Compendium in Wind-Rotors
for Water-Pumping and
Electricial Power-Generation

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NB:

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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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Terra Moya Wind Generators. 2020 Carey Ave. Cheyenne Wyoming 82001 USA,
Biel www.ecotools.net & Solavent Freiburg Germany Fax: + 49 (0)761 709647

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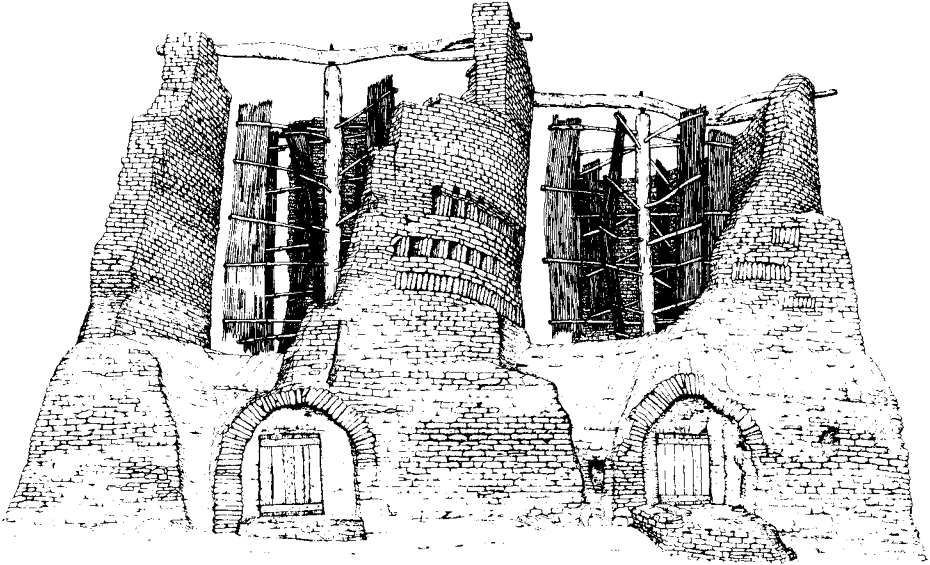
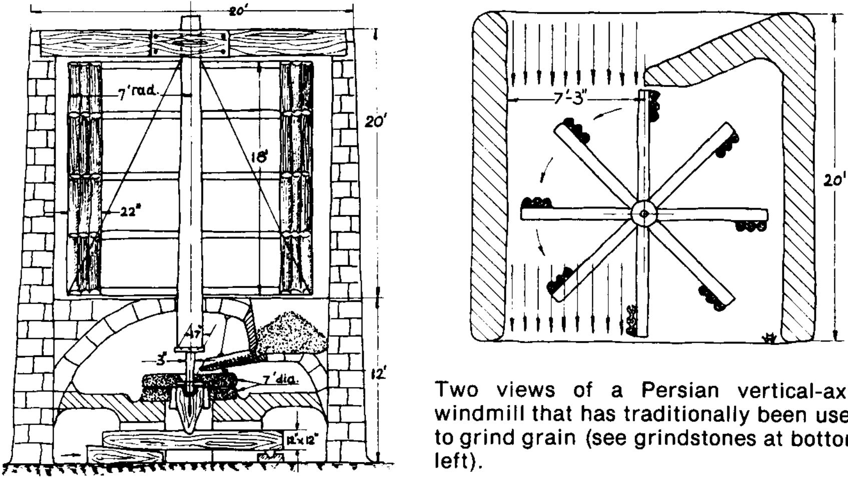
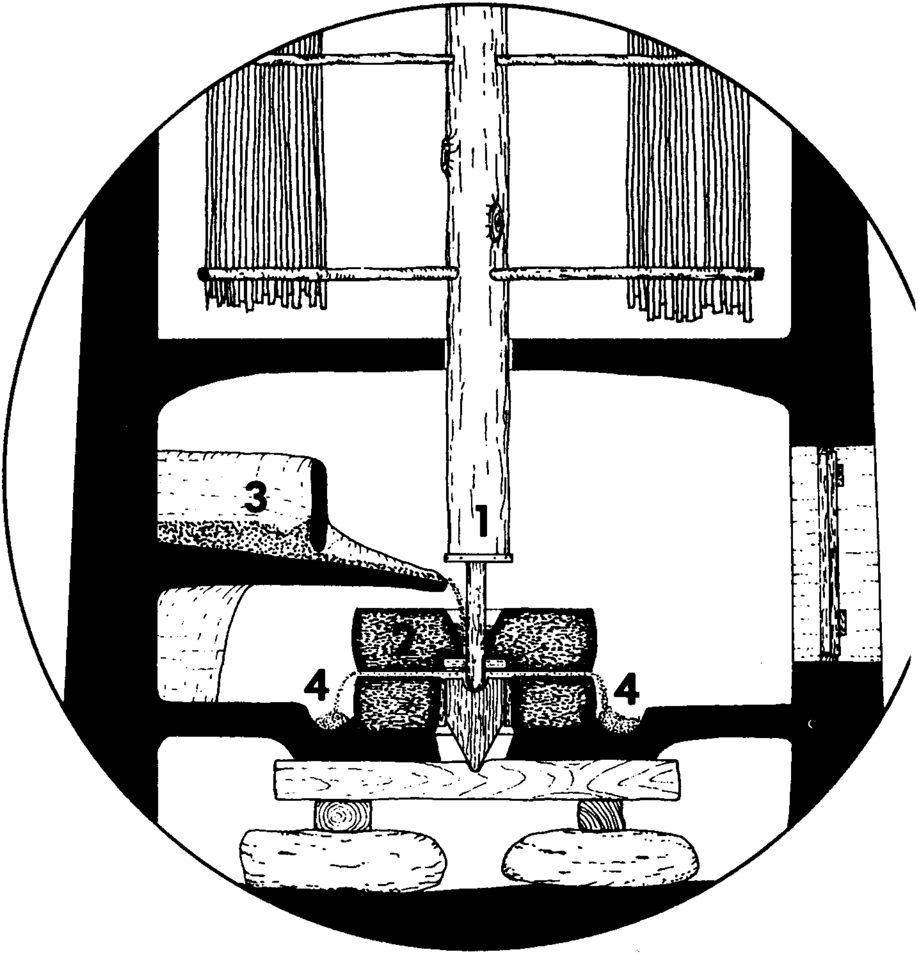


1. Eastern, or Persian, windmills. Sketch from *Windmills*, by Anne and Scott MacGregor



Two views of a Persian vertical-axis windmill that has traditionally been used to grind grain (see grindstones at bottom left).

Traditional Crafts of Persia, book, 304 pages, Hans Wulff, 1966, $7.95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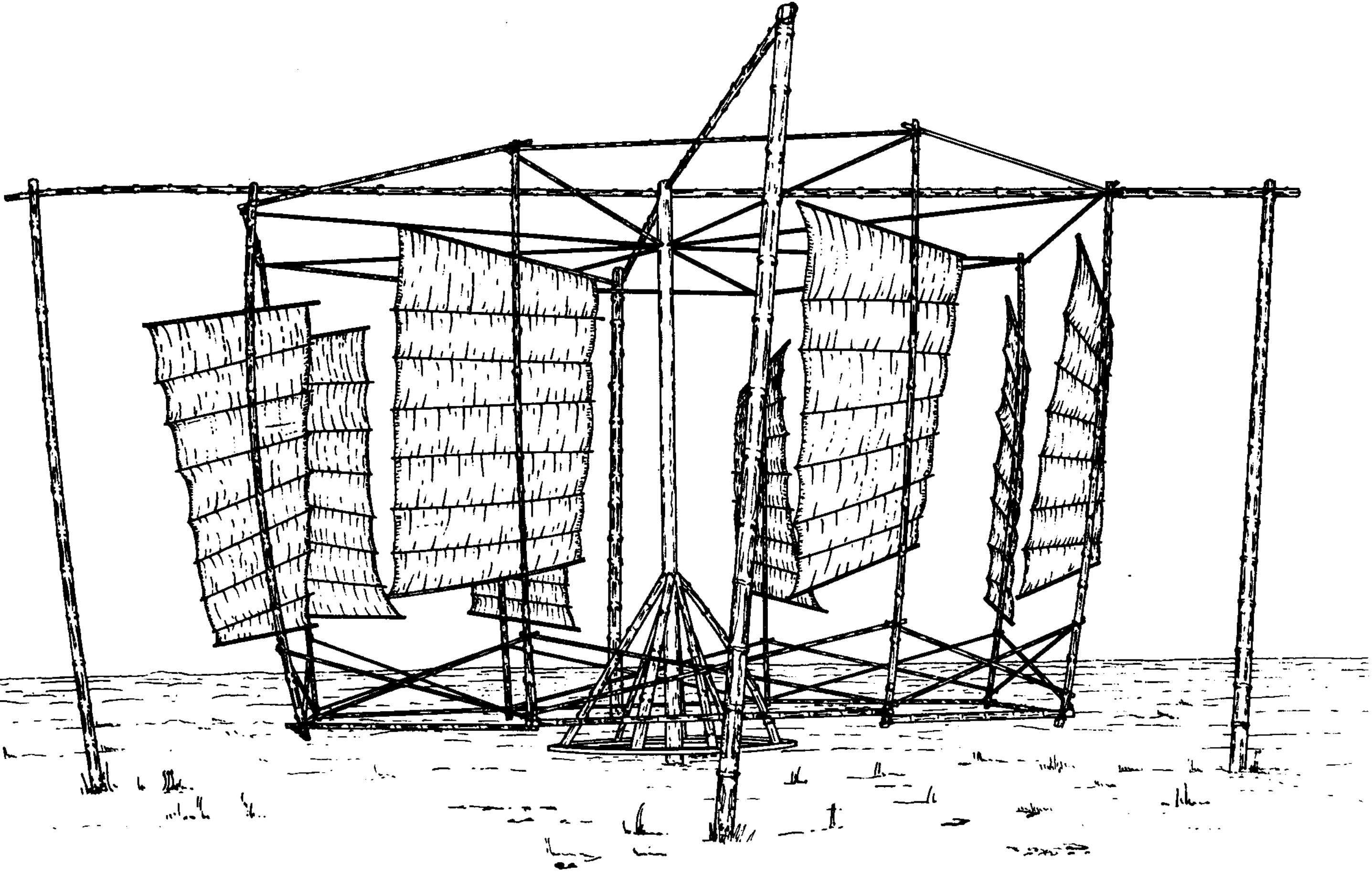


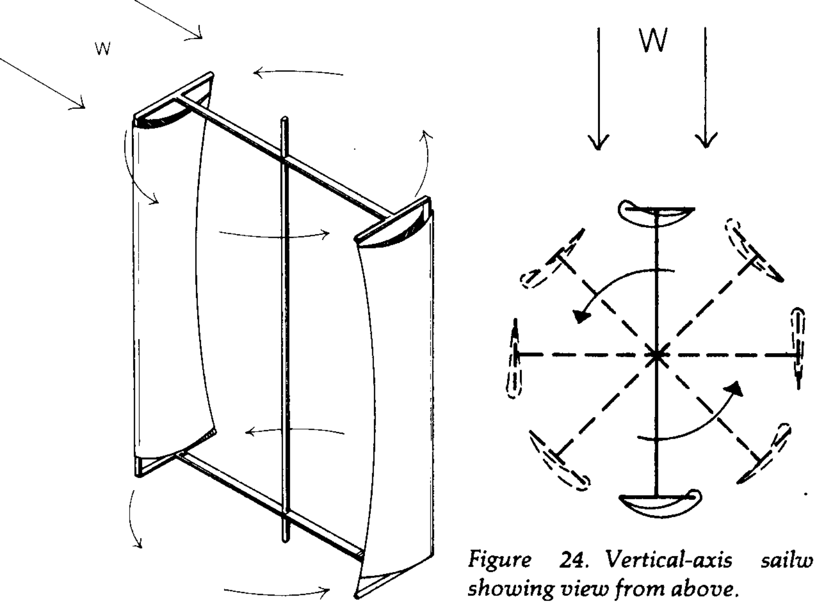
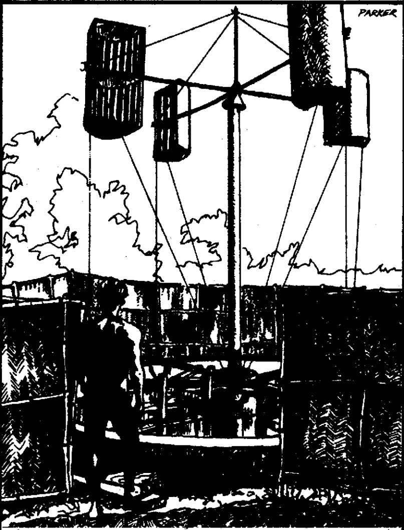
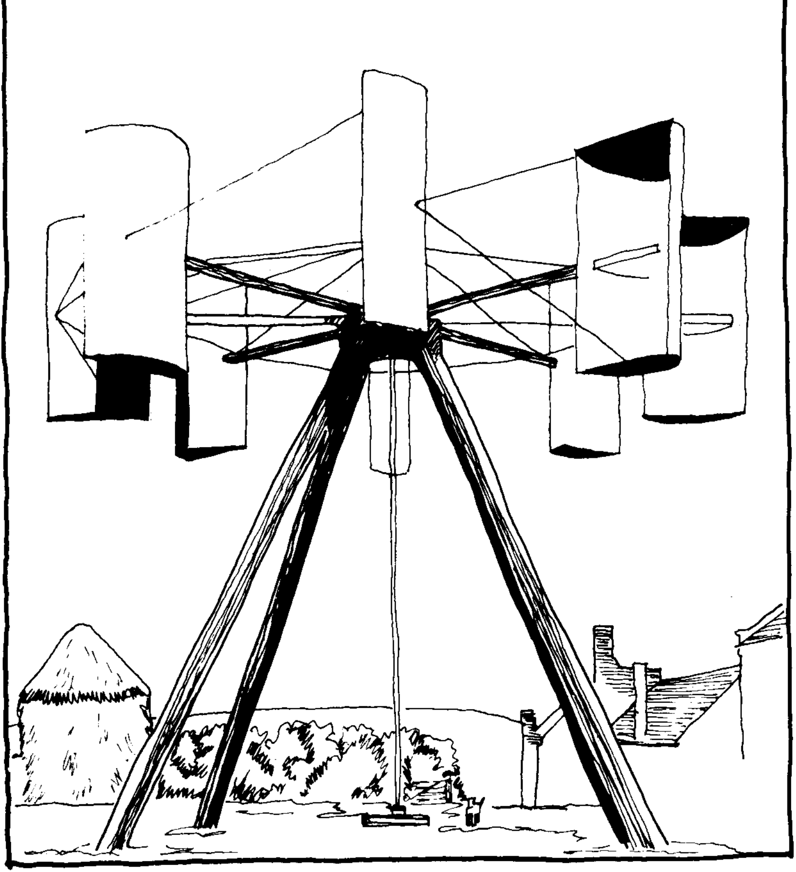


Figure 24. Vertical-axis sailwing, showing view from above.

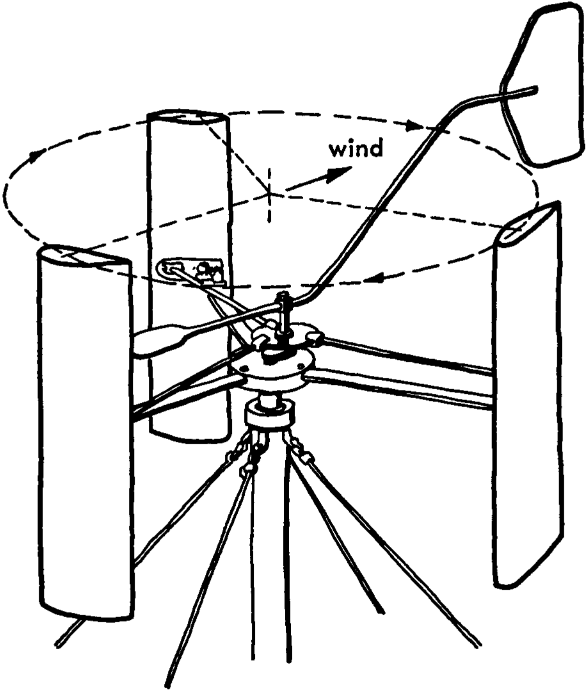


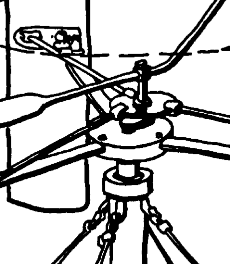
Algae culture in India

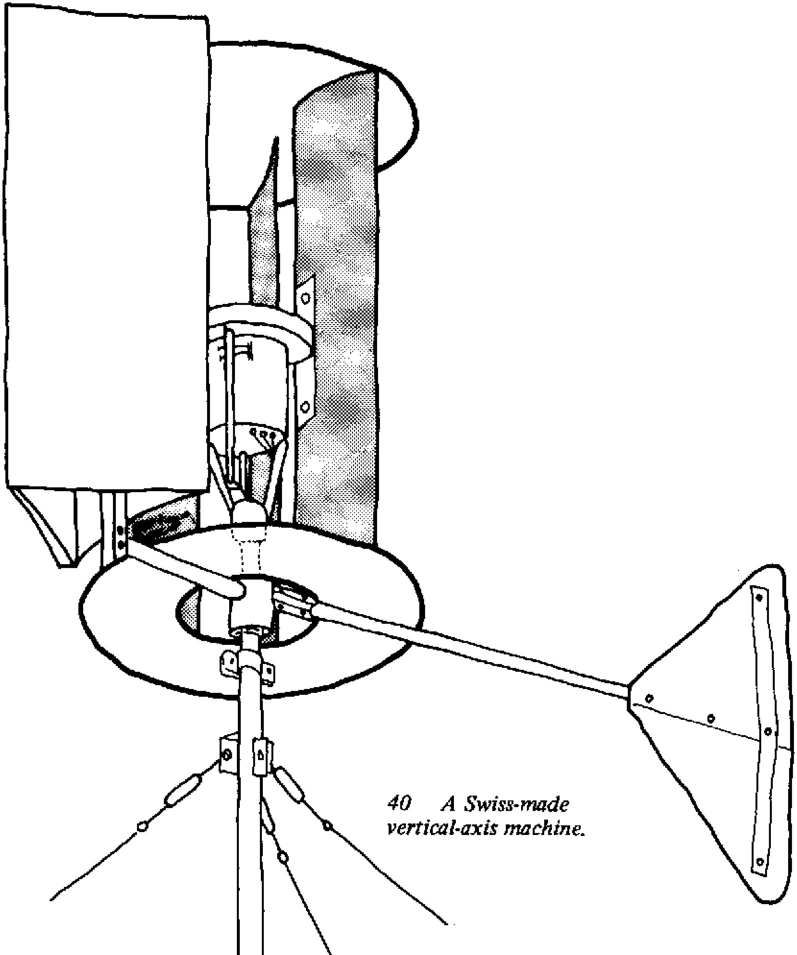


35 A very large vertical-axis wind-powered generator built in Scotland at the beginning of this century.

Horizontal wind motor built by J.C. Donaldson in Cocoa, Florida in the 1940s.







40 A Swiss-made vertical-axis machine.

The Flettner Rotor

In light of today's revived interest in commercial sail, it is interesting to look again at the aspirations and achievements of one of the few original developments in wind powered ships since sail went into a coma in commercial terms — the Flettner rotor.

It is the story of a brave attempt in the 1920's to harness a principle that up to then had been little more than a scientific curiosity, develop it technically and put it to work in the tough commercial world of shipping between the wars.

That it failed at the time to achieve lasting acceptance was probably due less to inherent defects than its inability to demonstrate overwhelming advantages at a time of rapidly advancing diesel engine technology and cheap fuel.

The Rotor ship was born when Anton Flettner in Germany turned his attention from rudders using trim tabs for servo operation to the use of rigid movable planes for wind propulsion of ships. After some success with wing sails he concentrated on the possibilities of the Magnus effect.

This effect had been first explored by Prof. Magnus at Berlin University in 1853 and later used to explain the swerve of balls with spin applied. More thorough investigation followed in 1922 at Göttingen Aerodynamics Institute, and Flettner patented the application to ship propulsion.

Magnus effect occurs when any body spins in a current of gas or liquid. The interaction between the boundary layer round the body and the fluid flow distorts the flow patterns compared with a stationary body giving rise to a component of force at an angle to the direction of current flow.

The effect is most usefully applied to a spinning cylinder, though it affects any shape of object. Flettner quickly ascertained that the best shape of all was a fairly slim cylinder with large end discs to reduce the losses caused by flow "shortcircuiting" over the ends of the cylinder. The optimum rotational speed was found to be that which gave a peripheral speed at the cylinder wall between 3 and 4 times the air speed.

The resultant force on the cylinder depended for any given windspeed on the speed of rotation. The maximum force occurred at a direction of between 100° and 110° to the direction of the wind, but ship trials showed that there was sufficient force available in practice to sail "closehauled" within 30° of the wind. Plotting the pressure distribution around the spinning cylinder indicated that the pressure was negative over about three quarters of the circumference and positive only over about a quarter, so the resultant force was essentially "lift", as in a wing.

Model tests were sufficiently good for the Flettner rotor, as the spinning cylinder became known, to be fitted to a sizeable vessel. The ship chosen was the Hanseatic Motor Shipping Co.'s three masted topsail schooner BUCKAU, 780 tons displacement. Two rotors were fitted, one at the existing foremast position and one just ahead of the mizzen mast position, the rotors' height being about the same as the gaff jaw position on the original masts.

Surprisingly enough, it was found that the resistance of the stationary rotors was considerably less than the resistance of the former rig. A trial over the measured mile in a wind of 30 ft/sec. gave a maximum speed of 8.19 knots.

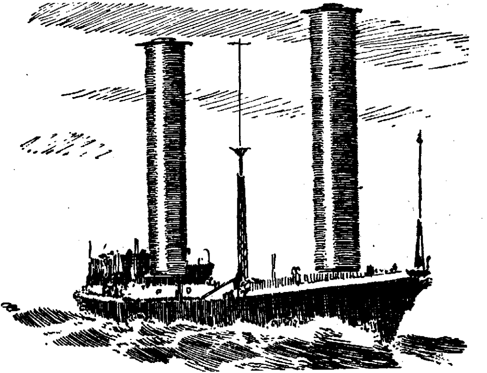
BARBARA was fitted with three rotors, one mounted on the navigating bridge between holds 1 and 2, one on the midships superstructure and the third on a deckhouse between hatches 3 and 4. They were considerable structures. Each cylinder was 56 ft. high by just over 13 ft. diameter. Originally the intention had been to use a single rotor 92 ft. high, but due to difficulties in obtaining suitably large ball-bearings the three smaller rotors were eventually chosen.

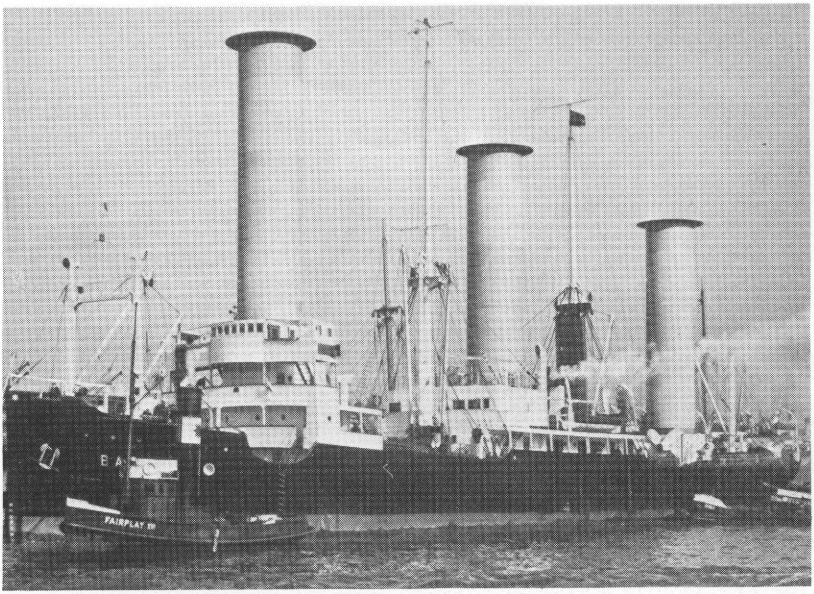
Following trials, BARBARA was set to work by Sloman on the Mediterranean trade and some hard facts on the Flettner rotor in commercial service emerged. The main conclusions reached were that the rotors had few adverse effects operationally and some positive advantages.

Under engines alone, when fully operational, the ship would do between 10 and 10.5 knots. with suitable wind strength and direction the rotors added another 2—3 knots, and under rotors alone a little over 6 knots was available. Against this it was estimated that only during 25 per cent of time at sea were the rotors usefully employed, though in the course of the first few trips they were run about 40 per cent of the time to build up experimental data.

(from Marine Propulsion March 1980).

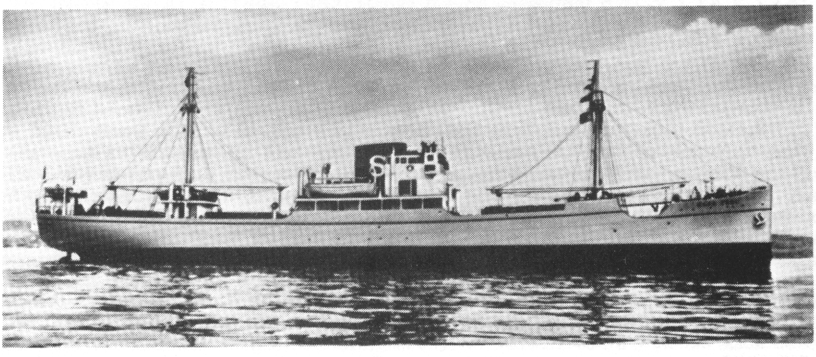
Rotor- eller Flettnerskibet.





ELSE SKOU (I) as the Rotorship **BARBARA**

13. ELSE SKOU (I) (1947-1963)
1958g, 1077n, 3050d.
284.6 × 43.4 × 16.6 feet.
Two 6-cyl. 4-str. SA oil engines (M.A.N.-type) by the shipbuilders coupled by hydraulic transformers to one shaft. Re-engined in 1948 with two 8-cyl. 4-str. SA oil engines made in 1926 by Deutsche Werke A.G., Kiel, Germany. 12 knots.
7.1926: Completed by Act. Ges. Weser, Bremen (yard no: 398), Germany as the Flettner rotor vessel BARBARA for Deutsches Reich Marine-Verwaltung (Robert M. Sloman jr., Manager), Germany. After two years' service the rotors were removed from the vessel. *10.1933:* Sold to Bugsier Reederei und Bergungs A.G., Bremerhaven, Germany, and renamed BIRKENAU. *5.1945:* Taken by Allied Forces as a prize at Aarhus, Denmark. *9.1946:* Taken over by Great Britain. *5.1947:* Awarded as a prize to the Danish Government. *12.1947:* Acquired by joint ownership D/S Ove Skou A/S and D/S af 1937 A/S and renamed ELSE SKOU. *2.1948:* Rebuilt and re-engined by Howaldtswerke, Kiel. *5.1961:* Transferred to Ove Skou Rederi-A/S. *11.1963:* Sold to Greek Libyan Lines (F. Petropoulakos Bros., Manager), Greece and renamed FOTIS P. *1966:* Renamed STAR OF RIYADH. *1967:* Sold to Orri Navigation Lines, Greece and later transferred to Saudi Arabian registry. *8.1978:* Scuttled off Jeddah.



ELSE SKOU (I)

The ELSE SKOU (I) had been built in 1926 as the experimental Flettner rotorship BARBARA. Her three tall light alloy cylindrical rotors were driven at a relatively low speed by electrical motors in order to take the maximum advantage of the Magnus effect. After two years service the rotors were removed, and the ship operated as a conventional motorship.

Image:Rotorship Uni-kat Flensburg.jpg

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Download high resolution version (833x552, 140 KB)

Summary

Picture of the rotorship Uni-Kat Flensburg, build up 2005/2006 on the Institut für Physik und Chemie und ihrer Didaktik, Universität Flensburg/Germany (Professor Lutz Fiesser and with students). The ship is a katamaran with a Flettner-Rotor. The picture is dedicated to the public domain (Prof.L.Fie).

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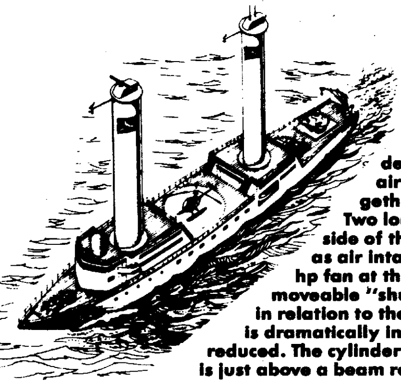
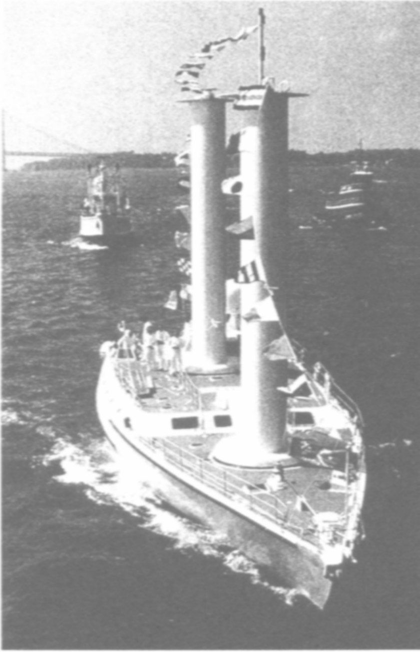
File history

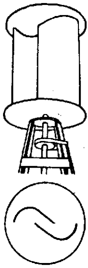


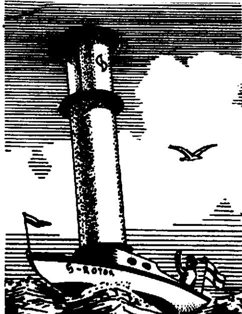
Artist's conception: CALYPSO II. The aspirated cylinder has the shape of two aircraft wings joined together, elliptical in section. Two long vents, one on each side of the leading edge, serve as air intakes, assisted by a 12-hp fan at the cylinder's top. A moveable "shutter flap" is oriented in relation to the wind direction; lift is dramatically increased and drag is reduced. The cylinder's best "point of sail" is just above a beam reach.

The design team of Prof. Lucien Malavard, Capt. Cousteau, and Bertrand Charrier expected the efficiency to be about five times that of a conventional sail with similar area, but discovered the factor was closer to six. Cousteau estimates that an average freighter equipped with his aspirated cylinder rig could expect about 35% fuel savings.



Jacques Cousteau's research vessel 'Alcyone', powered by vertical wind-turbines.

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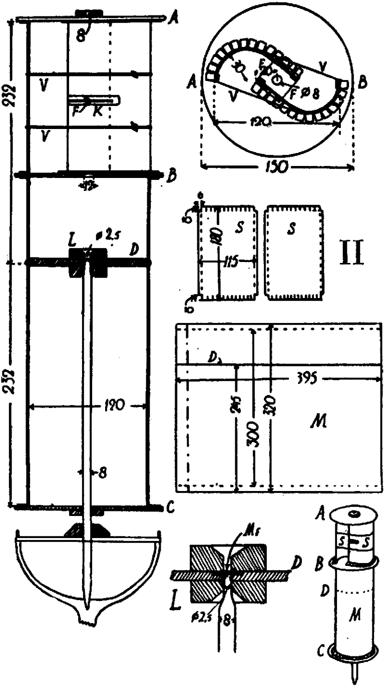
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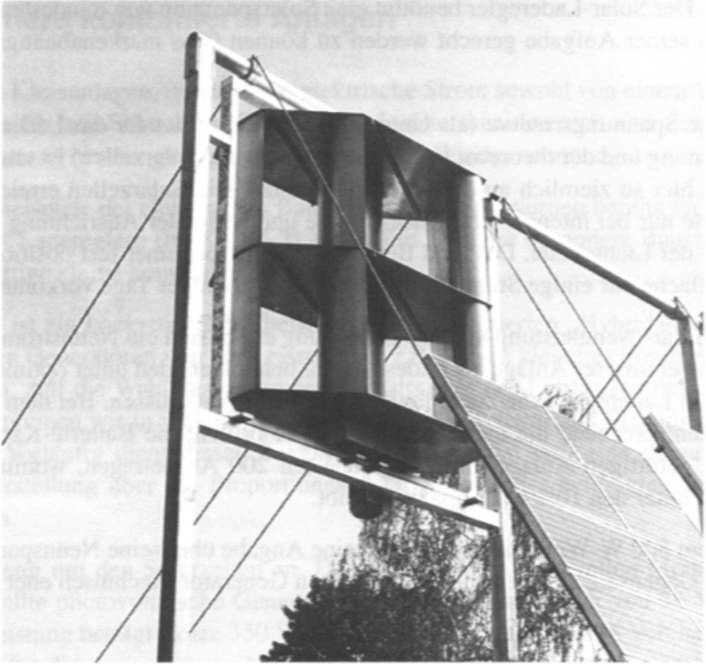
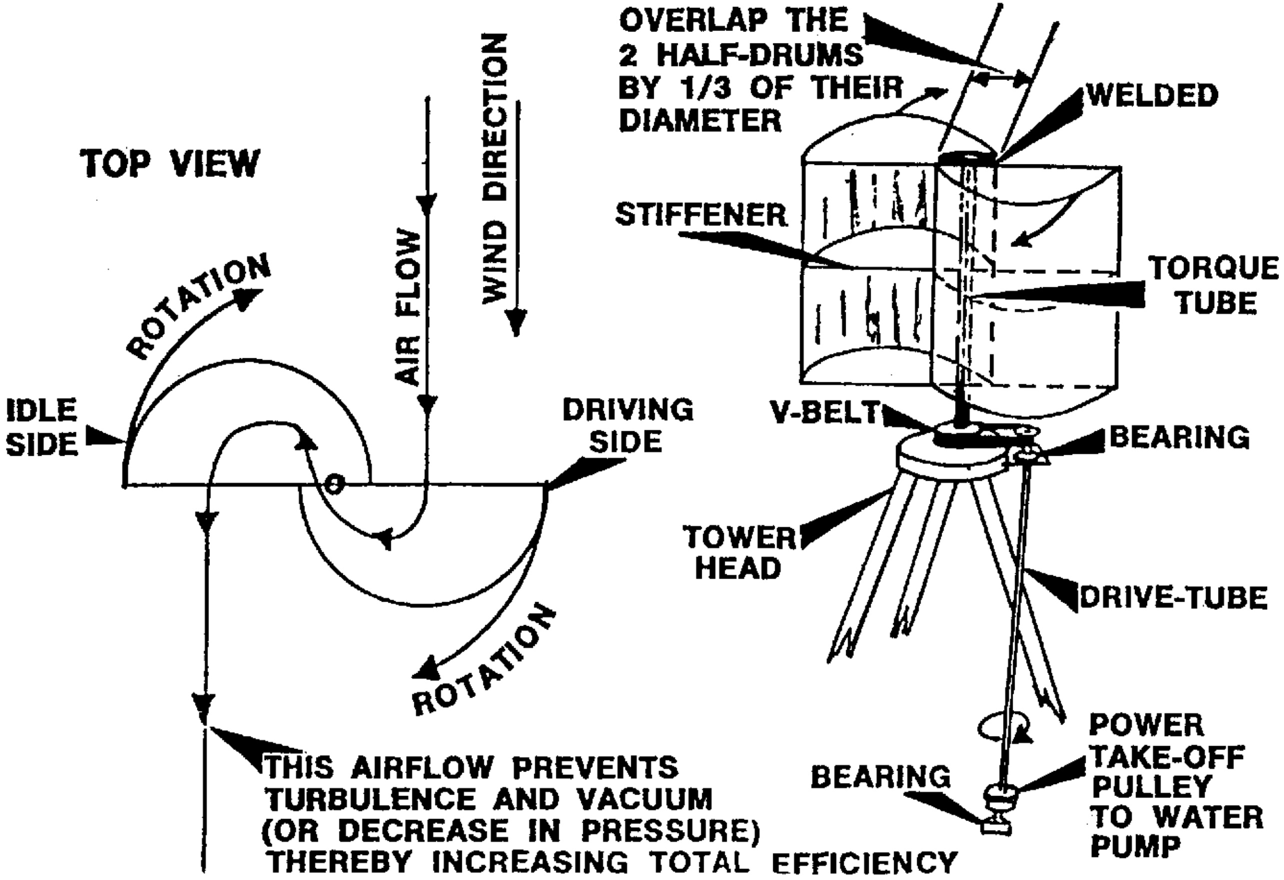


Abb. 1.4 Ausführungsbeispiel einer Hybrid-Anlage mit einem Savonius-Windgenerator und einem aus mehreren Solarzellenmodulen zusammengestellten photovoltaischen (PV) Generator (FÜW AG, Ansbach)

HOW THE SAVONIUS ROTOR WINDMILL WORKS



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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Sol Power. S. & S. Behling Prestel Verlag München De./EU-Commission 1996 3-7913-1670-2 *

Appraisal of Projects. HMSO London UK 1988 0-11-580256-8 *

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[book, - video also available. (trans. - houses as living / responding entities)].

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- 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.
- An energy/development CD-library is available from Belgium. E-mail - humanity@innet.be http://www.oneworld.org/globalprojects/humcdrom

Plus:

- Rainbow Power Company Catalogue, Ninbin NSW 2480 Australia. Fax: + 61 66 89 11 09.
- Catalogue from Real Goods Co. Ukiah CA 95482-3471 USA. Fax: + 1 707 468 94 86 E-mail - realgood@well.sf.ca.us
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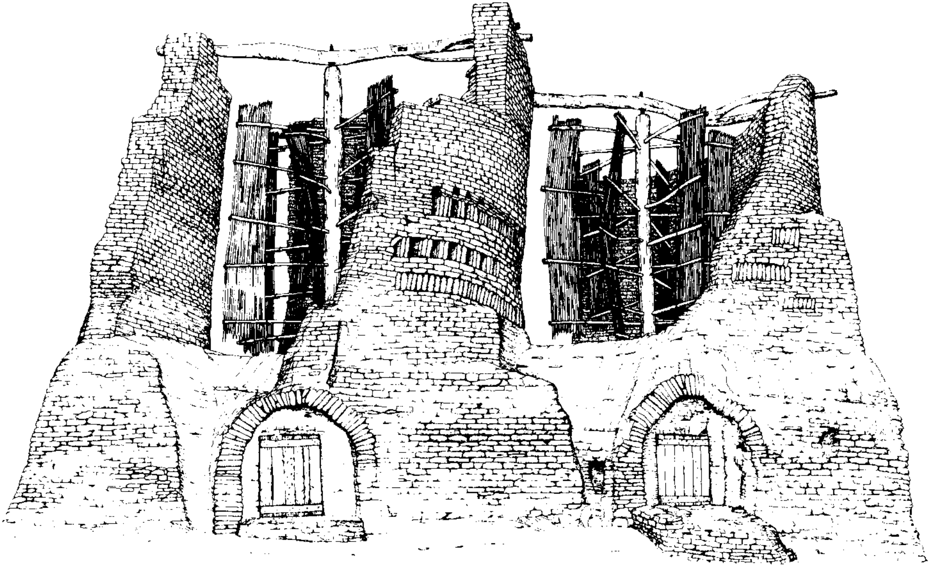

1. Eastern, or Persian, windmills. Sketch from *Windmills*, by Anne and Scott MacGregor

From Persia much earlier records are to be found regarding windmills. It is too speculative to decide whether the Chinese mills are older than those of Persia but in the latter case they have been in several instances described with more detail by early Arab explorers. The Seistan windmills of Persia are first mentioned by al-Mas'ūdi[7] who traveled into almost every country of Asia except perhaps China. In his journeys through Persia in 915 A.D., he states briefly that Seistan "was renowned for the industry with which the inhabitants employed the wind for turning mills." Among other things, he gave the story of the assassination of Omar in 644 A.D., by a carpenter or millwright of that day who had been captured at the Battle of Nevahend and afterward sold at Medina to a Moslem master. According to the account, a Persian slave known as Abū Lu'lu, complained to the Caliph that he was assessed too heavily by his master at two *dirhems*[8] a day. Omar, who knew the man, replied that for a clever artificer like he, who was believed to be able to construct a mill driven by wind, the amount was not excessive. Abū Lú'lu made a threatening reply and the following morning stabbed the Caliph while he was leading prayers in the mosque.

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[6] Page 194, *Book of Trades*, London, 1837.

[7] Al-Mas'ūdi compiled his travels into a thirty-volume work entitled *Murūj-al-Dhahab wa-Ma'ādin al-Jawhar* (meaning *Meadows of Gold and Mines of Gems*) from which has been made translations into both French and English. His birthplace is given as Bagdad and he died al-Fustat in 956 A.D.

[8] Dirhem, the principal silver coin of the Mohammedans after the 8th century. Originally it weighed approximately 45 grains.

This story is often quoted but its real interest here is that the construction of windmills was not an uncommon art at that time.[9]

Another Arab explorer was al-Istakhrī[10] who saw these windmills at Seistan about 921 A.D. He wrote a geographical work in which maps were the principal subject. A contemporary Ebn-Haukal[11] combined the maps of al-Istakhrī with his own explorations and from a translation of this more comprehensive work, said among other things of Seistan "there are no hills, in general there is a wind and they have windmills accordingly." Ebn-Haukal described the region as a "fertile and fine country * * * on the East it is bounded by the Desert of Markran and on the South by the Deserts of Sigistan and Kirman and on the North by Hindoostan." None of these early Arab explorers had any apparent interest in the construction of these windmills and we had to wait several hundred years until al-Dimashkī,[12] another geographer and explorer in about 1281 A.D., made a crude sketch of a Persian mill which he saw and also gave a fairly detailed description of its operation. At the time al-Mas'ūdi mentioned the Seistan windmills Persia was under Arab rule and had been since 652 A.D. Though the Arabs cultivated the sciences, especially mathematics, astronomy and chemistry, they did not contribute anything in the way of mechanics and it may well be supposed that the Persian mills were in use long before the Moslem occupation and were not due to Arab ingenuity. Al-Mas'ūdi's manner in describing these mills rather indicates that they had long been a traditional feature of the landscape but he did not seem to have any knowledge of their origin.

Geographically, even as late as the 13th century, Seistan was far removed from the regular caravan and trade routes between the East and the West. The nearest connection was at Herat some two hundred miles to the north or with the Hormuz to Trebizond route three hundred and fifty miles to the west. No doubt through the centuries isolated travelers must have noted these windmills but they did not apparently leave any other impressions than that of wonder or indifference according to the observer's temperament. It is strange that the later explorers of western Asia seem to have missed these ancient mills for in the *Voyages de Chardin,*[13] published at Rouen in 1723, it is stated that "there are no windmills at Ispahan nor in any part of Persia, the mills are all driven by water, by hand or by cattle."

Few of the later day explorers ever crossed the Kirman desert which cuts off Seistan

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[9] It can be assumed that Abū Lu'lu would have built his windmills after the Persian manner and constructed them on the horizontal principle. However, this is not certain but it does indicate that windmills were known in Arabia during the middle of the 7th century. Most early authorities such as Beckmann (*Hist. of Inventions* p. 248, vol. I, 3rd ed.), Chardin and others emphatically state windmills were never employed by the Arabs. It may, therefore, be suggested that after the death of Omar the making of windmills was forbidden or that they were subsequently discontinued by the Arabs as of no importance to their domestic economy.

[10] Al-Istakhrī was more a cartographer than a historian. He was born at Istakhr, now Persepolis. After 921 A.D. his life is obscured and there is no record when or where he died.

[11] Ebn-Haukal, born 943 A.D., died 977. His cosmographical work entitled *The Oriental Geography of Ebn-Haukal,* was translated into English by Sir William Ouseley at London in 1800.

[12] Al-Dimashkī or Muhammad ibn Abi Falib Dimashkī born 1256 and died in Syria in 1327 A.D. An Arab historian and cosmographer. A translation of his manuscripts into French was made by August Ferdinand Michael Van Mehren under the title of *Manuel de la Cosmographie du Moyen-Age* which was published in 1874.

[13] Sir John Chardin, a French explorer whose travels in Persia and the East Indies are considered extremely important. The revocation of the Edict of Nantes drove Chardin to England where he was well received by Charles II who knighted him. Chardin died in 1713 and his *Voyages* was published posthumously by his friends.

to the east. It has only been in quite recent years that several British officials whose work called them to the district have actually seen these Persian windmills which will be described in more detail further along under draft mills.

Draft mills are those that operate, not by the free wind blowing from any quarter, but through the medium of a fixed aperture which directs the wind onto the sails. Such windmills are peculiar to one certain district of Persia called Seistan.[44] The wind conditions here are peculiar for it blows steadily for four months from April to July, often with a maximum velocity of seventy-two miles per hour. This wind called the Bád-i-Sad-o-Bist-Ruz or wind of 120 days, roars through the land during the summer and is followed by the shorter winds of winter, all from the same point of the compass, called Shamistar or the sword. This condition evidently prompted at a remote period some ingenious man, such as Abū Lu'lu, the Assassin, to construct the first of these typical Persian corn mills. While several Arab explorers, as mentioned previously, had noted these mills at an early period only al-Dimashkī considered a drawing of value to posterity. In the following account will be given a description of the Persian mill which al-Dimashkī saw early in the 13th century and as far as a double translation can serve, it is in his own words:[45]

> "In the west of Sedjestan is situated a country where winds bringing sandstorms are very frequent; this is why the inhabitants employ the high winds to turn their mill stones and grind stones and to carry off the sands to another spot: so that the winds are constrained to usefulness according to the words of Solomon (may he rest in eternal peace) the natives build these mills in the following manner:—after having chosen the summit of a high hill, a mountain or even the rampart of a fortress, they build an edifice like a tower devised in two parts: in the upper part is located the grind stones which in turning grind the grain and the lower part is placed in motion by the winds and made to turn the axle of the grind stone in such a manner that the axle and the millstone continue to turn in every wind. After having erected the two parts of the edifice it is the practice to place in the lower part four windows or openings which orifices are large on the exterior but recede in size towards the interior like the bellows of a blacksmith, the better to receive all the winds which put the mill stone in movement. The winds enter through the openings and meet the wings of the axle which resemble the loom of a weaver. These number from six to twelve and are covered with a kind of cotton material such as one employs to cover a lantern or window. Each sail or wing covered with cotton cloth, receives the wind and starts the following one; thus the wings, so placed in motion are made to turn the axle which combined with the millstone, imparts to these the necessary rotation to grind the grain. These mills are very common in this country which suffers from lack of water."

A crude sketch of this mill was also made by al-Dimashkī, but the author has failed to find this in Mehren's translation from the Arabic into the French. From another source the original was located[46] and a better drawing from it has been prepared which is shown at Fig. 33. To clarify al-Dimashkī's description it is evident that the sails of the mill were circular frames to which bags of cloth were attached and these bellied out as they passed one or another of the wind apertures. The fact that there was an aperture in the face of each wall indicated that this type of horizontal windmill could have been used in localities where the wind was more variable as to direction. It is interesting to note that in this mill the upper millstone is the stationary one and it is the lower one which is turned, a practice never employed in European mills but which was quite usual in the Orient, notably in China, where their horizontal water mills were constructed on this plan as early as 1300 A.D.

In recent years there has been further exploration around Seistan where some interesting ruins have been found of early Persian corn mills. These mills were observed by Lieutenant Colonel R. L. Kennion who was at one time British consul in that district; these were particularly noted in his book *By Mountain, Lake, and Plain* as the "oldest form known." A photograph taken of these mills,[47] see Fig. 34, shows a solid line of several

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[44] This place or district is spelled in various ways: Seistan is given in the modern English atlas, others are Siestan, Sejestan, and Segestan by Ousley; Sistán or Sagistán by Sykes, Sedjestan by Mehren, Sijistan or Sigistan in *A History of the Arabs;* Sistan or Sdjistan in *Encyclopaedia of Islam,* Sakastane the ancient name in the *Jewish Encyclopaedia.* Inhabitants of the district are Sistánis and Baluchis.

[45] Translated from Mehren's French translation from the Arabic.

[46] The original sketch made by Dimashkī is reproduced on page 95 of *The Story of the Rotor,* translated from the German *Mein Weg zum Rotor* by Anton Flettner, 1926.

[47] Colonel Kennion's book, published in 1911, was devoted principally to hunting and sports in eastern Persia and except for a fine photograph of these ancient windmills gives very little further information as to how they were constructed.

towers, one wall of which was set to face the prevailing winds and in each tower was a long slit-like opening through which the air rushed with considerable violence and expended its force on eight horizontal sails covered with matting. These were fixed to a long vertical wooden shaft which revolved the millstone below in a separate chamber. See author's model[48] at Fig. 35. Some draft mills of a different construction were noted in active operation on the Afghan border by General Sir Percy M. Sykes in 1900. It will be best to give Sir Percy's own description of these mills, which is as follows:[49]

> "To the ordinary traveller perhaps the most striking feature is the immense number of windmills, of which we had observed very few in Seistan or on the road, whereas at Tabas there are twenty or thirty in a row. These windmills are mentioned in Seistān by Istakhrī in the 10th century, long before they were introduced into Europe and here perhaps we see the original pattern, which merits some description, as, although rough, it struck me as extremely practical. Two mud walls are constructed parallel to the prevailing wind, one of which either curves or is inclined so as nearly to close the north east entrance, from which the wind comes, while the other end is wide open. The upper millstone has a stout pole fixed into it, which in its turn has flanges constructed of reeds. The wind entering the narrow end bears on each flange as it rotates, and thus a most efficient mill is produced at a minimum cost."

If we substitute vanes for the word "flanges" it will be evident that here was a very powerful and efficient type of windmill, for with the wind blowing often at fifty miles an hour, according to the Beaufort scale of winds, the pressure would be 7.7 pounds on every square foot of vane surface. In addition, the effect of the converging side walls would have a tendency to increase the velocity of the wind at the aperture and add many additional pounds to the turning effort. These mills were observed only at Tabas Sunnikhana which is just across the Afghan border. It was noticed by Major Sykes that the millstones ran at a high rate of speed which suggests that they were of quite small diameter. From these three independent accounts, it is apparent that there were many variations of the Persian draft mill, but all were on the horizontal principle. No doubt these Persian windmills gave very satisfactory service but they depended entirely upon a certain geographical situation and would have been quite impractical elsewhere. Situated as they were, between the east and the west, they have been considered by some writers to indicate clearly the origin of the European windmill, but if this were so, the transition period from a vertical wind shaft to a horizontal one is still a matter for very serious consideration unless the vertical sail mill can be accepted as purely an independent invention of western ingenuity.

Except for the draft mills of Persia, there is little more to tell about this form of the horizontal windmill. An early American inventor of such a mill was Samuel Goodwin of New York who obtained a patent on October 31, 1803, for a "horizontal draft windmill," but no trace can now be found of its construction.

All horizontal windmills that have shutters or louvers to deflect the air onto the wind wheel, are a form of draft mill. In this case the wind is definitely directed onto the vanes

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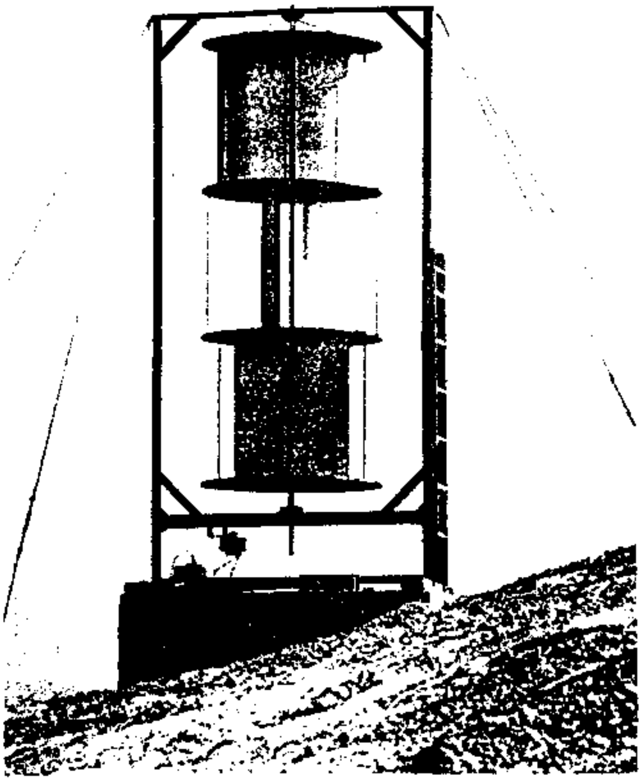
[48] In the absence of a suitable illustration of the Persian mill, a model made by the author some years ago has been substituted. This model stands about 13 ins. high and has six vanes 5 ins. long by 2 ins. wide, and the draft slot measures 4½ ins. by 1¼ ins. It is surprisingly efficient and when placed on the sill of an open window, even in a gentle breeze, revolves at a steady rate while in a strong draft it attains great speed. The wind after turning the vanes, passes out through a large aperture in the front of the tower. Undoubtedly the efficiency of this kind of mill is due to the considerable difference of air pressure between the weather face of the tower and the comparative calm on the lee side.

[49] From *Ten Thousand Miles in Persia or Eight Years in Iran* by Major Percy Molesworth Sykes, London, 1902.

through pre-determined apertures and the efficiency of such windmills is greatly enhanced through such means.

VERTICAL AXIS WINDMILLS



Vertical axis windmills generate power equally well with wind from any direction because these machines do not need to move on their mounts as wind direction changes. These devices are usually easily constructed, lend themselves well to roof-top simplified mounting, and perform reasonably, though not typically as well as high-speed horizontal axis machines.

Design concepts for vertical axis machines extends from simple flat plates at ends of swinging arms, to turbine type devices. The less exotic turbine, or "Savonious" types rotate relatively slowly. This can be advantageous for water pumps and other applications which need neither high rotation rates or high power.

Consider the fact that wind turbine type devices develop power by moving in the same direction as the wind. Power results from wind force acting on the surface which is moving with the wind. Obviously, the surface cannot move faster than the wind or no power would result. Recall, however, from the discussion of u/V ratios that the outer extremities of the machine move faster (not in revolutions per minute, but in the mile-per-hour surface speed) than areas closer to the center of rotation. From this, we can see that the average speed ratio across the radius of a wind turbine will be lower than the wind, say about 0.4, while the tip u/V ratio might be, say 1.2. The tip, in this case isn't contributing to the generation of power, but the surface, on the average, is.

One can determine from this that the vertical axis wind turbine is not as efficient as other types. Obviously, the concept of efficiency does not have the same importance for windmills as it does for other power devices. Wind is available in unlimited quantities and the main problem is not necessarily efficient conversion, but rather low cost conversion of power. It may be considerably cheaper for a designer to cut a 55-gallon oil drum in half to make a Savonious Rotor than, say, for the same individual to build a highly efficient machine of another design. If, however, the 55-gallon Savonious Rotor doesn't satisfy power requirements it's really not the cheapest solution.

A wind machine is any device that converts wind energy into other, useful energy forms. To remove kinetic energy from the air, its mass must be removed (I've not figured out how, but I'm sure it's illegal) or its speed reduced. Many things can reduce windspeed and extract energy. Trees, for example, are better than solid fences because trees flex and dissipate wind energy within the trunk and branches. People have harnessed wind-driven tree motion to power water pumps by means of ropes, pulleys and springs.

Solid fences only create an obstacle around which air must pass, thereby losing only a small amount of energy to friction. Crash a car into a solid fence and you will convert *all* of its kinetic energy into heat energy and broken bones. Crash a bunch of air molecules into a fence and they pile up in front to form a ramp that allows the rest of the air to pass the fence virtually undisturbed. The best you can hope to do is slow the air down. That is the basis of windmill design: to create a machine that slows the wind and does something useful besides.

Two different types of wind machines have evolved that operate by slowing air down. The first type uses *drag* forces—much as the tree does. The second is a *lift*-type rotor that uses forces of aerodynamic lift. A familiar configuration for a drag-type wind machine is shown here. In this simple machine, kinetic energy in the wind is converted into mechanical energy in a vertical rotating shaft. One vane is pushed along by the wind while the opposite vane moves against the wind around a circular path. The drag force on the latter vane must be overcome by the force on the first vane. Any extra force available is wasted unless a load is placed on the rotating shaft.

Suppose that a small electric generator is now driven by the power shaft. This generator will "load" the shaft, and the vanes will turn more slowly than an unloaded rotor under the same conditions. The downwind travelling—or power producing—vane will not be moving quite as fast as the wind. Thus, the wind will push harder on this vane.

If the shaft is held tightly and prevented from turning, no energy will be extracted from the wind, because the moving air will simply flow around the device and surrender only a small amount of its energy as heat. If the shaft is completely free, with no load impeding rotation, the machine will extract only the amount of energy required to push its vanes through the air—a small amount compared to that available. The vanes will spin very fast, and the machine will do very little useful work.

Lift-type machines use aerodynamic forces generated by wind flowing over rotor surfaces shaped much like an airplane wing. Lift force is generated *perpendicular* to the wind while a small drag penalty results that is parallel to the wind. Fortunately, the lift force is usually 10 to 50 times as strong as drag on the airfoil. The ratio of lift force to drag force, called the lift-to-drag ratio L/D, is an important design parameter. How does lift produce the thrust which pushes the blade against its load? Note that the airfoil illustrated is moving at an *angle of attack* off the relative wind. Lift is pointed slightly in the forward direction and, because the airfoil has a high lift-to-drag ratio, a net forward thrust results. This thrust tugs the blade along its rotary path.

Wind Machine Characteristics

All windmills have certain characteristics related to windspeed. At some low value of windspeed, usually from 6 to 12 mph, a windmill can begin to produce power. This is the *cut-in windspeed,* where the force of the wind on the vanes begins to overcome friction and the rotor accelerates enough for the generator or crankshaft to begin producing power. Above this speed, the windmill should generate power proportional to the windspeed cubed, according to Equation 1. At some higher speed, say 25–35 mph, wind loads on the rotor blades will be approaching the maximum strength of the machine, and the generator will be producing its maximum or *rated power.* A maximum useful windspeed, sometimes called the *rated windspeed,* will have been reached. It may also be the *governing windspeed,* at which some form of governor begins to hold power output constant, or even reduce power output at higher windspeeds. At some very high windspeed, say 60 to 100 mph, one might expect complete destruction of the machine if it were permitted to continue generating power. Wind loads on the blades or structural members will have surpassed their material strength, and catastrophe is the only possible result. The machine is usually shut down entirely before that, at a speed called the *furling windspeed.*

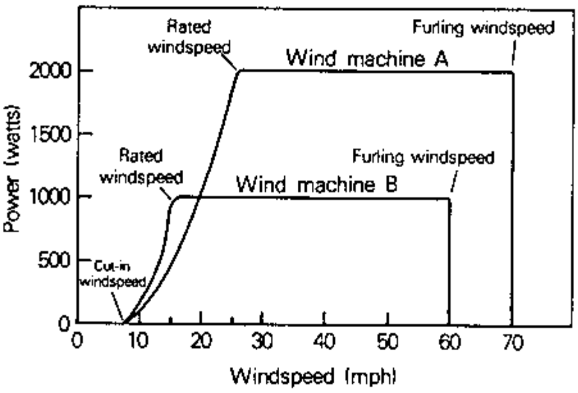
The characteristics for two hypothetical wind machines are illustrated in the accompanying graph. Machine A is a 2-kW machine with a rated windspeed of 25 mph, and machine B is a 1-kW machine rated at 15 mph. Machine B has a smaller diameter than machine A and is perhaps more fragile—its recommended furling speed is 60 mph, as compared with 70 mph for machine A.

These characteristics are very important. You have complete control of most of them during the design process. You first select the rated windspeed and power output. By designing for a given structural strength, you can calculate when furling *must* occur. You really cannot calculate the exact cut-in speed. It is as much determined by blade aerodynamics—which you can calculate—as it is by the thickness of oil in the transmission, bearing friction, and the phase of the moon.

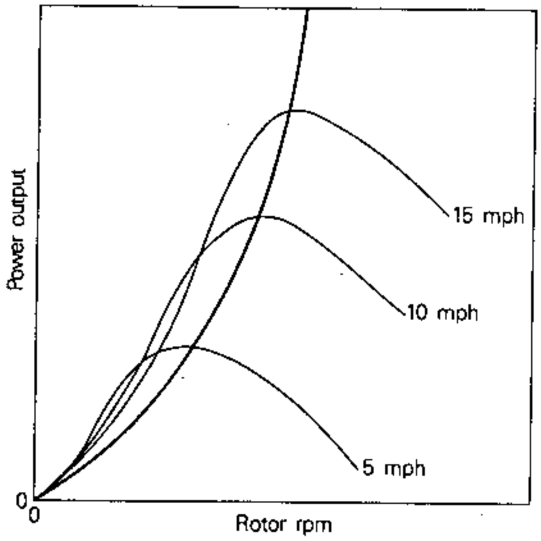
Let's use the drag-type Savonius rotor to illustrate how rotors can be overloaded, underloaded, or loaded to their optimum power output by a generator or other load. The generator that loads the power shaft might draw enough power to overload the shaft and slow the rotor rpm to the extent that most of the wind just piles up and flows around the machine—causing efficiency and power output to drop. Or, the generator might not extract enough power, and the rotor will spin too fast—causing extra drag on the upwind vane, lower efficiency, and added power loss. Somewhere between overload and underload is the *optimum load.* This optimum load is the extracted power that you calculated in Equation 1. All you need is the windspeed and the size and efficiency of the machine. The first two are fairly straightforward, but the last one depends on a number of factors that are discussed in more detail in the box

Suppose you want to study more closely how wind power and rotor loading are related. How would you represent the relationships of loading, windspeed, and windmill performance? The bottom graph illustrates these factors. For a hypothetical wind machine, rotor power output is plotted against rotor rpm for several windspeeds. For example, the curve for a windspeed of 5 mph shows how power output at optimum loading is much greater than for overload or underload conditions (which allow the rotor to underspeed or overspeed, respectively). For the 10 mph and 15 mph curves, the effect is the same but stronger. Connect the peaks of the power output curves and you get the optimum load power curve for that rotor.

What causes the shapes of the peaked curves? Each curve gets its shape from the response of the rotor to loading and to wind gusts. Some rotors respond well, with a somewhat flat-topped curve. Such



Output power for two typical wind machines. A rotor produces its maximum power at windspeeds between the rated and furling windspeeds.



Variation of power output with rpm for a typical rotor. At each windspeed, there is a point of optimum performance (heavy line).

Drag-Type Machines

A drag-type wind machine harnesses the component of wind force perpendicular to the surfaces of its vanes. Such a machine might be a Savonius rotor or, even more simply, a flat board nailed to the end of a swinging arm. In this case, the drag force on the vane is given by the formula:

$$\text{Drag Force} = \tfrac{1}{2} \times \rho \times (V - u)^2 \times A_v \times C_D\ ,$$

where

ρ = *the air density in slugs/ft*^{3},
V = *the windspeed in ft/sec,*
u = *the vane speed in ft/sec,*
A_v = *the area of the vane in ft*^{2},
C_D = *the drag coefficient of the vane.*

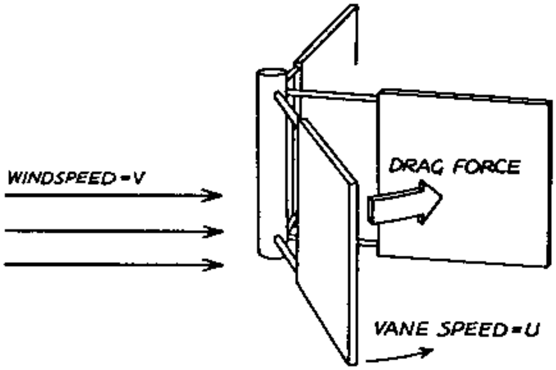
Generally, the drag coefficient of a vane has a value between zero and one.

If the rotor is at rest, the vane speed (u in the above equation) is zero, and maximum force occurs when the vane is perpendicular to the wind. If you multiply this maximum drag force by the radius to the center of rotation, you get the starting torque supplied by the vane. Of course, the net torque of the entire machine will be less because the wind is pushing against other vanes on the upwind side of the machine and retarding this rotation.

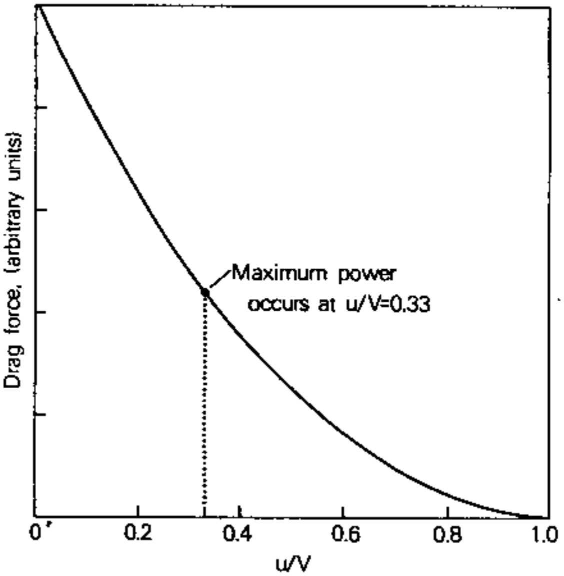
The power developed by a drag-type machine is just the drag force multiplied by the vane speed:

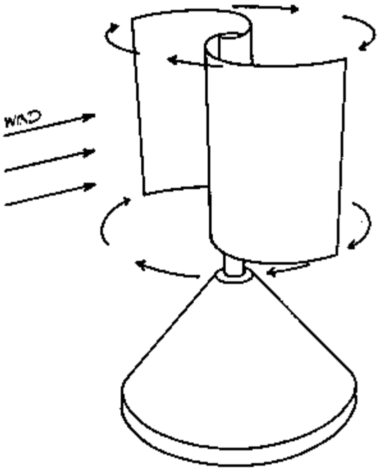
$$\text{Power} = \tfrac{1}{2} \times \rho \times (V - u)^2 \times u \times A_v \times C_D\ .$$

As the vane speed increases, the drag forces drop sharply (see graph), but the power extracted from the wind increases. When the vane speed equals one-third the free-stream windspeed V, maximum power extraction occurs. Of course, you still have to subtract the power wasted in driving other vanes upwind on the other side of the machine.

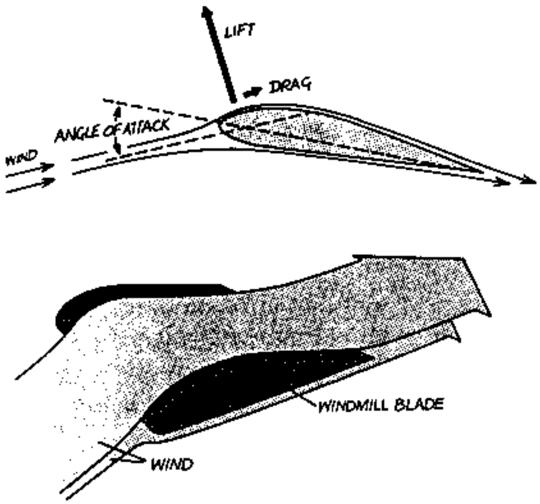


The drag coefficient C_D for a curved, two-vane Savonius rotor is about 1 for the concave, or torque, side and from 0.12 to 0.25 for the opposite, upwind-moving side. With these numbers you can easily calculate the difference in drag force between the two sides and estimate the net torque on the device. But be careful. Note that you should use V + u instead of V − u on the upwind vane. By a similar procedure, you can also estimate the net power developed by a Savonius.





A simple, drag-type wind machine. Wind pressure on the high-drag, concave surface turns the rotor about its vertical axis.



The flow of wind about a windmill blade. Lift forces act perpendicular to the local wind direction, while drag forces act parallel to it.

Forces on an Airfoil

All airfoils, even flat boards tilted into the wind and used as lifting surfaces, have predictable lift and drag characteristics. Lift is the force produced on the airfoil in a direction perpendicular to the "relative wind" approaching the airfoil. This relative wind is the wind that an observer sitting on the airfoil would face. The aerodynamic lift can be calculated from the formula:

$$Lift = \tfrac{1}{2} \times \rho \times V_r^2 \times A_b \times C_L ,$$

where

ρ = *the air density in slugs/ft*^{3},
V_r = *the speed of the relative wind approaching the airfoil, in ft/sec,*
A_b = *the surface area of the airfoil or blade, in ft,*
C_L = *the lift coefficient of the airfoil.*

The drag force on the airfoil occurs in a direction parallel to the relative wind; it acts to retard the forward motion of the airfoil. Its value is calculated by replacing the lift coefficient in the above equation by the airfoil drag coefficient, C_D.

To understand airfoils in more detail, you need to grasp a few other definitions. The "chord line" of an airfoil is a line extending from its leading edge to the trailing edge. The "angle of attack" is the angle between the chord line and the relative wind approaching the leading edge. The "pitching moment" is a measure of an airfoil's tendency to pitch its leading edge up or down in the face of the wind. It is important to the structural design of the blades and feathering mechanism. Certain airfoils are neutral; they have no pitching moment.

The graph presented here gives values of the lift and drag coefficients for a particular standard airfoil shape—the FX60-126. Similar curves are available for every airfoil tested.

The curves shown here give the lift coefficient C_L versus angle of attack and include a "drag polar" that shows how the drag coefficient C_D varies with the lift coefficient. Note that the maximum lift occurs when the angle of attack is 12° and that the minimum drag occurs at $C_D = 0.006$, corresponding to a lift coefficient $C_L = 0.2$.

Example: *At an angle of attack equal to 4°, the FX60-126 airfoil has a lift coefficient $C_L = 0.96$. What is the lift force produced if the windspeed at the leading edge equals 40 mph and the blade area is 2 square feet?*

Solution: *First convert 40 mph to 58.8 ft/sec by multiplying by 1.47. Then, using the above equation for the lift force,*

$$\text{Lift} = 0.5 \times 0.00238 \times (58.8)^2 \times 2.0 \times 0.96 = 7.9 \text{ pounds} .$$

From the graph, $C_D = 0.0098$ when $C_L = 0.96$, so the drag force on the airfoil under the same conditions is:

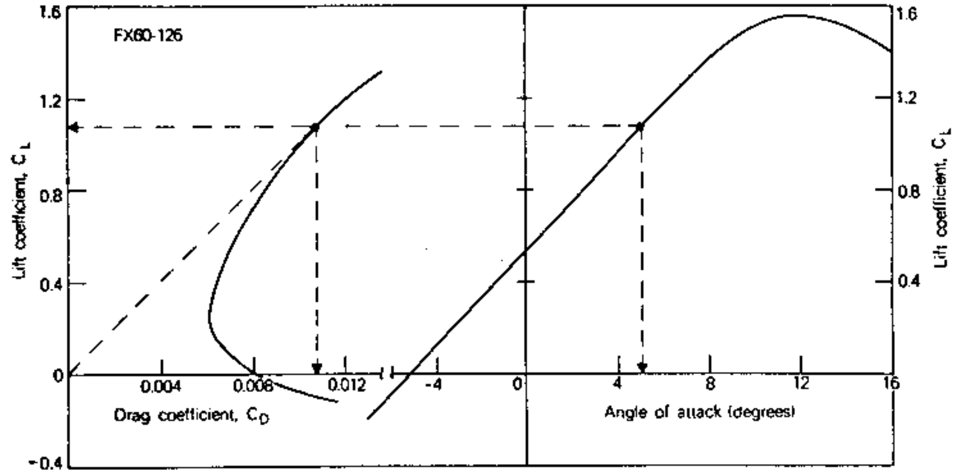
$$\text{Drag} = 0.5 \times 0.00238 \times (58.8)^2 \times 2.0 \times 0.0098 = 0.081 \text{ pounds} .$$

By taking the ratio of the lift force to the drag force, you can calculate the lift-to-drag ratio, L/D:

$$L/D = \frac{7.9}{0.081} = 98 .$$

Of course, this is the same result you would obtain if you just took the ratio of the lift coefficient to the drag coefficient.

The best airfoil performance occurs at an angle of attack where the lift-to-drag ratio is a maximum. There you get maximum lift for minimum drag, but not necessarily the absolute maximum possible lift. On the FX60-126 airfoil, note that minimum drag occurs when $C_L = 0.2$—a low value compared to the maximum possible ($C_L = 1.6$). To find the angle of attack at which L/D is maximized, simply draw a line from the origin of the drag polar curve to the point where it just touches tangent to this curve. The point of tangency corresponds to maximum L/D for the airfoil. Draw a horizontal line from the point of tangency right to where it intersects the lift coefficient curve, and you get $C_L = 1.08$ in this example. As the drag coefficient here is $C_D = 0.0108$, the lift-to-drag ratio has a maximum value of 100. Note also that the angle of attack for maximum L/D is 5.2°. Setting the blade edge at this angle of attack to the relative wind will allow the airfoil to fly at its optimum performance.



rotors are insensitive to non-optimum loadings or wind gusts. A large change in rpm means only a small change in power. Other machines might be so sensitive that slight overloading "stalls" the rotor—it quits turning altogether. You would expect the performance curve for such a rotor to have a sharply peaked shape. A small change in rpm can mean a large change in power output for constant windspeed.

In our discussion of rotor performance, the term *tip-speed ratio* (TSR) will often be used instead of rotor rpm. The TSR is the speed of the rotor tip (as it races around its circular path) divided by windspeed. For any given windspeed, higher rpm means higher TSR. If the tip is travelling at 100 mph in a 20 mph wind, the TSR = 5. Typical values of the TSR range from about 1 for drag-type machines to between 5 and 15 for high-speed lift-type rotors. By using the tip-speed ratio we can ignore the rotor rpm and diameter, and consider rotor performance in a more generalized discussion.

Wind Machine Performance

The basic formula used in calculating wind machines. Notice that the American Farm multibladed machine and the Savonius rotor are both low-TSR machines, operating at a TSR close to 1. The high-speed two- and defined earlier as rotor power output divided by power available in the wind. The efficiency of a wind machine depends on its design, on how carefully that design is built, and on whether the machine is optimally loaded. No matter how well-designed and built, if a windmill is overloaded or underloaded it loses efficiency. In a plot of efficiency versus tip-speed ratio for several wind machines, each curve shows a distinct peak corresponding to optimum loading. The response of the machine to overspeeding and underspeeding of the rotor is indicated by the dwindling efficiency on either side of the peak. The graph here shows how efficiency—also called the *power coefficient*, Cp—relates to the tip-speed ratio for several types of wind machines. Notice that the American farm multibladed machine and the Savonius rotor are both low-TSR machines, operating at a TSR close to 1. The high-speed two- and

Tip-Speed Ratio

The tip-speed ratio, or TSR, is a term used instead of rotor rpm to help compare different rotors. It is the ratio of the speed at which the blade tip (the furthest point from the center of rotation) is travelling to the free-stream windspeed:

$$\text{Tip-Speed Ratio } TSR = \frac{\text{Blade Tip-Speed}}{\text{Windspeed}}.$$

If you know the windspeed, the rotor diameter or radius and its operating rpm, you can calculate the tip-speed ratio, or speed ratio SR at any fixed radius between the center of rotation and the tip:

$$\text{Speed Ratio} = \frac{2\pi \times r \times N}{60 \times k \times V},$$

Or

$$SR = 0.105 \times \frac{r \times N}{k \times V},$$

where

N = *rotor rpm,*
r = *radius at which SR is being calculated,*
V = *free-stream windspeed, in ft/sec,*
k = *a constant to adjust V:*
$k = 1.47$ *if V is measured in mph,*
$k = 1.00$ *if V is measured in ft/sec.*

To calculate the tip-speed ratio with this equation, just use $r = R$ (radius of blade) = $\frac{1}{2} \times D$ (rotor diameter).

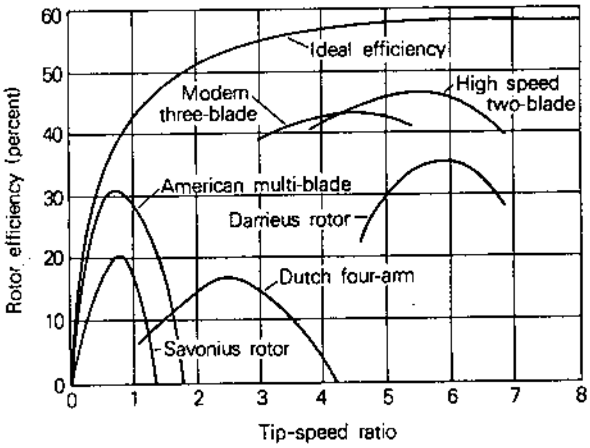
Example: *A rotor turns at 300 rpm in a 15 mph wind. If its diameter is 12 feet at the tip, calculate the TSR.*

Solution:

$$r = R = \frac{12}{2} = 6 \text{ ft};$$

$$TSR = 0.105 \times \frac{6 \times 300}{1.47 \times 15} = 8.6$$

The blade tip travels 8.6 times as fast as the wind.



Typical performance curves for several wind machines. Rotor efficiency is the percent of available wind power extracted by the rotor.

Maximum Rotor Efficiency

The analysis of maximum possible efficiency for lift-type rotors was originally done by Betz in 1927. Here, the rotor extracts power from the airstream by slowing down the free-stream windspeed V to a lesser speed V_2 far downstream of the rotor blades. The power extracted is just the difference in wind energy upstream and downstream of the rotor, or

$$Power = \tfrac{1}{2} \times M \times (V^2 - V_2^2)\ ,$$

where M is the mass of air that flows through the rotor per second. If V_2 equals zero in the above equation, you might expect that power would be maximized. But no air would flow through the rotor in this case, and the power is zero. The mass flow through the rotor is just the air density times the rotor area times the average wind velocity at the rotor, or:

$$M = \rho \times A \times \frac{V + V_2}{2}\ .$$

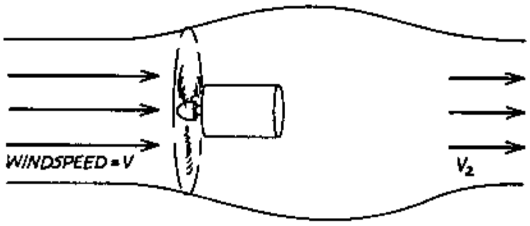
Substituting this formula into the power equation yields:

$$Power = \tfrac{1}{4} \times \rho \times A \times (V + V_2) \times (V^2 - V_2^2)\ .$$

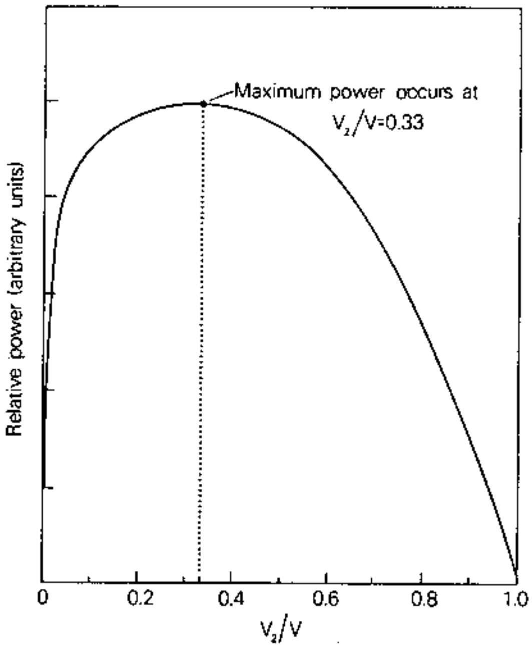
A graph of the relative power generated versus the ratio of V_2 to V is presented here. Note that maximum power occurs when V_2 equals one-third of V. Under such conditions,

$$Maximum\ Power = \tfrac{1}{2} \times \rho \times A \times V^3 \times \frac{16}{27}\ .$$

Thus, maximum possible (theoretical) efficiency of a lift-type rotor is 16/27, or 59.3 percent. In reality, swirl in the downwind airstream and other inefficiencies limit the practical efficiency even more.



Airflow through lift-type rotor.



Power output of lift-type rotor.

three-blade machines operate at high TSR, from 4 to 6, and higher efficiencies.

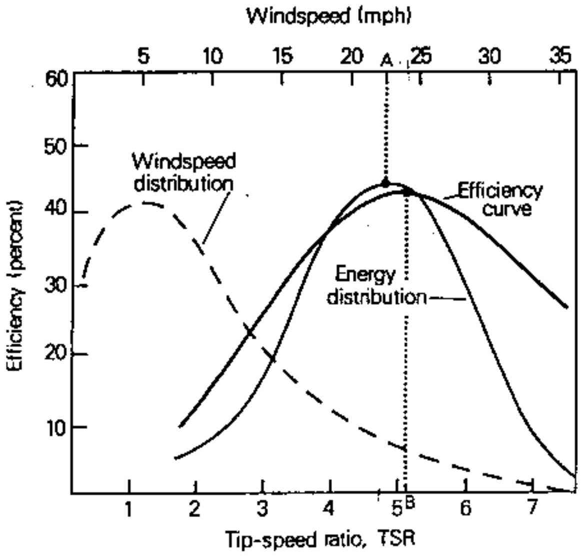
In Chapter 3, you saw that wind is actually a series of individual gusts. With this in mind, suppose that a Dutch four-arm windmill is spinning in a continuous 10-mph wind and a generator is loading the rotor to its optimum power output. The tip-speed ratio equals 2.5 in this steady wind; that is, the tip of a vane is moving at 2.5 × 10 mph, or 25 mph. Now add the gusts. Suppose the first gust passes the rotor and doubles the windspeed to 20 mph. For a brief moment, the new tip-speed ratio is 25 ÷ 20, or 1.25. At this same instant, rotor efficiency drops to about half its original peak value, but the doubling of windspeed means that eight times as much windpower is available to the rotor. The actual power output only quadruples (½ × 8 = 4).

Because the rotor doesn't speed up instantly, it is actually averaging the effects of gust-induced variations in the tip-speed ratio. Over a long time period, a rotor whose efficiency curve drops off steeply on either side of the peak is less apt to convert as much wind energy as one whose efficiency curve is relatively flat. A rotor with a flat efficiency curve is insensitive to gusts. An important point to consider with efficiency curves is the change in performance that can be expected from halving or doubling the tip-speed ratio. Both height *and* shape of the efficiency curves are important design considerations.

In Chapter 3, the energy content in the wind was shown to be a peaked curve. As much as possible, the peak operating efficiency of a wind machine should coincide with the peak of the wind energy distribution. It's not always possible to have them coincide exactly, because a different wind machine cannot be designed for every individual site. But try to make the rotor efficiency curves look like, and peak at about the same windspeed as, your site's wind energy distribution curve. This visualization is the first step in selecting appropriate operating characteristics for your wind machine.

The accompanying diagram shows how wind energy distribution and rotor efficiency curves might coincide. The energy distribution was calculated from the windspeed distribution curve. Note that most of the wind energy is available at windspeed "A", while the rotor efficiency peaks at TSR "B", corresponding closely with windspeed A. As the TSR is a ratio of tip-speed to windspeed for fixed rotor diameter, this relationship determines the optimum rotor size for this hypothetical site.

So far I have discussed only the rotor and its efficiency. Overall efficiency of the wind machine is related to the actual performance characteristics of any component that can rob the wind machine of power. Often the bearings and transmission have losses that can be considered constant, but the rotor, generator, and other loads such as pumps have efficiencies that vary with windspeed, rpm, and TSR. These all combine to give the performance curve its final shape.



Matching a rotor to the wind characteristics of a site. The maximum efficiency of a well-matched rotor occurs at about the same windspeed as the peak in the wind energy distribution.

Sizing a Wind Rotor

There are two principal ways to determine the frontal area of a wind machine rotor. You can merely guess how large a machine you want, calculate the power it produces, and stop there. Or you can first determine your average power needs and the wind resources at your site, and then equate the two to determine the rotor area. The first method is the one most often used. The second is more complex but results in a much closer match between your power needs and the wind power available.

Suppose you know in advance your average power needs—denoted here by the letter P. Equation 1 tells you that this power, if supplied by a wind machine, depends on the windspeed V, the rotor area A, the air density ρ, and the system efficiency E:

$$P = \tfrac{1}{2} \times \rho \times V^3 \times A \times E.$$

This formula can be rewritten to express the rotor area A in terms of five factors:

$$A = \frac{P}{E \times F \times C_A \times C_T}\ , (Eq.\ 4)$$

where F is a factor that depends on windspeed and is presented in the first table here, and C_A and C_T are the altitude and temperature correction factors to the air density that are given in the tables on page 48 of Chapter 3. Equation 4 gives you the area in square feet when the power P is expressed in watts; if P is in horsepower, multiply A by 0.737.

If you are purchasing a factory-built machine and know its system efficiency, this formula can tell you whether its frontal area is suited to your power needs. If you intend to design and build your own machine, you need an estimate of the efficiency before you can begin. Use the second table here to get a rapid but rough estimate. Then get values of F, C_A and C_T for your site from the appropriate tables. The rest is calculation.

Example: *You have chosen a three-bladed propellor-type machine to produce 1000 watts. A site survey shows that the energy content of the winds at your site, which is at sea level, peaks at 15 mph. What size rotor is needed?*

Solution: *Begin by estimating the system efficiency. For small propellor-type systems, you can expect an efficiency from 15 to 30 percent. You elect to use 25 percent (E = 0.25) for a carefully designed machine. From the first table F = 17.30 at 15 mph, and $C_A = C_T = 1$ at sea level, for standard temperature (60°F). So,*

$$A = \frac{1000}{0.25 \times 17.30 \times 1 \times 1}$$

$$= 231\ ft^2\ .$$

You usually need to know the diameter of the rotor that can do the job. In this case, a diameter of 17.3 feet is needed.

Power Factor F

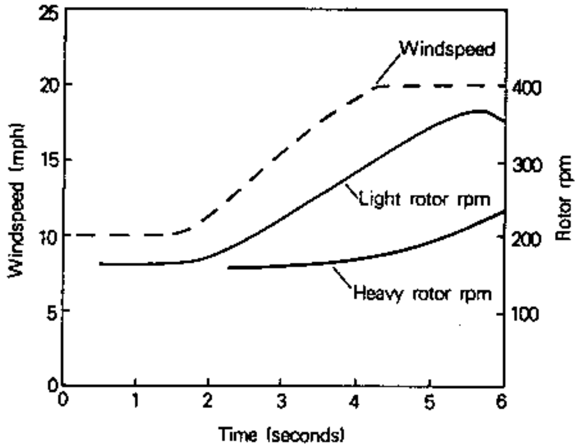
V	F
6	1.07
7	1.76
8	2.62
9	3.74
10	5.13
11	6.82
12	8.86
13	11.26
14	14.07
15	17.30
16	21.00
17	25.19
18	29.90
19	35.17
20	41.02
21	47.48
22	54.59
23	62.38
24	70.88
25	80.11
26	90.12
27	100.92
28	112.55
29	125.05
30	138.43

Rapid Efficiency Estimator

Wind System	Efficiency, %	
	Simple Construction	Optimum Design
Multibladed farm water pumper	10	30
Sailwing water pumper	10	25
Darrieus water pumper	15	30
Savonius windcharger	10	20
Small prop-type windcharger (up to 2 kW)	20	30
Medium prop-type windcharger (2 to 10 kW)	20	30
Large prop-type wind generator (over 10 kW)	—	30 to 45
Darrieus wind generator	15	35

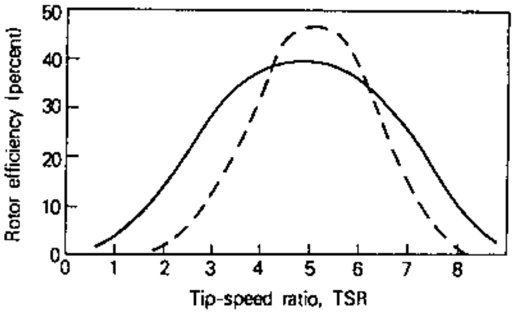
In small design projects, the process of load matching is often reduced to selecting the transmission gear ratio that minimizes the effects of mismatch. For certain types of pumps and compressors, a gear ratio can be selected that almost ideally matches rotor to load. For alternators and generators, however, some amount of load mismatch will occur.

How the rotor performs when the windspeed changes abruptly is another important design consideration. The diagram shows a typical wind gust that nearly doubles the windspeed in a few seconds. For clarity, the windspeed is illustrated as staying at the new speed, a very unlikely occurrence. Two typical rotors respond to this gust by accelerating to higher rpm. One rotor is lightweight (low inertia), perhaps a Savonius rotor made of aluminum; the other is heavy (high inertia), perhaps the same size S-rotor, but made of steel drums.



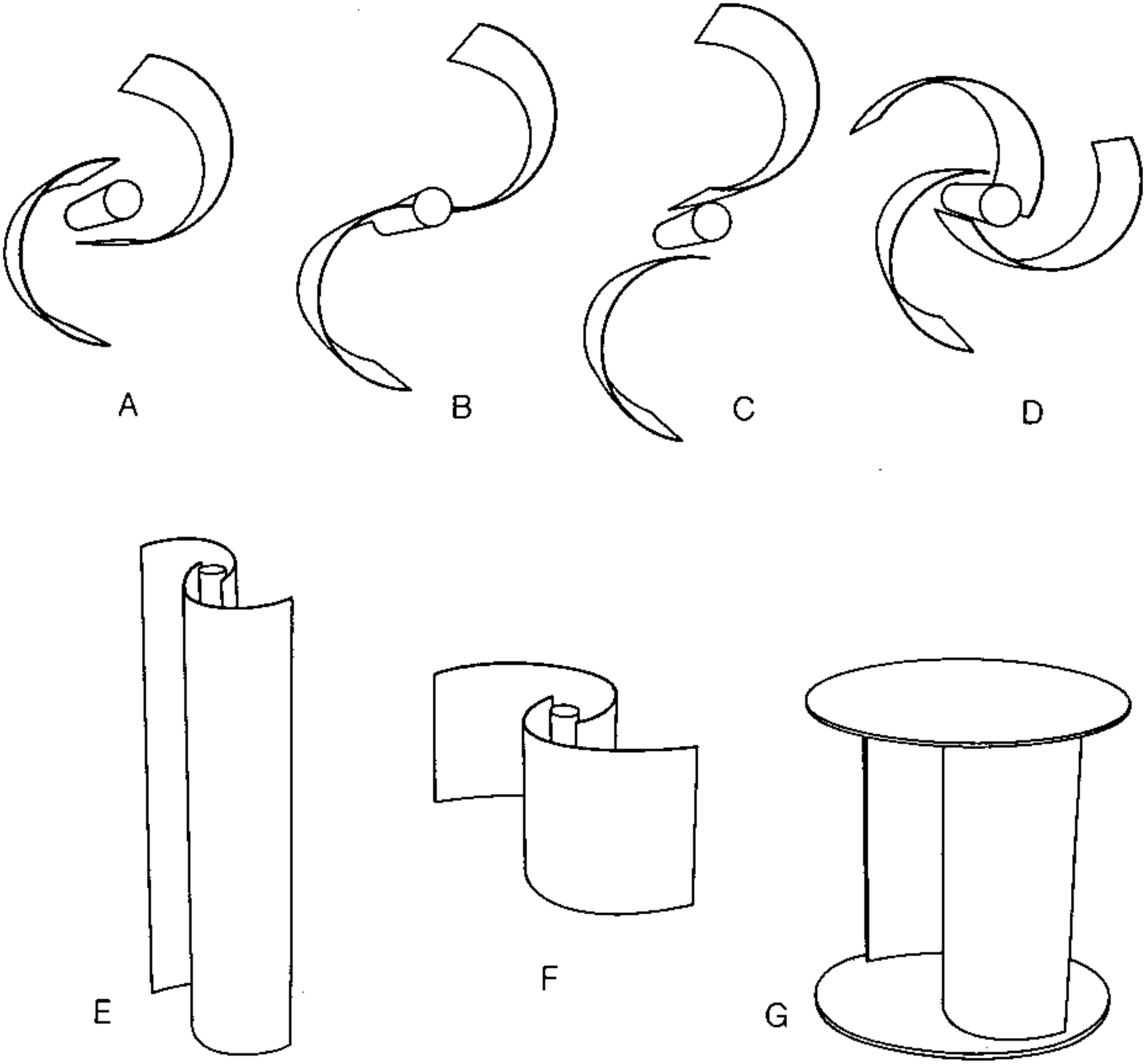
The response of two rotors to a gust of wind. A light rotor speeds up more quickly than a heavy one.

Notice that the heavy rotor accelerates more slowly than the light one. Really large rotors might take half a minute to follow a gust, which disappears before that time. Heavy rotors tend to average the windspeed—staying at an average rpm. Light rotors also average, but they experience more fluctuations in rpm. The significance of this averaging effect is that a rotor cannot always operate at its optimum tip-speed ratio. It will operate at an average TSR, yielding less than maximum efficiency.



Performance curves for two small wind machines. A broader curve is the more desirable, even though peak efficiency may be slightly reduced.

The shape of the curve depicting the relationship of rotor efficiency to TSR is very important in the overall performance of that rotor. Two different efficiency curves are shown in the next diagram; the dashed curve shows a higher maximum efficiency than the solid curve. But the solid curve is broader and flatter, so a gust-induced change in TSR would produce a much smaller change in rotor efficiency. Hence, because of the averaging tendency of rotors, a flatter efficiency curve is often more desirable than a peaked curve—even if its maximum is slightly lower. Over the long run, the machine with a broad, flat efficiency curve will generate more wind energy than a machine with a sharply peaked curve.



Savonius rotor design options include the intervane gap, number of vanes, aspect ratio, and tip plates. Option E has a much higher aspect ratio than F, and the tip plates in option G improve the rotor performance at low rpm.

Savonius Rotor Design

Aerodynamic design of the Savonius rotor and other simple drag machines is mostly a matter of drawing something that looks like it will work. For most Savonius projects, the shape is determined less by design factors and more by available materials. The usual "home-brew" rotor is made from oil drums cut in half; an occasional rotor is built from sheet metal. Either the drum size or sheet metal width will determine rotor diameter. Most S-rotors are about 3 feet in diameter, but some have been built 30 feet across.

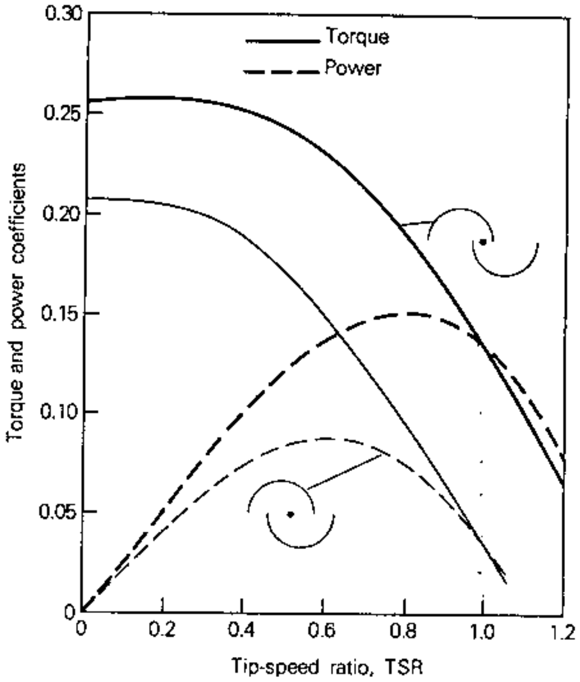
Many studies have been conducted to determine optimum shapes for Savonius rotors. The results are summarized in the diagram on this page. Options start with the *intervane gap.* In the diagram, option A is an improvement over options B and C. Air can flow through the intervane gap in design A and push on the upwind-traveling vane, reducing the drag on this vane and increasing torque and power. The number of vanes is the next consideration, and A seems to be an improvement over D. Theoretical explanations for this effect are complex and possibly incorrect. But experimental tests show that two vanes work the best. Because of the materials you have available, such as old oil drums with which to make an S-rotor, the number of vanes and the intervane gap might be limited by your ability to fit the pieces together. There is not an enormous difference in performance between the various options, but better performance is possible when you can use the best options.

The next design variable is the vane *aspect ratio*—in this case, the ratio of vane height to diameter. There is probably no best design in this case. For a given frontal area, higher aspect ratio rotors will run at higher rpm and lower torque than those with a low aspect ratio. Tip plates improve S-rotor performance slightly, especially at very low start-up rpm.

What kind of performance can you expect from an S-rotor? The graph here presents typical performance curves for two S-rotors with different vane gaps. The best one shows a maximum efficiency of about 15 percent—a typical value for a small machine like an oil-drum S-rotor with a 3-foot diameter. For a machine with a diameter of 10 feet or more, you could expect an efficiency of 20 percent. Note that the graph shows both torque and power coefficients and illustrates the S-rotor's characteristically high starting torque. Loads driven by a Savonius should have roughly similar torque and power requirements. See Appendix 3.2 for a sample design calculation that uses the Savonius performance curves presented here.

Propellor-Type Rotor Design

If you wish to use a wind machine to drive an electrical generator, the high rpm needed by the generator will require a high-speed rotor. In general, only propellor-type and Darrieus rotors can develop the high rpm needed. In both cases, careful aerodynamic design of the rotor blades is important if maximum rotor efficiency is desired.



Performance curves for two S-rotors. Use these curves to estimate rotor torque and power.

Types of Machines

A major factor used to classify the various types of wind machines is the method of rotor propulsion; the rotor is propelled either by drag forces or by aerodynamic lift. The first rotor discussed in this chapter uses direct impact of the wind against a vane to provide motive force. This machine depends on a difference in drag between the power-producing vane moving downwind and the opposite vane, moving upwind. The curved shape of the vane permits this difference in drag forces. But for power production, the vane tip-speed cannot be much faster than the windspeed. Otherwise, the vane would be moving away from the wind that is supposed to be pushing against it (not very likely). So drag-type wind machines operate best at a TSR close to 1.

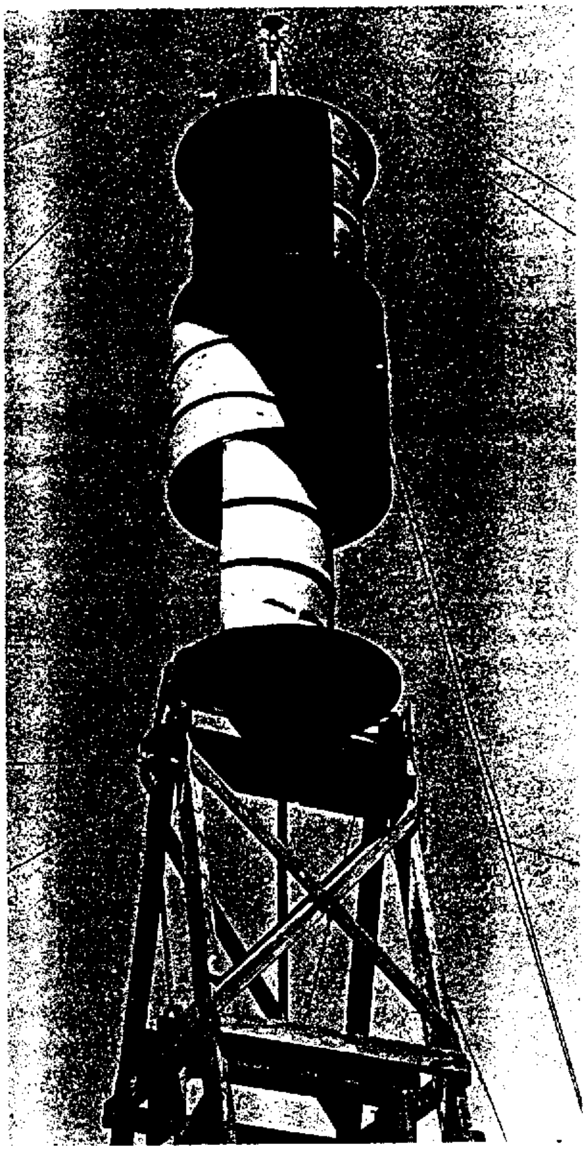
Lift-type, or airfoil, rotors use the aerodynamic lifting forces caused by air flow over blades shaped like airfoils to turn the rotor. Smooth air flow over an airfoil produces lift that pulls the blade in the thrust direction. Simultaneously, a small drag force acts against this thrust. Drag is the penalty one must pay for hanging anything out in a breeze. Well-designed airfoils don't have anywhere near the drag of such unsophisticated shapes as flat boards. Lift-type rotors are not restricted by any limitations on the tip-speed ratio. In general, the higher the tip-speed ratio, the higher the rotor efficiency.

There are four generic types of wind machines discussed here: the Savonius rotor, Darrieus rotor, multibladed farm windmills, and highspeed propellor-type rotors. These are the types most often encountered in design discussions and in the field.

Each of these types has evolved to serve specific needs or conditions. Savonius rotors and farm windmills are slow-turning with high starting torque—which suits them well to mechanical tasks such as lifting water. The Darrieus and propellor-type rotors spin much faster and have little or no starting torque at all. Their higher rpm make them well-suited for driving electric generators. The range of actual design types is vast, and even includes wind generators with no moving parts. Before you can make a thorough evaluation of your wind system's efficiency, you must select a design type that will form a basis for your analysis.

Savonius Rotor

The Savonius rotor, or S-rotor, looks something like an oil drum that has been sliced in half and separated sideways, as shown in the photo. It was officially invented by Sigurd J. Savonius of Finland in the early 1920's, although it was probably built by many other experimenters prior to that time. The rotor was originally developed to power specially designed sailing ships then being tested. The Savonius is a drag-type rotor. In addition to drag on the vanes producing rotary shaft power, that drag produces downwind forces (also called drag loads) on the tower.



A low-technology Savonius rotor. Easily fabricated from surplus oil drums, this drag-type machine offers only limited power.

A rotor that slows air down on one side while speeding it up on the other, as does the S-rotor, is subject to the Magnus Effect: lift is produced that causes the machine to move in a direction perpendicular to the wind. Spin on a baseball causes it to curve because of the Magnus Effect. An S-rotor can easily experience lift forces equal to two or three times the drag load placed on its supporting tower. Many owner-built S-rotors have toppled to the ground because their designers overlooked this phenomenon.

Recent theoretical studies have shown that the rotor efficiency of an S-rotor will most likely be less than 25 percent. If you add water-pump losses and other equipment inefficiencies in calculating overall efficiency, that's a maximum system efficiency of 15 percent for pumping water with a Savonius. Tip-speed ratios are about 0.8 to 1.0 at peak efficiency—as you would expect with a drag-type rotor.

The desirable features of the S-rotor are as follows:

- Easily manufactured by owner-builders
- High starting torque for starting under heavy load.

Undesirable features include:

- Difficult to control—other than a brake mechanism, controls to limit rpm in high winds are not readily devised
- Poor materials usage—presents a small frontal area for a fixed amount of construction materials

Often claimed, but not particularly important, is that the Savonius can convert energy from winds that rapidly shift direction. In most installations, the winds used for the major portion of energy production do not shift directions. The gusty, so-called energy winds are often stronger than windmills are normally designed to respond to. The big plus for an S-rotor is that it is easily built with readily available materials and can produce high torque while it is starting to spin. Thus, it is suited to a variety of direct mechanical uses such as pumping water, driving compressors or pond agitator vanes, and even powering washing machines, if that's your fancy. The number of vanes is not limited to two as shown here; three, four and more blades are common.

We saw earlier that a difference in drag force on the downwind-moving vanes to the upwind-moving vanes is needed to produce a net torque on the power shaft of a Savonius. By increasing this torque at the highest possible rpm, you can maximize the power output of this type of machine. There are two ways to accomplish this feat:

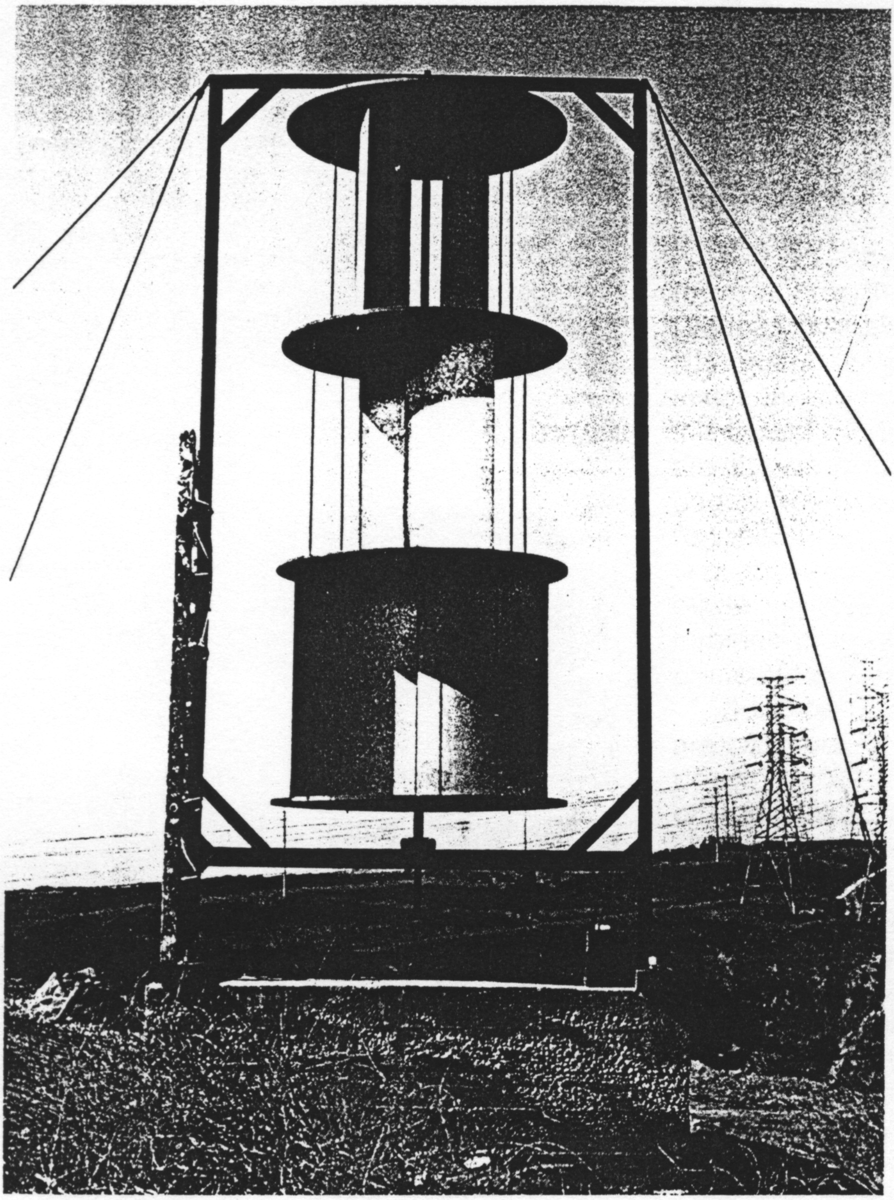
1. Maximize the difference in drag coefficients between upwind and downwind vanes, or,
2. Minimize the wind force against the upwind-moving vane.

Shapes that maximize this difference in drag coefficients have evolved mainly to the familiar Savonius rotor shape. Minor variations on this shape are possible with cones, wedges, or flat vanes that flop over edgewise as they advance into the wind. To minimize wind force against the upwind-moving vanes, simply build a shield in front of them. With such a solution, you can use simple flat vanes rather than the more complex curved vanes.

Darrieus Rotor

Not long after Savonius patented his S-rotor, a French engineer named G.J.M. Darrieus invented another vertical-axis rotor. His patents anticipated virtually all of the major innovations being tried today with this type of windmill. Several Darrieus rotors are shown in the photographs on these pages. The two primary variations are the "eggbeater"—so named because of a distinct similarity in shape—and the straight-blade versions, sometimes called cycloturbines or cyclo-gyros by various developers of this design.

Both the Savonius and Darrieus rotors are *crosswind-axis* machines in which the power shafts are mounted either vertically or horizontally, perpendicular to the wind stream. But there is one important distinction: the Savonius is a drag-type device, while the Darrieus is a lift-type machine. The diagram illustrates how lift forces on the blades act in a direction ahead of the blades, as all airfoils produce lift perpendicular to the airflow approaching the airfoil's leading edge. As the blade moves along its path, it is actually moving at a speed several times faster than the wind. Thus, even when the airfoil appears to be moving downwind, it is not. Lift is produced



A three-tiered Savonius rotor designed to generate electricity.

over almost the entire circular path. Contrast this case with the drag-type Savonius rotor, in which power-producing forces on the downwind-moving vane are fighting drag forces on the upwind blade vane. You can well imagine that the efficiencies of Darrieus rotors are greater.

Some theoretical studies indicate a 54 percent efficiency for the Darrieus rotor, not including losses in gears, generators, and elsewhere. Others think the Darrieus is actually capable of higher efficiencies than the theoretical maximum of 59.3 percent. There are good reasons for such claims; but neither of them has been proven correct, yet. In careful tests, the measured efficiencies ranged from 20 percent for the "egg beater" design, to greater than 50 percent for highly sophisticated straight-blade designs. This diversity of results suggests that the question is probably still open.

In any event, the efficiency curve for the Darrieus [redacted] suggests the performance you might expect from a well-designed rotor. The steep slope on the low-rpm side of the curve indicates that this rotor is easily stalled when overloaded. Should the windspeed increase quickly while a fixed load is applied to the rotor, its tip-speed ratio falls rapidly. The rotor, which was operating at the peak of its performance curve, slips over to the steep underspeed side of the curve, even though more wind power is available to the rotor. Properly designed rotor and generator controls will prevent complete stalling of the rotor under this condition. Without such controls a rotor stall is almost guaranteed.

The desirable features of a Darrieus rotor are as follows:

- Possible ease of construction by owner-builders if lower performance is acceptable
- Low materials usage for high power output
- Adaptability to sail and other appropriate technologies
- Possible high wind-energy conversion efficiencies.

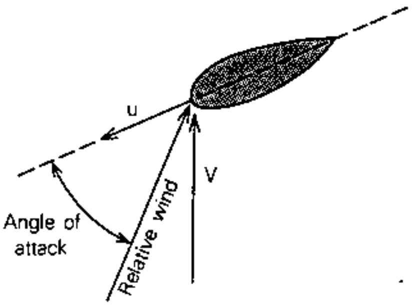
Undesirable features include:

- High-performance machines need complex controls to prevent rotor stall
- Difficult to start rotor.

Darrieus rotors are well adapted to driving electric generators or other high-speed loads. Because of the need to apply starting power to the rotor to accelerate it to high operating speeds, they are not well suited to lifting water directly or powering similar mechanical loads. In Chapter 2, however, a Darrieus used for pumping water in Bushland, Texas, was described. The rotor adds its power to the pump along with that of an electric motor. That same motor becomes an electric generator whenever the Darrieus is generating more power than is needed to pump water.

How a Darrieus Works

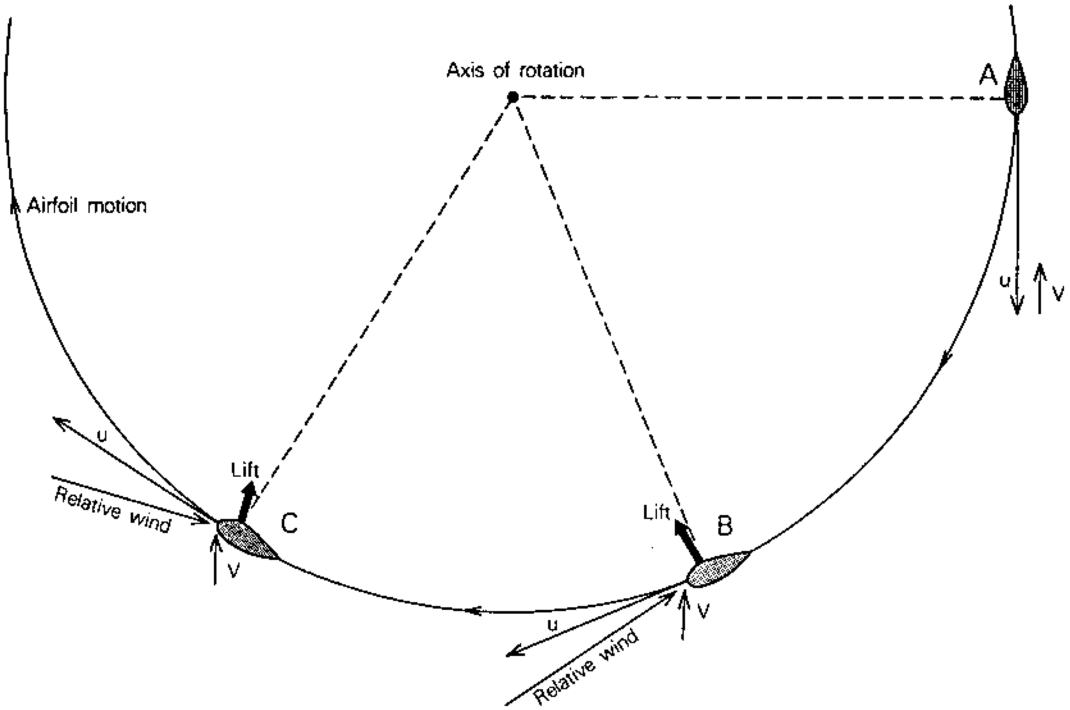
The Darrieus rotor works in an aerodynamic fashion similar to other lift-type rotors, but because of the carousel path of the blades, its operation appears complex. It really isn't that difficult. Recall that airfoils generate lift perpendicular to a wind approaching the leading edge. In the Darrieus, that "relative" wind changes its angle from almost straight at the airfoil to nearly perpendicular to it. Thus, the amount of lift produced by the airfoil changes constantly as it sails around its path.



Low-speed aerodynamics of a Darrieus blade.

At position A in the diagram, blade motion and wind direction are parallel, although pointed in opposite directions. No thrust occurs at this position. As the blade advances towards position B, however, the blade is at an increasingly steep angle to the wind. The lift force is directed ahead, along the direction of blade motion, and thrust is developed. Notice that blade speed is much greater than windspeed. So the tip-speed ratio is much higher than 1—maybe 5 or 6. A high tip-speed ratio is the key to successful operation of a Darrieus rotor. At a low TSR, the blade speed vector becomes shorter than the length of the windspeed vector, as illustrated in the next diagram. In this case, the angle of attack between the relative wind and the airfoil motion is too large, and stall can occur. Turbulent airflow, loss of lift, and high drag result in stall—obviously an undesirable condition. Compare the angle of attack that results from low TSR with the angle of attack in normal, high-TSR operation. At really low tip-speed ratios, stall is so prevalent that the rotor may require additional power from a starter motor to accelerate it up to operating speed.

Stall of the fixed-pitch Darrieus at low speeds results in an efficiency curve that looks like the one on page 79. At initial start-up, the rotor has a zero, or mildly positive efficiency. As rotation speeds up, stall effects rob the blades of power to the extent that the efficiency is actually negative. External power is usually required to accelerate the rotor through the stall region. Once beyond the stall region, acceleration is rapid up to the operational tip-speed ratio. Unless a gust



Aerodynamics of a Darrieus rotor. Under normal operating conditions, lift is produced along the entire carousel path, tugging the blades forward.

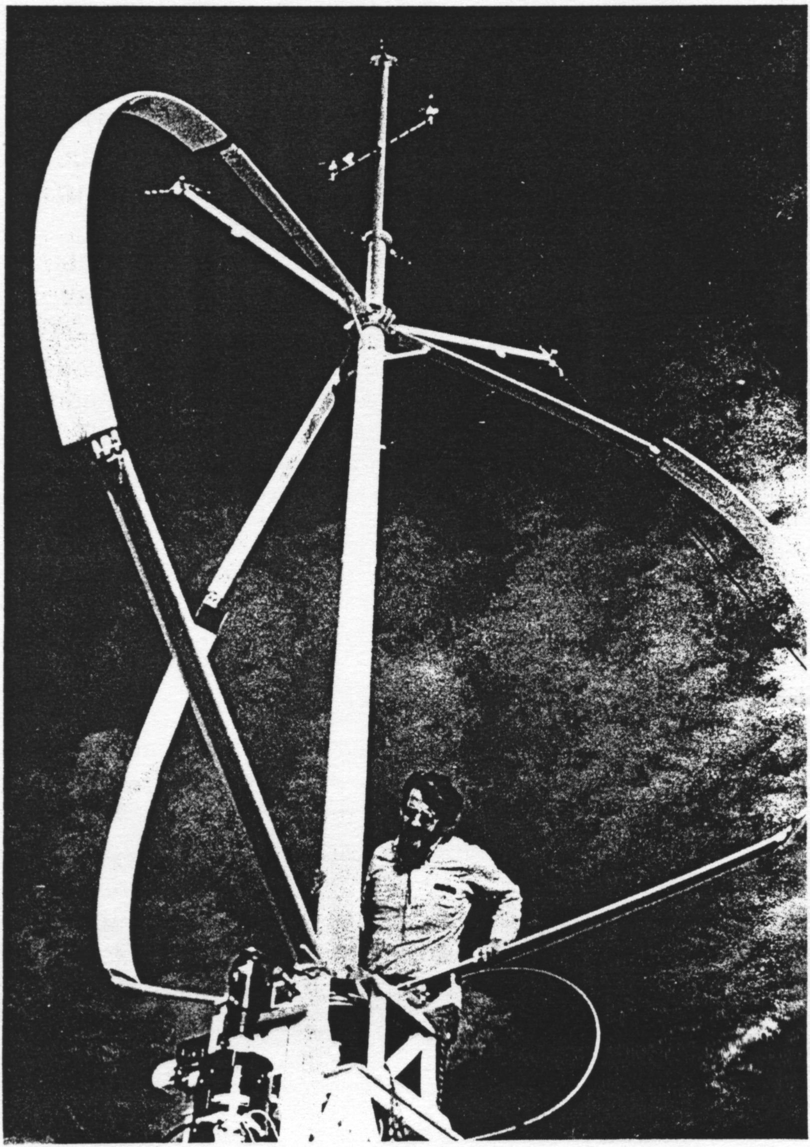
suddenly drops the TSR back into this stall region, the Darrieus will continue to generate power unaided.

Under certain wind conditions, a Darrieus rotor can start without help. Peculiar, but not uncommon, wind gusts will accelerate a stationary rotor to operating speed. Often such a self-start occurs when the crew is off at lunch; nobody is around to see what happened. The result can be a thoroughly trashed rotor; if you don't expect the rotor to start, why hook up the load? Right? Absolutely wrong! Always expect a Darrieus rotor to self-start, even though the experts have told you it won't.

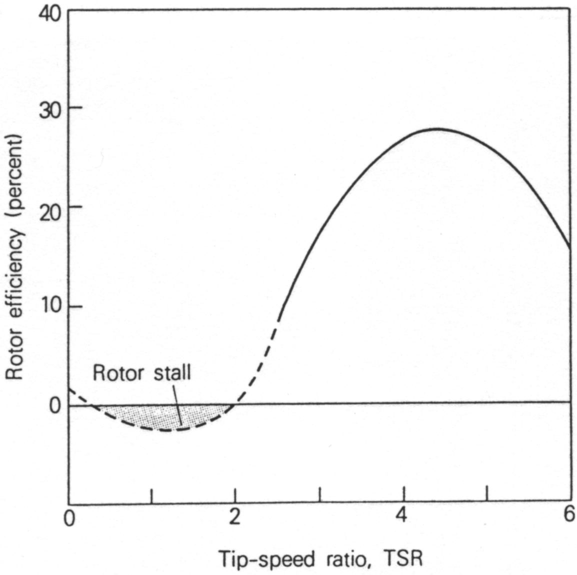
What are some of the alternatives for starting a Darrieus rotor? Electric starter motors are common. Such starter motors use a wind-sensing switch and a small electronic logic circuit to decide when it's appropriate to apply current to the motor. Another starting technique is to combine a Savonius rotor with a Darrieus. The Savonius has a high starting torque—enough to coax the Darrieus through its stall region. By making the Savonius just large enough for starting, it won't contribute to operational power.

An increasingly common starting method is that of *articulating* variable pitch blades that are hinged so that their pitch angle can change as they travel around the carousel path. The eggbeater is an unacceptable design for articulated blades; its curved blades cannot easily be hinged. The straight-bladed Darrieus can easily be hinged, and it often is. To see how articulation works, start with the fixed-pitch blade diagram at blade position B. The blade is fixed exactly tangent to the circular path. At low TSR, this results in a high angle of attack.

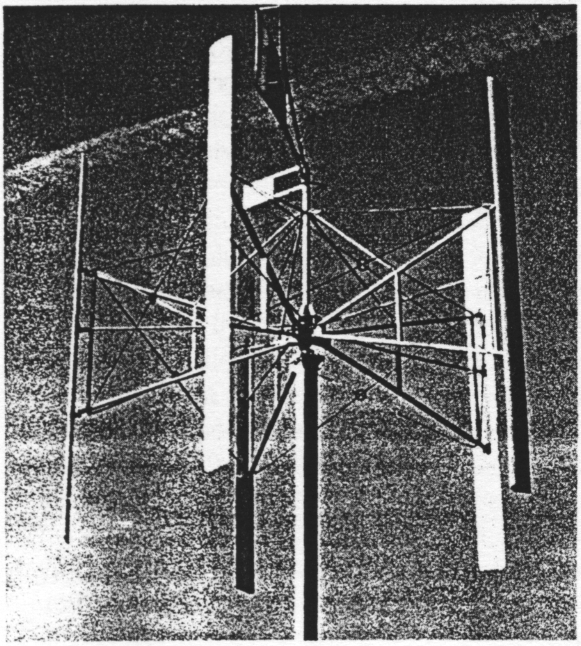
Now, suppose that the blade pivots on its attached arms so that it points directly into the relative wind (i.e., its angle of attack equals zero degrees). Stall is eliminated, but so is lift. Optimum articulation lowers the blade angle to an angle of attack that produces maximum lift. But simple mechanical controls that articulate the blades often do not hold the blades precisely at optimum angles.



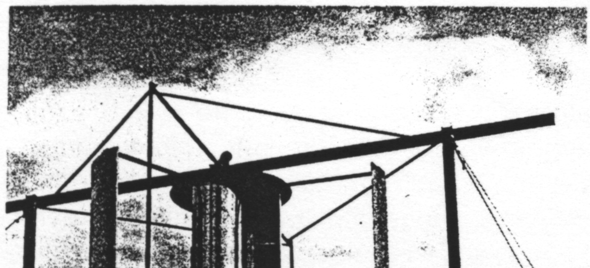
Eggbeater-style Darrieus rotor being tested at Sandia Laboratories in Albuquerque, New Mexico. This high-performance machine uses extruded aluminum blades.



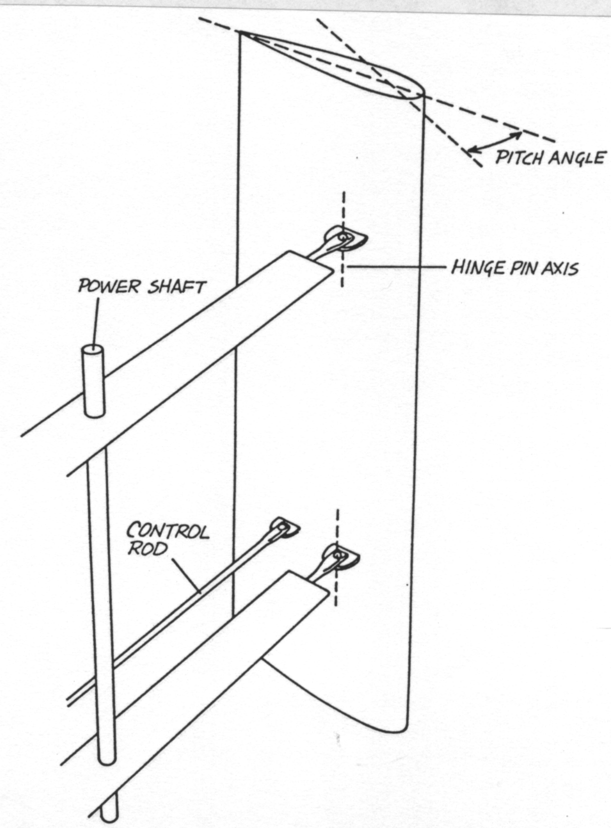
A typical Darrieus power curve. The rotor must be accelerated through a region of stall before it attains normal operating conditions.



A straight-bladed Darrieus rotor. The pitch angle of the blades is changed automatically.



Small Savonius rotors along the axis help accelerate this straight-bladed Darrieus rotor through the stall region.



A common method of Darrieus blade articulation. Varying the blade pitch eliminates rotor stall.

The drawing above shows a typical structural configuration for articulating the blades of a Darrieus rotor. Each blade is supported from the power shaft by two arms. Each arm is attached to the blade with a hinge pin that allows the blade to pivot through the pitch angle illustrated. The blade is held at its pitch angle by a control link connected to any one of several control systems. The simplest control is a central wind vane that holds a cam in a position corresponding to the wind direction. The cam tells the control links to position the blades at a pitch angle approximating the optimum blade angle. Other methods of blade control usually involve electric or hydraulic servomechanisms driven by a small electronic circuit or computer. Whether fixed-bladed or articulated, the Darrieus rotor is very sensitive to its tip-speed ratio. Allowed to overspeed, the power coefficient drops until the lower power output equals the load. Overloaded or in a strong gust, the TSR drops, blade stall sets in on the fixed-blade machine, and the power coefficient drops severely on both types of Darrieus rotors.

Rotor Swept Area

The rotor swept area, or frontal area, is a parameter frequently used in wind power calculations. This area, denoted by the letter "A," is the total surface area perpendicular to the wind direction that is swept by the rotor blades. It is measured in square feet or square meters.

The first illustration on the facing page indicates the swept area for a propellor-type rotor. This category includes all rotors with a horizontal axis parallel to the windstream; they sweep out an area perpendicular to the wind direction equal to:

$$A = \frac{\pi}{4} \times D^2 = 0.785 \times D^2 ,$$

where $\pi = 3.14159$, and D = diameter is measured from blade tip to blade tip as shown. A convenient graph presented at left will help you convert diameter measurements into rotor swept area, or vice versa.

For vertical-axis, cross-wind machines similar to the second illustration (i.e., those with a uniform radius about the axis of rotation), the swept area is:

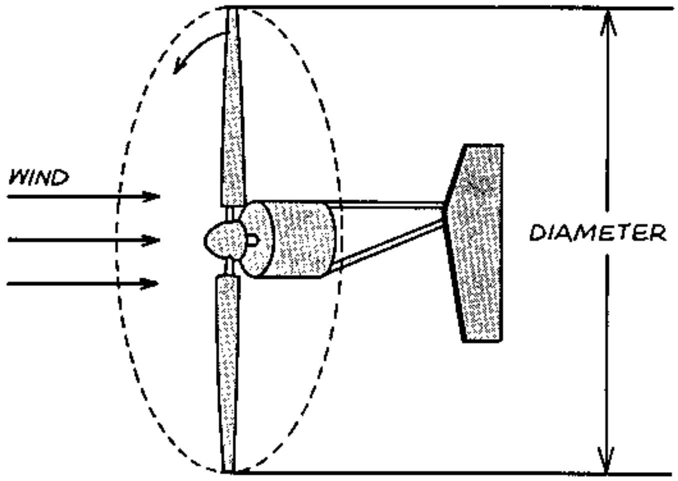
$$A = \text{Height} \times \text{Width} .$$

This is the formula to use with Savonius and straight-bladed Darrieus rotors.

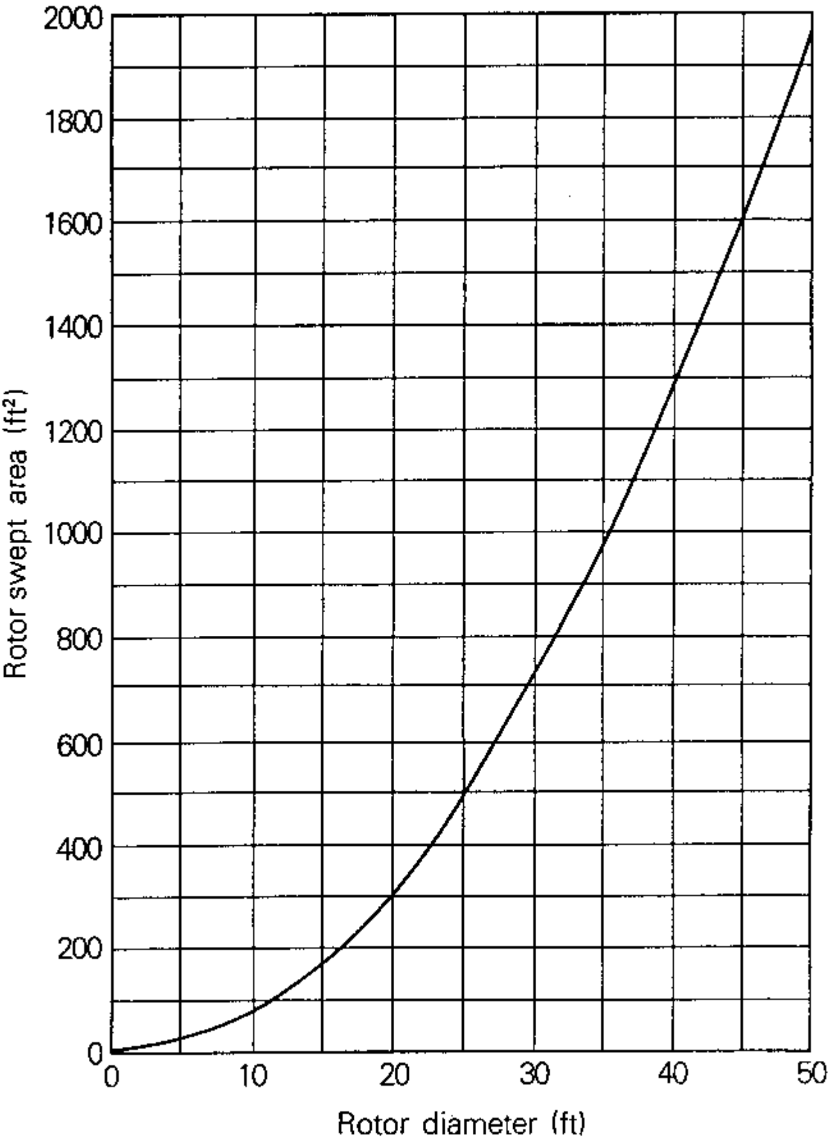
In an eggbeater-style Darrieus, the blades assume the shape of a *troposkein* — a complex mathematical curve involving elliptic integrals. Fortunately, this shape can be approximated fairly well with a parabola, and the swept area is about equal to:

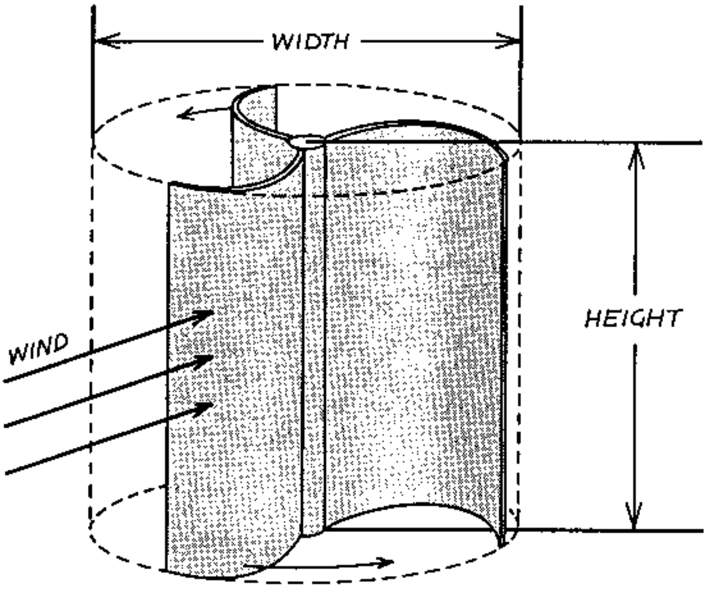
$$A = 2.67 \times \text{Radius} \times \text{Half-Height} .$$

The radius and half-height of a typical eggbeater Darrieus are indicated in the third illustration.

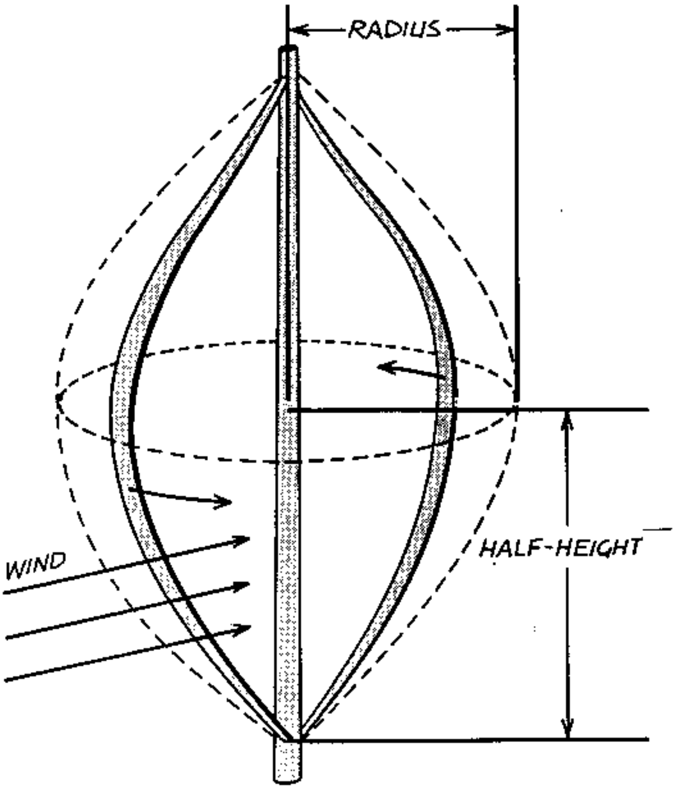


1 Propellor-type rotor

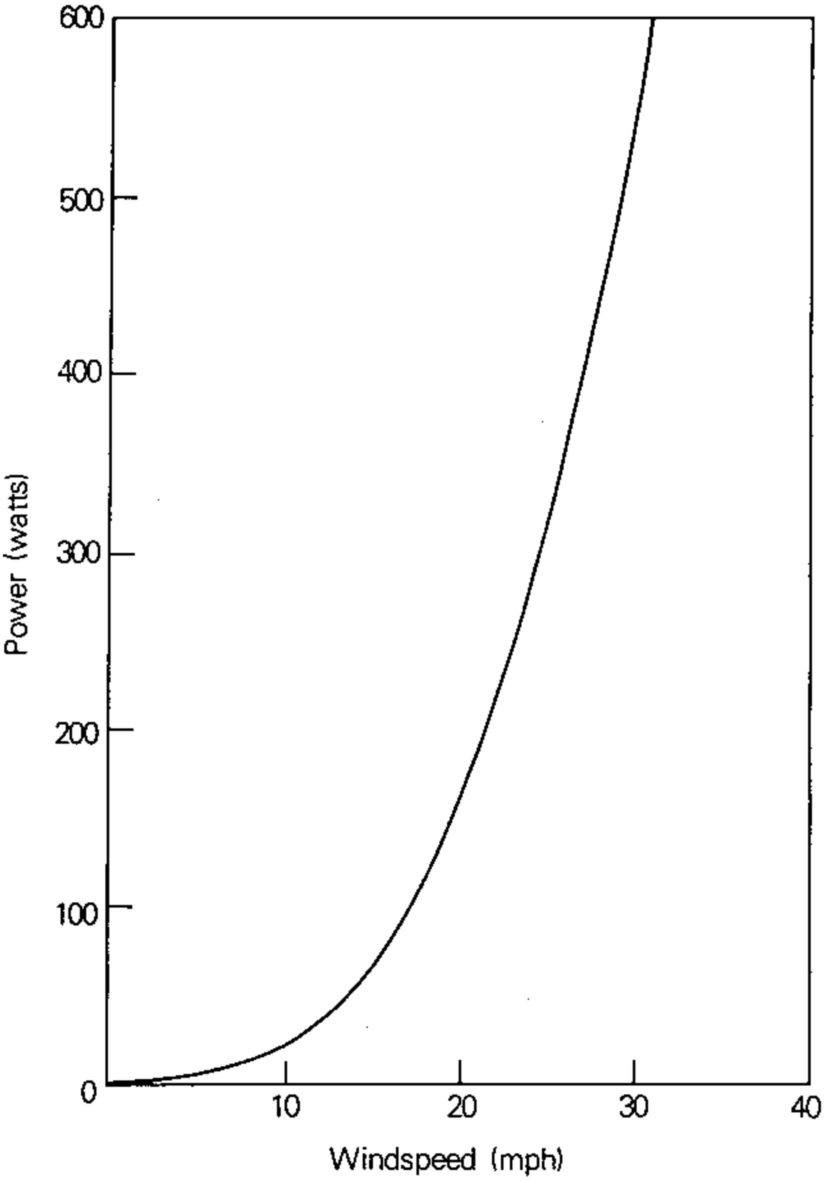




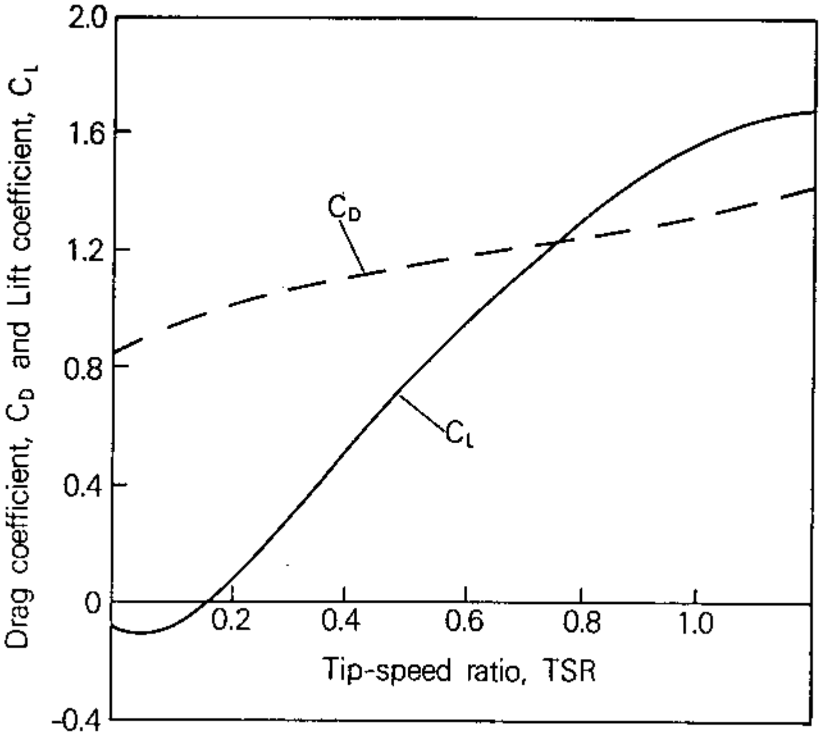
2 Vertical axis rotor



3 Darrieus rotor



Power curve for a typical Savonius rotor.



The total force on the Savonius is the vector sum of the lift and drag forces. To calculate the total force, use the following formula:

$$\text{Force} = \sqrt{(\text{Lift})^2 + (\text{Drag})^2}$$

Then, in our case,

$$\begin{aligned}\text{Force} &= \sqrt{(37.6)^2 + (32.2)^2}\\ &= \sqrt{2450.6}\\ &= 49.5 \text{ pounds}.\end{aligned}$$

This force is the total load on the support structure. Note that both lift and drag increase with the square of the windspeed—double the windspeed means quadruple the force. In our example, then, the rotor would experience a total force of 198 pounds in a 40 mph wind.

Propellor-type rotors usually employ some kind of governor to prevent the machine from encountering such high forces. But Savonius rotors are difficult to govern; if you apply a brake to slow the rate of rotation, the torque produced by the rotor increases and fights the brake. Moving the vanes so that the S-rotor becomes a cylinder with no exposed vane surface might work. Some people design the tower support system to hold the rotor up in the highest expected wind and just hope for the best.

Savonius Rotor Design

Suppose you are designing a three-tier Savonius rotor, . You need to know the power it can deliver at various windspeeds. To calculate this power, use Equation 1 together with the values of the relevant parameters and dimensions of the machine. For example, say the rotor efficiency is given by the graph on page 95, and you expect it to operate at a tip-speed ratio of TSR = 0.8. Then you would read E = 0.15 from that graph for the efficiency of this machine, and use this number in Equation 1. Suppose also that the height of the rotor is 9 feet and its width (or diameter) is 3 feet. Then the rotor swept area is A = 3 × 9 = 27 square feet. Putting this and other information into Equation 1, you get:

$$\begin{aligned}\text{Power} &= \tfrac{1}{2} \times \rho \times V^3 \times A \times E \times K \\ &= \tfrac{1}{2} \times 0.0023 \times V^3 \times 27 \times 0.15 \times 4.31 \\ &= 0.020 \times V^3 .\end{aligned}$$

Here, you have used K = 4.31 so that power is expressed in watts if the windspeed V is given in miles per hour. Thus, if V = 10 mph, the output power of this Savonius rotor equals 20 watts. Performing similar calculations at windspeeds ranging from 5 to 30 mph, you get a power curve like the one shown at left. A similar series of calculations will determine the powershaft torque over the same range of windspeeds.

You should also calculate the lift and drag forces on an S-rotor. Lift is produced by the rotor because of the Magnus Effect—the wind is slowed on one side of the rotor and accelerated on the other. The lift force pushes sideways on the rotor; drag is a downwind force. Many people estimate drag and forget lift; this oversight could be disastrous.

Use the following formulas to estimate lift and drag forces on a Savonius rotor:

$$\begin{aligned}\text{Lift} &= 1.08 \times C_L \times \rho \times V^2 \times A ; \\ \text{Drag} &= 1.08 \times C_D \times \rho \times V^2 \times A ,\end{aligned}$$

where C_L is the lift coefficient (see Chapter 5) and C_D is the drag coefficient of the rotor. The parameters ρ, V and A are the usual air density, windspeed and rotor swept area.

Using the accompanying graph of lift and drag coefficients, you can estimate lift and drag forces on this S-rotor. At a TSR = 0.8, the lift coefficient is $C_L = 1.4$ and the drag coefficient is $C_D = 1.2$. Thus, at a windspeed of 20 mph, the lift and drag on this rotor are:

$$\begin{aligned}\text{Lift} &= 1.08 \times 1.4 \times 0.0023 \times 20^2 \times 27 \\ &= 37.6 \text{ pounds} ;\end{aligned}$$

$$\begin{aligned}\text{Drag} &= 1.08 \times 1.2 \times 0.0023 \times 20^2 \times 27 \\ &= 32.2 \text{ pounds} .\end{aligned}$$

THE MERRY-GO-ROUND MILLS

In the Merry-go-round mill is found another attempt at the construction of mills of unlimited size. However, some of these mills have natural limitations, especially those mounted upon towers. Such mills are of rather complex construction, and are not put up by the farmer, but by a carpenter, and at considerable expense. Mounted as they are upon towers, like the Turbine mill of the shop, they can soon reach a size where the wind can upset them, however well anchored. This has led to the towerless Turbines, which stand low upon the ground, hence are capable of a greater circumference. In the smaller ones which we class with the Merry-go-rounds, the shutter-like fans form a sort of revolving cylinder, which revolves about a central axis. The shutters close on one side and so exclude the air, and open upon the other so as to catch the air, and even the amount is easily regulated by an encircling rope, which allows them to open much or little, according to the velocity of the wind.

This form of mill though useful once, is now antiquated, and has been replaced by cheaper and better forms, so it needs no further mention here. Several are still to be seen in the vicinity of Lincoln, at Grand Island, Greeley Center, and elsewhere.

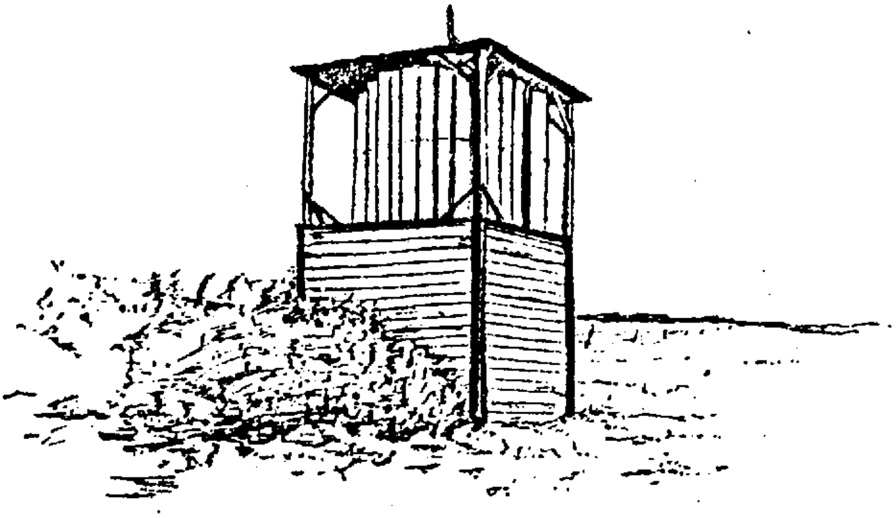


FIG. 34. Windmill of Mr. Henry Joenck, Grand Island, Nebraska. Diameter ten to twelve feet. Fourteen years ago this mill did good service irrigating the garden truck for the local market. Cost $100.00.

They often escape notice from the fact that they are mistaken for water tanks mounted upon high towers.

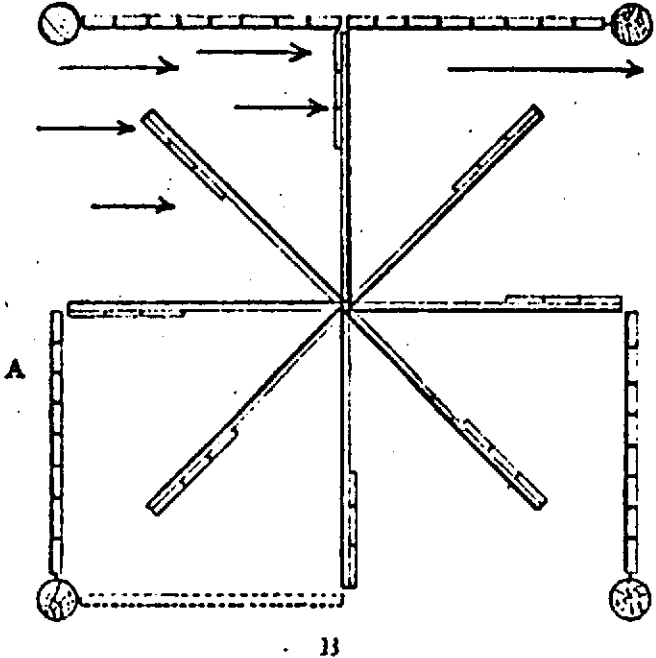


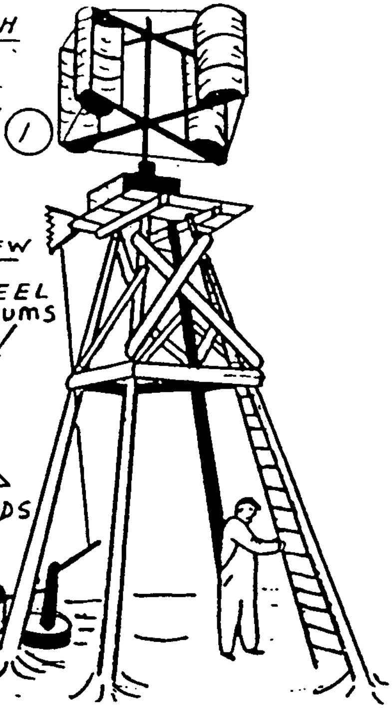
FIG. 36. Ground plan of a form of Merry-go-round proposed by the writer. Diameter twenty to twenty-five feet or more. Each of four posts carries a gate which may be opened and closed to admit or shut out the wind. Each gate is to be so arranged as to turn backward through an angle of 270°, as from position A, to position B.

PLATE No. 57

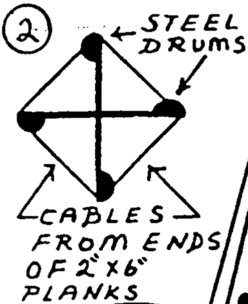
DESIGN ALTERNATIVE III
THE POLISH WINMILL I

-VERTICAL AXIS - STEEL DRUM SAILS-
- AUTO REAR END DRIVE - MULTIDIRECTIONAL
- NEADS NO TAIL VANE

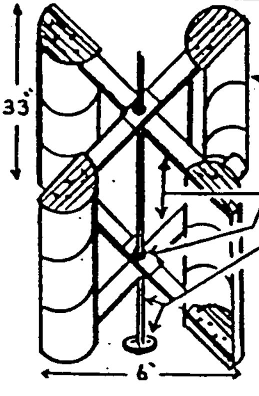
THE POLISH WINDMILL SIDE VIEW ①



SAILS TOP VIEW ②



SAILS TOP 3/4 VIEW

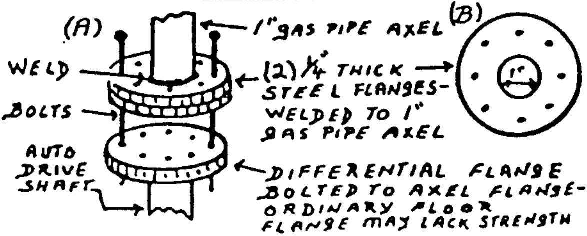


(4) SAILS-½ STEEL DRUMS BOLTED TOP AND BOTTOM TO 6FT PIECES OF 2"X6" LUMBER

4+4 (TOP AND BOTTOM) PIECES OF 2"X6" LUMBER - ATTACHED TO AXEL WITH FLOOR FLANGE HUBS-

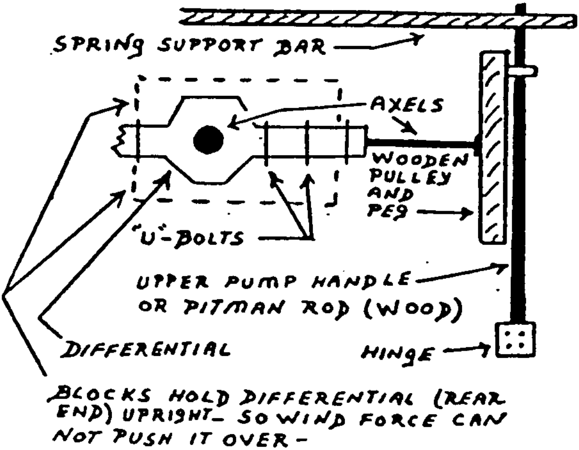
1"-GAS PIPE AXEL BOLTED TO AUTO REAR END WITH STEEL FLANGE-

STEEL VERTICAL AXEL FLANGE



TOP VIEW

AUTO REAR END AND PITMAN



SIDE VIEW

AUTO REAR END RT. ANGLE DRIVE

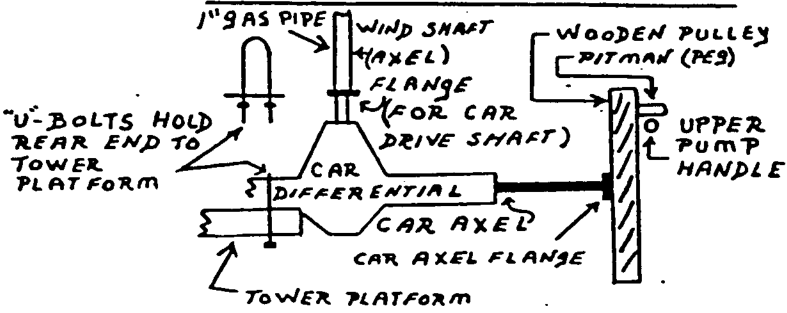


PLATE NO. 57

The biggest advantage of this design is that it is multidirectional and, thus, requires no tail vane. No matter what the direction of the wind, it just keeps on turning. The only way to stop it is to either tie it down or block it from the wind.

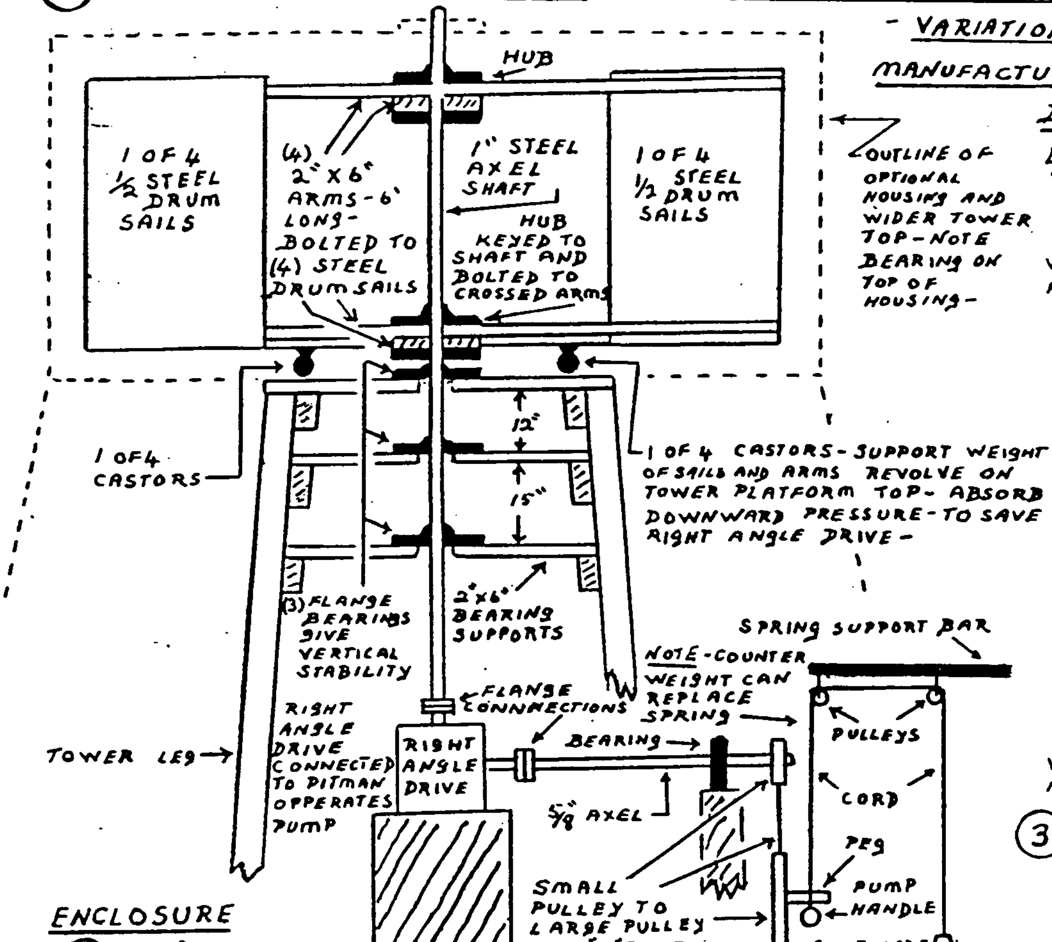
By increasing the length of the arms, and by adding quarter sections of steel drums to the half drums on the ends of the arms, you will increase the torque.

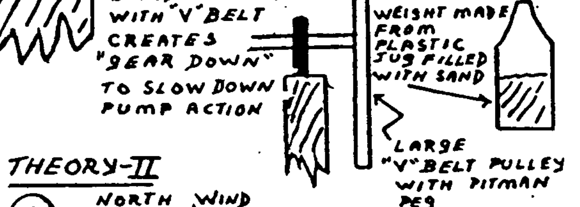
The 1", (or 2"), gas pipe sail axle is welded to a 1/4" thick steel plate disc, which bolts to the auto rear end drive shaft flange, (see fig. 3, 4 and 8).

PLATE No. 58

DESIGN ALTERNATIVE - IV
THE POLISH WINDMILL II
- VARIATION - USING MANUFACTURED RIGHT ANGLE DRIVE AND ENCLOSURE

① BEARINGS ETC - SIDE VIEW





OUTLINE OF OPTIONAL HOUSING AND WIDER TOWER TOP - NOTE BEARING ON TOP OF HOUSING -

1 OF 4 CASTORS - SUPPORT WEIGHT OF SAILS AND ARMS REVOLVE ON TOWER PLATFORM TOP - ABSORB DOWNWARD PRESSURE - TO SAVE RIGHT ANGLE DRIVE -

RIGHT ANGLE DRIVE CONNECTED TO PITMAN OPPERATES PUMP

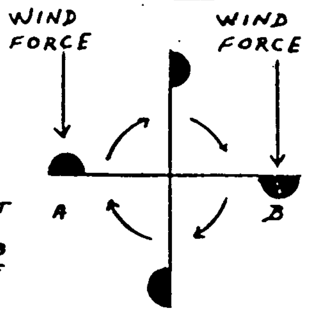
NOTE - COUNTER WEIGHT CAN REPLACE SPRING

SMALL PULLEY TO LARGE PULLEY WITH "V" BELT CREATES "GEAR DOWN" TO SLOW DOWN PUMP ACTION

WEIGHT MADE FROM PLASTIC JUG FILLED WITH SAND

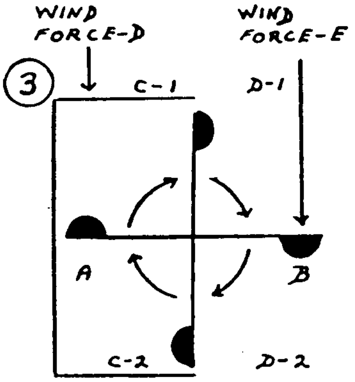
LARGE "V" BELT PULLEY WITH PITMAN PEG

② THEORY - I



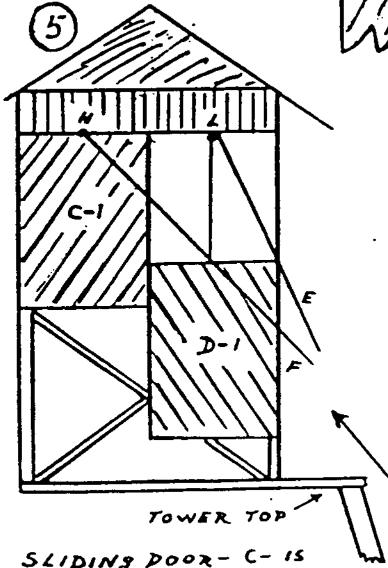
NOTE - WITHOUT ENCLOSURE - WIND STRIKES SAIL - A WITH SAME FORCE AS SAIL - B - SLOWS ROTATION AS - A - ACTS AS A BREAK ON - B -

③



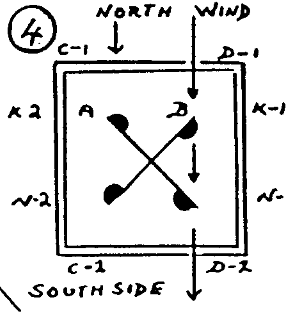
NOTE - ENCLOSURE - C - PREVENTS WIND FORCE - D FROM STRIKING SAIL - A AND IMPEDING THE SPEAD OF ROTATION WIND FORCE - E - STRIKES SAIL B - ONLY - ENCLOSURE - C - MUST BE ADJUSTABLE ACCORDING TO DIRECTION OF WIND -

ENCLOSURE ⑤



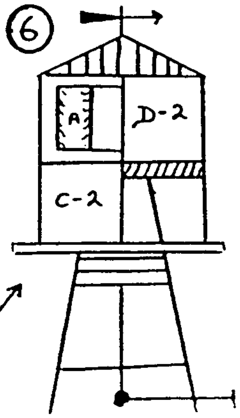
SLIDING DOOR - C - IS PULLED UP BY ROPE - F - ON PULLEY - H - TO SHIELD SAILS IN POSITION - A - (SEE THEORY) - - WHEN WIND DIRECTION CHANGES - LOWER - C - AND RAISE - D - WITH ROPE - E -

THEORY - II ④



- NOTE - FOR NORTH WIND OPEN DOORS D-1, D-2, K-1, N-1; - CLOSE DOORS C-1, C-2, K-2 N-2; FOR SOUTH WIND DO THE REVERSE -

ON TOWER ⑥



ON ROOF TOP ⑦

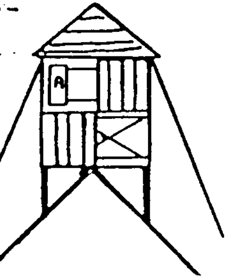


PLATE NO. 58

Note the counter weight replacing the spring in fig. 1. The counter weight is simply a plastic tub filled with the proper amount of sand. A counter weight will not wear as a spring will. A spring, however, will last a long time if it is not extended beyond its proper stretching limit.

Note the important concept, illustrated in fig. 2, 3, 4, 5, 6 and 7.

Left alone, the wind blows at the same time on both sides of the machine, the open sail going as well as on the back side of the returning sail coming back.

If the returning sail side is blocked off, the speed and power of the machine will increase dramatically. This can be done in a number of ways as illustrated. A good alternative is the replacement of the doors (fig. 5), with venetian blind type louvre boards which can be opened or closed at will.

A more simple solution is to erect canvas or wooden barriers which can be easily raised or taken down.

Eco-Tech. R.S. de Ropp Delacorte Press NY. USA 1975 0-440-02233-9.

1. Savonius rotor

A simple wind machine for pumping water is described by A. Bodek of the Brace Experiment Station, St. James, Barbados, West Indies (Do-It-Yourself Leaflet no. 5, February 1965; for copies, write Brace Research Institute, Macdonald College of McGill University, Ste. Anne de Bellevue 800, Quebec, Canada). This machine can be easily constructed by anyone having access to welding equipment. It consists of three parts: rotor, drive and pump. Building it involves essentially the following steps:

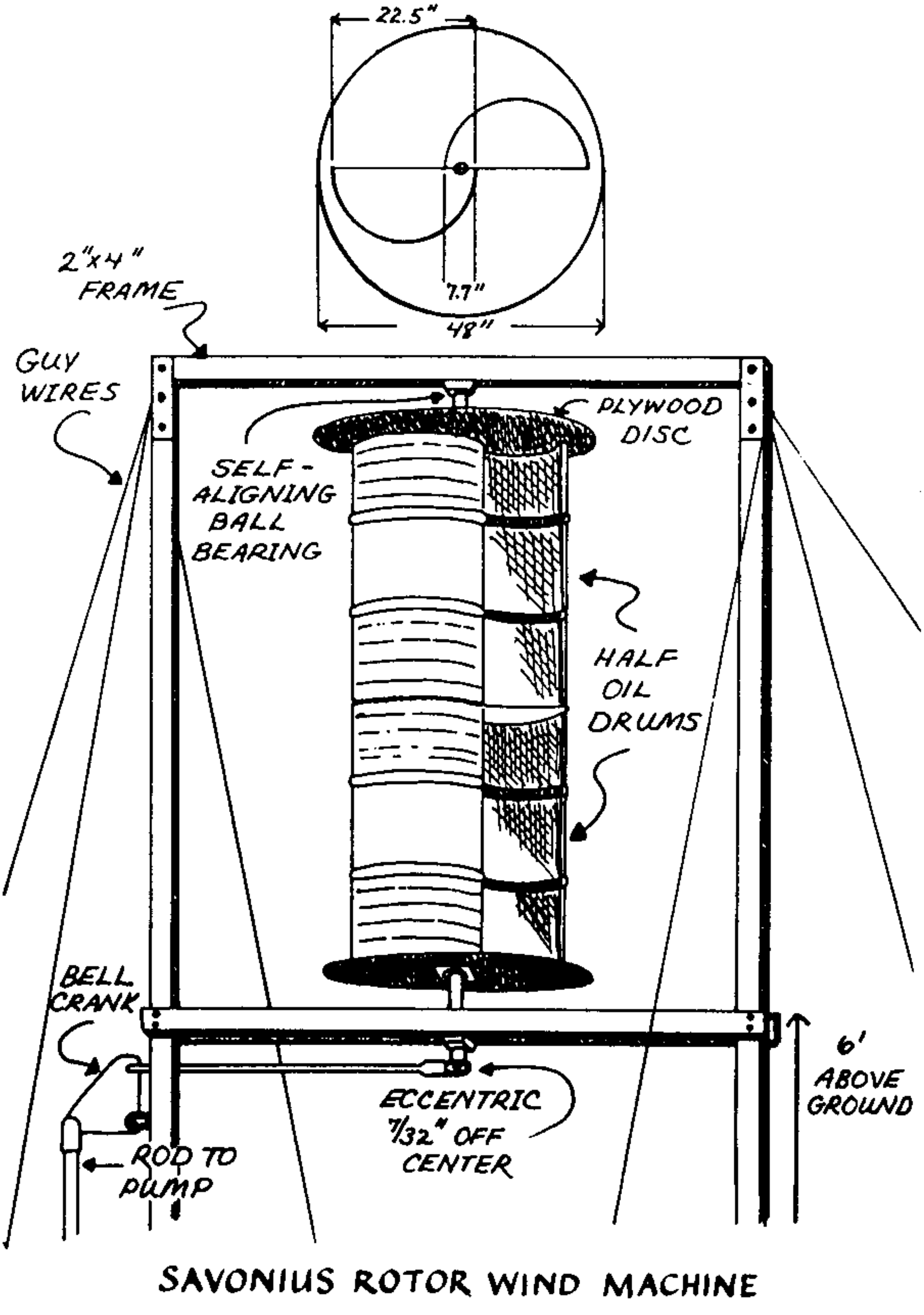
(1) Procure two oil drums (45- or 50-gallon). Cut them lengthwise and weld them to form two troughs (fig. 37). Attach the two troughs spaced as shown to two discs cut from ½-inch plywood with ⅜-inch bolts. Pass a shaft (water pipe of 1¼-inch inside diameter) through the rotor, extending 6 inches beyond the end plates. Secure shaft to end plates with two flanged collars bolted to the plywood with four bolts and to the shaft with a ¾-inch bolt inserted in a hole drilled for this purpose. Support the rotor shaft in the frame on two self-aligning ball bearings. Attach two adaptors, one to each end of the shaft, to attach the bearings. Make the lower adaptor long enough to pass through the frame and the eccentric on its lower end. Balance the rotor carefully before mounting in the frame by placing it horizontally between two straight edges and adding weight to the circumference until perfect balance is achieved.

Mount your rotor when balanced in a frame consisting of four 2 × 4's securely bolted at the corners with metal plates. Raise the structure at least 6 feet and preferably 10 feet above the ground, anchoring the rotor by guy wires and turnbuckles.

To transmit power to a pump the rotary motion of the wind machine must be converted to reciprocating motion. This can be done quite simply. Prepare an eccentric drive by fitting a steel cup to the lower end of the rotor shaft. Drill and tap a hole 7/32 inch off center and screw into it a bolt. This bolt must fit snugly into the big end of the connecting rod which can be made from the connecting rod of a motorcycle or small car engine. Cut the rod and weld on 6 inches of tubing of 1-inch inside diameter to receive a connecting rod made of wood 1 inch square. Attach a fork connection to the other end of the rod drilled to receive a pin ½ inch in diameter.

Connect the rod to the bell crank, which can be made from a piece of ¼-inch steel plate. Drill three holes in the plate after reinforcing the steel with welded bosses. If possible, line the holes with bronze bushings to increase the life of the pins and make arrangements for lubrication.

This wind machine can be attached to any piston or diaphragm pump, provided the pump stroke is not too long.



SAVONIUS ROTOR WIND MACHINE

The Survival Handbook. Michael Allaby Macmillan UK 1975 0-330-24813-8.

The Savonious Rotor

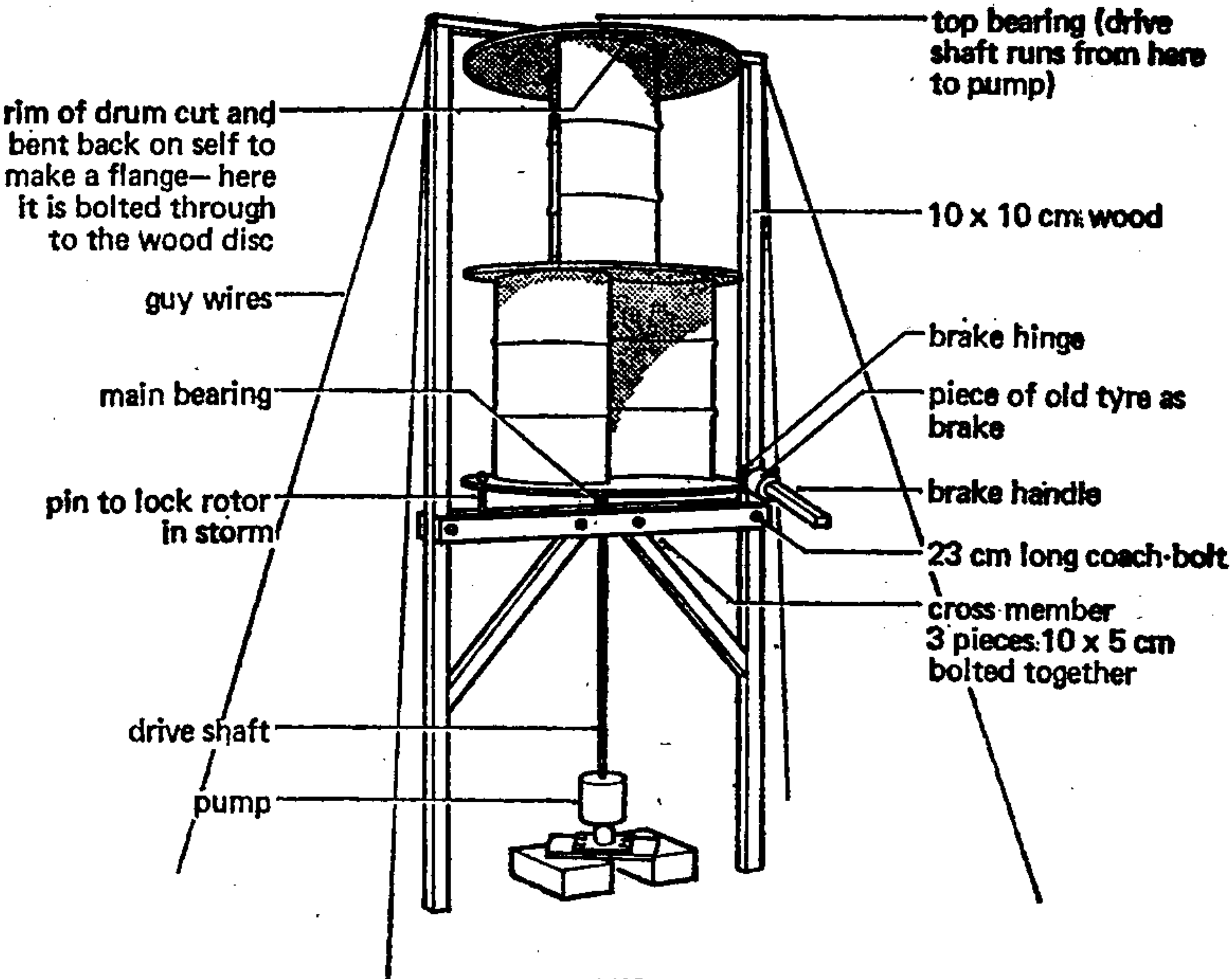
The Savonious Rotor was developed in 1973 by BRAD and the Intermediate Technology Development Group, from original work done in the 1920s by a Finnish engineer.

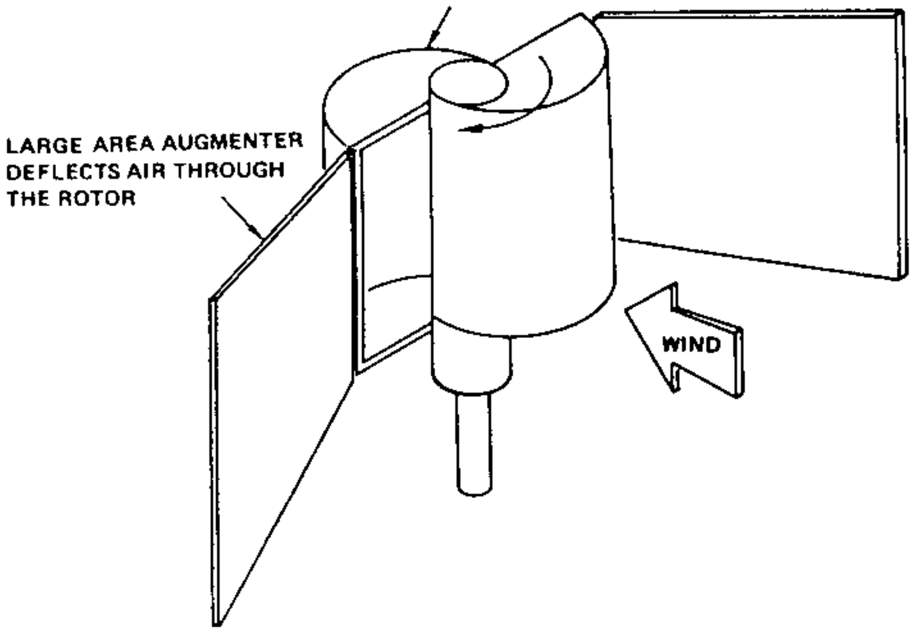
It comprises two 200-litre oil drums, three 1.14-m-diameter discs of 1.25-cm marine-quality plywood, and 3.6 m or so of 3-cm-diameter steel driveshaft. Their ends removed, the drums are cut in half lengthwise. Each semi-circular rim is cut every 2.5 cm and bent back on itself to make a small flange for bolting the half drums to the plywood discs.

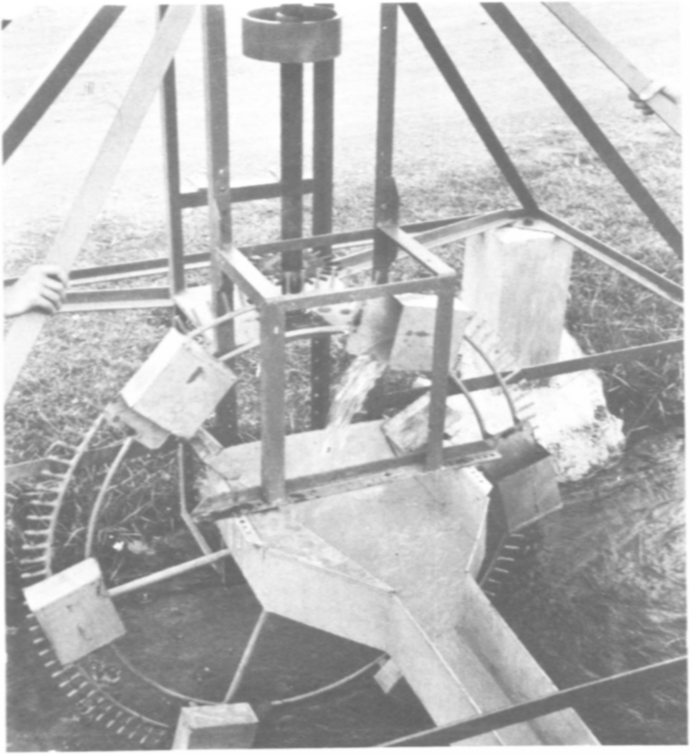
A wooden frame, held by guy-wires tensioned by turnbuckles, is made from two 10 × 10-cm vertical members about 4.5 m long, to allow 45 cm to be concreted into the ground. The brake handle, cross members and supports are made from 10 × 5-cm wood, three lengths being bolted together to make a 10 × 20-cm cross member, which carries the weight of the rotor via the main bearing. For smoother rotation, the two rotors have a quarter-turn difference in alignment.

It is probably only half as efficient as a multi-bladed windmill sweeping the same 160 square decimetres of Welsh air, but the Savonious has several advantages. Unlike a bladed windmill, it always spins on the same vertical axis and does not need to be turned into the wind. This makes it easier to take power directly from its rotating shaft. Its relatively low rotational speeds make precise balancing less important, and it is very simple and cheap to build.

It begins to turn in the slightest wind, but its location is constrained: no pump can raise water more than about 6 metres vertically. At present it has an Archimedes screw pump, but a reciprocating pump might be better. There is no reason why it should not generate electricity.


top bearing (drive shaft runs from here to pump)
rim of drum cut and bent back on self to make a flange— here it is bolted through to the wood disc
10 x 10 cm wood
guy wires
brake hinge
main bearing
piece of old tyre as brake
brake handle
pin to lock rotor in storm
23 cm long coach-bolt
cross member 3 pieces 10 x 5 cm bolted together
drive shaft
pump


SAVONIOUS ROTOR
LARGE AREA AUGMENTER DEFLECTS AIR THROUGH THE ROTOR
WIND

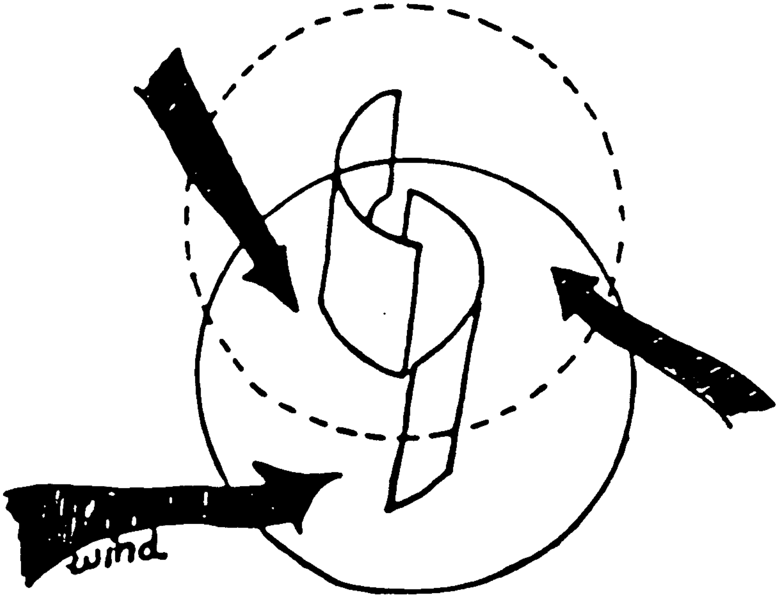


Above: Wheel for lifting water one metre, driven by a small Savonius windmill. Note "peg gears" welded from round bar.

SAVONIUS ROTOR CONSTRUCTION: VERTICAL AXIS WIND MACHINES FROM OIL DRUMS

BY

JOZEF A. KOZLOWSKI



a VITA publication

INTRODUCTION

VITA is pleased to make available the work of Jozef A. Kozlowski, who has contributed his expertise in the areas of water, wind and methane power generation to technical problems worldwide through VITA for almost 10 years. Kozlowski, who holds an advanced degree in engineering, specializes in onsite consultations and project work relating to solving problems in developing countries.

Jozef Kozlowski has built two Savonius rotors -- one in Wales and the other in rural Zambia. This manual details the construction of these machines. Both VITA and the author offer this manual with the hope that it first puts the rotors in a perspective which allows potential builders to judge the applicability of such machines for meeting their needs and then provides effective guidelines for constructing each.

The S-rotor, as it is more popularly known, is easy to construct. For this reason and others (not the least of which is that an S-rotor can be built for relatively small expense), people build rotors before they have investigated their own needs fully and/or have weighed these against the rotor's somewhat limited potential. The rotor will not meet all needs, and careful consideration of all factors and possibilities is essential for success.

For those who decide to build rotors, step-by-step construction details are provided. The manual includes a two-stage rotor for pumping water and a three-stage rotor designed to charge automobile batteries (the latter can be constructed using only hand tools). Both rotors depend upon use of discarded oil drums.

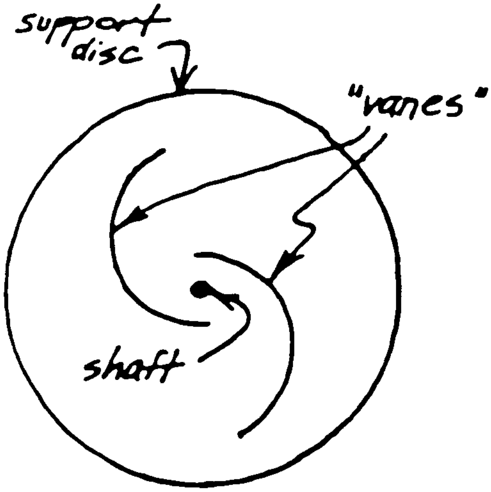
To provide additional information and guidance to the potential S-rotor builder, the author has reviewed a number of articles and books on the subject. The reviews, which are included as an appendix to this manual, are entirely an expression of the author's findings and opinions.

September, 1977

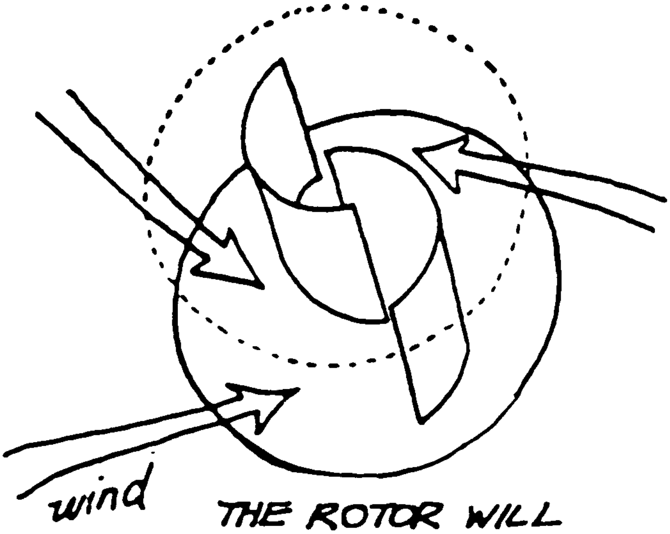
The Savonius rotor -- also called the S-rotor -- is a vertical-shaft wind machine invented by Sigurd J. Savonius of Finland some fifty years ago.

The rotor is relatively easy to construct, especially if made from standard 45 Imperial gallon (55 US gallon) oil drums which are generally available throughout the world, at a nominal cost for second-hand drums.

Because it rotates on a vertical shaft, the rotor can turn in wind coming from any direction and will start turning in very low winds.



S-ROTOR CONFIGURATION (LOOKING DOWN)



THE ROTOR WILL TURN IN WIND FROM ANY DIRECTION

A survey of available literature shows that the rotor is very suitable for manufacture in village and home situations and that it is not difficult to construct. However, the author feels the potential user should be aware of the fact that the Savonius rotor, when compared to other wind machines, may be less efficient and/or require higher wind speeds to achieve a power output more easily achieved by another type of wind machine.

The text on the following pages provides data compiled by various investigators on the amount of energy available from S-rotors at various wind speeds. The author feels the potential rotor builder should use these data carefully to see if an S-rotor can meet his needs--before he begins the construction process.

EXAMPLES OF POWER AVAILABLE FROM S-ROTORS

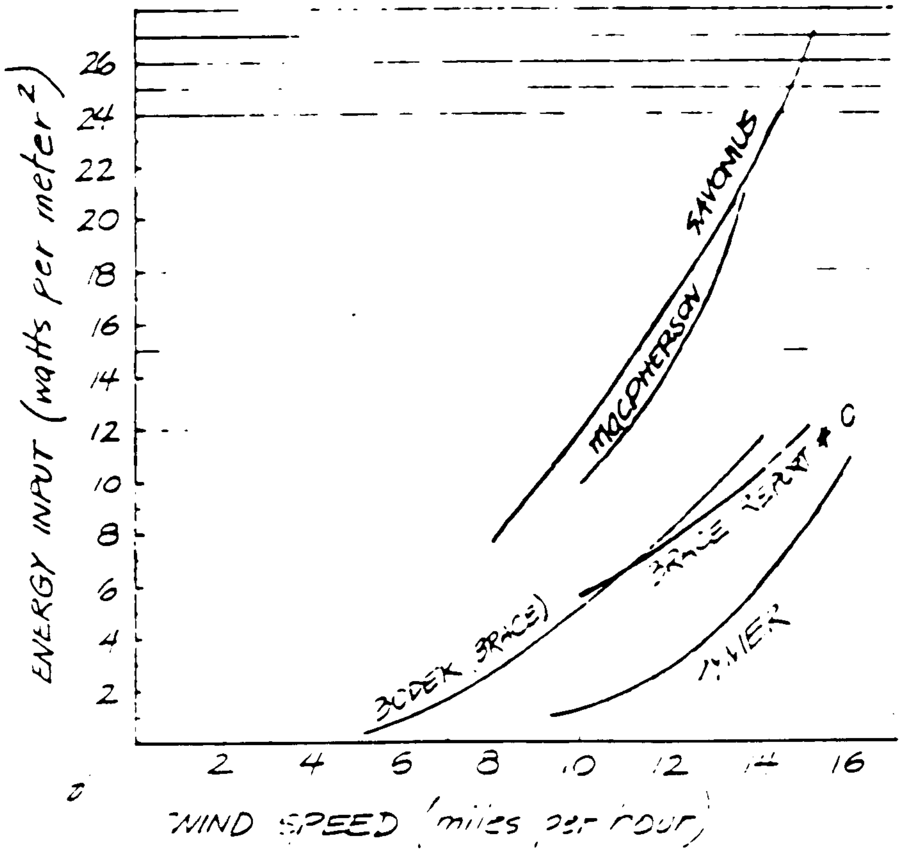
The following graphs provide specific figures on the power available from Savonius rotors.

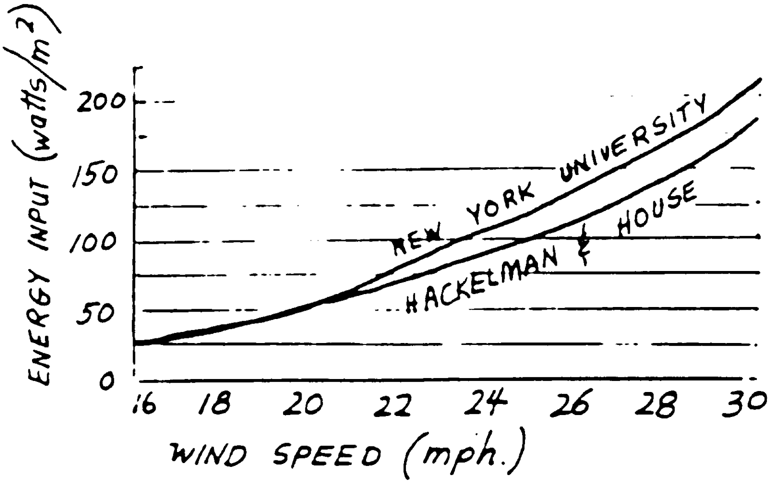
Different rotors--reduced to the same size--are compared in graphs 1 and 2 and the accompanying tabulation. Graphs 3 and 4 show rotor output for a two-stage rotor and a rotor of 1m projected area respectively.

Here "input" figures measure energy available directly from the rotor. "Output" figures take into account losses based on the efficiencies of pumps or electrical transmission.

Note that in graphs 1, 2, and 4, the energy input figures are given in "watts per meter^2." The calculation of area is based on the "wind-swept area," or the total area swept by the rotor, as you are looking straight at it from the side (as the wind would). Multiply the height of the rotor by the width at its widest point (the distance in a straight line between the outer tips of a pair of vanes).

graph 1.





graph 2.

tabulation of data from graphs 1 & 2.

ENERGY INPUT INTO PUMPING WATER AT 60% PUMPING EFFICIENCY

wind speed (mph)	simonds	brace bodek	brace rot #10	macpherson M.I.T.	pymer Imp. Col.	new york univ	hackelman & house
5		0.45					
[illegible]							1.4
[illegible]		1.76					
8	[illegible]	2 36					3.34
[illegible].2					0.95		
10							6 56
10.3	12.7	[illegible]	[illegible]				
[illegible]				11.40			
[illegible]					2 88		
[illegible].6				[illegible]			
[illegible]	[illegible]	3.55	8.22				11.8
[illegible]					4.16		
[illegible]		2.92	9.57	18.5			
[illegible]				20.8			
[illegible].6							
[illegible].8					[illegible]		
[illegible]	22.9		10.60				
[illegible]				22.8			
[illegible].5					5.75		
15	26.7		12.0				
[illegible].7					10.7		
[illegible]							26.7
18							33.5
20						49	52.7
22							70.0
24							91.5
25						125	
[illegible]							115.5
28							[illegible]
[illegible]						222	[illegible]

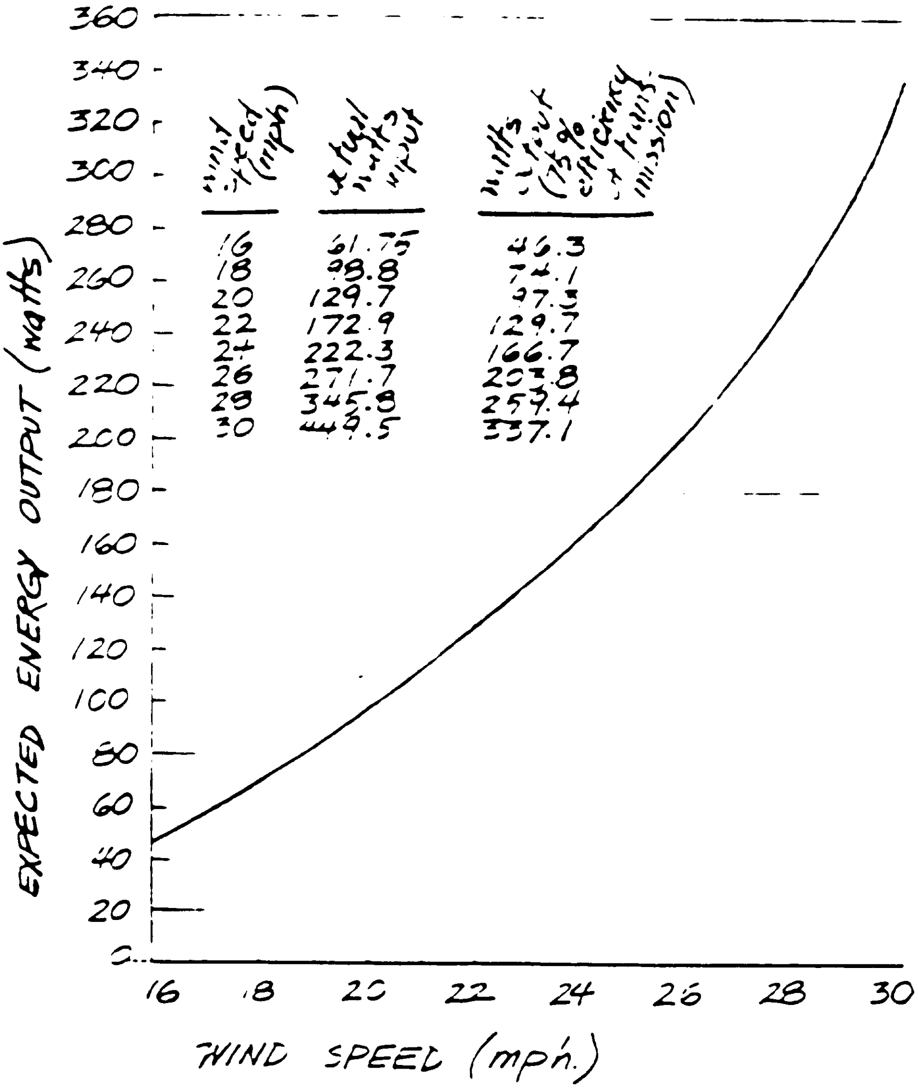
In graphs 1 and 2 the power per square meter of projected area of S-rotors is plotted against the wind speed, using test data from seven different sources. Although there are differences, all the results show that in wind speeds below 20mph the power generation is very small.

For example, the data from Bodek and Simonds' experimental S-rotor in the West Indies shows that the useful energy from a 12mph wind imparted into pumped water is 6.5 watts/m^2. This means that one can pump

75 Imperial gallons/hour up to 30' above the water level (341 liters/hour up to 9,14m). In an 8mph wind the useful energy is only 2.8 watts/m^2, which means that only 25 Imperial gallons/hour (104 liters/hour) can be pumped to the same height.

Note that for a 33 percent decrease in wind speed, the water output -- which is proportional to the power generated by the S-rotor -- dropped by approximately 66 percent. The power developed in a wind machine is proportional to the wind speed cubed. The significance of stronger winds is noticed immediately.

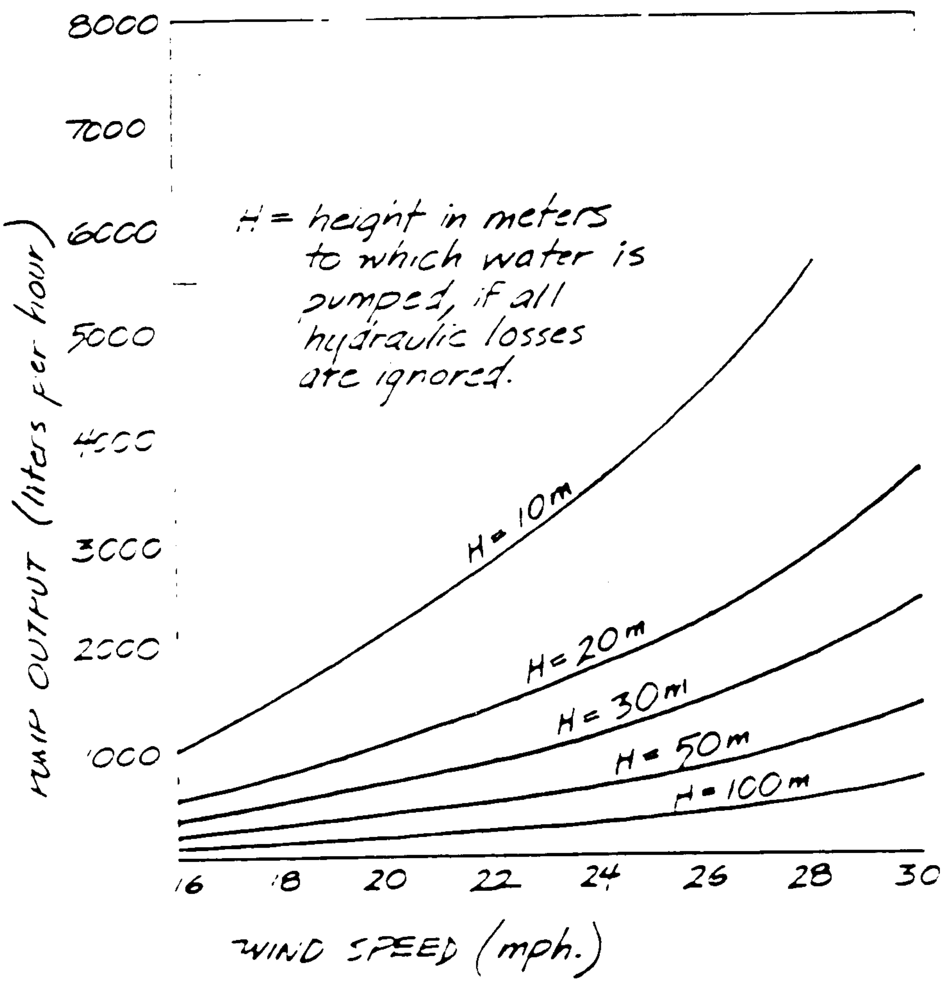
graph 3. EXPECTED ENERGY OUTPUT FROM TWO STAGE S-ROTOR



wind speed (mph)	actual watts input	watts output (75% efficiency of transmission)
16	61.75	46.3
18	98.8	74.1
20	129.7	97.3
22	172.9	129.7
24	222.3	166.7
26	271.7	203.8
28	345.8	259.4
30	449.5	337.1

A 20mph wind will get the smallest commercial electrical generator working, producing about 100 watts of electricity. About a 30mph wind will be required for a car generator or alternator to start charging a 12-volt car battery.

graph 4. EXPECTED PUMP OUTPUT (AT 60% EFFICIENCY) PER SQ. METER OF PROJECTED AREA OF S-ROTOR.



It is up to the user to decide if it is worthwhile to build an S-rotor for winds of less than 20mph if stronger winds are rare in the area. Unlike horizontal-axis wind machines, S-rotors will begin turning in very low-speed winds -- but will produce only small amounts of usable power at those low speeds. It is not possible to give a precise formula for the power available at the generator or a pump because the friction and transmission losses are largely dependent on the design and accuracy of manufacture of the rotor. Since the rotor is intrinsically not very powerful, friction losses due to bad bearings and transmission losses could absorb most of the available power. Therefore, proper construction and excellent fitting of the bearings is most important.

DETERMINE IF AN S-ROTOR IS SUITABLE FOR YOUR USE

It is very important to establish the following before attempting to build any wind machine:

Availability of wind. Find how often wind comes, its intensity, and its annual patterns. This information can generally be gotten from the nearest meteorological station. An alternative and more accurate method is to use an anemometer (wind speed measuring instrument) to measure wind speeds on a chosen site for a period of perhaps one year.

Intended use of the windmill.

- pumping water for household use
- generating electricity
- other applications

Choice of a suitable site. The choice of site will of course depend upon the intended use of the windmill. Then it is very important to select a location that will allow the windmill maximum exposure to wind, i.e., to get maximum power.

The top of a gently sloping hill with no trees, bushes or other obstructions to the wind is ideal.

However, if the windmill is to be used for pumping water, often the most likely place for a well is the bottom rather than the top of the hill, or even in the vicinity of buildings where the water will be used. If the site is sheltered from the prevailing winds by buildings, trees or other obstacles, it would be quite unsuitable for a windmill -- unless it is built on top of a tall tower or on top of a building itself. If this is the choice, then the windmill must clear the tallest obstacle by a minimum of about 10' (3m).

If the rotor is to be used for charging batteries, the top of a nearby hill, clear of obstructions, would seem to be a logical choice. Take into account that power will be lost when transmitted over a distance, and locate the rotor as close as possible to the place where the power will be used.

At almost any site, the higher the windmill is mounted, the stronger the winds will be. The benefits of extra power should be compared against additional costs of a tower or a support structure.

CONSTRUCTION

The author has built two S-rotors. They are different in design and construction method.

The first one, presented here as Rotor #1, is a two-stage rotor (two oil drums, each split in half and stacked vertically in pairs of half-drums) attached to a water pump. It can be duplicated easily where suitable materials and workshop facilities are available.

The second one, Rotor #2, is a three-stage rotor (three pairs of half-drums stacked vertically) designed for hook-up to small electric power generating equipment. Its method of construction would be appropriate in rural conditions with access to a village forge.

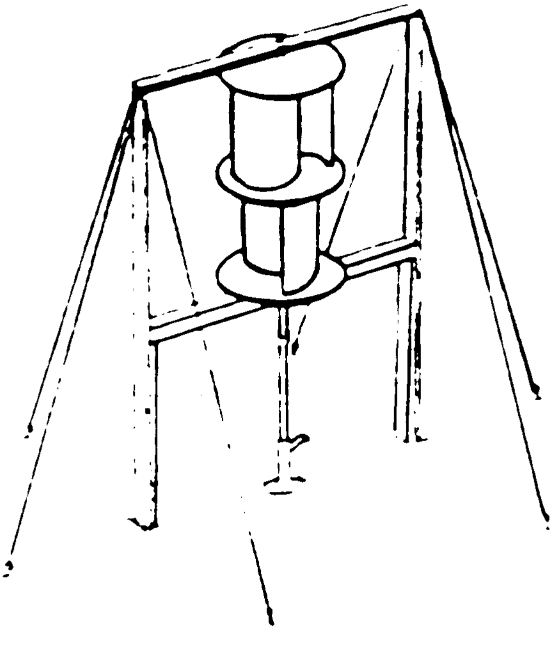
Access to a small machine shop, or something on that order, would be very helpful in the assembly of either of these rotors. Some sort of facility in which to form and cut mild steel will be required.

Both rotors use split oil drums for vanes. The drums are standard 45 Imperial gallon (55 US gallon) oil drums, which are available throughout most of the world; approximate dimensions of each drum are 34" (86cm) high x 20" (51cm) diameter.

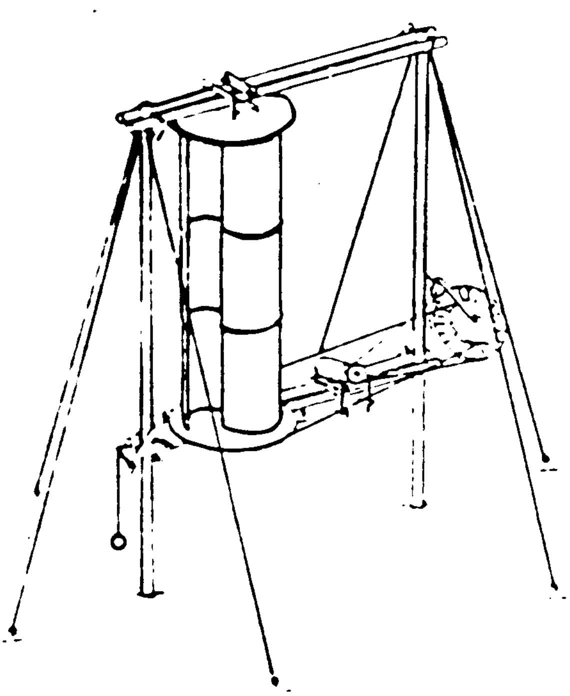
A two-stage rotor, such as Rotor #1, which uses four half-drums, will produce approximately twice the power input of a one-stage rotor using two half-drums. A three-stage rotor such as Rotor #2, using six half-drums, will produce approximately three times the power input of a one-stage rotor.

A rotor having more than three stages would require design modifications, and would be difficult to build in rural conditions.

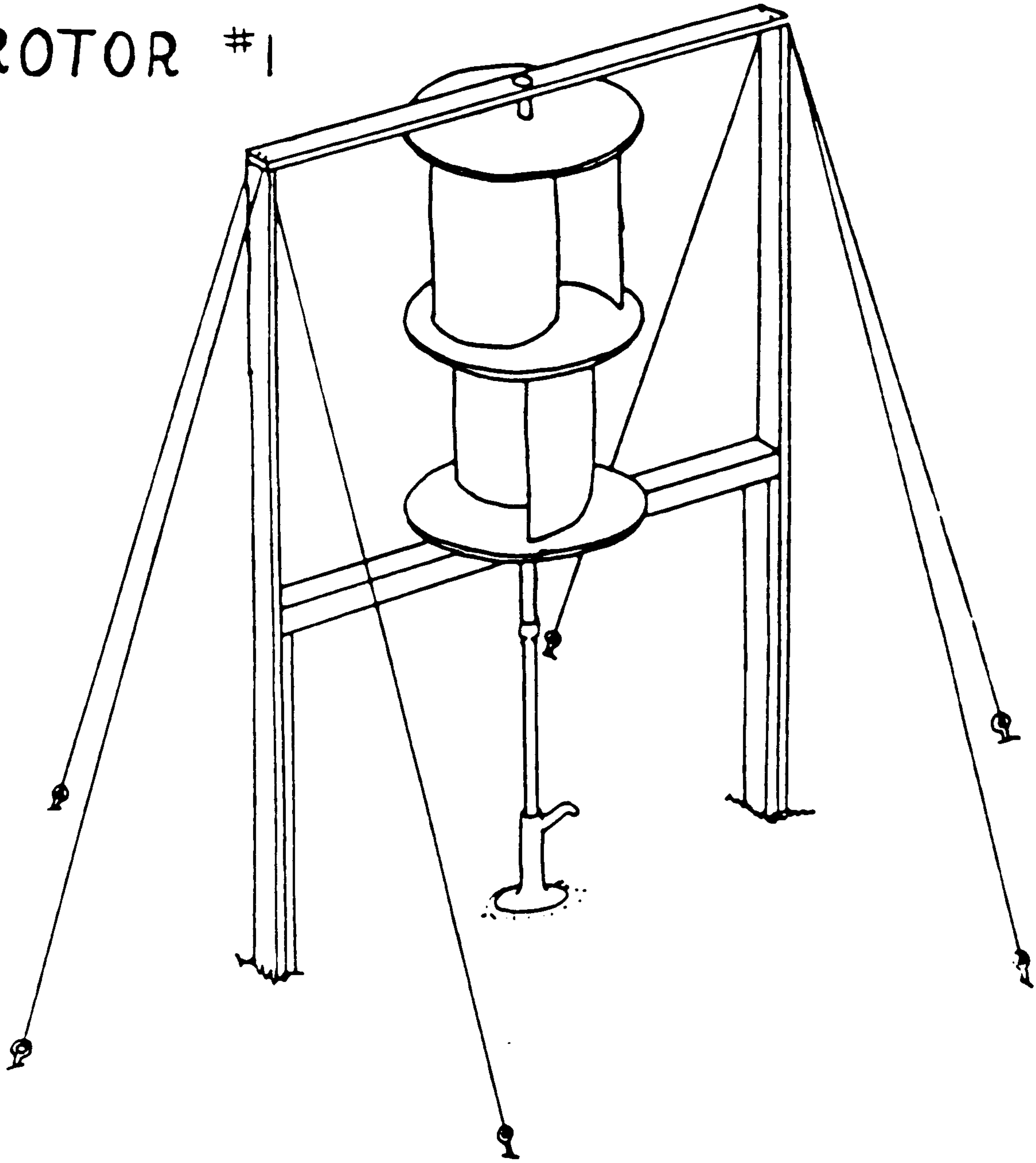
ROTOR #1



ROTOR #2



ROTOR #1



This is a two-stage S-rotor. A connecting shaft is attached to a positive-displacement rotary borehole (submersible) pump, manufactured by Mono Pumps (Engineering) Ltd. in England. Water is pushed up the borehole by a rotating screw-like mechanism. The vanes of the S-rotor are placed so the wind will turn the rotor in the same (counterclockwise--looking from the top) direction as that in which the Mono pump operates. Using a rotary pump of this type enables a direct rotor/pump hook-up--with an extension piece connecting the S-rotor shaft to the shaft extending down the borehole to the pump. IF YOU USE A ROTARY PUMP MADE TO OPERATE IN A CLOCKWISE DIRECTION, MAKE SURE TO REVERSE THE DIRECTION OF ALL THE S-ROTOR VANES FROM THAT SHOWN IN THESE PLANS.

VITA offers a number of technical bulletins containing plans for pumps. If you choose a pump that uses a reciprocating (back and forth) motion to lift the water, you will have to devise a mechanism to convert the rotary motion of the rotor to this kind of movement. Expect a certain loss in efficiency. Diaphragm pumps may be used if placed on the ground surface over a low head (that is, they cannot easily be rigged to operate down a borehole).

MATERIALS

- 2 standard 45 Imperial gallon (55 US gallon) oil drums
- One and a half 4x8' sheets of 1/2" thick plywood. 3 discs of 46" diameter will be cut from these. Marine quality plywood is best.
- About 45' of 2x4" wood, for rotor support frame. 2 pieces must have a continuous length of about 13' each.
- 1 wood beam, 4"x4"x6'
- About an 8' section of straight pipe (preferably steel), nominal (approximate) outside diameter of 1 1/4".
- About 1 sq. ft. of 1/4" thick flat mild steel sheet; about a 7" length of mild steel tube, with an inside diameter large enough to slide over the 1 1/4" pipe (above), and 1/4" wall thickness. These are to fabricate disc support brackets.
- 1 - 1 1/2' of solid steel bar, for shaft end pieces. See "MAKE SHAFT END PIECES" (page 21) for further considerations.
- 2 roller bearings, 1" minimum inside (shaft) diameter, with housings. The bottom bearing must be self-aligning in all directions. See "BEARINGS," page 18.
- Bolts. Nuts are not listed -- each bolt will take a nut of the appropriate size. Note: Bolt lengths are measured from the under-surface of the head to the tip.
    - To fasten disc support brackets to discs: eighteen 3/8"x22"; thirty-six 3/8" lock washers; eighteen 3/8" plain washers.
    - To fasten disc support brackets to shaft: three 1/2"x3"; six 1/2" lock washers.
    - To fasten drum brackets to discs: about sixty or seventy 1/4"x2"; twice as many 1/4" lock washers.

  - To fasten shaft and pieces to shaft: two 1/2" x 2 1/2"; four 1/2" lock washers; two 1/2" plain washers.

  - Whatever number and sizes of bolts you need to fasten the particular bearings you select to the bearing support beams.

- About 10 large thick wood screws, 3 1/2" long, with good-sized threads, to fasten together rotor frame

- Cement, sand and water to make about 2 cubic feet of concrete for anchors

- A few feet of about 1" thick boards to make anchor mold

- About 8'-12' of 1/2" diameter steel rod, for anchor loops

- Strong wire or cable for guy wires. Length needed depends on number and arrangement of guys you use.

- Screw eyes or other strong connectors to fasten guy wires to rotor frame

TOOLS

- Hacksaw; you also may need a steel chisel (cold chisel), flame torch, or cutting electrode.

- Other hand tools--including screwdriver, hammer, saw, round file, wood rasp or sandpaper, metal rasp, nails (a few 3 1/2" ones), coping saw, pliers, wooden mallet, wood chisel, wrenches

- Drill--electric or hand, and a few different size bits, for wood and metal

- Level; measuring tape or rule; right-angle square

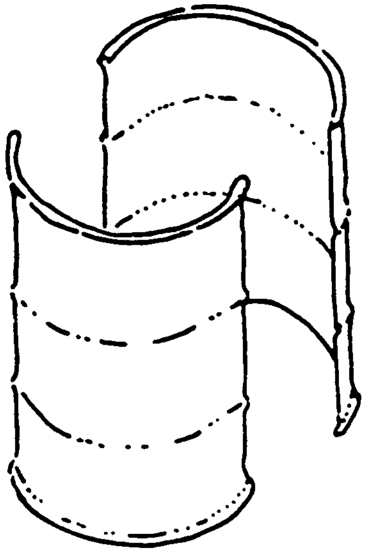
- Shovel

- Access to welding equipment to fabricate disc support brackets; access to forge to cut and form mild steel

- Access to a metal lathe would enable you to form your own shaft end pieces; access to a milling machine would enable you to make a top bearing housing (although the author has made the bearing housing on a lathe alone)

- Tapping and threading tools to make connection between bottom shaft end piece and shaft extension pump

PREPARE HALF-DRUMS



Take off removable top and bottom lids from two 45 Imperial gallon (55 US gallon) steel oil drums. If lids are permanently fixed to the drums leave them on.

Cut the drums vertically into two equal halves. You can cut with a flame torch, electric cutting electrode, mechanically with a saw (quite difficult) or a steel chisel (cold chisel).

File away rough edges from all four half-drums. Beat out any disfiguration to shape with a wooden mallet.

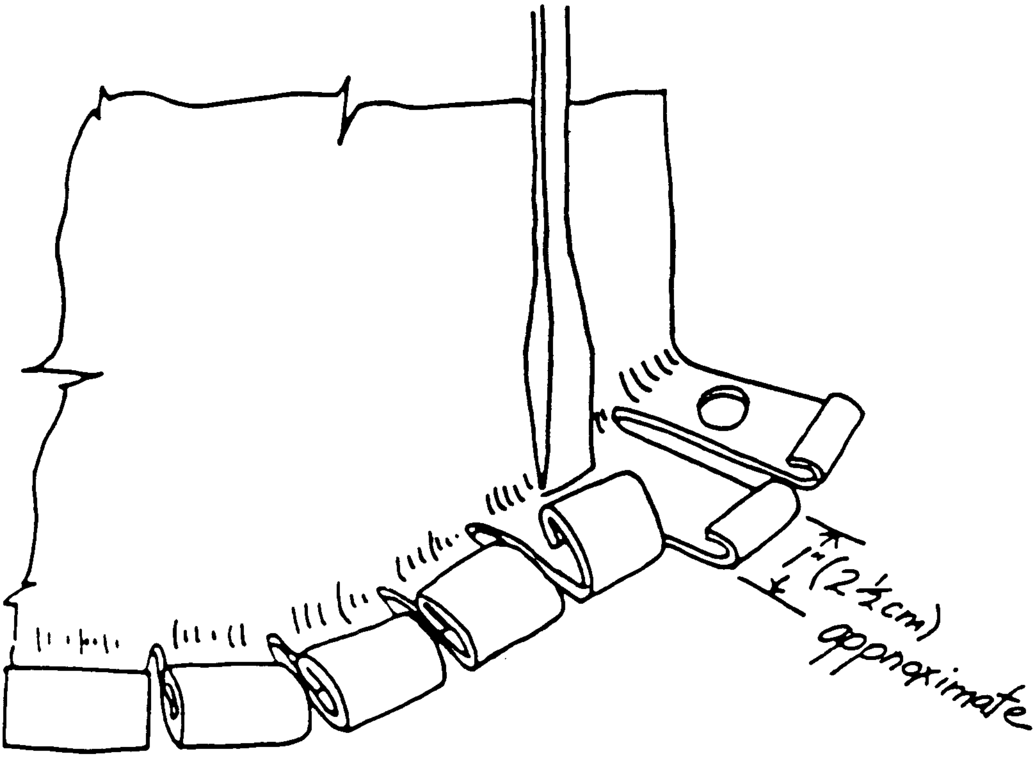
PREPARE DRUM (ATTACHMENT) BRACKETS

Slot the top and bottom lips of each half-drum with a hacksaw. Slots should be approximately 1" (2 1/2 cm) apart. Small variations are not important.

Open up the curls with a large screwdriver.

Call these "drum brackets."

Drill 1/4" holes in every third or fourth drum bracket -- space the holes as evenly as possible. A hole must be drilled into the end bracket of each side of the half-drum, top and bottom.



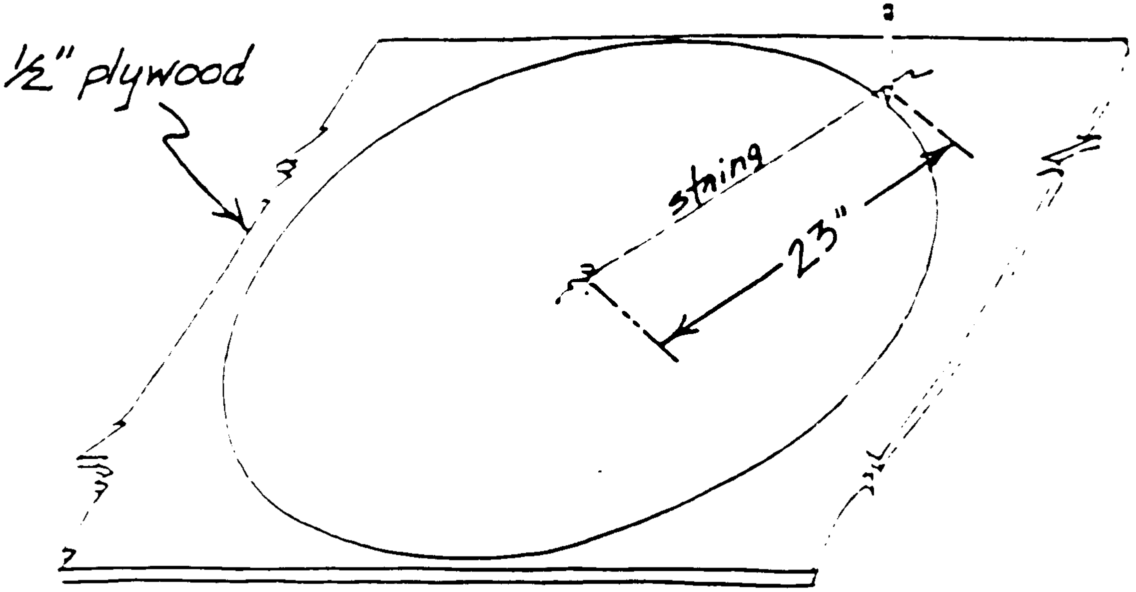
Use a round file to remove the burrs and to open the holes slightly, if necessary, to accomodate 1/4" bolts.

MAKE THREE CIRCULAR WOOD DISCS

Draw three circles of 23" radius on 1/2" thick plywood (marine quality is best). Drive a nail into the plywood at the point which will be the center of each circle. Tie one end of a string to the nail and the other to a pencil--make sure the length of string between the nail and pencil measures 23". Keep the string tight and the pencil in a vertical position, and draw an accurate circle.

After drawing the circles, spot check the distance from the center of each circle to the edge in several places.

Cut out the three circles. Smooth the edge of each disc with a wood rasp and/or sandpaper.

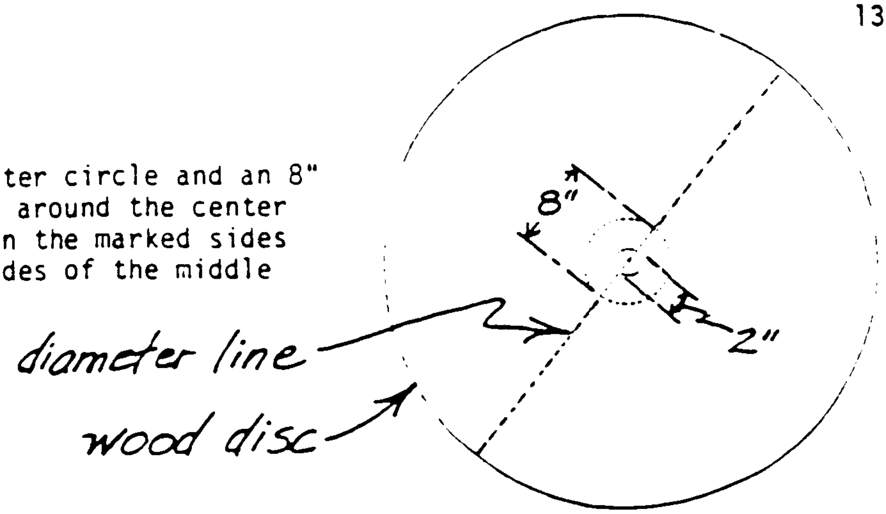


On one side of each disc, draw a line from edge to edge through the center. This forms a diameter line.

On one of the discs draw a diameter line on the back side <u>exactly</u> at right angles to the line on the front side. This disc will be the middle of the three discs.

Draw a 2" diameter circle and an 8" diameter circle around the center of each disc, on the marked sides (and on both sides of the middle disc).

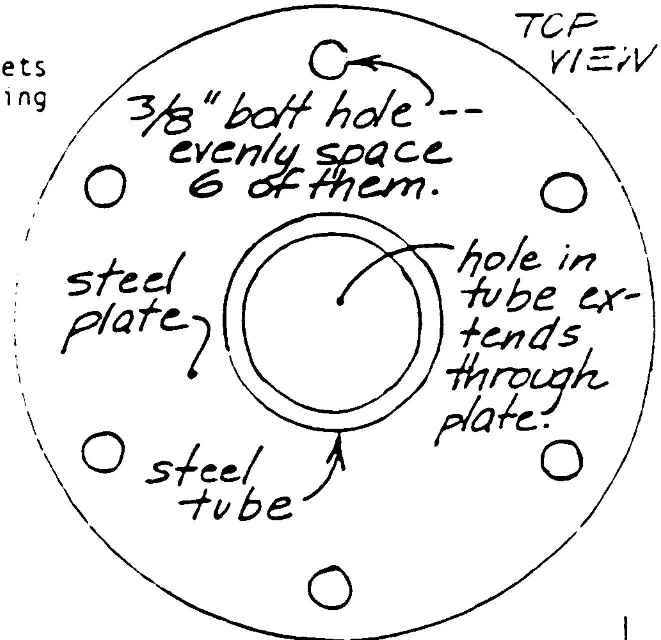
Drill a hole in the center of each disc.

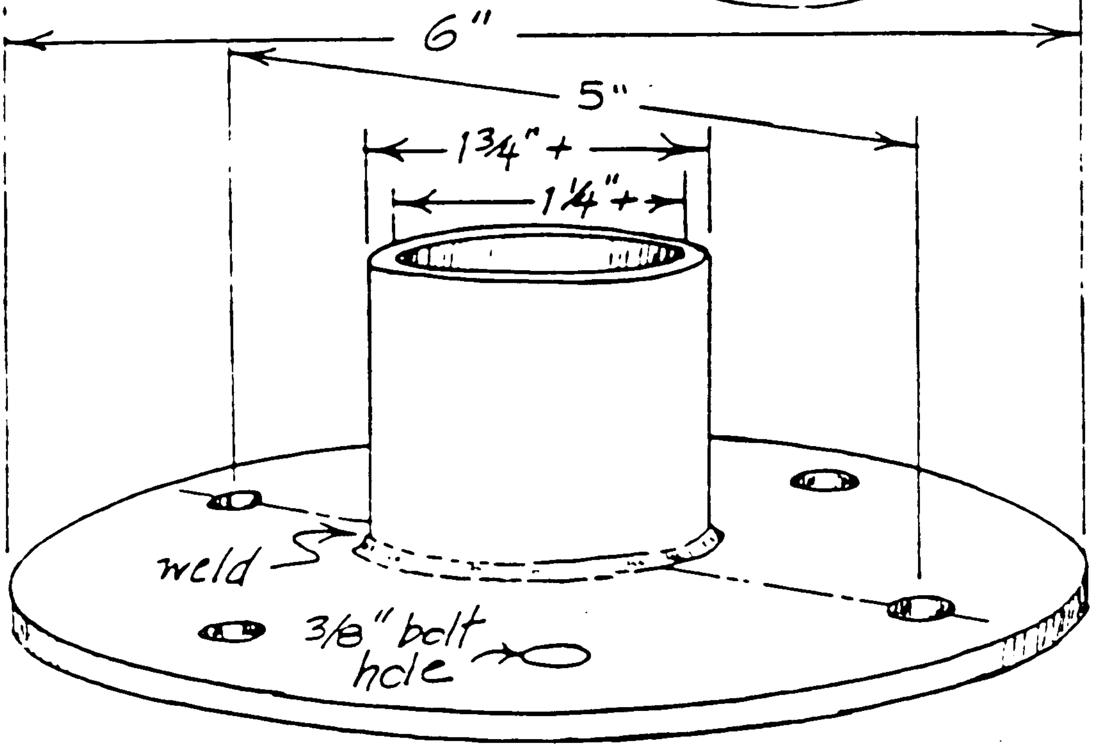


MAKE DISC SUPPORT BRACKETS

Make three disc support brackets by cutting, welding and drilling mild steel plate and tube.

These brackets will attach the plywood disc/half-drum assembly to a pipe shaft. Make sure each bracket slides over a chosen, straight 1 1/4" (nominal -- that is, will not be exact) diameter pipe at least 8' long. (Lead pipe out of question--too heavy and too soft.)





INSTALL THE DISC SUPPORT BRACKETS

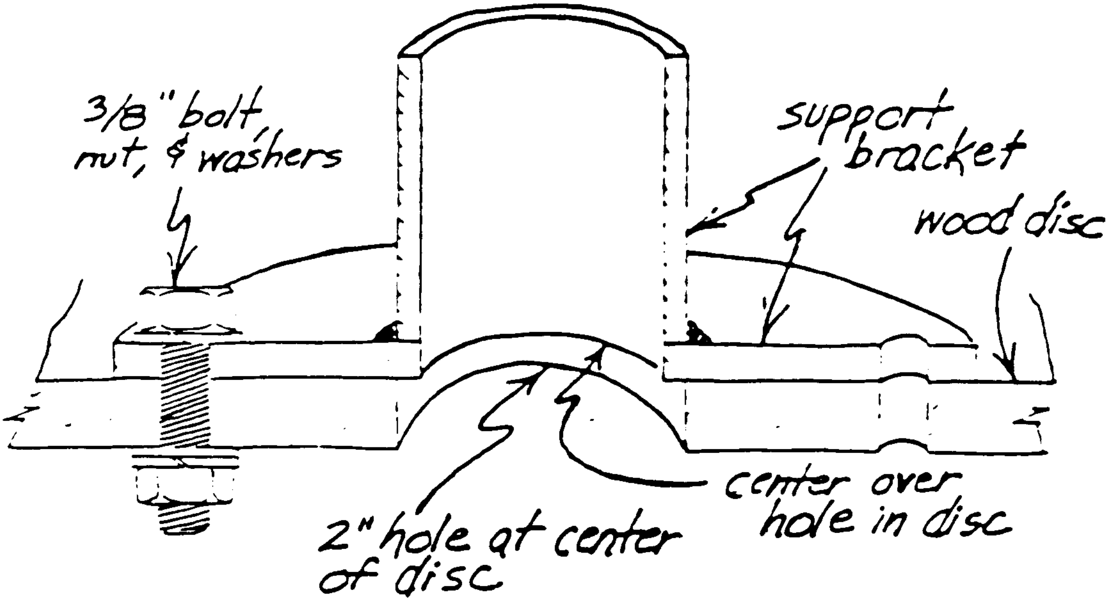
Center a disc support bracket on the marked side of one of the wood discs. Trace its outside edge onto the disc.

Cut out the 2" diameter circle marked on the disc to form a hole in the center of the disc. Use a 2" hole cutter, or: drill holes all round the inside of the marked 2" circle with a small drill bit; cut the spaces in between the holes with a sharp chisel, tapping gently with a hammer; smooth out the hole with a wood rasp or file.

Hold the bracket firmly on the circle traced around its edge. Drill 3/8" holes into the wood through the six holes in the bracket.

Insert bolts and washers and tighten nuts to fasten the bracket to the disc.

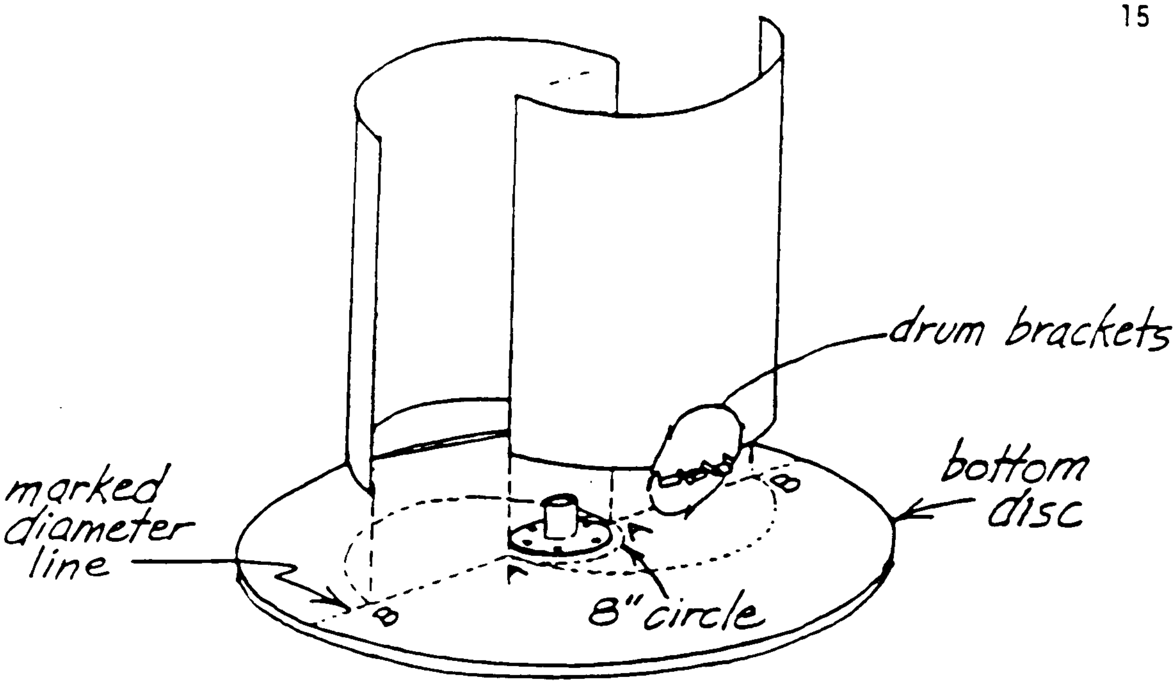
Repeat the same procedure to attach the other two brackets to the other two wood discs. You may use either side of the middle disc for this purpose -- in assembly the bracket will be underneath the middle disc.



CROSS SECTION OF SUPPORT BRACKET
—ATTACHMENT TO PLYWOOD DISC

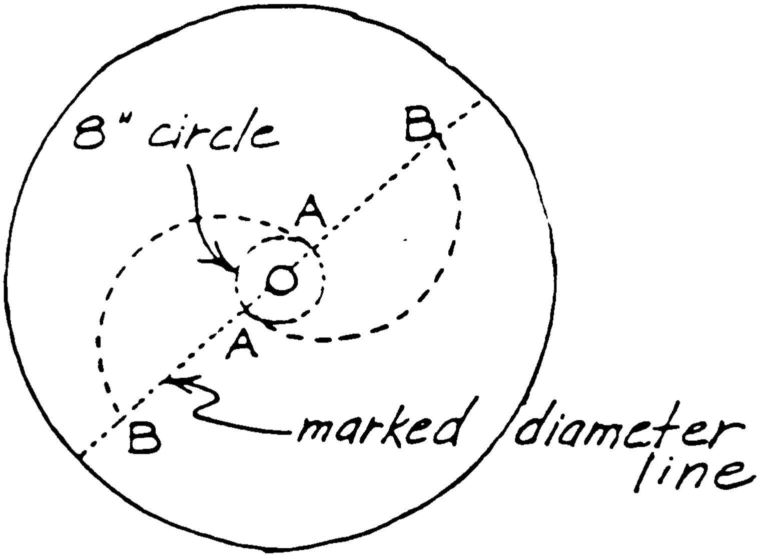
PREPARE HALF-DRUMS AND DISCS FOR ASSEMBLY

As you go through the following preparations, mark all discs and half-drums so they can be reassembled later exactly as you have prepared them -- otherwise bolt holes will not align.

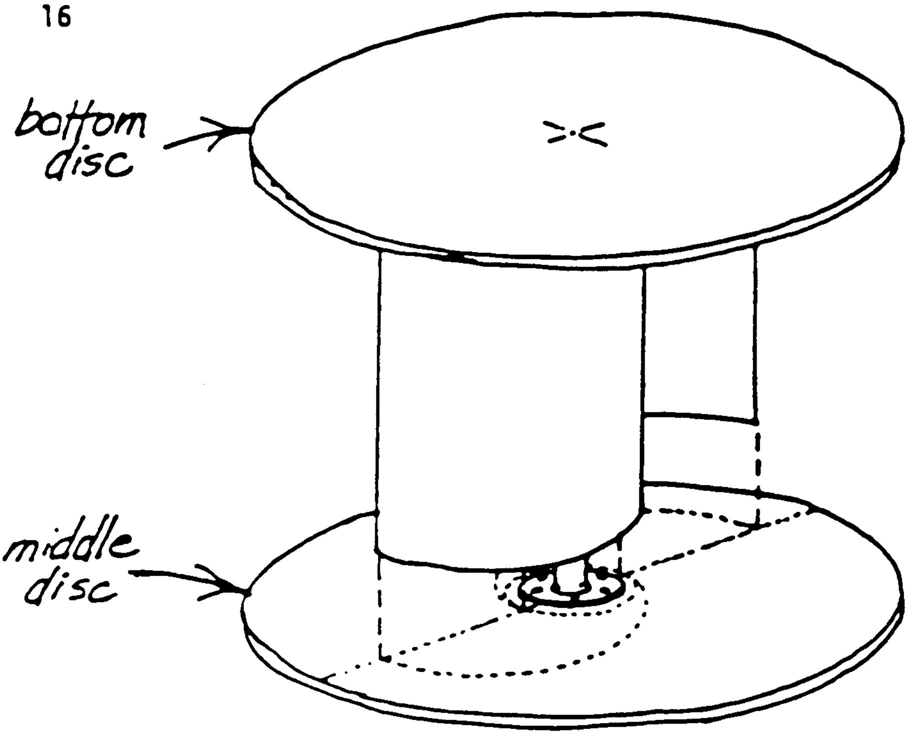


Place one of the two discs marked on only one side flat on the ground with the support bracket facing up. Mark this the bottom disc.

Place two half drums along the marked diameter line. The two tips A and B of each half-drum must be exactly on the line, and the inner tip A of each must also touch the circumference of the 8" circle drawn on the disc.



While the half-drums are in this position drill 1/4" holes into the disc through each hole in the drum brackets, inserting 1/4" bolts and nuts, and lock washers (underneath the bolt head and the nut) as you go. Start with the outer tip B of a half-drum, go directly to the inner tip A, and then drill the holes in between -- this will stabilize the half-drum for most of the drilling.

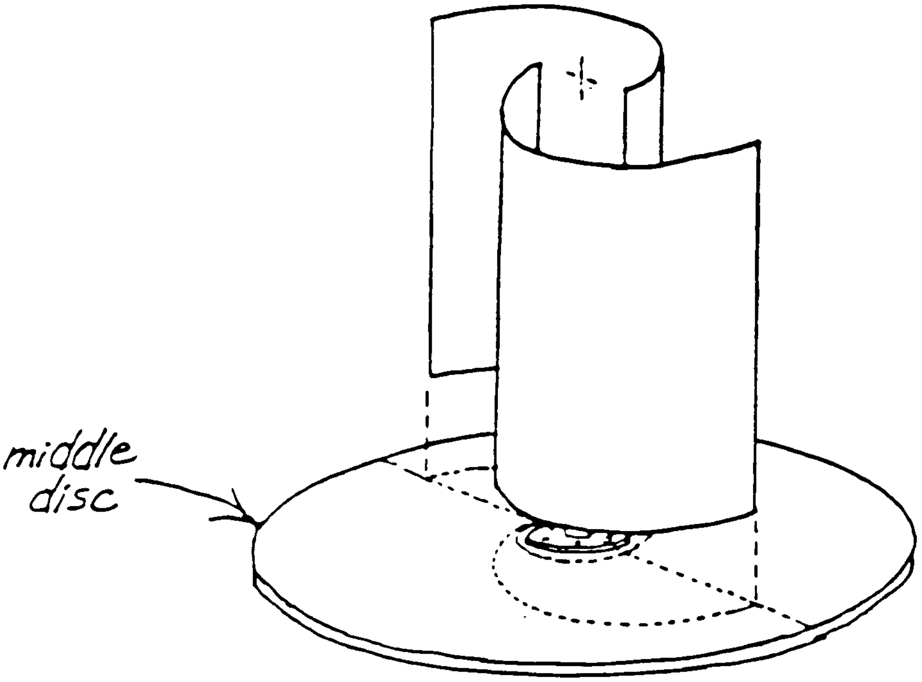


Place the middle disc flat on the ground with the support bracket facing up (that is, the bottom of the disc facing up).

Invert the bottom disc with the two attached half drums onto it, so that the free ends of the half-drums line up along the marked diameter line the same way as on the bottom disc. The pattern will form a mirror image of the bottom disc.

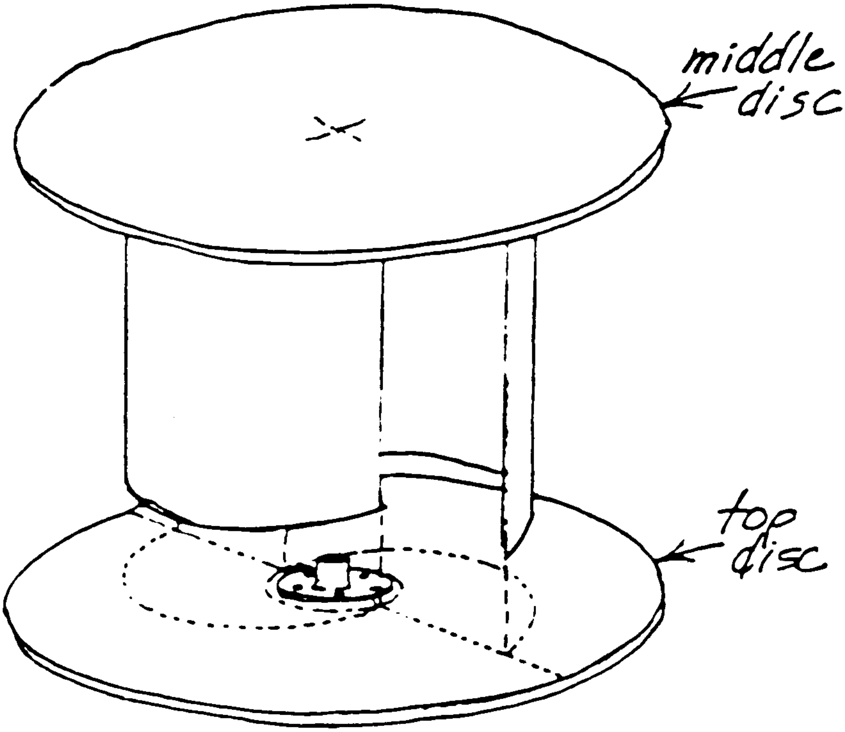
Drill holes through the drilled drum brackets in both half-drum edges into the middle disc. If you bolt through some of the holes to assist in drilling, remove the bolts when you are finished.

Remove the bottom disc and half-drum assembly.



Flip the middle disc over on the ground. Place the two remaining half-drums in position along the diameter line. (They will be at right angles to the alignment on the other side of the disc.)

Drill holes through the drilled drum brackets in the half-drum edges into the disc, bolting through some of the holes as you go.



Place the top disc flat on the ground with the support bracket facing up (that is, the bottom of the disc facing up).

Invert the middle disc with the two attached half-drums onto it, so that the free ends of the half-drums line up along the marked diameter line.

Drill holes through the drilled drum brackets in the half-drum edges into the top disc.

Take apart any discs and half-drums that remain together and set aside for final assembly later.

While handling the half-drums they may change shape slightly, causing bolt holes to move out of alignment with holes drilled in the discs. They may be brought into exact shape when bolting up by exerting hand pressure.

BEARINGS

End pieces of the top and bottom of the rotor shaft each rest in a roller or ball bearing attached to a horizontal support beam. This insures smooth and efficient rotation. It is important to select good bearings and install them properly.

The author recommends using bearings with a minimum inside -- or shaft -- diameter of 1". The bottom bearing must be self-aligning in all directions, and must be capable of taking the dead weight of the rotor, which -- depending on its construction -- should not exceed 200 lb.; that is, the bottom bearing must withstand both an axial thrust and side loads of 200 lb.

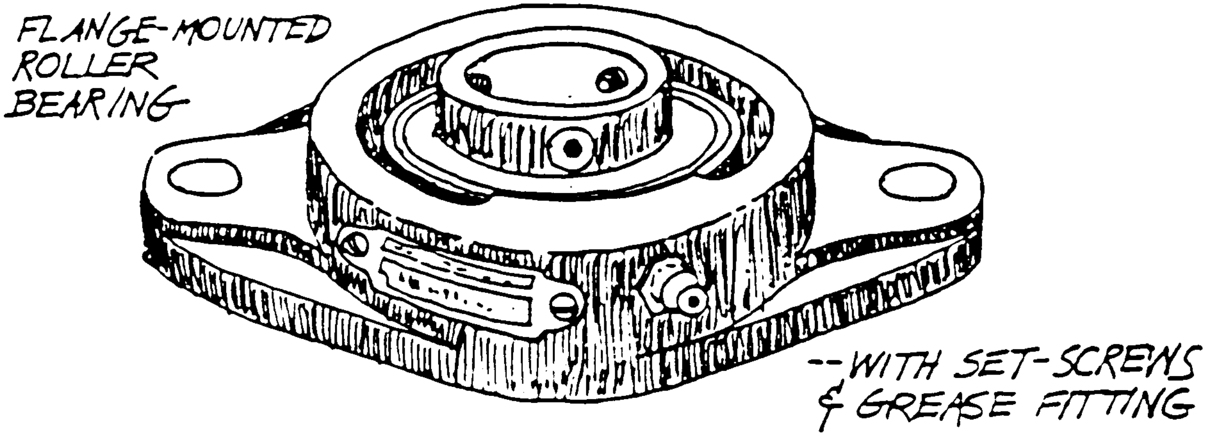
The author has used a Fafnir 1" bearing type RCJ P1 (bearing #GC1100KRRB5) for the bottom bearing.

These are two other roller bearings which will do the job, top or bottom:

- Seal Master MSFT-16 (or MSFT-16C with a moisture-proof seal); costs about US$12.00 (may be more now).
- Seal Master LFT-16 (or LFT-16C with a moisture-proof seal); costs about US$6.50 (may be more now).

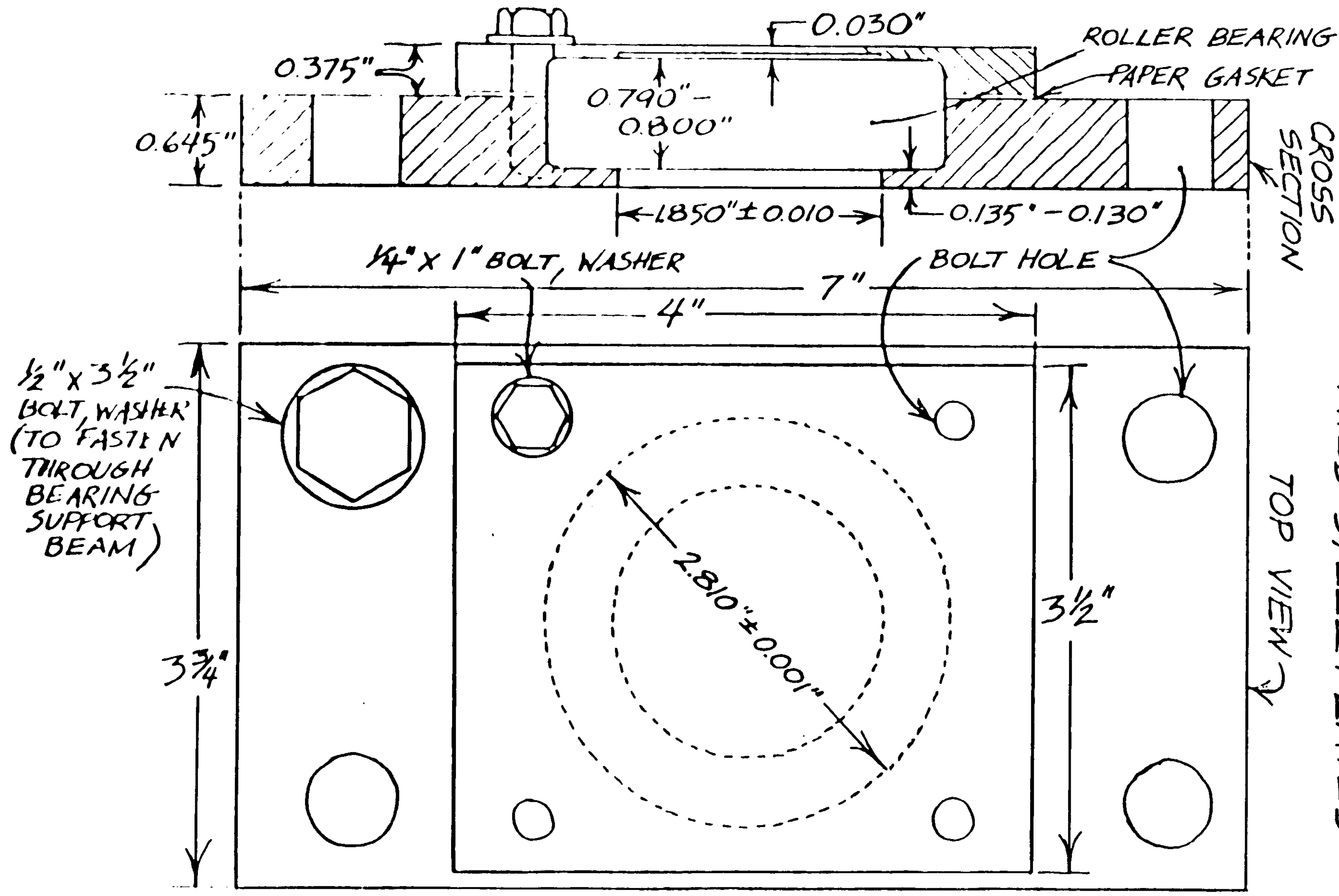
Bearings which provide for periodic lubrication without requiring disassembly will ease the job of maintenance.

There may be many bearings that you can find ready to install or adapt to use in the rotor. Keep in mind the loads involved, especially for the bottom bearing. Good bearings, installed properly, are essential to the successful operation of the rotor.



If you have access to workshop facilities you can make a housing to fit snugly around a suitable ball or roller bearing for the top rotor bearing. On the opposite page are diagrams of the housing the author made to fit around a bearing with an outside diameter of 2.31".

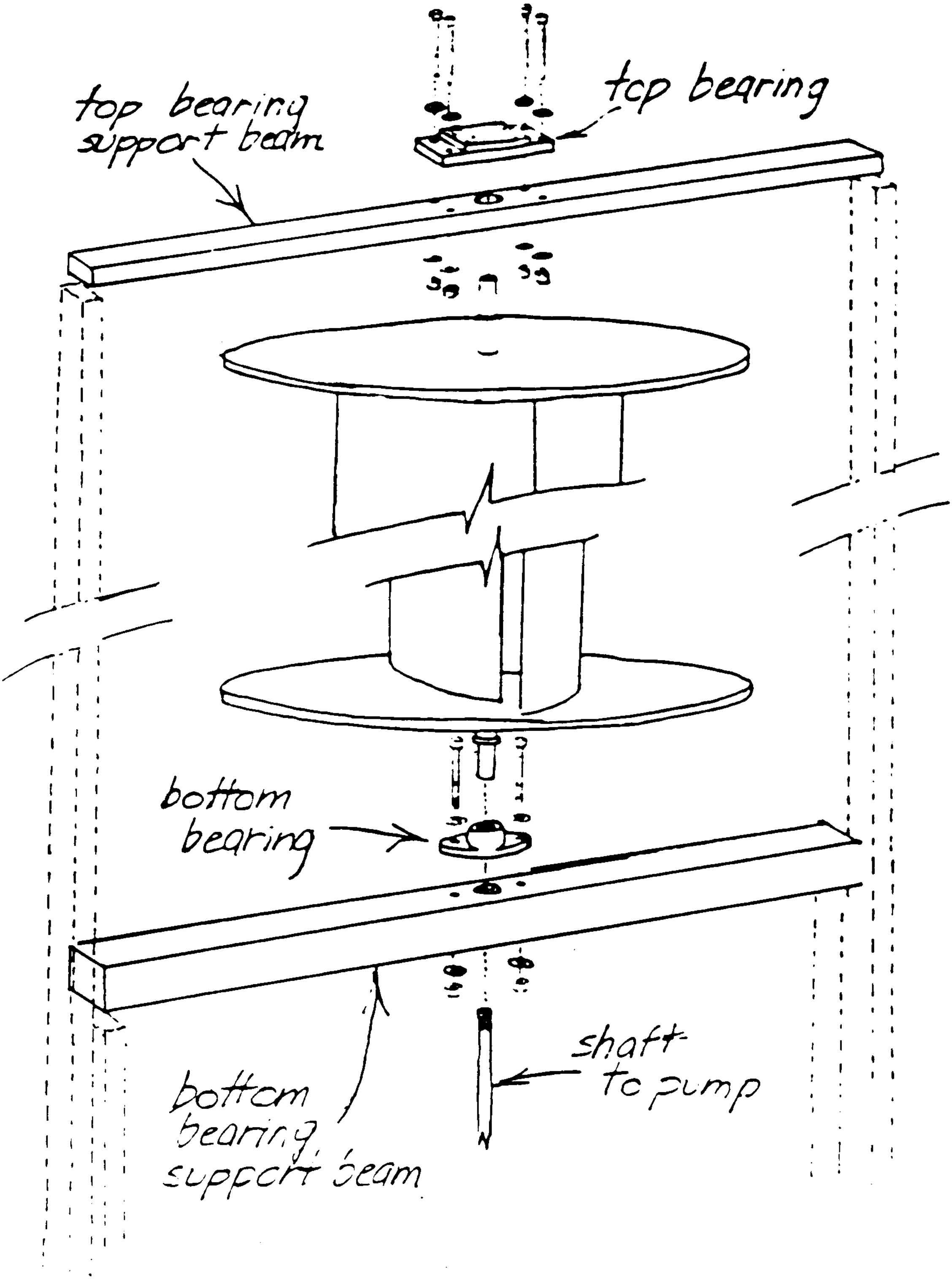
A TOP BEARING ASSEMBLY -- CUT & MILLED FROM MILD STEEL PLATES



PREPARE BEARING SUPPORT BEAMS

Cut a 6'4" length of 2x4" wood beam for the top bearing support beam. It will rest and be fastened over the ends of the two tall vertical rotor frame supports.

Cut a 6' length of a 4x4" wood beam for the bottom bearing support beam. It will fit and be fastened between the tall vertical rotor frame supports.



The bearings will fasten onto the topside of each beam, at the center point. Drill or cut a hole in the center of the 4" wide side of the top bearing support beam large enough so that the end of the rotor shaft may extend up through to the bearing and rotate freely, without touching. Drill or cut a hole in the center of the bottom bearing support beam large enough so that the shaft extending down to the pump from the bearing will be able to rotate freely.

Drill holes through the beams in the pattern and sizes that match the holes in the flanges on the particular bearings you are using. Take care that your bearings will be accurately centered on each support beam. Fasten the bearings to each beam with bolts, nuts and lock washers.

You may have to prepare the wood surface of the bearing support beams differently, with chisels, rasps and files, or use good-sized, sturdy shims, to accomodate bearings with housings of configurations other than a plain, flat under-surface. THE BEARING HOUSING MUST SEAT FIRMLY WHEN BOLTED.

MAKE SHAFT END PIECES

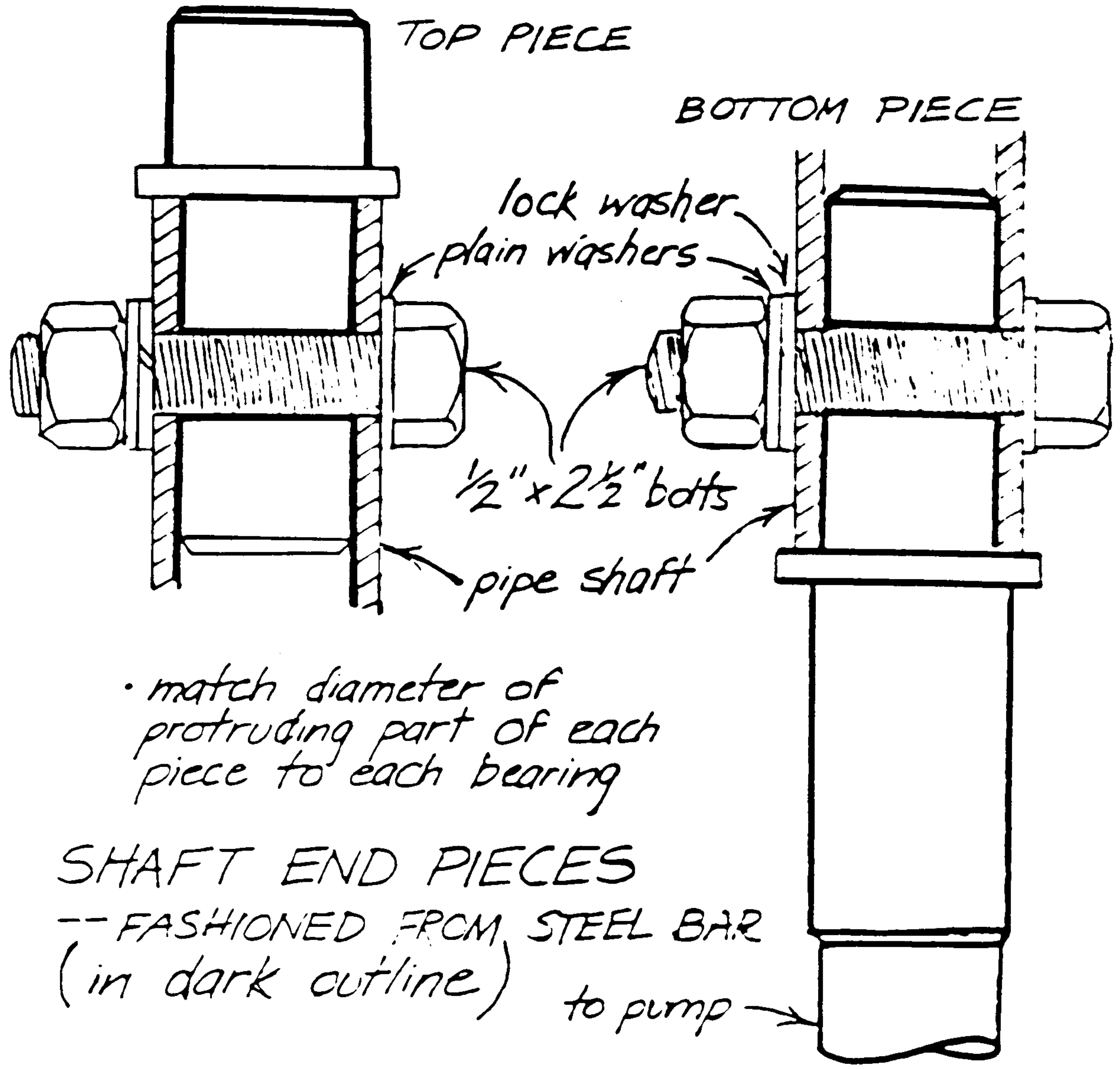
Solid steel end pieces fastened to the ends of the pipe shaft provide smooth surfaces to fit into the bearings.

Whether fashioned on a lathe or adapted to this application from already-fashioned materials, the end pieces must be of solid steel and -- especially important if the bearings you use are not equipped with set-screws to lock the shaft in place -- have a smooth cylindrical surface that makes an interference (tight) fit into each inner bearing surface.

If you fashion the pieces yourself, make the portion that slides into the pipe end the appropriate diameter to fit into the pipe (you may be able to file the inside surface of the pipe end somewhat). Incorporate into the shape of the bottom end piece a protruding collar, with an under-surface milled smooth and flat, that will rest on the lip of the bottom rotor bearing. A collar fashioned into the top end piece may provide a surer fit into the particular bearing you are using, or may not be necessary.

The bottom end piece must be long enough to protrude out of the bottom of the bearing. Drill out and tap the center of this end piece with a left-hand thread to match the thread on the extension of the shaft of the Mono pump, which rotates counter-clockwise (as viewed from the top).

If you have no access to a lathe, find steel bar with a diameter that will fit tightly into each bearing that you have chosen to use. Depending on the bearing sizes and the actual inside diameter of the pipe shaft you are using, either grind down or build up (with a sleeve) at least a 3 or 4" length of each end piece to fit snugly into the end of the pipe shaft. If the bottom bearing you are using does not have set-screws to lock the pipe shaft positively in place, use a locking collar -- that can be purchased with some bearings -- around the



• match diameter of protruding part of each piece to each bearing

SHAFT END PIECES
-- FASHIONED FROM STEEL BAR
(in dark outline)

protruding shaft of the bottom end piece, to rest on top of the lip of the bottom bearing. A Seal Master MSFT16-T (or MSFT 16-TC with a moisture-proof seal) is sold with a locking collar -- for US$13.40 (may be more now). You can do without a collar on the top end piece; take care in final assembly to account in your measurements for a space between the lower lip of the top bearing and the unmilled end of the pipe shaft.

ATTACH THE BOTTOM END PIECE TO THE PIPE SHAFT

Trim the bottom end of the pipe shaft to remove any threads. If necessary, file the inside surfaces to accomodate the shaft end piece.

Push the pipe end of the bottom shaft end piece into the pipe until the collar rests on the pipe end. Mark 1" from the end of the pipe with a punch. Drill a 1/2" hole through the pipe and the end piece, and deburr it. Keeping the end piece in place, bolt through the hole with a 1/2" x 2 1/2" bolt and tighten down with nut and washers.

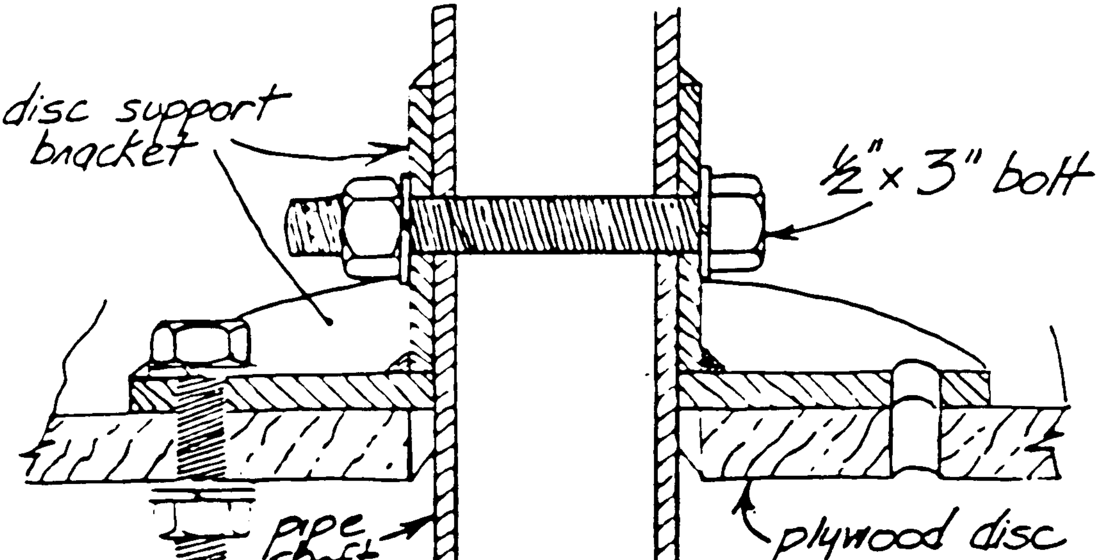
ASSEMBLE THE ROTOR

Seat the bottom end of the pipe shaft in the bearing on the 4x4" bottom bearing support beam.

Support the bottom beam about three feet off the ground, with the pipe shaft projecting out sideways from it.

Slide the bottom plywood disc over the top end of the shaft, with the disc support bracket facing the top end. Position the bottom face of the disc 2 1/2 - 3" awav from the top side of the bearing.

Holding the bracket firmly, drill a hole large enough to accept a 1/2" diameter bolt through the hole in the bracket collar and the pipe, and back out through the other side of the bracket collar. (If necessary, undo the bolts holding the support bracket to the disc and remove the disc.) Insert a bolt through the bracket and pipe, and tighten with lock washers and nut. Bolt back the disc if you have removed it.



Bring one of the bottom half-drums into position against the bottom disc -- make sure to match the correct half-drum to the position on the disc according to the marking system you have set up. Fasten it firmly against the disc with bolts, nuts and lock washers.

Slide the middle disc over the top end of the shaft with the support bracket facing the bottom end of the pipe shaft. Bolt it firmly to the top end of the bottom half-drum that is in place.

Drill a hole through the support bracket collar and pipe as before -- 1" away from the bracket flange, and large enough to accept a 1/2" diameter bolt. Insert a bolt and tighten with lock washers and nut.

Place the remaining bottom half-drum in its marked position between the two discs and bolt into place.

Fasten the top disc to the pipe shaft:

. fasten one of the top half-drums to the middle disc.

. slide on the top disc -- support bracket facing down -- and bolt to the top of the half-drum.

. drill and bolt the support bracket to the pipe shaft.

. bolt the remaining top half-drum into place.

Bolt any remaining un-bolted drum brackets to the discs.

Leave about 6" of pipe projecting beyond the top disc. Cut any remaining pipe off squarely, and remove any sharp edges.

File the inside of the pipe so the top shaft end piece makes a push fit with the pipe. With the end piece in place, drill a hole all the way through it and the pipe, about 1" away from the pipe end. Insert a 1/2" x 2 1/2" bolt and tighten with washers and nut.

Seat the top shaft end piece in the bearing on the 2x4" top bearing support beam. Support each end of the beam about three feet off the ground, just like the bottom beam.

BEARING MOVEMENTS

The rotor must rotate freely in the bearings, without resistance.

The pipe shaft should be at right angles to the plane of rotation of each bearing. The bearing support beams should be parallel to each other. If either of the bearings you use are adjustable with set-screws, and the rotor does not turn freely enough, loosen the bearing from the beam, adjust the screw, and then tighten the bearing back to the beam. Test the adjustment by giving the rotor a turn. Repeat as necessary until smooth movement is achieved. If there is no way to adjust the shaft placement in the bearings you use, you may have to make slight compensations in the placement of the bearing support beams relative to the pipe shaft.

Balance the rotor according to the procedure given on page 39. Final adjustments should be made on the rotor in its final, vertical position.

NOTE: New bearings may be stiff until they are broken in a little, because of the (grease) packing. Turr the rotor a number of times to begin this process. Do not confuse tight movement with rough movement.

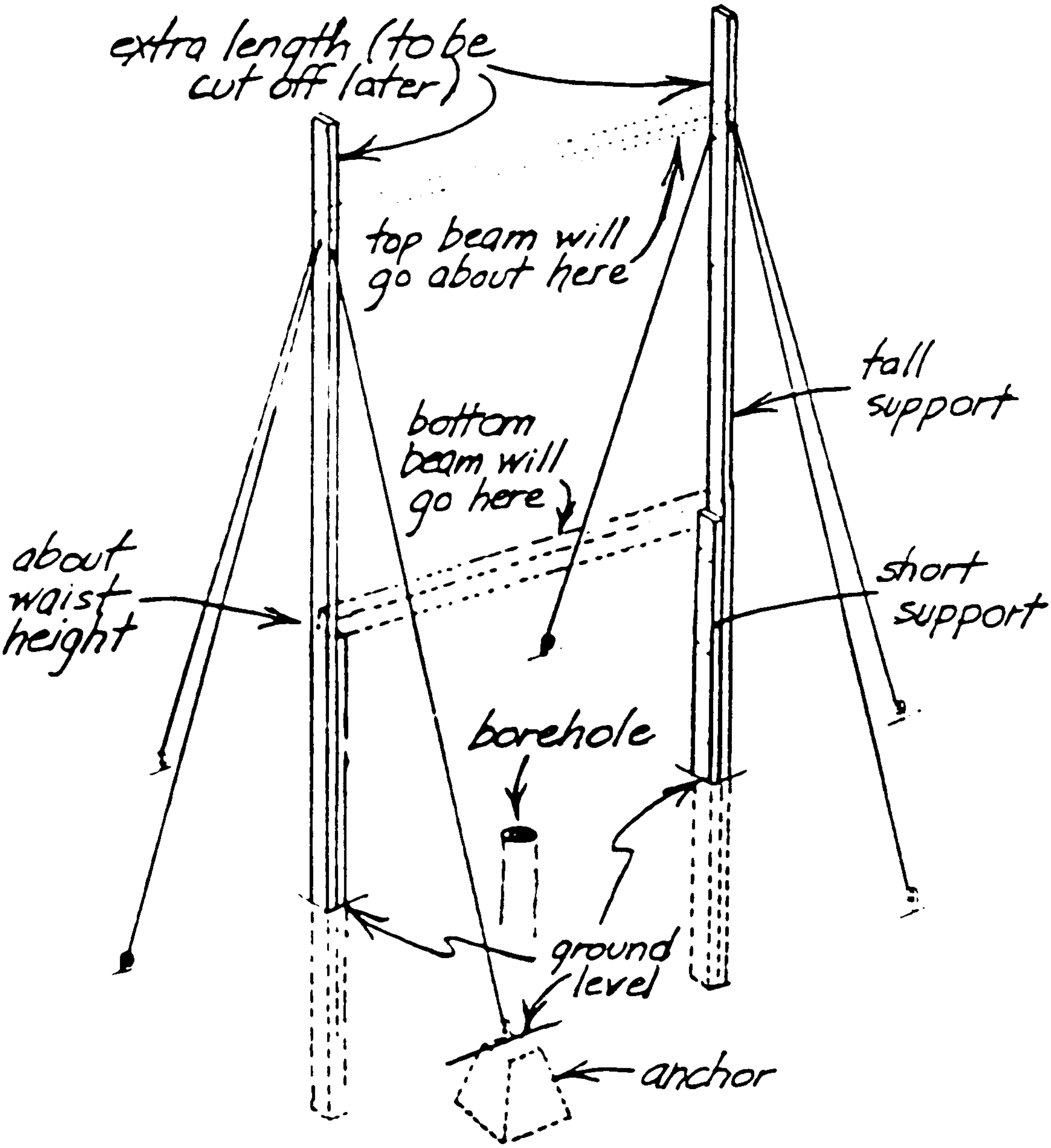
BEGIN ERECTING THE ROTOR FRAME

You may assemble the frame and rotor on the ground and then erect into position; or proceed as follows.

Sink two tall 2x4" wood vertical frame supports into the ground so that their inside surfaces are 6' apart, and two shorter pieces of 2x4" wood right up next to the inside surface of each of the taller supports. All the supports should be firmly embedded in the ground.

The bottom of the rotor should be about waist high. Cut each of the tall vertical supports long enough to include the portion that will be in the ground, the distance from ground to waist, a distance equivalent to the height of the rotor itself (from the point where the top bearing meets the shaft to the point where the bottom bearing meets it), plus an extra foot or so.

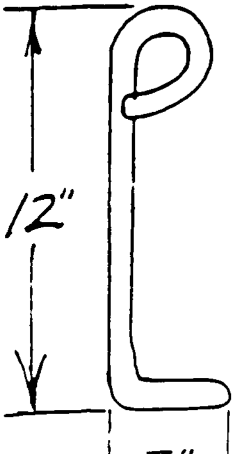
The top ends of the shorter supports should be at least waist height; the bottom bearing support beam will rest on them. This beam should be perfectly horizontal, so make sure the ends of the short supports are aligned at the right heights. Nail them into the tall supports.



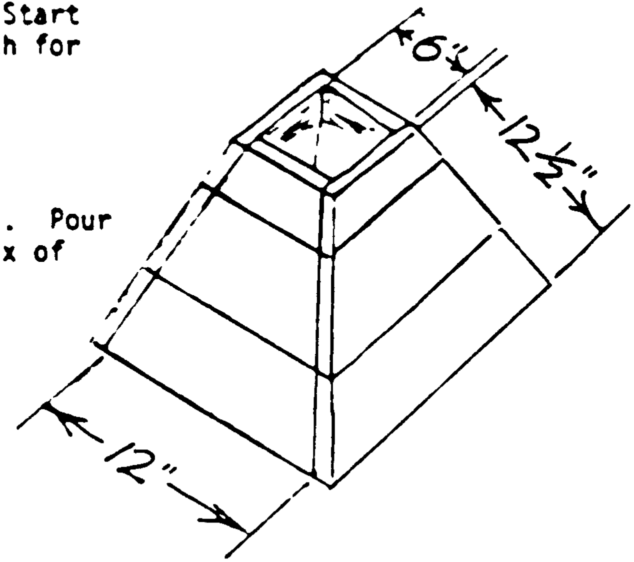
MAKE ANCHORS AND ATTACH GUY WIRES

You must provide some sort of anchors and guy wires to stabilize the rotor frame. Sturdiness and structural integrity are important not only to protect the machine in high winds, but also to insure minimum wear on the moving parts in ordinary winds.

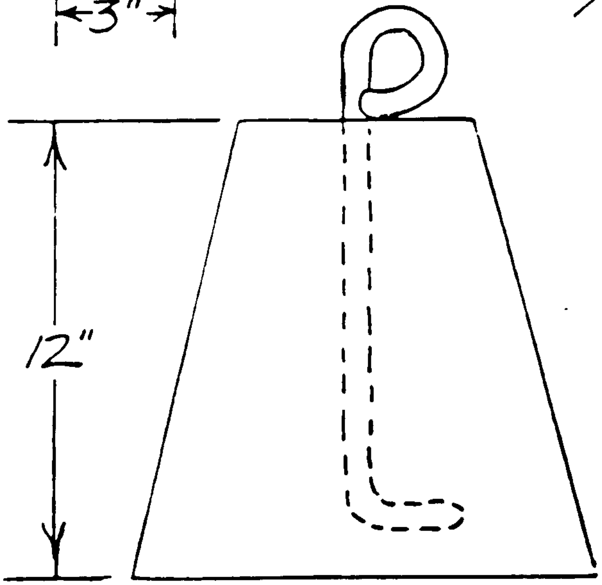
Four or six of these concrete anchors will work well. If you substitute some other device, make sure it will hold firmly in the ground against strong pulls that may be exerted by the machine and frame in high winds.



Hot-form 1/2" thick steel rods to this shape. Start with about a 2' length for each piece.



Make a wood mold. Pour in a standard mix of cement, sand and water.



Push a formed steel rod into place in the wet concrete mix. Allow to set for 24 hours, in the shade. Tap the mold to lift it off the anchor.

Make the rest of the anchors. When all dry -- they are strongest after curing for a week -- bury them in the ground with the loop in the steel rod just above the ground surface. The anchors must be placed far enough away from the rotor frame so the guy wires can exert a good pull against movements in the structure -- but not so f - away that the wires are too long and elastic.

Attach guy wires -- good, strong wire or cable -- to the anchor loops and to screw eyes (or some other type of strong connector) placed near the tops of the tall vertical frame supports (make sure to attach them below the point where the supports will be cut off to correctly position the top bearing support beam when the rotor is in place). Make them tight enough now to keep the rotor frame in position while installing the rotor, but not so tight that they pull the top ends of the tall vertical supports away from each other. Turnbuckles along the wires will help you adjust the wires for maximum tightness after installing the rotor into the frame.

FINAL ASSEMBLY

Remove the bottom bearing support beam, with bearing attached, from the rotor assembly. Place it horizontally between the tall vertical frame supports with the ends resting on the top ends of the shorter vertical supports. Hold in position and drill holes for large wood screws through the tall vertical supports and into each end of the beam. Screw the beam into place.

On the rotor assembly, measure the distance from the bottom surface of the collar on the bottom bearing end piece to the bottom surface of the top bearing support beam, which is in place on the pipe shaft. Add the thickness of the bottom bearing housing to this figure. Mark off the distance of this total measurement on each tall vertical frame support, starting upwards from the top surface of the bottom bearing support beam. Cut off the top of each vertical support squarely at this mark.

Remove the top support beam from the rotor assembly and place it over the free ends of the vertical supports, bearing on top. Hold or clamp in position and drill holes for large wood screws through it and down into the vertical supports. Do not split the wood. Remove the beam.

Raise the rotor into position. This is at least a two-man job. Push the bottom shaft end piece down into its bearing, tapping gently if necessary. While the rotor is being held up by hand, position the top beam. Slide the bearing down over the end piece on the end of the pipe shaft, tapping gently with a mallet or heavy piece of wood. Screw the ends of the beam down into the vertical supports.

If the bottom bearing support beam has been installed perfectly level, and the pipe shaft is vertical -- at right angles to the beam, and the bottom bearing is properly aligned in its housing, then the rotor should rotate smoothly in that bearing. If there is any roughness in the rotation of the shaft end piece in the top bearing, you may try to make further adjustments (in an adjustable bearing) in the alignment of this bearing. If that doesn't do the job (or the bearing is not adjustable), you can try inserting shims between one end or the other of the top beam and the top end of the vertical support until there is smooth movement of the shaft in the bearing.

It is very important that the rotor turn freely. The bearings, especially the bottom one, could be ruined, with consequent damage to the rotor and frame, if improper bearings and installation procedure cause uncontrollable stresses and strains as the machine turns continually in the wind.

Take your time and be as resourceful as you can in these final steps. It is possible that you may have to do something like the following:

. dismantle the rotor from the frame to make adjustments.

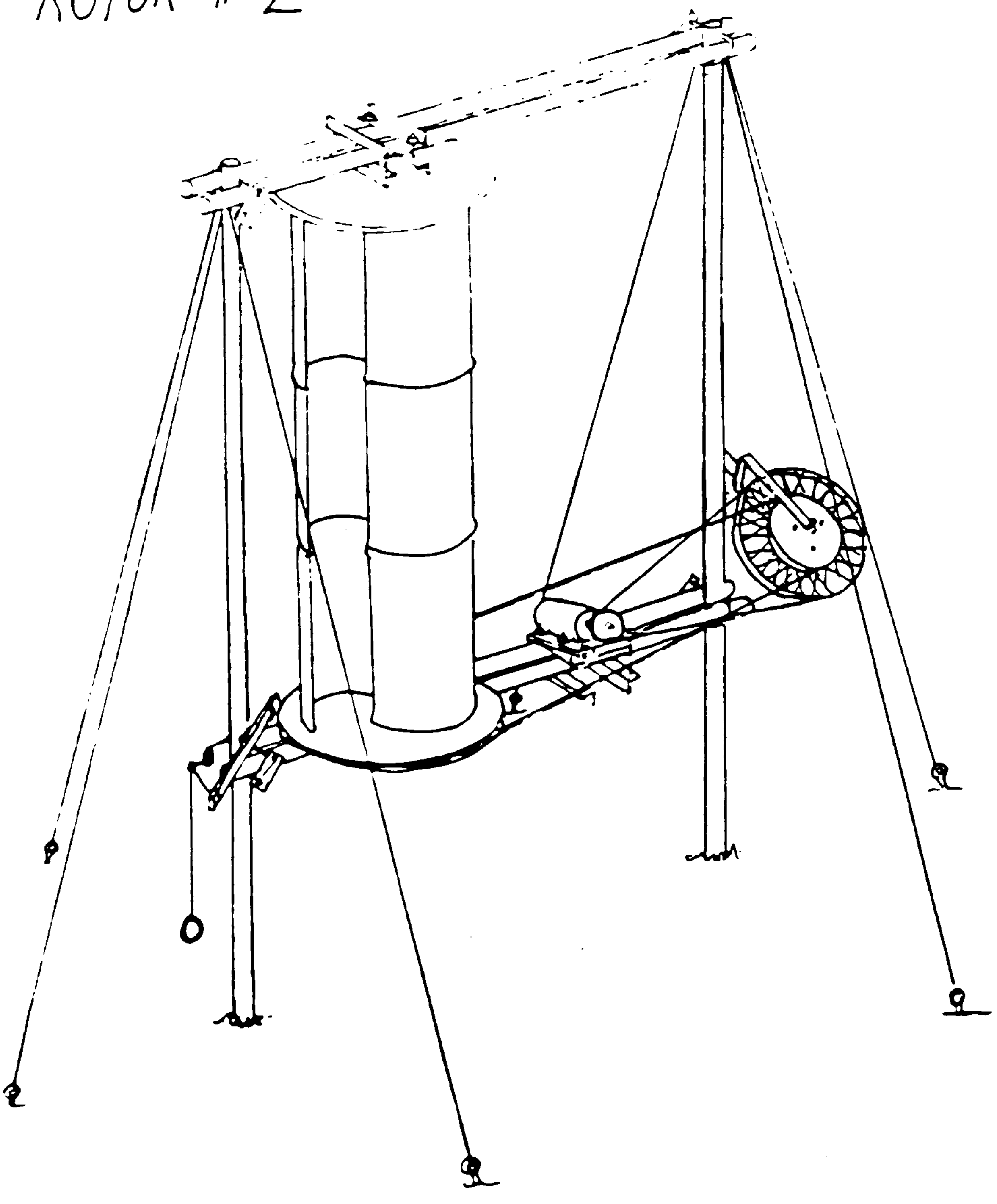
. plane down the wood surface of a beam under the bearing to adjust the bearing to the correct angular relationship to the rotor shaft.

. go to a better bearing than one you were hoping would work.

Whatever you do now to get the rotor running smoothly will be worth the trouble you are thereby going to avoid later.

You may find it easier to make the final assembly on the ground in a horizontal position and raise it up after assembly by means of ropes. At least half a dozen men are required for this final operation.

ROTOR # 2



This is a three-stage rotor design that the author built in rural Zambia. By means of belts and a bicycle wheel pulley mechanism it is geared to drive an automobile alternator or generator, which generates electrical current that is stored in automobile batteries.

An understanding of the procedures followed in assembling Rotor #1 will help you in putting this rotor together. Specific references are frequently made here to steps in Rotor #1 assembly where the same procedures or other information apply, rather than repeat the same material; but even in other steps it may be helpful to read through the corresponding material given for Rotor #1.

MATERIALS

. 3 standard 45 Imperial gallon (55 US gallon) oil drums

. About 32' of 12" wide x 1" thick boards, to be used in 3 1/2 - 4 1/2' lengths, for rotor discs

. About 10' of steel angle for disc braces

. About 14' of flat steel strip for disc braces

. About 5' of 1/4" thick x 1 1/2" wide steel strip, for disc/shaft brackets

. About 2' of 1/8" thick x 1" wide steel strip, for lid/shaft brackets

. A 10' length of straight pipe, 1 1/4" nominal (that is, will not be exact) outside diameter.

. 1 - 1 1/2' of solid steel bar, for shaft end pieces. See "MAKE SHAFT END PIECES," page 21, Rotor #1 and page 38, Rotor #2 for further considerations.

. 2 roller or ball bearings, 1" minimum inside (shaft) diameter, with housings. The bottom bearing must be self-aligning in all directions. See "BEARINGS," page 18, Rotor #1.

. 6 straight, sturdy wood poles (4 - 8" diameter), for rotor frame: 2 poles approximately 17' long for vertical supports; 4 poles approximately 10' long for horizontal supports.

. About 10' of 1/2" diameter mild steel rod, for U-bolt frame brackets

. About 3' of 3/16" thick steel angle, for frame brackets

. Up to 12' of 3/16" thick steel angle for bearing mounts

. Cement, sand and water to make about 4 cubic feet of concrete for anchors

. A few feet of about 1" thick boards to make anchor mold

. About 8' - 12' of 1/2" diameter steel rod, for anchor loops

- Strong wire or cable for guy wires. Length needed depends on number and arrangement of guys you use.

- Screw eyes or other strong connectors to fasten guy wires to rotor frame

- An assortment of bolts, nuts or other small, heavy objects to balance the rotor

- BOLTS. Nuts are not listed -- each bolt will take a nut of the appropriate size. Note: Bolt lengths are measured from the undersurface of the head to the tip.

  - To fasten drum brackets to wood discs and to each other: about sixty or seventy 1/4" x 2"; twice as many 1/4" lock washers.

  - To fasten braces to wood discs: about fifty or sixty 1/4" x 2 - 2 1/2", and twice as many lock washers.

  - To fasten disc/shaft brackets to pipe shaft: four 1/2" x 2 1/2"; eight 1/2" lock washers.

  - To fasten disc/shaft brackets to wood discs: sixteen 1/2" x 2 1/2"; thirty-two 1/2" lock washers.

  - To fasten lid/shaft brackets to pipe shaft: two 1/2" x 2 1/2"; four 1/2" lock washers.

  - To fasten lid/shaft brackets to half-drum lids: eight 1/2" x 2 1/2"; sixteen 1/2" lock washers.

  - To fasten bearing mounts over bearing support poles: eight 1/2" x 5" - 7"; sixteen 1/2" lock washers.

  - To fasten bearings to mounts: appropriate number and sizes, according to the particular bearings you use.

  - sixteen 1/2" <u>nuts</u> for U-bolt frame brackets; eight 1/2" lock washers.

<u>for accessory equipment</u>:

- for rotor brake: 2-3' of 2" diameter wood pole; hinge and screws; small coil spring; a few feet of cord; small pieces of rubber.

- for transmission pulley and holder: bicycle wheel without tire; 1" thick board, 1 square foot; about 4' of 1/4" thick, 2" wide steel strip; a few bolts, nuts, washers, and wood screws.

- tire inner tube(s) to make transmission belts.

- up to 6' of 3/16" thick steel angle, appropriate numbers and sizes of bolts, nuts and lock washers -- to mount alternator or generator.

The following equipment must be compatible in operation -- as if from the same automobile or other similar system (author has used auto parts):

- alternator or generator
- voltage regulator
- storage battery or batteries
- suitable wire for hook-ups

TOOLS (the author used only handtools to construct this rotor)

- hacksaw; you also may need a steel chisel (cold chisel), can use a flame torch if available
- other hand tools -- including screwdriver, hammer saw, round file, wood rasp or sandpaper, metal rasp, wood chisel, small carving tool, wrenches
- drill -- electric works best --, and a few different size bits, for wood and metal
- level; measuring tape or rule; right-angle square
- access to a simple forge, or some facility to cut and form mild steel
- threading tool to thread 1/2" steel rod -- if you make metal rotor frame brackets
- shovel

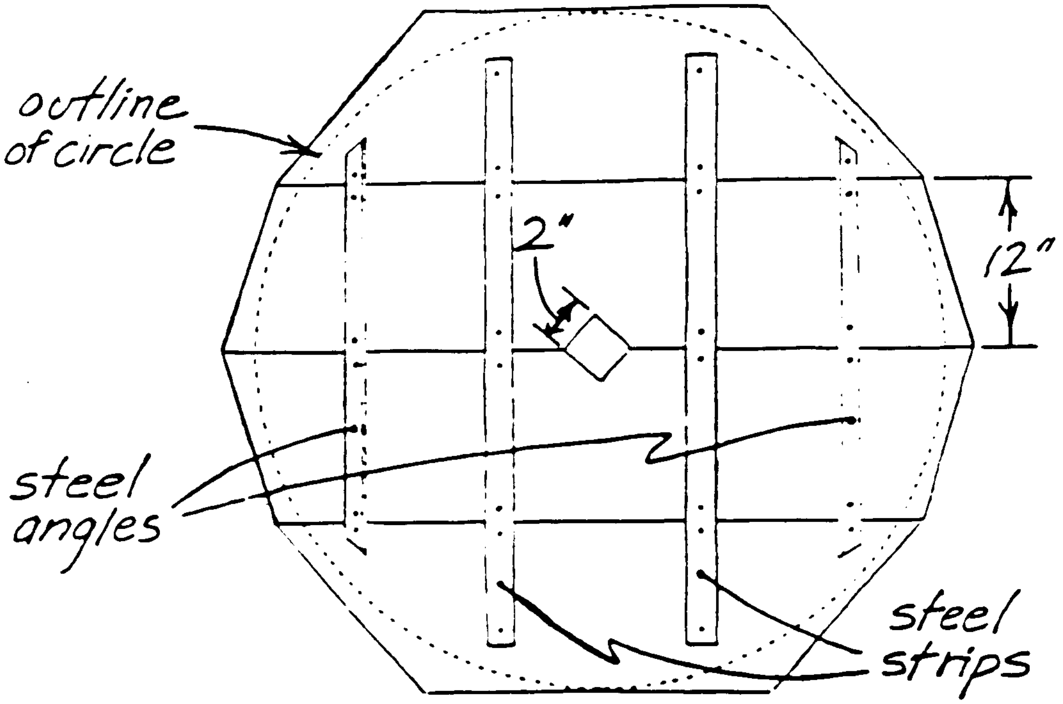
You may have to find someone or some way to machine a cylindrical surface of the appropriate diameter onto steel bar, to fit into bearings.

MAKE WOOD DISCS

Make two wood discs. In this design there is only a disc at the top and a disc at the bottom of the rotor; there are no discs between the stages.

For each disc, lay four 12" wide boards (1" thick) side by side. Though the boards may be different lengths, they must be arranged so a 48" diameter circle can be traced on them.

Tack the boards for each disc together temporarily. Trace the circular outline of the discs onto each set of boards with a pencil on the end of a 24" length of string which is attached at the other end to a nail driven into a point marked as the center. Check the accuracy of the circle by measuring from the center to the edge in several places.

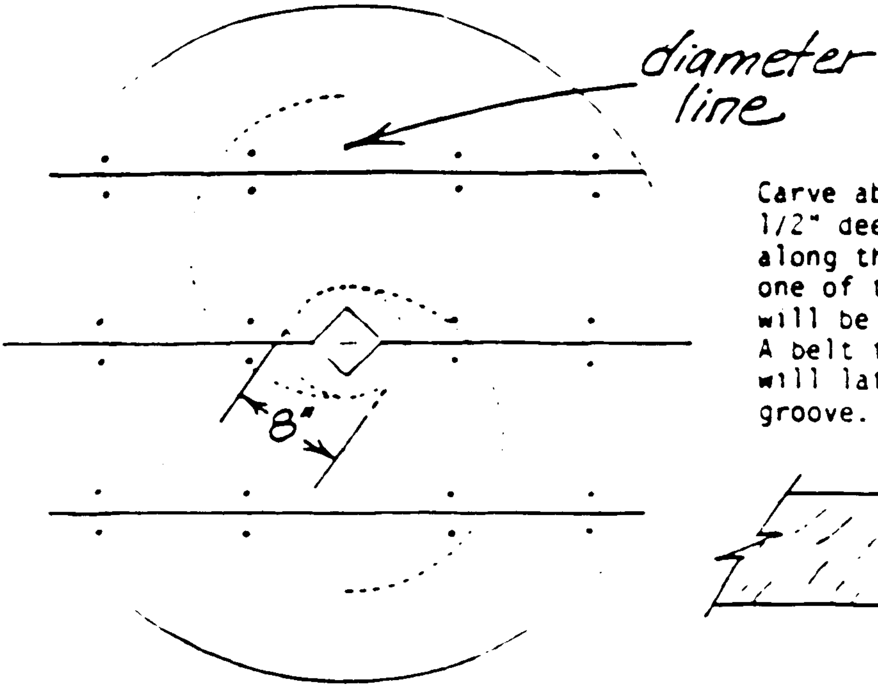


Fasten and brace the boards together with two parallel metal strips and small backup strips on opposite side each -- two angle-shapes toward the outside of the circle and two flat strips nearer the center.

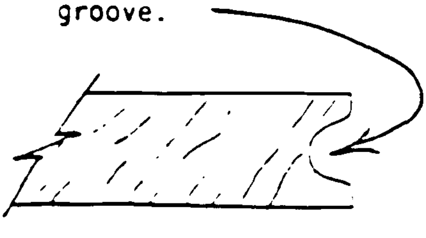
Cut each disc to shape along the edge of the circle you have traced.

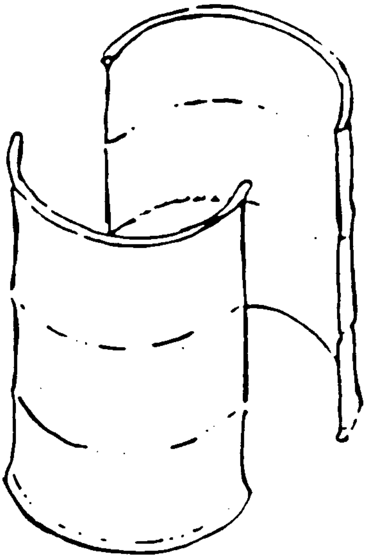
On the unbraced side of each disc, trace an 8" diameter circle around the center. Draw a diameter line on each disc, at right angles to the seams between the boards.

Cut a square with 2" sides at the center of each disc. Center the square as accurately as possible.



Carve about a 1/2" wide & 1/2" deep rounded groove along the 1" thick edge of one of the discs -- which will be the bottom disc. A belt to turn a pulley will later fit in this groove.





Prepare six half-drums from three standard 45 Imperial gallon (55 US gallon) oil drums. Take off any removable lids, and cut each drum vertically into two equal halves.

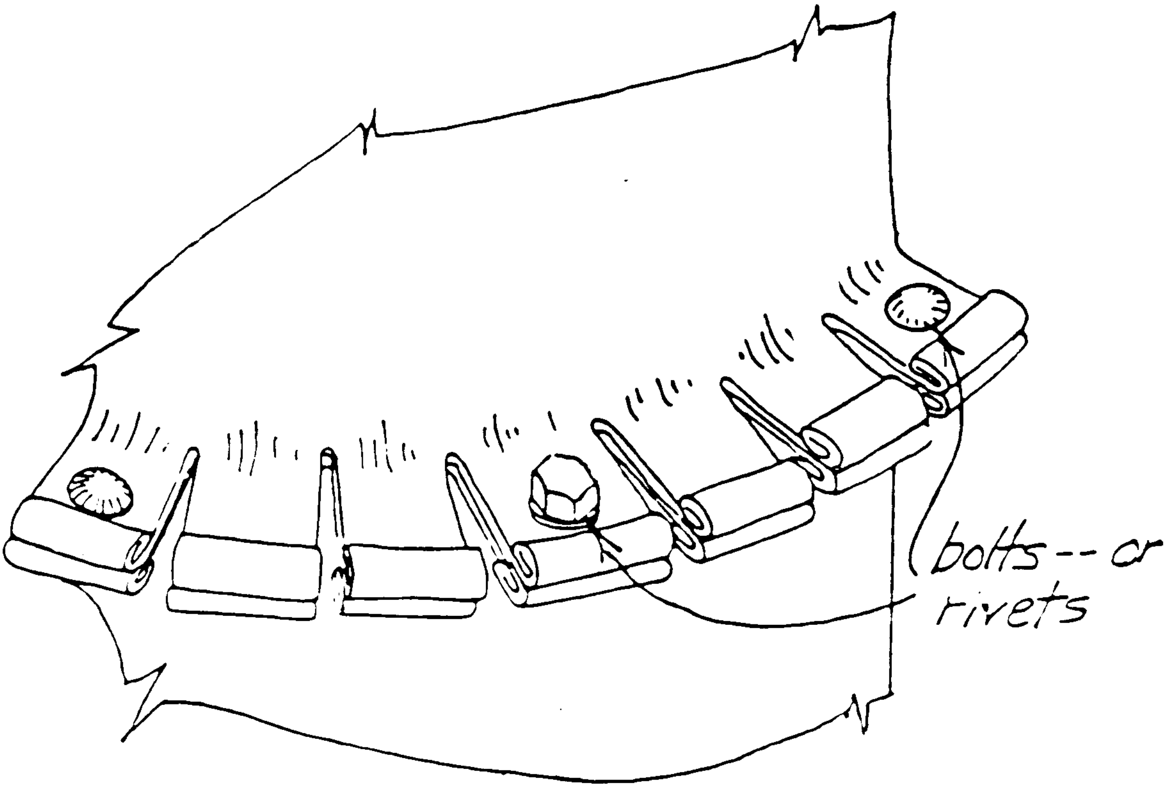
In the same way shown on page 11 in the instructions for Rotor #1, make drum brackets to fasten the half-drums to the wood discs, and to each other. Two stacks of three half-drums each will form this rotor. At about five (or more) points on each set of joining edges make the brackets line up evenly enough to drill a hole through each pair (see drawing below).

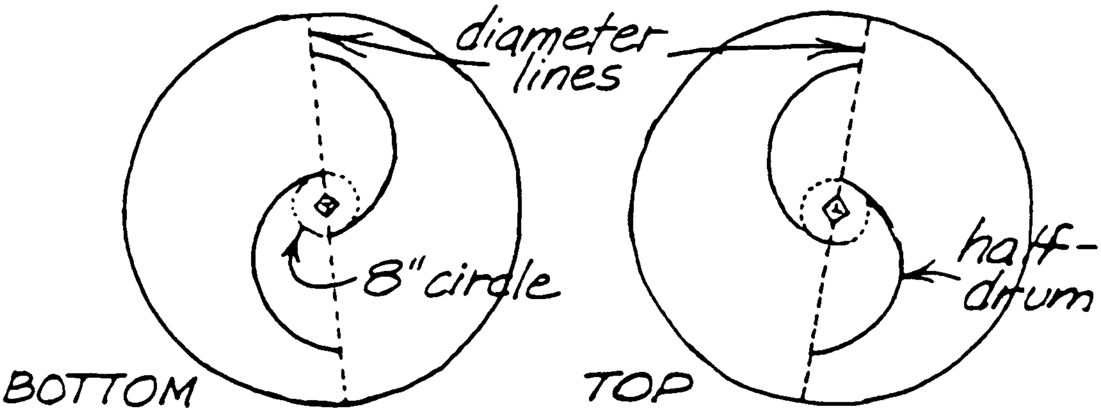
If the drums each had a removable lid at one end, you must also take care to plan that there will be a lid on a half-drum at each joining point between the stages of the rotor -- to provide a means of attachment to the rotor shaft.

The brackets on the half-drum edges that will fasten to the wood discs may be prepared without regard to alignment. As in Rotor #1, drill into every third or fourth bracket.

Mark each half-drum as you prepare it in this way, so you will know which ones belong together.

Drill all holes large enough to accept 1/4" bolts.





ASSEMBLE THE HALF-DRUMS AND DISCS

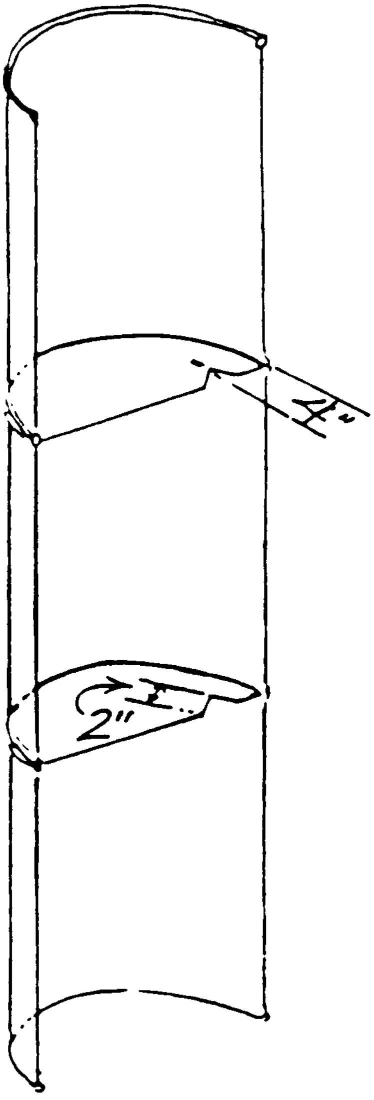
Place the appropriate edge of one of the half-drums that will fasten to a disc onto the marked side of the bottom disc (the one with the groove around the edge). Touch the two tips to the marked diameter line, and the inner tip to the circumference of the marked 8" diameter circle. Starting with the tips, drill through the holes in the drum brackets into the disc, bolting as you go with 1/4" diameter bolts, nuts and lock washers.

Repeat this procedure to fasten the other half-drum to this same disc, placing it opposite the first half-drum and aligning the tips in the same way.

Repeat this whole procedure to fasten the two appropriate half-drums to the top wood disc, MAKING SURE TO <u>MIRROR</u> THE CONFIGURATION ON THE BOTTOM DISC.

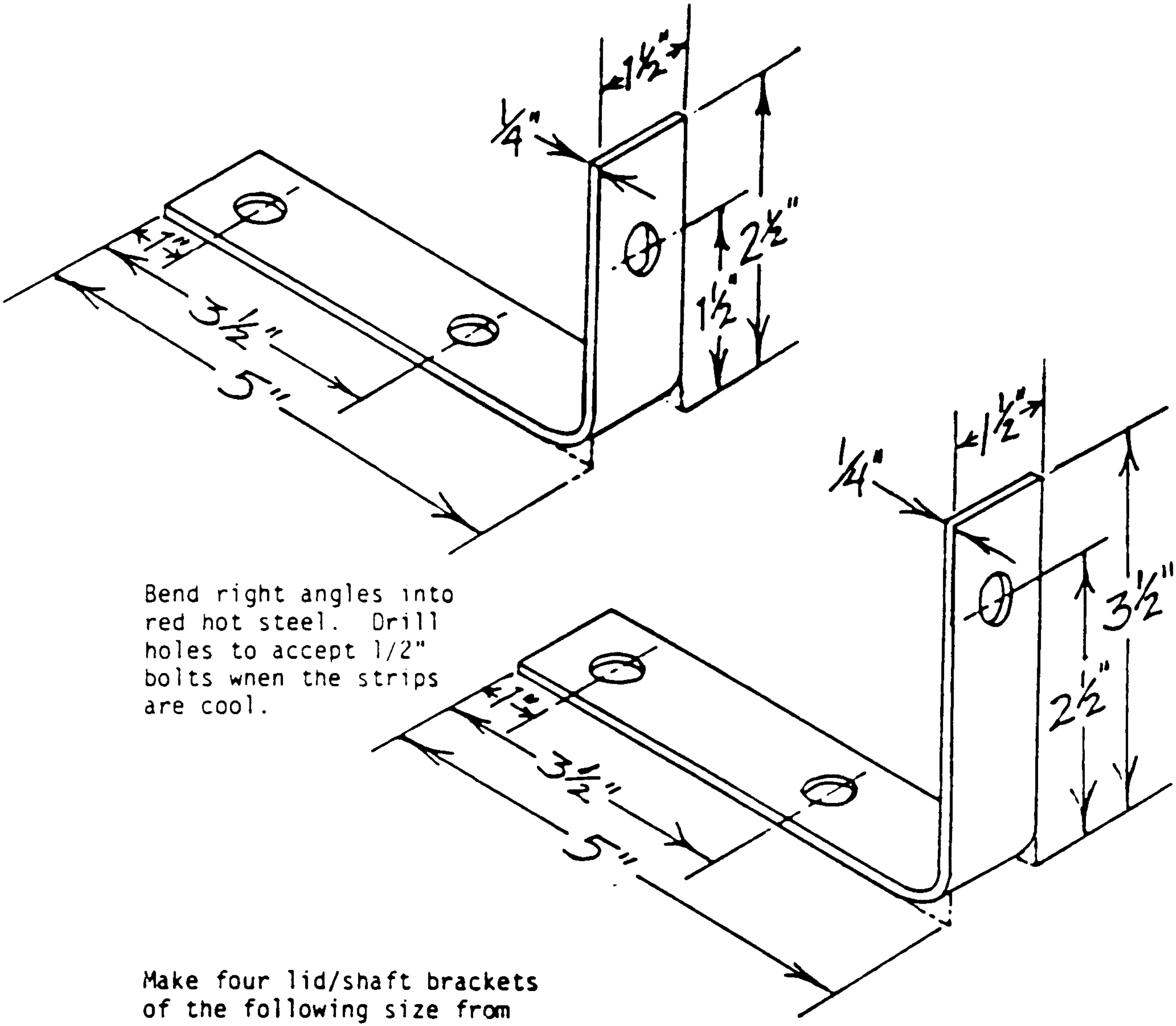
Complete the assembly of the drums and discs by bolting (or riveting if you wish) the remaining half-drums into place between the two disc/half-drum assemblies. Follow your marks on the half-drums to get the right joints together. Any changes in shape in the half-drums caused by handling can be overcome by hand pressure.

Cut a triangular-shaped notch with 2" sides into each half-drum lid between stages, centered 4" from the inside edge of each stack. These notches will fit around the pipe shaft.



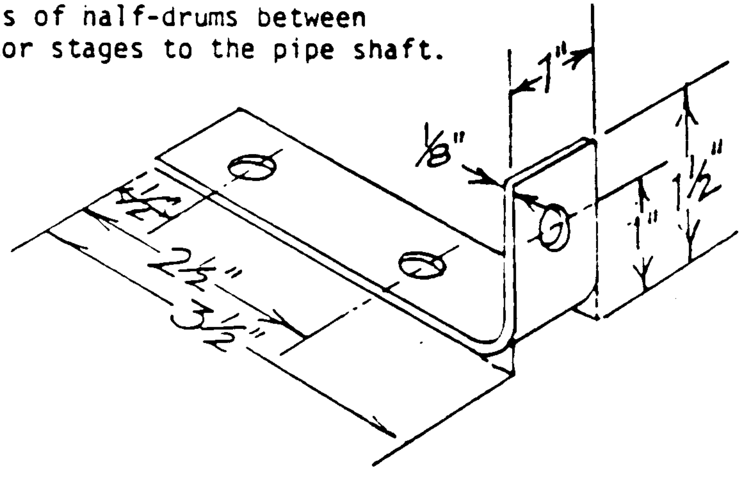
PREPARE BRACKETS TO ATTACH DISCS AND HALF-DRUMS TO PIPE SHAFT

Prepare four disc/shaft brackets each of the following two sizes from steel strips (eight brackets altogether). These brackets will attach the wood discs to the pipe shaft.



Bend right angles into red hot steel. Drill holes to accept 1/2" bolts when the strips are cool.

Make four lid/shaft brackets of the following size from steel strips. These will attach lids of half-drums between rotor stages to the pipe shaft.

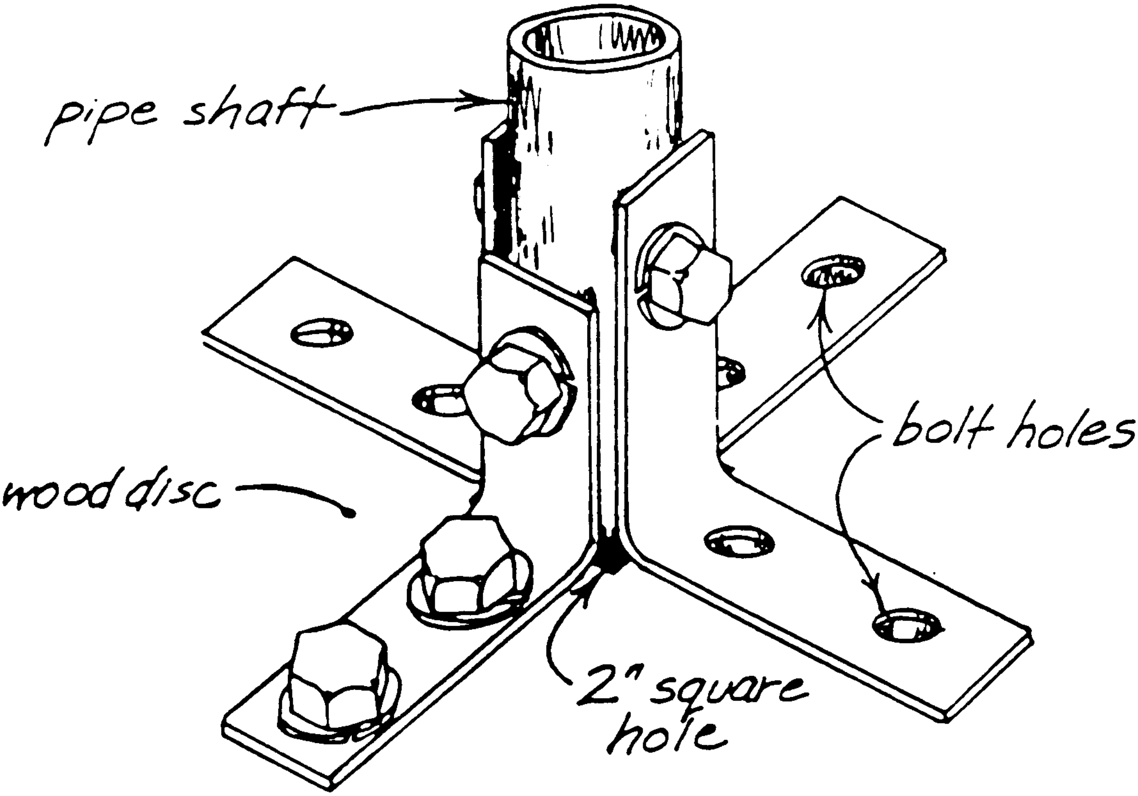


ASSEMBLE THE ROTOR

Select a 10' length of straight steel pipe with a 1 1/4" nominal (that is, will not be exact) outside diameter.

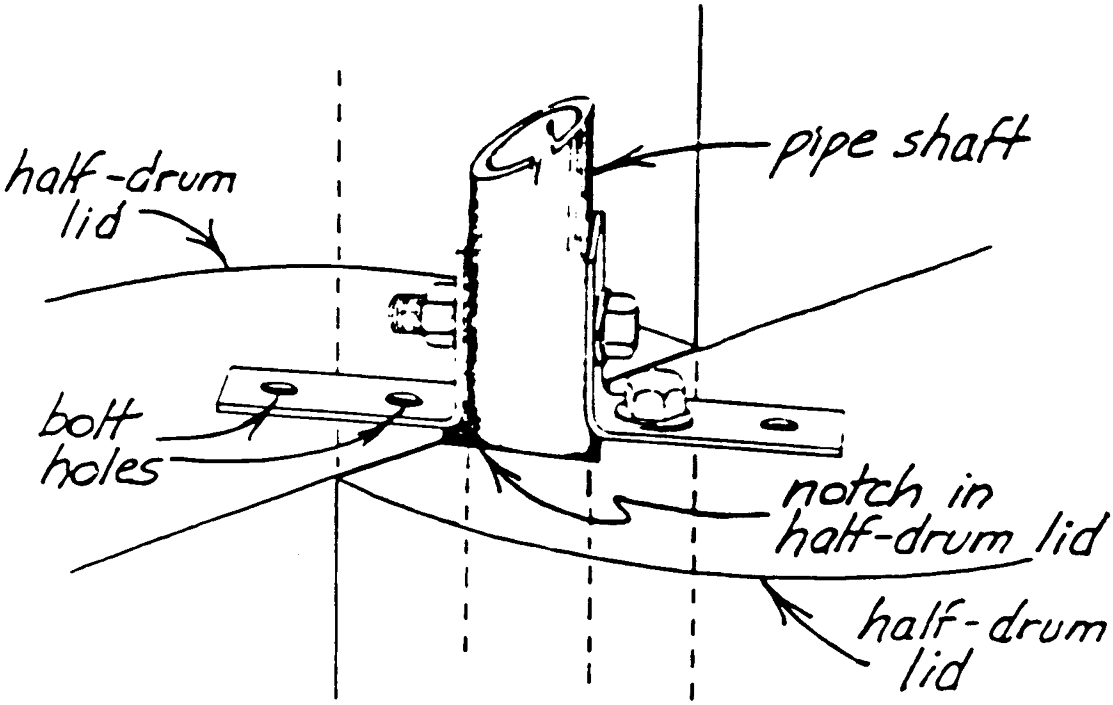
Push the pipe through the square hole in one of the wood discs, through the notches in the half-drum lids, and out the square hole in the wood disc at the other end of the rotor. Approximately equal lengths of the pipe should extend out from each end of the rotor (at least 6" on each end).

Fasten 4 disc/shaft brackets -- 2 of each size -- in a cross formation onto the outside surface of one of the wood discs, so that the 5" arms are on the disc and the shorter arms make opposite pairs up against the pipe shaft. The brackets with 2 1/2" vertical arms should be across from one another, and the brackets with 3 1/2" vertical arms should be across from one another. Place them first, mark the positions, and drill 1/2" diameter holes through the bracket holes into the wood disc and into the pipe shaft. Insert 1/2" x 2 1/2" bolts and tighten with nuts and lock washers. The 2 bolts through the pipe will form a cross, one above the other.



Repeat this procedure with the 4 remaining disc/shaft brackets on the wood disc and the pipe shaft at the opposite end of the rotor.

Fasten pairs of the smaller, lid/shaft brackets to the half-drum lids and the pipe shaft at each place where the lids are notched to let the pipe shaft pass through. Place them opposite each other, one on each half-drum lid. Use 1/2" x 2 1/2" bolts, nuts and lock washers.



BEARINGS

End pieces attached to the top and bottom ends of the rotor shaft each rest in a roller or ball bearing mounted on horizontal support poles. This insures smooth and efficient rotation. It is important to select good bearings and install them properly (good second hand bearings may be used).

Follow the same considerations given in "BEARINGS," page 18, Rotor #1.

MAKE SHAFT END PIECES

Solid steel end pieces fastened to the ends of the pipe shaft provide smooth surfaces to fit into the bearings.

See "MAKE SHAFT END PIECES," page 21, Rotor #1 for specific information. For this rotor, both shaft end pieces may be made the same -- like the top end piece in Rotor #1. No extra length is needed on the bottom end piece to attach to a pump extension shaft.

ATTACH THE END PIECES TO THE PIPE SHAFT

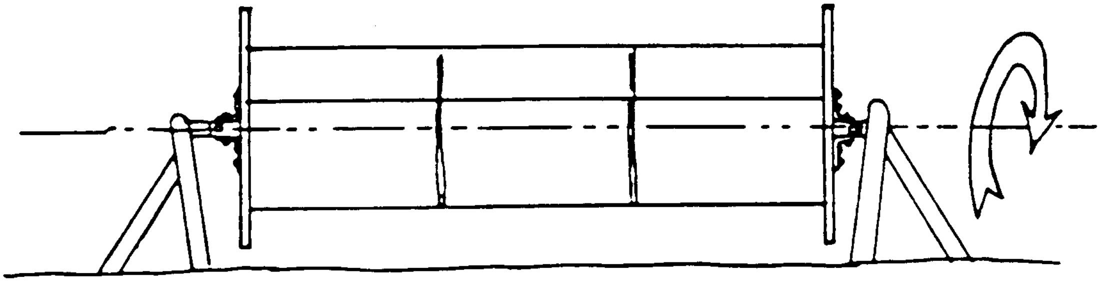
Cut off each end of the pipe shaft squarely about 3" beyond the edges of the disc/shaft brackets -- if there is that much pipe; if not, simply make sure that the ends are trimmed squarely. If necessary, file the inside surfaces to accomodate each shaft end piece.

Push the pipe end of one of the end pieces into one end of the pipe until the collar rests on the end of the pipe. Mark 1" from the end of the pipe with a punch. Drill a 1/2" hole through the pipe and the end piece, and deburr it. Keeping the end piece in place, bolt through the hole with a 1/2" x 2 1/2" bolt and tighten down with nut and lock washers.

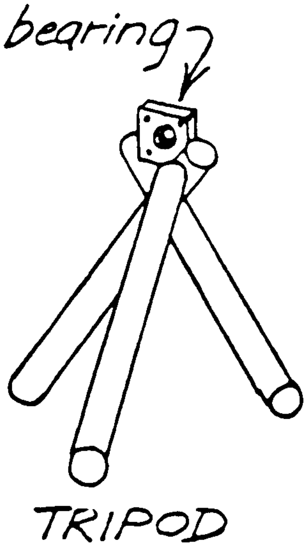
Repeat the same procedure for the other end piece on the other end of the pipe shaft.

BALANCE THE ROTOR

Prepare two simple wood pole tripods. Place the top bearing in one and the bottom bearing in the other. Suspend the rotor horizontally between the tripods, with the shaft end pieces in the bearings. The bearings must be operating smoothly in order to detect any other causes of uneven movement in the rotor.



Give the rotor a few twists. If it tends to stop in the same position every time, then the side that comes to rest at bottom is the "heavy side." Tape one or more bolts close to the edge of the top side of each wood disc -- equal number on each disc. Spin the rotor again. Keep adjusting the number, size and position of the bolts until the rotor stops in any position.



Drill holes in the discs about 1 1/2" from the edge in the areas where the bolts were temporarily attached and insert them in the holes. If you drill the holes slightly smaller than the outside diameter of the bolts, then the bolts may be turned in like screws. Otherwise fasten them with nuts and washers; if you do this then the nuts and washers must be used in the balancing process.

After the balancing bolts or equivalent weights are placed in position, spin the rotor again to make sure it is well balanced. If the rotor is poorly balanced it will shake apart at higher speeds.

THE ROTOR FRAME

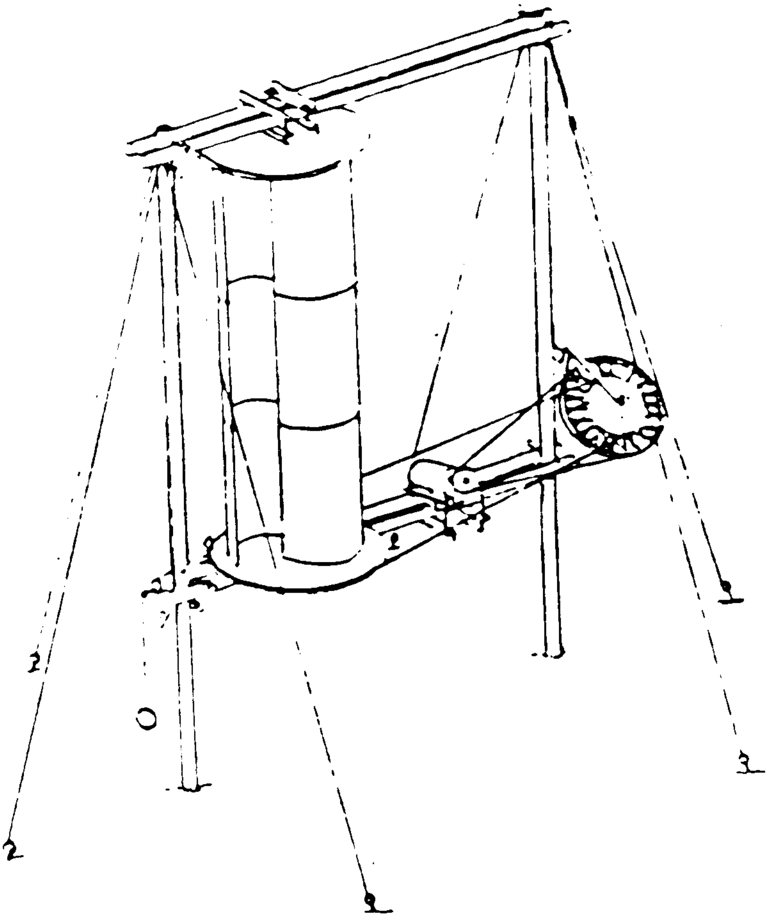
The frame which will support the rotor is in the same basic configuration as the support frame for Rotor #1, with these differences:

- it is taller
- it is wider, to give room for a pulley and an alternator or generator mounting.
- it uses locally cut wood poles instead of boards that are cut at a sawmill.
- the horizontal supports (bearing supports) are in pairs -- notched and bracketed, lashed or otherwise fastened around the vertical supports.

Cut the straightest, strongest wood poles you can find (4"-8" diameter).

The frame is designed to combine strength and simplicity of construction.

Joints in the frame must be fastened together securely. One way is to make 4 frame brackets from 1/2" diameter mild steel rod. Bend suitable lengths to a U-shape while red hot. Thread the ends. Drill 2 holes in a section of steel angle to accomodate the ends of the U-bolt.



ANCHORS AND GUY WIRES

The rotor frame should be stabilized with at least 4 (preferably 6) guy wires running from the frame to anchors that are firmly embedded in the ground. See "MAKE ANCHORS AND ATTACH GUY WIRES," page 26, Rotor #1 for an anchor design and information on guy wires. Do not attach guy wires now; the frame will be assembled to this rotor before it is raised into position.

BEGIN ASSEMBLING THE FRAME

It will be better to assemble the rotor and frame on the ground, and then raise into position -- since the whole structure is so tall.

The bottom of the rotor should be at least waist high; so cut the vertical support poles long enough to include: a 2' or 3' portion that will be in the ground; the distance from ground to waist; a distance equivalent to the height of the rotor (from pipe end to pipe end); plus an extra foot or so. (It should be remembered the higher you mount the rotor above ground the better.)

Lay the vertical supports about 8' apart, parallel to each other. Place a pair of 10' poles across from one to the other, so that they cross the vertical supports at points that will be about waist high, and at right angles to the vertical supports. These will be the bottom bearing supports.

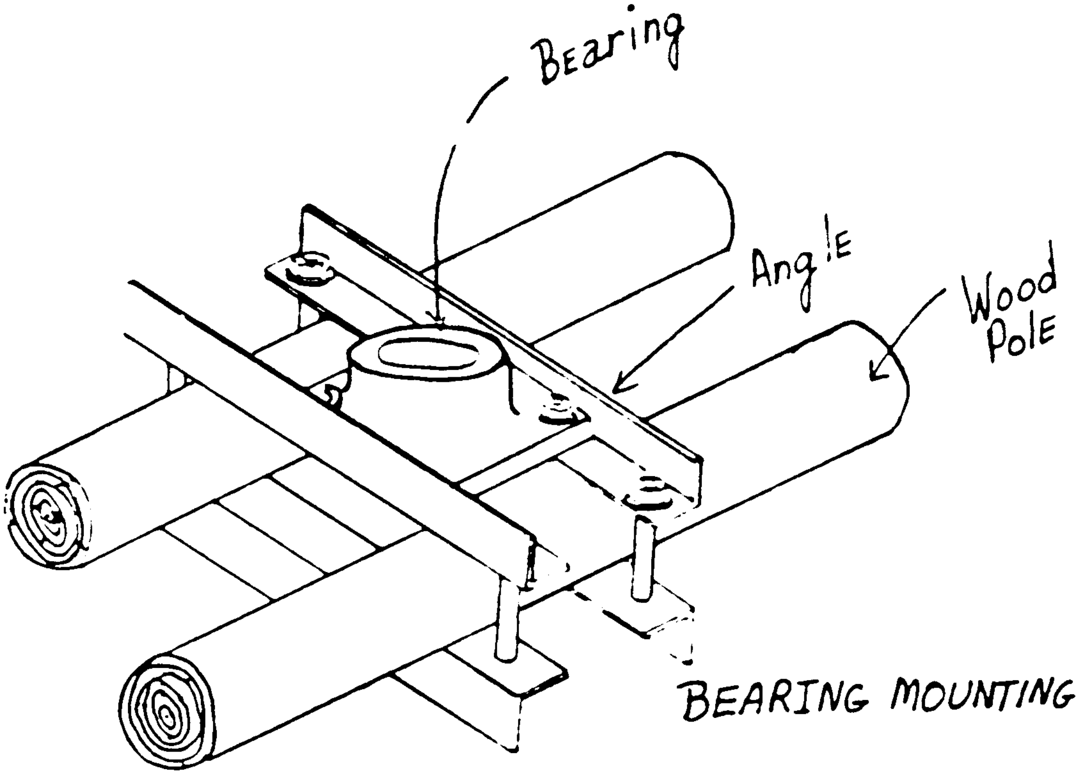
Check for right angles, and mark the places where all the poles cross. Notch all the poles a little at these places. Fasten together, checking to maintain the right angles.

If you are using U-bolt brackets to fasten the poles, tighten the steel angle up against the wood with nuts and lock washers, and then tighten <u>another</u> nut up against each nut, for extra locking.

MAKE BEARING MOUNTS; INSTALL THE BOTTOM MOUNT AND BEARING

Each of the 2 bearing housings will bolt to the inside of steel angle assemblies that are bolted around the top and bottom bearing support poles.

Since the bottom bearing support poles are already installed, you can judge the lengths of steel angle-needed to cross over the top bearing support poles also. Cut 8 lengths of steel angle. Drill one 1/2" hole at each end of all 8 pieces. Position the holes so they will line up vertically with each other when the angle pieces are paired.



Work from the center point of each piece. Drill holes in the top two pieces of each bearing mount to accommodate the particular bearings you are going to use.

Install the bottom mount onto the bearing support poles. Place it over towards one side, leaving enough room for the wood rotor disc to clear the vertical support. Center the mount across the poles. Bolt in place with nuts and lock washers.

Remove the bottom bearing from the end of the rotor on the tripod and install onto the mount with bolts, nuts and lock washers.

ASSEMBLE THE ROTOR AND FRAME

Remove the rotor from the tripods and lay it on the ground. Bring the portion of the rotor frame that is completed up around it. Push the bottom shaft end piece as far down as it will go into its bearing, which has just been mounted onto the support poles.

Assemble the top bearing mount and bearing loosely onto the top bearing support poles, in approximate position.

Bring the top bearing support poles into position, straddling the vertical supports. Slide (tap gently if necessary) the bearing over the top shaft end piece of the rotor as far as it will go.

Check these alignments:

- The rotor shaft should be parallel to the vertical support poles.
- The top bearing support poles should be parallel to the bottom bearing support poles.
- The plane of rotation of the top bearing should be perpendicular (at right angles) to the rotor shaft. This also applies to the bottom bearing.

Mark, and then notch, the top bearing support poles and the vertical supports where they cross. Fasten them together, maintaining all alignments. Tighten the top bearing to its mount and the mount to the support poles.

Support the frame horizontally, with the rotor in it, on temporary supports high enough off the ground so you can spin the rotor. The rotor must rotate freely in the bearings, without resistance.

Check all frame/rotor shaft/bearing mount alignments. You can make angular adjustments in the bearing mounts by inserting good-sized, sturdy shims. Loosen and retighten bolts and nuts as necessary.

If either of the bearings you use is adjustable with set-screws, you may further adjust for smooth movement. Loosen the bearing slightly from the mount to make these adjustments; then re-tighten.

NOTE: New bearings may be stiff until they are broken in a little, because of the (grease) packing. Turn the rotor a number of times to begin this process. Do not confuse tight movement with rough movement.

Final adjustments may best be made when the rotor is in its final, vertical position.

INSTALL THE FRAME IN THE GROUND AND SUPPORT WITH GUY WIRES

Determine where you will place your anchors and bury them in the ground, with the connectors for the guy wires remaining above ground.

Attach screw eyes, or some other strong connectors, near the top of the rotor frame and fasten guy wires to them.

Dig two holes 2 or 3' deep, 8' apart. Raise the rotor and frame up vertically, placing the vertical supports into the holes. This is at least a six-man job. The bottom of the rotor itself should be at least waist high. Pack earth firmly around the vertical supports in the holes.

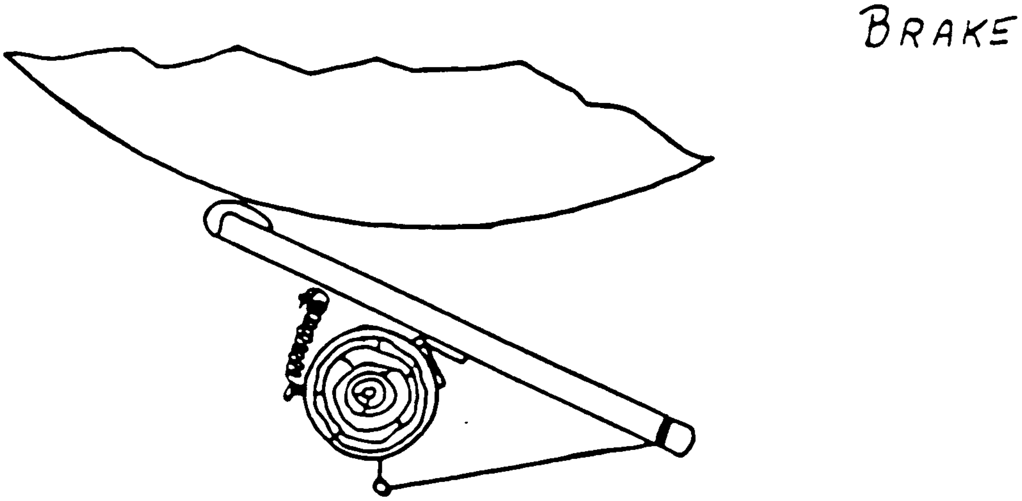
Pull guy wires tight through the connectors in the anchors, and fasten them. Turnbuckles installed along the wires will help you adjust the wires for maximum tightness.

Read through the last few paragraphs of "FINAL ASSEMBLY," Rotor #1 beginning with the last paragraph on page 27. The same basic considerations apply (excepting any planing of the beams).

CONSTRUCT AND INSTALL ACCESSORY EQUIPMENT

Rotor Brake

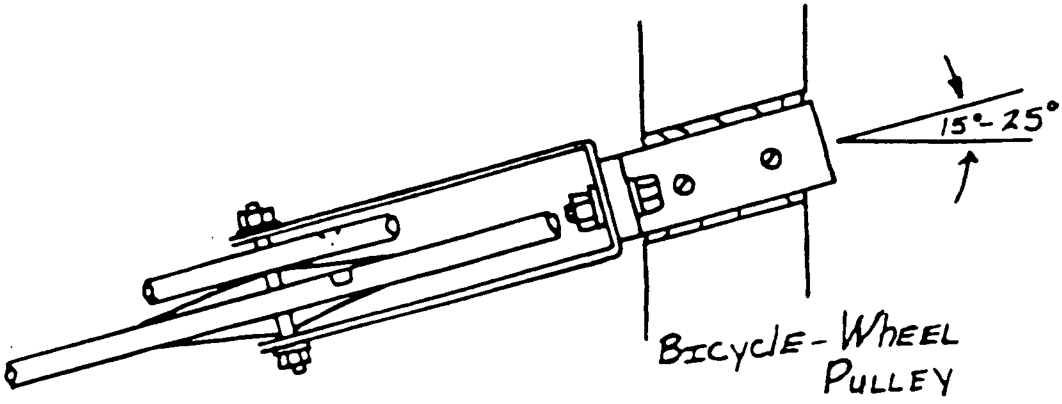
A hand-operated brake can slow or stop the rotor in high winds that might damage it. Attach a rubber-padded wood pole (of about 2" diameter) on a hinge to the vertical support next to the rotor, at the exact height of the wood edge of the bottom rotor disc (that is, not over the groove where the transmission belt will be). A spring keeps the brake lever away from the disc. Pull a cord (running through a guide attached to the vertical support) to bring the rubber-padded end of the lever against the rotor disc.



A positive lock can be made by drilling a hole near the edge of the bottom rotor disc to accommodate a 1/2" rod on a piece of cord. The rod would engage a hole in a small plate screwed to the bottom bearing support poles underneath the rotor disc.

Transmission Pulley

Make a pulley from a bicycle wheel (without tire) and a wood disc. Assemble them onto a "fork" and fasten the whole assembly onto the rotor frame with a bracket.



Cut a 10" diameter wood disc from a 1" thick board. Cut a rounded groove into its edge that is 1/2" wide and 1/2" deep. Drill a hole into the center of the disc to accept the end of the bicycle wheel axle. Drill 3 holes into the disc in a symmetrical arrangement around the center hole. Slip the disc over the bicycle wheel axle and bolt tight. Push bolts through the 3 holes, through the bicycle wheel spokes, and into small plates hooked behind the spokes -- tighten lock washers and nuts onto the bolt ends behind the small plates. The heads of these 3 bolts must be countersunk into the wood disc so they do not project above its surface -- to keep them out of the way of the large bracket, or "fork," that will hold the wheel and disc to the rotor frame.

Make a U-shaped "fork" out of 1/4" thick steel strip measuring 2" across. Start with a piece approximately 3' long.

Make a bracket from 1/4" thick steel strip, 2" across.

Fasten the pulley holder to the bicycle wheel axle. Bolt the small bracket to the pulley holder.

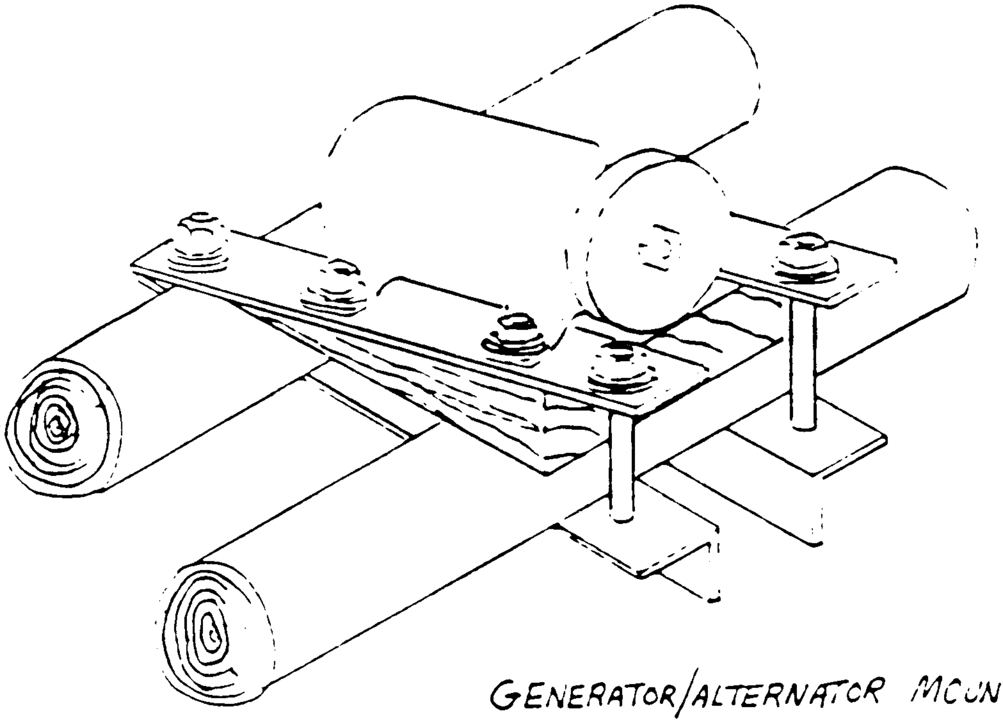
Whittle a groove into the rotor frame vertical support that is a few feet distant from the rotor. Make the groove on the outside of the pole, slightly above the bottom bearing support poles, and at a 15 - 25° angle to the horizontal.

Screw the bracket that is bolted to the pulley holder into the vertical support at this groove, with large wood screws.

A transmission belt can be made from an old automobile inner tube, provided the rubber is still elastic. An approximately 1" wide strip is cut "spirally" along the tube with a razor blade so that it is a continuous strip. Well over 100' of such strip can be cut from one inner tube. This is then twisted, and looped around the groove of the bottom rotor disc and the groove in the 10" wood disc that turns with the bicycle wheel. Tighten the belt, cut overlapping ends, tie a knot, and bury the knot in the twisted rubber.

ALTERNATOR OR GENERATOR

Mount an automobile (or other similar) alternator or generator onto the bottom bearing support poles of the rotor frame, between the rotor and the vertical support with the transmission pulley on it. Use bolts, steel strips and steel angles to secure it, and a wood wedge to incline it at a 10-20° angle.



GENERATOR/ALTERNATOR MOUNTING

Make another transmission belt and loop it around the bicycle wheel and the pulley on the alternator or generator.

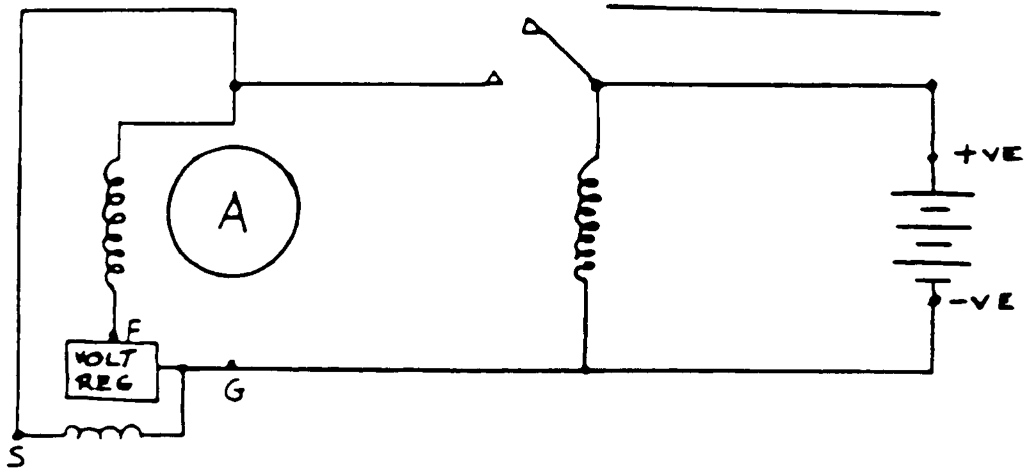
ELECTRICAL CONNECTIONS

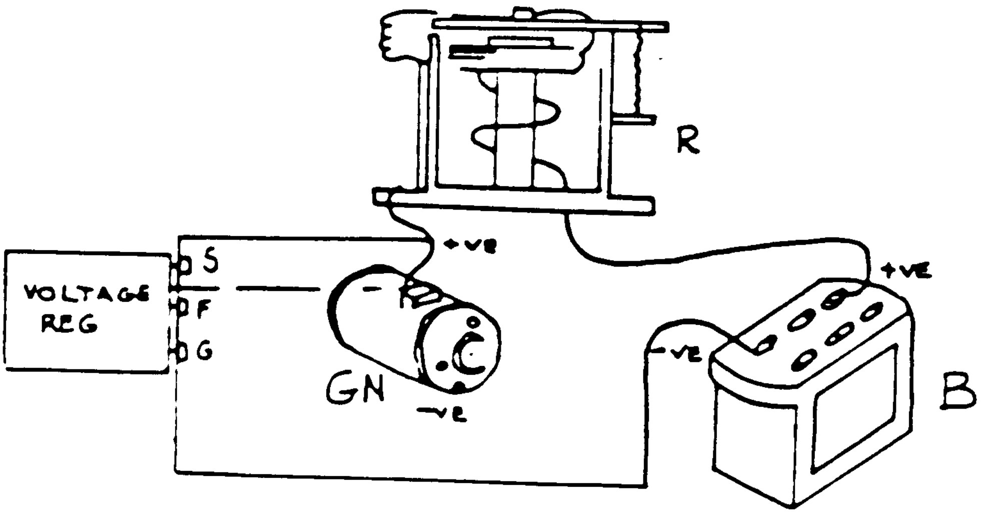
The wire connections and other electrical equipment such as voltage regulator should be similar to those in automobiles. Preferably suitable equipment from the same automobile should be used.

NOTE: As small as possible alternator/generator should be used as the more powerful machines will not turn in the lighter winds.

Two typical wiring diagrams are shown. Standard automobile parts might be used but must be compatible. That is, an appropriate voltage regulator to the alternator and the battery to be charged must be used. (Space limitation here does not allow elaboration on the generating equipment. Reference should be made to the literature on the subject or an experienced auto-mechanic should be consulted.) Both the alternator and the generator circuit should be in principal the same as those in the motor cars from which they were removed.

alternators or generators require fewer rpm's of the rotor to "cut in" and begin generating electricity.





APPENDIX

An Overview of Some S-Rotor Publications . . .

1. The Wing Rotor in Theory and Practice, by Sigurd J. Savonius, Eng. Capt. Lt.N.R., published by Savonius & Co., Helsingfors, Finland, 1925, 39 pp.

Written by the inventor of the wind machine, this booklet describes principles of operation, construction of various models built by the inventor, and some test results on those models. A comparison is made with the performance of the rotor and some standard multi-blade windmills. The conclusions which Savonius drew from his tests seem to contradict the experience of all others: he claimed that his rotor was considerably more efficient than a multiblade windmill of the comparable swept surface area.

Since the details of Savonius' experiments are not given, it is impossible to say where he has erred. By comparing the curves on graph #1, it can be seen that his results are more optimistic than those obtained by others.

2. How to Construct a Cheap Wind Machine for Pumping Water, Do-it-Yourself Leaflet #5, February 1965, by A. Bodek, published by Brace Institute.

This booklet presents a fairly simple method of building an S-rotor from 45 (Imperial) gallon oil drums. The construction steps are somewhat sketchy and may not give enough detail for someone not familiar with construction procedures.

Alternative materials and construction methods should be specified for making the discs, or end plates, in conditions such as those prevailing in developing countries -- ordinary plywood is not always available or affordable; and marine quality is far better in this application anyway.

A design is given for transmitting a rotary motion into a reciprocating motion suitable for operating a piston or a diaphragm pump. But I think that the friction losses of the proposed system would be considerable. Also, the suggested diaphragm pump has several structural limitations: it is comparatively large in diameter and therefore quite unsuitable for a borehole; it must be secured at the bottom of the borehole against the pull of the connecting rod -- a very impractical proposition. The pump is not suitable for large heads of water; the 15' (5m) head suggested in the example has little practical application. Because the moving structure and the connecting rod are quite heavy, they will absorb a substantial portion of the available energy. It seems likely that the diaphragm of of the pump will not last long. And since the pump has to be immobilized at the bottom of the well, changing the diaphragm could be very difficult.

The support structure requires welding -- difficult to do in the average village. And a rubber compound is needed to mate some surfaces -- also difficult to find in a village.

As given, the curve of the wind speed plotted against water delivered at a 10' head will apply only in the best conditions.

There is no provision for governing or braking systems, which are necessary to protect the device in very strong winds.

3. <u>Performance Tests of Savonius Rotor</u>, by M. H. Simmonds and A. Bodek, Brace Research Institute Technical Report No. 5.

The method for testing the rotor is fairly accurate and appropriate. The power coefficient plotted against tip speed ratio for various wind power machines shows correctly that the rotor has the lowest coefficient of performance (is the least powerful).

Various test curves included in the report are very useful to a designer and will help with making an intelligent decision as to whether the machine will work in a given wind condition.

The conclusions given in the summary, however, imply that the rotor is suitable for pumping water in relatively low wind speeds -- which I believe to be untrue.

4. <u>An Investigation Into the Suitability of Savonius Rotor for the Use as a Power Source in Underdeveloped Countries</u>, by A. N. Bymer. Imperial College of Science and Technology, London S.W.7.

The report describes an exercise in building and testing a S-rotor. This rotor was placed horizontally, which is not a typical position for the rotor. Due to various difficulties, the errors in reading are very high. The report gives a limited bibliography and attempts to make an evaluation of economic merits of the rotor. The general conclusions are that the machine is not very powerful; but may be suitable for pumping limited amounts of water.

5. <u>The S-Rotor and its Applications</u>, by S. J. Savonius. Mechanical Engineering Vol. 53, May 1931, No. 5.

The author describes his earlier work and his experimental and theoretical comparison of various wind machines with the S-rotor. He claims 30% efficiency for his S-rotor against 20% as the highest theoretical maximum for all vertical-shaft airwheels, calculated by Professor Betz. The author himself states that "Either the author's tests and results were altogether at fault, or in making their theoretical calculations Professor Betz and the German School of aerodynamic experts had overlooked something of importance." From the results of numerous tests by others, it is rather evident that Savonius' "tests and results were altogether at fault."

The optimum tip speed to wind speed ratio of about 1.0 found by Savonius seems to be correct; this is confirmed in tests by others.

Numerous applications are given the rotor, some of which are questionable and some more reasonable.

The author proposes two alternative braking systems, i.e., a brake drum, and "air brakes consisting of small flaps which open out from the wing surface when a predetermined speed is exceeded." According to the report, the rotor's performance in water is analogous to that in air, taking into account the differences in the densities of the two media. The author claims that 1.6 horsepower per square meter of surface area at a water speed of 2 meters per second was attained.

An interesting and feasible application described is the placement of the rotor with its axis in a horizontal position so that it is turned by the wave motion. A device of this type was installed in Monaco around 1930 and pumped water 200 ft up. A power output of 1.8 to 2.7 HP per square meter is claimed at a wave speed of 3 meters per second.

6. Design, Development and Testing of a Low Head, High Efficiency Kinetic Energy Machine, by Russel B. MacPherson, U. Mass. School of Engineering, Amherst, Massachusetts.

The paper presents wind tunnel test data on an S-rotor model. Curves are plotted showing relationships between efficiency, rotor speed and power output. A polar torque diagram is given. The test curves are of some use to the designer, and indicate a rather low capability of the S-rotor, except in very high winds.

7. Appendix C, The Savonius Rotor. A Study Conducted for the OFFICE OF PRODUCTION RESEARCH AND DEVELOPMENT, WAR PRODUCTION BOARD, Washington, DC, January 31, 1946, by Engineering Research Division, New York University.

The article describes tests on a model in a wind tunnel. The results are tabulated, and power vs efficiency, power vs rpm of the S-rotor and efficiency vs rpm of the rotor curves are plotted. Analysis of a hypothetical rotor operating in a 30 mph wind and developing 1000 kw was made. The rotor would have to be 360 ft tall, mounted on a 50 ft base, and would have a diameter of 60 ft. The calculated cost of building such a Savonius rotor was much higher than for an axial flow windmill producing the same power.

8. Wind and Windspinners, by Michael A. Hackleman and David W. House, published by Peace Press Printing and Publishing, 3 28 Willat Ave., Culver City, California 90230 USA.

Several chapters on such fundamentals as energy concepts and generation of electricity are included in this book, plus some construction information. The explanations are clear, but over-simple. The book contains many contradictions and numerical errors. Overall, the authors overestimate the capabilities of the S-rotor.

In some instances it may be that misprints are responsible for data that is in error by as much as a factor of 10! (In chapter 7, figures for generated power should be 82.85 watts instead of 828.495 watts, and 37.5 watts instead of 373.5 watts.) In other cases, the errors combine with unsupported optimism to confuse or mislead the reader. Table 1 on page 96 contains arithmetical errors, and further, leaves a layman under the impression that the S-rotor is capable of generating several kilowatts of electricity, which could only be the case in a hurricane -- which would blow away the whole structure. The table starts off with a wind velocity of 32 mph; there are few places in the world where steady winds are that high.

The "cube law" pertaining to wind energy is simply explained. The section on generators and alternators is useful for a layman who wants to know something about their application. The chapter on batteries details how to choose, charge and test batteries. It specifically applies to American conditions, and would be of little use to someone in a developing country. Likewise, the chapter on "Using Electricity" applies to American conditions.

The authors provide information on what I believe to be rather costly and complicated control systems.

Detail construction is described for three alternative designs. The end plates are made of plywood (use marine quality if you use plywood!). The method of locating center points and marking circles is described in detail. Cutting oil drums in half with a gas torch, as suggested, would be impractical in a developing country; it can be done easily enough with a hammer and cold-chisel. L-brackets are used to attach half-drums to discs instead of the lips of the drums. The "skeletal" assembly which is the alternative to the basic design seems unnecessarily complicated and expensive. As the author suggests, its only merit might be for experimental purposes.

Recommended bearings do not have to be both flange mounted and eccentric-locking. The bottom bearing should be preferably flange-mounted and self-aligning, but the top bearing need not be.

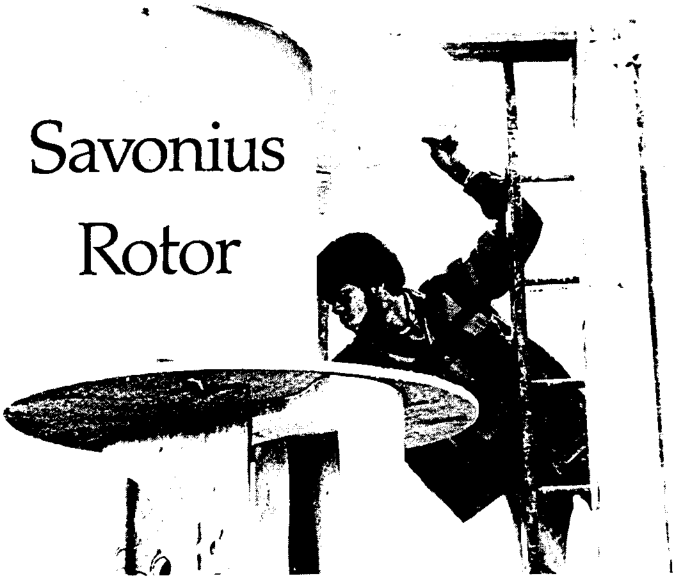
The authors do not recommend using a water pipe for the shaft of the rotor. In both of my S-rotors I have used ordinary water pipe and have experienced no problems. The suggested method of using flanges and threaded nipples is unnecessarily expensive, particularly in a developing country.

Two basic types of supporting structure are suggested: one is a vertical shaft on a pivot, which enables the rotor to be brought to the horizontal position on the ground for maintenance, etc.; and another is an external structure. I believe both to be somewhat impractical. A simpler framework is shown, whose ends can be dug into the ground and which can be supported by four or six anchored guy wires with turnbuckles.

Spoilers are suggested to slow the rotor in very high wind speeds. I believe it would be very difficult to come up with an arrangement where both spoilers move and open up by exact amounts. Small errors in the design and construction of the mechanism could cause very serious imbalance and vibrations at higher speeds.

It would help the reader to emphasize that steady wind speeds above 12 mph (at which only a fraction of one watt is generated per one square foot of the S-rotor's surface) are very rare in most parts of the world. And surely a cautionary statement about the suitability of an S-rotor for wind speeds below 10 mph should be included at the beginning of the book rather than on page 105.

Savonius Rotor



One of the most reliable yet simplest windmills at the Cape Cod Center is the Savonius rotor. It is used to pump fresh water out of the ground into our open aquaculture pond, intermittently displacing a portion of the pond water and stirring it in the process. Our first experience with the Savonius rotor was with a simple rotor comprised of steel drums, based on the Brace Research Institute's design (1, 2). It worked well, but its small size resulted in a comparable limitation in power. In his original developmental work on the rotor Finnish engineer, Sigurd J. Savonius, eventually decided that semi-cylindrical wings such as those made with steel drums may not be as efficient as wings resembling a modified J (3, 4, 5).

When we decided on a second Savonius rotor, we built a larger more efficient rotor of three tiers, each oriented 60° from the others. This results in an even starting and turning force regardless of wind direction. Each of the three tiers has curved sheet-metal wings, three feet high and four feet in diameter. The special curves are formed by attaching the sheet metal to curved plywood templates. There are plywood discs placed between each tier and at the top and bottom of the rotor, which direct the wind through the rotor. The three segments and five discs are slid onto a ten foot shaft. Each one is attached with a flange to the shaft. The rotor assembly is then mounted on bearings inside a rectangular wooden frame.

The simplest and sturdiest tower for the Savonius rotor consists of a set of two permanent wooden posts, set in concrete, between which the rotor frame is placed. Each post has three guy wires. Two large bolts pass through the posts at chest level and through the rotor frame. This enables the rotor to be swung upright, as though on a hinge, for securing at the top. This method is a variation of the hinged tower used by Earthmind, a group doing valuable

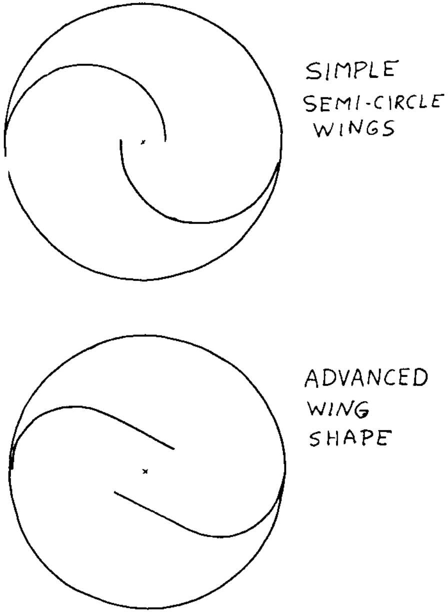


Figure 1
Simple and Advanced Shapes for Savonius Rotor Wings.

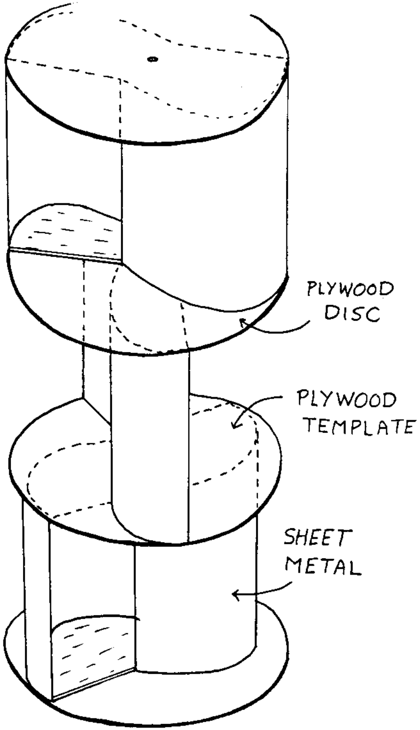


Figure 2
Three-tiered Savonius Rotor Showing Wing Templates and 60^o-60^o-60^o Twist.

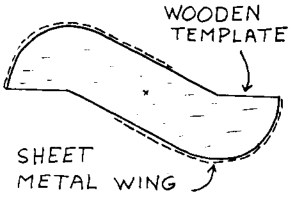


Figure 3
Use of Plywood Template to Form Complex Curves on Savonius Wings.

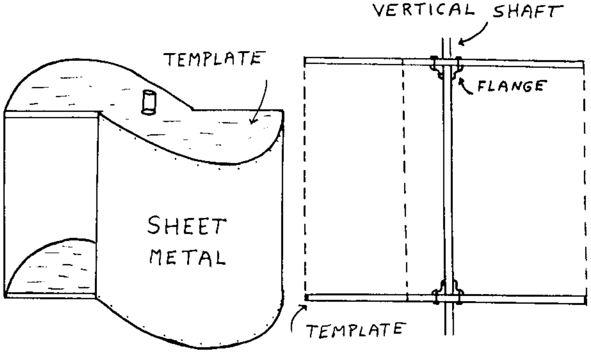


Figure 4
Savonius Wing Assembly.

research on vertical axis windmills (6).

One difficulty we have encountered in pumping water with a Savonius rotor is in tracking down a suitable pump. A diaphragm pump, as suggested by the Brace Research Institute, will not lift more than six feet. Centrifugal pumps invariably require very high RPM's. Rotary impeller pumps generally are quite hard to turn. Reciprocal pumps require some sort of mechanical linkage such as gears, cranks, V-belts, etc., which begin to get complicated. When one's water source is not directly below the windmill, the situation is even more difficult.

Our current plan is to have the Savonius rotor turn a small air compressor, to pipe air to the well, and to pump water with compressed air. This strategy solves the problems of variable speed and power input, freezing of pumps and pipes, and transmission of power from one place to another. While compressing air is somewhat less efficient than other means of energy transmission and storage, the simplicity and durability of the mechanism is an advantage. It is, however, no small matter to find a compressed air-driven water pump. We are aware of only one commercial model (7), which is excellent, but expensive. We are working on a pump which is less efficient but much cheaper and combines the merits of a diaphragm pump with a simple air-control device. The pump design evolved from three sources; the commercial diaphragm pumps (8), C. J. Swet's solar pump (9), and the Stauffer's compressed air pump (7). In operation, compressed air forces the rubber diaphragm down simultaneously forcing water out. Eventually the pressure on the diaphragm pulls the exhaust plug from the exhaust opening, letting the pressure out and allowing the diaphragm to pull in new water. When refilled, the stopper seats in the exhaust opening and the cycle repeats.

It should be mentioned here that while this pump can undoubtedly be improved, its present form lends itself well to home-scale manufacture. Interestingly enough, enameled wash basins and metal dish pans have the appropriate shape and wide lip for such a pump. Inner tube rubber is also suitable.

Our future work in the development of the rotor/compressor/pump system will include using compressed air for other uses, such as fish pond aeration and circulation, and investigating the benefits of compressed air storage to cope with the fluctuation of the winds.

— *Earle Barnhart*

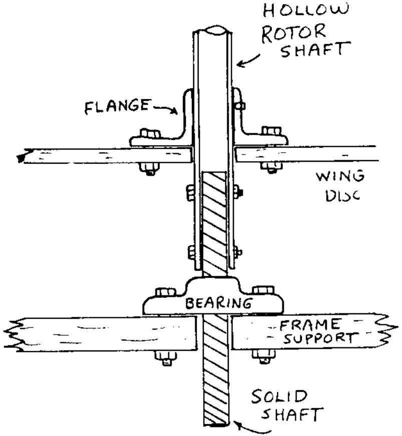


Figure 5
Details of Savonius Rotor Bottom Bearing and Wing Attachment.

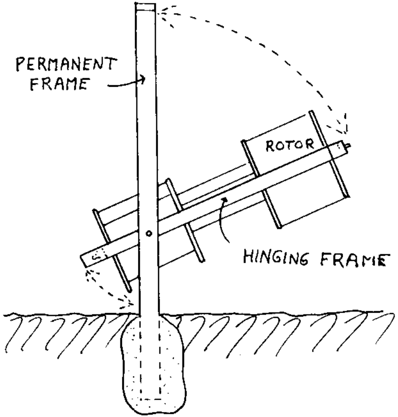


Figure 6
Savonius Rotor Tower – Permanent Outer Frame and Hinging Inner Frame.

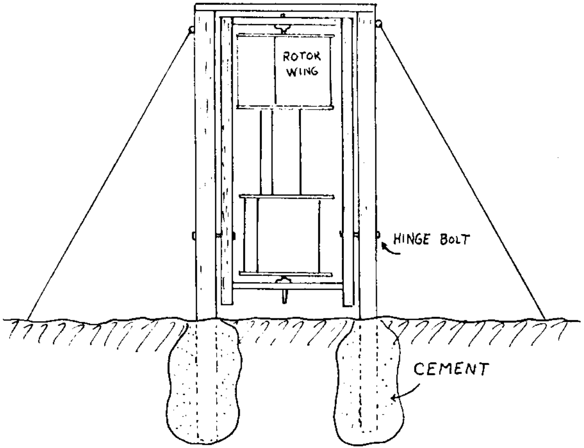
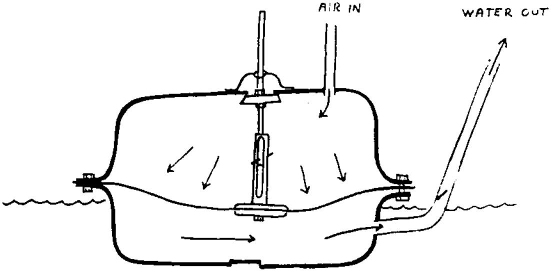
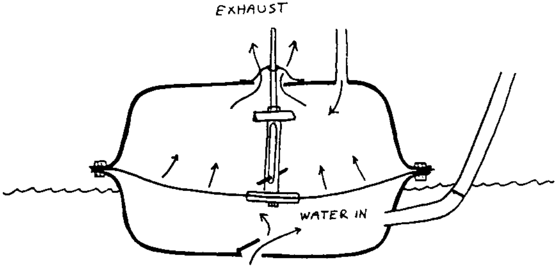


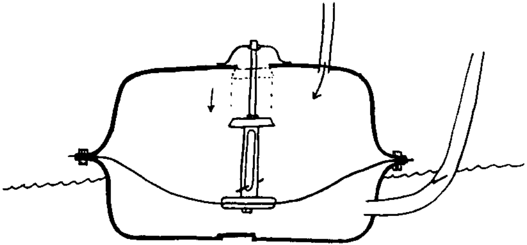
Figure 7
Savonius Rotor Tower – Rotor is Swung into Position.



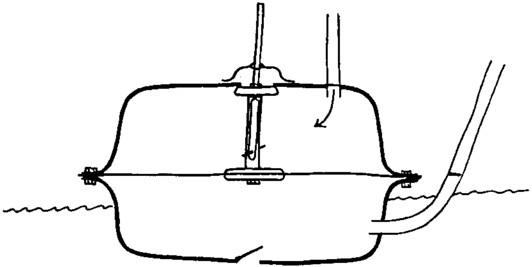
WATER PUMPING STAGE



AIR EXHAUST STAGE



RELEASE OF STOPPER



RE-SEATING OF STOPPER
BEGIN NEW CYCLE

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7. Stauffer's Machine Shop Pump Division, R. D. No. 3, Ephrata, Pennsylvania 17522. Air-operated fresh-water pumps; drilled-well and open-well pumps. $257.50 - $339.50 (April, 1975).

8. Edson Corporation, 460 Industrial Park Road, New Bedford, Massachusetts. Hand-operated and power-driven diaphragm pumps.

9. Swet, C. J., and H. G. Fox. 1973. "Low Head Solar Water Pumping." Presented at the 8th Intersociety Energy Conversion Engineering Conference (IECEC), Philadelphia, Pennsylvania - August, 1973, 341-347 pp.

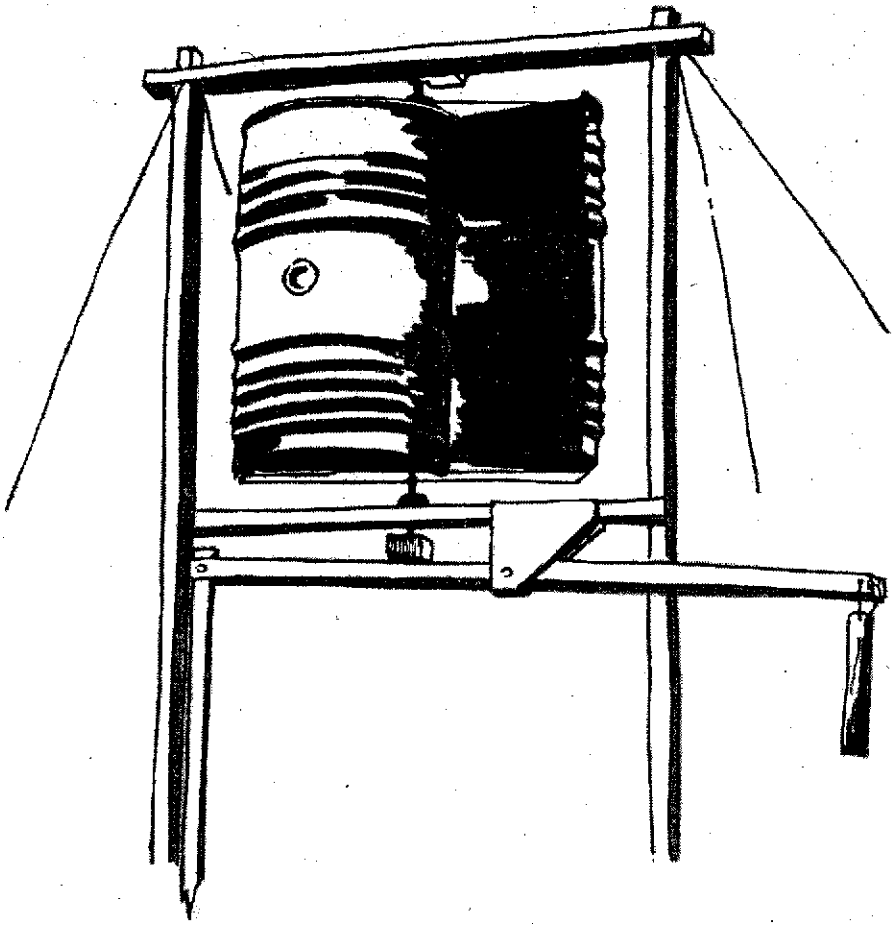
D.I.Y. PLAN 3

PUMPING WINDMILL (SAVONIUS)

A low speed wind rotor which works in any wind direction, with enough torque to do light pumping work.

ADAPTATION

A 45 Gall. drum (both ends intact) is cut in half and mounted in a gallows construction of timber, to drive a small plunger pump, (D.I.Y. Series No. 2) by means of a cam (swash-plate) driven rocker arm.



COST

Depends upon ability to find appropriate bits: we used a number of found parts and costing in these leaflets is thus a problem. (How much is an old oil drum?)
The only fair thing to do, it seems, is to give current prices for new materials, where possible, and leave the reader to reduce these where second-hand stuff is available.

45 Gall. Drum	? Free/£1.50
Timber - new, without VAT	£10/£11
Bearings - 2 1" Flange Ball Races	£7
1 2" Outside Diameter (O.D.) Ball Race	£1
Shaft - find 1" O.D. Pipe	50p
Bolts, screws, etc.	£1.50
TOTAL Max	£22.50

TOOLS

Basic D.I.Y. - no power tools needed.
An Eclipse, or similar, pad metal saw essential.

MATERIALS

		Quantity	Length
Timber	3" x 2" Sawn	2	10' 0"
	4" x 2" Sawn	2	4' 6"
	2" x 2" Sawn	4	10' 0"
		2	6' 0"
	2" x 1"	4	4' 6"
		2	6' 0"
		1	4' 0"
	6" x 1"	2	4' 9"
	6" x 1½"	1	12' 0"
	15" x 15" x ½" Ply		

Drum 1 45 Gall., with two ends

Bearings 2 1" Flange Bearings
1 2" O.D. Ball Race

Shaft 7' 0" x 1" O.D. - anyway to fit Flange Bearings.
We used an old electric conduit pipe (unseamed)

Bolts 5/16" Carriage Bolts 3 x 6"
8 x 4½"
2 x 3½"
8 x 1½"
¼" Carriage Bolts 1 x 6"

Screws No.10 C/S 4 x 1½"
2 x 1"
4 x 2"

CONSTRUCTION

ROTOR

We found an old 45 gallon oil drum, long empty. Watch for dangerous contents!

With a pair of dividers we found the centre of one end and scored a diameter. Chalk rubbed on will help show the line. Look around the drum to check the cut will not be going through any awkward holes or thick seam.

FIG. 1 Turning the drum on its side on a table, we rigged up a straight edge to score longitudinal lines, continuing that of the diameter. We used a straight board chocked up to about half the diameter of the drum, making sure it was parallel to the table, and scored both sides. It is important for balance that both halves are equal. Check with a piece of string stretched round half the cicumference, from scored line to scored line, that the halves are the same.

Saw the drum in half with a metal-cutting pad saw. It is an ear-splitting racket, but take heart - we timed it at only an hour and a half, excluding breaks!

SAVONIUS ROTOR.

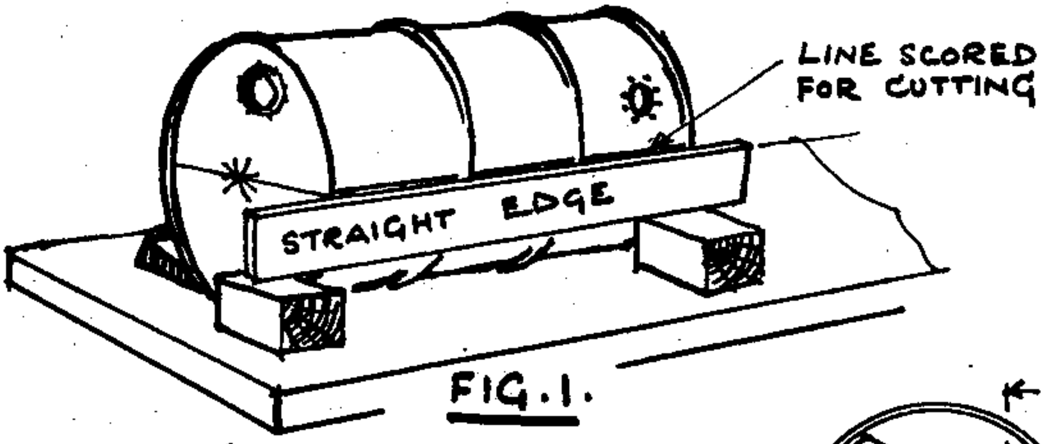


FIG. 1.

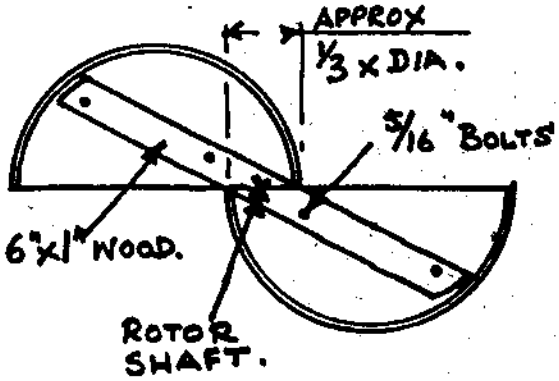


FIG. 2.

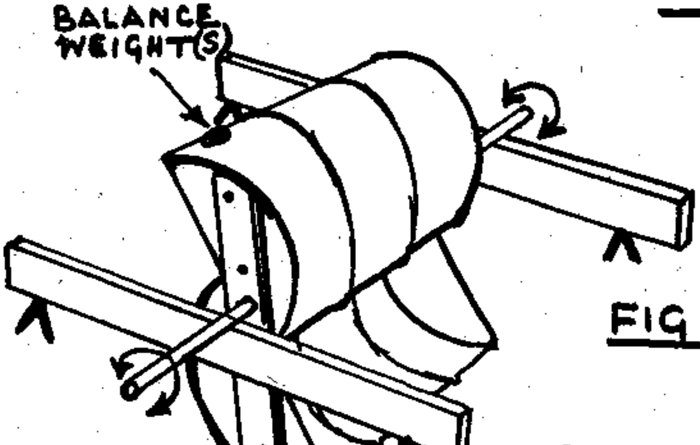


FIG. 3.

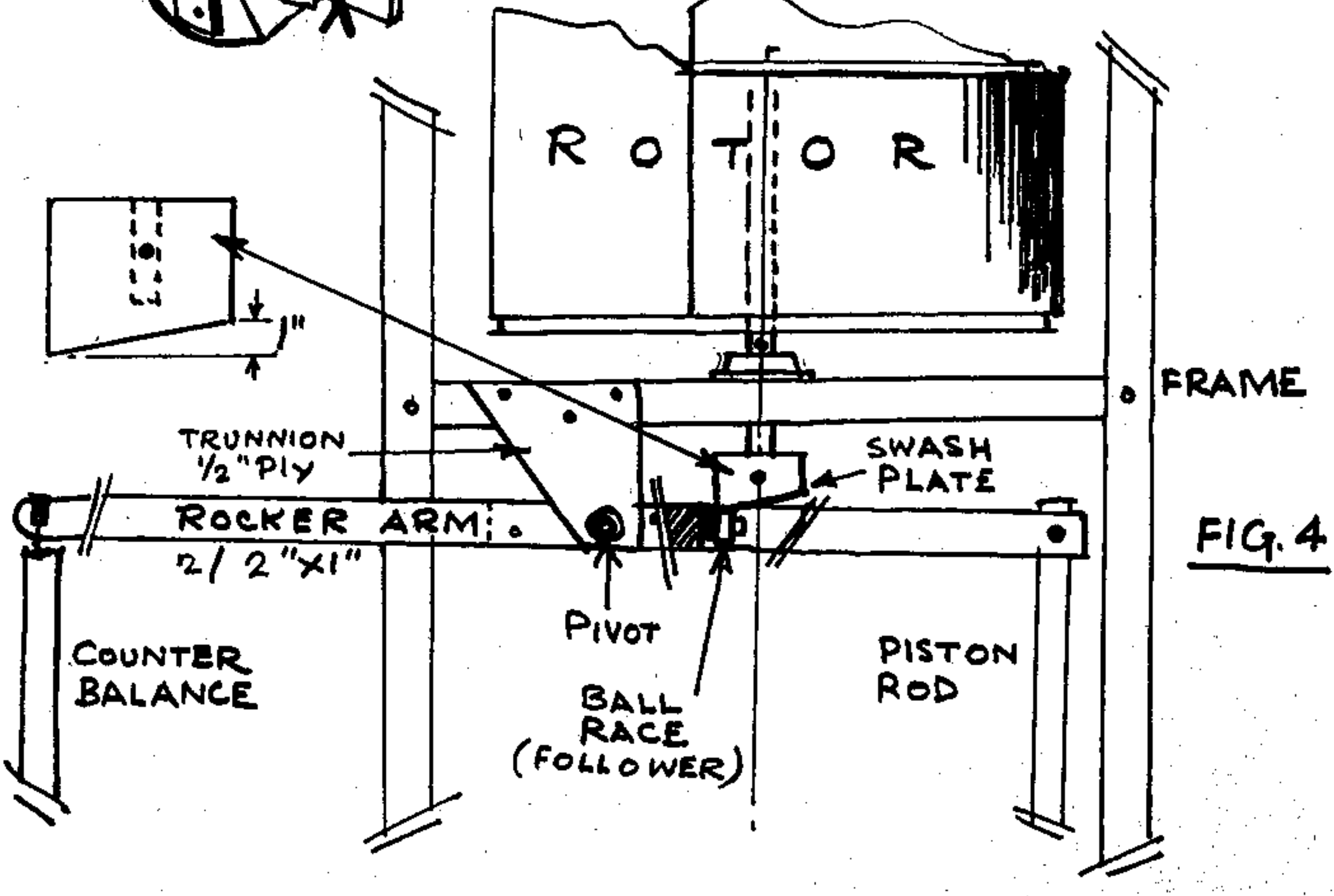


FIG. 4.

File the ragged edges.

If you should settle for oxy-acetylene burning, make absolutely sure that there's no ancient petrol lurking inside, permeating the steel.

There are at least two ways of joining the drum halves. They can be sandwiched between two circles of ¾" ply - which can add about £8 to the cost - or they can be welded.

FIG. 2 We used two pieces of 1" x 6" timber.
The overlap of the drum halves (which probably helps to clear air turbulence) can be about ⅓ of the diameter. We measured DIA x ⅓ from the edge and clearly marked it. Be exact - it is the centre of the rotor and balance depends on it. Cut clearance Vees to accommodate the shaft.

We then bored a hole the size of the shaft in the centre of each 1" x 6" board, and inserted a small off-cut of shaft to locate the drum edges. We had to cut a couple of clearance slots in the edge of the boards to take the rim of the drum.

FIG. 2 We bolted the boards to the drum with 5/16" x 1½" bolts, making sure the drum edges touch and are in one straight line.

Pass the shaft through the rotor leaving about a foot at the top and at least two feet at the bottom - they can be cut off later.

There are several ways of fixing the shaft to the rotor; we clamped a found U-Bolt round the shaft to a short length of angle iron, and screwed this to the 1" x 6" board.

Equally good would be a 6" nail used as a cotter pin and driven into a hole drilled through the edge of the board and the shaft. The turning moment of a one-tier Savonius is small enough for this to be adequate.

BALANCING

Though the rotor speed will be slow - in the order of tip speed to wind speed of ¾ to 1 - the height of the drum calls for conscientious balancing to stop the structure shaking to bits over the years.

FIG. 3. Ideally knife-edges should be used; we used ¾" boards clamped on edge to two saw-stools and made sure they were exactly level. The rotor we placed between them and rolled it to find the light side. Cellotape on washers or bits of metal, and remember to include the bolt that will hold the bits in place, until balance is achieved. It is a crude, but quite effective, method.

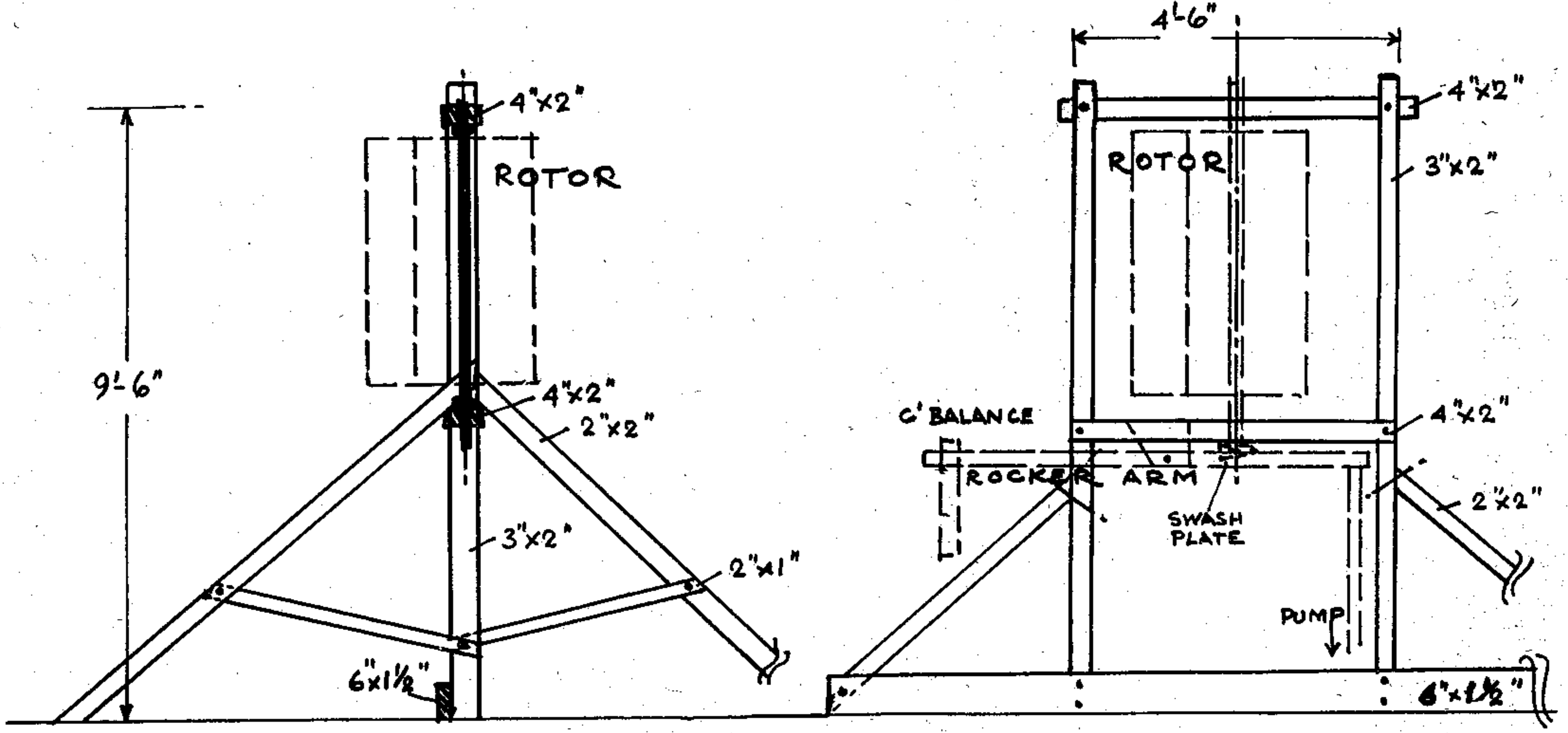
FRAME

FIG. 5. Living as we do on a slate tip, concrete foundations and/or guy ropes are a daunting prospect. We therefore made a free-standing triangulated structure, weighted with slate.

The gallows themselves should be mortised and tenonned to ensure rigidity. Large clearing holes for the shaft should be bored together before assembly to make sure they are central.

Flange bearings are bolted in place, and rotor and gallows assembled together. The lower end of the rotor shaft was then drilled for a pin that would take the weight of the rotor on the bottom bearing and allow it to turn clear of cross-timbers. In our case, a sawn off 6" wire nail was used as a cotter pin.

SAVONIUS ROTOR
FRAME



PUMP DRIVE

The cam/swash plate and rocker arm were next made and fitted.

We began with the idea of crank, connecting rod and bell crank for the pump drive, but hit upon the idea of a swash plate and rocker arm, which have the distinct advantage of simplicity, as well as allowing a counter balance that will suit any weight of piston rod - if, for example, the pump is deep in a bore hole.

The cam is a block of hardwood 4" x 4" x 4" cut at an oblique angle, and bored to go over the edge of the shaft. We used mahogany

FIG. 4. The rocker arm was made of two lengths of 2" x 1" screwed in the middle onto a foot length of 2½" timber, making, in effect, a long fork. The follower, a 2" O.D. Ball Race, was bolted into the end grain of the 2½" timber, and the whole mounted within two ½" plywood trunnions, as shown, which were then screwed to the frame in such a position that the ball race was in contact with the oblique face of the cam during its full rotation.

The rocker magnifies the ¾" throw of the cam to about 2½" stroke at its end; it is important only to make sure that the cam stroke suits that of the pump. The outer end of the rocker arm should be long enough to allow a reasonable size of counter weight - we used a piece of scaffold pole - but, if the pump is deep, and the wooden piston rod long, you may have to increase the section of the rocker arm for strength.

If everything has been lined up well, and if the cam is suitably chamfered to clear the rocker arm, the rotor will turn in the slightes breeze; and will work well in an 8 mph wind.

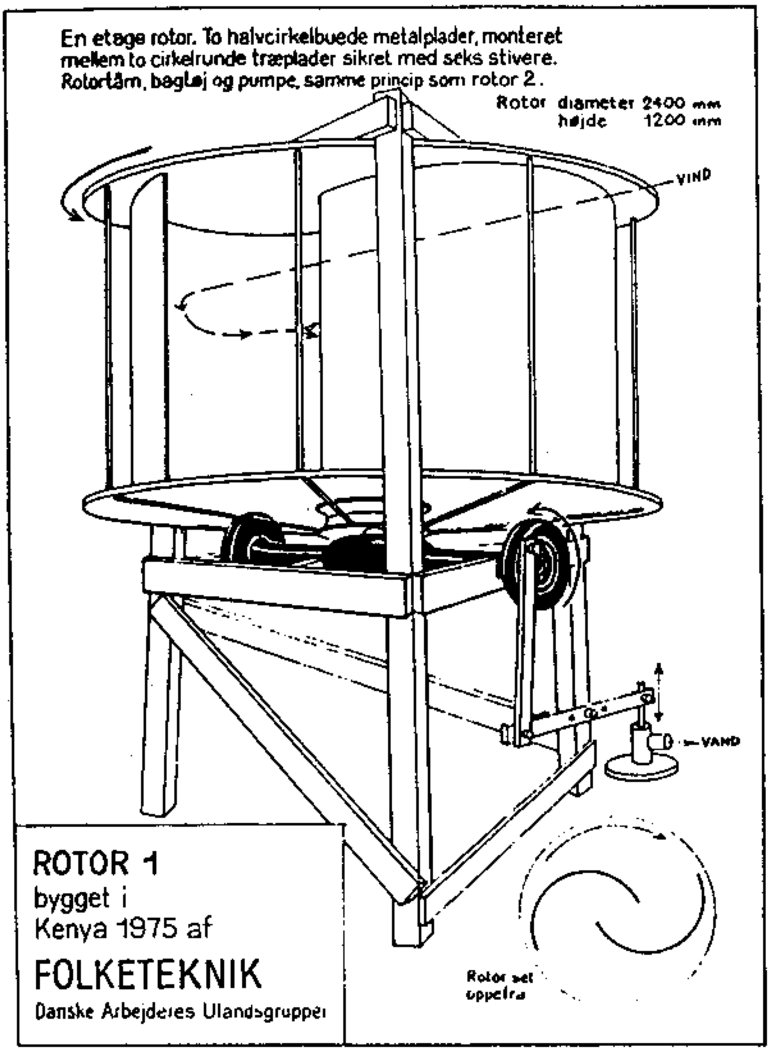
Other D.I.Y. plans, information sheets and books are available (list 5p) from the 'Quarry Bookshop' at the Centre. Please enclose a S.A.E. with any correspondence as we are a charity. Visitors are welcome.

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

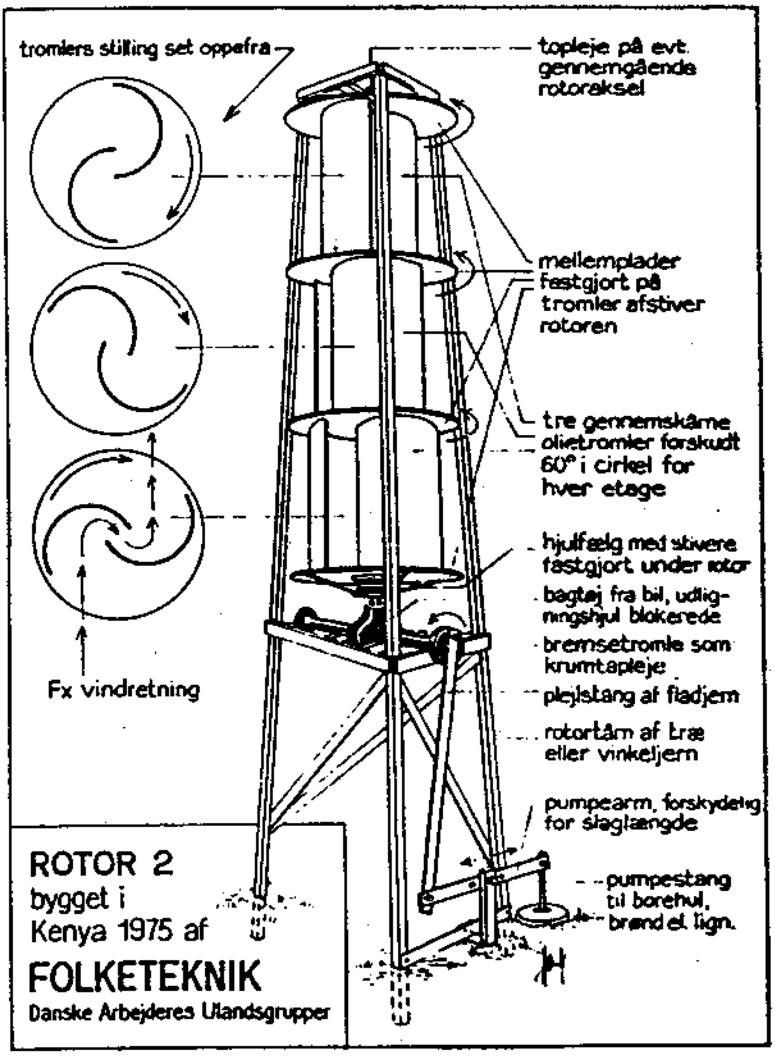
November 1975
Reprinted April 1977

100% Recycled Paper

Sun and Wind.
Herforth, Nybroe
Denmark 1976.


En etage rotor. To halvcirkelbuede metalplader, monteret mellem to cirkelrunde træplader sikret med seks stivere. Rotortårn, bagtøj og pumpe, samme princip som rotor 2.

ROTOR 1
bygget i
Kenya 1975 af
FOLKETEKNIK
Danske Arbejderes Ulandsgrupper



ROTOR 2
bygget i
Kenya 1975 af
FOLKETEKNIK
Danske Arbejderes Ulandsgrupper

200 WATT SAVONIUS WIND GENERATOR

This plan gives details of how to construct a 200W wind generator for 12v battery charging using a Savonius Rotor.

The Savonius Rotor is a vertical axis wind turbine developed by the Finnish engineer S.J. Savonius during the years 1925-28.
Although of lower efficiency and speed than propeller designs it has the advantages of simple construction, low cost and does not require heading into the wind.

These plans should serve only as a guide as it is necessary for the constructor to use his own judgment depending upon the engineering facilities available and the allowable cost.

The rotor is constructed from two 45 gallon oil drums which drive a car alternator or dynamo.
The 12 volt output is used to charge one or more heavy duty batteries.
If 240 volt AC power is required a transistor inverter or rotary converter may be added to the system.

The performance of the wind generator will depend upon the quality of construction and components used, but typically the generator should start charging at 15 mph wind speed and produce 200 watts at 32 mph wind speed.

This performance is satisfactory for high wind areas, but for low wind areas the 15 mph cut in speed is rather high.
This cut in speed can be reduced by either using a larger rotor, or using a low speed alternator. (see Appendix)

SAVONIUS ROTOR RPM

The Savonius Rotor has a typical tip speed ratio of 1. This means that the rotor tip travels through the air at the same speed as the wind.

The rpm for any wind speed or rotor diameter can easily be calculated as follows :-

$$RPM = \frac{V \times 60}{D \times \pi}$$

where V = Wind speed in ft/second
D = Diameter of rotor in ft
π = 3.142

e.g. If wind speed = 15 mph = 22 ft/second
and rotor diameter = 3 ft

$$\text{Then} \quad RPM = \frac{22 \times 60}{3 \times 3.142} = 140 \text{ rpm}$$

This is an average rpm and in practice the rotor will run about 30% faster with no load and 30% slower on full load.

GEARING

A car alternator does not start to charge a 12v battery until 1000 rpm is reached and a car dynamo until 1200 rpm is reached.

This means that the rotor will require gearing up by 8:1 for a car alternator and 9:1 for a car dynamo.

At 15 mph "cut in" speed the generator rpm will be as follows :-

Car Alternator	140 x 8 = 1120 rpm
Car Dynamo	140 x 9 = 1260 rpm

Car alternators usually have a 2½ inch pulley so that a 2½" x 8 = 20" diameter large pulley will be required. Car dynamos usually have a 3 inch pulley so that a 3" x 9 = 27" diameter large pulley will be required.

VEE BELT GEARING

This is a cheap and robust form of gearing and has an efficiency of about 85% at full load.

At part load however the frictional losses are quite high and the efficiency drops considerably.

Two disadvantages of vee belt are that it requires regular tension adjustment and is also prone to slip under wet conditions.

If vee belt is used a single large pulley should be used to keep power loss to a minimum.

TIMING BELT GEARING

Timing belt gearing or toothed belt gearing is a very efficient form of gearing.

On full load efficiency is 90-95% and even on part load it is still very good.

It requires no regular maintenance, is none slip and silent.

The belt itself is quite cheap, but the gears can be expensive particularly large diameter ones.

It is possible to use a large diameter flat pulley in place of gear wheel to keep the cost down.

Alternatively, two stage gearing can be used if an extra lay shaft and bearings are fitted to the wind generator.

Timing belt ¾ inch wide is recommended.

CHAIN GEARING

This is an efficient type of gearing and bicycle or motor cycle chain could be used.

Lubrication is essential and also protection from the weather.

GEAR BOX

A gear box is the most efficient and reliable form of gearing and usually used on professionally built wind generators.

The problem for diy constructors is to find a box with the desired ratio and power rating.

It is always worth looking for a suitable secondhand gear box and some types of industrial power tools have a gear box of the right sort of ratio.

ESTIMATED POWER OUTPUT

The estimated power of a Savonius Rotor can be calculated as follows :-

$P = 0.00087\ A\ V^3$ where

A = Frontal area of rotor in sq. ft

V = Wind speed in mph

P = Watts power (shaft hp)

Note: 746 watts = 1 hp

e.g. If Rotor area (A) = 18 sq. ft (Two oil drums approx.)

and Wind speed (V) = 32 mph

$$\text{Shaft hp} = 0.00087 \times 18 \times 32^3$$
$$= 513 \text{ watts}$$

But the gearing will probably not be better than 85% efficient and the generator better than 50% efficient.

So the estimated electrical output at 32 mph will be :-

$$513 \times 0.85 \times 0.50 = 218 \text{ watts}$$

At low wind speeds the efficiency of the gearing and generator will tend to be worse and it must not be forgotten that the first 30 watts generated is required to supply the field coil of the alternator/dynamo before any power is available for battery charging.

ROTOR CONSTRUCTION (see Figs 1 & 2)

The rotor blades are constructed from two 45 gallon drums, bisected lengthwise and welded together to form two troughs.
These troughs are mounted between two end plates made from plywood 48 inches diameter.

The dimensions for mounting the drum halves are given in Fig. 1.
The ends of the oil drums are simply bolted to the wooden discs with 3/8 inch bolts, washers and nuts.

The shaft through the centre of the rotor is 1¼ inch I.D. mild steel tube (e.g. water pipe).
This should extend about 6 inches beyond either end of the plates.
To secure the shaft to the end plates, two flanged collars are used. They should be a close fit onto the shaft.
They are bolted to the plywood with 4 bolts, and after inserting the shaft are drilled and secured to it with a ¼ inch bolt, spring washer and nut.

To support the rotor shaft 3 self aligning ball bearings are required. One at the top of the rotor, one at the bottom of the rotor and a third at the bottom of the output shaft.

Two adaptors have to be made to fit the two ends of the rotor shaft to the bearings. (See Fig.2)
The lower adaptor shaft must be long enough to give a reasonable distance between the two bottom bearings.

Before mounting the rotor in the frame it must be carefully balanced to avoid vibrations at high speeds.
This is easily done by placing the assembled rotor horizontally on two level staight edges and adding weights to the circumference in the centre of the rotor, until perfect balance is achieved.

FRAME CONSTRUCTION (See Fig. 3)

The frame consists of five pieces of 6 inch by 4 inch timber. The joints must be securely bolted with gusset plates to make it as stiff as possible.
Alternatively it can be constructed of steel channel.

It must be steadied with guy wires, securely anchored to the ground and tensioned by turnbuckles.

The lower cross member should be 6 feet or more above the ground.

THE GENERATOR

A car alternator or car dynamo can be used with this wind generator. Unlike a car however, an alternator does not have an great advantage over a dynamo when used on a geared wind generator.

CAR ALTERNATOR

Advantages:	Requires slightly lower gearing. Good bearings
Disadvantages:	Does not self excite (requires manual or automatic exciting) Efficiency only fair.

CAR DYNAMO

Advantages:	Efficiency good. Cheap and reliable. Self excites.
Disadvantages:	Bearings not as good as alternator. Requires slightly higher gearing.

Voltage Regulation

With small wind generators it is often better not to use a voltage regulator as this reduces the power output. It depends upon how many batteries are used and what type.

If only small batteries are used then a voltage regulated circuit must be used to avoid over charging and possibly damaging the batteries.

If large batteries are used then an un-regulated circuit is best, since the full output of the generator will be incapable of raising the charging voltage above 14 volts. Hence the charging current will never be enough to damage the batteries.

Generator matching

It is most important to match the size of generator as close as possible to the rotor.
If a generator too large is fitted, the power will be much reduced as the rotor will be over loaded and stall in a similar fashion to a petrol engine.

To obtain the best output for a given wind speed, it is necessary to vary both the gear ratio and field current of the generator.

USING A CAR ALTERNATOR

The most suitable car alternator to use is the Lucas 17ACR which is now fitted to most British cars. It is a 36 amp alternator and starts to charge at 900 rpm.
Other ACR alternators which can be used (though less suitable) are the 15ACR (28 amp), 16ACR (34 amp) and 18ACR (43 amp).

Voltage regulated version (see Fig. 4)

This version is wired basically the same as the alternator on a car.
The output voltage is regulated to 14.2 volts by the transistor regulator fitted on the back of alternator.

To start the alternator charging, the field must be excited by operating the press button when the alternator is running at 900 rpm or above.

Instead of the button an automatic system can be used. Three possible methods are:-

Electronic pulse unit.

Centrifugal switch.

Wind operated switch.

To keep voltage drop to a minimum, the alternator should be wired to the battery with 30 amp cable.

Un-regulated version (see Fig. 5)

This version requires the wiring on the alternator to be modified.
The regulated is disconnected by wiring a shorting link from the LHS slip ring terminal to earth (case) and by disconnecting the regulator wire to the rectifier.
Finally the RHS slip ring wire is connected to the centre rectifier output.
This effectively connects the field across the alternator output.

To stop the field slowly discharging the battery when the alternator is not charging, a blocking diode is fitted in the ground control unit.
A 30 amp 50 volt silicon diode is used and mounted as shown in the bottom RHS of Fig. 7.

As before the alternator is excited with a press button or an automatic switch.

The alternator must not be run without a battery connected on either version unless a short circuit is put across the alternator output.

CONVERTING 12v DC TO 240v AC

Rotary Converter

A rotary converter is a DC motor and alternator combined in one machine. It is robust and reliable and gives a sine wave output suitable for any type of equipment.
Its main disadvantages are that quite a lot of power is consumed by it even when giving no output and it is relatively noisy.

Square Wave Inverter

This is the cheapest type of inverter and normally uses a transistor circuit and transformer to produce 240v AC.
It is efficient and quiet in operation but has the disadvantage that the square wave output is not very suitable for some equipment (Induction motors and TV).
Also the cheaper quality inverters are easily damaged by overloading.

Sine Wave Inverter

Similar to square wave inverters they can however be used with any equipment and are probably the ideal means of producing 240v from 12v. Unfortunately they are expensive.

STORAGE BATTERIES

Lead Acid - car type

Car batteries are the cheapest form of storage battery.
However they are designed to give very high starting current and are not very suitable for the charge and discharge characteristics of a wind generator.
Life expectancy is only 2-3 years.

Lead Acid - Heavy duty

Similar to car batteries but with heavy plates and with special separators. Life is 8-10 years and efficiency 70-75 per cent. Cost is approximately 50% higher than car batteries.

Lead Acid - Tubular type

Special lead acid batteries in which the positive plates consist of a number of tubes.
Efficiency is about 80% and life expectancy 12-15 years.
Cost is approximately 40% higher than heavy duty type.

Nickel Iron - Nife type (also Nickel Cadmium -Nicad)

A very robust alkali battery which can stand high charging and discharging. Life expectancy is 15 years or more.
These are expensive batteries but can sometimes be obtained for a reasonable price from XWD sales.

APPENDIX

3 OIL DRUM SAVONIUS ROTOR

If three oil drums are used istead of two for the rotor, the power available will be increased by 50%.

In terms of performance the generator could be expected to produce about 300 watts output and start to charge a battery at 13-14 mph wind speed.

Other modifications recommended are:-

1. Rotor Uprate the rotor shaft and bearings by 20% diameter.
2. Gearing Increase the gear ratio to Alternator 9:1 and Dynamo 10:1.
3. Generator Due to the greater power output an Alternator is preferable to a Dynamo.
4. Brake A brake to stop the rotor in gale force winds is strongly recommended and is a good idea for the two oil drum rotor also.

ELECTRONIC PULSE UNIT

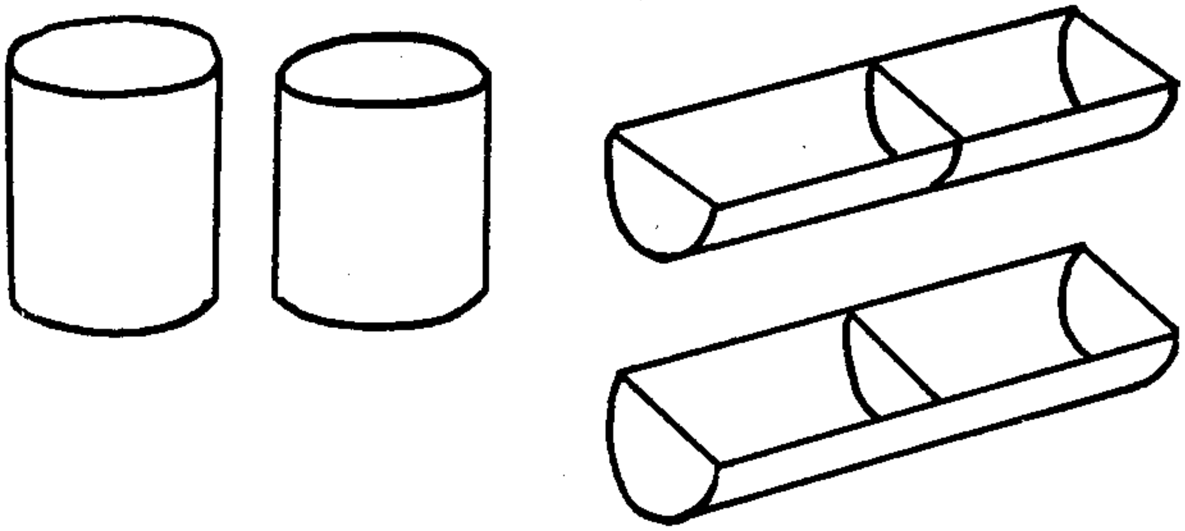
One of the most reliable methods of exciting the alternator is to use an electronic pulse unit.
This sends a half second pulse of current every 20 seconds from the storage battery to the alternator field.
This ensures that when the alternator is running fast enough to start charging the field will excite.
Battery consumption is negligible.

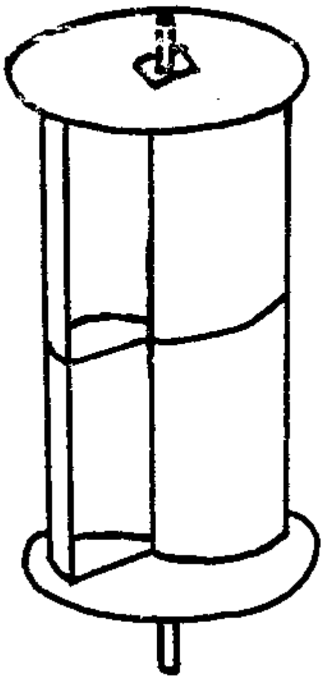
SERIES FIELD RESISTOR

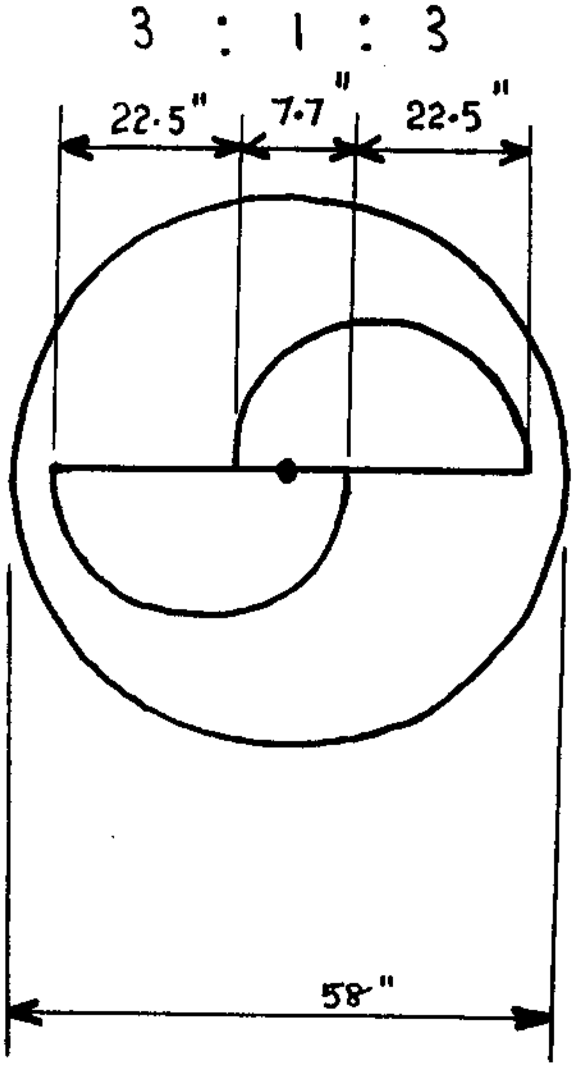
Good performance from a wind generator depends upon matching as close as possible the power output of the rotor to the power input of the generator.
While it is not easy to vary the size of generator or gear ratio, the output and hence input power can be simply varied by changing the field current.
This is easily done by connecting a resistance in series with the field coil.
For the alternators and dynamos mentioned the value of resistance required will be between 1 and 2 ohms.
Experimentally a 5 ohm 25 watt rheostat can be used to find the best resistance value. This can be replaced then by a 10 watt wire wound resistor.
This modification is normally fitted on an un-regulated alternator or dynamo, i.e. in place of shorting link on the alternator and in place of the wire linking the 'D' and 'F' terminals on the dynamo.

FIG. 1

ROTOR CONSTRUCTION







Note: For different rotor diameters always keep the same rotor proportions.
i.e. 3:1:3

Collar flange

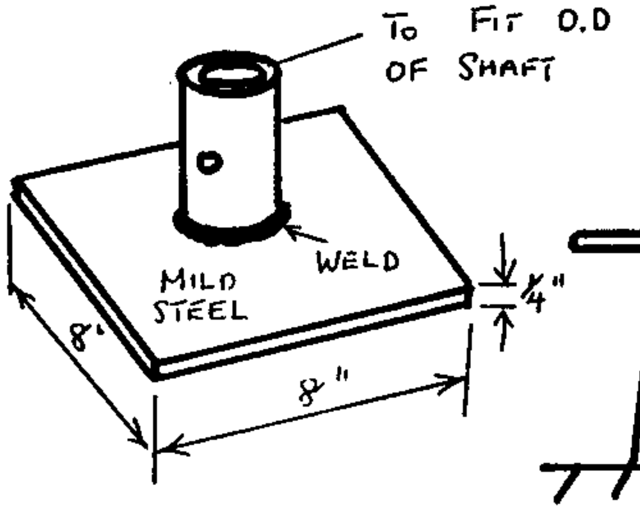
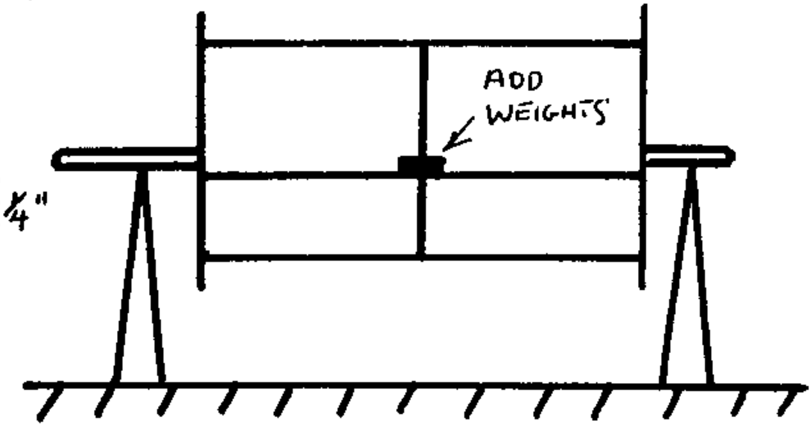
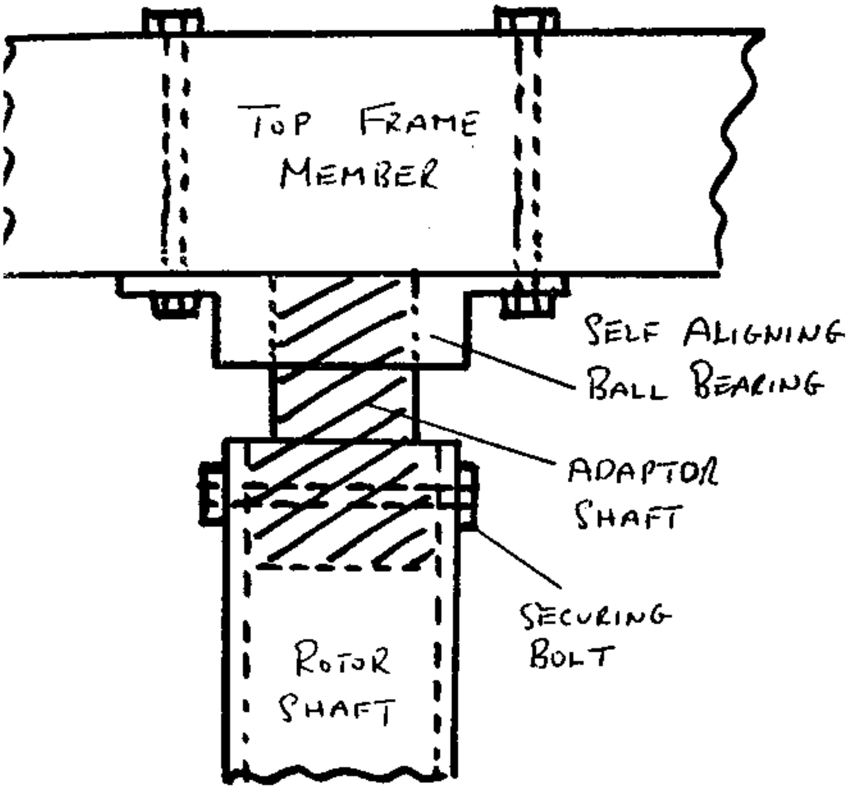


FIG. 2



Method of balancing rotor

Top rotor bearing assembly



Bottom rotor bearing assembly

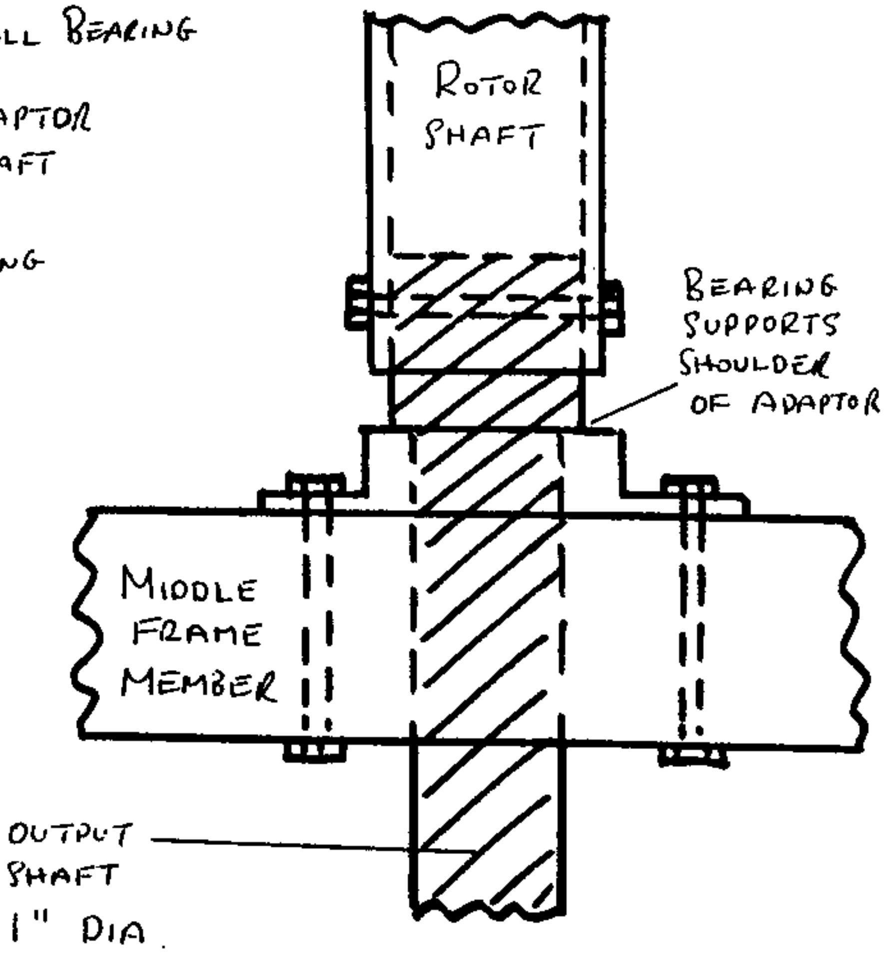


FIG. 3 - FRAME AND GENERAL LAYOUT

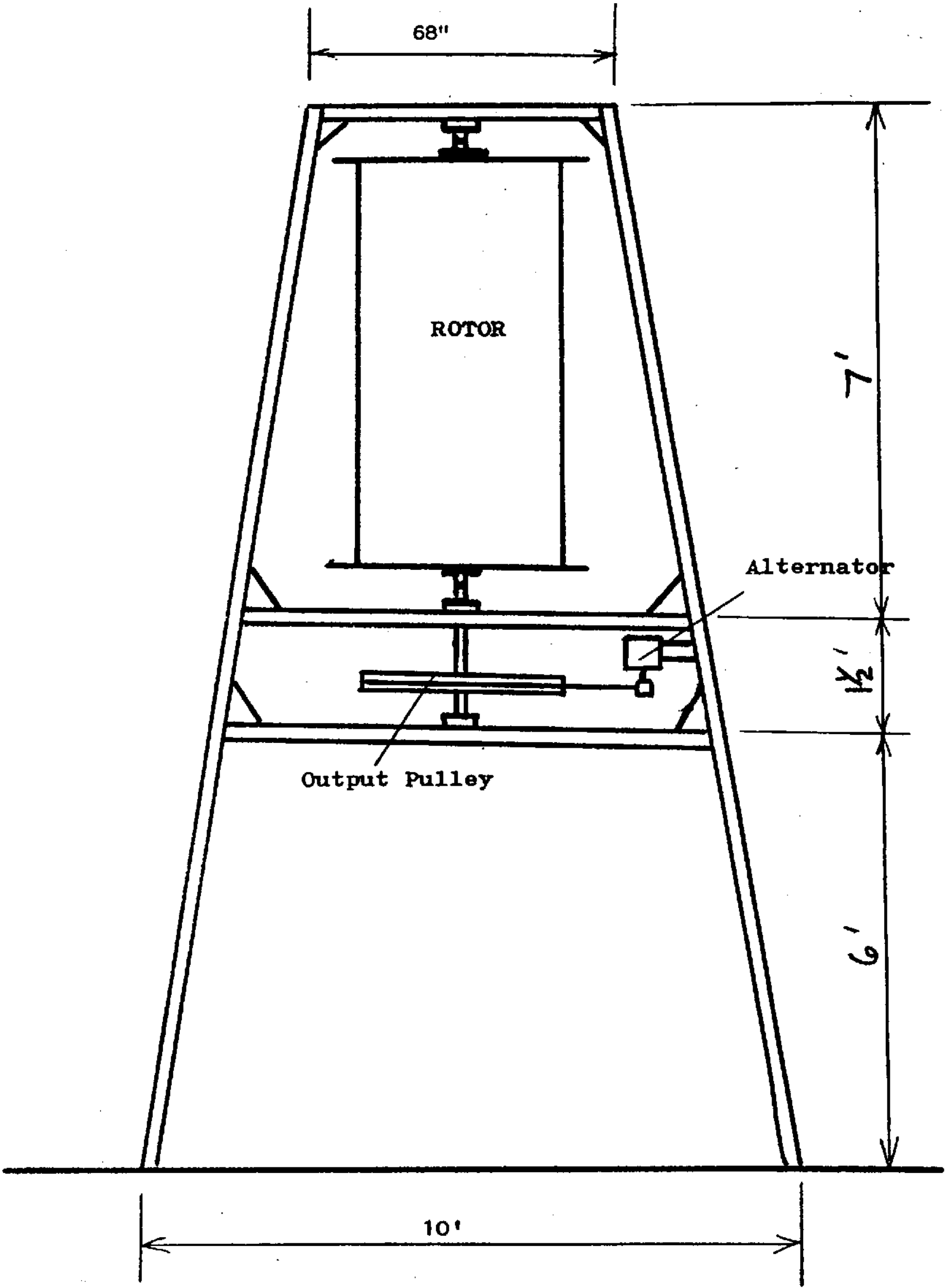
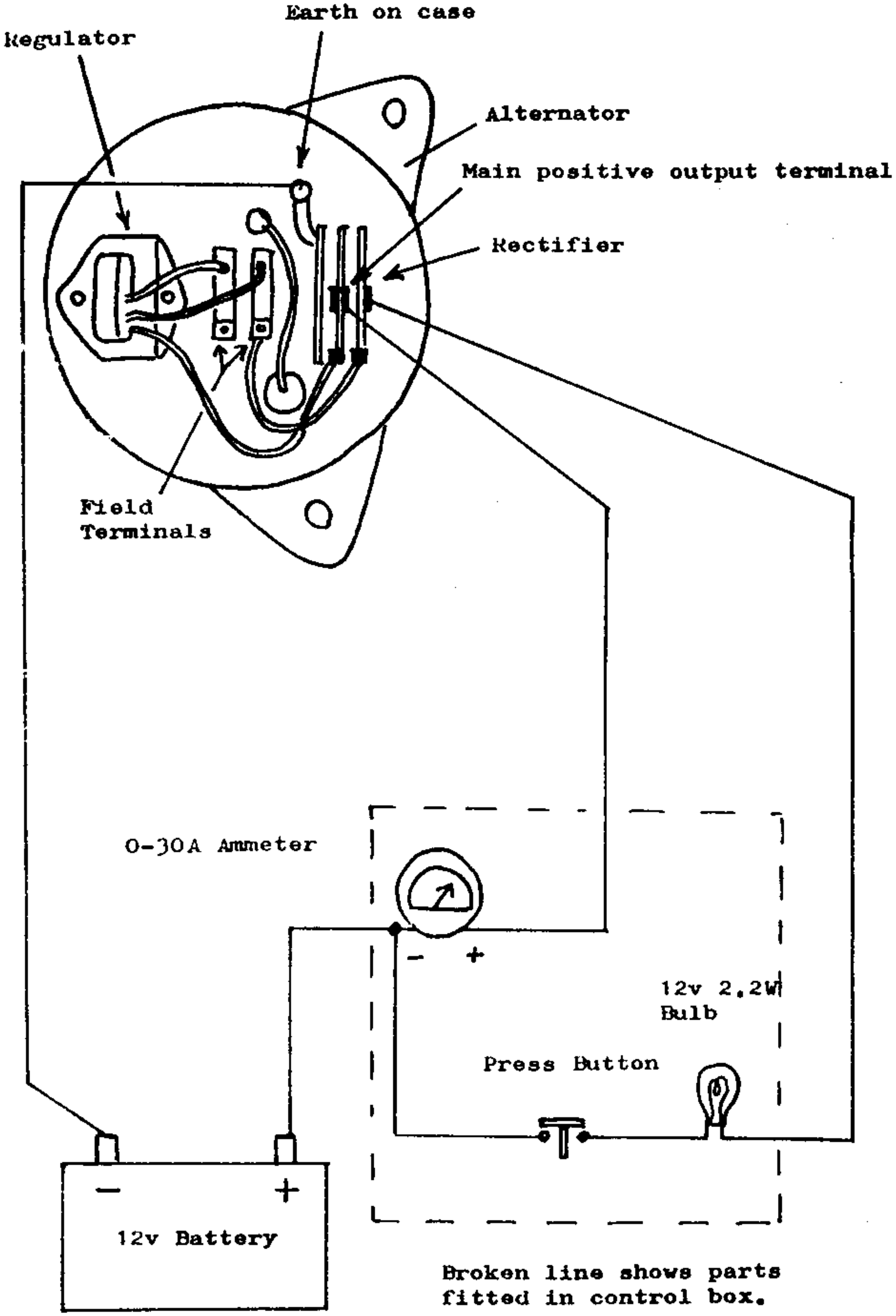
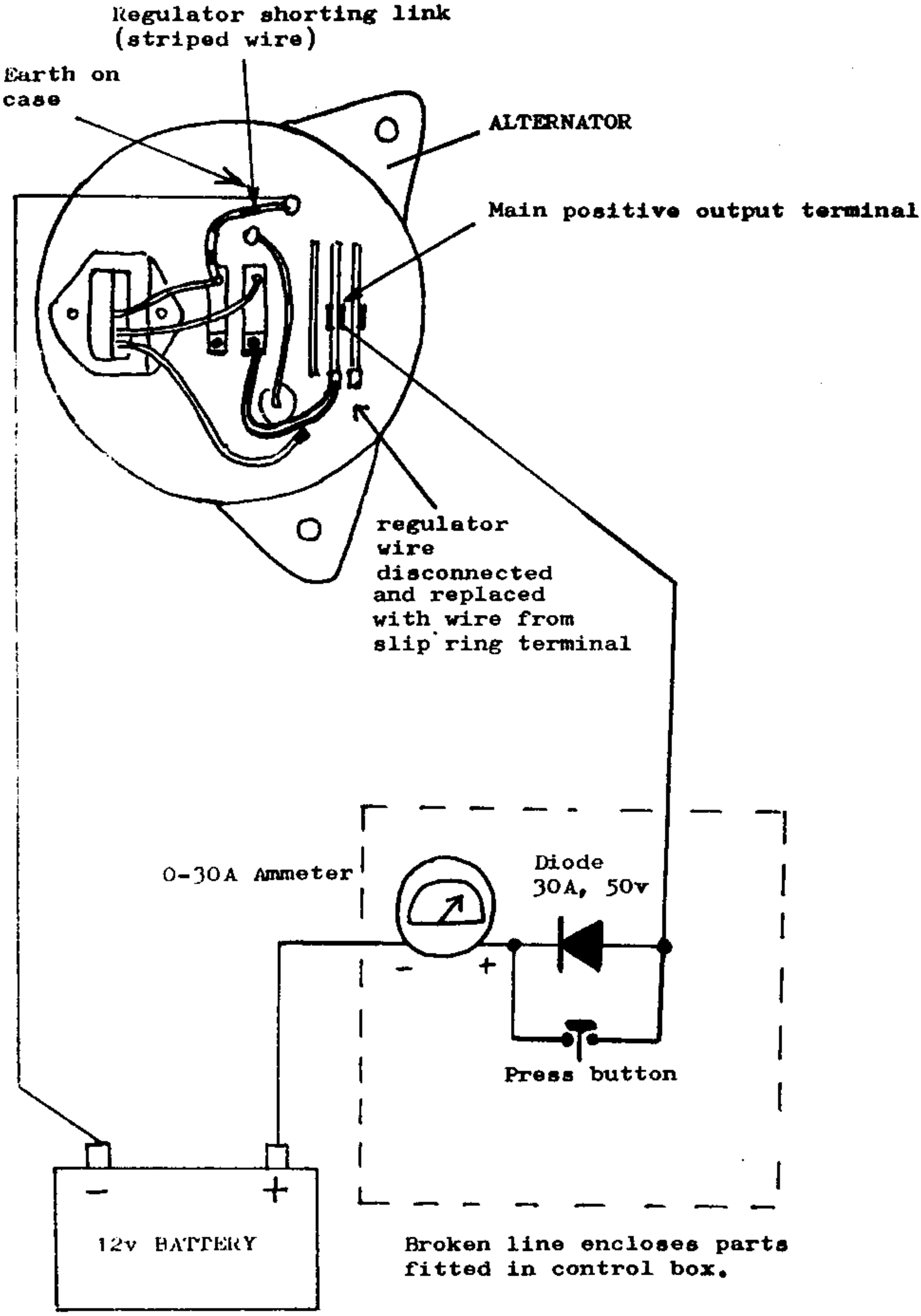


FIG. 4 -- 12 VOLT REGULATED VERSION WIRING DIAGRAM - ALTERNATOR



Broken line shows parts fitted in control box.

FIG. 5 -- 12 VOLT UN-REGULATED VERSION WIRING DIAGRAM



Broken line encloses parts fitted in control box.

FIG. 6 - GENERATOR WIRING DIAGRAM

VOLTAGE REGULATED VERSION

Note: Some control boxes have
a 'B' terminal instead of
'A1' and 'A'.
Wire 'B' the same as 'A1'.

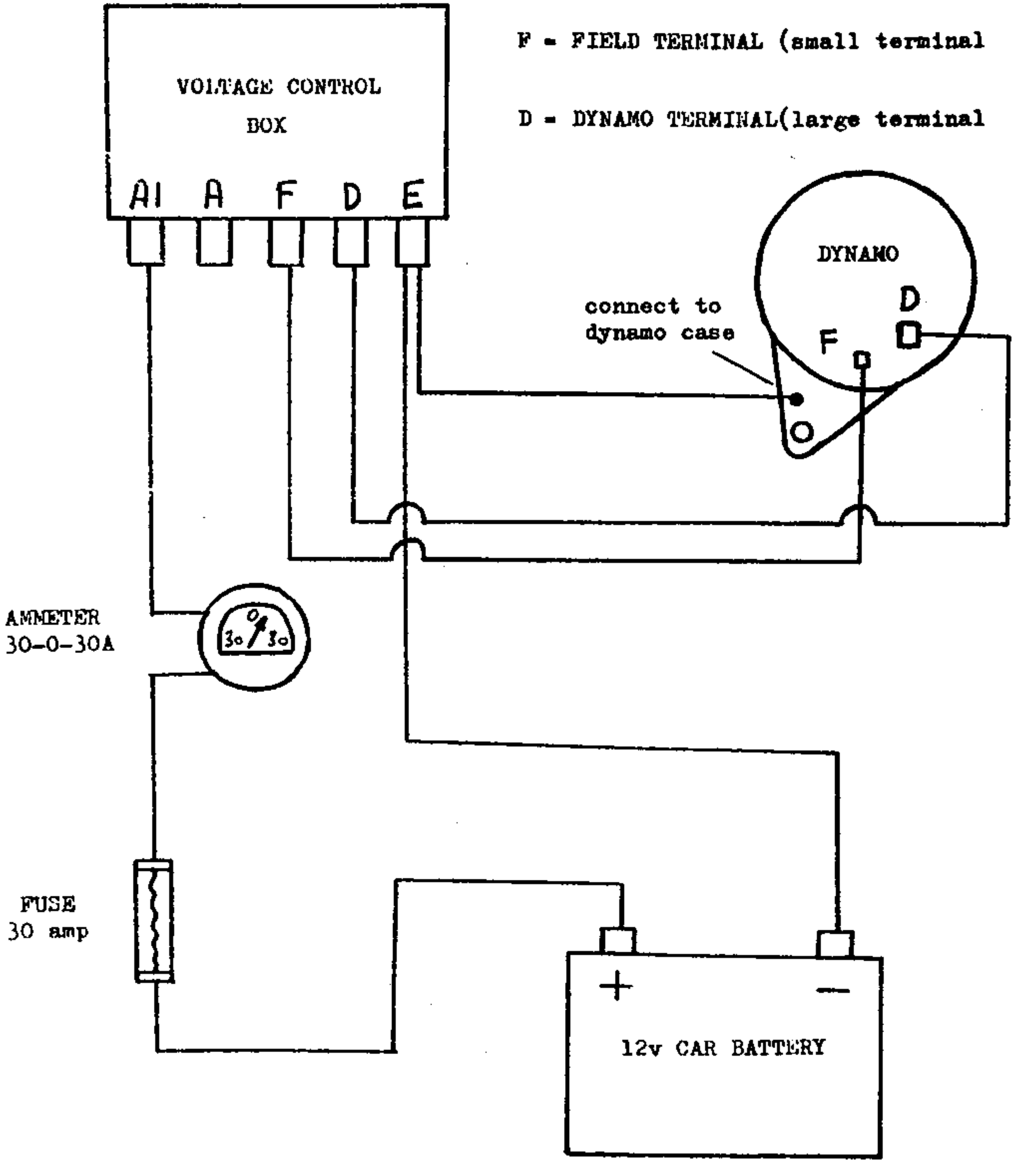
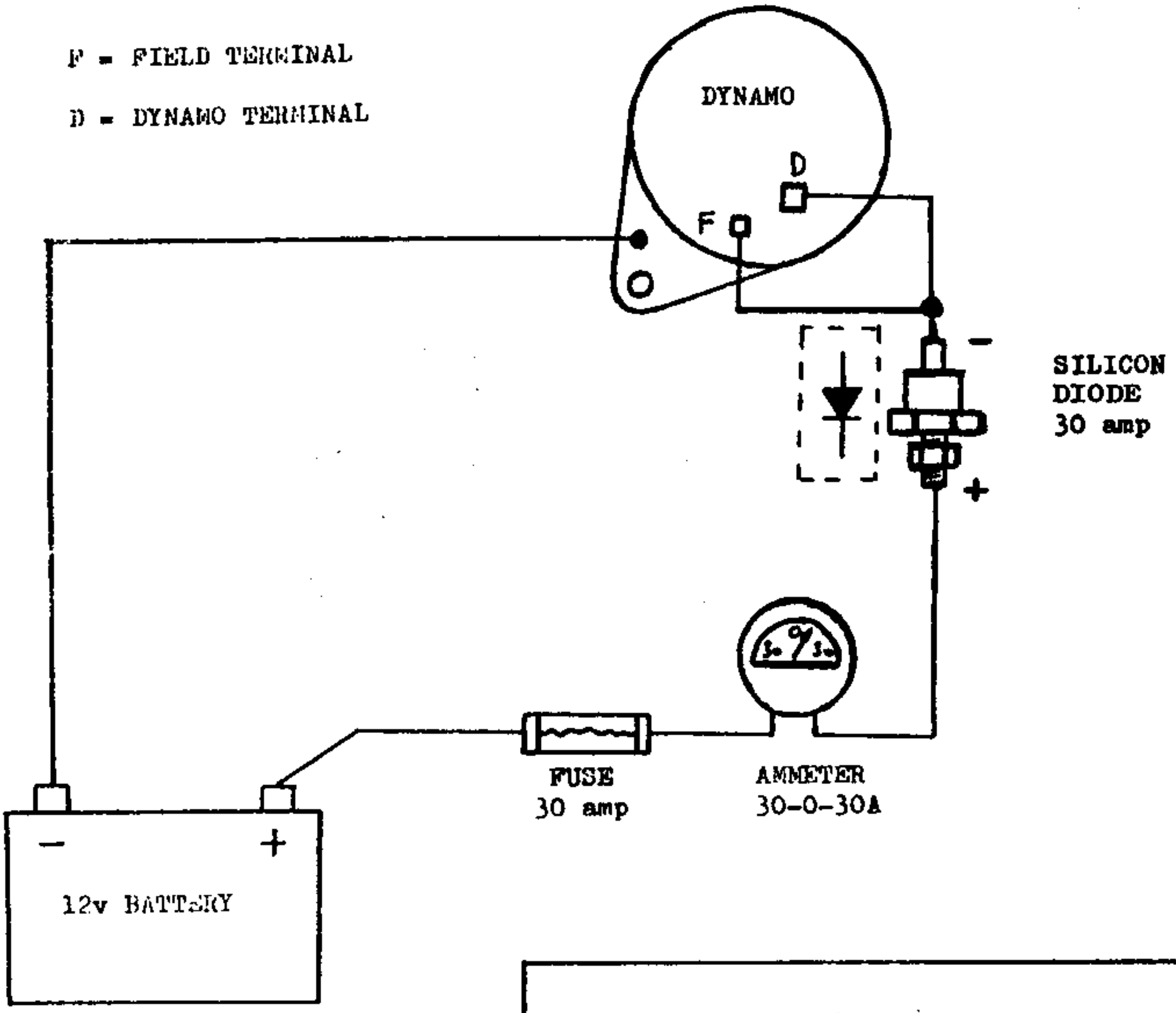


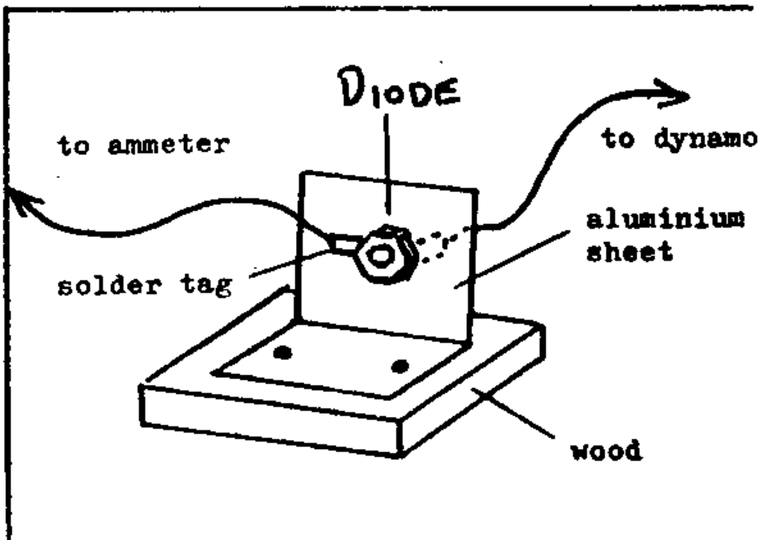
FIG. 7 - GENERATOR WIRING DIAGRAM

UN-REGULATED VERSION

F = FIELD TERMINAL

D = DYNAMO TERMINAL



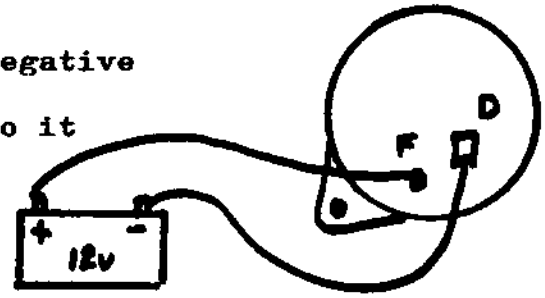


DIODE MOUNTING

USING A CAR DYNAMO

The most suitable car dynamos to use are Lucas C40 or C41 (22 amp) or Lucas C40LO or C41LO (25 amp).
These dynamos start to charge at 1100-1200 rpm and are self exciting.
However before use they must have the field polarised, negative earth is normal.

To polarise the dynamo to negative earth.
Connect a 12v car battery to it as shown for 2-3 seconds.



Voltage regulated version (see Fig. 6)

This version is wired basically the same as a dynamo on a car.
The wiring diagram shows a C40 dynamo and regulator box from a Mini car. (other dynamos are the same or similar)
It is recommended that a fuse is fitted as shown.

Car dynamos must be driven in the direction of the arrow marked on the case

Un-regulated version (see Fig. 7)

This version is very simple to wire up and requires no regulator box.

The field is connected directly to the dynamo output by wiring a link between the F and D terminals.

To stop the battery slowly being discharged by the field a blocking diode is fitted.

The diode, ammeter and fuse are mounted in the ground control unit.
The diode (30 amp, 50 volt) is mounted as shown on an insulated aluminium sheet.

As with alternators, the dynamo must not be run without a battery connected unless a short circuit is put across the dynamo output.

Wind-Generator - JEPH 7. Jemmett Engineering UK 1994.

SMALL WIND GENERATOR

This manual gives full details of how to build a small wind driven battery charger. It may be used wherever a battery requires trickle charging and will be of intrest to boat and caravan owners.
The generator will charge at 6v or 12v at up to about 400 mA depending upon the wind speed. It will start to charge a 6v battery at approximately 10 mph wind speed and a 12v battery at approximately 14 mph.
Maximum output is reached at about 30-35 mph.

Wind generators are notoriously tricky to build and this design has been kept as simple as possible to ensure success.
The design is a good basis for further development and constructors with well equiped workshops will no doubt be able to improve upon the mechanical aspects of this wind generator.
The dyno-hub generators used should be in good condition as their magnetism tends to deteriorate with age and reduce their output.

The Rotor

A vertical axis "Savonius" type rotor is used in preference to the conventional horizontal axis rotor blade.
There are three main reasons for using this design :-

(1) It does not require heading into the wind.
(2) It is easier and less critical to construct than a propeller.
(3) No slip ring assembly is required to bring the current from the generator(s) to the windmill base.

The rotor is constructed from 18 swg aluminium sheet which is light and easy to bend and 6 mm (¼") plywood.
The dimensions of the rotor are a compromise between obtaining reasonable performance in light/medium winds and not getting the structure too large. However if size is not important performance can be improved by increasing the height of the rotor to 24 inches or more.

The Generators

Two bicycle front wheel dynohubs are used to generate the charging current. These have the advantage of giving full power at low rpm, and also good bearings for mounting the rotor on.
The "Sturmey Archer" dynohub, despite its name, is in fact a multi pole permanent magnet alternator. Because it is an alternator it produces AC current, and this must be rectified to DC current before a battery can be charged.
Each dynohub requires a bridge rectifier, and then the two rectifier outputs are added together to give I2 volts DC.
The output of a dynohub at normal operating rpm is 6v RMS at 0.3 amp.
When two dynohubs are used together, they tend to operate out of phase with each other and the overall effect of this is that the dynohubs give 400-420 mA at I.4 times normal rpm.
This current which is achieved at approximately 250 rpm cannot be exceeded, either by increasing the rpm or short circuiting the output.
The dynohubs should be in good condition, especially the bearings.
The bearings may be adjusted by tightening the inner nut at the hub end of the unit until the play in the bearings is <u>just</u> removed.
Take care not to overtighten.

The Frame

The frame can be made from a variety of materials depending upon the workshop facilities available.
The simplest method is to use mild steel angle (or Dexion).
This can be quickly cut to length and bolted together, or the frame could be made of 2" x I" timber.
One advantage of bolting the frame together is that together with rotor the whole wind generator can be dismantled for storage in about ten minutes.
A more professional job of the frame could be made with mild steel or aluminium tubing of square or round section welded together.

PARTS AND MATERIALS REQUIRED

	Description	Quantity
FRAME	Mild steel angle.(or "Dexion") 1¼" x 1¼" or 1" x 1"	
	30" long	2 off
	27" long	2 off
	18" long	2 off
	12" long	2 off
	11" long	2 off
	¼" diameter nuts, bolts and washers.	As required
ROTOR	18 swg aluminium sheet. 18" x 18"	4 off
	6 mm(¼") plywood sheet. 24" x 24"	2 off
	Pop rivets or 2 BA screws.	48 off(approx.)
	¼" or 0 BA nuts, bolts and washers.	20 off
	3/8" long wood screws.	As required (see text)
	¾" diameter mild steel pipe (conduit) 12½" long.	1 off
	Jubilee clip, ¾" diameter.	2 off
ELECTRICAL	Sturmey Archer bicycle front wheel dynohub.	2 off
	2 core electrical wire. (plain)	5 feet(approx.)
	2 core electrical wire. (Red & Black or Brown & Blue)	As required
	Crocodile clips.	2 off
	Small box. e.g. 2 oz tobacco tin.	1 off
	Bridge rectifier, 1 amp 50 volt rating.	2 off
	1 amp fuse in holder.	1 off
	Terminal block. (Cut one length into two halves)	1 off
	6 BA screws, nuts and washers.	4 off
	Rubber grommets, ¼" diameter hole.	2 off
PAINT	Polyurethane varnish. e.g. PU-15	Small tin
	Enamel paint. e.g. Humbrol	Small tin

BUILDING INSTRUCTIONS

Aluminium Rotor Blades (see fig. I)

(I) Take two of the I8" x I8" aluminium sheets and carefully mark out 4 semi circles to the dimensions shown. (i.e. one circle on each sheet).

(2) Using tin snips cut out the 4 semi circles and bend the side tabs 90 degrees. Thus making four end plates.

(3) Take the remaining two I8" x I8" aluminium sheets and put a curve in them by bending them around a suitable curved object of approximately II" diameter. e.g. 5 gallon oil drum.

(4) Pop rivet or bolt end plates to each curved sheet.

(5) Cut a 2" radius semi circle out of each end plate.(to accomodate dynohub).

Rotor Disc Plates (see fig. 2)

(I) Take the two 24" x 24" plywood sheets and mark out two circles of 3.6" and 22" diameter as shown.

(2) Using a jigsaw cut out the circles and check that the dynohub just fits the centre of the disc.

Rotor Shaft (see fig. 3)

(I) Cut a slot with a small hacksaw approximately ½" long at each end of the I2½" conduit tube.

(2) Fit two jubilee clips loosely onto the tube.

(3) Fit two nuts onto a dynohub shaft and push fit the first nut into the tube until it is just inside. Repeat this procedure with the other dynohub at the other end of the tube.

continued

(4) With both dynohubs on the tube, tighten the locknuts, and then tighten the jubilee clip on each tube end onto the first nut. Check that the tube turns true. Adjust as necessary until it does. This tube alignment is most important and must be right if the rotor is to run smoothly.

(5) Release the two locknuts and unscrew one of the dynohubs from the tube.

<u>Frame Assembly</u> (see fig. 4)

(I) Cut the ten lengths of angle to size.

(2) Drill a 5/I6" hole in the middle of each cross member.

(3) Using a round file, file each hole into an oval shape until the dynohub shaft will fit into it.
The shaft should fit slightly loose to allow some shaft misalignment, but the flat on the shaft must stop the shaft rotating in the hole.

(4) Bolt the frame together. (It is often better to only clamp the top cross member in position until the rotor is fitted , and its correct position is found.)

<u>Rotor To Frame Assembly</u> (see fig. 5)

(I) Fit the dynohub with the tube into the bottom cross member, fit a washer and nut and loosely tighten up.

(2) Fit a plywood disc onto the dynohub flange.

(3) Place the two aluminium rotor blades onto the plywood disc so that the cut outs fit around the dynohub.

(4) Place the second disc on top of the rotor blades, and then fit the second dynohub through the disc, and screw it into the tube.

continued

(5) Check that the rotors are square with each other, and then tighten the dynohub shafts until the plywood discs just grip the rotor. Fit the shaft into the top cross member, fit a washer and nut, and loosely tighten the nut up. Bolt the cross member to the frame.

NOTE : The top and bottom dynohub shaft nuts must only be tightened up lightly to avoid straining the dynohub bearings.
Since there is not sufficient thread for a locknut to be fitted, before the generator goes into service the nut must be stopped from undoing. Possible ways to do this are :-

(a) By fitting a anti-vibration nut.
(b) Use "Locktight" fluid on thread. (recommended method)
(c) Drill hole in shaft and fit a split pin.

(6) Bolt the aluminium rotors to the plywood discs with twenty ¼" or 0 BA screws. (5 on each end plate).

(7) Screw the dynohub flanges to the plywood discs with 3/8" long wood screws. (3 or 4 screws per hub is usually enough to hold them)

(8) Tighten the locknuts at each end of the tube and check that the rotor spins freely. (some resistance will be felt from the dynohub magnets.)

Rotor Balancing (see fig. 6)

Check the balance of the rotor by placing the rotor frame on its side, and noting which position the rotor comes to rest at.
Add weights equally onto the rims of the two wood discs until perfect balance is obtained.

Wiring Connections (see fig. 8)

(1) Connect a 2 core wire to each dynohub output terminals and bring the two wires to the base of the frame. (tape or clip wires to frame)

(2) Connect the two bridge rectifiers to the terminal blocks, and mount inside a small box (e.g. tobacco tin) with 6 or 8 BA screws.

(3) Fit a small rubber grommet at each end of the tin.

(4) Bring the two wires from the dynohubs through one of the grommets and connect to the terminal blocks as shown.

(5) Connect a I amp fuse to the terminal blocks as shown. (to prevent damage to rectifiers if battery is wrongly connected)

(6) Bring a Red and Black wire through the remaining grommet and connect to the terminal blocks as shown.

(7) Fit crocodile clips to the ends of the Red and Black wires.

Testing the Wind Generator

Set a test meter to the milliamp range and connect it across the two crocodile clips.
Spin the rotor by hand, the meter should read 200-300 mA.
Set the test meter to the DC volts range.
Spin the rotor by hand, the meter should read approximately 12 volts.

NOTE : If you do not have a test meter use a small torch bulb.
Connect the bulb across the crocodile clips.
Spin the rotor by hand, the bulb should glow dimly.
When you measure the charging current do not forget to multiply readings by 1.11 e.g. 200 mA reading is 222 mA true current.
(This is because a meter measuring rectified AC measures mean current and not rms current.)

Weatherproofing

(I) The plywood should have several coats of paint or polyurethane varnish.

(2) The steel should be painted with enamel paint.

(3) The aluminium blades do not generally require painting, however for added protection near salt water they can be coated with an etching primer paint.

(4) To stop water getting into the top dynohub a small cover of approximately 4 inches diameter should be fitted onto the shaft underneath the cross member. (The end cut off a plastic bottle is suitable)

Using the Wind Generator

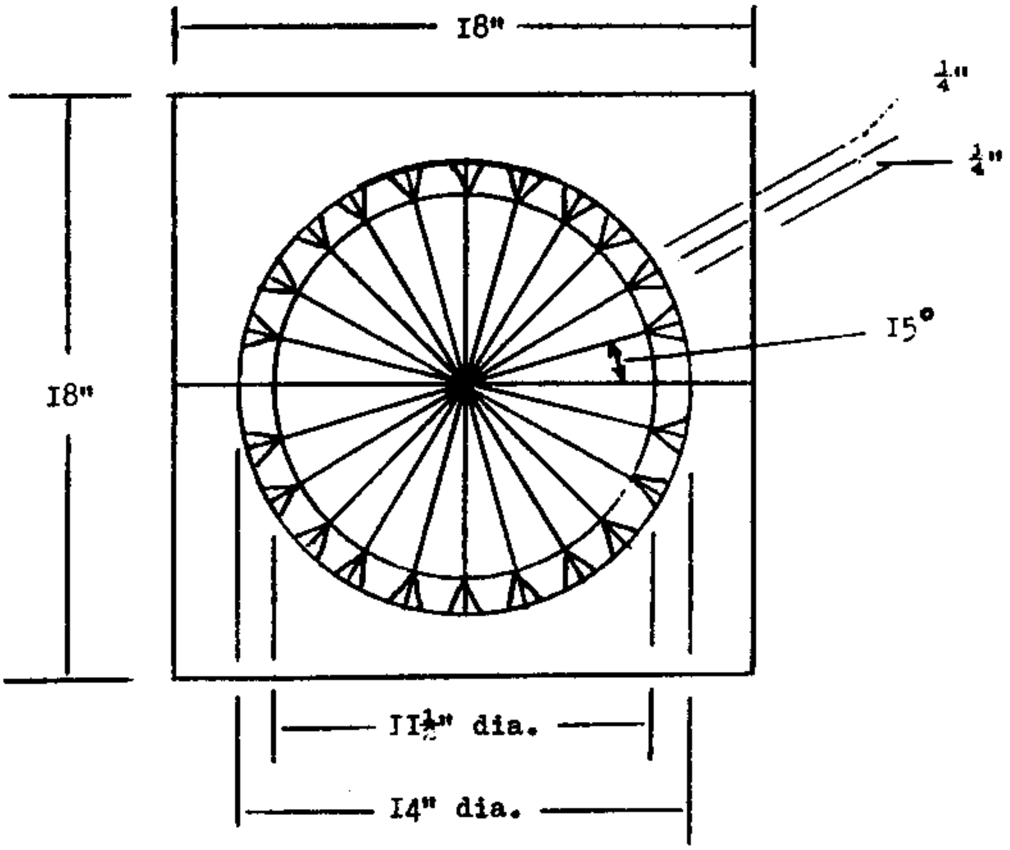
The generator frame shown in this plan is designed to be mounted on top of a flat roof of a boat, house or caravan. It must be firmly bolted in place. Within reason it does not matter how long the two wires to the battery are.

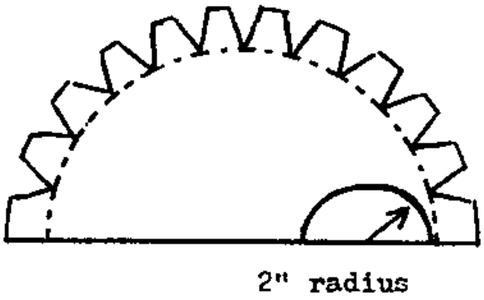
If the generator is erected on the ground, it should be fixed as high as possible, preferably IO feet or more in the air. The frame could be supported on two scaffolding poles held by guy ropes.

IMPORTANT NOTE

I. All the information supplied in these plans is given in good faith and believed to be correct. However, no liability can be accepted for any accident or injury resulting from their usage.

FIG. I - ALUMINIUM ROTOR BLADES

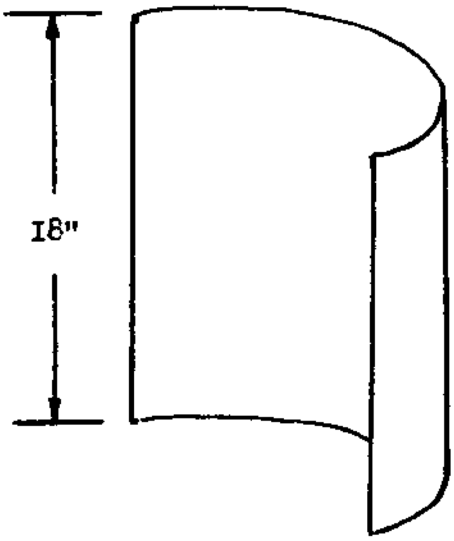


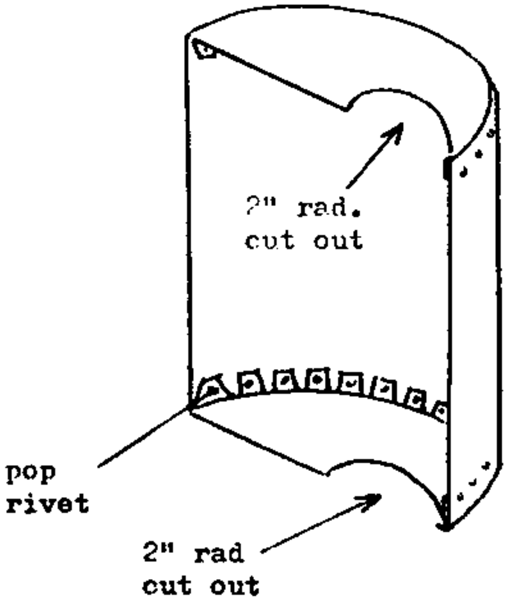


End Plate

(note: mark out 2" radius semi circle, but do not cut out until end plates are rivetted to sheet.)

Curved Sheet





Completed Rotor Blade

FIG. 2 - ROTOR DISC PLATES

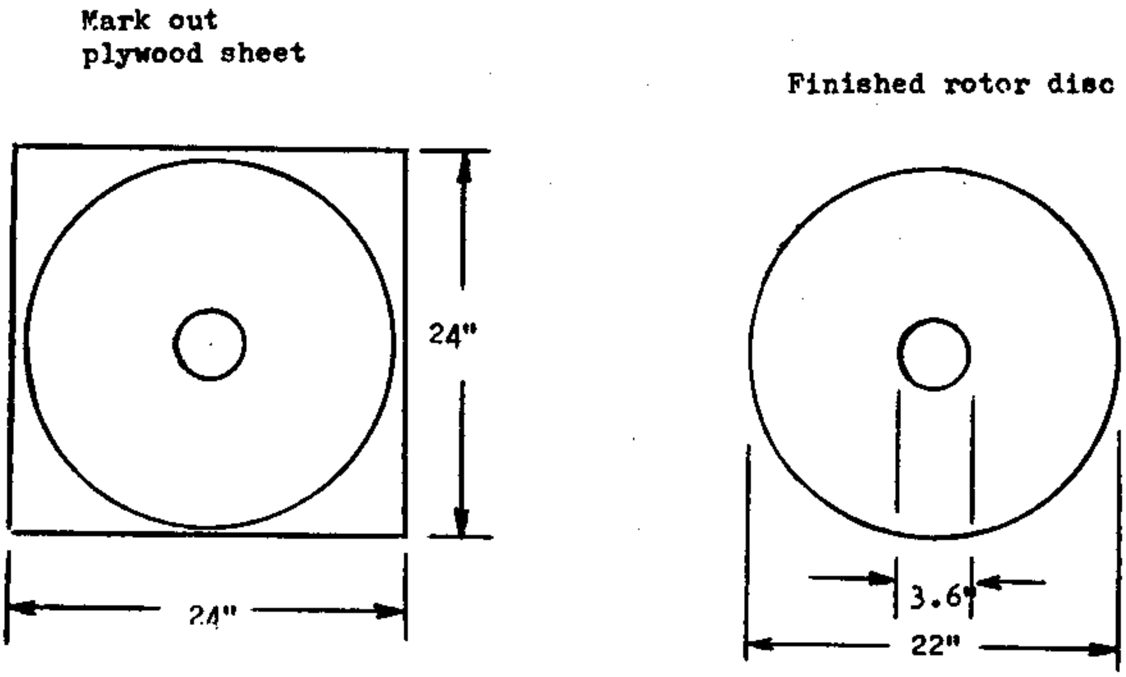


FIG 3 - ROTOR SHAFT

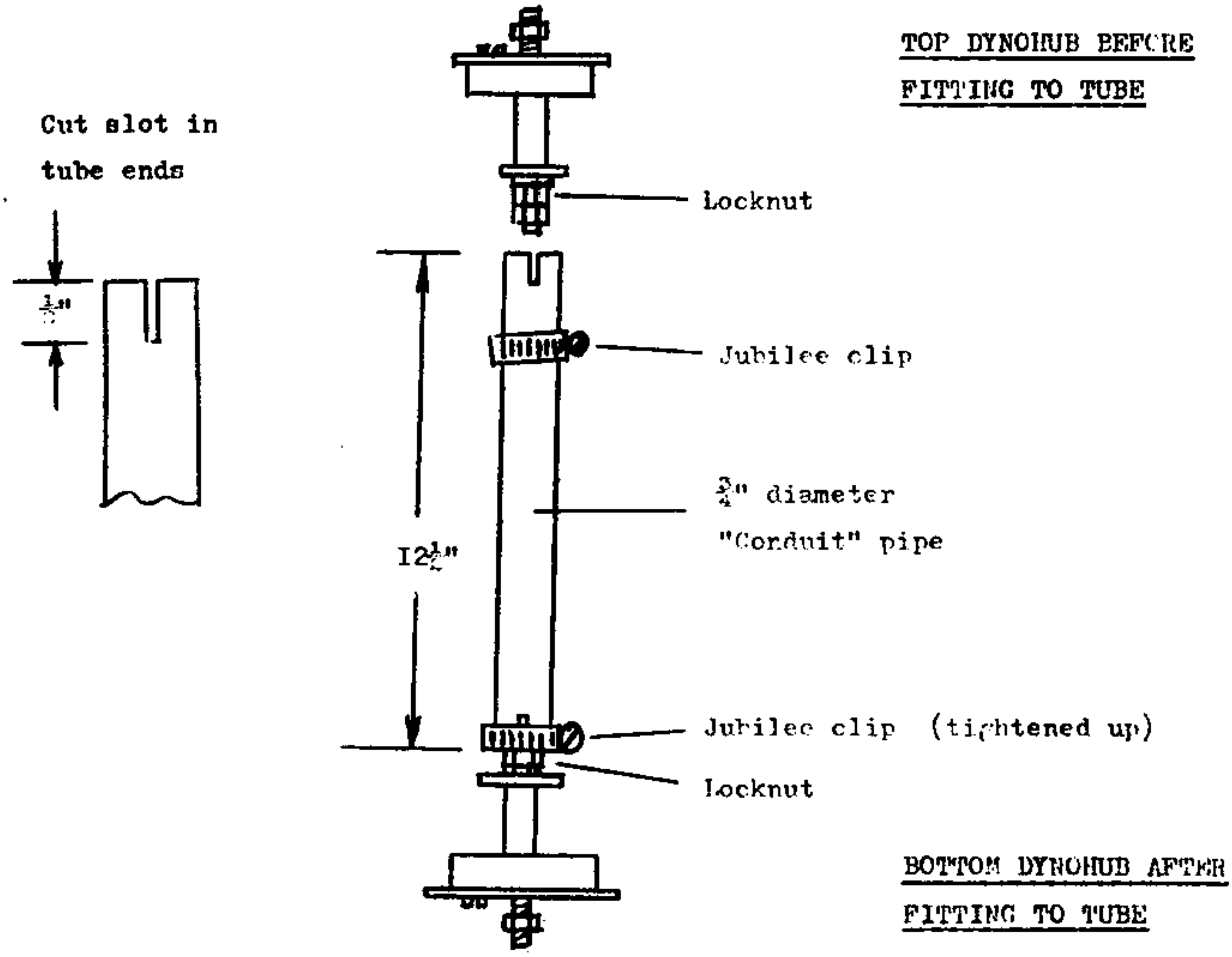
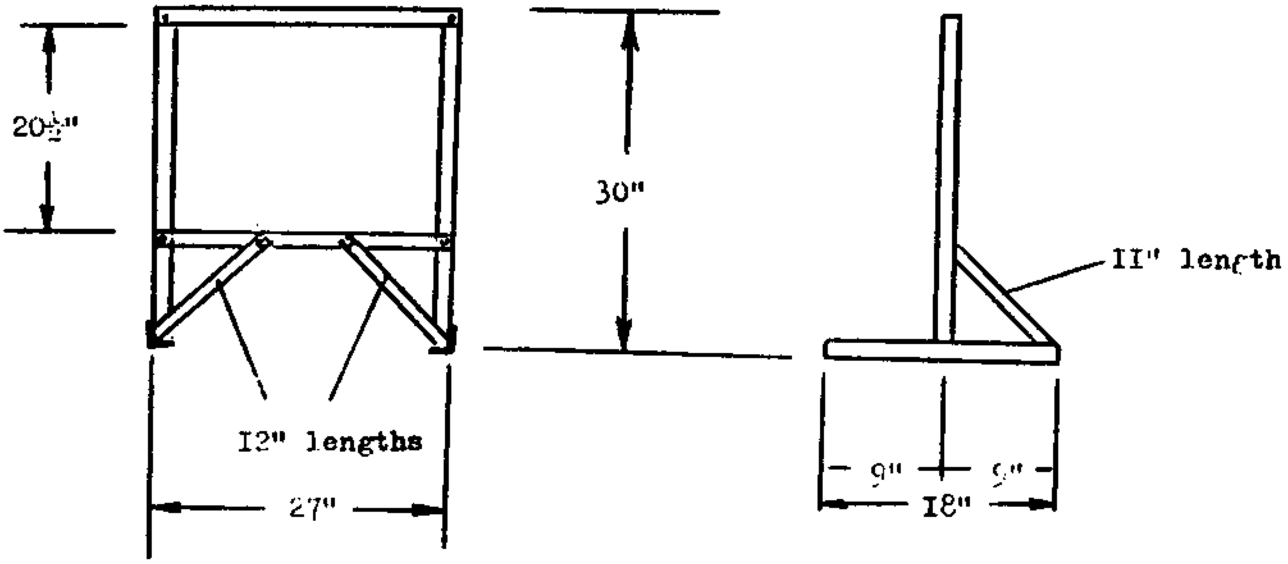


FIG. 4 - FRAME ASSEMBLY


FRONT VIEW

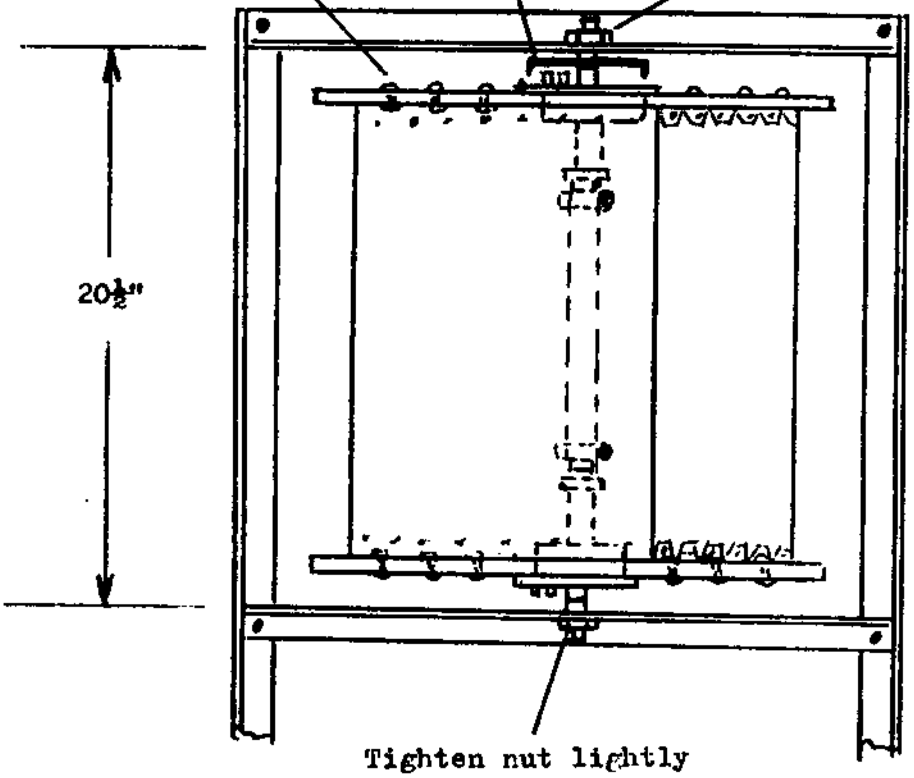
SIDE VIEW

FIG. 5 - ROTOR TO FRAME ASSEMBLY

Bolt rotor blades to disc

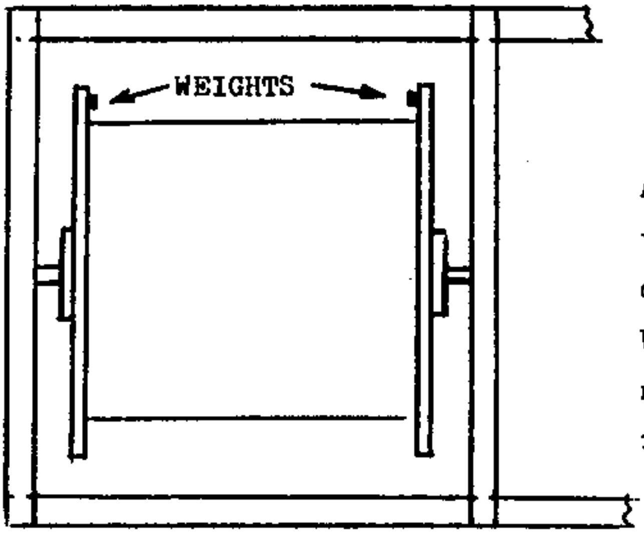
Plastic cover to keep rain out

Tighten nut lightly but lock in position



Tighten nut lightly but lock in position

FIG. 6 - ROTOR BALANCING



Add weights equally to the each rotor disc until the rotor balances and shows no preference to stop in one position.

FIG. 7 - ROTOR PLAN VIEW

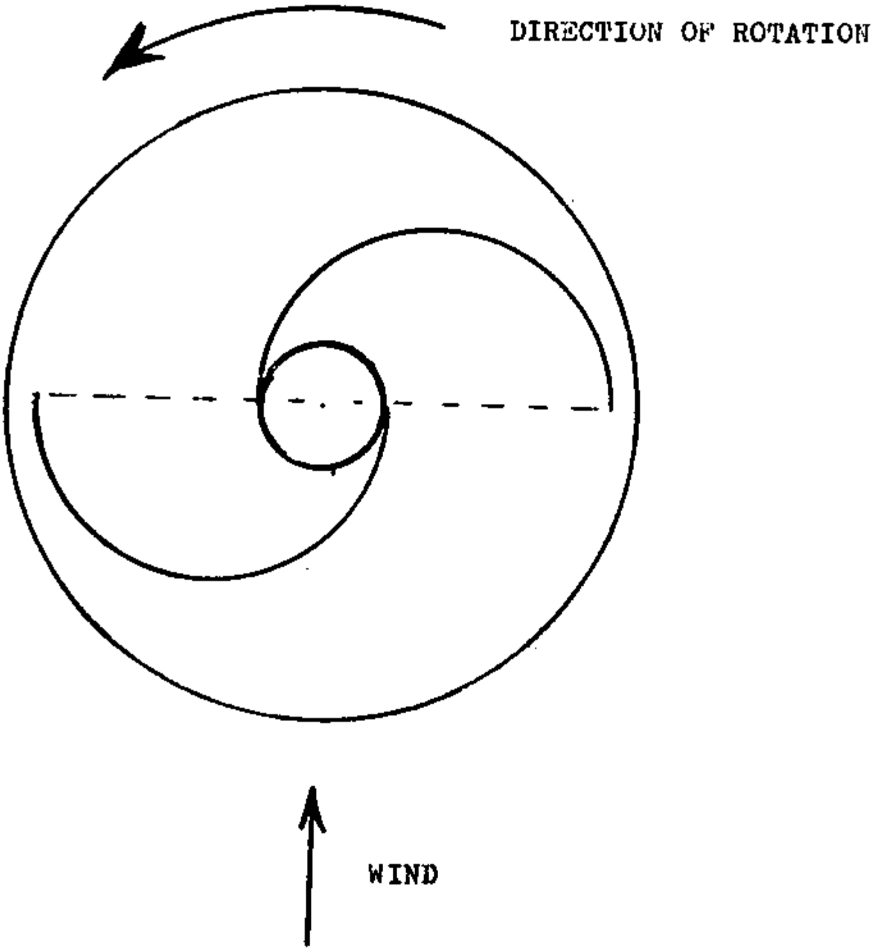
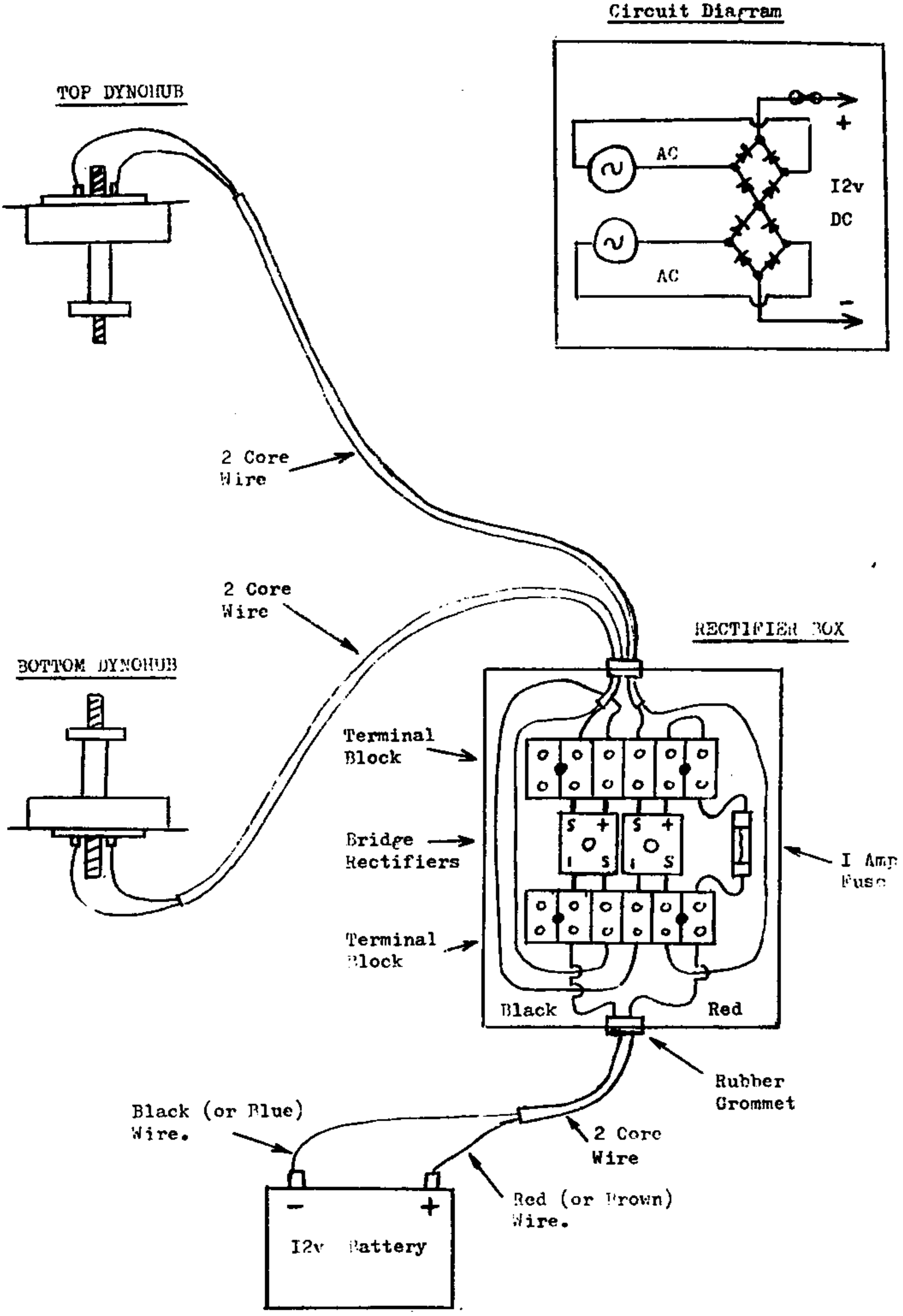


FIG. 8 – WIRING CONNECTIONS



PicoTurbine 250 Plans
Part 1: Blade Design

Instructions and Technical Notes

An easy to build and inexpensive Savonius blade design for use with the PicoTurbine 250 alternator.

BETA

This is an unproven design meant for experimentation only. This plan is intended for adults.

Revision 1.0A, October 1999

www.picoturbine.com

PART 1: Building Instructions

INTRODUCTION

The PicoTurbine-250 project is an ambitious research effort, with the goal of creating a set of plans for a 250 watt wind turbine that can be built for $1 per watt or less by a person of average mechanical skills in one to two days. These plans are for the blade design of the PicoTurbine-250 project. Two other documents will be a part of this set: Part 2 will give the alternator design, and Part 3 will present the design for a load controller that maintains optimal rotor loading.

The reason for this separation of plan documentation is that one could theoretically use a different blade design with the same alternator, or vice versa one could use a different alternator or generator with this blade design. For example, one could potentially use a surplus DC motor (used as a generator in this case) with this blade design, or one could design a Darrius style blade for the PicoTurbine-250 alternator. Please note, however, that precise matching must normally be ensured between blade specifications and alternator specifications.

Design Patent Information

This blade profile is loosely based on a profile documented in US Patent 5494407 by the inventor Alvin H. Benesh. There are differences between this profile and the one documented by Benesh. It is unclear whether this blade design infringes on Mr. Benesh's design. US patent law allows you to build a patented design for your own testing purposes, but you may not sell the resulting machine for commercial profit. For this reason, PicoTurbine.com only furnishes plans for the blade design, we do not furnish any finished parts, you must make them yourself and you must not sell them to others. If you wish to produce a commercial product based on this design, you must contact Mr. Benesh and negotiate appropriate license fees with him to do so. For his address, go to http://www.patents.ibm.com and search for the patent number above. Alternatively, you could modify the blade profile so that it implements a design that is not covered by any active patent. There are several expired patents for Savonius blade designs which are quite serviceable.

Modular Design

The design allows you to build blades in 4 foot [1.2m] tall segments. Multiple segments may be attached together to attain a larger swept area. The PicoTurbine-250 alternator will require 2 segments, resulting in a blade 8 feet [2.4 meters] tall and 2 feet [600mm] wide, with a corresponding swept area of 16 square feet (1.47 square meters).

You could decide to build more or fewer segments to suit the needs of generators other than the PicoTurbine-250 alternator, however there are practical considerations as the number of segments increase. See Part 2: Technical Notes for details.

CONSTRUCTION TIME

You should allow approximately 1 hour to build each segment, with some additional time to assemble all the segments into a single rotor. For assembly of four segments, allow approximately 1 hour. Thus, to build the entire blade set for a PicoTurbine-250, allow approximately 5 hours. Your actual building time may be more or less than this depending on how good your tools and skills are. For example, having built many test models, we can now build one segment in approximately 30 minutes. There is also some savings when building multiple segments in one sitting. For example, once you cut out one blade support you can use it to easily mark the wood for all the supports you need and cut them out at one time, the same goes for drilling holes and other tasks that must be repeated for each segment. This saves you time switching between tools, changing drill bits, etc.

BEFORE YOU BUILD THE BLADES

Step 1: Check Your Materials

The following materials are needed to build the PicoTurbine 250 blade set:

- An 8-foot by 4-foot piece of corrugated plastic cut into 8 sections two feet square. Corrugated plastic can be obtained from plastics supply houses or sometimes from sign supply or sign making companies. We use 2mm thick plastic, but that is usually hard to find. The most common is 4mm which will also work.
- An 8-foot long piece of pressure treated 4x1 wood, cut into 2 foot lengths.
- 24 angle brackets approximately 2 inches long (each side is 2 inches) and ¾ inch wide.
- A 10-foot section of 1.5 inch diameter PVC pipe. This must be cut into two sections each four feet long (there will be a couple of feet left over).
- A 10 foot piece of 1 inch diameter galvanized water pipe. This is available at any large hardware store or plumbing supply store.
- A 4-foot section of 1 inch black pipe and a floor stand (sometimes called a flange) for 1 inch pipe, and a "T" connector for a 1 inch pipe.
- Eight pipe clamps, 2 inches in diameter. These are metal strips with a screw that allows them to be tightened around a pipe.
- Approximately 100 screws. They should be about ¾ inch long and should have a rather large pan head. Number 8 screws are ideal.
- Approximately 100 washers of a size that fits the screws above.
- Four ¼ inch diameter bolts, 2 inches long.
- Approximately 10 inches of teflon tape, ½ inch in width or more. This item is optional if you have trouble finding it. We bought ours from Grainger (www.grainger.com).
- Approximately 25 feet of 3/8 inch plastic coated steel cable.
- A pulley rated at 100 pounds for a 3/8 inch cable.
- Four wire rope clamps.

The following tools are needed:

- An electric hand drill with a 2 inch wood cutting bore. Also, a ¼ inch metal cutting bit (such as a cobalt bit), and a 1/8 inch bit for drilling pilot holes in wood.
- A jigsaw, saber saw, coping saw, or some other saw capable of cutting curves in wood.
- A screw driver or screw driver attachment for the drill.

Step 2: IMPORTANT: Review Safety Rules

The PicoTurbine-250 blade set is not a dangerous project to build, but as with any construction project certain safety rules must be followed. Most of these rules are just plain common sense.

- **This project is experimental in nature. There may be unknown risks associated with building this project, this list of risks does not purport to be complete. This project is intended only for adults who are willing to experiment.**

- **The tree-mount described in this project is undesirable from a number of standpoints. The tree may suffer damage or be killed, so do not mount this project on any tree you are not willing to put at risk. Be certain to have a good footing and use a stable ladder when attaching parts. Pole mounting is preferred.**

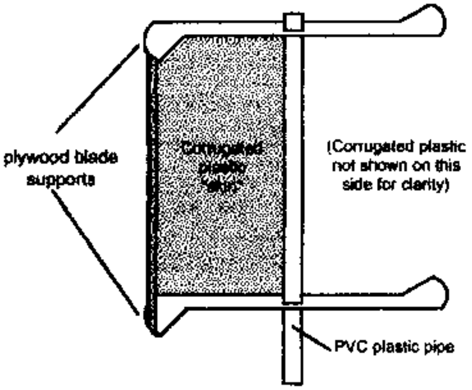
- **The pole mount described in this document is experimental in nature and has not undergone extensive testing. Construct it according to the rule: "build it so it can never fall down, and place it expecting that it absolutely will fall down." Place this structure in an area where it will not damage property if it fails, and away from areas frequented by people or animals. If you are unsure of whether you are building the structure securely enough, consult a local engineer.**

- **Follow all manufacturer safety guidelines when working with power tools or other tools. Appropriate eye protection and footwear should be used. Avoid loose jewelry. If any recommendations in this document conflict with manufacturer recommendations, follow the manufacturer recommendations instead.**

BUILDING THE BLADES

BUILDING A BLADE SEGMENT

A blade segment consists of a piece of 1.5" PVC pipe with two wooden blade supports which support a corrugated plastic "skin". See the diagram below.



Step 1: Building the Blade Supports

Cut out the three templates given at the end of this document. Tape them together such that sides marked "A" match up, and sides marked "B" match up as shown in the final page of templates.

Using the template you taped together, mark a piece of 3/4" plywood. Cut out the shape using a coping saw, scroll saw, jig saw, or other saw capable of cutting curves in wood.

Drill a hole 2 inches in diameter in the center of the blade support. Repeat this process to construct a total of 4 identical blade supports.

Step 2: Attaching Blade Supports to PVC Pipe

On each blade support, attach three angle brackets as shown in the diagram. Use ¾" wood screws.

Now, place a pipe clamp over the 3 angle brackets, and slip the whole assembly onto the PVC pipe. Tighten the screw on the pipe clamp. Attach the four supports so that there is precisely 2 feet between the outer edges of each pair of two supports.

Step 3: Attaching the Plastic "Skin"

Take a piece of 2 foot square corrugated plastic. Going with the "grain" of the corrugations, make a 1" wide bend along the length of the plastic. A yardstick or other piece of wood will help you make a straight bend. Make additional such bends at 1" intervals for approximately a six inch area.

If you are using 4mm thick corrugated plastic (which is much more commonly available than the 2mm we use) then you may need to score through one side of the plastic. To do this, place a piece of wood to be used as a guide down the length of the plastic (in the same direction as the corrugations), and score through only the top surface of the plastic, do not score all the way through. This will allow you to easily negotiate the curved blade, but will result in some loss of strength of the material.

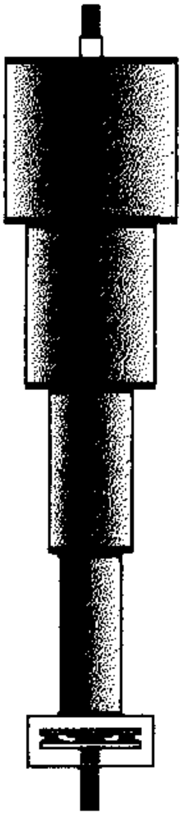
Starting at the tip of the curved portion of the blade, drill 1/8" pilot holes in the plywood blade supports. Space these pilot holes about 2" apart. Do this on each side of the supports, as indicated in the figure below.

Starting again at the tip of the curved portion of the blade support, attach the corrugated plastic using a screw and washer. The washer is needed to help distribute the pressure over a wider area of plastic helping to avoid breakage. It is best to put first one screw on the top support, then one screw on the bottom support. Adjust the spacing between the blade supports if necessary using the pipe clamps. Continue until the plastic is secured along the length of both blade supports, then repeat for the other side of the blade. Finally, repeat this entire process for the lower pair of blade supports.

MOUNTING SEGMENTS

One or more segments may be mounted on a 1" (inner diameter) pipe. Simply place the PVC pipe of each segment over the 1" pipe. Make sure that each segment is oriented the same way, i.e. so that they will all spin in the same direction. Segments may be attached to each other simply by using screws through an adjacent pair of blade supports. Drill pilot holes to make it easier.

In order to smooth out torque and enhance startup from any wind direction, it is desirable to offset each segment as shown in the figure below. In fact, it is desirable to offset each section of a single segment. Our preferred spacing would be a 30 degree angle between each subsection, making the bottom-most subsection a right-angle with respect to the top-most subsection.



If you have access to Teflon tape, it is desirable to clean the outer surface of the 1" pipe and apply several rings of tape. The tape should be oriented such that the rotation of the blades will tend to wrap it tighter rather than to rub against the outer edge of the tape and cause it to unwrap. Several rings of tape should be placed near the top and the bottom sections of PVC pipe, where the most friction occurs.

After applying the tape, if any, you should thoroughly oil or grease the 1" pipe. This results in quite low friction between the PVC and the pipe, whether or not you are using the Teflon tape.

The bottom bearing, on which the weight of the blade set rests, will be the PicoTurbine-250 alternator. If you wish to test out the blades before constructing the alternator, you may use a piece of metal or large washer, greased, to rest the bottom of the PVC pipe upon. Although this will have significant friction compared to the ball bearings of the alternator, we have done weather testing in this way and have found the blades will turn quite nicely with this simple bearing except in the lowest of winds. If you have a ball bearing of the proper size, or could make it the proper size using wooden inserts, this would make for a better bearing for weather testing.

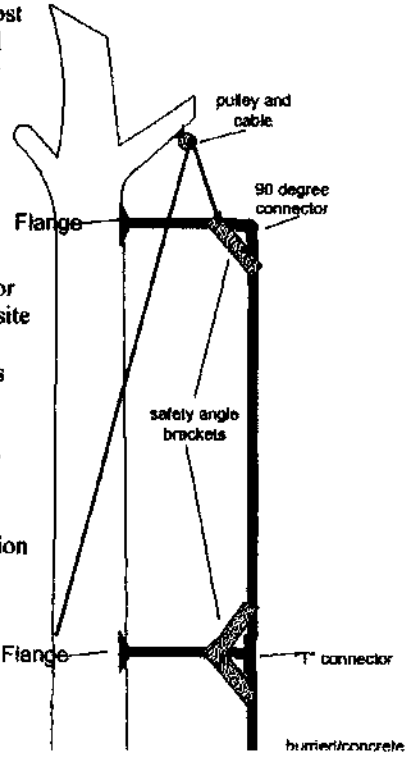
MOUNTING THE BLADES OUTDOORS

There are several different ways to suspend the pole. The ideas presented here are to be considered only suggestions, none of them has sufficient testing to insure they are safe and effective. Always follow the adage: "mount your wind turbine in a way that it cannot possible fall; and place the turbine expecting that it absolutely will fall." Be sure that a setting is selected that is clear from areas that people or livestock regularly traverse, and that if the structure fails no property, buildings, electric wires, etc., will be damaged. Mounting is probably the most dangerous part of wind turbine deployment. Be sure to use a good sturdy ladder with good footings on the ground. Always plot your moves carefully to avoid falling. Never attempt this in high wind conditions or during bad weather. Use common sense.

Tree Mount

For our initial testing we used tree mounts. We should point out that tree mounts have many disadvantages, among which is the possible death of the tree involved. In our case the convenience of this type of mount outweighed the disadvantages for initial testing, however we are testing out pole mounts for actual production. Our site has many 40 foot tall oak trees, which make reasonably good mounts. These trees are about 1 foot wide at the base of the trunk and so are quite sturdy. The branches on oak trees start quite high, about 20 feet, making for a clear section that makes mounting easy. Other types of tree will not work as well due to branches that start lower. Evergreen trees such as spruce would be completely unsuitable due to their shape.

The figure below shows how we use a tree mount for testing. A simple configuration using standard pipe parts is easily constructed. To prevent the pipe parts from



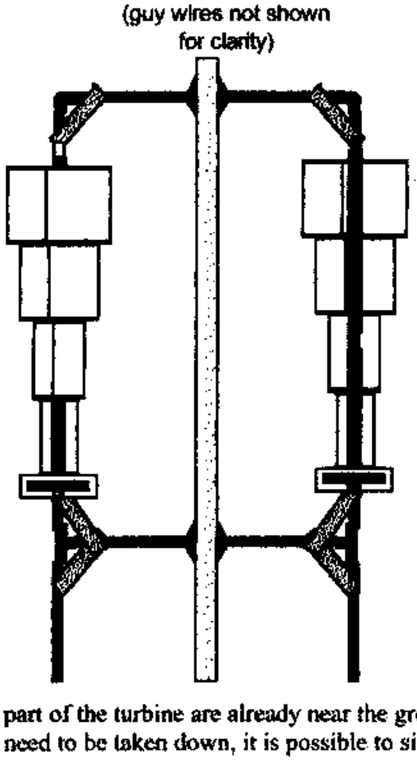
unscrewing themselves (a problem we had with early prototypes), we drill a ¼" hole near the connectors on the pipes and use bolts to affix a small section of angle iron. To hoist up the pipe and provide added safety, we used plastic coated steel cable and a pulley. We leave the steel cable and pulley attached to the tree for easy lowering if ever necessary, and for added safety in case the mountings come loose. The bottom of the steel cable is attached to nails driven in the trunk near the base.

We secured the top section of pipe first by nailing the pipe flange to the tree and screwing in the four foot section and 90 degree angle fitting, securing with the angle iron discussed above. The blade section can then be inserted from the bottom, along with any washer or steel disk used as a temporary bearing. Then, the "T" connector is attached and a second four foot section is affixed to the tree, along with another safety bracket made from angle iron. If desired, another section of pipe can be placed on the lower section of the "T" and buried in the ground. A permanent footing of concrete would be suggested for a permanent installation. In our temporary testing stations we often just use several cinder blocks or large rocks to stabilize the bottom pole, but that would not be desirable for a permanent installation.

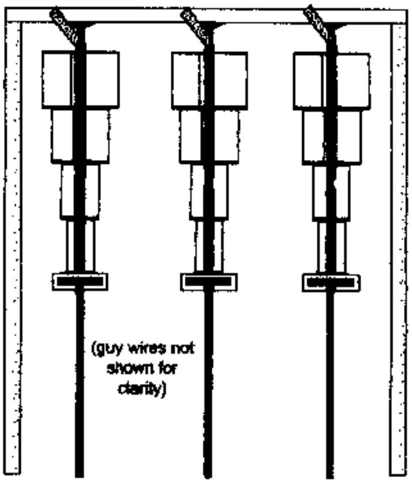
Sometimes the pole will not be straight as mounted above because the tree trunk narrows or curves slightly as it gets higher. We have found that there is little measurable effect on performance if the pole is not perfectly straight. As long as the top is within a few inches of vertical when compared to the bottom it should be ok. You could use longer or shorter sections of pipe for the upper or lower supports to adjust if necessary, or build out the top or bottom flange from the tree by placing a piece of wood board between the flange and the tree.

Pole Mount

A pole can be used in place of a tree for a much more desirable mounting structure. We are experimenting with 4x4 inch poles 14 feet long. Such poles must be sunk several feet into the ground and guyed with wire. It would be possible to put 2 turbines on a single pole as shown in the figure below, as long as you are in an area with a "prevailing wind" this will not hurt performance significantly. Position the two turbines such that they do not block each other during a typical "prevailing wind".



Another type of multi-turbine installation that could take advantage of a prevailing wind direction would be a line of turbines supported by a horizontal wooden beam. This beam could either be suspended by other beams or pipe poles in concrete footings, or could be suspended from two trees (if you are willing to risk losing two trees). In this case the flanges could be connected directly to the mail axle pipe without the cross-bar piece. The angle bracket to prevent unscrewing of the flange would be connected from the axle pipe to the top beam in this case. Once again, guy wires would be needed to ensure stability in high winds.



In most cases, it is possible to do maintenance near the ground. This is because the alternator is at the bottom already, so all electrical connections and the most complex part of the turbine are already near the ground. If the blades ever need to be taken down, it is possible to simply disconnect the lower safety angle brackets, unscrew the lower horizontal support pipe from the flange, unscrew the "T" connector, remove the bolts holding the alternator stator to the pole, and then simply lower the whole structure down from the pipe. There is rarely a need to go back up a ladder because of this ability to remove the turbine from ground level. The only regular maintenance that would require a ladder would be to grease the entire pipe, and even that could often be done simply by using a oil rag on a pole.

PART 2: Technical Notes

INTRODUCTION

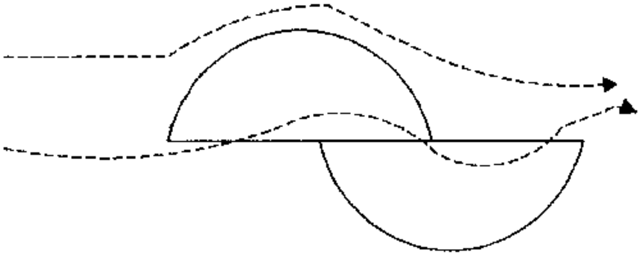
This section explains some technical points about the blade design described, and discusses some possible modifications and other auxiliary material.

SAVONIUS BLADE THEORY

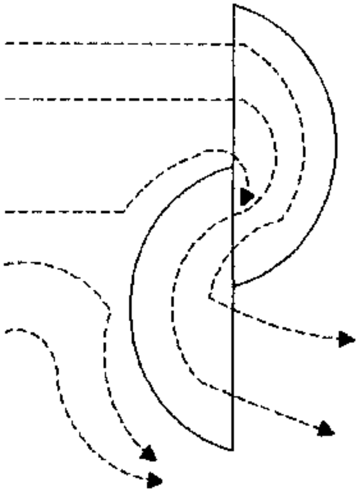
The Savonius blade design was invented by S. I. Savonius in the 1920s. The idea behind the blade design is twofold:

1. Produce torque by both lift and drag by using a semi-airfoil shape.
2. Allow air to flow through a cavity connecting the two blade halves, resulting in decreased turbulence and friction.

The traditional Savonius design, called the "split barrel", can literally be made by cutting a 55 gallon drum in half. From the top it looks like this:



With the wind coming from the left side of the page, this shape assumes a simple air foil-like configuration, causing some lift to aid the rotation of the turbine. It is also this effect that allows the turbine to start up even if it has this profile from a dead stop. However, torque is minimal in this position relative to the wind.



When the blades are oriented 90 degrees from this position, the blade profile acts in a purely "drag" fashion as shown here. The open cup at the top makes the blade spin clockwise. There is drag opposing this movement from the back of the lower cup, but because of the shape there is a net torque clockwise. The fact that the two cups are connected by an open area in the center allows the air to pass through and reduces turbulence, which robs any wind rotor of power.

Barrel Savonius Efficiency

The degree to which the two cups are offset from each other can be varied, both horizontally and vertically. In 1974 , Sandia National Laboratories (www.sandia.gov) published an extensive study of this shaped rotor called *Wind Tunnel Performance Data for Two- and Three-Bucket Savonius Rotors* (you can search for this document on their web site, search for the terms "Savonius" and "bucket"). They found that an optimally loaded Savonius rotor was about 24 percent efficient, and this optimal loading happened when the rotor tip speed ratio (TSR) was approximately 0.80. In other words, the very end of the rotor must be travelling at about 80 percent of the wind speed to achieve this maximum efficiency. At tip speeds both above and below this speed, the rotor performs more poorly.

By way of comparison, modern horizontal axis wind turbine blades typically have an efficiency (Cp is the technical nomenclature) of approximately 30 to 40 percent. The maximum possible efficiency, derived by the fluid dynamics scientist A. Betz and known as the *Betz Limit*, is about 59 percent. It is physically impossible for any wind capturing device to exceed this limit of efficiency.

Benesh Profile Savonius Blade

Many patents have sought to improve on the barrel design. If you search at www.patents.ibm.com for the term "Savonius" you will find many. In 1996 Alvin Benesh patented his design for a Savonius rotor (US Patent number 5494407). Although he does not say so in the patent, this design obviously seeks to improve the lift part of the Savonius blade by making the shape closer to a true air foil. Another advantage of this design, which is mentioned in the patent, is that the long, flat area of the blade is very easy to construct from low cost materials. Benesh claimed that his tests showed this blade profile has a Cp of 0.37, which compares well with some of the best horizontal blade designs. We do not know of any independent confirmation that the Benesh blade profile actually can achieve a Cp of 0.37, and frankly we have our doubts based on theoretical grounds. Our own tests are not yet complete, and will in any case not be definitive since we lack funding for the sophisticated equipment required to perform a conclusive test. However, we do feel, based on preliminary results, that the Benesh blade profile achieves a Cp somewhat better than that reported for simple barrel style blades. Our current estimate is 0.28 when optimally loaded.

Aspect Ratio and Alternator Considerations

Another result of the Sandia Labs tests was that for a Savonius to be practical, it must have a high *aspect ratio*. In layman's terms, it should be tall and skinny instead of short and fat. In the PicoTurbine-250 project we use a 4 to 1 aspect ratio, since the blade structure is 8 feet tall and 2 feet wide. The reason you need a high aspect ratio has to do with the tip speed of the Savonius rotor. Recall that the tip speed will be somewhat less than the speed of the wind, about 80 percent. So, in a 10 meter/second wind (about 22 MPH) the PicoTurbine-250 blade will be turning, under load, at about 300 RPM. If we had made the blades twice as wide, it would only be turning at 150 RPM at the same wind speed. Note that the power available would be the same, just the ratio of rotational speed to torque would be different (power is torque times rotational speed). However, in order to extract that power, we must use an alternator, and the alternator cares very much what the rotational speed is. Doubling the speed of an alternator increases the power output by a factor of four for the same material costs. We can make an alternator that produces an arbitrary amount of power at any speed, but it will cost more (require more magnets, more coils) at a lower RPM.

You might ask, "why not increase the aspect ratio still further to take advantage of this effect?" Well, we cannot play this game forever! The skinnier you make the blade, the taller you must also make them to derive the same amount of power. At some point, it becomes impractical to keep making the blades taller and taller. Also, at some point the blades are so skinny that there is not enough torque for the rotor to overcome startup friction and inertia.

We feel we have chosen a good compromise in the PicoTurbine-250 design. The two foot wide blade also has the advantage that the plastic covering turns out to be an even divisor of the most commonly available size for corrugated plastic sheets, and the entire blade structure requires exactly one such sheet (4 feet by 8 feet).

ALTERNATIVE CONSTRUCTION IDEAS

We chose these materials after months of investigation, in which we tried many different materials. But, there are always choices to be made, and we will discuss some of them here.

Corrugated Plastic Characteristics

The best characteristics of the corrugated plastic material we decided on are:

- Low cost, a 4x8 foot sheet only costs about $15.
- Lightweight, a whole sheet only weighs a few pounds.
- Safe, no sharp edges.
- Easy to work with. Can be cut with ordinary razor blade.
- High strength. This material is actually used to make packing containers that hold hundreds of pounds of materials.
- Very quiet. Even in high winds this material gives off almost no sound that can be heard beyond a few dozen paces.
- Easy to obtain. This material is widely used for signs and can be found world wide in sign stores or plastics supply companies.
- Recyclable, at the end of its operating life the material can be recycled.

The only drawback we are aware of is that the material is not UV tolerant. According to the manufacturer, when used as a sign material it will start to degrade in two to three years. We have been weather testing pieces of plastic for about five months now, and we have seen no deterioration yet. However, we have not had extreme cold temperatures of winter yet, so only time will answer the question of how long it will last in a windmill application.

Also, we would like to point out that just because the material does not last more than 3 years in a signage application does not necessarily rule out that it will last longer in our application. While the material will be under much more stress when used as a wind turbine blade material, the judgement of whether it is still usable is quite different from a plastic outdoor sign! In fact, the manufacturer may have meant that color fading and minor imperfections would start to occur in two to three years. In a wind turbine application such considerations are not important. The only important thing is whether it holds together. We believe some patching could be done to extend the life the material as well. A little duct tape might repair minor defects that arise over the years and extend the life significantly.

In any case, we do not feel a $15 replacement cost once every few years is a major problem. Using an electric screw driver, the blade coverings could be replaced in about one hour. This would be quite within a normal maintenance requirement of most commercial wind turbines in terms of both time and money.

Other Possible Blade Coverings

Other possible blade coverings include:

- Sheet metal. We rejected aluminum flashing material after testing it last winter. It was found to be very noisy in high winds. It also suffered from small fatigue cracks after only a few months, and we feel it would be quite shredded in a year or two. It is also rather sharp and presents cutting hazards. It is possible that a heavier grade of aluminum sheet metal would work properly, but it would be unlikely to be as lightweight and easy to work with as the corrugated plastic.
- Sail cloth. We rejected these materials based on price. There are many different grades and types, but all the ones we looked at were between five to twenty times more expensive than the plastic. We never tried to see how they worked, however, and sail cloth might be fine to use if you have a source of used or surplus material.
- Tyvek. This material is used to wrap houses and even to make lab coats. We tried it, and it shredded to pieces in the first 40 MPH wind storm. A heavier grade might work better, though. It was also rather noisy, sounding like large sheets of paper being rattled. We did not pursue investigating other grades of the material.
- Other sheet plastics. There are more grades and types of sheet plastic than we can mention here. It is quite possible that a much better material is out there. In terms of price and availability, though, the corrugated plastic is hard to beat. Every other plastic material we looked at was more expensive for the same strength and size characteristics, or would be very hard for people to find locally.
- Fiberglass. This was both more expensive, and also heavier, than the plastic material. But if you care to make things using fiberglass it would probably make a very nice blade set. It is commonly used for horizontal axis wind turbine blades. It would probably last more or less forever at the slow speeds of a Savonius.

HIGH WIND AREA MODIFICATIONS

We are testing our designs in Northern New Jersey, USA. We are in a class 3 wind zone, rather average. If you are in a much windier place, such as a class 4 or 5 wind zone, you might consider beefing up the blades to handle the larger amount of wind. Here are some ideas we have had, but have not tested. We would enjoy hearing other ideas, or hearing whether these ideas were useful.

It is important to note that these reinforcement ideas add expense to the wind turbine, and also add weight and extra inertia that detracts from startup. If you are in a high wind area then neither of these caveats are of much concern—if you have a lot of wind you need a stronger machine, and the added cost is made up by the fact that you will be getting a greater amount of energy out of the machine. In a high wind area the extra inertia of a heavier blades is also not as much of a concern, since presumably there is plenty of wind on most days for start up purposes.

Reinforced Plastic Edge

The place where the plastic meets the wood, held in place by screws, is under a good deal of stress in high winds. It is possible that over time the screws will eventually pull through the plastic. This top edge could be reinforced by placing a three-quarter inch strip of metal along the length of the plastic, and punching holes in this metal for the screws to be inserted through. Such strips can be found in hardware stores, they are used in plumbing for hanging pipes in basements, and already have holes in them in some cases. They are often made from copper which will not rust. This strip would help distribute the pressure from the screws along a wider area and would also offer some weather protection and UV protection to this crucial area of the plastic covering.

Another area of concern at the wood/plastic interface is that the screws will pull out of the plywood. If a good grade of plywood is used and pilot holes are drilled for each screw the hold should be good. But, over time as the wood wears out the screws may start to pull through. Small angle brackets could be placed once every few screws to combat this. The angle brackets could be screwed in both on the edge where the plastic is, and also on the top of the blade support, through the plywood rather than edgewise. This would be most important at the curved area of plastic, and less so on the flat area that is under less stress. So, you could put several brackets on the curved portion, then space them out more along the flat section, perhaps only having two or three along the entire flat area.

The leading and trailing edges of the plastic could also be reinforced in a number of ways. A simple piece of duct tape or some other weatherproof tape would help shield this part from weather and give it more strength. Another idea would be to thread a heavy wire through the corrugation along this edge and attach the wire to the top and bottom of the blade supports with a screw. This would serve to reinforce the entire length of the leading edge, which faces the heaviest stream of wind.

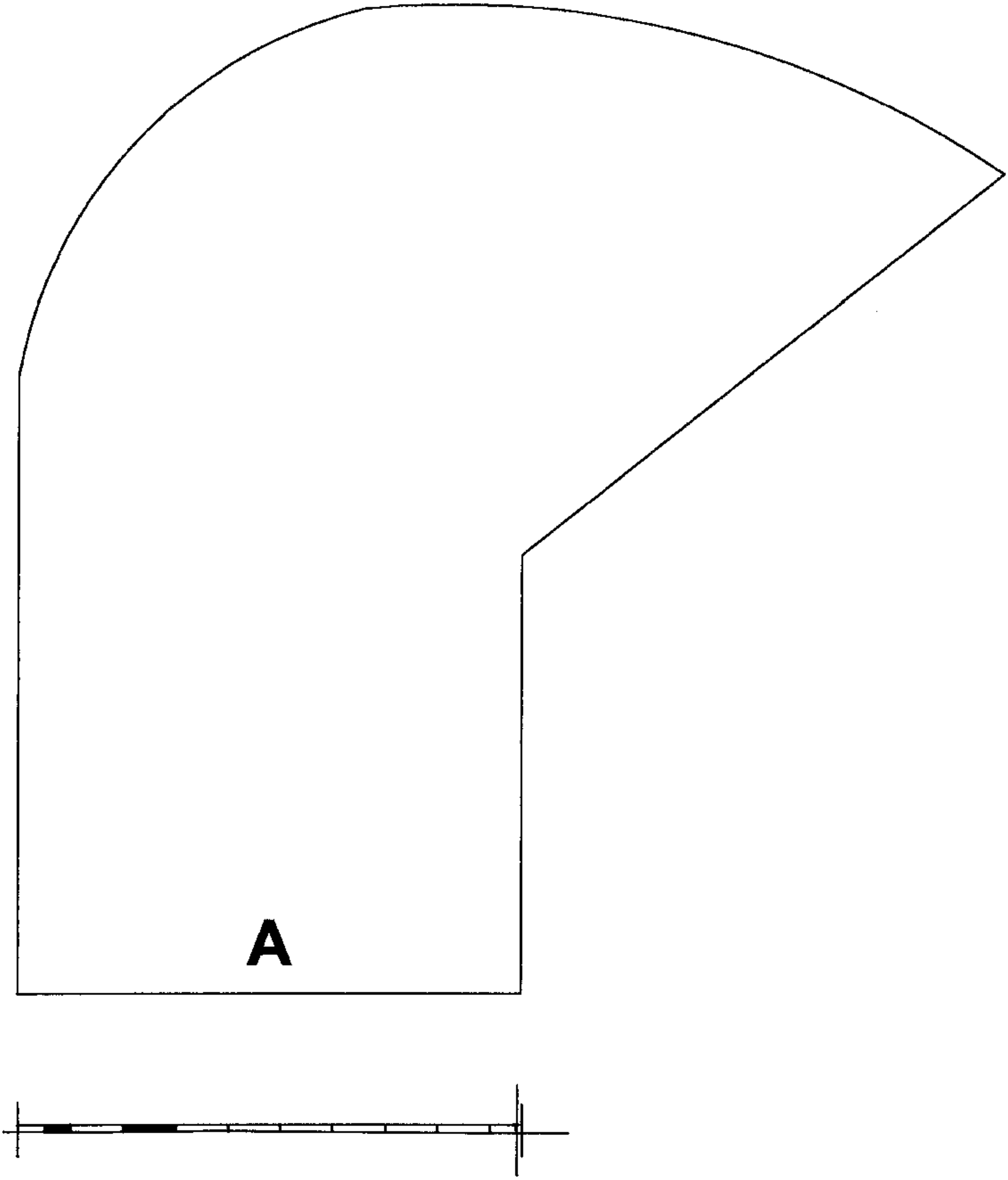
Reinforced Blade Support

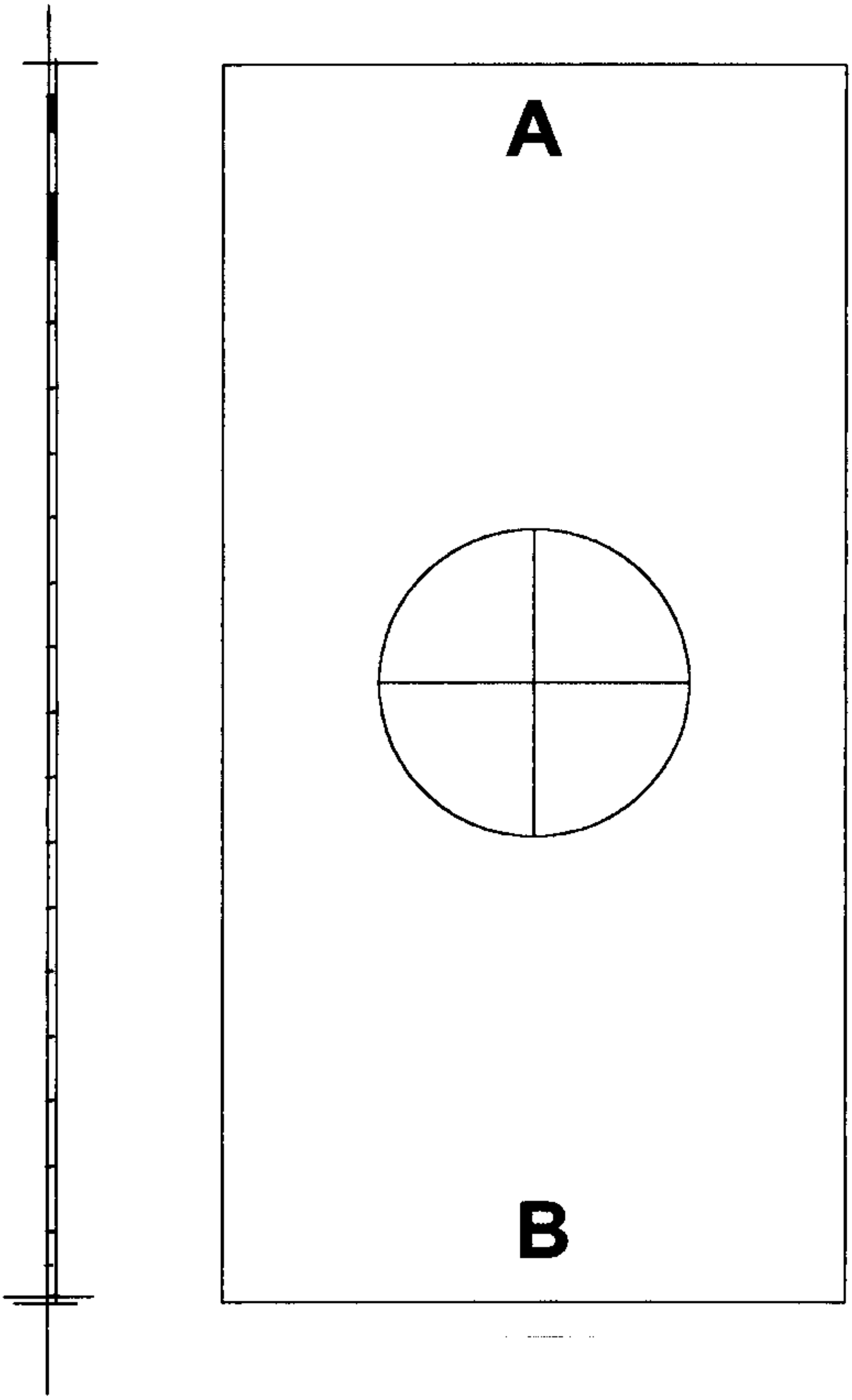
The blade support can be made from 1" thick wood instead of plywood. There is a lot of waste in this case because you must use a 12" wide board and much of it will end up being cut away. Another idea is to just reinforce the central section by running a piece of 1x4" wood underneath the plywood, stopping when you get to the curved sections. This can be affixed using about a dozen screws, put in from the plywood side with pilot holes.

Doubling up the pipe clamps by using two per blade support would give an extra bit of hold to the blades against consistently strong winds. Longer angle braces might be needed in this case to accommodate the two clamps.

A4 paper size
8.27 x 11.69 in.
210 x 297 mm.

TEMPLATES





A4 paper size
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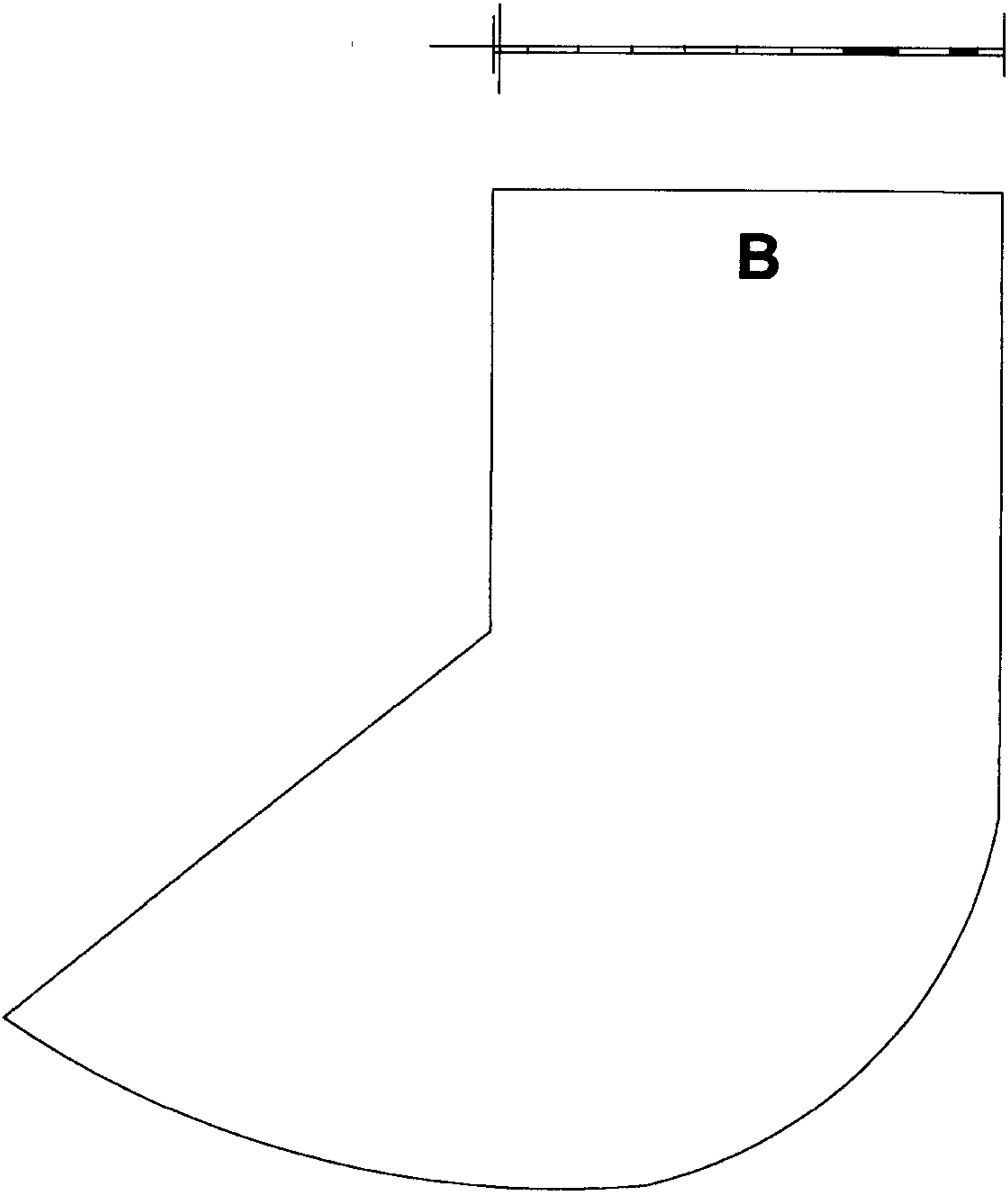
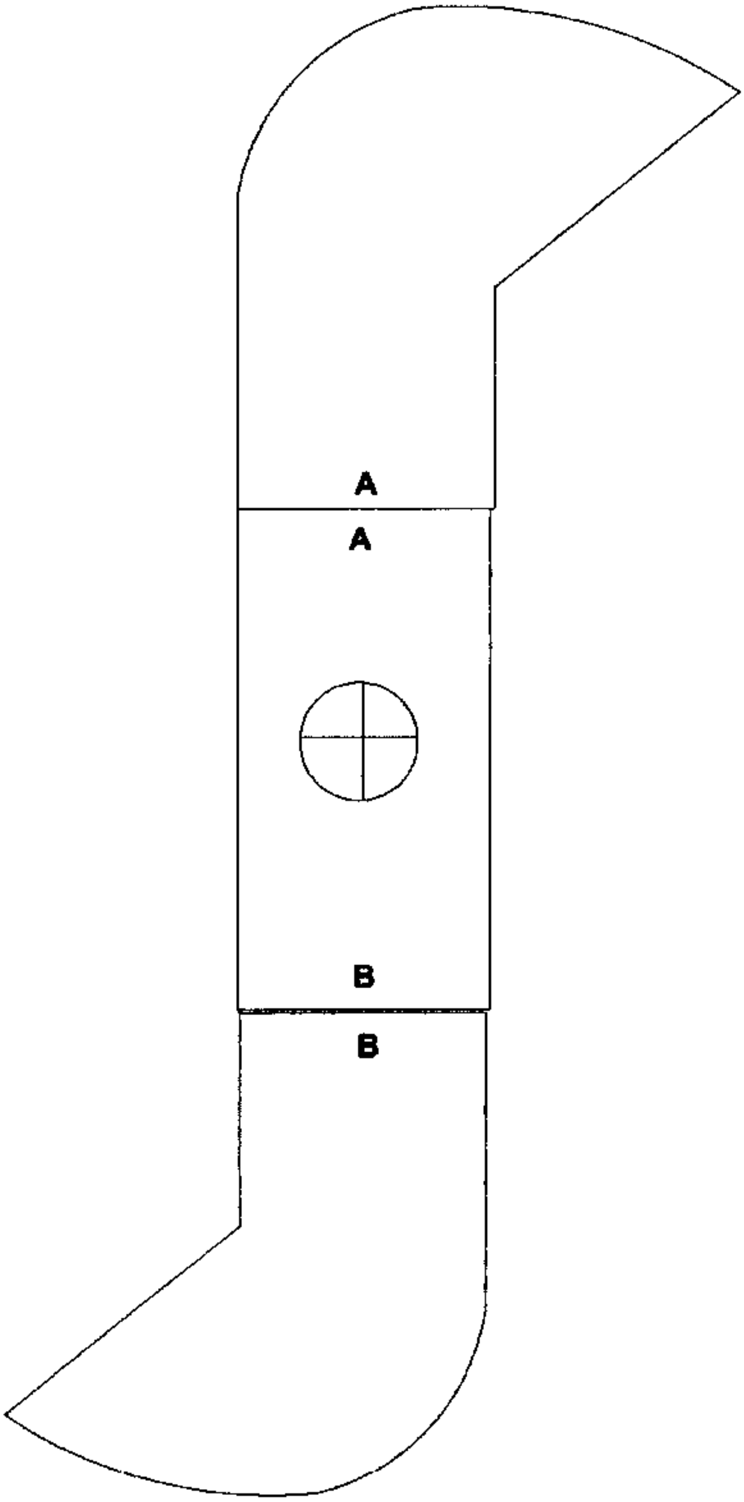
210 x 297 mm.



A4 paper size
8.27 x 11.69 in.
210 x 297 mm.

The templates are to be cut out and assembled like this using tape:



PicoTurbine Deluxe Windmill Plans

Instructions, Teacher's Guide, and Technical Notes

An easy to build project for adults and children grade 10 and above. Explains wind power generation concepts, including three phase alternators, rectification of three phase current, battery charging, and load regulation concepts.

BETA

⚠ WARNING:
CHOKING HAZARD - Small parts, wire. Not for children under 4 years.

Revision 1.0A, October, 1999

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CONTENTS

PART 1: Instructions for Building PicoTurbine Deluxe

RELATED PLANS AND KITS

This plan and the associated kit build on concepts explained in the following related kits from PicoTurbine.com. All plans are free for download and can be built with locally available parts. If you cannot obtain parts locally or just want the convenience of ordering a ready made kit, they are available for a nominal charge.

- **PicoTurbine Educational Windmill Kit**
  This inexpensive kit is easy enough for children as young as fifth grade to build with some adult supervision. Using only cardboard, wooden dowels, magnets, and wire, a complete working windmill can be constructed in about 1 hour. The kit includes a bicolor LED that lights up from the electricity produced by the eight inch tall wind turbine. PicoTurbine.com has shipped this kit all over the world, and it is distributed by Paxton/Paterson throughout the United States to High Schools as part of their Alternative Energy course module.
- **PicoTurbine DC Experiments Kit**
  This easy to use kit teaches AC to DC rectification concepts. It includes a solderless breadboard and electronic components such as diodes and capacitors to allow projects to be built without soldering, making it safe for a classroom environment. Building on the PicoTurbine windmill, it teaches four different circuits for use in rectifying AC current to direct current, explaining the concepts with interesting experiments.

For more information or to download free plans or order kits, visit http://www.picoturbine.com and visit the “Project List” page.

PICOTURBINE DELUXE MOTIVATION

The original PicoTurbine Educational Windmill kit is a great way to learn about renewable energy technology. It produces just enough power to light up a small lamp or LED (about 2 volts at 25 milliamps). While it makes for a very cost effective educational experiment, many people have asked for a larger version that is weatherproof and actually produces enough power to be useful.

PicoTurbine Deluxe is the answer to this request! While it only costs about three times as much as the little PicoTurbine kit, it is weatherproof and produces about 30 to 50 times as much power as the small version. In fact, the power produced is sufficient to charge NiCad batteries, or with alternative wiring could even provide a 12 volt battery bank a small trickle charge in a good stiff wind (see Alternative Designs section).

This project builds on the smaller PicoTurbine Windmill kit, which explained basic wind power theory. This kit goes several steps farther, and explains 3 phase wiring concepts as well as battery charging vs. resistive load concepts. Once this project is mastered, the student or adult hobbyist will understand a great deal of wind power and alternator construction theory, and if desired will be ready to try a full sized wind turbine such as the PicoTurbine-250.

PICOTURBINE DELUXE BUILDING TIME

The total build time will vary with your skill level, but generally speaking you should allow 6 to 8 hours of building time to complete this project, especially if you have not done similar types of projects in the past. This assumes you have all materials on hand and organized. Because of the need to paint certain parts and allow glue to dry, the actual build time must typically be spread over a 2 day period. Allow 3 to 4 hours for each day with an overnight period to wait for parts to dry and set. These times are approximate, of course, and it may take you more or less time than estimated here.

BEFORE YOU BUILD PICOTURBINE DELUXE

THESE PLANS ARE CONSIDERED BETA TEST LEVEL. This means they are not fully tested and are only for people who don't mind building an experimental project. In particular, there has not been enough testing to ensure the NiCad batteries used can withstand repeated charge/discharge cycles with the electronic components used, or whether the overcharge shunt circuit will protect it sufficiently in sustained high winds. We believe the main risk of this lack of testing is that the lifespan of the NiCad batteries could be shorter than normal, although there could be other problems that are unknown at this time.

Step 1: Check Your Materials

The following materials are supplied with your PicoTurbine Deluxe kit. If you did not purchase a kit but are using free downloaded plans, you must obtain these items from local supply houses:

- One steel disk, 14 gauge, 8" in diameter with a 3/8" hole in the center. You may need to contract with a local metal shop to have these made if you do not have tools to cut steel. You may be able to find steel "punch-outs" of the correct size at a scrap metal supplier and bore the center hole using a cobalt drill bit. A small variation in diameter is ok. Thicker metal is also ok.
- 16 ceramic grade 5 magnets, 1.875" by 0.75" by 0.375" thick, magnetized on the large faces.
- About 1.5 pounds of 20 AWG enamel coated magnet wire.
- 2 pieces of corrugated plastic, 24" long and 8" wide. Best is 2 millimeter, which is what ships with our kits. Most suppliers only carry 4 mm which is harder to work with but can be made to work by scoring one side half way through (see instructions below).
- A 3/8" inner diameter roller thrust washer. This is a small set of roller bearings about the size of a large washer.
- A small solderless breadboard.
- Six diodes rated 1 amp and 100 volts (1N5400 or similar).
- Two "AA" sized NiCad batteries plus holder.
- One small lamp, rated 3 volts and 100 milliamps.
- A zener diode, with a zener voltage of 2.4 volts and rated at 500 milliwatts.
- A power resistor rated at 2 watts and 10 ohms.
- A red LED.
- A plastic enclosure large enough to hold the battery pack and circuit board.
- A small SPST switch.
- A ¾" wire nut.

The following items are not supplied with your kit in order to reduce shipping costs. They should be easy to obtain from a hardware store. All together these items cost in the neighborhood of $20 to $25. You may have some parts lying around in your basement such as scraps of wood or washers.

- One 3/8" threaded rod, 3 feet long.
- Twelve flat washers and eight nuts to fit the 3/8" rod. The washers should be 1" wide, of the "fender washer" variety. At least 2 of the nuts should be locking nuts, such as serrated locknuts or nylon insert lock nuts.
- One sheet of Plexiglas (or similar plastic sheet) 8" x 10" x 0.09" in thickness. The thickness is not critical. Some other materials that will work are polycarbonate (Lexan or similar), acrylic sheet, or any hard plastic material that can be drilled. Most large hardware stores have Plexiglas in this size because it is used for framing pictures. Try a glass store or picture frame store if your hardware store does not stock such a material.
- Three pieces of plywood 1 foot square, ½" thick (or thicker).
- A small scrap of ¼" plywood, about 2" square or more.

- Four pieces of 2x2 wood 48” long. (Note for non-Americans: 2x2 wood is actually about 1.5” x 1.5”.)
- About two ounces any good waterproof glue such as silicone or hot glue gun, or epoxy resin. Be careful if using hot glue. If you use epoxy, be sure to wear impervious gloves as recommended by the manufacturer.
- A can of metal paint, such as “Rust-oleum” or similar. Only a cup or so will be needed.
- If desired, wood paint can be used to paint the wooden support structure. Alternatively, you can use pressure treated wood that is weather resistant. Painting is recommended to reduce swelling due to water absorption. Only a pint or so is needed.

You need the following tools:

- Screw driver.
- Electric drill plus 3/8” bit, ¼” bit, and a small bit such as 1/8” for drilling pilot holes for screws.
- Shop scissors or a razor knife.
- Pliers or monkey wrench.
- Jigsaw, coping saw, or some other saw capable of cutting curves in wood.
- A few square inches of sand paper to strip wires.

It is also helpful to have the following tools, but not entirely necessary:

- A digital multimeter that can measure AC/DC millivolts is useful for displaying the exact voltage created and adjusting the alternator.
- If an oscilloscope is available, it is instructive to look at the waveforms output by the alternator before and after rectification. This is an expensive piece of equipment and not necessary unless one happens to be available.

Step 2: IMPORTANT: Review Safety Rules

PicoTurbine Deluxe is not a dangerous project to build, but as with any construction project certain safety rules must be followed. Most of these rules are just plain common sense. Be sure to review these rules with students if you are building this project as part of an educational curriculum.

- **Adult supervision is required for this project.**

- **This project is not recommended for children under 14 years old.**

- **Children must be supervised when working with scissors, saws, razor blades, power tools and sharp parts and tools to avoid cutting injuries.**

- **Children under 4 years old should never have access to wire or small parts because they represent strangulation and choking hazards. Keep the kit parts out of the reach of small children.**

- **PicoTurbine Deluxe generates low levels of electricity (under 10 volts) that are generally considered safe. But, to avoid shock hazard never work with electricity of any level when your hands or feet are wet.**

- **Persons wearing pacemakers should not handle strong magnets such as those found in the PicoTurbine alternator.**

- **Do not allow magnets to “snap” together, they may shatter and send pieces through the air that can lodge in eyes. The magnets supplied are grade 5 ceramic material and are powerful, if care is not taken they can snap together and pinch fingers or skin causing minor injuries.**

- **Use caution when working with power tools. Use extra caution when drilling through Plexiglas plastic. Secure the sheet of Plexiglas using a clamp between pieces of wood. Do not hold it with your bare hand when drilling, it is possible for the plastic to bind up with the drill bit and spin rapidly, slashing your hand.**

- **Follow all tool and material manufacturer recommendations. If the recommendations of this document conflict with those of the manufacturer, follow the manufacturer’s recommendations instead.**

- **Do not allow NiCad batteries to short circuit. NiCad batteries can be damaged or destroyed in a matter of seconds when short circuited. They can generate very large currents for brief periods of time under such conditions which can destroy electronic components like diodes very rapidly.**

- **This list does not purport to be a complete list of hazards. Use common sense, follow manufacturer recommendations for all tools and materials, and follow standard safety procedures such as the use of protective eyewear, gloves, and boots when using tools.**

Step 3: Building the Rotor

The rotor consists of a metal disk on which the magnets are attached. The templates section at the end of this booklet has an actual size template for the magnet layout. Make a copy of this page, cut out the disk diagram. Cut out the magnet shapes and the center hole using a razor knife. Hint: the corners of the magnets are very close on the inner diameter, leave some paper there so the template does not fall apart.

Obtain a steel disk, 8” in diameter with a 3/8” hole bored in the exact center. Line the template up on the steel disk using the center holes of the template and the disk to ensure a precise match. Use several pieces of tape to hold the template firmly to the disk. Using a marker or pencil, trace the outlines of the magnet shapes you cut out from the template. Be as precise as possible. Remove the template.

Arrange magnets by placing them in the marked spots on the steel disk. The magnets must alternate poles going around the stator disk. Your magnets are marked with a red dot on one side. To alternator poles, you should see first a magnet with a dot, then next to it a magnet with no dot (the dot is on the underside) etc. There should never be two dots showing next to each other, nor two magnets with dots face down next to each other. Now, remove the magnets one at a time, place some glue on the steel disk in the place you just removed the magnet, and replace the magnet. If you are using epoxy glue follow all manufacturer instructions carefully. If you are using hot glue be careful not to burn yourself. Repeat for each magnet, making sure you maintain the same alternating pole pattern (don’t turn the magnet over by accident).

Double check before the glue sets that all magnets are alternating poles going around the circumference of the disk.

Set aside the disk/magnet assembly and allow to set thoroughly. (For epoxy drying time varies, read the instructions. For hot glue setting time is typically only a few minutes.) If you used hot glue, it is a good idea to reinforce the magnets by squeezing some glue around the edges of each magnet, especially on the outer perimeter where centrifugal forces will tend to pull the magnets outward.

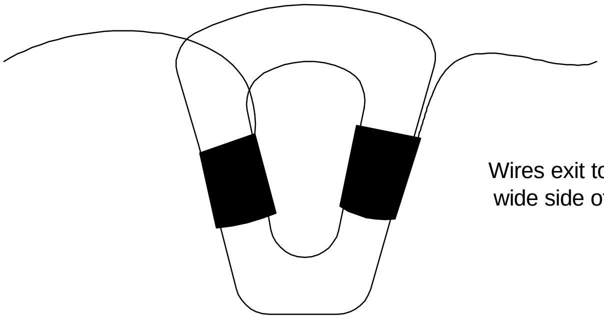
Step 4: Building the Stator

The stator holds 12 coils of wire that actually produce the electricity. PicoTurbine Deluxe uses a 3 phase winding instead of the single phase used in the smaller version. A 3 phase winding provides much smoother operation under load (more is explained in the section Technical Notes).

Step 4a: Winding the Coils

Start by constructing a coil winding tool. This is simply 3 pieces of plywood held together with a bolt. Two of the pieces should be 3” x 3”, and the third should have the shape as shown in the template section titled “Coil Former Template”. Affix that template to a piece of ¼” thick plywood or cut out the template and trace around it on the plywood using a pencil. Cut out carefully with a coping saw, jigsaw, or similar saw capable of cutting curves. Drill a ¼” hole in the centers of these 3 pieces of wood. Insert a ¼” bolt through the pieces, with the smaller piece sandwiched in between the two larger pieces.

Wind 65 turns of #20 AWG magnet wire around the inner core of the winding tool, leaving a 6” long lead at the beginning. Do not cut the remaining wire when you are finished winding! When you are finished, remove the nut and carefully remove the outer side piece. Ready a piece of electrical tape before you remove the wire. Carefully work the wire off the winder without allowing it to uncoil much. As soon as you have it off, securely tape it as shown in the diagram below to prevent unwinding. Make sure it does not get any thicker than the ¼” former it was wound on. Leave a 6” piece of wire and then wind three more coils like this, all as a single piece with about 6” of wire in between. When you are finished, cut the wire 6” beyond the third coil.



Wires exit toward the wide side of the coil.

Use a piece of sandpaper or the edge of a knife to strip the ends of the leads approximately 1”. You must strip the wire completely, removing all of the red enamel coating and leaving nothing but shiny copper. Fine grain sand paper is quite efficient at doing this.

Repeat this process to create three groups of four coils. Each of the 3 groups is made from a single piece of wire that is uncut. Each of these groups will be used to form a single phase of the alternator.

If you have a multimeter, it is useful to check the resistance of each coil group. All should be about the same (within 10 to 15%). The ones we wound in our test models were about 2.0 ohms. Your results will vary based on how tightly the coils are wound and other factors.

Step 4b: Positioning the Coils

Take the Stator template from the Templates section. Take a piece of 8” x 10” Plexiglas and carefully drill a 3/8” hole in its exact center. Find the center by drawing the two diagonal lines with ruler and pencil or marker. Also, drill ¼” holes about 1 inch in from each corner.

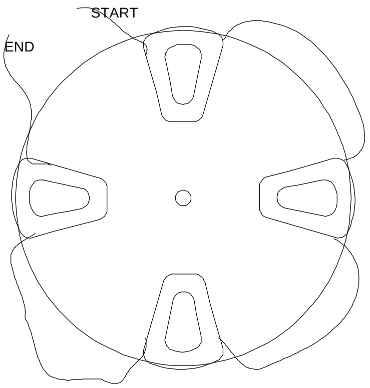
CAUTION: When drilling Plexiglas you should never hold it with your bare hands. If the drill binds to the plastic material it can whip the piece around and slash your hand. Carefully clamp the piece between two pieces of wood or between wood and your work bench, or hold tightly with heavy leather gloves on. Stand back so if the piece does come loose and rotate it will not contact your body. Do not press too hard when drilling or you will crack the Plexiglas material. Also, use a high speed setting if you have a variable speed drill.

Place the Stator Template underneath this piece, aligning the center hole as marked on the template with the center hole you just drilled. Tape it in place so it does not move. You will be able to see the template through the Plexiglas (or similar clear plastic) and precisely position the coils.

Using hot glue or other glue, glue down a single phase of the coils as indicated on the template. The template marks each coil phase by a number, 1 to 3. Use the number 1 for the first phase coils, and so on. The coils must be oriented exactly as shown in the following figure, especially taking note of how the wires come off one coil and go to the next coil. You must not reverse the direction of the coils, they must all be facing the same direction (clockwise or anti-clockwise, it does not matter which as long as all are the same). Coils from a single phase are placed in every third position. There should be two empty spots between each coil.

The second and third phase are placed similarly. Place the second phase by putting coils after each of the coils in the first phase, then place the final phase by filling in the last set of empty spaces. In all cases, there must be two other coils between each coil of a given phase.

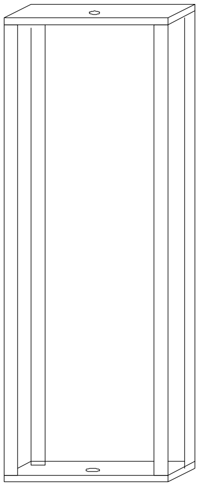
When finished, glue down the wires that connect coils down to the Plexiglas perimeter to keep them out of the way.



One phase of the alternator, note how all wires exit the coils in the same way, no coils have direction of the wire reversed.

Place a flat piece of plywood or board on top of the coils affixed to the Plexiglas. Make sure all the coils are the same height. Place a large, heavy object on top or use clamps to press down the coils and make sure they are nice and flat at ¼” in thickness. Use hot glue or epoxy to help hold down any coils that are too high if needed.

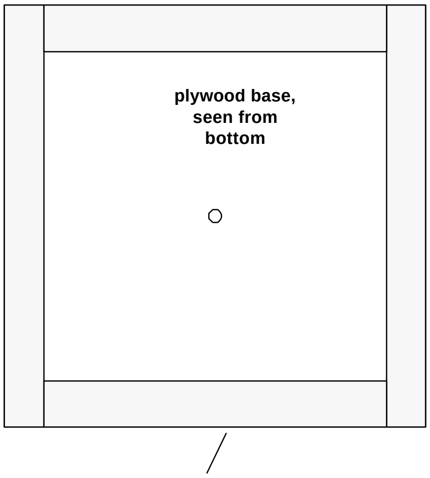
Step 5: Building the Frame



Cut 2 pieces of ½” thick plywood to 12” by 12”. Drill a 3/8” hole in the exact center of each piece of plywood.

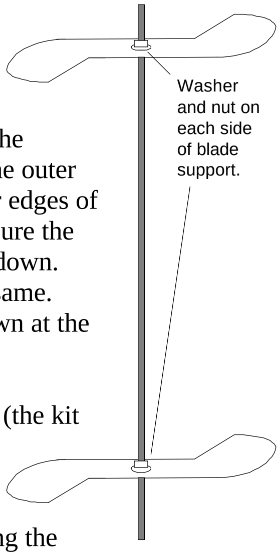
Cut 4 pieces of 4 foot long 2x2 wood to 34” in length, and keep the approximately 14” pieces you cut off. Affix each piece of 2x2 wood to a corner of one of the pieces of plywood by first drilling a 1/16” pilot hole then using 1 ½” wood screws. Drill pilot holes for the top piece of plywood but only insert one screw for now and keep it loose. The whole assembly is basically a “box” with two plywood pieces for a top and bottom and four posts at each corner, very simple.

Using the approximately 1 foot long pieces you cut off the 2x2 wood, create a square reinforcement frame on the underside of the bottom plywood base. Do this by cutting 2 pieces to exactly 12” long and attaching them to two opposite sides of the 12 x 12” plywood base, then cut the other two pieces so they fit in between as shown in the following diagram. Use wood screws from the top side of the plywood. It is recommended you drill pilot holes first. This frame is necessary for two reasons. First, it will allow the axle rod to extend below the bottom edge of the plywood which can be helpful for adjustments. Second, it will help to prevent the plywood base from warping, which could cause magnet/coil collisions in the alternator.



Step 6: Building the Blade Assembly

Cut out the Blade Support Template from the templates section of this booklet. Trace it twice onto a piece of ½” plywood and cut out the pieces using a coping saw, jigsaw, or similar tool that can cut curves in wood. Drill a 3/8” hole as marked on the template.

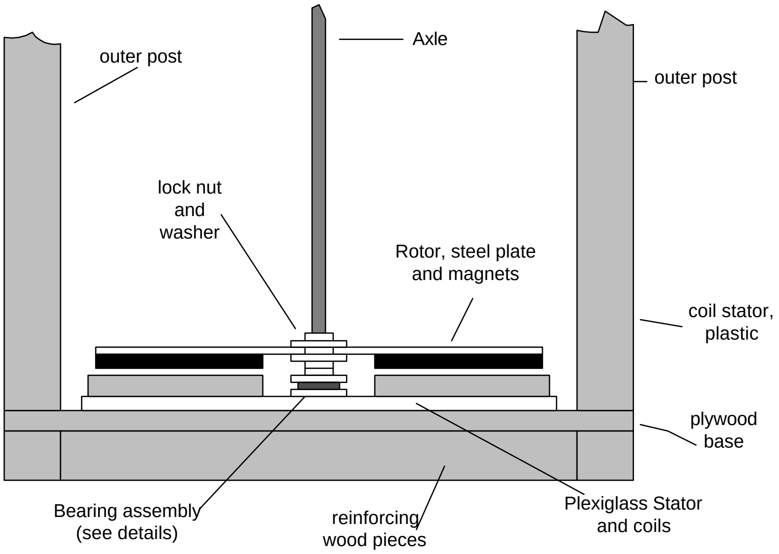


Thread a nut about 6” from the bottom of a 3/8” threaded rod. Then place a washer under the nut and then one of the blade support pieces you just cut. Use another washer and nut to secure this support to the rod, tighten using a wrench. Do the same on the other side of the 3/8” threaded rod, but make sure the distance between the two blade supports is exactly 24” when measuring from the outer edges (in other words, it is 23” between the two when measuring from the inner edges of each piece of ½” plywood that the blade supports are made from). Also, make sure the two blade supports are positioned in the same way, do not position one upside-down. When viewed from above, the two shapes should overlap exactly and look the same. They should be rotated so they match up when viewed from above (looking down at the top surfaces of the blade supports. See the following diagram.

Take a piece of corrugated plastic and cut a piece exactly 24” long and 8” wide (the kit has these pre-cut for you). To make it easier to bend the plastic around the curved supports, it is suggested that you use a piece of scrap wood or a stiff yardstick to make 1” wide folds in it. Just press the ruler or wood strip against the plastic and fold over, forming a crease. These creases should be along the long edge of the plastic, i.e. in the same direction as the corrugations, not against them. About 3 such folds equally spaced is sufficient. The creased part will be attached to the bend as shown in the blade support template.

Drill 1/16” pilot holes as marked on the blade support template. Using small wood screws (1/2” long, thin) attach the plastic where indicated on the template, screwing into the side of the plywood blade support.

PicoTurbine Deluxe Rotor/Stator
Assembly (side view)



Step 7: Putting the Turbine Together

Place the stator on the bottom piece of plywood with the center holes of the two parts matching exactly. Use several wood screws around the outer edge to securely fasten down the bucket bottom stator.

Thread a nut about 3 inches down one side of the threaded rod, followed by a washer. Place the steel plate below this nut and washer, with the magnets facing down as shown in the following diagram. Place another washer and two more nuts below the steel plate. Then place another washer, the needle bearing, and yet another washer below the final nut, leaving about ½” of threaded rod exposed. Tighten the nuts to just light finger tightness so the steel disk remains fixed in place. Put this assembly through the center hole (keep the top piece of plywood swung out of the way for the moment.

Adjust this whole assembly so that the magnets float about 1/8” above the coils. You could use more washers if that makes things easier. Once it looks good, swing the other piece of plywood (the top) over and insert the top of the threaded rod into it. Screw it down lightly with only 2 screws on each diagonal. Spin the top of the threaded rod between thumb and forefinger, it should spin freely and there should be no collision with the coils (listen for a scraping sound). If there is a collision, adjust the nuts again or insert another washer at the bottom, but make sure it is not too far away, 1/8” is the most it should be. If you have built your coils very flat this should be possible. Once it looks good, tighten up the nuts using two wrenches and screw down the top piece of plywood tightly.

A few drops of oil on the bearing assembly and in the hole on the top plywood piece will help the assembly spin smoothly and with very little friction. If you take it outside even a very gentle breeze should start it up (about 2 to 3 miles per hour, even though you will not get much electricity from such a light wind).

Step 8: Wiring for DC Output

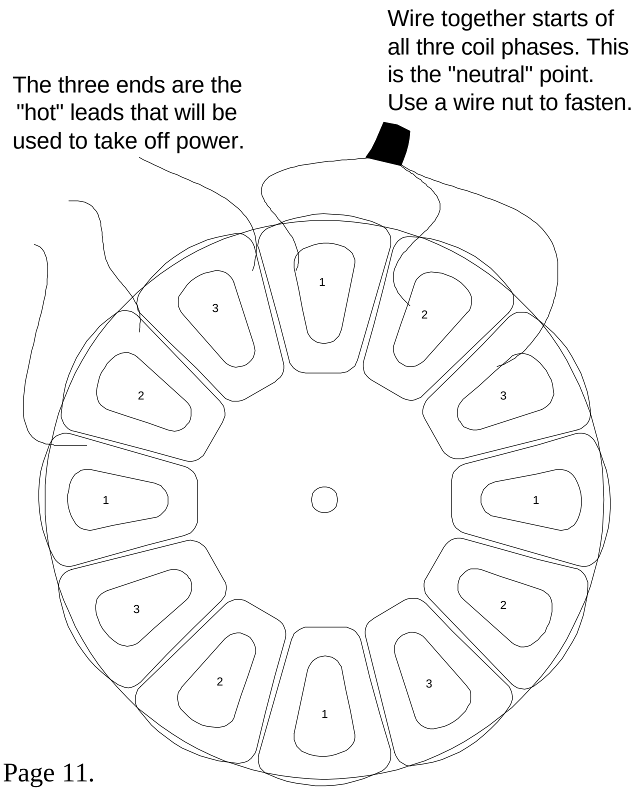
The PicoTurbine Deluxe alternator creates 3-phase AC power. For most applications this must be translated to DC (direct current). This is accomplished using a circuit called a rectifier that uses diodes to ensure current flows only in one direction.

If you have a digital multimeter, you can check the output from each phase before beginning. Connect the multimeter in AC volts mode, and give the turbine a good spin. From a single phase, you should get between 2 and 3 volts depending on how fast you spun the turbine and how well built it is (most critical is how small the air gap is between coils and magnets). Each phase should perform approximately the same.

You cannot simply connect the three groups of wires in series or parallel. This is because the waveforms of the voltage and current are out of phase between the three groups. If you simply connected them in series or parallel one phase would partially cancel out the other phases and power would be lost. Each phase must be rectified individually.

The wiring diagram to the right shows how the output wires from the alternator should be connected. Starting wire from each of the 3 phases are connected together, forming a “neutral” point. This point will be a reference of zero volts, and will not be used for rectification. It can be tied off with a wire nut. The other three wires are the “hot” wires that will be used in the rectifier circuit given in the next section.

After making this connection, you can connect your multimeter in DC volts mode to any two of the hot output leads. Give a good spin and you should see approximately 1.7 times as much voltage as you saw from a single phase. To test how much voltage

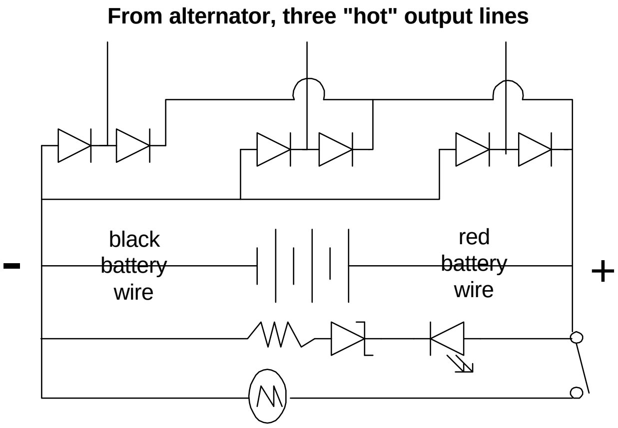


comes from a single phase, just measure from the neutral point to any of the three hot leads.

This type of wiring is called “star” configuration. When rectified, it sums the voltages of the three coil groups but leaves current the same as a single coil group. An alternative wiring is shown in the technical notes section, called “delta” wiring. It leaves voltage the same as a single coil group but multiplies the current by a factor of 3 on rectification.

Step 9: Wiring for Battery Charging

We can easily build a battery charging application from the rectified current produced by the circuit. Connect the battery as shown in the following diagram. BE VERY CAREFUL. You must connect the correct leads of the battery as shown. Shorting a NiCad battery can quickly destroy it and cause a surge of current that could destroy the diodes as well.



Zener diode shunts power to resistor if battery voltage exceeds 2.4 volts, reducing risk of overcharge. When the shunting occurs, the red LED lights indicating an overcharge situation.

You can place these components into a waterproof box with a clear lid (supplied with kit) and create a small wind powered night light. Be sure to switch it off during the day and let the wind charge up the battery. At night you can turn on the switch and let the light be powered by wind and/or battery. By morning the battery will likely be discharged unless you had a lot of wind that night. The circuit shown also has a simple overvoltage feature.

A zener diode is used to shunt voltage to a power resistor if the battery exceeds a voltage of about 2.4 volts. Thus, power may be drained even if the switch is open, if the battery is full and the wind turbine is still charging it. This provides some protection for the battery, since overcharging can quickly limit its life. However, in a protracted strong wind this may not dissipate enough power to save the batteries, so caution should be used. During protracted windy periods it would be best to keep the light turned on to provide an additional load, or disconnect the battery entirely if you will not be in a position to monitor the situation from day to day.

PART 2: TEACHER'S GUIDE

Key Concepts

The key concepts taught by this project are:

- Three phase alternator wiring,
- Power rectification of three phase current,
- Battery charging issues such as dump loads,
- Resistive load issues such as cut-in.

As such, this project builds on the information found in the PicoTurbine Educational Windmill Kit and the PicoTurbine DC Experiments Kit. If those projects were not built first, you might want to review the technical information and teacher's guide for basic wind power information. The plans are available free for download.

The concepts in this project are obviously much more advanced than the small educational kit, and are appropriate for high school students or perhaps gifted children of a younger age who are interested in electronics and renewable energy.

Group Projects

In a classroom setting this is best built as a group project. If you do not have the capability to use power tools in the classroom, the wooden and plastic parts that need to be cut could be pre-cut in the school's wood shop or elsewhere. With all wooden parts cut and drilled to the proper dimensions, and the coil former constructed, no other power tools are needed. Simply a screw driver and pliers are sufficient to finish the project.

In a classroom environment a hot glue gun is probably not a good idea. The safest adhesive to use would be silicon glue, but it has a long drying time. If it is not necessary for the project to be used in severe weather you could substitute waterproof double-sided tape to hold the magnets to the rotor. The magnets tend to stick to the rotor anyway because of magnetic attraction, but if not taped or glued they could fly out of position at high RPM. If silicone glue is used, then final assembly would normally have to wait until the following day to allow 24 hours for full setting of the glue.

Mounting

The finished turbine could be mounted out of doors and monitored by the students over a period of time. It is best to mount the turbine at least four to five feet off the ground. This is to keep it clear of snow drifts (if you are in a temperate region) and also to get better wind. Near the ground the wind is usually much weaker. Mounting could be as simple as nailing the unit to a heavy base of some kind, such as a 4x4 beam, or perhaps by screwing the bottom of the unit to a flange screwed onto a 1" black pipe driven into the ground. It is necessary that the unit be held steady, or it will not be able to reach its maximum speed.

Experiments

Here are some experiments and project ideas that go beyond what is discussed in the building section.

Data Logging

A good long term project would be to measure output from the unit at the same time of day over a period of days or even weeks using a voltmeter. Another method would be to leave the light turned on for a certain number of hours each day and measure the state of charge of the battery periodically using the voltmeter. The measurements could be graphed and compared over time to note seasonal wind conditions and power production potential from a larger unit.

Electric Brakes

It is possible to implement a simple “electric brake” for this wind turbine. This is a very instructive experiment to perform on a windy day.

First, short circuit one of the three alternator hot leads to the neutral lead. This should slightly slow down the turbine, but it should be noticeable except in very strong winds. Remove the short and allow the turbine to speed up again, then try shorting two of the three hot leads with the neutral. This should slow the turbine down still further. Finally, short all three hot leads to the neutral lead. Unless the wind is very strong, this is likely to bring the rotor to a halt, or at the very least slow it down dramatically. This is because you are trying to take too much power off the alternator and this causes a magnetic drag effect.

You could build such a brake in a more permanent fashion using a single pole triple-throw (SP3T) switch. Connect the neutral point of the star to all 3 of the connections on one side, then connect one of each of the hot leads to each of the other switch terminals. Now, throwing the switch will connect each of the hot leads to the neutral lead, which should stop or at least greatly slow down the turbine. You could mount such a switch inside a waterproof enclosure with a lid, perhaps under the top section of plywood to help keep it dry.

Where is this power going? It is being dissipated as heat from the alternator coils. In this small turbine this is unlikely to ever cause a problem. In a larger, more efficient commercial turbine the heating could be very detrimental if the turbine fails to stop within a few seconds of applying the brake. The coils could literally melt from the heat generated.

Many small commercial systems use exactly this method to stop the turbine blades. It works as long as the wind power is not so strong that it can continue to turn the blades even on a short circuit. Because most commercial turbine alternators are built to be about 80% or more efficient, that means the wind would have to be so strong that it can keep turning the blades even though more than five times as much power is being drawn than normal.

Hybrid Systems

An excellent study would be to mount some solar photovoltaic (PV) cells on top of the unit (the plywood section on top has plenty of room for some cells) and produce a hybrid wind/PV system. We would suggest a PV cell that produces between 2 and 5 volts peak at 100 to 400 millivolts peak. Note how often the wind system compensates for the solar system and vice versa, providing an increase in reliability of the system. A blocking diode will be needed so the battery does not back-feed the PV at night. Connect the PV cell to the battery in parallel with the wind turbine output so that either or both can feed the battery. You should use a larger battery or have more load available (or both) to avoid overcharging on days that are both windy and sunny.

PART 3: Technical Notes

Three Phase Alternator Windings

The PicoTurbine Deluxe uses a three phase alternator. Each group of three coils is slightly out of phase with each other group. For example, when a magnet is directly over the center hole of the first magnet in phase 1, then the same pole of some other magnet is directly over the center hole of each other coil in that phase. Conversely, no other coil of any other phase has a magnet so positioned.

The effect of this is that waveforms for voltage and current overlap as shown in this figure:

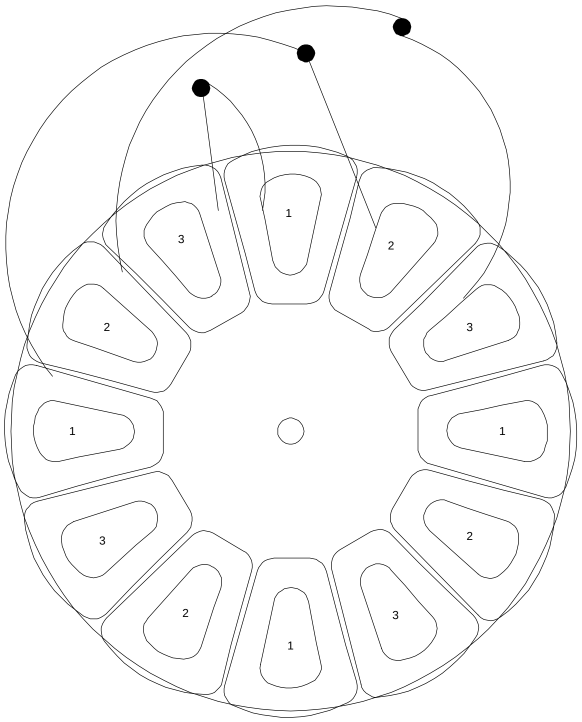
There are several advantages to a three phase winding (as opposed to a single phase winding as used in the small PicoTurbine Educational Windmill kit):

- The turbine experiences much smoother operation because power is taken off more evenly. In a single phase winding the power is taken off of all coils at the same time (as magnets cut across the plane of the coil legs) and power goes to zero all at the same time (as magnets are between coil legs). This causes a “jerky” motion of the rotor assembly, resulting in wear and tear and noise.
- For similar reasons, rectified voltage and current are much smoother using three phase windings, even without the use of smoothing capacitors. Voltage and current remain more nearly in phase overall after rectification, meaning the “power factor” is better.

Star and Delta Wiring

You might think at first that six wires would be needed to take power off of a three phase winding. Actually, some wires can be shared, resulting in 3 wires emanating from the alternator. The two standard ways of achieving this are called “star” and “delta” wiring. In general, “star” configurations are used to attain a higher voltage, while “delta” is used to attain higher current. Power output from either is the same since power is voltage times current. In the text, a “star” winding is used to achieve high enough voltage to charge the two series NiCad batteries in low winds. “Delta” wiring is shown here and would result in lower voltage and higher current.

The three black dots mark the "hot" leads that will be used to take off power. There is no "neutral" in delta wiring.



One interesting idea is to use a relay to switch between “star” and “delta” wiring configurations depending on wind speed. This is a simple form of voltage regulation, and could be used to optimize two different points on the power curve, for example for battery charging. More on this topic is discussed in the next section.

Another idea, used by some commercial turbines, is to wire two sets of three phases, and have one of these sets wired star and the other delta. The star wired set will cut in at a lower wind speed but provide less current, the delta set will cut in at a higher wind speed and provide more current. A third idea along these lines, used by Hugh Piggott of Scoraig wind electric, is to have each coil contain two separate sets of wires, one heavier gauge than the other with fewer turns and the other thinner with more turns.

Again, one set of wires cuts in sooner but provides less current (for low winds) and the other provides higher current to take advantage of higher winds.

Battery vs. Resistive Loads and Efficiency

The circuit described in this booklet is a battery charging circuit. It is interesting to compare the mathematics of battery charging versus a resistive load such as a light bulb.

Battery Load Formula

The formula below shows the current flowing into the battery (IBAT) depending on the rectified voltage coming from the alternator (VALT) and the battery voltage (VBAT) as well as the coil resistance (RALT):

IBAT = (VALT – VBAT) / RALT

So, for example, if the battery is a NiCad and it currently holds a charge of 1.0 volts, and our alternator is currently outputting a rectified voltage of 2.0 volts and has an internal coil resistance of 5 ohms, then we would expect that (2.0 – 1.0) / 5 = 200 milliAmps to be flowing into the battery. The power being produced is this current times the battery voltage—in this example 200 milliAmps times 1.0 volts which is 200 milliWatts.

Resistive Load Formula

On the other hand, the mathematics of a resistive load are a bit different. A new variable must be added: the resistance of the load (RLOAD). The output power of the alternator is maximum when the load resistance is equal to the alternator's internal coil resistance. The current sent to the load would be:

ILOAD = (VALT * RLOAD) / (RLOAD + RALT)^2

For example, if as before our alternator is outputting 2.0 volts and has an internal resistance of 5 ohms, and we are driving a light bulb that has a resistance of 3 ohms, then the current flowing through the bulb would be (2.0 * 3) / (5 + 3)^2 = 6/64 = 93 milliAmps. If the bulb was 5 ohms, we achieve maximum current flowing to the bulb of 100 milliAmps. Load resistances of more or less than 5 ohms will result in less current making it to the load. Useful power is the alternator voltage times the load current. In the first example, 93 milliAmps times 2.0 volts, or 186 milliWatts.

Comparison of Battery vs. Resistive Loads

Let's compare how much useful power is generated in resistive vs. battery load conditions. The voltage coming off the alternator is proportional to its RPM. If you have built this project reasonably well, you might expect something like 1 volt for every 60 RPM (rectified, star wiring). Let's compare a 1.0 volt charge state NiCad battery vs. a 5 ohm light bulb at various speeds and note the amount of useful power being produced by the turbine:

RPM	Voltage (rectified)	Power to 1.0 Volt NiCad (watts)	Power to 5 ohm lamp (watts)
60	1.0	0	.05
120	2.0	.2	.2
180	3.0	.4	.45
240	4.0	.6	.8
300	5.0	.8	1.25
360	6.0	1.0	1.8
420	7.0	1.2	2.45

As you can see, the characteristics are quite different. The NiCad does not begin drawing current until the alternator voltage exceeds the battery voltage, and after that point the power increases linearly with increased RPM. On the other hand, the resistive load starts drawing power immediately, no matter how low the voltage from the alternator is. It draws power at a much higher rate as RPM increases. In fact, power drawn increases with the square of the RPM—doubling the RPM increases power by a factor of four to a resistive load but only a factor of two to a battery.

This behavior is brings both advantages and problems. If used for battery charging, a wind turbine that is directly connected will “cut in” as soon as its output voltage exceeds the battery voltage. This is good—it means the rotor can come up to speed with no load. In the resistive load case special controls are needed to prevent the load from cutting in before the rotor reaches a reasonable speed, in the battery case this happens automatically. If controls were not used with a resistive load then an efficient alternator might never allow the rotor to get started in the first place, and no power would be produced.

The disadvantage of a battery load is that without special controls the power take-off is linear and does not come near to matching the power curve of the wind (which is cubic). So, system efficiency degrades rapidly as wind speed increases. A resistive load matches wind power much better, being a quadratic curve (although it still lags the cubic nature of wind power).

One improvement to the battery charging curve matching problem would be to switch from “star” to “delta” at a certain RPM. This would have the effect of cutting VALT and also cutting RALT. This would increase the power take-off in a battery situation and help the power curves more closely match. In effect you could “bracket” two wind speeds that would have reasonably high efficiency instead of just one.

Commercial wind turbines often use sophisticated voltage regulation systems to help the power curve of the alternator match that of the wind. These systems typically use power transistors to regulate the voltage and current being delivered to the load.

Dump Loads

The building instructions include a simple circuit to provide a “dump load” if the battery is nearing an overcharge state. This is a common method of protecting batteries while at the same time maintaining a load on the rotor.

For the Savonius design used in this project, it is actually not very important to maintain a load on the rotor. This is because the Savonius design is relatively low speed and even in very strong winds the rotor is in little danger of overspeeding to the point of causing damage to the materials. This is not true of larger wind turbines based on either the usual horizontal axis design or other vertical axis designs such as the Darrius rotor. Those designs will rotate several times faster than the wind (the speed of the tip of the rotor will be up to 11 times the wind speed). A large Darrius or horizontal axis turbine might have a tip speed on the rotor near the speed of sound! Without a load the tip speed increases even further and the machine can literally tear itself apart from centrifugal force.

It is common for small wind turbines to depend on a load always being present to avoid this situation. Large power resistors are often used. An alternative that attempts to take advantage of this excess power would be to dump the extra power into a heating unit such as a hot water heater or space heater. Note that the lamp is not used as the dump load. It would be a bad design to depend on a lamp as a safety dump load: if the lamp burns out during a big windstorm then the dump load is gone!

In commercial systems, the simple zener diode shunt is not typically used. Typically power electronics are used to more precisely monitor voltage and allow for fine tuning of the shunt voltage. This zener based circuit was used in this educational kit because it is cheap and easy to wire and understand.

Alternative Designs and Materials

This section discusses some alternative designs and building materials you could use. We will not present detailed plans and diagrams, just discuss ideas. You should be able to make building adjustments yourself and experiment with these ideas.

Double-disk Alternator

It is possible to quadruple the power output of the alternator by placing a second magnet disk below the coils. To do this:

- Construct a second magnet disk identical to the first.
- Suspend the plexiglass stator above the plywood base several inches, perhaps using bolts or pieces of wood or brackets attached to the uprights.
- Thread the second disk below the plexiglass stator, about 1/8” away so it does not touch it when spinning. The second disk will strongly attract to the first disk so be careful when you assemble this that your fingers don’t get slammed in between the two disks. The second disk will naturally align itself so that its North poles will align with the first disks South poles and vice versa. This is the right way for it to be aligned.
- Move the thrust washer assembly down to the wooden base, don’t support it on the plexiglass which will not be strong enough. Allow the base to bear the weight.
- Use a six foot 3/8” threaded rod instead of a 3 foot rod. Construct blades that are 5 feet long instead of 2 feet long by using multiple sections of supports and plastic (3 sections each 1’ 8” long). Make the blades 1 foot wide instead of 9 inches wide. You can use the same blade templates to cut the curves at the ends, just add three extra inches of wood in the center. You can rotate these three sections from each other 120 degrees to smooth out the torque and help startup in low winds from different angles.
- Increase the length of the side posts to accommodate the taller blades, and increase the size of the top and bottom plates to accommodate the increased blade width.

This design is harder to build and obviously costs more because of the use of the second set of magnets and disk and the extra blade material. It is harder to adjust the spacing for the magnets and coils to avoid collisions yet maintain a small air gap. However, all this trouble is worth it: this version can produce four times as much power as the standard version.

Woodless Construction

The weak point in this design is the use of wood. After a period of time, wood can warp, shrink, or absorb water and swell, which might cause a coil/magnet collision. This will cause the turbine to require adjustments periodically.

It is possible to build the project using no wooden pieces that affect the alternator. Substitute:

- Angle irons for the upright sections of wood,
- ¼” plexiglass sheet for top and bottom supports, or alternatively any type of hard, stiff plastic material such as Lexan, acrylic, etc. Do not use metal (steel, aluminum, etc.) for the bottom plate! This will cause loss of efficiency because the alternator magnets will induce eddy currents in the metal, just like the “electric brakes” discussed previously.

Use angle brackets and bolts to connect the angle irons to the plexiglass. Be very careful when drilling plexiglass as mentioned above in the text. The thicker grade of plexiglass is required for stability. It is not necessary to replace the plywood used for the blade supports with any other kind of material because a little warping of that part will not affect the alternator.

The advantages of this design are that you should be able to reduce the gap between magnets and coils because you won’t have to worry as much about structural warping, and also the plexiglass will provide a better, smoother bearing for the 3/8"”threaded rod. You might expect to get some extra power out of the turbine because of these factors, and it will clearly last longer and require less maintenance.

Alternative Blade Designs

It is possible to use this same basic framework to test different blade designs. It might be instructive to attempt to build a Darrius style blade, which is aerodynamic instead of drag based. This could be built by cutting out air foil cross sections from plywood, stringing them all together with threaded rods, then attaching a “skin” made from corrugated plastic. To find a suitable cross section simply do a patent search on the word “Darrius” on http://www.patents.ibm.com. It is legal to build patents for your own experimental purposes as long as you do not commercially profit from the design. Many patents are expired anyway. An “H-bar” Darrius will be the simplest to construct. Do some web searches and you will find a great deal of information about this design, which has been extensively researched.

Better Bearings

The bearings used in this small wind turbine are not optimal and are a source of friction and loss of efficiency. This is especially true of the top bearing, which is simply a hole in a piece of wood. The bottom bearing is a small needle point roller bearing and is reasonable, however the threaded rod still contacts the wooden frame and causes significant friction.

We have experimented with using a small scrap of plexiglas for the top bearing and have gotten better results. To do this, simply drill out the top plywood hole to a larger diameter (7/16” or ½”). Then drill a 3/8” hole in a piece of Plexiglas about 3” by 1”. Drill smaller, 1/8” holes near the edges to accommodate smaller screws to hold the Plexiglas in place. Position the Plexiglas bearing so that the threaded rod does not contact the wood. Put a drop or two of oil where the rod meets the Plexiglass hole.

It is of course also possible to use ball bearings or other more sophisticated methods of reducing friction. For a small project like this it is probably not worth the expense of purchasing such items, but if you build a larger machine then the efficiency gained can be worth the trouble.

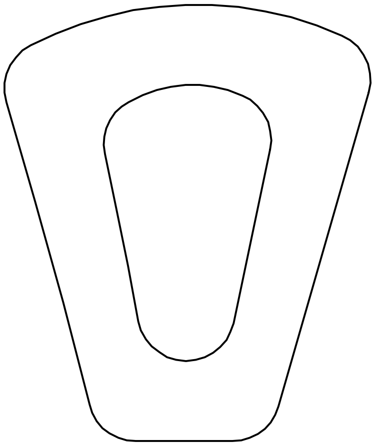
TEMPLATES

The following templates are actual size. As described in the text, they can be used to easily mark parts for cutting or for gluing together. The back sides of these templates are purposely left blank so you can use them directly, but you may want to make a copy of them for safe keeping in case you want to build these projects again later.

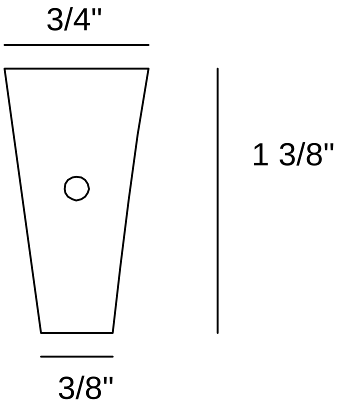
Some of these templates are slightly too wide to print completely on the edges of standard paper. They are still quite useable even though a small amount of the edges are blank.

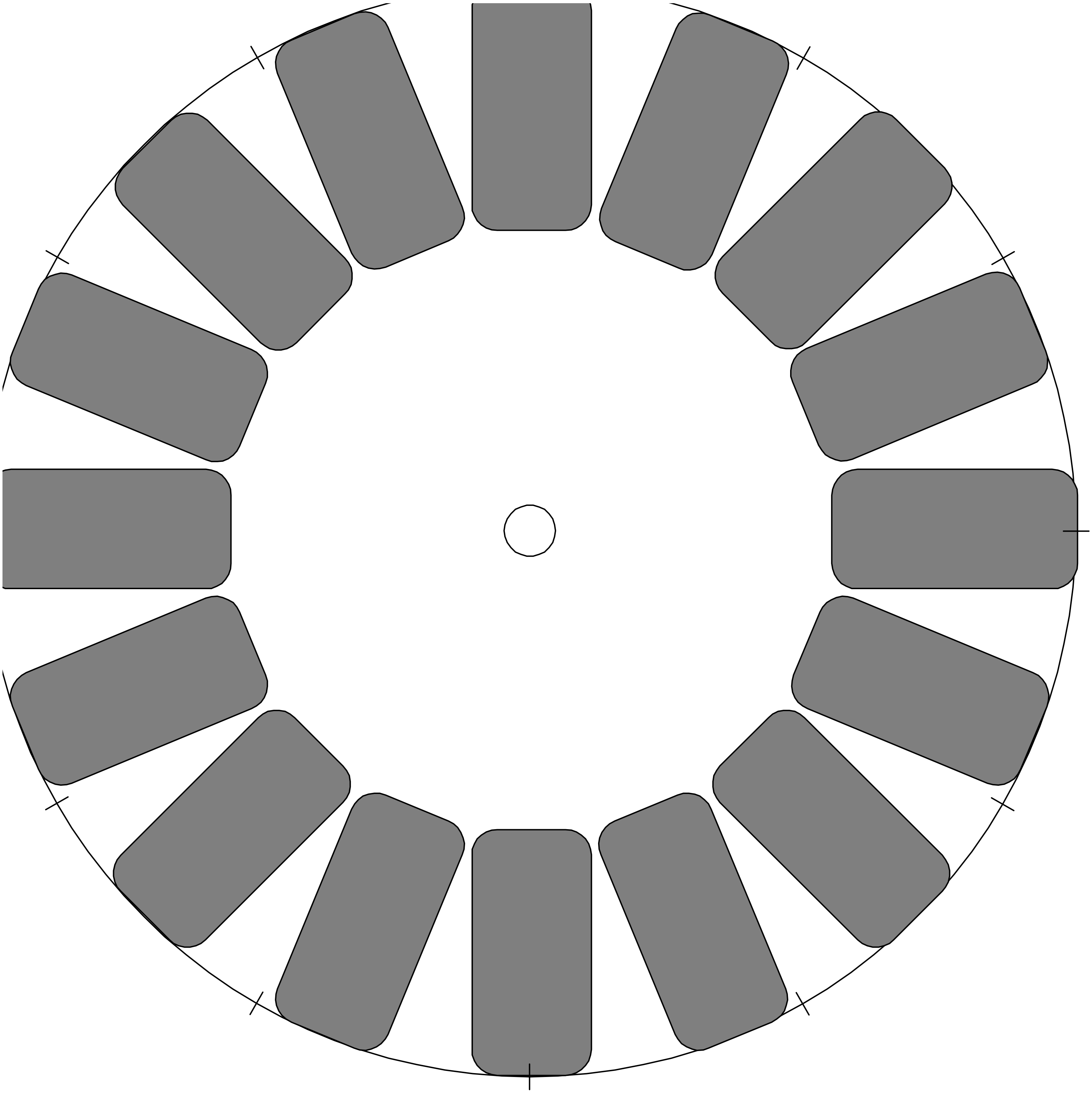
COIL WINDING FORM TEMPLATE

Approximate Coil size
and shape (actual size)

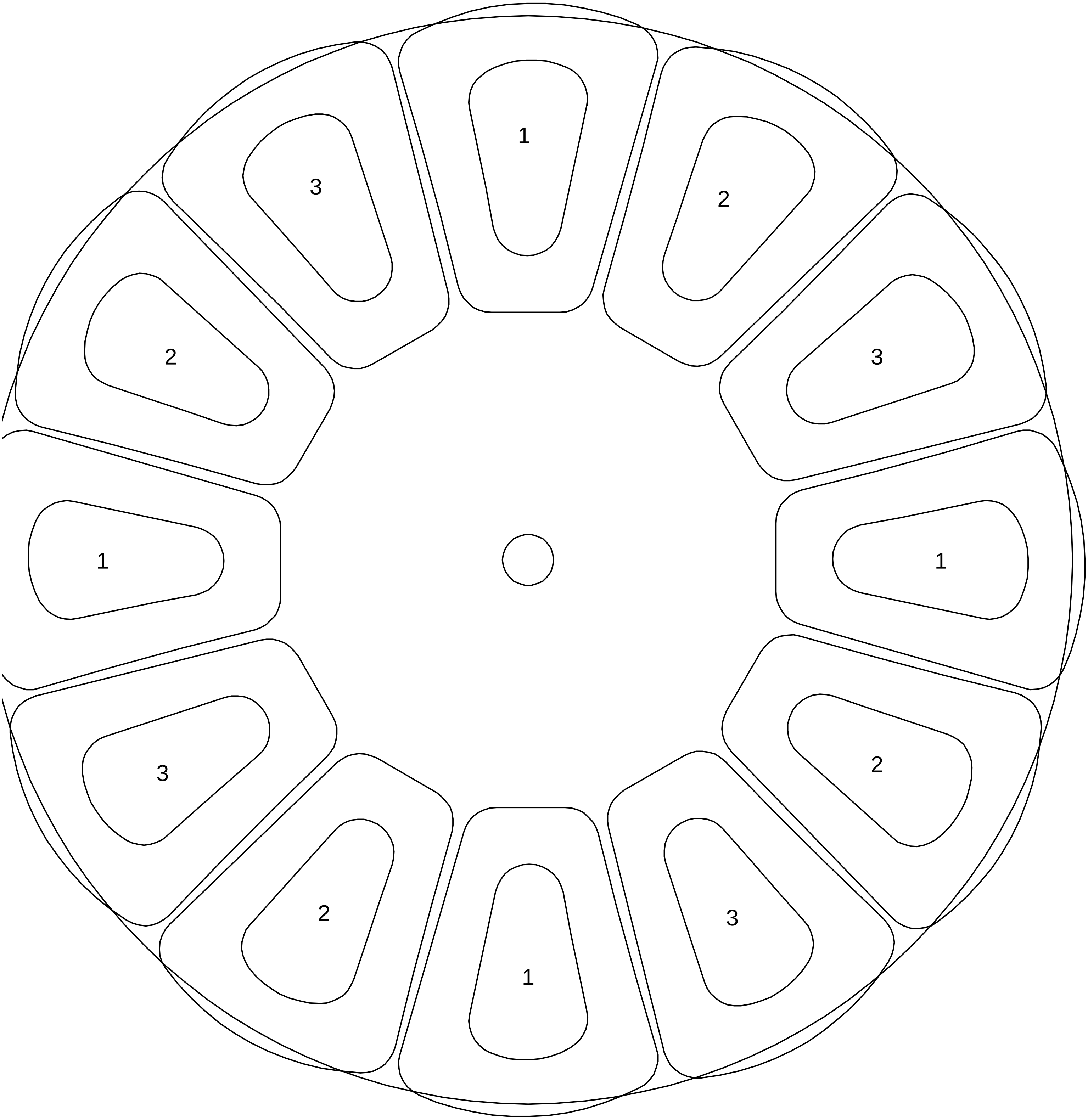


Former wood pattern
(actual size)
Former is 1/4" thick



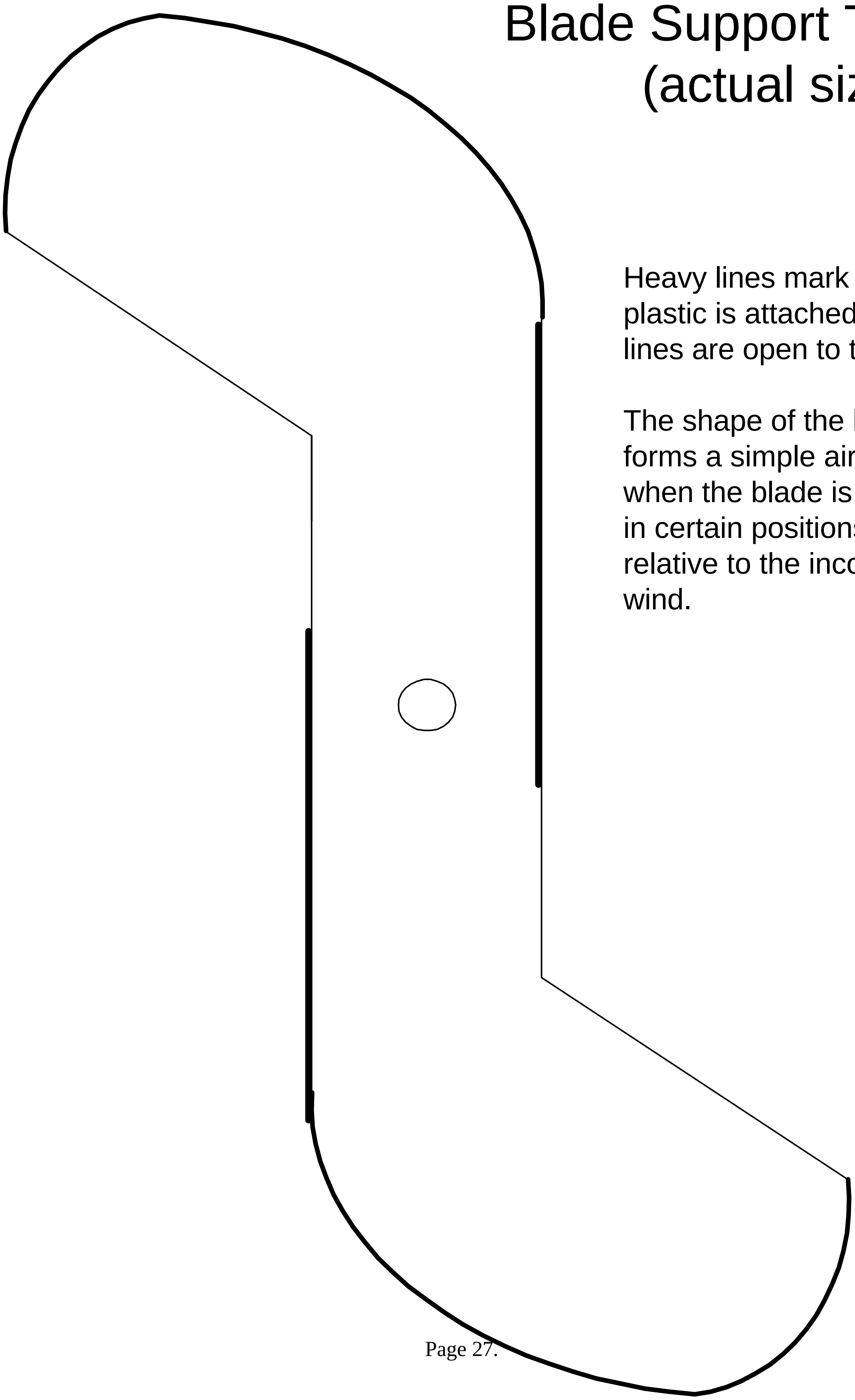


ROTOR TEMPLATE



STATOR TEMPLATE

Blade Support Template (actual size)

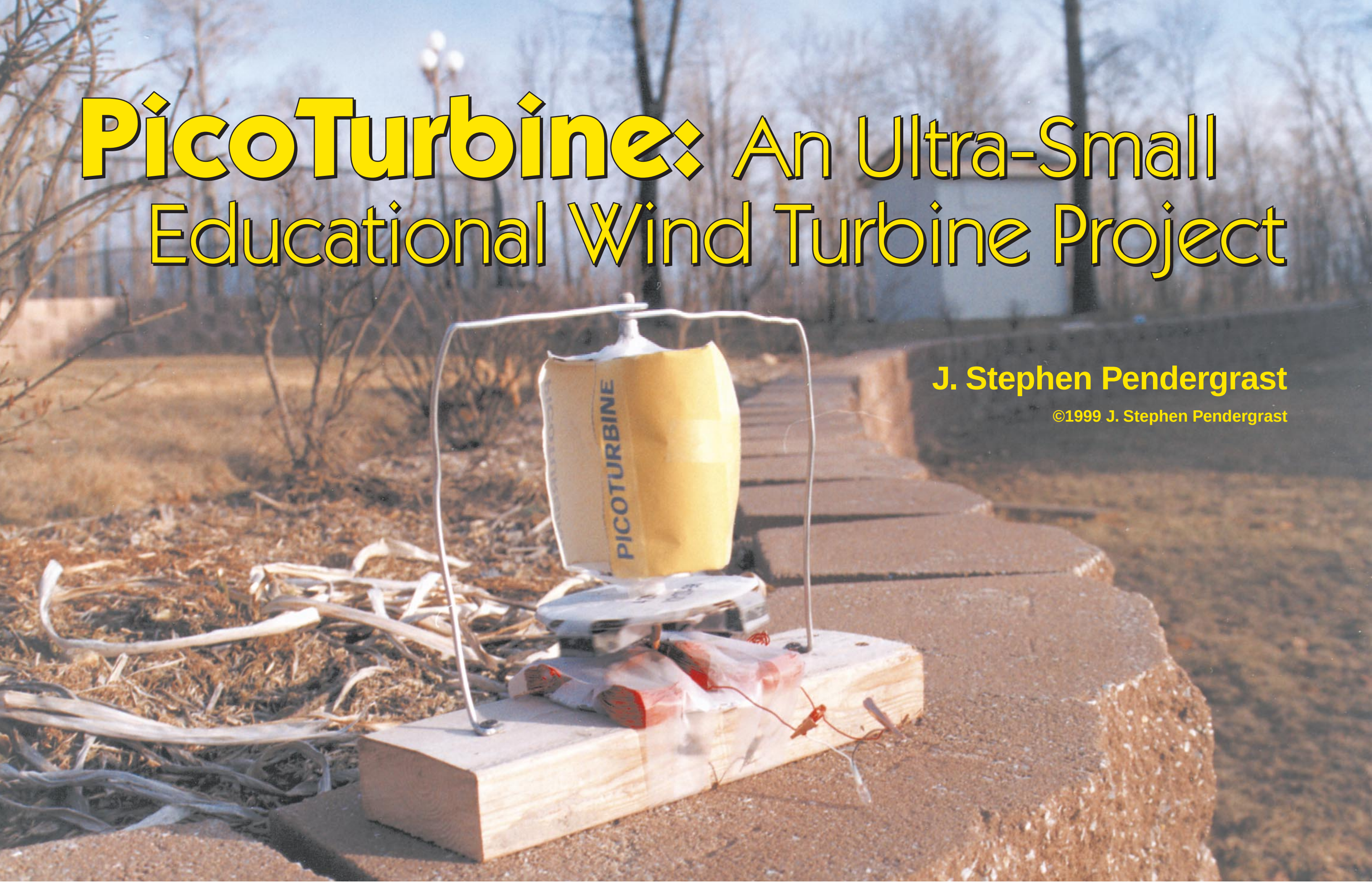


Heavy lines mark where plastic is attached. Light lines are open to the wind.

The shape of the blade forms a simple air foil when the blade is oriented in certain positions relative to the incoming wind.

PicoTurbine: An Ultra-Small Educational Wind Turbine Project

J. Stephen Pendergrast



PicoTurbine can produce 1/3 watt—that's a lot of power when converted to education!

This article will show you how to build PicoTurbine—a fully functioning, electricity-producing scale model of a wind turbine. The entire project costs only a few dollars, and uses commonly available materials like magnets, cardboard, tape, wood screws, and a pencil.

PicoTurbine can be built in less than two hours. With some adult supervision, PicoTurbine can be assembled by children as young as ten years old, making it an excellent project for renewable energy education.

PicoTurbine stands less than 8 inches (20 cm) tall—but don't let its size fool you. This version of PicoTurbine produces about one-third of a watt of power from a direct-drive, single-phase, brushless, permanent magnet alternator. More advanced versions the same size can produce a full watt, but are more challenging to build.

The design is naturally self-limiting for overspeed protection. I've left mine out all night during a windstorm with 50 mile per hour (22 m/s) gusts that made my brick house shake. In the morning, I looked out my window—fully expecting to see it shredded—only to find PicoTurbine still spinning at top speed in the early morning gale!

Materials

You will need the following materials and tools to build PicoTurbine:

- A pencil.
- A piece of stiff wire about 2 feet (0.6 m) long. I use 10 gauge (5.2 mm^2) aluminum wire in this article, but a wire coat hanger will work if carefully straightened with pliers.
- An 8 inch (20 cm) long scrap of 2 by 4 inch (5 x 10 cm) wood.
- Three medium-sized Phillips head (cross groove) wood screws, about three quarters of an inch (19 mm) long.
- A piece of corrugated cardboard about a foot (0.3 m) square.
- A sheet of paper.
- Scotch tape and any type of glue.
- 300 feet (91 m) of 24 AWG enamel coated magnet

wire (a very inexpensive vendor is Electronix Express).

- Four ferrite magnets, about 1.75 by 1.0 by 0.25 inches (44 x 25 x 6 mm). They must have poles on their faces. The ones used in this article are part number 99MAG1875 from Electronix Express, but virtually the same ones can be obtained from Radio Shack. (Note: people using pacemakers should not handle magnets.)
- Scissors, ruler, screwdriver, and pliers.
- A digital multimeter that can measure AC millivolts is useful for tuning and testing the alternator, and for displaying the amount of electricity produced.
- One 1.5 volt, 25 milliamp miniature incandescent lamp. These "mini-lamps" are available from Radio Shack.

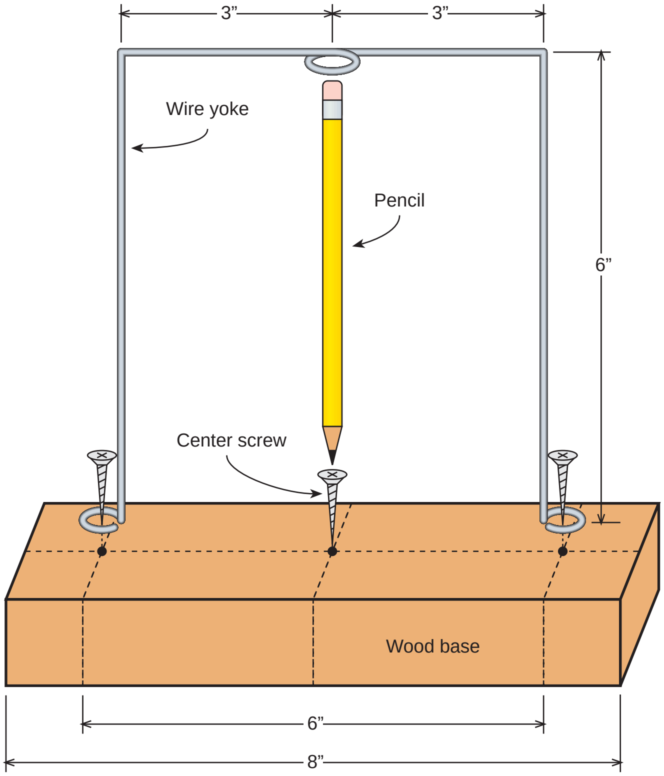
You can obtain kits with the materials you need from the Web site (see Access), and download templates and step-by-step photographs of this project for more detail. If you use different magnets or wire than those specified, your output will vary, and you may need to adjust slightly from the plans presented here because of size differences.

Building PicoTurbine

Step 1—The Axle and Yoke

There is a common axle used by both the blade assembly and the alternator, made from a pencil. The pencil point rests in the center groove of a Phillips head screw, and the eraser end is held by a wire loop (see Figure 1).

Figure 1: Base & Yoke Assembly



To make the base and yoke assembly, start with the heavy, 2 foot (0.6 m) section of wire. Using pliers, bend a small loop on one end. Bend the loop so it forms a 90 degree angle with the rest of the wire. Measure 6 inches (15 cm) up from the loop and make a 90 degree bend in the wire. Measure 3 inches (7.6 cm) from this bend and form another loop, slightly larger than the diameter of a pencil. Measure 3 inches (7.6 cm) from the center of this loop and make another 90 degree bend, forming a large square U shape with the wire. Measure 6 inches (15 cm) from this bend, and form another loop. Clip off any excess wire. This U-shaped piece of wire is the yoke.

Fasten the yoke to the wooden base using two screws. The legs of the wire yoke should be centered on the wide face of the wood as shown in Figure 1. Insert the pencil in the center hole of the yoke and rest the point in the groove of the center screw. The pencil should stand as near vertical as possible. Adjust the yoke by bending the wire if necessary to make the pencil vertical both side to side and front to back. Make sure the pencil turns freely in the yoke's center loop. If you wish, you can put a drop of any type of oil on the screw to make the pencil turn more freely.

Step 2—The Alternator

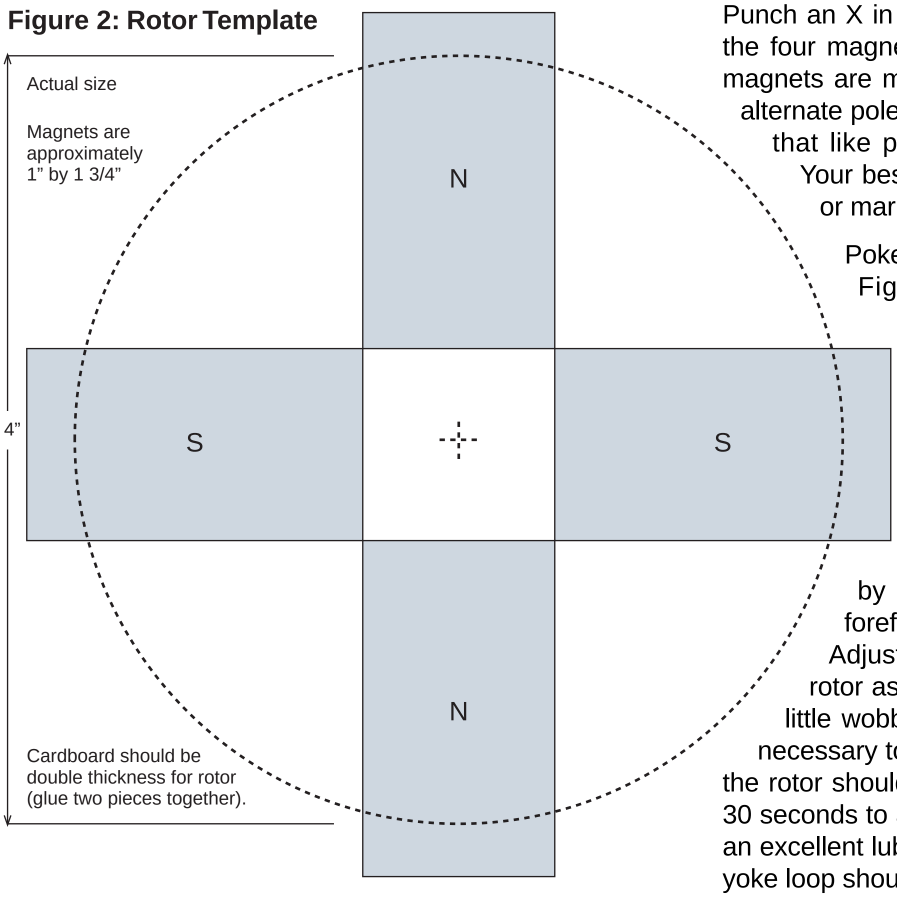
An alternator is little more than magnets moving relative to wire loops. The magnetic flux density changes as the magnets (or wire) move around, inducing an electric current in the wire. In PicoTurbine, the magnets will spin on an assembly called the rotor, while the wires will remain motionless on a part called the stator (see Figures 2 and 3).

Building the alternator is by far the most challenging part of this project. If you build it carefully, you can achieve about 200 milliamps of electricity at about 1.5 volts in a 20 mile per hour (9 m/s) wind. This is almost one-third of a watt of power.

Step 2A—The Permanent Magnet Rotor

Cut out two pieces of 4 inch (10 cm) square cardboard. Glue them together, forming a double-thick piece, as the rotor will be under a lot of stress. If you are using the templates from the Web site, glue the rotor template to this double piece of cardboard, and after it dries, cut it out. Otherwise, cut a circle out of the double cardboard 4 inches (10 cm) in diameter.

Figure 2: Rotor Template

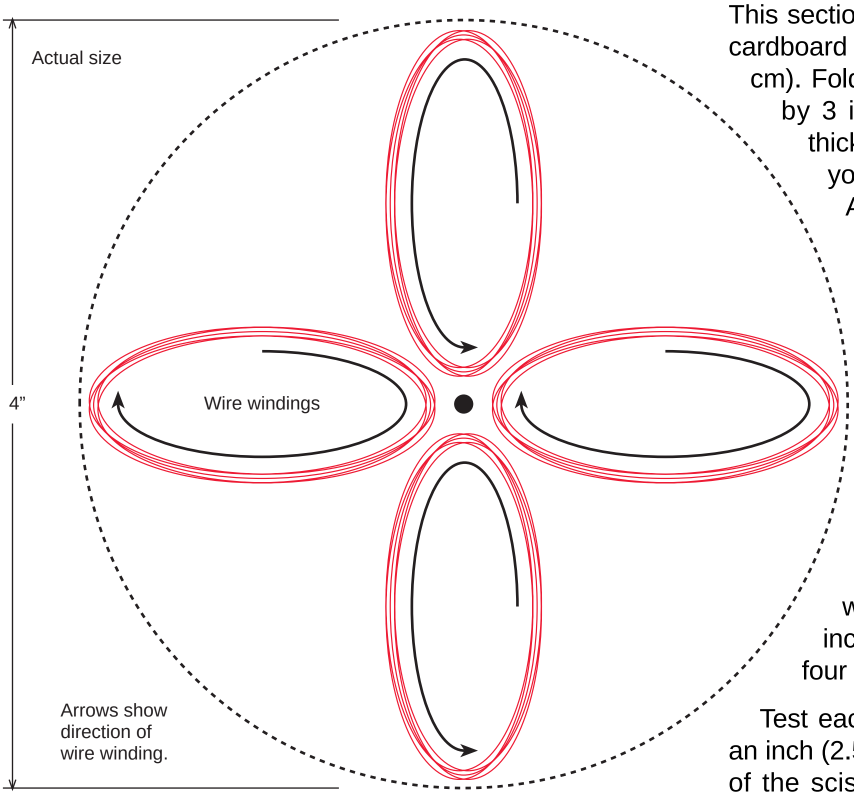


Actual size

Magnets are approximately 1” by 1 3/4”

Cardboard should be double thickness for rotor (glue two pieces together).

Figure 3: Stator Template



Actual size

Arrows show direction of wire winding.

Punch an X in the exact center with the scissors. Tape the four magnets as shown in Figure 2. Note that the magnets are magnetized on their faces, and you must alternate poles going around the diameter. Remember that like poles repel, and opposite poles attract. Your best bet is to mark the poles using a pencil or marker before beginning.

Poke the pencil through the rotor as shown in Figure 6, being careful not to break the point. Work it down slowly so as not to stretch the hole bigger than needed—it must be quite tight. Use some tape to make sure it's a tight fit.

With eraser end up, slip the pencil from the bottom into the yoke loop, pull it through, and lower the point into the center screw. Spin the rotor by twisting the eraser between thumb and forefinger. It should spin freely and vertically. Adjust the wire yoke if necessary. Watch the rotor as it spins—it should rotate evenly, with as little wobble as possible. Adjust it and use tape if necessary to fix it in place. If you give it a good twist, the rotor should spin on its own for quite a long time—30 seconds to a minute. The graphite tip of the pencil is an excellent lubricant and there is very little friction. The yoke loop should not be too tight around the pencil.

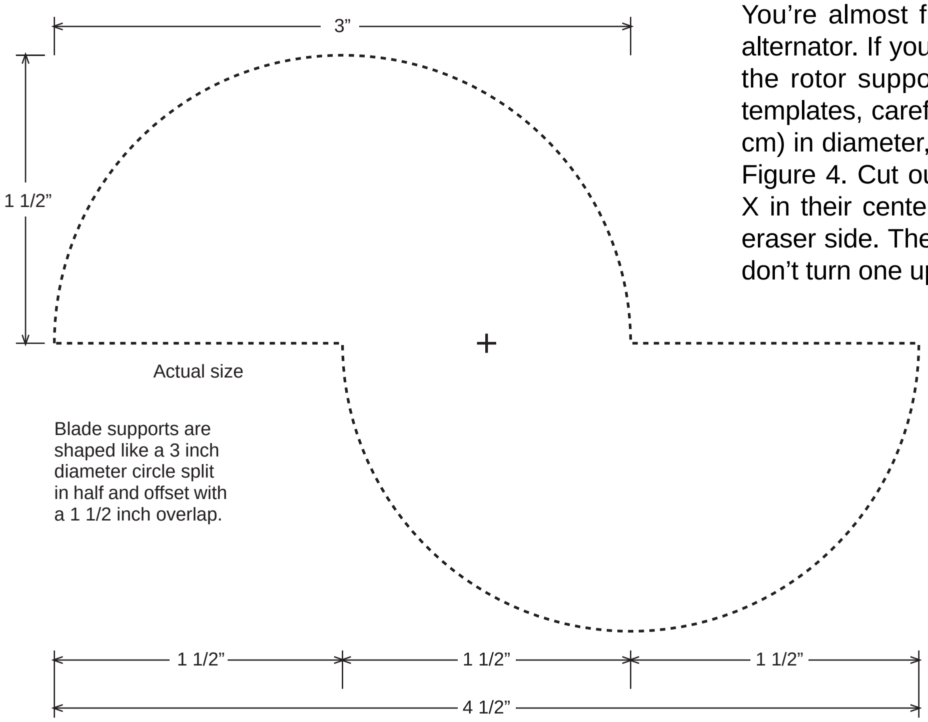
Step 2B—The Wire Loop Stator

This section requires care and patience. Cut a piece of cardboard 1.5 inches wide by 6 inches long (3.8 x 15 cm). Fold it in half to make a piece about 1.5 inches by 3 inches (3.8 x 7.6 cm), double the original thickness. Tape this together so it holds. This is your wire wrapping tool. Take your spool of 24 AWG wire. Leave a tail about 4 inches (10 cm) long and start wrapping loops around the 1.5 inch (3.8 cm) dimension of the cardboard.

Make at least 250 turns of wire around your cardboard wrapping tool. Leave 4 inches of wire (10 cm) after the last turn. Carefully slide the wire off the tool, and immediately wrap tape tightly around the bundle of wire so it doesn't spring apart. The tighter you can form the bundle, the better. You will have a slightly oblong coil of wire, about 2 inches (5 cm) long by about 1 inch (2.5 cm) wide. Do this four times, creating four coils.

Test each coil to make sure it functions. Strip about an inch (2.5 cm) of wire from each end, using one blade of the scissors or sandpaper. Hook to the leads of a

Figure 4: Rotor Support Template



Actual size

Blade supports are shaped like a 3 inch diameter circle split in half and offset with a 1 1/2 inch overlap.

multimeter. Set the multimeter for AC millivolts. Holding the coil close under the magnet section of the axle/rotor assembly, give the rotor a good spin. If you spin it hard and hold the coil close to the magnets, you should see 250 to 300 millivolts or more.

If you are using the templates, glue the stator template to a piece of cardboard and cut it out. Otherwise, cut a 4 inch (10 cm) circular piece of cardboard. Affix the coils as shown in Figure 3. Note that the coils should alternate between clockwise and counterclockwise rotation. Twist together the stripped wires from one coil to the next—you're wiring them in series. Leave the final two wires (the first and last) unattached. Tape the coils to the stator cardboard. They should lie very flat.

Cut a circle in the center of the stator cardboard. Remove the rotor/axle assembly by pulling up on the eraser and angling it out. Put the stator assembly over the center screw, and tape it down firmly. It will overhang the ends of the wood slightly in front and back. Put the rotor/axle back on. The gap between the coils and magnets should be as small as possible (about 1/4 to 3/8 inch, or 6-8 mm), but not so little that there is any chance of the magnets crashing into the coils when you spin them. Adjust the center screw to change the height of the rotor magnets over the wire.

Now, hook the two remaining wires to your multimeter and give the rotor a spin. If you spin fast, and everything is aligned well, you should get about 1.2 to 1.5 volts (or more, if you've built very well).

Step 3—The Blade Assembly

You're almost finished! This is easy compared to the alternator. If you have the templates, glue two copies of the rotor support to cardboard. If you don't have the templates, carefully draw two semi-circles 3 inches (7.6 cm) in diameter, shifted 1 1/2 inch (3.8 cm) as shown in Figure 4. Cut out the two blade supports, and poke an X in their centers. Slide them onto the pencil from the eraser side. They should be aligned with each other, so don't turn one upside down accidentally.

If you have the templates, cut out the blades. Otherwise, cut two pieces of paper as shown in Figure 5. Cut the top and the bottom into 1/2 inch (13 mm) strips, “feathering” the paper. Glue each paper blade on the circular side of the blade support, both top and bottom. Use the feathered edges to negotiate around the circular support.

The final effect is like taking an oil drum, cutting it lengthwise, and offsetting the two halves horizontally before fastening them back together. Put tape along the two leading edges, and tape over the glued top and bottom parts, just for good luck in high winds.

Step 4—Testing

Carefully insert the blade/rotor/axle assembly back into the yoke and set it down into the center screw. Blow into the blades from any direction, and they should start up very easily. Short, puffing blows are best. Hook up your multimeter and blow again. If you have very good lungs, you'll get a couple of hundred millivolts. The wind will do much better than you can do! For classroom demonstrations, a small fan can provide the wind. Finally, if it's a windy day, give it a real test using Mother Nature.

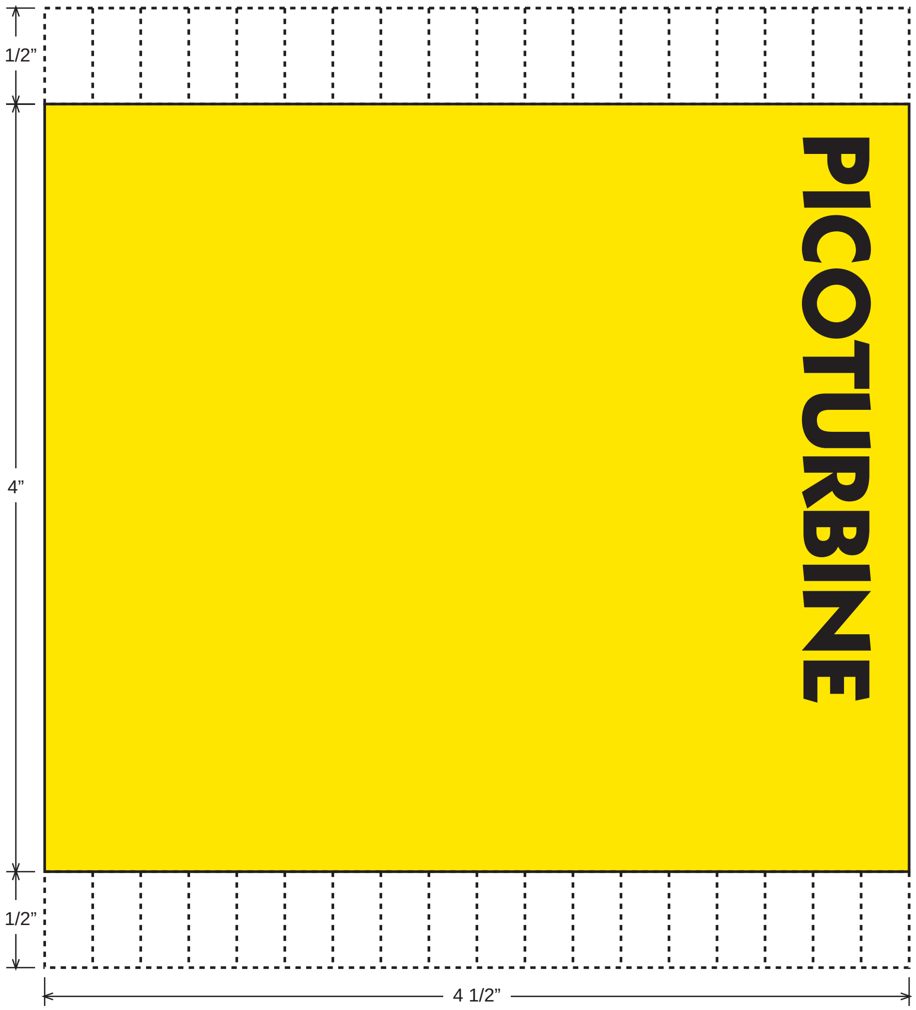
Hook the mini-lamp up to the alternator leads, twisting tightly to make a good connection. When PicoTurbine spins about four to five revolutions per second, it will glow dimly. It will be quite bright at ten to fifteen revs per second.

Conclusions and Future Work

PicoTurbine is a small, easily constructed, fully functioning wind turbine. It was designed for ease of construction and low cost of materials so it could be used for educational purposes. Building PicoTurbine is a great way to learn about wind energy concepts and engineering design tradeoffs.

I am undertaking several related projects, including plans for a simple weatherproof version of PicoTurbine, and other design improvements. A version with a three-

Figure 5: Rotor Covering Template



Cut on the dotted lines. Feather the ends to make gluing to the rounded blade supports easier. Make two.

Actual size

phase alternator and a scaled-up design that produces about 5 watts for school group projects are also in the works.

Check the Web site to get up-to-date information on these projects and to see more pictures and design alternatives to the model presented in this article. Ideas for classroom use, educational experiments, and projects that use PicoTurbine are also available, free of charge, for personal and educational use.

If you have any comments, corrections, or suggestions for improvements, you may send them by email to comments@PicoTurbine.com.

The Savonius Turbine Controversy

PicoTurbine is a vertical axis wind turbine—VAWT for short. More specifically, it is a Savonius design, named after its inventor, S. I. Savonius, who patented it in the 1920s. There has been much controversy surrounding the Savonius design, as compared to the traditional, horizontal axis wind turbine (HAWT) for electricity production.

The Savonius design is based primarily on drag (like a cup anemometer). Most commercial electric generating wind turbines use lift (like an airplane wing) instead, and sport the traditional horizontal axis. There are advantages and disadvantages to both designs.

Keep It Simple

The chief advantage of the Savonius is simplicity, as is amply demonstrated by PicoTurbine. Because the design is vertical, it doesn't need a yaw mechanism to keep it turned into the wind. In fact, PicoTurbine has only one moving part, whereas the simplest small horizontal designs have at least three. In theory, this means that Savonius designs could be built more cheaply and should be more reliable than the more complex horizontal designs.

Everyone's a Critic

Critics of the Savonius focus on its drawbacks. For one, the academics don't like drag-based designs because they are not as efficient at converting wind energy to mechanical energy. A good lift-based design can be about 40 percent efficient. There are reports of the Savonius achieving nearly 30 percent efficiency under controlled conditions. In practice, these machines perform at around 15 percent.

The second major criticism centers on how fast the Savonius design revolves. A drag design cannot exceed about a 1 to 1 tip speed to wind speed ratio. Basically, if you look at the speed that the outer edge of the blade travels, it can't go much faster than the wind speed. A large 3 yard (2.75 m) wide Savonius would spin at a leisurely one revolution per second. In contrast, lift-based designs can achieve a tip to wind speed ratio between 6 to 1 and 11 to 1.

Whither, Savonius?

These drawbacks have given the Savonius a reputation as a design of little practical use for electricity production. One prominent wind technology Web page implies that its slow speed is an insurmountable Achilles' heel. The authors say that although it could be made usable with a gearbox, that would increase the startup inertia and decrease efficiency further. Another online article says the Savonius is flat-out useless for power generation, and jokes that its main use is to take up space in the garages of would-be inventors!

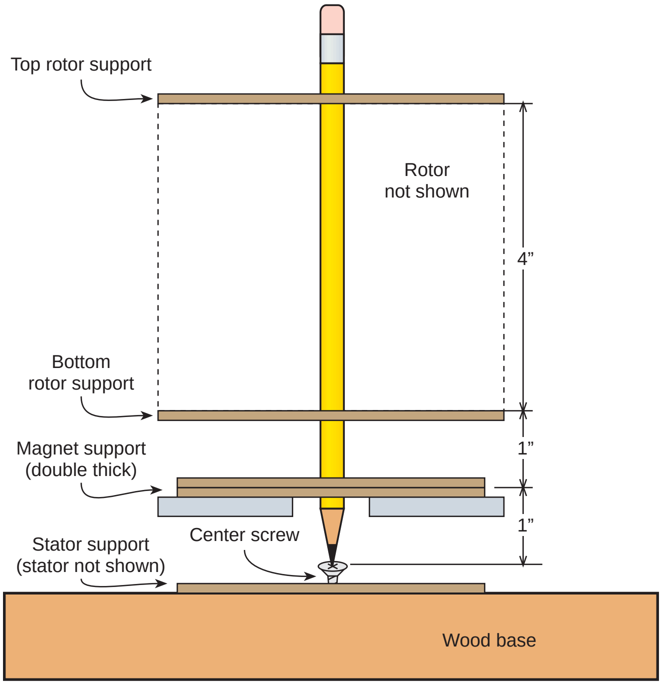
While there is certainly some truth to these criticisms, I believe them to be somewhat overstated. On closer examination, we'll find that the Savonius—while certainly not the choice for commercial power production—could indeed have a niche in the small home system category. I have seen at least one example of a small commercial trickle charger based on the Savonius design.

The Whole Efficiency Story

Like most things in life, the matter of efficiency is more subtle than simply saying that the Savonius is 15 percent efficient and thus inherently inferior to the horizontal design's 40 percent efficiency. The efficiency difference is partly mediated by the fact that a Savonius does not lose efficiency while yawing into the wind. It doesn't care what direction the wind comes from—it's perfectly happy with gusty, shifting, inconstant winds that drive horizontal machines nuts. Paul Gipe, a noted wind turbine expert, estimates this loss at about three percent in his book, *Wind Power for Home and Business.*

In addition, the Savonius sweeps a rectangular section of wind, while a horizontal design sweeps a smaller, circular area. For example, a 2 yard wide by 2 yard tall (1.8 x 1.8 m) Savonius sweeps 4 square yards (3.3 m^2) of wind, while a horizontal turbine 2 yards (1.8 m) in diameter only sweeps a tad over 3 square yards (2.5 m^2).

Figure 6: Rotor, Magnet, & Stator Assembly



The finished PicoTurbine ready to spin.

The power output of any wind turbine is directly proportional to its swept area. When it comes to the space needed for installation, the circular sweep takes up just as much room—you can hardly claim to be able to do anything with the space "saved" due to the corners being rounded off!

After taking into account these factors, the Savonius is still at a significant efficiency disadvantage versus a good horizontal design, making it unsuitable for large-scale electricity production. However, the ease of construction and low wear and tear design offsets much of this disadvantage when the application is small-scale electricity production, especially of the homebrew variety. If the Savonius is a few percent less efficient, then simply make the blades a few percent taller—problem solved.

It's the Alternator, Stupid!

Now let's discuss the rotation speed issue. It is true that many attempts at building a homebrew Savonius generator fail. Consider a popular formula for a Savonius windmill that I actually found on the Web:

- Take a 55 gallon oil drum. Cut it in half lengthwise, and weld the parts into the offset Savonius shape.

- Affix this contraption to an old car axle welded to the shaft of a junked car alternator.
- Voila! You have just made a wind turbine.

Unfortunately, even in a gale this thing is unlikely to make a 10 watt light bulb glow. Many people blame such failures on the Savonius design. In reality, the problem is not the wind turbine—it's the alternator!

Alternators For Dummies

Let's talk alternator physics. (It won't hurt, I promise!) As we learned from PicoTurbine, an alternator is basically just some wire loops in motion relative to some magnets. The power produced depends on several factors: how strong the magnets are, how many loops of wire, how thick the wire is, how fast the magnets move, etc. Now, here's an important point: by varying these design parameters, you can make an alternator that produces any arbitrary amount of power at any speed you choose to optimize for.

The power output varies with the square of the speed. If you run an alternator at half its design speed, the power is cut by a factor of four, not just two. So, let's say our intrepid homebrewer tries to use a car alternator designed to turn at 30 revs per second on a barrel Savonius that only turns 3 revs per second. That's 10 times slower than the design speed, so power will be cut by 10 squared—a factor of 100! If that alternator were designed to output 100 watts, our homebrewer will get a paltry 1 watt output. (He would get the same wattage from the high power model of PicoTurbine!) The result is predictable—another Savonius taking up the corner of a garage.

Alternative Alternator

By increasing the number or strength of magnets and/or the thickness and number of loops of wire, we can in fact make an alternator that produces 100 watts (or any other power) at 3 revs per second (or any other speed). But that alternator will bear little resemblance to one designed for a car. For one thing, it will likely be much larger to accommodate more magnets and thicker wire. This is no big problem—there's plenty of room below the Savonius blades for a large alternator.

Cheers for Magnets, Jeers for Gears

And, just to dispel one final myth, there is no compelling reason why we must use physical gears to increase shaft speed. We can in effect "gear up" the speed using more magnetic pole changes per revolution. The wire loops only care how many pole changes they "see" per second. They can't tell the difference between two magnets flying by ten times per second and ten magnets flying by two times per second.

PicoTurbine uses four magnets to cause two north-to-south pole changes per revolution. This is equivalent to using a 2 to 1 gear ratio—but without the friction losses and other headaches of physical gears. This concept can be extended to any ratio desired by simply adding more and more magnets to the design.

Access

Author: J. Stephen Pendergrast is a computer scientist by trade and is also an Internet consultant, freelance writer, and amateur renewable energy researcher. He is currently in the process of installing a commercial 3 KW wind turbine to provide power for his home in northern New Jersey at 146 Henderson Rd., Stockholm, NJ, 07460 • 973-984-2229 • Fax: 973-208-2478
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Many thanks to electrical engineer Randal B. Elliot of Portland, Oregon, for verifying the technical accuracy of this article.

WIND and WINDSPINNERS

a 'nuts 'n bolts' approach to wind-electric systems

MICHAEL HACKLEMAN

an Earthmind/Peace Press Publication

1st printing -- June, 1974

2nd printing -- August, 1974

3rd printing -- February, 1976

4th printing -- July, 1976

5th printing -- May, 1977

Additional single copies of this book
may be obtained by writing to

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WIND POWER DIGEST

FOREWORD

In principle, the generation of electricity from wind energy is simple and evident to most of us; the wind turns an S-rotor (or propeller) which turns a generator that produces electricity. The questions, however, begin to form when we go forth to build such a device. How big a machine? Which generator? Where do I put it? What happens when the wind isn't blowing? How much electricity do I need? Do I have enough wind? Who can repair it? Can I get parts? How much will it cost?. . . .

Good questions, for certain, but where are the answers? A check with a library will quickly reveal a lack of information on wind energy in general. A trip down to a shop (like a generator rebuilder) will be a bit discouraging. "A generator for a wind machine? Let's see, they use to have those before rural electrification; but, now, I haven't seen one of those in years." A few places sell wind machines that will generate electricity; getting their information will tell you that the state of the art is just not there. A comparison of the amount of electricity these machines develop with the amount of electricity you use now will quickly indicate you'll need a dozen of their machines. If someone turns you on to the fact that there are some companies overseas manufacturing a wide range of wind generators, a look at the prices will probably make you gag. If you get an uneasy feeling about using them, you're probably wondering if you aren't going to be in the same situation that you are now. Who's going to repair the thing? How long do I wait for parts?

This book aims to answer those questions and answer others that would develop naturally in anyone's mind as they commenced to investigate using the wind's energy. Because this book will focus on the owner-built wind/electric system, information is provided in such a way as to allow modification of the units we have constructed to fit individual circumstances, or situations. 'Situations' may be described by (1) the level of skills one possesses, (2) the tools one owns (or has access to), (3) one's budget, (4) the time one can afford, and (5) the confidence one has in one's self in carrying out these modifications. Many factors contribute to the design and construction of wind energy systems, but they may be (essentially) reduced to (1) the availability (and properties) of the materials used, (2) the amount of energy required, (3) wind availability, (4) operational requirements (semi- or fully-automated), (5) efficiency, (5) maintenance, and (7) safety.

These factors vary in importance with the location; situations vary with the individual. The use of wind energy is quite individualistic and because of this, it is difficult for any one system to fit all people and all places. So, it feels right to describe the interrelationships of these factors and provide the useful information that will allow you to make the decisions; it feels wrong to make them for you.

INTRODUCTION

I can't know your particular situation. Maybe you've been in a blackout somewhere and you didn't like the feeling of not being able to do something. Maybe you don't like the rising prices of electricity and you know they'll just keep going up. Maybe you live in an area where there isn't any power and it's going to cost you a mint to bring it in. Maybe you're ecology-minded and can't stand the tons of coal smoke, smog, sulphur, etc., that goes into our air or the rape of the land to produce the power we use now. Maybe you want to be the first on your block to have a wind machine. Maybe you like trees and not power lines and poles. Maybe you just like the wind.

The S-rotor is a good wind machine, but then I'm prejudiced -- it's the only type of wind machine I've ever worked with. Why? Perhaps it is because I couldn't seem to find any good info on it and I wondered why. Perhaps it is because I couldn't find anyone else working on it. Perhaps it's because anyone working with wind energy doesn't seem to know what to do if you take their propeller away from them. It's these and more.

The S-rotor is an alternate to the propeller-type wind machines; both, however, are alternatives to today's polluting, nonrenewable, nonindividualistic energy sources. I'd like to see wind machines; I don't care if they are S-rotors or propellers or sail-wings. This book -- the way it is written and the information it contains -- reflects this dream. You won't see much of anything on the S-rotor aeroturbine until Chapter 6. Why? Because things like wind info, electricity, generators, gearing, storage, control, use, site location, etc., are basic to any wind/electric system.

I can't know what you already know, so I make the assumption throughout this book that you know little or nothing on these subjects. As well, I can't know if the S-rotor is the <u>best</u> wind machine for your situation; I can provide sufficient information on it so that <u>you'll</u> know wheth it is or isn't. Shop around. Use the bibliography to contact other folks doing the same thing. The S-rotor is, at this time, only about half as efficient (in extracting the wind's energy) as a comparable-size propeller unit. It's main virtues are in the area of construction and cost. Weigh the factors, consider the options, but build a wind machine!

Everyone dedicates books. . . so it's my turn. I dedicate this book to the memory of the tree that it is printed on.

Thanks to David House for Chapter 1, the Introduction to Chapter 2, and Data Sheet #1; they are fully of his own writing. And my thanks to Ginger, Dell, and the lil' beeps. Thanks also to Jack Park for his help.

Cover photo credit---Ginger Hackleman

Michael A. Hackleman

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CHAPTER I - WIND ENERGY

Someone once said, when writing anything, you should "tell 'em what you're going to tell 'em, tell 'em, and then tell 'em what you've told 'em..."

Well, that seems like a good plan, so the first section of this chapter is called:

Tell Them What You're Going To Tell Them

In this chapter we will talk about many different things, all designed to give you a greater understanding of wind and it's relationship to wind generated electricity. More specifically, we will talk about the equity/rent concept of energy, energy in general, efficiency in general, percentage efficiency, getting more for less, wind, energy in the wind, increasing usable energy, and average energy in the wind.

The Equity/Rent Concept of Energy

Even though this might be explained later, it's included here because it's so basic to alternate sources of energy, and the first thing to remember is: There's no free lunches. If we want energy, we either pay for it in money, or we pay for it with time and less money. By this I mean that we either rent our energy (pay for it in money) from some outfit like Con Ed, or we take the time to learn how to acquire the energy which everywhere surrounds us; in this second case, we have an equity. We not only have our energy gathering device (which we payed for with time and money, unless we're able to outright buy the thing), but as well, if we did our homework, we have something a good deal more valuable - applicable knowledge, and knowledge that liberates us from paying our rent. That's our equity, and it will go on increasing in value in direct proportion to the rise in the cost of fossil fuel.

When we rent energy, we have no equity; even if we pay our bills for ten years at a stretch, we can expect to have the utilities baying at our doors if we miss a payment or two, (if you've ever gotten an arrogant letter from them, you know what I mean).

However, even though an equity is, or sounds better than merely paying rent, we run up against a few basic facts if we happily assume that all we need to do is cut the power lines an hang a wind device (or some other device) on our roof. Reality will almost always step rudel to the fore if we try this without adequate knowledge/preparation, and the reason is quite simple - we have gotten very used to wasting truly incredible amounts of energy. All we can do, if we expect to acquire our cherished equity, is to need less; there is no other way to achieve independence from the electric meter. It is the things we think we need that tie us most powerfully to a system which pollutes and exploits. But, let's not start foaming at the mouth (just yet anyway); we might as well get on with it.

Energy In General

Energy can be neither created nor destroyed - so modern physics tells us, and even Man's most ancient sources of scientific information (such as the Vedas) agree, though their view of energy may be more all-encompassing. But while it is neither created or destroyed, energy can only be useful to us in certain states, and in certain amounts. Energy changes states, tending to go from a condition of less randomness to a condition of greater randomness (entropy), unless acted upon by an energetic intelligence. Energy tends to go from concentration to diversification, from higher vibrational states (light) to lower vibrational states (heat), and from either positive or negative to neutral.

And every time energy changes states, from electrical energy to light, or from the potential chemical energy of gasoline to the kinetic mechanical energy of a moving car, or from the kinetic energy of wind to the kinetic mechanical energy of the generators which produce (by change of state) electricity, or the kinetic etherial energy of sunlight to the potential nutritional energy of tomatoes, or from that tomato life energy to the life energy of people, it changes from that state to more than one other state.

This generally means a loss in efficiency, since, for instance, some of the electrical energy which is being transformed into light will appear as heat, which is useless in this application. A great deal of the potential energy locked up in gasoline will not appear as kinetic mechanical energy of the moving car, but will show up as heat, sound, and smog. With present designs, none of this energy is put to use, but is allowed to pass off, and is therefore wasted. This is a question of efficiency. The most efficient energy systems are biological, since biological systems utilize energy in all its many forms.

Whenever energy is transferred from place to place, some of it is 'lost', or becomes unusable, since some of this energy must generally be degraded into another, more random and less useful state (such as low grade heat), as a result of accomplishing its own transfer. Electricity for example, when it is transferred over wires, will transform some of itself into heat (in the wires) and thus be lost to other electrical applications.

There is also the question of storage of energy; we gather solar energy by day and wind when it blows, but how are we to use this energy at night, or when the air is still?

Kinetic energy states (energy which 'moves') are hard to store effectively with simple tools; in somewhat inaccurate, but effective language, it could be said that since kinetic energy states are active and fluid states, they tend to 'leak' out of whatever we try to store them in, preferring freedom.

Electricity can be stored in capacitors, but they must be expensive if they are to be effective (unless you've got a better way). Did you ever try to 'store' light? Where does it go? (I understand that Einstein was working on that one).

Wind energy is most often stored by putting it into the chemical potential energy of storage batteries, but some energy is lost (or not used) whenever such a change of state occurs. Sunlight is often stored as heat, but heat, being kinetic, leaks. Batteries also 'leak' energy, but they happen to be the most effective, simple way to store wind generated electricity. Many people are experimenting with storage of wind generated electricity by using it to dissociate water into hydrogen and oxygen, but so far as I am aware, this is not at present highly feasible. I'd like to hear differently though...

So, next up, lets consider efficiency...

Efficiency In General

Efficiency is a word that we tend to throw around a lot without realizing that it depends absolutely on the criteria used. For example, when talking about the efficiency of a wind system, we can consider how well it transforms the actual total kinetic energy of the wind into the kinetic energy of electricity (and a high efficiency here generally means an expensive system), or we can consider the price of the system, its ease of construction or maintenance, whether or not we have to buy all the parts or if they need to be specially manufactured, and so on. It's purely a matter of criteria - what aspect are we considering? Generally however, the term 'efficiency' refers to how well a device transforms energy from one state into another, relative to the (theoretical) maximum which can be extracted from the first energy state. (The term 'theoretical maximum' means that there are certain limits which cannot theoretically be overcome; therefore, no more than a certain amount of one energy state will be transformed into another state, regardless of the technical quality of the device used.)

In the case of wind devices (to make every thing a little clearer), the theoretical maximum efficiency is 59.3%; this means that no more than (approx.) 60% of the actual total energy in the wind can be transformed into the energy of the spinning wind device. And since efficiency is generally considered relative to the theoretical maximum, a wind device which extracts (approx.) 60% of the actual total energy of the wind is said to be 100% efficient. Now does it make sense? If the wind device extracts only 30% of the actual total energy of the wind, it is said to be 50% efficient (since 50% of 60 is 30). Hereafter, theoretical maximum energy in the wind will be called T.M. wind energy. The actual total energy of the wind will be called A.T. wind energy. O.K.?

Now, the energy of the wind is the energy contained in a moving mass of air. When a wind device is spun around by the wind, it cannot extract all of the energy from it, or the wind itself would stop dead. Of course, the moving wind device would then be slowed down by this 'dead' air, and thus it would have to give back some of the energy it took from the wind in the first place. Enough energy must be left in the wind to enable it to move on. Make sense?

So, it is important to understand these things, and be able to ask the right questions. If someone is talking about efficiency, what are their criteria? If they speak of a percentage efficiency, they are probably referring to the ability of that device to 'gather' energy, by change of state (as, for instance, the change from the kinetic energy of the wind to the kinetic mechanical energy of the Savonius aeroturbine, or the blades of a prop type device). But, are their figures based on the T.M. wind energy, or on the A.T. wind energy? Hereafter, whenever we speak of the efficiency of the Savonius, unless we say otherwise, we are speaking of its efficiency relative to T.M. wind energy. It is wise to remember as well that most of the figures given for the energy 'gathered' by a wind device are given for energy at the impellers, or at the blades; as we shall shortly see, this is very different from the energy which may end up being useful.

(By the way, if terms like 'theoretical maximum' irritate you with their implication of sacrosanct barriers, remember that it is aerodynamically impossible for a bumblebee to fly... if you wish to overcome their 'limits', make new assumptions, or try a completely different approach to the problem than is ordinary. This is the way such limits are overcome, generally speaking.)

Percentage Efficiency

We cannot directly illuminate a light bulb with the wind, but rather, we first have to make several changes of state of the kinetic energy of the wind, in order to make it into electricity, with which we can illuminate the ordinary incandescent bulb. As well, the wind system contains several sub-systems, which do not transform the energy from one state to another, but rather transfer it from place to place. You remember we said that whenever energy is transferred from place to place, some of it is lost, since it changes into unusable energy states as a result of accomplishing its own transfer.

So, we have change of state devices - the aeroturbine (or wind device itself), the alternator, the batteries, the inverter (which changes DC current into AC current), and the light bulb, among others - and we have transfer systems - mainly the gearing from impeller to alternator, and the wiring systems between other components - all of which make up the wind/electric system, and each one of which extracts a 'tax' in energy from the system, in order to operate itself. This is where we come up against percentage efficiencies, for unless each device is very efficient (extracts a small tax, rather than a large one) then tremendous amounts of energy must be gathered in the first place, not to do useful work, such as illuminating the light bulb, but rather to support the system (to 'feed' it).

Lets examine this in terms of percentage 'taxes'. First, of course, there is the energy of the wind. This is transformed (1) by change of state to the kinetic mechanical energy of the moving aeroturbine, or wind device. Then the gearing system transfers(2) this energy to the alternator, where it is transformed (3) by change of state into the kinetic energy of electricity. The electricity is transferred (4) to the batteries, where it is transformed (5) by change of state into the potential chemical energy of batteries. When demanded, these batteries transform (6) this potential chemical energy back into electricity, which then is transferred (7) thru wires to the light bulb, where it is transformed (8) into light. (We won't deal with the inverter just yet, that comes in Chapter 5; we just want to get to basic ideas here so we all have the same mental vocabulary.)

Now, if we only experienced a 10% 'tax' or loss of energy at each transfer or change of state, we might be very happy indeed. With the 8 transfers or transformations we have listed above, a loss of 10% each time will still give us 43% (at the end of the line) of the original 100% of the winds energy (10% loss from 100 equals 90; 10% loss from 90 equals 81; 10% loss from 81 equals 72.9; 10% loss from 72.9 equals 65.61, and so on).

The losses are not additive; rather, they multiply.

But, we can reasonably expect nothing like this kind of efficiency in transfer, and transformation; remember, T.M. wind energy is only 59.3%, and any wind device will be hard pressed to meet that kind of efficiency. The Savonius, being homebuilt and using rather funky 'kitchen sink style' technology, will only get about 20% of T.M. wind energy (or about 12% of A.T. wind energy) for the lower efficiency models (see Chapter 6). While we can expect to have 90% efficiency (or a 10% loss) at the gearing from the aeroturbine to the alternator, we can only expect about 50% of this transferred mechanical energy to appear as electricity.

Then we will assume 90% efficiency of transfer of the electricity from the alternator to the batteries, and we will assume the efficiency of storage (by which we mean the amount of electricity that went in versus the amount that comes out), to be 80%. Then we have another transfer of electricity (assume 60%) from the batteries to our old friend the light bulb (see Chapter 2 for the reason behind this low efficiency) and then (here's a shocker) we finally have the efficiency of the light bulb in converting electricity into light (5 to 15% only!). When we pause for breath long enough to multiply this all out, we find the following: The wind (this is A.T. wind energy) can only transfer 12 percent of its energy to the S-rotor. After transfer thru the gearing to the alternator, only 10.8% of the original is left. The alternator takes this mechanical energy and transforms it into electricity, and only 5.4% is still in usable form (as electricity). Trundle this electricity down the wires to the eagerly waiting batteries... only 4.86% of the original energy arrives to be stored. Then when this electric energy is pulled out and used, we find that all but 3.89% has disappeared! We scoot this off thru wires, hoping we won't lose much more, (but we lose 40% along the way) finding only 2.33% of the original amount of energy left to light the light bulb. Somewhat discouraged, we switch on the light and - to our dismay - only about 0.233% of the (A.T.) energy which was in the wind survives to illuminate the page we read.

If we consider that this is more like 0.388% of the energy we could extract if our rotor was 100% (of T.M.) efficient, we might feel somewhat better, but I doubt it.

Getting More for Less

At any point along the way, if we can increase the efficiency of the part, we can increase the efficiency of the whole; the efficiency of the whole system cannot exceed the efficiency of the least efficient part. In other words, if any part of the system is no more efficient than 10%, the whole system cannot be more efficient than 10%. But the part of the system which will have the most effect on the system, is any part through which all of the energy of the system passes. For instance, if we increase the efficiency of the S-rotor, or of the electrical transfer system, both of which transform or transfer the energy of the whole wind/electric system, this stands to gain us more than merely increasing the efficiency of a single light bulb, which only carries a part of the energy of the whole wind/electric system. If we increase the efficiency of all the light bulbs and other devices which we are trying to power with this system, then we will increase the efficiency of the whole system considerably.

But, as far as changes to a single part of the system are concerned, we can probably achieve better results by trying to increase the efficiency of the S-rotor than we can by making any other single change. (This is not true in all cases, since if you already have increased the efficiency of the S-rotor, then you would probably wish to direct your attention to some other part of the wind/electric system - but the details of this will be covered in other chapters...)

As we point out in the note on page 11, equation #1-8 assumes that the S-rotor is only 20% efficient. Increasing the efficiency of the aeroturbine to 33% (and by the way, all these figures are a percentage of T.M. wind energy), will increase the energy available to the system by 1.65 times, or about one and two thirds times the amount of energy we can gather at 20% efficiency.

The S-rotor aeroturbine can be increased in efficiency by decreasing the weight, and/or changing the shape of the impeller (wing, or drum half), so that it makes better use of the wind which is blowing past it. Suffice it to say at this point, that, by exchanging the simple half circle wings with wings of a more aerodynamic shape, (somewhat like an airplane wing curved around in a 'cup'), more power will be extracted from the wind. (More about this in the newsletters, and a little further on.)

Wind

Now, before we apply our newborn ability to find out what goes in and what comes out, let's talk about wind in general. We are shortly going to give you an equation (more numbers!) which will allow you to calculate the energy in wind of a given speed and so on, but first, we need to understand wind and its patterns.

The wind is, in the most mundane terms, a moving mass of air; when we gather energy from it, we must slow this mass down somewhat, and the energy lost by the wind is gained by the wind device.

Wind almost never blows at a steady speed, for long periods of time in most places. There are many factors which enter into determining wind speed and direction (and they are not, by any means, all known and understood), and these tend to work together in such a way that the wind, from hour to hour, and from day to day, varies considerably.

However, wind speed and direction (and the energy in the wind, as we will come to see) tend to remain quite predictable over a period of a month or a year. If December is windy year after year, we can pretty well count on December being windy this year (or next).

Now, it is, of course, difficult to make generalizations about such a dynamic force as the wind; this difficulty is increased by the fact that we are trying to give information about the wind in Maine, as well as the wind in Hawaii. Near the ocean, (which, acting as a large reservoir of heat, tends to stabilize weather to a very great extent), the wind pattern is quite consistent, and if there is generally an onshore evening breeze, one can begin to expect it evening after evening. In rough country, and particularly in places which are far from any great bodies of water, the wind tends to be extremely varied. Generally, however, in these, and in other situations, the wind tends to follow a recognizable pattern, (even if it is not exactly the same for all areas), during the month and year. Many places even have a rather predictable weekly pattern. Most areas (in the northern hemisphere) experience a low (or minimum of wind) in July or August, when the solar energy is at its maximum. The wind high tends to occur in winter or early spring, when solar energy is at its minimum (these two were made for each other!).

It can also be said that there is a general pattern to most winds, where the wind that does come, comes in two more or less distinct groups. The first is called the 'prevalent winds' since they tend to 'prevail' or blow more of the time than the second group, which is called the 'energy winds'. This second group contains most of the energy of the wind for that particular period. The prevalent winds blow most of the time (5 out of 7 days), and are generally from 5 to 15 MPH; the energy winds blow less often (2 out of 7 days) and are generally higher in velocity, at 10 to 25 MPH. It may seem odd that winds which blow only about 30% of the time contain more energy than winds which blow about 70% of the time, but this is the case as we will demonstrate in the next section.

The energy winds tend to 'ride' the prevalent winds, and are generally experienced as 'gusts, which come into the wind site from a direction different than that of the prevalent winds -- usually from 15 to 70 degrees 'off' the direction of the prevalent wind. This gives the S-rotor a slight advantage over the propeller-type unit, since the former can accept winds from any direction at any time, and the latter can only fully use and accept winds which blow from the direction it faces.

Energy in the Wind

While a whole sky full of wind must have an incredible amount of energy, the wind device can only develop its power (or 'gather' energy) from that amount of moving air which directly contacts it; this must seem obvious -- the larger the device, the more power it can extract and, of course, the faster the wind blows, the more energy there is in it to be extracted.

If we were a wandering dust mote, which had accidentally stuck to the impeller of an S-rotor, we would be able to 'see' (use your imagination now) that a molecule of air hits its particular portion of the impeller, and helps to turn it, by 'bashing' it, and giving up some of its energy to it. The more molecules of air that hit per second, the more energy that gets transferred to the S-rotor aeroturbine. The faster these molecules are moving, the more energy each one of them imparts to the aeroturbine. OK -- resume normal size.

Now, it may seem like it's almost the same thing to say that you get more energy because you have more molecules per second, as it is to say that when they're moving faster, you're getting more energy. And in one sense, it's true that these are the same thing; the faster the molecules move, the more per second will bash into the aeroturbine. But, just think, if we were talking about water hitting the aeroturbine, (can you become a fish for a little while? then with our fishy eyes we would see a great many more molecules hitting the S-rotor (now a hydroturbine) per second, even at a lower speed than we were considering for air, (you can come up for air now).

To make this all clearer, let's consider a cubic foot of something, air or water, hitting the aeroturbine; as this cubic foot (in slow motion) bashes into the S-rotor, we can see that the number of molecules that hit the S-rotor impellers is not only a matter of the speed of that cubic foot of stuff, but also it's a matter of its density (number of molecules per cubic foot). Does that make sense? Just think for a little about the differences between water and air, and how it feels to get 'bashed' with a mass of air moving at twenty miles an hour, (a good breeze), and how it would feel to get 'bashed' by a mass of water moving at twenty miles an hour.

So, the energy which can be extracted by the aeroturbine is related to its (1) size, (2) the velocity (or speed) of the air, (3) the density of the air, and (4) efficiency; this is generally written as follows:

Equation #1-1: $P = \frac{1}{2}\rho A V^3 E$ (now don't go getting nervous on us just because we wrote down some numbers)

In the above equation:

P = power
ρ = the density of air (the symbol is called 'rho')
A = area of the aeroturbine, in silhouette, or height times width (for a propeller type, $A = \pi r^2$)
V = the velocity of wind
E = efficiency, in % of A.T. wind energy

At this point it would probably be tedious, and it is certainly unnecessary to go thru the why of the derivation, so for those of you who do want to know this, refer to Data Sheet 1. For the rest of us, the equation we will use to find out how much energy there is in the wind is:

Equation #1-8 - $P = 0.0006137\ A V^3$ * (or see Data Sheet 1, Section G)

But, whenever we plug different numbers into equation #1-8 to find out what's happening, we should remember that:

P = power, in watts
A = area, which must be measured in square feet
V = wind speed, which must be measured in miles per hour

This means that we have to use numbers which are in square feet (for A, or the area of the S-rotor aeroturbine), miles per hour (for V, or the wind speed), and we will get answers out in watts (for P, or power).

Let's try it out and see what happens. Let's assume that the aeroturbine is 27 square feet (which is what an aeroturbine made of 55 gallon steel drums, three tiers, will nearly measure out to). Let's further assume that the wind is blowing ten miles an hour (see Data Sheet 1 for wind speed determination). Plugging these values into equation #1-8, we get:

$$P = 0.0006137\ (27)\ (10)^3$$

And doing the hard part (got a sharp pencil?), we find:

$$P = 16.57 \text{ watts}$$

Not a great deal, but real home made power. But (remember...) this is only a figure which tells us what power we have at the impeller. This figure does not tell us what power we will have once we transfer this energy to the alternator (90% efficiency), and then transform it

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*Note: It should be pointed out that equation #1-8 assumes the wind device we use is only 20% efficient. We use this efficiency figure since it is almost certainly low, except for those units which are constructed with sand in their bearings (!). In estimating power with this equation, you won't be disappointed when you construct your wind machine, for the power figures you develop will be low estimates. We believe that with certain modifications, the S-rotor can be made 30% efficient, or more; the equation for a wind device at thirty percent efficiency would be $P = 0.0009205\ A V^3$. A propeller type unit, if it is well designed and constructed, can expect to achieve 70% efficiency. The equation for this kind of efficiency is $P = 0.002148\ A V^3$ (see Data Sheet 1 for further info...).

into electricity (assume 50% efficiency). By the time it's real honest to goodness American electricity, we've only got:

$P = (0.90)\ (0.50)\ (16.57)$ watts

Or, after using our abacus:

$P = 7.16$ watts

Not enough to make much ice cream, for sure.

Now, none of this is really useful to you, unless you can use it. (I hope you don't think I'm insulting your intelligence with that one...) And you won't be able to use it unless you use it, usefully speaking...

So, we're going to give you several problems, and if you intend to build this wind device, we recommend that you do them; if you're going to build any other wind device, or experiment with this one, we recommend that you read and understand Chapter 7, Data Sheet 1.

Problem #1-1 take equation #1-8 and plug in $A =$ 40 square feet, $V =$ 15 MPH. What is P?

Problem #2-1 take the answer from problem #1, and, assuming the same alternator and gearing efficiencies we were just using, figure out energy losses for power at the impeller, when it is made into electricity. (Interestingly enough, if you generate power from a wind device, and know the wind speed and have some clear idea of how much power you generate, you can make the same assumptions about alternator/gearing efficiency, and come up with the assumed efficiency of your wind device... But that's only included here for those brave and gallant souls who can absorb this much information at one sitting...)

The answers to the above problems - one and two - are on Page 96, in Data Sheet 1.

Increasing Usable Energy

We can now begin to appreciate that it is going to be hard to develop the kind of power we have been used to using/wasting. Whenever anyone gets serious about alternative energy, the first thing he/she does is to stop wasting/needing so much energy.

In order to increase usable energy, we can, 1) increase the efficiency of the aeroturbine or the whole wind system; 2) increase the size of the aeroturbine; or 3) increase the velocity of the wind. We have already discussed the first possibility (1), so we'll start here with the second.

(2) Increasing the size of the aeroturbine is, or seems to be a simple way of increasing the energy out of the wind system. However, if we look at our wind energy equation (equation #1-8), we will find that increasing the area of the aeroturbine will not necessarily have a tremendous effect. Twice the size S-rotor will generate twice the power, but it may take more than twice the labor, materials, etc., to do. Here we come up against the cost/benefit ratio; the amount something costs us is not always tangible, and the 'cost' is always in relation to the benefit. If we can, the best plan is to increase the benefit by a factor of

three or four while holding the 'cost' increase to a factor of two. Of course, if we don't have enough energy (time/knowledge/materials/money) to be able to pay the increased cost, then even this three or four fold increase in benefit will not be of use to us. You have to make your own decisions here. An S-rotor twice as large might require much more than twice the materials, etc., or, on the other hand, it might not. Everything depends on you and your level of understanding/ingenuity/scavenging ability, and so on.

(3) While it might seem impossible to increase the velocity of the wind (ever hear of a wind dance?), we don't need to increase the velocity of all the wind, merely that portion of it which is flowing thru the S-rotor aeroturbine. Increasing the velocity (assuming it can be done at a low energy cost) stands to benefit you according to the cube. This means (once again looking back at our formula) that where, for a wind speed of 10 MPH, the cube of that velocity is only 1000, for a wind speed of 20 MPH, the cube is 8000, or eight times the power at twice the speed. This ratio holds all up and down the scale (see Data Sheet 1, Table 1, or Table 4).

But how can you increase the velocity of the wind around the aeroturbine? Well, there are two ways to do this. The first is to get the aeroturbine further off the ground, since the wind blows faster at a higher elevation (see Data Sheet 1 for a method of approximating the wind speed at different altitudes). Wind is slowed by certain obstacles (trees, houses, etc.) and it is slowed by the land itself, nearer the ground. Greater height can be gained by putting the aeroturbine up in a tower, or by putting it up on top of a hill. However, don't place it on the side of a hill unless the wind blows towards that side continuously. Even then, it is probably better to place it either on top of a hill, or as far away from it and other obstacles as possible. In any case, build the tallest tower that you can. (Chapter #6, support assembly section.)

The reason you want to keep the aeroturbine away from the side of a hill is the same reason you want to keep the aeroturbine away from the side of your house. Air is a very fluid and responsive medium, and whenever there is an obstruction or an area of higher pressure, the incoming air will flow around that obstruction or area. (An area of higher pressure gets formed in front of any wind device, and this is another reason that only a certain amount of the energy can be extracted by any wind machine. Wind tends to form a 'boundary layer' around any obstruction, and in the case of the hill, you might not be able to get away from this layer of slower moving air, which 'cushions' the faster moving air.)

The second way to increase the velocity of the wind through the aeroturbine is to place an airfoil around it. An airfoil operates on much the same principle as an airplane wing; when air goes over the top of the airplane wing (which is curved in a way familiar to most of us), it must move a longer distance (over the curve) in the same amount of time as the surrounding air moves a smaller distance (in a straight line). Whenever something must move through a longer distance in the same amount of time, it must travel faster. In the case of the airplane wing, this means that the faster moving air molecules become more separated, and thus they create an area of lower pressure (less density) above the wing. This causes the 'lift' by which airplanes fly. (Reread this paragraph if you didn't understand it, and try to visualize what has been said.)

Using this principle to increase the energy which can be extracted by a wind device, we find that by giving the air a curved surface * to travel past, we can increase the velocity of air which travels through the wind device, and thus increase (according to the cube of the velocity) the amount of energy which the wind device extracts. This may sound as though we are getting something for nothing. Theoretically, however, it should work. In practice, it doesn't, always or very well.

By the way, the 'lift' principle is the principle which makes the aerodynamic impeller more efficient. In a sense, the wind is not only pushing on the impeller, it is also pulling it around in the same direction.

These, then, are the three 'basic' ways to improve the amount of usable power in the wind system: 1) increase the efficiency of the whole or the parts; 2) increase the area of the aeroturbine; 3) increase the velocity of the wind thru the aeroturbine.

You may be disheartened that the aeroturbine will not (with the 27 ft^2 size and the low M.T. efficiency) give you a tremendous output of electricity. But, as we said, there are no free lunches. (Unless you know about edible weeds - but then you've paid the prices involved in learning...) The amount you will get out of your aeroturbine, or any alternative energy device, is directly related to the amount of energy (equals: time/thought/money/knowledge/materials) that you invest in it. It's more than possible to buy (with money) a wind device which can give you the amount of electricity you need (assuming you have the money), since there are many individuals, groups, and corporations which are presently making (and a great many more in the near future who will make) an array of alternative energy devices. In fact, it's more than possible for a great many of those who are reading this book to rent your energy from the utilities. But again, we come into the cost/benefit ratio. The amount something costs you should be related to the benefit it gains you. The independence afforded by needing less and gathering some is (for many) far and away better than renewing one's ability to consume by buying a new gadget or continuing to pay rent. When you make it yourself, you gain knowledge: There is no other commodity with less inertia (unless it's the ability to love, or to be courageous...) and more value, which is less transferable to another person, than knowledge.

Another point which might be made here is this: There is a definite relationship between the amount of time we invest in something, and its energy cost. The faster we must have it, the more it's going to cost, in terms of watts and dollars. Lloyd Kahn (of Shelter) says: "economy: durability: time". This means: cost less, last longer, takes time.

This is another kind of efficiency, not so involved with theoretical maximum as it is revealing of a beauty of economy.

Average Energy In The Wind

Well, enough of the philosophy (for now). Now that you know how to calculate the energy which

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*Note: This curved surface is similar to an airplane wing which has been placed with its top - the curved part - next to the wind device, which has been bent around the wind device in its axis of rotation.

can be gathered from a wind of a specific velocity by a wind device which is 20% efficient, the question arises - How do you calculate the energy which is available to be gathered, stored, and used by you over a period of time for a particular average wind speed? While at first glance this may not seem to be a very complex question, it truly is, depending as it does on so many variables. As we have tried to point out a number of times, the energy that's in the wind is different than the energy that's gathered from the wind. (And the energy that's gathered from the wind is different from the energy that ends up being stored and used.) The energy that's in the wind is related to the cube of its velocity. This concept is so basic that it's even spoken of as a law, "the law of the cube".

This law of the cube means that the bulk of the energy in the wind is in the winds of higher speed. If a wind of 10 miles an hour gives us 1000 units of energy, then a wind of 20 miles an hour will give us 8000 units of energy, or eight times the energy for twice the speed. This relationship holds up and down the wind speed scale, so that where a wind of 5 miles an hour gives us 125 units of energy, a wind of 30 miles an hour will give us 27000 units of energy, or 216 times more energy for a 6 times increase in wind speed.

This has several interesting effects, one of which is that the average energy in the wind of a particular area for a particular time of year is always greater than the energy of the average wind speed, same area, same period of time. So, even though a wind of 8 MPH might have 512 units of energy in it, the wind for an area of 8 MPH average wind speed might have an average of from 770 to 10200 units of energy in it.

This average speed/average energy relationship holds because the wind in an area of 8 MPH average wind speed does not always blow at 8 MPH. Even if it only blows a couple of miles an hour faster at times, (10 MPH), the energy in the wind is almost doubled.

This sort of throws things out of whack towards the high end, since so much more energy is up there. In most cases the average energy in the wind is about 160% greater than the cube of the average velocity would have us suppose. For areas which are particularly erratic in their winds, the difference might be as high as 200% (or more), but in any case it does not generally fall below 150%. The lower figures would be appropriate for areas of very smooth and constant winds, but, as all areas experience gusts, it is very rare that it would fall below this. (See Section L, Data Sheet 1.)

The problem of the average energy in the wind, versus average wind speed, is at best complex, and at worst, impossible to determine. In this as in other areas of wind/electric systems, it's possible to learn enough so that it becomes paralyzing. There is a point of diminishing returns to this kind of detailed and sophisticated knowledge. People who have the technical expertise to begin to worry about decimal points of difference, generally also have the tendancy to wait around for someone to give them a grant to study the problem, rather than just up and whanging something together, regardless.

Gathering Wind Energy

Of course, as we said, the amount of energy that's in the wind, (average wind speed or specific wind speed), is different from the amount of energy which you can gather. And that amount of energy is different from the amount you can store, or use. All wind machines have certain lower and upper wind speed limits, below which they won't charge batteries, and above which they won't put out any more energy. The lower wind speed limit is called the 'cut in' speed. This is the lower wind speed limit at which the generator/alternator will put out current, or, more accurately, the lower limit at which the generator/alternator is generally expected to put out usable current. This lower limit may vary according to certain factors, which are discussed in the following chapters, particularly Chapter 4, on control.

The upper wind speed limit is determined by the rating of the generator/alternator, the gear ratio between the generator/alternator, and aeroturbine design. While this also may vary in any given situation, depending on a number of factors discussed further on in the book, this upper wind speed limit is generally at the point where the wind speed is great enough to cause the alternator to put out its maximum current. Since further wind could possibly damage the unit, most wind devices are designed to control the output of the generator, or limit the amount of wind which is thereafter used by the device, either of which will effectively limit the electrical energy output of the wind device, so that it stays at that plateau. In other words, if a wind device is designed to put out its maximum rated current at 25 MPH, it will generally put out no more than that amount of current at any higher wind speed as well. People talk about a "one kilowatt wind plant", and this is really what they are referring to. That expression generally means that at the upper wind speed limit of the machine, it is expected that it will put out 1000 watts (one kilowatt), at the blade, or at the impeller. When this amount of power at the blade is translated into honest-to-America electricity, it must be lower than that value, depending on the efficiency of the gearing, and the efficiency of the generator/alternator. This means that a "one kilowatt wind plant" at what is called its "rated wind speed" (its upper wind speed limit), will only put out 450 watts (assuming 45% efficiency of the gearing-generator/alternator system).

While this is generally the case, many of the manufactured units will speak of power out of the generator/alternator, which, in the case of the manufactured units, is designed for that unit. Once again, it is well to be aware of what criteria are being used. "Rated wind speed" is most generally 25 MPH.

Tell Them What You've Told Them

Well, obviously, if this section were going to live up to its name, then we'd have to list everything we spoke of before. Since we really jam packed this chapter, listing everything we said would essentially mean that we'd just rewrite it here at the end, and that doesn't seem like that's an intelligent use of paper, so, we just suggest that you re-read the chapter (after a few days) if anything doesn't digest well. The information we've tried to present here is really so basic to wind/electric systems, that it could stand some study. After all, in this case, the hard work of study-and-learn is the only thing you can replace money with...

And that's not a bad trade off.

CHAPTER 2 - GENERATING ELECTRICITY

In the last chapter, we talked about the wind, and certain concepts and equations related to that. In this chapter, we are going to introduce several new concepts, and some formulas -- simpler formulas -- to describe electricity.

Now, in the last chapter we talked a lot about 'energy,' and really, in some places this was not the most accurate term. But there's only a certain amount you can absorb at once, right? We'll start out then, by making certain distinctions between force, work, energy, and power. We are not going to use each one of these words as they are commonly used by most people, but rather, we will use them in the same way engineers and physicists use the words.

A force, for example, is a push or a pull, or we could say a repulsion or an attraction. And this force, only if it results in motion, produces work. So work (as we use the word here) is the action of a force in moving something through a distance. Sometimes it is said:

Equation #2-1: Work = (Force) (Distance), or,
'work equals a force times a distance.'

But time is not involved in this definition. In other words, the same amount of work is done when a pound of wood is raised a foot in one second, as the amount of work that is done when the same pound of wood is raised a foot in one hour. In both cases we have a force (of one pound, required to lift the mass of the wood) and a distance (of one foot). In terms of equation #2-1, the work done is force times distance, or one foot-pound of work.

But, as we said, time is not involved in this. When we speak of the rate of work, then we are speaking of power. In terms of an equation:

Equation #2-2: $\text{Power} = \frac{\text{(Force) (Distance)}}{\text{Time}}$ or,
'power equals a force times a distance per unit time.'

In this equation, raising a pound of wood one foot in one second would equal one foot-pound per second. Doing the same amount of work in two seconds would give us one-half a foot-pound per second, or half the power of the previous example. Power is the rate of work done.

Energy is the capacity to do work. Work and energy are measured in the same units, but work is spoken of as having been (or being) done, and energy is spoken of as being possessed by something. For example, it takes a certain amount of work to put something in motion. Once in motion, the object 'has energy,' which it gives up to something else when it is brought to rest. Ignoring, for the moment, factors like friction and air resistance, we could say that it takes a certain amount of work to get an automobile moving 10 miles per hour. After it is moving, then it has a certain energy, which it must 'give up' before it can stop. Ordinarily, of course, the car will stop because of internal friction, air resistance, etc., but the car we're looking at now is 'perfect,' and it's traveling over a perfectly level, perfectly smooth plane. So, the car will travel on 'forever,' at 10 MPH, until something stops it. Realizing this, and not wanting to spend our entire lives traveling across what is really a very boring bit of scenery, we step on the brakes. The energy of the moving car gets transformed into heat by the brakes, and their friction (resistance) stops the car.

Recapping then: force is a push or pull; work is force times distance; and power is rate of work. Energy is capacity to work, and the energy is potential if it's posessed by a stationary object (a heavy book on a shelf -- which may fall) , or kinetic , if posessed by a moving object (such as our car-- which by the way was a '54 Dodge).

The reason the technical boys use these words in this way, is that it allows them to use these words for any particular application. In other words, power is power, whether it's the power in a mass of air moving at a certain velocity (wind power), or the power of a certain mass of aeroturbine rotating at a certain number of RPM's (power at the impeller, or at the blade), or the power of a certain number of people moving toward a more independent lifestyle at a certain rate (power to the people), or the power in a certain number of electrons moving thru a wire at a certain rate (electric power).

In the 'nuts and bolts' of wind/electric systems, these things are important and they enable us to get a clearer idea of the whole picture.

For electricity, the terms force, work/energy, and power have the same meanings, but since electricity is different than the wind, the details are different.

Force, for example, in electricity, is not measured in pounds, but in newtons. Work is measured in volts, instead of foot-pounds, and power is measured in watts, rather than foot-pounds per second.

There seems to be no simple analogy to fully describe electricity. But we could think of electricity as being a 'wind' of electrons moving through a wire. Or, we could think of electricity as 'water' (but instead of water molecules we have electrons) moving through a 'pipe' (or wire).

In a water pipe, a smaller diameter means greater resistance to water flow. Water flows easier in a pipe of larger diameter, and it requires a higher pressure to achieve the same rate of flow in a smaller pipe. Because of resistance, water will not continue to flow through a pipe without continuous pressure.

In terms of electricity, pressure is voltage (also referred to as 'potential'), measured in volts, or the work units of electricity. Rate of flow is amperage, (also referred to as 'current'), measured in amps, or the per-unit time component of electric power. And since power is work per unit time, electrical power, or wattage (measured in watts) is volts times amps. In mathematical terms,

Equation #2-3: $P = (E)\ (I)$, or
'power (in watts) equals volts (E) times amps (I).'

This can also be expressed in terms of either E (volts) or I (amps) thus:

Equation #2-4: $E = \frac{P}{I}$ or

Equation #2-5: $I = \frac{P}{E}$

'P' is always in watts in these equations.

As well, we have resistance, or 'electrical friction,' called R, measured in ohms, and also referred to as 'load.' Resistance is very important, since it has a tendency to change electricity into heat, and therefore that amount of electricity which gets transformed into heat is 'lost,' or it cannot be further used in electrical applications. In mathematical terms, these losses are referred to as 'I^2R losses' or 'line losses.' The losses are expressed in terms of watts, so the symbol P is the same:

Equation #2-6: $P = I^2R$

One last equation tells us about the relationship of R to E and I; so that we may find R, knowing only E (volts) and I (amps):

Equation #2-7: $R = \frac{E}{I}$

To put this wealth of information to use, we will do a few problems.

If we buy a 75-watt light bulb for our house, we know that the bulb is designed for 120 volts. Finding amperage for this bulb using equation #2-5, we find:

$$I = \frac{75}{120}, \text{ or,}$$

$$I = 0.625 \text{ amps.}$$

If we bought a 75-watt bulb for a camper, this bulb would be designed for a 12-volt system, and, using the same equation, we find

$$I = \frac{75}{12}, \text{ or,}$$

$$I = 6.25 \text{ amps,}$$

or 10 times the amps (same wattage) for 1/10 the volts. In other words, a 12-volt, 75-watt light bulb requires 10 times the current of a 120-volt, 75-watt light bulb.

So far, everything seems equable. It makes no difference whether we run our 120-volt bulb on A.C. (Alternating Current, or electric current which changes directions) or D.C. (Direct Current, or electric current which always flows through the wire in one direction). We must, however, continue to run it on 120 volts.

Our 12V (volt) bulb is the same; that is, it can be run on either A.C. or D.C. as well.

It is interesting to note that either bulb will burn brighter on D.C. than it will on A.C. The reason this is true. . . but we won't go into that here; find out for yourself.

Now, however, it is necessary to discover some other differences between A.C. and D.C., when we are running the same power (watts) in both 'circuits.' (A 'circuit' is just that, a completed 'circle' of battery (or generator), wire, 'load' (the thing being powered), wire, and, again, the battery (or generator). An On/Off switch completes/breaks the circuit. (See Chapter 4 - Control - for examples.) It is very informative to use equation #2-6 -- our I^2R losses equation -- to examine these two circuits.

In the examples we will run, we will assume the same resistance in the wires, connections, etc., and also, we will only look at the losses 'in the line,' rather than in the whole circuit, since we only wish to illustrate a point. Remember, as we run these calculations, that the same power (E times I) is being handled by each circuit. Using equation #2-6, assuming 0.2 ohms resistance in both circuits, and substituting the values of I (current) we found in either case, we find:

for 12V, $P = (6.25)^2(0.2)$, or
$P = 7.8$ watts

and for 120V, $P = (0.625)^2(0.2)$, or
$P = 0.078$

Now, 7.8 watts (at 12V) may not seem like a tremendous loss, but it is 100 times the loss in the other (120V) circuit (0.078 watts).

The effect becomes more pronounced when we are trying to shunt one or two hundred watts through the circuit. Going back to equation #2-5, and using a 150-watt (twice the wattage as before) figure, we find:

for 12V, $I = \frac{150}{12}$, or
$I = 12.5$ amps

for 120V, $I = \frac{150}{120}$, or
$I = 1.25$ amps

Then, again, calculating line (I^2R) losses at the same resistance value for both circuits (0.2 ohms), using equation #2-6, we find:

for 12V, $P = (12.5)^2(0.2)$
$P = 31$ watts

for 120V, $P = (1.25)^2(0.2)$
$P = 0.3$ watts

This means that in the 12V system, we lose 20% of the power we are using. With the 120V system, we haven't even lost 1% of our usable power -- in fact, it's less than 1/3 of 1%!

While a number of other factors enter into this, modifying this effect, the end result is the same. So, we can say: For a similar amount of power, higher voltage results in smaller line losses. Higher voltage systems tend to be more efficient, strictly in these terms.

According to I^2R, we will lose 4 times the power whenever we are using twice the current in the same system.

Also, A.C. (Alternating Current) tends to be more efficient than D.C. (Direct Current). This is because with A.C., the electrons are 'jostled' or pushed back and forth very rapidly as a result of the rapid change of polarity. In A.C., positive is, for a fraction of a second, 'down' the wire, and then, the polarity changes, and positive becomes 'up' the wire for a fraction of a second. Then it changes again. In D.C., positive is always in one direction, and the electrons, instead of being jostled, or vibrated, must be 'pushed' through the wire, always in the same direction.

These concepts should explain why ConEd and that gang choose to use such high voltages in the 'high tension' wires, and (part of) why they use A.C. The amount of power which is transferred is the same -- but line losses are much less.

Of course, a much more efficient 'system,' would be one where power is generated as close as possible to where it is used, such as in your own wind/electric system. Or, if power must be 'transmitted,' it would certainly save (on materials anyway) if it were transmitted without wires. Nicoli Telsa invented and built such a 'wireless' power transmission system back in the Twenties, but no one would give him any money to develop it, since they realized that there was no way to attach a meter to it. The wind suffers the same 'disadvantage.'

But, back to the forest. The relative advantages and disadvantages of changing 12-volt D.C. into 120-volt A.C. are discussed in other chapters -- notably, Chapter 4 and Chapter 5.

It seems wise to mention here the designation called 'kilowatt hours,' which is the delivery or production of 1000 watts (a kilowatt) for an hour. We might say that if a kilowatt is a measure of power, then a kilowatt hour is a measure of power expended, or required.

Since power is power, whether it is wind power or electrical power, and whether it is measured in horsepower, foot-pounds per second, or kilowatts, these terms can be mathematically transposed. For instance, one horsepower is equal to 746 watts in terms of equal power. But when we actually transform one horsepower of mechanical energy (which is generally measured in horsepower) into electricity (which is generally measured in watts or kilowatts), we will not get 746 watts. So one horsepower is equal to 746 watts, mathematically, but not in terms of any real transfer. But more about this in the next sections.

SECTION A --- ELECTRICITY-GENERATING THEORY

Design Notes:

An alternator (or generator) produces voltage and current (amps); the amount of each is determined by speed -- increasing the speed increases both. The alternators we will talk about will usually be charging twelve (12)-volt batteries (when 6-volt batteries are used, they will be made to appear -- to the alternator -- as 12-volt batteries); and what we are interested in is: At what speed will the unit produce at least 12 volts? This RPM (speed) is determined by the design of the alternator or generator and it varies between different units. When it has reached this RPM (or a higher one) it is capable of putting current into (charging) a battery (this speed is called 'cut-in' speed). At any RPM below this point, it will not charge the battery; in fact, if you are using a generator and operating at this lower RPM, current could flow from the battery into the generator (it is generally prevented from doing this by a cut-off relay, which 'disconnects' the battery from the generator).

Now, an alternator (or generator) consists of two major components; the armature and the field. Both of these are windings of wire; one turns with the shaft and the other is stationary. In the alternator the armature (called the stator) is stationary and the field rotates; in the generator, the armature spins and the field is stationary. In both, however, the armature (or stator) produces the power (or all the current) and the field controls that power; the field exercises this control because it determines the strength of the electromagnetic field in a generator which, in turn, is how the electricity is generated in the first place!

In an alternator, if no voltage is applied to the field (windings), no charging current will flow out of the alternator (it will produce no power), and the shaft spins freely. In a generator, even if no voltage is applied to the field (windings), some current will flow and, therefore, the shaft will not spin freely. This is the reason why the generator will heat at very high RPM -- because it is 'dragging.'

When either the alternator or generator reaches the RPM where the voltage is higher than the battery voltage (even by a small amount) it can begin charging the battery. It won't do this, however, until the field winding is activated (by putting voltage on it and, thus, letting some current flow through it); this speed is referred to as the 'cut-in' speed. For an alternator, this will be (depending on the unit) between 750-950 RPM; in a generator, this will be at an RPM (generally) higher than 1000 RPM.

The amount of current that will flow out of the generator (once the field is activated) will depend on the state of charge of the battery. If the battery is 'low' (discharged) it will always draw more current than if it is 'full' (fully-charged). At a certain voltage (which is regulated in this system by rapidly turning the field on-and-off), the generator or alternator can only put out so much current (amps).

All generators and alternators have a rating, which is only a specific number of amps (or an amount of current) it can put out; in both units, this must not be surpassed (except briefly) or the unit will be heated and damaged (or destroyed); the heat that the units will develop in themselves during normal operation, depends on the size of wire used for both windings (and its resistance), the friction in bearings or bushings, and arcing (in the case of a generator, at its brushes). The size of wire used will determine the current it can handle (which is expressed by its rating) and its speed will determine the heat factor from friction or arcing. The rating is always expressed in amps (current).

This brings up an important point. From the introduction (to this chapter) we see that power (in watts) is the product of voltage and current (E·I, or volts x amps) whereas heat is the product of current and resistance (I^2R, or amps x amps x ohms). Therefore, voltage does not 'participate' in the formation of the undesirable heat in an alternator.

The significance of this can be illustrated in an example. Say we have a 40-amp alternator and we are charging a 12-volt battery. Now, the alternator will produce about 14 volts at its rated current (40 amps). This means the maximum power that can be obtained from this alternator (at 14 volts) is 560 watts (40 x 14 = 560). Now, if we use a 24-volt regulator and a 24-volt battery (or two 12V batteries in series), we can also draw the rated current at this voltage, which means the power that can be obtained from the same alternator (at 28 volts) is 1120 watts (40 x 28 = 1120)! This can happen all the way up to 120 volts in the same alternator and it can still draw its rated current -- 40 amps; this means the alterator can put out (at 120 volts) about 5600 watts (140 x 40 = 5600)!

Remember, though, it takes proportionately about twice as much energy to turn the alternator at these various speeds (and voltages) as the alternator puts out in electrical power. Considering the efficiency of the transmission and alternator itself (see Chapter 1 - Wind Energy), this means that the aeroturbine must provide about 2 horsepower for every horsepower's worth of electrical energy from the alternator (740 watts). To produce 560 watts (at 14 volts), the aeroturbine must provide 1.5 horsepower (560 watts = .75 horsepower, and 2 x .75 = 1.5 HP). To produce 1120 watts (at 28 volts), the aeroturbine must provide 3.0 horsepower (1120 watts = 1.5 HP, and 2 x 1.5 = 3 HP). To produce 5600 watts at 120 volts, the aeroturbine would have to provide 30 HP (5600 watts = 15 HP and 2 x 15 HP = 30 HP!).

The only point I'm trying to make is that if you have a aeroturbine capable of developing a lot of horsepower, you don't have to buy a moose-size generator for it. Nor do you necessarily have to hook a whole bunch of alternators up to the aeroturbine; one will do. More control will be required (regulators, relays, etc.) but it can be less expensive/troublesome than another alternator (see Chapter 4 - Control Systems).

Note: I have tried to explain essential differences between the alternator and generator to show what prompted me to select the alternator. I have not said (nor will I) that a generator shouldn't be used in a wind-energy system, even an S-rotor aeroturbine. If you already have a generator you may want to use it instead of an alternator. If this is the case, consult an auto repair manual and it will show you proper connections, etc., for its use. From this point on I will describe only the alternator (excepting the comparison which follows); to try to continue explaining each would be not only confusing, but require more space than I can allot to this subject at this time. If you are going to use a generator may I suggest that you write us if you require further information about its use. Remember, your order is a subscription to a newsletter on these subjects. If we receive enuff inquiries, we will provide some of that information in our newsletters.

SECTION B --- THE ELECTRICITY-GENERATING UNIT

Design Notes:

An automobile alternator is the unit used in the Earthmind aeroturbine for generating electricity; it was selected over other types (and sizes) of generators because of its:

(1) widespread availability
(2) low cost, and
(3) simplicity in use.

The alternator is generally referred to as an A.C. (alternating current) generator, to distinguish it from the D.C. (direct current) generator also found in automobiles; this is, however, a misnomer. Both produce A.C.; in the so-called D.C. generator, the A.C. produced is changed into D.C. by the action of the commutator and brushes, while in the alternator (or so-called A.C. generator), the A.C. produced is changed into D.C. by its diodes (electronic 'check-valves' permitting the flow of current in only one direction). So, both do produce A.C., but both change it to the D.C. required in an automobile (A.C. will not charge a battery). (See any reference work on automobiles for more info.)

The alternator was developed to replace the D.C. generator in cars because of the increased electric power requirements of newer cars: electric windows, power steering, power brakes, air conditioners, etc. It was also necessary to produce some of this power at 'curb idle' (car stopped, engine going -- such as in a traffic jam); generators don't put out any current in this situation and, if some of the above-mentioned power-hungry units are on, this puts all the load on the battery (which shortens battery life). The alternator, at engine idle, will put out at least 60 watts (or more) and this has helped the situation. The alternator has several other advantages over the generator:

(1) while it normally rotates clockwise (as seen while facing the pulley, or drive, end) the alternator can rotate in an opposite direction as well; a generator cannot be reversed (or rotate in an opposite direction) without damaging it, unless it has been internally modified for this purpose.

(2) an alternator will provide more power for a given mass; a generator would have to be much heavier to provide the same power.

(3) the alternator is easier to service; diodes, bearings, etc., are available (for most units) and inexpensive; the bearings in an alternator will last longer than the bushings which are used in generators for the same purpose.

(4) an alternator is generally more efficient (in the conversion of mechanical to electrical energy) than a comparable generator, primarily because of the energy 'lost' in the generator (in the form of heat) from bushings and brush 'arcing' (a flash spark across inside contacts).

(5) the most commonly-available alternators are of a higher current rating than the most-commonly available generators; most common alternators are in the range of 45-52 amps whereas most common generators are in the range of only 25-30 amps.

(6) the alternator does not require a current regulator (relay) nor a shut-off relay (its diodes prevent reverse current, and battery drainage); the generator does require these relays. Both units require a voltage regulation relay (the only control that the alternator does need).

(7) the alternator allows complete control of its output (power) through its field; the generator only has partial control of its output (by the field) because 'residual magnetism' (in the generator) activates the field as well. If both are speeded up (beyond normal operating speed) this will cause more heat to build up in the generator.

(8) an alternator is capable of putting out 110-120 volts (D.C., or, if its diodes are removed, A.C.); this occurs at approximately 4000-4300 RPM. No rewiring of the alternator is required but the diodes (if used) would require replacement with ones capable of handling the higher voltage (which is easily/inexpensively done). It is probably true, as well, that the bearings will wear much faster at the higher RPM's required to produce this higher voltage. Don't be thinking, however, that the 110-120 volts A.C. is the same as that which you get from utilities; theirs is 60 cycle whereas this would be over 4000 cycles. If you try to run your 60-cycle stereo or TV with this, you'll 'execute' the thing!

Voltage Regulation

To control the output of an alternator, so that it is in accordance with what a battery (that it is charging) can use, a voltage regulator is required. This is a separate unit (from the alternator) and it has 4 to 6 connections. It will always have a ground connection (marked 'G' or 'GRD'), an ignition connection (marked 'I' or 'IGN'), a relay connection (marked 'R'), and a field connection (marked 'F' or 'FLD'); it may have a battery connection (marked 'B' or 'BAT') and a stator connection (marked 'S').

The voltage regulator controls the alternator voltage and regulates its output (current) by varying the amount of current that flows through the field winding. It may allow full current to the field (and thereby allow maximum output for that RPM) or no current to the field (no output); by rapidly switching on and off the field, it may allow a varying amount of output (between 'dead' minimum and full maximum) from the alternator. Just how much it will 'allow' is determined by the speed of the alternator and the state of charge of the battery (this is further explained in Chapter 3 and Chapter 4) according to the adjustment of the regulator itself in response to these conditions.

It is important to get the right voltage regulator for your unit (alternator); if you don't have one for the alternator that you now have, don't just get one from an auto wrecking yard unless you know what you're looking for.

Finding an Alternator

If ya don't know what an alternator looks like, have someone (that does know) point one out; they are usually large in diameter and short in length. A generator is generally longer (in length) than it is wide (in diameter). The armature connection (marked 'ARM'), field connection (marked 'FLD'), and ground connection (marked 'G' or 'GRD') are generally on the side for a generator but always in back (opposite the pulley end) for an alternator. The alternator, additionally, will only have a pulley attached to its shaft whereas a generator will have a small, many-bladed, fan-type thing (for cooling) in addition to the pulley.

If you are only going to use one alternator for the S-rotor, try to get one that puts out a lot of current. The higher the current rating, the fewer control circuits required; the higher the rating, however, the higher the cost, too.

The approximate and particular rating of alternators can be found in a number of ways:
(1) by name plate -- some will indicate their maximum current but most don't. If you see 45A, 52A, etc., that's it; the A stands for amps.
(2) by serial number -- most have at least this, and it might help, but usually a manufacturer's name is needed, too. Some auto-parts places might have the info but a service shop or an auto-electrical place will be a better bet.
(3) by size -- increased ratings generally mean increased size (and weight), but you have to have a reference (know the rating and size of one) before you can tell if another's got a larger rating simply because it's bigger.
(4) by removing it from a car (junked or not) -- this is the best way to find the rating; any auto shop should be able to give you the rating if you tell them the year, make, model, and engine size of the vehicle you pull it out of.

Auto-wrecking places are the best places to go to find alternators; some strip the cars of things like alternators, then shelve or pile them on the ground. When you're looking for ratings, this kind of place can make it rough -- you don't know which vehicle it came out of originally. Other places may have a pile of alternators, but still have vehicles with the alternators unremoved, so check out the cars first. When you find one that looks good, you can copy down the info on the vehicle, check it out at the auto-parts place, and come back for it.

Note: When you're trying to find out information, be gentle (and not insistent) when you approach these people -- don't be in a hurry. Tell 'em why you need the rating or what you're going to do with it, etc. You may get more than you're looking for; some of these folks have provided me with excellent info, turned me on to where (or how) I can get bigger units, or pointed me to someone who can. Don't be afraid to barter or haggle over the price of an alternator but don't worry about being 'taken' either; if you decide to scrounge for the parts used in your wind machine, you'll be going to such places a lot and attitude will make it or break it -- it's called 'the art of hunkering,' by the way. The faster you learn to say "do you know anybody that knows. . . ?" instead of "do you know. . ." the more you're going to learn.

One further note: You can learn a lot at these places but don't take everything that is said as gospel truth (you should check out the things I've said); even oldtimers disagree. I generally check out something I hear with a few other people and average it out; occasionally, that doesn't even work!

Checking the Alternator

The only, real, good way to know if an alternator is okay is to check it out in a dynamic (operating) state; a shop that services or rebuilds generators/alternators might have the machine that can do this. It might cost a dollar or two but it's worth the minute it takes to strap it on, run it up to speed, and 'load it' or draw its full rated current.

Things that can go wrong with an alternator are as many as there are parts in it. A local generator rebuilder tells me the most common are, in order of frequency, bad: bearings, diodes, brushes, armature. The first three aren't expensive (like the last one is), but the bearings are tougher to work on than diodes or brushes are; I've replaced the bearings once and can verify it's a real tiger if you don't have the tools.

Let's get back to the auto-wrecking yard and finding the alternator; order of preference should be alternators (1) in cars, (2) on shelves, and (3) in piles on the ground. The yardman can tell you if there are any in the cars; if so, here's what to check for and avoid: (1) cars with front-end damage, especially 60 MPH head-ons where the alternator is barely distinguishable from the rest of the metal that was once an engine, (2) cracks in the alternator case, (3) any burned wires (especially the alternator connections), (4) missing, or bent, alternator pulley, (5) alternators exposed to the elements, and (6) a nonrotating frozen shaft. Removal of the pulley without the proper tool will hurt the bearings and (if it's gone) we don't know how it got pulled or bent, do we? If the shaft won't move, the unit is most likely burned up. If it's noisy when it moves it might have bad bearings, semi-burned up, or just dirty; whichever, it goes down on the list as a last choice, only. Get serial numbers and vehicle info (if you do find a serial number, the make of car -- Ford, Chevy, etc. -- is enuff). Now go find out the rating.

If there weren't any in cars, try 'shelved' alternators next; look for the same stuff -- cracks, pulley damaged or missing, etc. -- and start with the larger units first. Get serial numbers. Ask the yardman if he knows the make; most often he will know, and he can probably tell you the rating within a few amps -- but check out his figures anyway.

Piles of alternators on the ground are the last resort; they have been exposed to rough handling, weather, and who knows what. Forget the ones on the very bottom -- they've probably been flooded with water. If they pass the inspection you'd give shelved ones, rotate the shaft. Most will be noisy (like they have sandpaper bearings); if a unit from a car sounds like that, it's most likely not dirt but with these it will be at least that!

Once you have found an alternator and verified that it works okay, the remaining few jobs are:

(1) to secure it to the aeroturbine support assembly
(2) to connect its shaft to the aeroturbine shaft so that power may be transmitted between the two

As the type of transmission will determine the alternator mounting (to the support assembly), methods of power transmission will be discussed first.

Transmission

The simplest means of transmitting the power which is developed by the aeroturbine to the alternator is by pulley and V-belt. This is primarily because a pulley is normally used with an alternator and it may, in fact, be still attached; it will vary in size (diameter) from 2"-4" and thickness (width or depth). The availability of V-belts makes them a good possibility but there are some drawbacks to their use.

The automobile alternator is designed to operate at relatively high RPM's compared to the RPM's developed in, or by, the aeroturbine; thismeans that some sort of "step-up" gear ratio is required whenever these specific alternators are used in any aeroturbine (S-rotor or prop-type). However, an even higher gear ratio is required in the S-rotor than in a prop-type unit because the S-rotor rotates much more slowly.

What is required, therefore, is for the alternator shaft to rotate faster than the aeroturbine shaft; an understanding of gear ratios will provide us with the information on how this can be done. If we find, for example, a 2" (diameter) pulley on the alternator and we put a 6" (diameter) pulley on the aeroturbine, we will have a 3:1 ratio; the alternator shaft, then, will rotate 3 times for every revolution of the aeroturbine. Depending on circumstances, the ratio to use (with an S-rotor aeroturbine) will vary from 6:1 to 11:1; this means the diameter of the pulley on the aeroturbine will be 12"-22" (if a 2" pulley is used on the alternator shaft).

As well as the requirement of a rather large pulley for the aeroturbine, a pulley/V-belt arrangement suffers a 20-30% loss in transmitting the aeroturbine's power to the alternator (it is only 70-80% efficient). This is because slippage is a problem unless good V-belts are used and they match the pulleys used.

A chain-and-sprocket arrangement will not slip and a higher efficiency is possible (80-95%); they are readily available (as the pulley/V-belts are) from bicycles, motorbikes, etc. They do require placement of a small-tooth sprocket on the alternator; if you must remove a pulley from the alternator, use the proper tools or have it done at a shop. The only objection I have to using a chain/sprocket combination is the noise.

Another method of transmitting power is by gearbelt; this is a newer type of device (it is used in some of the newer cars as a timing belt) and is a cross between a V-belt/pulley and a chain/sprocket. It has good efficiency (95-98%), extremely low noise, and can be obtained without too much difficulty at reasonable prices. It won't wear like the V-belts and it won't stretch like the chains.

Mounting the Drive Units

Once a gear size and type has been selected for the alternator and the aeroturbine, next comes the job of securing them. This will be difficult for bicycle sprockets but it can be done. For the aeroturbine, the sprocket must fit on the rotor shaft; if the sprocket center hole is too large, it can be sandwiched between a couple of flange/nipple assemblies (see Fig. 6-13, Chapter 6) but if you use this arrangement insure that the complete assembly is quite strong; I built a paddlewheel boat once that used this technique (sprocket sandwiched between 2 flanges) and the flanges would occasionally 'break-up' (the flange is a casting and it's what's called 'pot-metal,' which is basically the process of throwing everything into the pot and calling the final product metal).

If a chain/sprocket or gearbelt/gear arrangement is used, a sprocket or gear must be inserted on the alternator shaft. Usually they will be secured with a setscrew to keep them from slipping.

The length of V-belt, chain, or gearbelt will depend on the size of pulleys, sprockets, or gears used and the distance between their centers. Don't arbitrarily select the belt or chain length, however, as it is very important that there be a proper distance between gears, from

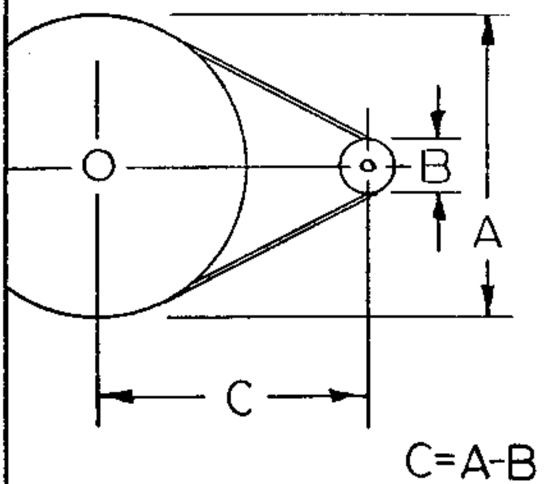


FIG. 2-1: SPACING GEARS

center to center. A general rule is to separate the centers of the gears (see Fig. 2-1) by a distance C, equal to the difference between A and B (i.e., if an 18" sprocket gear is used on the aeroturbine and a 2" sprocket is used on the alternator, then the distance between the two when mounted should be 18"-2" or 16"). That's a *minimum* distance; you *can* go *more* but don't go any less or you'll have the chain come off!

Mounting the Alternator

Once you've selected the chain, V-belt, or gearbelt length, you're ready to mount the alternator; its pulley, sprocket, or gear should be in line with the one on the alternator. Probably the best way to do this is bolt the alternator to part of the support assembly. It will have several holes to help implement this securing but however you do this, you should try to secure it so that it will pivot *about* one hole (see Fig. 2-2); this will help to tension it. This isn't always necessary (tensioning) but it will allow for wear and sloppy securing (seldom does kitchen-sink technology provide machine-shop accuracy). There are many ways to secure the alternator and allow for tensioning, so don't get stuck with Fig. 2-2 if it doesn't apply to your situation.

Hooking up the Alternator

You may have to check with an auto shop or rebuilder to determine what terminals are what on the alternator (they're seldom marked on this unit or its regulator); when you find one (in a car) that has a multi-connector plug connected to the regulator, get that, too. The alternator will normally have a ground (marked 'G' or 'GRD'), a stator (marked 'S' or 'STAT'), a relay (marked 'R'), and one or two field terminals (marked 'F', or 'FLD'). If there's a FLD #1 and FLD #2, ground one of these and connect the other to the regulator; there's no use for the relay terminal in this system (in a car, it's used to light an idiot light in the dash).

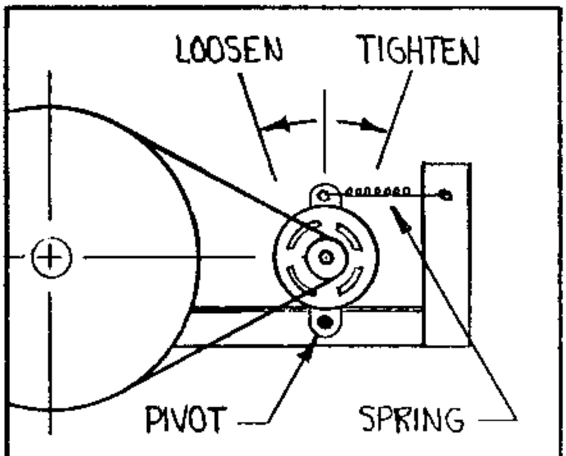


FIG. 2-2: ALTERNATOR MOUNTING

When you have completed the wiring to the alternator and the voltage regulator, you can confirm that you have the correct connection for the field by putting voltage across it and seeing the amount of current flowing through it (on a meter). Use a battery (12-volt); connect its negative pole to ground (on the alternator) and its positive terminal to an ammeter. Then connect the other side of the meter to the field terminal (on the alternator) or the ignition terminal (on the regulator); you should notice 2-3 amps of current flow.

CHAPTER 3 - BATTERIES

To effectively use wind energy requires some means of storing it for periods of non-wind use. This means changing the kinetic energy of electricity into a potential energy which can be efficiently reclaimed (as electricity); at this time, the least expensive and most reliable means of doing this is chemically -- in a battery.

The battery selected for our system is a lead-acid (wet cell) type, secondary (recyclable) battery; it was selected for its:

1) availability
2) low cost
3) ability to store a large amount of energy
4) requirement for little maintenance, and
5) its ability to be repeatedly cycled (discharged and charged).

The first battery group we've worked with is that which is found in automobiles; it fails, however, to meet #3 (large storage capacity) and #5 (its ability to be repeatedly cycled). The average automobile battery is of rather low quality and is not designed for deep cycling (discharged to exhaustion repeatedly). It would last reasonably long if it were not deep cycled but the only way to get any appreciable amount of power from a system using these batteries is to have many of these batteries and to only draw a small percentage of the energy from any individual battery.

A very good alternative to the automobile battery is either a truck-type battery or the type of battery used in electric vehicles -- golf carts, fork-lifts, and other industrial-type units. These are not as readily available but their cost is still fairly low. As well, these are designed for deep-cycling and store more energy per pound of battery than an auto equivalent.

Edison cells and NiCads (nickel-cadmium) are two other battery types that can be used in a wind energy system. Both are expensive and harder to find (used). I know little about the Edison cell except that they seem to be a quality battery. NiCads, however, have a controversial reputation. They are known to take overcharge (over-voltage and over-current) conditions and they are not as susceptible to poor performance at lower temperature (as lead-acid are). However, there is some question as to their ability for deep-cycling; my present understanding is that they will be severely damaged if discharged completely (to exhaustion) twice in a row without a "forming" charge in between. On the basis of this information, I cannot recommend them. I may be wrong; if you know more -- pro or con -- on this battery, let me know and we'll let others know (via the newsletter). If you were planning on using them or if you already have NiCads, contact a battery manufacturer for more info.

The preceeding information encompasses the extent of information that I can provide at this time on types of batteries other than lead-acid; the remainder of this chapter is devoted to the lead-acid battery. The subjects of discussion are listed as sections; they are:

A. Fundamental Principles
B. Capacity
C. Charging/Discharging
D. Test Equipment
E. Testing Lead-Acid Batteries

I (personally) consider the battery to be the "weak" link in the wind energy system. The modern battery has a few refinements over the ones from the old days but it has one decided disadvantage; unlike the old-time batteries it cannot be taken apart. You can, if you know how, open it up without damaging it but that's about all you can do. A battery rebuilder will do this if the thing has a bad cell but he will only replace it. It used to be that batteries could be completely disassembled and quite thoroughly overhauled but, alas, in this day of 'throw-away,' the end process for most batteries is just that -- throw it away.

A battery is different from other system components -- for example, an alternator. You can check out an alternator and, if it checks good, you can (with proper care) expect it to perform very well. As well, you can overhaul it; bearings, diodes, slip rings, brushes, etc. But a battery is different; it is hard to check and you can't take it apart and fool around with it.

The next best thing to "taking it apart and seeing what makes it tick" is to know as much as possible about it, so that you can make some fairly good assumptions about its worth, life expectancy, etc. Then there's a lot more that has to be known to insure its proper use in a wind energy system; most of these are observational tests that will indicate if something is not occurring as it should. These are the subjects covered below.

A. Fundamental Principles

A lead-acid battery is basically just that -- lead and acid. The lead is formed into square plates of two kinds; the positive plates are lead peroxide (PbO_2) and the negative plates are sponge lead. The plates are arranged together, (separated by their partitions of plastic or paper) and placed in a container called a cell. When this cell is filled with electrolyte (most often dilute sulphuric acid and water), and charged with a current, it will produce about 2 volts. If we hook three cells together, we have a six-volt battery; if we connect six cells together, we have a twelve-volt battery. As each cell will have a 'vent' plug, counting these plugs is a good way of telling a 6-volt from a 12-volt battery.

Now, I could take up the next few pages discussing what happens inside a battery when we discharge and charge it but that information can be found in any chemistry text. So what is important to know in this context, as practical knowledge, is how specific gravity (a measure of how much H_2SO_4 -- sulphuric acid -- is in a given amount of water) changes as the battery is discharged or charged. Let's take a look at the process to see what I mean.

Suppose we have a fully-charged battery and we begin to discharge it -- what happens chemically? The H_2SO_4 breaks up into H_2 (free hydrogen) and SO_4 (sulphate). At the positive plate (PbO_2), O_2 (free oxygen) is liberated and it will combine with the free hydrogen to form water (H_2O). As well, the SO_4 (sulphate) combines with both plates (positive and negative) to form lead sulphate.

Now, what happens when the battery is charged? The reverse. The SO_4 is pushed out of the plates (and back into the electrolyte) and the positive plate absorbs free oxygen to become (again) lead peroxide (PbO_2). And how does this affect the specific gravity? Well, during discharge it decreased. Why? Because acid (SO_4) was going into the plates (and out of the electrolyte) and, as well, the H_2 that was released made more water; therefore, the ratio of acid to water decreased. During charge, the acid (SO_4) went back into the electrolyte and water (H_2O) was disassociated (changed into H_2 and O_2) and the oxygen was absorbed by the plates. So, the ratio of acid to water increased.

It would then be reasonable to assume that if we were able to "read" what the specific gravity is in a battery, we could determine if it was charged or discharged. The device that reads this is a hydrometer and it is able to tell us a lot more than just whether the battery is either charged or discharged; as well, it will (or can) tell us how much of a charge a battery has, because it will read out points in between the two extremes of fully charged and fully discharged.

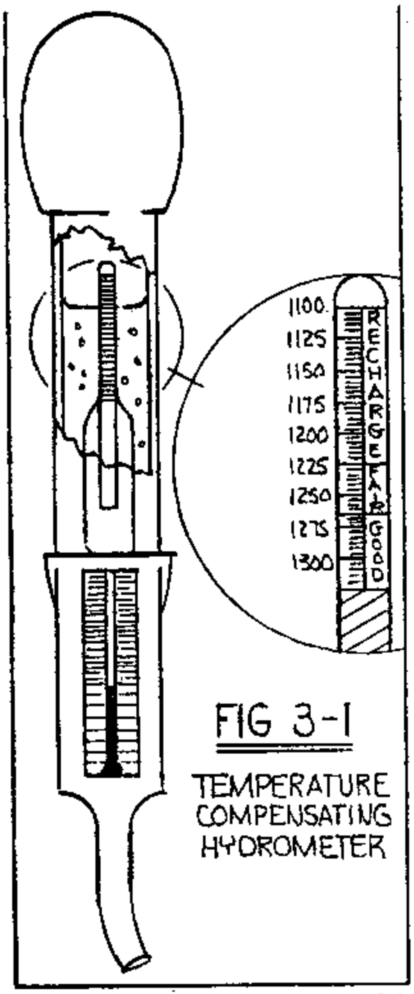


FIG 3-1

TEMPERATURE COMPENSATING HYDROMETER

A hydrometer (see Fig. 3-1) is a bulb and tube apparatus that can "suck" some of the electrolyte from each cell in a battery; a calibrated float inside the tube will then settle low or ride high in this electrolyte depending on the temperature of the electrolyte and its specific gravity. By compensating for the temperature, and reading the specific gravity (the mark on the hydrometer in line with the surface of the liquid), a battery's state of charge can be determined.

Now, the value of the information given by a hydrometer is determined by how much you know. I mean, you can go borrow (or buy) a hydrometer and take all kinds of readings; if, however, you want to really know what's going on inside the battery (instead of merely knowing what your hydrometer is reading), you should know how the hydrometer (or you) can be "fooled."

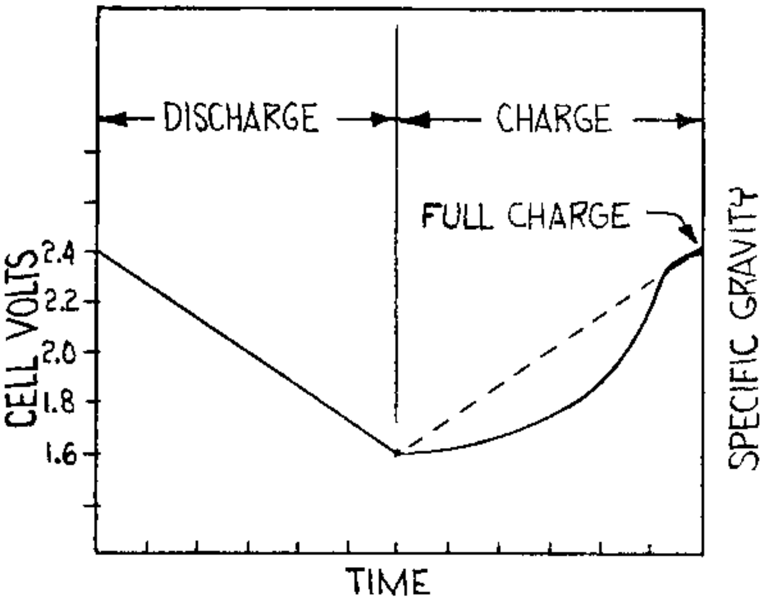
I've found about 10 conditions that will make the readings of a hydrometer inaccurate, but they can all be included in:

(1) the temperature of the electrolyte
(2) the level of electrolyte in the cell, and
(3) if the battery is being charged.

Temperature may vary somewhat from the normal reference temperature (77° F.) but this must be compensated for if the reading is to mean anything. As the temperature goes up (above 77° F.), the specific gravity will read lower than it is. If the temperature goes down (below 77° F.), the specific gravity will read higher than it is. A rather neat hydrometer which eliminates having to take electrolyte temperatures with a thermometer is an Edelmann 40-B; it has a built-in thermometer that tells you how much to correct the specific gravity (in points) as well as the real temperature. (See Sources, Data Sheet 3, Chapter 7)

The actual level of electrolyte in the cell will influence the specific gravity reading. When a battery is being charged, some of the energy that goes into the battery will be lost because it disassociates the water in the electrolyte; this breaks the water into oxygen and hydrogen, which escape from the battery. This is the condition called gassing and it cannot be eliminated; as a result, we must add water to the battery occasionally to offset the loss. However, if the water is not replaced, it will give a high specific gravity reading (because the ratio of acid to water goes up). As well, when water is added, a reading at that time will tend to be false because the water has not had an opportunity to thoroughly mix with the acid.

FIG 3-2 BATTERY SPECIFIC GRAVITY



A further condition leading to possible misrepresentation of the true specific gravity is that which occurs in the charging of a battery. As you begin charging, the specific gravity will not rise (as you might expect it to) as the battery is charged; in fact, you can charge for quite a while before the specific gravity will rise at all. This is, however, normal, although it is quite different from the "opposite' set of readings you might receive when discharging the same battery; in that event, you will notice a steady decrease of specific gravity from the time you start the discharge until exhaustion. (See Fig. 3-2.)

Hopefully, all of this imparts some kind of meaning as to the limitations of a hydrometer. It is a simple and effective tool but it requires knowing when to read and what to allow for when you do. One further point should round off this discussion -- your readings should be referenced to the specific gravity initially in the charged battery. For automotive service, 1.260 is best; heavily-worked (or deep cycled) batteries use 1.275. A wind energy system should use something between these two readings. The point is -- if you get a used battery you may have to change its specific gravity to meet the optimum performance and life. You can raise the gravity by adding sulphuric acid and lower it by removing some of the electrolyte and adding water. This is tedious, but exercise caution; too high a specific gravity (too much acid) can eat away the active material of the plates, and too little can result in a lot of sulphation. This is covered in Section B (Capacity).

Unless the battery is tipped over and electrolyte is spilled out or the specific gravity needs to be (initially) changed, there is no other reason to add sulphuric acid (or ready-made electrolyte) to the battery. Periodically, water must be added to replace that which is evaporated or disassociated but that is all; the only type that should be added is distilled water as any other source will contain minerals or impurities which will only harm the batteries. As well, though there are many claims to the contrary, the addition of any of the chemicals advertised to give "new life" to a dead (or dying) battery are rip-offs. Where you have a battery that is performing poorly (because it has been ignored or badly maintenanced), this stuff will "perk" it up but only at the sacrifice of a good battery (it will now have a very definite -- and short -- life). If the battery is truly "beyond repair," the money you spend on such "miracles" is far better spent toward the purchase of a new battery.

B. Capacity

A battery's capacity is rated according to the amount of energy it can store or deliver; this amount is expressed in amp-hours. 'Amp-hours' is a term which fairly well describes its own meaning; this is a measure of the ability to deliver a certain number of amps for a certain number of hours. There are several factors which affect a battery's capacity (other than physical construction) for any given amp-hour rating; they are:

(1) the rate of discharge
(2) specific gravity
(3) temperature.

The rate of discharge will determine how much energy is delivered by the battery; each type of battery, however, does have a standard rate (of discharge). For automotive use the rate is 20 hours and for golf cart-type batteries, the rate is 6 hours (all others are usually 8-hour rates); therefore, for a 60 A.H. (amp-hour) automotive battery, 3 amps can be delivered for 20 hours (or 3 amps times 20 hours equals 60 A.H.); likewise, a 180 A.H. golf cart-type battery will deliver 30 amps for 6 hours (their product equals 180 A.H.).

It is not true that a 180 A.H. battery (which is 'rated' to deliver 30 amps for 6 hours) will deliver 60 amps for 3 hours, because the higher the discharge rate (in amps), the less amp-hours worth of capacity the battery will deliver (relative to its rated discharge). This is primarily because there will be a buildup of heat (and a loss, therefore, of some of its energy) at higher rates of discharge. It is true, though, that this same battery will deliver 15 amps for 12 hours (and a little more). This should indicate that an amp-hour rating does not define the true capacity of the battery but just what it will deliver at a particular rate of use.

The specific gravity of a battery determines its capacity because, after all, the acid concentration determines the chemical action of the battery. A high specific gravity (like 1.275) will give more capacity and allow higher discharge currents (for brief periods) but it will reduce the 'life' of a battery. It is, then, a matter of what's important (or optimum) for your situation. You can get high capacity and shorter life in a system, vice versa, or something in between. If you have only a few batteries in your system, they have to work hard and this will shorten their life; a lot of batteries means less work for each battery and more life, but it costs more to set up the initial system.

The ambient temperature in the battery's environment (and thus the battery's 'stable' temperature) will greatly affect its capacity; at higher ambient temperatures, a battery tends to have more capacity, but the high temperature will shorten its life. At lower temperatures, it will deliver less capacity, but the battery will last longer (provided it doesn't freeze).* Understand though, that a battery doesn't lose the energy (stored in it) at lower temperatures; it just can't deliver it. The normal range of temperature (for optimum performance and life) is 75°-80° F.

C. Discharging/Charging the Batteries

In its discharging, a lead-acid battery is unique since it can deliver the maximum current that it will deliver, without harm; this means you can short it out and it will not damage the battery (this would destroy a NiCad). However, a lead-acid battery can be damaged by draining it to the point of exhaustion (at either a normal or excessive rate of discharge); this is primarily due to the fact that the sulphate formed on the plates expands and can short, crack, or warp the plates. The point at which this occurs is called the 'final voltage'; for high rates of discharge this will be about 1.0 volt per cell (or when a 12-volt battery reads 6

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*Note: freezing temperature for a battery is lower than that of water, depending on its specific gravity.

volts), or, for low rates of discharge, this is as high as 1.85 (or 11.1 volts for a 12-volt battery). Draining a battery beyond the final voltage is referred to as 'over-discharging.'

Charging a lead-acid battery can occur at any rate of current which will not produce excessive gassing or cause the battery to get hot; these are two very good indicators that some of the energy is being wasted in disassociating water or producing heat. Some gassing will inevitably occur; just don't let it 'boil.' The temperature should not exceed 110° F. but lead-acid batteries will survive 125° F. for short periods. The amount of current is far more critical toward the end of the charge than at its start; this value (in amps) is called 'normal' or 'finish-rate.' For automotive batteries, it is between 1 and 3 amps; for industrial heavy-duty batteries, it is between 5 and 10 amps (this information can be obtained from the manufacturer of your battery). At the beginning of charge a battery can take up to 10 times that amount of current but the rule applies -- it must not gas excessively nor heat up. As the battery becomes charged, however, the rate must be lessened (gradually, or in steps) to prevent the gassing or heat which will occur even at progressively lower rates of charge.

Both undercharging and overcharging are going to decrease the battery's life; undercharging will result in excessive sulphation formation which eventually 'strangles' the battery, while overcharging 'eats up' the plates. It is, therefore, important that the battery be given the right rate of charge.

There are some indicators which will help identify an incorrect rate of discharge; they are:

(1) the specific gravity should read normal at the end of charge; it will be high if overcharged, low if undercharged.

(2) the amount of replacement water required will be 'normal'; this is a tough one to determine because you don't know what's 'normal' and what isn't (but you will after you've worked with it for a while). Excessive water replacement means lots of gassing and overcharging.

(3) if a battery is cold after it's been charging, chances are it is being undercharged; if real hot, it is certainly being overcharged.

When charging a battery, the amount of energy you put into it must exceed that which is taken from it; this extra amount varies between different batteries and their capacities, and ages; but it will generally be at least 110%. Batteries that you are testing for use in your system (especially if they are in desperate need of charging) will often require many times the energy they will deliver until (if they finally respond) they are again 'normal.' In normal use, batteries which are new are about 80% efficient while batteries that you've breathed some life into (reconditioned) will seldom surpass 70% efficiency. Of course, these 'restored' batteries probably cost one-tenth of the price of a new one (or less); this is where, again, you must consider the factors -- time, budget, and benefit.

All batteries which are charged and, then, left to stand (i.e., on a shelf) will drain themselves; this is due to internal losses and is called 'local action.' This occurs (primarily) due to the impurities in the materials used in making the plates and those that enter the cell when the caps are left open or water is added. This is why only distilled water should be used when replacing that which is electrolyzed or evaporated. This process, incidentally, can be increased (and the battery drained faster) by placing the battery on a damp surface; therefore, keep the battery off of concrete or metal where possible (wood makes a good insulator).

When operating a system (using batteries) in cold climates the effect of low temperatures on the battery's electrolyte must be understood and provided for if the batteries are to survive. A discharged battery's electrolyte can freeze at 25° F. but the same battery when fully charged won't freeze until the temperature drops below -40° F.!

Maintenance and Precautions

Set up a schedule to periodically check and maintenance the batteries; by doing this you will not only insure their proper operation but learn more about them. Keep records. This is the only way you will know if they're consuming too much or too little water, that the specific gravity is getting progressively lower, etc. Make a point to check them only after they have been topped off (fully charged).

While a standby (auxiliary-power) system is discussed in Chapter 5, it should be pointed out that batteries which are as heavily cycled as those in a wind energy system should receive a full, equalizing charge at least once every two weeks. My own experience clearly indicates (at least to me) that batteries have a memory; failure to keep them charged during low wind periods of the year can adversely affect their future performance.

The greatest precaution or the best maintenance for a battery is its proper operation -- charging and discharging-- or how you use it; there is no single one other thing that can provide the best service/longest life as preventing overcharge, undercharge, or the loss of too much water.

Batteries should be kept dry and clean of chemicals, dust, grease, etc.; besides the possibility of these 'contaminants' getting into the electrolyte they might also provide a conducting path between the battery's poles or from one of them to ground.

Adequate ventilation is required for batteries used in deep cycling; as indicated before, free hydrogen and free oxygen are formed when the battery is charged and their release provides the phenomenon of gassing. A mixture of 4% hydrogen with this oxygen (or the surrounding air) is explosive; never use a match to check the level of electrolyte in a cell. As well, make certain that all battery-post connections (cables, straps, etc.) are tight; a small spark at one of these posts could well destroy a whole battery bank.

D. Test Equipment

Testing a used lead-acid battery involves both charging and discharging it under fairly controlled conditions. The basic tools required to do this are:

(1) a charger -
(2) a hydrometer - for specific gravity readings
(3) a thermometer - unless the hydrometer is temperature-compensating
(4) a 'dummy load' -
(5) an ammeter - (measures current in amps), and
(6) a voltmeter.

The charger will be the most expensive item for testing batteries unless you have a car; remember that an automobile has a battery and that it's charged by the generator. If you drive more than 10 miles, chances are it will, in that distance, have recharged the battery

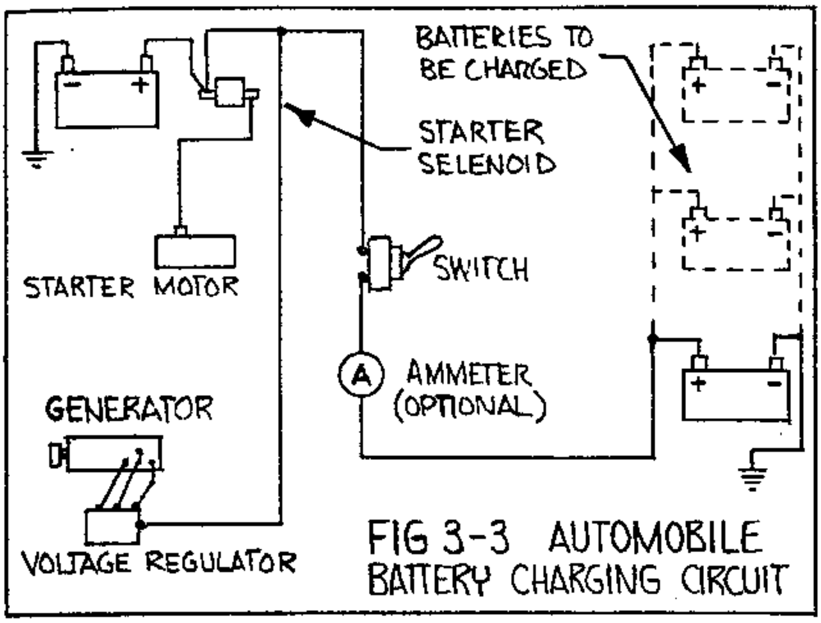


FIG 3-3 AUTOMOBILE BATTERY CHARGING CIRCUIT

in the car. When that's done, the regulator in the car will have 'shut down' the generator. By putting a few extra wires, and a switch under the hood, you can use the car's generator to charge another battery (or several batteries) that you want to test; these can be placed in the trunk or wherever they won't get knocked over, or be in the way.

To do this (see Fig. 3-3) find a place where you can twist, secure, or 'alligator-clip' a wire to a positive (12-volt supply) in the vehicle; this can be at a number of places -- at the battery, starter solenoid, under the dash, at the ammeter (if you have one), etc. -- but if you're not sure of what you are doing, ask! Any auto shop (and some service stations) will help. Make the wire long enough to reach wherever you are going to put the switch (which should be within reach of a person driving the car); you're going to have to route it under seats, around hoses, etc. Then run another wire from the switch to the place where you'll put the batteries. After securing some connectors to the battery's posts, secure this wire to the positive (+) terminal. Then, with the switch in the 'Off' position, run a wire from the negative (-) terminal to ground (any metal that's part of the car) in the immediate vicinity of the battery.

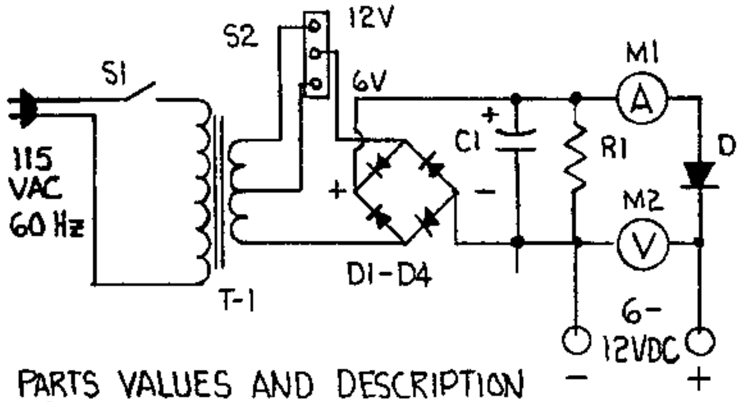
If you are not sure if you did all of this right, disconnect one of the connectors from this battery and strike it very quickly against the other; this should crackle and spark for you (make sure you put the switch on 'On' beforehand and don't do this while the car is running).

Proper procedure is to operate your car normally for about 5 minutes and then flip the switch to 'On' and leave it on for as long as you drive; don't worry about the battery or the generator, the voltage regulator can handle two (and more) batteries with ease. Try to remember to switch it off when you stop the engine and don't turn it on until after you've got the engine running. All the wire used should be #12 size and the switch should be able to handle 25 amps. By the way, you don't absolutely need the switch; you can put the connectors on the battery after you've started the engine and disconnect it right after you've turned the engine off. Just don't let that positive connector short out against any metal in the car or you'll have a private 4th of July and ruin a good regulator (or a generator).

A battery charger is the answer if the auto is not a workable solution to charging batteries; these can be made, or bought ready-made. If you are not 'into' electronics, I recommend the store-bought; for the electronically inclined, Fig. 3-4 illustrates a simple battery charger circuit. The parts can all be purchased from surplus electronic places;
B & A (Burstein-Applebee) is a good mail-order place. (See Data Sheet 3, Chapter 7, for addresses on all sources.) By writing these places you can obtain a catalog and select parts that are similar to the ones used in the circuit. As well, you can buy ready-made chargers from them; Heathkit is another good source of battery-chargers and, if you get a kit, you'll begin working toward the confidence and skills necessary for such things. (See Data Sheet # 2, Chapter 7, for the details on the parts used in this battery charger.)

A hydrometer will be needed to determine what's happenin' in the battery; know its limitations -- what it can tell you, what it can't tell you, and when -- and it will be a good tool.

A thermometer will be required to determine battery temperature when specific gravity readings are taken; generally, for each 10° of temperature difference (from 80° F.) the specific gravity will change .004 points; if the temperature is higher than 80° F., you will add this amount to the reading. Subtract it if the temperature is lower than 80° F. An example: if the reading is 1.240 and the battery temperature is 60° F. (or 20 degrees low), then you will subtract .008 and the true reading will be 1.232. If a temperature-compensating hydrometer is used, a thermometer will not be required.



PARTS VALUES AND DESCRIPTION LISTED IN DATA SHEET 2 CHAPTER 7

FIG. 3-4 : 6 OR 12VDC BATTERY CHARGER

The best test of a battery's condition is its response to discharge under normal conditions; to find this we need to draw current from it. Anything that normally operates on 12 volts (or the battery's voltage) can be used as the load; this can be automobile lites, horn, fan, etc., and the test can be conducted in a car. But another way to discharge it is to make up a 'dummy load' (which just simulates an appliance); what I found worked the best is baling wire (from hay bales). This will generally be about 10 feet long -- a 10' length of the baling wire we use will draw 50 amps from a 12-volt battery or 25 amps from a 6-volt battery. By wrapping the wire around a rod of some sort (like a broom handle), the resultant coil of wire takes up a lot less space. More about this after we talk about the rest of the test equipment.

An ammeter is required to read out the amount of current which is being drawn from the battery and used in the dummy load; one similar to that used in a car will do but these are frequently not very accurate and can be hard to read. Many surplus electronic centers (mail-order type) have good meters (see Data Sheet 3, Chapter 7); one that will read 50 amps (full scale in one-amp divisions) is necessary. You should have one for the system anyway (see Chapter 4 - Control) so it won't be a one-time-use item.

A voltmeter is also necessary to the system (see Chapter 4 - Control) and it will certainly help the test procedure; it should read 15 or 20 volts (full scale in one-volt divisions). However, don't get a meter that reads higher or the inaccuracy of reading voltages in the range of 6 to 12 volts will be greater. Multi-meters are useful here, and can be purchased at fairly low cost, and can be used for many other parts of the system; as well, these can be mail-ordered.

Now that we have gone through the basic components required for testing a battery -- charger hydrometer, thermometer, dummy load, ammeter, and voltmeter, the next step is to acquire the batteries. Get everything set up to test before you get them because you might have to agree to return them (if they test bad) to the yard within a short period of time; just make sure you give yourself enuff time. Look over the actual test procedure to get an idea of what time is required and figure out what kind of time you'll have to put toward it.

Inspection of the batteries can begin at the yard; there's no sense in carting home an obviously bad battery. If it has any one of the following conditions, it fails:

(1) loose or pitted poles (where the pole is partially eaten away)
(2) cracks in case or around poles
(3) found lying on its side
(4) electrolyte below tops of plate (in any cell)
(5) does not float the hydrometer bulb (in any one cell)

A flashlight will come in handy for checking the electrolyte's level and the hydrometer will be needed for the specific gravity check. Depending on the type of charger you may use, you may be able to charge several batteries at a time but, you can only 'break-down' (discharge test) one at a time. So don't cart off 20 batteries at a shot unless you're allowed and have the time (and the bread to lay down as a deposit).

Test Procedure

New batteries (or used ones still in excellent condition) need to be charged to (at least) 110% of the battery's amp-hour capacity; i.e., a good 45 amp-hour battery, at a 5-amp rate, would require 9 hours for 100% capacity plus another hour for 110% capacity. Used batteries obtained from auto-wrecking yards (or any battery whose condition is otherwise questionable) will require more of a charge initially, or a series of charge/discharge cycles before sulphation can be broken up and the battery can be (again) fairly efficient at storing and releasing energy.

These 'junk' batteries, then, may have to be charged to 200-300% of the normal battery capacity; this may seem impossible but most of the 'energy' will go toward making heat or disassociating water. They should, however, be charged only at a rate between 2-4 amps (per 100 A.H. capacity) to avoid excessive gassing (even at start of charge); otherwise, the sulphation (on the plates) will 'break-off,' rendering the plate area (from whence it came) useless, and adding to the layer of sediment at the bottom of the battery (which will eventually short-out the batteries). A low rate of charge will aid in dissolving the sulphation, if it can be dissolved.

The most important part of running these tests is to keep records; I don't care for pencil-pushing, but it's that, or wasted effort. Data Sheet #2 (in Chapter 7) provides a sample of the record sheet I use here; use a separate one for each battery. I call mine a B.R.S. (Battery Record Sheet) and will use that 'name' whenever I indicate, during the procedure, that something should be filled in on the B.R.S.

(1) after having obtained some batteries for testing, the first step is to clean them up a bit. It's dirty work but I wouldn't let one of them into my shop the way I usually find them. A toothbrush and baking soda (which neutralizes the acid) will work wonders; keep the vent plugs closed, and after scrubbing a bit, wash the batteries down with water and let them dry in the sun.

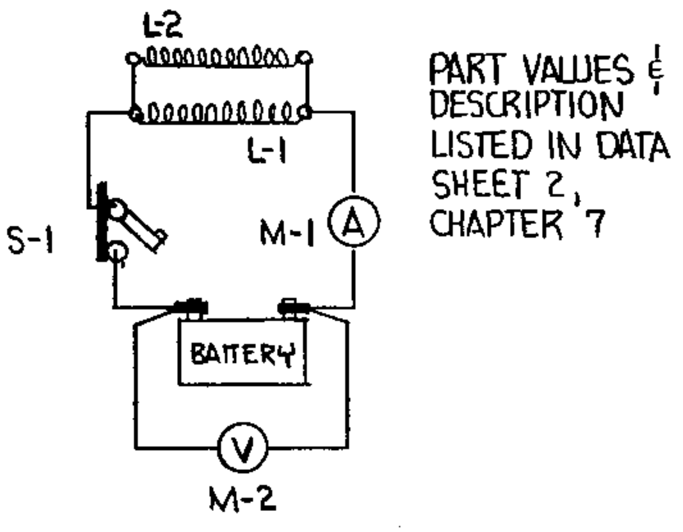
(2) when you establish a place to charge the batteries, keep them off the ground, preferrably on something that isn't damp but is expendable (if the cells flood over, the acid could ruin whatever it gets on). I used wood pallets, but a great many things will serve.

(3) if you have more than one battery, number (or mark) them in some way so that they don't get mixed up; tape (or whatever will stick to the battery) can be used here. Indicate each number on a different B.R.S.

(4) whether you charge the battery in a car or with a charger, the first thing you need to do is take some readings; more specifically, the battery voltage, and the specific gravity of each cell. Indicate these readings on the B.R.S. for that battery.

(5) if you are using a car's generator to charge the batteries (while you're driving), it's going to be difficult to tell when the battery is fully charged. If you hook up the ammeter in series with the wire going to the battery you will be able to tell when it is no longer charging (it will read at, or near, zero); without its use, an allowance of two hours should be sufficient.

If you are using a charger, allow a minimum of 12 hours (per 50 A.H. capacity) for charge. Most chargers will 'taper-down' the charge (reduce it) as the battery reaches full charge, so you can generally leave the battery on 'charge' much longer without having to worry about overcharge.



PART VALUES & DESCRIPTION LISTED IN DATA SHEET 2, CHAPTER 7

FIG. 3-5 : BATTERY DISCHARGE CIRCUIT

(6) after the battery is charged, let it stand for about six hours; a battery should not be discharged immediately because you should find out how much 'local action' (self-discharge) it experiences.

(7) when you are prepared to discharge the battery under test, take a battery voltage reading and, again, the specific gravity of the cells. Write these down on the B.R.S.

(8) if you can find the fuse (in your car) for the headlights, you can use the automobile (again!) to test this battery. Disconnect the car's battery, replace it with the battery under test (make absolutely certain it's the same voltage!), hook the ammeter across the fuse contacts (with the fuse removed, so all the current will flow through the meter), and put the headlights on 'hi-beam.' Don't actually turn the lights on until you are ready to test (except briefly to make sure everything's working or that you have the hi-beams on).

If using the car (for the test) is out, then use a 'break-down' (discharge) circuit similar to that illustrated in Fig. 3-5; S-1 should be a knife switch (or any other type rated at 25-50 amps). L-1 can be any 12-volt device (appliance, light, motor, etc.) that will draw at least 25 amps (or a combination of such devices). (See Data Sheet #2, Chapter 7, for a parts list.)

For our break-down unit I used a 10-foot-long piece of baling wire which I coiled around a broom handle (to form it) and then removed (as a coil). This will draw 50 amps at 12 volts (at least the wire used on our alfalfa bales does). I used #10 wire throughout the rest of the setup and put battery-type connectors on the battery leads so that the battery was easily connected to, or disconnected from, the circuit.

(9) whichever arrangement is used, when you are ready for the test, allow yourself enuff time and get a clock (preferrably with a 'second' hand). You should take readings at specific intervals (such as every 5 minutes); you can read a book in between readings!

(10) as you close the switch, note the current reading and the voltage reading and write these down on the B.R.S., along with the time. Then every 5 minutes read current and voltage, writing them down as well. When the voltage drops to (or below) 6 volts for a 12-volt battery (or 3 volts for a 6-volt unit), end the test (open the switch).

Note: A look at the curves for three batteries tested at Earthmind should indicate that it is not absolutely necessary to hook up both an ammeter and a voltmeter; when voltage or current readings are plotted against time in the graphs, both have identical-looking curves. As the ammeter is more difficult to mount in the circuit, the voltmeter is the best choice if only one is used. The ammeter, however, should be used initially to determine the load's draw (how much current it pulls from the battery).

My own experience in these tests indicates that a battery which is good, or worthy of reconditioning, will stabilize itself, in both voltage and output (amps) within two or three minutes of the time the test is started. A whole series of patterns seem to develop along this line but two (2) that appear fairly consistantly are:

(1) the battery should deliver one-half (1/2) its amp-hour rating (in amps) for half an hour.
   a) a 50 amp-hour, 12-volt automotive battery should deliver (into a 50-amp load) at least 25 amps for 30 minutes.
   b) a 180 amp-hour, 6-volt (golf-cart-type) battery should deliver (into a 180-amp load) at least 90 amps for 30 minutes.

(2) the battery voltage should not drop (during the first half-hour of testing at the rate of discharge described above in #1) to less than:
   a) 10 volts for a 12-volt automotive battery
   b) 5 volts for a 6-volt, golf-cart type battery.

In actuality, I don't necessarily 'fail' a battery if it doesn't meet up to these two standards; it's just that it doesn't 'pass.' If it came real close, then I'd (generally) charge it up again and try another discharge; if it's badly sulphated, it might take a few cycles of charge/discharge A lot depends on the curve; if it levels off and then (finally) plunges, that's more OK than if it just keeps dropping (in both voltage and current) as the test proceeds.

See Data Sheet 2, Chapter 7, for three graphs of batteries tested here at Earthmind . These graphs are taken from actual test data, but they illustrate what three different kinds of your graphs may look like; one of these batteries was accepted, one was taken back and recharged to see if it would then test better, and one was 'failed', and taken back to the yard. In the graphs, voltage, current, and power (one graph apiece for each battery) are plotted against time.

CHAPTER 4 - CONTROL

Control in a wind-energy system encompasses a wide variety of functions; for the most part they must be automatic or we would end up spending much of our time monitoring the process of converting the wind's energy into a readily-usable form (electricity). For proper operation and protection of the aeroturbine, alternator, and batteries some type or form of control must provide for each (or a combination) of the following conditions:

(1) insufficient wind (includes no wind)
(2) excessive wind
(3) insufficient alternator current
(4) excessive alternator current
(5) insufficient alternator voltage
(6) excessive alternator voltage
(7) discharged batteries
(8) fully charged batteries

These conditions are interrelated to such an extent that we cannot independently provide for each one; to do so would interfere with normal operation or jeopardize the system's components (aeroturbine, alternator, batteries). (We will discuss these separately, and then discuss them as a unit, the way they will be in the system.) An example should illustrate the relatedness of these conditions:

Suppose that condition #4 exists (excessive alternator current). This will quickly heat up and damage or perhaps destroy the alternator. A first thought might be to shut off its field (control) current, thus stopping the armature (generated) current (see Alternator Control section). But what if the reason for the excessive current is condition #2 (excessive wind)? Shutting down the alternator will remove its "loading-effect" on the aeroturbine; if the aeroturbine has its own feathering device, it will be okay, but what if it is depending on the alternator for upper windspeed control? Field current removal under these conditions will make for one very-fast spinning, and out-of-control aeroturbine. Or what if the reason for excessive alternator current is condition #7 (discharged batteries)? Again, shutting down the alternator means that the batteries are going to stay that way!

The control system, therefore, must not only protect the wind energy system's components but it must also allow for normal operation. It must, to some extent, then, "sense" a combination of these conditions and "know" when to shut down and when to limit, or resist, the effect of these conditions. What, when, and how it can do this is the subject of this chapter.

First we'll look at the range of control required for the aeroturbine, alternator, and batteries. Then we can investigate control methods and circuits.

SECTION A --- AEROTURBINE CONTROL

Design Notes:

Control of the S-rotor aeroturbine is required only for high windspeed conditions; as the windspeed increases above its normal operating range, so will the speed (RPM's) of the aeroturbine. Finally, at some upper value, the aeroturbine will begin vibrating or wobbling; if this is left unchecked, it will probably destroy the aeroturbine with a good chance of some further destruction to its immediate environment. Why?

The effects of centrifugal force and imbalance are very pronounced in a rotating mass at higher RPM's. All rotating bodies are, to some degree, unbalanced; the effect of imbalance, however, is a function of speed. It would be expensive and time-consuming to 'balance' a rotating body for a speed of 5000 RPM, if that device will never exceed 500 RPM in operation. The S-rotor aeroturbine is no different; if each of us had the facilities to balance the unit for 500 RPM, we would not have to concern ourselves with at least this problem. (The S-rotor aeroturbine will operate in the range of 100-400 RPM). But the effect of centrifugal force is also evident at higher RPM's; here the mass of the aeroturbine is its foe. It is only the strength of the construction materials (and the bolts that hold them together) that prevent the materials from traveling away from the center of rotation (axis) instead of whirling around it. When this force becomes greater than the restraining forces, the aeroturbine will die (boom!). Such forces weakened one of the two 7-1/2 ton blades on the 175' diameter propeller on the Smith-Putnum wind aeroturbine in 1945 (Grandpa's Knob, Vermont) and hurled it over 900 yards!

Control of the RPM's an aeroturbine can achieve in high windspeeds is, therefore, essential to its continued existence. The control process if called 'feathering' and it can be accomplishe in one (or a combination) of the following ways:

(1) spoiling
(2) braking, or
(3) side-facing.

Spoiling is a process that progressively interferes with the aeroturbine's efficiency in extracting energy from the wind at higher RPM's. In a prop-type unit, an air brake can be centrifugally activated to cause considerable drag, or the blades may change pitch and lose their normal efficiency; in either case, less RPM's.

Braking is just that -- some counterforce is activated (like friction) that slows the aeroturbine this would be a brake similar to that used in an automobile. As well, electrical braking can be used; this makes use of the 'loading-effect' an alternator (or generator) has, when producing electricity (whenever field current is activated).

Side-facing is one of the more ancient and reliable means of uniting the upper RPM's of an aeroturbine, and is used extensively with propeller-type units. In high windspeeds a windvane causes the propeller to swing to the side and it may (depending on windspeeds) swing until it's blades are parallel with the wind (or facing out of it).

Spoiling, braking, and side-facing may occur automatically or may be tripped manually (or both); when automatically activated, they are triggered centrifugally (air brake, pitch change), electrically (voltage, current, or windspeed sensing) or by wind pressure (side-facing); friction brakes are most often applied manually whereas side-facing is only sometimes manually engaged.

Spoiling and braking have essentially two major disadvantages. First, their action is similar to braking an automobile with the gas pedal still depressed; the aeroturbine may slow down (or not go any faster) but the windspeed is still high and this puts a lot of stress on the aeroturbine. As well this results in the second disadvantage which is that this type of speed control does not relieve the forces (of wind) acting on the tower (or support assembly); they are quite capable of toppling it. Side-facing, however, is most effective in both these areas but, unfortunately, can only be applied to a prop-type unit; an S-rotor aeroturbine 'faces' all directions. (Ah, the mysterious East!)

The S-rotor aeroturbine, therefore, can only use spoiling or braking as a means of upper windspeed control (when it's required). If the aeroturbine weight is kept low, if it's well balanced, and the design criteria is correct for any given location, it can easily 'ride-out' most tempests (spinning free); design criteria means that in a high-windspeed area, the shape of the aeroturbine is designed for those conditions (i.e.,a large diameter, small height is good for low-windspeed areas whereas a small diameter, large height is good for high-windspeed areas).

I can think of about half a dozen possible ways that an S-rotor aeroturbine might be spoiled but have not built even one of them. The primary reason is that we would not be able to test them, for we lack (in our present area) both the frequent high winds and the extremely high windspeeds of some areas (hurricane country; sometimes, however, full winds gust 40-50 MPH here, so perhaps we'll test in the fall). Spoiling methods for the S-rotor aeroturbine are discussed (and illustrated in Section H - Spoilers) in Chapter 6.

Electrical braking (the 'loading-effect' of an alternator) is my own preference for upper windspeed control (discussed in Section G - Control Circuits - of this chapter). As well, the aeroturbine can be equipped with a friction brake (drum/brake shoe); this would serve as (1) a backup for the alternator control, (2) a safety device when working on the aeroturbine (i.e., greasing the bearings), and (3) a locking device for the wind machine whenever hurricane-type winds are forecast. It may be manually or electrically activated; as well it can be activated automatically by sensing excessive alternator current, large centrifugal forces, or high windspeeds.

SECTION B --- BATTERY STORAGE CONTROL

Design Notes:

Control of the energy storage (battery) system is primarily determined by the following factors:

(1) the type of battery (lead-acid, nickel-cadmium, etc.)
(2) the size (capacity) of battery (amp-hour rating)
(3) the number of batteries used
(4) their intended use
(5) their state of charge.

(1) The type of battery used determines the allowable range of current and voltage it can experience for good service and long life. Lead-acid batteries will not tolerate over-voltage, and excessive current is acceptable only in the initial period of charging a fully-discharged battery. NiCads are reportedly capable of handling over-voltage and over-current conditions (see Chapter 3 - Batteries).

(2) The size (capacity) of battery will determine the length of time required to reach a full charge (or discharge) state.

(3) The number of batteries will provide either a multiple of the time required to charge just one of that size or will allow a larger amount of power to be stored in the same interval of time (by a factor equal to the number of batteries). As well, provision must be made when charging several batteries to prevent them from discharging into one another.

(4) The intended use of the power stored in the batteries will also determine the arrangement of charge and discharge circuitry (and its complexity). If an inverter is used (to change the D.C. voltage in the battery to 120 VAC, 60 cycle), this circuitry is simplified. If, however, the D.C. is to be used directly and the batteries must be placed in series to provide larger voltages (to avoid large I^2R, or transmission line, losses), this circuitry will be more complex.

(5) The state of charge (of the batteries) will determine their 'loading' effect on the alternator (and, thus, the aeroturbine). A fully-charged battery will not accept alternator current (because it has a high internal resistance) and a fully-discharged battery will probably accept all that can be delivered (because it has a low internal resistance). If, however, the aeroturbine depends on the alternator for upper windspeed control (braking), whenever a high wind is present and the batteries are already fully charged, then the alternator cannot act as a brake. There are solutions to this problem but their proper functioning (and activation) depends on some means of detecting these conditions in this combination.

SECTION C --- ALTERNATOR CONTROL

Design Notes:

The alternator is the heart of the wind energy system; here the aeroturbine's energy (mechanical) is converted into the form of energy (electrical) that the batteries require to store power (chemically). The alternator functions to generate both voltage and current; only specified amounts of each, however, are useful (or desired) and then only under certain conditions.

One of the controls the wind/electric system must have, to insure the alternator's long life, is a means of preventing current from exceeding the rating of the alternator (see Chapter 2 - Generating Electricity); this is accomplished by sensing voltage and/or current, and by limiting the field (control) current in the alternator, when necessary.

The alternator must also be protected from extremely high operating RPM's; this will affect wear of its bearings and generate voltages capable of destroying its diodes. These are not of special concern for this system as these diode-destroying speeds are several multiples of the normal, upper RPM's attained in the system.

SECTION D --- CONTROL FUNCTIONS

Design Notes:

In the preceeding sections -- aeroturbine control, alternator control, and battery control -- I have indicated the operational requirements (and the protection requirements) for each part of the wind/electric system. In order that you may further understand the function of the control system, let us now look at the desired responses for each of the eight (8) conditions it must detect and control in normal operation (as listed in the Introduction).

For a Condition of:	The Control System Must:
(1) insufficient wind (or no wind)	(1) prevent activation of the field current to the alternator (or the batteries will be drained).
(2) excessive wind	(2) (a) protect the alternator from exceeding its rating, (b) protect the batteries from high voltage/ excessive current, (c) protect the aeroturbine from excessive RPM's.
(3) insufficient alternator current	(3) prevent insufficient charging current -- this is determined by the type, size, number, and state of charge of the batteries used (see Chapter 3 - Batteries).
(4) excessive alternator current	(4) prevent the alternator from exceeding its maximum rating (other than momentarily).
(5) insufficient alternator voltage	(5) same as condition #1 (insufficient wind).
(6) excessive alternator voltage	(6) limit the voltage produced by the alternator; this amount is determined by: (a) the type of battery used (b) the battery voltage (6V, 12V, etc.) (c) whether the batteries are series or parallel charged.
(7) discharged batteries	(7) prevent both insufficient alternator current (#3 above) or excessive alternator current (#4 above).

(8) charged batteries	(8) prevent overcharging these batteries and provide for sufficient 'loading' of the aeroturbine when excessive wind (#2 above) is present while the batteries are in this state.

Something should be obvious at this point (or become more obvious as we proceed); while the control system must 'sense' conditions at the aeroturbine, batteries, and alternator, it is the alternator that will be acted upon (to a large extent) by the control system to perform these functions. If this doesn't make sense now, analysis of the actual circuits (below) that perform the sensing and activation of control circuits should clarify things. Don't be thinking that it'll probably take a Univac-size computer (and Univac-size cost) to properly detect conditions and control the system; I still haven't discussed what can be done with what, and how!

SECTION E --- ALTERNATOR FIELD CONTROL

Design Notes:

The alternator is controlled by field current, which is turned on, off, or on-and-off very rapidly (see Chapter 2 - Generating Electricity); this switching control is accomplished by its regulator but that, as well, must be switched on. The important thing in all of this switching is when. The regulator (and, thus, field current) should only be activated when the alternator shaft is spinning fast enuff to charge the batteries. This particular RPM is designed into an alternator and it will be at the RPM where the alternator voltage (when activated) is greater than battery voltage; this 'lower speed limit' varies between alternators but it is in the range of 750-950 RPM's. (This is called 'cut-in' speed.) Unlike the generator, most alternators won't put out any charging current whatsoever until field current is applied. So, for proper control, the system must sense alternator RPM's or the windspeed. It is generally easier to sense this last -- windspeed; most aeroturbines (with alternators) use a device similar to the one in Fig. 4-1 to turn 'on' the alternator's regulator (and then the regulator turns on the alternator field current). The device in Fig. 4-1 is a wind-vane-activated microswitch.

The principle and operation of this device is rather simple; a hinged vane (flat surface) is held upright by a spring. As the wind blows it will push the vane over; at a preselected point (at a certain windspeed) the vane will be pushed into, and will activate, the microswitch. As the spring tension on the vane is adjustable, the microswitch can be activated by the vane over a wide range of windspeeds. To properly work, this device must be able to pivot, so that it always 'faces' the wind (it must be able to swing freely.) It is turned by a tail vane, in the same way as prop-type aeroturbines are.

The S-rotor aeroturbine, of course, doesn't 'align' itself with the wind (like a propeller-type aeroturbine does); this means the construction of a separate, self-orienting wind sensor if this method (for activating the alternator's regulator and its own field current), is used.

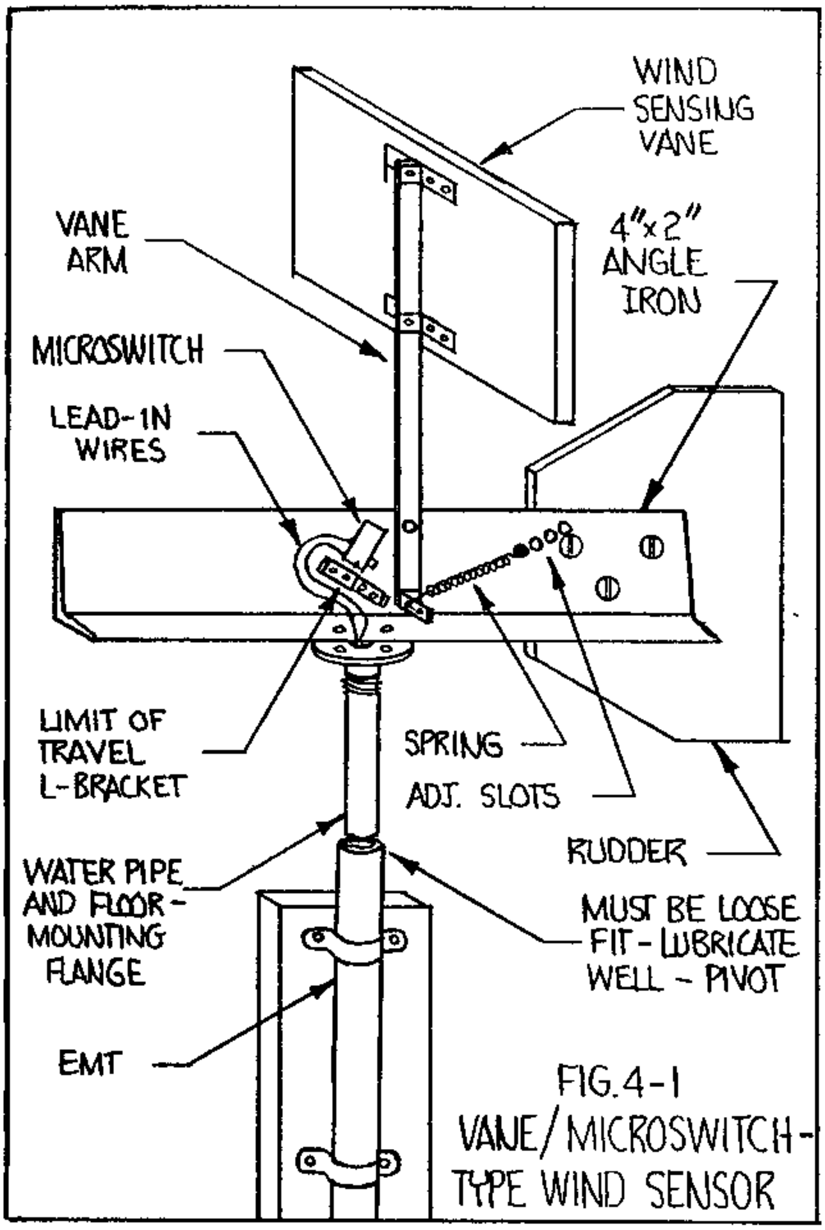


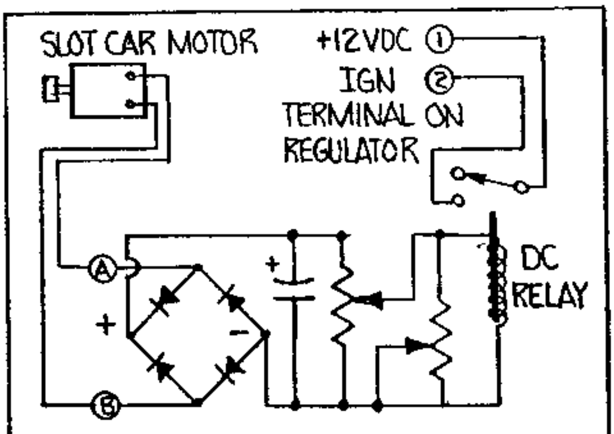
FIG.4-1
VANE/MICROSWITCH-TYPE WIND SENSOR

This unit can be mounted atop the support assembly for the aeroturbine, or beside it; in this latter arrangement, it should be installed far enuff away from the aeroturbine to prevent interference (from the S-rotor) of the wind required to activate it (if the wind direction effectively places the S-rotor 'upwind' from the wind sensor the 'turbulence' created by the aeroturbine could interfere with this sensor's accurate functioning). As well, note (in Fig. 4-1) that the leads (wires) to the microswitch are long enough to allow them to 'twist'; this avoids the necessity for 'slip rings' as the accumulated twist of the wires can be relieved when the bearings (in the aeroturbine) are periodically greased. (If some kind of 'plug' is used at the bottom of the leads, to connect them into the control circuit, these can be 'unplugged' and easily untwisted.)

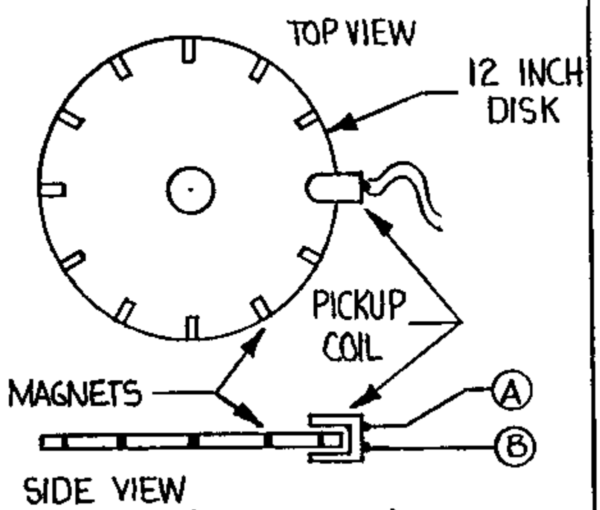
The activation of field current can be achieved in several ways other than by a wind-vane-activated microswitch; for example, electrical (or electronic) activation. This is (or can be) more complex than the above method but we are working to simplfy some of these 'other' methods. Again, this will be information supplied in our newsletters but, for the experimenter, they are presented now, in 'rough' form. This is another area in which feedback would be appreciated.

(1) a slot-car motor can be used as a miniature generator (like a tach-sending unit); make sure it has permanent magnets. Ride it on the rim of the S-rotor end caps. Most of these motors have very linear outputs (3V at 2000 RPM, 6V at 4000 RPM, etc.); its output can trip a sensitive relay (see Fig. 4-2) or gate a transistor.

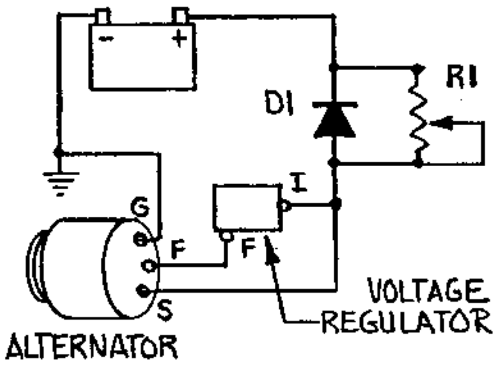
(2) implant a dozen or so magnets equi-distant along the perimeter of a 12"-diameter circle (wood or the like) attached to the S-rotor aeroturbine's lower rotor shaft. (See Fig. 4-3.) Use a telephone pick-up coil, ringer coils, or whatever; the electricity generated (by the magnets spinning through or past this coil) can activate a circuit similar to the one described for the slot-car motor (#1 above). The gentleman that suggested this to me -- Ray Martin, from Crosby, Texas -- has done it successfully (for an S-rotor!). If you send me a stamped, self-addressed envelope and a dollar, I'll forward it to him; I'll bet he'll send you a schematic (and parts list) for his working unit!



(EXPERIMENTAL)
FIG. 4-2: FIELD CONTROL CIRCUIT



(EXPERIMENTAL)
FIG.4-3: RPM SENSOR



(EXPERIMENTAL)
FIG.4-4: FIELD CONTROL CIRCUIT

(3) one method that particularly appeals to me is to keep the field on all the time but limit the amount of field current to a very small value (1/10 of an amp or so). Then, as the alternator is speeded up (and approaches 'cut-in' speed) it will produce a small amount of output which will then boost the field more, produce more output, more field current, more output, etc. (see Fig. 4-4). The value of R-1 will depend on the alternator but it will probably be between 120-1200 ohms; D-1 (a silicon rectifier) should be a 50 amp, 25 PIV diode. This will be one of the first methods I will experiment with.

(4) A bicycle generator might also be used to provide the external excitation of the field current; it might be made to ride on the rim of one of the aeroturbine's end caps and, like the slot car motor, activate a relay. This would certainly activate the field current but I think a potential problem might exist in its burning up at the upper RPM's the aeroturbine might experience.

SECTION F --- VOLTAGE/CURRENT REGULATION

Design Notes:

As indicated before, voltage regulation is necessary for proper operation of the lead-acid batteries. An alternator, when used in a car, uses a voltage regulator the regulator controls the alternator's voltage by rapidly switching on and off the field current (this has a limiting effect). When the battery is in a discharged state, the field current is 'On' more often than it's 'Off' (permitting higher voltage, and higher alternator current flow); as the battery approaches full charge, the field current is 'Off' more often than it's 'On' (permitting lower voltage, and lower alternator current flow); until, finally, the battery is fully charged and the field current is off.

This very same regulator may be used in a wind-energy system; it will provide excellent control of voltage and current to the batteries and will insure that the alternator does not exceed its maximum rating. While it can be adjusted, it is probably already correctly set; however, make certain that it is the regulator for the particular alternator you are using!

FIELD CONTROL

In Wind and Windspinners, a number of ways were given to take care of the problem of alternator field current activation; more specifically - switching it on when power-generating winds were present, and having it off when they were not. Even then we were working on some other ways this could be done simply and reliably. After some comments on the previously "proposed" circuits, we will present them here.

An error exists in the drawing for the slot car motor circuit; as a slot car motor is a DC device, the full bridge rectifier is unnecessary (see Fig. 4). This circuit, however, would (at the very least) incorporate a diode if the magnet/coils excitation is used; this insures that the charged capacitor would not discharge back into the coils whenever a magnet is not in the vicinity of the coil (see Fig. 5).

The wind paddle method of switching has some disadvantages, and let's look at them more closely.

(1) An aeroturbine can rotate at different speeds (for any given windspeed) because of varying "load" conditions, ie., state of charge in the batteries. Setting it to come on at a proper time for a discharged set of batteries will be a different setting than would be needed for a half-discharged or fully charged set of batteries.
(2) A wind paddle can't distinguish between a gust and a more constant windspeed but an aeroturbine can---thus loss of energy transfer becuz it doesn't activate at all, or comes on too soon.
(3) A wind paddle only switches field current on or off and this action can cause severe stress to take place in the gear train (sudden loading of a rapidly accelerating aeroturbine is synonomous with pushing the brake pedal hard to the floor in a car).
(4) A wind paddle is exposed to weather and temperature. Rusting, icing, dust, and temperatures can affect the resilency of the spring or freeze the pivot's movement; these would, therefore, affect a change in the windspeed required to activate the micro-switch.

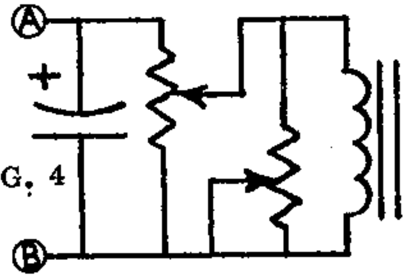
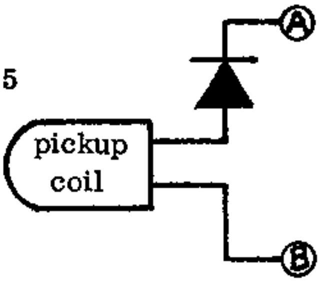


FIG. 4

FIG. 5



A more precise way to activate field current is to sense aeroturbine RPM's because, when properly calibrated to the specific alternator and gear ratio used, it assures that the alternator has reached a speed where it is capable of supplying at least the current required to keep the fields excited (around 2.5 amps for most alternators). The slot car motor circuit can precisely turn on the alternator (at a specific RPM) but, unless other circuitry is provided, it won't cut out when the RPM's go below the cut-in RPM. This is primarily because the relay used needs a certain amount of current to activate but will hold in until the current falls to a value sometimes as low as one half of cut-in current. As well, the relay (like the microswitch) is hard on or off and geartrain stress will still exist.

The desirable characteristics for a device to control field excitation (beyond those functions of the voltage regulator) are:

(1) RPM sensing.
(2) Zero hysteresis--cut-in and cut-out occur at the same RPM.
(3) State of charge detection--the device should be responsive to the state of charge in the batteries.
(4) Duty cycle at cut-in--the device should not just switch on field current but, rather, limit it (to a certain extent) at cut-in and then come full on as the RPM's increase.
(5) Weatherable components-- as few moving parts as possible and complete insensitivity to changes in temperature or weather conditions.
(6) Good cost/benefit ratio-- relatively inexpensive, simple, effective, reliable, and serviceable.

Incidently, in some tests with our S-rotor, we found that the alternator was capable of exciting its own field; Fig. 4-4 (in Wind and Windspinners) shows the hookup if the variable resistor shown across the diode is removed for such a possibility. Unfortunately, another alternator we tried (different make) wasn't capable of self-excitation (near the same RPM) so we don't know which might have been the exception; I suspect it has to do with the quality of alternator used. The unit that did work had a large hysteresis (went to a low RPM -- about 1/3 of cut-in--before it cut-out): This wasn't unexpected, but it does mean additional circuitry would be required to provide a more positive cut-out (near cut-in RPM). We will (eventually) investigate how this might be done, but some preliminary study seems to indicate no simple way to affect this condition, nor a manner in which to provide this method with the other desired characteristics present in our FCU circuit.

The use of any of these circuits still requires the use of a voltage regulator unit; FCU-1, -2, -3, however, will be further developed to replace the alternator's standard voltage regulator and further allow the use of one FCU to serve not only as a field cut-in and voltage regulator but as a unit capable of regulating voltages in the range of 12-120 volts.

SECTION G --- CONTROL CIRCUITS

Design Notes:

Fig. 4-5 illustrates a basic wiring diagram of a control circuit in a wind energy system; it consists of the alternator, a regulator (for that alternator), a wind-vane-activated microswitch, and a battery. If this system is used, the regulator and battery should be located as close to the alternator as possible (to reduce line losses) or large wire (#10 or larger) used for the stator-to-battery connection.

The advantages to this circuit are:
- (1) simplicity
- (2) excellent regulation of voltage and current for the battery
- (3) excellent protection against exceeding the rating of the alternator.

The disadvantages to this circuit are:
- (1) it makes no provision for aeroturbine control (at high windspeeds) if the battery is fully charged
- (2) it has limited storage capacity
- (3) the wind energy system cannot produce any more power than the rating of the alternator (in amps) times the voltage used (14 volts); i.e., if a 52-amp alternator is used, it can produce no more than 728 watts (52 amps X 14 volts).

Obviously, this situation can be improved on; more batteries can be added, a larger alternator (or several alternators) can be added, a higher voltage regulator can be used (24 volt), etc. We'll have a closer look at what's involved in doing this, but for a moment, let's discuss a vital point -- 'loading'.

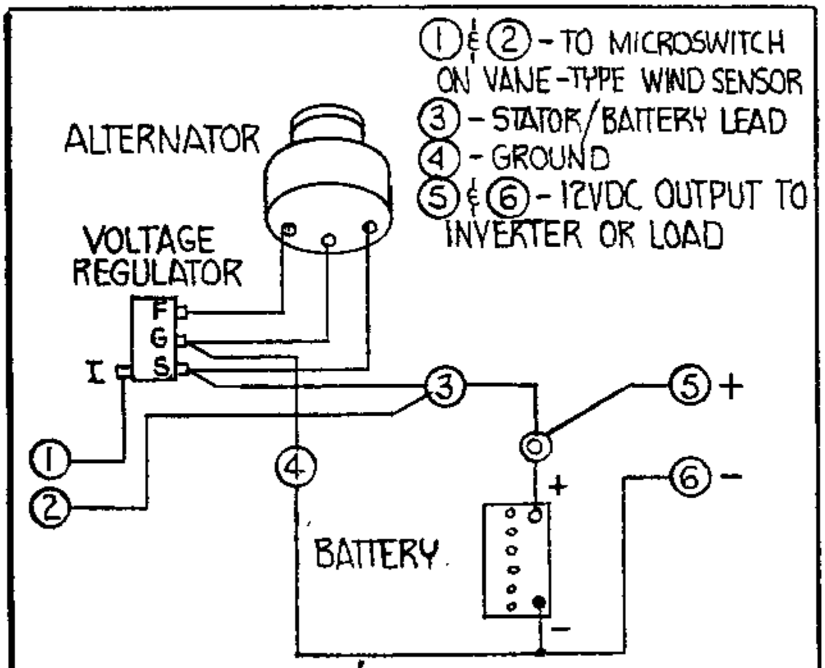


FIG.4-5: BASIC WIND/ELECTRIC CONTROL CIRCUIT

Loading Effect

In several instances I have discussed (1) the 'loading effect' an alternator has on the aeroturbine, and (2) the 'loading' effect a battery has on the alternator. 'Loading' means that an energy exchange is taking place, but this also means that energy is being removed from one place and put in another place. Let's use an example to clarify this: say that, at a given windspeed, the aeroturbine is producing about 2 horsepower. About one-half (1/2) of this (or one horsepower) is lost in transmitting it to the alternator (via the drive train) and in the alternator itself. Therefore, only one horsepower shows up as electrical power; this will be 746 watts. If the battery is in a discharged state, it will probably use all of this power. In a manner of speaking the battery will 'reflect' its use of this power back to the alternator, which in turn will 'reflect' its use of power back to the aeroturbine. The result of this will be that the aeroturbine will slow down because the alternator and batteries are 'using' the power the aeroturbine is taking from the wind.

All of this occurs instantaneously (or quicker than you can sneeze). But suppose (in this same example) that the battery is in a fully-charged state. The 2 HP is still developed (in the aeroturbine), one horsepower is still 'lost' in the gear train and alternator, and the alternator will want to 'deliver' 746 watts. Here, though, the battery will 'reflect' back to the alternator (again, in a manner of speaking) that it doesn't need, or can't use, the power. As a result, the regulator for the alternator will shut off field current to the alternator and, thus, no current will flow to the battery. Then, the alternator will 'reflect' back to the aeroturbine that it can't use the power the aeroturbine is producing; the aeroturbine will then speed up because it will 'use' the power it would have otherwise transferred to the alternator and to the batteries to spin itself.

This explains why an aeroturbine (of any type) will rotate at different speeds for the same windspeed. If the batteries are 'empty,' the aeroturbine will rotate much slower than it would if the batteries are 'full.' Expressed another way, it all has to do with where the power is going -- into the batteries or into the aeroturbine (giving it more kinetic energy by turning its mass just that much faster!).

One further point: you cannot produce more electrical power than is available in, or given by, the aeroturbine. For a certain size aeroturbine (given its efficiency and the system's efficiency), only a certain amount of power will be produced at a certain windspeed -- independent of the size of alternator used (or the number of alternators attached). You can't get more than you've got, because these devices don't create energy. They just gather it.

Increasing Storage Capacity

Okay -- now let's deal with improving the basic control circuit (given in Fig. 4-5). The first question is -- how much capacity does the battery have? If we were using a 52-amp alternator, and operating at 14 volts, we'd have 728 watts (total generator capacity). If we had a 55 amp-hour battery (12-volt automotive), we could 'store' 660 watts (approx.) in this battery. If the wind were strong enuff to operate the alternator at capacity (728 watts) for just a little less than one hour (60 minutes) we would be able to store in the battery as much energy as it could 'hold.' If we were to take another battery (of equal capacity) and place it in 'parallel' with the first battery (see Fig. 4-6A for this 'arrangement'), we could expect to store twice the energy that just one could, which would be 1320 watts (2 X 660 watts); of course, the wind would have to operate the alternator at capacity for twice the period of time. In fact, we may add even more batteries. They don't all have to be the same capacity (amp-hour rating), yet, their storage capacity in watts (amp-hour rating times voltage) is additive!

Let's try an example; suppose we have four 12-volt automotive batteries and their ratings are (in amp-hours) 45, 50, 60, and 60. If we add these together, we get 215 amp-hours; now, if we multiply this times the final battery voltage (12.6 volts), we get 2710 watts (this would be the absolute power we could expect to realize -- a more real figure, after considering battery efficiency, transmission line losses, heat and water disassociation losses, would be 75% of this figure, or 2032 watts usable power out). With the alternator's maximum power output at 728 watts, it would take 3 hours running at full capacity to fill these batteries, or 6 hours at 1/2 the full capacity of the alternator (364 watts), or 12 hours at 1/4 the full capacity of the alternator (182 watts). Get the picture ?

What happens if we use 6-volt, heavy-duty batteries? Well, the alternator can charge 6-volt batteries but the regulator would have to be modified; a better way of using these batteries is to hook two of them in series (see Fig. 4-6B for this arrangement) to make the equivalent of a 12-volt battery (the voltage here is additive but the amp-hour capacity is the same as just one). If both of these batteries were 180 amp-hour capacity, then the total storage capacity (for the two of them) is 2160 watts (or again using a 75% overall efficiency, we could realistically expect 1620 watts usable power out). Again, using a 728-watt alternator running at full capacity, we could expect these to be charged to their full storage capacity in a little over 2 hours, or in 4 hours at 1/2 the capacity of the alternator (364 watts), or in 8 hours at 1/4 the capacity of the alternator (182 watts). To double this storage capacity (to 3240 watts), two more 6-volt batteries (each of the above amp-hour rating) could be placed in 'series' with eath other, and then in 'parallel' with the original two (see Fig. 4-6C).

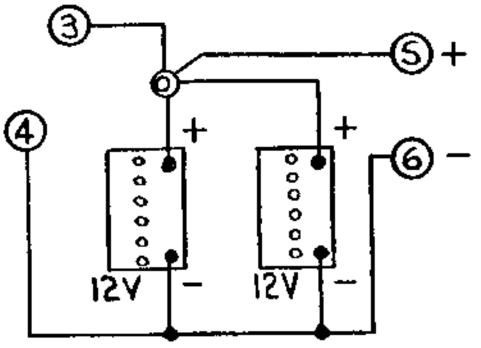


FIG. 4-6A: BATTERIES IN PARALLEL

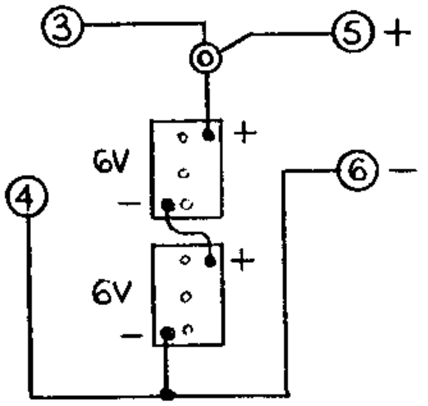


FIG. 4-6B: BATTERIES IN SERIES

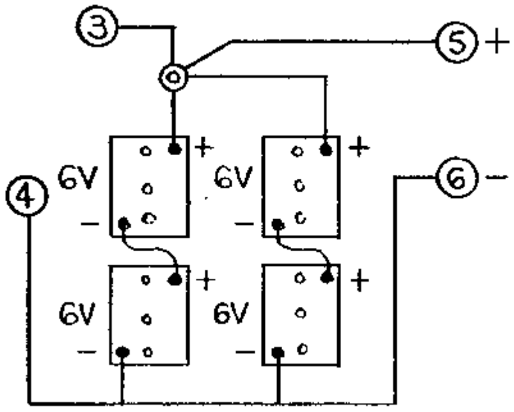


FIG. 4-6C: SERIES/PARALLEL BATTERIES

This appears to be the proper time (and place) to indicate a few things about parallel and series operation of batteries.

(1) try to get batteries of equal amp-hour capacity when using 12-volt automotive batteries. You can use a wide variety of ratings but you may have to install diodes (see Fig. 4-7A) to prevent them from discharging into one another (or into the weakest one, of least capacity, or most 'local action' -- self-discharge). For each battery, 2 diodes would be required; they are not very expensive, nor are they difficult to install, but it's a bit of a hassle.

(2) you must use batteries of equal amp-hour capacity if you are using 6-volt batteries and arranging them in series (or the lower-capacity battery will restrict proper charge/discharge of the higher one, perhaps with irreparable damage to itself). Diodes are only required if a 'set' (consisting of two 6-volt'ers in in series) is in parallel with another set of dissimilar capacity; for each 'different' set, 2 diodes would be required. Diodes would not necessarily be required if the paralleled 'sets' were of equal amp-hour capacity. (See Fig. 4-7B.)

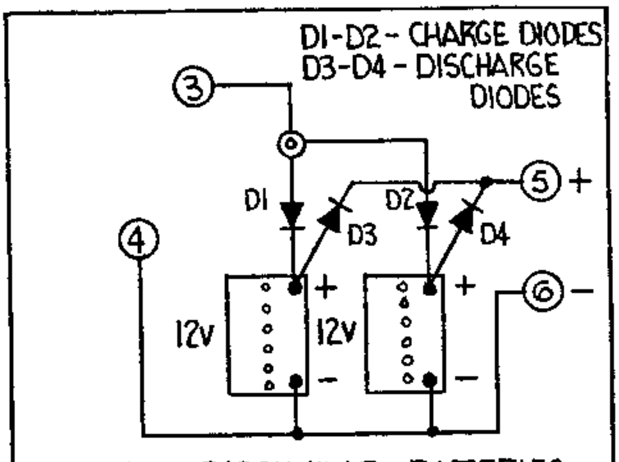


FIG. 4-7A: DISSIMILAR BATTERIES

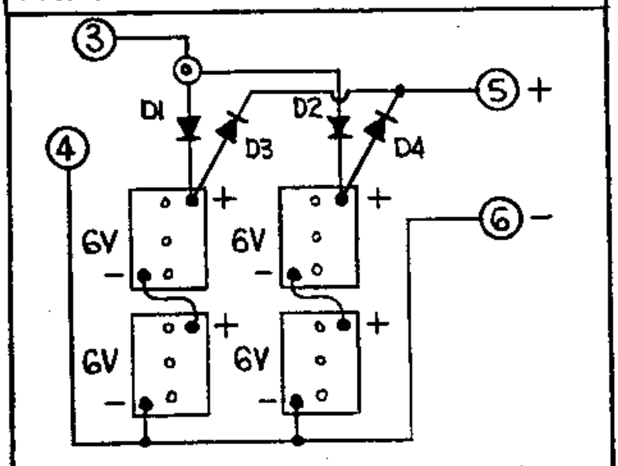


FIG. 4-7B: DISSIMILAR BATTERY SETS

(3) there is a limit to the number of batteries that you should place in parallel but the number depends primarily on what size alternator (rating) you have and how much wind you experience. As indicated in Chapter 3 - Batteries - underchcaring is just as serious a mistake as overcharging; too many batteries, then, will prevent any one of them from being fully charged. At the same time, too few batteries will 'lose' some of the wind's energy. 'Too few' and 'too many' vary with the installation's location so they are tough to determine. The thing to look for is whether or not the batteries are fully charged by an 'average blow'; if 'yes,' increase the capacity and, if 'no,' maybe you have too many! To start out with, a good rule of thumb is:

(1) the number of batteries should not exceed 1/10th the alternator rating and

(2) the combined amp-hour ratings of the batteries should not exceed 5 times the alternator rating.

For example: a 60-amp alternator should use a maximum of six batteries (60 ÷ 10) and their combined amp-hour capacity should not exceed 300 amp-hours (5 x 60); with six batteries, this means an average (individual, or per battery) rating of 50 amp-hours (300 ÷ 6). However, 5 batteries of 60 amp-hour capacity or 4 batteries of 75 amp-hour capacity or 3 batteries of 100 amp-hour capacity, or 2 batteries of 150 amp-hour capacity could also be used.

No-load and Full-load Shutdown

Before I further discuss and illustrate increased power capability for the system or positive aeroturbine control, it would be wise to discuss the final relationship existing between these two.

When describing 'loading effect' (in this chapter), I explained how an aeroturbine might rotate at different speeds for the same windspeed; this would primarily be determined by the 'state-of-charge' in the batteries. If the batteries were fully discharged, the aeroturbine would rotate more slowly at a given windspeed than if the batteries were fully charged.

As well, it was indicated (under aeroturbine control in this chapter) that the aeroturbine had some upper RPM where the effects of imbalance or centrifugal force would destroy it. Just below this destructive RPM is what we call 'shutdown' speed and the aeroturbine should either be shut down (spoiled, braked, etc.) or, at least, some measure enacted to keep it from 'surpassing' the shutdown RPM or windspeed.

Combining the effects of windspeed and state of charge, it should be realized that the aeroturbine is quite capable of being destroyed at either a lower windspeed or a higher windspeed (depending on the batteries' state of charge) because it could achieve, in either case, its 'maximum (operating) RPM.'

If a spoiler is installed (see Section J - Spoilers - in Chapter 6), it could be adjusted to activate itself (centrifugally) at this 'maximum-rated RPM' and we would have no need to further control this problem (unless the spoiler did not, for some reason, work when it was supposed to). If we had some means of 'sensing' aeroturbine RPM's (such as those proposed under Section E - Alternator Field Control - in this chapter), we could adjust the control circuits to activate spoilers, friction braking, additional (aux.) storage capacity, dummy loads, auxiliary alternator cut-in, etc. (these are discussed farther on). The state-of-the-art for the S-rotor aeroturbine is, however, not that far along (centrifugal spoiling or electrical, RPM sensing are not perfected yet), so a separate wind sensor will be needed to activate whatever additional 'loading' is used to keep from having to 'shut down' the aeroturbine.

So, we are here faced with some limits; as we will shortly investigate some circuits to deal with these limits, it might be helpful, at this point, if we could distinguish between the different limits in definition and name.

(1) 'full load' shutdown speed: that windspeed at which the alternator 'peaks out' (is delivering its full power at the system's voltage) while the batteries are in a discharged state.

(2) 'no-load' shutdown speed; that windspeed at which the aeroturbine has reached its 'maximum operating RPM' because the alternator is shut down (the batteries are fully charged).

(3) 'maximum operating RPMs': that aeroturbine speed beyond which the aeroturbine will suffer vibration, damage, or destruction, due to imbalance or centrifugal force.

Increasing Power Capability

There is a way the alternator can be made to develop more power out at the higher windspeeds - if the windspeeds that could produce more power in the aeroturbine were present. The voltage regulator and battery arrangement determine the voltage (and power) the alternator can produce. Removal of the regulator (from the wind/electric control circuit) would allow the alternator to produce higher voltages at the higher speeds; however, without proper 'matching' of batteries and alternator (in terms of voltage), this would be 'disastrous.' Think of the battery as a 12-volt light bulb (for a moment) and consider what would happen if you attached a 24-volt generator to it. Well, it would burn out! But long before that happens to a battery (it's no longer a light bulb), the alternator would burn out. Why? Because it will try to deliver twice the current, and this would make it exceed its rating at the higher windspeeds.

If the batteries 'appeared' (from the alternator's point of view) to be 24-volt batteries (two 12-volt batteries in series, or four 6-volt batteries in series), then everything would be okay. A 24-volt regulator would be needed for proper control - but they're hard to find (for most alternators). A 12-volt regulator, on the other hand, can become a 24-volt regulator. How? Well, there are a couple of resistors in the regulator which make it a 12-volt regulator; if these resistors were replaced with others (of a certain value, in ohms), the regulator would then be a 24-volt unit.

Regulators vary so much that it would be impossible for me to tell you exactly how each one could be changed in order to make this 24-volt changeover. But, then, you might want to consider the effect of generating at 24 volts. The windspeed required to begin charging at 24 volts is higher than the windspeed required to begin charging at 12 volts. This would mean the windspeeds below 'cut-in' would not be of any use to the system and in some areas (of low average annual windspeeds) this would be a distinct disadvantage. Of course, a 24-volt changeover does increase (double) the peak power rating of the 12-volt alternator and because it takes a higher windspeed to reach peak output, the 'full load shutdown' windspeed is also higher. However, the 24-volt system only gets more out at the higher windspeeds at the expense of the lower windspeeds; as well, it makes no provision (as described) for 'no-load shutdown' windspeeds.

Another way to increase the system's power capability, and provide for 'no-load' and 'full-load' shutdown windspeeds without sacrificing lower windspeed cut-in, is to add another alternator (see Fig. 4-8); as the primary alternator 'peaks out,' the auxiliary alternator could then be 'cut in.' Its own voltage regulator and, thus, its field current, could be switched on by a separate windspeed sensor (similar to the one described in 4-1 but adjusted to activate its microswitch at the 'no-load shutdown' windspeed). The auxiliary alternator must charge a separate set of batteries; if this were not deemed feasible (too expensive or whatever), a 'dummy load' could be used (instead of the batteries). Of course, the power would be dissipated into waste heat, but the aeroturbine would be well protected even to extremely high windspeeds, and the heat might not be 'wasted,' if it was used. (Many areas experience high windspeeds in the winter).

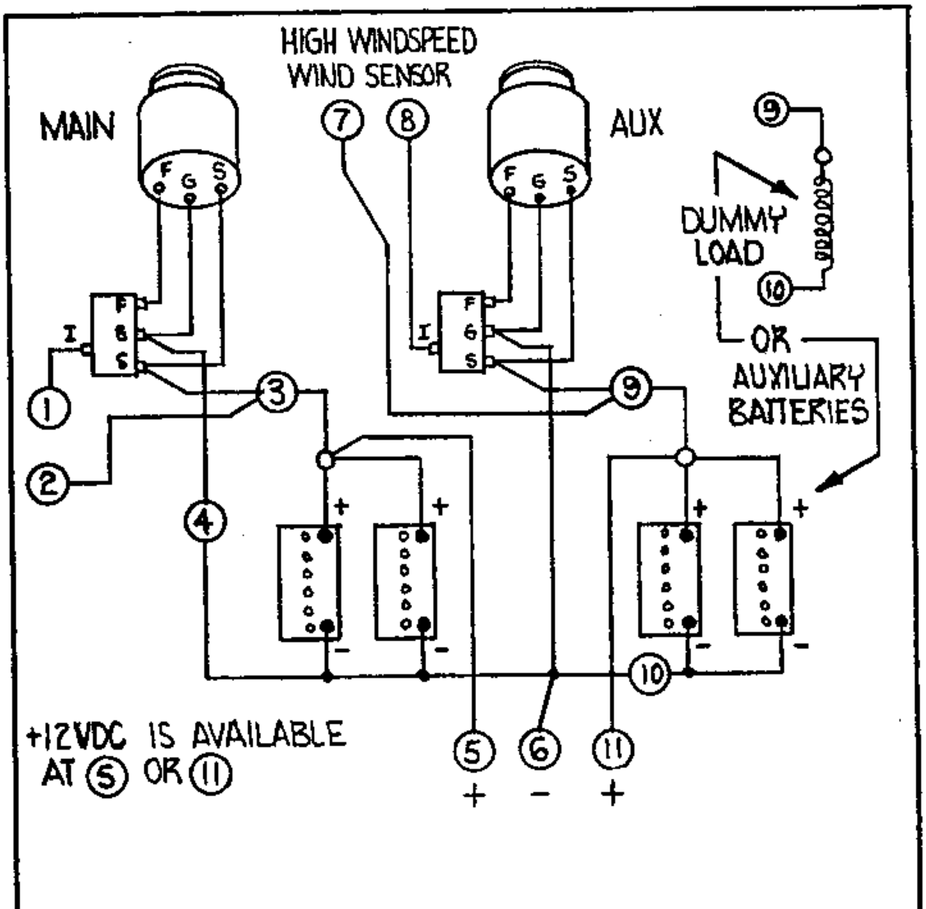
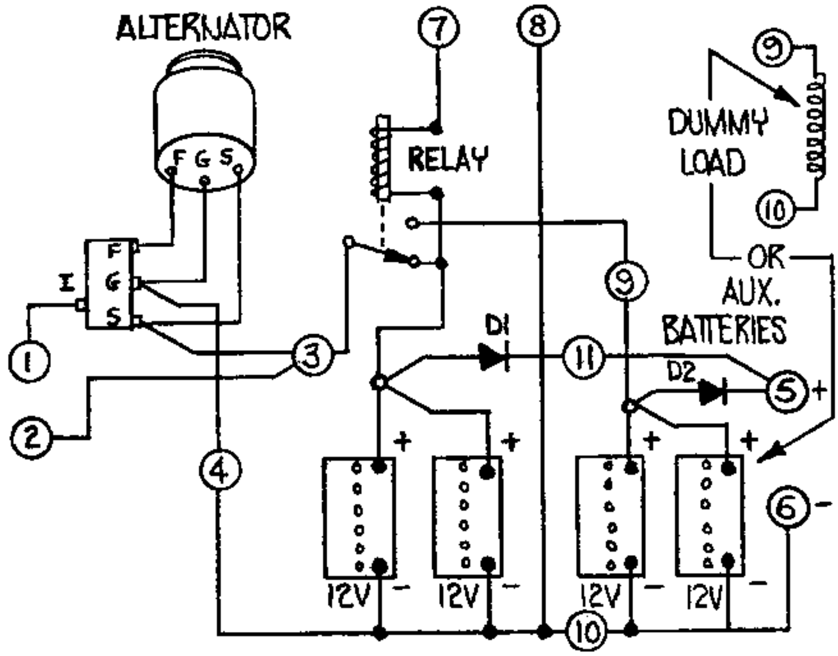


FIG 4-8: AUX. ALTERNATOR/BATTERY CONTROL CIRCUIT

The addition of another alternator with its own regulator and drive-train might be a bit expensive for some folks. A less-expensive system that would provide good aeroturbine control with only one alternator is described by Fig. 4-9; again, a second windspeed sensor (like the one described in 4-1), adjusted to activate the microswitch at the 'no-load shutdown' windspeed, would be required. However, instead of activating a regulator, the micro-switch would engage a 12-volt relay which would switch the alternator (stator, or battery, lead) from the primary set of batteries to another set of batteries or a dummy load (as shown).



NOTE: IN THIS DRAWING, D1 & D2 PERMIT SIMULTANEOUS USE OF MAIN & AUX. BATTERIES. THIS OUTPUT CAN BE WIRED AS SHOWN IN FIG. 4-8, WHICH IN TURN CAN BE WIRED AS SHOWN IN THIS DRAWING (USING DIODES).

FIG. 4-9: RELAY/AUX. BATTERY CONTROL CIRCUIT

Adjusting the Control System

Normally, the voltage regulator will not require any adjustment to work well in the wind/electric system; its operation here will not be dissimilar to its operation in an automobile, so if it was adjusted correctly there, it will be correct here.

Adjusting the Alternator Cut-In Wind Sensor

What will require adjustments is the wind-vane-activated micro-switch (for alternator field 'cut-in'); to do this, a battery/light setup (see Fig. 4-10) should be added to help the 'calibration.' It is highly recommended that you use a wind-speed indicator (see Sources - Data Sheet 3 in Chapter 7) of some type to initially adjust the wind vane to contact the microscitch at a given (or known) windspeed; the procedure may occur as follows:

(1) install the wind-vane-activated microswitch assembly at its final location; it should be at the same height as the aeroturbine.

(2) use a setup as shown in Fig. 4-10; in this manner, the light bulb (that is temporarily hooked up) will light when the microswitch is activated.

(3) stand downwind (or to the side) of the wind sensor; position yourself so that you can observe windspeed on the windspeed indicator and still see the light bulb.

(4) initially the wind sensor spring should be adjusted to contact the microswitch (and turn on the light) at 10 MPH.

(5) watch the windspeed indicator and note at what windspeed the light goes on. If it is higher than 10 MPH, loosen the spring tension; if it is lower than 10 MPH, tighten the spring tension.

(6) again observe the windspeed at which the light goes on; with repeated observations and spring adjustments, get the light to come on at 10 MPH.

(7) disconnect the bulb and battery and connect the leads (from the microswitch) into the wind/electric circuit; one lead should go to the regulator (hooked to the terminal marked 'IGN') and the other lead to 'A+' (positive battery voltage).

Note: The aeroturbine itself does not participate in this adjustment; in fact, it should never be allowed to rotate without a fully-operating control system, of some kind.

Further note: The above procedure is for a 20% efficient aeroturbine. A more efficient aeroturbine might use a lower cut-in speed.

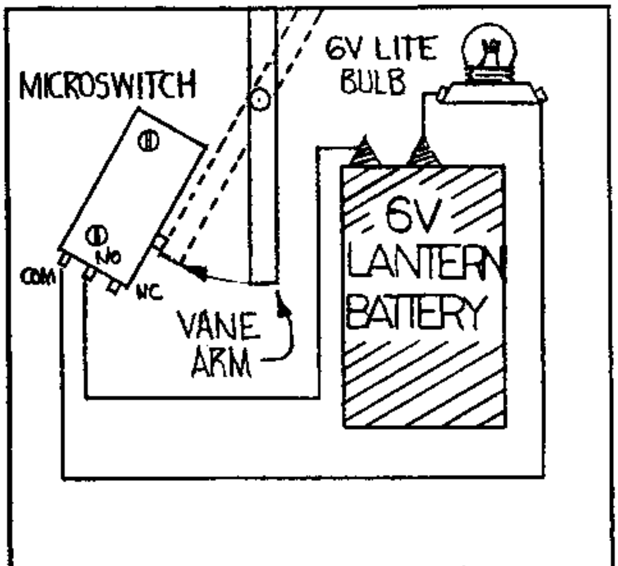


FIG. 4-10: WIND SENSOR TEST CIRCUIT

Adjusting the High-Windspeed Sensor

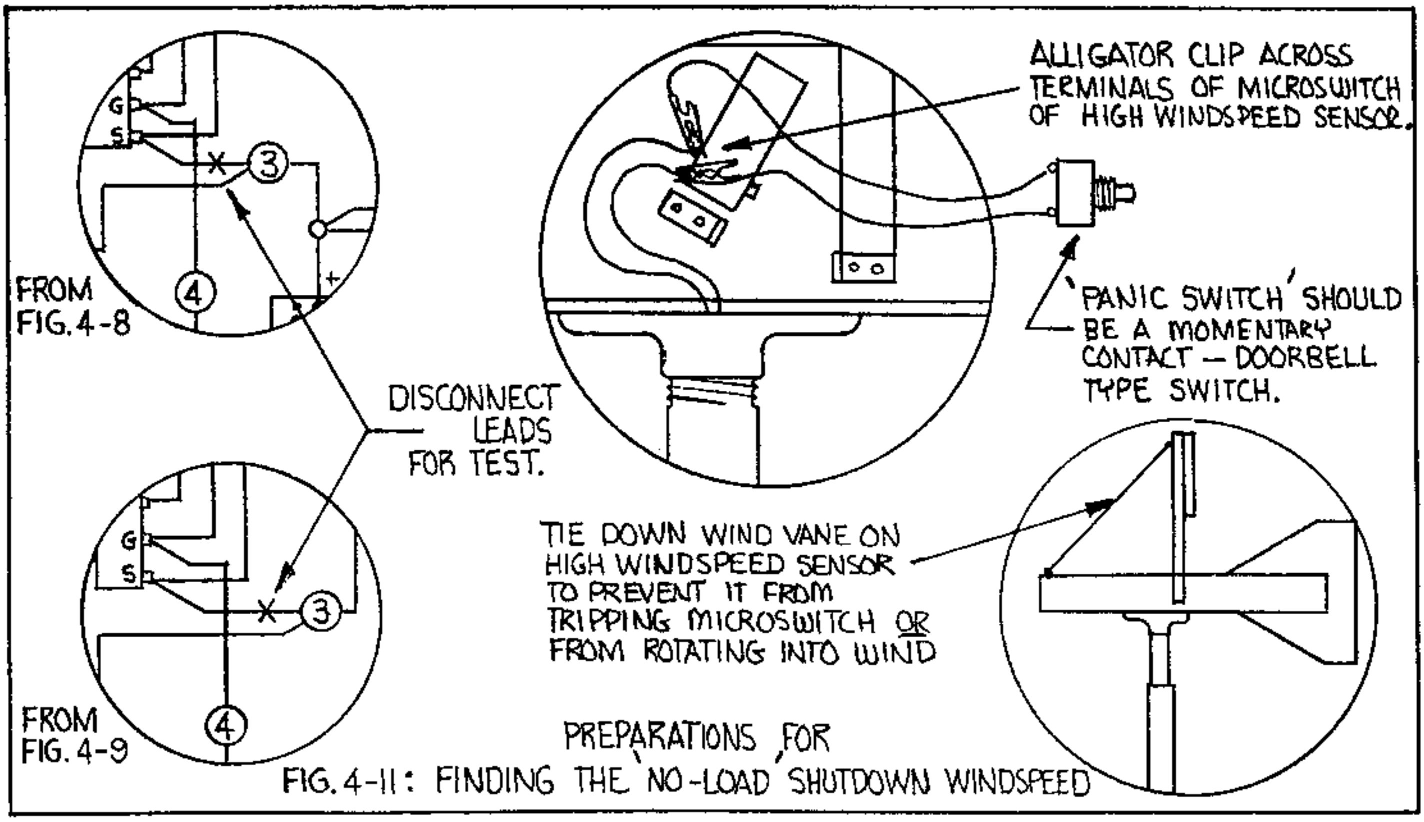
If a second wind sensor (vane-operated microswitch) is required (it will be referred to as the secondary or 'high-windspeed' sensor), it must be adjusted to activate at a windspeed below the windspeed which pushes the aeroturbine (under a 'no-load' condition) to its 'maximum operating RPM.' The adjustment itself is not difficult but determining which windspeed it must be adjusted to (to activate) is not for the weak-of-heart; it will involve letting the aeroturbine approach its 'maximum rated RPM.'

This could be very dangerous if not properly set up; study closely the circuit illustrated in Fig. 4-11; the following conditions must be met prior to preparing for the 'run.'

(1) the 'cut-in' wind sensor must be properly adjusted (at 10 MPH), hooked into the circuit, and 'known' to be working (anytime the wind sensor activates the microswitch and thus the field current, a perceptable slowing of the aeroturbine will be noticed). As well, both the voltage and current meters (mounted in the control panel) will be moving.

(2) the alternator must be in place, its drive train properly tensioned, and its wires connected to the voltage regulator.

(3) the auxiliary batteries/or dummy load must be in place; if an auxiliary alternator is being used, it must as well be hooked up to its regulator, which in turn must be connected to its batteries/dummy load.



PREPARATIONS FOR
FIG. 4-11: FINDING THE 'NO-LOAD' SHUTDOWN WINDSPEED

Note: the secondary set of batteries (if used) must be in a discharged state (ready to 'load' the aeroturbine); otherwise, substitute a 'dummy load.'

(4) a switch must be jumpered to the microswitch (shown as S-3) on the high-wind-speed, vane-operated microswitch sensor (the one that has to be adjusted; S-3 should be easily accessible to the individual watching the aeroturbine (this is the 'panic' switch).

More than one person is needed for this 'run'; at least two are required, a minimum of three recommended; and if you can get a few more, do it! The jobs are:

(1) aeroturbine observer
(2) windspeed indicator observer
(3) windspeed recorder
(4) 'panic-switch' operator

The person doing #1 can do #4 as well and job #3 isn't absolutely necessary. The extra people that I spoke of can be 'safety' personnel; their job would be to slow the aeroturbine by hand (with gloves on) if the drive train breaks up. If a mechanical friction brake has been installed, only one person will be required to operate it.

There's much to do to get ready for the test but, of course, you must wait until that day when winds of sufficient velocity (15-25 MPH) are present to actually conduct the test. Don't try to conduct this test in a high steady wind (above 25 MPH); gusty winds (peaking 25 MPH maximum) and riding on 10-13 MPH steady winds are best. Remember! Keep the aeroturbine tied down until these circuits are calibrated and fully operating!

While I am going to go through the test procedure, I cannot over-emphasize the importance of practicing the procedure beforehand. Both the accuracy of the information you gather from the test and the safety of the aeroturbine depend on everybody involved doing their job at the right time. Make sure you pow-wow just before you actually begin the test.

The last thing to do before beginning the test is to disconnect the lead (wire) that connects the positive (+) terminal of the battery (or batteries) to the main alternator (terminal) or to the regulator terminal (if it connects there). Make certain, however, that the lead coming from the 'cut-in' wind sensor is, along with the lead coming from the 'high windspeed' sensor, still attached to the battery. This will 'simulate' charged batteries (to the main alternator) but still allow field control to the alternator (and the auxiliary alternator, if one is used).

Now -- positions everyone. The aeroturbine observer should stand where he/she can easily see the aeroturbine (about 10' away) and still have the panic-switch within easy reach (unless someone else is doing this). The windspeed (indicator) observer should be stationed at the aeroturbine's level, and distant from any obstacles that might cause turbulence. If the wind is gusting over 25 MPH, the test is postponed.

When it is right, turn the aeroturbine loose. As it comes up to speed, observe the 'cut-in' wind sensor to see that it is properly working; once this is activated (bent over and contacting the microswitch) have the windspeed observer start calling out the windspeeds every 5 seconds or so (and the windspeed recorder writing them down). (Here's where practice makes. . . !)

Now, whoever is watching the aeroturbine should have a few fingers wrapped around that panic switch; it is absolutely amazing how elusive the switch can be if you are frantically groping for it . What this person is looking for is 'wobble.' It will start 'shaking' before it 'wobbles' but that's not it; watch for the wobble (it's quite unmistakable). At the first sign of a wobble, yell "On!" The person observing windspeed (and the recorder, if any) should note the reading. And whoever has got it should hit the 'panic-switch'!

Here's the tricky part. If that switch is thrown to "On" and left there, it's going to be quite a shock for that alternator, its drive train, and the aeroturbine (it's exactly like slamming the brakes through the floor of a car). So, 'toggle' the switch on-and-off (like you'd pump the brakes on a car). This should (at first) be at one-second (or less) intervals, so count it! "On" -- one thousand, "Off" -- one thousand, "On" -- one thousand, etc. (anybody with rhythm would be a natural for this job!).

If the aeroturbine isn't slowing, keep it "On" more than "Off." If it still doesn't slow down, throw it to "On" and leave it. And if it still doesn't slow down, something's wrong; get your gloved friends to work or apply the mechanical, friction brake and get it stopped.

If it does start slowing down, leave it "On" more than "Off" until you can just leave it "On." It won't come all the way to a stop except with help, so glove or brake it to a stop and tie it up. Sit down and have some carrot juice!

Now -- you've got the windspeed at which you must adjust the 'high-windspeed' wind sensor, right? You've still got winds, so adjust it now! Whoever read the windspeed indicator gets this job; if she/he read low or high before, he/she will do it again and the adjustment will be more accurate because of it.

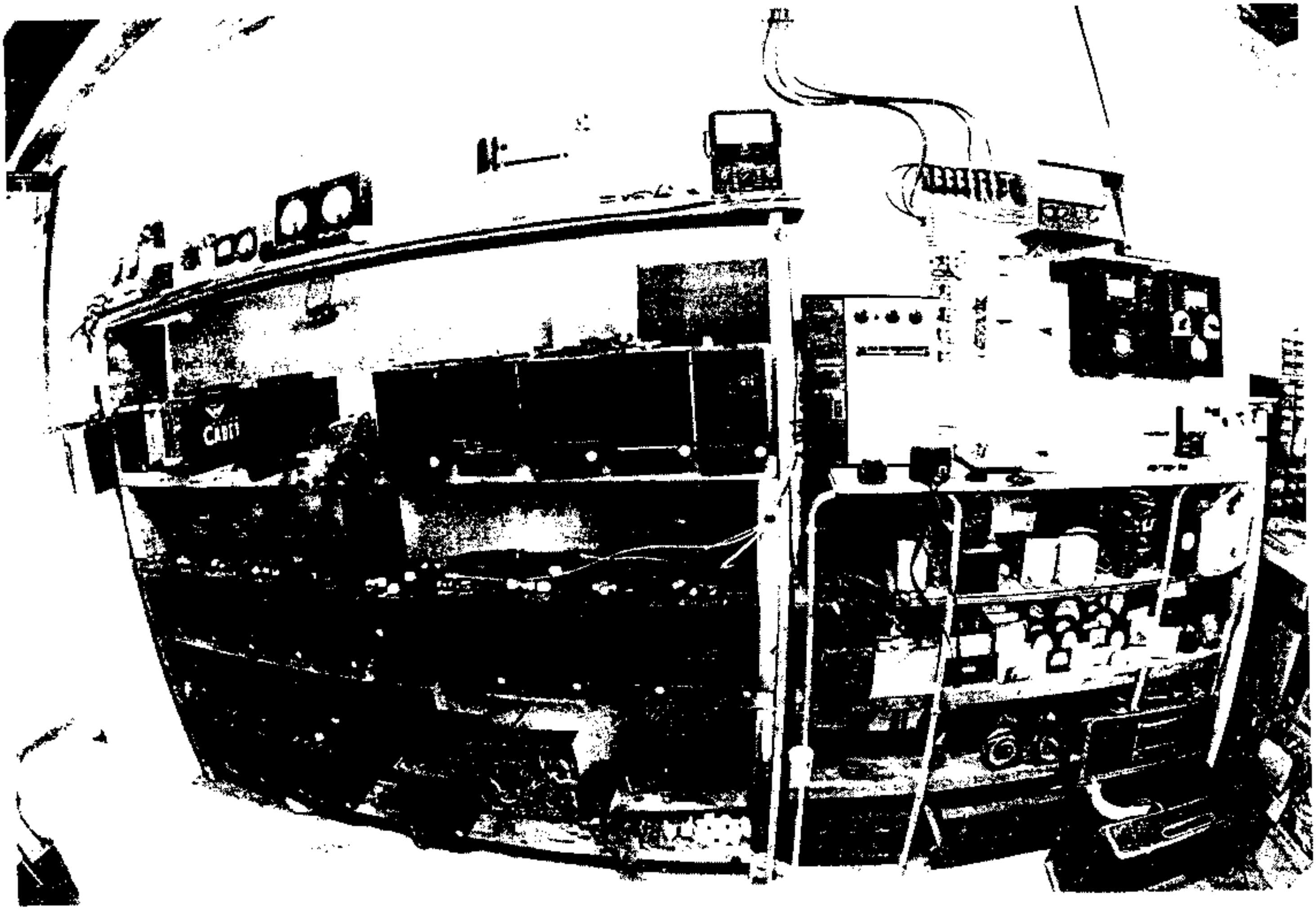
Hook up the light/battery arrangement as before (see Fig. 4-10) and when the light comes on, have her/him say whether the wind sensor is set too low or too high. If it's too high, lessen the spring tension; if it's too low, increase the spring tension. Keep at it until he/she says it's right. When it is, disconnect the battery/bulb arrangement and reconnect the wires to the microswitch.

Full-Load Shutdown

While there is no adjustment for the 'full-load shutdown' windspeed (unless you install a spoiler), it would be wise for you to know at what windspeed this condition exists. It is determined primarily by the size of alternator (its power rating) that is used, so the first thing to do is find what that is. Multiply the rating of the alternator (in amps) times the voltage (14 volts) to obtain the peak power capacity (i.e., a 50-amp alternator, at 14 volts, will produce 14 x 50, or 700 watts).

Once you have determined this rating, you should find the value which comes closest to the rating of your alternator in column D or column F of Table 1, Data Sheet 1, Chapter 7. If you are using a 55-gallon drum half-type impeller, column D will apply; if you are using a lighter impeller, column F will probably apply (both apply to this table only if a 27 ft.^{2} aeroturbine is constructed). When you find this value, read to the left (in column A) to find the windspeed at which this occurs; this is the 'full-load shutdown' windspeed.

If you experience higher, steady windspeeds, you must: install spoilers, an alternator with a higher rating, auxiliary alternators (to use for electrical braking), or switch to a higher voltage (and, hence, a higher wattage/power rating) to prevent possible aeroturbine damage. If you only experience short-duration gusts exceeding this windspeed, the aeroturbine will not generally respond fast enuff to them and these may not be required. Switching to more batteries will not help here because, by definition, the 'full-load shutdown' windspeed assumes that the batteries are fully discharged and are, thus, presenting as much of a load as possible to the alternator, and the alternator is putting out as much as it can.



CHAPTER 5 - USING ELECTRICITY

We've now gone through gathering the wind's energy, generating electricity from it, storing it, and the control required to complete these processes and protect the system as well. Now, let's discuss using it.

As indicated in the equity/rent concept (Chapter 1), in using energy, we must need less energy or fork out a seemingly large sum of money to build a system which can compare (in quantity) with the level of consumption we can 'enjoy' when we rent energy. Even our awareness that many of the costs in renting energy are hidden while those of a wind/electric system are not, may not be of much consolation when we stare at the figures. As well, while we can learn to change our wasteful habits, we are nevertheless confronted with the fact that all of the machines we own (toaster, refrigerators, lights, etc.) still require 120VAC, 60 cycle. Or do they?

For certain, any device which directly uses 120VAC, 60 cycle must use 120 volts, but it may not always require A.C. (alternating current) nor does it always require 60 cycles (120 direction 'changes' per second). Wherever electricity is changed into heat (toaster, oven, heaters, etc.) or light (incandescent or fluorescent) 120 volts D.C. (Direct Current) can be used.* Light bulbs (incandescent) would last longer and burn brighter, allowing use of lower wattage ratings for the same intensity of light. Some motors that operate on 120VAC, 60 cycle are 'universal motors'; this means they were designed to operate on A.C. or D.C. Stereos, record players, radios, etc., that are transistorized (solid-state) in many cases actually convert the 120VAC, 60 cycle to a lower voltage (in a transformer) and then change it into D.C. for use (with diodes); for these devices, bypassing the transformer and diodes allows direct use of 12-24 volt D.C.

Inverters

Still, it is true that many appliances require 120VAC, or even 240 VAC, at 60 cycles. And so we are presented with a dilemma -- how do we produce this 120 VAC, 60 cycle when we are only developing 12VDC in the wind energy system? The answer is: by using a 'motor-generator', or by using an 'inverter.'

A motor-generator (or a 'rotary inverter' as they're often called) was used -- back in the old-timey days -- to produce 120VAC, 60 cycles from a wide range of D.C. voltages; this apparatus is basically a D.C. motor which runs off of a D.C. voltage source (such as batteries) and, in turn, drives a generator which produces 120VAC, 60 cycle. These things are fairly efficient (60%) in converting the low to the high voltage, and the D.C. to the A.C. Today they may be found primarily in electronic-surplus, mail-order places (see Sources, Data Sheet 3, Chapter 7); they generally cost about $25.00 per 500 watts of power (i.e., a 1500-watt unit would cost about $75.00).

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*Note: The fluorescent fixture would require some modification; the ballast resistor would have to be shorted out -- momentarily -- by a switch to start, and the tubes would have to be reversed occasionally.

Inverters are electronic devices (they have no 'moving' parts); the D.C. is changed to A.C. (by an oscillator) and this is then fed into a transformer and stepped-up to 120 volts. They boast higher efficiencies than a motor-generator (around 80%) but, as can be expected, at a much higher cost. As well, they are quite inefficient if they are not operated at their rated capacity. The price range, of course, depends on the size (power rating) of the inverter purchased; my latest check indicated that these units are running $100.00 per 500 watts (i.e., a 1500-watt unit will cost about $300).

Both the motor-generator and the inverter have a quiescent (no-load) power use; this means that if they are on, they will use power themselves, even if you are not running anything off them. A switch must be provided (somewhere) to switch them on only when you are using them; this quiescent power consumption is on the order of 1/10 of their rating (i.e., a 500-watt inverter will draw 50-60 watts under no load).

Placing an inverter or a motor-generator in the wind/electric system (with the circuits described in Chapter 4) is easily done; they may be attached directly to the outputs of these circuits at #5 and #6 terminals (applies to Figures 4-5, 4-6A, -B, -C, 4-7A, -B, 4-7, and 4-9). These units should be located as near to the batteries as possible; to deliver 1 amp at 120 volts (120 watts) requires 10 amps at 12 volts (120 watts) and that's assuming 100% efficiency in the inverter and no I^2R (line) losses! You can't do much about the 20-30% loss in the inverter or the 40-50% loss in the motor-generator, but you can keep from losing any more by keeping the lead-in wires (between battery and inverter/motor-generator) as short as possible.

An alternative to the inverter/motor-generator, or at least to the large units that would be required to handle everything is to (as indicated) use high voltage D.C. for those appliances -- lights, heaters, etc. -- that could use them. This can be done by hooking up the wind/electric batteries in series for higher voltages. In actuality, this can be almost any voltage that's a multiple of 6 (for six-volt batteries) or a multiple of 12 (if 12-volt batteries are used). For example, twenty 6-volt'ers or ten 12-volt'ers can be used to produce 120VDC. The problem with using voltages in between 12 volts and 120 volts is that nothing will work on them (unless designed and specially manufactured to do so; there are -- or were -- many devices designed to use 24 or 32 volts, for example). This is not the only problem, though; if the batteries are hooked up to work this way, then they have to be changed back over to a parallel arrangement (at 12V) for charging (from the wind/electric system). This wouldn't necessarily have to be done manually; relays or diode arrays could perform this job. However, the number of batteries required for this setup will be some multiple of the maximum number of batteries that should be paralleled for charging from the alternator (see Increasing Storage Capacity, Section G, Chapter 4). And therefore, this can't be done unless several aeroturbines, or a larger aeroturbine, are employed.

Determining Use

Before considering/buying an inverter or a motor-generator, it would be wise to assess your present power consumption. This involves two things:

(1) determining the power consumption of every appliance, light, motor, etc., used in the home, and

(2) determining the approximate amount of time they are used per day, week, and month.

One way of doing this is described in Section J of Data Sheet 1 (Chapter 7). By law, the power a device consumes must be indicated on a tag or in a place somewhere on the appliance; it may be in watts or in amps. If you make a list of everything you have that runs on electricity in your home, shop, etc., you can use it later on when you begin thinking more seriously about what you really need, and what it is you don't (and can eliminate).

If you aren't into pulling the refrigerator out, looking under the stove, climbing ladders to check light bulbs, etc., to find their ratings, there's a rather neat table which gives typical power consumption of many appliances from 12V or 120V and gives typical use (frequency and duration) and monthly kilowatt hours consumed in Henry Clew's 32-page booklet, "Electric Power from the Wind" (see Sources, Data Sheet 3, Chapter 7). I recommend the former (determining your own) because of its 'awareness' value and the fact that you may not by 'typical,' but it's your decision!

Cutting Down

A comparison of your present consumption versus the power production (by the wind/electric system) will indicate a gap which will exceed even that supposed to exist between generations. On one side is the possibility for enlarging the S-rotor aeroturbine, going to a different (and possibly more efficient) aeroturbine, or building several aeroturbines. On the other side is another good possibility and certainly a less-expensive one: cutting back on the energy requirements of both home and individual.

Most folks who consume power at present day-levels feel that anything less than, perhaps, a 5% cutback will result in personal sacrifices. In many cases, this is not the case; a much more reasonable estimate would be that cutbacks on the order of at least 50% can occur with sufficient knowledge on how we waste (our own habits) and how the appliances we use waste. In my own experience, I can relate that when you start thinking that you've done all you can to save energy, then you haven't!

Whole books could be written on the ways in which we waste or how to conserve energy; even though I have explored this subject extensively, I still feel as if I could only write a few of the chapters (of just one!). Heating (in winter) and air-conditioning (in the summer) are two of the biggest consumers and they need not be; the money spent on air-conditioners or the wind/electric system power needed to operate them is better spent on better insulation and employing natural cooling techniques (in home construction, air flow, etc). If you think that folks a long time ago didn't enjoy summer coolness or winter heat, you are wrong. The kind of information required to do it like they did isn't lost but it's not readily available, either; magazines like Mother Earth News and Alternative Sources of Energy (see Sources, Data Sheet 3, Chapter 7) are just beginning to get it out.

Auxiliary Power

As the windspeeds will average less (per month) in the summer (compared to winter months) it would be unnecessarily expensive to build a system that would provide for every peak-usage throughout the year. As well, the batteries should periodically be charged to capacity to prevent sulphation and to extend their useful life; the wind/electric system can provide this in the winter's windy months but will not necessarily adequately fulfill this requirement in the summer's calm. For these reasons, an auxiliary electricity unit should be considered for use with the wind/electric system.

This would be an alternator/generator unit powered by propane, methane, gasoline, steam, water, or hand; the alternator unit would not have to be large; a small unit operated for a period of time can charge the batteries and effectively store a lot of power as a larger unit would do in a shorter time. Small gasoline engines (lawn-mower type) would easily drive a small alternator. Larger engine/alternator devices could supply 120-240VAC, 60 cycle directly for use with larger shop machines as they were used.

Installing such a unit in remote areas (that are presently without electricity) could facilitate construction and installation of the wind/electric system itself and then be used to back it up. I'm not particularly crazy about using gasoline-powered generators but if they help to build alternatives, it isn't the same; once the wind/electric system is installed and operating, they can be used to build up solar, methane, or other alternative energy systems which could then power the engine/alternator.

An alternative to the auxiliary electricity-generating unit would be ConEd (for those that already have it). (Note: Just for the record, I don't recommend this but only list it as an alternative.) The wind/electric system can be 'interfaced' (used in conjunction) with utility power. As the building codes will vary in various locations, how this can be done legally is a question I can't answer for everyone.

For those that want to use existing wiring in the house and plan to altogether discontinue ConEd service, a way in which the wind/electric system can be hooked into it, is to use any heavy wiring (like 220 lines running into the garage for a washer/dryer, etc.) in the locality of the batteries, inverter, etc., as the main feed line. In this way, power can be transmitted back to the breaker/fuse box and then distributed throughout the building (in actuality this can be done without any modification but codes might require some kind of rearrangement).

If you do not have any wiring already existing in your home (or haven't built it yet), locate the main panel (breakers, feed lines, etc.) as near to the wind/electric batteries and/or inverter as possible. As well, use as large a size of wire as you can afford (becuz it will have less resistance) and make wire runs as short as possible (to prevent those I^2R losses).

If you use a combination high-voltage D.C. (for heaters, stoves, lightes, etc.) and inverter (for those things requiring 120VAC, 60-cycle) system, and plan to use existing wiring for the system, you can operate some outlets on D.C., others on A.C., but mark them clearly as to which one is which and the positive (+) polarity of the D.C. as well (proper polarity is essential for some things -- electronic devices, D.C. motors -- but not others -- heaters, lights, etc.). If you still have to install wiring, provide for this other wiring (the A.C. from the inverter); it can be smaller wire, if you use only a small inverter.

CHAPTER 6 - THE S-ROTOR AEROTURBINE

Aeroturbine (air-turbine) is a term that I will use to define the entire unit that converts the kinetic energy of the wind into the mechanical energy of a rotating body. The aeroturbine described here is multi-tiered (three S-rotors stacked vertically in tiers) with each S-rotor oriented 60° out-of-phase with the others (see Fig. 6-1). The stacking arrangement resulted from an invertigation into how the machine could be enlarged (to intercept more wind) without sacrificing integral strength. The out-of-phase orientation (of the tiers) resulted from a close look at a problem which plagues a single-tier, or basic, S-rotor; if the wind momentaril died, the S-rotor might come to rest in several positions (relative to the wind's direction) where it would not restart easily (under load) as the wind came back up. These positions are expressed by the gaps (indicated by arrows) in the torque curve for the simple (or single-tier) S-rotor (see Fig. 6-2) ; three S-rotors stacked 60° out-of-phase eliminated these gaps (or positions).

This chapter will describe three different models of S-rotor Aeroturbine--- Model A, Model B, and Model C. Model A is the aeroturbine that was described in Mother Earth News #26; it uses 55-gallon drum halves for wings (we shall refer to them as impellers). Model B differs from Model A in that it has a skeleton-type structure (within it) to provide the strength and rigidity that the 55-gallon drums give to the completed Model A aeroturbine. It was made this way in order that lighter, modified impellers might, as they were developed, be used instead of 55- gallon drums. Where

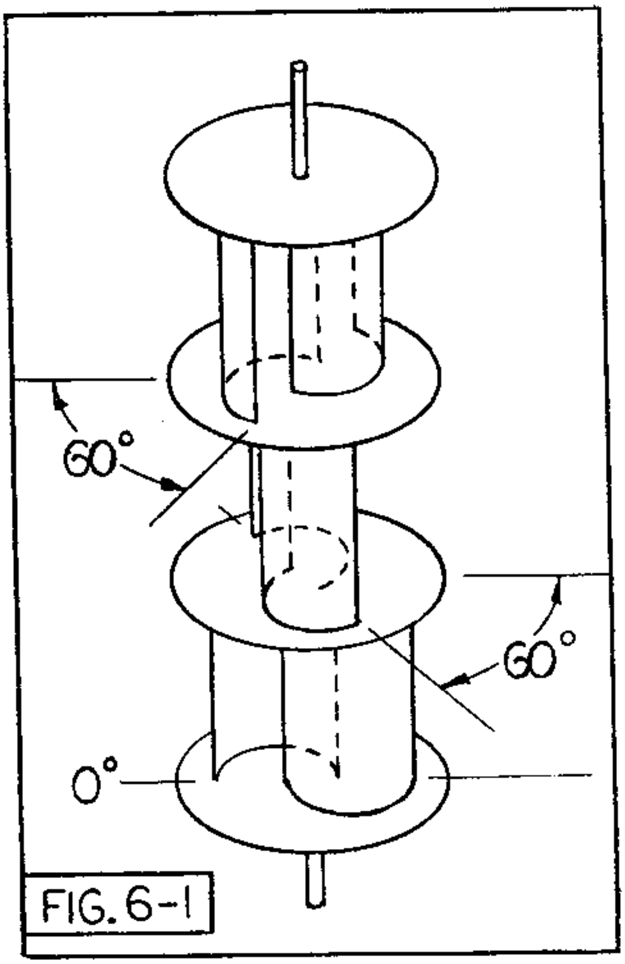


FIG. 6-1

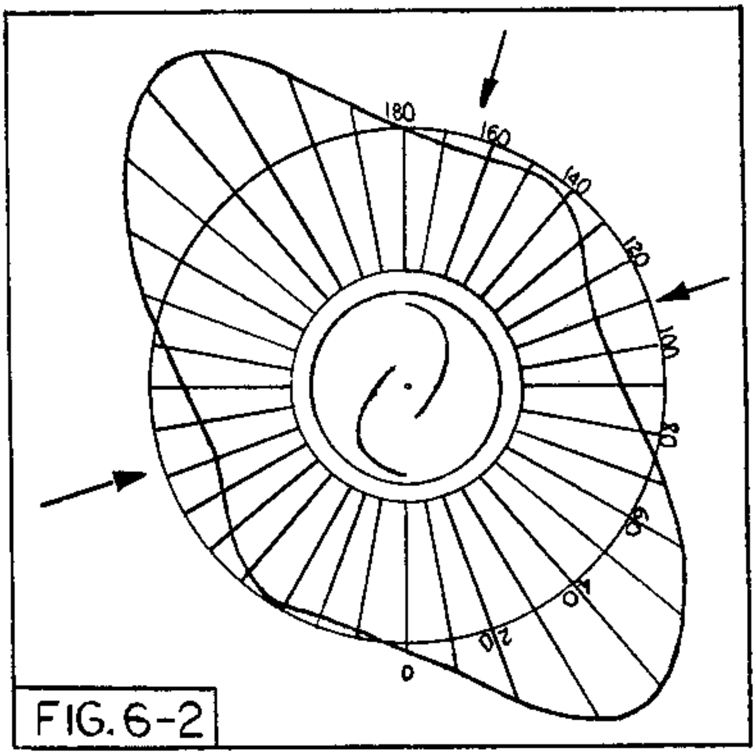


FIG. 6-2

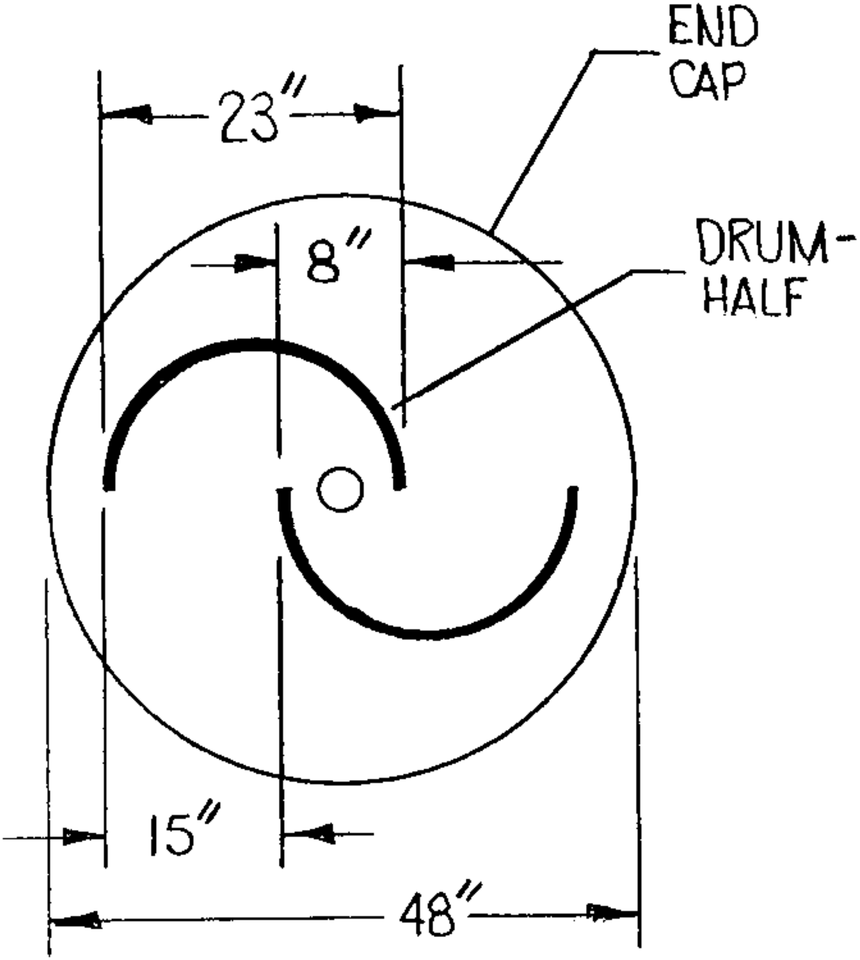


FIG. 6-3

Model A would require complete disassembly to incorporate the new impellers and some additional bracing, Model B would allow the exchange while it was still in an upright, operating mode, without disassembly and without further bracing. Model C is the same as Model B except that it may be mounted as illustrated in Fig. 6-11; Model A and Model B require the support assembly illustrated in Fig. 6-10.

These three models have their similarities and their differences; within the sections (listed below) their similarities will be discussed within the text (or under Design Notes) whereas their differences will be clearly indicated within each section under the listing of Model A, Model B, or Model C. This is to avoid confusion; once you have decided which model best suits your situation, you will be able to quickly reference through each of these sections and find what information is required to complete the construction of any one model.

The essential parts of a three-tier, S-rotor aeroturbine are:

A. End Caps
B. Impellers
C. Bearings
D. Rotor Shaft
E. Skeletal Members (inner framework)
F. Support Assembly

These are, as well, the alphabetical listings of the sections within this chapter. Section G - Decisions- will aid in making the final decision and provide cost analysis. Section H will outline balancing methods for the aeroturbine while Section J will discuss spoilers for high windspeeds.

SECTION A --- END CAPS

Design Notes:

The end caps serve several functions; they provide (1) increased performance of the aeroturbine by preventing spillover (and loss) of wind captured by the impellers, (2) an easy means of securing the impellers to the aeroturbine assembly, (3) an accurate means of orienting the impellers 60° out-of-phase, and (4) an accurate means of locating the center of the aeroturbine (which aids in balancing the entire assembly).

The diameter of the circular end caps is dependent on the size of impeller used; for 55- gallon drum halves, this diameter is 48" (Fig. 6-3 describes the correct positioning for 55-gallon drum half-type impellers). Two 48" diameter circles can be cut from one 4'x8' sheet of plywood (2 sheets are required as 4 end caps are used). The thickness should be at least 3/8" (1/2" is recommended); however, don't exceed 1/2" unless you want an unnecessarily heavy aeroturbine. A 48" diameter plywood circle, 1/2" thick, weighs 20 lbs and with 4 of them, that's 80 lbs. Add that to the 17 lbs per drum-half (with 6 impellers, that makes 102 lbs) and you'll have a 182 lb aeroturbine, minimum!

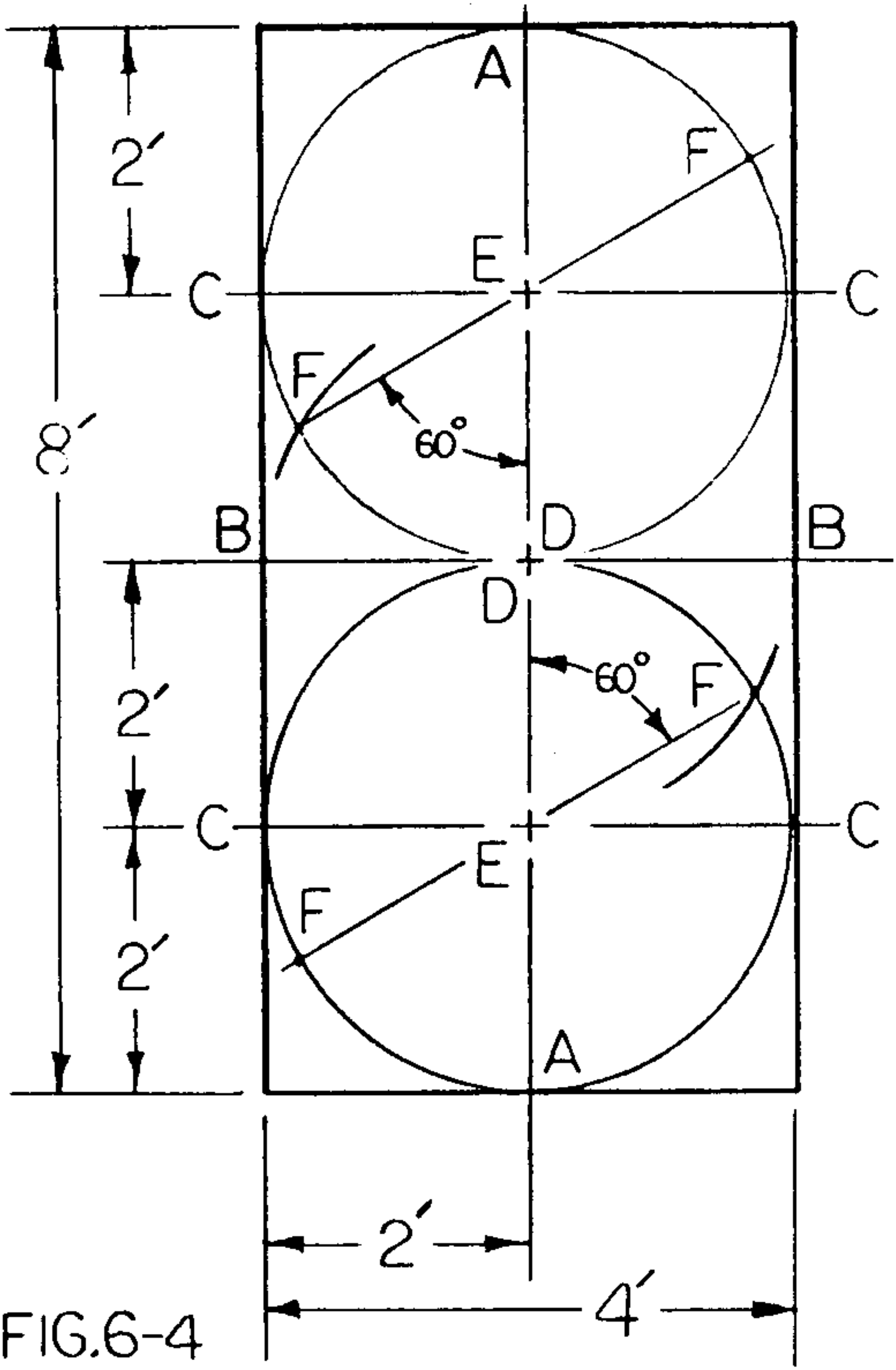


FIG.6-4

Plywood circles are available in various diameters but I recommend that you cut your own from 4'x8' sheets. Why? To make a 48" circle on the sheet you have to rotate a pencil-string combination around a centerpoint (located 2' from one end of the sheet and midway between the sides, as in Fig. 6-4). The accuracy of the final cut is not too important but having that centerpoint is ! Store-bought, ready made, plywood circles are not only more expensive but they don't have that centerpoint, and accurately locating it is a job!

Drawing, Marking, and Cutting the End Caps

Don't be tempted to first complete one end cap and then use it as a template for making the others. Because of inaccuracies in drilling and the problem of accumulated error, this is not advisable unless you are fully aware of the implications.

(1) accurately locate the center of the 4'x 8' sheet (see Fig. 6-4) along its length (points B) and across its width (points A); then find points C. Connect these points as shown in straight lines dark enuff to see clearly. Where they cross at the centermost point is point D ; the centers of the two circles are at points E. Drive a tack or a small nail in at points E and point D. Mark all letters within the circles (as shown in Fig. 6-4) on the plywood sheet.

(2) make up a pencil-and-string apparatus (as in Fig. 6-5) and loop the end of the string over the nail (or tack) head at point E. Wrap the other end of the string around the pencil as close to the lead point as possible and allow it to slip until its taut and adjusted to exactly 2 feet (24"); then tie it, checking to be sure it doesn't change as you knot it (get it right as you will use it repeatedly). Get the string taut, keep the pencil perpendicular to the sheet, watch the nail end (to see that the string loop slips easily around the nail or tack) and swing the pencil around. Get the line dark the first time (use a soft lead) and sharpen the pencil for each circle. Do both circles on both sheets.

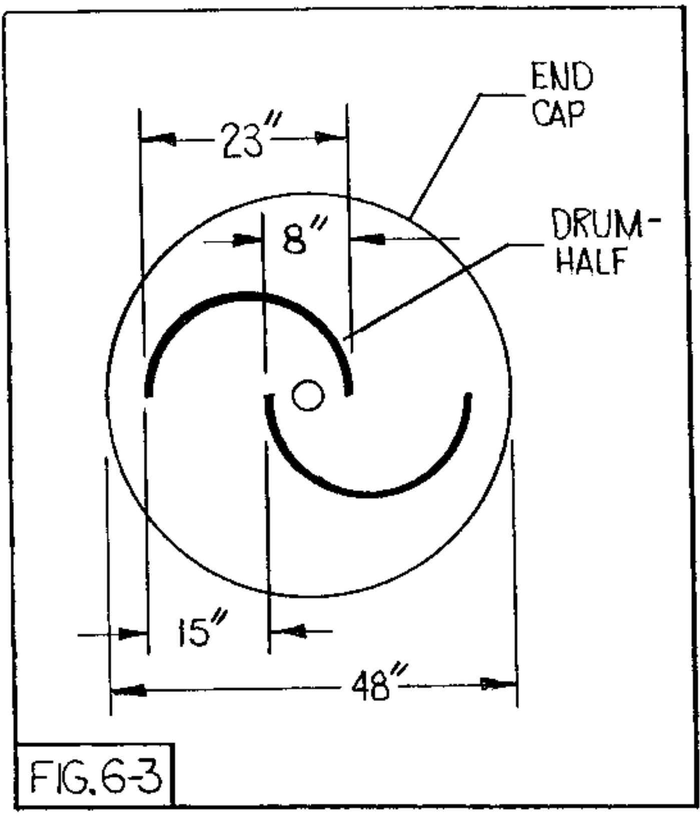


FIG. 6-3

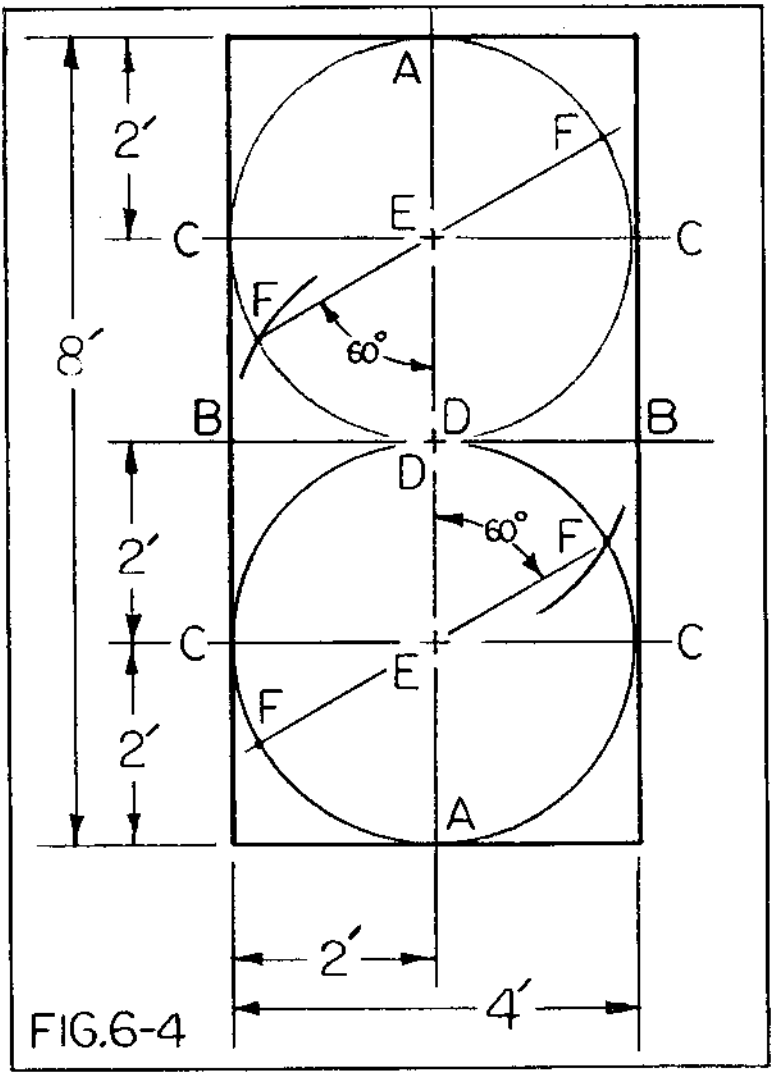


FIG. 6-4

(3) to help orient each tier of impellers 60° out-of-phase with the others, the line connecting points F must be formed. Slip the loop of the string off the nail/tack at point E and put it over the nail/tack at point D. You can swing a complete circle (lightly) or just stretch it to where it intercepts the perimeter of the circles (as in Fig. 6-4); that point (F) will be 60° from the A/D line. Mark the point clearly and draw a straight line from that point (F) thru the center (E) and to the edge on the other side. Do this for the other circle; the plywood sheet should appear exactly like the illustration (Fig. 6-4). Do this as well for the other sheet (and its two circles).

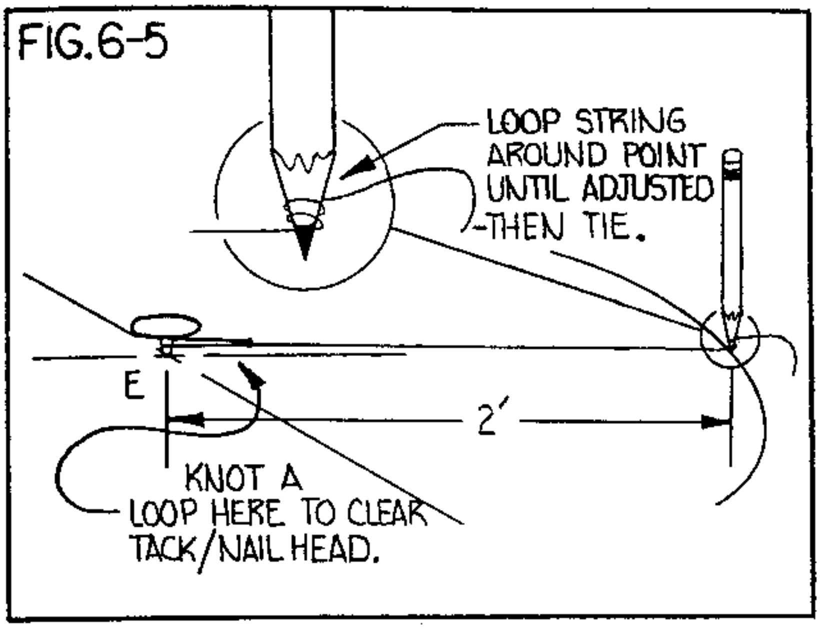


FIG.6-5

(4) cut the circles using a hole saw, jig saw, or saber saw. In a pinch, a hacksaw blade wrapped at one end (for a handle) will work; it is admittedly slow, a bit dangerous, and tedious, but a greater teacher of patience!

(5) once all 4 end caps are cut out, you have one more line to draw; this will be a reflection of the 60° line that you've drawn on the front ($\overline{FF}$). At points F, extend a line across the thickness of the end cap to a point on the other side. Then, with a straight edge, connect these two points in a line on the back side of the end caps.

(6) a centerhole (at E) must be drilled in all 4 of the end caps; the size of this hole depends on two things: the size and the type of rotor shaft (these are discussed in Section D of this chapter). Both of these factors depend on which aeroturbine (of the following three) that you decide to build; procedures for making the end caps used on each are as follows:

Model A - the size of the hole at the centerpoint of the end caps (points E) will have an I. D. (inside diameter) equal to the rotor shaft O. D. (outside diameter) used. The rotor shaft should just fit (snugly) through the end cap. Take the time to insure this happens; the quality and precision of the work here will save a quantity of work when it comes time to balance the aeroturbine. A good procedure is:

a. drill a pilot hole (1/4" drill bit or smaller) using a drill guide; this will insure that the hole is perpendicular. Hardware stores generally carry a device that does this and it is very important that this hole be straight.
b. drill the hole for the shaft size used. Several types of devices (which fit a drill chuck) are available for holes larger than 1"; don't sway from side to side as you drill, or the hole will be larger than desired.
c. check to see if the rotor shaft fits through the hole; if it doesn't, carefully ream it out with a rat-tail file, checking often to see if the rotor shaft fits. Remember, you want it snug!

Model B - same procedure as Model A

Model C - the hole for the outermost end caps (and at the centerpoint) should be twice the diameter of rotor shaft used. The two innermost end caps will be drilled to fit the bearings that are recessed into them. Use the procedure for Model A to drill the pilot holes and final, sized holes; do not drill these holes, however, until the holes for the skeletal members are located and drilled (see Section E in this chapter---and the procedure description, for Model C, in that section).

Arranging the End Caps

Arrangement of the end caps is necessary for final aeroturbine assembly; if the end caps are properly positioned, the tiers will be 60° out-of-phase and the impeller positions will be easily marked on the end caps. It's advisable to use some kind of numbering system here; most of the parts should be interchangable but a lot has to be accounted for---hand drill inaccuracies, work interruptions, accumulated error, material variations, etc. -- so play it safe and don't try to keep it all in your head.

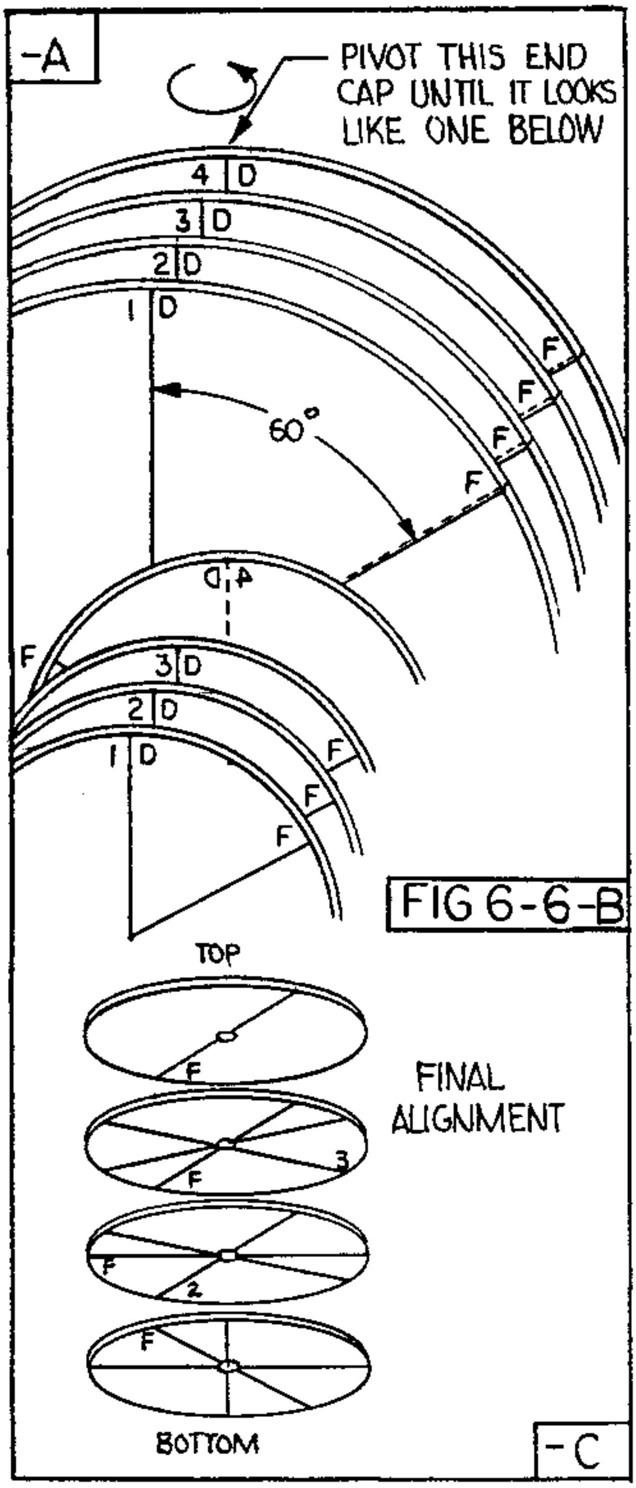


FIG 6-6-B

(7) arrange the end caps so that the sides with the three lines (and all the letter markings) are facing you (as in Fig. 6-6a); make sure you have them all exactly as in the drawing.

(8) now, grab the one in back (farthest from you) and pivot it around until it looks like Fig. 6-6b. Now mark them 1, 2, 3, and 4 as shown. Anytime that you have to 'arrange' the end caps, they should appear like they do in Fig. 6-6b.

Aligning the End Caps

Alignment of the end caps correctly positions them for final assembly. This will serve two purposes:

a. it simplifies mounting/securing the impellers in their correct positions (respective to each other) and
b. it insures that the aeroturbine will spin clockwise (when viewed from its lower end; this is especially necessary if a generator is used (because it must rotate clockwise).

(9) rotate the arranged end caps (Fig. 6-6b) until they are aligned; they then should appear exactly like Fig. 6-6c.

(10) the end caps should be protected from weather;

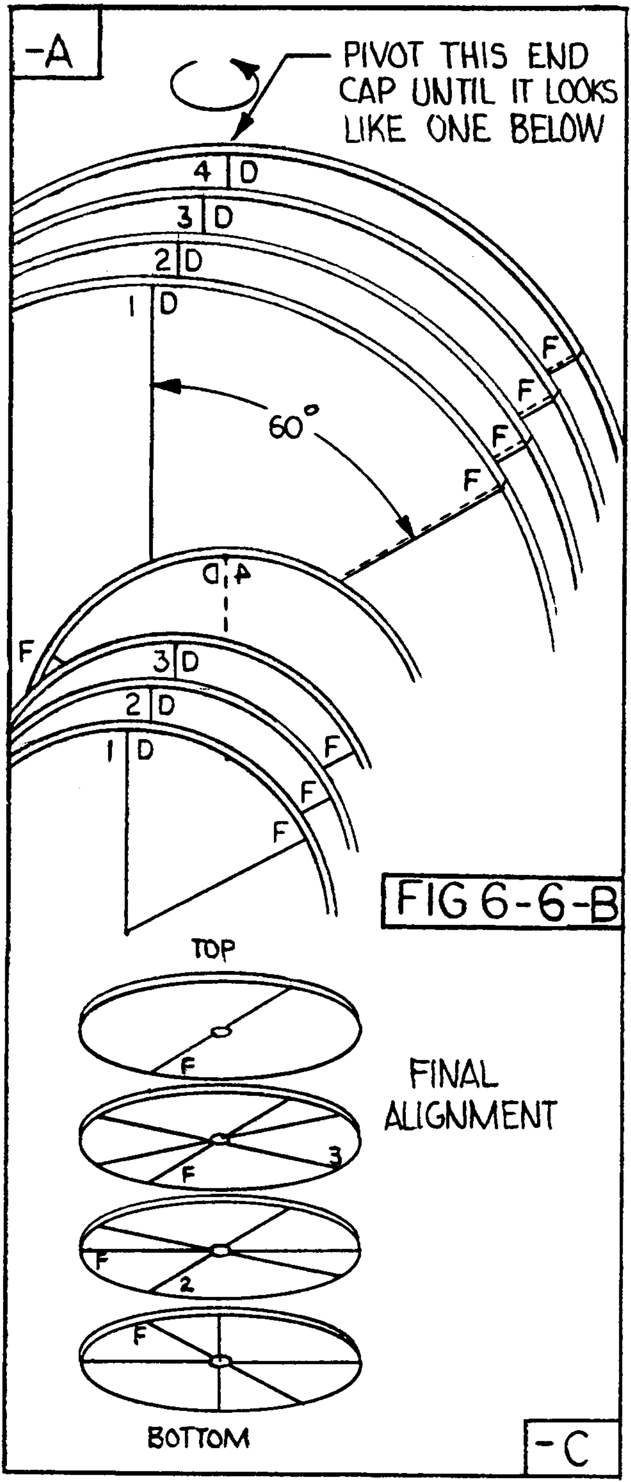


FIG 6-6-B

-A
PIVOT THIS END CAP UNTIL IT LOOKS LIKE ONE BELOW
4 D
3 D
2 D
1 D
F
F
F
F
60°
A
F
3 D
2 D
1 D
F
F
F
TOP
F
FINAL ALIGNMENT
F
3
F
2
F
BOTTOM
-C

they may be stained or coated with some type of wood sealer and/or painted; a quart of (oil-base) paint and a gallon of thinner mixed together makes a good sealer. Insure that all identification marks are still visible if the end caps are coated before final assembly.

SECTION B --- IMPELLERS

Design Notes:

Impeller is a word that I will use to define the wings, drum-halves, or whatever name might be used to describe the sections of the aeroturbine that actually capture the wind's energy. In this book, I will describe 55-gallon drum halves; this, however, is not the only type of impeller that can be used, nor is it the best. At the time I began designing my first aeroturbine (a Model A), the steel drum-halves were chosen because of their availability and their strength and rigidity. I was very unhappy with their weight but, at the time, the other factors won out.

Since that time I have completed the construction of an S-rotor aeroturbine that permits an easy exchange of impellers (a Model B); the design of this new aeroturbine is different from the first in that it employs a skeletal member (or inner framework) which provides the strength /rigidity that the drum-halves would have provided in the first aeroturbine.

Any device that aims to provide the best extraction of the energy in the wind must provide the best ratio of lift to drag. Lift in an S-rotor aeroturbine is determined primarily by the type of impeller (shape, aerodynamic curve, etc.) while drag is determined (primarily) by the weight. To improve performance, therefore, the lift can be increased or the drag reduced (or both may occur). The new impellers (that we will install in our newest unit --- a Model B) will reduce drag (because they are lighter) and increase the lift (because they have a better curve and shape). They do not, however, necessarily provide the overall rigidity and strength that the aeroturbine needs (1) to keep from 'twisting' (from top to bottom) and, (2) to stay together in extremely rough weather. Strength is needed for this, and is provided for, by use of the skeletal frame; water pipe and floor-mounting, pipe flanges are used to separate the end caps and hold the aeroturbine assembly together (whether the impellers are in place, or removed).

Note: Both kinds of aeroturbine are presented. The Model A requires the rigid impeller and it is non-skeletal; Model B and Model C are both skeletal and employ a removable impeller. I recommend the Model B to experimenter and non-experimenter alike. Why? The Model B may cost more than the Model A (it uses more parts) but it is more flexible and will be more efficient (if lighter wings are eventually used). While both the Model B and Model C offer this advantage over the Model A, Model B is less expensive and far less difficult to construct, balance, and erect than the Model C.

We are continuing work on the lighter, more aerodynamic impeller for use in the Model B. Its construction, for the experimenter, will allow use of materials other than heavy steel (as in the drum halves). For the non-experimenter, remember that you have a subscription to a newsletter we will put out later in the year; it will contain information on the tests we run with these impeller and plans for their construction. As this will certainly improve the aeroturbine's efficiency, realize that you don't have to complete the aeroturbine (or even start building it) first; spend the time getting materials --- batteries, control system parts, etc. ---and determine the site, build a tower, etc.

If you decide to build the Model A, or to use the drum-halves for impellers (until the information on these lighter impellers arrives) in the Model B or Model C, here's the procedure:

Selecting the Drums:

It is important to find three (3) 55-gallon drums that are identical: same height , width, and weight.

(1) weigh and measure the drums before you buy (or use them). If they have junk in them (dirt, oil, etc.), remove it so the weighing is accurate. If some have tops and others don't, this will throw off the weighing, so account for it. If they are all the same color, markings, etc., weighing may not be necessary but take the height measurement anyway; you'll need it later. Be sure to write it down!

(2) the drums can be without ends; these will be removed anyway. If the drums are badly dented or bent, don't accept them (I've never seen one not dented but I'm referring to a whole side being crushed in!). They can be lightly rusted, but plan to use a wire brush, sandpaper, or steel wool on them because it is advisable to paint them (after they're cut), and they must be quite clean before painting.

Marking the Drums:

The drums must be split lengthwise into two, equal sections (and the top and bottom, if any, removed); this is most easily done with an acetylene torch. If you don't have a torch (or a friend that does) have the drums cut at a shop. If you get them cleaned and marked before you take them in, you'll save money (because the shopman's time is your money) and you'll get a better job done.

Remember, the final product will be rotating, and unequal impellers means an unbalanced aeroturbine. It's a tough job to balance a completed S-rotor aeroturbine, so the balancing should be done by preliminary, and very careful, workmanship during construction.

(3) all drums have one seam and that's where the initial cut will be. The other line (for the other cut) must be drawn on the opposite side of the drum; to locate its position, I used a piece of string (about 35" long), measuring first one way, and then the other around the circumference (as shown in Fig. 6-7). Take your time and get it right; if the drum has dents, avoid them, or the measurements may be off). Do this at first one end of the drum, and then the other (I even did it at the midpoint of the drum); mark these clearly (pencil or nail scratch).

(4) use a yardstick (a 55-gallon drum is only 35"-36" long) and make sure it's straight

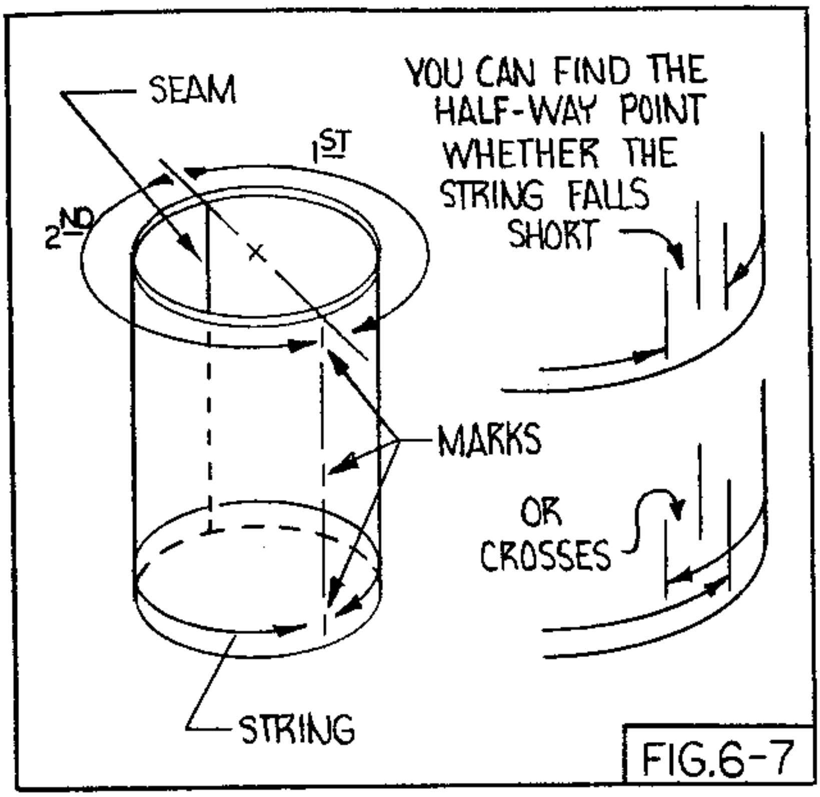


FIG.6-7

(check it ! look along its edge to make sure it's not warped) and line up with the two (or three) marks you've made, connecting them with a pencil line, or a nail scratch, or whatever's visible. If you scratch the metal (and not just the paint), it can probably be seen as it is being torched, but if you've used pencil or chalk marks, you have to do better. If the torchman can't see the line clearly (the torch's flame will burn off pencil or chalk marks), he's going to get off and ---bing ---you've got unequal impellers.

(5) a standard procedure for "set-up" (getting something ready to torch) is to make 'notches' (or indentations) with a centerpunch (and hammer) about every 1/2" along the line to be cut. One tap from the hammer will penetrate the steel and that's good enuff (you don't have to drive it all the way through!). You won't have to do that on the side of the drum with the seam becuz the torchman can see that, but be sure to tell him he must cut it right on the seam! Also, let him know what you are doing and what it's for (you might offer to share the plans with him, and get the drums cut free!). The important thing is --- all the time you spend in "setting-up" isn't going to be worth very much if he's sloppy, or can't cut a straight line. The cut drum-halves will have rough edges---that's normal. Grinding them smooth is tedious work but don't bother with it unless you're worried about getting cut (while handling them); they can be covered with tape to avoid this.

Incidently, jig saws can be fitted with metal-cutting blades and, I suppose, used to cut the drums if torching is out of the question (too expensive, or not available); judging by the thickness of the metal, it'll dull the blades pretty fast.

(6) one important thing to do before cutting the drums is to mark the two sections (to be formed by the cut) of each drum in such a way as to insure any drum-half can be re-united with its original mate and that both will be oriented in the same way (top and bottom). I used different numbers for each drum, written near one end, halfway between the two cutting lines (to insure the torch didn't burn them off).

Cutting the Drums

(7) if you're cutting the drums yourself, set each drum (in turn) between blocks (or whatever); they are under tension, so they will 'pop' apart at the end of the cut (on one side). They won't pop very much, assuredly, but if ya aren't expecting it, it might startle you (and you might proceed to burn the sleeve off your shirt, or the arm inside!).

(8) wirebrush or sandpaper the drum-halves (after they've cooled) and paint them first chance you get (or you'll have some more rust to scrape off). If you have to paint over

your identification marks, immediately re-mark them!

Final Preparation:

(9) one remaining job is to get the drum-halves ready for mounting on the end caps; this requires six (6) L-brackets per drum-half for the Model A and, if used, four (4) for Model B and Model C (see Fig. 6-8a).

(10) drill 2 holes (for each L-bracket) in the drum half; use the bracket for a guide. I secured my brackets with pop-rivets but bolts may be used instead. In several cases, I used small, metal washers to 'shim-up' the L-bracket wherever the drum's metal lip might have caused the unshimmed bracket to 'lean in' to the drum at an angle (see Fig. 6-8b). The brackets may be made from 2" by 1/2" flat-stock (scrounging around or behind a metal-supply store or talking to a shopman might get you some surplus metal so you can make them yourself; mine were ' store-bot').

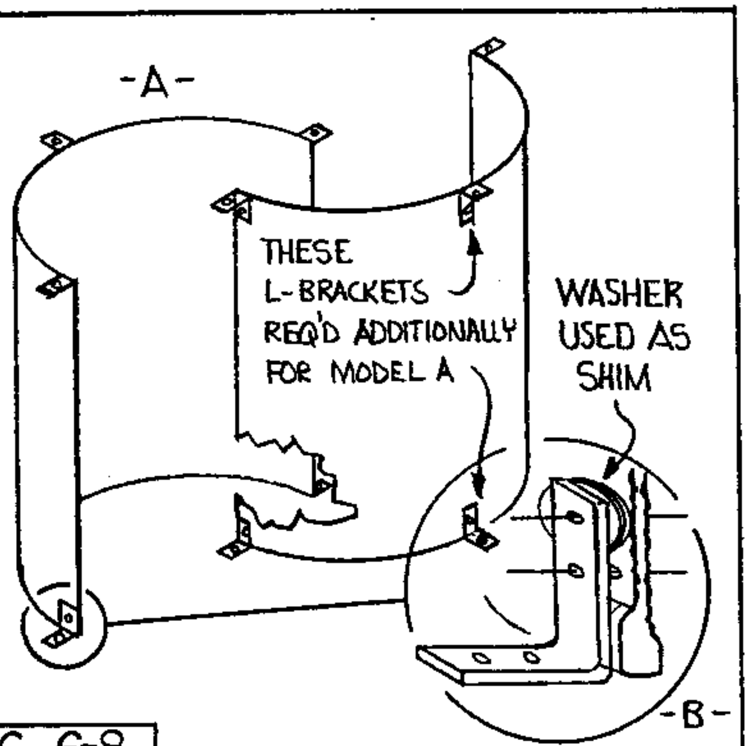


FIG. 6-8

Woodscrews may be used to secure the L-brackets (and drum-halves) to the end caps; if you're using an end cap that's 1/2" or thinner you might have to use small bolts. Don't drill any holes, however, until final assembly is in process; after the drum-halves are positioned (according to Fig. 6-3), a pencil can be used to mark the holes (using the L-brackets as guides) and the end cap removed for drilling or for making a starter hole (for screws).

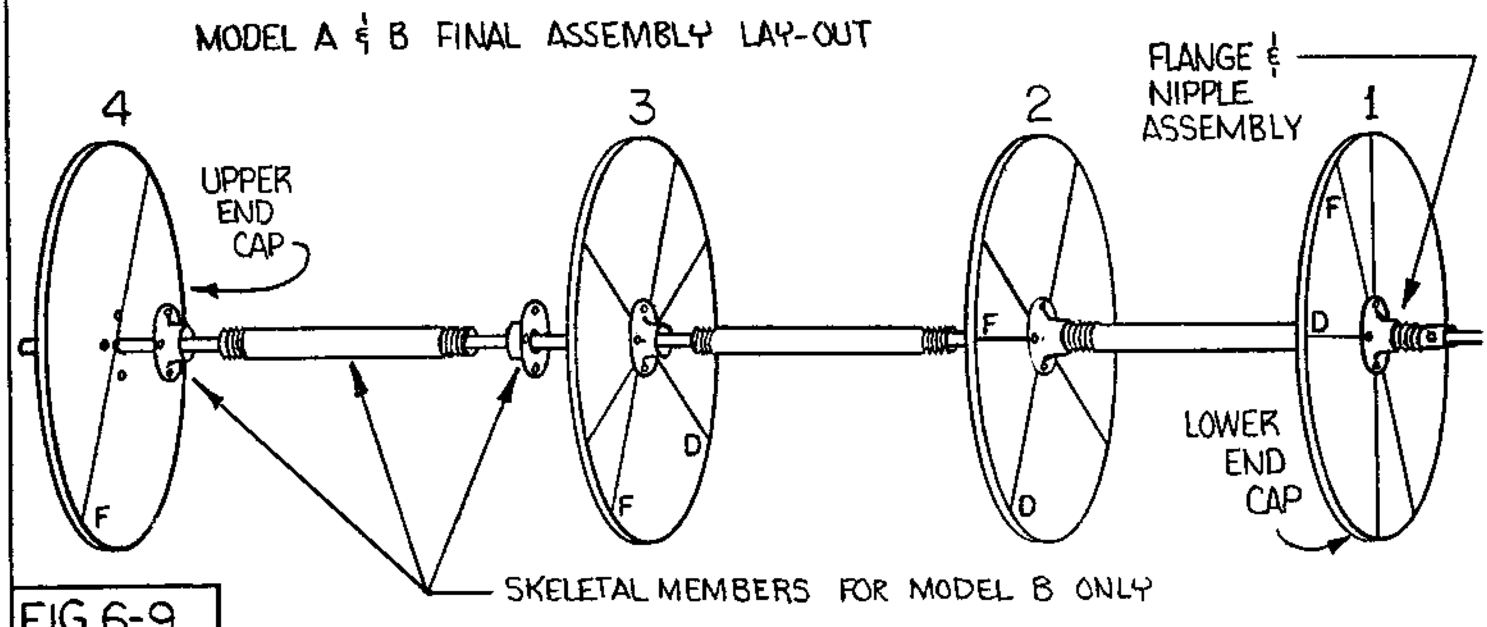


FIG. 6-9

(11) it might be easier to mark the positions for the impellers (on the end caps) before assembly; study the drawing of final alignment and positioning (Fig. 6-6a, b, c, and 6-9) and then mark these positions on the end cap. This will be necessary because the drum-halves (when used) will have spread apart after cutting (they were under tension, remember?) and they will have to be compressed a bit before they are completely bolted/screwed down. I did this by first bolting/screwing down the innermost L-bracket (on the side of the drum closest to the center of the aeroturbine) and then, I sat on the outermost portion of the drum-half, got it to align with the mark (where it should be) and then bolted/screwed it down; of course, I 'sat' on the aeroturbine when it was on its side. As well, this was a Model B; the procedure might be a little bit more difficult for a Model A, rigid impeller (without a skeletal frame).

Note: If you have a hard time compressing the drum half and getting it on the mark, then forget it; bolt/screw it down the way it is. It's not going to interfere with the efficiency of the aeroturbine that much, but if you can't get them all at the proper mark, the aeroturbine will be out of balance. So . . . compress and get all of them at their respective marks (compressed) or make new marks (uncompressed) and bolt them down where they are,all the same.

SECTION C --- BEARINGS

Design Notes:

The bearings used in the S-rotor aeroturbine should meet the following criteria:

1. Provide for axial and radial loading
2. Sealed
3. Flange-mounting
4. Eccentric locking
5. User lubricated (not self-lubricated for life)

Two types of loading are imposed on the rotor shaft and, hence, the bearings. The first is radial loading (forces acting perpendicular to the shaft) and this comes from the (1) wind itself, trying to turn the aerot urbine and (2) tension imposed by (and at) the gear train (where the generator hooks up to the aeroturbine). The second type of loading is axial (forces acting parallel and along the shaft); because the aeroburbine turns about a vertical shaft, this force is gravitational, or that produced by the weight of the aeroturbine itself.

The bearings should be sealed if they are to withstand exposure to the elements.

The bearings should be flange mounting; this is simply a housing for the bearing that permits bolting of the housing (and, thus, its bearing) to a flat surface (like wood).

The bearings should be eccentric locking; setscrew locking is okay, but the collar that is locked to the rotor shaft is secured much more evenly by the eccentric method.

Lubricated for life-type bearings, in my opinion, are not as good as the type you lubricate yourself. The top bearing is not going to be that easy to get to, but the difficulty will depend on what kind of aeroturbine support assembly you decide to build. We are presently using Browning FB-250 bearings. If we were going to continue using impellers that are 55-gallon, drum-halves (and not replace them with lighter impellers), we would have to use an FB-900 (or its equivalent) on the bottom. The reason? Our present aeroturbine weighs 250 lbs. and that's quite a load for a ball bearing (like the FB-250); replacement of the impellers, however, with lighter ones will bring the weight of the aeroturbine down to 160 lbs. and the FB-250's might take that (and we can take their cost -- $7.00 per bearing). The FB-900's are timken taper-roller bearings but, while they are real beefy, they cost $25.00 apiece. If you are going to build the Model A aeroturbine, you'll need at least one (for the bottom); the top bearing can be on FB-250.

There are, of course, many other manufactured bearings that meet the requirements; they may be less expensive than Brownings are. If you are into some experimenting along this line, try the bearings found in the rear-axles of junk cars -- especially Fords and Chevys. Mounting them may be a problem, but experimenters generally thrive on that kind of challenge.

How and where the bearings mount depends on what kind of model you are building. Again, when you have made this decision, you will mount them as follows:

Model A - the bearings here are mounted on the wood crosspiece of the support assembly and 2 will be required. One must be equivalent to a Browning FB-900 and it will mount on the lower crosspiece; the other will be a Browning FB-250 (or equivalent) and it will mount on the upper crossmember. Refer to Section F -- support assembly -- for the mounting of these bearings.

Model B - same as Model A (above), except that the lower bearing may be the same as the one used at the top (an FB-250), if lighter impellers are used.

Note: A Browning FB-250 (or equivalent) should be able to handle the load but it's almost borderline (as to the weight it will take); our present unit has not been operating long enough to accurately say that it will take this stress for any extended period of time. There is no doubt, though, that the FB-900 can last a long time.

Model C - the bearings here must attach to the end caps but 4 are required all together. Two will be housed in flange blocks and bolted to the outermost (top and bottom) end caps. A Browning FB-250 (or equivalent) is recommended for the upper end and a Browning FB-900 for the lower (see note under Model B above). The other two bearings must be mounted to the other end caps (innermost) but they must be recessed into the holes in these end caps so that they do not interfere with the mounting of the skeletal-member flanges.

Note: I am not recommending the Model C unit to the inexperienced or the unskilled. Section D -- rotor shaft -- will reveal some of the problems I encountered in the construction of this model, one of which is the installation of bearings in the unit.

SECTION D -- ROTOR SHAFT

Design Notes:

The rotor shaft is the axle (and pivot) of the aeroturbine; depending on which model you use, it can be a "live-axle" or "dead-axle" type.

Model A: This aeroturbine uses a 'live-axle' type rotor shaft and the term means just that -- the axle is alive, or moving and rotating as part of the aeroturbine; the rotor shaft is locked to it. The bearings for this kind of rotor shaft must be mounted in a framework (see Fig. 6-10) which is held in place, or upright, by guy wires.

Model B: Same as Model A (above)

Model C: This aeroturbine uses a 'dead-axle' type rotor shaft and, here the rotor shaft does not move; rather, the aeroturbine rotates (or moves) about it (the rotor shaft is prevented from moving). The bearings, in this arrangement, are mounted on each end cap of the aeroturbine. This reduces the need for a frame and allows attachment of the guy wires directly to the top end of the rotor shaft (to hold it upright, as in Fig. 6-11).

My own experience with both of these arrangements leads me to vote emphatically in favor of the live-axle (Model A & Model B) arrangement. As this is the only essential difference between the Model B & Model C, this is a vote against the Model C. The only simple thing about the Model C aeroturbine is the way it looks. Unfortunately, it seemed rather simple to build at the time I wrote my first article (which was published in Mother Earth News, issue #26) on the S-rotor aeroturbine and, as Model C was easier to draw than the support assembly required for the Model A or Model B, it was the one depicted in the drawing for the article. That was Nov. of 1973, and to date, it has caused us considerable grief. Why? Let me count the ways!

(1) the skeletal members (see Section E) have to be about twice the diameter of the rotor shaft (or the shaft will hit the inner walls) -- this is twice the cost and weight of the one used in Model B.

(2) the inner bearings have to be selected to recess into the end cap; otherwise, they will interfere with the floor flanges used in the skeletal member.

(3) the outer bearings (or their flange blocks) must be carefully selected in order that the hole pattern be the same as that of the skeletal member's floor flange or each will interfere with the other when bolted to opposite sides of the outermost end caps.

(4) as the uppermost end of the rotor shaft receives side tension from the guy wires used to support it (or hold it upright), the slightest pull to any side (by these guys) will bind the shaft against the bearings along the length of the aeroturbine. This will not only wear these bearings, but will spoil their efficiency and, at high speeds, cause a potentially dangerous stress. Of course, the guy wires can be carefully tensioned but this will only minimize the condition (as there is no easy way to know if it has been wholly eliminated).

(5) as the gear (mounting on the lower end cap) must clear the rotor shaft and attach to the aeroturbine itself, it must be made to clear the bearings mounted there. As well, to remove it (and install another, as operation might dictate) would require lowering the aeroturbine.

FIG.6-10

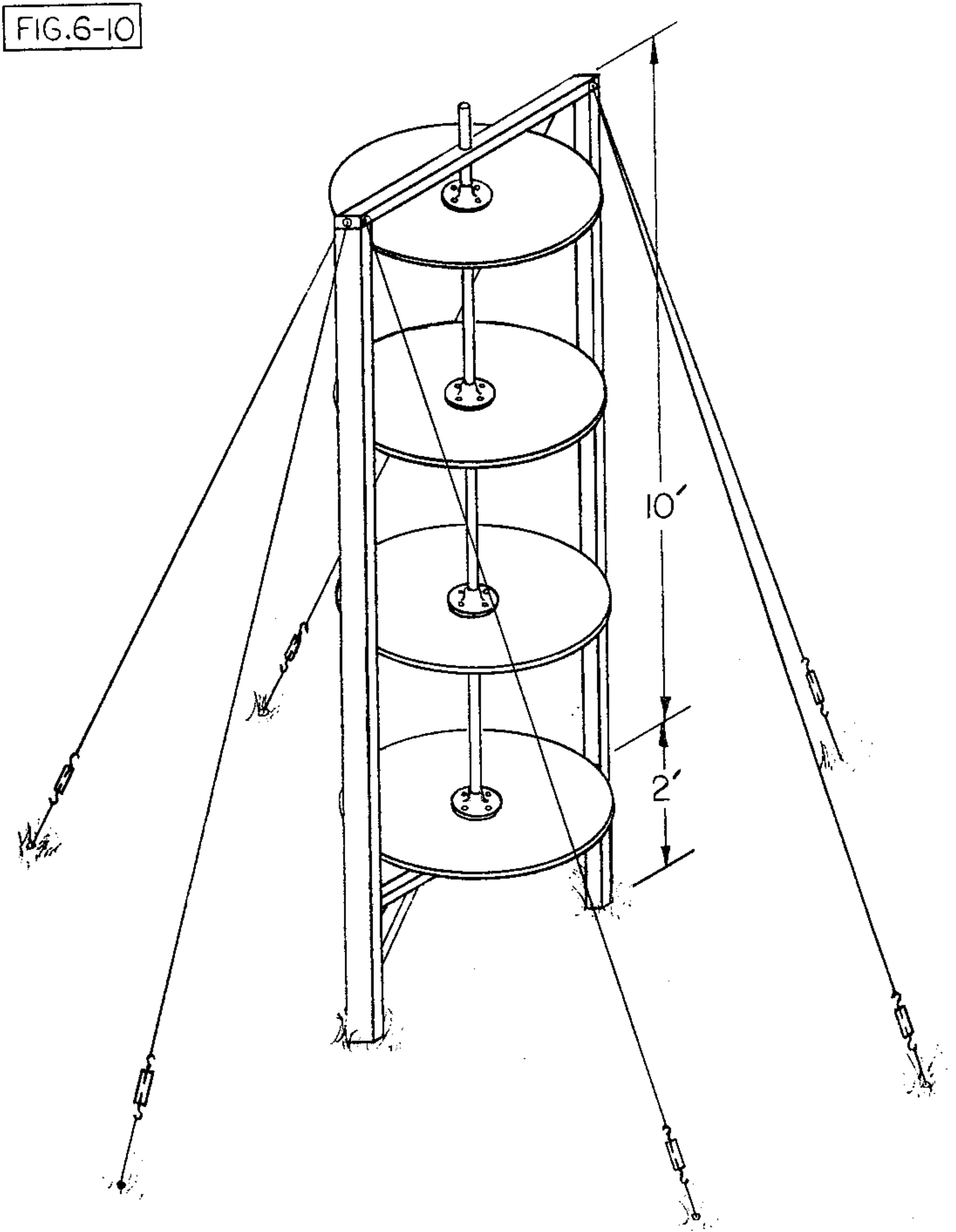
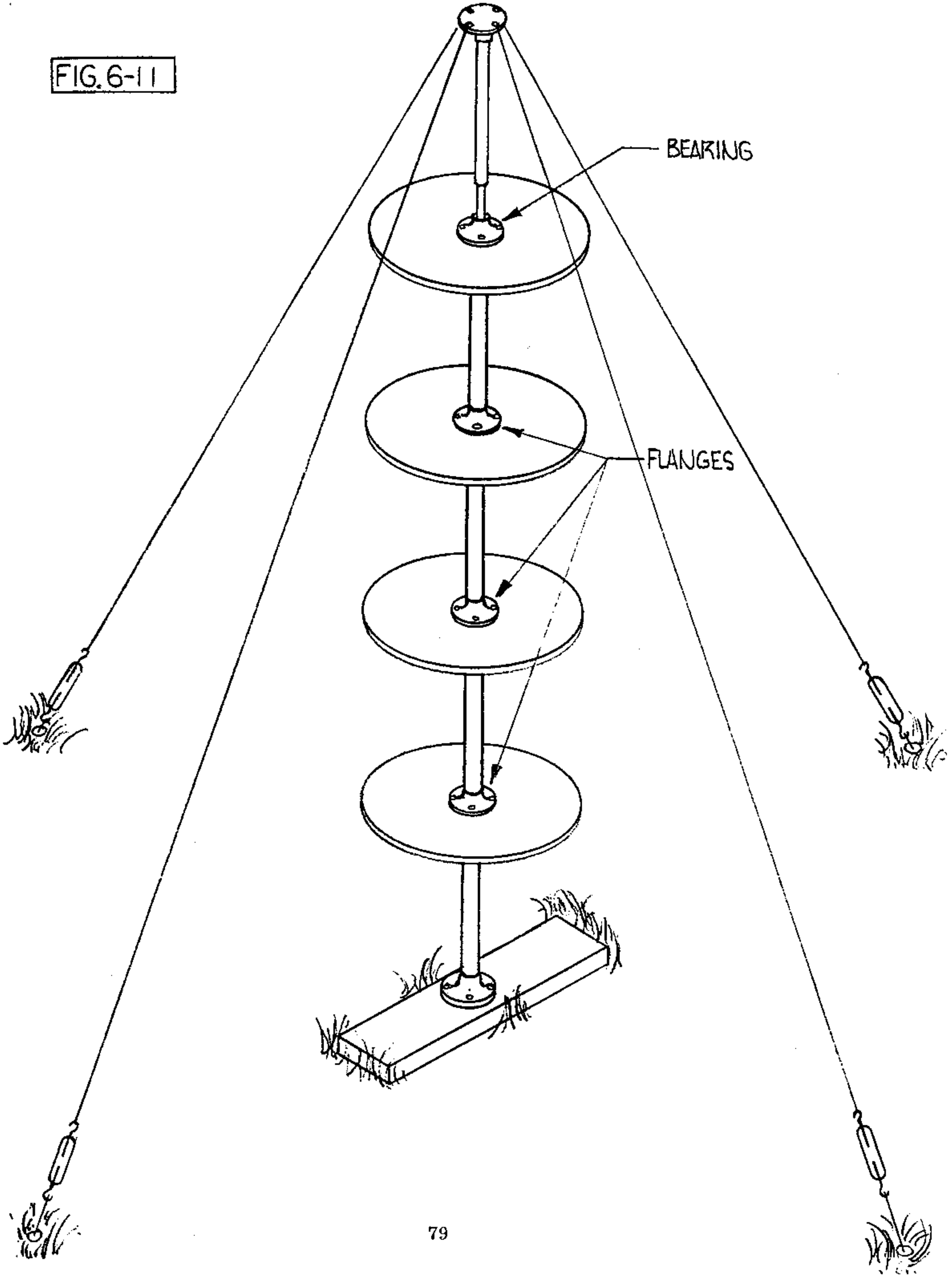


FIG. 6-11



There are more objections to this model, but they are more situational; if I had a better-equipped shop, I might be able to minimize the accumulated error that pipe flanges, warpage, etc., seem to add to all the above listed problems. I am intrigued by the possibility of this type of mounting but I must admit that the energy is not there to further work out these problems at this time. If any of you decide to tackle it, I'd like to hear the results. Good luck.

The Rotor Shaft

The rotor shaft can be constructed in a number of ways. The simplest way is to use a long section of round bar stock (cold-rolled steel, see Fig. 12-A). This costs about $1.25 per foot and it comes in 12' lengths. As the minimum length of the rotor shaft required is 10' (the aeroturbines described here are 9' long), I recommend buying a full 12' long piece. Why? It's easier to work with, gives you clearance for the gear train, and it's nearly the same cost as a 10' section (since you not only pay for the length, but also for having it cut).

Another way to make the rotor shaft (see Fig. 12-B) is to buy a long section of pipe (which is only 65¢/ft.) and insert two smaller sections of round bar stock in each end (for the bearings). I tried this first, incidently, and don't recommend it. The pipe has to be seamless (you can't use water pipe), so that the round stock and pipe rotate concentrically. Even with seamless pipe, the round stock goes in too easily and the 'slop' has to be "shimmed-up." As well, the biggest problem is securing the round stock inside the pipe without changing the O.D. of the pipe (or it will not clear the holes in the end caps). Besides, by the time you add up the lengths of pipe and round stock required, the all-round stock shaft is only $3.50 more; the problems and extra time weren't worth the "savings" of the pipe/round stock rotor shaft; our newest rig runs only round stock.

Securing the Rotor Shaft

Again, once you've decided on the model of aeroturbine to build, you will use one of the following procedures:

FIG-12

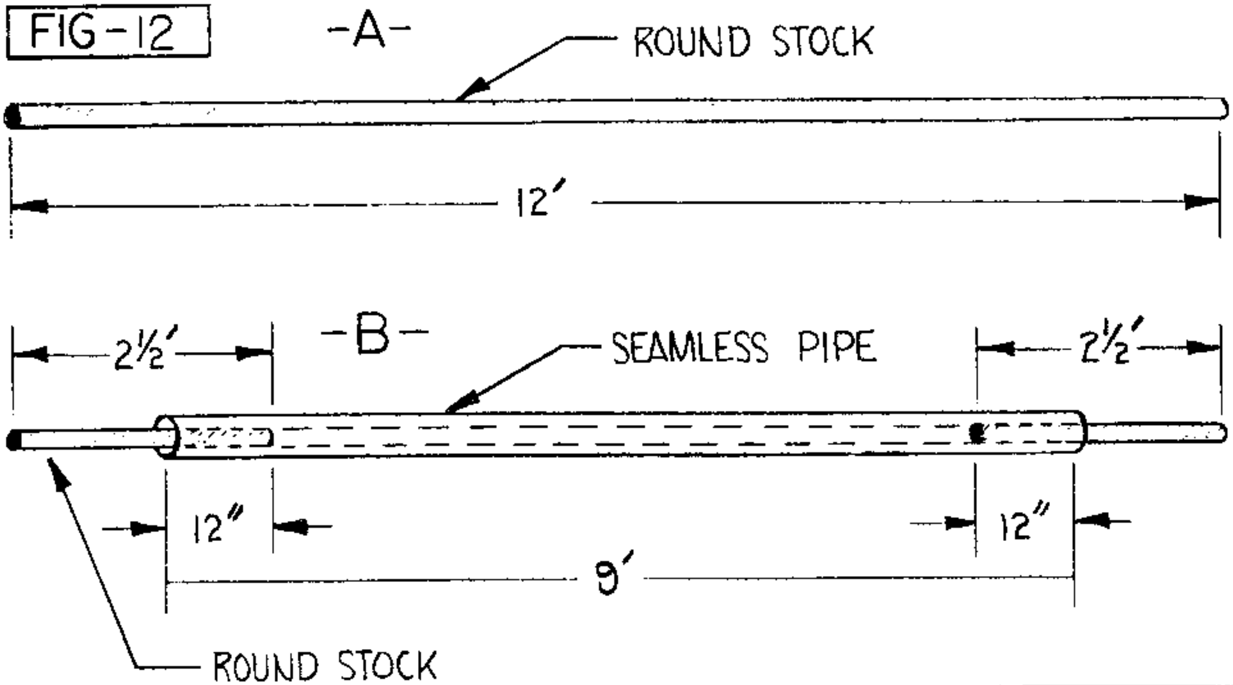
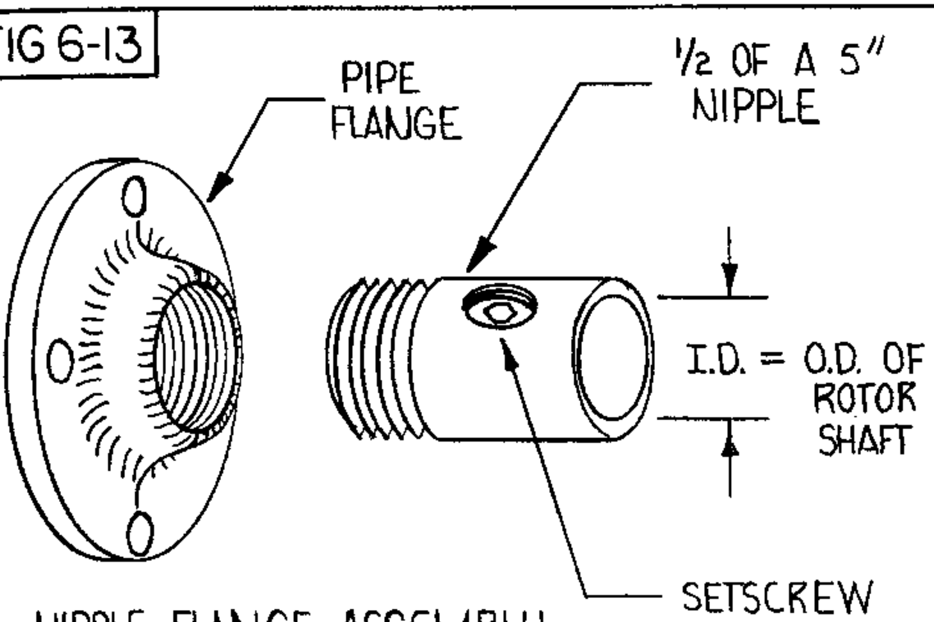


FIG 6-13



NIPPLE-FLANGE ASSEMBLY
2 REQ'D

Model A - as the rotor shaft must be secured to the aeroturbine in this model, a method of doing this is required. One that is particularly strong is a short-nipple and flange (water pipe, 4-hole floor-mounting type) assembly (see Fig. 6-13); two will be required, one for each end.

(1) obtain a 5" nipple (water-pipe type) with an I.D. equal to the rotor shaft O.D. (so it fits over the shaft).

(2) cut this in half (only one end will then be threaded); this will form the nipple for each end of the aeroturbine.

(3) drill both nipples in two places and tap (thread) the hole for a standard-size setscrew.

(4) insert the 4 setscrews.

(5) screw each nipple-half to the same size flange and see that they fit the rotor shaft, making sure the setscrews aren't causing interference.

After the aeroturbine is completely assembled, and the rotor shaft is inserted through all the end caps, continue with the procedure as follows:

(6) slide the nipple/flange assembly onto the rotor shaft at each end (flange toward the end cap); slide it until the flange is securely resting against the end cap. Using a pencil (with the flange holes for a guide, mark the location of the 4 bolt holes on the end cap.

(7) mark each end cap and nipple/flange assembly so that it will be replaced on the same end (of the aeroturbine), and precisely as it was marked. Remove the nipple/flange assembly.

(8) using a drill guide and a bit the same size as the bolt that will just fit through the flange's bolt holes, drill out these holes (at each end).

(9) remount the flange/nipple assembly, line up the notches, and bolt it to the end cap; do the same for the other end.

(10) at the end of the aeroturbine designated as the bottom, the shaft should stick out twice as much as it does at the other end (upper); if you have a 12' shaft, then the lower end will be sticking out 2' and the upper 1'. If you are using an 11' shaft, it will stick out 15" on the

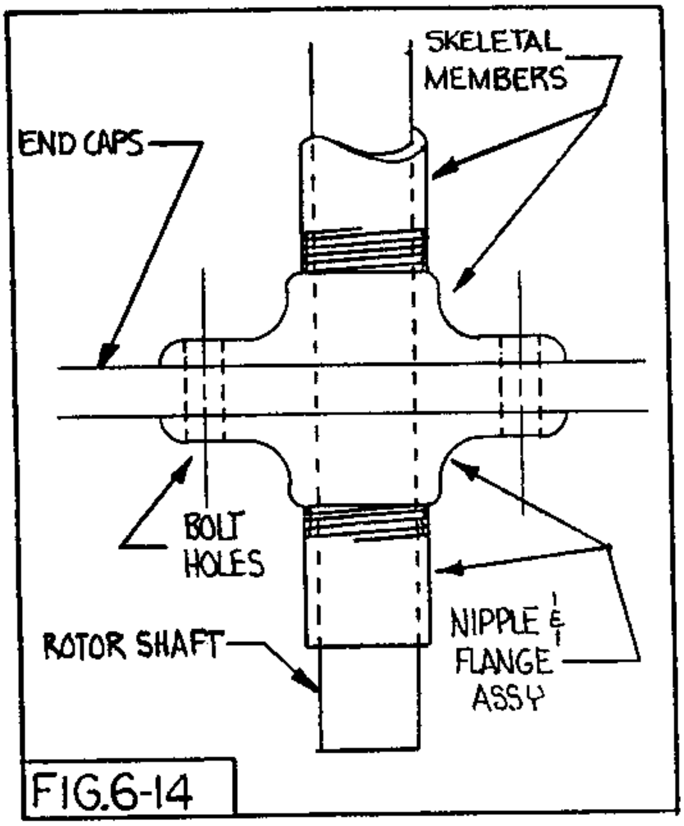


FIG.6-14

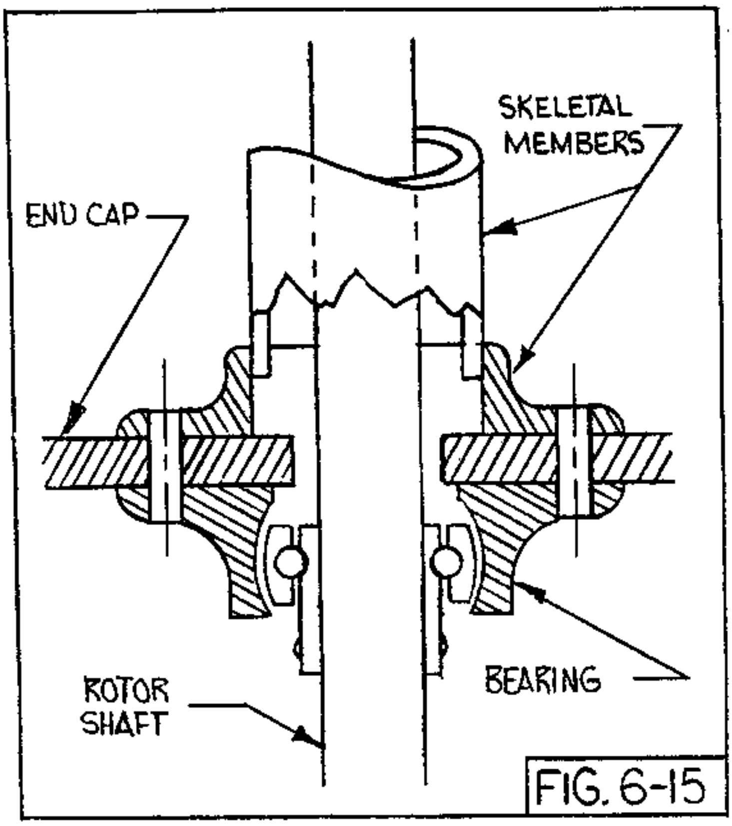


FIG. 6-15

lower, 9" on the upper. You need more at the lower end because you have a gear (or two) to install; but you need at least 9" at the upper end. Incidentally, you are measuring these distances from the end cap, and not from the end of the nipple/flange assembly.

(11) once the rotor shaft is positioned, tighten down the two setscrews on each nipple/flange assembly.

Model B - securing the rotor shaft to the aeroturbine here is the same as in Model A except that steps 6, 7, and 8 are not required. As this model uses a skeletal member, the holes will have already been drilled in the end caps. This was necessary to installing the skeletal member (see Section E - skeletal members - and Fig. 6-14). Steps 9-10-11 apply.

Model C - the rotor shaft in this model does not lock to the aeroturbine but the flange mounting block for the bearings will. Try to get one that has the same hole pattern as the skeletal member flanges have (see Fig. 15).

SECTION E --- SKELETAL MEMBERS

Design Notes:

The skeletal member was introduced in our 2nd aeroturbine design (described as Model B) to provide: (1) easy exchange of impellers while the aeroturbine was upright and (2) strength and rigidity in the aeroturbine so that a lighter, less-rigid impeller could be used. The skeletal member is nothing more than sections of water pipe with floor-mounting pipe flanges at each end (see Figs. 6-9 and 6-16); these fixed-length sections then 'space' the end caps apart, a distance equal to the height of the impellers. As the flanges (4-hole type) are bolted to the end caps, this provides a rigid skeleton which can be balanced and raised to (or lowered from) its operating stance with or without the 6 impellers attached; when 55-gallon drum-halves are used as impellers, their removal from the aeroturbine eliminates much of the manpower otherwise required to raise, lower, or move it -- becuz it's 102 lbs. lighter!

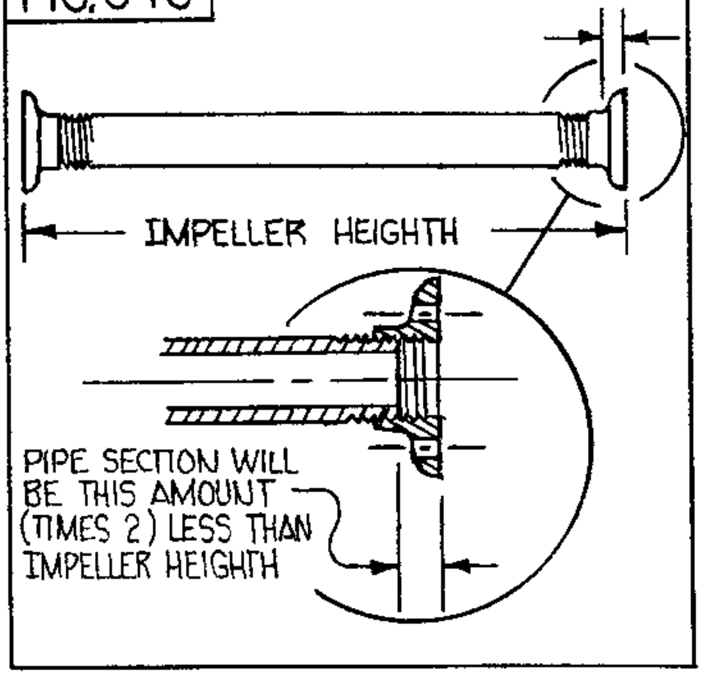
The length of the pipe sections (with flanges attached) used in the skeletal member is determined solely by the height of impellers used; if a steel drum-half is the desired (or selected) impeller, the overall length of pipe/flange section (from flange bottom to flange bottom) will be the height of drum half -- this will be 35"-36" (depending on the drums used). The pipe length itself will be less than this height as the flanges do not allow the pipe threads to screw in all the way (see Fig. 6-16). Most hardware stores that sell pipe will cut it to the desired length and thread both ends; sometimes the flanges will screw on quite a way and sometimes they will not -- you might check them.

Constructing the Skeletal Members:

(1) the best procedure is to determine the height of your drum halves (all 6 should be the same), and have one pipe section cut that length minus one inch (1"); then have it threaded at both ends and screw a flange on at each end. If it's still too long after tightening them down (more than 1/2"), have them cut a little more off at one end and try again. Remember, it's better to have it a little long than to have it short; if it's short, you won't be able to get the impeller between the end caps. Once you get a good section length, cut the others; check them, too.

(2) mark the flanges and pipe used for one section in such a way as to insure you don't swap ends putting them together after you've pulled them apart. As well, use a different number or color so that you don't exchange flanges with the other pipe sections.

FIG. 6-16



The size of pipe and flanges used in the S-rotor depend on the size of rotor shaft O.D. and the model built. With both of these decisions made, you will use one of the following procedures:

Model A - does not use a skeletal member.

Model B - the pipe and flanges used in the skeletal member will have an I.D. equal to the rotor shaft O.D. (i.e., a 1" rotor shaft will use 1" pipe and flanges). Make sure the flanges are a 4-hole, floor-mounting type. You will need three (3) sections of pipe and six (6) flanges.

Before these can be mounted:

(1) the pipe sections must be cut to the

proper length (see preceeding text this section).

(2) the end cap center holes must be drilled (see Model B procedure in Section A - End Caps).

(3) the end caps must be arranged and aligned according to Figures 6-6A, -6B, and -6C.

(4) now, insert the rotor shaft through the end caps, installing the skeletal members as you go; the flanges should be on each pipe section and the whole assembly tightened down to the impeller height.

(5) line the floor flanges up with the crosslines (D-A and C-C, see Fig. 6-4) so the bolt holes in the flanges are centered on these lines.

(6) run a pencil around inside each of the 4 holes in the flanges on one side of the end cap only; once the holes are drilled, the flange on the other side should line up also.

(7) notch the flanges with their respective end caps and disassemble the end caps, skeletal members and rotor shaft; make sure you keep the skeletal sections in their respective positions (per tier, and as you marked them).

(8) lay each of the end caps flat as you drill out these holes. It is imperative that you use a drill guide to get a hole which is absolutely perpendicular to the end cap, select a bit that will make the holes slightly larger than the size of bolt which will just fit through the flange holes. Do all the end caps (but don't do them more than one at a time).

(9) reassemble the aeroturbine's end caps, rotor shaft, and skeletal members and match the flanges up with the holes and their marks. (Everything's carefully marked, right?)

(10) once the end caps are properly aligned, slip bolts through the innermost end caps; the bolts must be long enough to fit through the flanges on each side and, of course, the thickness of end cap. Tighten these bolts evenly (as you would when putting on a tire -- tightening them progressively tighter as you go around, or across).

(11) insert the nipple/flange assembly on each end of the aeroturbine and put bolts through the flanges on each side of these outer end caps.

(12) position the rotor shaft (measured as indicated in Section D) before tightening the set-screws in the nipple/flange assemblies.

Model C - the pipe sections used in this model will have an I.D. which is twice the O.D. of rotor shaft used; i.e., a 1" rotor shaft should use a 2" pipe (and flange) for the skeletal member.

a) before you drill even the pilot hole (for the center-hole), use a compass to draw a circle that has a diameter equal to the distance between opposite bolt holes in the floor flanges to be used (center to center). Where the circle intersects the crosslines (D-A and C-C -- see Fig. 6-4), you will drill a hole large enough for a bolt that fits the flange holes. Use a drill guide.

b) drill the center-holes in the end caps. The outermost end cap holes will be drilled the same size as the pipe used (which is about twice the size of rotor shaft). The inner end cap center-holes will be drilled to fit the bearings used; remember that these bearings must recess in the end cap and not interfere in any way with the floor flanges.

c) if the outer bearings (and their flange blocks) have been carefully selected, their mounting holes will be the same as those of the floor flanges used in the skeletal members (See Fig. 6-15).

d) mount the flanges to their respective end caps. Insert the rotor shaft through the inner bearings and then add the skeletal member's pipe sections.

e) arrange the end caps (Figs. 6-6A and -B) and align them (Figs. 6-6C and 6-9).

f) install the impellers, checking to insure you use drum-half mates and that they're both oriented the same way; step #11 in Section B -- Impellers -- gives procedure.

SECTION F --- SUPPORT ASSEMBLY

Design Notes:

The support assembly holds the aeroturbine in its operating mode (upright). It consists of two parts: the lower and the upper support.

The lower support assembly for the aeroturbine must:

a) take the full weight of the aeroturbine and the electricity-generating equipment (alternator or generator, plus gearing). Further, it must be able to handle the downward force exerted by the tensioned guy wires (this will easily be as much as the aeroturbines weight).

b) allow sufficient room to mount the transmission (chain/sprocket, U-belt/pulley, etc.) and to secure (or house) the generating equipment.

c) allow access to the lower bearing grease fitting(s).

d) be secured (in some manner) to prevent side-slippage. Generally, this is not a problem once the aeroturbine is in place; however, it is a very real problem when raising or lowering the aeroturbine.

Supporting the aeroturbine fully is more critical; three (3) forces will tend to topple the aeroturbine: wind, weight, and centrifugal force (if the aeroturbine is unbalanced). Obviously, all can generally be accounted for at any one location, aeroturbine, etc. Suggesting a means of insuring adequate aeroturbine support for all locations and situations is a bit difficult to do; an effective design for hurricane country is a bit like overkill (and overspend) for an area which does not experience such maelstroms.

All models of S-rotor aeroturbine require an upper support assembly. Model A and Model B use a frame-and-guy wire upper support (See Fig. 6-10) while Model C may use only guy wires (see Fig. 6-11); remember, however, that a Model C is not recommended.

Installation Site

The S-rotor aeroturbine may be mounted (1) near the ground, (2) on a roof, or (3) atop a tower.

The ground installation is probably the easiest to construct but undoubtedly is the most difficult to properly locate. The people who have aeroturbines (like props) on tall towers don't put them there for the challenge or the thrill in climbing to such heights; they are simply using the towers as a vehicle to get the wind machine (a) clear of surrounding trees, buildings, etc., and the turbulence, or low wind conditions, they create, and (b) to intercept wind of a higher velocity (relative to that found at ground level) and thus, generate more power (see data sheet 1 -- chapter 7 -- on wind and height).

At ground level (or above it), the S-rotor aeroturbine does have an advantage over the prop-type aeroturbine; it can operate in this turbulent area without experiencing extreme vibration hazards. Both will suffer from the low wind, so if a ground installation is the only choice, know where your wind comes from (its most frequent direction) and avoid getting it close to obstructions which lie in that direction.

Make an all-out effort (the old college try) to have the lowermost portion of the aeroturbine (bottom end cap) at least six feet (6') above highest ground (Fig. 6-10 shows 2' but it's a basic drawing -- right?) Get it higher than 6' if you can afford (or find) the wood or metal for the framing and support -- the higher, the better.

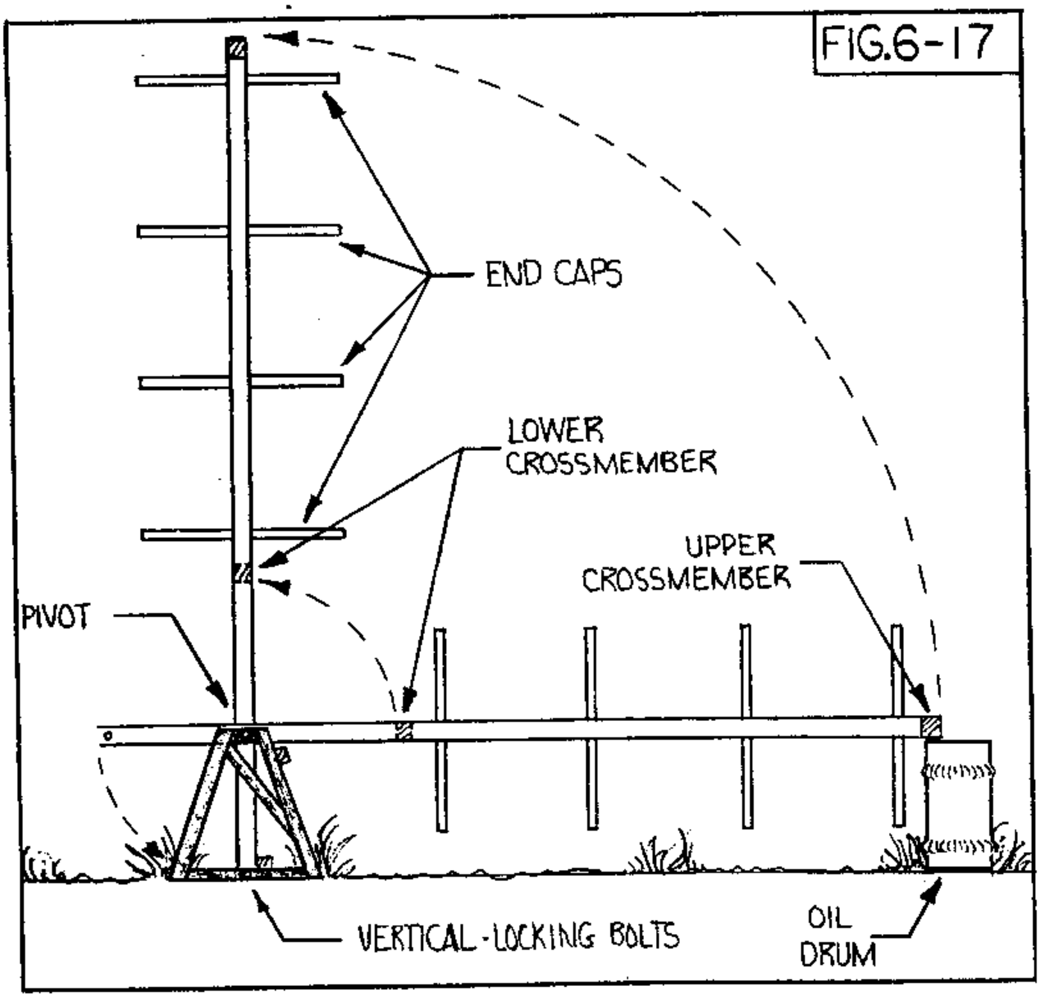
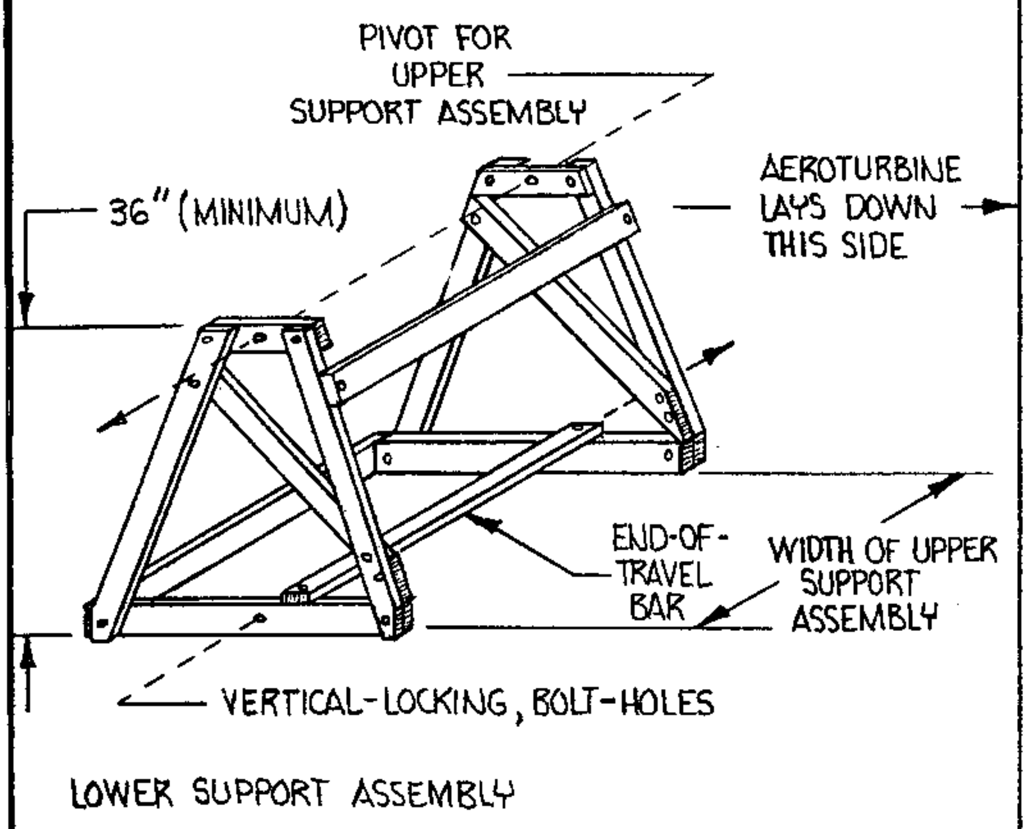


FIG.6-17

Fig. 6-17 and Fig. 6-18 show one way to build the bottom support so that the aeroturbine can be inserted into its frame horizontally and swung up into a vertical position; this will insure a safe raising (if the support is firmly guyed down) because it will be difficult for the aeroturbine to topple to the side (becuz of its 2 pivot points). As well, the upper support assembly (and the aeroturbine) is prevented (by the lower support assembly construction) from further travel after it reaches a

FIG. 6-18



vertical attitude; it won't just keep going, falling to the side opposite from where it started. Bolts may be quickly slid through holes in both the upper and lower support assembly to hold the aeroturbine in place once it is upright (see Figs. 6-17 and 6-18).

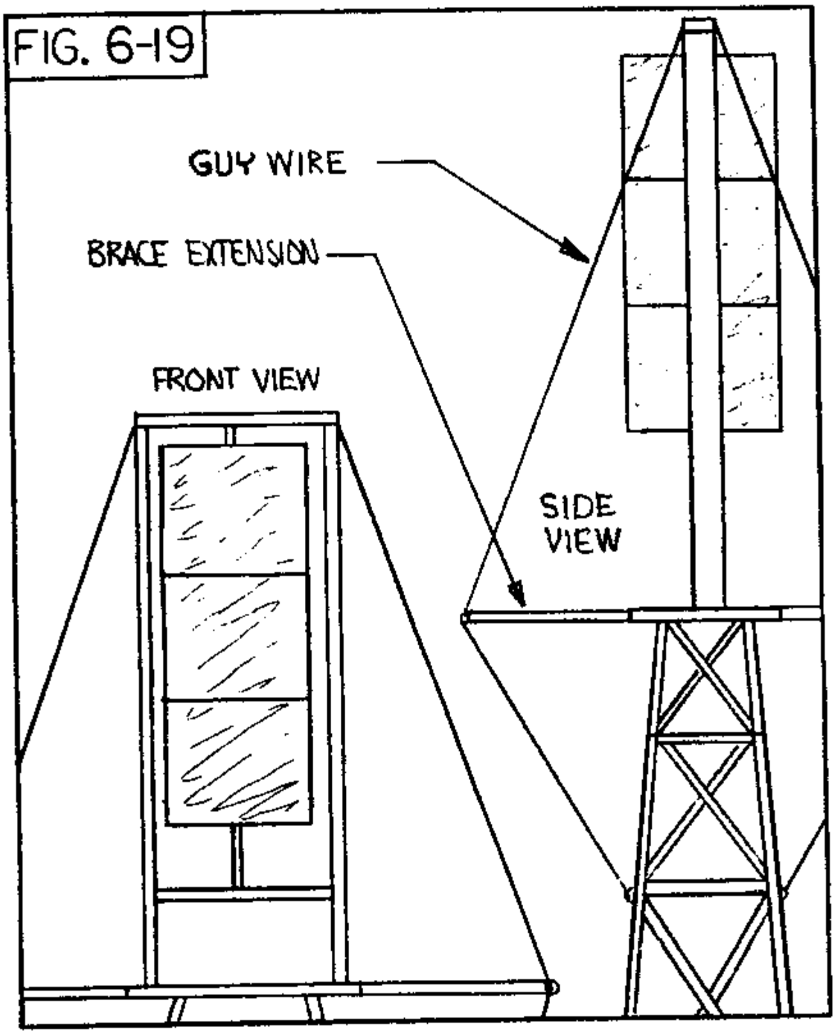
The lower support assembly is, as indicated, also guyed down; this serves to keep it from slipping (or tipping) as the aeroturbine is raised (or lowered). As well, it makes the entire assembly more rigid which will help dampen any vibration experienced in first tests, or in high winds. It is not impossible that vibration in the support assembly (in a heavy gust) could cause the aeroturbine to do likewise; if the aeroturbine is close to its upper operating RPM's, the resulting oscillations could be disastrous.

A rooftop installation is a good second to a tower and certainly better than a ground installation. A lower support assembly similar to the one used for the ground installation will work; it may have to be slightly modified, of course, for a sloping roof or for straddling a roof's peak.

The lower support assembly should be secured, as with the ground installation, by guy wires; they may eliminate the need for actually securing the assembly (with bolts, screws, etc.) to the roof. Wherever it is finally located (on the roof) check the roof support or you may end up having the entire assembly join you in bed some windy evening.

A tower installation would, as aforementioned, be the best situation but, unfortunately, it will be the most difficult. I haven't done this myself but I have figured out the way I'd do it when I find a tower (see Fig. 6-19). Raising the aeroturbine to the top of the tower would be the biggest problem and securing the thing into its support assembly a close second. I wouldn't raise it as a complete assembly but would assemble it up there. Here's where a Model B wins out over a Model A; the removable impellers would greatly improve the situation.

FIG. 6-19



The Upper Support Assembly

The type of upper support assembly used with the aeroturbine depends on the model used. Once determined, its discussion/construction is as follows:

Model A - the upper support assembly here will be part of the lower support assembly; it is best described as a framework of metal or wood in which the aeroturbine rotates. The bearings for the aeroturbine are secured to its upper and lower crossmembers.

(1) the top crossmember will be longer than the lower crossmember by twice the width of the vertical frame members (see Fig. 6-20); it will rest atop these vertical members whereas the bottom crossmember rests between them.

(2) the lower crossmember must be at least 4-1/2' long; the aeroturbine is 4' wide and you should allow at least 3" of gap between it and the vertical crossmembers on both sides.

(3) once the two crossmembers are cut to their proper lengths, accurately locate their center points; do this for their length and their width (see Fig. 6-21).

(4) center the bolt holes in the bearing's flange block over the lines you've drawn to find each of the crossmember's centerpoint. Then mark (with a pencil) these bolt hole positions on the crossmembers. Remove the flange blocks.

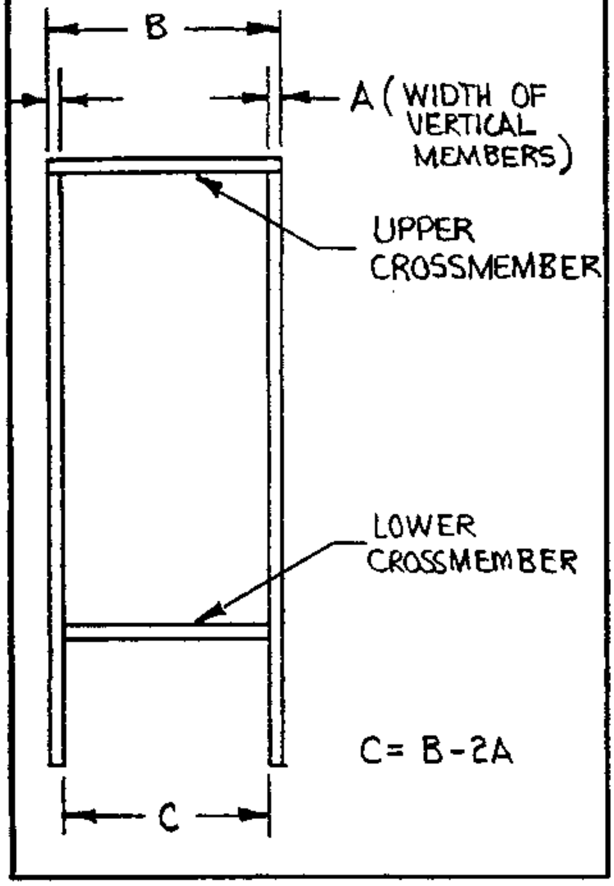
(5) using a drill guide and a drill bit larger than the bolt that will just slide through the flange block's bolt holes, drill out the 4 holes in each crossmember.

(6) Now drill out the center-point of each crossmember; make the hole at least 2 times the diameter of rotor shaft used.

(7) mount the flange blocks to their respective crossmembers to insure they fit; then, remove them for safekeeping.

Construct the rest of the frame assembly; the layout of Fig. 6-20 will assure a rigid structure. If you've had experience in building (i.e., are a structural engineer) then you'll understand what has to be supported and how; there are many possible variations. If you don't have the experience, stick with the outline (in Fig. 6-20) as this provides the essential

FIG 6-20



support criteria; the frame should be rigid entirely of itself. The guy wires will add to this rigidity but don't expect them to replace the frame. If you cut corners here, you'll pay for it in worry some night when the wind is really howling!

(8) the upper and lower crossmembers should be secured to the vertical frame member with two wood screws (the ones with hex heads) on each side.

Finish making and guying the lower frame assembly, and when all is in readiness, proceed as follows:

(9) slide the upper bearing onto the shaft at the top of the aeroturbine; face it so that it may be mounted to the upper crossmember (underneath), but don't lock it to the shaft yet.

(10) lift the aeroturbine over the frame assembly (which is horizontal) and slide the lower end of the rotor shaft through the center-hole in the lower crossmember until the upper end of the rotor shaft clears the upper crossmember; then put the upper end of the rotor into the center-hole for the upper crossmember.

(11) slip the upper bearing along the rotor shaft until it rests against the crossmember; align the bolt holes in the bearing flange block with those in the crossmember and slip the bolts through. Put on washers, lockwashers and nuts; then, tighten them.

(12) the lower bearing mounts under the lower crossmember; slide the bearing onto the lower end of the rotor shaft until it rests against the crossmember, align the bolt holes and slip the bolts through. Put on washers, lock washers, and nuts; then, tighten them.

(13) slide the rotor shaft until its upper end rests flush (and not sticking above) the top of the upper crossmember. Now, lock both setscrews (or tighten the eccentric on the bearing) into the rotor shaft. As well, tighten the setscrews (or eccentrics) on the lower bearing. The shaft should now only rotate and not travel up or down!

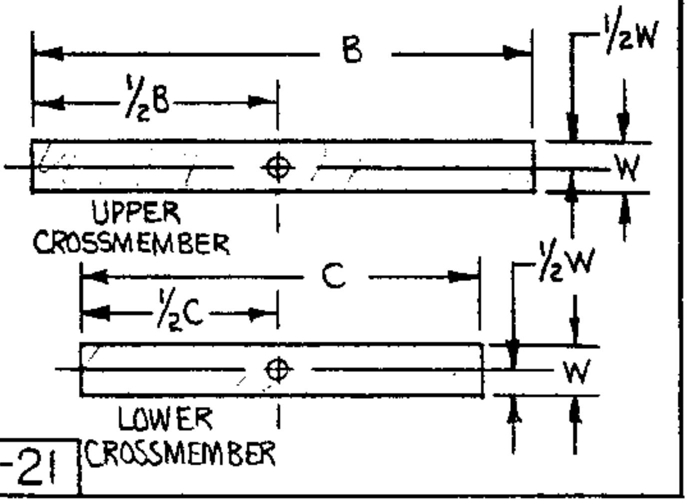


FIG. 6-21

(14) slide the aeroturbine until it's centered between top and bottom crossmembers in the frame assembly; you may have to loosen the setscrews in the nipple/flange assemblies (that lock the shaft to the aeroturbine) to do this.

The aeroturbine can now be raised. The transmission (sprocket/chain, pulley/V-belt, or gear/gear belt) can now be installed, as well as the generating equipment (this is covered in Chapter 2 - Generating Electricity).

Model B -- this aeroturbine model uses the same support assembly as Model A (above); begin procedure with #1 (under Model A, above); all other steps are as above, in Model A.

Model C -- there is no 'upper' support assembly for this model, except that given by the rotor shaft and guy wires. Although it is possible (and recommended) for a frame assembly like that used for Model A or Model B to be used here. If it isn't used, the guy wires should be affixed to a flange/nipple assembly at the uppermost end of the rotor shaft. The lower end of the rotor shaft should be secured into the lower support assembly but with the ability to be pivoted as the aeroturbine is raised to a vertical, from a horizontal, position.

SECTION G --- FINAL DECISIONS

As the bearings and rotor shaft for the S-rotor aeroturbine are the most expensive (or least available as scavenged material), it is probably best to start with these two when making decisions. If you acquire the bearings first, the rotor shaft will have to be selected to fit them. I recommend at least a 1-inch (O.D., outside diameter) rotor shaft for Model A and Model B; Model C should use at least a 1 1/2-inch shaft (and bearings).

Selection of the model of aeroturbine to build is the major decision; as previously indicated, I recommend the Model B. It is not unlikely that we will eventually develop an impeller that is strong enuff to replace the 55-gallon drums required for the Model A but still lighter than the steel drums; this would eliminate the weight of the skeletal member (even though it accounts for only 20-30 lbs. of the aeroturbine's weight). To date, though, the Model B offers the best versatility: changeover to lighter impellers without disassembly of the aeroturbine.

In each section, specific information pertaining to the model selected is listed under the headings bearing the model number. Do not, however, fail to read the text in those sections as it contains information on all models, necessary for the completion of any one of them.

The parts of the aeroturbine -- end caps, impellers, bearings, flanges (water pipe, floor-mounting type), nipples (water pipe), 3' pipe sections, round stock (for the rotor shaft), woodscrews, 2 x 4's, bolts, guy wire, turnbuckles, setscrews, etc. -- will depend on the model built, the size of rotor shaft, bearings, etc., and the type of impeller used. Once you have decided on the model to build, you should read through the sections, make further decisions, and compile the list of parts you'll need to acquire.

Let's do an example.

It is difficult to draw up a parts list for the aeroturbines becuz we have 3, and some other possible variations within each.

Supposing a 1" round stock rod was selected for the aeroturbine, 1" bearings were purchased, and this is a Model B, a parts list might be:

A. End Caps

4	48"-diameter, plywood, 1/2" thick, end cap with a 1"-diameter centerhole and 4 bolt holes (5/16") for a 1" flange, (all 4 end caps) about the centerhole.

B. Impellers

6	36" high, 55-gallon drum halves, painted yellow/orange
24	L-brackets, 4 per impeller
24	woodscrews, 1/2" long (L-bracket to end cap)
24	pop rivets (L-bracket to steel drum)

C. Bearings

1	Browning FB-900-1" flange block (lower end)
1	Browning FB-250-1" flange block (upper end)
8	3/8" x 2 1/2" hex-head bolts/washers/nuts

D. Rotor Shaft

1	12', 1" round bar stock
1	5" nipple (flange/nipple assembly)
4	setscrews (flange/nipple assembly)
2	1" flange, pipe, floor-mounting type (nipple/flange assembly)

E. Skeletal Members

3	3' (approx.) pipe sections, 1" water pipe, threaded 3/4" each end
6	1" flange, pipe floor-mounting type
16	5/16", 1 1/2" hex-head bolts/washers/nuts

F. Support Assembly

2	12', 2" x 6" studs
1	4 1/2', 2" x 6" stud (lower crossmember)
1	4'10", 2" x 6" stud (upper crossmember)
16	feet (approx), 2 x 4's or 2 x 6's to complete lower assembly
8	3/8" bolts, woodscrews, hex-heads, for construction
6	turnbuckles
100	feet (minimum) guy wire, 3-strand (minimum)
10	eyebolts (6 for upper support, 4 for lower)

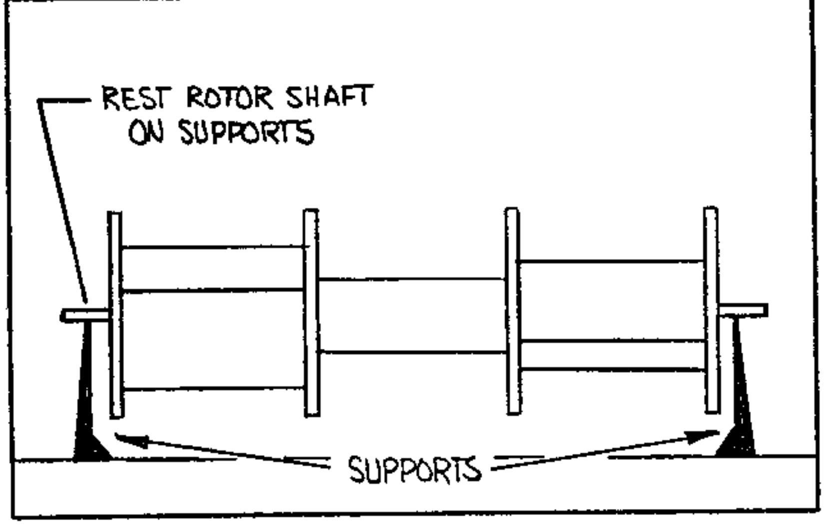
SECTION H --- BALANCING

As aforementioned, the easiest (and best) way to balance the S-rotor aeroturbine is by careful, preliminary workmanship in the preparation of the essential parts and actual construction of the final assembly. I cannot emphasize this enough. The S-rotor aeroturbine might not, therefore, require any balancing (whereas a propeller-type will, no matter how carefully constructed) because it will rotate quite slowly (compared to the prop-type). Do not, however, delude yourself into thinking it won't need to be well balanced; there is quite a bit of weight to the S-rotor aeroturbine and it doesn't need much imbalance to begin the vibrations that are the 'death throes' of any type of aeroturbine!

No matter how careful the workmanship, slight imbalances are possible, so at least the balance should be checked. (See Fig. 6-22.) The completed S-rotor aeroturbine should be laid on its side with the projecting rotor shaft at each end resting in the bearings (which are attached to the upper and lower crossmembers) which, in turn, are resting on some kind of support (which allows the aeroturbine to 'clear' the floor and spin freely).

Once the aeroturbine is mounted in this fashion, it should be given a slight 'push' to start it spinning. Wherever it stops, in some way mark it (at its lowest point) so that, after you 'spin' it again, you'll know if it does (or does not) stop in the same place again. If it doesn't, mark the second place it stopped, and spin it again. If it misses both marks, you have a well-balanced aeroturbine.

FIG. 6-22



Most will not be so lucky; the aeroturbine will probably stop at the same point (on the second spin) as it did on the first spin. The next thing to determine is -- how badly is it out of balance?

Watch the S-rotor as it spins, especially as it <u>begins</u> to slow down and <u>before</u> it reverses itself. If it starts slowing down and speeding up, then stops, reverses itself for a <u>full</u> revolution, and stops, reverses itself for 3/4 of a revolution, it's pretty far out of balance. A slight imbalance will cause very little reversal (and only a quarter of a revolution, or so, if it does reverse).

Whether unbalanced only slightly or greatly, correcting the imbalance can be done in two ways:

(1) remove material from the heavier side
(2) add material to the lighter side.

The second is a far better method than the first; you still don't know how much weight to add nor do you know if more than one point is out of balance. So, use some clothespins and attach them to one of the innermost end caps on the high side of the aeroturbine (see Fig. 6-23). Spin the unit. If it comes to rest on the old mark, it's not enough weight (add more). If it comes to rest with the clothespins on the bottom, it's too much weight (remove some). If it comes to rest at a new place -- not the old mark and not at the clothespins -- shift some of the clothespins to the side to compensate. It would appear to be far more complicated than it really is if I tried to tell you how to shift the pins or how many to add; just experiment -- you'll get the knack if you pay attention to the result of whatever you do. You want to get it to the point where it doesn't stop in any particular position with the <u>least</u> amount of clothespins

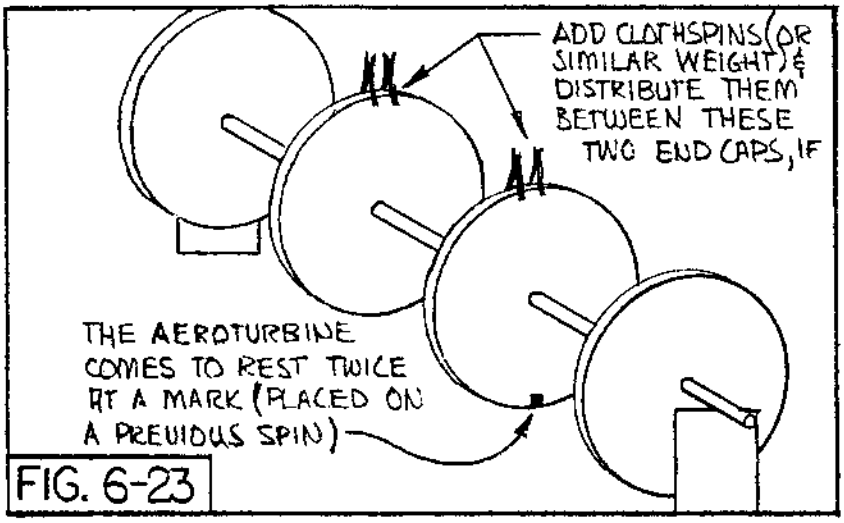


FIG. 6-23

attached. After all, they will have to be replaced with an equivalent amount of weight at the same spot they're located now. The weight can be just about anything as long as it can be screwed, glued, or otherwise securely fastened.

Once you've carried out the additions or subtraction of materials to balance the aeroturbine, recheck the balance. This will suffice for the time being. If you find, in preliminary tests of of the aeroturbine's operations, that it wobbles or shakes violently at low windspeeds, set up the procedure again for static balancing (Fig. 6-22) and recheck the balance.

SECTION J --- SPOILERS

It may be necessary, in some locations, to provide a means of protecting the aeroturbine against high rotational speeds resulting from strong wind conditions. The various means available for aeroturbine control have been extensively covered in Chapter 4 - Control - but the subject of this section will focus on spoilers.

Even our latest aeroturbine does not employ a spoiler (although it is protected by electrical braking -- see Aeroturbine Control, Chapter 4) and, as also indicated, we would not be able to test any of the possible spoilers for the S-rotor aeroturbine, for we lack (in our location) both the frequent high winds and the extremely high winds of some areas (hurricane country).

However, this is not to say that we have not given serious thought to spoilers for the S-rotor aeroturbine; for those who are inclined to experimentation, we offer this information.

(1) As indicated in Section A of this chapter, if it were not for the end caps, the aeroturbine would 'spill' a large amount of the wind it captures; this, then, is one way in which the aeroturbine's efficiency may be spoiled.

Fig. 6-24 illustrates one way the end caps might be 'opened' up under high-speed conditions; a sliding flap could be held closed by a spring for normal operating RPM's but (if properly adjusted) would stretch with increased centrifugal force on the flap (as the RPM's went higher than desired) allowing wind to spill through the slot.

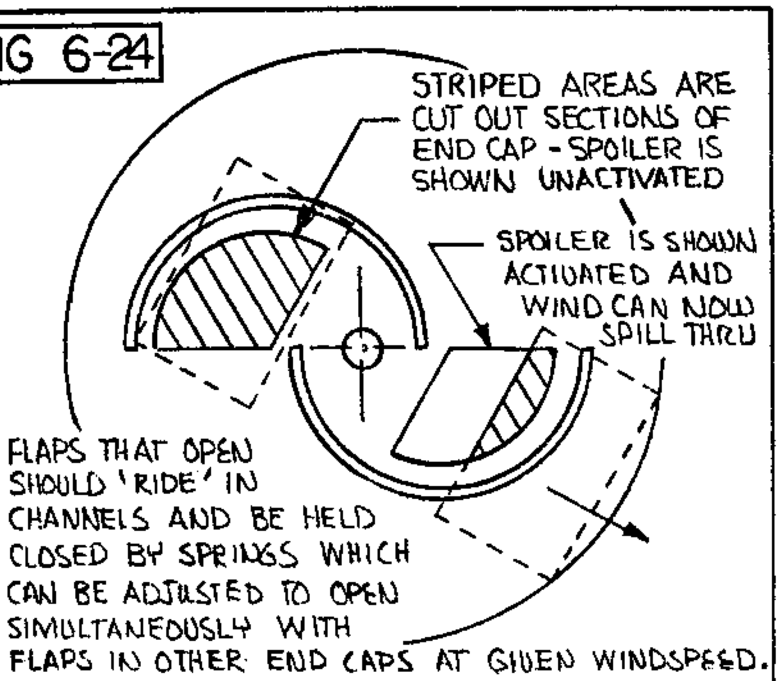
(2) As the S-rotor aeroturbine is essentially an 'impulse-turbine,' its efficiency could be spoiled by misalignment of the impellers; Fig. 6-25 indicates one way this might be intentionally accomplished at high RPM's (in high wind). The innermost edge of each of the impellers might be attached to a spring (as shown) and tensioned to allow the impeller's

outward movement under high wind, high-RPM conditions.

(3) If a portion of the impellers were to open under high-wind conditions, this would certainly spoil the efficiency of the aeroturbine; Fig. 6-26 shows one way this might be accomplished. In this arrangement, some means of limiting the distance the flap can travel (when it opens) is recommended. Adverse wind conditions and the specific location of the flap itself (in the impeller) might keep it from closing when the windspeed falls below the windspeed required to activate it, or damage the flap if it flaps back and forth when activated.

If you decide to experiment with spoiling for the S-rotor aeroturbine, please contact us if you develop anything simple and effective; via the newsletters we send out, it would reach a lot of folks.

FIG 6-24



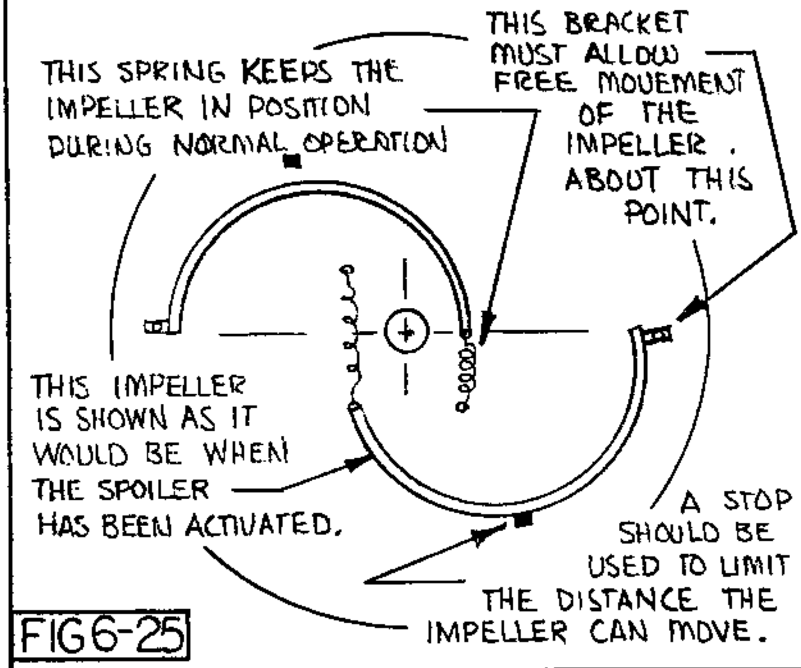
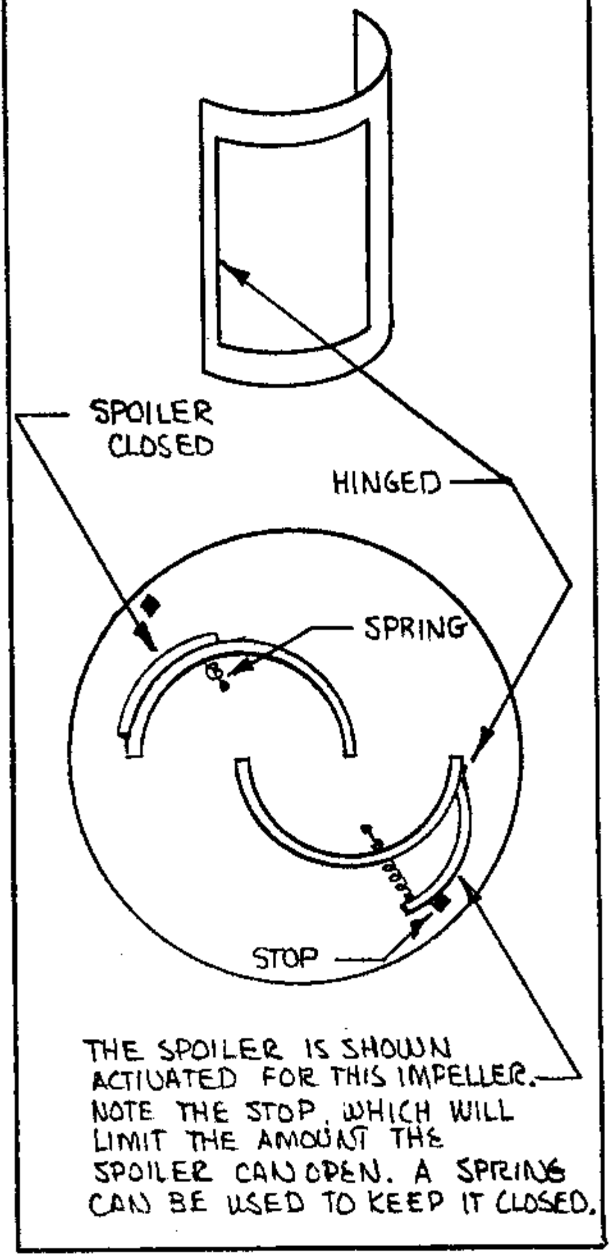


FIG 6-25

FIG. 6-26



IMPELLERS

Okay - now you can see what we are doing in this area. But maybe you have been patiently awaiting impeller curve information— your skeletal S-rotor frame is just sittin' there, waiting for its impellers. Well, if you won't use the 55 gallon drum halves, then try a lighter material and temporarily shape it semi-cylindrically. The most important change you can affect (in replacing drum halves with higher performance impellers) will be one of decreased weight; in the lift/drag ratio, weight helps determine lift and shaping affects drag (these associations, incidently, were expressed in the reverse in the book -- sorry!). I might have to eat these words at some later date but it rings valid (with my intuition and experience to date) to say: Reducing the S-rotor aeroturbine weight will provide the most notable increase in power (from it) whereas re-shaping the impellers will only squeeze out a few more watts.

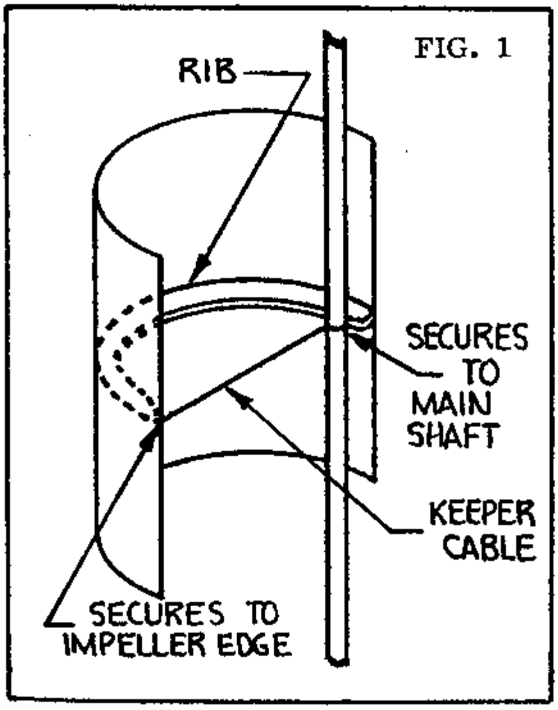


FIG. 1

We're not convinced that this is true (or we wouldn't be testing re-shaped impellers) but we're realists, too. Many of the models we will test have been tested before (we do not believe they were tested under exacting conditions); this does not mean, however, that we believe we will achieve phenomenally different results. And for the ones that we will test (that we believe we are the first to test), we just don't know. So little appears known about the parameters of an S-rotor; a friend's recent computer analysis was unable, when provided with everything known about the S-rotor, to put forth the design for an optimum impeller curvature or spacing. So it's back to the GGM (guess-and-golly method).

One alternative to aluminum (for the impellers) is sheet steel; I honestly don't know how thin they make it, but you'll want the thinnest (and yet still somewhat rigid) that you can find. It will weigh more than its aluminum counterpart but it will be cheaper, easier to work with, very strong, and weigh far less than 55-gallon drum material. While most sheet-metal working shops have a bender which will uniformly contour an impeller to the desired radii (or diameter) inserts or ribs of the type illustrated in Fig. 1 can be fashioned and the sheet metal bent over them to give the desired shape. These ribs should be used whichever way you do it; they will prevent the centrifugal forces (exerted on the impeller at high rotational speeds) from severely distorting the shape of the impeller and thereby damaging it, or adversely affecting its performance. One advantage in not having the impellers contoured (by a bender) is that they may be later reshaped into another curve (which may be found more efficient) by merely substituting the present rib with one similarly fashioned. Stay versatile-- it saves time and money !

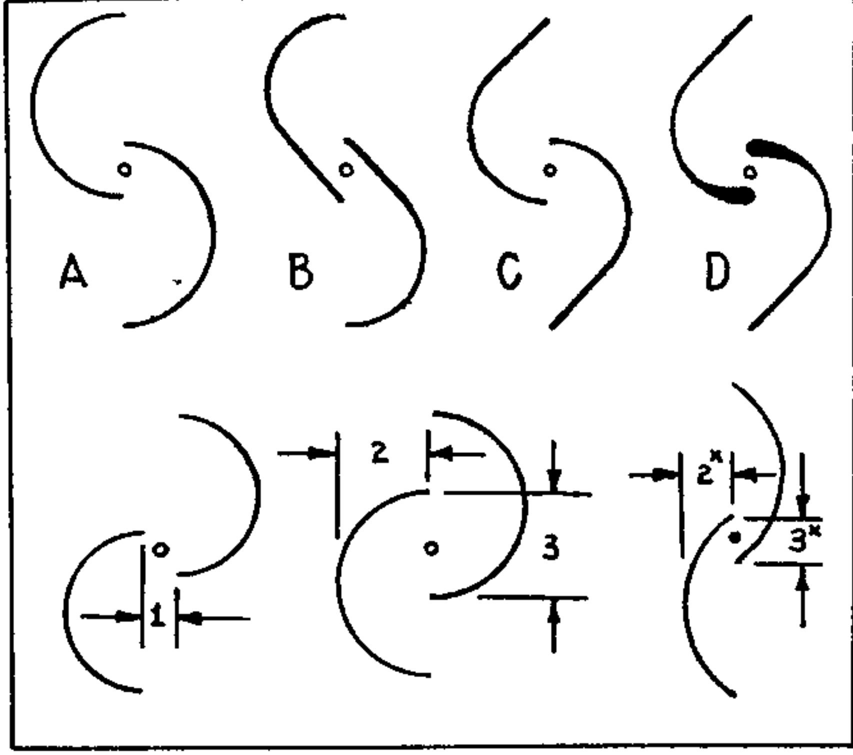


FIG. 2

In addition to testing the impeller shapes marked A thru D, we will (for each of these curves) vary (1) line offset, (2) impeller depth, and (3) impeller overlap. New curves and further testing will be generated from an analysis of the test results.

Still another alternative to the sheet metal, aluminum, or drum halves is cloth. Generally this material will be stretched over some kind of framework as it will not have intrinsic, self-support properties; it may then be doped, resined, fiberglassed, or otherwise treated to give the complete frame-cloth assembly both rigidity and weather-protection. Wood, metal or aluminum can be used for framework. Our newest S-rotor (see the MAXI-ROTOR section) will use corrugated aluminum impellers over which we will stretch cloth.

One final point on impellers: We have had some feedback on securing them to the end plates and the consensus seems to be that the screws pull out and the bolts sheer off. We haven't had any problems with our aluminum job, but then it doesn't experience the forces a steel-drummed S-rotor will. So don't get chincy on those lock washers and bolts, or screws. Make them large, strong, and get them tight (check them once in a while, too). Don't be afraid to use more of them. And install a keeper (like that shown in Fig. 1); it will take up some of the strain caused by centrifugal forces and prevent impeller deformation at high RPM's.

THE VAW: Some notes on Orienting, Governors, and Support Assembly

VAW Orienting

Vertical axis windplants do not require wind-direction orientation; they are omni-directional; this may be thought of as being oriented into the wind irrespective of the specific wind direction. However, if a Venturi shroud (or wind focuser) is used with the wind machine, a tail may be required to keep it properly oriented.

VAW Governor

A good governor mechanism for a vertical axis machine is not an easy thing to come by, at least not for the S-rotor type windplant. A centrifugal unit coupled with the impellers or blades will help somewhat but there is really no direction to orient them in which they won't be affected by wind action . With the Savonius type, this represents a genuine problem; many designs have been offered but none tested to a satisfactory or publishable state. Here the Venturi shroud might come in handy in itself, however, as a windblock. One truly intriguing idea, other than those offered in Wind and Windspinners, is to have the impellers fold in on themselves and create a cylinder of sorts. Manual shut-down represents more of a problem becuz you can't side-face the machine into the wind. A trip lever might allow full activation of a normally activated centrifugal governor but I'd work with separate units -- one for automatic and one for manual; if one fails, you've still got the other.

VAW Support Assembly

The VAW's tend, becuz of their lower efficiencies, to be physically larger than the horizontal counterparts. There will be an optical illusion as well; the HAW blades (if of the high-speed type) appear very thin but many people do not realize that at operating speeds these blades are moving so fast so as to appear, to the wind, to be a large circular wall. The VAW, on the other hand, will generally expose a lot of frontal area (unless it's a Darrieus type); a 1500 watt prop-type windplant may only have a 14 foot diameter blade but an equivalent power Savonius rotor would be 18 feet tall and about 8 feet in diameter. The point (before we forget it all together) is that the support assembly for the VAW will be much more involved than the HAW.

Becuz of their need for support at both the top and bottom of the main shaft, VAW units are difficult to mount as high as the comparable-powered HAW. Fig. 7-1 illustrates the way it can be done on a conventional tower but we've lately come to the conclusion that it's better to "tailor" the tower to the machine than vice versa. Given the versatility of the octahedron-segment tower (see Chapt. 3), we designed one to fit our newly-designed 18-ft by 8-ft Maxi-rotor (see Fig. 7-2). By building the rotor inside the tower, it's easy to reach all of the main shaft bearings and to otherwise service the rotor. A real bonus is that the top of the tower can still be used for a conventional HAW. I'm sure that there are other answers to the problem of how to get the VAW "up there", so use the ole noggin.

HAW and VAW Generators

There are some essential differences in the generator requirements for the HAW and VAW; this could be best expressed as a difference in the operating position of the generator itself and perhaps the normal operating speed. Let's take 'em one at a time.

The HAW will usually employ a generator which has its shaft also horizontal; this will allow a more efficient and easier transfer of power from the aeroturbine to the generator (if the shaft is not outright one in the same between the two). The VAW will also want the generator shaft to be parallel to the aeroturbine shaft, so it'll be mounted vertically, with its shaft perpendicular to the ground. Not hard and fast with either, though. I've seen some HAW's using a car axle to transfer the power to a vertical shaft so that the generator can be mounted at the base of the tower (beware of leaking oil). And some VAW drive shafts are coupled to a 90° gearbox so the generator can be mounted horizontally. I don't necessarily recommend either. . . but becuz there are very few generators designed for vertical mounting, a 90° gearbox is quite understandable and probably necessary. If you want to mount a generator or alternator vertically and it's designed to be (or is normally mounted) horizontal, understand that you might burn out its bearings and otherwise damage it. Know what you are doing.

Any type of aeroturbine (whether a VAW or a HAW) will rotate over a range of RPM. The bottom end will be zero (unless you've perfected a perpetual motion machine) and there's a design RPM beyond which damage or destruction is a certainty. Somewhere in between these two is the normal "operating" range and this will be on the lower end, the cut-in speed (where the windplant begins charging) and on the upper end, the cut-out speed (where the governor activates to limit generator output). If you averaged the operating ranges of all the different types of HAW, and then did it for the VAW, you'd probably find a higher value for the HAW than the VAW. So, generally speaking, the VAW will require a lower-speed generator than the equivalent HAW. I reckon that's the same as when MAW SAW PAW RAW in the DRAW and figured it was against the LAW. If gears are used (instead of direct-drive), this won't necessarily be true, but the whole idea is to use the minimum gear ratio (or no gears at all) and employ a slower speed generator.

FIGURE 7-1

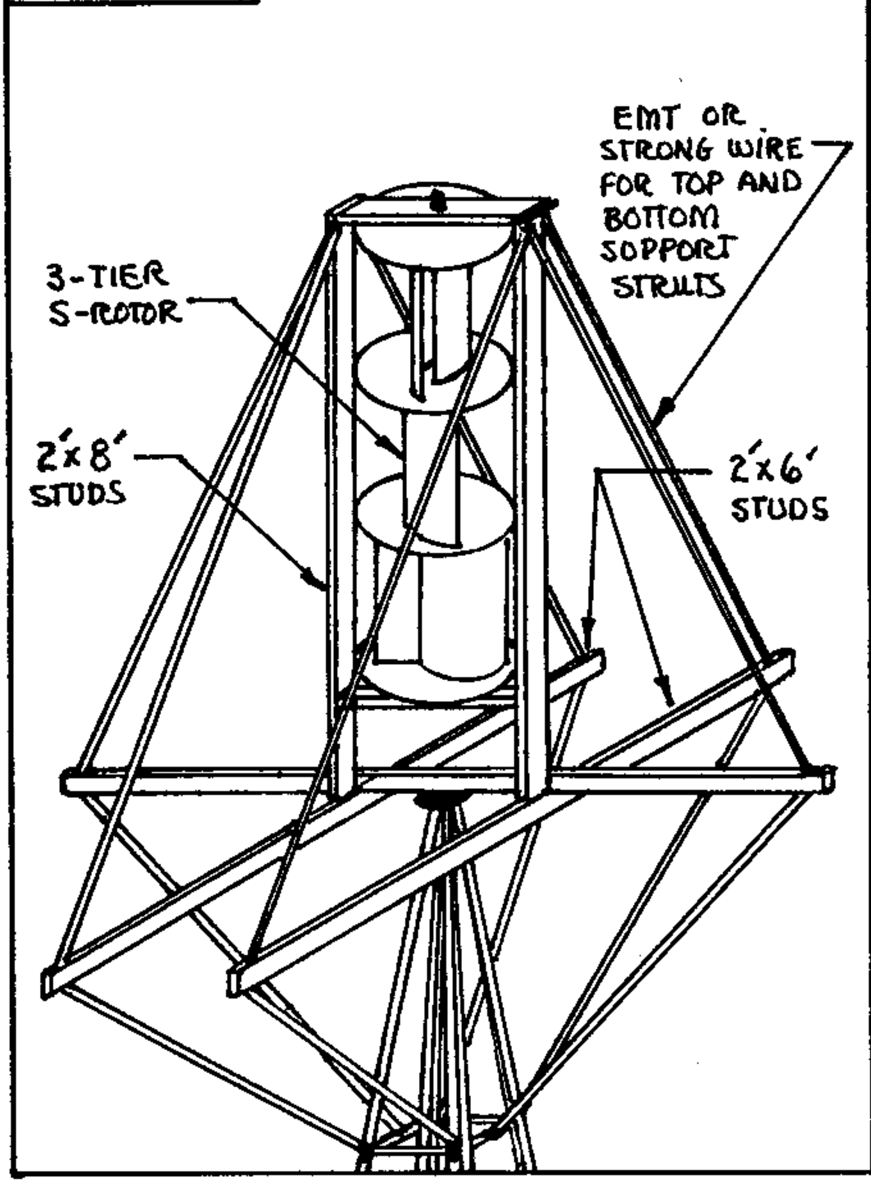
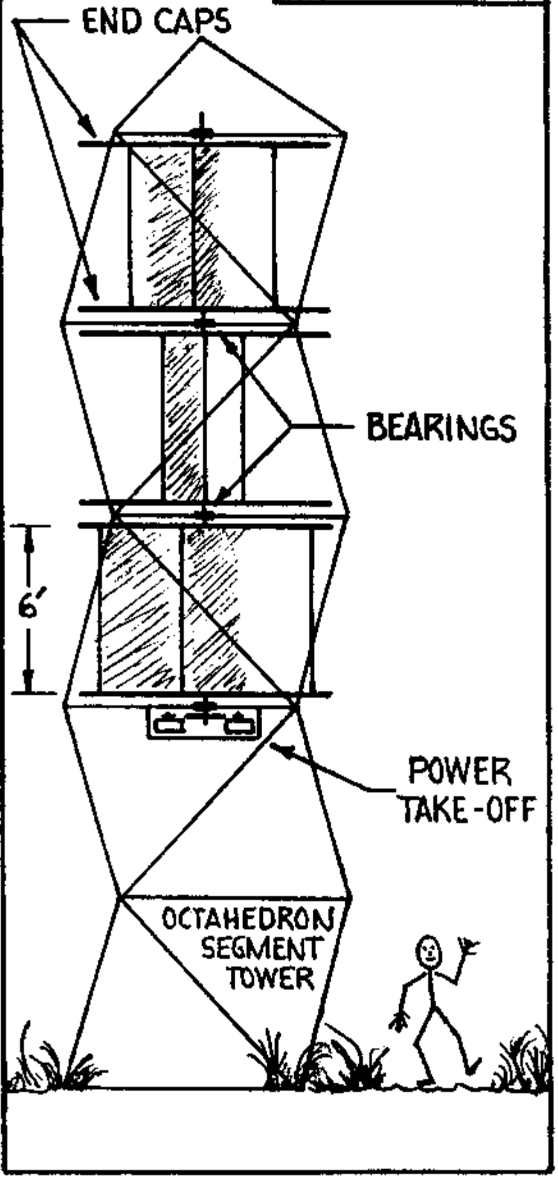


FIGURE 7-2



CHAPTER 7 - DATA SHEETS

We've included this chapter (and its 'Data Sheets'), for several reasons: One, to explain what we couldn't explain because of complexity in the text; two, to give info which is better located in one place than scattered throughout the book; and three, to provide more room for philosophical asides.

Data Sheet #1 contains information relevant to the wind, and the chapter on wind.

Data Sheet #2 will contain related information on batteries, Chapter 3.

Data Sheet #3 will contain info on sources (references throughout the text) and as well, a brief bibliography.

DATA SHEET #1

The sections in this data sheet lettered A thru L are:

A	Table 1
B	Solutions to problems 1-1 and 1-2
C	Wind Power Equation Derivation
D	Air Density
E	Estimating Wind Speed
F	Wind and Altitude
G	General Power Estimates
H	Finding Average Windspeed
I	Usable Average Energy
J	KWH/Month Needed
K	Measuring Aeroturbine Efficiency
L	Cube/Average

SECTION A --- TABLE 1

The following table will enable you to estimate the full load 'shut-down' speed of your S-rotor, as described in Chapter 4, Section G. The aeroturbine described in the power figures is 27 ft.^{2}, such as one would be if it were made out of 55-gallon drums. Alternator/gearing efficiency is assumed to be 50%.

TABLE # 1

WINDSPEED		WATTS @ 20% EFF.		WATTS @ 30% EFF.	
in MPH	in $(MPH)^3$	IMPELLER	ALTERNATOR	IMPELLER	ALTERNATOR
A	B	C	D	E	F
32	32768	560	280	840	420
37	50653	840	420	1260	630
40	64000	1120	560	1680	840
44	85184	1400	700	2100	1050
47	103823	1680	840	2520	1260
49	117649	1960	980	2940	1470
50	125000	2240	1120	3360	1680
53	148877	2520	1260	3780	1890
55	166375	2800	1400	4200	2100
57	185193	3080	1540	4620	2310
59	205379	3360	1680	5040	2520
60	216000	3640	1820	5460	2730

SECTION B --- SOLUTIONS TO PROBLEMS

The solution for problem 1-1 (see page 12) is:

$$P = 0.0006137\ AV^3$$
$$P = 0.0006137\ (40)\ (15)^3$$
$$P = 82.8495 \text{ watts}$$

The solution for problem 1-2 (see page 12) is:

$$P = (0.90)\ (0.50)\ (83)$$
$$P = 37.35$$

Now, you may be wondering why we used 830 watts (power at the impeller) to derive our answer to problem #2, 373.5 watts (power in watts after conversion to electricity). The reason is simple. Even though our data, as presented, could give us an answer to several decimal places (828.495), in the real world of hammers and nails, we can never hope to achieve such accuracy in measuring wind speed, so there is no point in thinking of our answers as accurate. Besides, if your computer happens to look a great deal like a pencil, the figuring is easier. The answer we would have gotten if we had decided to pay attention to all those decimal points is 372.822, not a great deal different from our answer anyway.

The point is, these calculations are based on a great deal of estimation anyway. If they happen to give answers that agree with your actual power out (if you can measure that figure), then you've probably made a lucky guess (or six) somewhere along the line. Otherwise, don't worry too much about it. Estimate low on efficiency, and high on needs, then pray for wind.

SECTION C --- WIND POWER EQUATION DERIVATION

This is the tough one. Hang on, 'cause we're going for a ride.

Power, in any way it's measured, is spoken of as a force times a distance, divided by a period of time, or, for example,

$$P = \frac{(F)(D)}{T}, \text{ or } \qquad P = \frac{(X \text{ feet})(Y \text{ pounds})}{Z \text{ seconds}}$$

Now, we obviously can't multiply a foot times a pound and divide by a second in the real world. Such terms are only abstract conveniences, and it seems to be a misunderstanding of this distinction which confuses the practical but non-mathematical folks, and causes the physics boys to lose touch with the world of dirt, sow bugs and tree forts.

This distinction we make when we say 'red.' 'Red' is 'a color,' and we use it as a noun, or a word which represents an object, but we never have 'red' all by itself, we have a red sky, or a red box, but 'red' is only a convenience. It's the same way with measurements like 'foot-pounds.' They don't exist, except in connection with other things, such as a blue '54 Dodge, going 42.7 miles per hour (62.77 ft./sec.). Important point, 'nuff said.

Wind power is measured in many different units, such as horsepower (550 ft.lb./sec., or 550 ft.lb.sec.^{-1}), watts (.7367 ft.lb.sec.^{-2}), and so on, depending on the application for which you wish to use the wind power, and the units of measurement commonly available.

The basic wind-power equation, in fact the basic equation for estimating extractable power from any moving fluid mass (water being the other common 'moving fluid mass'), is:

Equation #1-1: $$P = \frac{1}{2}\rho A V^3 E$$

where:
P = power
ρ = rho, the air density
A = area (as explained below)
V = velocity, and
E = total efficiency

The equation for estimating power in any particular moving body, fluid or not, is:

Equation #1-2: $$P = \frac{1}{2} MV^2,$$

where:
P = power
M = mass, and
V = (once again) velocity

Now, to get from equation #1-1 to equation #1-2, we take each term in turn. M (mass) of the wind, equals density times volume--

Equation #1-3: $M = \rho \text{Vol.}$

and the volume of air we are considering is found by multiplying the speed (V) of the wind, times the 'silhouette area',* of the S-rotor (height times width),

Equation #1-4: $\text{Vol.} = AV$

since we need three dimensions to have a volume. In other words the 'silhouette area' of the S-rotor gives us 2 dimensions, and the distance the wind travels per unit time (velocity) gives us the third dimension. Substituting into equation #3, we get:

Equation #1-5: $M = \rho AV,$

then plugging this expression back into equation #2, we get:

Equation #1-6: $P = \frac{1}{2} (\rho AV) V^2$, or, even better,

$$P = \frac{1}{2} \rho AV^3$$

This gets us much closer. This equation describes the power in the wind (which we called A.T. wind energy), but it does not describe the power we can extract from the wind. In order to derive this, we need to multiply by T.M. wind energy (59.3%, or 0.593), and, as well, by the efficiency of the S-rotor, or whatever wind device we are studying. If we assume 20% efficiency for the S-rotor, then taking equation #1, and substituting, we find:

$$P = \frac{1}{2} \rho AV^3 (.593) (.20) \text{ or,}$$

Equation #1-7: $P = 0.0593 \rho AV^3$

But, what of ρ (rho), the air density constant? That doesn't show up as a variable in the final wind energy equation -- therefore, we must have assumed that it was a constant (the same in all cases) and simply made it part of the number which appears in the equation.

In fact, that was our assumption. And we're in good company, since even the 'big boys' make similar assumptions. The reasons are several:

(1) with 'funky' equipment (translates: any wind-speed measuring device costing less than \$400-\$1000) the margin of error in wind-speed 'estimation' is bound to be more than the effect any change in the value of ρ is going to have. A 10% margin of error in V becomes a 30% margin of error in V^3.

(2) While it is true that ρ has an effect on Indicated Air Speed (IAS), versus True Air Speed (TAS), the equations which fully cover the very synergistic effects of these and other

---

*Note: for a prop-type, the principle is similar -- depth of the blades is not considered. The area (A) of a prop-type is pi times the radius squared ($A = \pi R^2$).

variables are complex and many. After you know enough to be able to design an airplane wing, then you can adjust for ρ.

(3) the term "exact science' is another abstraction. Einstein said that 'everything is relative,' and so a more exact term is 'relatively exact science.' Wind is invisible, as is thought. We measure the effect of wind, just as we see the effect of thought. But in neither case can we deal directly with the thing itself.

(4) wind is tremendously variable -- beyond the capacity of calculus to really 'describe.' It may vary in speed 10 MPH in 1/2 second, making a series of peaks and valleys on a recording anemometer (wind speed indicator). This makes it next to impossible to talk about 'wind speed," even at any given moment -- we always deal with some kind of 'average' wind speed!

We could go on and on, but the point is made: accuracy is not a practical goal. Ballpark figures are good enough for government work, and they are good enough for us.

So, our value for ρ will be 0.0024 slugs per cubic foot, or otherwise;

$$\rho = 0.0024 \text{ ft.}^{4}\text{sec.}^{-2}*$$

Substituting this into equation #1-7, we find:

$$P = (0.0593)(0.0024)\ AV^3, \text{ or,}$$
$$P = 0.0001423\ AV^3$$

But, all the values for our variables (P, A, and V) are also variable -- meaning, P is in watts, A is in square feet, and V is in miles per hour. In order to get everything working together, we have to multiply miles per hour by 1.46 to convert into feet-per-second (which gives us answers in foot-pounds per second) and then we have to multiply that by 1.36 to convert to watts. Back where the numbers dance and sing, that means:

$$P = (0.0001423)\ A\ (1.47V)^3\ (1.36)$$

Equation #1-8: $$P = 0.0006137AV^3$$

(If you have a calculator, you may get a slightly different constant -- don't worry -- it's close enough.)

Now, as we said before, this equation assumes that our aeroturbine is 20% efficient. For translating this constant into other efficiencies, we need only multiply the constant 0.0006137 by that new efficiency, divided by the 20%, or, at 70% efficiency, our new constant is:

$$C = \frac{70}{20}\ (0.0006137), \text{ or,} \qquad C = 0.0021479,$$

Note: for you diehards, a table relating ρ to altitude is included -- Table # 2. We also explain why ρ is in slugs/ft.^{3}, assuming you are interested, in the next section.

and substituting into equation #1-8, we get:

$$P = 0.00215\ AV^3,$$

at 70 % aeroturbine efficiency.

SECTION D --- AIR DENSITY

The energy in the wind is directly related to both its mass and its velocity (see equation #1-2, earlier in this Data Sheet).

However, its mass depends upon its density times its volume. For the details of this, refer to Section A of this Data Sheet -- here we are only concerned with mass and air density.

Mass is not the same as weight. Most of us are not used to making this distinction, and so we are not generally aware that the same object may have a different weight depending on where it is, even at different spots on the earth's surface.

This may not at first make sense, but consider that while a mass of 6 pounds generally weighs (approximately) 6 pounds on the earth, it will only weigh approximately 1 pound on the moon, or 0 (zero) pounds in deep space. Yet, in all these cases, its mass remains constant, and also its inertia, which is the tendency of a body to remain at rest (or moving in a particular direction at a particular velocity) unless acted upon by an outside force. A general physics' text will make this all much clearer if it isn't now, but those of you who read Science Fiction will be aware that a 5-ton girder in deep space can crush a man against a space station with its inertia alone, as surely as it would if it fell on someone on earth (and thus used its weight to accomplish the same end.)

So, inertia is the key. The air holds or gives energy relative to its inertia, which itself is relative to its mass. Therefore, air density is generally expressed in slugs (a measure of mass), per cubic foot. The metric system has a different measure of density, since it has a different measure of mass and distance. But the principle is the same.

'Density' is more correctly called 'mass density,' and it is found by weighing a certain amount of air (in this case a cubic foot), and dividing by the local value for the acceleration of gravity.

Gravity, in acting on mass, determines weight. If you have ever experienced the force of acceleration (as in an automobile) you will probably be aware that it 'feels' the same as gravity 'feels.' That is, it forces you in a direction opposite of the acceleration, as (in a car) against the car seats.

Gravity is indistinguishable, in its effects, from acceleration. So, it is measured in the same terms, that is, a distance per unit time (speed) per unit time. When we are traveling at a constant speed (say 10 feet per second) we are moving thru a distance in a certain time.

When we are <u>accelerating</u>, so that every second we are going 10 feet-per-second faster than the second before, then we say we are gaining a velocity of 10 feet-per-second every second, or 10 feet-per-second per second, or 10 ft. per sec.^2, or 10 ft. sec.^{-2} -- a measure of acceleration.

When we divide the weight of a cubic foot of air by the local value of the acceleration of gravity (which hovers around 32 ft. sec.^{-2}), we get (at 760 mm air pressure and 59.9° F.) a value of 0.002378 $\text{ft.}^{-4}\text{lb. sec.}^2$, since we divide pounds per cubic ft. (lb. ft.^{-3}) by an acceleration in feet per sec.^2 (ft. sec.^{-2}), or

$$\frac{(\text{ft.}^{-3}\text{lb.})}{\text{ft. sec.}^{-2}}\text{, or}$$

$$(\text{ft.}^{-3})\ (\text{ft.}^{-1}\text{sec.}^{+2})\text{, or}$$

$$\text{ft.}^{-4}\ \text{lb. sec.}^2$$

When we put these values into our equation for wind, we find that:

$$P = C\rho A V^3$$

where:
C is our constant (accounts for efficiency and conversion factors)
ρ is measured in $\text{lb. ft.}^{-4}\text{sec.}^2$
A is measured in ft.^2
V is measured in ft./sec.

When we plug these kinds of units into the equation, this gives us:

$$P = (\text{ft.}^{-4}\text{lb. sec.}^2)\ (\text{ft.}^2)\ (\text{ft. sec.}^{-1})^3$$

$$P = (\text{ft.}^{-4}\text{lb. sec.}^2)\ (\text{ft.}^2)\ (\text{ft.}^3\text{sec.}^{-3})$$

$$P = \text{ft. lb. sec.}^{-1}\text{, or}$$

P = foot-pounds per second.

is affected by elevation in feet $[(\rho\ a)\ (0.0024)]$ according to the table below:

TABLE # 2

ELEVATION IN FEET	ρ a	ELEVATION IN FEET	ρ a
0	1.000	5500	.849
500	.985	6000	.840
1000	.971	6500	.823
1500	.957	7000	.811
2000	.943	7500	.798
2500	.929	8000	.786
3000	.915	8500	.774
3500	.902	9000	.762
4000	.888	9500	.750
4500	.875	10,000	.739
5000	.862		

SECTION E --- ESTIMATING WIND SPEED

As we have already pointed out, wind is almost never directly measured, rather, it is averaged over greater or lesser periods of time, and, as well, the amount of estimation involved is greater or lesser.

It is recommended that you buy some kind of wind-measuring device (anemometer). There are several good but more or less inexpensive anemometers made by Dywer -- see Data Sheet Three (Sources) in this chapter.

If you don't have access to an anemometer of any kind, Table # 3, which follows, will allow you some kind of wind-speed estimation by phenomena:

TABLE # 3

SPEED RANGE	PHONOMENA	DESCRIPTION
0	Smoke rises vertically	Calm
1-3	Direction of wind shown by drift of smoke, but not by wind vane.	Light air
4-7	Wind felt in the face; leaves of trees rustle; wind vane moves easily	Light breeze
8-12	Leaves and small twigs in a constant motion; wind extends a light flag.	Gentle breeze
13-18	Raises dust and loose paper; small branches are moved.	Moderate breeze
19-24	Small trees in leaf begin to sway; crested wavelets form on lakes and ponds.	Fresh breeze
25-31	Large branches in motion; telegraph wires whistle; difficult to use an umbrella	Strong breeze
32-38	Whole trees move in wind; walking difficult	Moderate gale
39-46	Breaks twigs and branches off trees Generally impedes progress	Fresh gale
47-54	Outdoor flower pots and house tiles or slates are removed	Strong gale

By the way, if you should chance to build an anemometer (or buy one), which needs calibration, an excellent method of doing this was described in an article in 'The Amateur Scientist' section of Scientific American for October, 1971.

SECTION F --- WIND AND ALTITUDE

Wind, as a fluid medium, tends to be slowed down by obstacles near the ground, as well as the ground itself. In general, it can be said that wind at some altitude is relative to wind at 10 feet by the formula developed by Hellman:

Equation #7-1: $V_h = V_{10}\ (0.2337 + 0.656 \log_{10} (h + 4.75))$

where: V_h = velocity at height h (MPH)
V_{10} = velocity at 10 feet (MPH)
h = height of desired estimation, in meters
($\log_{10}$ means 'log to the base 10')

For example, at 200 meters, when V_{10} = 10 MPH,

$$V_{200} = 10 \text{ MPH } (0.2337 + 0.656 \log_{10} (200 + 4.75))$$
$$V_{200} = 10 \text{ MPH } (0.2337 + 0.656\ (2.3096))$$
$$V_{200} = 17.5 \text{ MPH}$$

(If you don't understand logarithms, consult Marks Engineers Handbook, or any mathematical reference.)

But, actually, that's rather complex and not as useful as it might be, since it assumes that there are no obstacles to be overcome (or to get above) except the ground.

Best advice is -- get as high as you can, keep your bowels clean, and trust in the Lord. Towers are mostly a matter of budget, anyway.

SECTION G --- GENERAL POWER ESTIMATES

This section centers around a table which gives windspeed (V -- in column A), its cube (V^3 -- in column B), the impeller watts per-square-foot at each windspeed (Watts/ft.^{2} -- column C), and the watts per-square-foot of impeller when translated into electricity at the alternator (Watts/ft.^{2} -- column D -- assumes 30% efficiency of transmission & translation).

The table allows anyone to calculate power at the impeller and alternator in watts, without using equation #1-8. The new, much simpler equation, is:

Equation #7-2: $P = AC_V$

where: P = power, in watts, at the impeller
A = area of your aeroturbine
C_V = reading in column C for the wind speed in question

For example, at 34 MPH, an aeroturbine of 40 square feet will develop:

$P = (40)\ (24)$, or $\qquad P = 960$ watts at the impeller

Using equation #1-8, the power would be:

$$P = 0.0006137\ (40)\ (34)^3, \text{ or,}$$
$$P = 964.835$$

Not a great deal of difference. These figures assume 20% aeroturbine efficiency, and can be translated to other efficiencies by multiplying by the ratio of the new efficiency to 20, or:

$$P = \frac{E_n}{20}\ AC_V$$

where E_n = new aeroturbine efficiency

At 50% aeroturbine efficiency, $\frac{E_n}{20} = \frac{50}{20}$, or , 2.5

(Note: Power in watts out of the alternator is found by substituting D_V for C_V in equation #7-2. This gives power in watts of * electricity, assuming 30% * efficiency of gearing/alternator.)

TABLE #4

A	B	C	D	A	B	C	D
V	V^3	$\frac{\text{Watts}}{\text{ft.}^2}$	$\frac{\text{Watts}}{\text{ft.}^2}$	V	V^3	$\frac{\text{Watts}}{\text{ft.}^2}$	$\frac{\text{Watts}}{\text{ft.}^2}$
6	216	0.13	0.044	30	27000	17.0	5.5
8	512	0.31	0.10	32	32768	20	6.6
10	1000	0.61	0.20	34	39304	24	8.0
12	1728	1.1	0.35	36	46656	29	9.4
14	2744	1.7	0.56	38	54872	34	11
16	4096	2.5	0.83	40	64000	39	13
18	5832	3.6	1.2	42	74088	45	15
20	8000	4.9	1.6	44	85184	52	17
22	10648	6.5	2.2	50	125002	77	25
24	13824	8.5	2.8	55	166375	100	34
26	17576	11.0	3.6	60	216000	130	44
28	21952	13.0	4.4	65	274625	170	56
				70	343000	210	69

SECTION H --- FINDING AVERAGE WINDSPEED

'Average wind speed' refers to the speed of all winds averaged out for the time of measurement. If a weather station has continuous monitoring of windspeed, then the 'average windspeed' for that day for that station would be the average of all windspeeds recorded for that day; or, if they are measured at the rate of one a minute, then 'average windspeed' for that day for that station would be all those recorded speeds divided by 1440 (the number of minutes in 24 hours).

However, it is expensive to record wind continuously, and so a great many weather stations only record at 7:30 AM, 1:30 PM, 7:30 PM, and 1:30 AM Washington, D.C., time. These readings are taken for only a few minutes, and thus the 'average wind speed' for that station for that day may not be very representative of 'true' average wind speed.

These considerations are important since the weather station nearest you may be your best source of information on the 'average wind speed' for your area. But, these records may be inaccurate for other reasons as well.

If the wind speed is taken at ground level, this will not be the same 'average wind speed' as one which is averaged from readings taken at 50 feet in the air. Wind speed reading will vary because different instruments are used in different places, because there are obstacles in the way (trees, etc.), because there is no standard wind-speed calibration, etc., etc.

Further, wind varies with the site, and may average significantly more at one particular spot on a piece of property than it averages at another.

Once again, the only thing all these words mean is -- do it if you feel it. That's nearly as good an indicator as any, because you're bound to be dealing with a certain amount of 'seat-of-the-pants' estimation, anyway.

Find out what 'average wind speed' for the nearest weather station is, and find out what that phrase means to them -- where and how they take their readings, etc. -- then figure out a way to guess or 'know' if your average is higher or lower.

Below 8 MPH average wind speed, consider 3 times carefully before investing much money in a wind/electric system. From 8-10 MPH average, look twice; from 10-12 MPH average, move on it; and from 15-20 MPH average, why don't you already have a wind/electric system??

SECTION I --- USABLE AVERAGE ENERGY

The extremely vague 'exact science' of wind finds its pinnacle here. The usable average energy in your wind system will vary according to the average wind speed and patterns, the time of year, the size and efficiency of your aeroturbine and alternator, the amount of your storage capacity and its efficiency, and the variables of your electric transfer system and its appliances.

If we make 6 a half-dozen assumptions, and cross our fingers, we could say that it might be that perhaps the figures below would be realized, maybe.

This table assumes that aeroturbine efficiency is 20% (of T.M.), negligible output below 10 MPH, 25 MPH rated windspeed, alternator puts out rated amps at 14V, alternator/gearing is 50% efficient over the whole range of wind speeds, and, further, that all factors are 'balanced' -- batteries are 'correct' in number and capacity, etc.

Once again -- even though the table may look impressively accurate -- these are only ball-park estimations. The efficiency of the alternator (assumed 50%) might well be lower at lower wind speeds, and higher at higher wind speeds.

To convert these average usable power figure estimates into power figure estimates for more efficient units, multiply by -- the new efficiency divided by 20. For instance, for a 50% efficient aeroturbine (all other parameters as described above) and a nominal amperage rating of 80, with a 10 MPH average wind speed for a certain month, we find:

$$\frac{\text{est. KWH}}{\text{month}} = \left(\frac{50}{20}\right) 67, \text{ or,}$$

$$\frac{\text{est. KWH}}{\text{month}} = 168$$

(NOTE: This is a 'questionable' use of Table # 5. In essence, in order to achieve this higher accumulated power out, the aeroturbine would have to use an 'altered' alternator - see Chapter 2, sec. A- or a larger alternator.)

The same conversion expression can be used to estimate a new area for a more efficient aeroturbine. For instance, if we have an aeroturbine of 70% efficiency (all other parameters as described), and we live in an area which experiences 12 MPH average wind speed for the month which concerns us, and if our aeroturbine should produce about 100 KWH for that month with a 90A alternator, then reading the chart, we find that at 20% efficiency, our aeroturbine should be 263 ft.^{2}. Instead of multiplying by the ratio of new efficiency to 20, we divide:

$$A_{70} = \frac{263 \text{ ft.}^2}{\left(\frac{70}{20}\right)} \text{, or}$$

$$A_{70} = 75 \text{ ft.}^2$$

Thus the table can provide us estimates for all different situations.

TABLE #5

AMPERAGE RATING OF ALTERNATOR	AREA OF S-ROTOR (FT^2)	MONTHLY AVERAGE WIND SPEED					
		6	8	10	12	14	16
30	88	8	17	25	33	41	49
35	102	10	20	30	39	48	57
40	117	11	22	33	44	55	65
45	131	12	25	38	50	62	74
50	146	14	28	42	55	69	82
55	160	15	31	46	60	76	90
60	175	16	34	50	66	83	98
65	190	18	36	54	71	90	106
70	207	19	39	58	77	97	115
75	219	20	42	63	83	104	123
80	234	22	45	67	88	110	131
90	263	24	50	75	99	124	147
100	292	27	56	83	110	138	164
110	321	30	61	92	121	152	180
120	351	33	67	100	132	166	196
130	380	35	73	108	143	180	212

SECTION J --- KWH/MONTH NEEDED

If you are familiar with the simple electrical formulas used in Chapter 2, this should be duck soup:

$$KWH = \frac{(W_1H_1) + (W_2H_2) + (W_nH_n)}{1000}$$

where:
KWH = Kilowatt hours <u>per month</u>
W_1 = Wattage of appliance one
H_1 = Number of hours per month appliance one is used
W_2 = Wattage of appliance two
H_2 = Number of hours per month appliance two is used
W_n = Wattage of appliance 'n'
H_n = The number of hours appliance 'n' is used per month

To use the formula, go around your house and get the wattage off of each electric appliance, light bulb, etc. -- anything which uses electricity -- and, as well, estimate the number of hours that appliance is used per month. Wattage or amperage is usually stated somewhere on the appliance. For instance, you may have a reading light of 60 watts that you turn on in the evening for 1/2 hour. This would be (30) (0.5) or 15 hours per month use, at 60 watts. To take a more complex example, here at Earthmind we have a toaster which we use in the morning to make toast. We don't use it every morning, but for the purposes of illustration, let's say we do. Further, let's assume we make 4 pieces of toast per morning. Since the toaster takes 2 slices of bread at once, this means the toaster is punched down twice, cycles, and pops up. This takes 2.5 minutes (I timed it), and so that's 5 minutes per morning for two cycles of the toaster and 4 pieces of toast. 5 minutes is 1/12th of an hour, (use each day), so we use the toaster $\left(\frac{30}{12}\right)$ 2.5 hours per month. (By the way, a toaster is an 'I^2R' machine.)

On the bottom of the toaster it says '110-120 volts, 7.7 amps.' This is (120 x 7.7) 924 watts. At 2.5 hours per month, that's (924 x 2.5) 2310 watt-hours per month. Dividing by 1000 to get KWH per month, we get 2.3 KWH per month.

The reading light we mentioned (15 hours per month at 60 watts) equals 900 watt-hours per month, or 0.9 KWH per month. If our household had only a toaster and a reading light, that would be (2.3+0.9) 3.2 KWH per month total for the household.

Look in Chapter 5 for some alternatives to energy-inefficient appliances.

SECTION K --- MEASURING AEROTURBINE EFFICIENCY

Because of the estimates and the number of simultaneous variables involved, this is not an easy or accurate measurement. The basic equation used is derived from information in Section C of this Data Sheet, and is:

Equation #7-3: $$\text{A. Eff.} = \frac{(EI)\ Ae}{0.000708AV^3}$$

where: A. Eff. = aeroturbine efficiency
E = voltage out of the alternator
I = amperage out of the alternator
Ae = alternator/gearing efficiency
A = aeroturbine area
V = wind speed

If you've read and understood everything which precedes this -- you're a real trooper! But, as well, if you've read and understood it, you know that the errors in estimation involved here will easily be great enough to give you errors on the order of a factor of ten.

For any given interval or moment, in order to use this equation, you must know (simultaneously)

Voltage out of the alternator
Amperage out of the alternator
Wind speed, and
Alternator efficiency

Since alternator efficiency varies widely at its lower RPM's, and only begins to level out at (say) 12-15 hundred RPM's, try to take readings at a wind speed which gives your alternator RPM's above this point.

This RPM/wind speed relationship will depend on your particular setup, but the best day to test in any case is a day of strong steady wind (which will give higher aeroturbine, and thus higher alternator RPM's).

Either get a manufacturer's data sheet on your alternator, or test it for output at a different RPM with a known load, so that you have some idea of alternator efficiency. Otherwise, assume 50% alternator efficiency, and 95% gearing/transfer efficiency (or make other assumptions).

A further simplification would be to assume a constant voltage: With a regulator hooked to the alternator, voltage will be below 14V. If you are generating enough juice so that the regulator begins to cut in and out (it makes a clicking noise) then you 'know' that voltage is approximately equal to 14. In terms of our equation (#7-3), that means:

$$\text{A. Eff.} = \frac{(14)\ (I)\ (.50)\ (.95)}{.000708\ AV^3}$$

$$\text{A. Eff.} = \frac{(9390)\ (I)}{AV^3}$$

In this case the only simultaneous variables to be considered are V (wind speed) and I (amps). Area is of course a constant, depending on your unit.

It is advisable to have an over-ride positive shut-down circuit on the aeroturbine, as described in Chapter 4 - Control, in the section describing upper wind speed determination.

Circuits which will allow you to read volts and amps are described in Chapter 4, Section G, Control Circuits.

A problem might be experienced with the 'loading effect' of the alternator, if you are using manual 'cut-in,' and trying to measure output at the lower wind speeds. The aeroturbine might put out a false high reading for a few moments until its excess inertia is converted to electricity, and then 'balances' so that wind power in 'equals' electric power out. Best, again, is a day of strong steady winds, but gusts, if they are prolonged (some gusts last less than 1/2 second) for 4-5 seconds, will do, assuming your aeroturbine is responsive enough to these gusts.

Take a number of sets of measurements, find Eff. for each set of measurements, and average these numbers. If some of the answers read far too high or low (as they might with 'funky' instruments and 6 or 8 people scrambling around) throw them out and average the others.

By the way, it will take 6 or 8 people (almost) to read all the instruments (simultaneously!) and write down the proper figures. You might make up sheets with 20 or 30 numbered spaces, and have a 'coordinator' call "Mark!" and the number of the reading ('mark twelve!. . . . mark 13!. . .'), at which time, and in which space each person writes his/her reading.

Gather sheets, do the calculations, and

Good luck --

SECTION L --- CUBE/AVERAGE

This is something of an afterthot, added because I'm not sure the point was clearly made in the text of Chapter 1. But -- the cube of an average is always less than the average of the cubes. In Chapter 1, page 15, we spoke of an 8 MPH average windspeed. This 'average' reading could occur if the wind blew 4 MPH, for 6 hours, 12 MPH for 6 hours, 6 MPH for 6 hours, and 10 MPH for 6 hours, making a total of 24 hours. The average windspeed for that (24-hour) day (8 MPH), cubed, is 512. The average of their cubes, (respectively 64, 1728, 216, and 1000), is 752. This is (almost) a 150% increase. In the real world, this percentage difference tends to be even greater.

DATA SHEET #2

Electronics List:

Parts list for Drawing 3-4 (page 38):

D1-D4	Diodes, 5 Amp, 25 PIV
D5	Diode, 8 Amp, 25 PIV
M1	DC Ammeter, 10 Amp Full Scale (minimum)
M2	DC Voltmeter, 15 Volt Full Scale (minimum)
R1	400-800 Ohm, Fixed (carbon) Resistor, 1 Watt
S1	SPST Switch, 1 Amp rating
S2	DPST Switch, 5 Amp rating
T1	Transformer, 12 volt secondary, 5 Amp, and centertapped.
C1	500MFD, 25WVDC, Electrolytic Capacitor

Parts list for Drawing 3-5 (page 41):

L1-L2	10 Foot length of baling wire wound in a coil
M1	DC Ammeter, 50 Amp Full Scale (minimum)
M2	DC Voltmeter, 15 Volt Full Scale (minimum)
S1	Knife Switch

Note: Use L1 and L2 as shown (in drawing) for 6 volt batteries; for 12 volt batteries, use only L1 or L2 (not both).

With the exception of the baling wire, all of these parts may be purchased from the first two listings under Electronics, Data Sheet #3, this chapter.

BRS---Battery Record Sheet: On the following page is a sample of the BRS used here to test lead-acid batteries. It should be fairly self explanatory. Use one of these per battery; if you decide, with a battery that is borderline on the first test, to run the test again, use a new sheet, but file the old one. Try to keep a battery history for each of the batteries used in your system. In this manner, variations in readings that are too gradual to notice each time you service or check the system will be more obvious.

Battery Discharge Plot : On the page following the BRS form, the breakdown curves for three batteries tested here at Earthmind are given. As well, the data is presented; this is the way that you use the Time/Amps/Volts block on the BRS. Battery A-1 was a good battery, Battery A-2 was borderline and subsequently tested again, and Battery A-3 tested bad. Look at the way the curves steady and fall; once these things are plotted out, it is unnecessary to examine the data closely---the curve tells the story.

BATTERY RECORD SHEET

--BRS --

_______ Battery number
_______ Volts (6 or 12)
_______ Amp-hour capacity
_______ Previous tests

CHARGING INFO

_______ Test date
_______ Charging method
_______ Charge rate (in amps)
_______ Start time
_______ # of charge hours
_______ Estimate completion time
_______ Test ended (date/time)
_______________________ Tester

DISCHARGING INFO

_______ Test date
_______ Load used (lites, breakdown circuit)
_______ Load (in amps)
_______ Time segments (5 min., 10 min., etc.)
_______________________ Tester

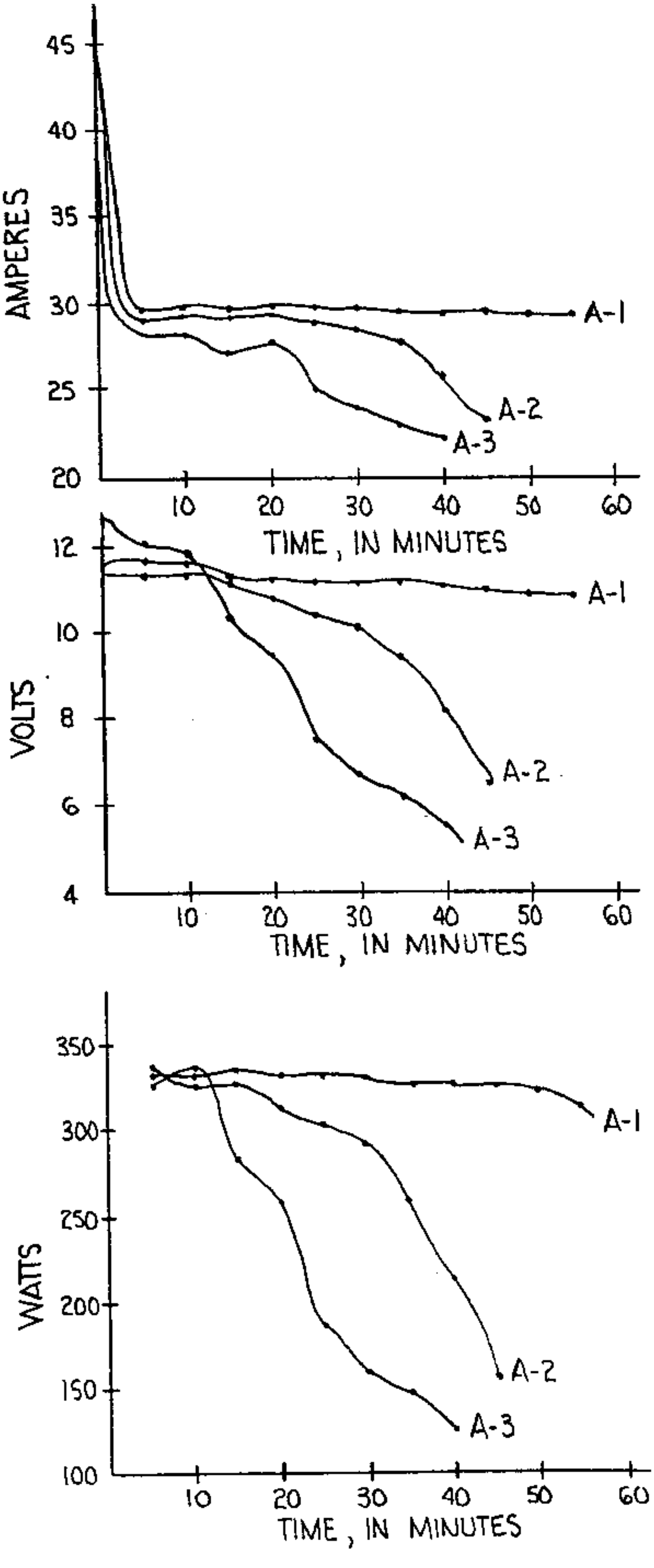
TIME	AMPS	VOLTS

SPECIFIC GRAVITY	CELLS (number from (+) end)					
	1	2	3	4	5	6
A						
B						
+						
C						
D						
–						

VOLTAGE	
A	
B	
C	
D	

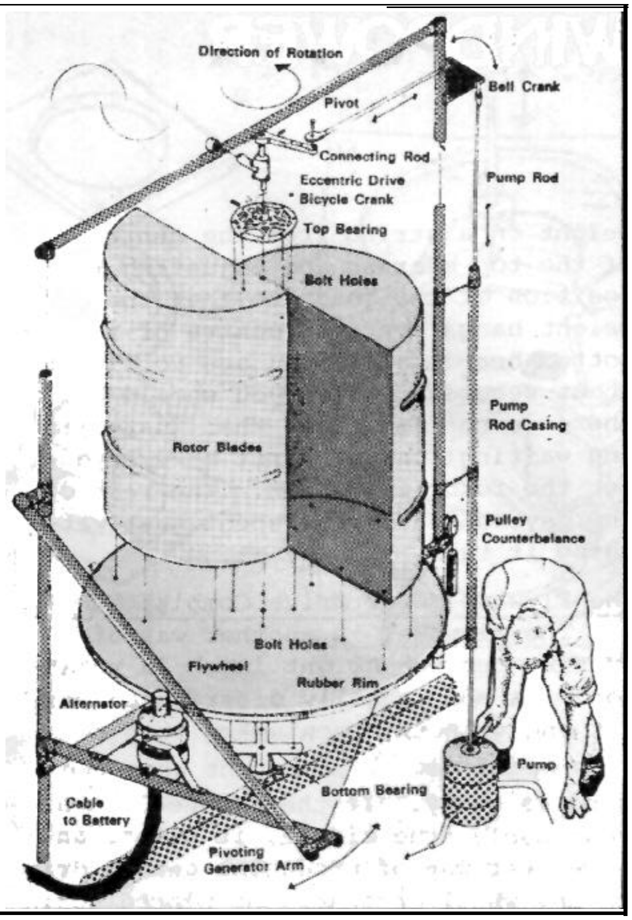
Designations for Specific Gravity/Voltage Charts

A -- Before charge
B -- After charge
C -- Before discharge
D -- After discharge



TIME	AMPS	VOLTS
A-1		
5	29.5	11.3
10	29.8	11.3
15	29.9	11.3
20	29.9	11.2
25	29.8	11.2
30	29.8	11.2
35	29.6	11.2
40	29.5	11.1
45	29.6	11.0
50	29.5	10.9
55	29.5	10.8
A-2		
5	29.1	11.5
10	29.2	11.3
15	29.2	11.2
20	29.0	10.8
25	29.0	10.5
30	28.2	10.1
35	27.8	9.5
40	26.0	8.2
45	23.5	6.6
A-3		
5	28.5	11.6
10	28.5	11.5
15	27.3	10.3
20	27.8	9.5
25	25.0	7.5
30	24.0	6.7
35	23.2	6.3
40	22.3	5.6

WINDPOWER:
pumping and Power from a Savonious Rotor



We found this information on do-it-yourself windpower buried in the bottom of a filing cabinet. The author is unknown even though the reference to pounds seems to indicate that these plans originated in Britain.

The plans start off with a design for a savonious rotor which both pumps water and generates electricity. By the looks of it the savonious is made from a 44 gallon drum cut in two. The plans have a number of pages missing, and this must have included some of the information on building the savonious, as the first page we have on this describes the flywheel/gear drive combination.

Nevertheless there is certainly enough information here for you to have a go at building the savonious or the novel bicycle airscrew pump made of bike parts.

The Frame

Timber as strong as you can get, 4" x 2" or even better 6" x 2" or 4" x 4". Floor joists from demolished buildings are good for the job or, if you can get hold of it, scaffolding is ideal. Whether using timber or scaffolding, an H frame closed at the top and guyed with rope should be erected. Check that the uprights are indeed vertical, but more important that the cross-members are horizontal. If the frame is attached to the ground, dig holes and cement the posts in before guying.

The rotor should be erected as high as possible as wind is less turbulent and stronger as height increases.

In built-up areas, it is probably worth considering erection on roofs or between the gables of neighbouring houses. We put one on a fairly exposed site about 15' off the ground attached to the side of our house. It rotates when the wind is otherwise not perceptible, In a breeze that is felt in your hair, the rotor is spinning rapidly.

Test your rotor by erecting low at first. Check for plumb by hanging a

WINDPOWER

weight on a string from the centre of the top bearing and adjusting the position of the rotor so that the weight hangs over the centre of the bottom bearing. If you are confident about security, which you should be, there is nothing finer than just sitting waiting for the first breeze to set the rotor in motion. The rest of the day can easily be spent just watching it turn... Enjoy it.

The Flywheel/Gear Drive Combination

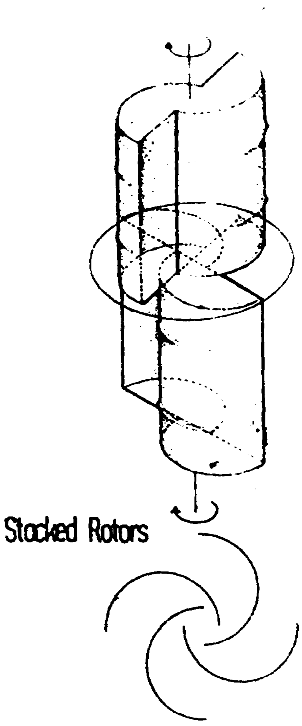
The flywheel is another way of evening out the slight lurch in rotation. It adds equally distributed weight and gathers momentum so that rotation speed remains constant when the wind is gusty. If the flywheel is a reasonably true circle, it offers an excellent way of producing geared drive to any wheel or generator placed against it. This is important if what is being driven - in the model illustrated an alternator - requires relatively high revs to operate.

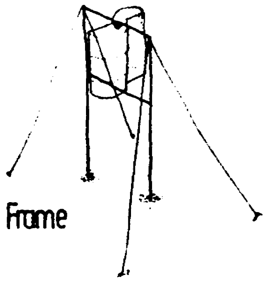
As Savonious rotors do not reach the high speeds that airscrew-type wind machines achieve, the use of a flywheel/gear drive makes it possible to use a Savonious with alternators and certain unmodified slow dynamos, if the flywheel is say 4' in diameter and the alternator axle has a 2" diameter, a gearing ratio of 24:l is achieved which means that at a mere 25 rpm, a rotation speed caused by light winds, the alternator is turning at 600 rpm, enough to provide a good charge. The flywheel can be made from ¼" chipboard or ½" ply suitably treated to protect it from the weather. A rubber strip pinned and glued to its edge makes a good friction drive to any other rubber wheel placed against it. Heavy duty sponge rubber is good for the job - the sort used for draught proofing car doors is ideal. The rotor is bolted to the flywheel so providing another means of joining the two halves.

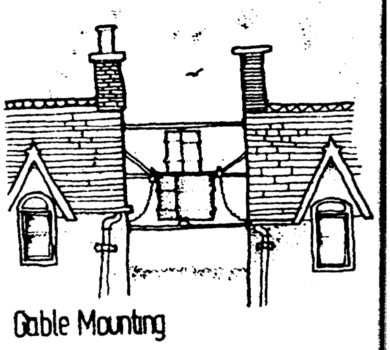
The Bearings

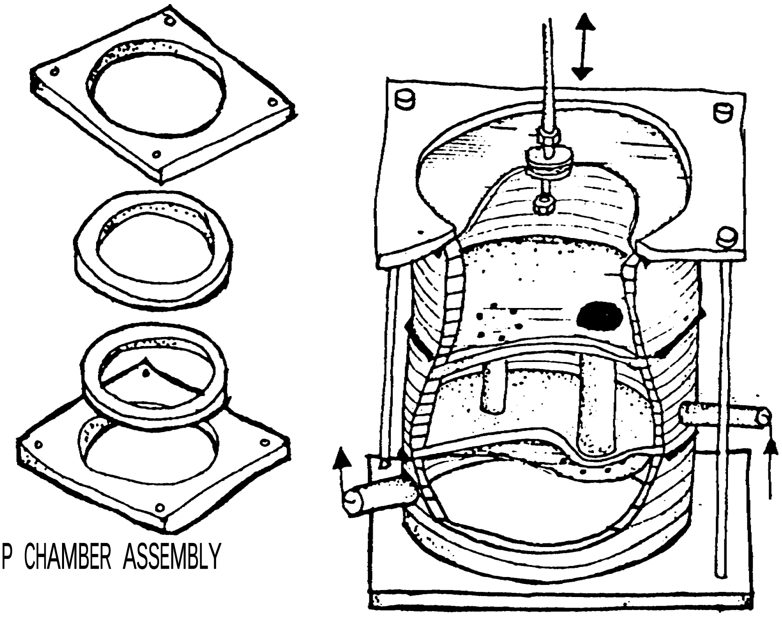
From modest experiments involving models made from tin cans and soap bottles, it was found that axles running through the rotor impair the rotation. Instead of an axle, top and bottom bearings should be used if possible. Bicycles, mopeds and cars provide suitable bearings.

The crankshaft from a bicycle was used for the top end of the Savonious illustrated. It's strong and turns easily, and the chain drive, when drilled in suitable positions, is a means of joining the two halves of an oil drum, The crank is sawn off and the chain drive is best fitted on the inside of the join of the two halves. The rotor is fixed by a cotter pin to the crankshaft as in bicycles. The other crank can be used to form the eccentric drive via a bell crank, or another chain drive can be attached to form the bottom bearing of another rotor stacked on top.









PUMP CHAMBER ASSEMBLY

A water pump and flattened fan (from the cooling system of a car) is another convenient bearing when stripped down and lubricated before re-assembly. The flattened fan is drilled to take the bolts that attach the rotor to the bearing and hold the two rotor halves together. On a water pump is a pulley drive that takes a u-belt that could be the basis of a geared driving system on rotors without a flywheel.

The pump part of the car water pump is not suitable for lifting water over a head but can be used for circulating water. However, more often, it is possible to remove only a part of the water pump that comes away from the engine casing. Some cars have a pump which can be removed in its entirety* If used as a bearing, only the easily removed part is necessary. It is attached to the engine by three or four bolts that can be used in fixing the bearing to the frame, If bearings can't be found, a bearing known as a Plummer Block can be bought for about 2- 3 each.

Making the Pump

The pump body can be made out of a shell case 155mm in diameter, divided into three compartments of equal length. Or as in the diagram with chipboard circles with holes in them stacked on top of each other, and glued and sealed. The lower part is drilled on its side by the base, and a steel pipe for exacuation is fitted to the hole.

On top of this part is a circular slab, cut from sheet iron or chipboard and placed between two soft rubber joints of the same diameter. The lower joint is circular and drilled with a circular series of holes. The upper joint is in the shape of a ring 20-30mm wide. The circular slab is drilled with a hole allowing for the passage of a tube which is fixed to it. The free end of this tube is threaded and then closed by two screw nuts. The tube can come from a water installation or from the front forks of a cycle.

The lower opening of the tube must coincide with the series of the holes drilled in the rubber joint to allow for drainage.

The middle compartment of the case, already fitted with its joints, is placed on the circular slab. A second joint in the shape of a ring is set up, together with a circular slab and another joint itself drilled with a series of holes. Both joints are identical to the first two but are inversely arranged.

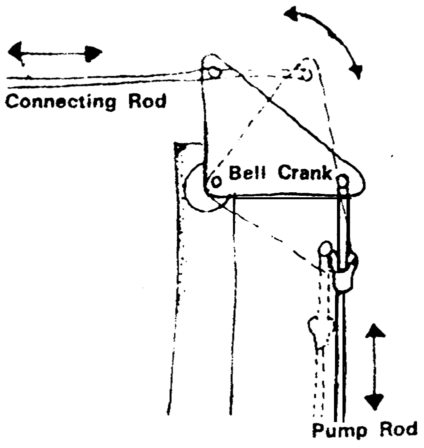
The circular slab is drilled with two holes and its length is calculated so that its lower end stops 10mm from the first circular slab. The second hole is for the threaded end of the tube fixed to the lower slab, on which a nut is screwed and a ring is placed. A hole drilled in the upper joint allows for the passage of the tube. A second supporting ring is placed and the complete assembly is tightened with a screw nut.

A delivery pipe is fixed on to the base of the middle compartment to carry water from the well. The third compartment is now placed over the two others and a soft but thick rubber membrane is put on top of it. Car inner tubes can be used. This is held close to the edge of the cylinder by a metal ring. The rubber joint must be encased between the edge of the cylind-

WIND POWER

er and the groove of the metal ring. The centre of the membrane has a hole drilled in it through which passes the threaded end of the connecting rod to the motion of the windmill. The rubber is tightened between two screw nuts and thick washers with chamfered edges so that the membrane is protected against deterioration.

All the elements of the pump are assembled and tightened together by four iron bars made with long strong bolts. These bolts pass through a thick board which forms the base. They also pass through the metal rings placed on the top and moderately tightened. The whole assembly must be perfectly airtight. The pump is fixed to the ground between the three legs of the tripod. It must lie perpendicular to the centre so that the transmission rod stands perfectly vertical.



Further Notes

The Bell crank converts rotational motion from the eccentric to reciprocating motion necessary to drive the pump make it from plywood or sheet metal. Devise a means that enables the pump rod to be disconnected when the pump is not in use. Establish the radius of the eccentric suitable to work the pump by trial and error.

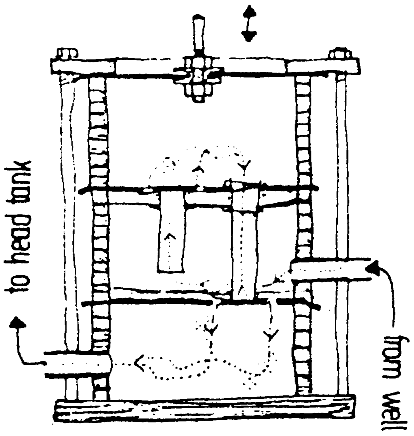
The modified head on the alternator replaces the usual pulleydrive and provides the latitude necessary to accommodate any slight wobble on the flywheel.

CONTINUED PAGE 31.

HOW IT WORKS!!

When the membrane is attached to the top, an intake is produced and the upper joint comes off the upper circular slab. The water is sucked by the tube connected to the middle compartment thus filling the upper compartment. Meanwhile a partial vacuum occurs in the middle compartment thus attracting the piped water from the well.

When the membrane goes back to its original position, the water in the upper compartment is sent to the lower one by means of the tube which joins them together and gradually fills it up. The water then travels to a tank through a pipe. Both joints drilled with holes act as stoppage valves by lying flat on the circular slabs when needed.

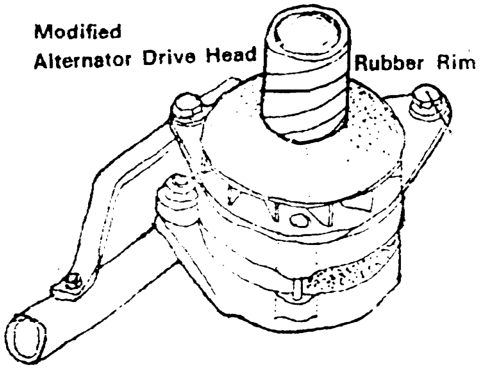


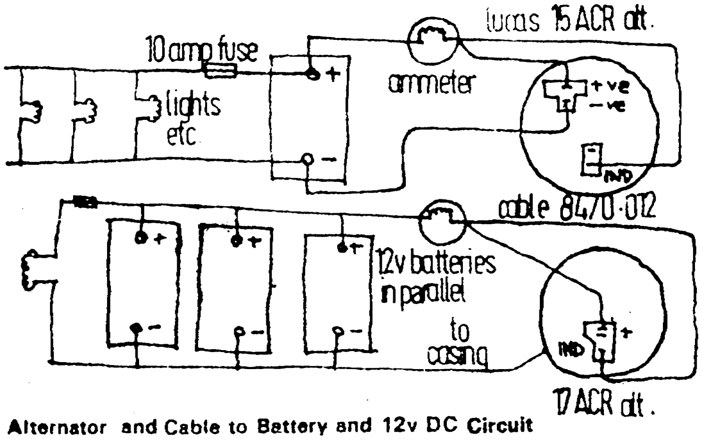
Section

All that remains to be done is to build the complete assembly near enough to the well in order to have the shortest possible length for the piping.

WINDPOWER
Continued from page 14

Provide a housing for the alternator by inverting a plastic bucket with appropriate holes in it, as a means of sheltering it from the weather.

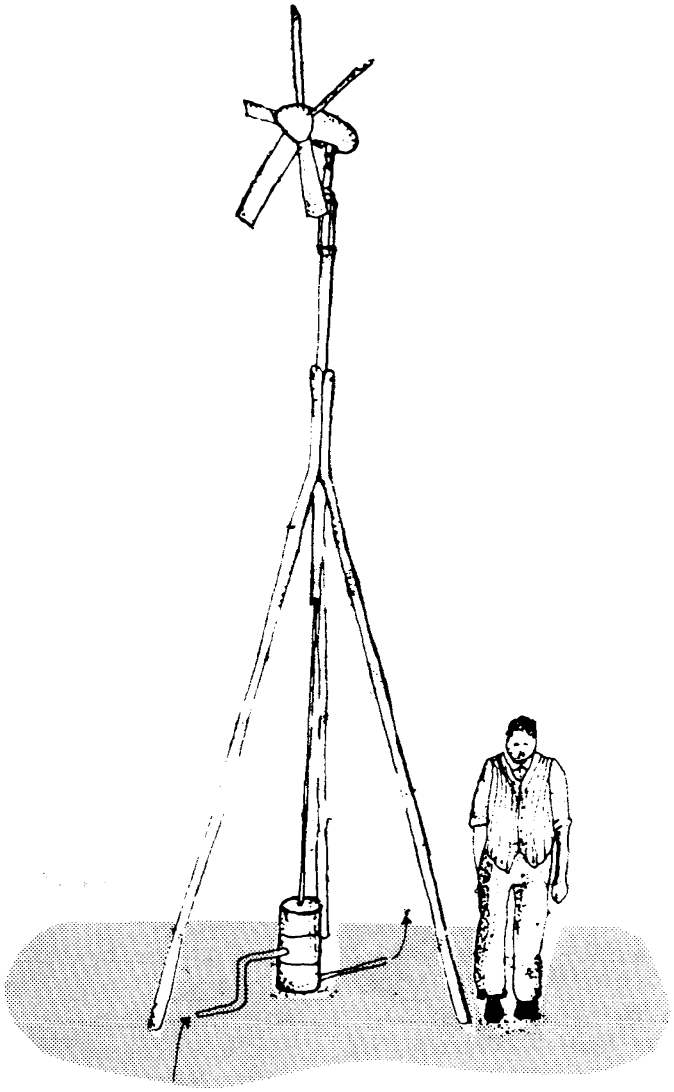




Alternator and Cable to Battery and 12v DC Circuit

Bicycle Airscrew Pump

This has been conceived to draw water out of a well and store it above ground level. Thus, water is available at any time with enough pressure to water a garden. The winding parts, mounted on ball-bearings, are bicycle parts.



Construction of the Tower

This is made of four tubes 45-50mm in diameter, three forming the legs and a central one supporting the mechanical part, The three legs are slightly bent at about 600rpm from their top ends to give enough distance to splay the legs at the bottom and to allow a joint with the central tube.

This joint can be made by either welding or slightly curved bolts, in which case each tube is drilled with two holes near the bend. Six bolts should be sufficient for the complete assembly.

The legs can be fixed to the ground in two ways, either by sawing along their axes for about 100mm and bending them to form fixing tabs which are then cast in concrete, or by welding the bottom of each leg to an iron tab drilled with a 12-14mm hole, This must rest flat on a rectangular concrete block to which it is fixed by a sealed threaded stud. This method has the advantage of allowing the tripod to be taken down.

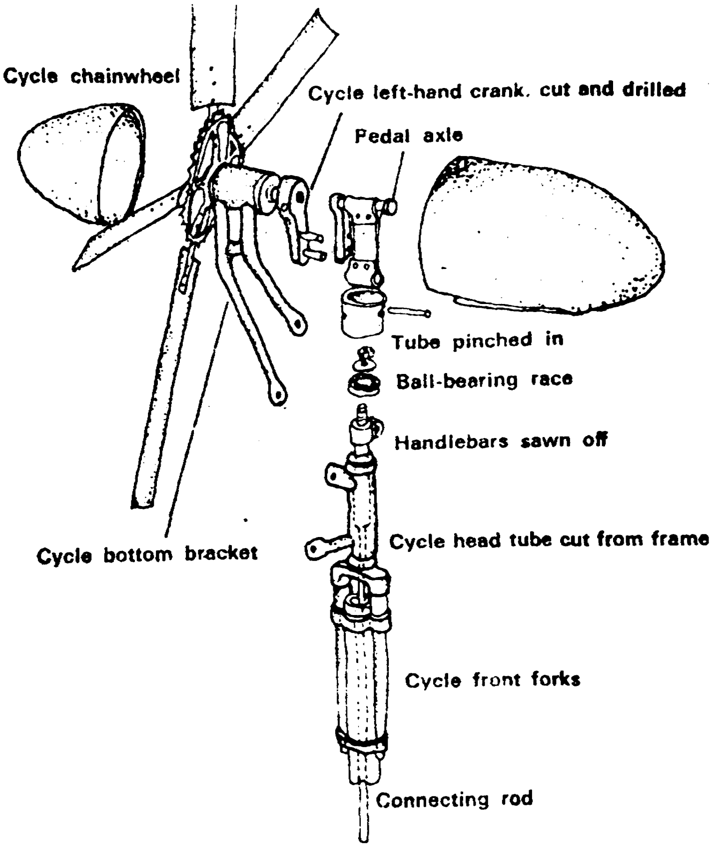
The leg tubes are about 3.3m long. The central tube is 2.lm. It rises lm above the others and is surmounted with the front forks of a bicycle, both fork tubes having been straightened out to allow their fixing by two iron rings. Each ring is made of two parts tightened together with bolts. The iron should encase the fork tubes without squashing them.

The Mechanism

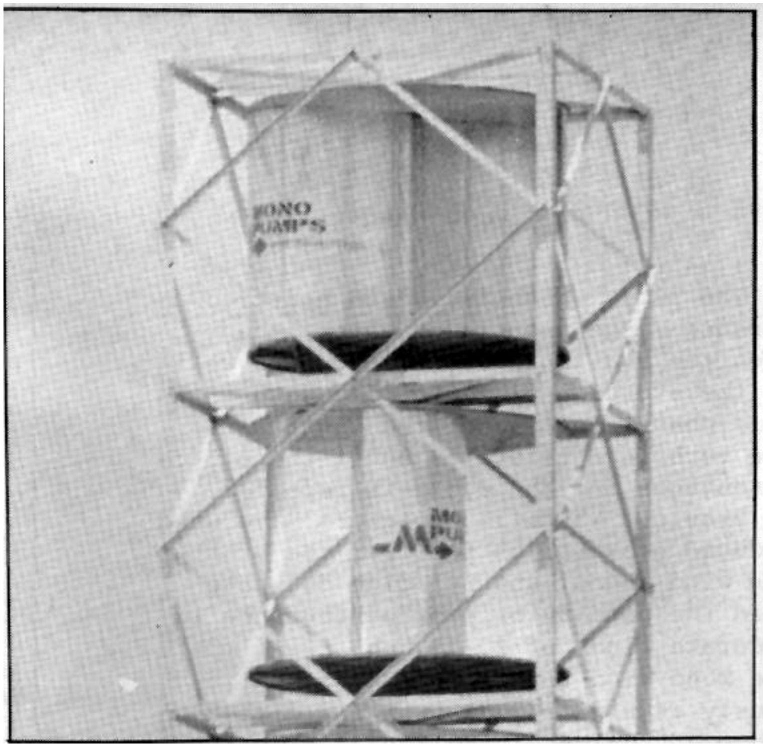
This has two parts: the airscrew with its bearing and motor-drive, and the pivot which is fixed to the tripod and allows the airscrew to rotate into the wind.

The pivot is formed by the main tube of the forks in which the front tube of the frame revolves. This has been separated from the rest of the frame' by sawing through the tubes which terminate in it, leaving enough length for the fixing of the mechanism, The cycle headset ball-bearing mounting has been kept as it was. It should be cleaned, greased and adjusted so that it rotates easily without any play.

The bearing of the airscrew is made from the rear forks of a bicycle frame from which only both horizontal tubes and the bottom bracket have been kept. The tubes are bent, as shown, near the small brace which separates them and then cut to different lengths to bolt on to the stubs of the tubes protruding from the pivot of the forks. To join these two pairs of tubes, they must be flattened and then drilled to accept bolts,

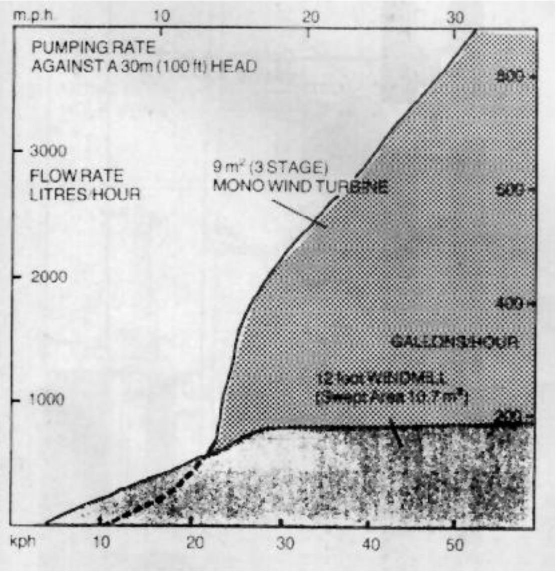


MONO WIND TURBINE



A SAVONIOUS REDEVELOPED

Over recent years a number of new wind turbines have appeared on the Australian market. These new turbines have been attempting to move in on the water pumping market, an area which has been dominated by the classic multi-vane wind pumps. One of these turbines was the Cobden wind turbine with its characteristic jet engine type appearance, The other wind turbine to appear was the Mono pump which is a development of the Savonius rotor type design.



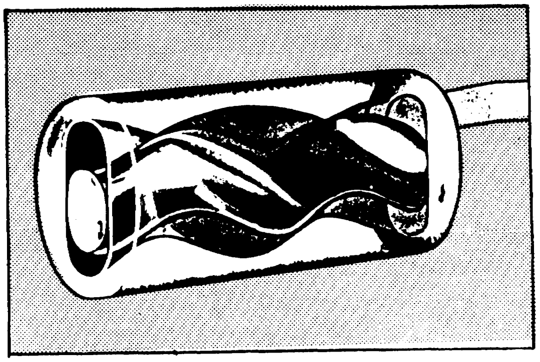
The manufacturers of these machines claim they have a higher efficiency with lower maintenance requirements. The S rotor design was selected after wind tunnel tests by a NSW University engineering team at Duntroon. Using a vertical axis rotor running on sealed bearings eliminates much of the machinery required at the tower head of existing mills and greatly reduces tower head maintenance.

A key component of the Mono pump is the clutch. The clutch has an "impulsive engagement" system which allows the drive to build up momentum at low wind speed. The clutch cuts in to allow pumping until the-momentum is used up, then cuts out while the rotors build up speed for the next input.

In winds between approximately 10-22 kph (643.5 mph), the turbine operates the pump in an intermittent manner. The cycle begins with the clutch disengaged. Without the drag of the pump the wind turbine stores the wind energy in its increasing rotational speed until it has sufficient speed to engage the clutch.

The pump, which is geared up to produce large amounts of water, then uses the available wind energy, as well as the stored energy, to pump water. In this phase, because of the light winds, the turbine decelerates until the clutch disengages and the cycle is repeated.

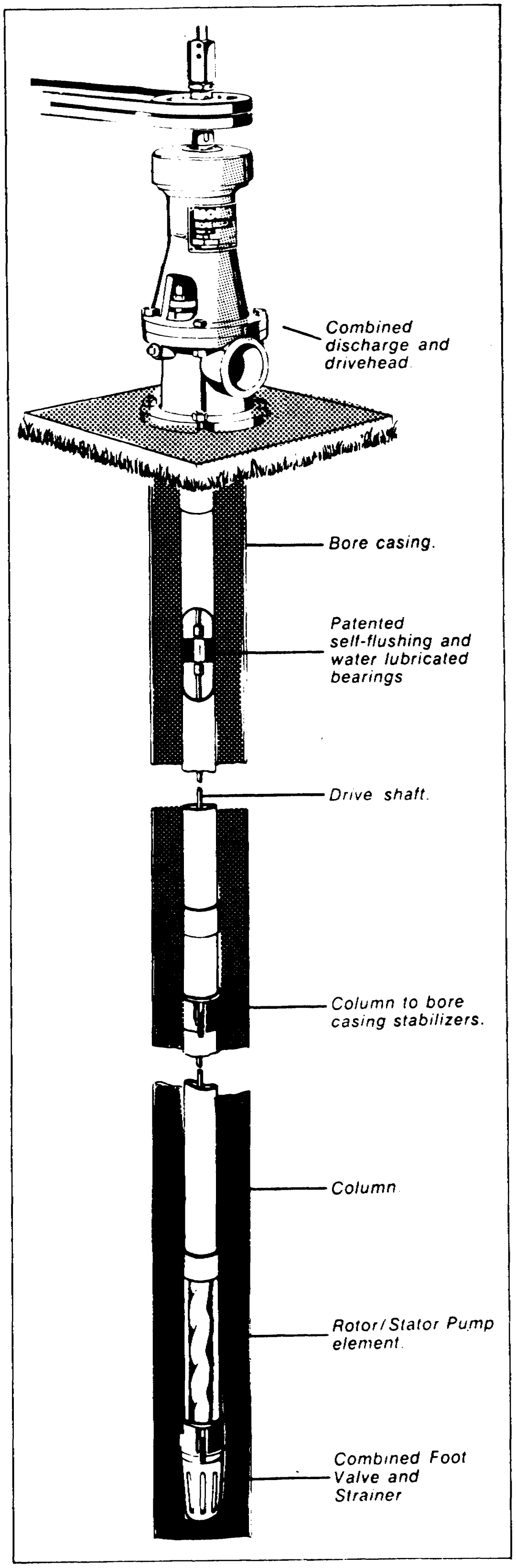
Previous windmill designers have used reduced gear ratios to lower the starting wind speed, and by doing so, have paid the penalty of poor performance in moderate winds of 20-46 kph (12-29 mph). The Mono Wind Turbine operates continuously at wind speeds from any direction above approximately 22 kph (1.5 mph).

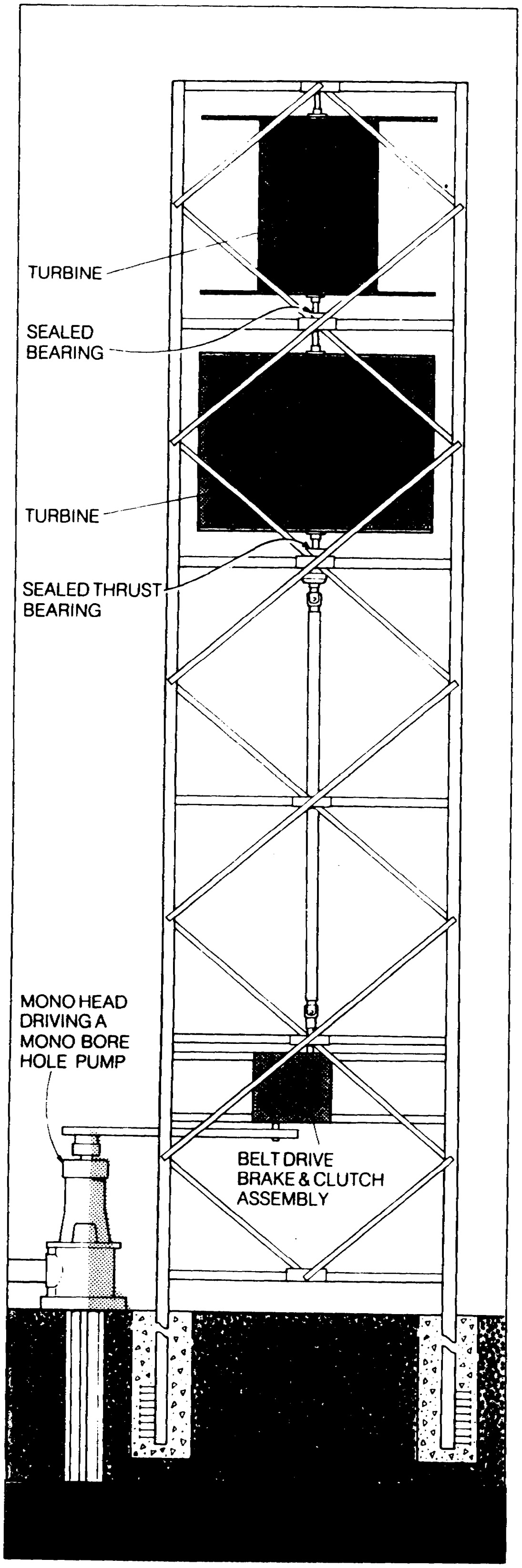


The Mono Pump has been designed to withstand wind gusts up to 160 kph (100 mph). A brake stops the wind turbine when sufficient water has been raised, or auxiliary power is required. During periods when more water is needed an auxiliary electric or diesel power source can be attached.

The Mono Pump uses a pump composed of a single helix metal rotor which revolves within a double helix resilient rotor. Rotor and stator are under continuous lubrication by the liquid being pumped. Because of the slow speed operation of the pump there is little wear and maintenance is minimized.

The manufacturers of the Mono Pump claim that their unit can pump more than twice the amount of water of a comparable multi-vaned unit.



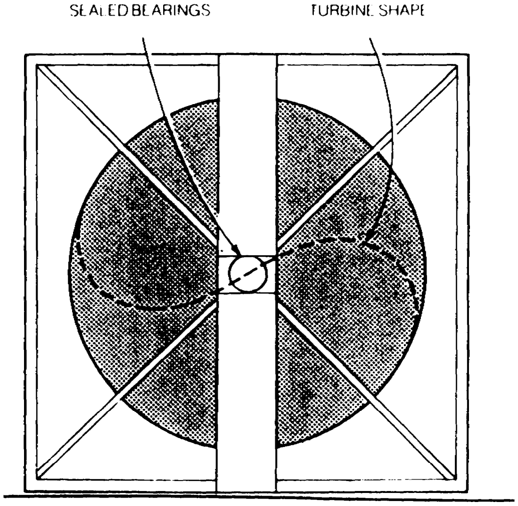


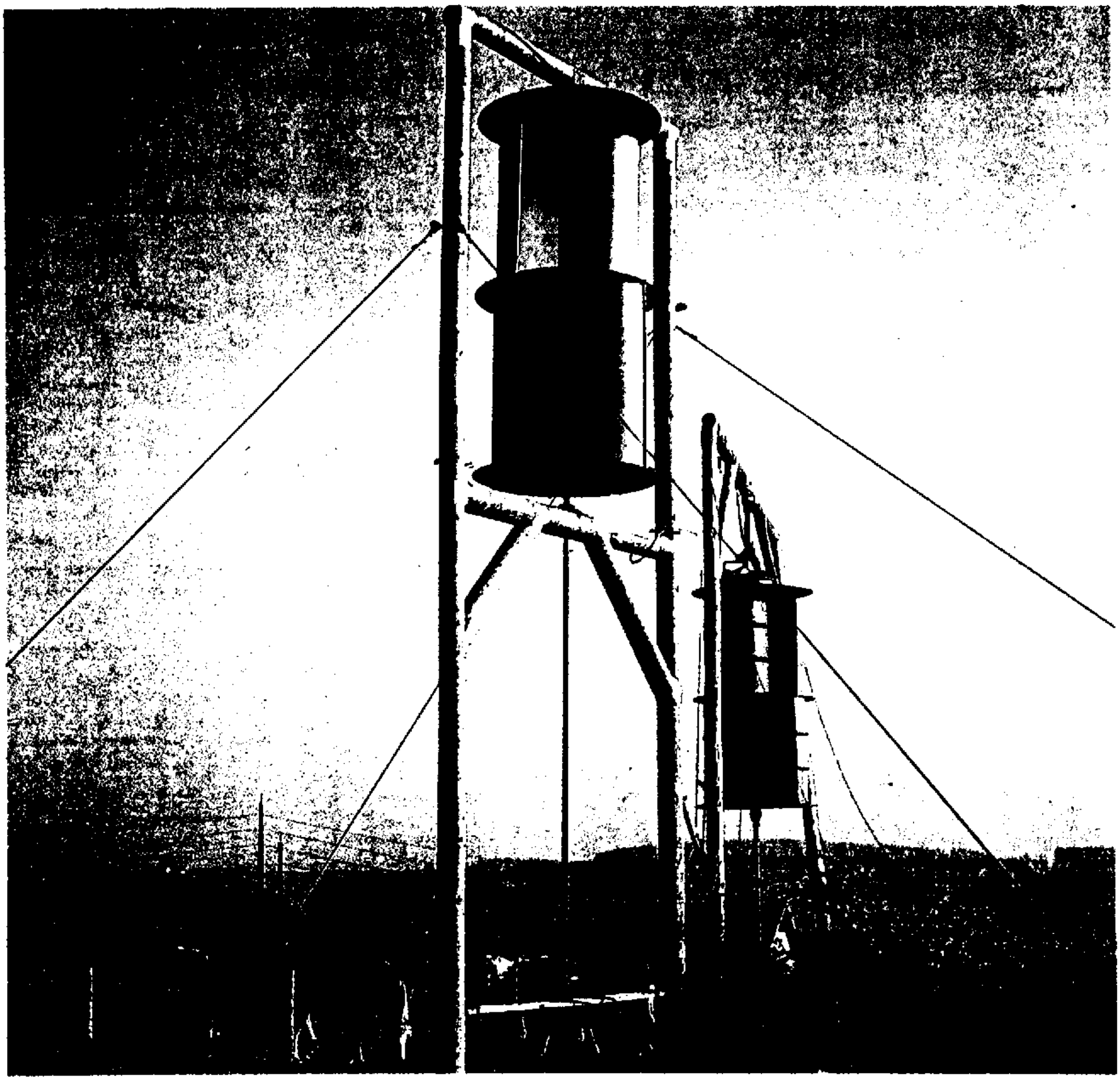
The Costs and Disadvantages

The biggest disadvantage of the Mono Pump is its cost. This can be close to five times the cost of a conventional multi-vaned wind pump. An installed Mono Pump with two tiers can cost $11,000 to $12,000 while an 8ft. wind pump would cost around $2,000. With this kind of price difference the Mono Pump has to be pretty good to beat the opposition.

Other questions can be asked about the claimed efficiency of the Mono Pump. The designers of the Mono Pump claim it uses the most efficient shape possible. However in the past all the available literature has stated that this shape is not the optimum. When Singurd J. Savonius of Finland invented the Savonius rotor, he conducted extensive tests on his design and found the optimum overlap for the rotor. This does not coincide with the Mono design.

Many of the Mono Pumps claims of improved design and greater efficiency will only be tested by time. Eventually we will know whether the claims are merely sales talk or true advances in wind water pumping technology. But the Mono Pump will have to be a lot more efficient and a lot easier to maintain if the added cost of the Mono Pump is not to be a disadvantage.





Heinz Schulz

Der Savonius Rotor

Eine Bauanleitung

ökobuch

CIP-Titelaufnahme der Deutschen Bibliothek

Schulz, Heinz:
Der Savonius-Rotor : eine Bauanleitung / Heinz Schulz
Staufen bei Freiburg i. Br.: ökobuch, 1989
ISBN 3 - 922 964 - 48 - 6

ISBN 3 - 922 964 - 48 - 6

Druck: Graphische Werkstatt GmbH, Kassel

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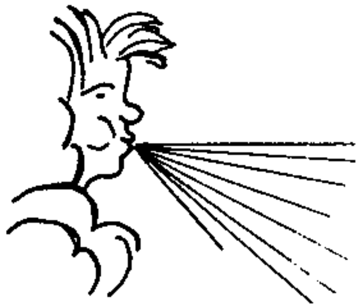
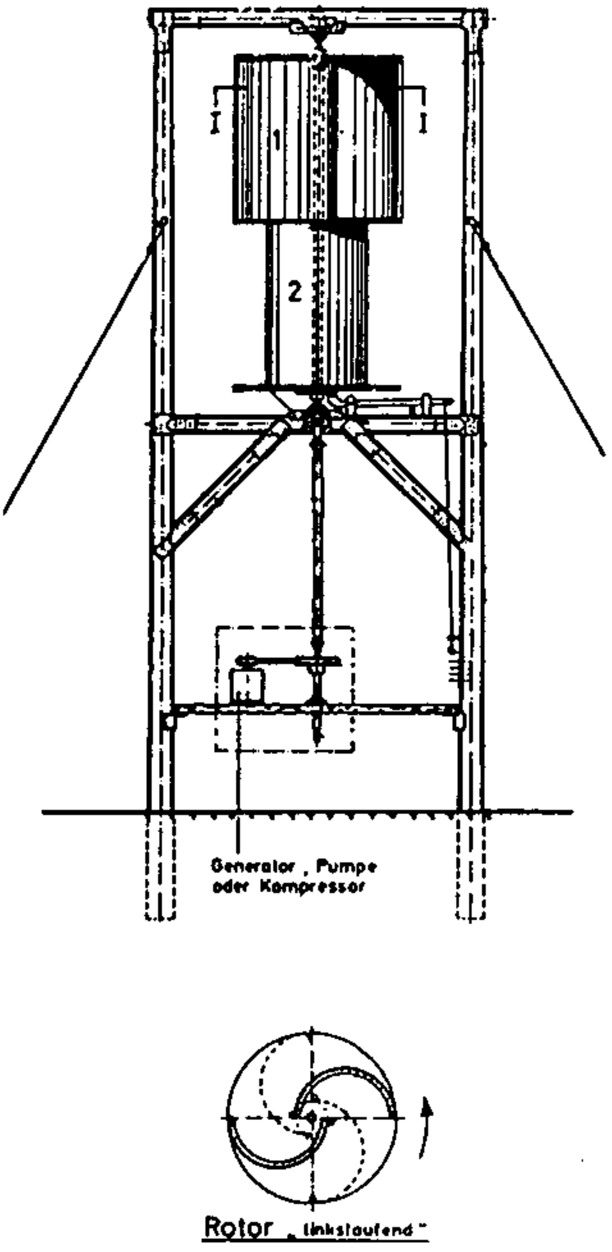
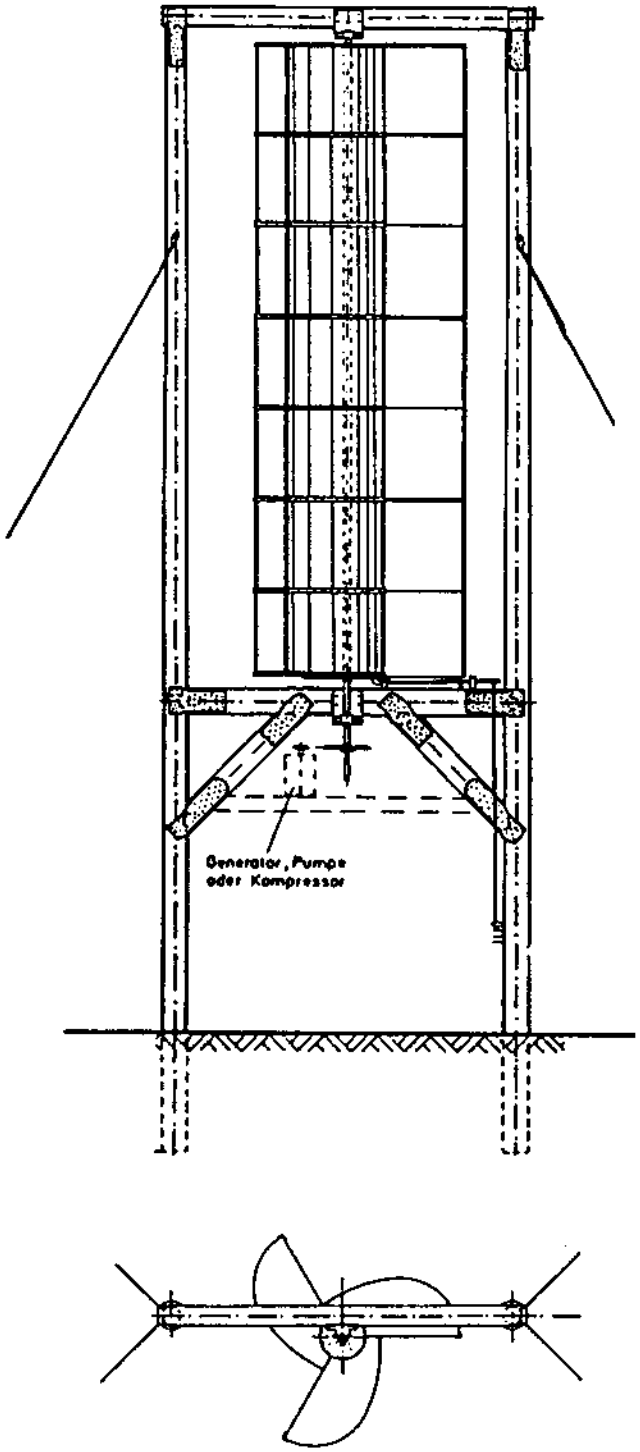




Savonius - Rotor



Durchströmrotor

1. Der Savonius-Rotor

1.1 Grundsätzliches

Der Savonius Rotor wurde um 1925 vom finnischen Schiffsoffizier Sigurd J. Savonius erfunden.

Ein Savonius-Rotor besteht aus 2 waagerechten Kreisscheiben, zwischen denen zwei senkrecht stehende, halbkreisförmig gebogene Flügel bzw. Schaufeln angebracht sind (Abb. 1 und 2). Diese werden in der Mitte um etwa 20% des Rotordurchmessers gegeneinander versetzt, so daß ein Teil des Windes von der gerade aktiven Schaufel umgelenkt wird auf die Rückseite der passiven. Je nach Anordnung der Schaufeln kann man links- oder rechtsdrehende Rotoren bauen.

Der Savonius-Rotor wurde in kleinen Ausführungen recht häufig zum Antrieb von Ventilatoren auf den Dächern von Transportfahrzeugen verwendet, wo der Fahrtwind die Schaufeln in Rotation versetzt. In neuerer Zeit gewinnt der Savonius-Rotor für Anwendungen mit kleiner Leistung in der dezentralen Energieversorgung zunehmende Bedeutung. Der Verfasser hat in der Zeit von 1976 bis 1979 mehrere Savonius-Rotoren gebaut, für unterschiedliche Anwendung eingesetzt und praktische Erfahrungen damit gesammelt. Nicht zuletzt aufgrund unserer ersten »Hinweise zum Bau und Betrieb von Savonius-Rotoren« haben geschickte Bastler zahlreiche weitere Anlagen erstellt, um kleinere Wasserpumpen und Gleichstromgeneratoren damit anzutreiben. In den 80 er Jahren wurde der Savonius-Rotor dann zum dreiflügeligen Durchström-Rotor weiterentwickelt, der sich auch für größere Anlagen im Leistungsbereich bis zu 2 kW gut eignet.

Um festzustellen, ob für den vorgesehenen Zweck ein Savonius-Rotor überhaupt geeignet ist, sollte man die Vor- und Nachteile dieses Systems im Vergleich zu modernen Windturbinen anderer Bauart kennen und abwägen.

Die *Vorteile* des Savonius-Rotors:

- Einfacher Aufbau aus leicht erhältlichen Werkstoffen, eventuell auch unter Verwendung von Altmaterialien (200 l - Ölfässer)
- Unabhängigkeit von der jeweiligen Windrichtung, daher keine Notwendigkeit zur Windausrichtung

- Direkte Kraftabgabe an eine senkrechte Welle, die bis in Bodennähe geführt werden kann und dort wahlweise oder gleichzeitig verschiedene Arbeitsmaschinen antreiben kann, je nach Bedarf und Windstärke. So läßt sich z.B. mit einer Anlage bei schwachem Wind Wasser pumpen und bei hohen Windgeschwindigkeiten zusätzlich noch Gleichstrom erzeugen.
- Ausnutzung eines großen Windstärkenbereichs: Richtig gebaute Savonius-Rotoren können im Gegensatz zu vielen anderen Windturbinen, die auf bestimmte Windgeschwindigkeiten optimiert sind, sowohl extrem niedrige Windgeschwindigkeiten (2 - 3 m/s) wie auch mittlere (4 - 10 m/s) und hohe (15 - 25 m/s) nutzen. Dabei gilt natürlich das Gesetz, daß Drehzahl und Leistung mit zunehmender Windgeschwindigkeit steigen (die Drehzahl steigt linear, die Leistung mit der 3. Potenz der Windgeschwindigkeit).

- Die Koppelung mehrerer Savonius-Rotoren zu einer größeren Anlage mit relativ hoher Drehzahl ist möglich. Während bei Windturbinen mit horizontaler Achse eine Vergrößerung des Propeller- oder Raddurchmessers zwangsläufig die Drehzahl verringert und oft Getriebeprobleme mit sich bringt, bietet der Savonius-Rotor die Chance, die Turbinenfläche und damit die Leistung zu vergrößern, ohne daß die Drehzahl stark absinkt. Man koppelt dazu mehrere Rotoren mit geringem Durchmesser und damit hoher Drehzahl durch horizontalen oder vertikalen Verbund (Abb. 3).
- Erweiterungsmöglichkeiten bei Anlagen mit horizontaler Koppelung der Rotoren: Man kann zunächst mit einer kleineren Anlage beginnen und diese bei steigendem Energiebedarf später nach einer oder beiden Seiten vergrößern, indem man weitere Rotorfelder anschließt. Dabei muß natür-

Abb. 1 ◄
Dies war der erste, vom Verfasser gebaute Savonius-Rotor.
Zwei wasserfest verleimte Sperrholzplatten bildeten die Kreisscheiben, auf welche die Flügel aus halbierten Faßhälften aufgenietet sind. Eine ausrangierte, halbe Autoachse mit Felge und Bremstrommel dient zur Lagerung.

Abb. 2 ►
Montiert auf dem First eines Scheunendaches konnte dieser Savoniusrotor von unten durch Ziehen an einem Seil bei Sturm abgebremst werden. Die einseitige Lagerung in Verbindung mit einer Unwucht führte nämlich zu starken Vibrationen bei hohen Drehzahlen.

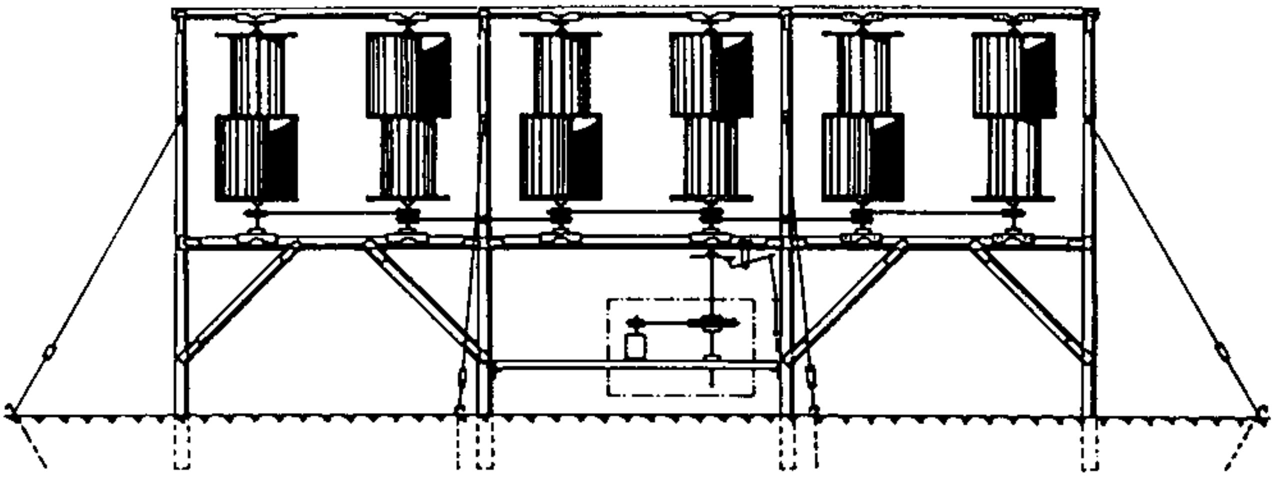
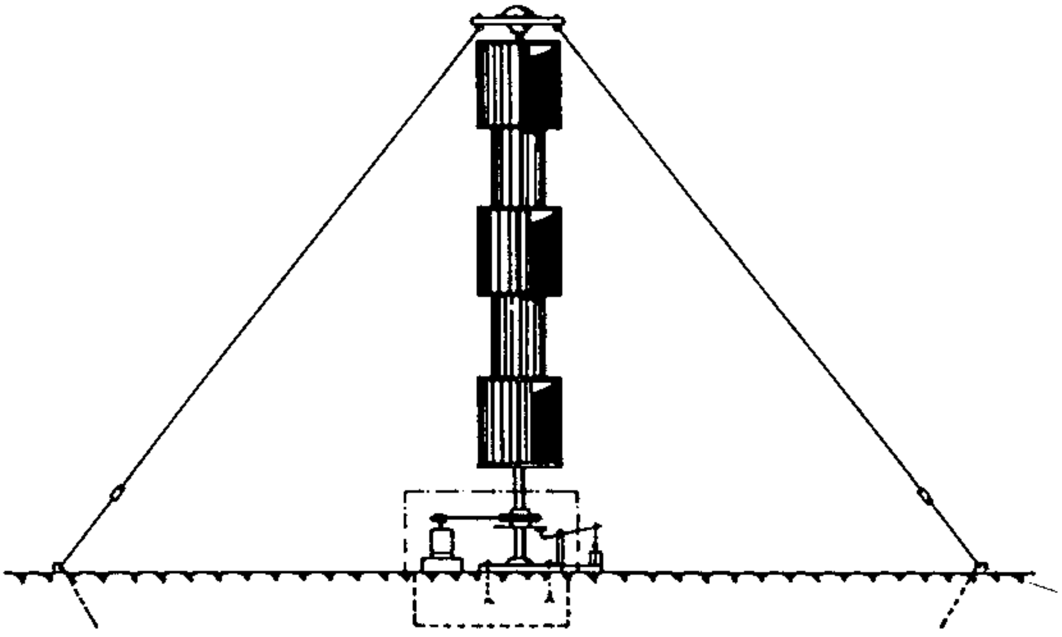


Abb. 3: Vorschläge für die Koppelung mehrerer Savonius-Rotoren

oben: Anordnung mehrerer Doppel- oder Dreifachrotoren nebeneinander quer zu den Hauptwindrichtungen; Koppelung der einzelnen Rotoren durch Riemen- oder Kettentrieb; Kraftabnahme an einer Zentralwelle; Erweiterungsfähigkeit nach beiden Seiten

unten: Anordnung mehrerer Rotoren übereinander auf einer abgespannten Welle



lich die Zentralwelle das vergrößerte Drehmoment aufnehmen. Die Anlage wird quer zur Hauptwindrichtung aufgestellt.

- Hohe Sturmsicherheit bei richtiger Bauweise: Savoniusrotoren sind insbesondere unempfindlich gegen Wirbel und Turbulenzen.

Diesen, oftmals entscheidenden Vorteilen stehen aber auch typische *Nachteile* gegenüber, die beachtet werden müssen:

- Ungewöhnliches, wuchtiges Aussehen, an das man sich erst gewöhnen muß. Horizontalläufer mit wenigen, schmalen Propellern fallen bei Still-stand weniger stark auf; und in windschwachen Gebieten stehen Horizontalläufer zumeist, während sich Savonius-Rotoren wegen ihrer größeren Angriffsfläche häufiger drehen.

- Hohes Rotorgewicht, das durch die Verwendung billiger Materialien zwar kostenmäßig nicht stark zu Buche schlägt, aber eine sorgfältige Auswuchtung nötig macht, um kritische Schwingungen bei hohen Drehzahlen zu vermeiden. Das hohe Gewicht wirkt sich besonders bei Böen gleichzeitig aber auch vorteilhaft, nämlich drehzahlstabilisierend, aus und vergrößert bei richtiger Rotorkonstruktion die Sturmsicherheit.
- Geringe Schnellaufzahl, das heißt relativ niedrige Drehzahlen und hohe Drehmomente: Wasserpumpen können direkt angetrieben werden, bei Generatoren müssen kraftzehrende Getriebe-, Ketten- oder Keilriemenübersetzungen vorgesehen werden.
- Relativ niedriger Leistungsbeiwert (Wirkungsgrad): Moderne Propellerturbinen kommen auf höhere Werte, aber nur bei bestimmten Windgeschwindigkeiten. Im praktischen Betrieb gleicht der Savonius-Rotor diesen Nachteil aus, weil er über einen größeren Windstärkenbereich Leistungen abgeben kann.
- In der deutschen Literatur gibt es nur wenige brauchbare Veröffentlichungen über den Savonius-Rotor. Umfangreiche Arbeiten sind inzwischen jedoch im englischsprachigen Raum erschienen (siehe Literaturhinweise), die allerdings im Original häufig nur schwer zu beschaffen sind.

1.2 Die Konstruktion

Savonius-Rotoren kann man auf vielerlei Art und aus unterschiedlichen Materialien bauen, wobei sich für die Teller und Flügel Stahlblech, Leichtmetallblech, glasfaserverstärkter Kunststoff und wetterfest verleimtes Sperrholz anbieten. Für die Flügel von Rotoren mit 1 m Ø können notfalls auch Faßhälften (200 l-Rillenfässer) verwendet werden, wobei jedoch stärkere Unwuchten auftreten können.

Um ein gleichmäßiges Drehmoment zu erhalten, empfiehlt es sich, die Anlage zweistufig mit um 90° versetzten Rotorstufen zu bauen. Damit steht immer ein Flügel voll im Wind und der Rotor kann auch bei geringen Windstärken leicht anlaufen. Eine dreistufige Anordnung mit um 60° versetzte Stufen bringt hingegen keine entscheidende Verbesserung des Drehmomentenverlaufes mehr.

Nur sehr kleine Savonius-Rotoren unter 50 cm Rotordurchmesser sollte man selbsttragend und mit einseitiger Lagerung bauen. Besser - und bei größeren

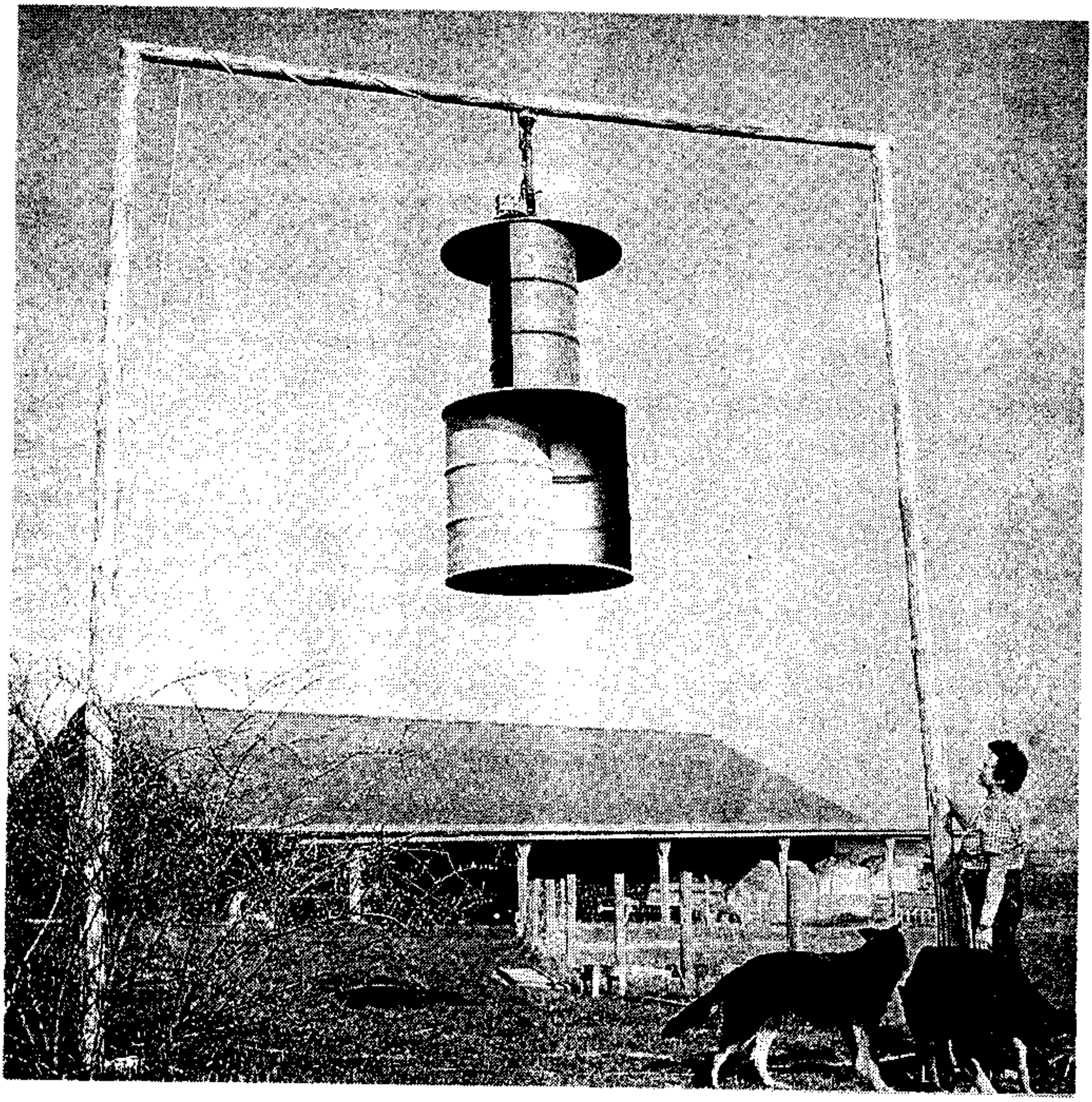


Abb. 4: Pendelnd oben aufgehängter, zweistufiger Savonius-Rotor.

Die Lichtmaschine zur Gleichstromerzeugung sitzt über dem oberen Teller. Diese Anordnung ist sturmsicherer und unempfindlicher gegenüber Unwucht als die einseitig starre Lagerung wie in Abb. 1 und 2.

Rotoren über 1 m Ø auch leichter zu beherrschen - ist es, die Teller mit einer durchgehenden Welle aus Stahlrohr zu verbinden. Bei einseitiger, starrer Lagerung besteht aber auch hierbei noch die Gefahr, daß der Rotor bei Sturm in kritische Schwingungen gerät. Eine einseitige Lagerung ist daher nur zu empfehlen, wenn man den Rotor wie eine Glocke am oberen Teil pendelnd mit einem Kardangelenk aufhängt (Abb. 4). Er kann sich dann bei vorhandener Unwucht nicht mehr so stark aufschwingen und schwenkt bei hohen Windgeschwindigkeiten selbsttätig aus. Noch besser hat sich die doppelte Lagerung

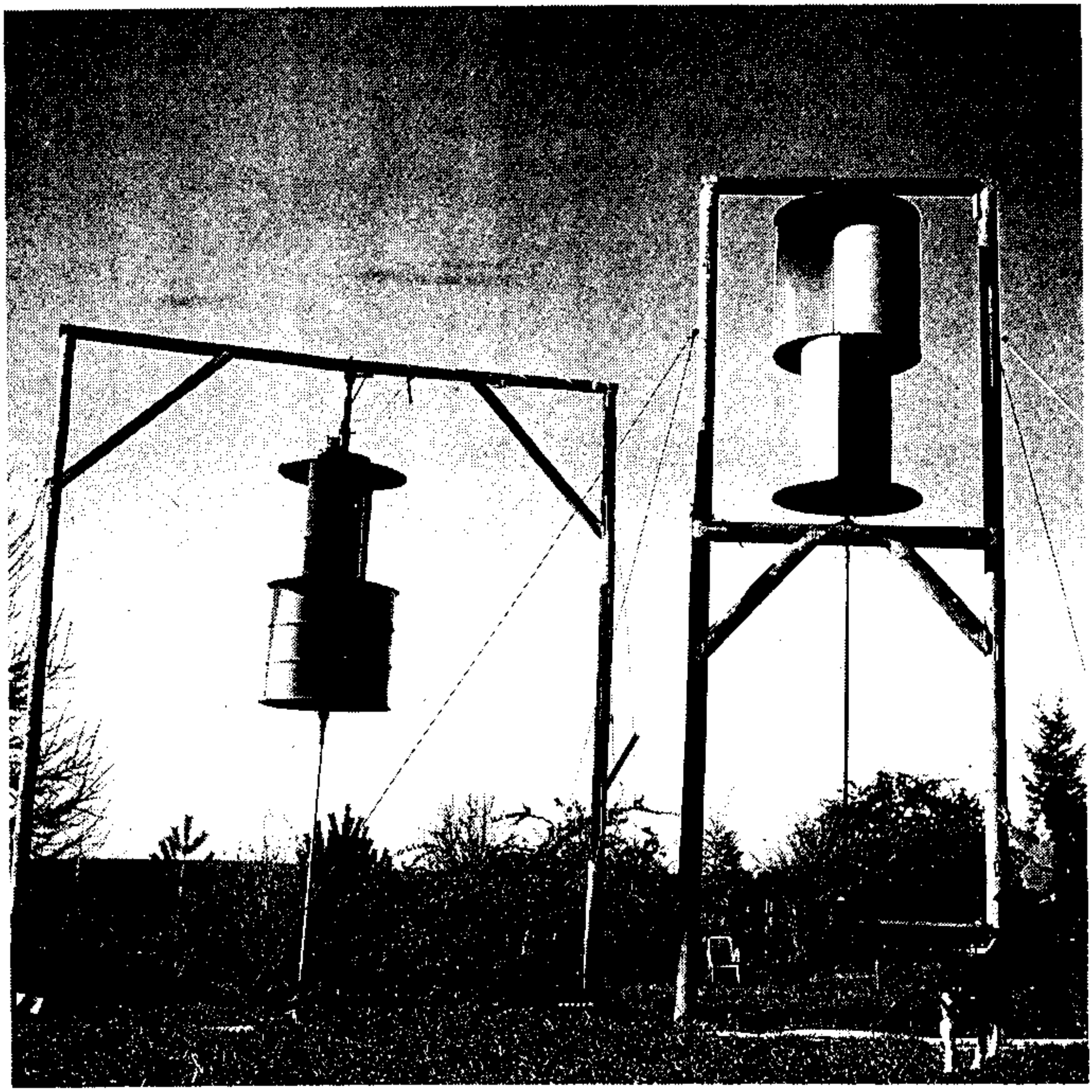


Abb. 5
Rechts die empfehlenswerte Anordnung von Savonius-Rotoren, wie sie auch in Abb. 6 und 7 zeichnerisch im Detail dargestellt ist. Links die pendelnd aufgehängte Ausführung mit einer zum Boden führenden Kardanwelle, die eine Wasserpumpe antreibt.

einer durchgehenden Welle bewährt, wie sie in den Abb. 5, 6 und 7 dargestellt ist. Der Querschnitt des Luftkanals zwischen den Flügeln wird durch die Welle zwar verringert, doch hat sich herausgestellt, daß dies im praktischen Betrieb nicht leistungsmindernd wirkt. Der Wellendurchmesser sollte allerdings nicht größer sein als 25% der Luftkanalbreite.
Der nachfolgend beschriebene Aufbau hat sich bisher gut bewährt. Anlagen dieser Bauart haben Windgeschwindigkeiten bis zu 25 m/s nicht nur ausgehalten, sondern auch genutzt.

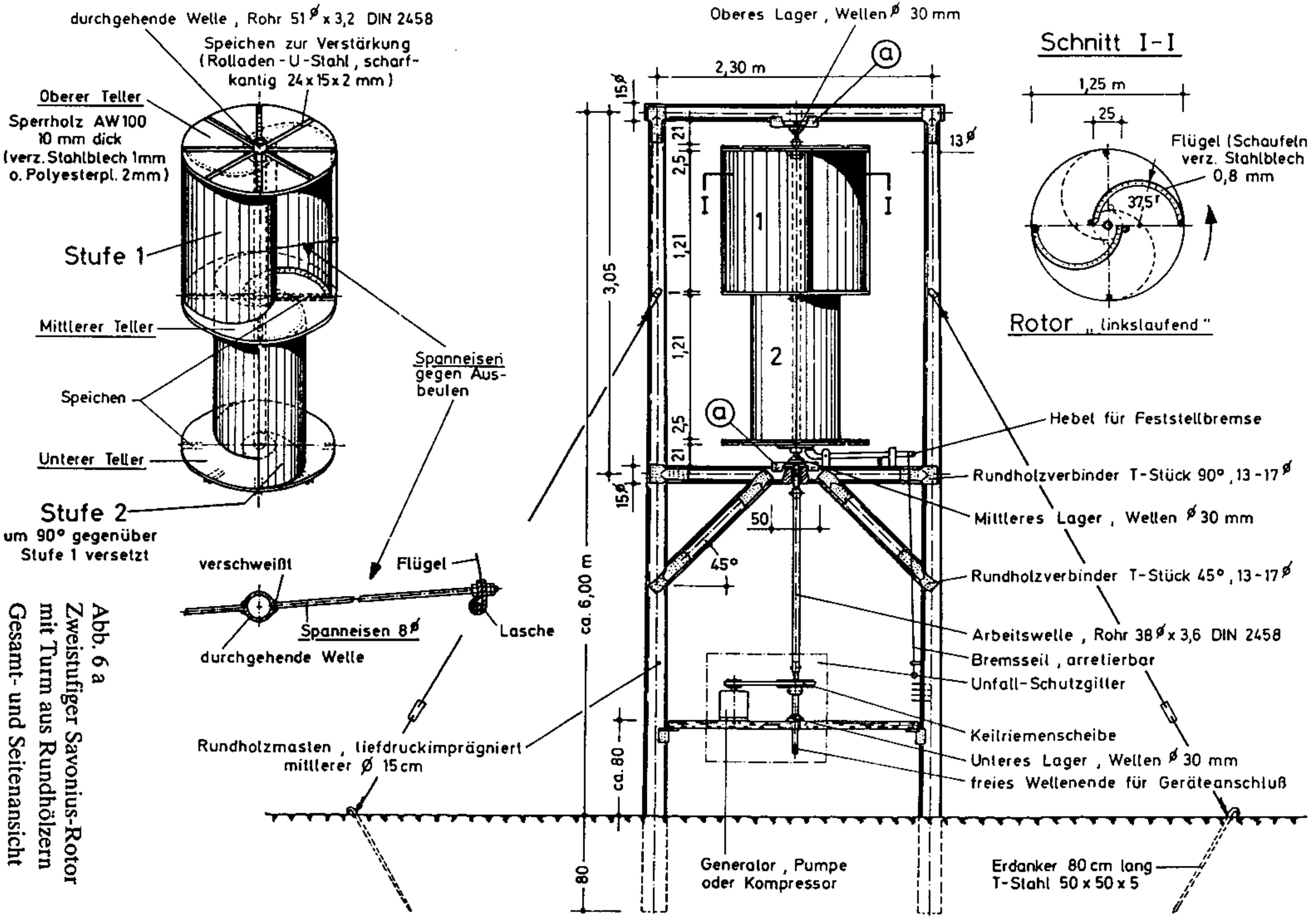
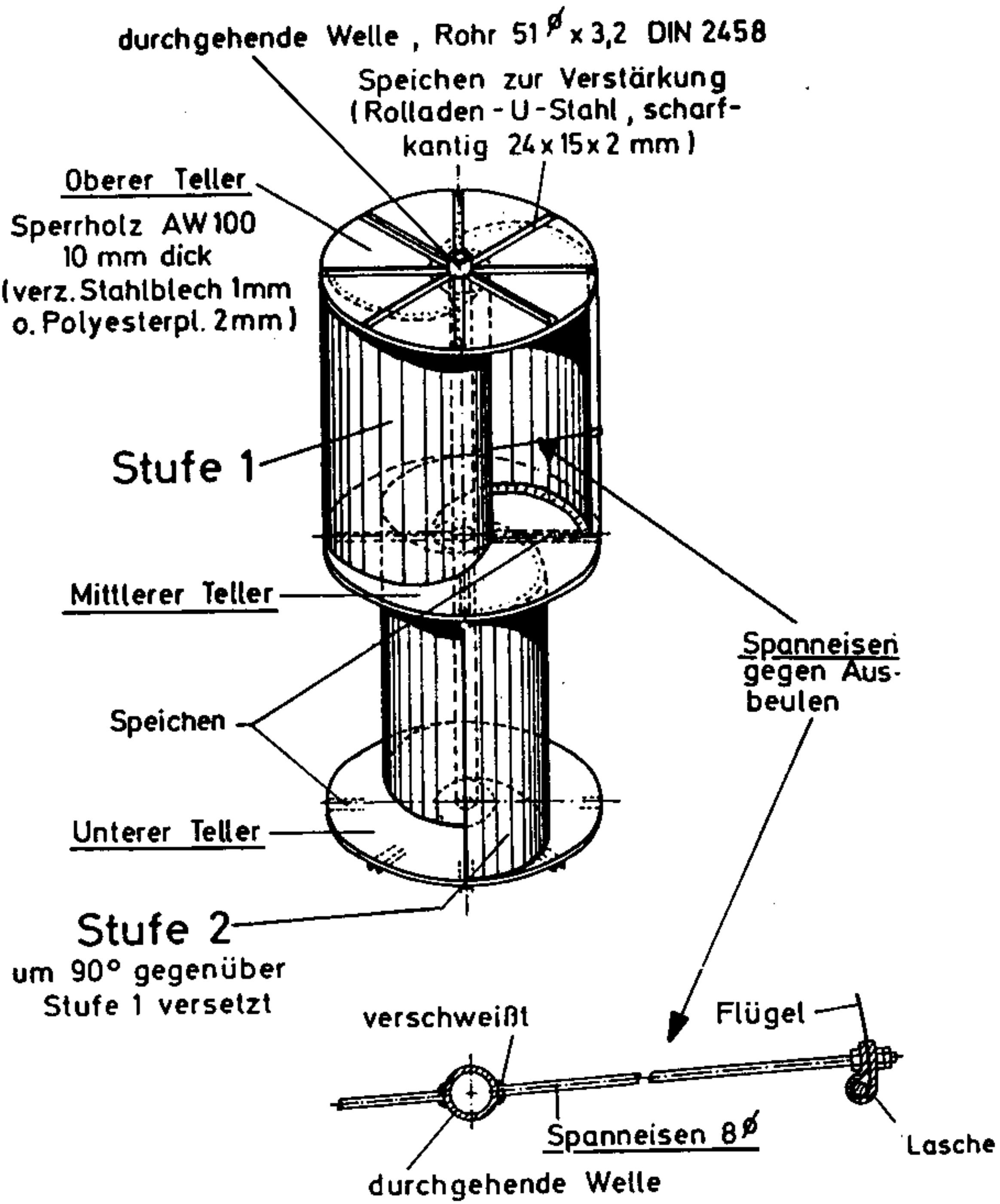
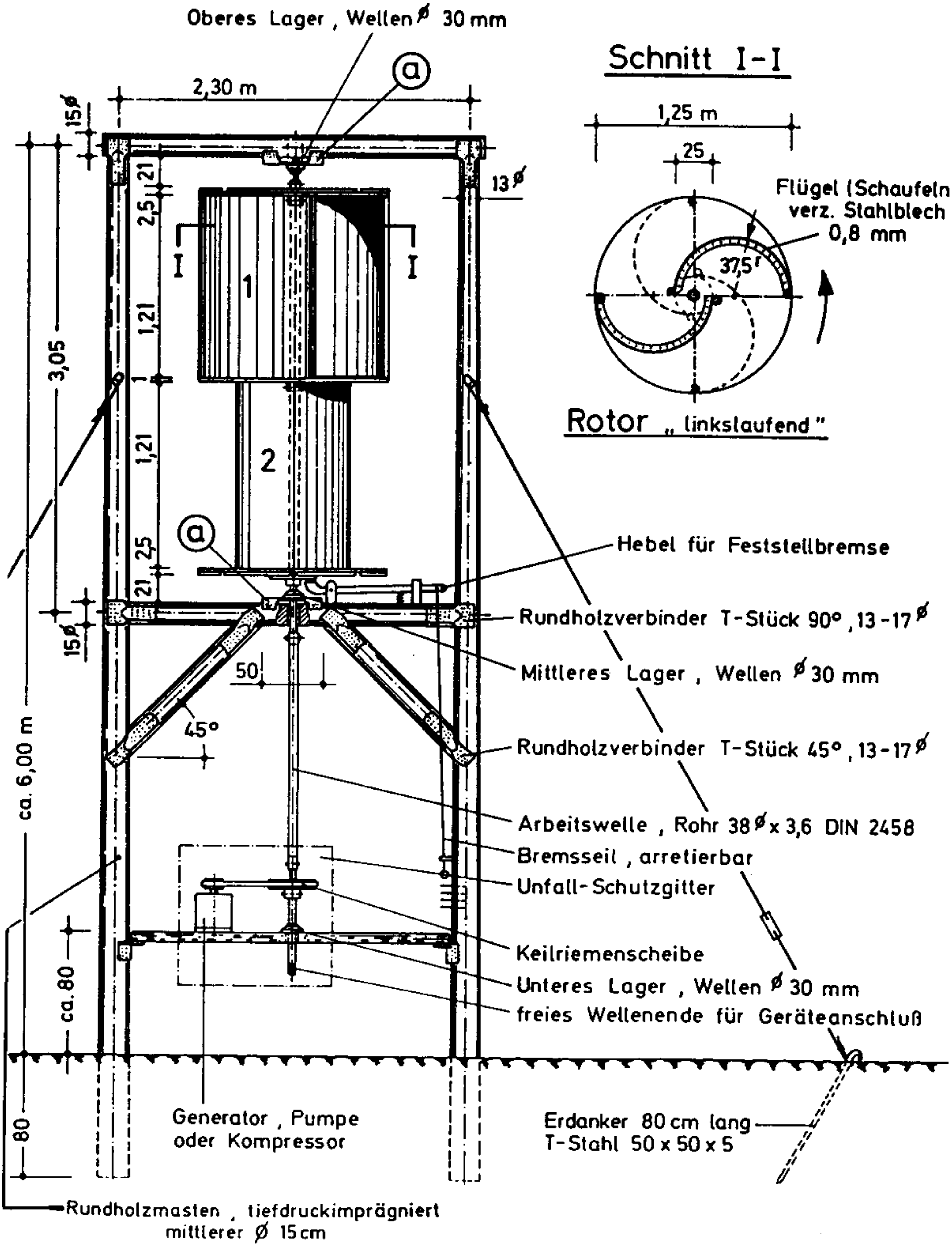
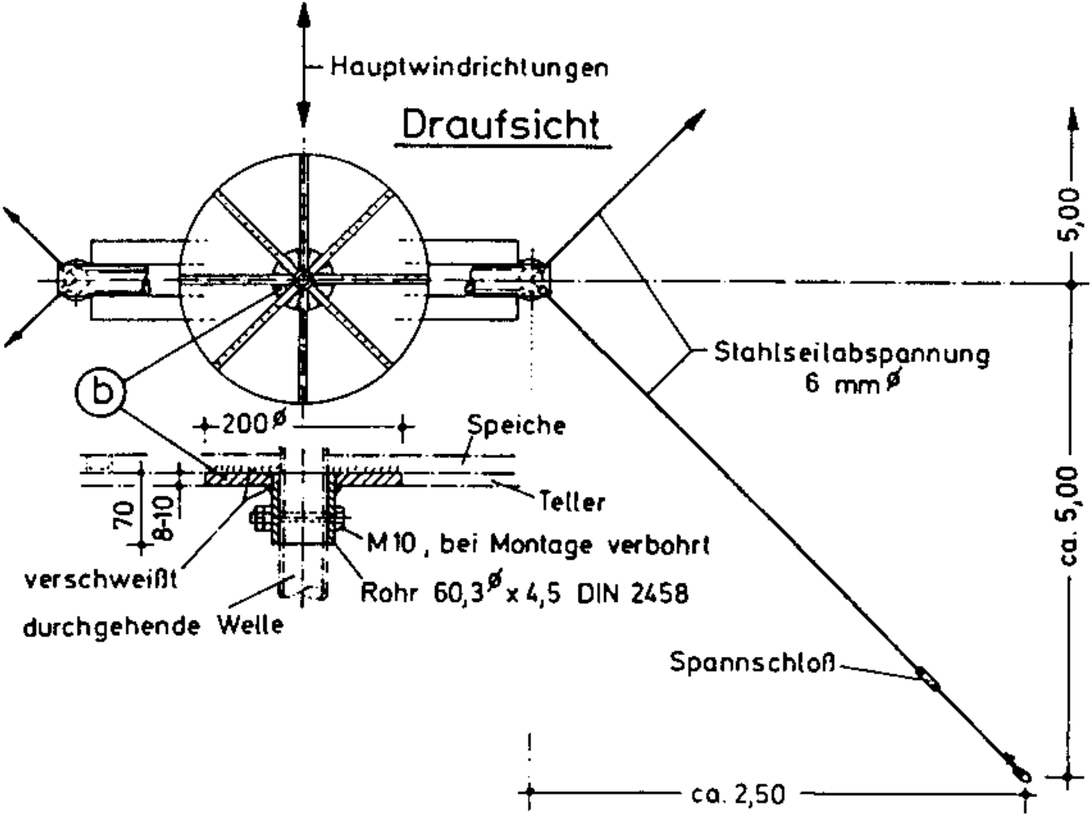


Abb. 6 a
Zweistufiger Savonius-Rotor
mit Turm aus Rundhölzern
Gesamt- und Seitenansicht


durchgehende Welle , Rohr 51 ø x 3,2 DIN 2458
Speichen zur Verstärkung (Rolladen - U - Stahl , scharfkantig 24 x 15 x 2 mm)
Oberer Teller
Sperrholz AW 100 10 mm dick (verz. Stahlblech 1mm o. Polyesterpl. 2mm)
Stufe 1
Mittlerer Teller
Spanneisen gegen Ausbeulen
Speichen
Unterer Teller
Stufe 2 um 90° gegenüber Stufe 1 versetzt
verschweißt
Flügel
Spanneisen 8 ø
Lasche
durchgehende Welle


Oberes Lager, Wellen Ø 30 mm
a
2,30 m
15Ø
13Ø
21
2,5
1,21
1,21
2,5
21
3,05
15Ø
I
I
1
2
a
50
45°
ca. 6,00 m
ca. 80
80
Schnitt I-I
1,25 m
25
Flügel (Schaufeln
verz. Stahlblech
0,8 mm
37,5r
Rotor „linkslaufend"
Hebel für Feststellbremse
Rundholzverbinder T-Stück 90°, 13-17Ø
Mittleres Lager, Wellen Ø 30 mm
Rundholzverbinder T-Stück 45°, 13-17Ø
Arbeitswelle, Rohr 38Ø x 3,6 DIN 2458
Bremsseil, arretierbar
Unfall-Schutzgitter
Keilriemenscheibe
Unteres Lager, Wellen Ø 30 mm
freies Wellenende für Geräteanschluß
Generator, Pumpe
oder Kompressor
Erdanker 80 cm lang
T-Stahl 50 x 50 x 5
Rundholzmasten, tiefdruckimprägniert
mittlerer Ø 15 cm


Hauptwindrichtungen
Draufsicht
5,00
Stahlseilabspannung
6 mm ø
b
200 ø
Speiche
Teller
70
8-10
M 10 , bei Montage verbohrt
verschweißt
Rohr 60,3 ø x 4,5 DIN 2458
durchgehende Welle
ca. 5,00
Spannschloß
ca. 2,50

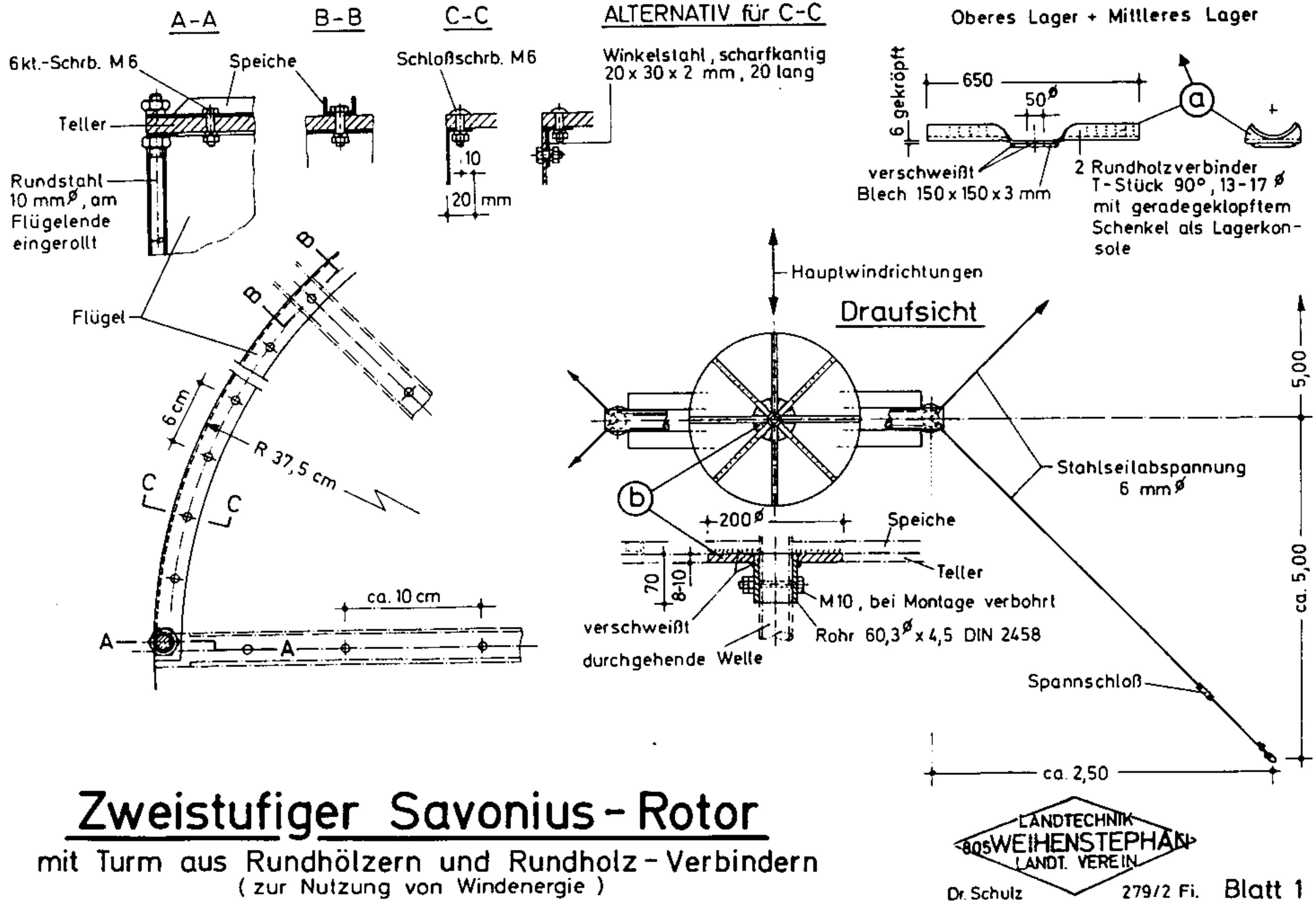
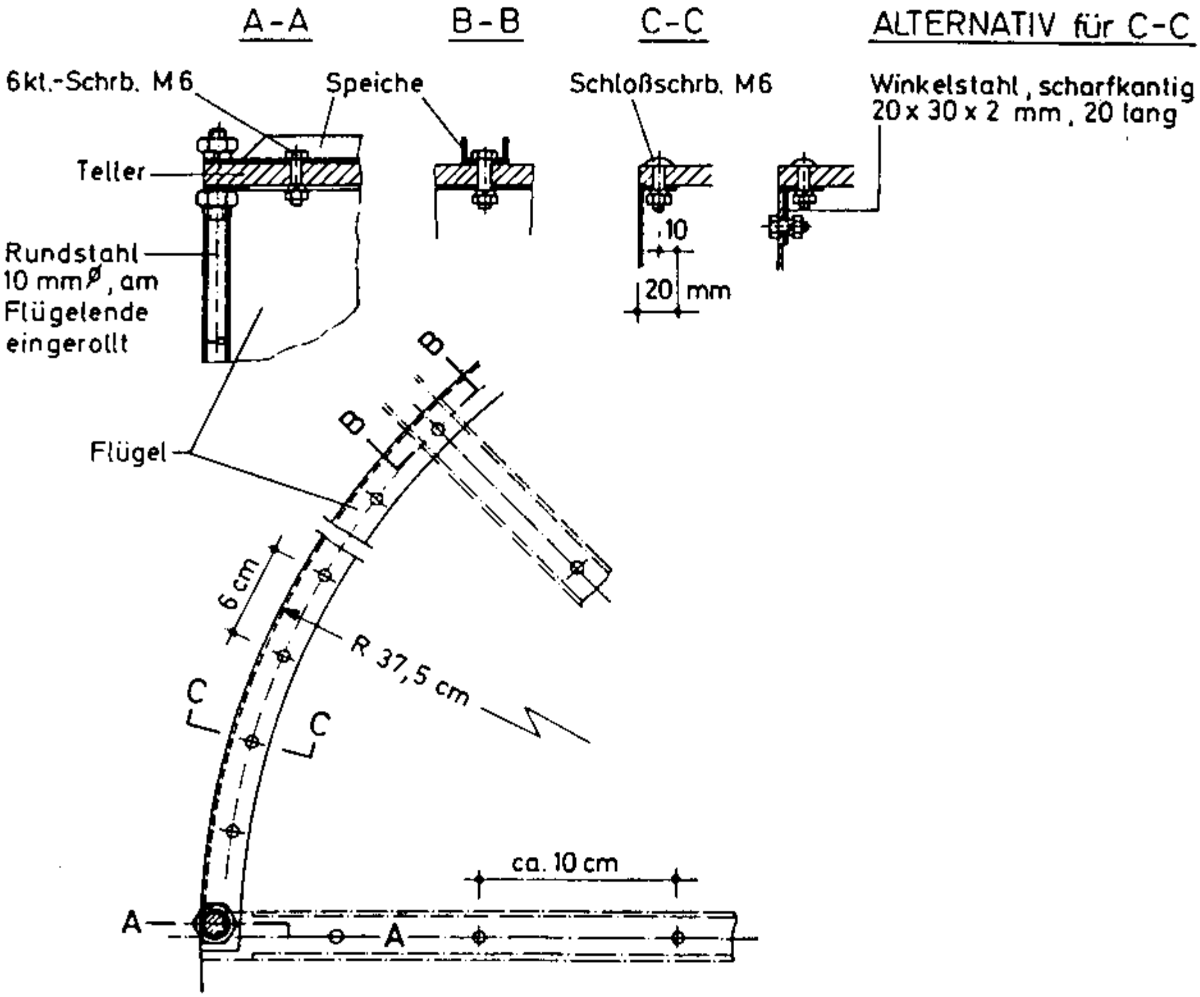
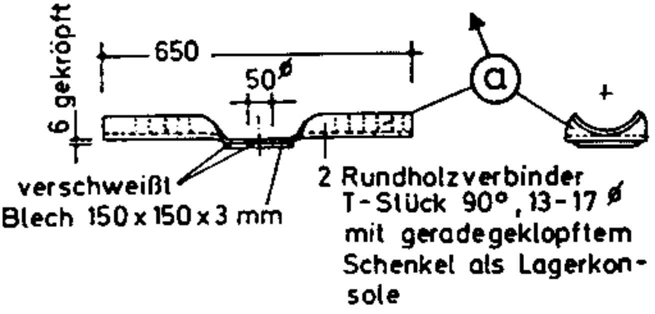
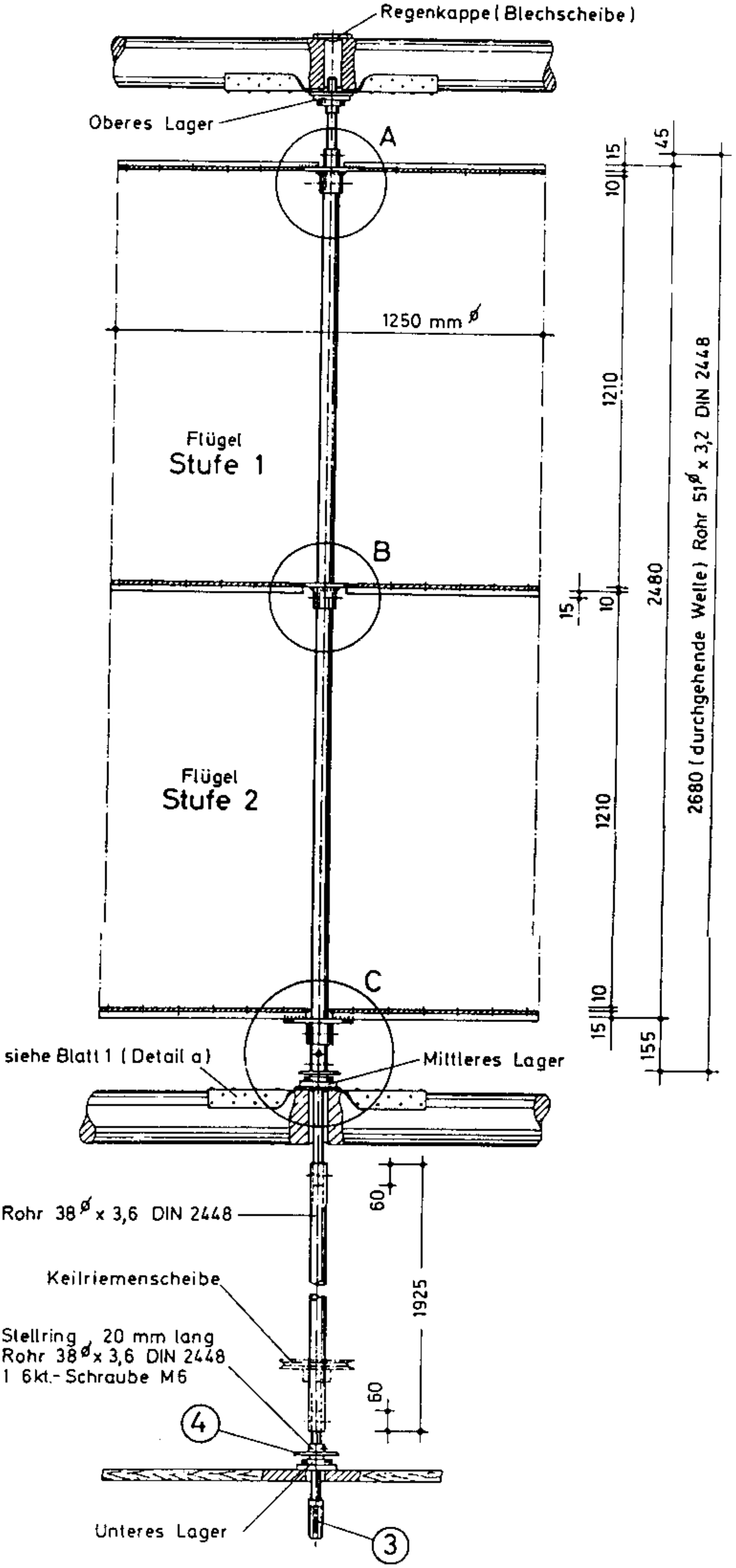


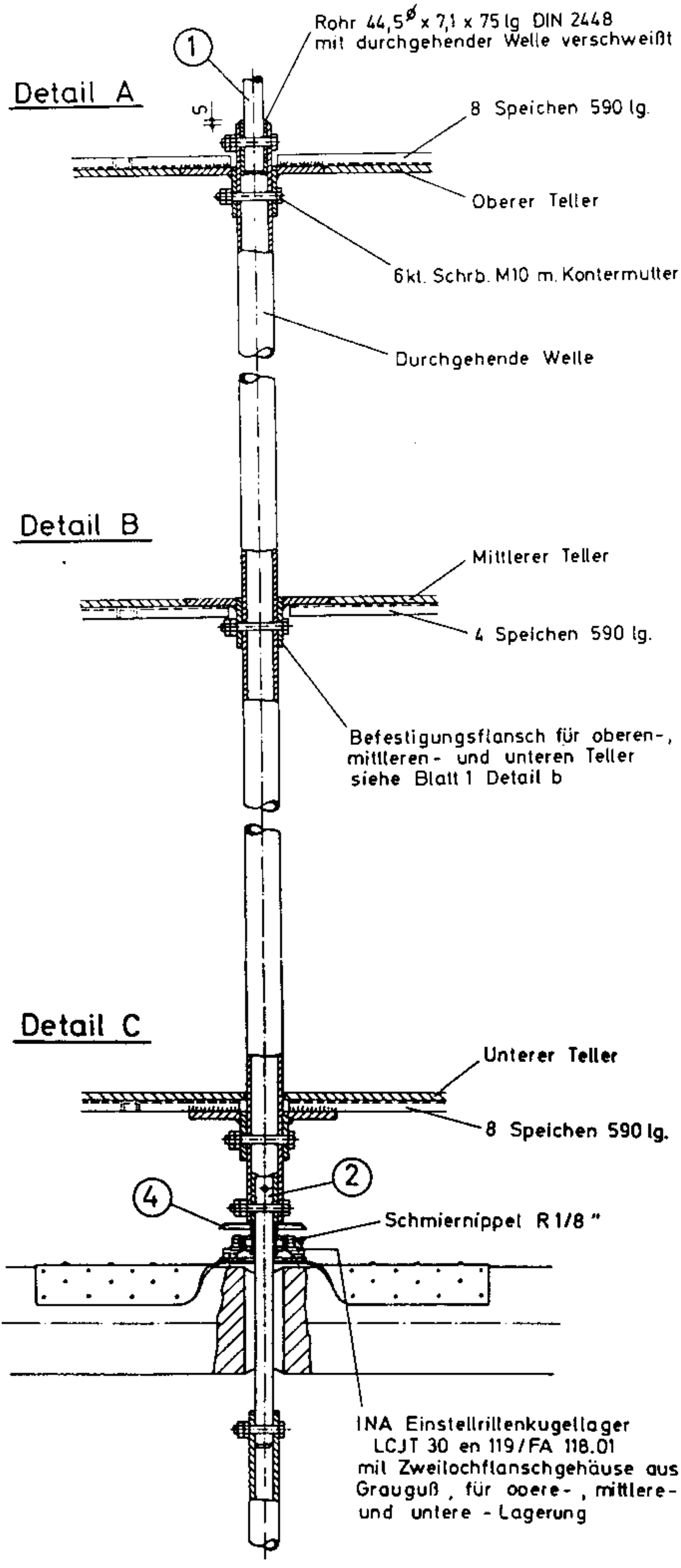
Abb. 6 b: Zweistufiger Savonius-Rotor mit Turm aus Rundhölzern
Details: Verbindung der Teller und Flügel; Montage der Lager

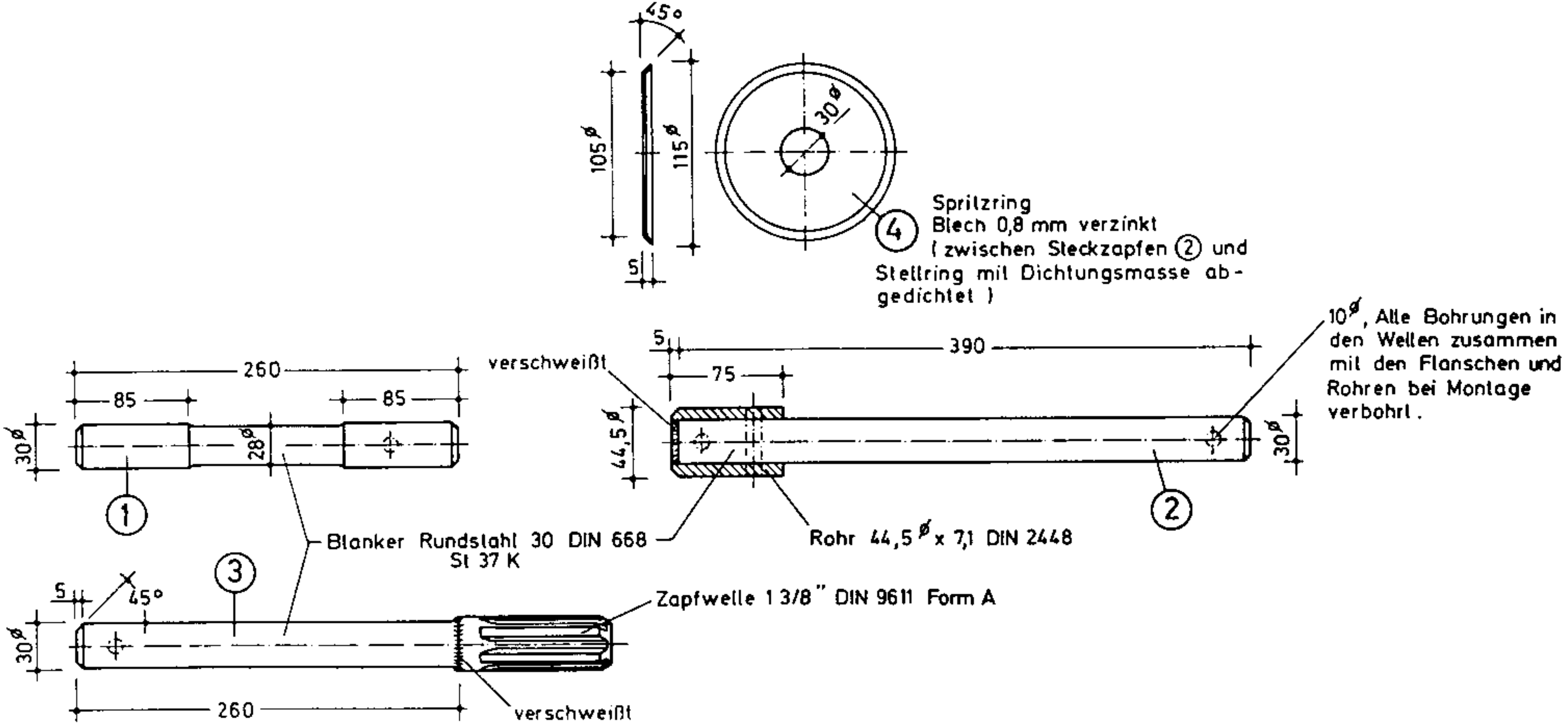


Oberes Lager + Mittleres Lager




Regenkappe (Blechscheibe)
Oberes Lager
A
45
15
10
1250 mm ⌀
1210
Flügel
Stufe 1
B
15
10
2480
2680 (durchgehende Welle) Rohr 51⌀ x 3,2 DIN 2448
Flügel
Stufe 2
1210
C
10
15
155
siehe Blatt 1 (Detail a)
Mittleres Lager
60
Rohr 38⌀ x 3,6 DIN 2448
1925
Keilriemenscheibe
Stellring, 20 mm lang
Rohr 38⌀ x 3,6 DIN 2448
1 6kt.-Schraube M6
60
④
Unteres Lager
③


Detail A
①
Rohr 44,5Ø x 7,1 x 75 lg DIN 2448
mit durchgehender Welle verschweißt
5
8 Speichen 590 lg.
Oberer Teller
6kt. Schrb. M10 m. Kontermutter
Durchgehende Welle
Detail B
Mittlerer Teller
4 Speichen 590 lg.
Befestigungsflansch für oberen-,
mittleren- und unteren Teller
siehe Blatt 1 Detail b
Detail C
Unterer Teller
8 Speichen 590 lg.
②
④
Schmiernippel R 1/8"
INA Einstellrillenkugellager
LCJT 30 en 119/FA 118.01
mit Zweilochflanschgehäuse aus
Grauguß, für obere-, mittlere-
und untere -Lagerung


45°
105ø
115ø
5
30ø
4
Spritzring
Blech 0,8 mm verzinkt
(zwischen Steckzapfen ② und Stellring mit Dichtungsmasse abgedichtet)
10ø, Alle Bohrungen in den Wellen zusammen mit den Flanschen und Rohren bei Montage verbohrt.
260
85
85
30ø
28ø
1
verschweißt
5
390
75
44,5ø
30ø
2
Blanker Rundstahl 30 DIN 668
St 37 K
Rohr 44,5ø x 7,1 DIN 2448
3
5
45°
30ø
Zapfwelle 1 3/8" DIN 9611 Form A
260
verschweißt

Der zweistufige Rotor mit 125 cm Ø und 250 cm Höhe ist in einem Turm aus tiefdruckimprägnierten Rundhölzern (Telefonmasten) gelagert, die mit Rundholzverbindern zusammengefügt werden. Diese vorgefertigten Rundholzverbinder (System Weihenstephan) werden auf die Verbindungsstellen der stumpf gestoßenen Hölzer genagelt oder geschraubt und erzielen hohe Festigkeiten. Es gibt sie aus verzinktem Stahlblech in verschiedenen Formen und Größen (siehe Bezugsquellenverzeichnis). Auch die Lagerkonsolen werden zweckmäßig aus Rundholzverbindern gefertigt. Turm und Abspannung sind aus Sicherheitsgründen etwas überdimensioniert, da noch keine Berechnungsgrundlagen für die an Savonius-Rotoren auftretenden Kräfte vorliegen. Anstelle der Seilabspannung könnte man die Masten auch in Betonfundamente einspannen, diese Lösung müßte jedoch noch berechnet und erprobt werden. Auch kann man natürlich anstelle der Rundholz-Konstruktion eine Ausführung mit Stahlprofilen wählen, was aber teuer werden dürfte. Zwischen Rotor und Masten muß ein Freiraum von mindestens 50 cm bleiben, da um den Rotor ein Luftfeld mitrotiert, das bei höheren Windgeschwindigkeiten leistungserhöhend wirkt (Magnus-Effekt). Dies trägt zur schon erwähnten Sturmsicherheit bei, weil es bei sehr hohen Windgeschwindigkeiten bis an die Masten reicht und dabei bremst.

Beim Bau des Rotors muß exakt gearbeitet werden, um einen möglichst guten Rundlauf zu erreichen. Auf die stabilisierenden Speichen (vgl. Abb. 6) sollte man bei dieser Rotorgröße nicht verzichten, da sonst zu große Materialstärken für die Teller erforderlich werden. Sehr wichtig sind die Spanneisen in der Mitte beider Rotorstufen, die verhindern, daß sich die Außenkanten der Flügel bei hohen Windgeschwindigkeiten durch Fliehkraft nach außen beulen bzw. zu flattern beginnen.

Bevor der Rotor montiert wird, muß er sorgfältig ausgewuchtet werden. Dazu legt man den Rotor waagerecht mit beiden Wellenenden so auf zwei Stahlschienen (Winkel- oder T-Eisen), daß er leicht abrollen kann. Die Schienen müssen selbstverständlich exakt mit der Wasserwaage ausgerichtet werden. Bei vorhandener Unwucht wird der Rotor in eine bestimmte Lage einpendeln. Auf der Gegenseite müssen nun Ausgleichsgewichte zunächst provisorisch angebracht werden, am besten an der Unterseite des mittleren Tellers möglichst nahe am Umfang. Durch Probieren werden Größe und Anordnung der Gewichte soweit ermittelt, daß der Rotor in jeder Stellung stehen bleibt und nicht mehr auf einen bestimmten Punkt pendelt. Die Ausgleichsgewichte werden dann endgültig festgeschraubt, und zwar so sicher, daß sie auch bei hohen Drehzahlen nicht abgeschleudert werden können.

Zur Lagerung des Rotors haben sich selbsteinstellende Ringrillenlager (Pendellager) bewährt. Sie brauchen nicht exakt fluchtend ausgerichtet werden und klemmen auch nicht, wenn der Turm sich einmal etwas verziehen sollte. Das mittlere und untere Lager ist durch einen Spritzring gegen Feuchtigkeit zu

schützen, die an der Rotorwelle herablaufen und selbst bei guter Abdichtung des Lagers in dieses eindringen kann. Man sollte auch Wert darauf legen, daß die Lager über Schmiernippel 2 x jährlich nachgeschmiert werden, um kleinere, sich unvermeidlich im Lager sammelnde Feuchtigkeitsmengen herauszudrükken.
Zur Montage der Anlage kann man Turm und Rotor am Boden montieren und gemeinsam z.B. mit Frontlader und Seilzug aufkippen. Hat man keinen Frontladerschlepper zur Verfügung, läßt sich auch der Turm in Einzelteilen stehend montieren und der Rotor mit einem Flaschenzug in die Lagerung heben.

1.3 Sicherheitstechnische Anforderungen

Zuerst eine *dringende Warnung*: Wer Windenergie nutzen möchte, muß sich darüber im klaren sein, daß er eine Naturgewalt beherrschen will! Spätestens beim ersten Sturm merkt er, welche Kräfte im Wind stecken und an den Materialien zerren. Alle wichtigen Schrauben sollten daher gesichert und nach dem Einlaufen nachgezogen werden. Eine Windturbine ist kein Gerät, das man hinstellen und problemlos nutzen kann, ohne sich auch darum kümmern zu wollen. Eine gewisse Mindestwartung (Kontrolle der Seilabspannung, Pflege der Lager, Nachziehen lockerer Schrauben) ist erforderlich, um die Anlage betriebs- und unfallsicher zu halten.

Ein sehr wichtiges Teil ist die Bremseinrichtung, die unbedingt in der Lage sein muß, den Rotor bei höchsten Windgeschwindigkeiten aus voller Drehzahl abzubremsen und festzustellen. Geschlossene Trommelbremsen haben sich nicht bewährt, da sie wegen der seltenen Nutzung leicht einrosten oder einfrieren. Eine offene Scheibenbremse mit direkter Betätigung durch Seilzug (keinen Bowdenzug verwenden!) erscheint besser (vgl. Abb. 6).
Die Arbeitswelle und die Arbeitsmaschine sind natürlich durch ein Schutzgitter abzusichern. Spielende Kinder müssen notfalls durch einen Schutzzaun ferngehalten werden. Die Angaben in dieser Schrift und den Zeichnungen entsprechen praktischen Erfahrungen, die im Einzelfall gemacht wurden. Gewähr für Haltbarkeit und Sturmsicherheit für den Nachbau an anderer Stelle kann natürlich nicht übernommen werden.

1.4 Leistungsmerkmale

Die Drehzahl eines Savonius-Rotors ist abhängig vom Rotordurchmesser, der Windgeschwindigkeit und der Belastung. Je größer der Rotordurchmesser, umso geringer ist die Drehzahl und umso höher das Drehmoment. Ohne Belastung ist die Umfangsgeschwindigkeit eines gut gebauten zweistufigen Savonius-Rotors etwa 1,8 mal so hoch, wie die Windgeschwindigkeit (Schnellaufzahl = 1,8). Hieraus kann man leicht die Leerlaufdrehzahl in Abhängigkeit von Rotordurchmesser und mittlerer Windgeschwindigkeit errechnen. Am beschriebenen Rotor wurden Spitzendrehzahlen von 500 U/min bei Windgeschwindigkeiten zwischen 12 und 20 m/s gemessen. Derartige Messungen geben aber nur Anhaltswerte, denn es ist außerordentlich schwer, Zeitpunkte mit stabilen Windgeschwindigkeiten und Rotordrehzahlen zu finden, da der Wind meist mehr oder weniger böig ist und der Rotor wegen seiner Schwungmasse nur träge auf wechselnde Windgeschwindigkeiten reagiert. Diese Fehlerquellen lassen sich nur durch eine Vielzahl von Meßwerten ausgleichen.

Unter Belastung sinkt die Drehzahl des Rotors natürlich ab. Die höchste Leistung (Produkt aus Drehmoment und Drehzahl) erbringt der Rotor, wenn

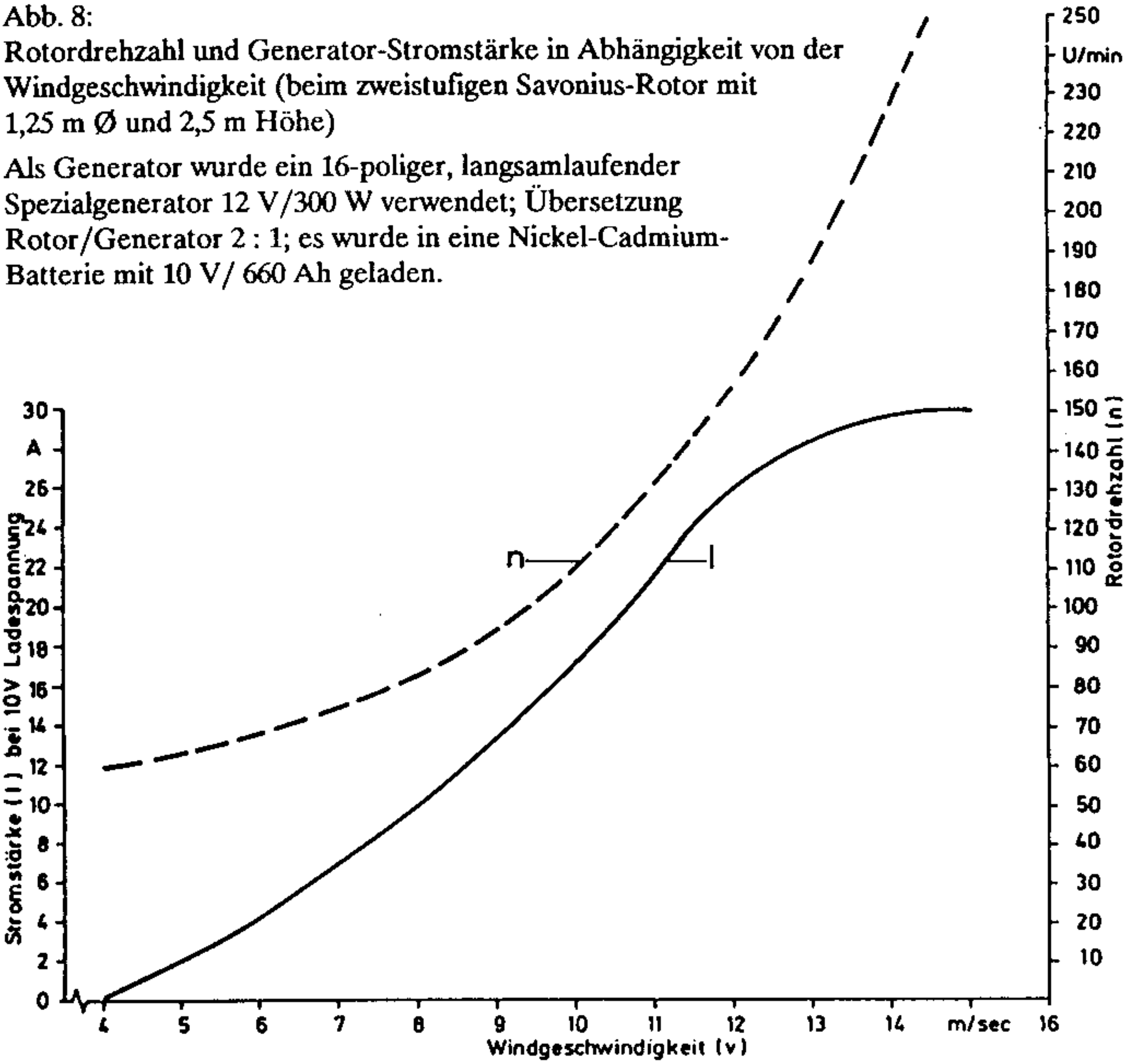


Abb. 8:
Rotordrehzahl und Generator-Stromstärke in Abhängigkeit von der Windgeschwindigkeit (beim zweistufigen Savonius-Rotor mit 1,25 m Ø und 2,5 m Höhe)

Als Generator wurde ein 16-poliger, langsamlaufender Spezialgenerator 12 V/300 W verwendet; Übersetzung Rotor/Generator 2 : 1; es wurde in eine Nickel-Cadmium-Batterie mit 10 V/ 660 Ah geladen.

seine Umfangsgeschwindigkeit in etwa der Windgeschwindigkeit entspricht (Schnellaufzahl 0,8 bis 1). In Abb. 8 sind Meßergebnisse mit dem später noch beschriebenen Generator der Windkraftzentrale zusammengefaßt. Man sieht, daß die Stromerzeugung hier bei 4 m/s Windgeschwindigkeit beginnt und zwar bei einer Ladespannung von 10 Volt (fast leere Batterie), einer Rotordrehzahl von 60 U/min und einer entsprechenden Generatordrehzahl von 120 U/min. Bei einer Windgeschwindigkeit von 12 - 14 m/s erreicht der Generator seine Höchstleistung von 300 W und wird elektronisch abgeregelt. An der stark ansteigenden Rotordrehzahl wird deutlich, daß die vom Rotor angebotene Energie nicht mehr voll genutzt werden kann.

1.5 Anwendungsgebiete

Obwohl Savonius-Rotoren auch für windschwache Gebiete geeignet sind, muß bei der Wahl des Standortes auf möglichst windgünstige Verhältnisse geachtet werden. Der Windschatten von Bäumen oder Gebäuden ist zu vermeiden.

Der beschriebene Savonius-Rotor eignet sich besonders gut für die Wasserförderung z.B. zur Hauswasser- und Weidetränken-Versorgung, zum Schwimmbeckenumwälzen, für Be- und Entwässerungszwecke und zum Füllen und Belüften von Fischteichen. Größere Anlagen könnten auch zur Wassererwärmung über Wirbelbremsen eingesetzt werden. Besonders interessant erscheint der Antrieb von Wärmepumpen, wenn es gelingt, Geräte für variable Drehzahlen zu entwickeln. Auch der Drucklufterzeugung kann Bedeutung zukommen, da Druckluft sich vielseitig verwenden und vor allem verlustlos speichern läßt. Außerdem ist eine einfache druckluftbetriebene Pumpe zur Wasserförderung aus großen Tiefen ab Seite 67 beschrieben.

Die Stromerzeugung ist bei sehr günstigen Windverhältnissen mit einem Spezialgenerator möglich, z.B. zum Aufladen von Batterien zur Versorgung eines kleinen Niedervolt-Netzes. Jagd- und Berghütten, Almen, und Campingplätze, Garten- und Wochenendhäuser, Teilaussiedlungen, Fischzuchtanlagen und ähnliche Einrichtungen können auf diese Weise mit dem allernotwendigsten Strom versorgt werden. Gut bewährt hat sich hier die Kombination der Windturbine mit einem Solargenerator zum Laden der Batterie in der windschwachen Sommerzeit.

Ungeeignet ist das Prinzip des Savonius-Rotors für den Bau großer Windkraftanlagen. Die Einsatzschwerpunkte dürften beim gegenwärtigen Entwicklungsstand vielmehr im Leistungsbereich unter 1 kW liegen - mit anderen Worten der Savonius-Rotor ist zumindest vorerst die Windturbine des kleinen Mannes auf dem Lande, der eine dezentrale Energieversorgung anstrebt.

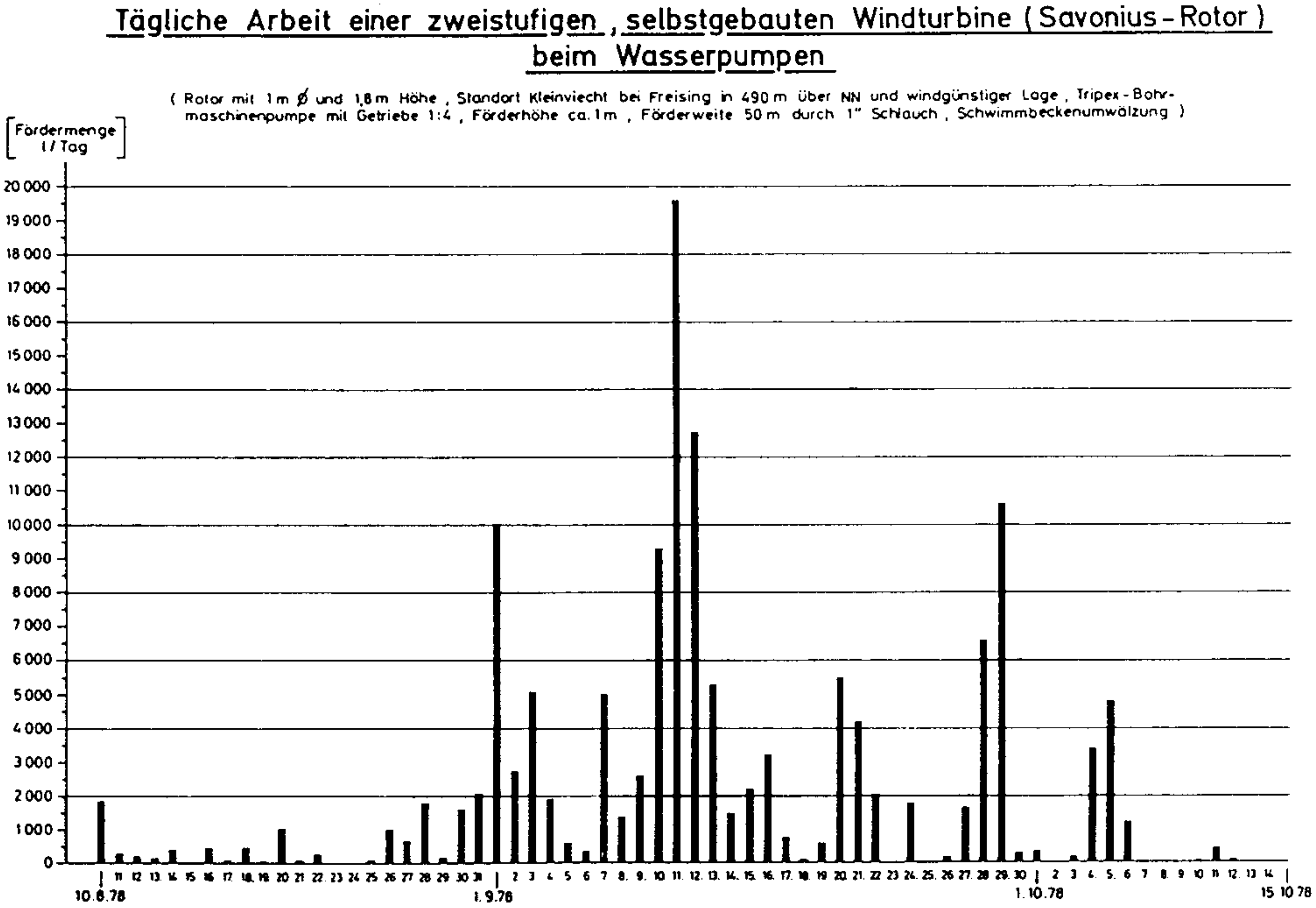


Abb. 9
Tägliche Arbeit eines zweistufigen, selbstgebauten Savonius-Rotors beim Wasserpumpen

2. Arbeitsmaschinen für kleine Windturbinen

Ein Hauptproblem bei der Nutzung von Windenergie ist es, Arbeitsmaschinen (Pumpen, Generatoren, Kompressoren) zu finden, die in ihrem Betriebsverhalten zur Leistungsabgabe der Turbine passen. Da bekanntlich die im Wind enthaltene Energie mit der 3. Potenz der Windgeschwindigkeit steigt, der Leistungsbedarf der meisten Arbeitsmaschinen aber linear oder höchstens im Quadrat mit der Drehzahl steigt, muß man bei der Dimensionierung der Arbeitsmaschine versuchen, einen Kompromiß für bestimmte Windgeschwindigkeiten zu finden.

Nun reizt aber gerade der Savonius-Rotor mit seinen guten Anlaufeigenschaften bei kleinen Windgeschwindigkeiten dazu, die *ganze* Windstärkenskala zu nutzen. Mit einer einzigen Arbeitsmaschine ist dies nur bei der Wärmeerzeugung durch Wasserwirbelbremsen (Schaufelrad im Wasserbad) oder mit fliehkraftgesteuerten Reibungsbremsen möglich, da die Leistung dieser Geräte ebenfalls mit der 3. Potenz der Drehzahl zunimmt. Übliche Pumpen und Generatoren haben hingegen nur in einem bestimmten Drehzahlbereich ihren optimalen Betriebspunkt. Man kann sich beim Savonius-Rotor mit seiner zum Boden führenden Welle aber insofern gut helfen, indem verschiedene Geräte angeschlossen bzw. gekoppelt werden. Membran-, Kolben- oder Exzenterrotorpumpen fördern schon bei niedrigen Windgeschwindigkeiten ab 1,5 m/s Wasser, während bei mittlerem Wind ab 4 m/sec Strom oder Druckluft erzeugt werden können.

Man kann diese Geräte nun von Hand oder automatisch (mittels Fliehkraft- oder Magnetkupplung) an- und abkoppeln und über eine Rollenkette oder ein Schlepperzapfwellen-Profil antreiben.

Ausprobiert wurden folgende Geräte, wobei über die Erfahrungen damit in den nächsten kapiteln berichtet werden soll:

1. Wasserpumpen mit über 2 m Förderhöhe
2. Drucklufterzeugung
3. Stromerzeugung mit Gleichstrom- und Wechselstrom-/Drehstrom-Maschinen

2.1 Wasserpumpen

Es wurden verschiedene Pumpen getestet und vermessen.

- Triplex-Bohrmaschinenpumpe: (Exzenter-Rotor mit Flachschiebern, Keilriemenantrieb 1 : 5, Preis ca. 50 DM) Tabelle 1 zeigt die für diese Pumpe gemessene Abhängigkeit der Förderleistung von der Windgeschwindigkeit. In Abbildung 9 ist eine längere Meßreihe mit dieser Pumpe dargestellt. Die Schwankungen der täglichen Fördermenge zeigen sehr deutlich den ungleichmäßigen Energiefluß des Windes.
- Apollo-Exzenterrollenpumpe Typ 128 (Preis ca. 400 DM): Diese Pumpe wird leider nicht mehr hergestellt. Sie wird normalerweise direkt mit der Zapfwelle angetrieben. Meßergebnisse zu dieser Pumpe finden sich ebenfalls in Tabelle 1.
- Apollo-Zahnradpumpe Typ Enorm 115 (Preis 415 DM): Meßbeispiele zeigt wieder Tabelle 1, wobei die Pumpe noch neu und dadurch zu schwergängig war.
- Membranpumpe der Windpumpenzentrale, Typ 22 (Preis ca. 350 DM): Die Pumpe wird direkt mit einem Exzenter angetrieben. Meßbeispiele finden sich ebenfalls in Tabelle 1.

Die aufgeführten Zahlen sollen nur Anhaltswerte über die Größenordnungen der Förderleistungen geben. Ein direkter Vergleich zwischen den einzelnen

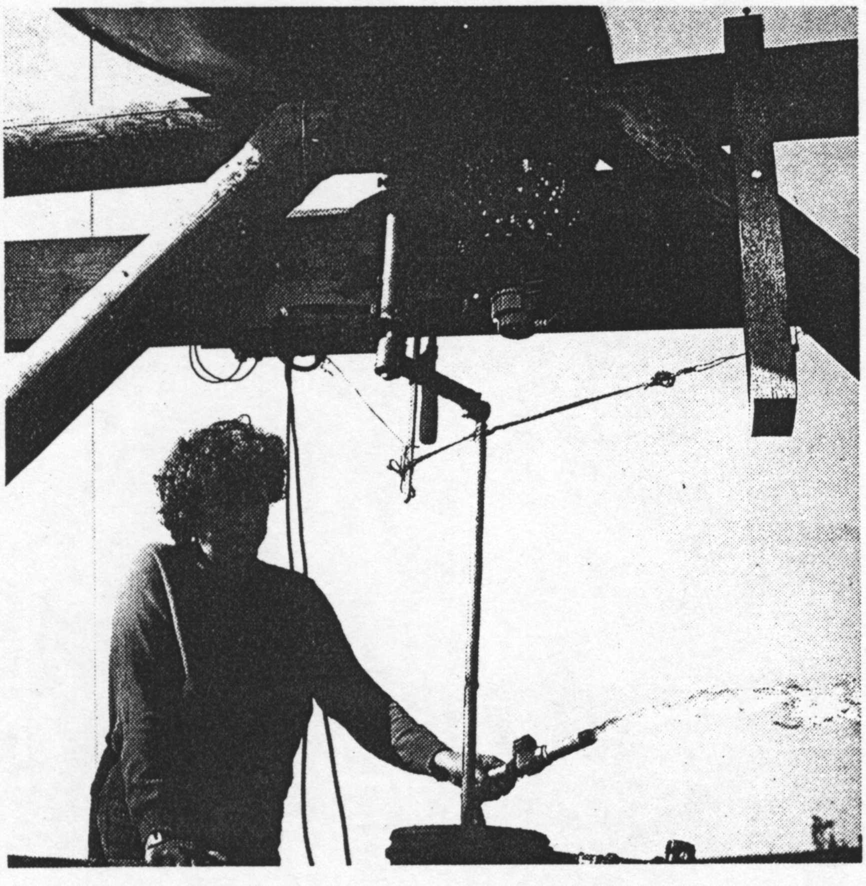


Abb. 10:
Selbstgebaute Reifenpumpe, die in Abb. 11 näher dargestellt ist.

Durch einen Taumelantrieb wird die Drehbewegung der senkrechten Rotorwelle direkt in eine ebenfalls senkrechte Hubbewegung umgewandelt.

Windgeschwindigkeit (gemessen in 2 m Höhe) m/s	Rotordrehzahl U/min	Förderleistung l/min
1. Triplex-Bohrmaschinenpumpe		
1,5	25	1
4,0	100	12
10	200	20
12	250	30
2. Apollo-Exzenterrollenpumpe Typ 128		
1	15	4
1,5	30	7
2	50	12
4	100	22
3. Apollo-Zahnradpumpe Typ Enorm 115		
3	40	8
4	70	14
4. Membranpumpe der Windpumpenzentrale		
1	8	0,5
1,5	15	2
2	36	5
2,5	62	8
4,5	120	20
6	150	18
7	180	16

Tabelle 1: Förderleistung verschiedener Wasserpumpen als Funktion der Windgeschwindigkeit

Pumpenarten ist nicht möglich, da aus technischen Gründen die jeweiligen Windgeschwindigkeiten in verschiedener Höhe über dem Boden gemessen werden mußten.

Um Aussagen über die täglichen Fördermengen des Savoniusrotors mit verschiedenen Pumpen im Vergleich zu einer handelsüblichen Propeller-Windpumpe zu bekommen, wurden Langzeit-Messungen gemacht. Hierbei brachte die *Membranpumpe* bisher die besten Resultate, insbesondere an Tagen mit sehr schwachem Wind. Hohe Windgeschwindigkeiten wurden hingegen von den *Rotorpumpen* besser ausgenutzt, da die Membran bei hohen Hubzahlen zu flattern beginnt. In Abb. 10 und 11 ist eine einfache Reifenpumpe dargestellt, die sich zur Wasserförderung bei geringen Saug- und Druckhöhen sehr gut bewährt hat.

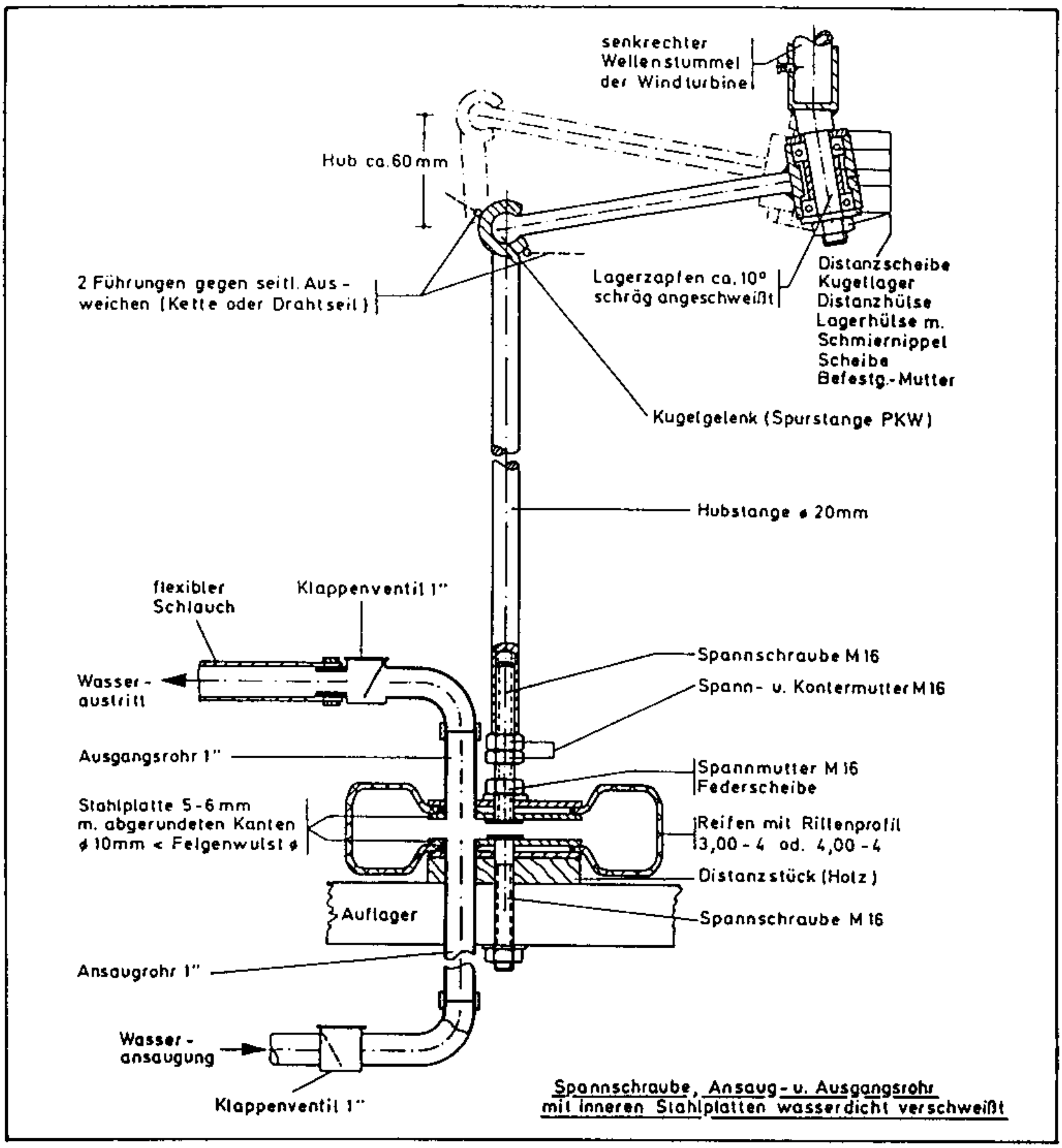


Abb. 11: Reifenpumpe für Savonius- und Durchströmrotoren

2.2 Drucklufterzeugung

Hierzu wurden bisher erst einige Versuche mit einem Kömag-Zapfwellenkompressor, Typ DK 520, (Preis 325 DM) angestellt, der direkt angetrieben wurde. Bei 4 m/s Windgeschwindigkeit wurde Druckluft mit 4,5 bar erzeugt (Abb. 12).

2.3 Stromerzeugung

Bei der relativ geringen Größe des Savonius-Rotors ist nur die Erzeugung von Gleichstrom zum Batterieladen interessant; die Erzeugung von Netzstrom wäre in diesem Leistungsbereich viel zu aufwendig. Eher kommt die Heizstromerzeugung zur Warmwasserbereitung bei den großen Durchströmrotoren (vgl. Kapitel 3) infrage, wie es bei der Anlage Bachmeier/Holzen praktiziert wird.

Abb. 12
Erster Versuch, mit dem Savonius-Rotor gleichzeitig Wasser zu fördern und Druckluft zu erzeugen. Von der senkrechten Rotorwelle wird im oberen Teil mit Keilriemen eine Exzenterrotorpumpe und unten direkt ein Zapfwellenkompressor angetrieben.

Die üblichen Versuche mit Kraftfahrzeug- und Zug-Lichtmaschinen verliefen negativ. Diese Generatoren sind bekanntlich auf hohe Drehzahlen über 1000 U/min ausgelegt. Bei entsprechend großer Übersetzung lassen sich diese zwar mit der Windturbine erzeugen, der Antrieb schluckt aber bei niedrigen und mittleren Windgeschwindigkeiten so viel Kraft, daß eine Stromerzeugung nur bei Sturm möglich ist. Durch Fremderregung des Generators über Batteriestrom gelingt es zwar, auf niedrige Drehzahlen von 500 - 600 U/min zu kommen, aber man steckt dabei mehr Energie in den Generator hinein, als man herausbekommt.

Lediglich durch Umwickeln des Lichtmaschinenstators mit dünnerem und entsprechend längerem Draht gelingt es, schon bei Drehzahlen unter 500 U/min auf die erforderliche Ladespannung zu kommen. Dabei sinkt natürlich die Stromstärke und Maximalleistung. Eine Bauanleitung hierzu liefert Christian Kuhtz, Sternwartenweg 40, 2300 Kiel. Zu einem Preis von 70-100 DM wickelt er auch eingeschickte geeignete Generatoren um (bisher wenigstens!).

Fertige Kfz-Generatoren für 12 Volt-Batterien mit einer Maximalleistung von ca. 150 W bei 1200 U/min, die bereits ab 450 U/min Strom liefern, bietet die Fa. A. Harbarth, Selbstbaubedarf für Windkraftanlagen, Hecheln 32, 7769 Mühlingen an. Da jedoch die in China hergestellten und ebenfalls von Harbarth gelieferten Drehstromgeneratoren (vgl. Seite 41 und 42) mit Permanentmagnet-Erregung und Brückengleichrichter recht preiswert sind und ausgezeichnete Eigenschaften besitzen, sollte man von der Verwendung von Kfz-Lichtmaschinen möglichst Abstand nehmen.

Der technisch sicherste Weg besteht nämlich darin, einen für niedrige Drehzahlen konstruierten, vielpoligen Generator zu verwenden, der wesentlich größer, aufwendiger und teurer ist, als eine Kfz-Lichtmaschine. Ein derartiger Generator wurde von der Windkraftzentrale für 12 Volt Gleichstrom mit einer Nennleistung von 300 W entwickelt und kostet ca. 2.200 DM. Er ist mit elektronischem Drehzahlschalter und Spannungsregler ausgerüstet und wird mit einer Batterie gekoppelt. Der Antrieb mit Keilriemen ist wegen der niedrigen Drehzahlen und hohen Drehmomente problematisch (Schlupf). Besser ist eine Rollenkette (Moped- oder Fahrradkette). Ein Betrieb ohne Batterie ist wegen Fremderregung nicht möglich.

Wie aus Abb. 8 ersichtlich ist, beginnt dieser Generator schon bei niedrigen Drehzahlen (ab 4 m/s) mit der Stromerzeugung. Nachteilig ist leider die Tatsache, daß gerade bei niedrigen und mittleren Windgeschwindigkeiten ein leistungsminderndes ständiges Ein- und Ausschalten der Erregung durch die Elektronik zu beobachten ist, die sich übrigens auch als kälteempfindlich gezeigt hat. Außerdem kann bei leerer Batterie kein Strom erzeugt werden, was in der Praxis Probleme mit sich bringt.

Für experimentierfreudige Leute, die auf der Suche nach preiswerteren Gleichstromgeneratoren sind, noch folgende Hinweise:

Abb. 13
Westinghouse AC-Generator, der dreiphasigen Wechselstrom (Drehstrom) erzeugt. Die Ankerwicklung wird von einem permanentmagneterregten Hilfsgenerator (rechts auf der Welle) mit Strom für die Erregung versorgt.

- Man kann aus einem langsamlaufenden Drehstrom-Kurzschluß-Motor einen selbsterregenden Generator bauen, indem die Kurzschlußstäbe im Läufer durch Permanentmagnete ersetzt werden (vgl. Abb. 14 - 16). Nähere Auskunft gibt: Albin Siegl, Seligerstr. 1, 8832 Weissenburg

  Da Arbeitszeit und Kosten für einen derartigen Selbstbau kaum zu kalkulieren sind und man auch noch nicht weiß, was am Ende dabei herauskommt, kann der Selbstbau solcher Generatoren nur Leuten empfohlen werden, die Zeit und Geduld haben und obendrein auch noch etwas von Elektromaschinen und Ankerwickeln verstehen.

- Bei den Bundesbahn-Ausbesserungswerken gibt es manchmal gebrauchte »Zuglichtmaschinen« älterer Bauart, von denen einige Typen auch für niedrige Drehzahlen geeignet sind. Es sind dies selbsterregte, »klassische« Gleichstromgeneratoren. Erprobt wurde die »Bosch D 25«, die bei 1.500 U/min eine Maximalleistung von 600 W bei 24 V Ladespannung bringt.
- Die Fa. Elektro-Artmann, 8304 Mallersdorf, Marktstr. 33 führt ein großes Sortiment an Generatoren unterschiedlicher Größe und Ausführung aus Sonderbeständen und erfüllt auch Sonderwünsche, z.B. durch Umwickeln der Generatoren für niedrigere Drehzahlen.
- Die kleineren LKW-Kälteaggregate der Fa. Thermo-King werden mit einem Westinghouse AC-(Wechselstrom)-Generator angetrieben, mit dem der Verfasser sehr gute Erfahrungen an seiner Windturbine sammeln konnte (Abb. 13). Es ist ein schleifringloser Drehstromgenerator mit Vorerregung durch kleine Permanentmagnete, der normalerweise bei 3.000 U/min Drehstrom mit 2 kW Maximalleistung bei 380 V erzeugt. Er läuft im Gegensatz zu Generatoren mit Kollektor oder großen Permanentmagneten sehr leicht an und erzeugt schon bei 220 U/min eine Leerlaufspannung von 6 V, bei 300 U/min von 12 V und bei 500 U/min von 24 V. Über eine Diodenplatte aus einer KFZ-Drehstrom-Lichtmaschine mit 6 in Brückenschaltung angeordneten Dioden wird der Drehstrom gleichgerichtet. Mit diesem Generator kann man der Windturbine in einem sehr grossen Drehzahlbereich Leistung abnehmen, wenn man die aufzuladende Batterie in mehrere Blöcke aufteilt, die je nach Windgeschwindigkeit mit niedriger Spannung parallel oder mit höherer Spannung in Reihe geschaltet werden. Bei den Thermo-King-Vertretungen kostet ein neuer Generator ca. 1.500 DM, ein gebrauchter ca. 500 DM.

Im Rahmen der Diplomarbeit von Noe (siehe Literaturverzeichnis) wurde an der Landtechnik Weihenstephan ein Prüfstand zur Untersuchung von Generatoren für kleine Windkraftanlagen bis ca. 2 kW Nennleistung aufgebaut. Dabei konnten Spannung, Stromstärke und Wirkungsgrad bei unterschiedlicher Drehzahl und Belastung gemessen werden. Hier zeigte es sich, daß die von Albin Siegl entwickelten Selbstbau-Generatoren schon bei sehr niedrigen Drehzahlen mit der Stromerzeugung beginnen und die besten Wirkungsgrade auch im Teillastbereich aufweisen, weil kein Erregerstrom nötig ist (vgl. Abb. 14, 15 und 16). Allerdings sind Spannung und Stromstärke direkt drehzahlabhängig und lassen sich nicht wie bei fremderregten Generatoren regeln. Beim Laden von Batterien oder für die Wassererwärmung über Heizstäbe ist dies jedoch kein grundsätzlicher Nachteil.

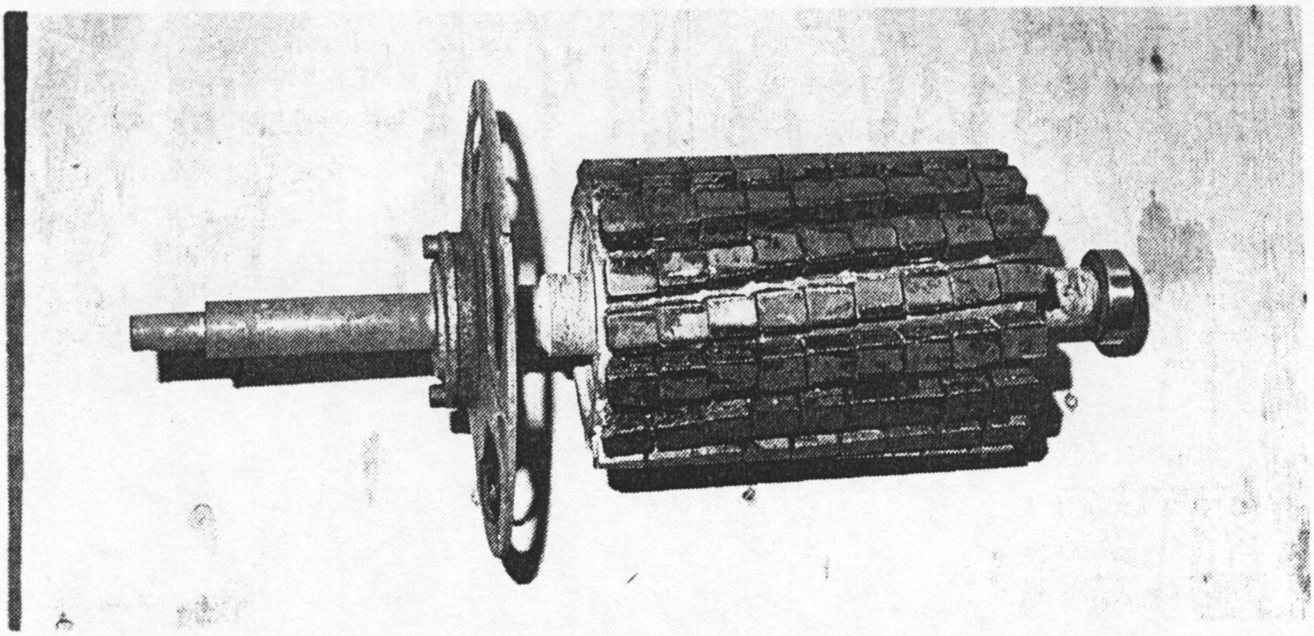
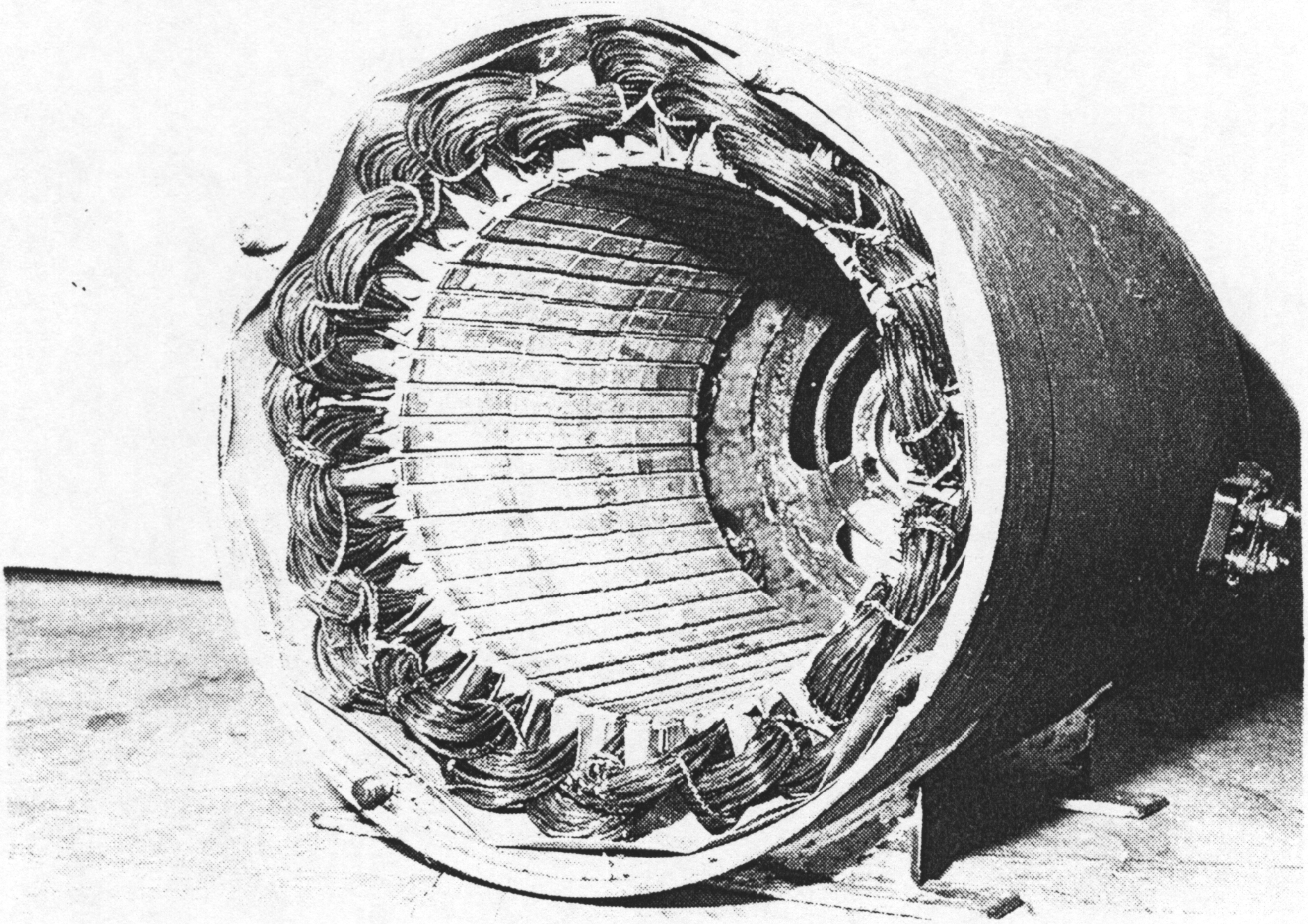


Abb. 14
Mit Permanentmagneten bestückter Anker eines Drehstromgenerators, von Albin Siegl selbst hergestellt. In leicht spiralförmiger Anordnung sind die handelsüblichen Magnete auf ein Aluminiumrohr aufgeklebt und in der Drehbank überschliffen.

Abb. 15
Von einem ehemaligen Kurzschlußläufer-Motor (Langsamläufer) stammen das Gehäuse und das Polblechpaket des Generators, dessen Anker oben abgebildet ist. Die Wicklung wurde neu eingebracht. Nur Leute mit Zeit, Geduld und Fachkenntnissen sollten an solch ein Projekt herangehen, zumal es noch keine schriftlichen Unterlagen dafür gibt.



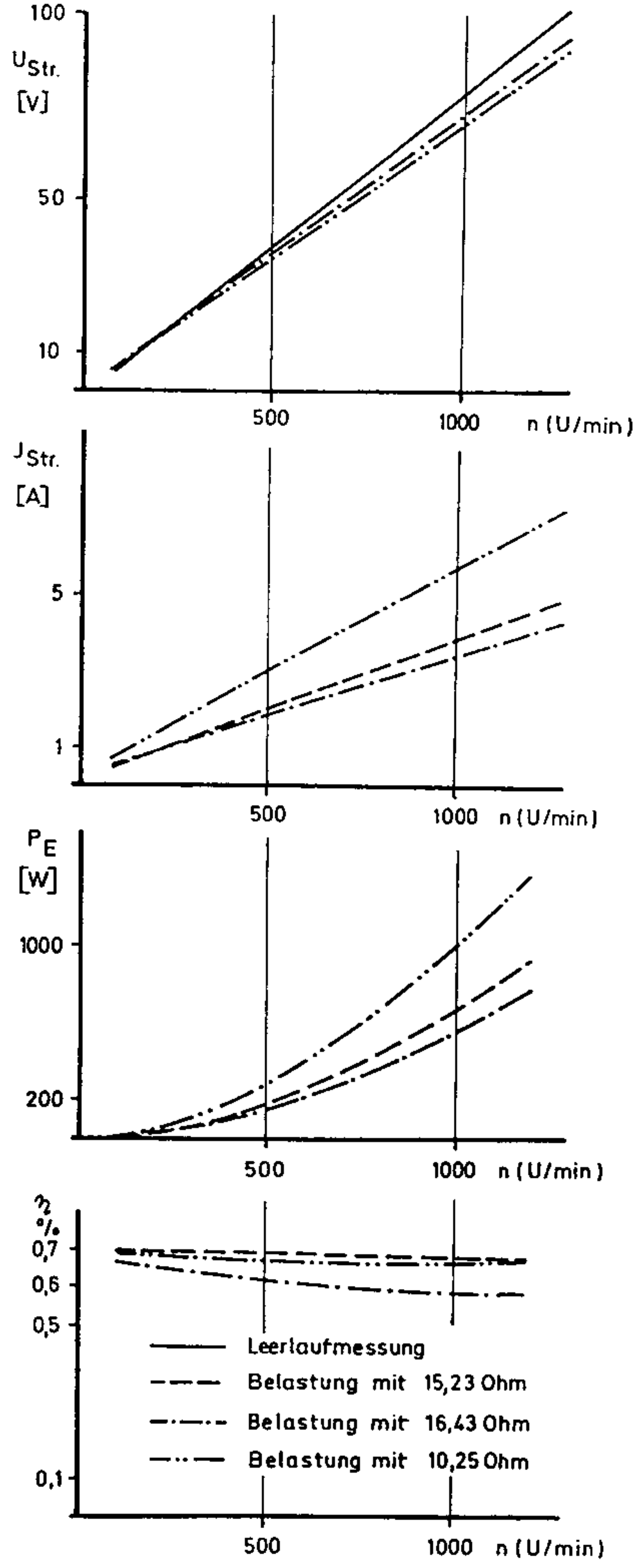


Abb. 16:
Kennlinien des Drehstromgenerators von Albin Siegl
Strangspannung, Strangstromstärke, Leistung und Wirkungsgrad des 8-poligen, permanentmagneterregten Drehstromgenerators bei unterschiedlicher Drehzahl und Belastung (Dreieckschaltung).

▲

Strangspannung U als Funktion der Drehzahl (Parameter: Belastung)

◄

Strangstromstärke I als Funktion der Drehzahl (Parameter: Belastung)

◄

Leistung P als Funktion der Drehzahl (Parameter: Belastung)

◄

Wirkungsgrad n als Funktion der Drehzahl (Parameter: Belastung)

Nun wird allerdings nicht jeder, der einen Savonius- oder Durchströmrotor baut oder plant, in der Lage sein, einen Generator »System Siegl« selbst zu bauen. Daher nachfolgend noch die Anschriften von Firmen, die auch kleinere Dreh- bzw. Wechselstromgeneratoren mit Permanentmagneten bauen, deren Produkte ich aber noch nicht erproben konnte:

- Fa. Elektro GmbH, St. Galler Str. 27, CH-8400 Winterthur
- Ing. H.G. Czech, Rosenhammer 22, 8581 Weidenberg/Ofr.
- Fa. Hübner, Elektromaschinenbau, Siemensstr. 7, 6300 Gießen

Dreh- und Wechselstromgeneratoren nach Kundenangabe mit Permanentmagneten baut die Fa. Elektro-Lips, Tretzendorf 13, 8729 Oberaurach. Da Teile von handelsüblichen Motoren verwendet werden, sind sie relativ preiswert. So kostet ein Generator mit 0,5 kW Nennleistung, der bei 500 U/min eine Leerlaufspannung von 120 V erreicht und bei Belastung mit 10 Ohm 40 V und 10 A bringt, ca. 650 DM. 12 V - Batterien können schon ab 50 U/min geladen werden.
Einen Generator dieser Art habe ich in der Erprobung und kann ihn für kleinere Savonius- und Durchström-Rotoren empfehlen, wenn man die hohe Spannung, die dieser Generator bei höheren Drehzahlen erzeugt (200 V bei 800 U/min) auch nutzen kann (eventuell mit Trafo oder Wandler heruntersetzen, um beim Batterieladen größere Stromstärken und Leistungen zu erhalten).

2.4 Bauarten von Permanentmagnet - Generatoren

Die Verwendung von Generatoren mit Permanentmagnet-Erregung erlangt bei Windkraftanlagen zum Batterieladen oder zur Heizstromerzeugung zunehmende Bedeutung, weil diese Maschinen relativ unproblematisch zu betreiben sind und auch im Teillastbetrieb gute Wirkungsgrade erreichen. Daher möchte ich nachfolgend näher auf die verschiedenen Bauarten eingehen und einige wichtige Hinweise geben.

Bei einem Generator (oder Motor) mit Permanentmagneten wird das für die Stromerzeugung (bzw. Drehbewegung) notwendige magnetische Feld nicht wie bei den meisten anderen Maschinen durch eine stromdurchflossene Wicklung erzeugt, sondern eben durch die Permanentmagnete. Dadurch entfällt der Stromverbrauch für die Feldwicklung, der bei niedrigen Drehzahlen des Generators größer sein kann als die erzeugte Nutzenergie. Im Gegensatz zu eigen- oder kondensatorerregten Generatoren, bei denen erst ab einer bestimmten, relativ hohen Drehzahl ein genügend starkes Magnetfeld aufgebaut wird, um

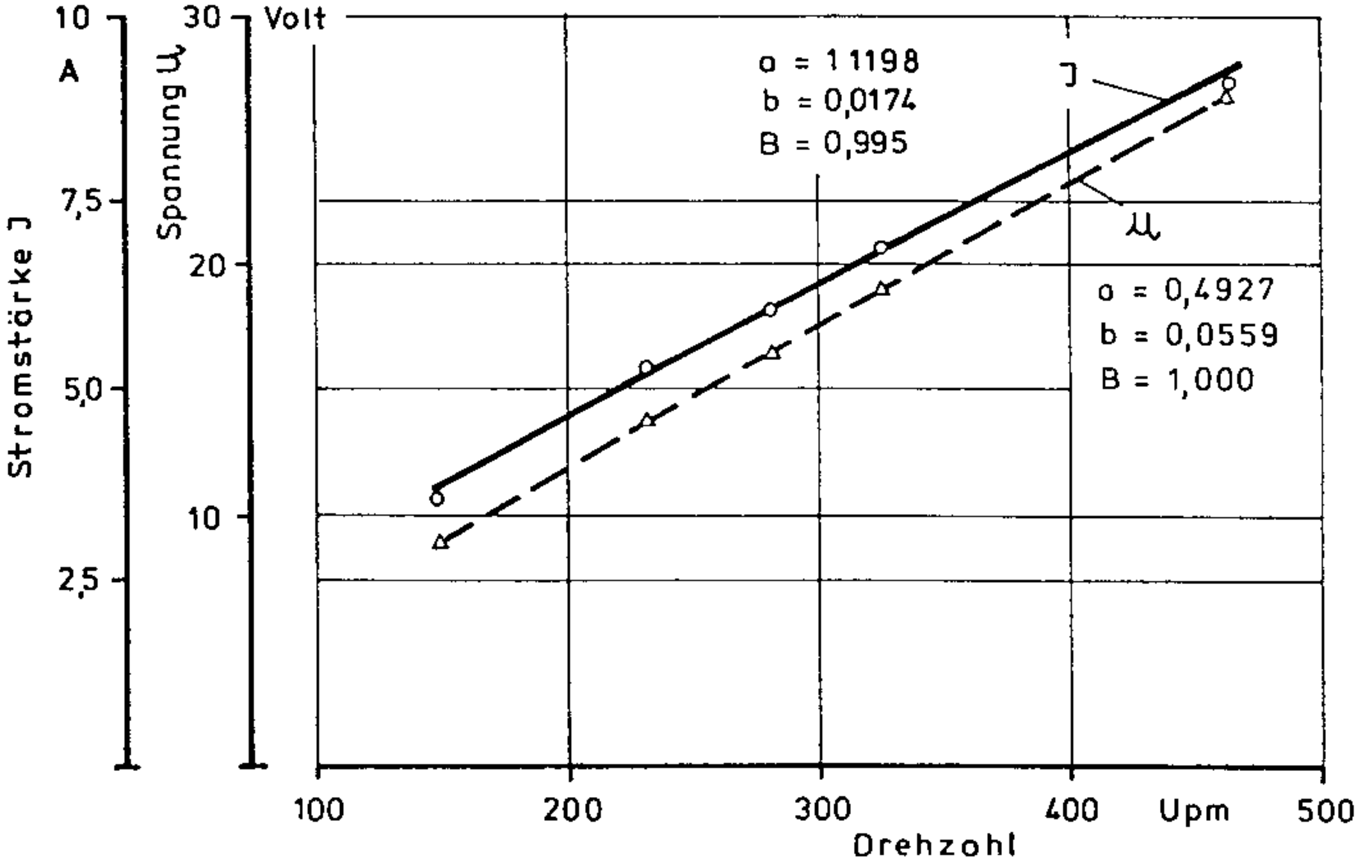


Abb. 17
Leerlaufspannung U und Kurzschlußstrom I der permanentmagneterregten Gleichstrommaschine EC von Artmann/Mallersdorf bei Antrieb als Generator

nutzbaren Strom zu erzeugen, liefern solche mit Permanentmagneten schon bei niedrigen Drehzahlen Spannung und Strom. So kann man mit jedem Permanentmagnetgenerator schon durch Drehen an der Welle einen Spannungsmesser (Voltmeter) zum Ausschlagen bringen. Schließt man die Generatorklemmen kurz, beispielsweise durch Zwischenschalten eines Strommessers (Amperemeter), so merkt man, wie schwer sich nun die Welle drehen läßt und wieviel Kraft die Stromerzeugung erfordert.

Spannung und Stromstärke sind bei Permanentmagnet-Generatoren linear abhängig von der Drehzahl (Abb. 17). Ist eine bestimmte Mindest-Spannung vorgegeben, wie z.B. beim Laden einer Batterie, so kann der Generator natürlich nur ab einer bestimmten Drehzahl (= Mindestgeneratorspannung) Strom in die Batterie schaffen und sie aufladen. Bei Erhöhung der Drehzahl vergrößert sich sich dann nur die Stromstärke, während die Batterie je nach Ladezustand und innerem Widerstand die Generatorspannung weitgehend konstant hält. Man braucht daher keine Angst zu haben, daß die Batterie bei hohen Drehzahlen durch »Überspannung« beschädigt wird. Allerdings ist darauf zu achten, daß die zulässige Ladestromstärke nicht überschritten und die Batterie nicht überladen wird.

Windturbine, Generator und Batterie müssen daher in Leistung und Kapazität aufeinander abgestimmt sein. Wird der Strom aus der Batterie nicht laufend verbraucht und besteht - wie etwa bei einem Wochenend- oder Ferienhaus - die Gefahr des Überladens, so muß ein Laderegler eingesetzt werden, der beim Erreichen einer oberen Grenzspannung den Generator von der Batterie trennt und sie erst wieder koppelt, wenn die Batteriespannung durch Entladen zurückgegangen ist. Will man vermeiden, daß die Windturbine bei der Trennung von der Batterie leer läuft und bei hohen Windgeschwindigkeiten zu hohe Drehzahlen erreicht, sollte man - durch den Laderegler gesteuert - einen ausreichend starken Lastwiderstand anstelle der Batterie aufschalten, der die Generatorenergie in Wärme umwandelt. Bei größeren Rotoren und guten Windverhältnissen kann man auch Heizwiderstände zur Wassererwärmung einsetzen. Geeignete Rohrheizwiderstände zum Einschrauben in Druckwasserspeicher für 12 und 24 V liefert z.B. die Fa. Harbarth (vgl. Bezugsquellenverzeichnis am Ende des Buches).

Neben der Drehzahl sind Spannung und Stromstärke auch noch von der Stärke des Magnetfeldes, der Polzahl und der Länge der stromerzeugenden Wicklung abhängig. Um schon bei niedrigen Drehzahlen ausreichend hohe Spannungen erzeugen zu können und eine hohe, mehrstufige und leistungsmindernde Übersetzung zu vermeiden, sollte man einen möglichst vielpoligen Generator wählen. In der Regel bringen 2-polige Generatoren ihre Nennleistung bei 3.000 U/min, 4-polige bei 1.500 U/min und so weiter. Brauchbar für unsere Zwecke sind Generatoren mit mindestens 4, besser 6 oder 8 Polen. Spezialisten haben sich schon Generatoren mit 32 oder gar 72 Polen selbst gebaut oder beschafft, die direkt, also ohne Übersetzung, von der Windturbine angetrieben werden. Wegen der extrem niedrigen Drehzahl sind sie naturgemäß groß, schwer und materialaufwendig.
Wieviel Pole ein Permanentmagnet-Generator hat, kann man auch von außen feststellen, indem man die Wicklungen am Klemmenbrett kurzschließt und die Welle von Hand dreht. Deutlich spürt man jetzt das sogenannte »Ribbelmoment« (Polfühligkeit) der Magnete, also einen wechselnden Widerstand gegen die Drehbewegung. Die Zahl dieser »Ribbelmomente« bei einer Wellenumdrehung entspricht der Polzahl.

Hat man - wie es mir oft ergeht - einen Generator aus Sonderbeständen oder vom Edelschrottplatz ohne Typenschild und Datenblatt in der Hand und möchte wissen, welche Spannungen und Leistungen er bei verschiedenen Drehzahlen bringt, so ist es am einfachsten, ihn mittels Bohrmaschine oder Drehbank anzutreiben und Spannung und Kurzschlußstrom zu messen. Trägt man die Werte in ein Diagramm nach Abb. 17 auf, so kann man sich schon ein gutes Bild von den Eigenschaften des Generators machen. Zu beachten ist aber, daß bei der Messung des Kurzschlußstroms hohe Drehmomente auftreten, welche

die Drehzahl der Bohrmaschine und auch einer kleineren Drehbank merklich reduzieren, so daß ein Drehzahlmesser hilfreich ist. Außerdem darf man zum Errechnen der Leistung nicht einfach die Leerlaufspannung mit der Kurzschlußstromstärke multiplizieren. Beide Werte fallen nämlich im praktischen Betrieb des Generators bei Belastung mit einem Arbeitswiderstand bzw. einer Batterie merklich niedriger aus. Dabei geht die Spannung umso stärker zurück, je niedriger der Lastwiderstand ist, während die Stromstärke bei zunehmendem Lastwiderstand zurückgeht.
Einen noch besseren Einblick in die Eigenschaften des Generators bekommt man daher, wenn man ihn bei verschiedenen Drehzahlen unterschiedlich stark belastet. Dazu benötigt man entweder einen Schiebewiderstand oder noch besser einen Akkumulator, bei dem die Pole der einzelnen Zellen offenliegen, so daß man verschiedene Spannungen abgreifen kann. Dies ist der Fall bei den älteren KFZ-Batterien mit Polbrücken aus Blei sowie bei stationären Nickel-Cadmium- und Bleiakkus, die aus Einzelzellen zusammengesetzt sind. Stehen nur moderne Autobatterien mit verkapselten Polbrücken zur Verfügung, so lassen sich damit immerhin die Spannungen 12, 24 und 36 V, usw. erzeugen, aber leider keine Spannungen unter 12 V und feiner abgestufte Zwischenwerte. Notfalls helfen auch die handelsüblichen, aufladbaren kleinen Nickel-Cadmium-Zellen oder Power-Packs weiter, wie sie heute vielfach in Taschenlampen, Tonbandgeräten, Transistorradios und batteriebetriebenen Heimwerker- und Gartengeräten verwendet werden. Vor allem die neuen, für Schnell-Ladung geeigneten »Superzellen« von Panasonic wie »Go Amp«, »Red Amp« und »High Amp Plus«, die sich durch einen sehr niedrigen Innenwiderstand auszeichnen und kurzfristig Ströme bis zu 30 A abgeben und aufnehmen können, sind in den Größen »Mono« und »Baby« für die Vermessung von Generatoren im niedrigen Spannungsbereich von 1,2 bis 12 V geeignet.
Man treibt also mit einer Bohrmaschine oder Drehbank den Generator an und mißt bei verschiedenen Drehzahlen die Spannung und den Strom sowie möglichst auch die genaue Drehzahl, indem man den Generator kurzzeitig mit einer oder mehreren hintereinandergeschalteten Zellen verbindet. Dabei muß natürlich auf die richtige Polung und bei Wechsel- oder Drehstromgeneratoren auf die Gleichrichtung des Stromes geachtet werden. Bei Gleichstromgeneratoren mit Kollektor sollte eine Sperrdiode zwischen Generator und Batterie geschaltet werden, damit bei niedrigen Generatordrehzahlen und höheren Batteriespannungen nicht der Strom von der Batterie in den Generator fließt und diesen als Motor antreibt (vgl. Abb. 22).

Die gemessenen Werte trägt man wieder in ein Diagramm gemäß Abb. 18 ein und erhält bei exakter Messung schön gerade und parallel verlaufende Linien. Aus diesem Diagramm läßt sich z.B. ersehen, daß der gemessene Generator in Abb. 18 bei nur 135 U/min schon eine 6 Volt-Batterie mit 1 A aufladen kann,

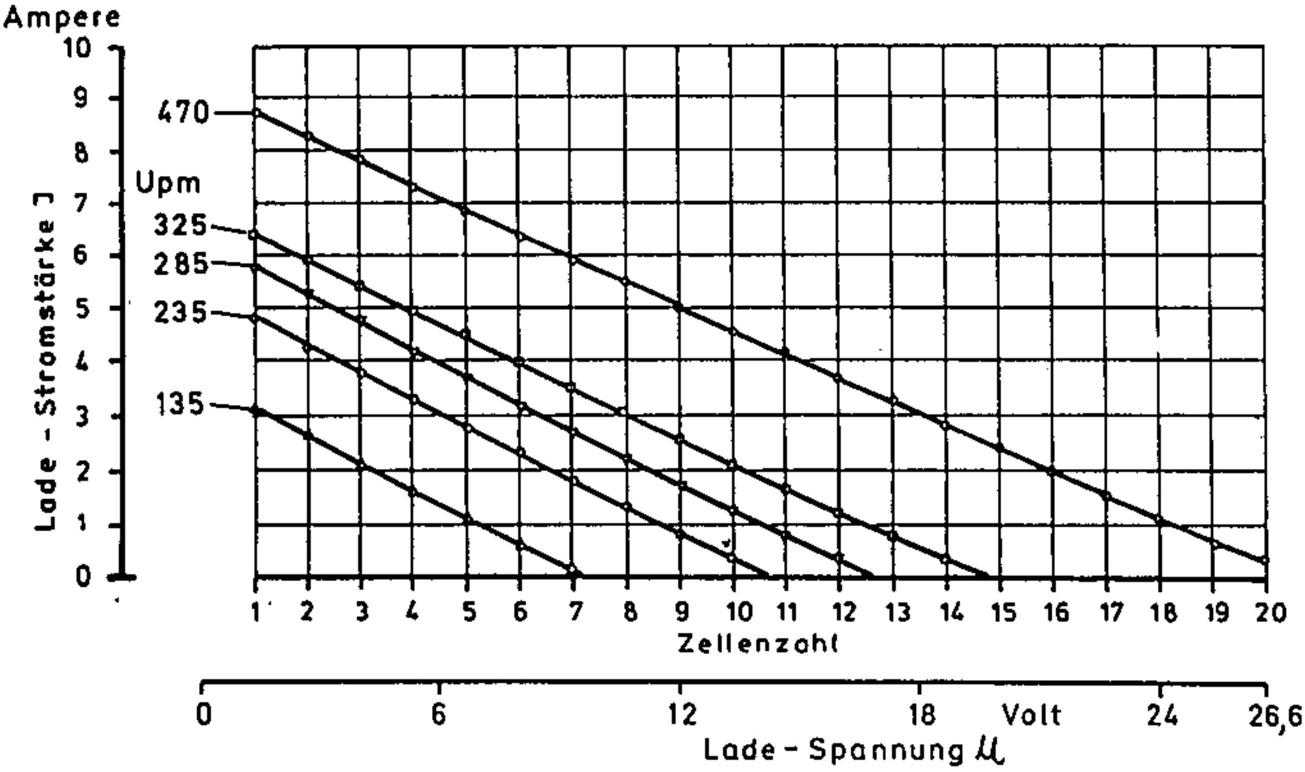
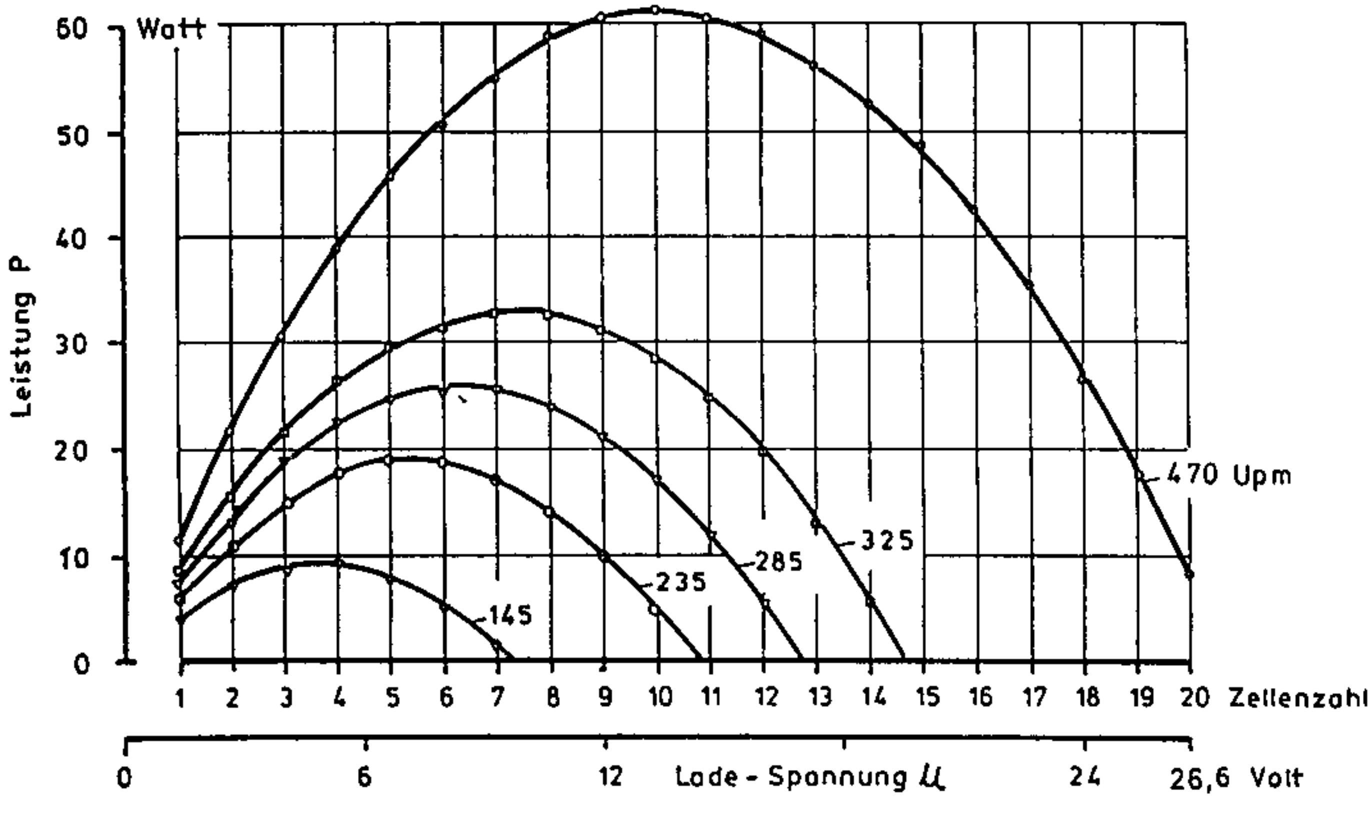


Abb. 18
Ladestromstärke I und Ladespannung U der permanentmagneterregten Gleichstrommaschine EC von Artmann/Mallersdorf beim Laden einer Nickel-Cadmium-Batterie mit 30 Ah Kapazität bei verschiedenen Drehzahlen und Zellenzahlen.

Abb. 19
Leistung N der permanentmagneterregten Gleichstrommaschine EC von Artmann/Mallersdorf beim Laden einer Nickel-Cadmium-Batterie mit 30 Ah Kapazität bei verschiedenen Drehzahlen und Zellenzahlen.



aber noch keinesfalls eine solche mit 12 oder gar 24 V. So sind für 12 V mindestens 235 U/min erforderlich und für 24 V sogar mindestens 470 U/min.

Noch mehr Einblick in diese Zusammenhänge gewinnen wir, wenn wir aus den Werten von Abb. 18 Leistungskurven erstellen, indem wir Ladespannung und -stromstärke multiplizieren, wie es in Abb. 19 dargestellt ist. Hier sehen wir eindrucksvoll, daß ein Leistungsoptimum des Generators (Gipfel der Kurven) bei den verschiedenen Drehzahlen immer nur in bestimmten Spannungsbereichen gegeben ist. So liefert dieser Generator bei 470 U/min eine optimale Leistung nur im Spannungsbereich von ca. 8 - 16 V. Das Laden von Batterien mit niedrigerer oder höherer Spannung ist bei dieser Drehzahl zwar möglich, aber nur mit wesentlich geringerer Leistungsausbeute.

Was aber kann man tun, wenn schon ein Generator vorhanden ist, der für die vorgesehene Batterie zu niedrige oder - was seltener vorkommt - zu hohe Spannungen erzeugt? Am einfachsten läßt sich die Spannungslage bei einem Drehstromgenerator durch Schaltung der 3 Wicklungen im Stern oder Dreieck beeinflussen, jedoch nur im festen Verhältnis von 1 : 1,7 (vgl. Abb. 22). Außerdem läßt sich bei Wechsel- und Drehstromgeneratoren mit Hilfe eines Transformators die Spannung nach oben oder unten verändern, allerdings mit gewissen Verlusten, die auch frequenzabhängig sind. Für kleine Gleichstromgeneratoren gibt es neuerdings bei der Fa. Conrad-Electronic (siehe Bezugsquellenhinweise) Spannungswandler zu einem Preis von 60 - 80 DM, die Gleichstrom bis 10 A von 6 auf 12 V, von 12 auf 24 V oder von 24 auf 12 V wandeln können, und zwar mit Wirkungsgraden von ca. 90%.

Der gegenwärtige Entwicklungsstand und die starke Verbreitung permanentmagneterregter Motoren und Generatoren konnte nur durch die neue Technologie der Sintermagnete erreicht werden. Diese Dauermagneten werden aus Metallpulver durch Pressen und Sintern oder Gießen mit Kunstharzbindung in weitgehend beliebigen Formen (Stäbe, Platten, Ringe, Schalen) hergestellt und zeichnen sich durch hohe Magnetkraft und geringe Entmagnetisierungsverluste aus. Bekannte Namen sind Ferroxdure, Ticonal, Samarium-Cobalt und RES. Der Bau stromsparender, kleiner und kleinster Elektromotoren, wie sie heute vielfach in Modellbau, Unterhaltungstechnik, KFZ-Technik und Haushalt eingesetzt werden, wäre ohne diese Magnete nicht möglich.

Für unsere Zwecke kommen folgende 3 Generator-Bauarten mit Permanent-Magneten infrage:

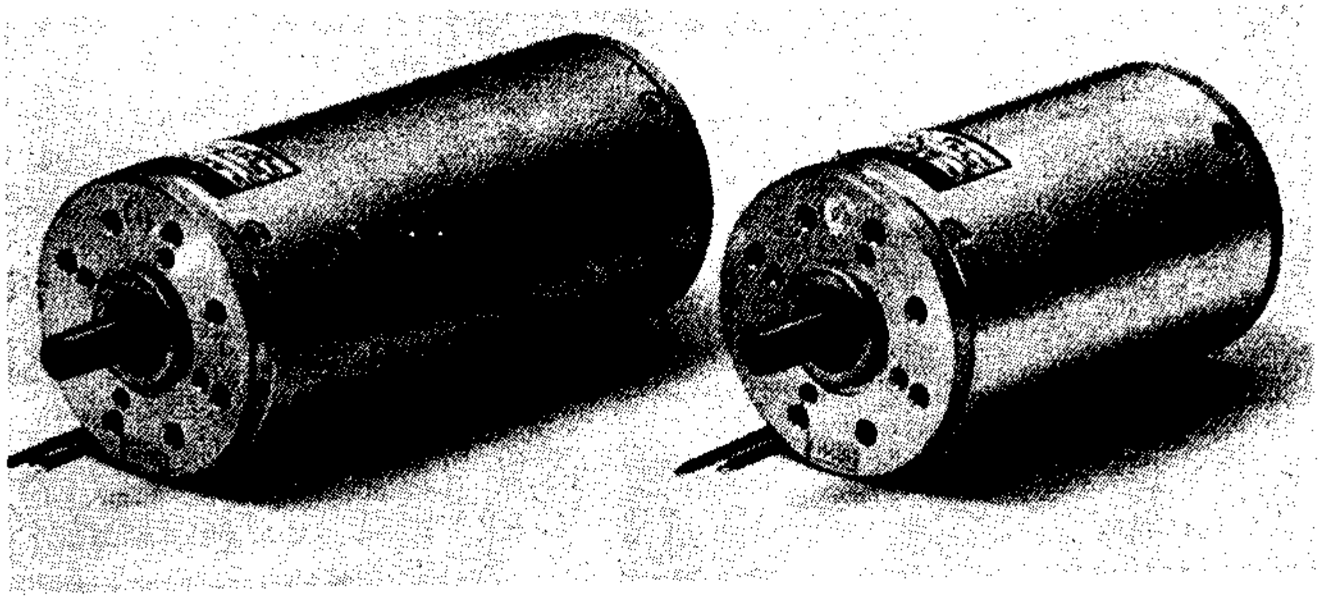
1. Gleichstromgeneratoren

Die Stromabnahme erfolgt über einen Kollektor mit Kohlebürsten, wodurch sie bei Gleichstromzufuhr auch als Motor laufen können. Diese Maschinen werden sowieso meistens als Motor konzipiert und eingesetzt. In der kleinen Ausführung mit ein paar Watt Leistung findet man sie in Photoapparaten, Film- und Videokameras, Kasettenrecordern und Spielzeugen, geeignet für den Betrieb an Trockenbatterien oder NC-Akkus. Treibt man sie über die Welle an, so liefern sie als Generator einige Volt Spannung und bis zu 1 A Strom, allerdings erst bei recht hohen Drehzahlen von 3000 U/min und mehr, da es sich in der Regel um 2-polige Maschienen handelt.

Etwas größere Typen, die man zum Experimentieren an einem kleinen Savonius-Rotor-Modell schon eher verwenden kann, haben Leistungen von 10 bis 60 W und finden in unseren Autos Verwendung, als Motoren für elektrische Fensterheber, Scheibenwischer, Scheiben- und Scheinwerfer-Waschpumpen, Heizungsgebläsen und bei einigen Fabrikaten auch zum elektrischen Antrieb des Kühlerventilators. Aufgrund der Ausführung der Lagerung und durch den Kohleverschleiß sind diese Typen natürlich nicht für den jahrelangen Dauerbetrieb in Windkraftanlagen geeignet; für den Anfang und zum Sammeln von Erfahrungen sind aber durchaus brauchbar. Da diese Maschinen Gleichstrom liefern, kann man sie direkt mit der Batterie verbinden (Plus an Plus und Minus an Minus). Eine Sperrdiode in einer der beiden Leitungen verhindert, daß bei Windstille oder zu niedrigen Drehzahlen Strom aus der Batterie zum Generator fließt und diesen als Motor antreibt (Abb. 22).

Leider laufen auch diese Maschinen noch mit recht hohen Drehzahlen von 1.500 - 3000 U/min, die eine entsprechende Übersetzung verlangen, wenn man eine 12 V-Batterie aufladen will und sich nicht mit 6 V zufrieden gibt. Besser wäre daher eine größere und auch robustere 24 V-Maschine aus einem LKW oder Bus, die schon bei niedrigeren Drehzahlen genügend Spannung für eine

Abb. 20
Permanentmagnet-erregte Gleichstrommaschinen, die als Motor und Generator arbeiten können. (Hersteller: Dunkermotorenwerk, 7823 Bonndorf/Schwarzwald)



12 V-Batterie bringt. Aber Achtung: hier sind nicht wie beim PKW grundsätzlich Permanentmagnet-Motoren eingebaut, manche dieser Motoren arbeiten auch mit der stromzehrenden Feldwicklung. Mit unserer oben beschrieben Methode (Drehen an der Welle bei kurzgeschlossener Wicklung) läßt sich jedoch schnell feststellen, ob Permanentmagneten vorhanden sind.

Die nächstgrößere Gruppe permanentmagnet-erregter Gleichstrommaschinen deckt den Leistungsbereich von 100 - 1.500 W ab (Abb. 20). Sie werden vor allem als Stellmotoren für Werkzeugmaschinen und Industrieanlagen sowie in der Wehrtechnik eingesetzt, und zwar deshalb, weil die Drehzahl streng linear zur angelegten Spannung verläuft. Die Messungen nach Abb. 17 bis 19 wurden an einer solchen Maschine gemacht. Da Stellmotoren meist für größere Gleichspannungen bis 70 V ausgelegt sind, bringen diese Maschinen beim Einsatz als Generator schon brauchbare Spannungen bei niedrigen Drehzahlen. Bei der Fa. Artmann in Mallersdorf (vgl. Bezugsquellenverzeichnis) gibt es immer wieder preiswerte Geräte dieser Bauart aus Sonderbeständen. Da sie meist mit Kugellagern und standfesten, leicht auswechselbaren Kohlen ausgerüstet sind, eignen sie sich gut für den Dauerbetrieb an kleinen Windturbinen.
Zu dieser Bauart und Größenklasse gehören auch die akkumulatorbetriebenen Elektro-Außenbordmaschinen mit Nennleistungen von 85 bis 1450 W für 12 und 24 V. Sie sind für besonders hohe Wirkungsgrade gebaut und weisen mehrere Wicklungsausgänge auf, so daß man sie mit verschiedenen Drehzahlen und Leistungen schalten kann. Bekannte Firmen sind »Accumot«, »Minn Kota« und »Noris/Shakespeare«. Im Yacht- und Bootshandel sind solche Motoren als Ersatzteil erhältlich (Abb. 21).

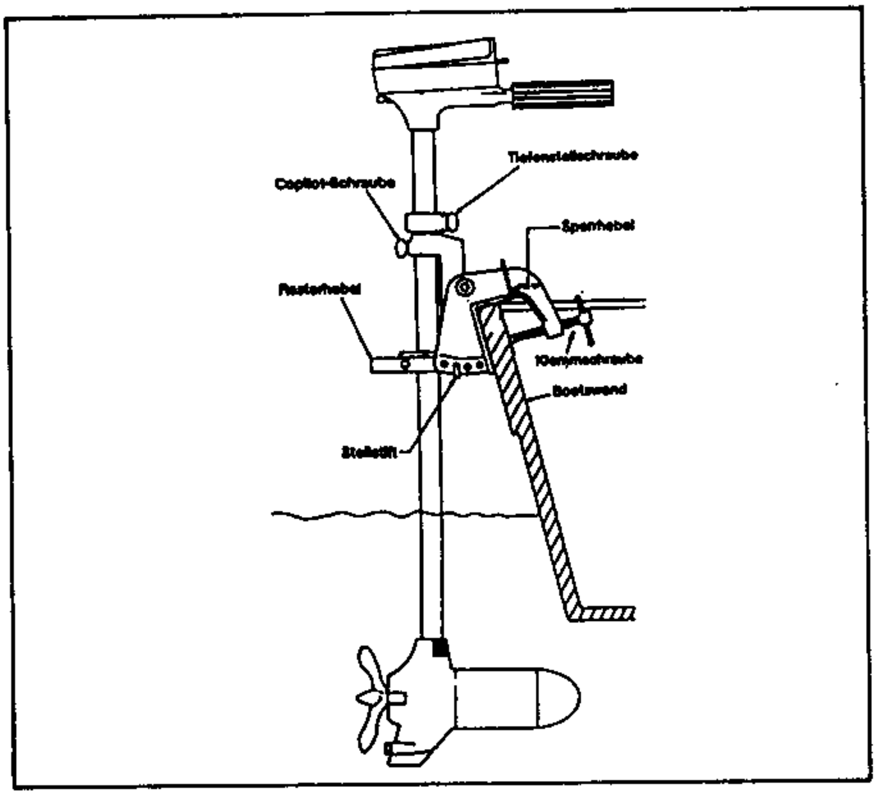


Abb. 21
Batteriebetriebene Außenbordmotoren werden derzeit zunehmend in Gewässern eingesetzt, die mit Verbrennungsmotoren nicht mehr befahren werden dürfen. Der die Schiffsschraube antreibende Permanentmagnet-Motor ist einzeln als Ersatzteil erhältlich und gut als kleiner Windgenerator geeignet.

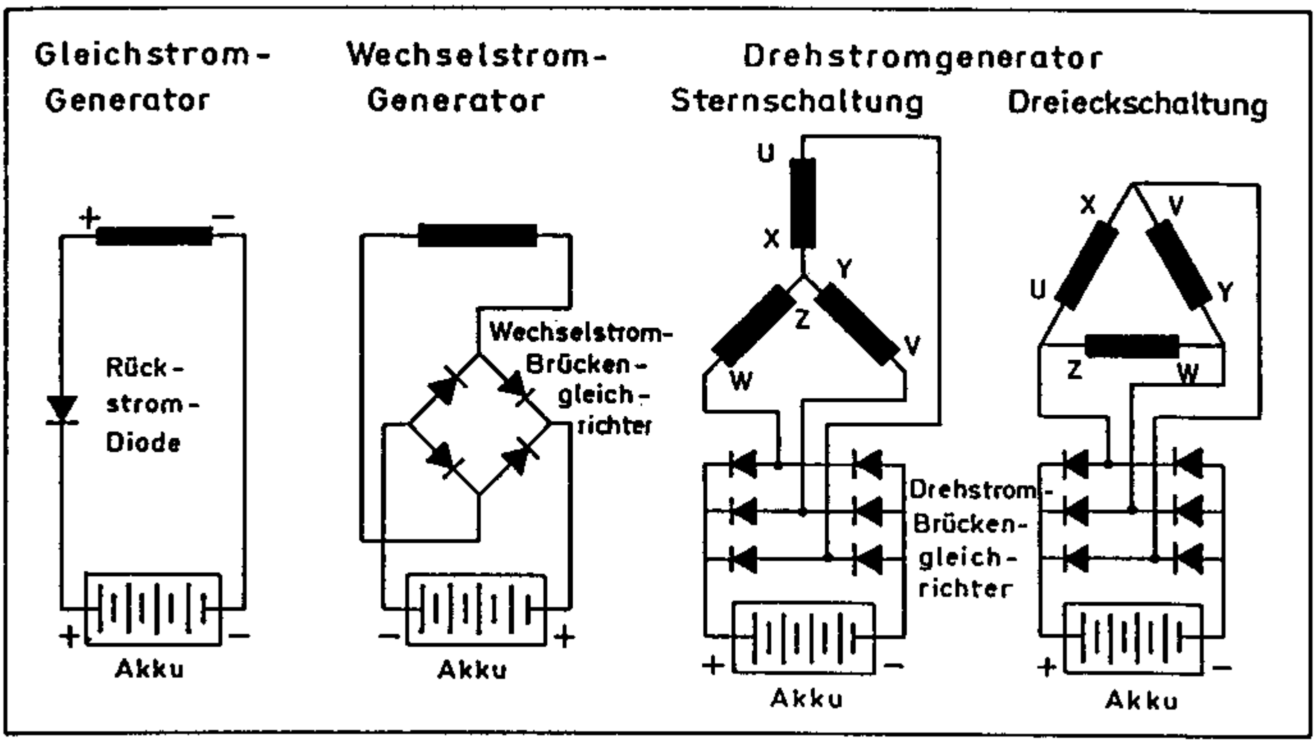


Abb. 22: Schaltungen zum Anschluß verschiedener Generatoren an einen Akkumulator

Bei den bisher beschriebenen Gleichstrommotoren bzw. -generatoren sind die schalenförmigen Permanentmagnete am feststehenden Gehäuse befestigt, während der Strom im rotierenden Anker erzeugt wird. Deshalb ist ein Kollektor (Kommutator) erforderlich, der den Strom gleichrichtet und an die Kohlebürsten abgibt. Dem Vorteil, daß man diese Maschinen unproblematisch als Motor oder Generator betreiben und sie preiswert in verschiedenen Größen bekommen kann, steht der Nachteil von Reibung und Verschleiß der Kohlen gegenüber.

2. *Wechsel- und Drehstromgeneratoren*

Hier ist die stromführende Wicklung als Stator am Gehäuse befestigt, während die Permanentmagnete mit der Welle rotieren. Kollektor und Kohlen entfallen und außer den zwei Lagern gibt es keine Verschleißteile. Einfacher, reibungsärmer und effizienter geht es nicht mehr (vgl. Abb. 14 und 15)! Man kann diese Generatoren, die natürlich nicht mit Gleichstrom als Motor laufen können, entweder für einphasigen Wechselstrom (2 Wicklungsenden am Klemmenbrett) oder für Drehstrom (6 Wicklungsenden am Klemmenbrett) bauen.

Vorteil des Wechselstroms: Für die Gleichrichtung kommt man mit 4 Dioden aus (bei Drehstrom mit 6 Dioden), und falls erforderlich läßt sich mit einem einfachen Transformator die Spannung herauf- oder heruntersetzen. Außer-

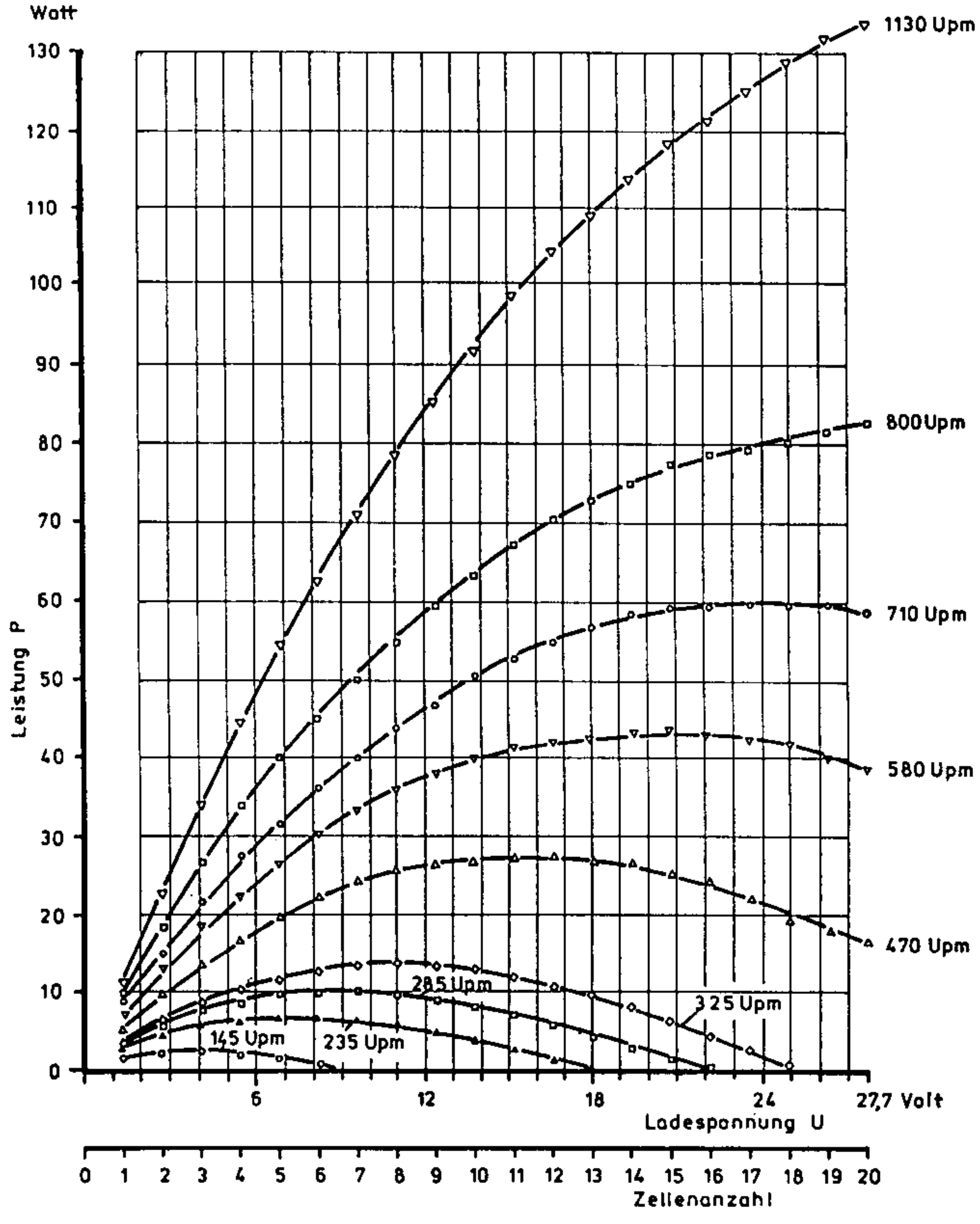


Abb. 23
Leistung des permanentmagnet-erregten Wechselstromgenerators mit Brückengleichrichter der Rutland-Windturbine WG 910 beim Laden einer Nickel-Cadmium-Batterie mit 30 Ah Kapazität bei verschiedenen Drehzahlen und Zellenzahlen.
(Vertrieb: Conrad Electronic, Hirschau)

dem kommt man mit einem Heizwiderstand aus, wenn man mit der Windturbine Wasser erwärmen will.

Vorteil des Drehstroms: Man kann bei gleicher Spannung mehr Leistung übertragen und die Spannung und Stromstärke durch Schaltung der Wicklungen im Stern oder Dreieck beeinflussen. Die erforderlichen 6 Dioden für einen Brükkengleichrichter sind kein schwerwiegender Nachteil, aber wenn man den Drehstrom direkt verheizen will, werden 3 gleich große Heizstäbe erforderlich, weil sonst der Generator »eckt«, das heißt durch ungleiche Belastung nicht rund läuft. Außerdem wird zur Spannungswandlung ein Drehstromtrafo erforderlich.

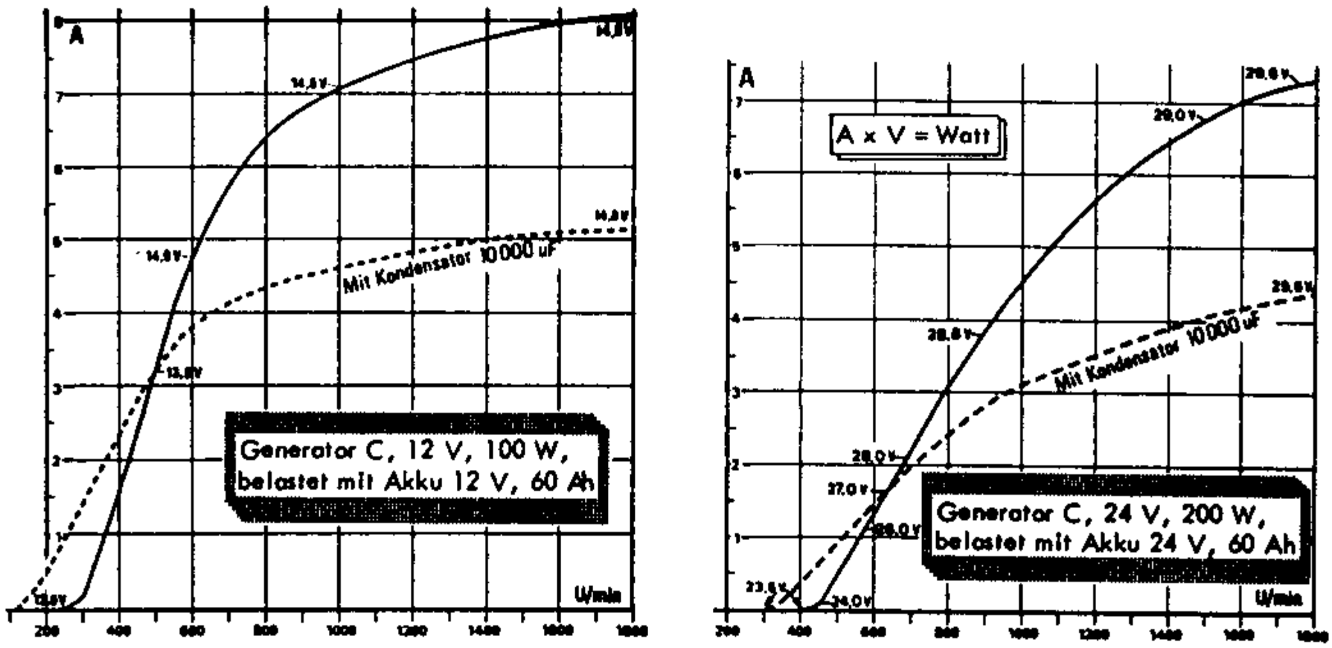
In der Praxis sieht es so aus, daß für kleinere Leistungen (50 - 500 W) Wechselstromgeneratoren eingesetzt werden und für größere Leistungen ab 100 W bis 10 kW meist Drehstromgeneratoren. Beide lassen sich in Scheiben- oder Trommelbauweise konstruieren. Das bei stärkeren Permanetmagnet-Generatoren so gefürchtete »Kleben« des Rotors in der Ruhestellung (durch die Wirkung der Magnetfelder), das große Anlaufprobleme mit sich bringt, wird heute verhindert, indem entweder die Magnete oder die Wicklung etwas schräg zur Welle angeordnet werden (vgl. Abb. 14).
Zu einer Meisterschaft im Bau extrem leicht anlaufender und durch Großserienherstellung preiswerter Wechsel- und Drehstromgeneratoren haben es nach meinen Erfahrungen die Engländer und Chinesen gebracht. So ist bei den von Conrad-Electronic vertriebenen, perfekt durchkonstruierten Wechselstrom-Scheibengeneratoren der englischen Firma Rutland/Marlec praktisch kein Anlaufmoment durch Magnetkleben zu spüren. Das führt dazu, daß der kleine 60 W-Generator durch Direktantrieb mit dem dazugehörenden 6-flügeligen Horizontalachsrotor (910 mm Ø) schon bei 0,2 m/s Windgeschwindigkeit anläuft. So etwas hat es bei Horizontalachs-Rotoren dieser Größe noch nicht gegeben. Wie Abb. 23 zeigt, wird die Nennleistung von 60 W schon mit ca. 700 U/min an einer 24 V-Batterie und mit 800 U/min an einer 12 V-Batterie erbracht. Bei nur 285 U/min fließt bereits Energie (ca. 5 W) in eine 12 V-Batterie! Die Fa. Conrad verkauft nicht nur das komplette Windkraftwerk WG 910 (998 DM), sondern auch den Generator einzeln (200 DM). Inzwischen gibt es außerdem einen größeren Dreiflügler FM 1800 mit 187 cm Ø und 400 W Nennleistung (komplett für 3.480 DM), ebenfalls mit Scheibengenerator, der einzeln bezogen werden kann (Preis auf Anfrage).
Nicht so perfekt verarbeitet, aber in der Funktion gleichwertig ist der »China-Generator«, den die Fa. Harbarth/Mühlingen importiert. Dabei handelt es sich um einen Drehstrom-Trommelgenerator (Abb. 24), der für 12 V / 100 W und 24 V / 200 W zum Preis von 412 DM geliefert wird. Durch Anschließen eines Kondensators an eine der 3 Phasen kann eine Spannungs- und Leistungserhöhung bei Drehzahlen unter 500 U/min erreicht werden, bei höheren Dreh-

zahlen wirkt der Kondensator aber leistungsmindernd, wie aus Abb. 25 ersichtlich ist. Ein kompletter Bausatz mit 2 Balsaholz-Flügeln (165 mm Ø), Generator, Mastkopf, Mastfuß, Rohrabspannung, Windfahne und Laderegler kostet für 12 V 1.495 DM und für 24 V 1.595 DM. Trotz des schmalen, schnellaufenden Propellers beginnt dieses chinesische »Volkswindkraftwerk« dank der Leichtgängigkeit des Generators schon bei 1,5 m/s Windgeschwindigkeit zu drehen und ab 1,8 m/s nutzbaren Strom zu erzeugen.

Zum Schluß noch ein wichtiger Hinweis für die persönliche Sicherheit: Beim Arbeiten und Experimentieren mit Windkraft-Generatoren ist dringend zu beachten, daß bei höheren Drehzahlen und fehlender Last unter Umständen hohe und gefährliche Leerlaufspannungen auftreten können. Eine Gleichspannung ab 60 V kann tödlich (!) wirken! Vorsicht ist daher auch dann am Platz, wenn die normale Betriebsspannung nur bei 12 oder 24 V liegt.

Abb. 24 ◀
Der chinesische Drehstromgenerator Typ C (Leistung 100 W/12 V bzw. 200 W/24 V) mit Permanentmagnet-Rotor und eingebautem Gleichrichter der Fa. Harbarth, Mühlingen
Quelle: Firmenprospekt der Fa. Harbarth

Abb. 25 ▼
Ladestrom-Kennlinien des Drehstromgenerators Typ C (aus Abb. 24) beim Laden eines Akkus mit 60 Ah Kapazität und 12 V bzw. 24 V Spannung
Quelle: Firmenprospekt der Fa. Harbarth



3. Der Durchström-Rotor

Beim zuvor behandelten zweistufigen Savoniusrotor hat die durchgehende Welle eine wichtige statische Funktion. Sie überträgt nicht nur das Drehmoment von den Flügeln auf die Arbeitsmaschine, sondern muß auch die Biegekräfte aufnehmen, die durch Winddruck und Unwucht auftreten. Die Flügel und Teller können bei dieser Rotorbauart nicht zur Aussteifung herangezogen werden. Dadurch ist die Bauhöhe auf etwa 2,5 bis 3 m begrenzt. Würde man den Rotor vergrößern, bestünde die Gefahr, daß die Welle bei Sturm in kritische Querschwingungen gerät.

Es wurde daher ein neuer Rotortyp entwickelt, der selbsttragend, biegesteif und von der Statik her als räumliches Tragwerk konzipiert ist. Damit lassen sich größere Rotoren bauen, wobei die obere Grenze gegenwärtig bei ca. 3 m Durchmesser und 6 m Höhe liegt. Dieser Rotor ist dreiflügelig, aber einstufig. Das Bauprinzip besteht darin, daß die senkrechten Flügel aus biegsamem Material (z.B. GFK, Bootssperrholz oder Blech) mit den waagerechten Segmenten oder Spanten eine konstruktive Einheit ähnlich einem Schiffsrumpf oder einem Flugzeugflügel bilden. Dadurch werden die einzelnen Bauteile wie auch die Welle nur auf Druck und Zug, nicht aber auf Biegung beansprucht. Der Rotor wird dadurch sehr leicht und gleichzeitig auch steif (Abb. 26).

Die an der Welle befestigten Segmente geben den Flügeln die gewünschte Form und übertragen das Drehmoment gleichmäßig auf die Welle. Als Material hat sich Aluminiumblech und kunststoffbeschichtetes, wasserfest verleimtes Sperrholz (Betoplan) bewährt. Am Flügelrand werden die Aluminium-Segmente eingeschnitten und zwischen zwei Sperrholzschablonen wechselseitig abgekantet, so daß die Flügel mit Ziehnieten befestigt werden können. Auch für die Flügel könnte Alublech verwendet werden doch erscheinen ebene GFK-Platten (Polyester), die in Form von Gewächshaus-Lichtbahnen als Rollenware überall erhältlich sind, günstiger. Sie sind preiswert, biegsam, großflächig und zugfest. Durch ihre Lichtdurchlässigkeit wirkt der Rotor sehr leicht und optisch ansprechend.

Der erste Prototyp mit 160 cm Durchmesser und 438 cm Höhe läuft nun seit 1981 und hat dabei zahlreiche schwere Stürme mit Spitzengeschwindigkeiten von 35 m/s schadlos überstanden (Abb. 27 und 28). Die Abbildungen 29 und 30 zeigen die wichtigsten Konstruktionsdetails und in Abb. 31 sind erste Messungen mit dem schon beschriebenen Generator der Windkraftzentrale dargestellt. Da die Flügelform inzwischen verbessert und auch ein geeigneterer Ge-

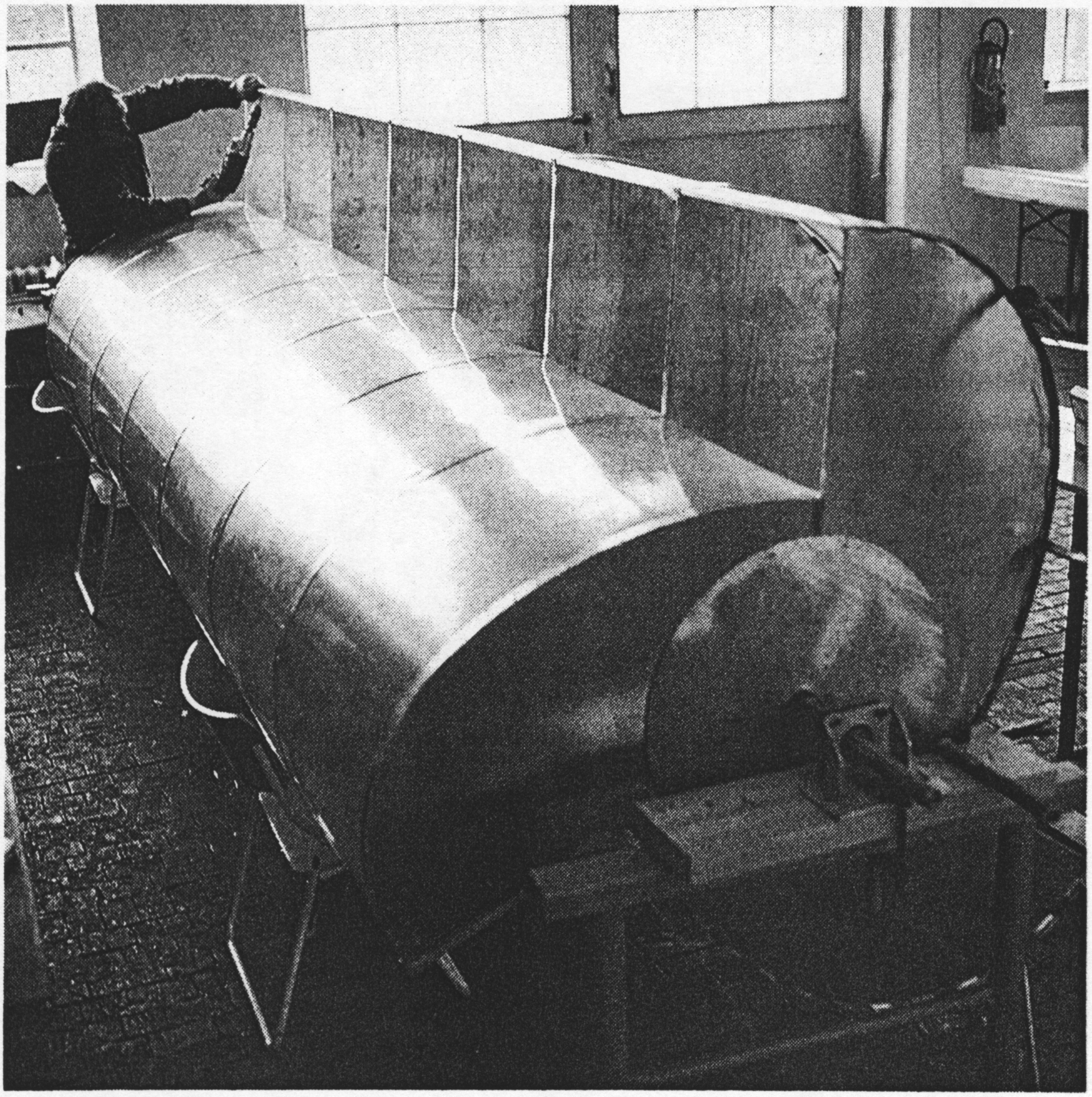


Abb. 26
Kleinere und mittelgroße Durchström-Rotoren kann man wie hier komplett vormontieren. Durch die selbsttragende Bauweise sind sie relativ leicht und dennoch sehr biege- und verwindungssteif.

nerator gefunden werden konnte, lassen sich noch bessere Werte erreichen. Daß in dieser Meßreihe die Stromerzeugung schon bei 1,5 m/sec Windgeschwindigkeit beginnt, hängt mit der Integrationszeit von 1 min zusammen. Das bedeutet, daß in der mittleren Windgeschwindigkeit auch kurze Böen enthalten sind, die den Generator für wenige Sekunden ansprechen lassen.
Im Rahmen der Diplomarbeit von Finger (vgl. Literaturverzeichnis) wurden Messungen über die optimale Flügelform des Durchströmrotors angestellt. In Abb. 32 sind die Ergebnisse dargestellt. Es zeigt sich, daß die Flügelform einen

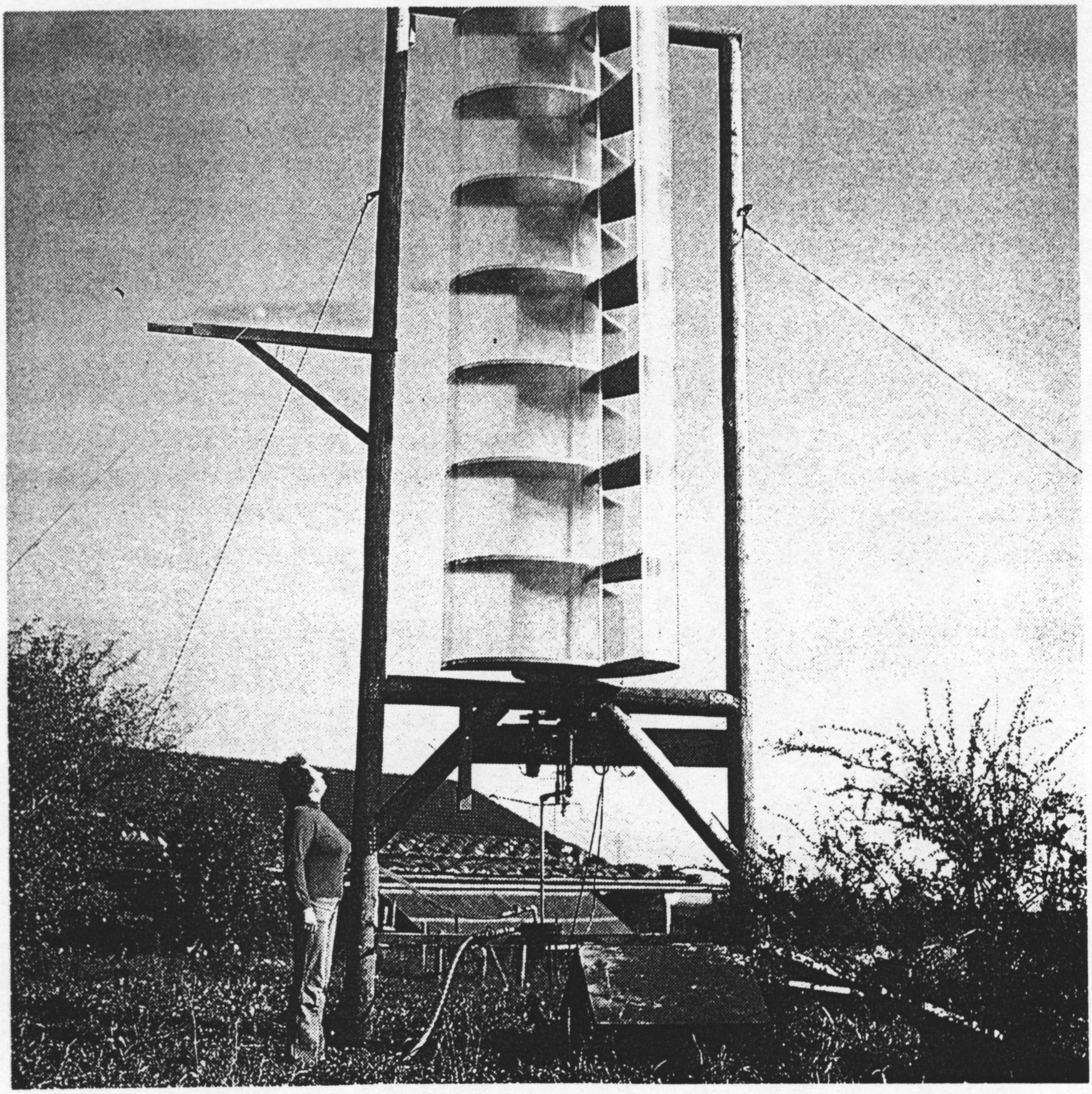


Abb. 27
Durch die Verwendung von lichtdurchlässigen GFK-Platten für die Flügel wirkt dieser Rotor trotz seiner Größe relativ leicht und wenig störend im Gelände.

sehr großen Einfluß auf den Leistungsbeiwert hat. Die Flügelform Nr. 4 bringt eindeutig die beste Leistung und zwar in einem sehr weiten Schnellaufzahlbereich. Während die Leerlauf-Schnellaufzahl bei dieser Flügelform bei 1,5 liegt (Umfangsgeschwindigkeit der Flügelspitzen ist 1,5 mal höher als die Windgeschwindigkeit), kann man den Rotor durch eine entsprechende Last auf Werte zwischen 0,4 bis 1,1 abbremsen, ohne daß die Leistung zu stark abfällt. Dieses günstige Verhalten gleicht im praktischen Betrieb den gegenüber einem Horizontalachsenrotor wesentlich niedrigeren Leistungsbeiwert bzw. Wirkungsgrad wenigstens teilweise aus.

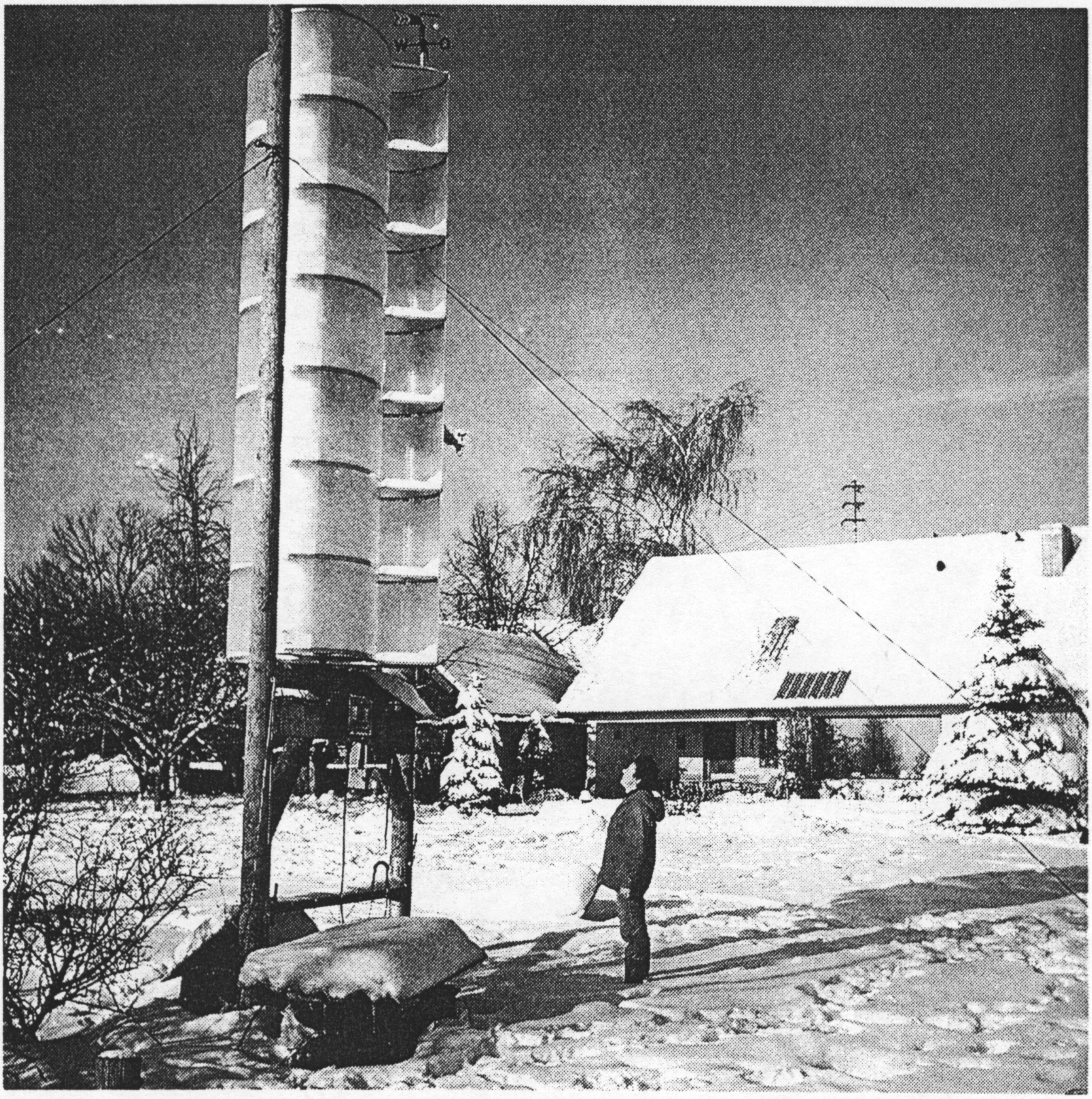
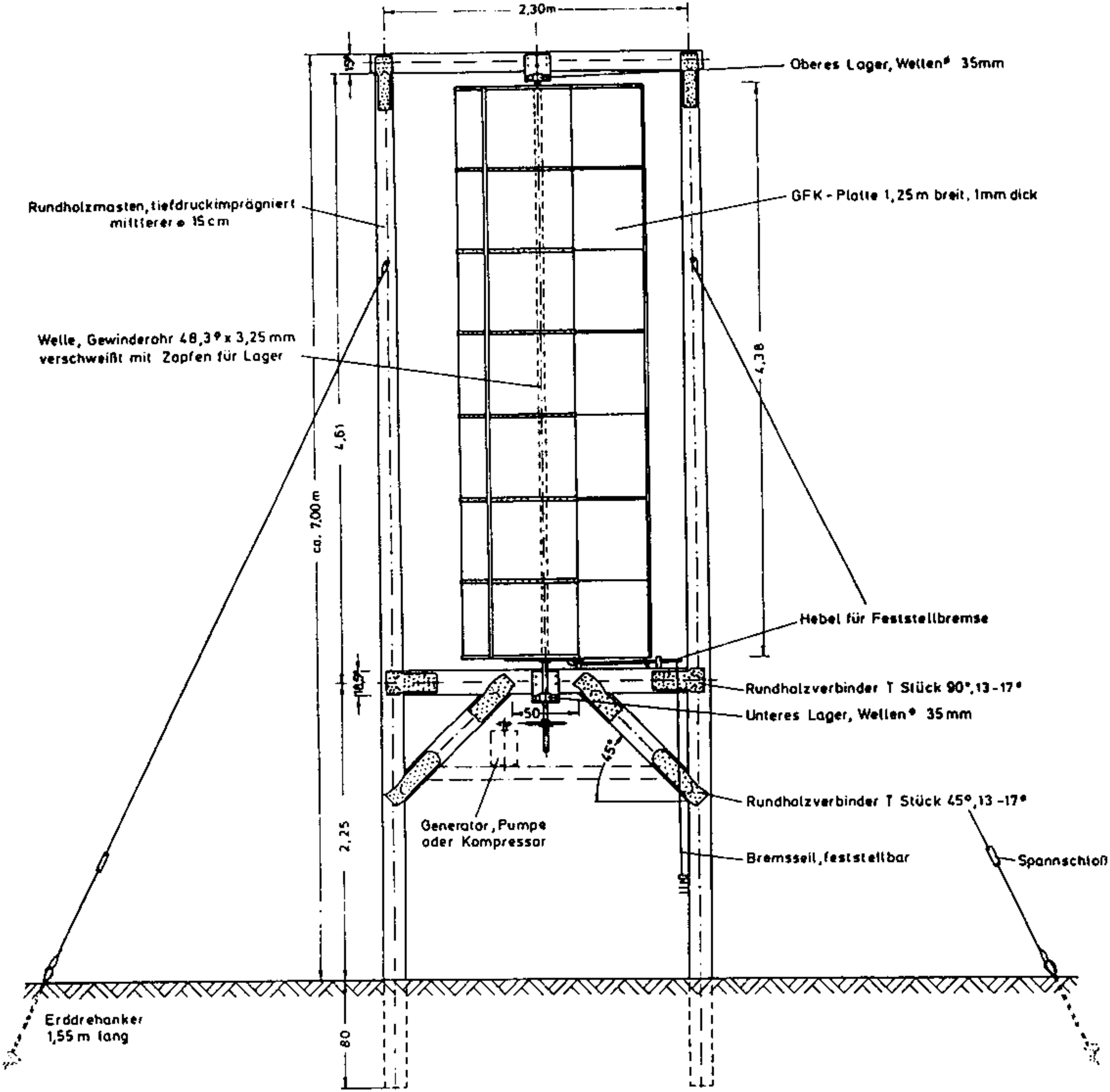


Abb. 28
Schneereiche Winter bereiten diesen Windturbinen keine Schwierigkeiten. Auf den Spanten liegender Schnee wird beim Rotieren abgeworfen.

Der von dieser Anlage erzeugte Gleichstrom (24 - 30 Volt) wird zusammen mit dem Strom vom Solargenerator auf dem Dach in Batterien gespeichert und zur Wohnraumbeleuchtung verwendet.

Mit der Flügelform 4 wurde ein großer Durchströmrotor mit 6 m Höhe und 3 m Durchmesser konzipiert und in 2 Exemplaren ausgeführt (Abb. 33). Der erste läuft seit April 83 auf dem Nebenerwerbsbetrieb des Verfassers in Kleinviecht (Abb. 34) und treibt über eine Kettenübersetzung 1 : 3 einen permanenterregten Drehstromgenerator von Albin Siegl (vgl. Abb. 14/15) an, der über einen Brückengleichrichter Nickel-Cadmiumbatterien im Spannungsbereich von 22 -


2,30m
15
Oberes Lager, Wellen⌀ 35mm
Rundholzmasten, tiefdruckimprägniert mittlerer ⌀ 15cm
GFK-Platte 1,25m breit, 1mm dick
Welle, Gewinderohr 48,3⌀ x 3,25 mm verschweißt mit Zapfen für Lager
ca. 7,00 m
4,61
4,38
Hebel für Feststellbremse
14,9
Rundholzverbinder T Stück 90°, 13-17⌀
50
Unteres Lager, Wellen⌀ 35 mm
45°
Rundholzverbinder T Stück 45°, 13-17⌀
Generator, Pumpe oder Kompressor
2,25
Bremsseil, feststellbar
Spannschloß
Erddrehanker 1,55 m lang
80

LANDTECHNIK
WEIHENSTEPHAN
Dr. Schulz 581/1 W.

Blatt 1

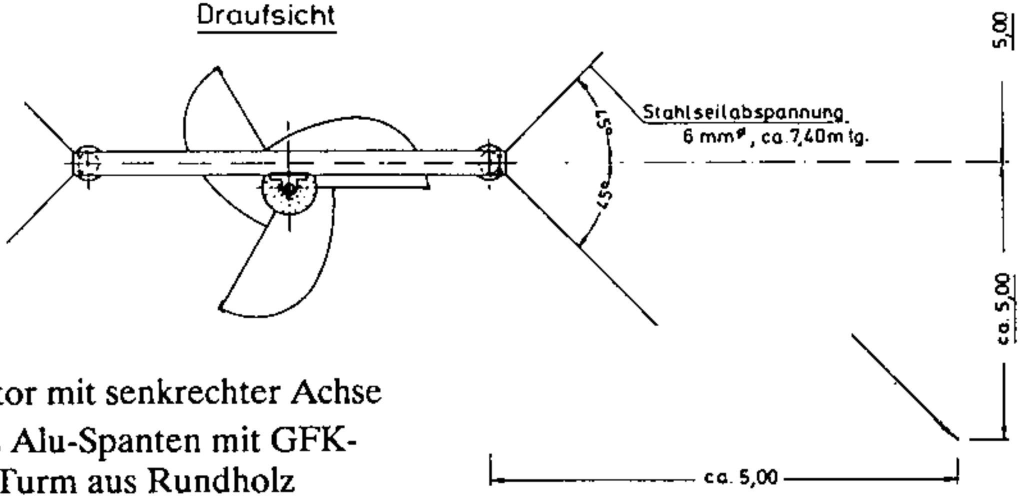


Abb. 29:
Dreiflügeliger Windrotor mit senkrechter Achse
Durchström-Rotor aus Alu-Spanten mit GFK-Bespannung in einem Turm aus Rundholz und Rundholzverbindern

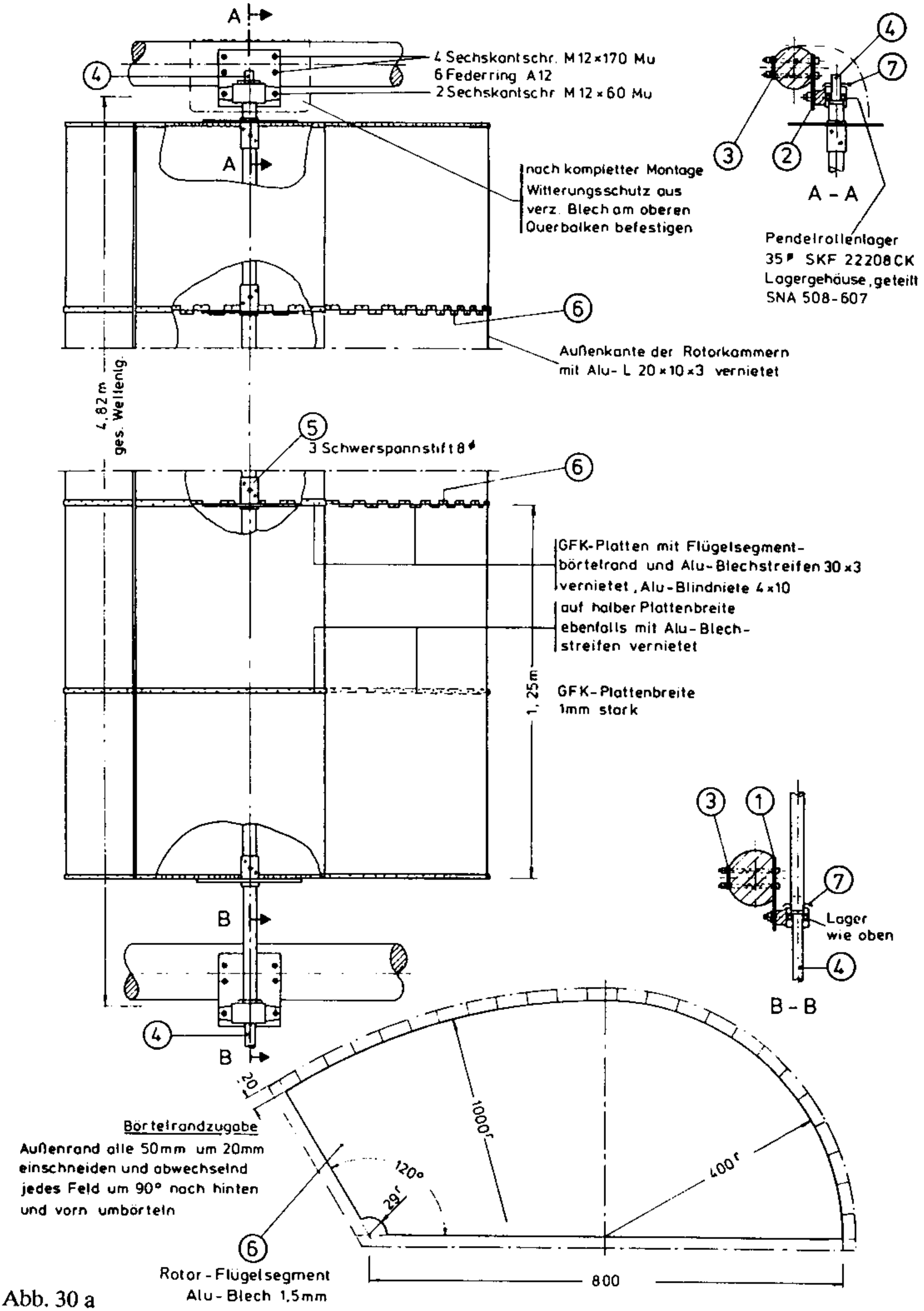
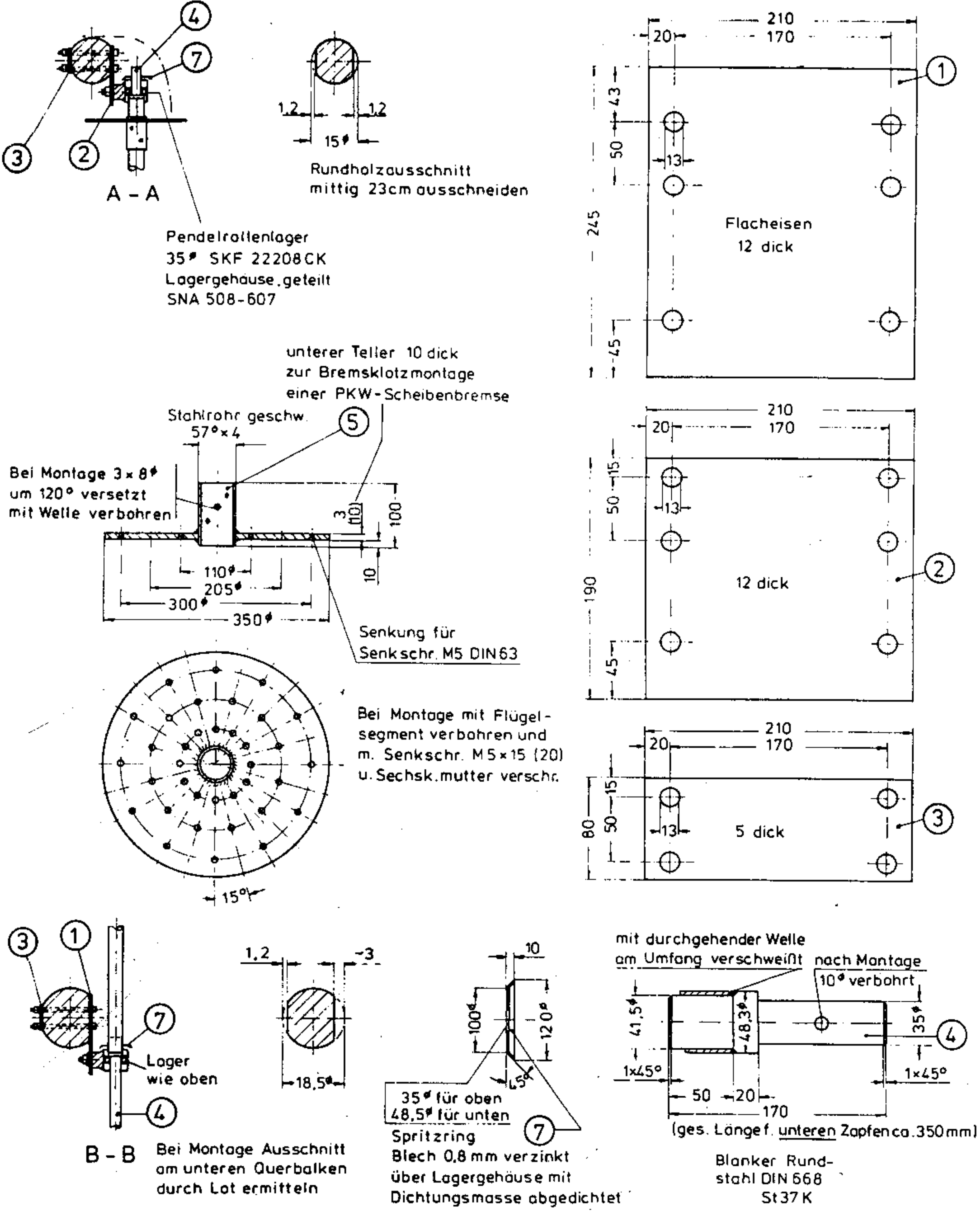
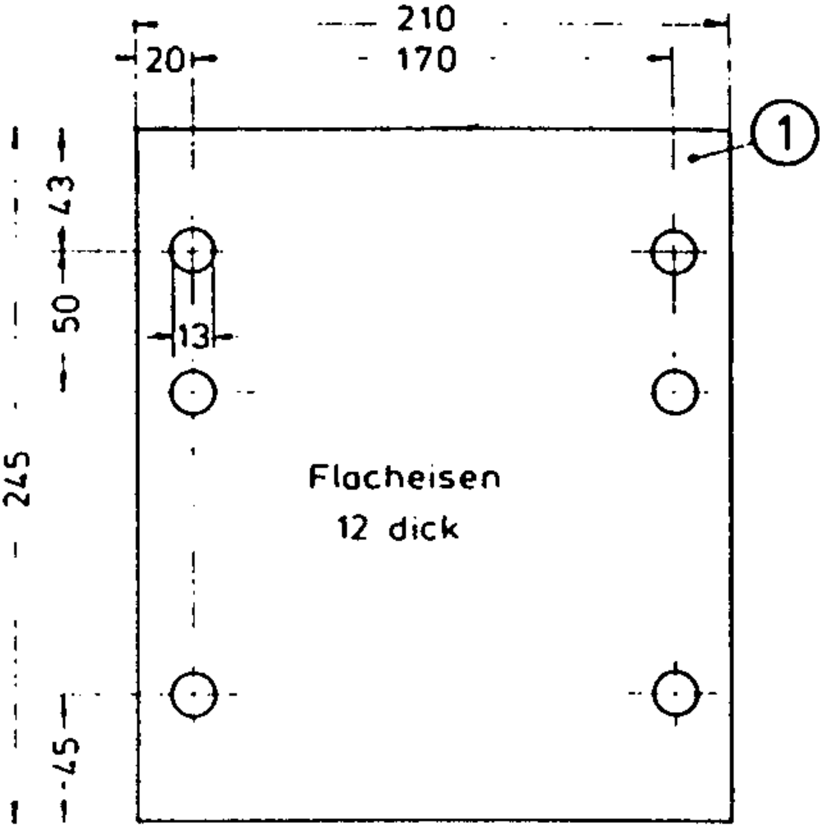

A
4 Sechskantschr. M 12×170 Mu
6 Federring A12
2 Sechskantschr. M 12×60 Mu
④
A
nach kompletter Montage
Witterungsschutz aus
verz. Blech am oberen
Querbalken befestigen
④
⑦
③
②
A - A
Pendelrollenlager
35⌀ SKF 22208 CK
Lagergehäuse, geteilt
SNA 508-607
⑥
Außenkante der Rotorkammern
mit Alu-L 20×10×3 vernietet
4,82 m
ges. Wellenlg.
⑤
3 Schwerspannstift 8⌀
⑥
GFK-Platten mit Flügelsegment-
börtelrand und Alu-Blechstreifen 30×3
vernietet, Alu-Blindniete 4×10
auf halber Plattenbreite
ebenfalls mit Alu-Blech-
streifen vernietet
1,25 m
GFK-Plattenbreite
1mm stark
③
①
⑦
Lager
wie oben
④
B - B
B
④
B
20
1000r
120°
29r
400r
800
Börtelrandzugabe
Außenrand alle 50mm um 20mm
einschneiden und abwechselnd
jedes Feld um 90° nach hinten
und vorn umbörteln
⑥
Rotor-Flügelsegment
Alu-Blech 1,5mm

Abb. 30 a



▲ Abb. 30 b: Dreiflügeliger Windrotor mit senkrechter Achse (Details)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170
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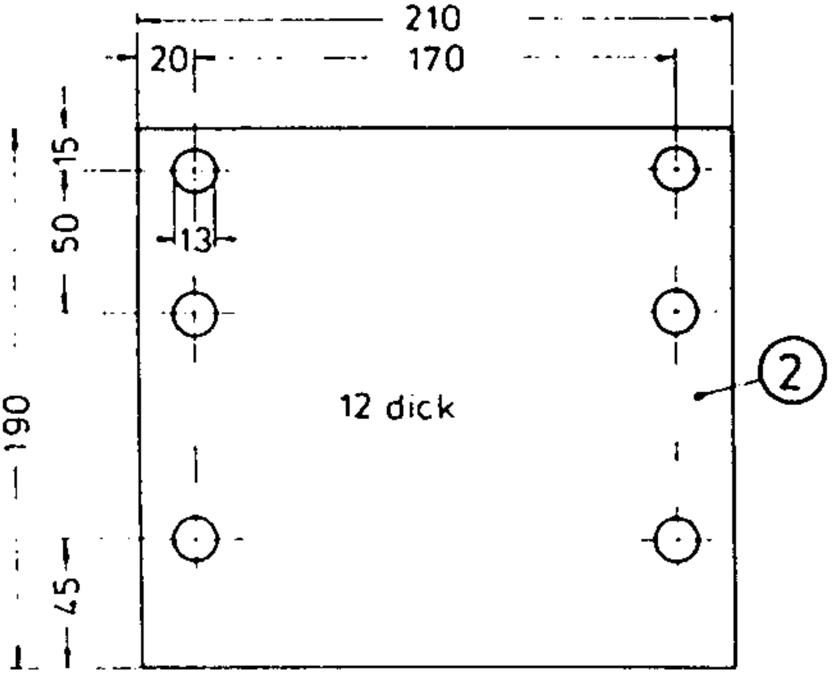
245
Flacheisen
12 dick
45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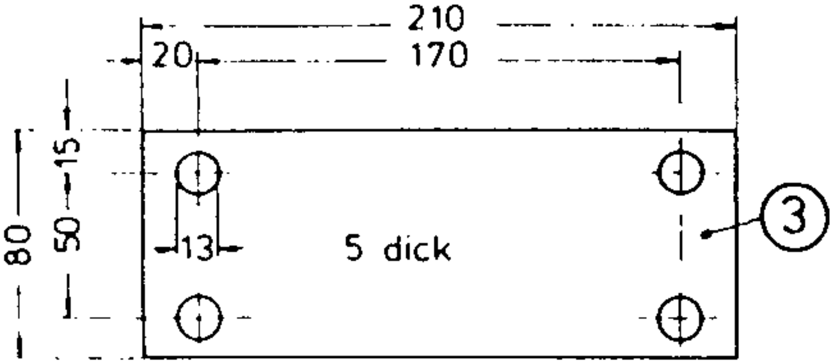
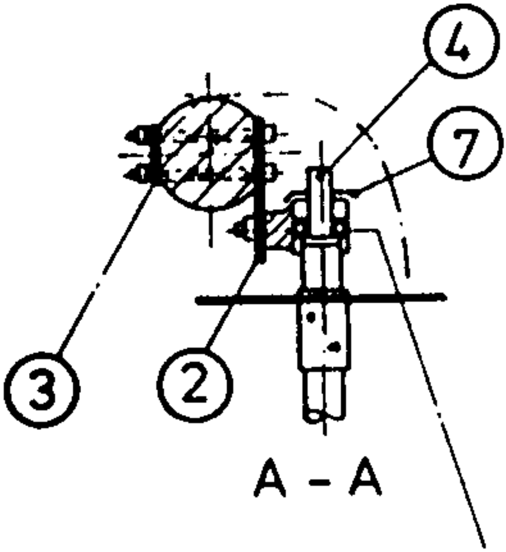
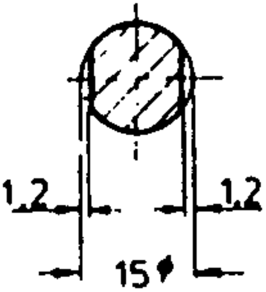
12 dick
45


210
20
170
15
50
80
13
5 dick
③

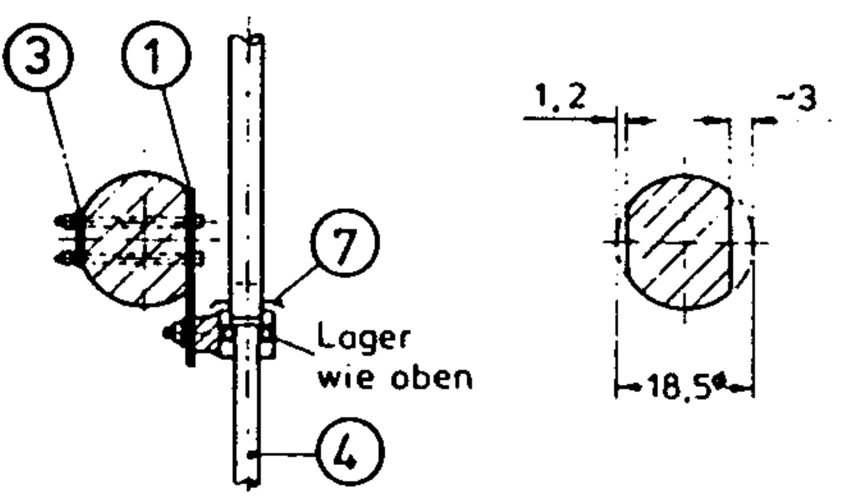


A - A

Pendelrollenlager
35Ø SKF 22208CK
Lagergehouse, geteilt
SNA 508-607

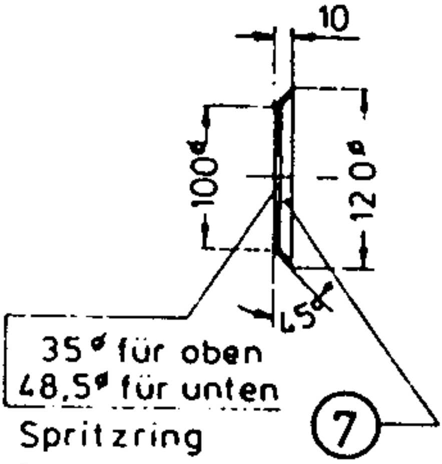


Rundholzausschnitt
mittig 23cm ausschneiden



B - B

Bei Montage Ausschnitt
am unteren Querbalken
durch Lot ermitteln

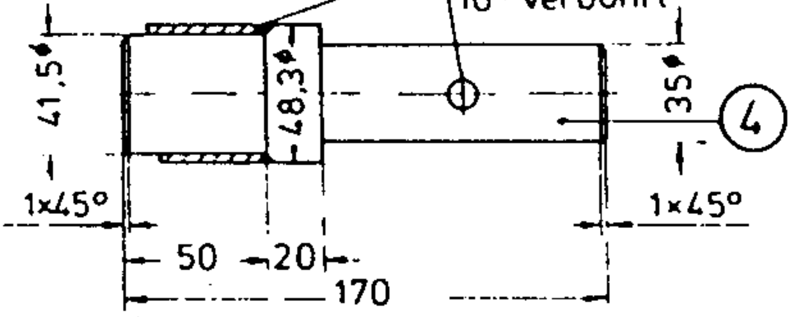


35ø für oben
48,5ø für unten

Spritzring
Blech 0,8 mm verzinkt
über Lagergehäuse mit
Dichtungsmasse abgedichtet

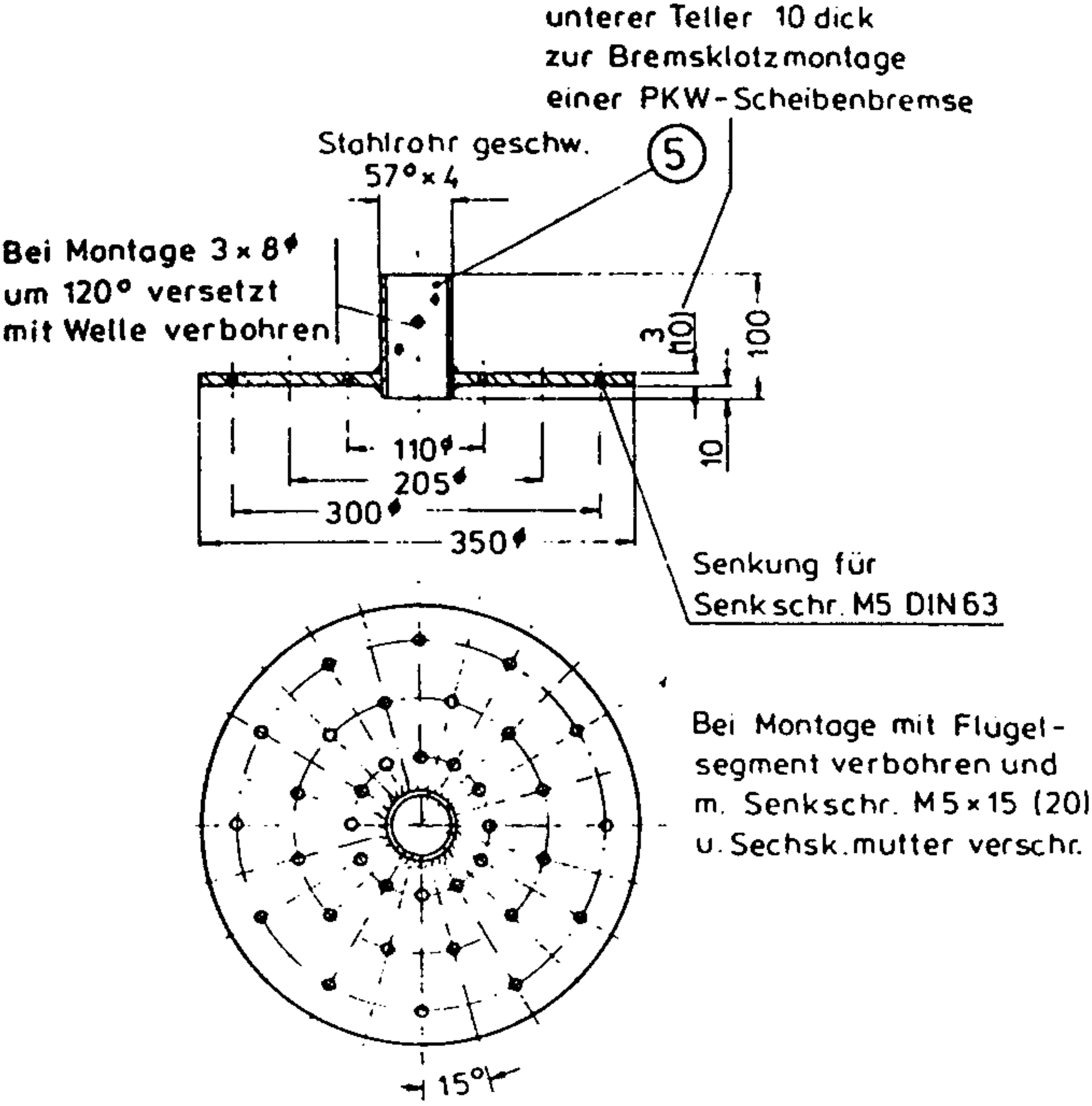
mit durchgehender Welle
am Umfang verschweißt

nach Montage
10ø verbohrt



(ges. Länge f. unteren Zapfen ca. 350 mm)

Blanker Rund-
stahl DIN 668
St 37 K


unterer Teller 10 dick
zur Bremsklotzmontage
einer PKW-Scheibenbremse
Stahlrohr geschw.
57⌀×4
⑤
Bei Montage 3×8⌀
um 120° versetzt
mit Welle verbohren
3
(10)
100
10
110⌀
205⌀
300⌀
350⌀
Senkung für
Senkschr. M5 DIN 63
Bei Montage mit Flügelsegment verbohren und
m. Senkschr. M5×15 (20)
u. Sechsk.mutter verschr.
15°

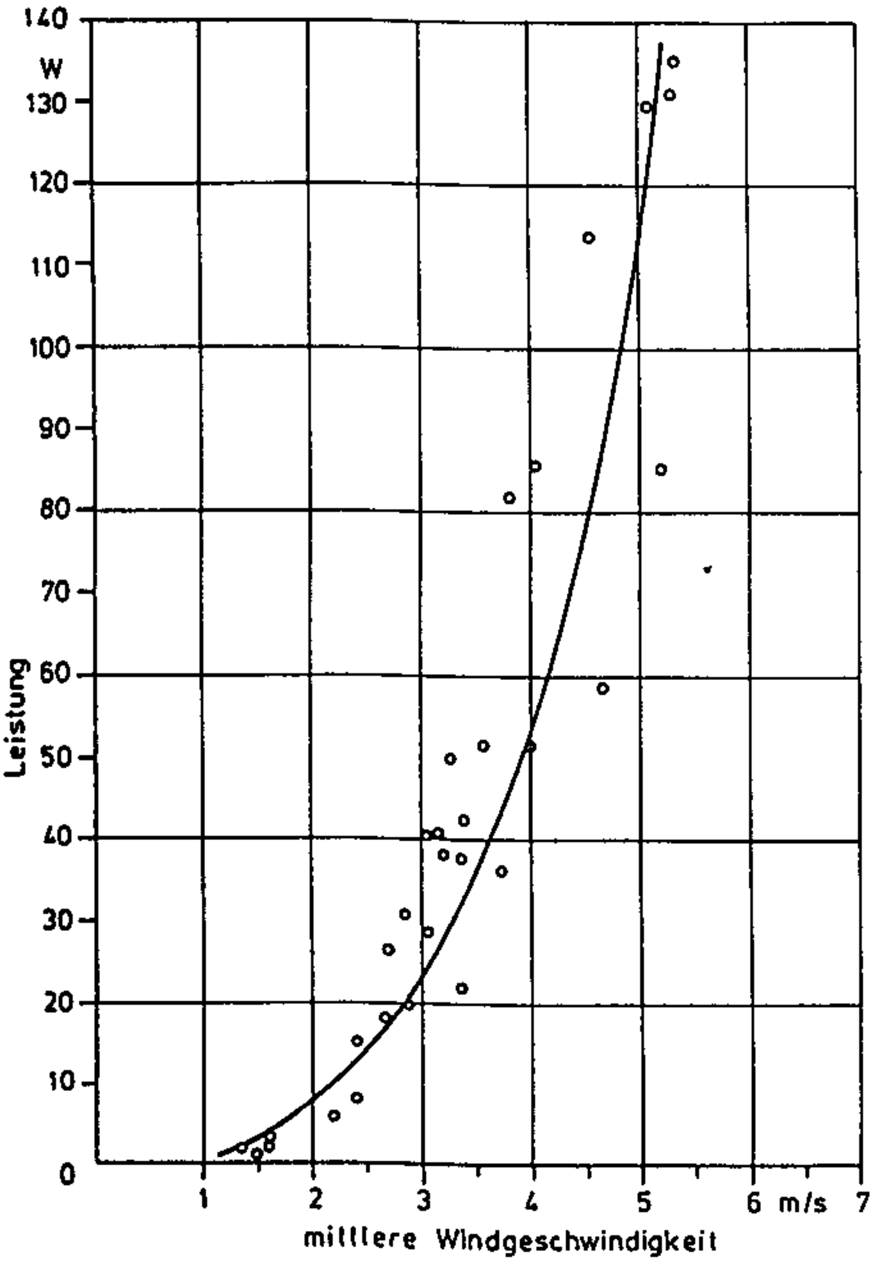


Abb. 32 ▶
Leistungsbeiwert c_p und Schnellaufzahl X bei dreiflügeligen Durchströmrotoren mit unterschiedlicher Flügelform
(gemessen an Rotormodellen mit 50 cm Höhe, 30 cm Ø und 2 Endscheiben)

Abb. 31: ◀
Generatorleistung in Abhängigkeit von der Windgeschwindigkeit bei einem 3-flügeligen Durchström-Rotor
Rotor: 160 cm Ø, 438 cm Höhe;
Integrationszeit: 1 min;
Generator: 16-pol. Gleichstromgenerator 12 V/300W

30 V auflädt. Rotor und Generator haben sich bisher gut bewährt, Probleme hat es nur an den zur Leistungsverstärkung angebrachten Endscheiben gegeben: die untere war zu schlecht befestigt und wurde bei Sturm zerfetzt (verbesserte Ausführung siehe weiter unten). Der zweite Rotor dieser Größe wurde im Sommer 84 auf dem Hof von Josef Bachmeier, Holzen Nr. 8 bei Buch am Erlbach, Kreis Landshut gebaut, und zwar teilweise im Rahmen eines Praktikums zum Selbstbau von Windkraftanlagen (Abb. 35). Die Zeichnungen (Abb. 36 und 37) zeigen nähere Einzelheiten. An diesem Rotor wurde erstmals ein interessantes Generatorsystem erprobt. Es besteht aus einer kleineren, permanenterregten Gleichstrommaschine, die sowohl als Motor, wie auch als Generator arbeiten kann. Sie erreicht als Generator schon bei 250 U/min eine Ladespannung von 14 V und kann damit bei niedrigen Windgeschwindigkeiten unter 5 m/s direkt 12 V-Batterien aufladen. Bei mittleren bis höchsten Wind-

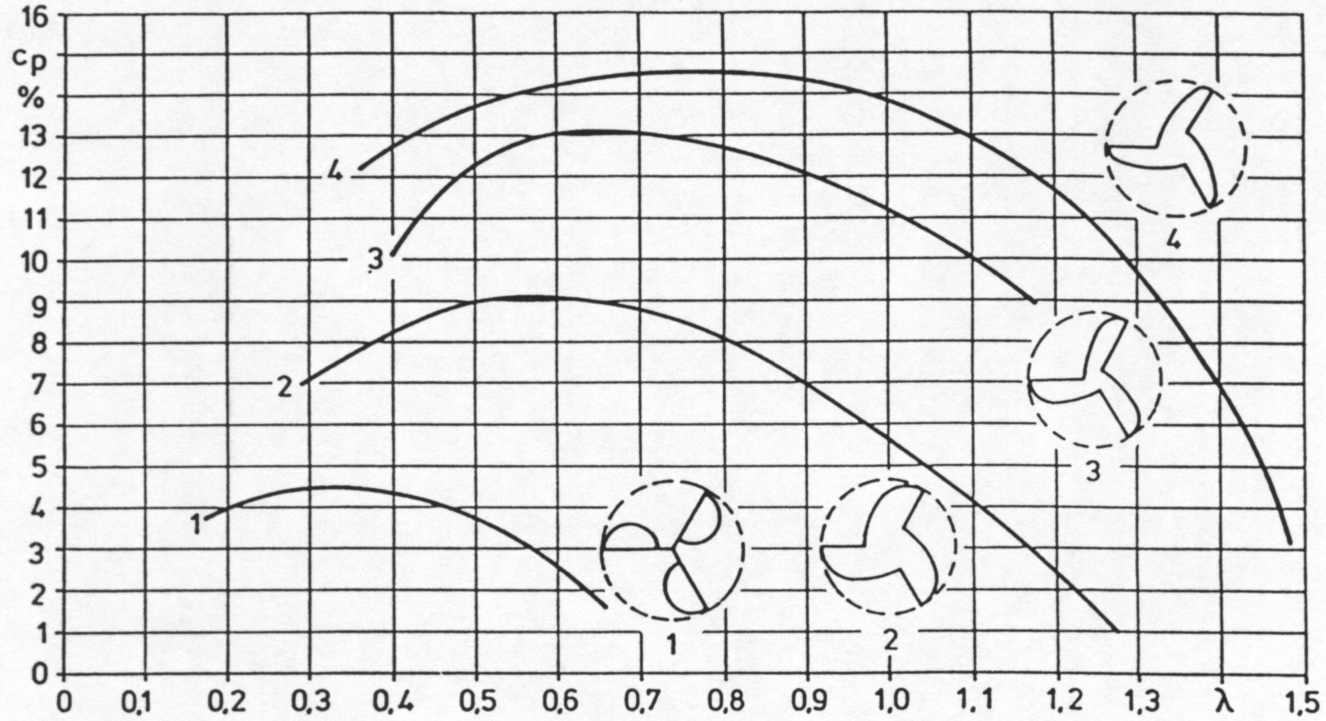
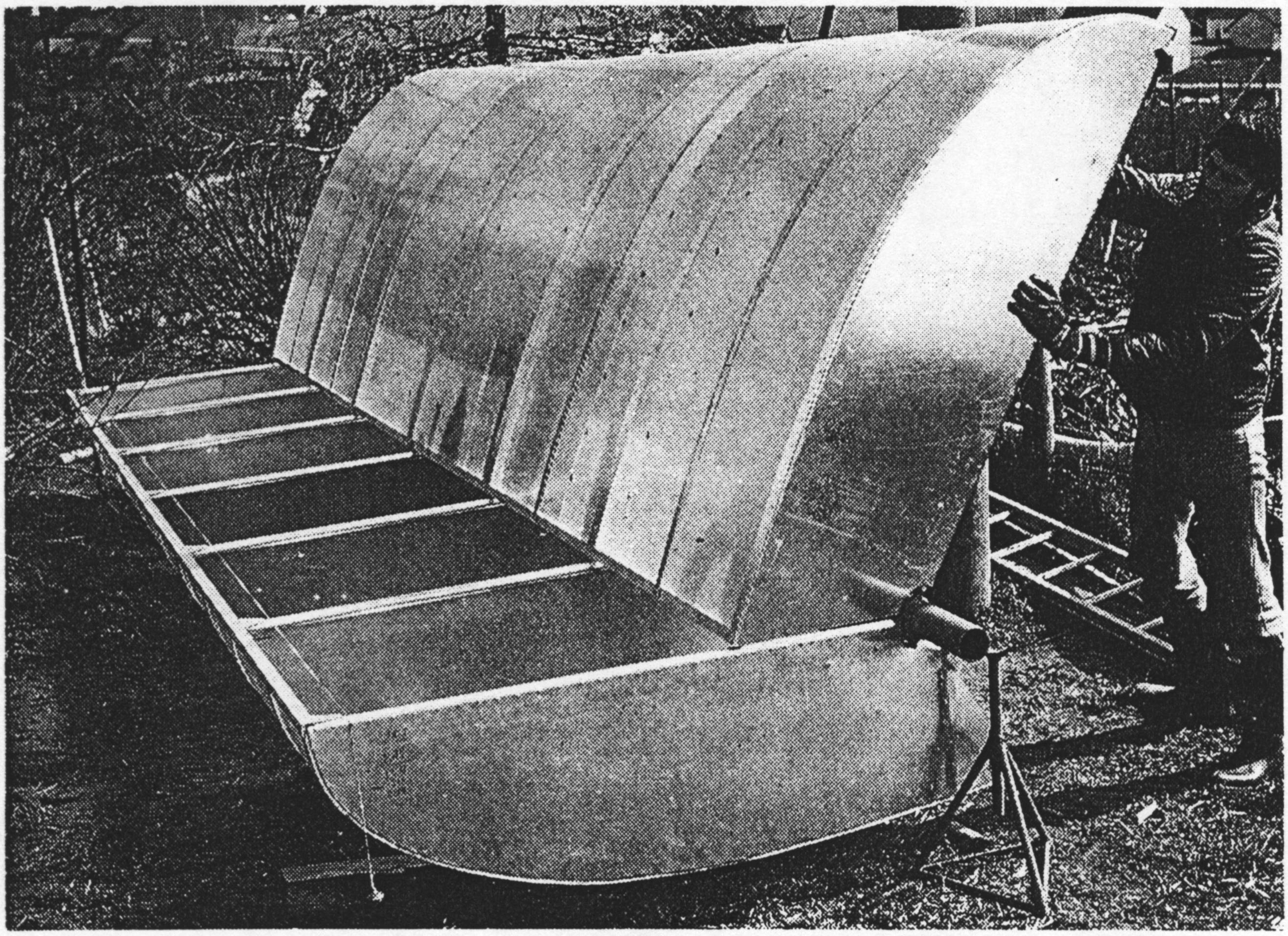


Abb. 33 ▼
Beim großen Durchströmrotor werden die 3 Flügelteile vorgefertigt und erst am Aufstellungsort zusammengefügt. Das Auswuchten vor der Montage erfolgt wie beim Savonius-Rotor.



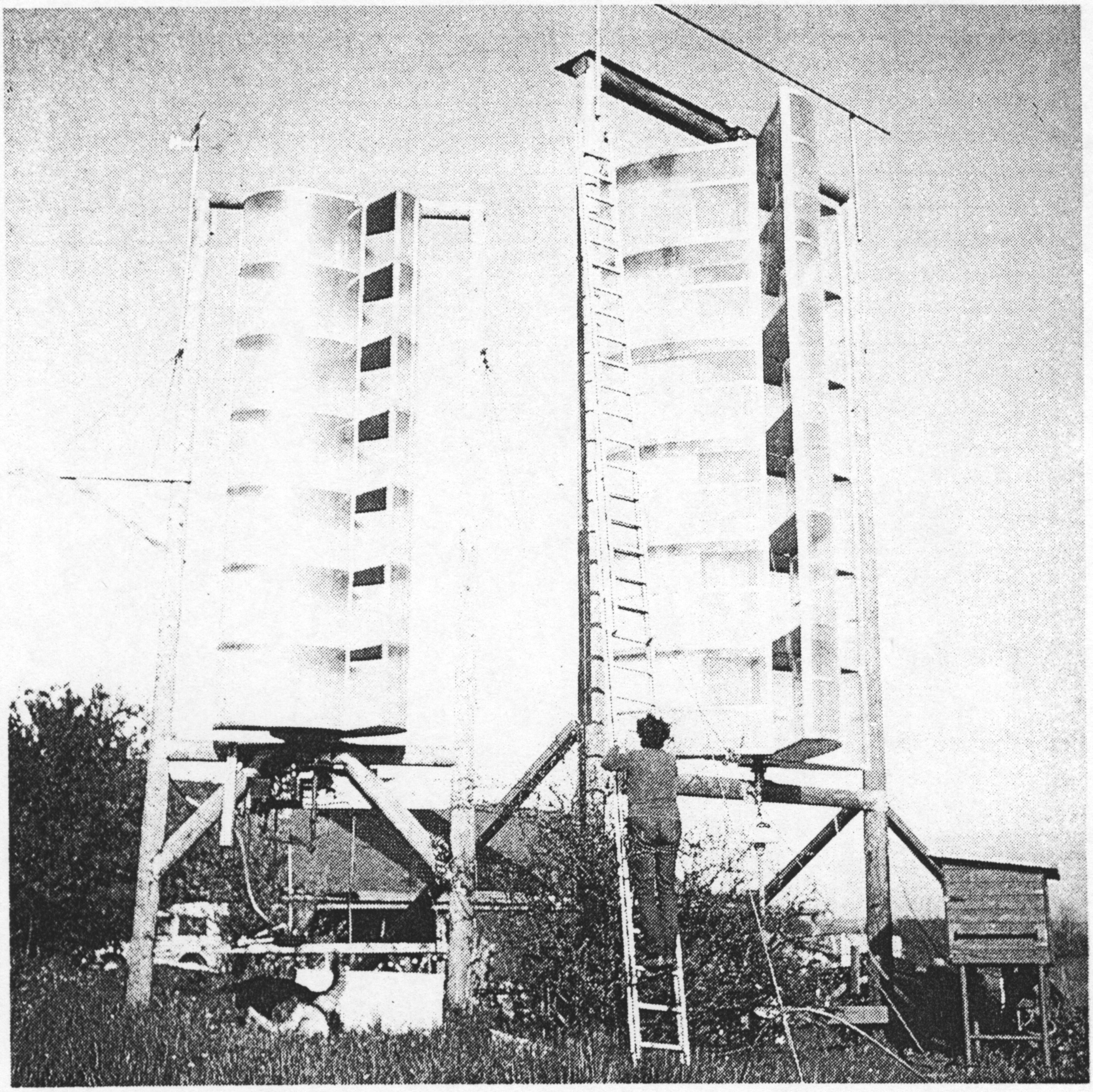


Abb. 34
Die beiden Durchström-Rotoren auf dem Hof des Verfassers laufen schon jahrelang ohne größere Probleme. Beide haben sich als ausreichend sturmsicher erwiesen.

geschwindigkeiten wird mit dem Gleichstrom dieses kleinen Generators zusätzlich die Ankerwicklung einer fremderregten Drehstrom-Panzerlichtmaschine gespeist, deren Leistungskennlinien im unteren Drehzahlbereich in Abb. 38 wiedergegeben sind. Die Fa. Elektro-Artmann, Mallersdorf (vgl. Lieferhinweise) rüstet derartige Maschinen aus Sonderbeständen mit Spitzenleistungen von 2 - 3 kW auf Betrieb in Windkraftanlagen aus. Über eingebaute Dioden kann wahlweise Gleichstrom zwischen 14 und 30 V oder mit Hilfe eines Drehstromtrafos auch Drehstrom bis 220 oder 380 V erzeugt werden, der natürlich nicht als Netzstrom mit konstanter Spannung und Frequenz, sondern beispielsweise zur Wasserwärmung über Heizstäbe vorgesehen ist.

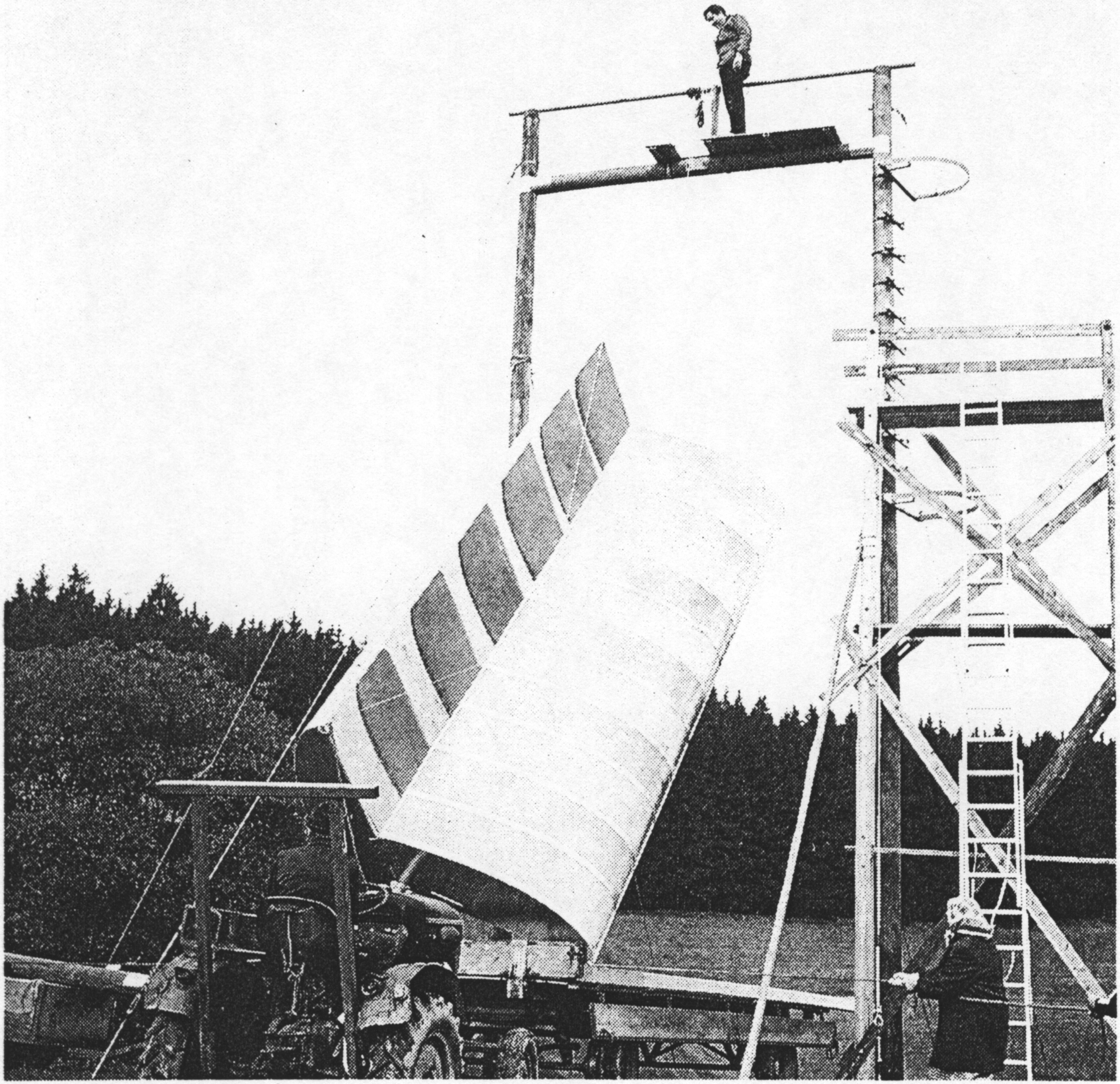


Abb. 35
Aufziehen des Durchström-Rotors bei Bachmaier/Holzen mit Hilfe eines Drahtseilzuges. Die Person auf dem Turm muß - wie hier - einen Sicherheitsgurt tragen.

Bei der Anlage in Holzen hat es sich gezeigt, daß der Bau eines Rotors in dieser Größe auf einem Bauernhof mit normaler Werkstattausrüstung und einem Handwerksbetrieb mit Drehbank für die Lagerzapfen zwar möglich, aber kein Kinderspiel ist. Vor allem das bisherige Fehlen genauer Konstruktionszeichnungen, Materiallisten und Bezugsquellenverzeichnisse hat Herrn Bachmeier vor große, aber bei seinem Engagement doch überwindbare Probleme gestellt. Herrn Bachmeier ist daher ebenso zu danken wie allen anderen, die beim Bau dieser Anlage mitgeholfen haben.

Als die wichtigsten Schwierigkeiten bei der Stromerzeugung gerade überwunden waren und Herr Bachmeier glaubte, aufatmen zu können, wurde der Rotor

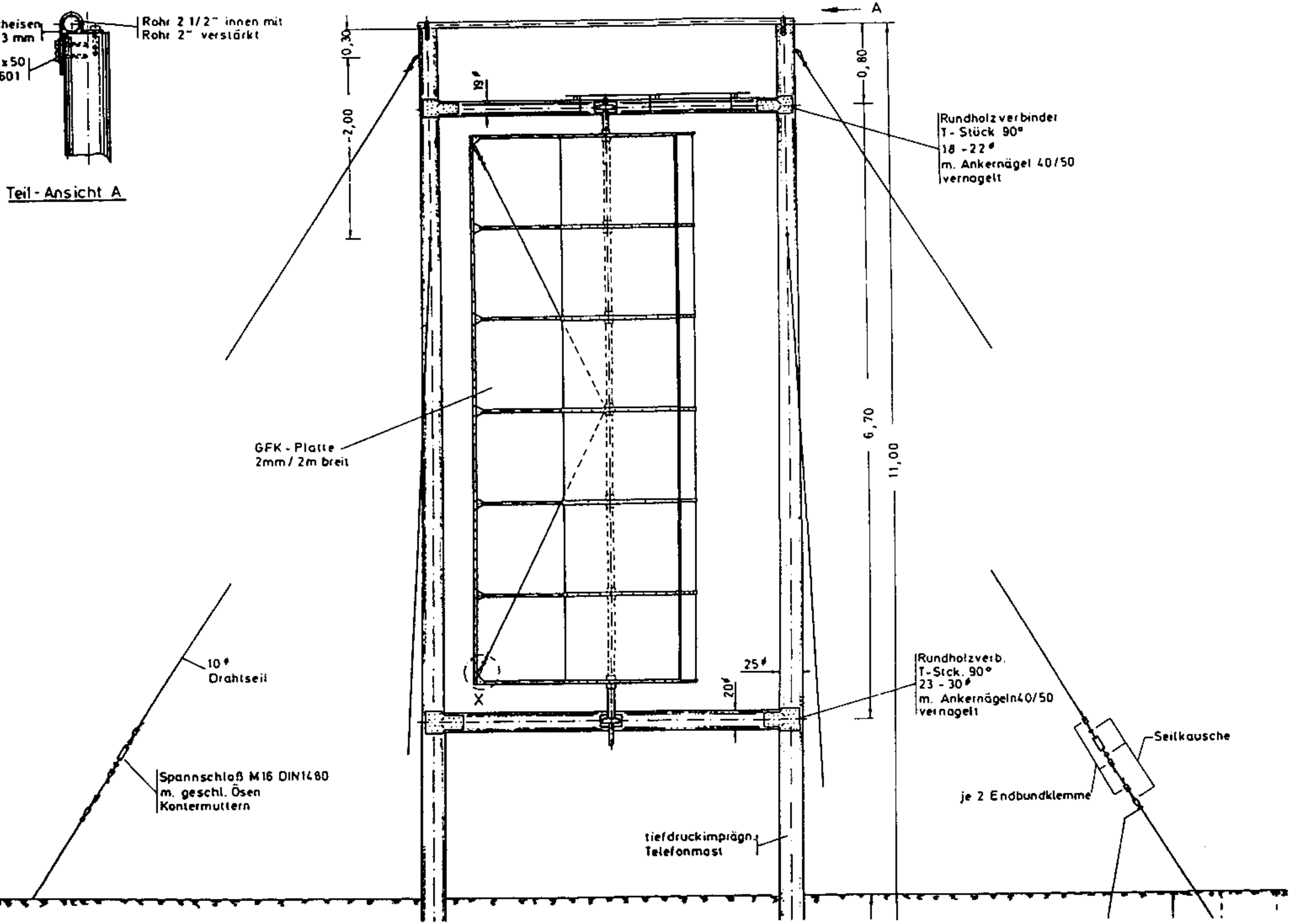


Abb. 36 a: Dreiflügeliger Durchström-Rotor (große Ausführung)

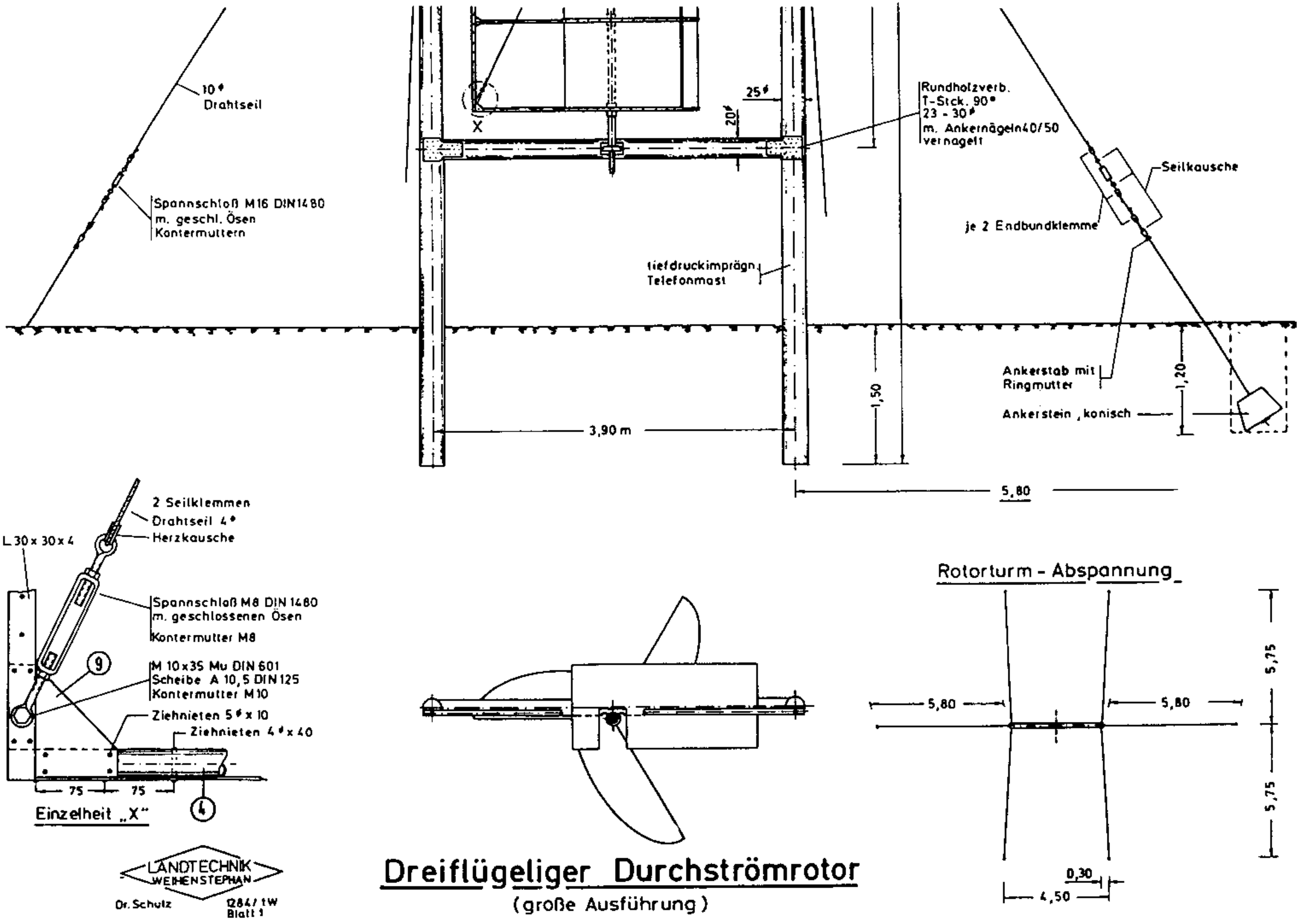


Abb. 36 b: Dreiflügeliger Durchström-Rotor

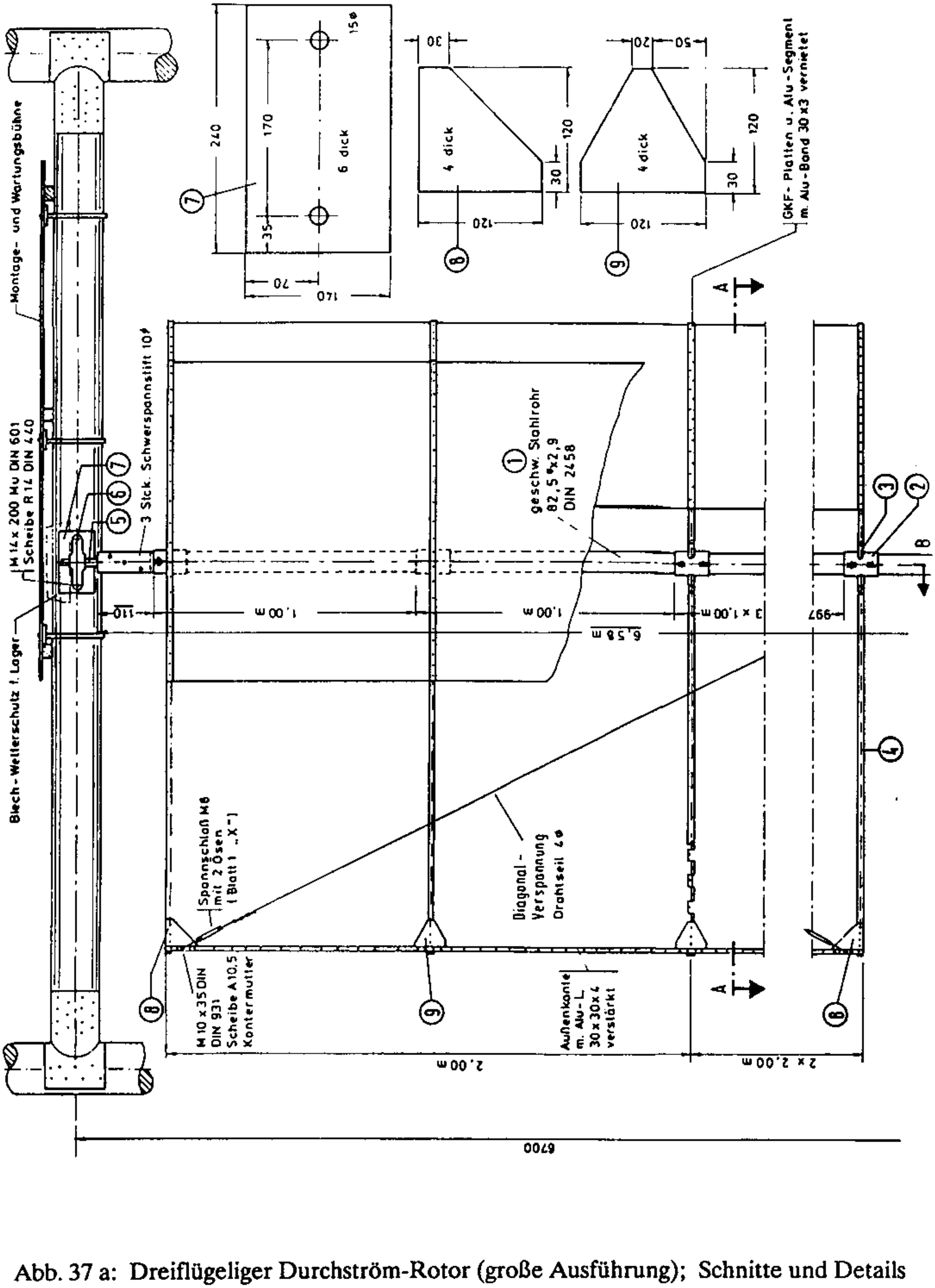


Abb. 37 a: Dreiflügeliger Durchström-Rotor (große Ausführung); Schnitte und Details

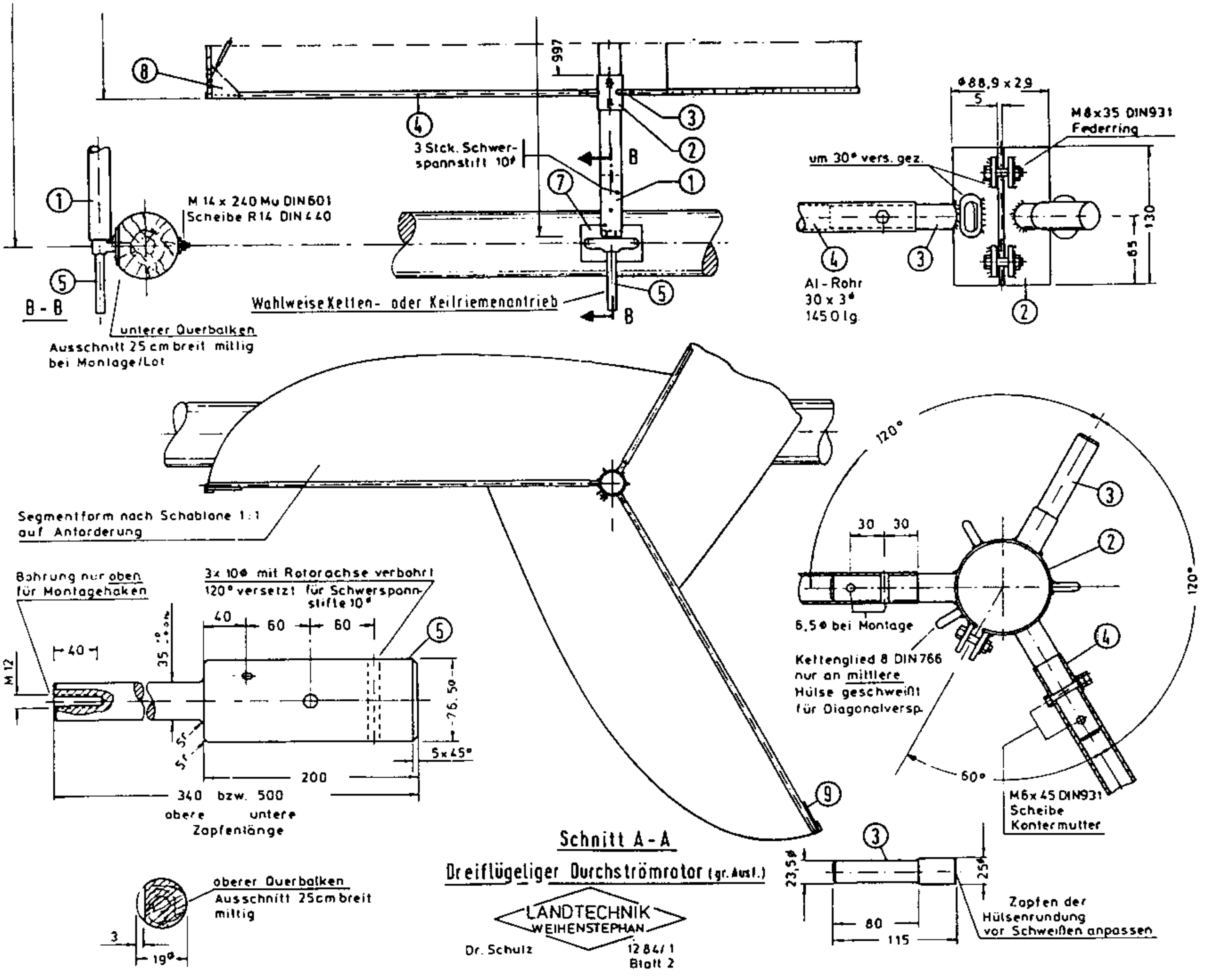


Abb. 37 b: Dreiflügeliger Durchström-Rotor (große Ausführung); Schnitte und Details

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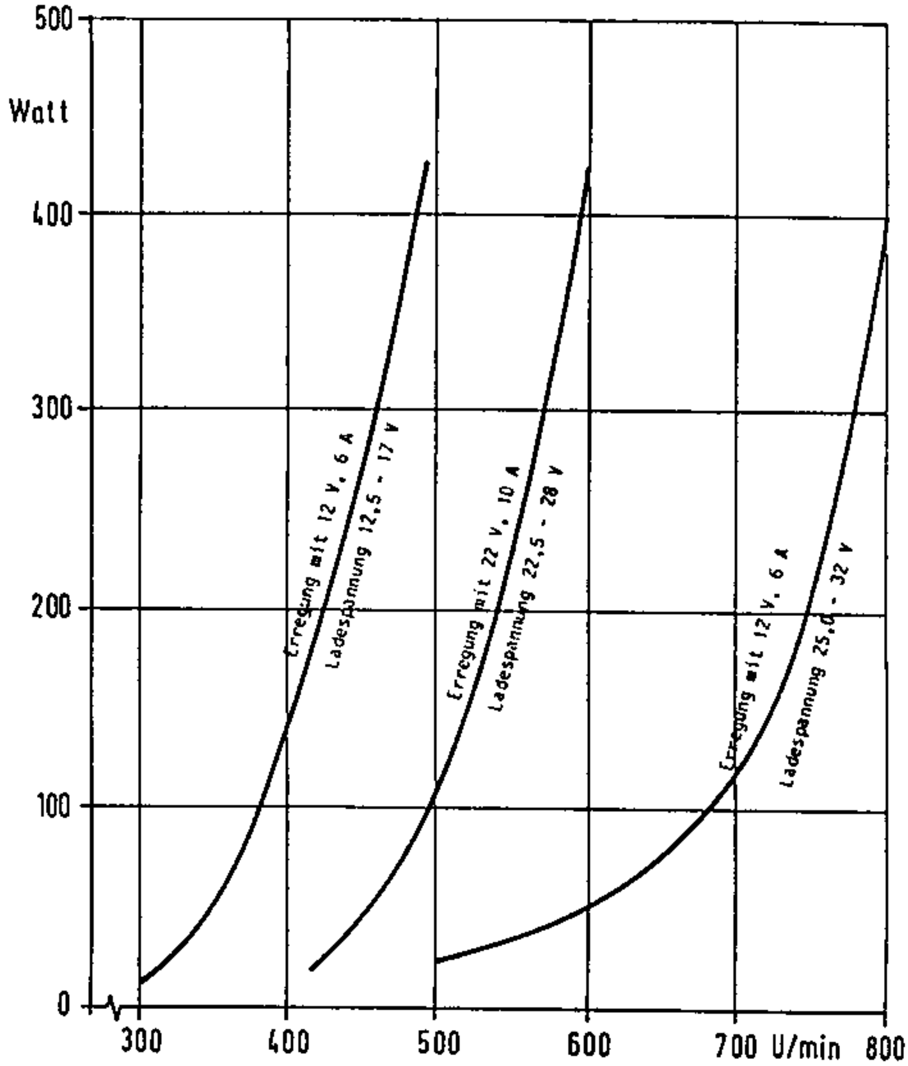


Abb. 38
Leistungskennlinien einer für Windkraftanlagen geeigneten Panzerlichtmaschine bei niedrigen Drehzahlen
(fremderregte Drehstromlichtmaschine 28 V, 100 A von Elektro-Artmann/Mallersdorf beim Aufladen einer NC-Batterie 20 Ah)

in dem orkanartigen Sturm am 23.11.83 zerstört, weil beim Bau ein kleiner, aber entscheidender Fehler gemacht wurde. Anstelle der vorgesehenen Spannschlösser M 8 mit geschlossenen Ösen, welche die 6 Seile der Diagonalverspannung im Rotor halten (siehe Abb. 36, Detail X) kamen Spannschlösser M 6 mit offenen Haken zum Einsatz. Dadurch konnte sich ein Seil lösen, wurde vom Rotor durch Fliehkraft gegen die senkrechten Masten des Turms geschleudert, wo es sich verfangen haben muß, wodurch die Rotorwelle geknickt und aus dem oberen Lager gerissen wurde. Dieser Schaden zeigt wieder einmal, daß der Sturm selbst die kleinsten Schwächen einer Windkraftanlage sucht, um dieses ihm im Weg stehende Hindernis zu zerstören.
Der Turm mit Seilabspannung sowie die Generatoren mit der zweistufigen Ketten- und Keilriemenübersetzung blieben unversehrt.

Die beiden Durchströmrotoren auf dem Hof des Verfassers überstanden diesen Orkan und luden die Nickel-Cadmiumbatterien mit 30 V und 800 Ah innerhalb von 30 Stunden bis zum Überkochen auf. Beim großen Rotor wurde lediglich auch noch die obere der beiden Endscheiben, die im Rahmen der erwähnten Diplomarbeit versuchsweise angebracht waren, beschädigt und nun-

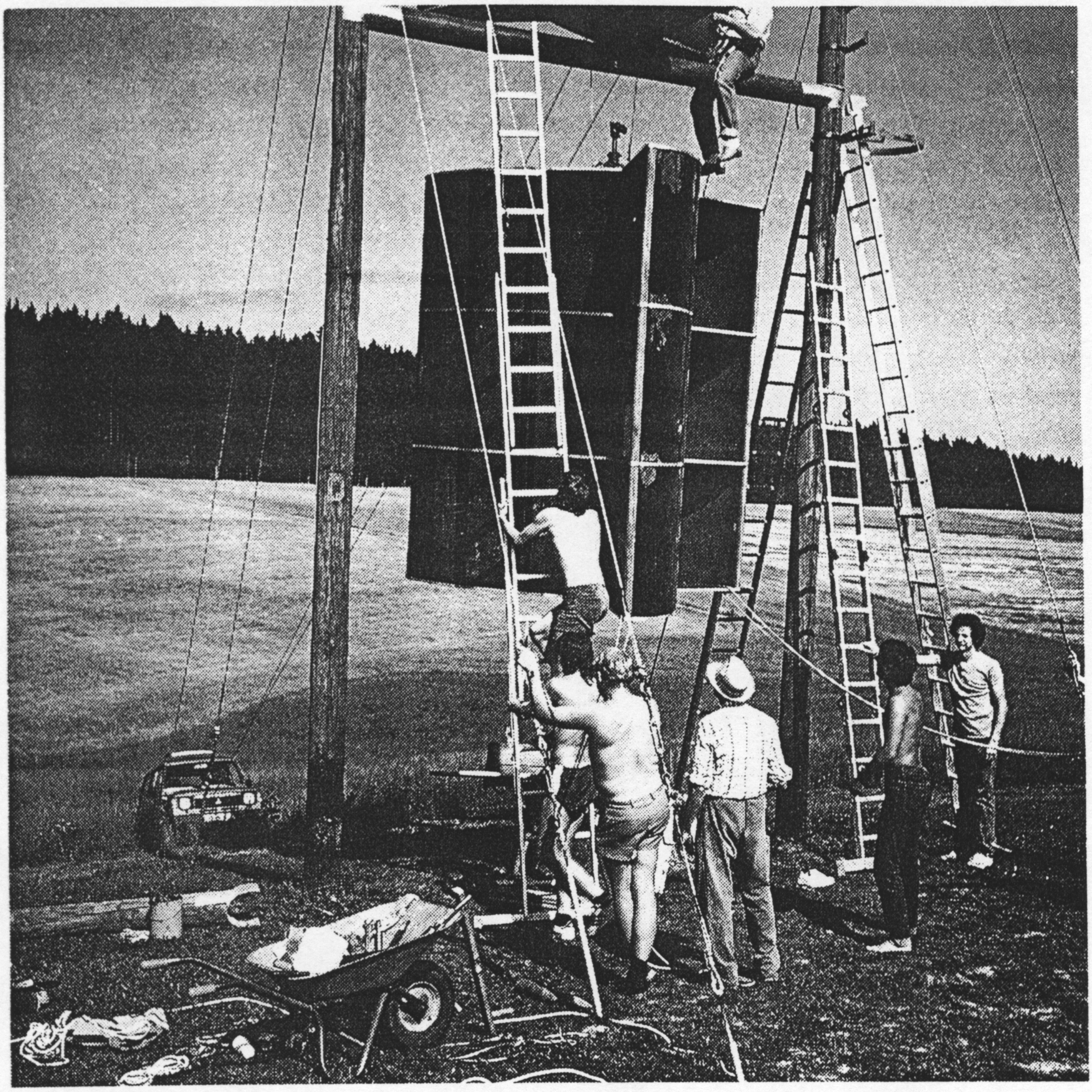


Abb. 39:
Montage der unteren Hälfte des neuen Durchströmrotors bei Bachmeier/Holzen

mehr ganz abgebaut. Es ist nämlich konstruktiv kaum möglich, solche kreisrunden Endscheiben mit 3 m Ø so steif zu bauen, daß sie bei derartigen Stürmen mit Spitzengeschwindigkeiten bis zu 140 km/h (ca. 40 m/s) nicht flattern.
1985 wurde im Rahmen von 2 Seminaren der Durchströmrotor bei Bachmeier wieder aufgebaut, und zwar versuchsweise in Sperrholzkonstruktion und zweistufiger, versetzter Bauweise (Abb. 39, 40, 41 und 42). Die zwei Rotorstufen mit je 3 m Ø und 3 m Höhe lassen sich wesentlich leichter herstellen und montieren und sind über ein mittleres Lager und eine Kardanwelle miteinander verbunden. Durch das höhere Gewicht der Sperrholzplatten (20 mm für die Segmente und 6 mm für die Flügel) wurden allerdings die Lager sehr stark in

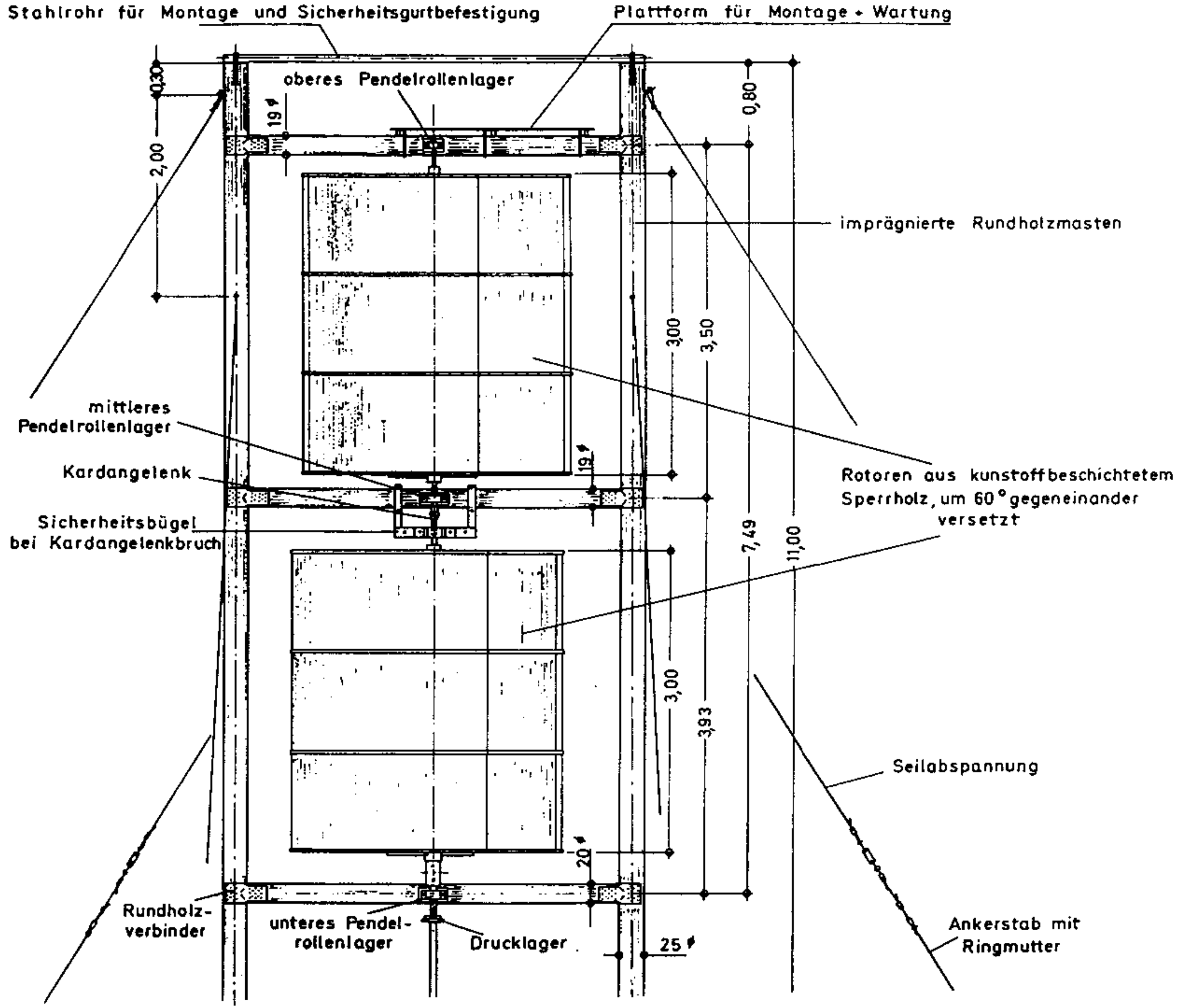


Abb. 40 a: Dreiflügeliger, zweistufiger Durchströmrotor (Ausführung bei Josef Bachmaier, Holzen bei Buch am Erlbach)

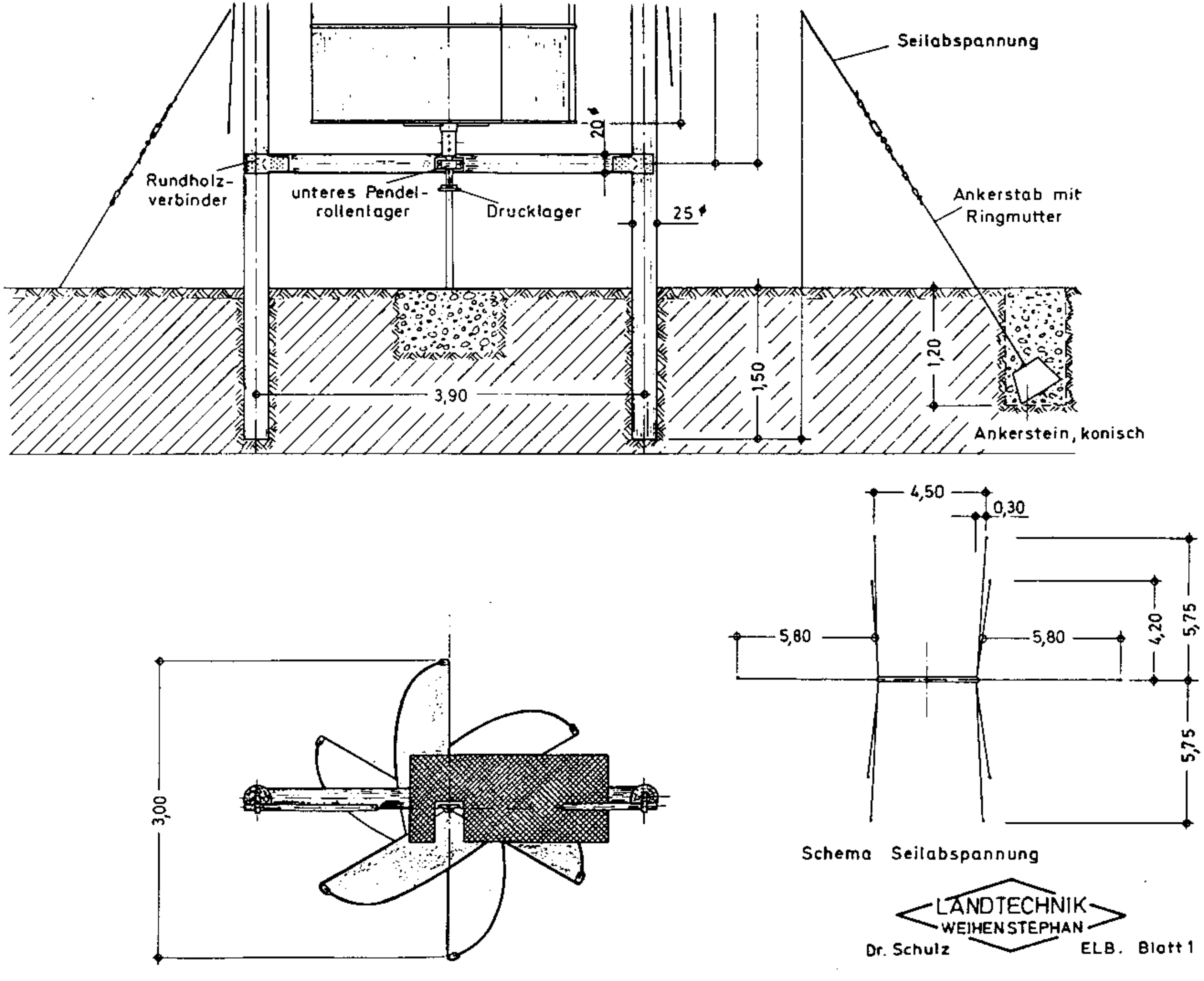


Abb. 40 b: Dreiflügeliger, zweistufiger Durchströmrotor
(Ausführung bei Josef Bachmaier, Holzen bei Buch am Erlbach)

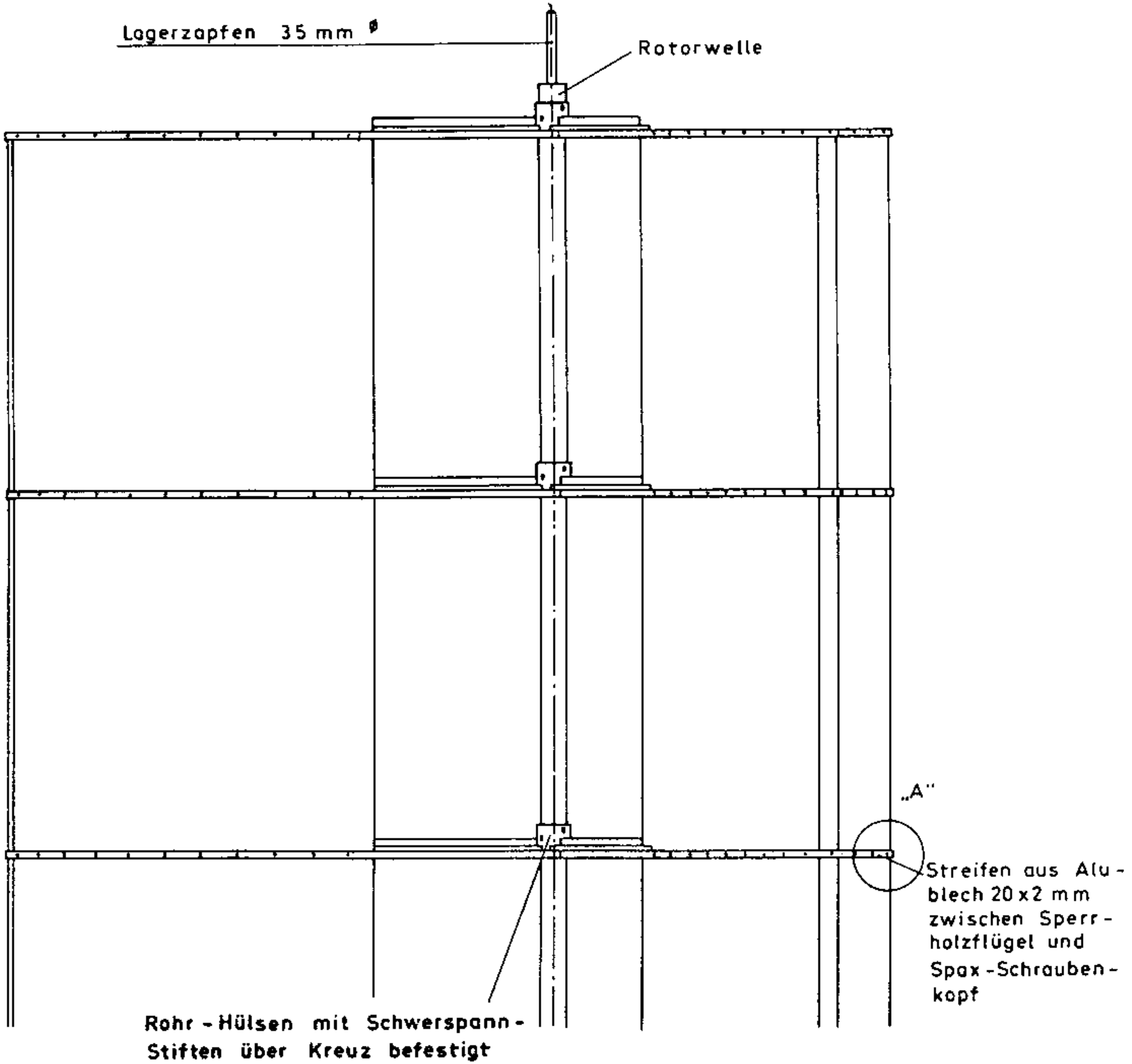


Abb. 41 a: Dreiflügeliger, zweistufiger Durchströmrotor (Details 1)

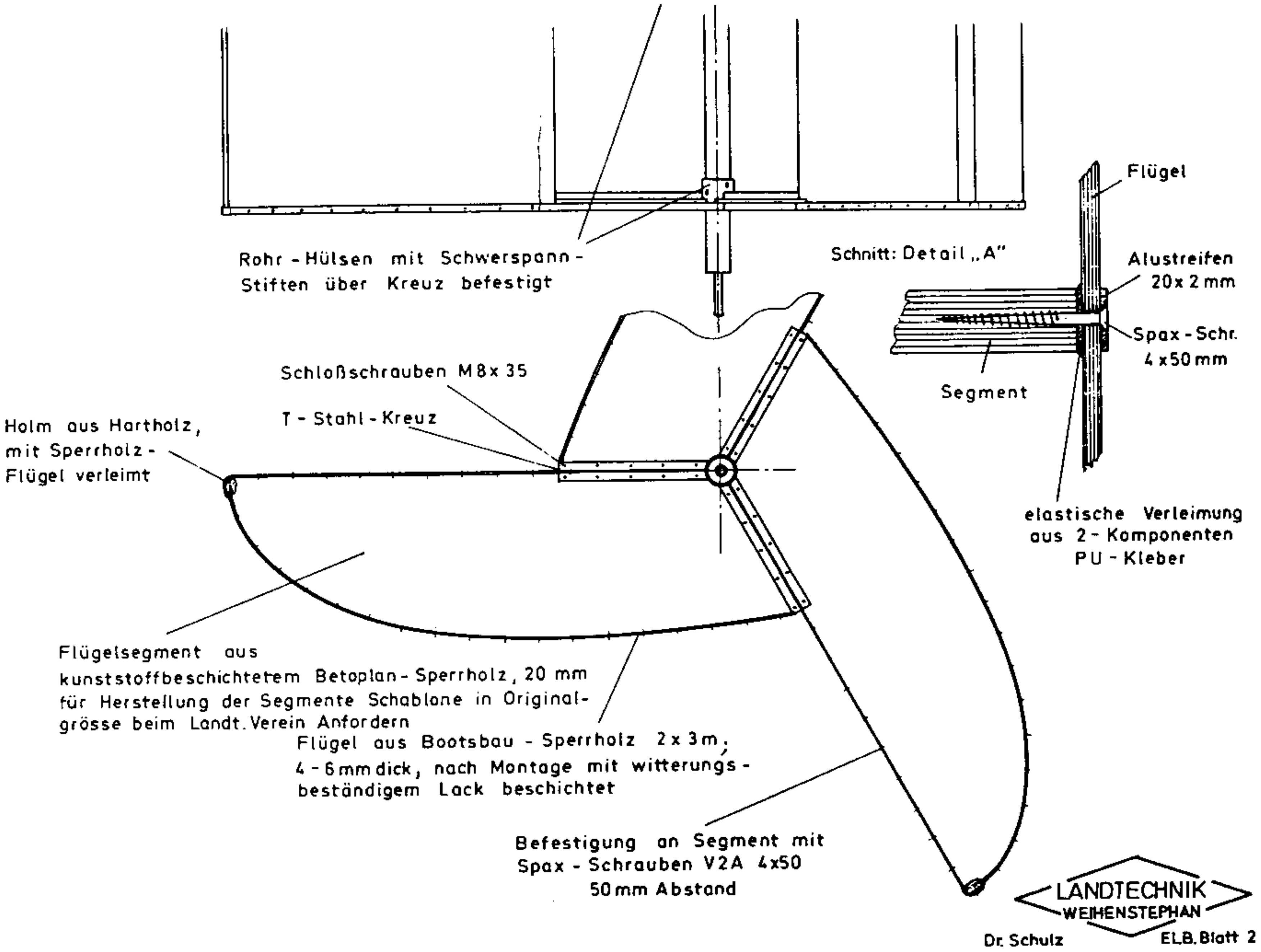
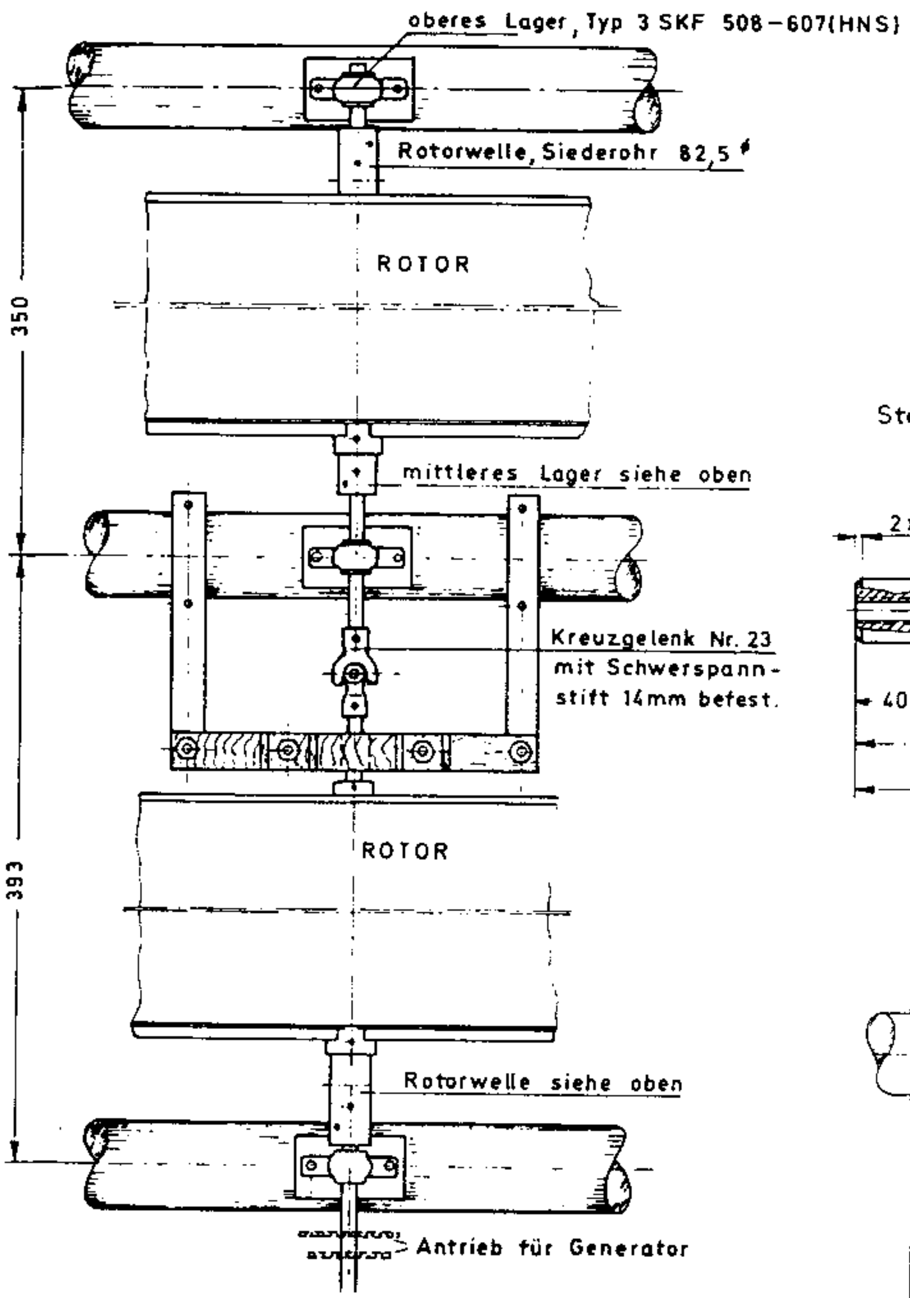
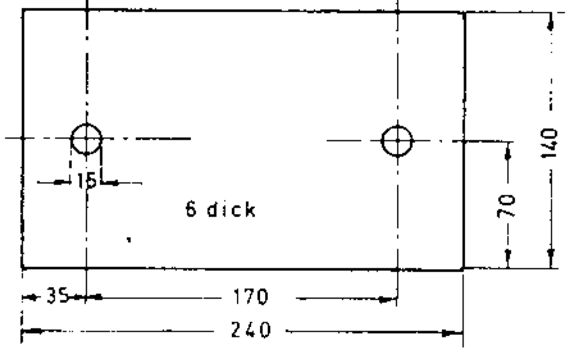


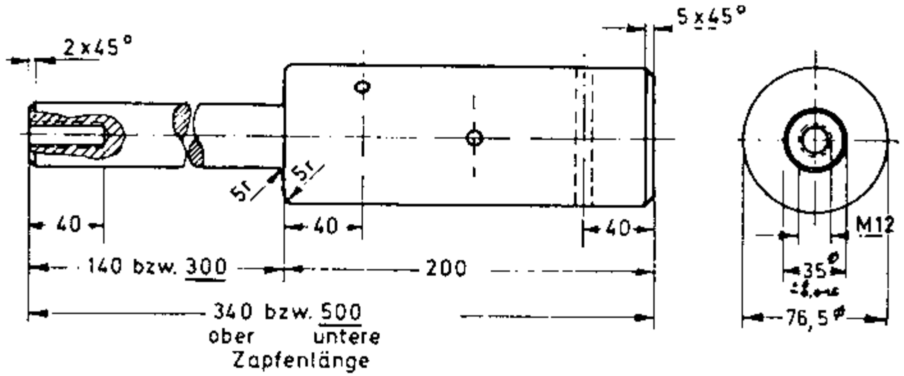
Abb. 41 b: Dreiflügeliger, zweistufiger Durchströmrotor (Details 1)

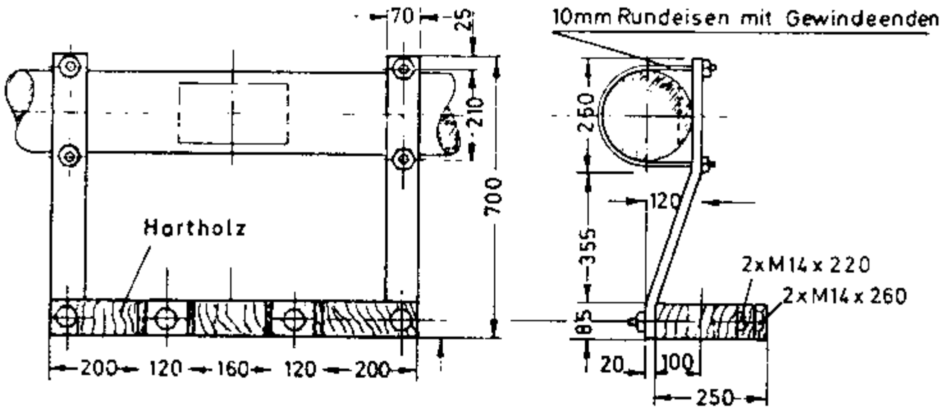


Stahlplatte zur Lagerbefestigung



Steckhülse mit Lagerzapfen, durch 3 Schwerspanstifte 12 mm mit Rotorwelle verbunden





Sicherheitsbugel bei Kardangelenkbruch

Abb. 42 a: Dreiflügeliger, zweistufiger Durchströmrotor (Details 2)

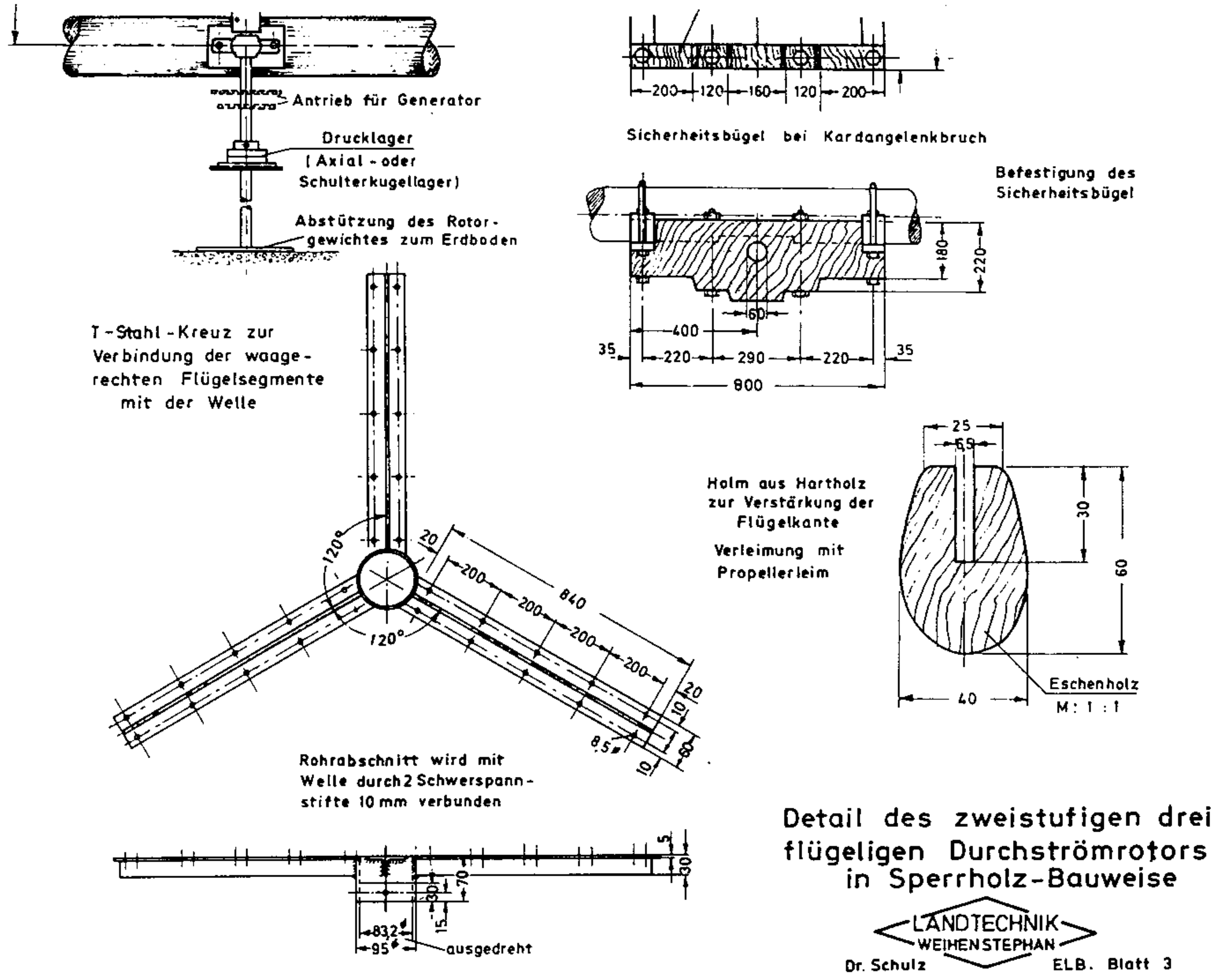


Abb. 42 b: Dreiflügeliger, zweistufiger Durchströmrotor (Details 2) axialer Richtung beansprucht. Deshalb wurde der unterste Wellenzapfen zusätzlich mit einem Drucklager zum Boden hin abgestützt. Seitdem läuft die Anlage weitgehend störungsfrei. Die um 60° gegeneinander versetzten Rotoren arbeiten sehr ruhig und vibrationsarm. Inzwischen hat die Anlage zahlreiche starke, teilweise orkanartige Stürme im vollen Betrieb überstanden. Durch die zweistufige Übersetzung mit Kette und Keilriemen geht allerdings wesentlich mehr Kraft verloren als beim Permanentmagnetgenerator von Siegl mit der einstufigen Kettenübersetzung am Rotor des Verfassers.

Abschließend sei noch einmal an die Warnung auf Seite 17 erinnert. Größere Savonius- und Durchströmrotoren wie auch andere Windkraftanlagen sollten nur Leute errichten, die einmal die handwerklichen Voraussetzungen, aber auch eine ausreichende Standfestigkeit haben und nicht beim ersten Windstoß oder Rückschlag körperlich und geistig umfallen. Da die Schwierigkeiten und Probleme bei Windturbinen etwa mit dem Quadrat ihrer Größe wachsen, muß vor allem davor gewarnt werden, gleich eine große Anlage zu bauen, wenn man nicht vorher Erfahrungen an einer kleineren gesammelt hat. Auch muß man sich hüten, die Erwartungen an Leistung und Energieertrag sowie an die Versorgungssicherheit zu hoch zu schrauben, denn einmal ist der Wind die wohl unzuverlässigste und am wenigsten zu berechnende Energiequelle und zum anderen ist bei der technischen Weiterentwicklung noch vieles nachzuholen.
Trotz dieser Warnungen sollen hier aber auch alle Windkraft-Pioniere ermutigt werden, weiterzumachen und nicht zu schnell aufzugeben. Die Windkraftnutzung zählt nämlich zu den wenigen verbrennungsfreien und damit schadstoffarmen Energietechniken, die wir in Zukunft immer dringender benötigen!

4. Druckluftbetriebene Pumpe

zur Wasserförderung aus großen Tiefen mittels Windturbinen

Es wurde ein einfaches Pumpensystem erdacht, das mit Windkraft betrieben werden kann und folgende *Vorteile* hat:

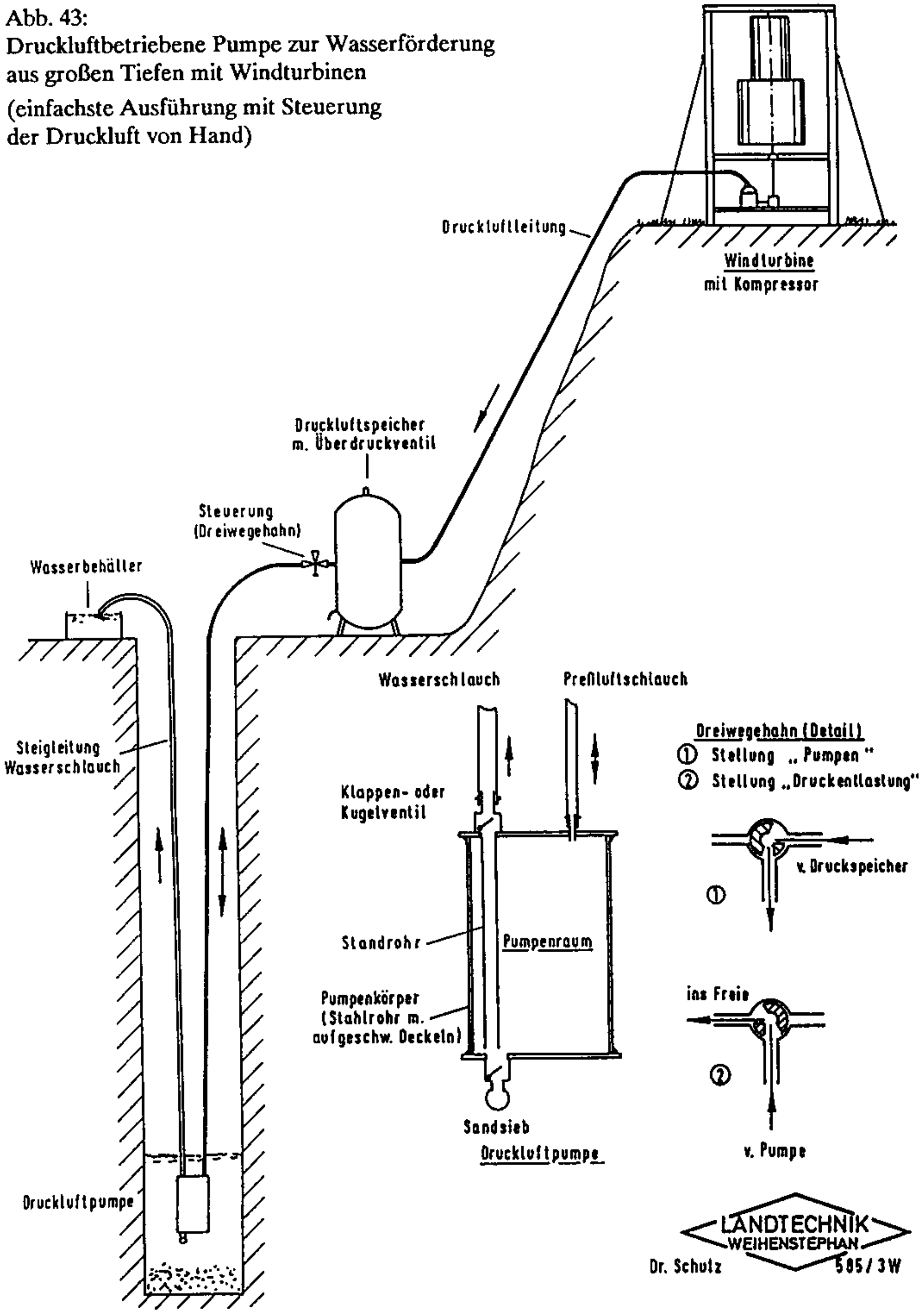
- Selbstbau unter Verwendung billiger Materialien.
- Aufstellung der Windturbine unabhängig von der Wasserstelle z.B. auf einem entfernten Hügel.
- Leichtes Einbringen oder Herausholen auch bei engen Brunnenschächten oder Bohrlöchern, da die Pumpe nur an 2 flexiblen Schläuchen bzw. bei größeren Einheiten an einem zusätzlichen Seil hängt.
- Geringere Störanfälligkeit, da die Pumpe außer den Ventilen keine bewegten Teile wie Kolben oder Membran hat.
- Es sind sehr unterscheidliche Größen von einigen Litern Volumen bis zu mehreren hundert Litern möglich.
- Bei längeren Windflauten kann die Druckluft auch notfalls von Hand mit einer Luftpumpe erzeugt werden.

Demgegenüber sind folgende *Nachteile* zu beachten:

- Geringerer Wirkungsgrad gegenüber Kolben- und Membranpumpen, die direkt über Gestänge angetrieben werden.
- In der einfachsten Ausführung muß das Steuerventil von Hand betätigt werden (z.B. beim Wasserholen in Entwicklungsländern).
- Es fehlt noch eine ausreichende Praxiserprobung, so daß der Bau dieser Pumpe vorerst nur experimentierfreudigen Leuten und Entwicklungshelfern empfohlen werden kann.

Die Pumpe besteht lediglich aus einem Stahlrohr mit aufgeschweißten oder luftdicht aufgeschraubten Deckeln (Abb. 43). Die Materialstärke hängt vom auftretenden Druck und dieser wieder von der Förderhöhe und den Reibungsverlusten in den Leitungen ab. So braucht man beispielsweise bei 20 m Förderhöhe einen Luftdruck von 2,2 bis 2,5 bar (atü), oder bei 50 m Förderhöhe einen solchen von 5,5 bis 6 bar. Die Pumpe muß so schwer sein, daß sie im Wasser untergeht, auch wenn der Pumpenkörper mit Luft gefüllt ist. Am unte-

Abb. 43:
Druckluftbetriebene Pumpe zur Wasserförderung aus großen Tiefen mit Windturbinen
(einfachste Ausführung mit Steuerung der Druckluft von Hand)



ren Deckel ist für den Wassereinlauf ein Sandsieb und ein leichtgängiges Klappen- oder Kugelventil (Rückschlagventil), das nicht mit Federdruck, sondern durch Eigengewicht geschlossen wird, befestigt. Auch am oberen Ende ist ein solches Ventil angebracht, das aber nicht direkt mit dem Pumpenraum in Verbindung steht, sondern nur über ein Standrohr, das fast bis zum Boden des Pumpenraums reicht. Zweckmäßig baut man die Ventile so an, daß sie von außen kontrolliert werden können, ohne die Deckel abnehmen zu müssen. Am oberen Ventil kann der Wasserschlauch (auf Druckfestigkeit je nach Förderhöhe achten!) angeschlossen werden, z.B. mit Schlauchschellen. Natürlich können auch halbflexible Kunststoffrohre (z.B. Polyaethylenrohre) oder Metallrohre verwendet werden, wobei letztere aber wieder stückweise auseinandergeschraubt werden müssen, wenn die Pumpe zur Reparatur oder Kontrolle aus dem Brunnenschacht gezogen werden muß. Außerdem ist am oberen Deckel ein Stutzen zum Anschluß eines Preßluftschlauchs vorhanden.

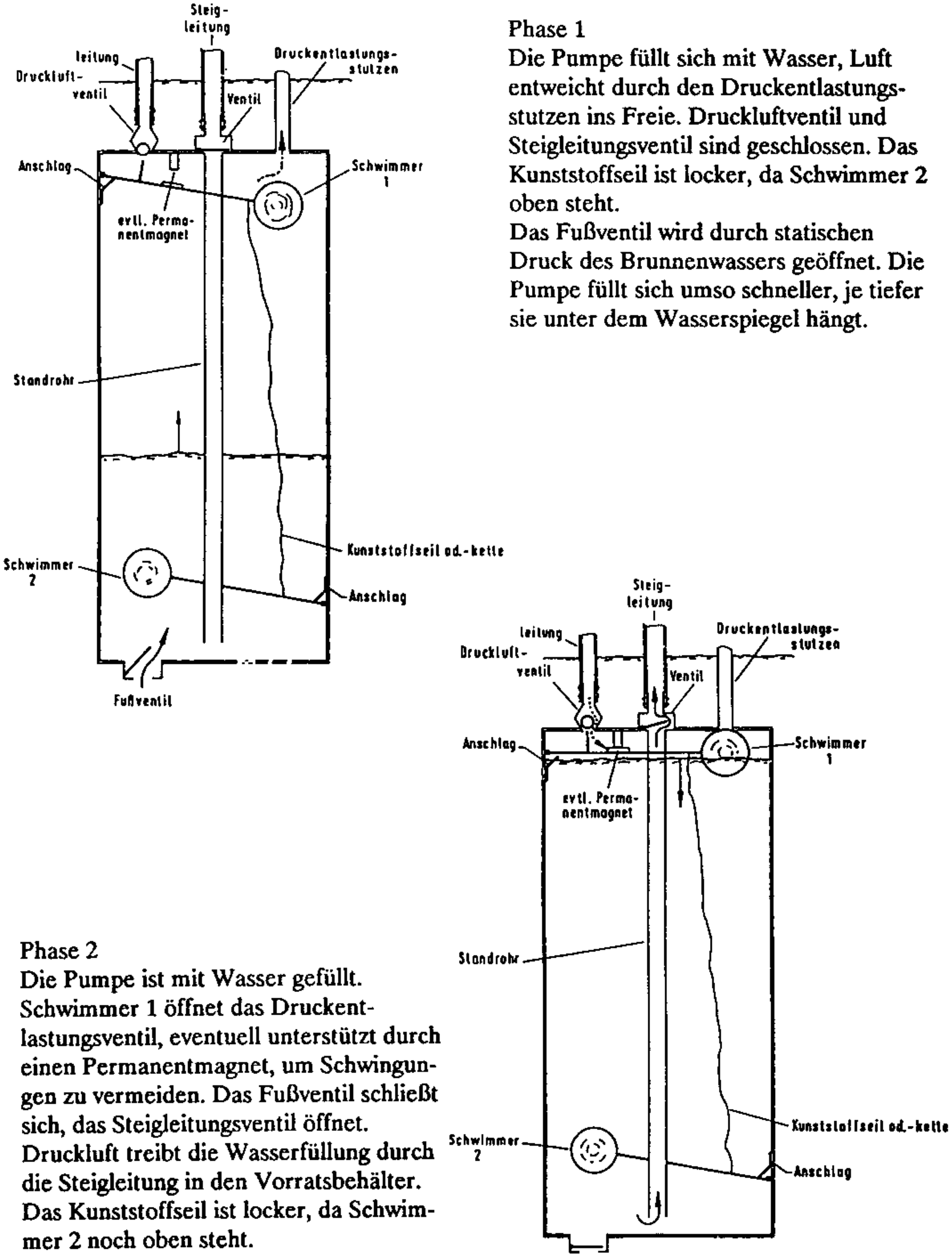
Die Pumpe funktioniert folgendermaßen:

Die Windturbine treibt einen handelsüblichen Hubkolben-Kompressor an, dessen Größe und Drehzahl der Leistungscharakteristik des Windrades einigermaßen angepaßt sein muß. Bei Savonius- und Durchströmrotoren mit senkrechter Welle wird der Kompressor am besten über ein leichtlaufendes Winkelgetriebe mit Übersetzung (z.B. Autodifferential mit gesperrten Satellitenrädern) angetrieben.

Die erzeugte Druckluft wird in einem Druckspeicher bevorratet, der mit Überdruckventil und Ablaßhahn für Kondenswasser versehen sein muß. Steht kein geeigneter Metallbehälter zur Verfügung, kann notfalls auch eine Reihe von parallelgeschlossenen, alten Auto- oder LKW-Rädern verwendet werden, bei denen die Reifen zwar abgefahren, aber noch genügend druckfest für Förderhöhen bis ca. 25 m (ca. 3 bar Luftdruck) sind. Auch einige parallelgeschlossene, zugeschweißte Wasserleitungsrohre größeren Durchmessers eignen sich als Druckspeicher.

Wird nun das Dreiwege-Steuerventil in Stellung »Druckentlastung« gebracht, das heißt der Pumpenraum mit der Außenluft verbunden, kann das Brunnenwasser das untere Ventil öffnen und in den Pumpenraum fließen. Dabei wird die im Pumpenraum befindiche Luft nach oben ins Freie verdrängt.

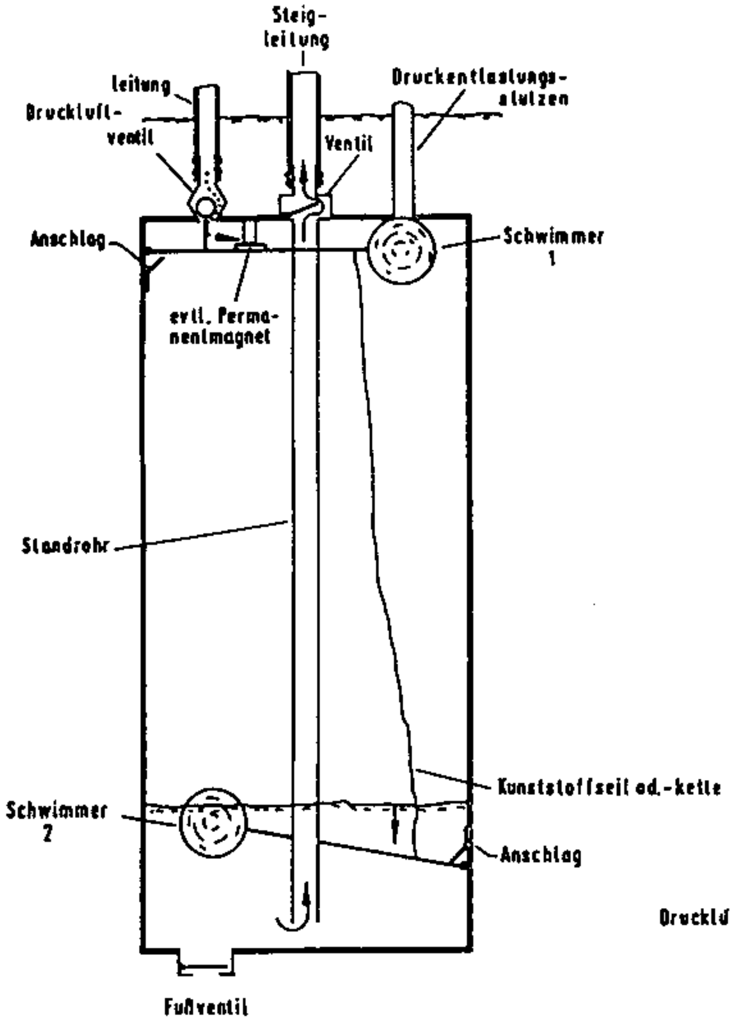
Wird jetzt das Dreiwegeventil auf die Stellung »Pumpen« umgeschaltet, drückt die gespeicherte Druckluft die Wasserfüllung des Pumpenraums nach unten. Da das untere Klappenventil ein Zurückfließen verhindert, muß das Wasser durch das Standrohr nach oben, wo es das obere Klappenventil öffnet und durch die Steigleitung in den Wasserbehälter fließt. Ist der Pumpenraum leer gedrückt, was am Volumen des hochgeförderten Wassers erkennbar ist, muß das Dreiwegeventil wieder auf Stellung »Druckentlastung« gestellt werden, wo-



Phase 1
Die Pumpe füllt sich mit Wasser, Luft entweicht durch den Druckentlastungsstutzen ins Freie. Druckluftventil und Steigleitungsventil sind geschlossen. Das Kunststoffseil ist locker, da Schwimmer 2 oben steht.
Das Fußventil wird durch statischen Druck des Brunnenwassers geöffnet. Die Pumpe füllt sich umso schneller, je tiefer sie unter dem Wasserspiegel hängt.

Phase 2
Die Pumpe ist mit Wasser gefüllt. Schwimmer 1 öffnet das Druckentlastungsventil, eventuell unterstützt durch einen Permanentmagnet, um Schwingungen zu vermeiden. Das Fußventil schließt sich, das Steigleitungsventil öffnet. Druckluft treibt die Wasserfüllung durch die Steigleitung in den Vorratsbehälter. Das Kunststoffseil ist locker, da Schwimmer 2 noch oben steht.

Abb 44 a: Druckluftbetriebene Pumpe zur Wasserförderung aus großen Tiefen (automatische Steuerung)



Phase 3
Der Fördervorgang ist noch nicht beendet. Schwimmer 1 wird durch Luftdruck und eventuell durch die Kraft des Permanentmagneten gegen die Öffnung des Druckentlastungsstutzens gehalten. Das Kunststoffseil ist noch locker, da Schwimmer 2 noch schwimmt. Die Ventile stehen wie in Phase 2.

Phase 4
Der Wasserstand in der Pumpe ist soweit abgesunken, daß der Schwimmer 2 mit seinem Gewicht den Schwimmer 1 herunterzieht (siehe Hinweise im Text). Der Druckentlastungsstutzen wird dadurch geöffnet, das Steigventil schließt sich und Phase 1 kann wieder beginnen.

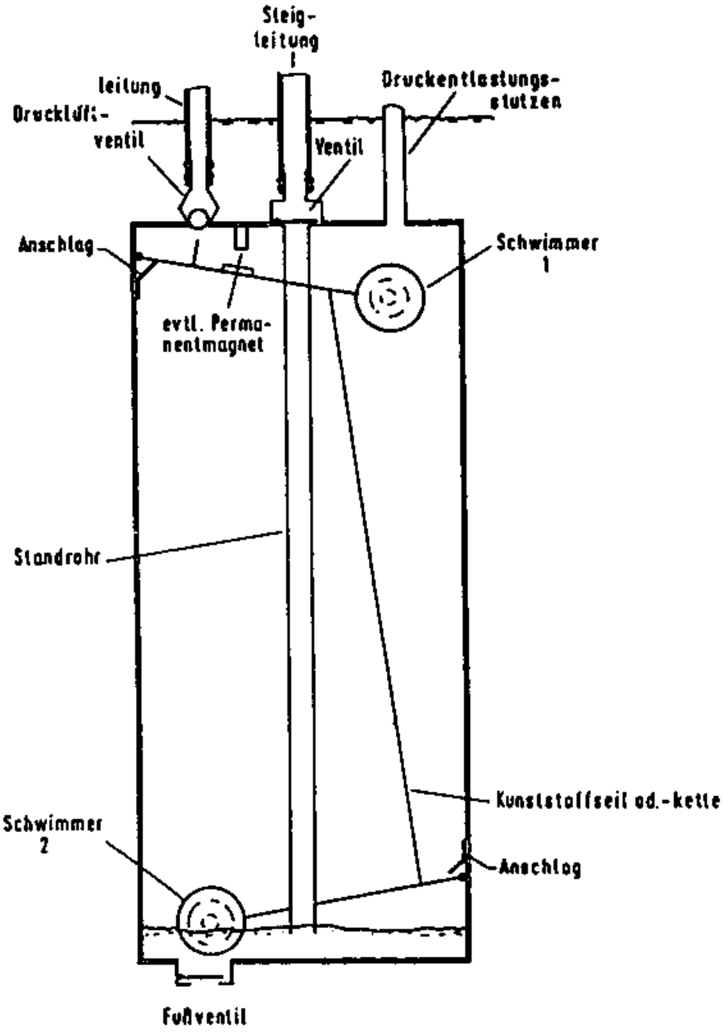


Abb 44 b: Druckluftbetriebene Pumpe zur Wasserförderung aus großen Tiefen (automatische Steuerung) nach sich der Pumpenraum wieder selbstständig mit Wasser füllt. Das obere Klappenventil am Pumpenkörper verhindert ein Zurückfließen des Wassers aus der Steigleitung in den Pumpenraum. Wird das Dreiwegeventil zu spät umgeschaltet, passiert nichts, außer daß Druckluft durch die Steigleitung ins Freie dringt und verlorengeht. Der erste Prototyp dieser Pumpe hatte einen Durchmesser von 15 cm und ca. 4 l Volumen. Das untere Ventil war ein 3/4 Zoll Rotguß-Klappenventil, wie es in Heizungsanlagen Verwendung findet. Oben war ein 1/2 Zoll Kugelventil angeordnet. Die Steigleitung bestand aus einem 1/2" Gartenschlauch und die Druckluftleitung aus einem 6 mm Preßluftschlauch. Die Pumpe funktionierte auf Anhieb.

Wegen Zeit- und Geldmangels konnte dieses Prinzip leider nicht länger erprobt oder weiterentwickelt werden. Einige Verbesserungen wären durchaus möglich. Einmal könnte das Dreiwegeventil direkt am oberen Deckel der Pumpe angebracht und mit Seilzug von Hand gesteuert werden, was den Vorteil hätte, daß die Druckluftleitung vom Speicher zur Pumpe immer unter Druck bleibt und nicht zur Druckentlastung dient. Dadurch könnte der Druckluftverbrauch gesenkt und eine schnellere Füllung des Pumpenraums mit Wasser erreicht werden. Auch eine automatische Steuerung mit Magnetventilen oder mit einem Schwimmer im Pumpenraum erscheint durchführbar. Auch läßt sich anstelle des in Entwicklungsländern wohl nicht überall erhältlichen Dreiwegehahns mit zwei einfachen Drucklufthähnen, notfalls auch mit Wasserhähnen oder Absperrventilen arbeiten, die allerdings umständlicher und langsamer zu bedienen sind, als ein Dreiwegehahn. Auch der Einsatz von Magnetventilen ist denkbar, wenn z.B. die Windkraftanlage genügend leistungsfähig ist, um bei höheren Windgeschwindigkeiten zusätzlich eine Batterie aufzuladen.

In Abb. 44 ist ein Vorschlag für eine automatische Steuerung der Ventile ausgeführt, wie sie beispielsweise für größere Pumpen an Bewässerungsanlagen infrage kommen könnte. Da dieser Vorschlag zwar gründlich durchdacht, aber noch nicht praktisch erprobt werden konnte, sollten Interessenten erst ein Modell mit einem durchsichtigen Plexiglasrohr anfertigen, um die Steuerabläufe zu studieren. Ganz wesentlich ist es, daß die Auftriebskräfte und Gewichte der beiden Schwimmer und auch die Anlenkpunkte des Kunststoffseils auf den maximalen Luftdruck und die Querschnitte des Druckventils und des Druckentlastungsstutzens abgestimmt sind. Ist beispielsweise der Querschnitt des Druckentlastungsstutzens zu groß, kann das Gewicht der beiden Schwimmer nicht ausreichen, um in Phase 3 den Druckentlastungsstutzen gegen den in der Pumpe noch herrschenden Luftdruck zu öffnen. Es wird dann erst das ganze Wasser aus der Steigleitung gefördert, bis oben Luft austritt, der Druck in der Pumpe fällt und die beiden Schwimmer herunterfallen. Auch der eventuell hilfreiche Permanentmagnet muß natürlich die richtige Größe und den passenden Abstand vom Gestänge des Schwimmers 1 haben. Ist andererseits der Querschnitt des Druckventils (evtl. Fahrrad- oder Autoventil verwenden!) zu

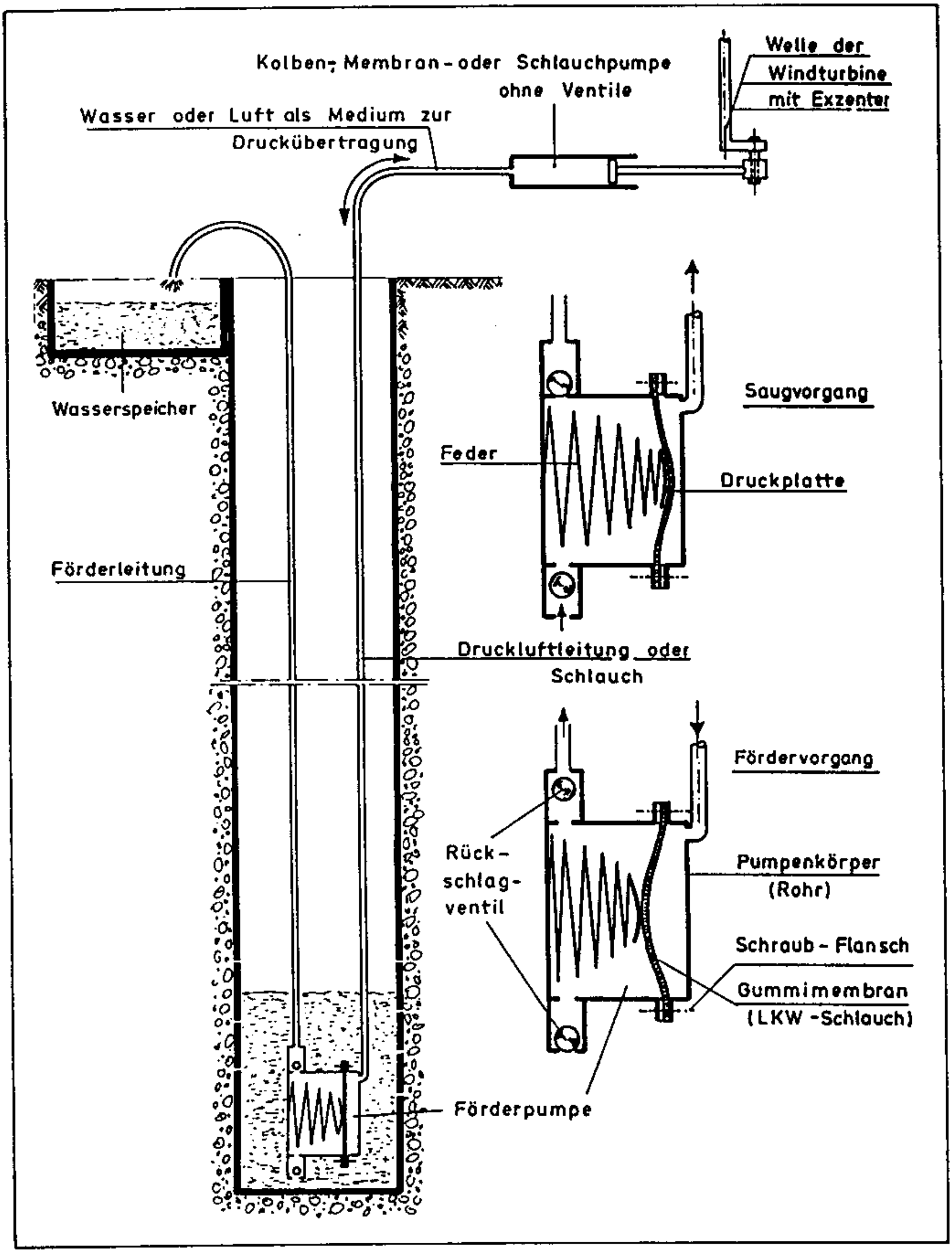


Abb. 45: Windkraftbetriebene Pumpe zur Wasserförderung aus großen Tiefen

groß, kann ein zu kleiner Schwimmer das Ventil nicht öffnen, noch dazu wenn ein großer Luftdruck darauf lastet. Daher sollte man die auftretenden Kräfte wenigstens größenordnungsmäßig berechnen, bevor man anfängt zu bauen. Außerdem ist zu raten, daß man eine automatisch gesteuerte Pumpe erst dann baut, wenn die einfache Ausführung mit Handsteuerung schon läuft.

Zur Zeit wird an der Entwicklung weiterer mit Druckluft oder Wasserdruck betriebener, einfacher und billiger Pumpen gearbeit, die mittels Windkraft aus großen Tiefen Wasser fördern können, insbesondere für den Einsatz in Entwicklungsländern. Abb. 45 zeigt eine Lösung, die in ersten Versuchen auf Anhieb funktionierte und weiterverfolgt werden soll.

Dabei wird über einen Exzenter an der Windturbinenwelle mit einer ventillosen Kolben-, Membran- oder Schlauchpumpe, die man leicht aus handelsüblichen Teilen selbst bauen kann, ein wechselnder Druck und Unterdruck erzeugt. Mit Hilfe von Luft oder Wasser wird der Druck auf die im Brunnenwasser hängende Förderpumpe übertragen. Diese kann man ebenfalls leicht aus Stahlrohr, Kugel- oder Klappenventilen, einer Feder und Gummimembran herstellen.

Die Pumpe funktioniert folgendermaßen: Beim Saugvorgang (vgl. obere Detailzeichnung) wölbt sich die Membran, unterstützt durch den Federdruck nach außen, wodurch sich der Pumpenraum vergrößert. Dadurch entsteht ein Unterdruck, der das untere Ventil öffnet und Wasser aus dem Brunnen ansaugt. Wird jetzt beim nächsten Hub der Windpumpe Druck erzeugt (untere Detailzeichnung), so wird die Membran gegen die Kraft der Feder nach innen gewölbt und Wasser bei geschlossenem unteren und geöffnetem oberen Ventil nach oben gefördert.

Bei Verwendung von Luft als Medium zur Druckübertragung muß die Leitung von der Windpumpe zur Förderpumpe einen möglichst geringen Querschnitt haben, da die Luft in der Leitung sonst als schädlicher Puffer wirkt und die Leistung minimiert. Die Feder braucht nur schwach zu sein, weil sie die Luft in der Leitung leicht nach oben drücken kann und von der Windpumpe, die dabei saugt, unterstützt wird.

Wasser als Medium hat den Vorteil, daß es nicht kompressibel ist, so daß die Leitung von der Windturbine in den Brunnen auch einen größeren Querschnitt haben kann, was den Wirkungsgrad verbessert. Die Feder muß dann aber so stark sein, daß sie fast die ganze Wassersäule der Druckleitung tragen kann. Denn bekanntlich kann man Wasser ja nur aus einer Tiefe von maximal 8 m ansaugen, so daß mit der Windpumpe allein nicht die Membran bewegt werden kann.

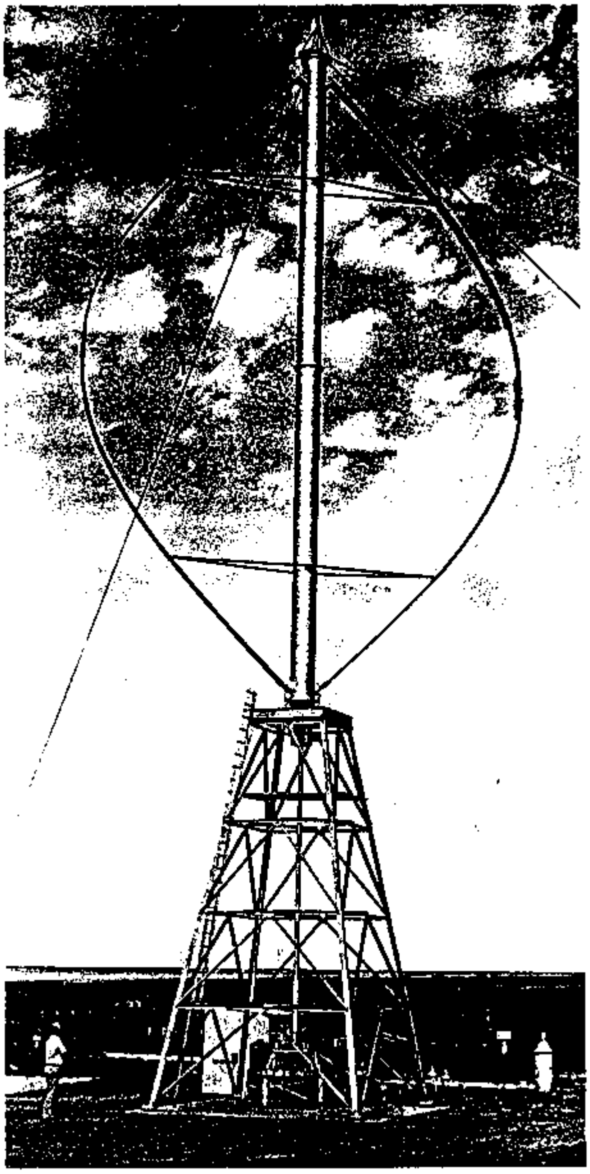
The Wind Power Book. Jack Park. Cheshire Books/Van Nostrand. USA. 1981

A Unique Darrieus Water-Pumper

At the other end of the spectrum from the sail-wing or farm water-pumpers is the Bushland, Texas, installation of a Darrieus "eggbeater" rotor tied mechanically to an electric 60-horsepower irrigation pump. This U.S. Department of Agriculture project at a windy location is examining practical approaches to water pumping with the wind. Since it is a relatively new research project, few performance data are available at this writing.

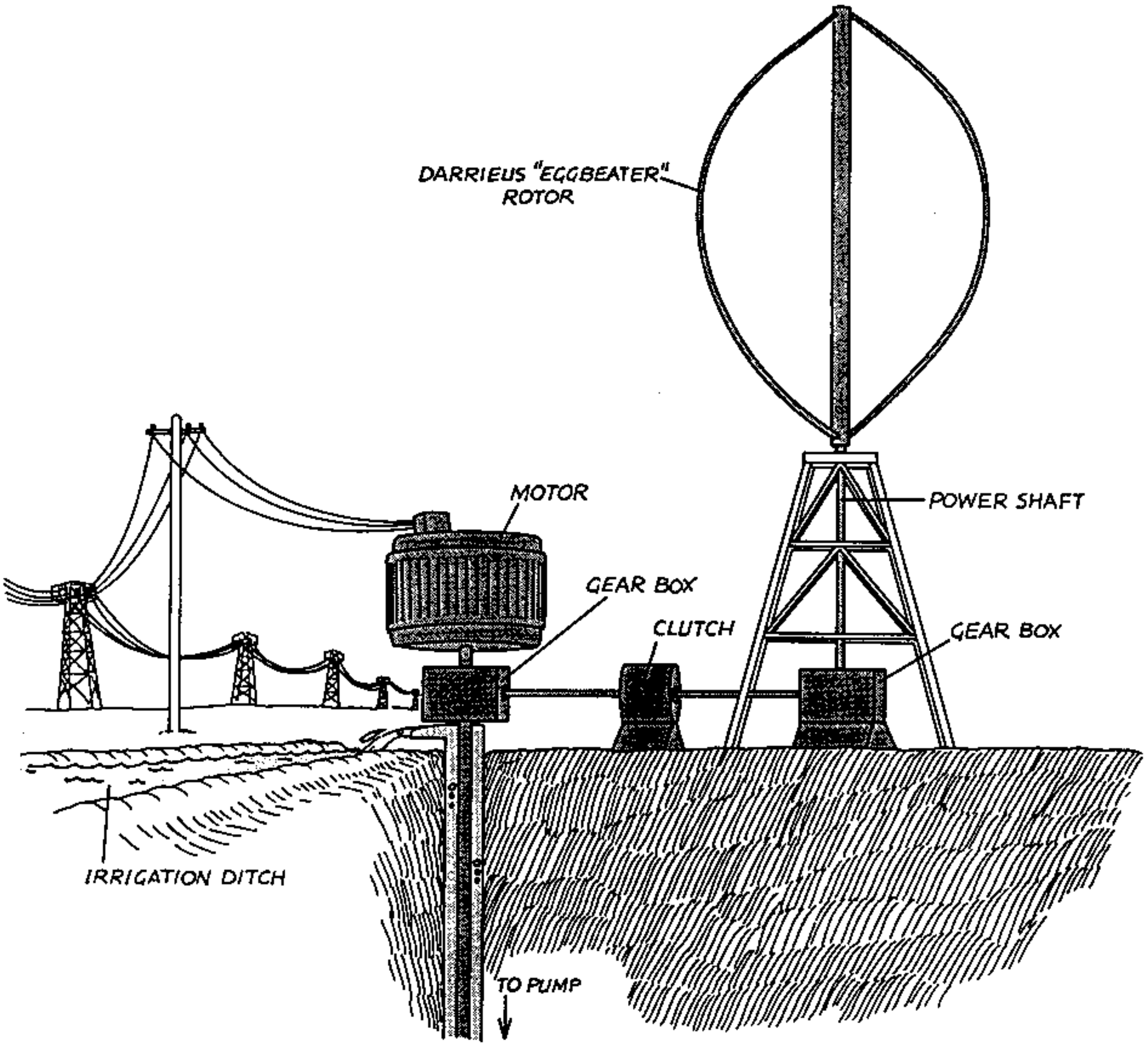
A Darrieus rotor has two or more curved, or bowed, airfoil blades that travel a circular path about a vertical power shaft at its center. Made with extruded aluminum, the streamlined airfoils have a rounded leading edge (the edge that cuts into the wind) and sharp trailing edge. The Darrieus rotor is linked to the pump powershaft by a clutch that allows the electric pump to turn freely but engages whenever the rotor is spinning rapidly enough. In periods of calm, an AC electric motor keeps the pump turning. The more wind power available, the less power drawn by the pump from the electric power grid.

This machine is also a *cogeneration system* that operates in parallel with the utility grid. It generates excess current that is delivered to the grid. In effect, the wind system becomes one of the many interconnected generators the grid uses for its power supply. At a certain windspeed, when more shaft power than the pump needs is available from the Darrieus rotor, the rotor overpowers the electric motor, trying to turn it faster than it was designed to turn. The motor then becomes an AC generator synchronized with the grid power. Should the electric power available actually exceed the demands at the site, the excess electrical energy is fed back into the grid, effectively "running the meter backwards." Thus, energy storage for this system is provided mostly by pumped water in a pond or a tank and occasionally by the grid power lines that "store" electricity sent backwards through the meter.



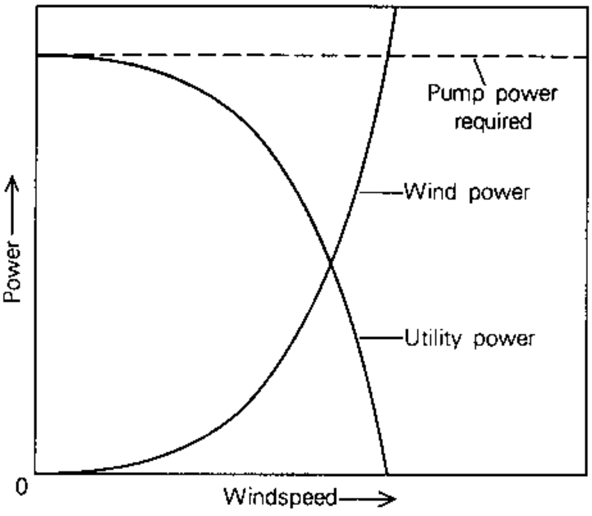
The Darrieus rotor used for irrigation in Bushland, Texas.

The unique advantage of the Bushland installation is that the electric motor actually serves three purposes—almost at once. First, the motor is the prime mover driving the well pump. Second, the motor is the governor for the wind rotor; it wants to turn only at an rpm determined by the AC frequency fed to it from the grid. By careful design, the rotor will never overpower the motor or cause it to overspeed by more than a few rpm. Finally, the motor is an electric generator whenever extra wind power is available.

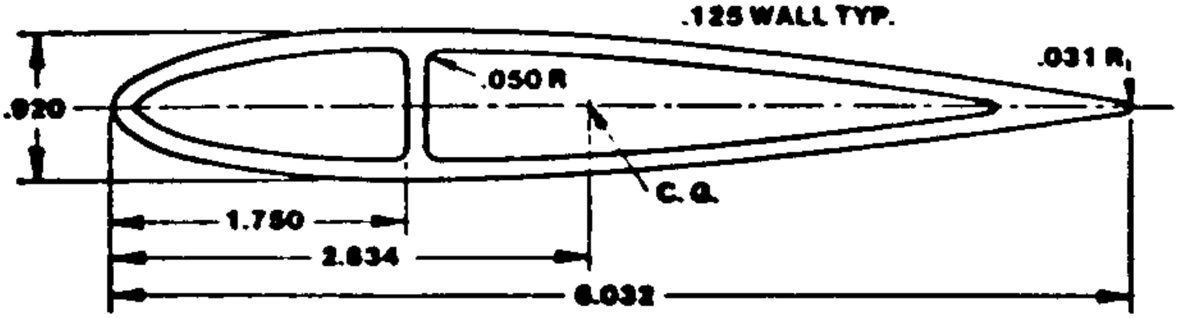


In the novel approach being tested at Bushland by the USDA, both wind power and an electric motor are used simultaneously to power the well pump. If excess wind power is available, the system delivers it to the utility lines.

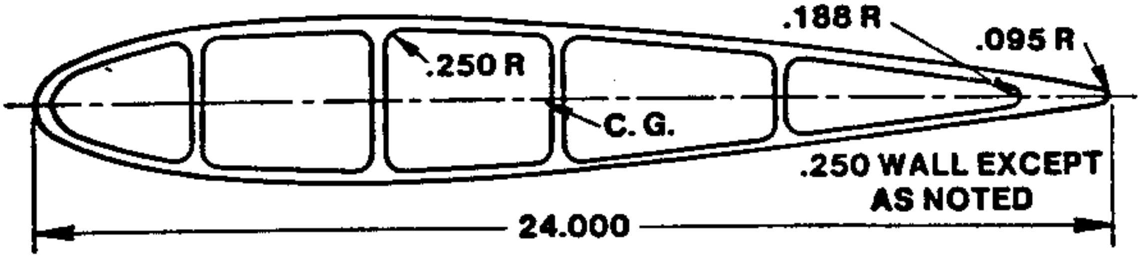
If no wind power is available during pumping, the motor does the entire job, spinning at about 1,750 rpm. When the wind increases, an electronic control circuit releases the windmill brake, and a small starter motor spins the wind turbine up to speed. At that point, a clutch engages to couple the torque from the turbine to the torque supplied by the electric motor. Motor rpm increases as more wind power becomes available. When motor rpm reaches about 1,800, no electricity is needed from the utility. As the rpm increases above 1,800, the motor turns into a generator, pumping juice back into the utility lines.



Power curves for the Bushland system. Utility lines supply whatever power cannot be provided by the wind.



ALCOA 15.3 cm (6") ALL-ALUMINUM BLADE



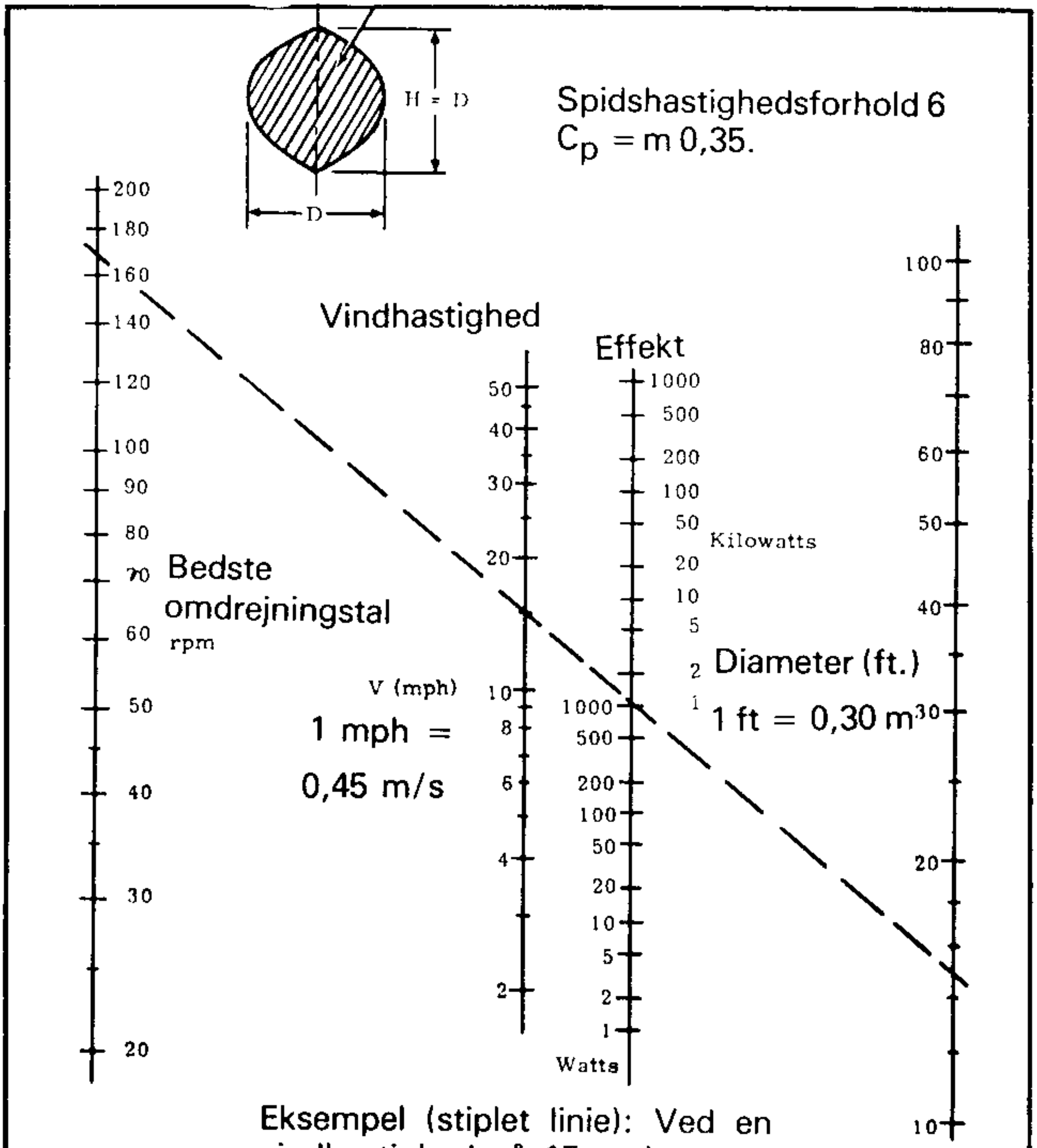
ALCOA 61 cm (24") ROTOR BLADE

Available Alcoa Rotor Blades
Lineals and Fabrications

NACA 0015 Blade Chord	Weight/Foot	Maximum Length
15.3 cm (6")	.85 kg (1.87#)	18.3 m (60')
35.5 cm (14")	3.46 kg (7.63#)	18.3 m (60')
61.0 cm (24")	8.24 kg (18.16#)	24.4 m (80')
74.0 cm (29")	10.09 kg (22.25#)	24.4 m (80')

ALCOA 1979.

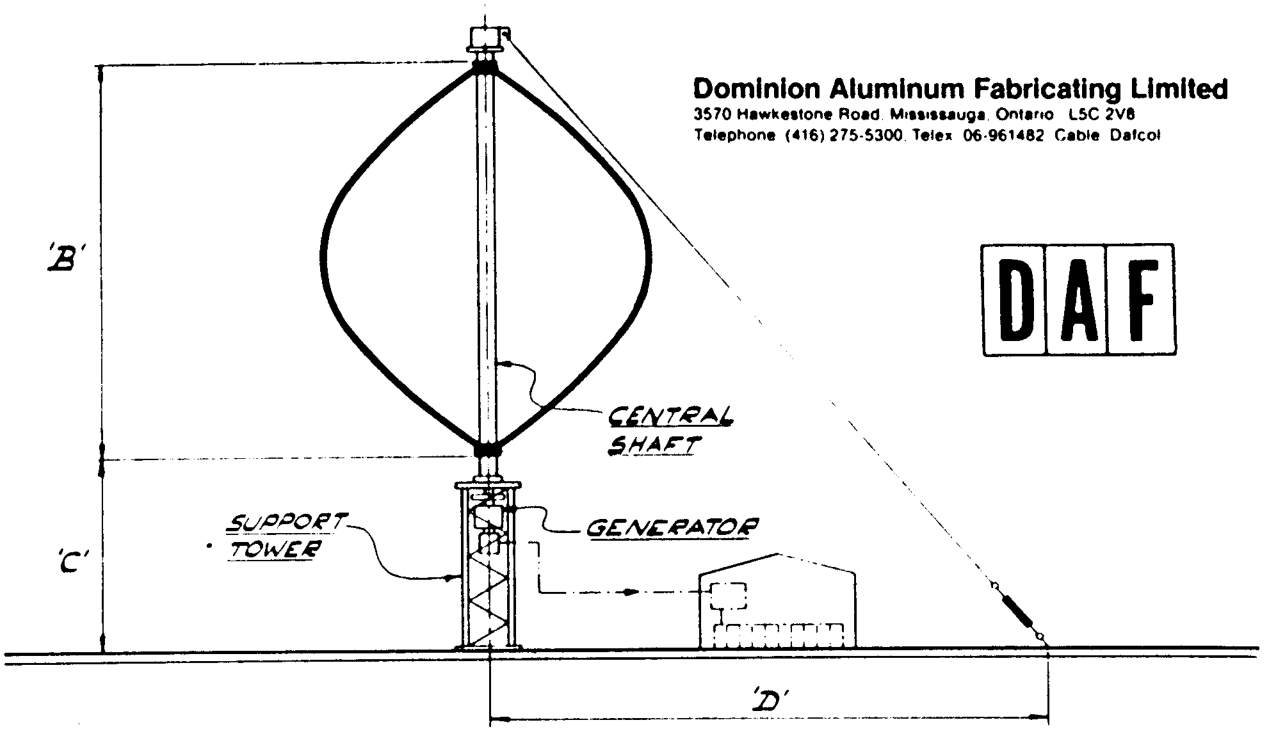
Sun and Wind [in Danish]. Claus Herforth, Claus Nybroe
Denmark 1976 87-87498-48-0.



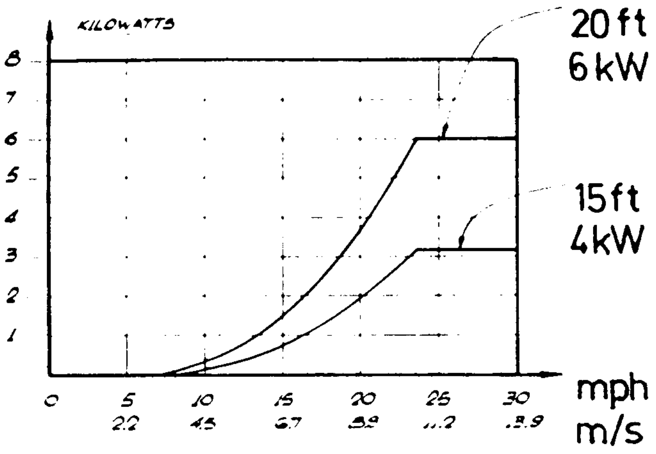
Eksempel (stiplet linie): Ved en vindhastighed på 15 mph og en rotor-diameter på 15 ft. er det ideelle omdrejningstal 168 rpm og den tilsvarende effekt 1080 W.

Dominion Aluminum Fabricating Limited
3570 Hawkestone Road, Mississauga, Ontario L5C 2V8
Telephone (416) 275-5300. Telex 06-961482 Cable Dalcol

DAF



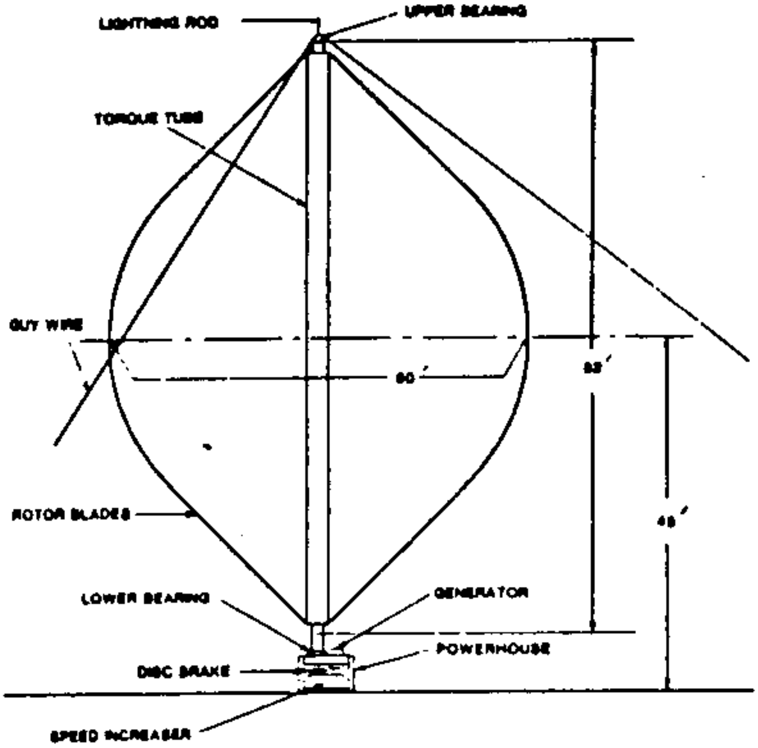
AIRFOIL SECTION



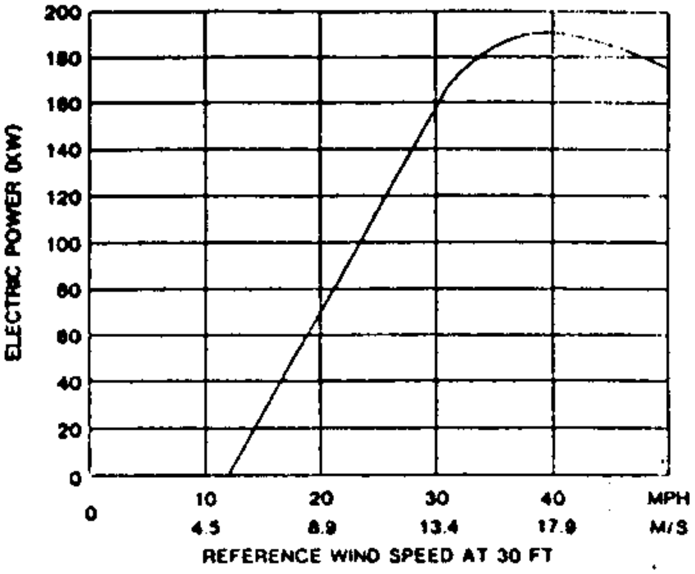
TURBINE DIAMETER (feet)	A	B	C	D
	FEET			
15	15	18	8.0	38.3
20	20	30	8.0	45
	METRES			
15	4.6	5.5	2.4	11.7
20	6.0	9.1	2.4	13.7

	AVERAGE MONTHLY OUTPUT—KILOWATT HOURS									
TURBINE DIAMETER Feet – Volts	AVERAGE MONTHLY WINDSPEED									
	Miles Per Hour					Metres Per Second				
	9	11	13	15	18	4	5	6	7	8
15 – 24V	110	190	290	420	680	110	200	310	500	670
15 – 110V	110	210	360	560	1000	110	220	390	640	990
20 – 110V	210	400	680	1070	1900	210	420	745	1040	1860

VAWTPOWER 185



GENERAL LAYOUT AND SIZE



POWER CURVE (KW VS. WIND SPEED)

TURBINE PHYSICAL CHARACTERISTICS

ROTOR DIAMETER	60 FT.
ROTOR AXIAL HEIGHT	82 FT.
BLADE CHORD	29 IN.
TURBINE CENTERLINE HEIGHT	49 FT.
OVERALL HEIGHT	94 FT.
SWEPT AREA	3200 FT.^{2}

OPERATIONAL DATA

VAWTPOWER 185 HAS AN ESTIMATED POWER GENERATING CAPACITY OF 185 KILOWATTS AT APPROXIMATELY 37 MPH.

THE 200 HP INDUCTION GENERATOR OPERATES AT A NOMINAL FULL LOAD SPEED OF 1820 RPM AT 230/460 VOLTS, 3 PHASE, 60 HZ.

SPEED INCREASER RATIO IS 37.5 AND NOMINAL ROTOR SPEED IS 48 RPM.

REFERENCE WIND SPEED IS MEASURED AT 30 FT.

POWER RATINGS ARE COMPUTED USING A SEA LEVEL AIR DENSITY OF 0.0765/FT.

BASED ON THE ABOVE, THE ESTIMATED ANNUAL ENERGY OUTPUT FOR A GIVEN MEAN ANNUAL WIND SPEED IS:

MEAN ANNUAL WIND SPEED MPH(m/s)	ANNUAL ENERGY OUTPUT KILOWATT HRS/YEAR(AKWh)
12(5.4)	165,000
14(6.3)	260,000
16(7.2)	360,000
18(8.0)	460,000
20(8.9)	550,000

A: INTRODUCTION

The DARRIEUS WINDTURBINE was invented by the French engineer G Darrieus in 1931. However, it was never really developed as a local power source in North America, with its rapidly growing centralized power systems. Although the windmill still paved a path for itself in the continent's energy picture, these windmills in rural areas were the conventional propeller type. In spite of their intelligent and feasible design, even these eventually ceased to exist.

With our currently bleak energy forecasts, many people are now seriously considering the possibility of using ALTERNATE forms of energy. The DARRIEUS ROTATING AIRFOIL can be built from local parts and tools. Being of a vertical shaft design, it is totally symmetrical and requires no directional devices as a result. These plans are quite flexible in nature, employing a "nuts and bolts" approach to this project. Any experimentation in altering the design of the airfoil is certainly encouraged, although modifications in the design may only increase the performance marginally and the difficulty of construction substantially.

B: LEGAL WAIVER

A FULLY ASSEMBLED DARRIEUS AIRFOIL CAN WEIGH IN EXCESS OF 200 POUNDS! Poor or improper construction can result in damage to personal property or even serious injury. These plans are your guidelines only. We take no responsibility in regards to the Success or Safety of this project. Acceptance of these plans warrants this on your part.

On this note, we wish you success in coming another step closer towards SELF-SUFFICIENCY...

C: CONFIGURATION

Figure 1: The Darrieus Airfoil

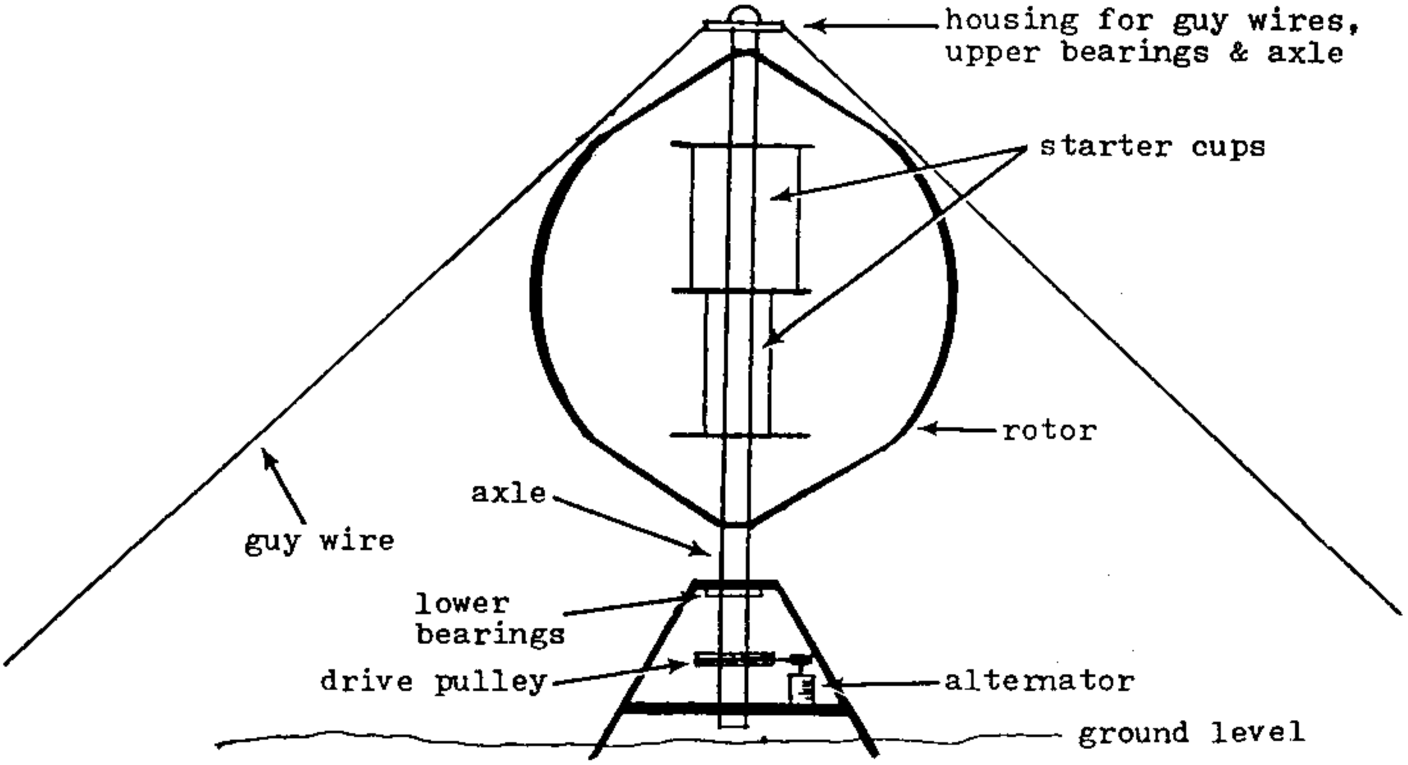
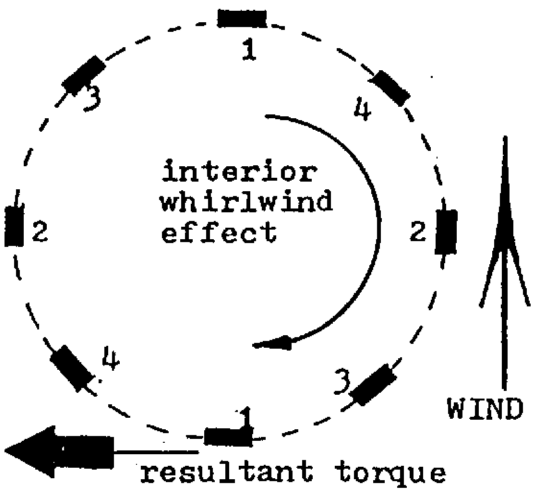


Figure 2: Principle of Operation



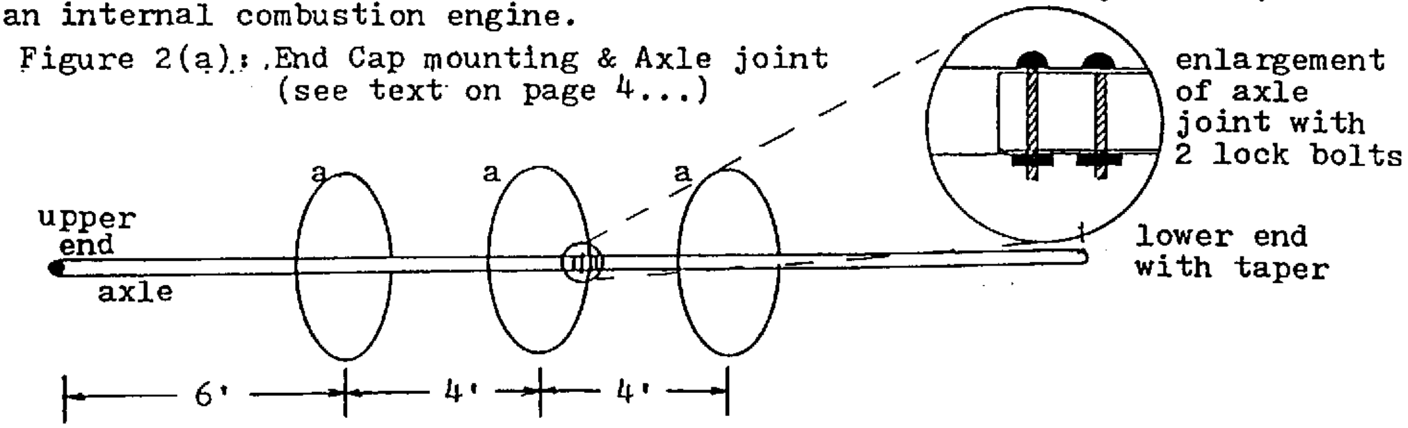
The principle of this rotational motion is a mixture of several effects. The Darrieus Airfoil is a medium speed Wind system, of a vertical axis variety. Being a medium speed system has two advantages. Firstly, it requires only moderate gearing ratios, and secondly, the maintainance required is moderate as well. The aspects in favour of this system is that its totally symmetrical, thereby eliminating the need for directional equipment. Also, it is not highly obstructive in appearance, and requires only a moderate amount of material to construct.

As mentioned earlier, the resultant torque produced by this airfoil is a result of a combination of effects brought about once this system is put into motion. In figure 2, there are always imbalances in forces (produced by the wind) acting on the two surfaces of the airfoil. In position 3 and 4, the imbalances are at a maximum. When the rotor halves are travelling downwind on the left side of the axle in this diagram (position 4) there is a high pressure area on the OUTER surface of the blade, and a lower pressure area on the INNER surface of the rotor. The lower pressure is produced by an interior whirlwind effect within the rotor as it spins, and the fact that the rotor itself obstructs the wind passing around its inner surface, thereby causing a partial vacuum as well. In position 3, same side, there is a reversal in the high and low pressure areas on the inner and outer surfaces, and on the right, the individual positions can similarly be analyzed. This principle of rotation is related to a situation called the "MAGNUS EFFECT".

The actual shape of the rotor is a compromise between a narrower width which would bring about high speeds, but less torque versus a wider arrangement that would bring about more torque but lower rotary speeds. Also, this is close to what the rotating airfoil would assume in shape, if not restricted in support while rotating naturally, due to centripetal forces. However constant distortion in the rotor would be undesireable, since energy would be expended in distorting the rotor.

In positions 1 and 2, the rotor at these brief moments experiences a balance of forces, and requires momentum within itself to carry it through these points. The Darrieus system is also a system that is not self-starting, especially at these neutral points. Consequently, four starter cups are needed to turn the rotor over until it can run by itslef, like an internal combustion engine.

Figure 2(a): End Cap mounting & Axle joint (see text on page 4...)

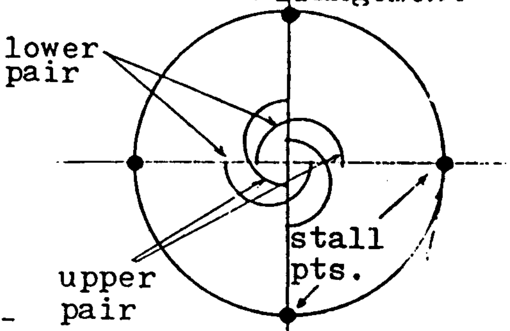


D: CONSTRUCTION

THE ROTOR ASSEMBLY

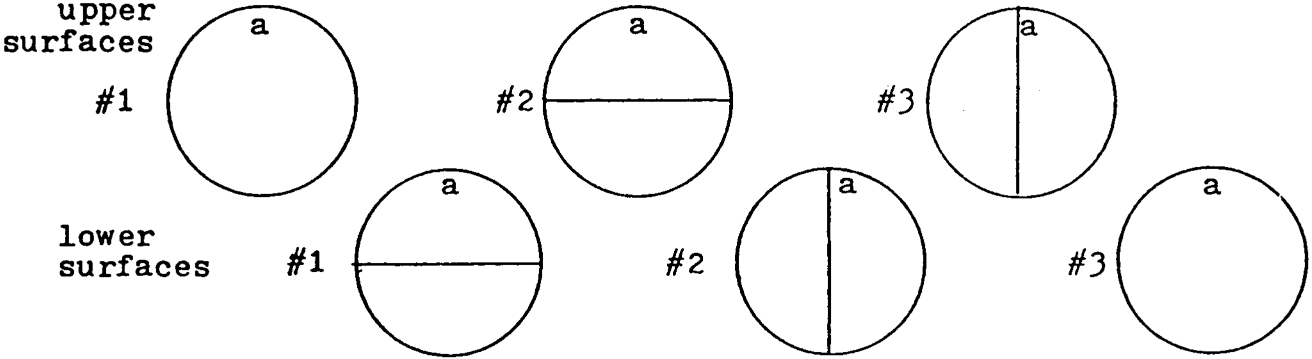
The rotor should be constructed from a flexible and weatherproof material. A good substance is the lamination that goes on top of sinks and countertops. In some areas it is sold under the trade name Arborite or Formica. If this substance cannot be found, simple masonite in a ¼" thickness can be used, provided it is coated with several layers of shellac and a weatherproof paint. It will be highly improbable that you will find any material in the lengths required to make the rotor. Therefore, joints will have to be made where you see fit. Before these are actually constructed, it will be necessary to construct and mount the starter cups first. These starter cups are specifically designed to catch the wind, even at low speeds and start the main rotor. Actually, they are a variation of the Savonius Windturbine, which is a viable system itself, but posessing somewhat different characteristics. There are two pairs of cups, resembling split cylinders, situated so that they offer maximum torque at points where the main rotor may stall. Since there are two positions, 90° apart where the rotor stall points are situated, the cups are placed similarly 90° out of phase. The first component to consider buildingis the axle. It is 22 feet in length, spanning the entire rotor assembly. The best material to use is a standard 1½" top running fence pipe, that are used in constructing the smaller chain link fence models. These are found in various lengths, up to 11 feet. So, two of these will be the perfect length when joined together. These pipes also facilitate joining since they have one tapered end, that fits into another length of pipe, in a consecutive successsion. Once you join the two, drill two holes in the joint and install two bolts to safely secure the joint. Measure down from the top of the axle 6 feet. This will mark the upper joining point of the upper starter cups. Also, when the two axle members are joired, make sure that the one remaining tapered end faces downward. The reduced diameter at the tapered end will be useful later on in installing the lower bearings, and drive pulley.

Figure 3: Starter Cup Arrangement



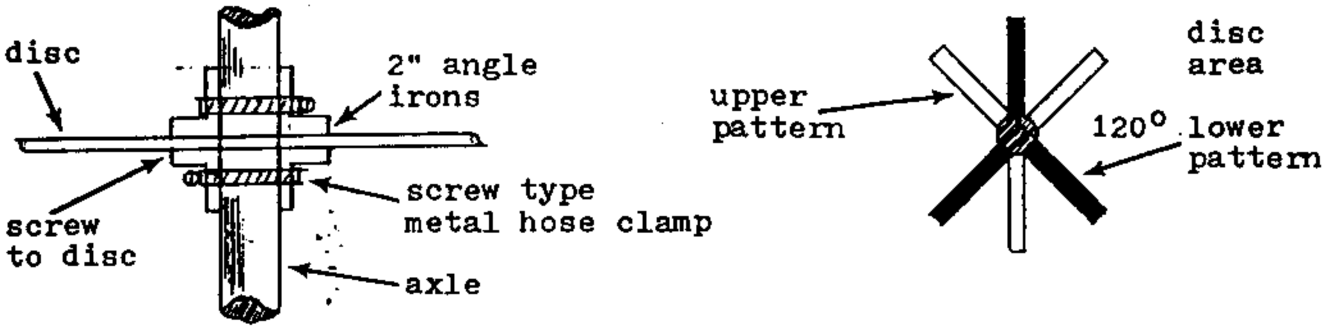
Now, construct the end caps of the starter cups. Out of 3/8" plywood cut out three 3' discs. Determine their center points and drill a 1½" hole in them, so that they shall fit snugly over the axle. The axies where the starter cups will be mounted can now be marked on the discs as well. Mark them as shown below.

Figure 4: Marking the end caps-90° rotation of the two pairs



The end caps should be mounted in the positions on the axle as shown in figure 2(a). They may be secured with the use of 3 2" angle irons on the upper surface and lower surface of the three plywood discs. The angle irons may be fastened to the discs with screws, and to the axle with metal hose clamps. See figure 5. Make sure that the impeller mount lines drawn on the end caps are positioned correctly, as shown below.

Figure 5: Mounting end caps with angle irons & hose clamps



Use three in a triangular pattern on the upper surfaces and lower surfaces of the discs. Once this is done, the actual cups may be installed. Remember to stagger the patterns between the upper and lower surfaces, so that the screws that are installed in the individual discs do not run into each other, from top to bottom.

The starter cups may be made out of a piece of arborite (if flexible enough) or simply a piece of ¼" masonite. Four sheets, 48" high by 31" wide will be needed. Along the two opposite 48" edges, fasten a piece of wood moulding, along its entire length. Use 1½" wood screws and white glue. If using masonite, use the rough side of the sheet for fastening, and the backside of the arborite in the other case. So, the smooth surfaces shall be curved inward to make the inside of the impellers. Place one sheet edge with mounted moulding against one of the starter cup's line of mounting and fasten in place with white glue and screws. Gently bring the other edge with mounted moulding around in a semi-circular path and fasten it to the disc along the mount line previously drawn. Small angle irons should be added for strength afterwards. The other starter cup may be added in the same manner, completing one pair. Then mount the other pair, but follow the 90° mount line for the second pair.

Figure 6: Cups and Mouldings

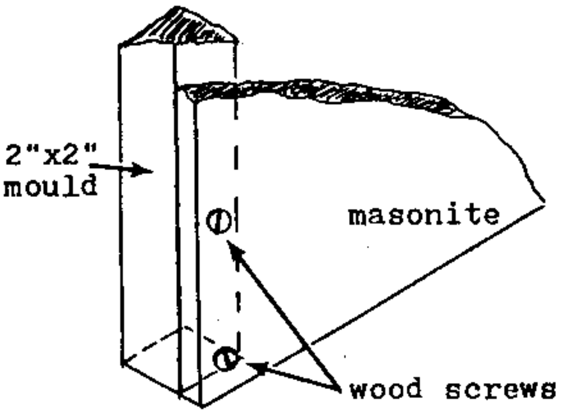


Figure 7: Top View of starter cup pattern

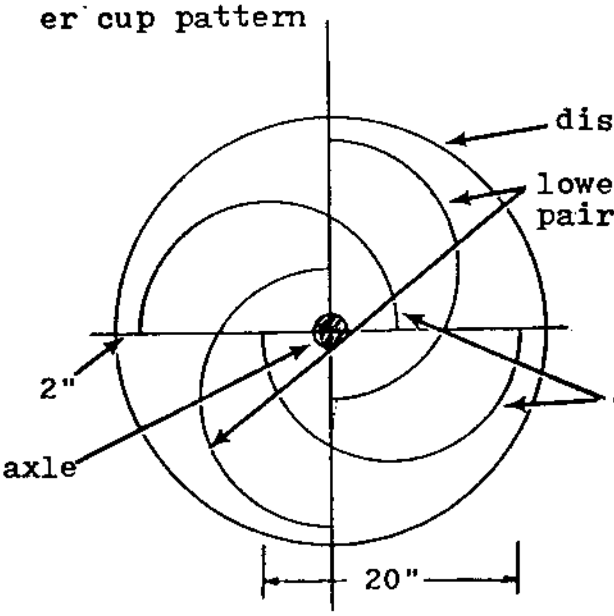
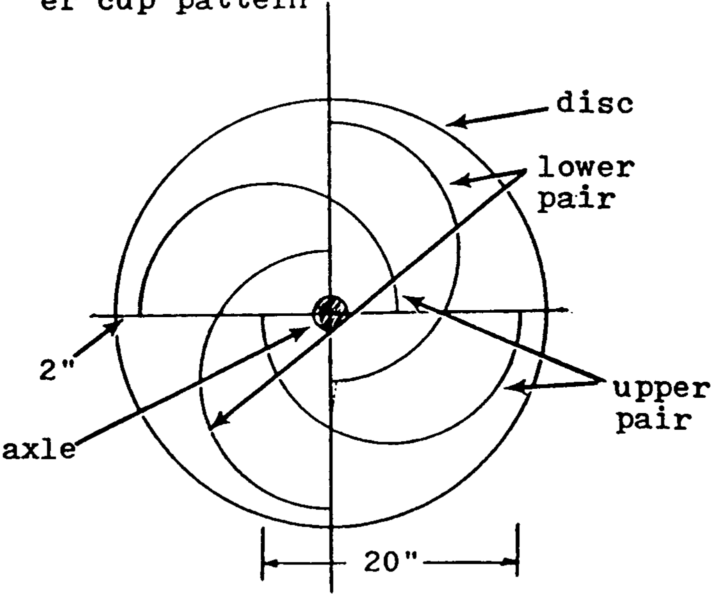
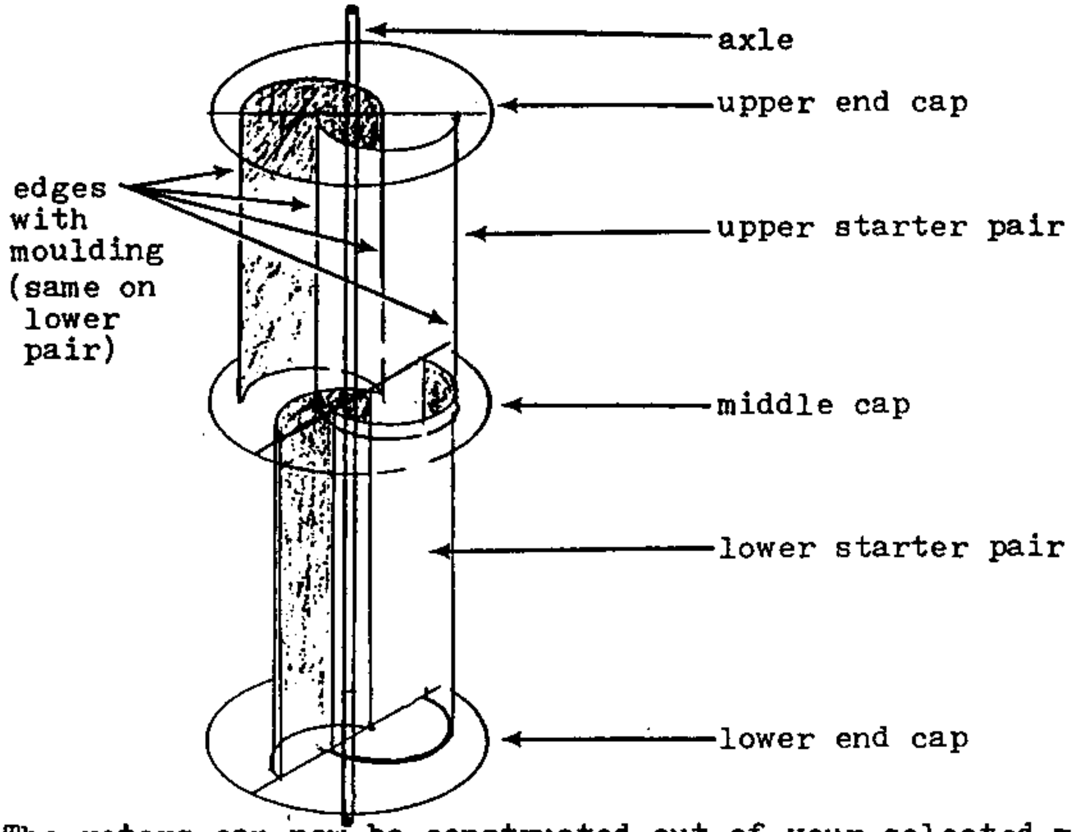


Figure 7: Top View of starter cup pattern



After the starter cups are mounted, they should appear like the set below:

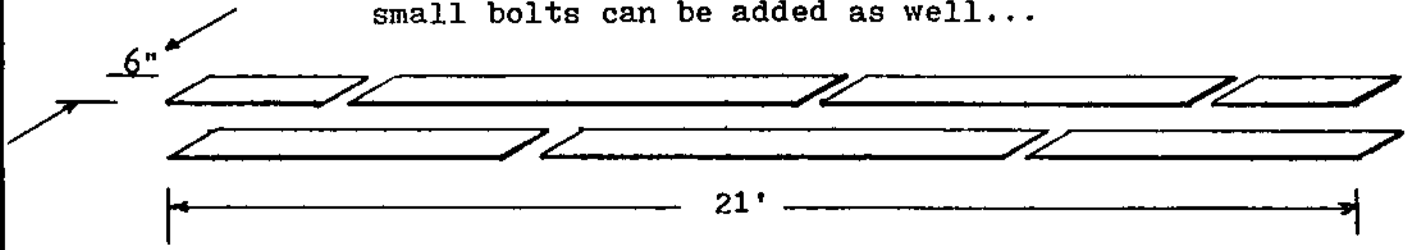
Figure 8: The Starter Cup Assembly



The rotors can now be constructed out of your selected material, as mentioned earlier. The pieces will have to be glued together, since it is highly unlikely that pieces over 8 feet will be found. Each rotor will actually be two laminations of arborite or masonite, glued together. Also, use small bolts for extra strength. Remember to stagger the joints between the two layers, like brickwork for extra strength. This will produce two solid rotor halves out of two layers of material. The rotor length is 21 feet, for each of the two rotors, and six inches wide. Once completed, we can then connect them to the axle by their ends.

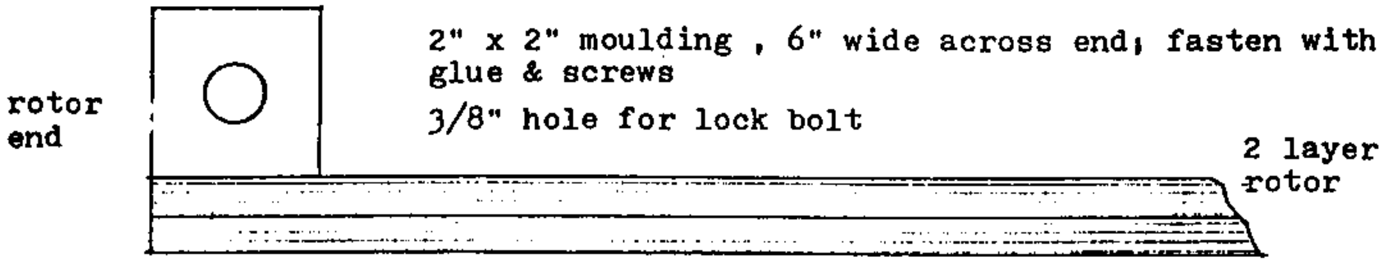
Figure 9: Rotor Blade Configuration (make two)

Glue the rougher sides of your selected laminations together small bolts can be added as well...



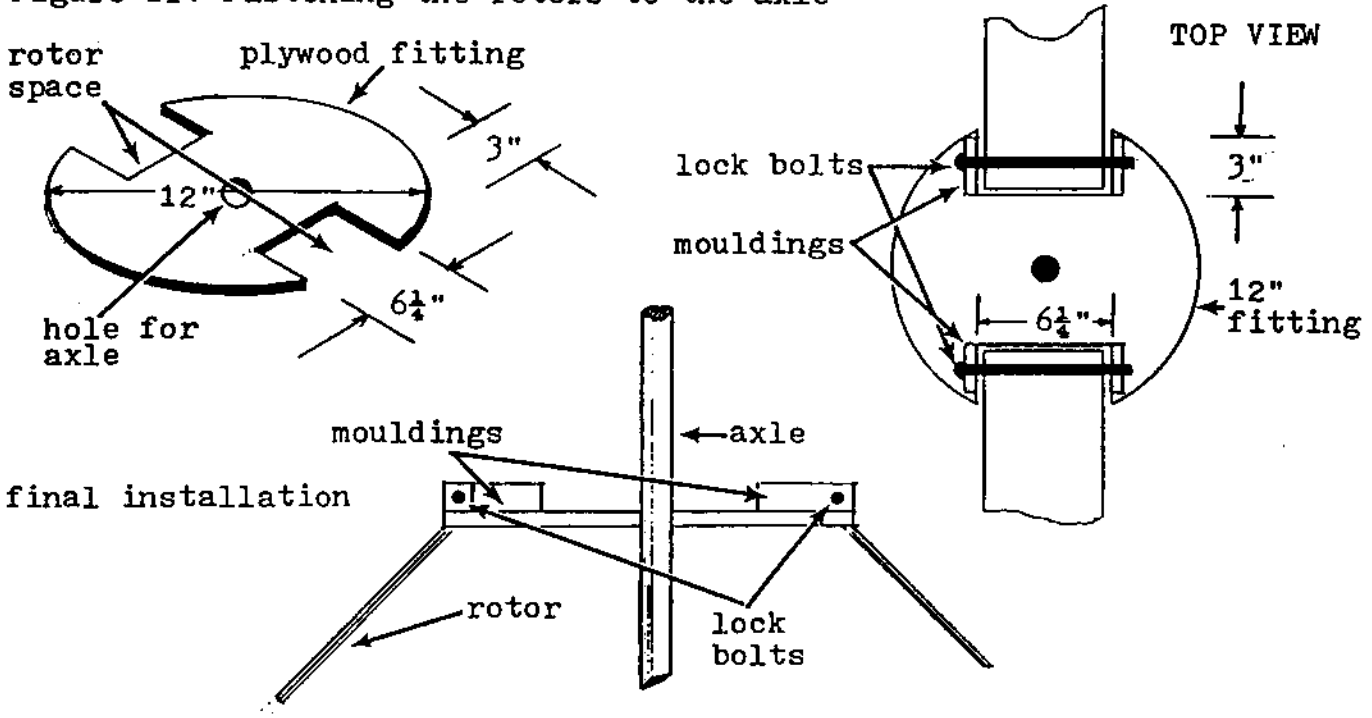
On the ends of each rotor half, fasten a 2" by 2" moulding of wood. Through these mouldings, drill a 3/8" hole to accomodate a locking bolt for fastening to the axle.

Figure 10: The Rotor Ends



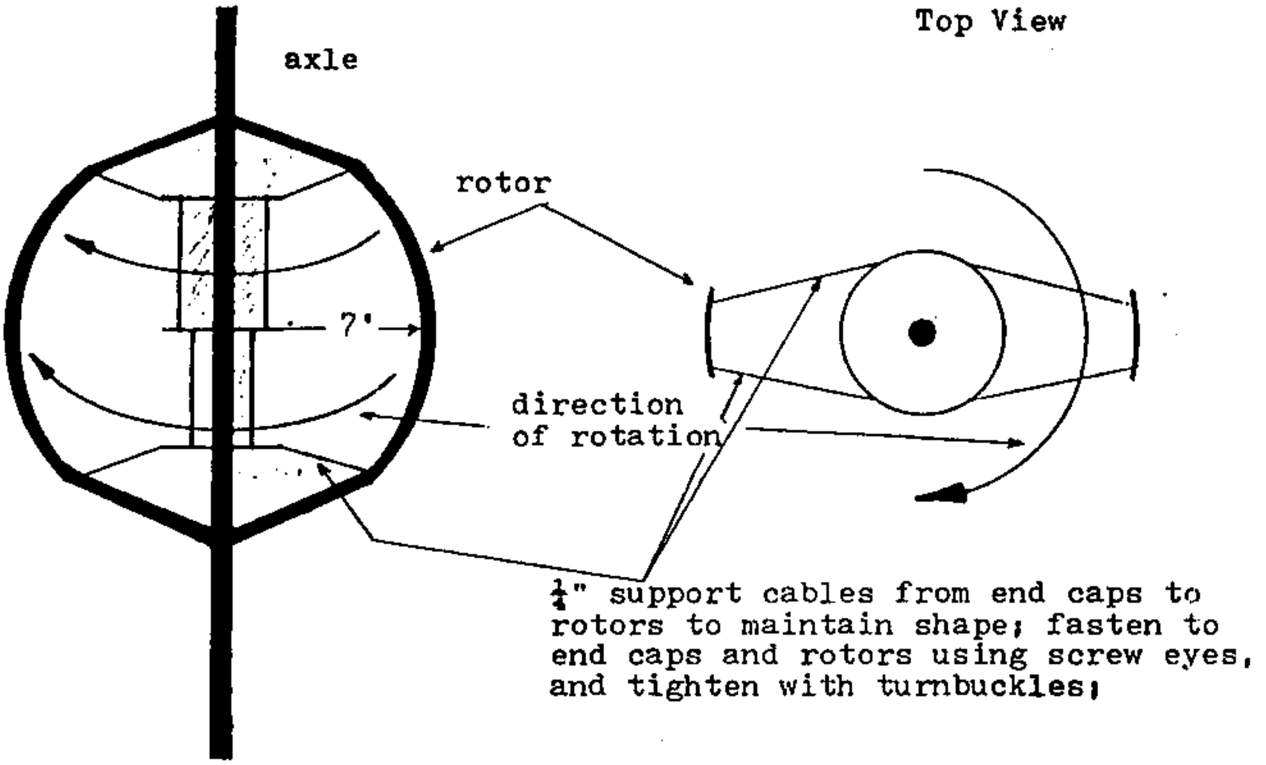
These ends should be attached to the round fittings shown below. Make these out of ½" plywood. Cut out two notches in these fittings just over 6 inches in width as shown below. Along the two edges of the notches, install similar mouldings as used on the ends of the rotors. These fittings can be fastened to the axle in the same manner as the caps used in the starter assembly. The two fittings should be installed 2½ feet from the top and 17½ feet from the top as well. Once the fittings are fastened to the axle, place the lower ends of the rotors into the lower fittings and lock them into place with the 3/8" lock bar. Then, bring each one around gently in a circular path and anchor the upper end to the upper fitting in the same manner. If the rotors lack adequate flexibility, soak the centers of them in water overnight.

Figure 11: Fastening the rotors to the axle



The rotor assembly is now essentially complete. The rotors should be fairly straight leaving the end fittings as shown directly above, but should assume a gentle curve in their centers, of about 7 feet radius. The rotor shape can be maintained with the extra support of 8 cables made of clothesline, with turnbuckles to maintain tension. By using the cables in pairs and fastening them to the upper and lower starter caps, lateral movement will also be eliminated in the rotors.

Figure 12: The Completed Rotor



¼" support cables from end caps to rotors to maintain shape; fasten to end caps and rotors using screw eyes, and tighten with turnbuckles;

It is better to construct the upper bearing housing at this point, since installation after erecting the axle will be more difficult. The upper bearing housing must be built very securely, since it will support the upper end of the airfoil, with the aid of four guy wires. A sensible angle for the guy wires is about 45 degrees, however the shallower the angle, the more groundspace required. Place this assembly at the very end of the axle to offer the most clearance between the guy wires and the upper part of the rotors as they spin. The upper bearing housing should be constructed out of two 7/8" thick plywood discs, 1 foot in diameter each. In between them will be two bearings, with mount cradles. These will be housed in 2" by 4" lumber, with four cylindrical posts around the perimeter to attach the guy wires. When selecting the bearings with matching mount cradles, they must obviously fit snugly onto the axle. However, select bearings that have as large an outside ring as possible. In other words, the actual balls in the bearings should be as large as possible, since small bearings will wear out and spin less freely.

Figure 13: The Upper Bearing Housing

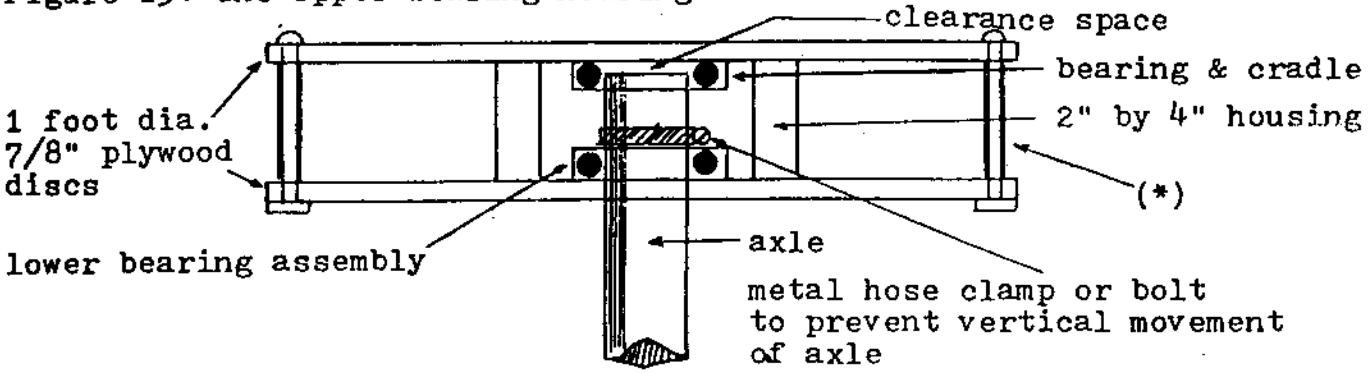
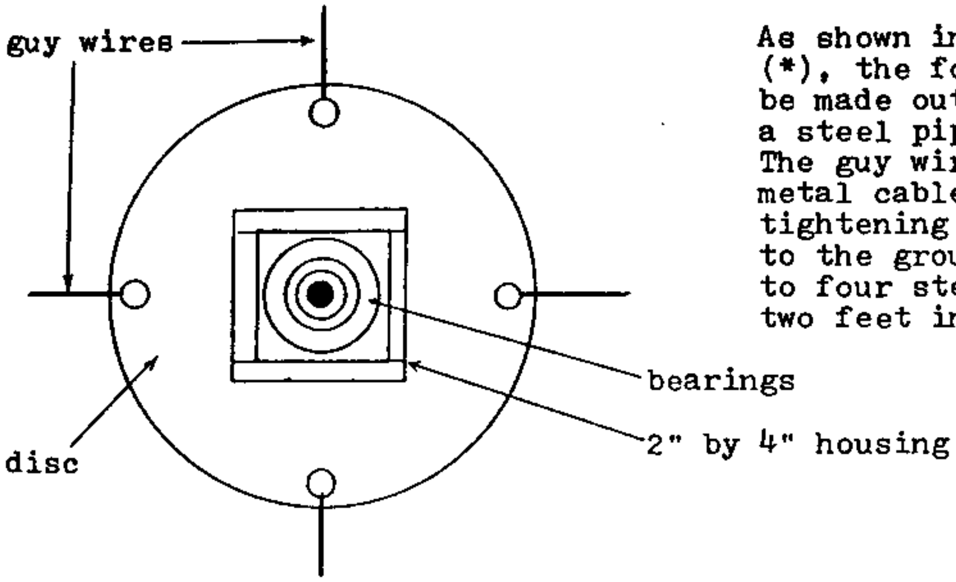


Figure 14: Top View of upper bearing housing



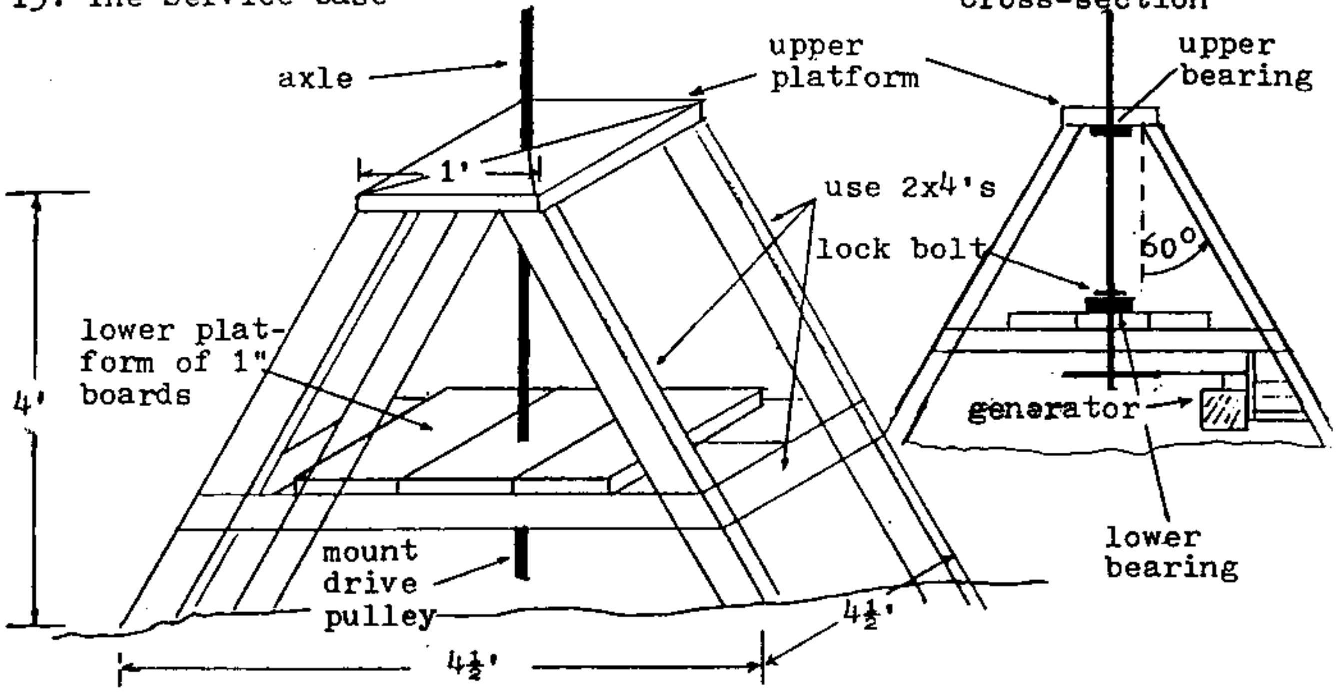
As shown in figure 13 by the symbol (*), the four vertical posts can be made out of a 3/8" bolt with a steel pipe sleeve around it. The guy wires should be ¼" or 3/8" metal cable with turnbuckles for tightening them. Secure the cables to the ground, by fastening them to four steel 1½" pipes placed two feet into the ground.

CONSTRUCTION OF THE SERVICE BASE

The service base will support the lower end of the rotor, and house the generator with its drive assembly. The base is approximately four feet high and is built simply of 2" by 4" lumber. Three feet from the TOP of the base, install a lower platform as shown below. The lowermost bearing will rest on this platform, and the second bearing set will rest underneath the upper platform. The main point to remember when building the base is to ensure that everything is "square" so that the axle will rotate with little resistance. If there are minor random errors in the base's alignment, the bearings may be correctly positioned with shims where necessary. This is likely in most cases.

Figure 15: The Service base

Cross-section



The upper and lower bearings in the service base are mounted in same manner is in the upper bearing housing. The two units are mounted to the upper platform and lower platfrom respectively. Again, use the same bearing size and mount cradles as in the upper case. The larger the actual ball bearings, the better. Above the lowermost bearing, pass a lock bolt, through the axle to prevent vertical slippage. Make sure that it does not rub against the bearing, other than its inside ring which moves freely with the axle. The alternator may be placed in any convenient place within the service base. Use a small bracket fastened to two legs of the base to mount the unit. The drive pulley will probably not have a mount hole that is large enough to fit over the axle. So, if mounted as shown in the cross-section, install a diameter reducing bar into the bottom of the tapered end. Since the airfoil rotates between 50 to 150 rpm, a step up of about 12 to 1 is necessary to drive the alternator. That is, the drive pulley should have a diameter of about 12 times the diameter of the pulley on the alternator. In some cases, depending on what's available in your area, it may be necessary to do this in two steps.
After the base is completed, it is a good idea to enclose the base to protect the drive system and the generator. Any wood parts should be liberally coated with shellac and then finished with a waterproof all-weather sealant. In the case of the base enclosures, mount one side like a door with hinges, so that easy access to the components for lubrication and maintaince is possible.

ASSEMBLING AND ERECTION OF THE TURBINE

Look at the site where you will be erecting your Darrieus Airfoil and try to estimate where the four guy support wires will be located. It is easiest to complete the airfoil in a horizontal position. Before erecting the entire assembly, place the airfoil on two level supports and rock the rotor back and forth to see if everything spins freely.

At the four holes where the guy wires will be fastened to the ground, dig a hole at each one about 18 inches into the ground. Insert a concrete building block and wire a 1½" pipe to it.Then bury the block to secure the post completely.

Attach the guy wires before erecting the airfoil. Then, dig a shallow hole about 6 inches for each post of the service base, right beside the Airfoil that is still resting on its side. With the help of several other people, hoist the Airfoil into a vertical position with the base inserted into the holes earlier made.

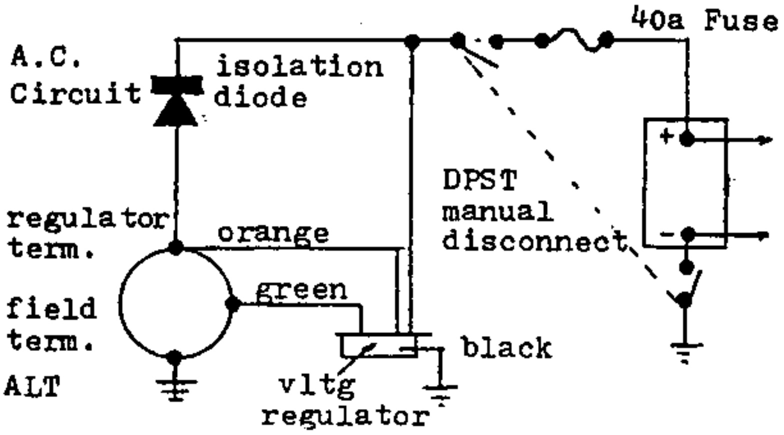
Once in a vertical position, fasten the guy wires to the ground support posts and tighten them to secure the system.

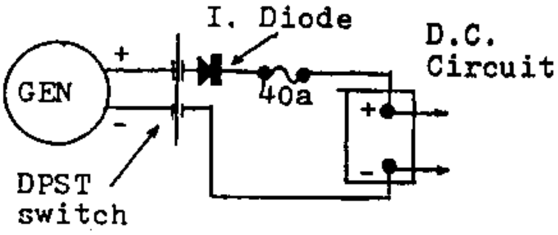
Fill in the holes around the legs of the service base.

The electrical system is on the next page. It delivers 12 volts of DC current. Conversion of the power to household current is possible with an inverter, but somewhat complex and unnecessary, since there are quite a few appliances designed to run on 12 VDC power. Also, DC current may be stored in batteries for delivery during periods of higher demand. Conversely, current generated during slower periods will be stored in order to provide power during these peak periods. This facilitates current output of up to 3000 watts (peak power rating).

E: CHARGING CIRCUIT

There are two basic charging curcuits, one using a PM DC generator, and one using an automotive alternator. In this case, we shall assume that the alternator is a newer model that has internally mounted rectifying diodes. In the alternator case, you can see that the field terminal requires current from the battery to create a surrounding field around the armature to facilitate charging. The PM DC generator is a much simpler system, and is recommended if one can be found in your area.





F: PARTS INVENTORY

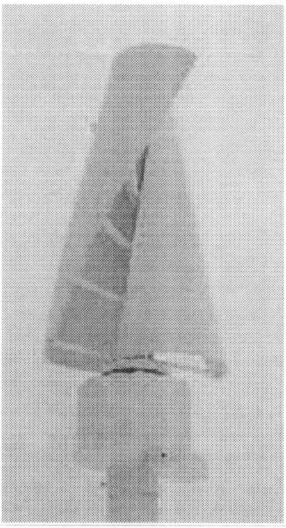
2 11 foot running fence members, with tapered ends for axle
4 bearings with matched mount cradles to fit axle snugly (get the biggest ball bearings available)
2 4 by 8 7/8" sheets of plywood
supply of small turnbuckles and clothesline or similar steel cable for support wires, rotor to starter caps
4 4 by 8 ¼" masonite sheets
supply of arborite, formica or masonite for rotor
supply of 2" angle irons for fastening members together
supply of 2 by 4 lumber
supply of 3/8" steel cable for support wires to ground
4 concrete blocks
4 15" by 1½" steel pipes for support pipes.
4 long 3/8" bolts and steel sleeves for attaching guy wires to upper bearing housing
supply of metal hose clamps
supply of 2" by 2" moulding
supply of misc. hardware

Windside models

WS-0,30C (~9A)

-can be used e.g. in cottages, boats, measuring and alarm systems

- price 12.000 FIM



WS-0,15 C/B (~9A)

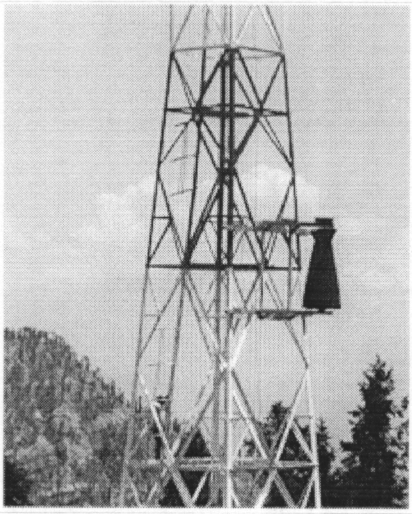
-to mountain and sea areas, measuring systems, signal equipment, boats

-price 8.400 FIM (C)
9.400 FIM (B)

WS-0,30A (~9A)

-for professional use in demanding conditions

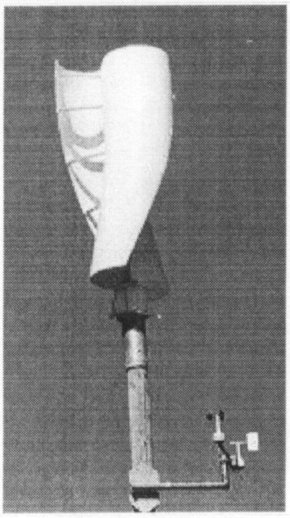
-price 29.000 FIM



WS-2A (~20A)

-for professional use in demanding conditions

-price 60.500 FIM

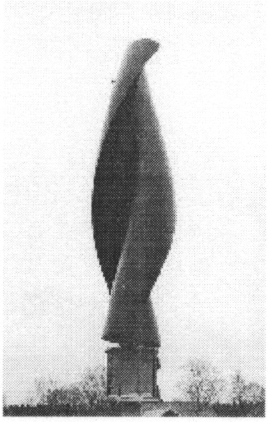


WS-2B (~20A)

-special construction for stormy winds

-measuring systems, water circulation

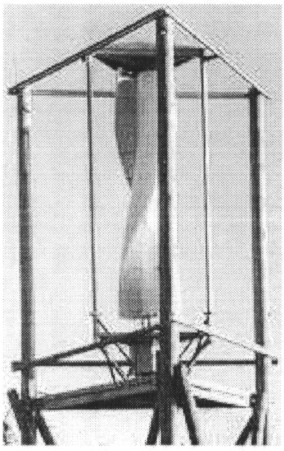
-price 55.000 FIM



WS-4C (~20A)

-summer/winter houses
-oxidation of lakes

-price 97.600 FIM



WS-4A (~20A)

-for professional use in demanding conditions

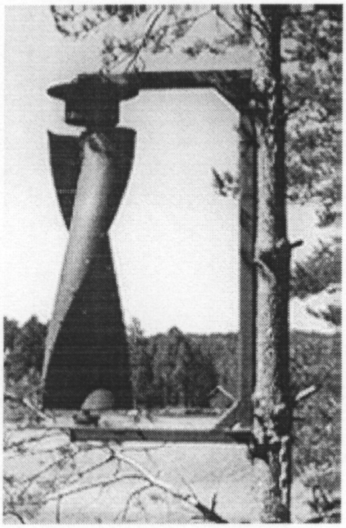
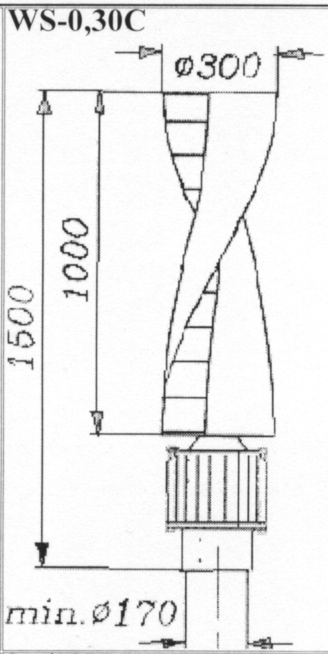
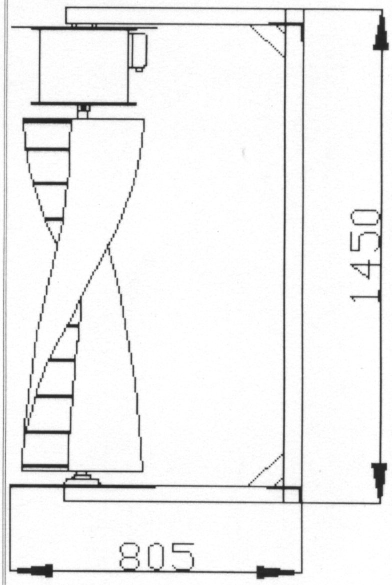
-price 118.000 FIM

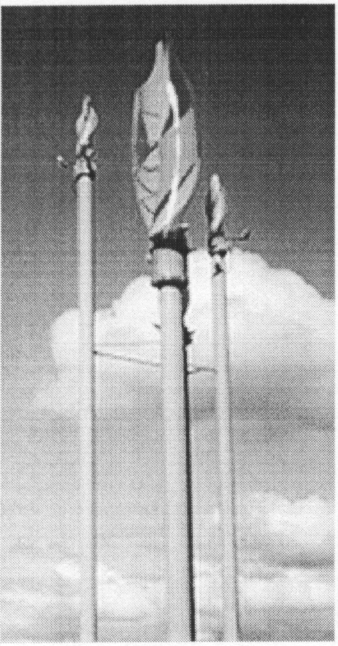
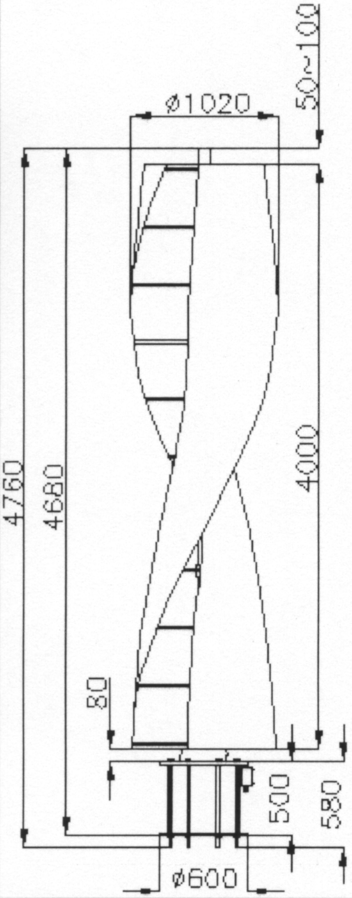
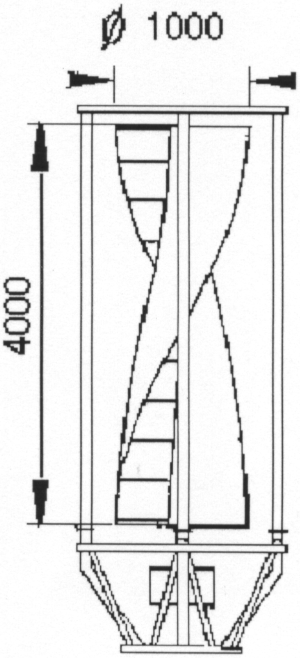
Technical data

Explanations for model markings:
For example WS-0,30A, which stands the storm of 60 m/s:

-number 0,30 = swept area of 0,30 m^2
-alphabet (A) = wind endurance class
A=60 m/s
B=40 m/s
C=30 m/s

Click the picture to go back to models.

Characteristics: 	**WS-0,30C** 	**WS-0,30A** 
Rated power	9A/12V	9A/12V
Mast recommendation	wood/metal	metal
Cut-in wind speed	2,8 m/s	3,0 m/s
Rated wind speed	15 m/s	18 m/s
Cut-out wind speed	none	none
Swept area	0,30 m^2	0,30 m^2
Vane weight	2 kg	2 kg
Total weight of turbine	46 kg	80 kg
Rotor speed control	not required, electronic	not required, electronic
Overspeed control	none required	none required
Generator model	Windside	Windside
Generator construction	permanent magnet	permanent magnet
Generator types	1-400 V/12,24,48 V	1-400 V/12,24,48 V
Gear box	without gear	without gear
Main brake system	electronic	electronic
Charging controller	Windside WGU-22	Windside WGU-22
Measured sound emission	0 dB	0 dB

Characteristics:	**WS-4C**	**WS-4A**
		
Rated power	20A/12 V	20A/12 V
Mast recommendation	wood	metal
Cut-in wind speed	1,5 m/s	1,9 m/s
Rated wind speed	15 m/s	18 m/s
Cut-out wind speed	none	none
Swept area	4 m^2	4 m^2
Vane weight	40 kg	40 kg
Total weight of turbine	700 kg	1.000 kg
Rotor speed control	not required, electronic	not required, electronic
Overspeed control	none required	none required
Generator model	Windside	Windside
Generator construction	permanent magnet	permanent magnet
Generator types	1-400 V/12,24,48 V	1-400 V/12,24,48 V
Gear box	without gear	without gear
Main brake system	electronic	electronic
Charging controller	Windside WGU-25/WGC-10	Windside WGC-10
Measured sound emission	0 dB	0 dB

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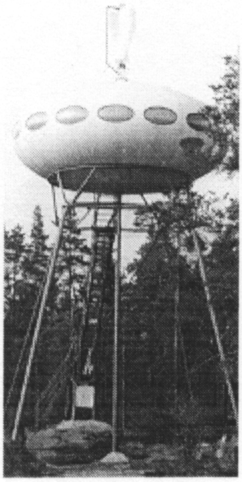
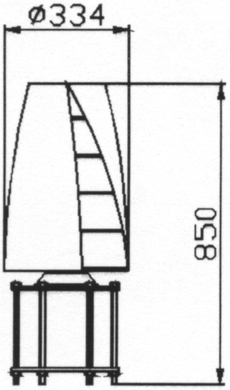
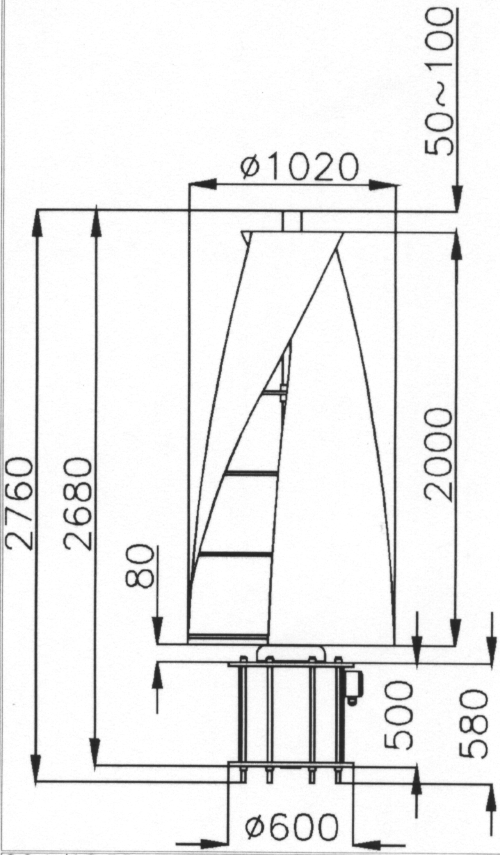
</th><th>WS-0,15C/B
 </th><th>WS-2B
 </th></tr>
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<tr><td>Cut-in wind speed</td><td>3,8 m/s</td><td>2,0 m/s</td></tr>
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<tr><td>Cut-out wind speed</td><td>none</td><td>none</td></tr>
<tr><td>Swept area</td><td>0,15 m^2</td><td>2 m^2</td></tr>
<tr><td>Vane weight</td><td>1 kg</td><td>20 kg</td></tr>
<tr><td>Total weight of turbine</td><td>40 kg</td><td>200 kg</td></tr>
<tr><td>Rotor speed control</td><td>not required, electronic</td><td>not required, electronic</td></tr>
<tr><td>Overspeed control</td><td>none required</td><td>none required</td></tr>
<tr><td>Generator model</td><td>Windside</td><td>Windside</td></tr>
<tr><td>Generator construction</td><td>permanent magnet</td><td>permanent magnet</td></tr>
<tr><td>Generator types</td><td>1-400 V/12,24,48 V</td><td>1-400 V/12,24,48 V</td></tr>
<tr><td>Gear box</td><td>without gear</td><td>without gear</td></tr>
<tr><td>Main brake system</td><td>electronic</td><td>electronic</td></tr>
<tr><td>Charging controller</td><td>Windside WGU-22</td><td>Windside WGU-25/WGC-10</td></tr>
<tr><td>Measured sound emission</td><td>0 dB</td><td>0 dB</td></tr>
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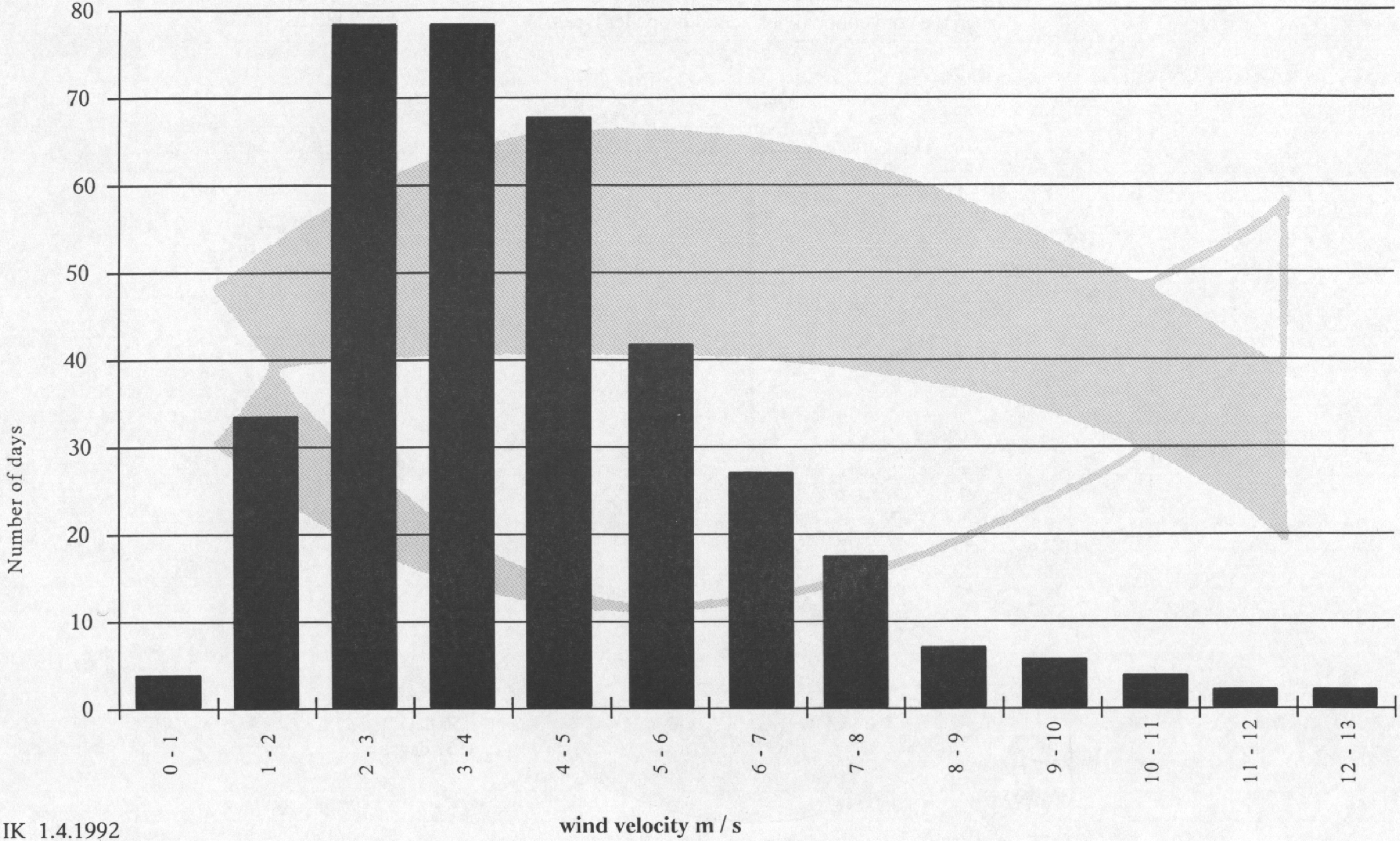
windside

The constancy of the wind
Finnish coast autumn 1989 - spring 1991

The diagrams show how many days the Windside wind turbine
can produce energy by each wind velocity



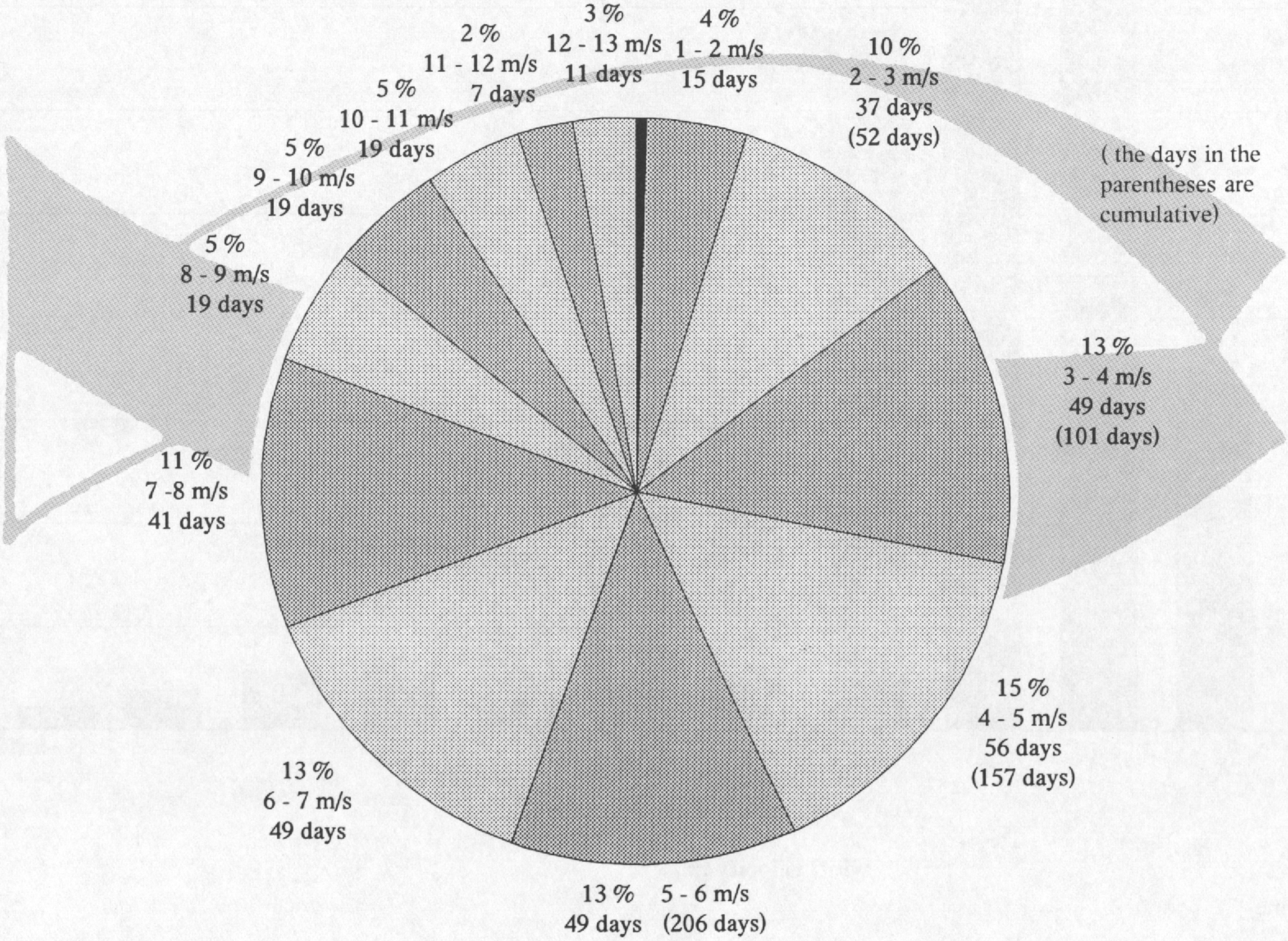
IK 1.4.1992
WS-4 wind turbine

windside

Generator production in Ah with different wind velocities in the Finnish coast, autumn 1989 - spring 1991

The measuring proves that Windside wind turbines produce energy at least 157 days more per year than the conventional horizontal propeller types.

371 days measured constantly, totally 7480 Ah



(the days in the parentheses are cumulative)

IK 1.4.1992
WS-4 wind turbine

Power production of wind turbines watts m/s

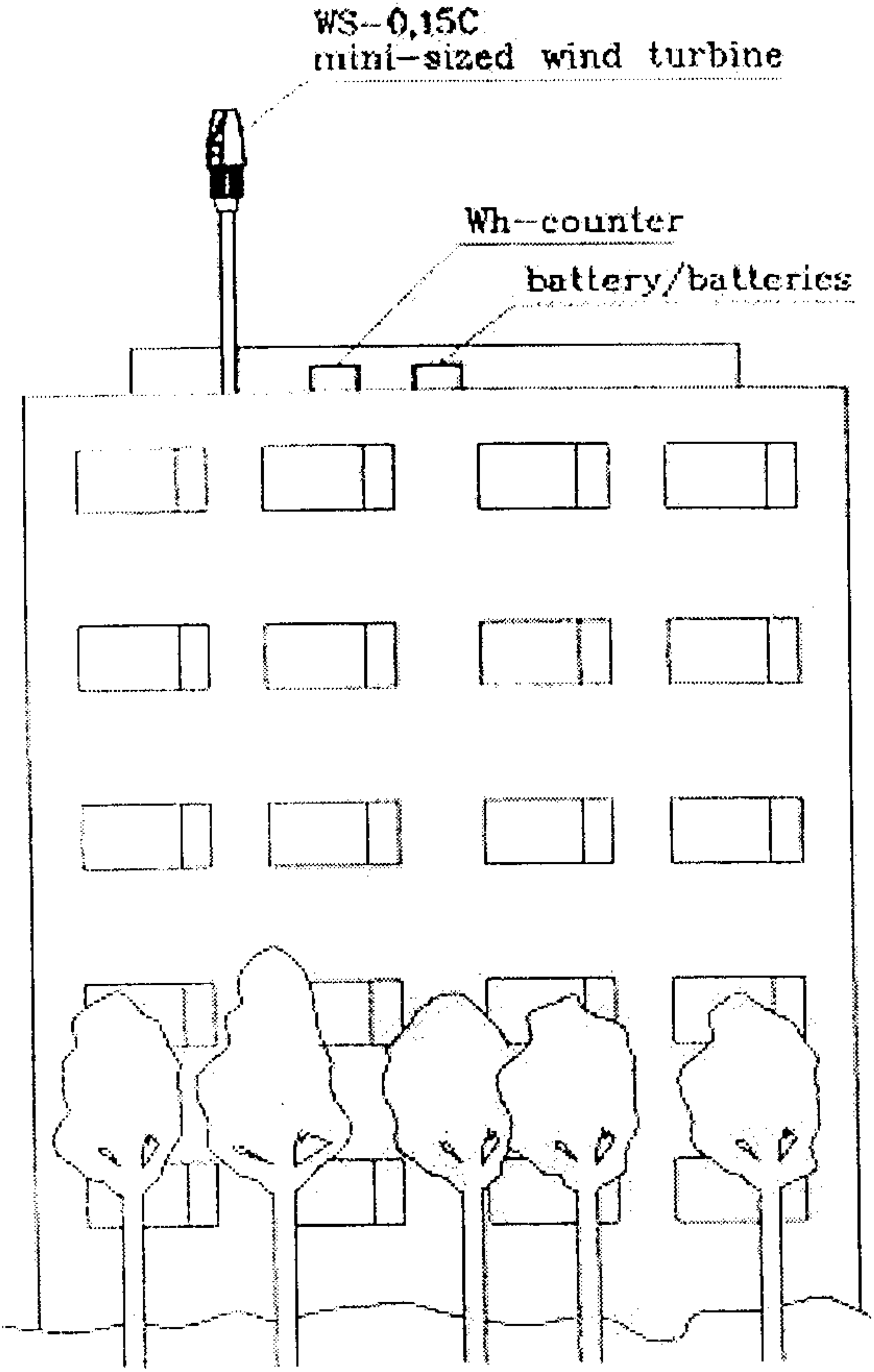
Starting of power production at m/s

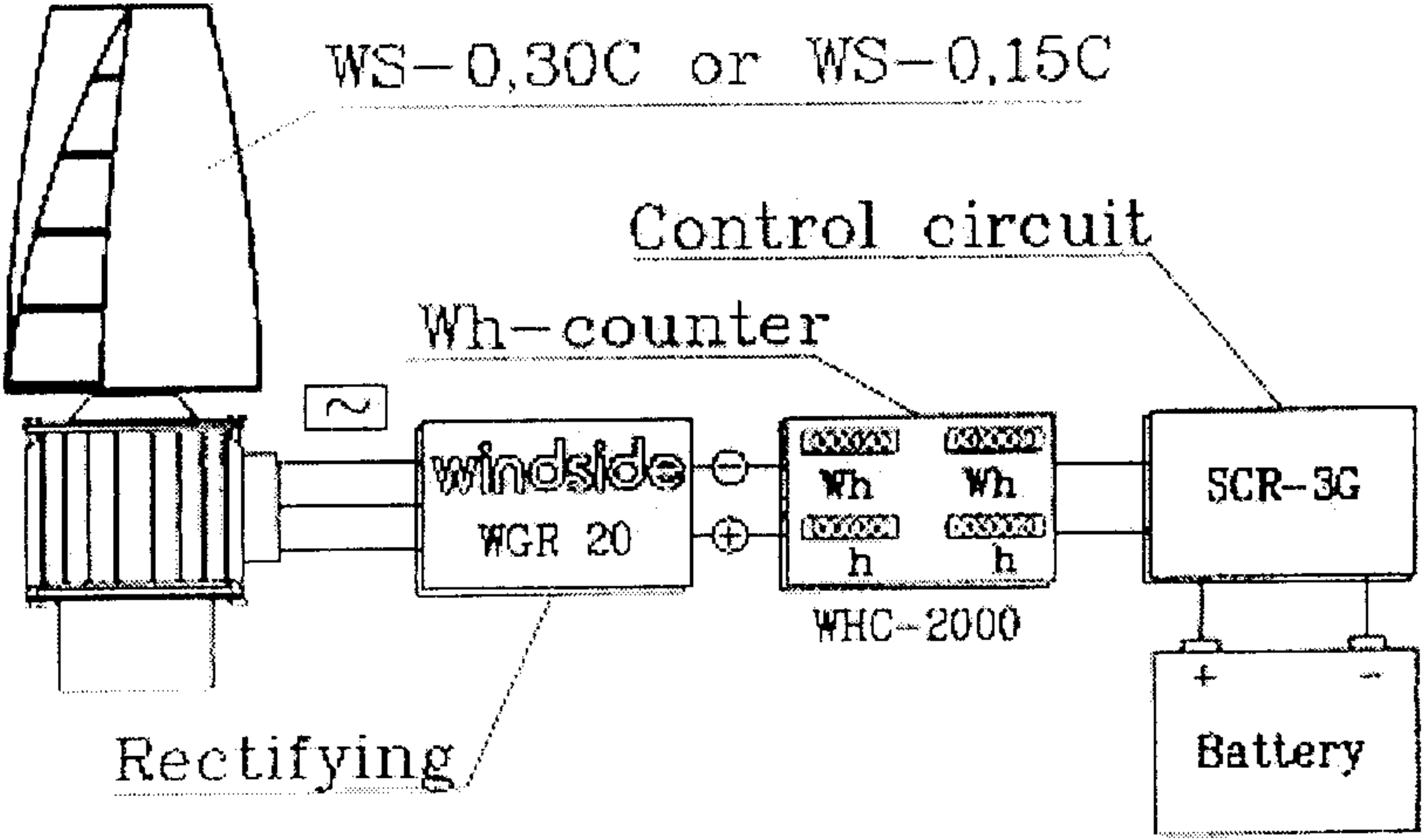
	4	3	2	2	2	2
Wind velocity m/s	**Model WS-0,15 W**	**Model WS-0,30C W**	**Model WS-2 W**	**Model WS-4 W**	**Model WS-30 W**	**Model WS-75 W**
3	1	2	10	20	150	375
4	2	4	20	40	300	750
5	3	7	35	70	527	1312
6	5	10	50	100	750	1875
7	7	15	75	150	1125	2812
8	10	21	105	210	1575	3937
9	15	30	150	300	2250	5625
10	20	40	200	400	3000	7500
11	22	55	275	550	4125	10312
12	35	70	350	700	5250	13125
13	45	90	450	900	6750	16875
14	60	120	600	1200	9000	22500

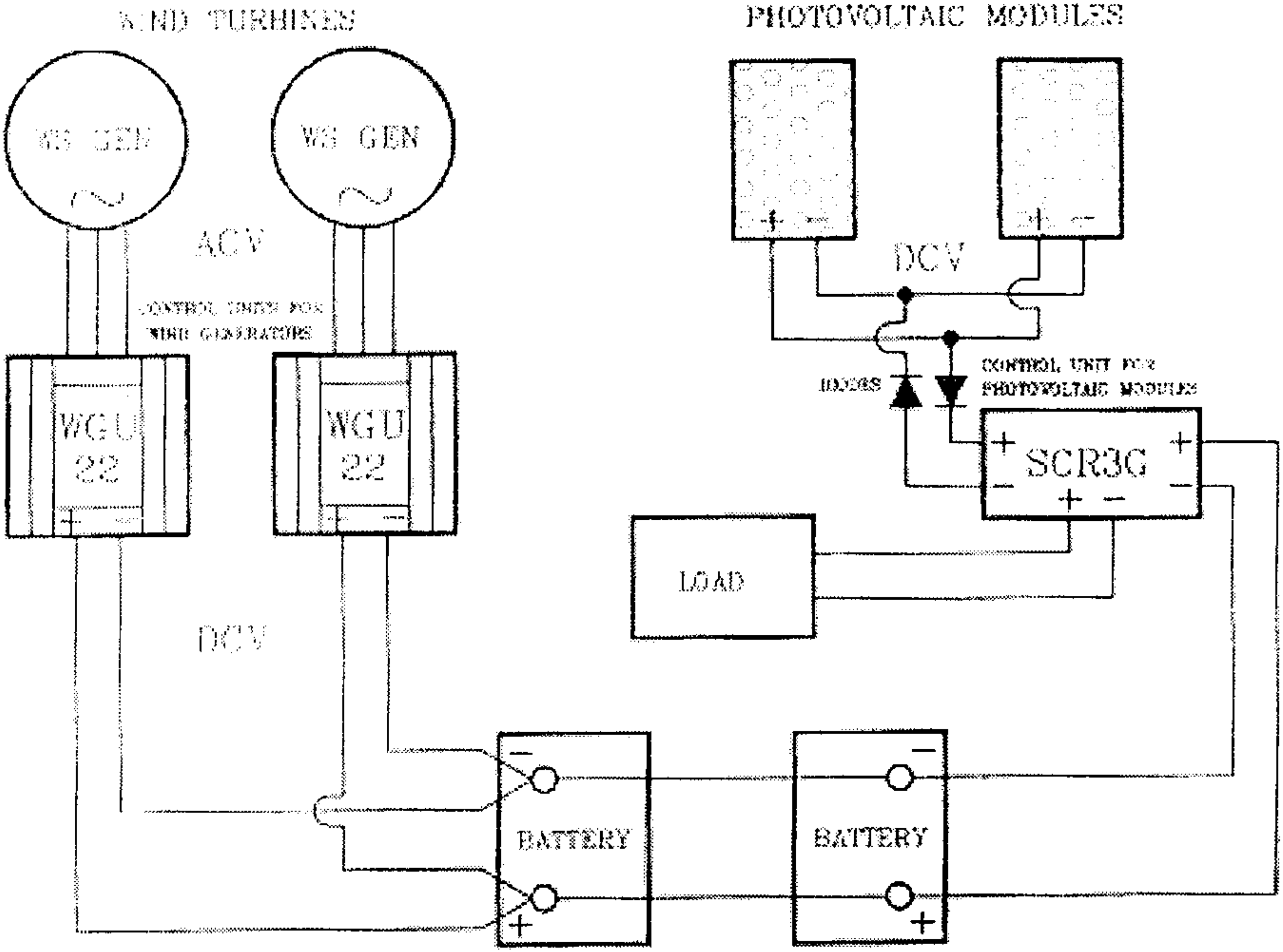
Expected annual production is -100W/m^2 = 860 kWh/m^2/year

Estimated annual production of different models:

Model:	Average wind speed	3 m/s	5 m/s	7,5 m/s	10 m/s	
WS-0,15	=	8	25	60	129	kWh/year
WS-0,30C	=	17	60	120	258	kWh/year
WS-2	=	86	301	800	1720	kWh/year
WS-4	=	172	602	1700	3440	kWh/year
WS-30	=	1290	4532	12000	25800	kWh/year
WS-75	=	3225	11283	32000	64500	kWh/year


WS-0,15C
mini-sized wind turbine
Wh-counter
battery/batteries

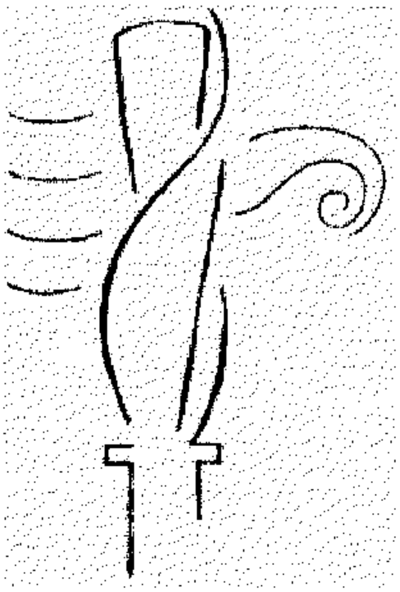

WS-0,30C or WS-0,15C
Control circuit
Wh-counter
~
windside
WGR 20
−
+
Wh
Wh
h
h
WHC-2000
SCR-3G
+
−
Battery
Rectifying


WIND TURBINES
WS GEN
~
WS GEN
~
ACV
CONTROL UNITS FOR
WIND GENERATORS
WGU
22
+
−
WGU
22
+
−
DCV
PHOTOVOLTAIC MODULES
+
−
+
−
DCV
DIODES
CONTROL UNIT FOR
PHOTOVOLTAIC MODULES
SCR3G
+
−
+
−
+
−
LOAD
BATTERY
−
+
BATTERY
−
+

SHIELD

Jaspira Wind Turbines

JASPIRA - MOBILE



Jaspira Mobile lightweight collapsible wind turbine. It is portable and can be carried by one person. It may be set up when needed, for example during encampment. The patented design of Jaspira enables this collapsibility. The electricity produced by Jaspira Mobile is sufficient to power portable electronic devices such as communication equipment.

Possible users:

- border guards
- hunters
- hikers
- soldiers

A specific application is in a survival pack for life boats.

JASPIRA - NAVAL

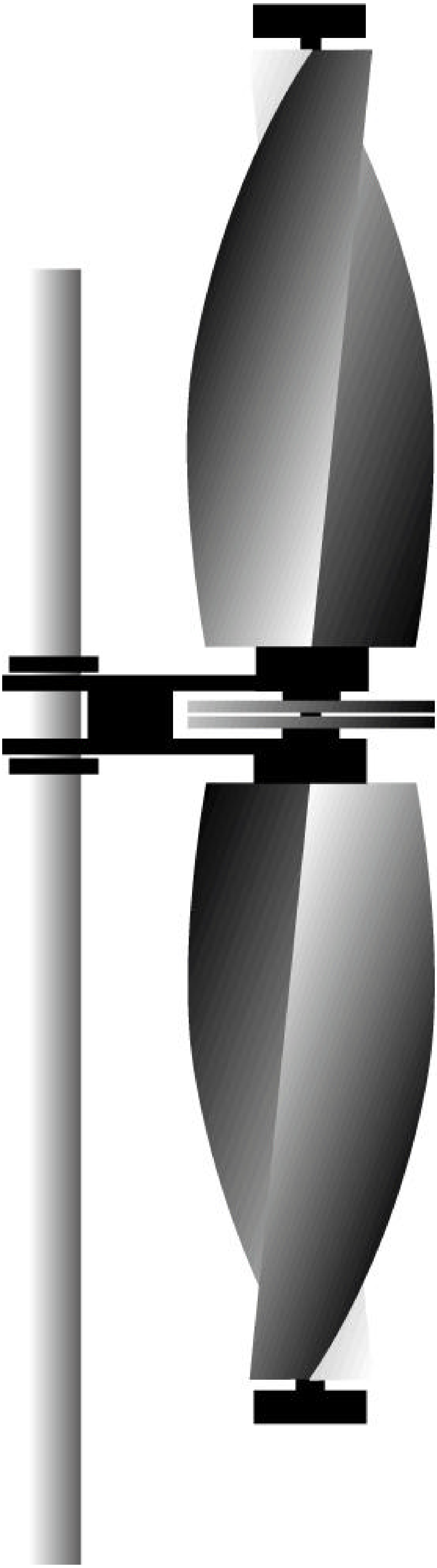
Jaspira Naval is designed for marine conditions. The special shape also prevents tangling with ropes or textiles in a sailing boat.

Applications:

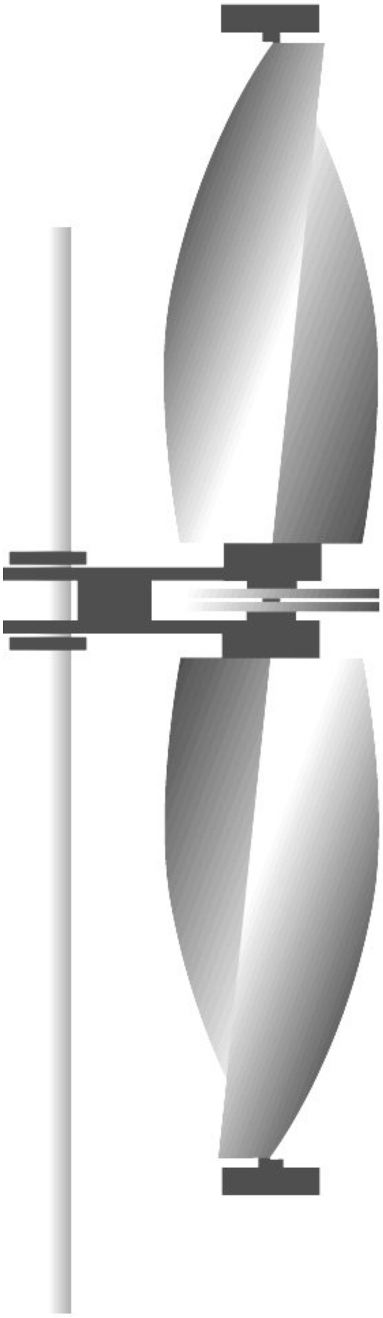
- sailboats
- life rafts
- buoys
- lighthouses

JASPIRA - ENERGY/ESTATE

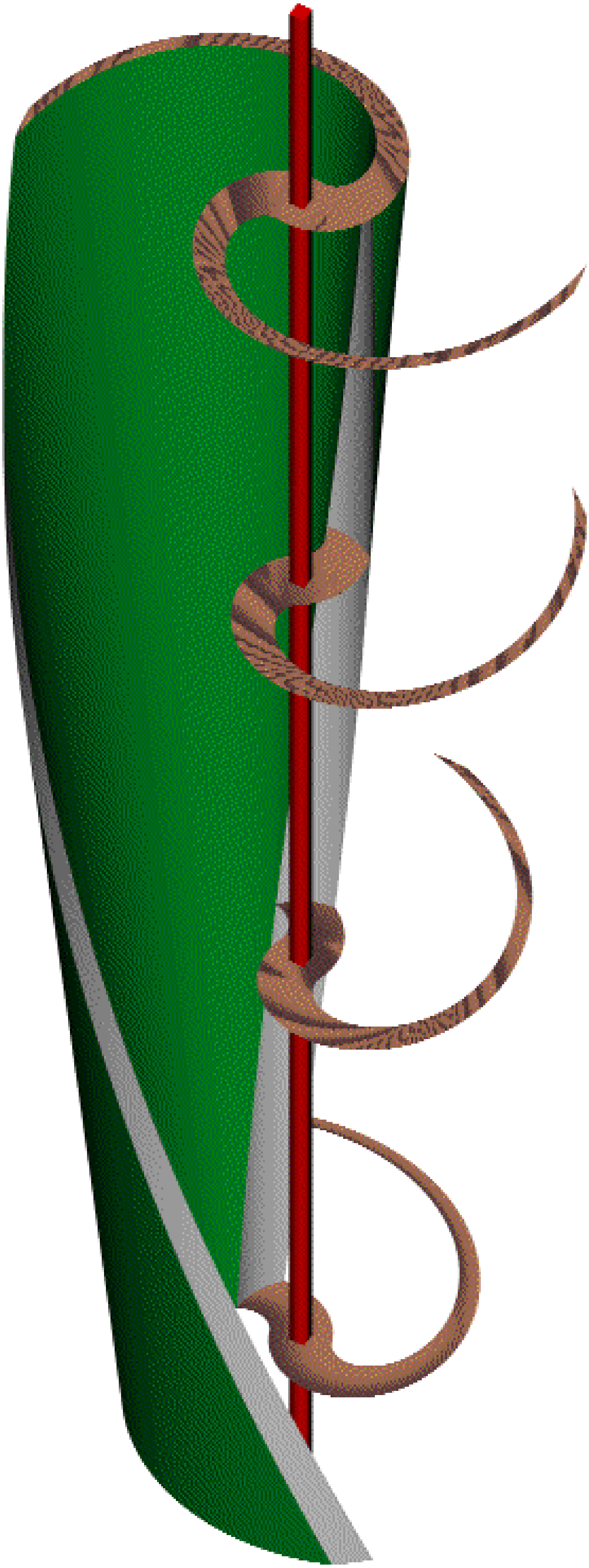
The Jaspira design is not limited to the turbine sizes in the above mentioned applications. It can also be used with larger turbines in stationary applications. If the nominal power increases above 2 kilowatts, we refer the rotors in general as Jaspira - Energy. The Jaspira - Estate model is intended for single-family homes, week-end cottages, and farms. Apart from producing electricity, it also can be used for water pumping. The nominal power is in the range 2 - 10 kilowatts.



SHIELD

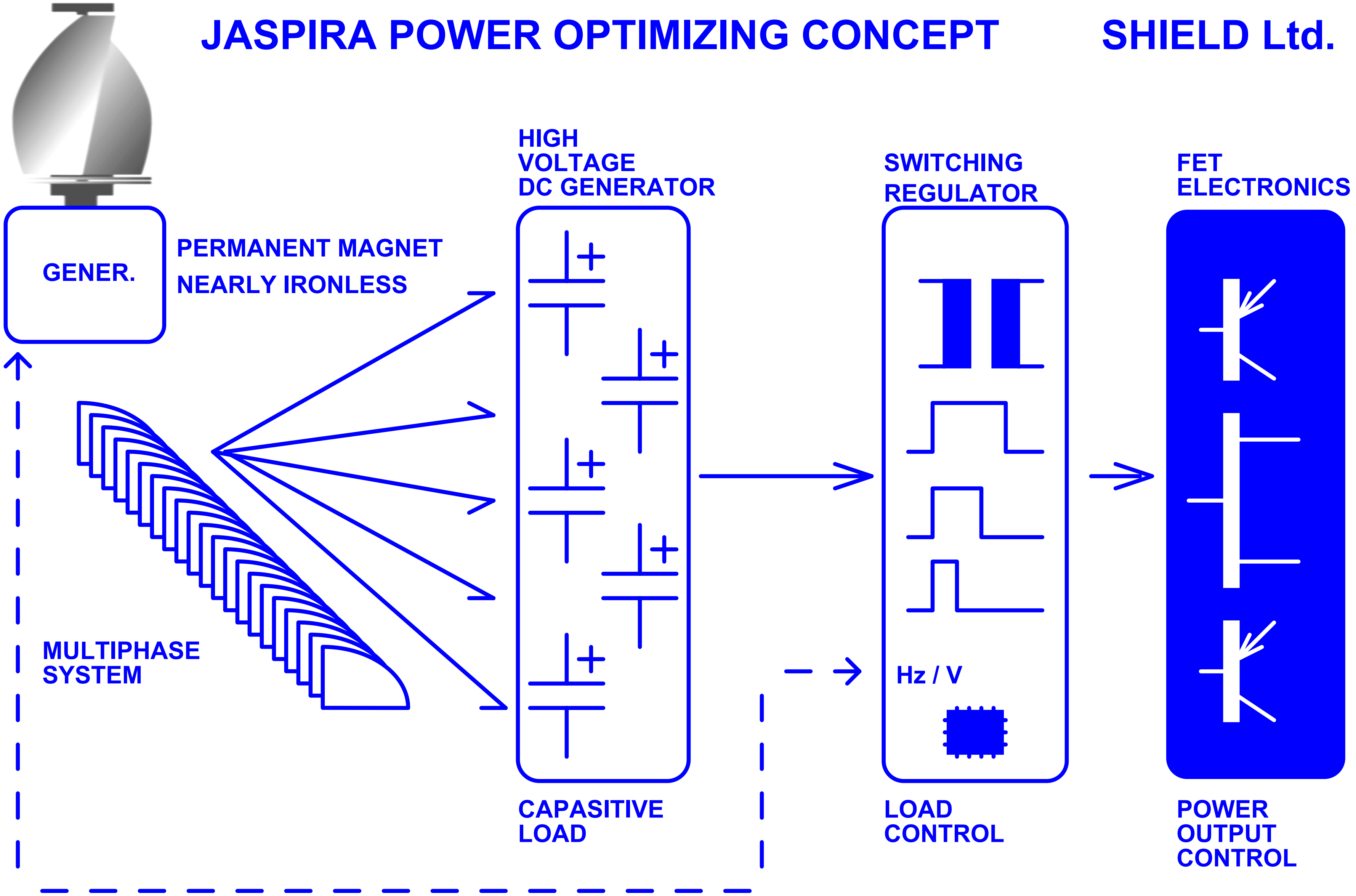


JASPIRA
VERTICAL WIND TURBINES



JASPIRA POWER OPTIMIZING CONCEPT

SHIELD Ltd.



GENER.

PERMANENT MAGNET
NEARLY IRONLESS

MULTIPHASE
SYSTEM

HIGH
VOLTAGE
DC GENERATOR

CAPASITIVE
LOAD

SWITCHING
REGULATOR

Hz / V

LOAD
CONTROL

FET
ELECTRONICS

POWER
OUTPUT
CONTROL

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ^{6} :
F03D 3/06

A1

(11) International Publication Number: **WO 99/04164**

(43) International Publication Date: 28 January 1999 (28.01.99)

(21) International Application Number: PCT/FI98/00386

(22) International Filing Date: 6 May 1998 (06.05.98)

(30) Priority Data:
972806 30 June 1997 (30.06.97) FI

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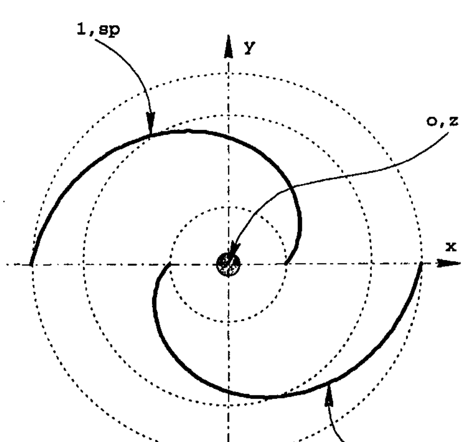
(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: JAAKKOLA, Reijo [FI/FI]; Huhdintie 6, FIN–16800 Hämeenkoski (FI).

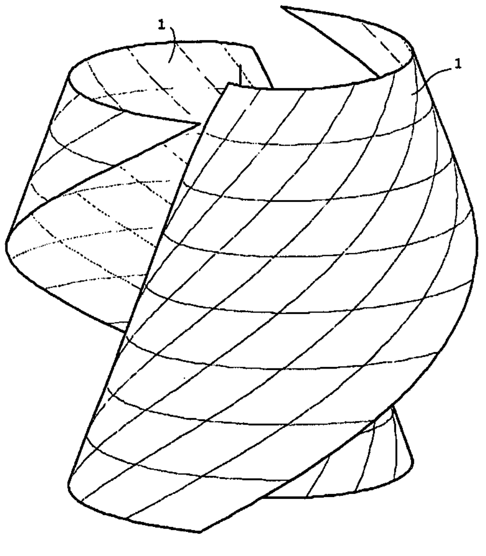
(74) Agent: KANGASMÄKI, Reijo; Finnish Patent Consulting FPC, Hermiankatu 14, FIN–33720 Tampere (FI).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
In English translation (filed in Finnish).

(54) Title: HELICAL WIND ROTOR AND A METHOD FOR MANUFACTURING THE SAME





(57) Abstract

Helical wind rotor, comprising at least two blades (1) which, as observed in cross section, are of substantially equivalent shape and curve, and are located parallel with the rotational axis (o) and so that the blades (1) are arranged most suitably at equal intervals with respect to the rotation angle of a cylindrical co–ordinate system (o, z). In order to bring about helical form of the wind rotor, the blade cross sections (sp) are arranged to revolve in the longitudinal direction (z) of the wind rotor. The blade cross section (sp) belonging to the wind rotor is arranged substantially different from the shape of semicircle, so as to enable manufacturing of the blade of a substantially planar blank. The invention also relates to a method for manufacturing a wind rotor of the above presented type.

Helical wind rotor and a method for manufacturing the same

The invention concerns a helical wind rotor, comprising at least two blades which, as observed in cross section, are of substantially equivalent shape and curved, and are located parallel with the rotational axis and so that the blades are arranged most suitably at equal intervals with respect to the rotation angle of a cylindrical co-ordinate system. In order to bring about helical form of the wind rotor, the blade cross sections are arranged to revolve in the longitudinal direction of the wind rotor.

A conventional rotor of the above presented type, the so called Savonius-rotor, patented e.g. in Finland with number 65940, consists of two blades of the shape of semicircular cylinder, which are located symmetrically with respect to the rotational axis. The cross section of this kind of rotor remains constant along the longitudinal direction and furthermore, the top and bottom edges are provided with cap plates.

In order to further develop the above mentioned rotor, a further reshaped wind rotor is presented in the Finnish patent number 67919. In this so called Windside rotor, the cap plates are removed and a helical form is added, so as to eliminate the so called dead positions in the rotor. In this wind rotor the xy-plane cross section revolves evenly around the wind rotor vertical axis while moving in the longitudinal direction of the wind rotor. The rotor design in question comprises a chassis and two oblong blades with a curved cross section, and which are arranged in the axial direction around the geometrical axis symmetrically, so that the concave blade sides partially overlap each other, leaving an axial gap between the blade inner edges. In addition, the blades are twisted in a helical manner relative to each other. The rotor shaft which is a part of the rotor structure is parallel to the geometrical axis and connected at one end to the chassis. The rotor structure contains, transversally to the rotor shaft, rib-like adapters which connect the blade edges to each other, so as to reinforce the structure. The wind rotor adapters are adjusted successively in the longitudinal direction and additionally, they are domed in cross section, for example in the form of an aircraft wing profile. The concerned publication presents wind rotor applications where the torsion of blades is 180°.

The above depicted developed wind rotor is especially due to its helical shape distinctly more advantageous than the former comparable ones, because wind from almost any direction causes wind rotor movement. A vital problem related to this type of wind rotor is, nevertheless, the difficulty of its manufacturing which necessitates always making a full wind rotor length mould, because the blades cannot be manufactured by forming of planar sheet blanks. Therefore also the manufacturing costs of the wind rotor type in question are very high, because the manufacturing requires firstly very accurate dimensioning and secondly also high professional skill, in order to arrive at the desired result. Another problem associated with this solution is also that when wind rotors are manufactured with slightly variant dimensioning, entirely individual moulds must be separately dimensioned and manufactured for each.

The helical wind rotor according to this invention is intended to bring about a decisive improvement in the problems described above and thus to essentially enhance the level of technology in this field. To achieve this aim, the wind rotor according to the invention is mainly characterised by that the cross section of the blade belonging to the wind rotor is arranged substantially different from the shape of semicircle, so as to enable manufacturing of the blade of a substantially planar blank.

The most important advantage of the wind rotor according to the invention is facilitating its manufacturing, because it is not necessary to make a concrete full wind rotor length mould, but the desired wind rotor shape can be created even very easily, depending on raw material, for example by mangling planar blade blanks or by bending to the correct shape blade blanks made of elastic material. Using for example thin metal sheets or polymer sheets, the blade may be supported to correct position at only top and bottom edges with for instance a tubular chassis, and the rigid shaft structure keeps the correct height and the rest of the blade settles to correct shape. Accordingly, the blade may also be supported along the helix curves of the inner and outer edges. The manufacturing costs of a wind rotor according to the invention are therefore particularly inexpensive, and also manufacturing of wind rotors of slightly variant dimensioning is easily and accurately feasible, owing to the computational shape definition for the planar blade blanks.

Advantageous embodiments of the wind rotor according to the invention are presented in the related independent claims.

The invention relates also to a method for manufacturing a wind rotor, which is defined in more detail in the introduction part of the independent claim related to it. The primary characteristics of the method are presented in the characterising part of the corresponding claim.

The most important advantages of the method according to the invention are its technical simplicity and clarity

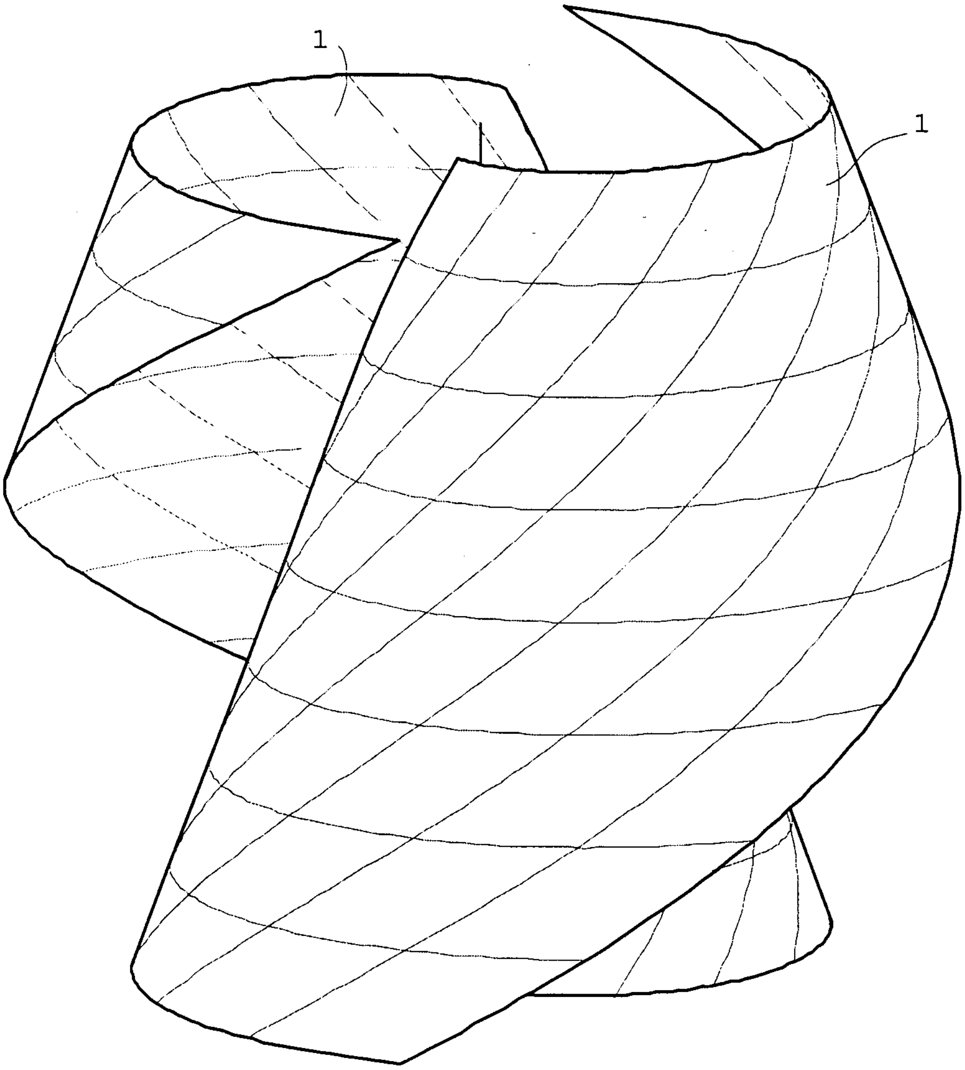
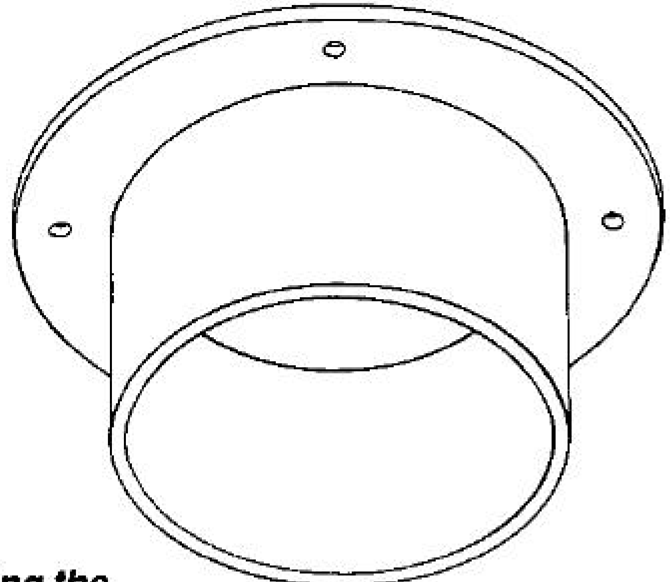


Fig. 7

FLETTNER VENTILATOR



Introducing the

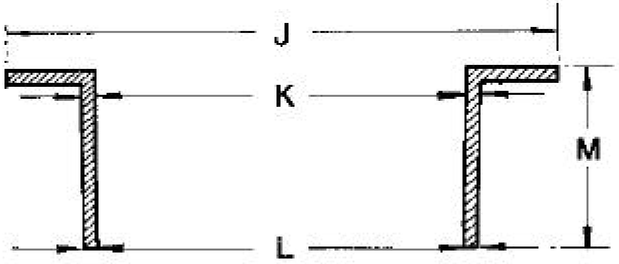
FLETTNER ADAPTOR

The FLETTNER Adaptor made of ABS plastic consists of a 50 mm tube with a flange matching the base of the '2000' Ventilator.

You may find it useful for:

1 Connecting the '2000' Ventilator to 110 mm vent ducting. A slight taper allows for ducting tolerances. Please check measurements against dimensions shown below.

2 Fitting the '2000' Ventilator on to double-skinned roofs. A single adaptor, or two cut down to the same length (because of taper) and joined end-to-end, may be used to bridge the roof space. Ventilator, adaptor(s) and shutter can be clamped together with a four bolt fixing.



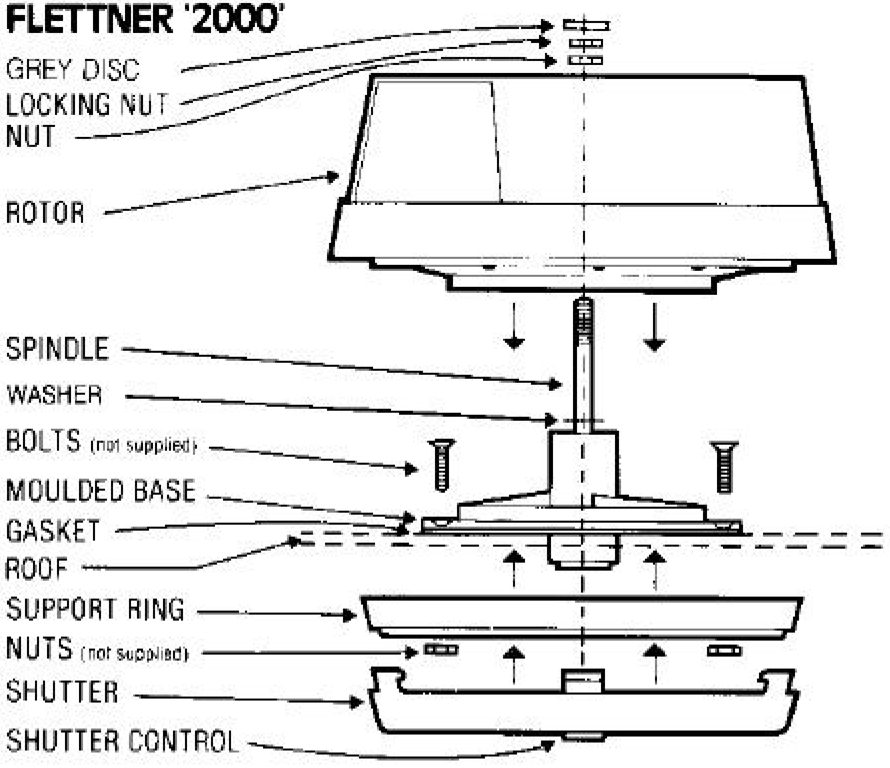
DIMENSION	mm	inches
J	145.0	5.70
K (int. diam.)	98.0	3.86
,, (ext. diam.)	105.5	4.15
L (int. diam.)	96.0	3.78
,, (ext. diam.)	103.5	4.07
M	50.0	1.97

FLETTNER VENTILATOR LIMITED · 2 BASING HILL · LONDON NW11 8TH · U.K.

Telephone: 0181-455 7469, 0181-209 0986. Fax: 0181-209 1539

ASSEMBLY INSTRUCTIONS

FLETTNER '2000'



1. **PRISE OUT GREY DISC FROM ROTOR.**
2. **REMOVE LOCK NUT WITH A SOCKET OR BOX SPANNER.**
3. **HOLD ROTOR AND UNSCREW SPINDLE FROM SECOND NUT WITH SCREWDRIVER INSERTED IN SLOT. SEPARATE ROTOR FROM SPINDLE.**
4. **MAKE 3¾" (96mm) DIA. HOLE IN ROOF**
5. **USE MOULDED BASE AS TEMPLATE, MARK POSITION OF HOLES AND DRILL FOUR CLEARANCE HOLES.**
6. **ASSEMBLE MOULDED BASE, GASKET AND SUPPORT RING (IF USING SHUTTER UNIT) TOGETHER WITH NUTS AND BOLTS. CLIP SHUTTER TO SUPPORT RING.**
7. **WHERE ROOF IS DOUBLE SKINNED, ADAPTOR (OPTIONAL ACCESSORY) OR A COLLAR CAN BE USED IF NECESSARY TO BRIDGE ROOF CAVITY BETWEEN VENTILATOR AND SUPPORT RING.**
8. **REPLACE ROTOR AND SECURE WITH BOTH NUTS. REPLACE GREY DISC.**

NOTE: TO FACILITATE DISASSEMBLY, THE LOCK NUT HAS NOT BEEN TIGHTENED DOWN FULLY. HOWEVER, IT MUST BE COMPLETELY TIGHT ON FITTED UNIT.

If decoration of polypropylene rotor is desirable information on suitable primers and paints is obtainable from: ICI Autocolor Ltd, Needham Road, Stowmarket, Suffolk, IP14 2AD – Tel: 01449 771771 (Primer B P5720212 Top Coat 2K + colour); Brown Brothers, Swindon – Tel: 01793 513315. Outside UK, contact local paint stockist for information.

FLETTNER VENTILATOR

FLETTNER VENTILATOR LIMITED · 2 BASING HILL · LONDON NW11 8TH

HOW TO BUILD A SAVONIUS ROTOR

Väderkvarner: Anne & Scott MacGregor. DK. 1984. 91-510-4205-3.

Material required:
A: 400 x 400 mm. thick cardboard for base plate.
B: Sheet of medium-thick cardboard - at least 450 x 300 mm.
C: Sheet of thin cardboard - at least 600 x 450 mm.
D: Two cotton-reels - 32 mm. in diameter.
E: One round pencil or a 7 mm. round wooden dowel or pin. These are cut into two lengths of 60 mm. each.

Tools required: Sissors, hobby or modelling knife, compass, ruler, pencil, ballpoint pen, carbon or tracing paper, paper-clips, staples, glue, etc.

1: Trace or copy the rotor end caps onto a sheet of medium thick cardboard and cut out **2** pieces. Cut **4** slits in each end cap, as illustrated.

2: Trace or copy the rotor blade pattern onto a sheet of thin cardboard and cut out. Carefully score along the striped lines with the back of a knife blade **-[with great caution]**, using a ruler for guidance, or with a sharp pointed pencil or pen, so that the rotor blade and the rotor blade end flaps may be easier to bend.

3: Insert **4** of the rotor blade flaps through the **4** slits in each of the two rotor end caps and glue down.

4: Bend and glue down the **2** end flaps over the outer rim of each of the two rotor end caps.

5: A sharp round pencil or short round sharp wooden dowel or pin is inserted in a cotton-reel and fixed tight by gluing. Another round pencil or wooden pin is inserted in the second cotton-reel and likewise glued fast.

6: Glue both cotton-reels on each of the two rotor end caps. Ensure that both cotton-reels are placed firmly in the exact center.

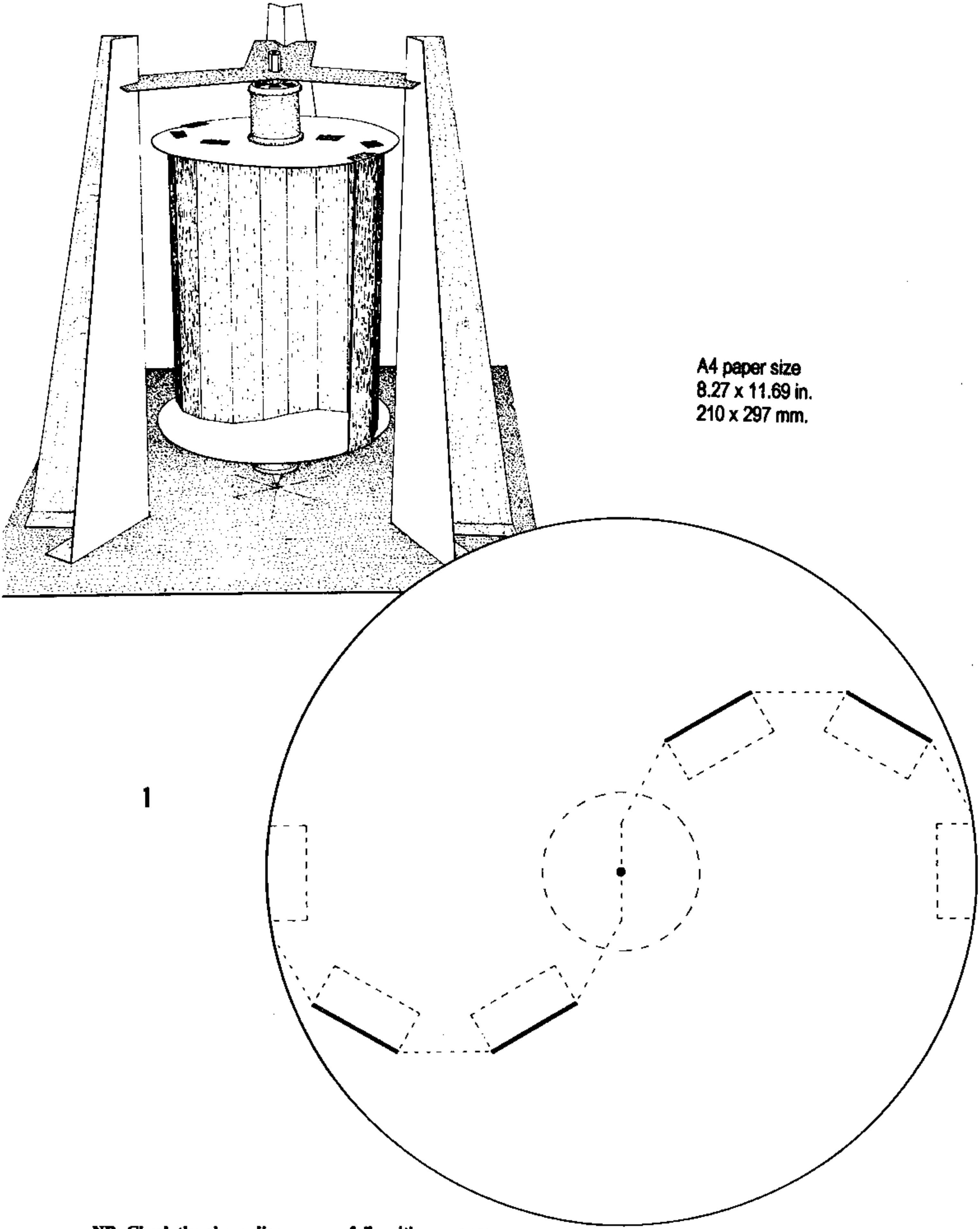
7: Trace or copy the pattern for the **3** tower legs on a sheet of thin cardboard and cut out. Bend the tower legs as shown.

8: Trace or copy the rotor support unit on a sheet of medium thick cardboard and cut out. Make a hole in the center, thereby allowing the pencil or wooden pin to rotate freely.

9: Place the rotor support unit on the base plate and mark out the tower leg positions. Mark out the center at point **A**.

10: Glue the tower legs onto the base plate.

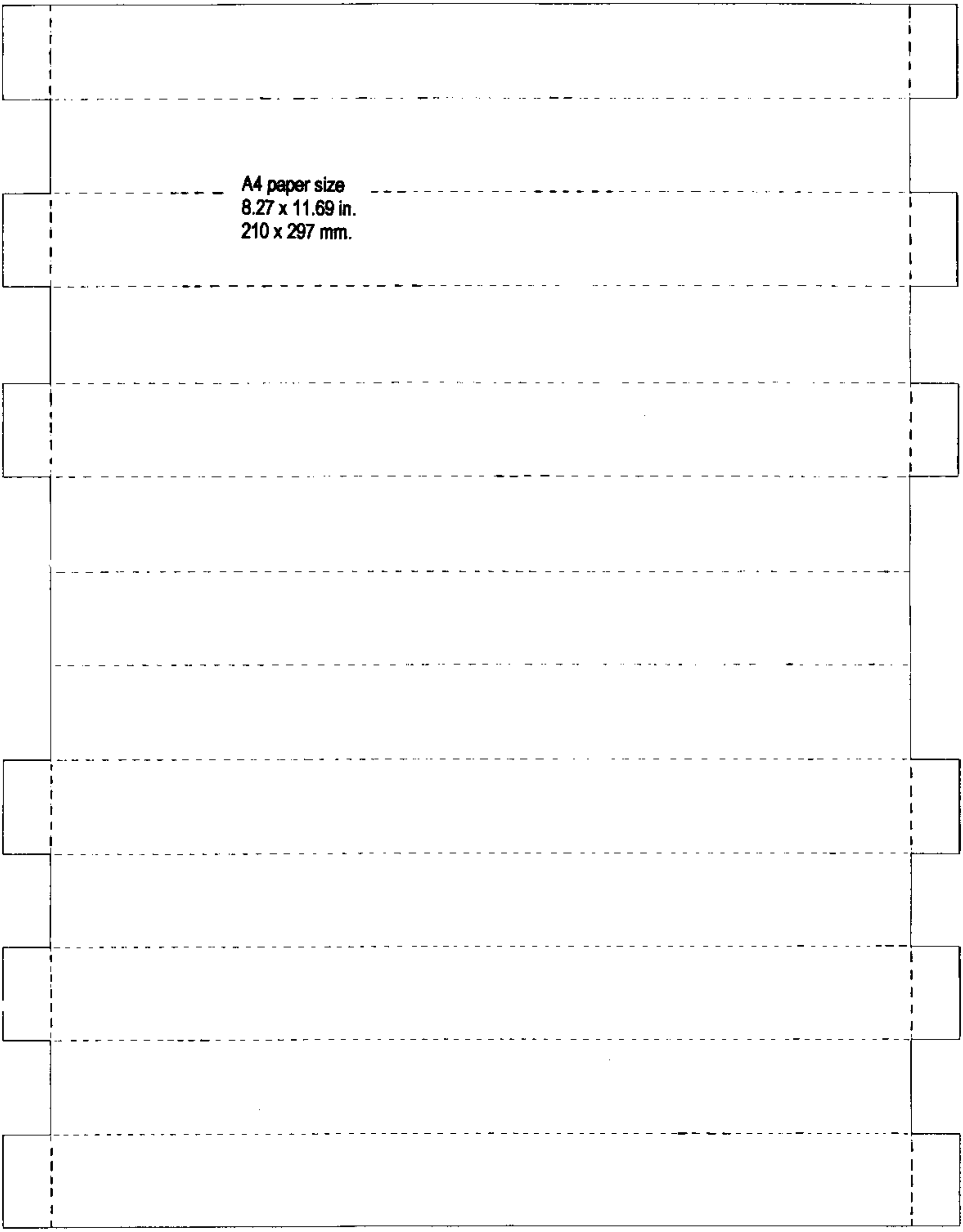
11: Place the assembled rotor between the 3 tower legs. Press the sharpened point down into the base plate at point **A**. Place the rotor support unit over the upper pencil or dowel or pin as shown in the first assembled-unit drawing.



A4 paper size
8.27 x 11.69 in.
210 x 297 mm.

1

**NB: Check the above diagram carefully with a compass.
Verify that the circle is true, - to avoid possible
error as a result of any copy or reproduction process.**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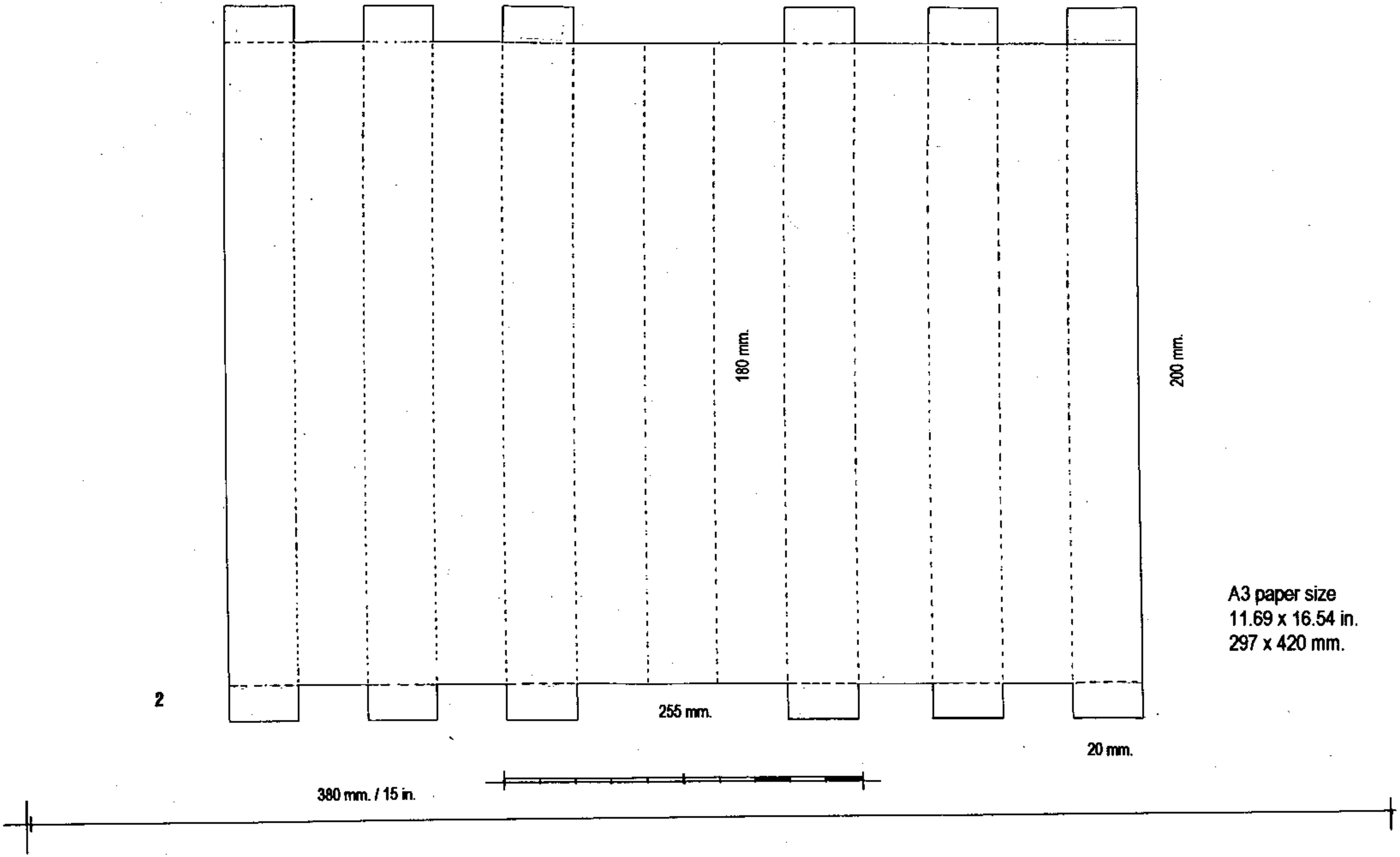
210 x 297 mm.

2



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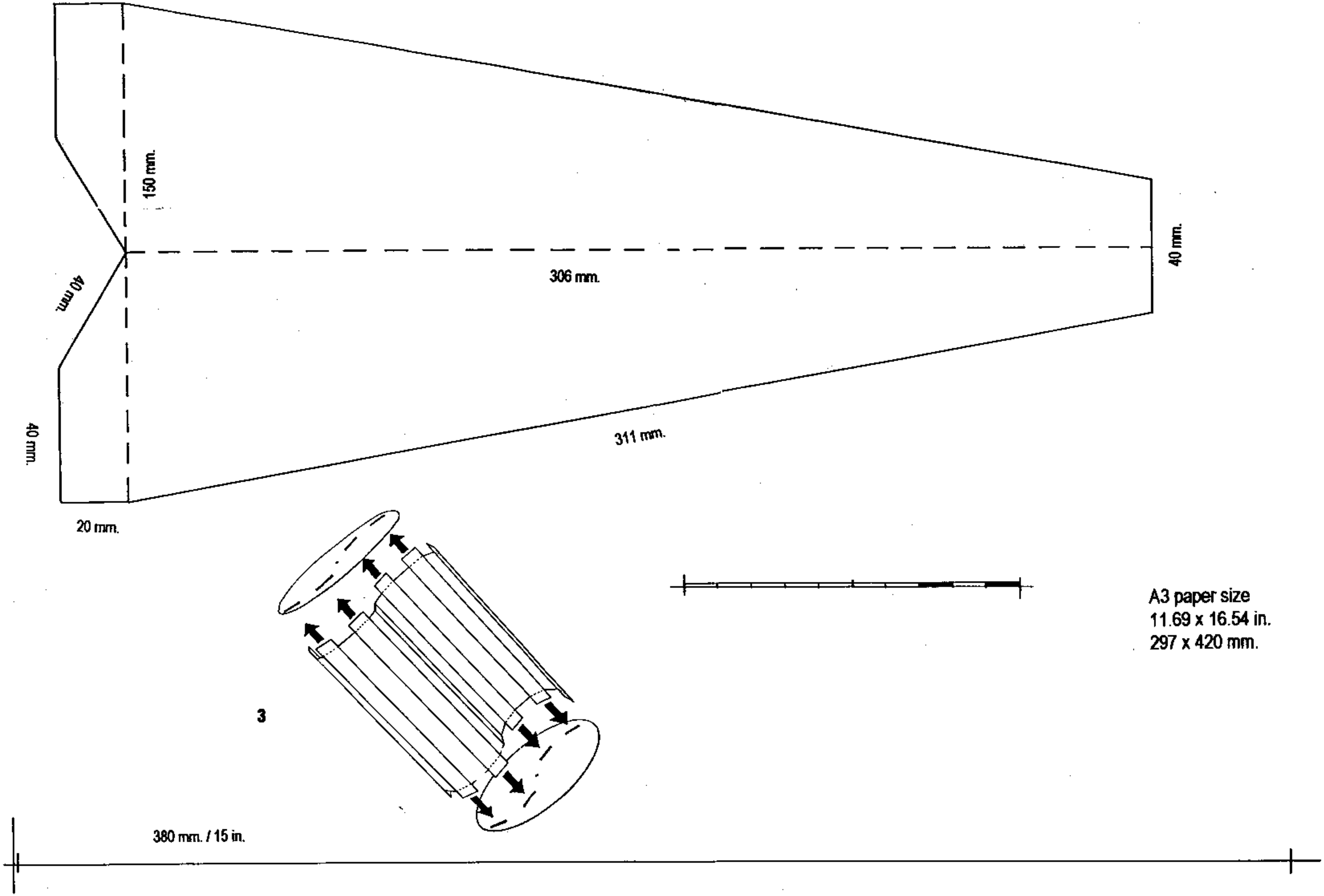
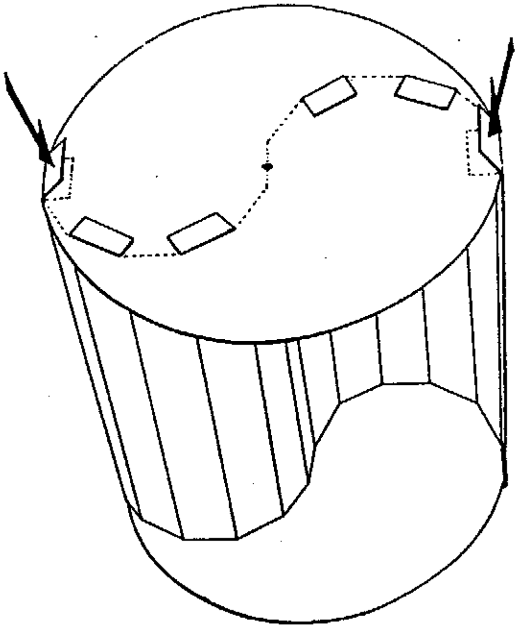
297 x 420 mm.



A3 paper size
11.69 x 16.54 in.
297 x 420 mm.



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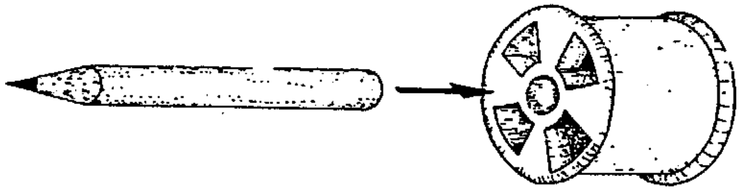

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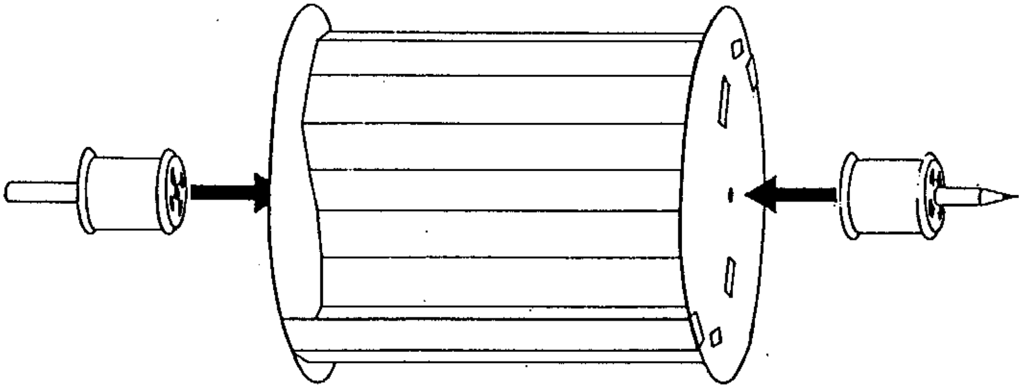

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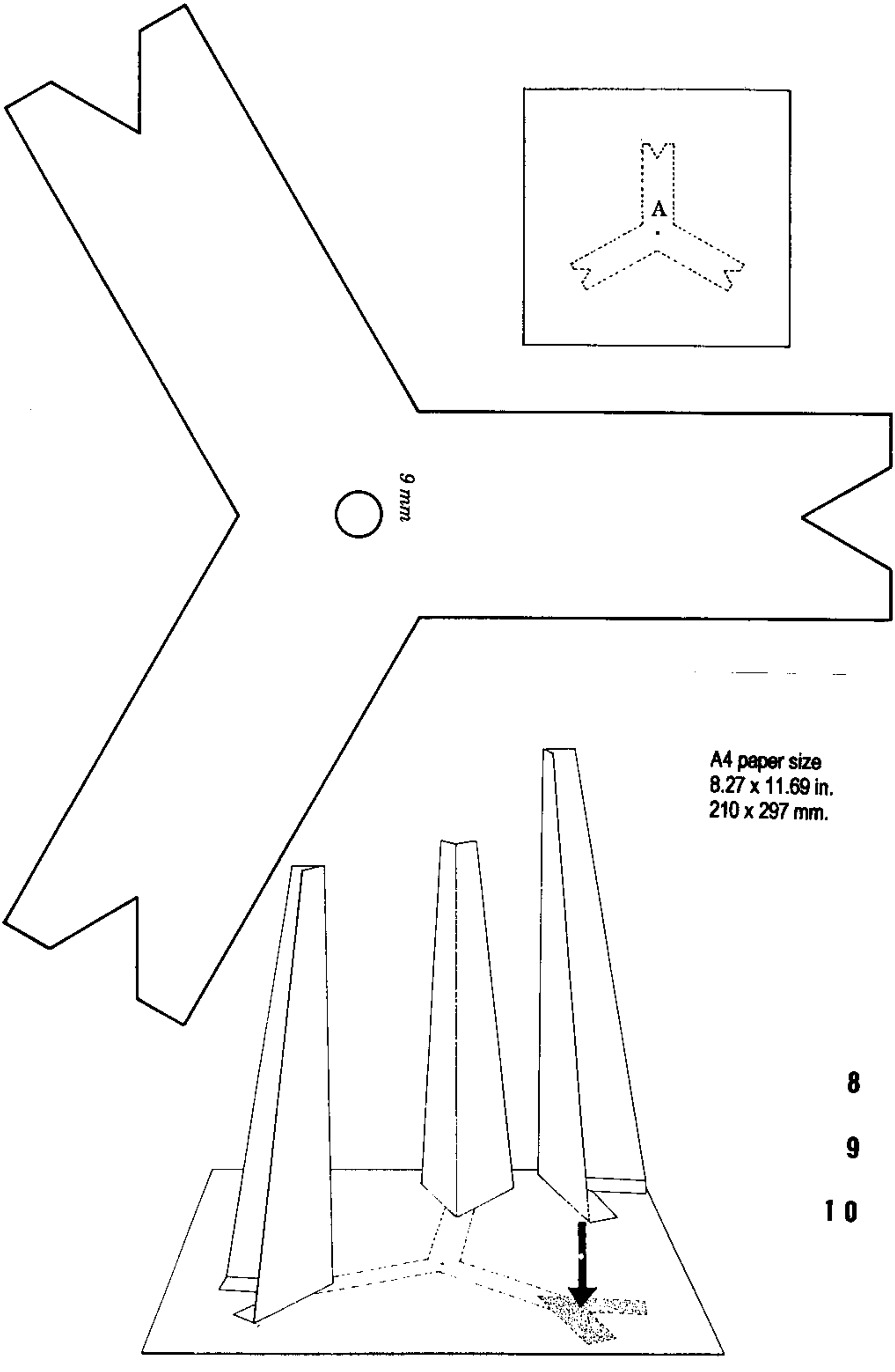

A4 paper size
8.27 x 11.69 in.
210 x 297 mm.

8

9

10

5. Bezugsquellen

Folgende Hersteller liefern Teile für Bau und Betrieb des Savonius-Rotors, sofern diese nicht über den örtlichen Fachhandel besorgt werden können. Hier werden nur Firmen aufgeführt, deren Produkte vom Verfasser erprobt wurden.

Rundholzverbinder für Turm aus Rundholzmasten

Fa. Rudolf Feicht, Post Falkenberg, 8331 Zell

Einstell-Gußflanschlager

INA-Walzlager Schaeffler KG, 8522 Herzogenaurach
SKF Kugellagerfabriken, 8720 Schweinfurt

Pumpen

Apollo-Pumpen, Friedrich Berger, Schwagenstr. 56, 8500 Nürnberg
KÖMAG, A. Köhler & Co, Am Bahnhof, 8228 Freilassing
Westfalia-Werkzeug-Co., 5800 Hagen/Westf. (Triplex-Pumpe)
Windkraftzentrale, Ing. H. Frees, Ellerüberweg, 2341 Brodersby bei Kappeln

Gleich- und Drehstromgeneratoren

Elektro Artmann, Marktstr. 33, 8304 Mallersdorf
Conrad Electronic, Klaus-Conrad-Str., 8452 Hirschau
A. Harbarth, Selbstbaubedarf f. Windkraft, Hechelner Str. 32, 7769 Mühlingen
Elektro-Lips, Tretzendorf 13, 8729 Oberaurach
Albin Siegl, Seligerstr. 1, 8832 Weissenburg
Windkraftzentrale, Ing. H. Frees, Ellerüberweg, 2341 Brodersby bei Kappeln

Schablonen für das Flügelprofil des Durchström-Rotors

Landtechnischer Verein in Bayern e.V., Vöttinger Str. 36, 8050 Freising

6. Literaturverzeichnis

(von den mit * gekennzeichneten Veröffentlichungen liegt dem Verfasser ein Exemplar vor, das gegebenenfalls gegen Erstattung der Papierkosten kopiert werden kann)

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J. Noe: *Mit Dauermagneten erregte Kleinstgeneratoren für Langsamläufer*. Diplomarbeit an der TU München (Maschinenbau-Fakultät) 1986 *

J. Finger: *Entwurf, Bau und Untersuchung einer neuartigen Windkraftanlage (Dreiflügeliger Durchströmrotor mit vertikaler Welle) anhand von Modellen und einer Großausführung*. Diplomarbeit an der TU München (Maschinenbau-Fakultät) 1983 *.

DATA SHEET #3

Bibliography/Sources/References

WIND

Alternate Sources of Energy magazine. Excellent sources, references, and communication for alternate energy systems. Subscription for $5/6 issues from Route 2, Box 90-A, Milica, Minnesota 56353. Get their back issues 1-10 in Book 1 for $4.00. Highly recommended.

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Electric Power from the Wind. Percy H. Thomas, Federal Power Commission, 1945. 72 pp. Not highly technical, general information, nice drawings.

Wind Energy Bibliography; Windworks, Box 329, Route 3, Mukwonago, Wisconsin 53149. $3.00. An excellent bibliography on wind, windmills, aerodynamics, electrical, towers, storage, conversion, hydrogen, catalogues. Sources and references.

How to Construct a Cheap (S-Rotor) Wind Machine for Pumping Water. 75¢ from Brace Research Institute (#L-5). 12 pp.

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Pulling Power out of Thin Air. Gary Soucle, Audubon Magazine, May 74, pp. 81-87. A whimsical, beautiful article on the prospects of developing wind power on a large scale in the U.S.

Simplified Wind Power Systems for Experimenters. Jack Park, 15237 Lakeside, Sylmar, Calif. 91342. A comprehensive, advanced but simplified book on aeroturbine design. and wind systems. Available for $8.00

Windmills in the Light of Modern Research. A. Betz, NACA, Tech. Memorandum #474, 29 pp. Extremely technical. Betz is the gentleman that formed the theoretical maximum (59.3%) of the wind's energy that could be extracted.

WIND MEASUREMENT

A Pendulum Anemometer. P. L. Clemens, Scientific American, Oct. 1961, pg. 108-110, in the Amateur Scientist section. This is a very neat, simple, and accurate method of calibrating (or checking the calibration of) a windspeed indicator.

Dwyer Windspeed Indicators. Couple of good models, inexpensive but better than most. A handheld windmeter with 0-10MPH and 0-70MPH is about $6 and a permanent mounting unit is $25. Dwyer Instrument, Inc., Michigan City, Indiana, 46360.

BATTERIES

The Storage Battery, Lead-Acid type. It's fundamental principles, operation, and care. Available for $1.00 from: Exide Power Systems Divisions, ESB, Inc., Philadelphia, Pa., 19120. A must if you use lead-acid batteries. Excellent.

The Storage Battery, Nickel-Cadmium. It's fundamental principles, operation, and care. Available for $1.00 from Exide (see address above). A must if you use Nicads.

Storage Batteries. G.W. Vinal, John Wiley and Sons, N.Y., 1955. 385 pages. Good but out-of-print and rare.

Battery Council International. Write to these folks for battery information, ratings, sizes, etc. BCI, 1801 Murchison Dr., Burlingame, California, 94010.

Edelmann 40-B, Temperature Compensating Hydrometer. About $5. Can be purchased or ordered through an Auto Parts store.

ELECTRONICS

Burstein-Applebee, 3199 Mercier, Kansas City, Missouri, 64111. Excellent Source of electronic parts at reasonable prices. Write and get their catalogue.

Surplus Center, 1000 West "O" Street, P.O. Box 82209, Lincoln, Nebraska, 68501. Another very good source of electronic equipment and rotatry inverters. Write and obtain their catalogue.

Heathkit/ Schlumberger Products Corp., P.O. Box 167, St. Joseph, Michigan, 49085. Kits only,but write for their catalogue.

GENERATORS

Autopower. S.W. Duncan, 1937. Rewinding generators, motors, etc. Excellent reference for such skills but out of print and very rare.

Auto Engines and Electrical Systems. Blanchard and Ritchen, 1970, pg. 407-674

GENERAL

Marks Handbook. McGraw/Hill Book Co., excellent source of information on just about everything technical or related to mechanical engineering-type stuff. Pretty expensive but worth a library of other books in related material.

The Way Things Work. Simon and Schuster, Publishers and Editors, Volume 1 & 2, 1967, 590 pages each. Very nice.

The Mother Earth News (Magazine) Down to Earth type stuff; chuck full of all kinds of info. Subscribe or obtain info from them at: P.O. Box 70, Hendersonville, N.C., 28739.

Shelter, Shelter publications. Available for $7.00 from: Mountain Books, P.O. Box 4811, Santa Barbara, Calif., 93103. Much information, many alternatives.

Domebook 2. Shelter Publications. Available for $4.50 from: Box 279, Bolinas, California, 94924. Also much information and many alternatives.

"Turbine having its rotating shaft transverse to the flow of the current"
G.J.M.Darrieus
United States Patent No 1.835.018, December 8, 1931

"Preliminary tests of a high speed vertical axis windmill model"
P.South and R.S.Rangi
NRC LTR-LA-74, marts 1971

"A wind tunnel investigation of a 14 ft. diameter vertical axis windmill"
P.South and R.S.Rangi
NRC LTR-LA-105, september 1972

"Aerodynamic performance theory for the NRC vertical-axis wind turbine"
R.J.Templin
NRC LTR-LA-160, juni 1974

"Measurements on the Magdalen Island V.A.W.T. and future projects"
R.J.Templin og R.S.Rangi
NRCC TM-WE-006, 6 oktober 1981

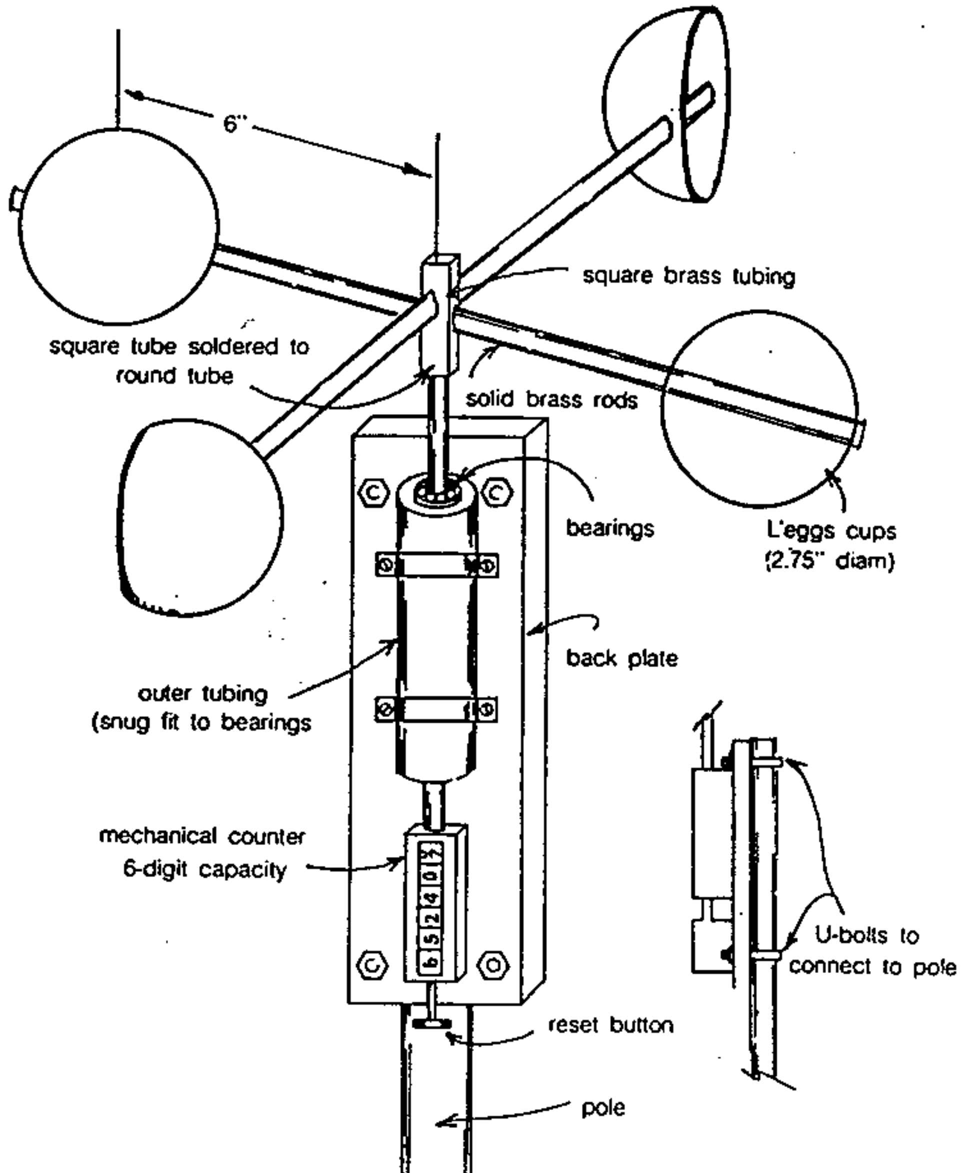
"Design, performance and economics of the DAF-Indal 50 kW and 500 kW vertical asxis wind turbines"
L.A. Schienbein and D.J.Malcolm DAF-Indal
ASME Conference, New Orleans, March 1982.

"Flowind model 170 Wind Turbine. April 1983.
Flowind corporation
21414-68th Avenue South Kent, Washington 98032.

"Forecast Vertical Axis Wind Turbines"
P.N. Vosburgh and F.M Wuerz
Forecast Industries, Inc.
3500 A Indian School Rd NE
Albuquerque, NM 87106.

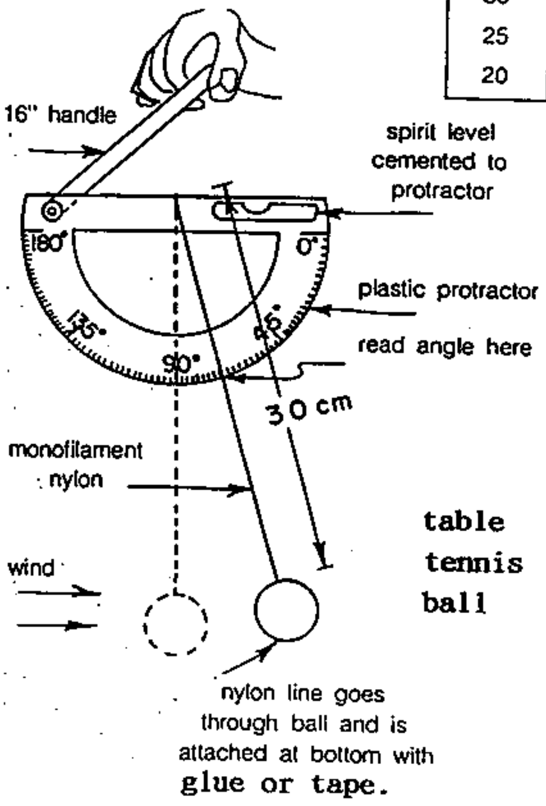
Wind Energy Report August 12, 1983 side 115-117.

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

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 *
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 %].

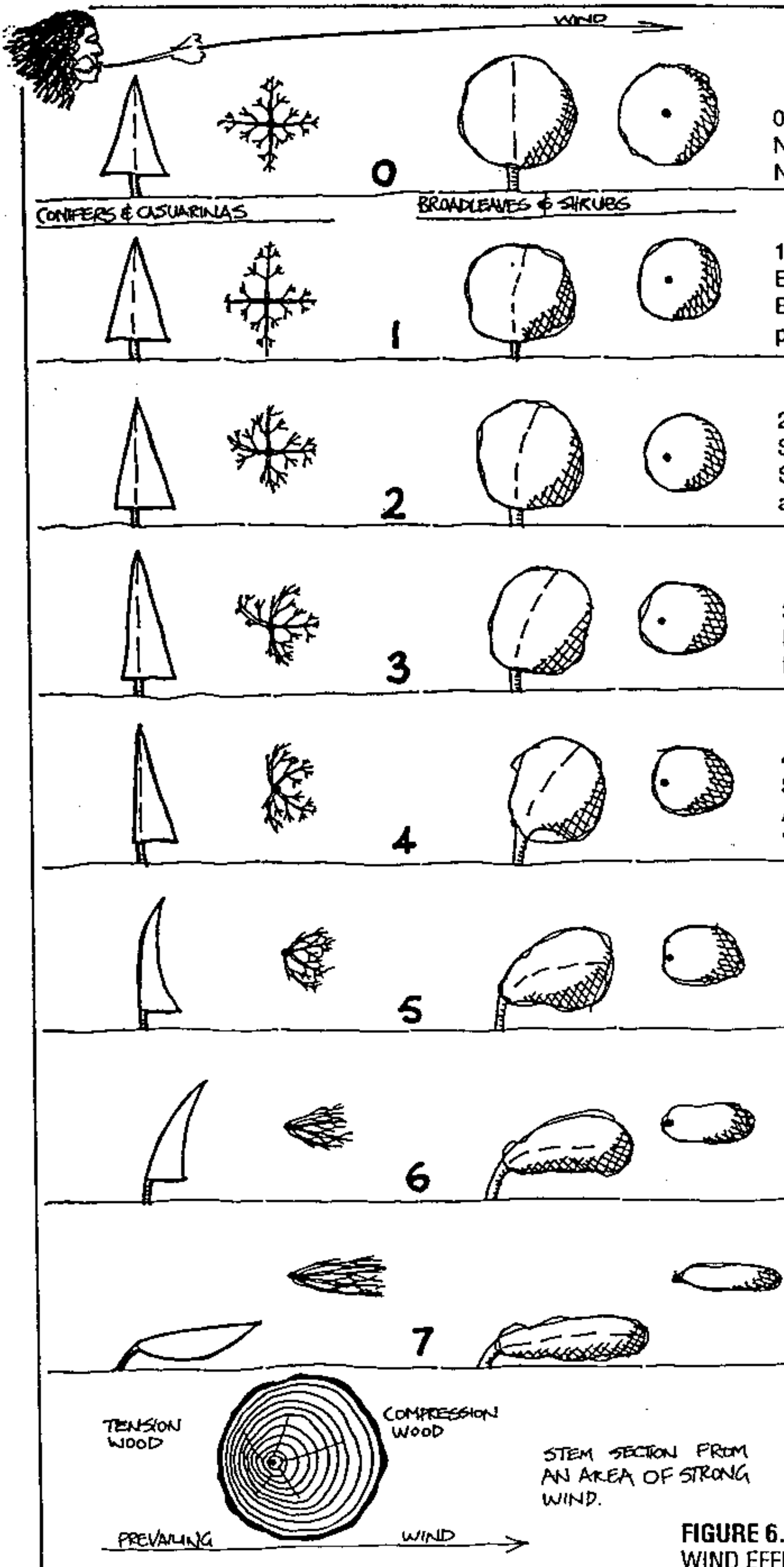
APPROXIMATE WIND SPEED ENERGY EFFECTS:

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:	Remaining velocity in % :
30 m.	60 - 80 %
60 m.	50 %
120 m.	15 %
300 - 1,500 m.	Negligible wind.

GRIGGS AND PUTNAM INDEX



0
NO EFFECT
No deformations of branches

1
BRUSHING
Branches or needles bent away from prevailing winds. Crown slightly deformed.

2
SLIGHT FLAGGING
Small branches bent. Tree markedly asymmetric.

3
MODERATE FLAGGING
Larger branches bent away from the wind.

4
STRONG FLAGGING
All branches swept to leeward. Tree a "banner".

5
PARTIAL THROW
Trunk bent to leeward but vertical near ground.

6
COMPLETE THROW
Trunk now quite bent to leeward.

7
CARPETING
Tree a creeping shrub–like layer of prostrate growth.

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.

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	pi = 3.14 (geometrical constant)
Density of air	rho	kg/m^3	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*Pi/4*V^3))^0.5
Power	P	watts	P = Cp*rho/2*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 x π x D/60/V
Shaft speed	rpm	rpm	rpm = 60 x V x tsr/(π x D)
Blade Design			
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
(NOTE:'ATAN( )' is a software function giving 'the angle whose tangent is' in radians.)			
Chord width	Cw	m	Cw = 1.4*D^2/Rs*COS(beta/57.3)^2/tsr^2/B/Cl
Tail Vane side force			
Area of vane	Avane	m^2	Avane > D^2/40
Side force	Fside	kg	Fside = Avane*V^2/16
Rotor thrust	Frotor	kg	Frotor = D^2*V^2/24
Copper loss in wires/cables			
Copper diam.	Wdiam	mm	Wdiam = diameter of wire
Copper area	Warea	mm^2	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
(NOTE: Resistance is at copper temp. = 40 deg.C, increasing by factor of.004/degC.)			
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**
Alternators			
No. of poles	Np	even no	Np = 120*f/rpm
Frequency	f	Hz	f = Np*rpm/120
Length of airgap	Lgap	m	length parallel to axis
Diam. of airgap	Dgap	m	Dgap = radius from shaft axis*2
Area of air gap	Agap	m^2	Agap = Lgap*Pi*Dgap
Cut-in speed	Crpm	rpm	Crpm = 12 volt cut-in speed
No. of coils		Ncoils	Ncoils = no. of coils in series
Turns/coil		Nturns	Nturns = 1200/Agap/Crpm/Ncoils

(Note this is only approximate. Increase by 50% for very large airgaps

Variables:

A	Cross-sectional area of copper wire in cable (in square millimetres)
AP	Average power (watts)
AV	Average windspeed (m/s)
CP	Power coefficient (measure of efficiency - cannot exceed 0.6 and should exceed 0.1)
D	Rotor diameter (metres)
DP	Power loss (watts)
DV	Volt drop (volts)
E	Energy (kWh)
I	Electric current (amps)
L	Length of a twin copper cable one way (metres)
P	Power (watts)
P (VW)	Power output of wind turbine at windspeed VW (watts)
RPM	Rotational speed (rpm)
T	Time (hours)
V	System voltage (volts)
VT	Tip speed (m/s)
VW	Windspeed (m/s)
x	multiplication symbol
/	divide by what follows

Cables:

Volt drop DV = L x I/(30 x A) Where I=P/V
Power loss DP = DV x I=L x I^2/(30 x A)

Energy: E = P x T/1000 = V x I x T/1000
= V x amp-hours/1000

Tip speed: VT = RPM x D/19.1

Power coeff. CP = P/(0.48 x D^2 x VW^3)

Algorithm for finding average power:

```
For VW = 1 to 20
AP = AP+1.57 x (VW/AV²) x EXP (-0.79 x (VW/AV)²) x 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

Use of the tables: the number to be converted, which is made up by adding the unit at the side of a line to the unit at the head of a column, is converted to the number in the position where line and column meet.
For example, 11 in = 10 in + 1 in = 279.400 mm

Inches to Millimetres 1 in = 25.4 mm

Note. This table can also be used for converting milli-inches (mils or 'thou') to micrometres ('microns')

in →	0	1	2	3	4	5	6	7	8	9 ←	in
↓	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	0
10	254.000	279.400	304.800	330.200	355.600	381.000	406.400	431.800	457.200	482.600	10
20	508.000	533.400	558.800	584.200	609.600	635.000	660.400	685.800	711.200	736.600	20
30	762.000	787.400	812.800	838.200	863.600	889.000	914.400	939.800	965.200	990.600	30
40	1016.000	1041.400	1066.800	1092.200	1117.600	1143.000	1168.400	1193.800	1219.200	1244.600	40
50	1270.000	1295.400	1320.800	1346.200	1371.600	1397.000	1422.400	1447.800	1473.200	1498.600	50
60	1524.000	1549.400	1574.800	1600.200	1625.600	1651.000	1676.400	1701.800	1727.200	1752.600	60
70	1778.000	1803.400	1828.800	1854.200	1879.600	1905.000	1930.400	1955.800	1981.200	2006.600	70
80	2032.000	2057.400	2082.800	2108.200	2133.600	2159.000	2184.400	2209.800	2235.200	2260.600	80
90	2286.000	2311.400	2336.800	2362.200	2387.600	2413.000	2438.400	2463.800	2489.200	2514.600	90
100	2540.000										100

in →	0	10	20	30	40	50	60	70	80	90 ←	in
↓	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	↓
0	0.000	254.000	508.000	762.000	1016.000	1270.000	1524.000	1778.000	2032.000	2286.000	0
100	2540.000	2794.000	3048.000	3302.000	3556.000	3810.000	4064.000	4318.000	4572.000	4826.000	100
200	5080.000	5334.000	5588.000	5842.000	6096.000	6350.000	6604.000	6858.000	7112.000	7366.000	200
300	7620.000	7874.000	8128.000	8382.000	8636.000	8890.000	9144.000	9398.000	9652.000	9906.000	300
400	10160.000	10414.000	10668.000	10922.000	11176.000	11430.000	11684.000	11938.000	12192.000	12446.000	400
500	12700.000	12954.000	13208.000	13462.000	13716.000	13970.000	14224.000	14478.000	14732.000	14986.000	500
600	15240.000	15494.000	15748.000	16002.000	16256.000	16510.000	16764.000	17018.000	17272.000	17526.000	600
700	17780.000	18034.000	18288.000	18542.000	18796.000	19050.000	19304.000	19558.000	19812.000	20066.000	700
800	20320.000	20574.000	20828.000	21082.000	21336.000	21590.000	21844.000	22098.000	22352.000	22606.000	800
900	22860.000	23114.000	23368.000	23622.000	23876.000	24130.000	24384.000	24638.000	24892.000	25146.000	900
1000	25400.000										1000

Millimetres to Inches 1 mm = 0.039 370 in

Note. This table can also be used for converting micrometres ('microns') to milli-inches (mils or 'thou')

mm →	0	1	2	3	4	5	6	7	8	9 ←	mm
↓	in	in	in	in	in	in	in	in	in	in	↓
0	0.000	0.039	0.079	0.118	0.157	0.197	0.236	0.276	0.315	0.354	0
10	0.394	0.433	0.472	0.512	0.551	0.591	0.630	0.669	0.709	0.748	10
20	0.787	0.827	0.866	0.906	0.945	0.984	1.024	1.063	1.102	1.142	20
30	1.181	1.220	1.260	1.299	1.339	1.378	1.417	1.457	1.496	1.535	30
40	1.575	1.614	1.654	1.693	1.732	1.772	1.811	1.850	1.890	1.929	40
50	1.969	2.008	2.047	2.087	2.126	2.165	2.205	2.244	2.283	2.323	50
60	2.362	2.402	2.441	2.480	2.520	2.559	2.598	2.638	2.677	2.717	60
70	2.756	2.795	2.835	2.874	2.913	2.953	2.992	3.031	3.071	3.110	70
80	3.150	3.189	3.228	3.268	3.307	3.346	3.386	3.425	3.465	3.504	80
90	3.543	3.583	3.622	3.661	3.701	3.740	3.780	3.819	3.858	3.898	90
100	3.937										100

mm →	0	10	20	30	40	50	60	70	80	90 ←	mm
↓	in	in	in	in	in	in	in	in	in	in	↓
0	0.000	0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543	0
100	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.693	7.087	7.480	100
200	7.874	8.268	8.661	9.055	9.449	9.843	10.236	10.630	11.024	11.417	200
300	11.811	12.205	12.598	12.992	13.386	13.780	14.173	14.567	14.961	15.354	300
400	15.748	16.142	16.535	16.929	17.323	17.717	18.110	18.504	18.898	19.291	400
500	19.685	20.079	20.472	20.866	21.260	21.654	22.047	22.441	22.835	23 228	500
600	23.622	24.016	24.409	24.803	25.197	25.591	25.984	26.378	26.772	27.165	600
700	27.559	27.953	28.346	28.740	29.134	29.528	29.921	30.315	30.709	31.102	700
800	31.496	31.890	32.283	32.677	33.071	33.465	33.858	34.252	34.646	35.039	800
900	35.433	35.827	36.220	36.614	37.008	37.402	37.795	38.189	38.583	38.976	900
1000	39.370										1000

Use of the tables: the number to be converted, which is made up by adding the unit at the side of a line to the unit at the head of a column, is converted to the number in the position where line and column meet. For example, 11 in = 10 in + 1 in = 27.940 cm

Inches to Centimetres

1 in = 2.54 cm

in →	0	1	2	3	4	5	6	7	8	9	← in
↓	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	↓
0	0.000	2.540	5.080	7.620	10.160	12.700	15.240	17.780	20.320	22.860	0
10	25.400	27.940	30.480	33.020	35.560	38.100	40.640	43.180	45.720	48.260	10
20	50.800	53.340	55.880	58.420	60.960	63.500	66.040	68.580	71.120	73.660	20
30	76.200	78.740	81.280	83.820	86.360	88.900	91.440	93.980	96.520	99.060	30
40	101.600	104.140	106.680	109.220	111.760	114.300	116.840	119.380	121.920	124.460	40
50	127.000	129.540	132.080	134.620	137.160	139.700	142.240	144.780	147.320	149.860	50
60	152.400	154.940	157.480	160.020	162.560	165.100	167.640	170.180	172.720	175.260	60
70	177.800	180.340	182.880	185.420	187.960	190.500	193.040	195.580	198.120	200.660	70
80	203.200	205.740	208.280	210.820	213.360	215.900	218.440	220.980	223.520	226.060	80
90	228.600	231.140	233.680	236.220	238.760	241.300	243.840	246.380	248.920	251.460	90
100	254.000										100

in →	0	10	20	30	40	50	60	70	80	90	← in
↓	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	↓
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	0
100	254.000	279.400	304.800	330.200	355.600	381.000	406.400	431.800	457.200	482.600	100
200	508.000	533.400	558.800	584.200	609.600	635.000	660.400	685.800	711.200	736.600	200
300	762.000	787.400	812.800	838.200	863.600	889.000	914.400	939.800	965.200	990.600	300
400	1016.000	1041.400	1066.800	1092.200	1117.600	1143.000	1168.400	1193.800	1219.200	1244.600	400
500	1270.000	1295.400	1320.800	1346.200	1371.600	1397.000	1422.400	1447.800	1473.200	1498.600	500
600	1524.000	1549.400	1574.800	1600.200	1625.600	1651.000	1676.400	1701.800	1727.200	1752.600	600
700	1778.000	1803.400	1828.800	1854.200	1879.600	1905.000	1930.400	195 .800	1981.200	2006.600	700
800	2032.000	2057.400	2082.800	2108.200	2133.600	2159.000	2184.400	2209.800	2235.200	2260.600	800
900	2286.000	2311.400	2336.800	2362.200	2387.600	2413.000	2438.400	2463.800	2489.200	2514.600	900
1000	2540.000										1000

Centimetres to Inches

1 cm = 0.393 701 in

cm →	0	1	2	3	4	5	6	7	8	9	← cm
↓	in	in	in	in	in	in	in	in	in	in	↓
0	0.000	0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543	0
10	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.693	7.087	7.480	10
20	7.874	8.268	8.661	9.055	9.449	9.843	10.236	10.630	11.024	11.417	20
30	11.811	12.205	12.598	12.992	13.386	13.780	14.173	14.567	14.961	15.354	30
40	15.748	16.142	16.535	16.929	17.323	17.717	18.110	18.504	18.898	19.291	40
50	19.685	20.079	20.472	20.866	21.260	21.654	22.047	22.441	22.835	23.228	50
60	23.622	24.016	24.409	24.803	25.197	25.591	25.984	26.378	26.772	27.165	60
70	27.559	27.953	28.346	28.740	29.134	29.528	29.921	30.315	30.709	31.102	70
80	31.496	31.890	32.283	32.677	33.071	33.465	33.858	34.252	34.646	35.039	80
90	35.433	35.827	36.220	36.614	37.008	37.402	37.795	38.189	38.583	38.976	90
100	39.370										100

cm →	0	10	20	30	40	50	60	70	80	90	← cm
↓	in	in	in	in	in	in	in	in	in	in	↓
0	0.000	3.937	7.874	11.811	15.748	19.685	23.622	27.559	31.496	35.433	0
100	39.370	43.307	47.244	51.181	55.118	59.055	62.992	66.929	70.866	74.803	100
200	78.740	82.677	86.614	90.551	94.488	98.425	102.362	106.299	110.236	114.173	200
300	118.110	122.047	125.984	129.921	133.858	137.795	141.732	145.669	149.606	153.543	300
400	157.480	161.417	165.354	169.291	173.228	177.165	181.102	185.039	188.976	192.913	400
500	196.850	200.787	204.724	208.661	212.598	216.535	220.472	224.409	228.346	232.283	500
600	236.220	240.157	244.094	248.031	251.969	255.906	259.843	263.780	267.717	271.654	600
700	275.591	279.528	283.465	287.402	291.339	295.276	299.213	303.150	307.087	311.024	700
800	314.961	318.898	322.835	326.772	330.709	334.646	338.583	342.520	346.457	350.394	800
900	354.331	358.268	362.205	366.142	370.079	374.016	377.953	381.890	385.827	389.764	900
1000	393.701										1000

Fractions to Decimals

Fraction	Decimal equivalent	Fraction	Decimal equivalent
1/2	0.5	1/32	0.031 25
1/3	0.333 333	1/33	0.030 303
1/4	0.25	1/34	0.029 412
1/5	0.2	1/35	0.028 571
1/6	0.166 667	1/36	0.027 778
1/7	0.142 857	1/37	0.027 027
1/8	0.125	1/38	0.026 316
1/9	0.111 111	1/39	0.025 641
1/10	0.1	1/40	0.025
1/11	0.090 909	1/41	0.024 390
1/12	0.083 333	1/42	0.023 810
1/13	0.076 923	1/43	0.023 256
1/14	0.071 429	1/44	0.022 727
1/15	0.066 667	1/45	0.022 222
1/16	0.062 5	1/46	0.021 739
1/17	0.058 824	1/47	0.021 277
1/18	0.055 556	1/48	0.020 833
1/19	0.052 632	1/49	0.020 408
1/20	0.05	1/50	0.02
1/21	0.047 619	1/51	0.019 608
1/22	0.045 455	1/52	0.019 231
1/23	0.043 478	1/53	0.018 868
1/24	0.041 667	1/54	0.018 519
1/25	0.04	1/55	0.018 182
1/26	0.038 462	1/56	0.017 857
1/27	0.037 037	1/57	0.017 544
1/28	0.035 714	1/58	0.017 241
1/29	0.034 483	1/59	0.016 949
1/30	0.033 333	1/60	0.016 667
1/31	0.032 258		

Note. For the decimal equivalent of other fractions with 1 as numerator, and a number from 0.01 to 100.9 as denominator, see reciprocals, pages 144–147.

Fractions				Decimal equivalent
3rds	6ths	12ths	24ths	
			1	0.041 667
		1	2	0.083 333
			3	0.125
	1	2	4	0.166 667
			5	0.208 333
		3	6	0.25
			7	0.291 667
1	2	4	8	0.333 333
			9	0.375
		5	10	0.416 667
			11	0.458 333
	3	6	12	0.5
			13	0.541 667
		7	14	0.583 333
			15	0.625
2	4	8	16	0.666 667
			17	0.708 333
		9	18	0.75
			19	0.791 667
	5	10	20	0.833 333
			21	0.875
		11	22	0.916 667
			23	0.958 333
3	6	12	24	1

Fractions						Decimal equivalent (all figures are exact)
1/2's	1/4's	8ths	16ths	32nds	64ths	
					1	0.015 625
				1	2	0.031 25
					3	0.046 875
			1	2	4	0.062 5
					5	0.078 125
				3	6	0.093 75
					7	0.109 375
		1	2	4	8	0.125
					9	0.140 625
				5	10	0.156 25
					11	0.171 875
			3	6	12	0.187 5
					13	0.203 125
				7	14	0.218 75
					15	0.234 375
	1	2	4	8	16	0.25
					17	0.265 625
				9	18	0.281 25
					19	0.296 875
			5	10	20	0.312 5
					21	0.328 125
				11	22	0.343 75
					23	0.359 375
		3	6	12	24	0.375
					25	0.390 625
				13	26	0.406 25
					27	0.421 875
			7	14	28	0.437 5
					29	0.453 125
				15	30	0.468 75
					31	0.484 375
1	2	4	8	16	32	0.5
					33	0.515 625
				17	34	0.531 25
					35	0.546 875
			9	18	36	0.562 5
					37	0.578 125
				19	38	0.593 75
					39	0.609 375
		5	10	20	40	0.625
					41	0.640 625
				21	42	0.656 25
					43	0.671 875
			11	22	44	0.687 5
					45	0.703 125
				23	46	0.718 75
					47	0.734 375
	3	6	12	24	48	0.75
					49	0.765 625
				25	50	0.781 25
					51	0.796 875
			13	26	52	0.812 5
					53	0.828 125
				27	54	0.843 75
					55	0.859 375
		7	14	28	56	0.875
					57	0.890 625
				29	58	0.906 25
					59	0.921 875
			15	30	60	0.937 5
					61	0.953 125
				31	62	0.968 75
					63	0.984 375
2	4	8	16	32	64	1