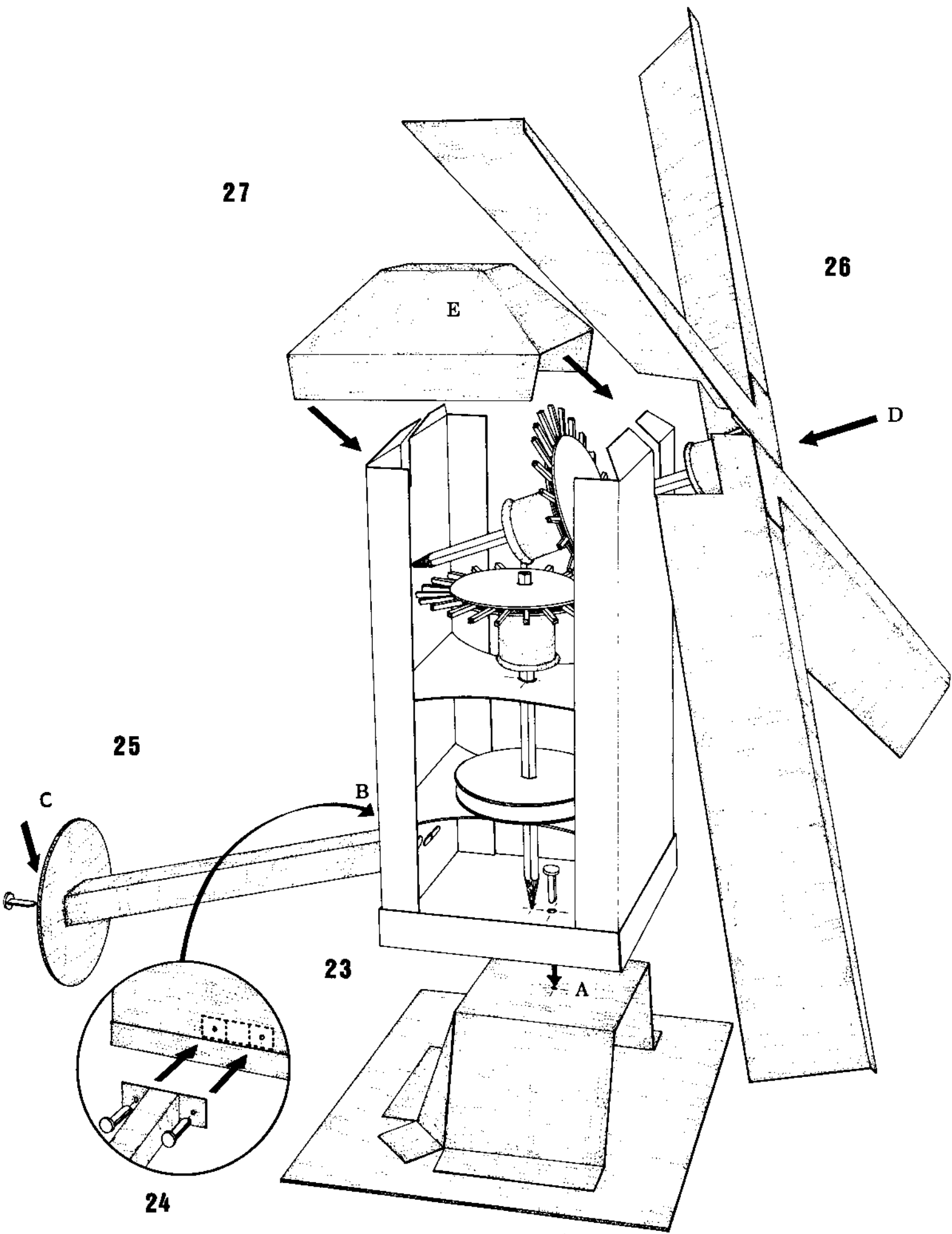




**21**

A4 paper size  
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210 x 297 mm.

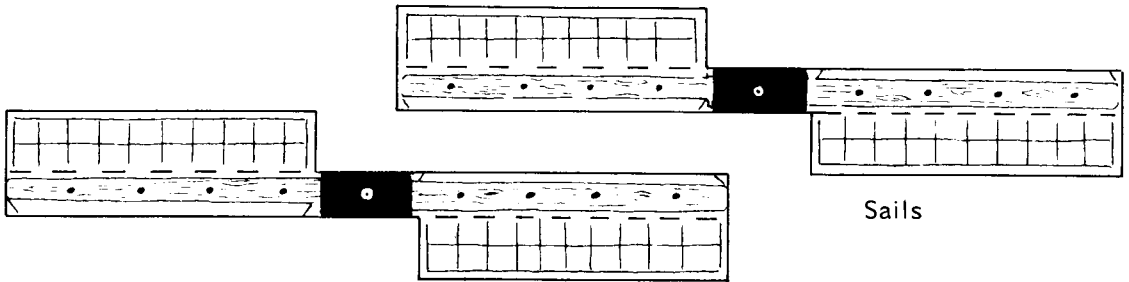
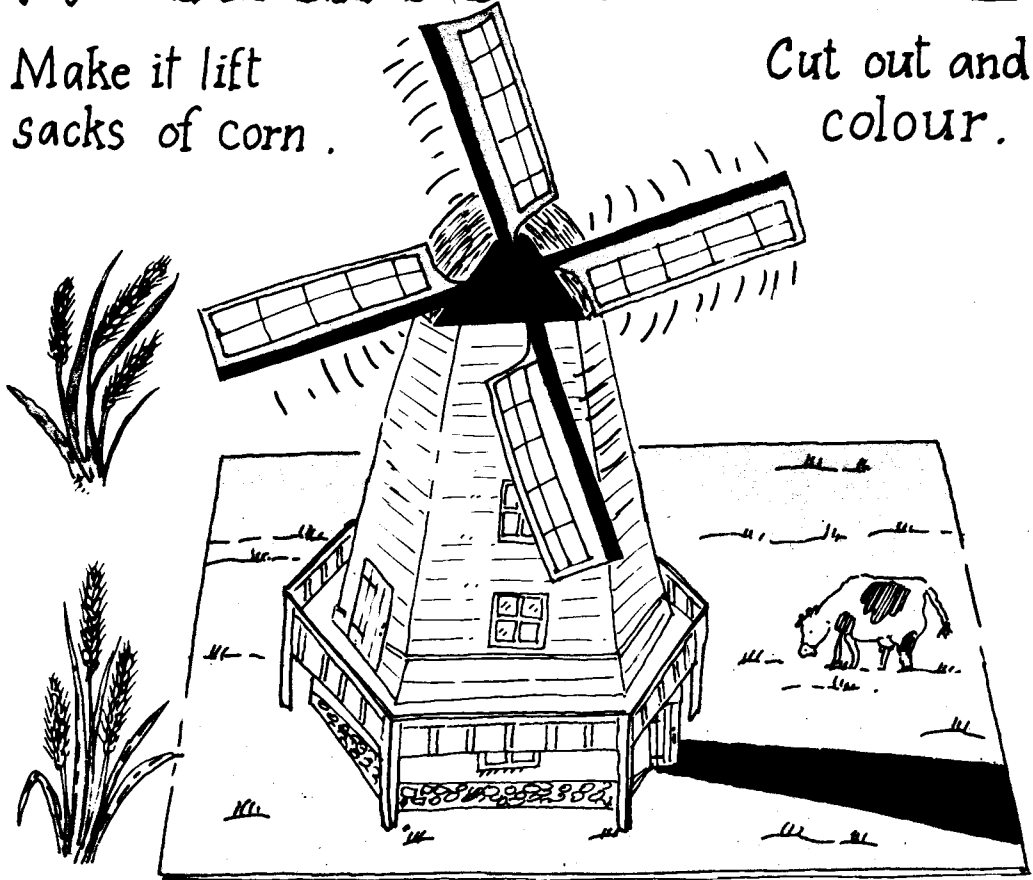




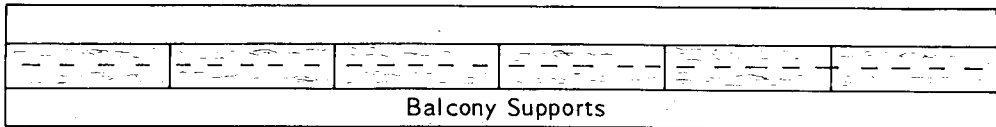
# WORKING WINDMILL

Make it lift  
sacks of corn .

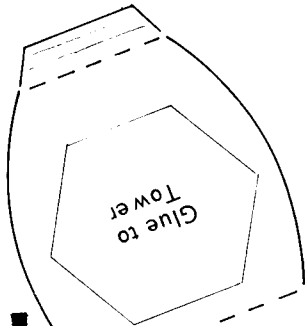
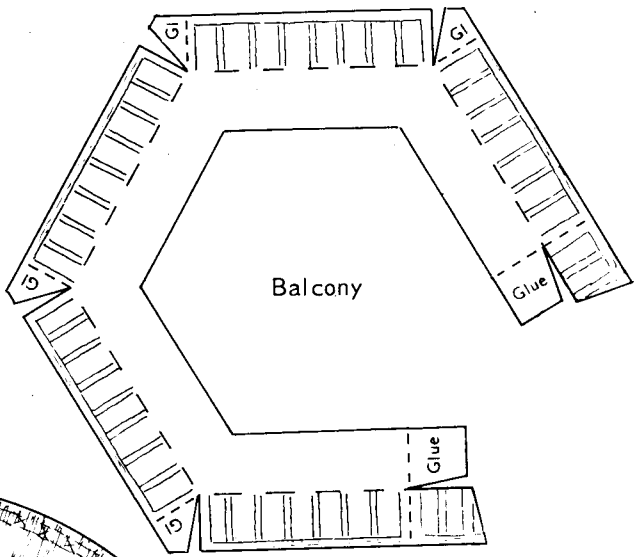
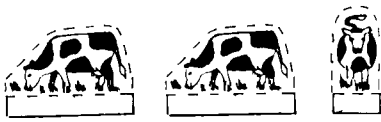
Cut out and  
colour .



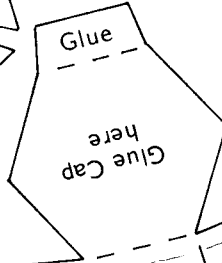
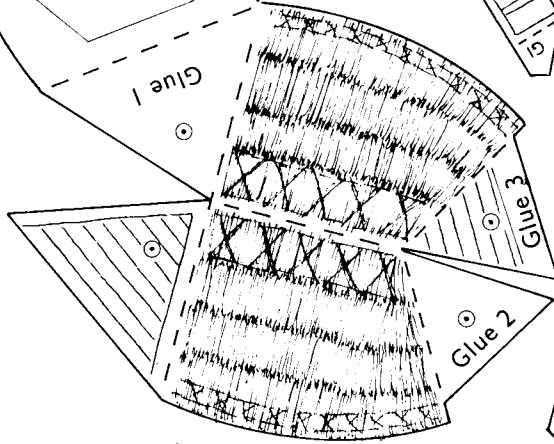
Sails



Balcony Supports

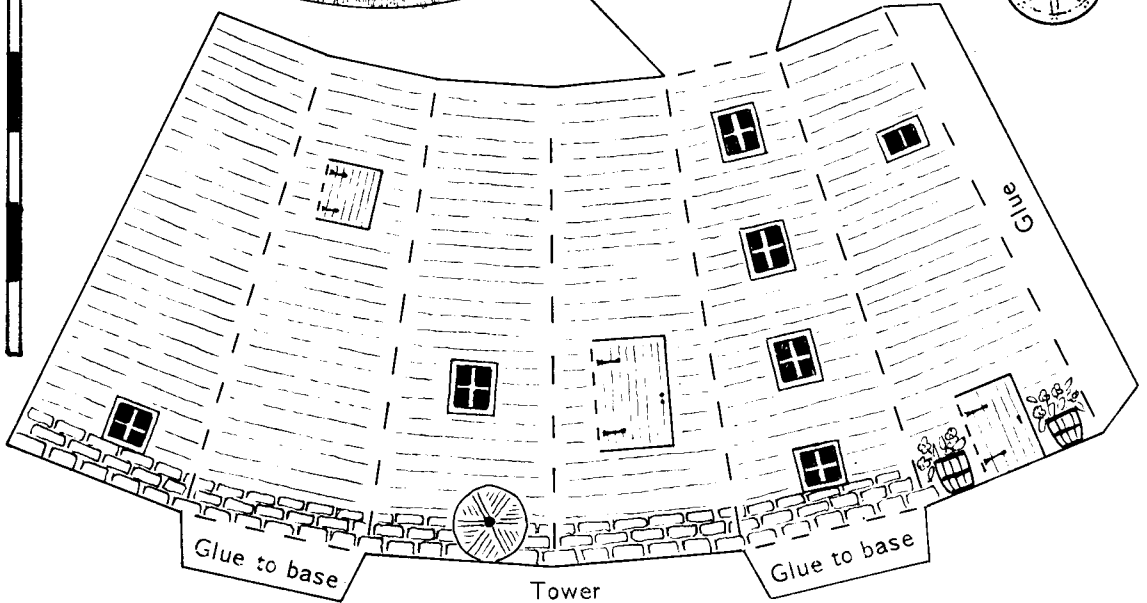
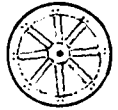


Cap



Cut straw to this length 4-9 mm.

Pulleywheel



Tower



\* Before starting note you have a choice of axles - either a used matchstick (household size) or a cocktail stick turning inside a straw. Both work but the latter gives the chance to see the power generated by a windmill by operating a hoist able to lift quite heavy loads.

Whichever you choose, the holes pierced in the cap will be the same size - fitting a matchstick loosely or a straw snugly. A meat screwer is ideal.

#### Tower

Cut round doors so they will open, perhaps with adult help. Score dotted lines including door hinges - the blunt edge of a tableknife. Glue side and top tabs inside tower. Then glue base tabs to any spare card to form base for fields, paths, cows etc.

#### Cap

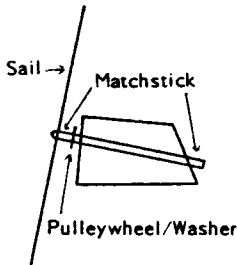
Pierce the 4 holes before cutting out. Glue tabs in order shown. Clear out holes. Cut straw to length shown, if applicable, and insert through cap. Glue cap on tower with rear above hoist door - the highest of the doors.

#### \* Axle

If using matchstick, sand down rough edges and slightly sharpen one end. Note that the pulleywheel will be used as a washer to keep the sails from rubbing against the tower.

#### Sails

Pierce the dot in the middle of each before cutting out to fit the tip of your axle with, say, a compass point. Cut out, score dotted lines and fold sails slightly forward before glueing to axle. Check sails are aligned and at right angles before glue dries.



#### Balcony

This is optional. It is easiest to cut out central part with a blade - ask adult help.

#### Balcony supports

Also optional. You need 6 thin slivers folded lengthways. As folding a sliver is difficult, cut round the outer line first, then score and fold; then cut up the inner lines and separate the 6 supports - they will be already folded.

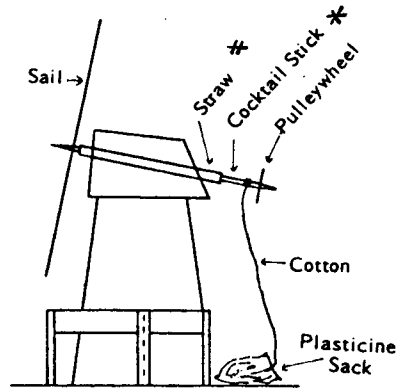
Glue one to each corner flush with top of balustrade. Carefully ease balcony round upper part of tower and lower into position with open part under hoist door.

#### Hoist

Also optional. Pierce centre of pulleywheel and glue to rear tip of cocktail stick. Wrap cotton 2 or 3 times round cocktail stick and dab glue on it - easier than tying a knot. Mould sack shape out of plasticine and embed cotton in it at ground level, allowing a little spare. Experiment with the amount of weight you can lift.

#### Comments

If you have any comments or queries, write to Jan Copeman, Jan Copeman Toys, 44 Overstrand, Prince of Wales Drive, London SW11.



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