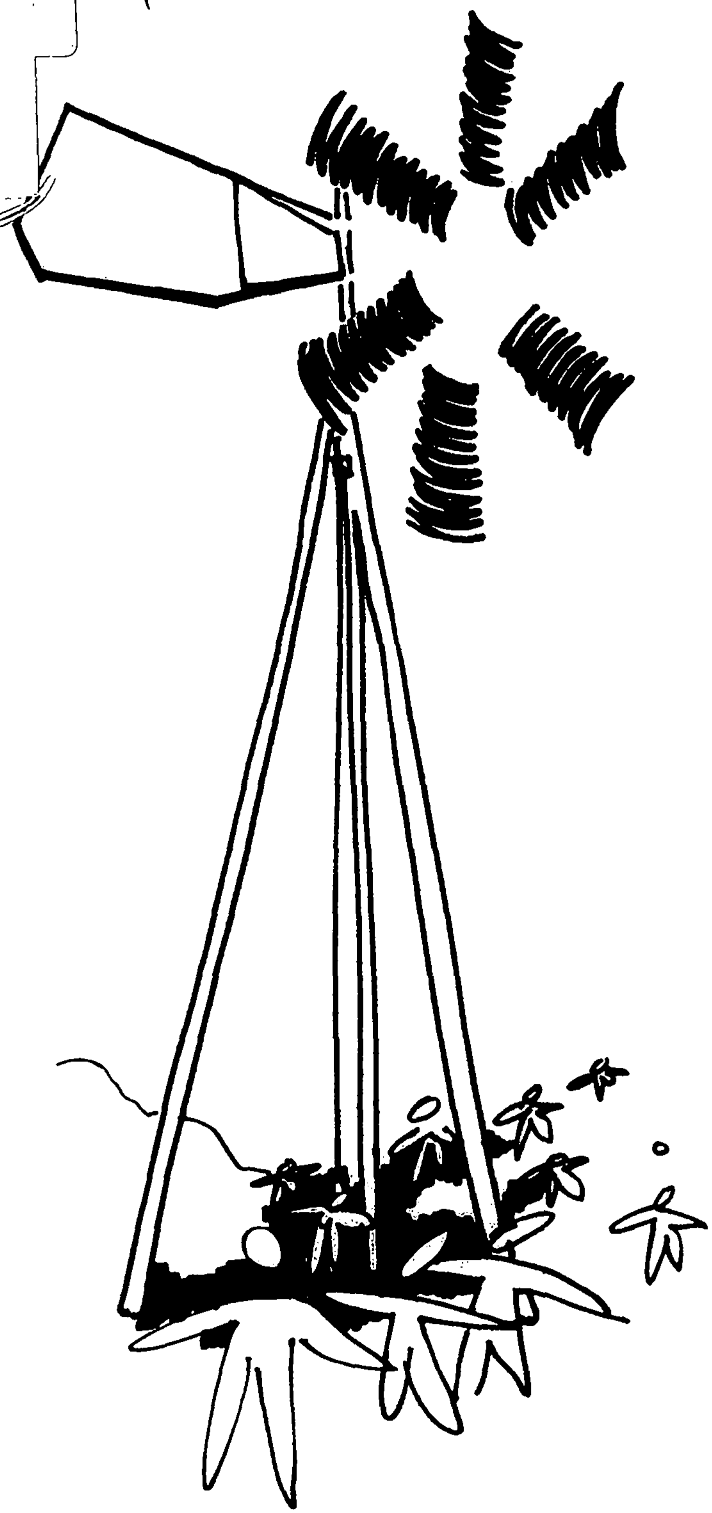
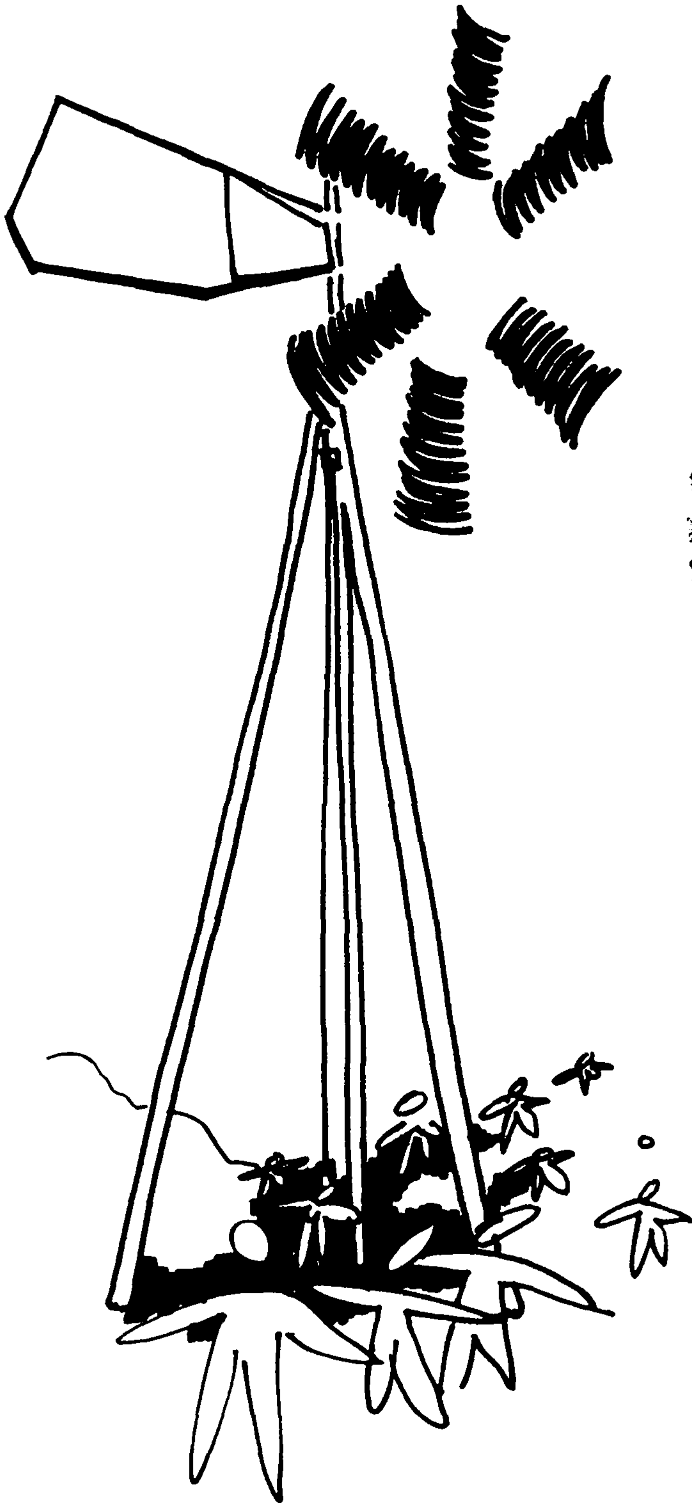


The Arusha Windmill: A Construction Manual

Written by Dick Stanley
Edited by Ken Darrow

A Volunteers in Asia/VITA Publication



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United Methodist Committee on Relief
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Credits

This manual was written by Dick Stanley, based on his experiences with the development of this design while working in Tanzania. Drawings are by the author.

This manual was produced by the Appropriate Technology Project of Volunteers in Asia. Edited by Ken Darrow.

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Volunteers in Technical Assistance (VITA) is a private, non-profit association based in the United States. Since 1960, VITA has supplied information and assistance, primarily by mail, to people seeking help with technical problems in more than 100 developing countries. This assistance is aimed at extending the ability of institutions and individuals overseas to select and implement technologies appropriate to their particular situations. VITA currently offers about 40 appropriate technology manuals.

Volunteers in Asia (VIA) has been sending volunteers to live and work in Asia since 1963. VIA's Appropriate Technology Project was started by two returned volunteers in January of 1975. The first major activity of this project was the production of a directory of practical plans and books for appropriate village and small community technology. This directory, the *Appropriate Technology Sourcebook*, has had two editions and five printings, and is now being used in more than 100 countries.

As a result of his work on the Arusha windmill, the author is now a staff member of the Arusha Appropriate Technology Project, in Arusha Region of Tanzania. This project, underway since late 1976, is an attempt to provide technical assistance, and conduct research and development in cooperation with the people of Arusha Region. Efforts are being made to develop appropriate technologies for power, fuel, agriculture, water supply, water storage, housing, communications, and related rural needs. The project can be reached by writing: Arusha Appropriate Technology Project, Box 764, Arusha, Tanzania.

Acknowledgement

The author is deeply indebted to Volunteers in Technical Assistance (VITA), a non-profit technical assistance agency whose consistent and reliable support has enabled full development and testing of this windmill in a relatively short time.

As well, the author would like to thank the Ministry of Water Supply and Power of Arusha, Tanzania, for early encouragement in this effort, financial support for the project, and recruitment of personnel who worked with what surely must have been the most unusual piece of metal fabrication they had ever seen. Also to be thanked are the regional Tanzanian authorities in Arusha who gave publicity and political support to this effort to develop something locally.

Volunteers in Asia deserves a special thanks for encouraging me to write this manual, and for carrying out all the work required to produce it.

Sincere thanks are also due the 3 or 4 Tanzanian fundis who worked on the project—in particular, Ndugu Saria Edward Mauky for his direct, steadfast, and very innovative work on the design and construction of the windmill.

We now have 7 or 8 of these machines made. They have had some problems—corrections for these have been made in the design. We've seen that the current design can be very useful here in Tanzania, and we hope the same will be true in other places.

One very exciting outcome of this whole windmill effort has been that we were able to see the need for analysis, evaluation, and planning for appropriate technology in general, which led to the development of the Arusha Appropriate Technology Project. That project will pursue the development of this kind of windmill and many other such devices. We hope to be able to offer some of the results of that effort in the future.

—Dick Stanley

Editor's Note

This manual is intended to do two things: 1) To provide the details needed to make the Arusha windmill in areas for which this design or a variation of it may be appropriate. 2) To illustrate the feasibility of the development of machines which cost only 1/5 to 1/10 as much as roughly equivalent imported machines. This is the kind of cost advantage that can really begin to put these technologies within the reach of many more people. But more than simply price are the advantages of: decentralized production, use of local skills and labor, use of locally available materials, design for local conditions, and the associated ease of repair and maintenance. The result is an entirely different technology with a real potential role in a different development in which the initiatives and benefits are to be found more among the people themselves.

—Ken Darrow
December, 1977

Foreword

In many developing countries there is a need today for a general windmill design which can be made of metal and can pump from several hundred feet. The design in this manual is the result of only 2½ years' development work. It has involved many modifications, some of which were made only 8 months ago. This windmill has been found to be a very low cost and highly efficient machine which can be used not only for pumping, but adapted for rotary motion as well. This should prove to be quite an advantage, as the reader may need wind power for other than piston water-pumping applications.

We hope that this design will help you put wind energy to use. This particular machine is not the final answer for windmills—it merely represents one additional design with a unique combination of materials and resources which may be useful in your area. It is also hoped that as we gain more experience with the windmill, the users of the design will share their ideas and in so doing enable the larger population to see the value in pursuing wind energy development through practical alternatives.

Table of Contents

How to Use This Manual

Please read this manual carefully several times until you clearly understand how the windmill operates and how it is to be made.

Read the section on wind measurement (page 42). After you have some data on the wind energy available do the calculations in the USEFUL DATA & DESIGN FORMULAS section. This will give you an estimate of how much power you need and how much power the Arusha windmill will provide under your wind conditions. Then you can decide whether to build the windmill. If you are pumping water 75 feet or less, you should use the crank drive mechanism described on page 35 instead of the more complicated eccentric wheel drive unit described in the main part of the manual.

Other windmill designs appropriate for different circumstances are described in the ADDITIONAL READING section (page 48).

Advantages of the Arusha Windmill

During an era of high fuel costs, windmills have an obvious attraction. The Arusha windmill has the following advantages when compared with imported manufactured windmills:

1) *low cost*—the Arusha windmill is very low in cost relative to imported manufactured windmills of comparable pumping capacity; approximately $250 vs. $2000 to $6000 for an imported windmill with tower (before shipping and import duties).

2) *better adapted to conditions in Arusha Region*—with its large tail and light-weight blades, the Arusha windmill is able to respond more quickly than conventional windmills to rapidly changing wind direction.

3) *deep pumping capability*—the Arusha windmill has a deep bore hole (250' and deeper) pumping capability that other low cost windmills do not have; the innovative eccentric wheel accomplishes the same gear reduction found normally only in commercially-made deep bore hole windmill pumps.

4) *locally available materials*—the Arusha windmill is made out of water pipe of standard sizes and other materials that are easily found in almost every small town around the world.

5) *locally available tools*—the Arusha windmill is made using very basic metal working equipment (welding machines and cutting torches) that is commonly available in rural towns in the Third World.

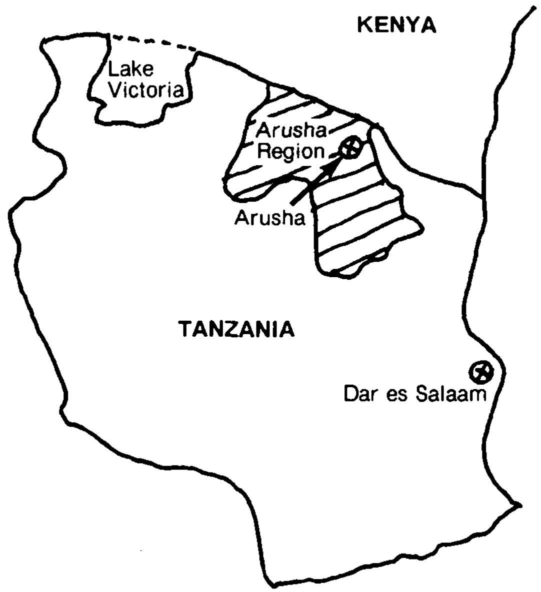
6) *local skills*—the Arusha windmill is made using basic metal working skills, in a craft process (most of the parts could also be standardized for production of many windmills in a single workshop).

7) *ease of repair and maintenance*—the skills and materials required for maintenance and repair are widely available; repair parts can be made on the spot or in a nearby workshop.

Background

This manual is intended to provide a guide to the construction, assembly and operation of a windmill for pumping water. This machine is light-weight and highly responsive to changes in wind direction. It is made of commonly available pipe and metal materials, and does not require any sophisticated metal working skills or equipment. It costs approximately 1/6 to 1/10 the price of an imported windmill with an equivalent capacity, in Tanzania.

This windmill design evolved over 18 months of research and testing in Arusha, Tanzania (see location map). Priorities in that nation include rapid development of water supplies in the rural areas—clearly an impossible task using conventional designs that require gasoline (petrol) or diesel powered water pumping plants. In addition to the cost of such pumps, the following problems exist: 1) rough road conditions, making transport to the site difficult, 2) maintenance problems of widely-scattered units, 3) cost and unavailability of spare parts, and 4) increasing fuel costs. The conventional approach is therefore both expensive and very difficult. Importing the equipment would also mean few jobs for the rural poor—a deficiency in opposition to the nation's goal of moving toward self-reliance and the productive employment of its people.



During the colonial period windmills were introduced to Arusha Region. These imported fan bladed windmills could provide some water, but not enough to meet the rural needs and justify their cost. These 21-foot (21') diameter windmills were designed for the relatively steady winds found in the western plains regions of the United States and Australia; they were not able to operate satisfactorily under the arid land conditions of much of Tanzania, where the wind constantly changes direction. A test on one of these units produced results similar to the chart in Table 1, in which wind speed is measured at the same time as the water yield of the pump. (Wind speed was measured by a cup anemometer; the water yield was from a 25-foot borehole fitted with a piston pump.)

Wind energy was not being effectively used by these windmills. A cup anemometer responds to all wind passing through it, even if the wind is rapidly changing direction. On site observation suggested that the wind was changing direction about 60 degrees every 15 seconds. The heavy, large diameter conventional windmill was unable to effectively respond to these variable winds. It was unable to pivot rapidly enough into the wind, due to gyroscopic and inertial forces, and was unable to accelerate rapidly when it had located the main wind stream.

The lack of a low-cost design to effectively harness the available wind energy for water-pumping led to the design and construction of the Arusha windmill. The author was assigned to the Ministry of Water for two years, and

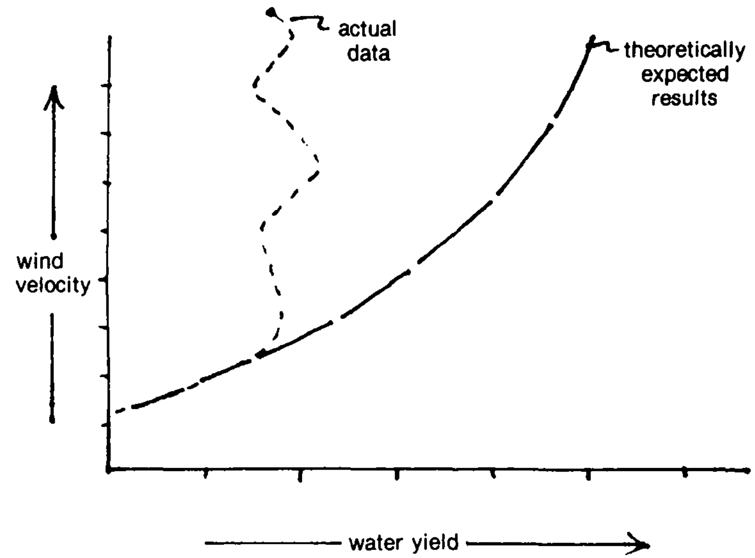


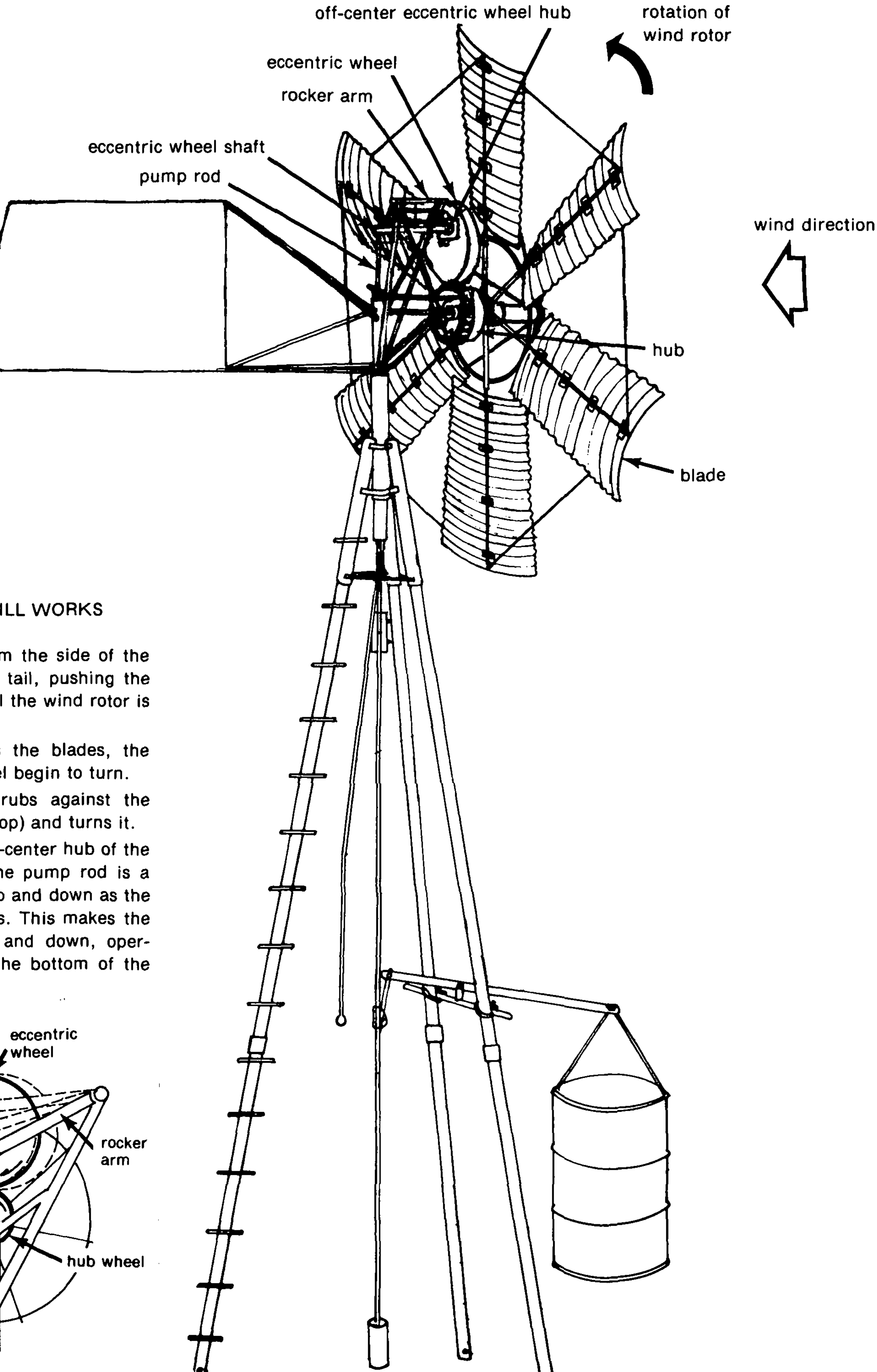
Table 1. Water Pumping Yield for Given Windspeeds. Data Generated by a 21' Diameter Fan-Bladed Windmill Imported into Tanzania

that ministry had the responsibility to install and maintain rural water systems. It was therefore desirable that the windmill be developed to fit the resource and skill base of that ministry. The Water Ministry, particularly through the strong support of the Regional Water Engineer, provided 18,000 shillings (US$2,000) for the establishment of a small workshop in the corner of the Water Ministry's yard in Arusha.

A staff of six men was hired and a review of all available designs for water-pumping windmills was started. We consciously limited ourselves to those resources which were regularly available to mid-level Tanzania Water Ministry staff technicians, who would continue the project after the initial testing was completed. This excluded foundry and casting, milling, boring and sheet metal forming facilities which existed in the town. For many social, cultural and financial reasons these would not be available to the Water Ministry staff, or to the rural African craftsmen who would be building the windmills on their own. There was a substantial gap between the outer limits of what might have been "available resources" for a foreigner with some influence in high places and what would likely be "available resources" for a mid-level Tanzanian technician.

Several of these windmills were completed by May 1976, and were installed and operating on test sites in the field for a total of over 2½ years' equivalent operating time. One more awaited assembly and erection at another field site; another was going up at the UNICEF-sponsored village technology exhibit in Karen Nairobi; and one more (the oldest) was cruising along in near-zero winds in the Water Ministry's own yard—for our hardy team's own morale building purposes.

How This Windmill Works



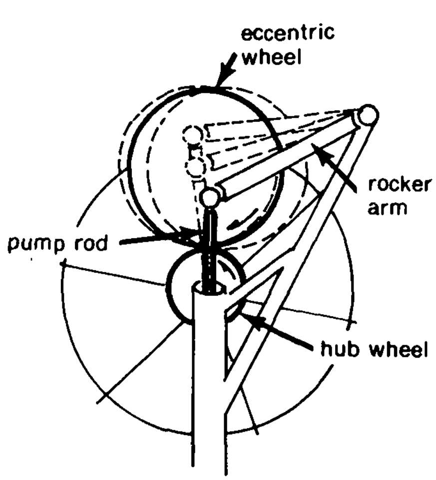
HOW THIS WINDMILL WORKS

1) Wind blowing from the side of the windmill will hit the tail, pushing the windmill around until the wind rotor is facing into the wind.

2) As the wind hits the blades, the blades and hub wheel begin to turn.

3) The hub wheel rubs against the eccentric wheel (on top) and turns it.

4) Connecting the off-center hub of the eccentric wheel to the pump rod is a shaft which moves up and down as the eccentric wheel turns. This makes the pump rod move up and down, operating the pump at the bottom of the well or bore hole.



OPERATION-Rear View

Design

The windmill was primarily designed to respond effectively to the rapidly changing gusts of warm air passing over the flat barren plains in arid parts of Arusha Region. The windmill has a large tail surface area for sensitivity to changes in wind direction, and a large total blade surface area for high start-up "torque." The blades are quite light-weight to make rapid pivoting and acceleration more possible.

The design has been modified several times before reaching the form shown in this manual. The drive mechanism is a friction-drive, eccentric (off-center) wheel mechanism that produces an up-and-down motion on the pump rod. This matches optimum pumping speed to optimum blade speed without the use of gears; three turns of the wind rotor are converted to two strokes of the pump. A different ratio could be obtained by using a smaller or larger eccentric wheel. The current design allows the operator to adjust the length of the pump stroke by changing the position of the axle on the eccentric wheel. (This axle is mounted in a movable flange to allow the pump stroke to be set between 2" and 12".)

Another modification was made in the drive mechanism. Heavy stresses on the rocker arm caused it to twist along its length. This problem was solved by increasing the diameter of the frame pipe for the rocker arm, and providing cross braces .

The whole unit has been tested to withstand a load of 1000 pounds while in motion. This is about twice the load on a 300-foot deep water pump working at 300 gallons per hour. No failure occurred during the three months' testing period. The test involved attaching a known weight to the pump rod and using the windmill to move it up and down under real field conditions.

Because of some design peculiarities and the wind characteristics of the Arusha Region, no mechanical governor is used on this machine. (A mechanical governor is a device that changes the angle of the blades relative to the wind so that the wind machine will not rotate at dangerous high speeds during high winds.) **No records of hurricanes or major gales exist in Tanzanian folklore or recorded literature**. There are occasionally 60 mph (100 km/hr) winds lasting perhaps two minutes, which can come from any compass direction. This windmill works well up to about 25 mph (40 km/hr) wind speed, but loses power at higher wind speeds due to the shape of the blades. A round pole on the back side of each blade creates a large drag effect at higher blade speeds. Thus, what evolved was a low-cost windmill which will not easily exceed about 90 revolutions per minute (rpm), even when the wind speed is much greater than 25 mph. With the reduction of 1.5 caused by the larger diameter eccentric wheel, the result is a nice maximum of 60 strokes per minute for optimum reciprocating pump conditions.

In one case we did experience problems with the blades being forced to hit the tower, under the impact of extreme and sudden gusts. Modifications to handle this problem were made by providing a series of 6 guy wires which fasten the tips of the blades to a 3-foot extension of the blade hub. This is an old method used in the sail bladed windmills in Crete. We suspect that the single case of blade failure was due to a mistake in the assembly of the blades. The guy wire system is offered for extra safety.

The tower design is unique. The tower has been left flexible, to absorb the impact of gusting winds. The flexibility is well within the structural limits of the 2½" dia. pipe legs, for the angle at which they are inclined and the amount of weight they must support. The tower design has helped keep the entire machine light-weight and easy to transport before assembly on one light truck or land rover with a roof rack (which we used). Field teams can assemble the windmill on the ground and raise it by pulling the tower into the vertical position with the help of about 40 people or the use of a Land Rover or truck.

There are two options for tower height. The first is a 20-foot tower using only the standard 20-foot (6-meter) lengths of metal pipe. The second is a 26-foot (8-meter) tower requiring three additional 6-foot (2-meter) lengths of tower pipe and three socket reinforcements to stabilize the additional lengths of tower pipe. Using this technique, it would be theoretically possible to extend the tower height to 30 feet (9 meters) by using 10-foot (3-meter) extensions, before larger diameter pipe or cross bracing would be necessary. This idea has not been tried, as it was unnecessary due to the low vegetation cover in the area. The reasons for choosing a specific tower height are explained in the ASSEMBLY and USEFUL DESIGN DATA sections (see pages 30 and 40).

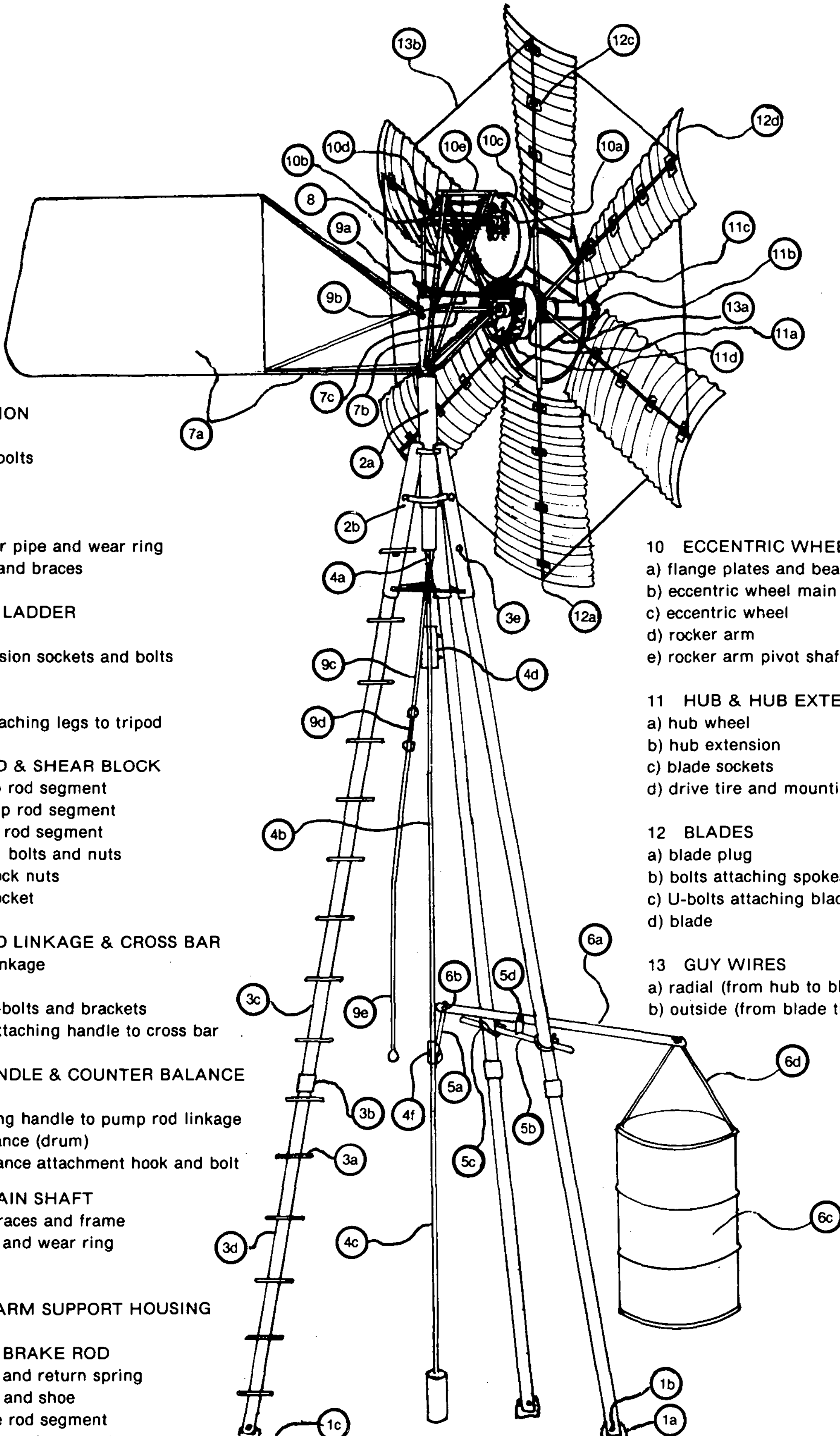
The tower legs are bolted to steel bars which have been placed into the foundation (which requires a total of about 24 cubic feet of concrete, poured into the ground at the site). The ladder is a series of steel bars welded on the inside of one of the tower legs.

The windmill frame is quite difficult to describe; the drawings and details in the following sections should make that unit understandable.

If you were to build this windmill in the manner described, the costs would be (in Arusha, Tanzania):

Materials costs:	Sh 1000/ or US$125
Labor costs: 6 man-weeks	Sh 700/ or US$87.50
Foundation:	
Cement	Sh 120/ or US$15.00
Labor	Sh 80/ or US$10.00
Total (1975 prices in Tanzania)	Sh 1900/ or US$237.50

This manual is not an attempt to provide a standard answer to all windmill problems; it simply illustrates a reliable machine for pumping water under a particular set of wind patterns and resource/skill constraints. Please consider the text in that light. What follows will be a detailed coverage of materials, construction techniques, assembly, raising the windmill, final adjustments, operation, and maintenance of this machine. Supplementary sections on pumps, alterations, useful data and design information, and additional readings are also provided with the hope that you will not necessarily duplicate this design, but instead *adapt* it to better fit the conditions where you are working.



1 FOUNDATION
a) anchor pins
b) anchor pin bolts
c) concrete

2 TRIPOD
a) tripod center pipe and wear ring
b) tripod legs and braces

3 TOWER & LADDER
a) ladder
b) tower extension sockets and bolts
c) upper legs
d) lower legs
e) bolts for attaching legs to tripod

4 PUMP ROD & SHEAR BLOCK
a) upper pump rod segment
b) middle pump rod segment
c) lower pump rod segment
d) shear block, bolts and nuts
e) pump rod lock nuts
f) pump rod socket

5 PUMP ROD LINKAGE & CROSS BAR
a) pump rod linkage
b) cross bar
c) cross bar U-bolts and brackets
d) pivot bolt attaching handle to cross bar

6 PUMP HANDLE & COUNTER BALANCE
a) handle
b) bolt attaching handle to pump rod linkage
c) counter balance (drum)
d) counter balance attachment hook and bolt

7 TAIL & MAIN SHAFT
a) tail vane, braces and frame
b) center pipe and wear ring
c) main shaft

8 ROCKER ARM SUPPORT HOUSING

9 BRAKE & BRAKE ROD
a) brake lever and return spring
b) brake shaft and shoe
c) upper brake rod segment
d) elastic brake rod segment
e) lower brake rod segment

10 ECCENTRIC WHEEL & ROCKER ARM
a) flange plates and bearing housing
b) eccentric wheel main shaft
c) eccentric wheel
d) rocker arm
e) rocker arm pivot shaft and end bolts

11 HUB & HUB EXTENSION
a) hub wheel
b) hub extension
c) blade sockets
d) drive tire and mounting bolts

12 BLADES
a) blade plug
b) bolts attaching spokes to hub wheel
c) U-bolts attaching blades to spokes
d) blade

13 GUY WIRES
a) radial (from hub to blade tip)
b) outside (from blade tip to blade tip)

FIGURE 1. THE ARUSHA WINDMILL

List of Materials Needed

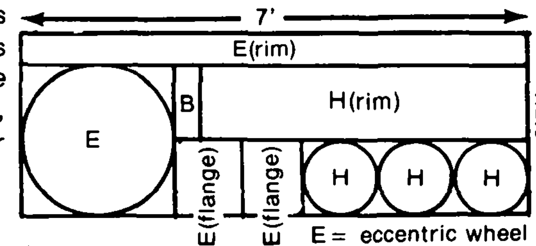
This section describes 1) the materials required from a typical selection of standard pipe sizes and lengths, and 2) the resources used in the metal-working process (for example, welding rods). The quantities of each material are divided according to the individual parts of the windmill.

The cost for all materials in Arusha (1975) was about Sh/1000 (US$125). As with other considerations, the costs of these materials in your area will probably be so different that itemizing costs would not be helpful. In Arusha today (1977), present costs would be at least 25% greater than our 1975 figures.

(The pipe diameters listed refer to the inside diameter of the pipe. The quantities shown below for the tower legs and pump rod are for the 26' tower height.)

MATERIAL/TOTAL QUANTITY	DISTRIBUTION AMONG PARTS
Pipe: galvanized iron or steel	
3" dia. — 21'	12'—tripod; 3'—hub extension; 6'—tower leg extension sockets.
2½" dia.—99'3"	9"—hub bearing housing; 78'—tower; 8'—tower cross bar; 8'—pump handle and counter balance; 4'6"—tail center pipe.
2" dia.—6'6"	6" eccentric wheel bearing housing; 6'—rocker arm.
1¼" dia.—12'	12'—hub sockets for blades.
1" dia.—49'7"	48'—blade spokes; 3"—rocker arm pivot shaft bearings; 1'4"—rocker arm.
¾" dia.—76'5"	61'2"—tail frame; 15'3"—rocker arm support housing.
Pipe fittings: galvanized iron or steel	
3" dia. socket—1	1—hub extension socket.
Metal rod: iron or steel	
1½" dia.—2'4"	2'4"—main shaft.
1" dia.—3'6"	1'2"—brake shaft; 1'4" eccentric wheel shaft; 1'—rocker arm pivot shaft.
¾" dia.—21'	21'—tower ladder rungs.
5/8" dia.—30'6"	29'6"—pump rod; 1'—counter balance.
½" dia.—12'6"	4'6"—lower tripod braces; 3'—counter balance hook; 3'—foundation anchor pins; 12"—tripod wear ring; 12"—tail center pipe wear ring; (add 3'6" if two cross bar U-bolts are to be made of rod).

MATERIAL/TOTAL QUANTITY	DISTRIBUTION AMONG PARTS
3/8" dia.—16'	16'—blade U-bolts (if these are to be made).
¼" dia.—20'	20'—brake rod.
Metal sheet: galvanized	
24 to 28 gauge (corrugated) 3' X 6' sheets—6	6 sheets—blades (each blade is 3' X 6', but can be made from smaller pieces of sheet).
24 to 28 gauge (flat) 3' X 8' sheet—1	1 sheet—tail (also can be made from smaller pieces of sheet).
Steel plate:	
1/8" plate—1 sheet 2'7" X 7'. (NOTE: The 7' length of this piece should allow some excess which can be used to make gussets for the hub wheel, pump rod linkages, and other small parts where required.)	Distribution shown in the following pattern:



(not to scale)

E = eccentric wheel
H = hub wheel
B = brake

MATERIAL/TOTAL QUANTITY	DISTRIBUTION AMONG PARTS
Metal stock: mild steel or iron	
1" X 4" bar stock—4'6"	4'6"—foundation.
¼" X 1" bar stock—16'2"	6'8"—upper tripod braces; 1'6"—brake shaft lever; 8'—blade U-bolt mounting brackets.
2" X 2" angle iron—2'	2'—tower cross bar U-bolt mounting brackets.
Wire: galvanized 1/8" dia. *spring steel or 3/16" dia.* mild steel	
1/8" dia.—106'	52'—outside (blade-to-blade) guy wires; 54'—radial (blade to hub extension) wires.
Rubber:	
4" X 4' length of 4- to 8- ply scrap tire from car or truck, cut from center section	1—hub wheel drive tire.
1" width strips of innertube from car (as alternative to tension springs for brake assembly)—6'	3'—brake lever (return); 3'—brake rod linkage.

MATERIAL/TOTAL QUANTITY	DISTRIBUTION AMONG PARTS
Bearings: sealed or semi-sealed ball bearings or roller bearings (if sealed, then two grease nipples are not needed).	
1½" inside dia. bearing with outside dia. that will fit tightly inside a 2½" dia. pipe—2	2—hub.
1" inside dia. with outside dia. that will fit tightly inside a 2" pipe—2	2—eccentric wheel.
(NOTE: If available bearings fit larger or smaller pipes, you can change the pipe sizes for the bearing housings.)	
Bolts & nuts: mild steel with threads standard in the area	
1" X 4"—3	3—anchor pin bolts.
¾" nuts—5	4—pump rod linkage arm; 1—eccentric wheel main shaft.
5/8" X 4"—1	1—counter balance/pump handle pivot.
5/8" X 3"—3	1—counter balance (drum) pivot; 2—pump rod linkage to pump handle.
5/8" nuts—6	4—pump rod linkage socket; 2—top pump rod fasteners.
½" X 4"—12	12—tower extension couplings.
½" X 3"—12	12—blades.
½" X 2"—1	1—main shaft, stop for hub.
¼" X 2"—2	2—rocker arm pivot shaft.
¼" X 1½"—13	12—hub tire; 1—eccentric wheel main shaft.
U-bolts (can be made from rod if available)	
½" dia. with 2¼" radius and 8" length—2	2—tower cross member for counter balance.
3/8" dia. with ¾" radius and 2½" length—24	24—blades.
Wood:hardwood, treated with preservative	
3" X 3" X 12"—1	1—shear block.
1" dia. dowel (or roughly rounded branch) X 3'—1	2'6"—blade plugs; 6"—spare plug.

MATERIAL/TOTAL QUANTITY	DISTRIBUTION AMONG PARTS
Miscellaneous materials:	
5/16" dia. grease nipples—5	1—hub wheel; 2—rocker arm; 1—eccentric wheel; 1—tripod.
Tension spring with 15 lbs. pull over a 5" extension—1	1—brake lever return.
Tension spring with 40 lbs. pull over a 3" extension—1	1—brake rod linkage.
(NOTE: You may substitute tire innertube rubber for these springs without affecting the performance of these parts.)	
55-gallon used oil drum—1	1—counter balance.
Turnbuckles—6	6—radial guy wires.
Workshop supplies used (NOTE: This list assumes the use of machine shop facilities as described in this section.)	
Welding gas-oxygen—½ tank	1/8 tank—blades and hub; 3/8 tank—all other parts.
Welding gas-acetylene—¼-tank	1/8 tank—blades and hub; 1/8 tank—all other parts.
Grinding wheels—1	½ wheel—consumed while making tower and superstructure; ½ wheel consumed making all other components.
Hacksaw blades—6	6—general.
Paint—2 gallons	2 gallons—general.
Cement—3 bags	2 bags—foundation; 1 bag—concrete surface around well and well seal.
Welding rod (electric), 1/8" dia.—24	24—superstructure.
3/16" dia.—24	24—tower ladder, drive mechanism (hub, eccentric wheel and rocker arm), and main shaft.
Flux for brazing—1 pint	1 pint—general.
Brazing rod, 1/8" dia.—15	12—blades; 3—tail.

After looking closely at the construction section and making a list of your own available resources, you will probably be able to cut this list of materials to buy in half. If pipes are available in metric sizes, use those sizes that are similar in diameter (see English/metric conversion chart on page 47).

Tools

If you follow this plan exactly, you will need a solid hand drill capable of forming ½'' (½-inch) diameter holes through 3/10'' metal plate, and ¼'' diameter holes through 1'' diameter steel rod. You will also need the following tools:

adjustable wrench
pliers
files (½-round is ok)
hacksaw
electric welding equipment (capable of welding up to ½'' thick steel)
gas welding equipment (including a cutting torch)
tin snips
ball peen hammer (medium weight)
anvil
chisel (10'')
2'' X 4'' paint brushes (several)
set of taps and dies from ¼'' to ¾'' diameter, in the thread type common to the area.

This is the minimum tool list for the production of this windmill, based on our shop experiences. Where a reliable supply of spare parts exists, you might add the following:

electric drill (½'', reversible)
cutoff grinder (hand held)
machine lathe with 3-foot bed and a feed-through chuck of 2'' minimum inside diameter
paint sprayer
pop rivetting tools
hydraulically-operated press

These tools are not necessary, but they would be useful if you intend to produce many windmills in one workshop.

We made the initial investment in equipment (plus the electric drill and cutoff grinder) for about Sh/10,000 (US$1200). Add another $700 for the complete list if you are in Tanzania over the next year.

The workshop requires about a 30' X 30' area (900 square feet = 84 square meters) area with large double doors and a floor-to-ceiling height of at least 10 feet (3.1 m). We suggest that you avoid using glass windows, especially at eye level, because many people will be continuously moving long metal pipes around the workshop.

Construction

It is important to understand what each of the parts does in this windmill design. This makes it easier to find the right substitute for a part which is unavailable, impractical, or too expensive in your area. There are many variations possible on the design presented here.

With this in mind we will take a look at the parts of the windmill. Each of these is constructed separately, and the entire windmill is assembled after being taken to the site. In some cases you will have to partially assembly several parts to determine the proper measurements for the part you are making at the time. Some of the parts can be disassembled after you have made them, for easier transport.

The parts of the windmill are presented in the following order:

1) Foundation
2) Tower, ladder & tripod
3) Pump rod & shear block
4) Pump rod linkage & cross bar
5) Pump handle & counter balance
6) Superstructure
   a) Tail & main shaft
   b) Rocker arm support housing
   c) Brake
7) Rocker arm & eccentric wheel
8) Hub wheel assembly
9) Blades
10) Guy wires

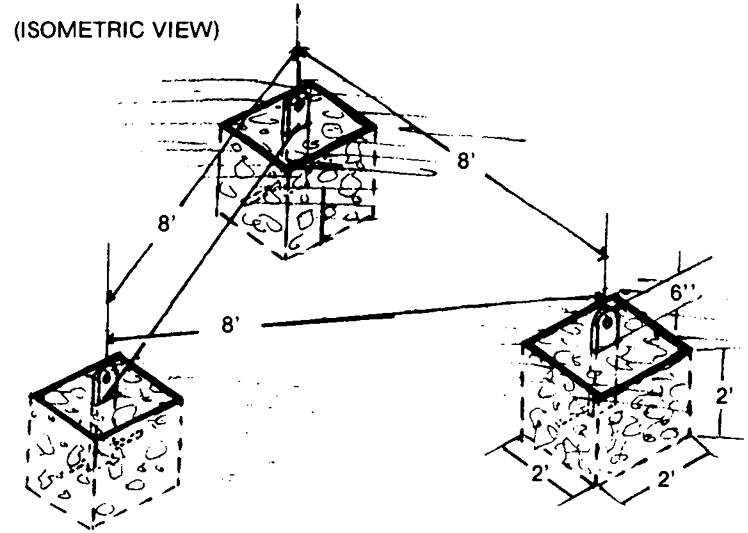


FIGURE 2. FOUNDATION BLOCKS

Foundation

A foundation is needed to securely hold the windmill in place. This consists of three holes filled with concrete, with anchor pins placed in the concrete to connect the foundation with the tower legs. *The foundation should be prepared at least 3 days before the windmill is installed.*

Dig three holes as shown in Figure 2. Each hole should be 2 feet deep, 2 feet wide, and 2 feet long. The center points of each hole should be 8 feet apart, as shown.

Three anchor pins should be made of 1'' X 4'' steel bar, 18'' long, as shown in Figure 2a. The position at which the cross bar is welded is not important; it serves only to keep the anchor pin in place in the concrete, so it must be below the surface of the concrete. If you have a cutting torch, the holes in the anchor pins can be cut out rather than drilled. Make sure that these holes are big enough so that 1'' dia. bolts can pass through them easily.

You will need a total of 24 cubic feet of concrete for the complete foundation (8 cubic feet per hole). This will require 2 large bags of cement. You can save much of this by using large rocks near the bottom of each hole, when pouring in the concrete.

It is important to place the anchor pins in line as shown in Figure 2b, and to *insure* that they are level and vertical. Otherwise you will not be able to raise the windmill properly. The centers of the holes in the anchor pins should be 6'' above the concrete.

A concrete surface to surround the pump can be poured at the same time the foundation is made.

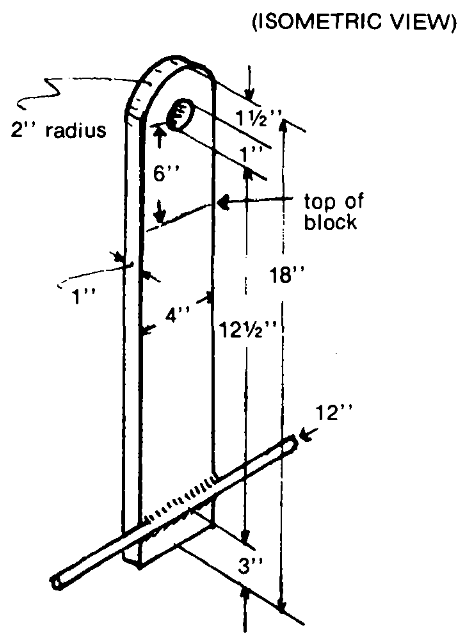


Fig. 2a. Foundation Anchor Pins

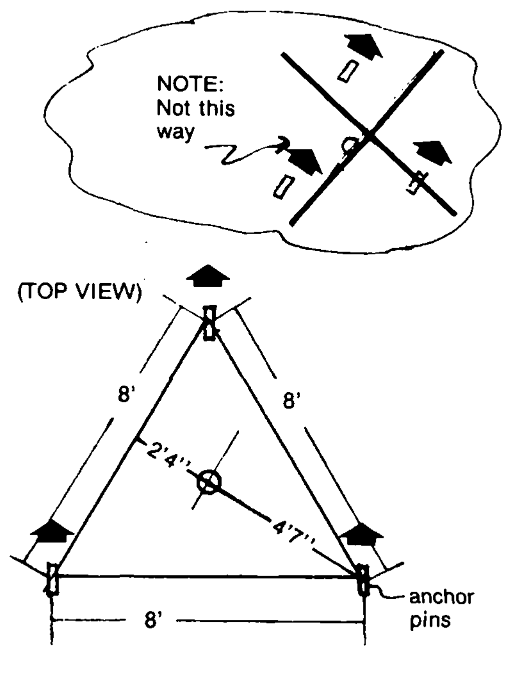


Fig. 2b. Alignment of Anchor Pins

Tower

The tower is an important and expensive part of most windmills. The Arusha windmill has a low-cost but strong tower made of 2½'' dia. pipe. This tower can be made either 20' or 26' high. The 20' tower would not use the 6' extension pipes and extension sockets shown in Figure 3. *(See page 44 for information on how to choose tower height.)*

This drawing shows a 26' tower. Each leg requires a connection between a 20' standard 2½'' diameter piece of pipe and another 6' piece, using a 2' piece of 3'' dia. pipe to serve as a socket (as shown in Figure 3a). Four 3/8'' dia. X 4'' bolts are required for each tower leg to make the connection for the 6' extension. This method of connecting the tower legs could be used to extend the height up to 30 feet by using 10' pipes instead of 6' pipes. Beyond that height, *either larger diameter pipes for the tower legs or cross bracing would be necessary for a safe structure.*

After making certain that the extension sockets fit, disassemble the legs for easy transport.

Ladder

One leg of the tower is made into a ladder by welding metal rods (¾'' dia. X 1'' along the inside of the tower leg, 15'' apart. Be sure to note the position of the holes in that tower leg **before** welding the bars on—it is rather frustrating to find that the ladder runs sideways after doing all that welding. *Note also that if a tower of greater than 20' height is desired, you will need to leave a few of the crossbars out of the ladder to allow clearance for the tower extension socket.* It is easy to weld bars onto the extension socket to complete the ladder.

Tripod

The tripod connects the legs of the tower and forms the central support housing for the windmill. This piece requires some very careful, accurate work including correct alignment and solid welding of the tripod legs to the center pipe. In order to insure that the alignment is correct, measure each tripod leg to spread out 5'' *from the center pipe over a distance of 24''* (see Fig. 4a). The top of each tripod leg is set to touch 12'' below the top of the center pipe.

The three tripod legs should be firmly welded in place, with ¼'' X 1'' straps (4 per leg—about 3'' on top and 7'' on the bottom) as shown in Figures 4a and 4b. Then, weld on the ½'' dia. lower tripod supports, making certain that each of the tripod legs is correctly aligned (Figure 4). Errors can be corrected by bending the ¼'' X 1'' metal straps.

After the basic tripod frame has been welded together, insert the tower

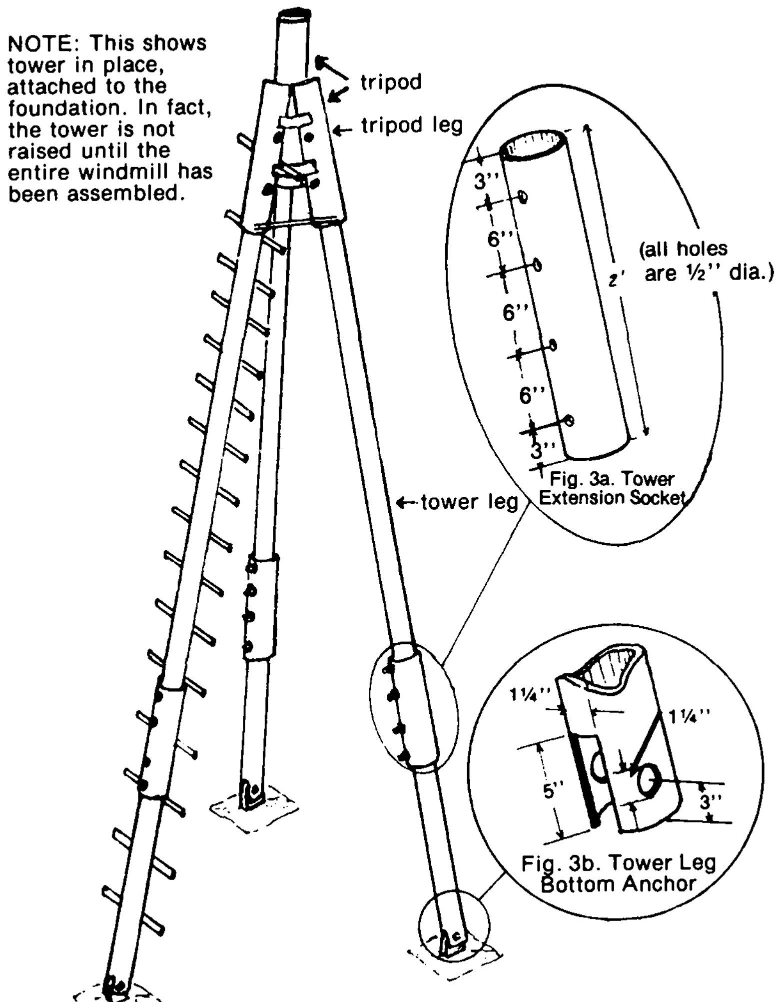


FIGURE 3. TOWER, LADDER AND TRIPOD IN PLACE

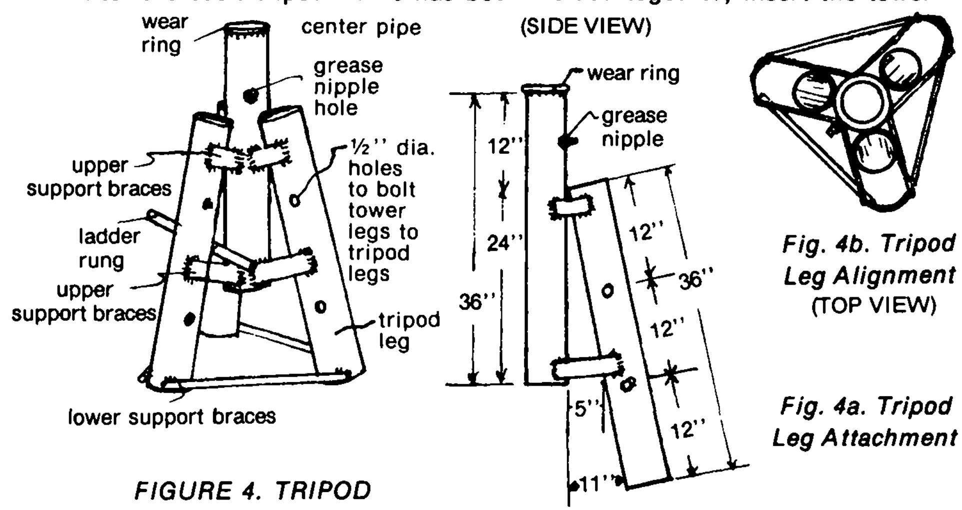


FIGURE 4. TRIPOD

legs into the tripod legs and drill two ½" dia. holes (where shown in Figure 4b) along each tripod leg. During final assembly at the site bolts will be placed in these holes to hold the tower legs in place.

Next, make the "wear ring." The wear ring is the load bearing surface for the windmill. This ring is easily made by tack welding one end of a ½" dia. rod about 12" long onto a spare piece of 2½" dia. pipe. Pound it around the pipe until you complete the circle. Cut off the excess rod and pound the ring ends until they touch and the ring fits loosely around the 2½" dia. pipe. Remove this from the pipe and weld it onto the top of the tripod center pipe (Fig. 4b).

Finally, drill a ¼" dia. hole and thread the hole for attachment of a grease nipple about 4" below the upper end of the tripod center pipe.

Pump Rod

The pump rod is a 29'6" piece of 5/8" steel rod, separated at two points, which extends from the top of the windmill down to the pump at the base of the windmill. This rod moves up and down as the windmill operates.

The pump rod has three parts. The upper pump rod segment (about 10' in length) extends from the drive mechanism down through the tripod to the shear block. The middle pump rod segment (17'6" long) goes from the shear block to the pump handle linkage. (If a 20' tower instead of a 26' tower is used, this middle pump rod segment should be about 11'6" long.) The bottom pump rod segment extends from the pump handle linkage to the pump itself (about 2'—depends on the pump used).

An easy way to make the pump rod without cutting threads is to butt weld the heads of 5/8" bolts onto the pump rod ends. By welding a short piece of rod across the second pump rod segment near the bottom, that pump rod segment can be turned by hand later, without the use of tools.

The third (lowest) segment of pump rod is required to connect the pump rod socket to the pump itself, when used with the pumps suggested in the APPLICATIONS section. (Otherwise, a conventional piston pump has a pump rod which could screw directly into the bottom of the pump rod socket—see this socket in Figs. 5 and 6a.)

Shear Block

The shear block is designed to be a weak point in the pump rod. If the pump gets caught or jammed for some reason, the shear block will allow the pump rod to separate without breaking or causing damage to the rest of the windmill. The shear block is actually two blocks of well-oiled or painted wood which clamp the upper and middle segments of pump rod together. The bolts holding the blocks together are tightened until the pump rod will not separate when forced to lift 1000 pounds while the windmill is operating. The pump rod *should* pull apart when 200 additional pounds are added to the weight the rod is pulling against. This method for adjusting the shear block is described more completely in the ASSEMBLY section. The blocks of wood measure 1½" X 3" X 12" each, and should be of seasoned hardwood quality. Figure 5b includes the details of these blocks.

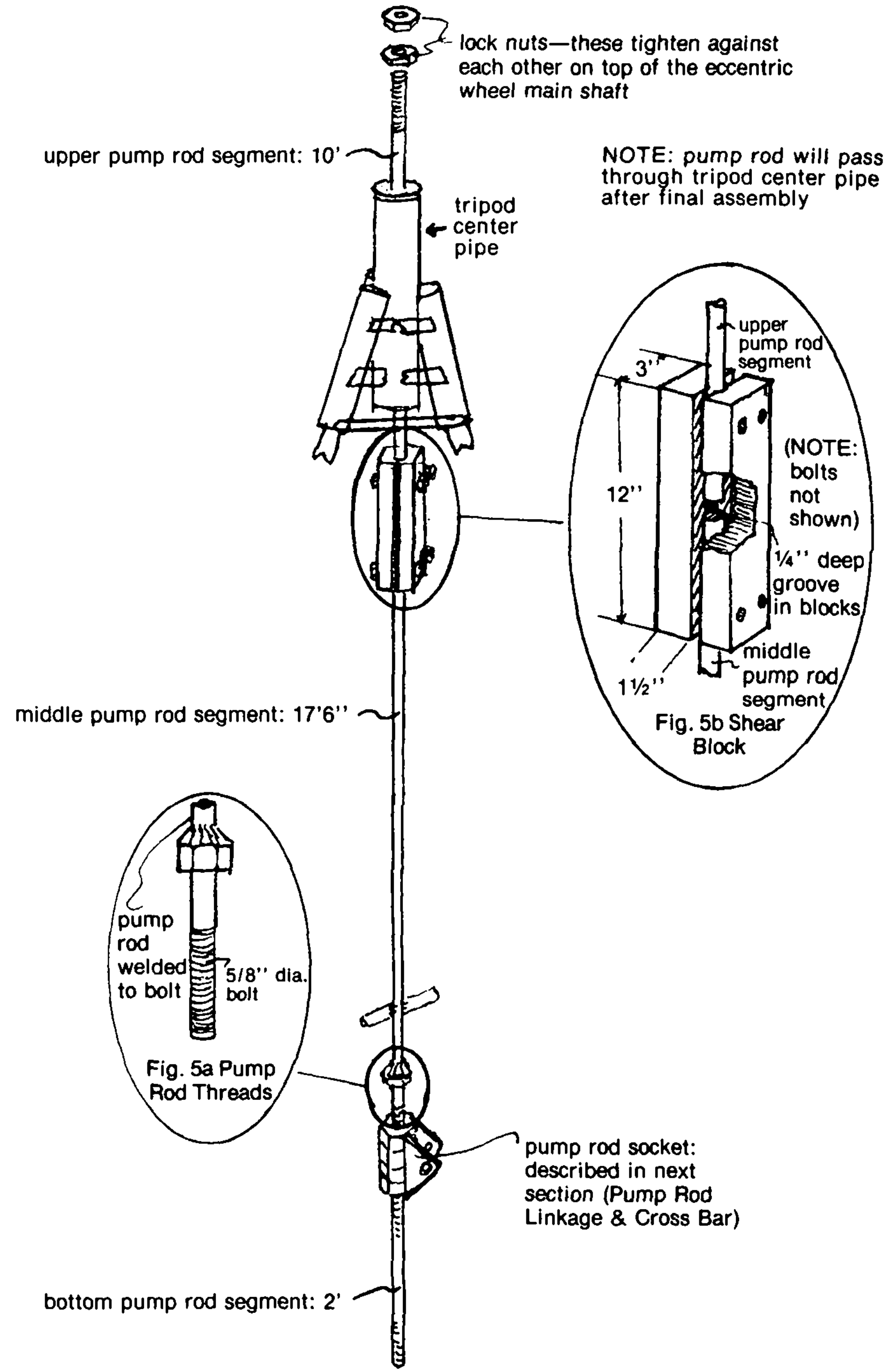


FIGURE 5. PUMP ROD & SHEAR BLOCK

Pump Rod Linkage & Cross Bar

The function of the pump rod linkage is to provide a flexible connection for pump handle movement and to allow the windmill to be disconnected from the pump—for pump repair or operation of the pump by other means.

Two details are important in the pump rod linkage: 1) the connecting rod between the pump handle and pump rod (as shown in Figure 6a); and 2) the pump rod socket, which connects the middle and bottom pump rod segments.

The connecting rod consists of a 6'' piece of 5/8'' dia. rod with ¾'' nuts welded on to the ends as shown in Figure 6a. Note that the 5/8'' dia. bolts which will fit into these must be parallel to each other. The pump handle connects to this linkage (see following pages).

The pump rod socket consists of a series of four 5/8'' nuts welded together and two pieces of 1/8'' plate (cut in the shape shown in Figure 6a and welded in place).

Tower Cross Bar

The tower crossbar is a piece of pipe (2½'' dia. X 8') which supports the pump handle and counterbalance. The crossbar is fitted with a pivot made of two pieces of ¼'' metal plate (or flattened 2½'' pipe) which should be about 4'' high and 3'' wide and spaced 3'' apart. These are welded in position at the center of the crossbar (as shown in Figure 6c). A 5/8'' dia. hole should be drilled in both pivot parts at a point 3'' above the crossbar pipe. A 5/8'' X 4'' bolt is used to fasten the pump handle to this pivot.

The crossbar is fastened to the tower legs by means of two U-bolts (shown in Figure 6b), which will probably have to be made. If no threading equipment is available, you can weld bolts onto the ends of a bent section of ½'' dia. rod as shown:

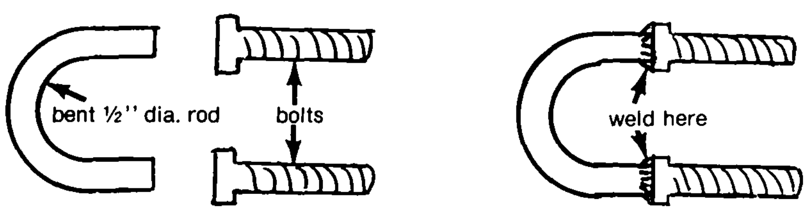


Figure 6d. Making U-Bolts

The mounting plates for the U-bolts are pieces of 2'' X 2'' X 12'' angle iron (you can substitute a 2'' dia. X 12'' pipe, flattened near the ends). Note that it is wise to make a rough shape of these U-bolts and the expected mounting hole positions before getting into the process during assembly in the field. The U-bolts have a maximum inside radius of about 2¼'' with a length of 8''. Note the position of these U-bolts—they must cross diagonally so that their mounting plates point down and towards the center.

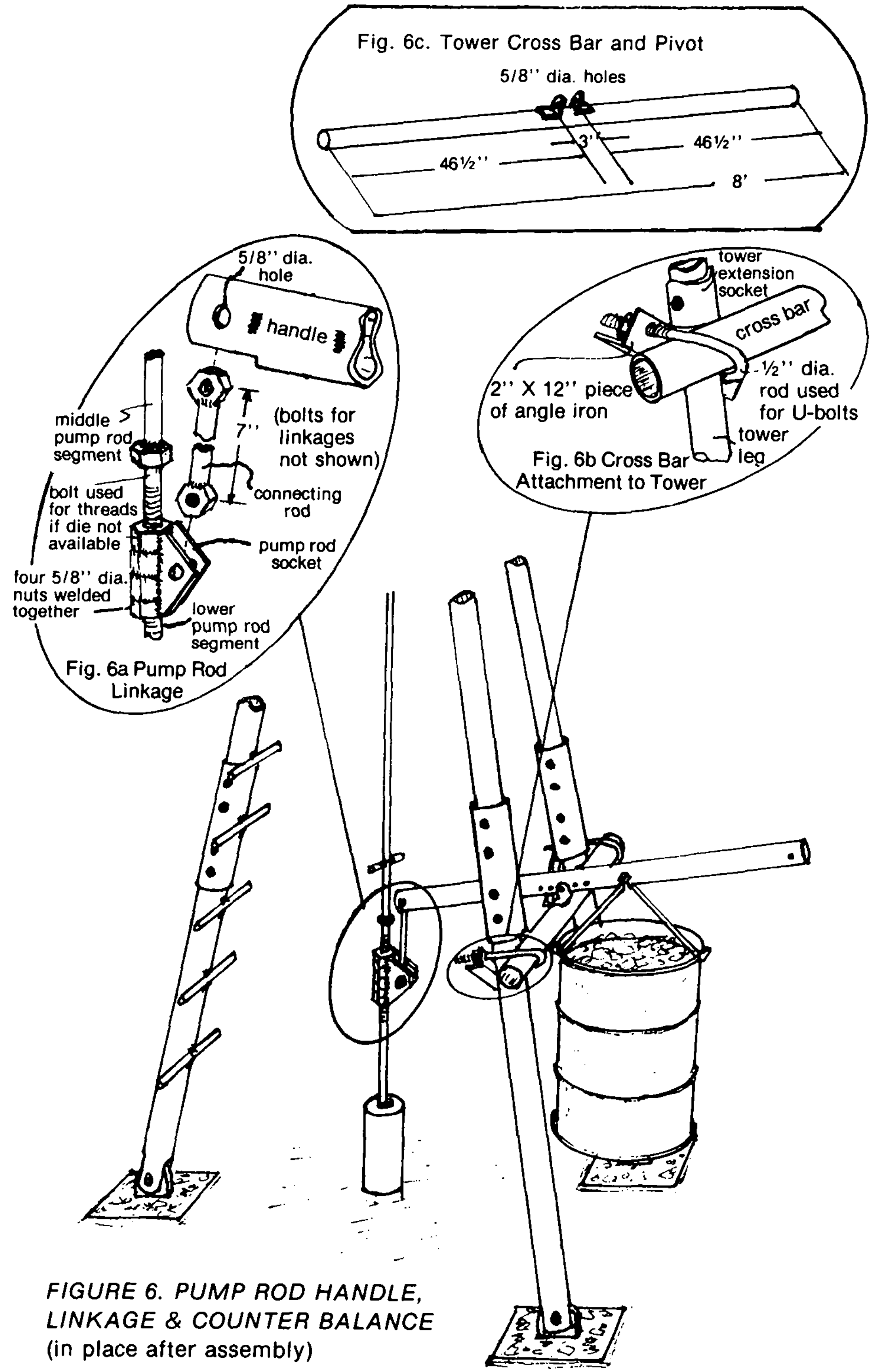


FIGURE 6. PUMP ROD HANDLE, LINKAGE & COUNTER BALANCE
(in place after assembly)

Pump Handle

The pump handle allows the pump to be operated by hand if the wind is not blowing. The pump handle is made from a piece of 2½'' dia. pipe, 8' long.

Cut it open at one end on the bottom, 1'' wide along a 3'' length, as shown in Fig. 7a.

Drill a pair of 5/8'' dia. holes 1'' from this end of the pump handle. Try to drill these and the next holes straight through the pipe, by center-punching the holes and drilling them using a drill press or another system to insure that the drill goes straight. Note that all of the holes will be in line along the length of the pipe. (Fig. 7a is a view from below and to one side of the pump handle.)

Drill five more pairs of 5/8'' dia. holes, each 1½'' apart—the center hole in this group should be 2'2'' from the pump linkage end of the pump handle. (These holes will allow adjustment of the pivot point during assembly.)

Drill two more pairs of 5/8'' dia. holes, as shown, one pair at a point 3'8'' from the pump linkage end of the handle; the other pair 10'' from the outer end of the pump handle. Cut a 5/8'' X 2'' long slot directly below the first pair of holes—this is for the counter balance hook.

The pump handle pivots at the cross bar on a 5/8'' X 4'' bolt, which should be tight so that the bolt itself does not turn. The same is necessary for the bolt used to attach the pump rod linkage to the handle (Fig. 6a).

Counter Balance

The counter balance helps the windmill to operate the pump more easily. Without it, the windmill would be lifting the pump rod, pump piston, and column of water during each up-stroke of the pump rod. By adding the counter balance, the windmill never has to lift this much weight. The counter balance almost equals the weight of the pump rod and piston. During the up-stroke the windmill therefore only has to lift a little more than the weight of the column of water. This fact makes the windmill easier to start.

The counter balance is an old oil drum with a few holes in the bottom to allow drainage of rain water. Two ¾'' holes are punched next to the top rim opposite each other, to permit attachment of the hook shown in Figure 7b. The hook is made of ½'' dia. soft iron or steel rod. It is attached to the pump handle with a 5/8'' X 4'' bolt (which is also tightened to avoid turning).

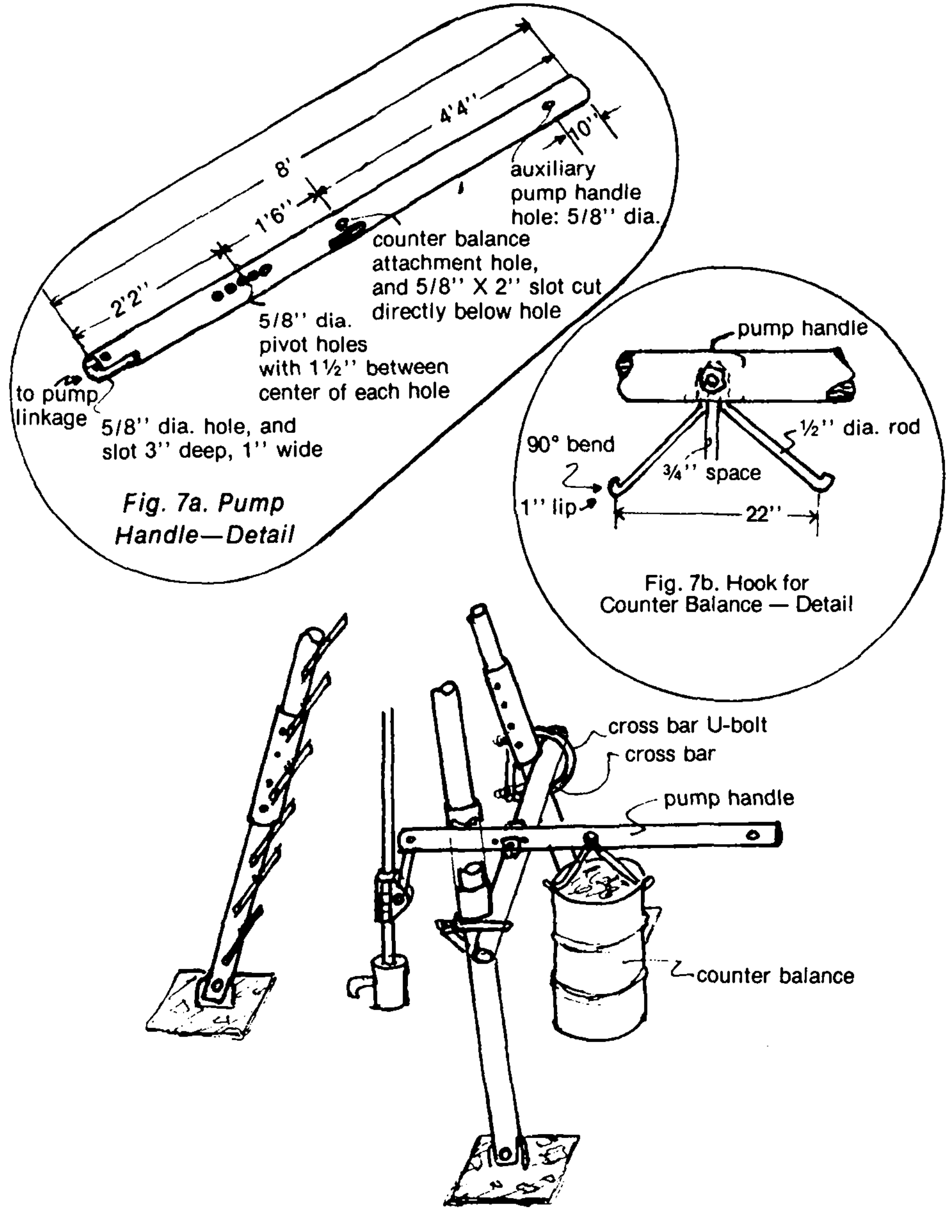


FIGURE 7. PUMP HANDLE & COUNTER BALANCE

Superstructure

The superstructure contains most of the non-moving parts which together pivot around the vertical axis of the tripod as the wind changes direction. The parts of the superstructure include the tail, tail center pipe, main shaft, rocker arm support housing, and brake.

A) Tail & Main Shaft

The first part of the superstructure to be made is a 4'6'' piece of 2½'' dia. pipe that forms the tail center pipe. It will later fit inside the tripod center pipe.

Weld a ring made of ½'' dia. rod around the tail center pipe at a point 2'6'' from what will become the lower end (this ring is made in the same way as the tripod wear ring, and will be rubbing against it—see page 17).

Next, prepare the main shaft, a piece of 1½'' dia. X 2'4'' steel rod. This rod should receive a ½'' dia. hole placed ¾'' from the end, to be used to keep the hub wheel in place. Inspect the surface and make sure that the bearings you are going to use in the hub will slide over the main shaft smoothly, but snugly. Remove burrs with a file, or if more material must be removed, have the shaft turned on a metal-working lathe. Be certain that the bearings will pass over the shaft smoothly—after this shaft has been welded onto the main superstructure, it will be too late to easily correct diameter problems.

Next, weld the shaft at a 90-degree angle onto the tail center pipe at the top end (2' above the wear ring).

The tail frame is made of ¾'' pipes. Two 12' pieces are welded to the main shaft, descend to the tail center pipe, and then go straight back to form the bottom of the tail frame. Weld these two pipes at a 56-degree angle to the main shaft at a point 14 inches from the outside of the tail center pipe (see Figure 8). These two pipes go around each side of the tail center pipe, passing on top of the tail center pipe wear ring. They are bent at a 90-degree angle to the tail center pipe after being tack welded at the points of contact. They are then extended straight back and the ends are pounded together to form a smooth tapered joint—weld the pipes at this point. Add a 2' piece of ¾'' pipe to extend the tail to its full length. With another single 12' piece of ¾'' pipe, form the back and top of the tail in the shape shown in Figure 8.

Complete the frame with ¾'' pipes for the remaining vertical and three diagonal tail braces. The exact shape of the tail is not important, but it must be relatively flat and sturdy. The tail frame should be as flat as possible, but it does not require precise measurements.

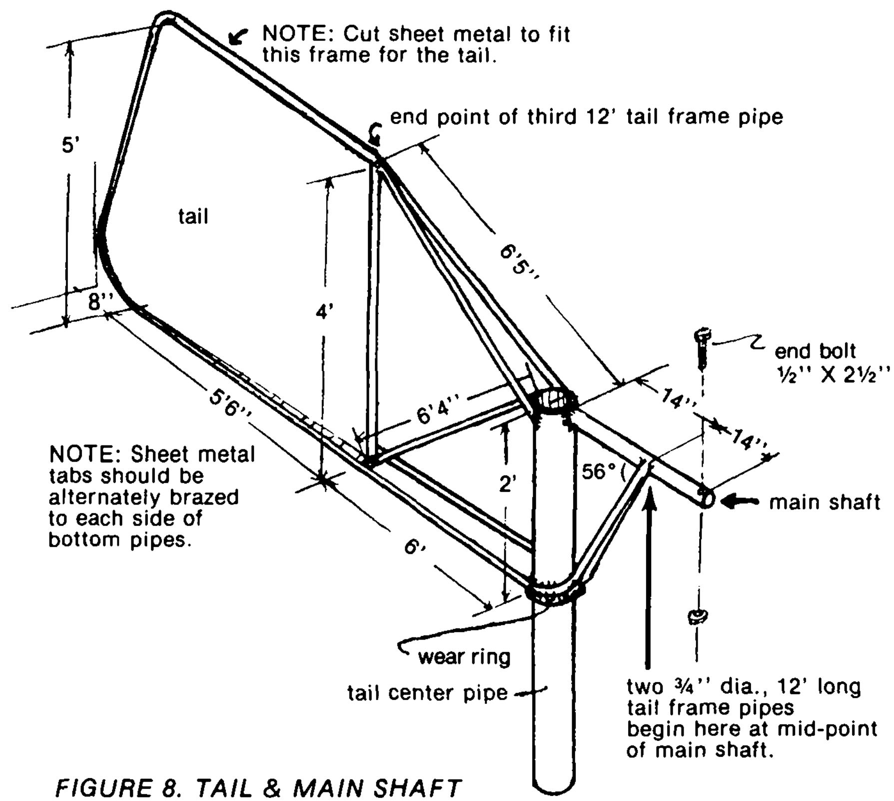


FIGURE 8. TAIL & MAIN SHAFT

The sheet metal can now be brazed onto the frame. The easiest way to do this is to cut the sheet metal to fit inside the frame and spot braze it to the top, front and back of the frame. Attachment to the bottom of the frame is a bit more difficult because there is a space between two pipes. This can be done by cutting 2'' deep slots every 4'' along the bottom edge of the sheet metal. Alternately bending these tabs into contact with each one of the two pipes will enable you to complete the spot brazing of the sheet metal to form a rigid tail structure. It is not important exactly how this is done.

B) Rocker Arm Support Housing

The rocker arm support housing is welded to the tail center pipe and the main shaft. The rocker arm (shown on page 24) will be attached to the top of the rocker arm support housing (in place in Figure 14 on page 25).

This support housing is made entirely of ¾'' dia. pipes. Because this part is the most complex of all, several detail drawings are provided (Figures 9, 9a, 9b, 9c). Each part is numbered and located in all the drawings. It is important to construct this unit carefully because each pipe will be under stress when the windmill is running.

These drawings do not show exact lengths for many of the pieces because there are many different ways to cut and join the pipes. The exact lengths depend on the method used by a particular craftsman. For example, one may choose to cut off a pipe end at a 90-degree angle and then fill in the space between that pipe and the curved surface it connects to. A different person

continued ⟶

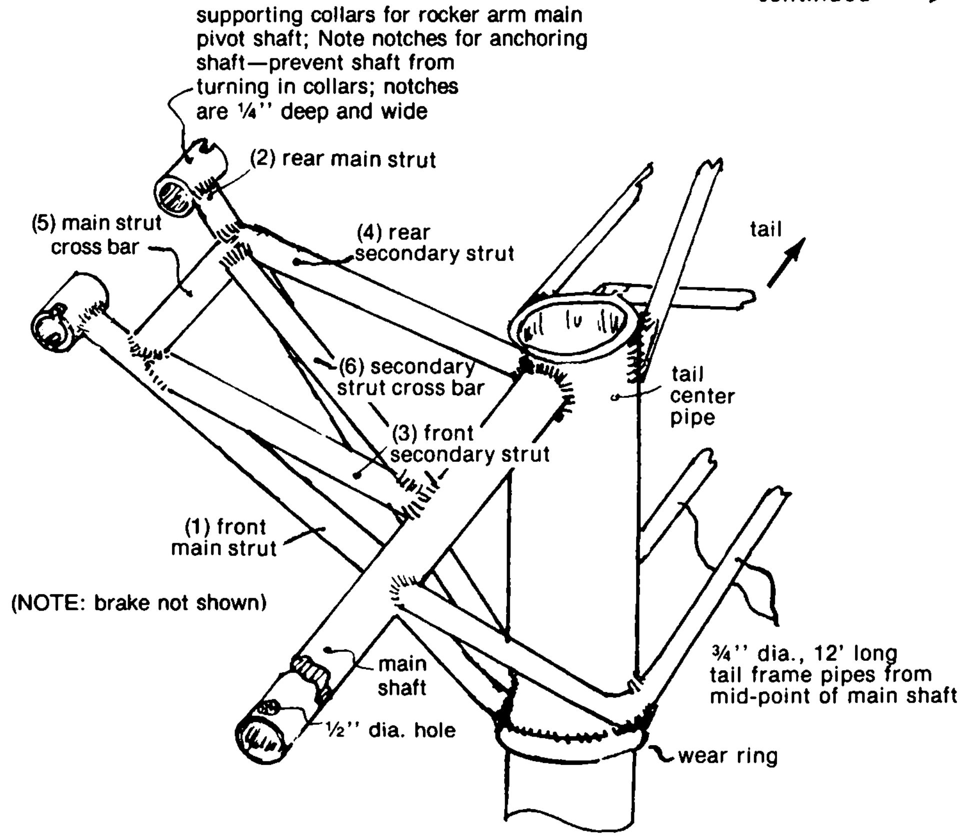


FIGURE 9. ROCKER ARM SUPPORT HOUSING

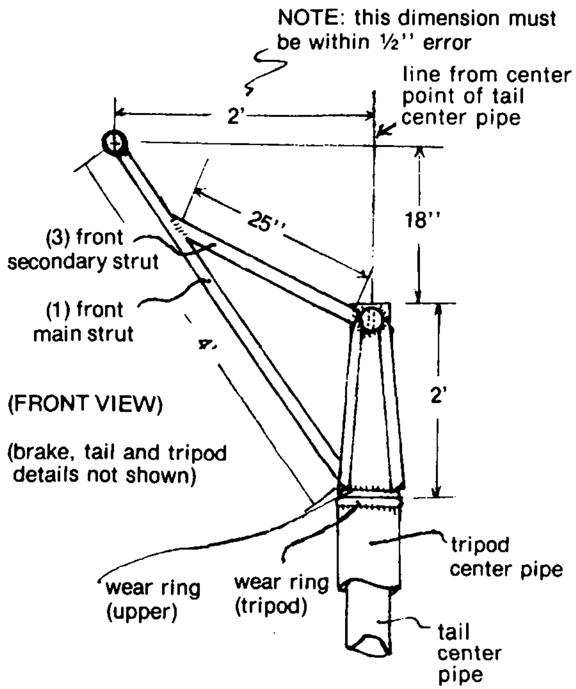


Fig. 9a.

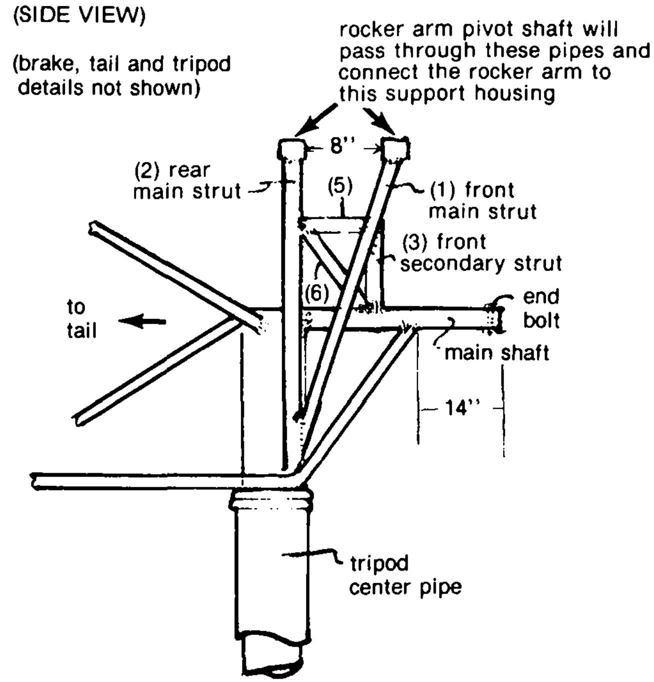


Fig. 9b.

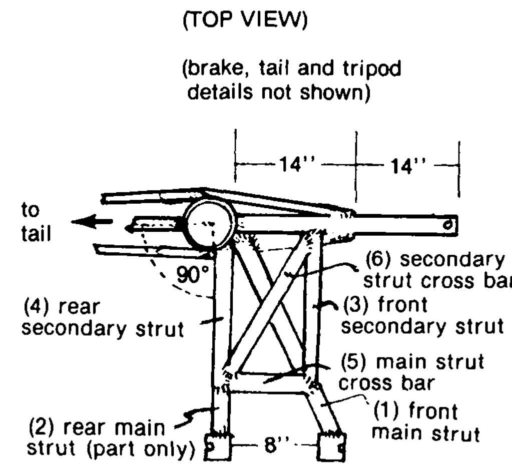


Fig. 9c.

might instead attempt to grind the surfaces to match before welding. Experience shows that it is best to decide upon a method of making the joints and then figure all of the dimensions on that basis. You may need some practice to make this unit accurately.

There are a total of six ¾'' dia. pipe pieces that together form the rocker arm support housing. They are identified in Figure 9 with the numbers 1 through 6: 1) front main strut; 2) rear main strut; 3) front secondary strut; 4) rear secondary strut; 5) main strut cross bar; and 6) secondary strut cross bar. Pipes 1 and 2 will be about 4' long; pipes 3 and 4 will be about 25'' long; pipe 5 will be about 7'' long; and pipe 6 will be about 26'' long. However, the actual lengths will be determined by the method of fitting the pipes, and by following the important dimensions in Figures 9a and 9c: a) the tops of pipes 1 and 2 must be 8'' apart; b) pipe 2 should be exactly 2' from a point 18'' directly above the center point of the top of the tail center pipe (Figure 9a, top).

The front and rear main struts are each fitted at the upper ends with a 1½'' piece of 1'' dia. pipe (see top of Fig. 9b.). These pieces will hold the rocker arm pivot shaft. Attach these 1'' dia. pipes after the rear, front, main and secondary struts are welded in place, and after the rocker arm has been made (see page 24). Note the notches made in each of these 1'' dia. pipe segments shown in Figure 9; the notches are made to lock the pivot shaft, preventing it from wearing out these 1'' dia. pipe segments. The wear will therefore occur on the pivot shaft and rocker arm, which can be easily replaced.

Attaching the 1'' dia. pipe segments last allows a final correction for error in the total alignment. These rocker arm pivot axes cannot be more than ½'' out of parallel alignment to the hub shaft, so construct the support frame and rocker arm carefully.

C) Brake

The brake allows you to stop the windmill while the wind is blowing; for inspection, maintenance, or repairs.

There are six parts of the brake:

1) The brake rod, made of 3/8" dia. rod, which extends from ground level up through the center pipe.

2) The brake lever, made of ¼" X 1" metal strap, 15" long, which connects the brake rod to the brake shaft, and is attached to a spring.

3) The brake return spring, which pulls the brake away from the hub wheel when the brake rod is released; 10" long, attached to brake lever (see Fig. 10).

4) The brake shaft, made of 1" dia. steel rod, which extends from the mid-point of the brake lever to the brake shoe.

5) The brake shaft housing, made of 1" dia. pipe, which supports the brake shaft and allows it to rotate.

6) The brake shoe, made of 1/8" steel plate and curved as shown in Figure 10a, which is welded to the brake shaft. The brake shoe rubs against the rubber tire on the hub wheel after assembly, when the brake rod is pulled.

The brake is welded together only after the hub wheel assembly is completed (see pages 26-27). The brake shaft housing is welded heavily under the rocker arm support housing pipes 3 and 4 (see Figure 9). The brake shaft housing must be parallel to the main shaft (see Figure 11). The thickness of the rubber tire bolted to the hub wheel affects the location of this brake assembly, so you will have to wait until you can place the hub wheel onto the main shaft. A space of about ½" between the brake shoe and the rubber is desired. When viewed from the top, the 1" dia. brake shaft housing pipe should extend forward up to the edge of the brake shoe, to provide maximum support for the brake shaft (Fig. 11a). You will have to determine the precise measurement of this shaft and housing after the rubber tired hub wheel is in place.

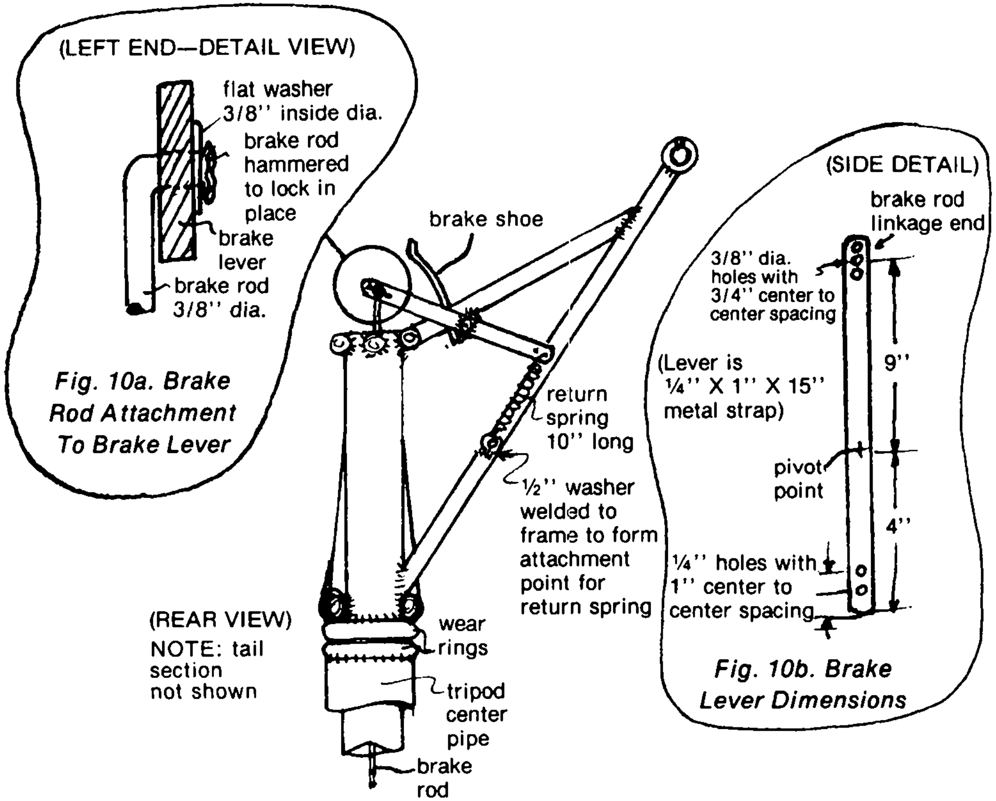


Fig. 10a. Brake Rod Attachment To Brake Lever

Fig. 10b. Brake Lever Dimensions

FIGURE 10. BRAKE LEVER ASSEMBLY IN POSITION

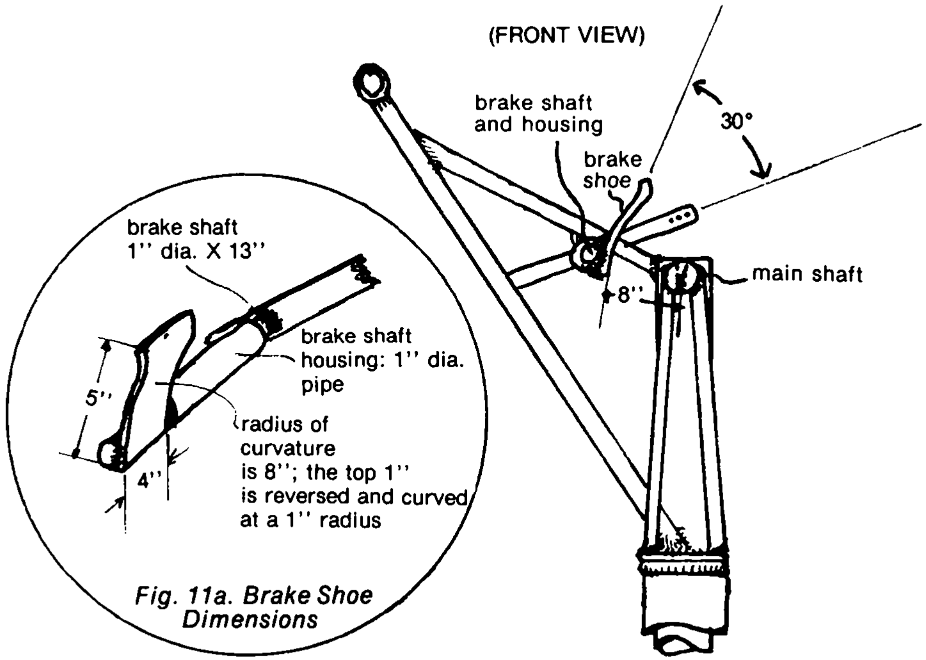


Fig. 11a. Brake Shoe Dimensions

FIGURE 11. BRAKE SHOE & LEVER ALIGNMENT

Rocker Arm

The rocker arm is a rectangular frame which pivots on the end attached to the rocker arm support housing. The other end of the rocker arm is connected by a shaft to both the eccentric wheel and the pump rod. As the eccentric wheel is turned by rubbing against the hub wheel, the rocker arm and pump rod move up and down because the hub of the eccentric wheel is off-center.

Strong twisting stresses are placed on the rocker arm—therefore, the frame must be accurately measured and each joint must be thoroughly welded.

The short end pieces are 1'' dia. pipe and the other pieces are 2'' dia. pipe. Slightly flatten each end of the 2'' dia. pipes to insure a closer fit to the 1'' dia. pipes.

The rocker arm pivot shaft connects the rocker arm to the rocker arm support housing. The pivot shaft is made of 1'' dia. steel rod, 12'' long (Fig. 12). It passes through one end of the rocker arm and the two 1½'' pieces of 1'' dia. pipe, at the tips of pipes 1 and 2 of the support housing (Fig. 9b.).

The 1'' (inside dia.) nut welded to the end of the eccentric wheel shaft will become the attachment point for the pump rod. A washer between this nut and the rocker arm 1'' pipe will allow this shaft to move freely as the rocker arm travels up and down. When the eccentric wheel is placed on the other end of this shaft you must have at least 1'' clearance from the rim of the eccentric wheel. If not, add washers or a short section of 1'' pipe to the eccentric wheel shaft between the rocker arm and the eccentric wheel.

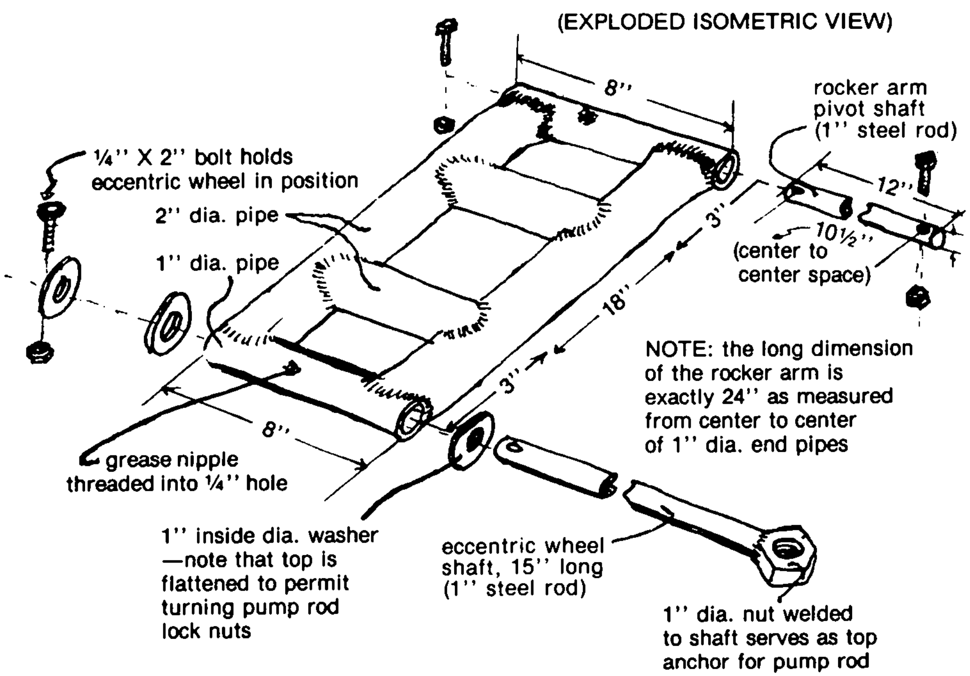


FIGURE 12. ROCKER ARM WITH PIVOT AND ECCENTRIC WHEEL SHAFT

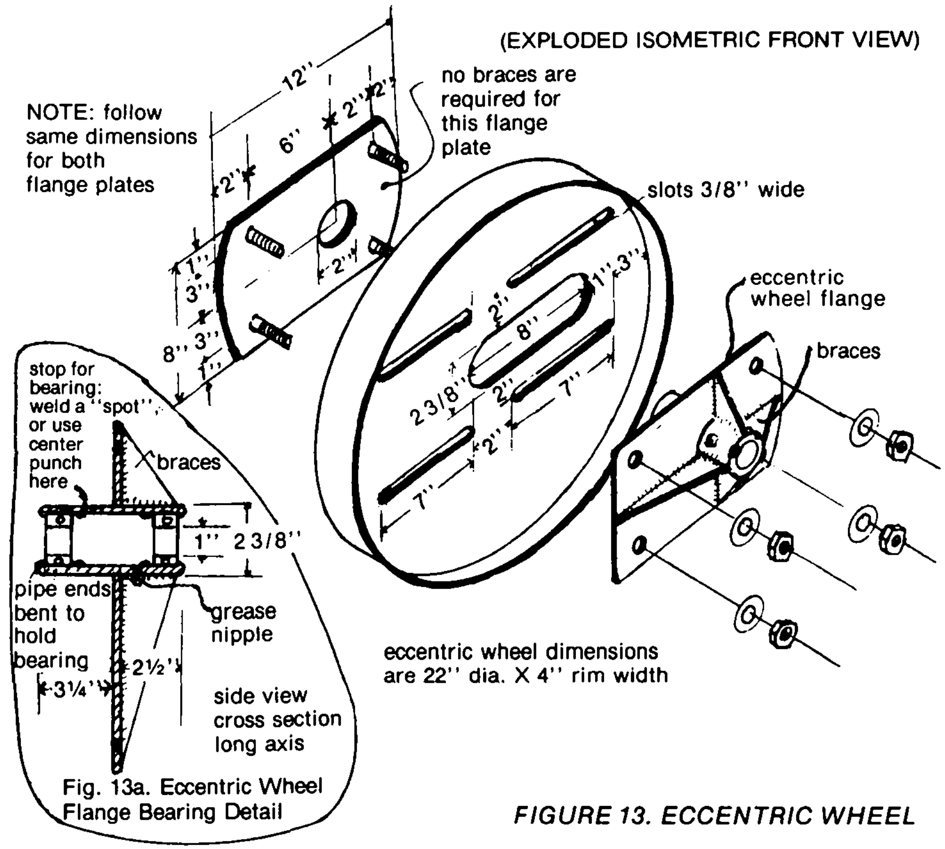


FIGURE 13. ECCENTRIC WHEEL

Eccentric Wheel

The eccentric wheel is a round metal wheel with a hub located off-center. As the eccentric wheel is driven by the hub wheel, this off-center hub forces the eccentric wheel shaft to move up and down. The eccentric wheel shaft passes through one end of the rocker arm and connects to the pump rod. All three of these parts move up and down together.

The eccentric wheel is cut from 1/8'' steel plate. It has a flange (also cut from 1/8'' plate) which consists of a male and a female part. The flange is made using 2'' dia. pipe for the bearing housing. This works well for Arusha, Tanzania, where there are a lot of bearings with 1'' inside dia. and 2'' outside dia. You should match bearings to a particular pipe size before beginning to make this part. The outside diameter of the bearing does not matter if it fits snugly into available pipe. The pipe size for the bearing housing could range from 1½'' to 3'' dia. without affecting the operation of the eccentric wheel. The eccentric wheel shaft diameter, however, can only be *increased* to meet the pipe size matching requirements, and this would require enlarging the rocker arm pipe into which it fits. (Decreasing the diameter of this shaft would make it too weak.)

If it appears impossible to match available bearings to available pipes, you can change the pipe diameter. Cut 8 slots (2" long) in the housing pipe and open up or close the pipe ends to insure a snug bearing fit. If you do this, be sure to weld closed all the slots after the proper adjustment has been made.

The female flange plate (shown in the upper left of Fig. 13) is provided with four 5/16" dia. X 1" machine bolts. These are to pass through the four 5/16" holes of this plate, through the slots of the eccentric wheel disk and through the male flange plate where they are tightened in place. Tack weld the bolts to the female flange plate for easier adjustment in the future.

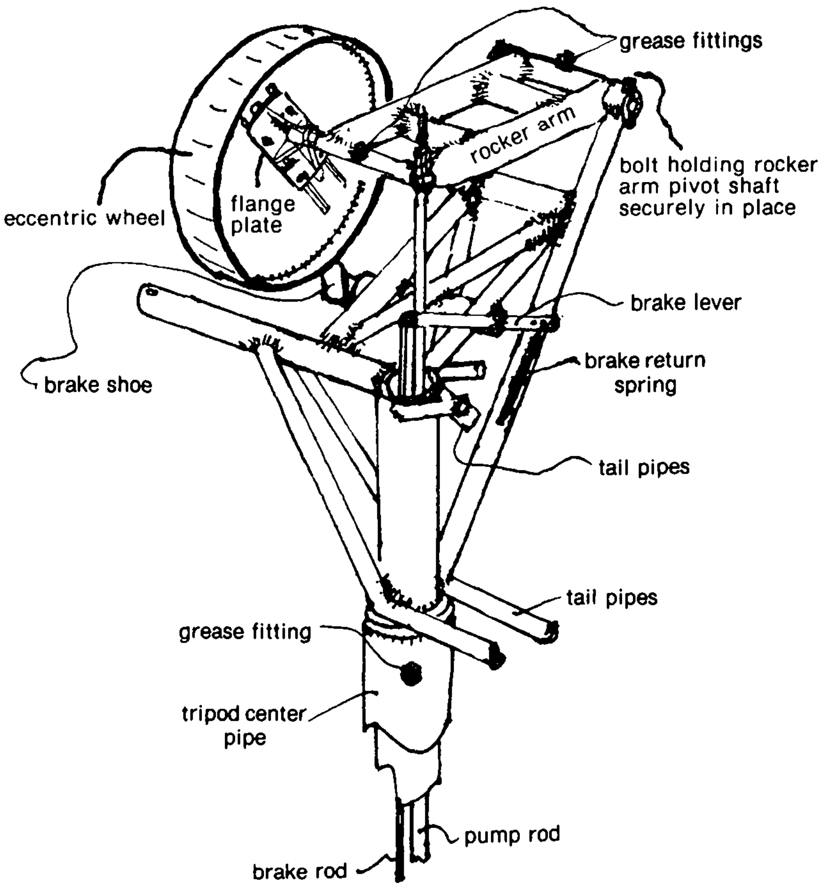


FIGURE 14. ROCKER ARM SUPPORT HOUSING, BRAKE, ROCKER ARM AND ECCENTRIC WHEEL IN POSITION (after assembly)

The male flange plate has the same dimensions as the female, but includes the bearing housing. If the bearings fit snugly into the pipe, the bearing housing is indented with a center punch to prevent the bearings from sliding too far into the housing. If the bearings do not fit snugly into the pipe, you should spot-weld some "stops", as shown in Figure 13a. At three equally spaced positions, the ends of the bearing housing are bent over to contain the bearings snugly in place (see Figure 13a). Note that the bearings should not be put in place until all welding on this section is complete.

When constructing the eccentric wheel: 1) cut out the disk (22" dia.); 2) cut the slots in the disk (Figure 13); 3) cut out a 4" X 70" strip of the same 1/8" plate. This strip is tack welded at one end to the edge of the disk. Mark a center line down the strip to insure that the disk and rim unit will be flat. The strip is then wrapped around the disk with short tack welds being located every 4 or 5 inches. When the rim ends come together properly, finish by welding the disk to the rim all the way around.

(FRONT ISOMETRIC VIEW)

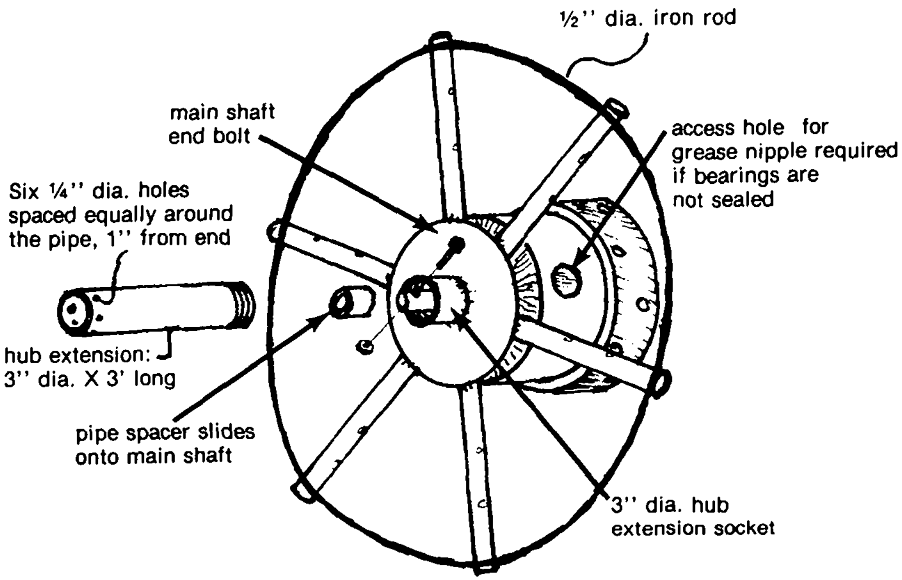


FIGURE 15. HUB WHEEL AFTER ASSEMBLY

(CROSS SECTION)

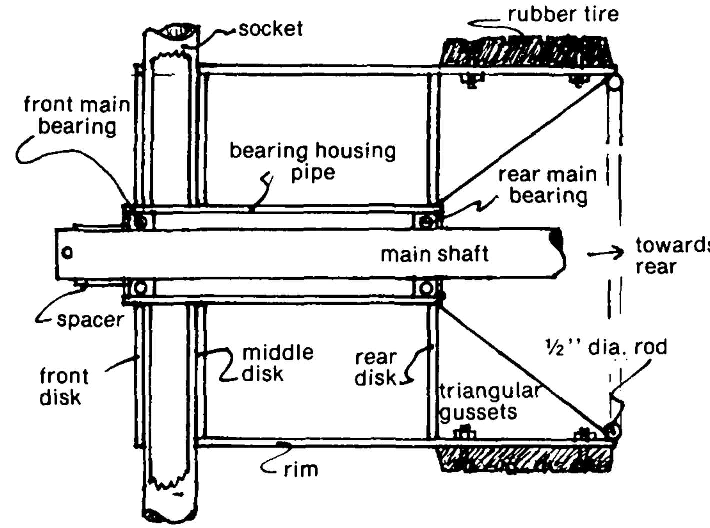


Fig. 15a. Hub Construction

Hub Wheel Assembly

The hub wheel is the central rotating part of the windmill. It slides over the main shaft, where it is held in place with a bolt. There are six hub sockets which connect to the blades. A 4'' wide strip of rubber tire is bolted to the back end of the hub wheel, and drives the eccentric wheel. This tire also provides a surface for the brake shoe to rub against when you want to stop the windmill.

The hub has the following parts:

1) Two 1½'' inside dia. X 2½'' outside dia. ball bearings (plus a grease nipple if the bearings are not sealed), which slide over the main shaft.

2) A 9'' length of 2½'' dia. pipe, to house the bearings.

3) A fabricated metal wheel rim (made from 1/8'' steel plate), 9'' wide.

4) Three 12'' dia. steel disks that fit inside this wheel rim and around the bearing housing, made from 1/8'' steel plate.

5) A 4'' wide strip of rubber cut out of an old 4- to 8- ply auto or truck tire.

6) Six 1¼'' dia. pipes, 2' long, to serve as the hub sockets for the blades.

7) A 3' length of 3'' dia. pipe and a 3'' pipe socket, for the hub extension.

8) Twelve ¼'' X 1'' bolts for attaching the rubber tire to the hub wheel.

9) One ½'' X 2'' bolt which passes through the main shaft and prevents the hub wheel from coming off.

The hub bearing housing should be made first. This is made of 2½'' dia. pipe. It is best to first carefully look at your resources to see if the available bearings and available pipe will match. If the bearings and pipe do not match, use the same method used with the eccentric wheel bearing housing correct this (see page 24).

After matching the bearings to the 2½'' dia. housing pipe, cut that pipe to a 9'' length.

Next, cut six pairs of slots ½'' deep into the end of the bearing housing (Figure 16a). This creates ¼'' wide metal tabs which will later be bent over the bearings to prevent them from sliding *out*. Before you bend these tabs, you must make several spots with a welding machine, around the inside of the bearing housing. This is to prevent the bearings from sliding *in*, and it must be done before placing the bearings inside. Be sure to consider the width of the bearings before welding these spots—they are hard to remove if you make a mistake.

If the bearings are not sealed on the inside of the bearing housing, it is necessary to drill and tap a small hole for a grease nipple on the bearing housing. This should be placed about the mid-point of the housing.

After making the bearing housing, cut three 12'' dia. disks out of 1/8'' steel plate. Cut holes in the centers of the disks, to allow them to slide over the bearing housing pipe. One disk is then welded to the bearing housing, ½'' from what will become the rear. The second disk is welded 2½'' from the other

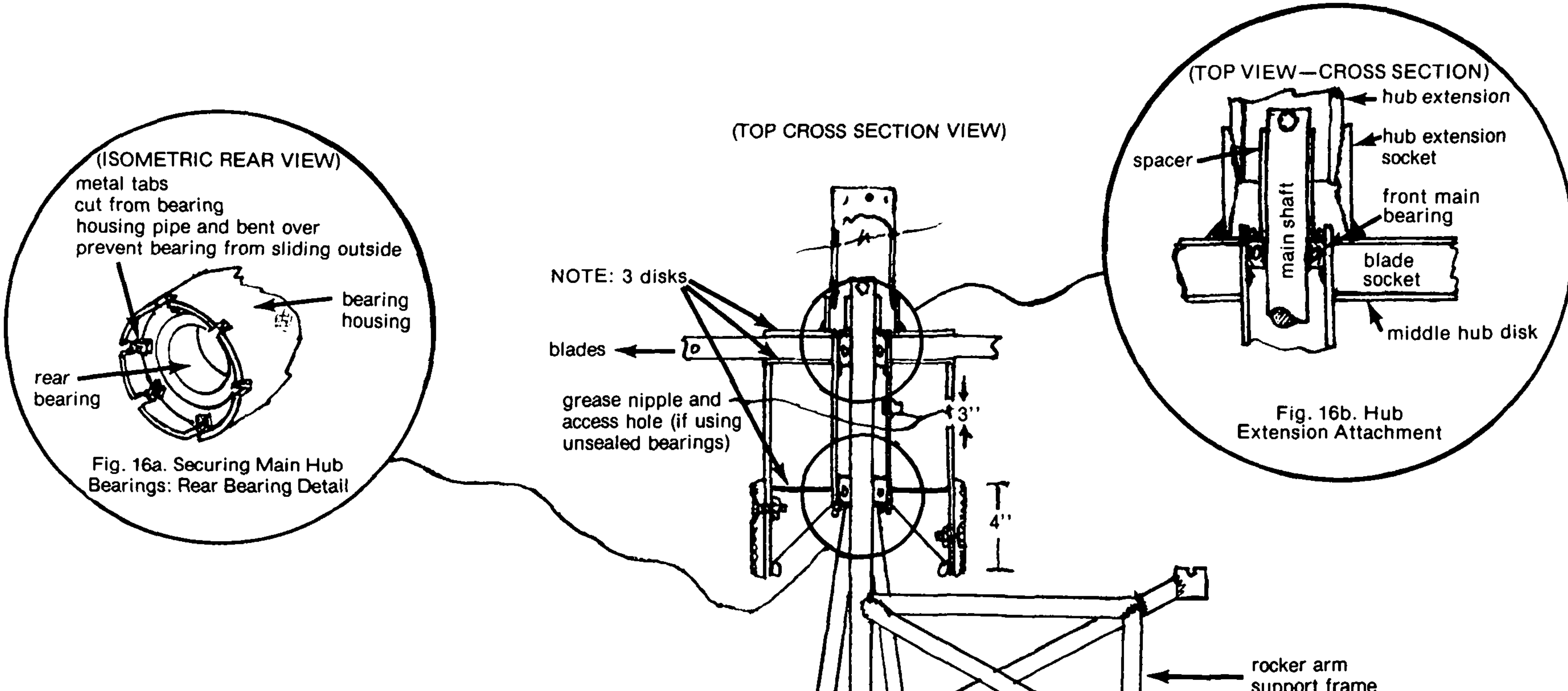


Fig. 16a. Securing Main Hub Bearings: Rear Bearing Detail

Fig. 16b. Hub Extension Attachment

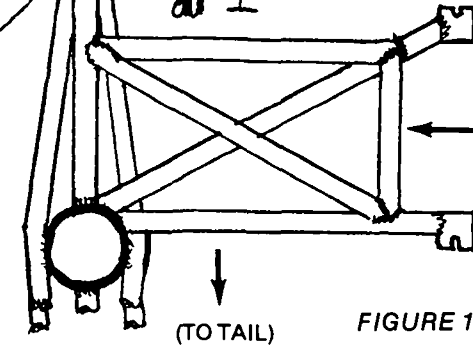


FIGURE 16. HUB WHEEL INTERIOR PARTS

end (front) of the bearing housing. Put the third disk aside, to be attached later.

Six triangular gussets, cut from 1/8'' plate are then placed around the outside of the rear disk and extending out beyond the rear of the bearing housing (shown in Figure 15a). These stick out from the bearing housing like six spokes. Weld the gussets to the rear disk and bearing housing.

Form a ring from ½'' dia. rod and weld it in place around the gussets (see Figure 15a), taking care to make a 12'' outside diameter.

Next, form a wheel rim out of 1/8'' steel plate, to cover the two disks and gussets. The piece of plate for this wheel rim is 9'' wide and about 38'' long. As with the eccentric wheel rim, you will probably find that it doesn't wrap around easily or accurately on the first try and that you will have to adjust the 38'' length. If a grease fitting is to be used on the bearing housing pipe, it will be necessary to cut a 3'' dia. access hole in this wheel above the grease fitting.

Attach the 4'' X 40'' strip of rubber tire (taken from the center section of an old 4- to 8- ply auto or truck tire) around the last 4'' of the hub rim. This can be done by using twelve ½'' X 1'' bolts, evenly placed along the rim. When drilling the holes for these bolts, leave at least 3/4'' of space (for the nuts) between the holes and both the gussets and the ring. Tighten the bolts until the heads sink deep into the rubber. The two ends of the rubber tire should each be given two bolts.

Next, attach the hub sockets. The blade spokes will fit into these hub sockets during assembly. These sockets are 2' lengths of 1¼'' dia. pipe, each of which is drilled twice with ½'' dia. holes (spacing shown in Figure 15). The ends of the hub sockets rest on the bearing housing pipe. It may be necessary to add shims to some of them to insure that all of the hub sockets lie in a plane perpendicular to the main shaft. Weld the sockets solidly to the 12'' dia. disk behind them. A ½'' dia. soft iron rod is welded to the outer edges of each hub socket to form a ring (about 4'3'' dia.) for all six sockets of the hub wheel (Figure 15). No precision is required—simply connect each socket to the rod with strong welds.

Next, weld the third 12'' dia. disk (cut earlier and put aside) solidly to the front of the hub sockets, and to the bearing housing. Then weld a 3'' pipe socket to this front disk so that it accurately fits over the bearing housing (Figure 16b). A 3' piece of 3'' dia. pipe becomes the hub extension—it is screwed into the 3'' pipe socket. Six ¼'' dia. holes are drilled ¾'' from the front end of this pipe, as shown in Figure 15, for attachment of the radial guy wires (next section).

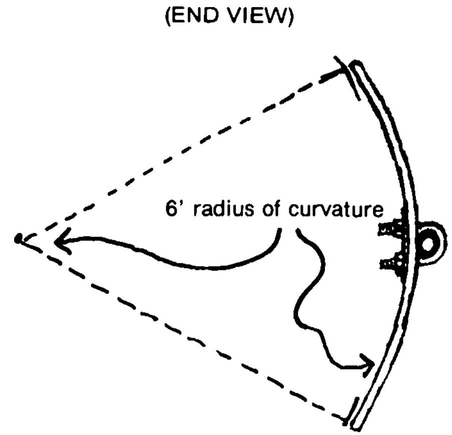


Fig. 17a. Blade Contour

Blades

The six blades provide the surface for the wind to push against. Because the blades are turned at a slight angle to the wind, when the wind hits them they move sideways. This causes the hub wheel to rotate.

The blades are made of 24 to 28 gauge galvanized corrugated sheet metal. The most difficult problem in making them is bending corrugated sheet without a bending machine. The method we used eventually, suggested by an elder Tanzanian craftsman, was to apply heat in two parallel strokes along the length of the blades, 12'' from each side. Heating with a welding torch was found to be most effective when we bent the material as we went along. You will need to braze two sections of corrugated sheet together to make a 6' piece with corrugations running perpendicular to the length. Brazing at five spots on both front and back of the blades was found to be sufficient.

When the corrugated metal of the blade is complete, the blade is fastened to the spoke (1'' dia. pipe, 8' long) with U-bolts. (Note that the U-bolts should pass through the part of the corrugation which comes into contact with the spoke. If you do it the other way, you'll find that tightening the U-bolt merely flattens the corrugation without providing a stronger attachment.)

For the present time attach the blades loosely to the spokes. Exact pitch adjustment, made only at the field site, is accompanied by final tightening of the U-bolts (see ASSEMBLY section). The blades should be carried to the site before placing them into the hub sockets (during final assembly).

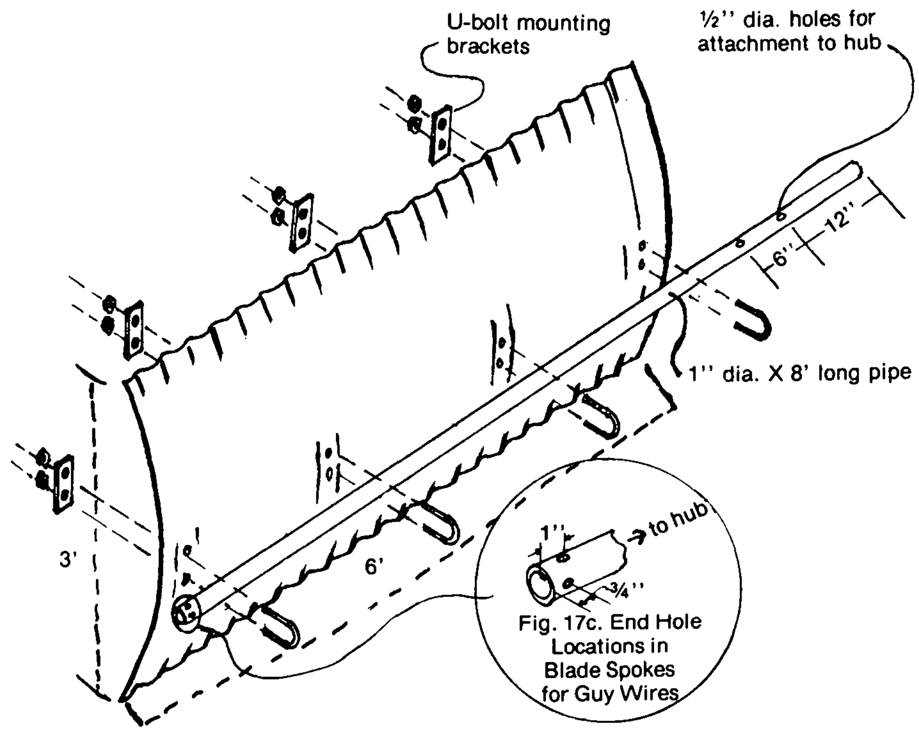


FIGURE 17. BLADE & BLADE SPOKES

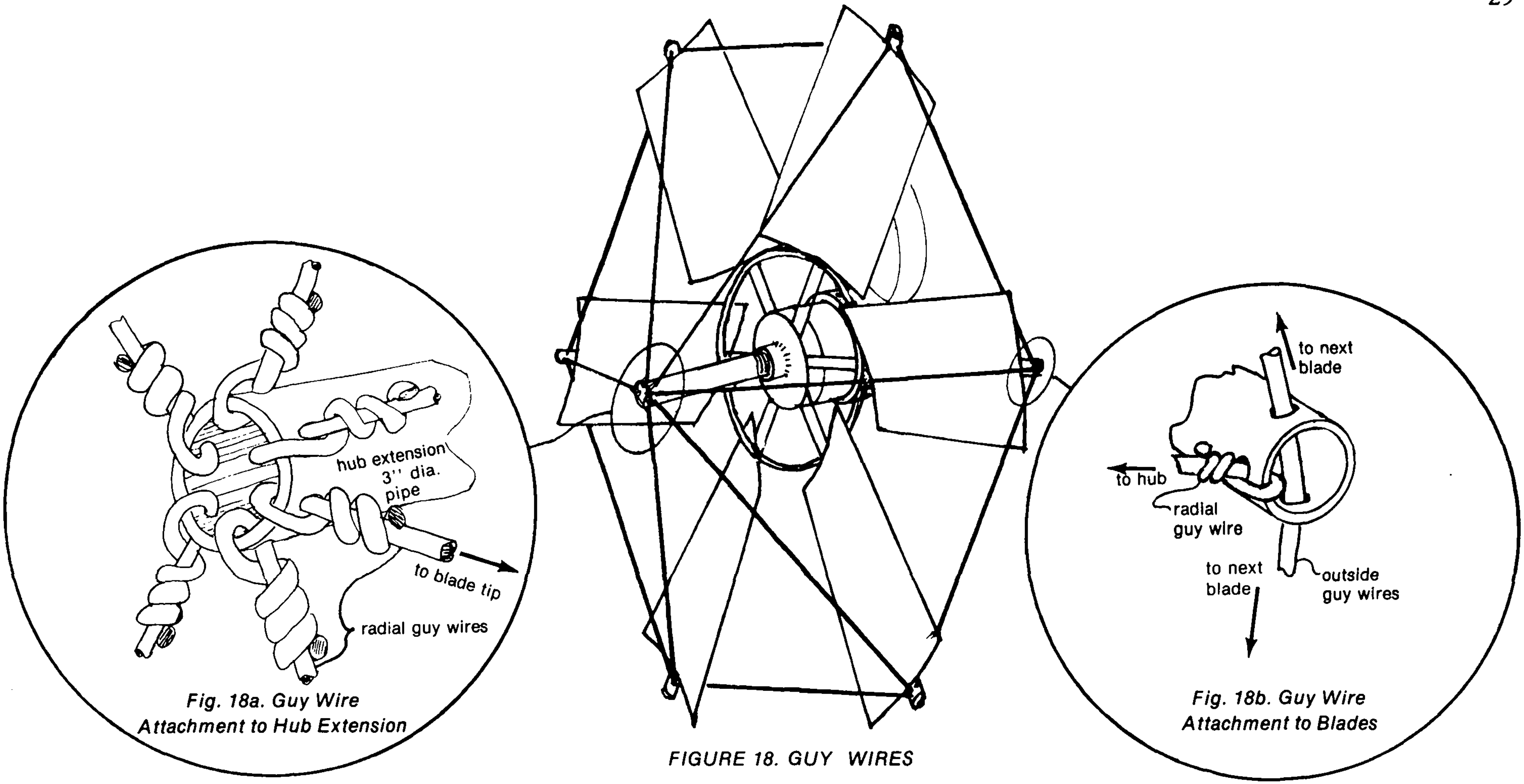


Fig. 18a. Guy Wire Attachment to Hub Extension

Fig. 18b. Guy Wire Attachment to Blades

FIGURE 18. GUY WIRES

Guy Wires

The guy wires are used to strengthen the blades. There are two types of guy wires. One is a set of radial guy wires which go from the tip of the 3' hub extension to the blade tips. The second type connects the tips of the blades. The radial guy wires are made of six 9-foot sections of 1/8-3/16'' dia. galvanized steel wire. The purpose of the radial guy wires is to keep the blades in line and no less than 12'' in front of the tower (measured from the blade tips).

The guy wires between blade tips should be one 52' long piece of the same *wire used for the radial guy wires.*

We have found that the best way to tighten the radial guy wires is to add a turnbuckle at or near the point where each radial guy wire is attached to each blade tip (not shown).

Concluding Remarks

This completes the construction details of the windmill. We hope you will investigate the resources in your area before beginning to build the windmill. You will probably want to consider some substitutions.

The next section explains the order of assembly of the various parts, after you have arrived at the field site. Remember that we designed this windmill to be transported long distances over rough terrain before assembly in remote areas.

Assembly, Raising the Windmill, and Final Adjustments

Take the following tools and supplies to the site:

- spare bolts and nuts of all sizes used
- two 50-foot lengths of 1'' dia. rope
- one 50-foot length of ½'' to 5/8'' dia. rope
- high-lift automobile jack
- round file
- flat file
- two hammers
- first aid kit
- cement (1bag)
- paint
- paint brush
- grease gun
- hacksaw
- adjustable wrenches
- center punch

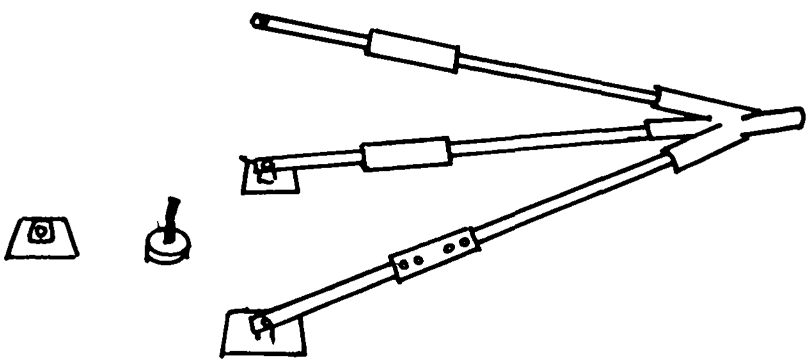
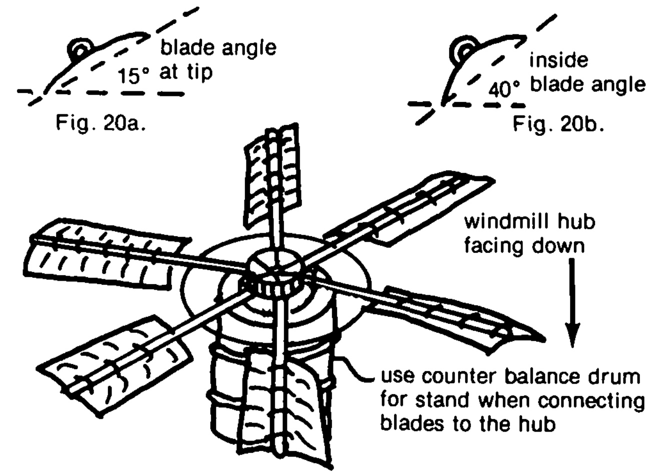


FIGURE 19. TRIPOD, TOWER & FOUNDATION

Assembly

1. Assemble the tower (Figure 19).
   —attach the leg extensions if used.
   —connect the legs to the tripod.
   —bolt two of the legs to the foundation anchor pins (as shown in Fig. 19).



NOTE: rubber tire end of hub on top;
all blade angles are in the same direction

FIGURE 20. BLADES & HUB

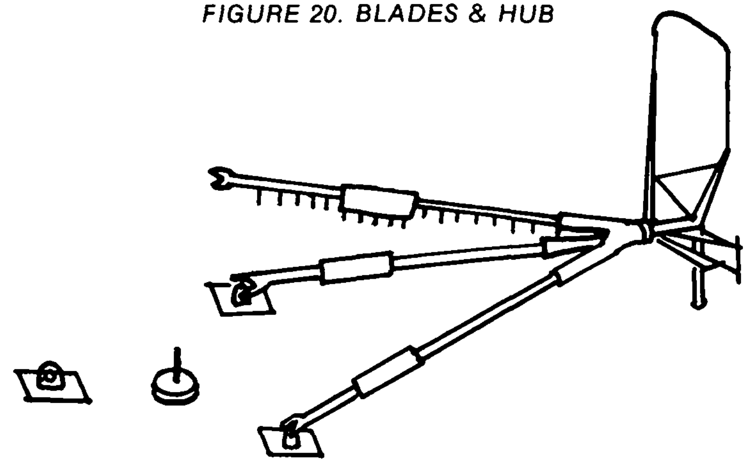


FIGURE 21. TAIL & FRAME INSERTED IN TRIPOD/TOWER

2. Connect the blades to the hub (Figure 20).
   —place spokes in hub sockets, insert bolts, and tighten bolts as much as possible—no movement of these spokes is allowable.
   —tighten the U-bolts that connect the blades to the spokes, making a 40° inside blade tip angle and a 15° outside angle (as shown in Fig. 20a and 20b.).
3. Assemble the top of the windmill (Figure 21 and 22).
   —lift the tripod end of the tower about 4 feet off the ground and set the tail center pipe into the tripod center pipe.
   —put the hub and blade assembly (from STEP 2) onto the main shaft. Secure it with the ½'' dia. bolt and the number of washers needed to insure a snug fit.

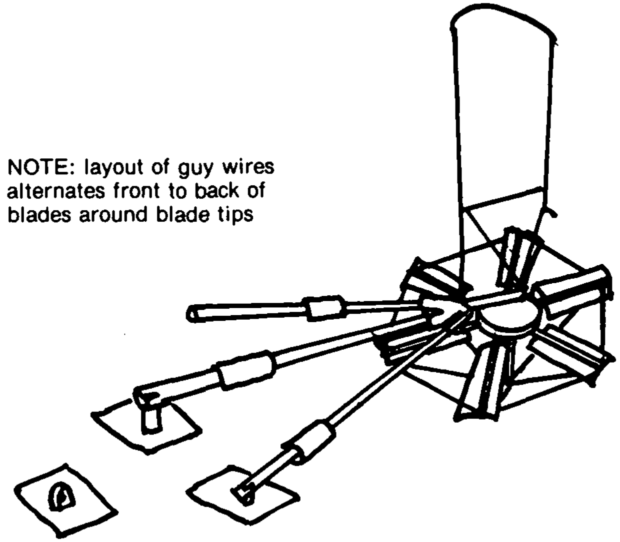


FIGURE 22. POSITION OF WINDMILL FOR HUB/BLADE ATTACHMENT TO TAIL & SUPERSTRUCTURE

4. Attach the hub extension and guy wires.
   —screw the 3' hub extension into the 3'' pipe socket welded to the front of the hub.
   —attach the guy wires to the end of the blades and the end of the hub extension, as shown in Fig. 18a and 18b on page
   —tighten the guy wires until they are stiff, keeping the blades in line and equally spaced. (These guy wires will be adjusted again when the windmill is up in position—see FINAL ADJUSTMENTS).
5. Attach the rocker arm.
   —anchor the pivot shaft connecting the rocker arm to the rocker arm support housing, using two ¼'' dia. bolts, so that the pivot shaft does not turn (see Figure 22a).
6. Attach the eccentric wheel to the rocker arm (Figure 22a).
   —insert eccentric wheel shaft through the rocker arm.
   —add washers to the shaft to make the eccentric wheel align with the hub wheel and clear the rocker arm.
   —place the eccentric wheel on this shaft, and secure it with a ¼'' X 2'' bolt.
7. Add grease for lubrication.
   —pump grease into the tripod center pipe, eccentric wheel hub, rocker arm pivot shaft, and eccentric wheel shaft.
   —smear some grease around the pump rod, and the nuts and wear rings of the tripod.
8. Attach the upper pump rod segment.
   —insert the upper pump rod segment through the tail center pipe and tripod

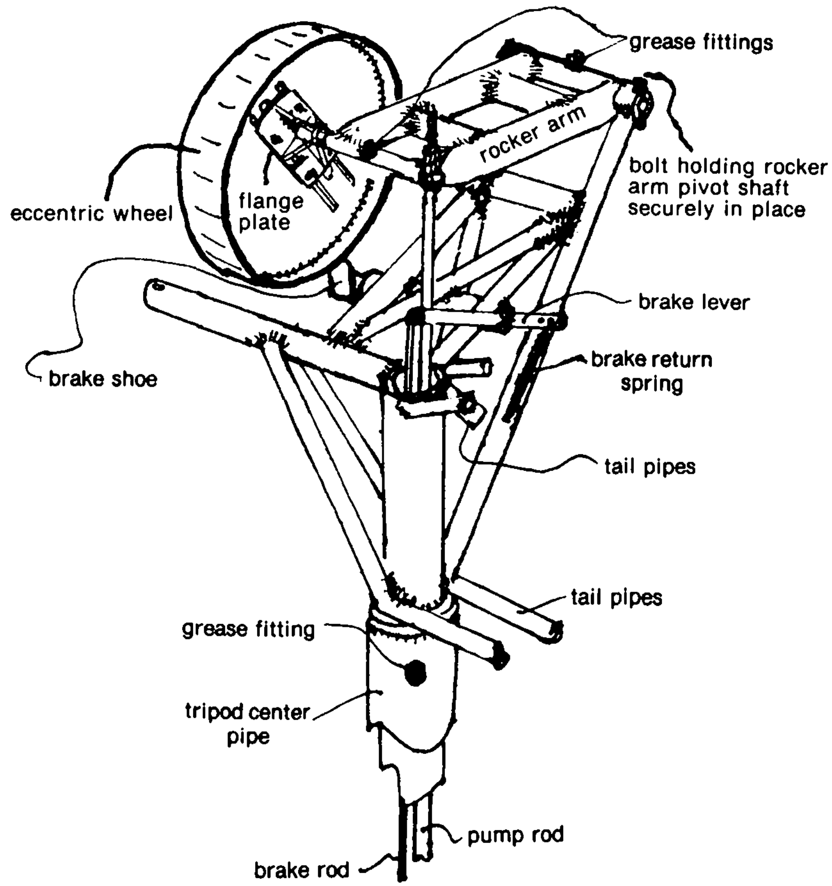


FIGURE 22a. ROCKER ARM, ECCENTRIC WHEEL, PUMP ROD, & BRAKE ROD IN PLACE (hub wheel not shown)

   center pipe (as shown in Figure 22a).
   —put the top of this pump rod segment (5/8'' dia.) through the 1'' dia. nut on the end of the eccentric wheel main shaft (see Fig. 12, page 24).
   —add two 5/8'' dia. nuts above the 1'' dia. nut. These two nuts will hold the pump rod in place, by being tightened against each other. Tighten them by hand—they will be tightened properly during final adjustments.
9. Attach brake rod.
   —insert the brake rod through the two center pipes (Figure 22a).
   —bend the brake rod if necessary, to allow smooth vertical motion of the pump rod.
   —insert the top of the brake rod into the brake lever arm, bending the rod and hammering it to secure it in place (as shown in Fig. 10a, page 23).
   —pull and tighten the brake, and secure it with wire or rope. This will prevent the windmill from turning when it is first lifted into position.

Raising the Windmill

Raising the windmill is perhaps as dangerous as it is exciting—one mistake now and you may lose the whole thing, so be careful!

Approximately 2500 pounds of pull on the rope will be necessary to achieve the first vertical movements in the windmill. By lifting the tripod (using a car jack or 15 people) until the tail can be moved around to the lower side of the tripod (about 10 feet high), you can get to a better position for lifting the windmill to its full height. This position is shown in Figure 23. Because you start pulling after the windmill is partially raised, and two of the legs are already attached to the foundation, pulling with a rope attached to the tripod will lift the whole machine up. Two 1'' dia. X 50' ropes (or cables of the same strength) are recommended for the actual pulling, and you will need another smaller diameter rope (½'' to 5/8'' dia. X 50') for keeping the tail down and for holding the tower steady—especially during the last ten feet of movement into position. Several people should hold on to this safety rope and stand well away from the windmill so that they will not be hurt if the windmill falls towards them.

By experience, we found that pulling the windmill up into position was not difficult, if a Land Rover filled with 500 pounds of weight, or a heavier truck was available. The vehicle must move slowly and smoothly—particularly at those crucial early moments when the rope tension is greatest—because a sharp movement of the vehicle can snap the rope. Be sure to attach the safety rope to the tail, so that the windmill will stop when it gets into position; otherwise, it may fall over towards the truck!

When the tower is in the right position, bolt the third leg to the proper anchor. The car jack will be helpful in aligning the leg and the anchor.

Final Assembly

Now the guy wires at the blades need to be tightened and adjusted to provide a 12'' clearance between each blade tip and the tower. Next comes the attachment of the main pump rod, shear block assembly, tower cross bar, pump handle, and counter balance (see drawings in the construction section, and Figure 24). The brake rod should be cut in two about 10 feet above the ground. Attach a short section of tension spring or rubber to the two brake rod ends (should withstand 40-pounds pull over a 5'' extension).

Final Adjustments

Doing the final adjustments of the windmill is about the easiest activity in the whole assembly process. Several minor details include: 1) finding the required weight of the counter balance barrel on the pump handle; 2) adjusting the eccentric wheel to match the desired pump stroke, wind velocity, water well depth, load and required water yield; and 3) final tightening of the bolts on the shear block.

If you are using this windmill with a borehole pump, the following series of final adjustments should be made in this order:

1) Set the counter-balance drum into position and add rocks or other weights to the drum until the pump rod just rises. Work the pump by hand until water begins to come out, then remove enough rocks to allow the windmill eccentric wheel to be turned by the hub wheel, without slipping. The diameter of the pump, pump rod material, depth, and aquifer level (ground water level)

continued ⟶

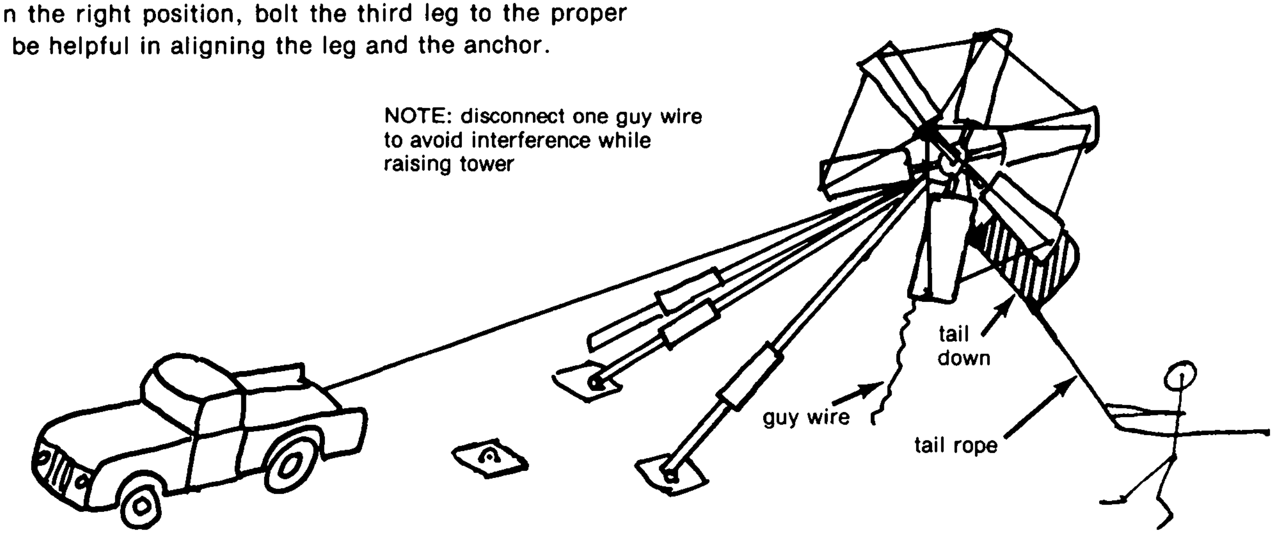


FIGURE 23. POSITION OF WINDMILL JUST BEFORE BEING PULLED INTO PLACE

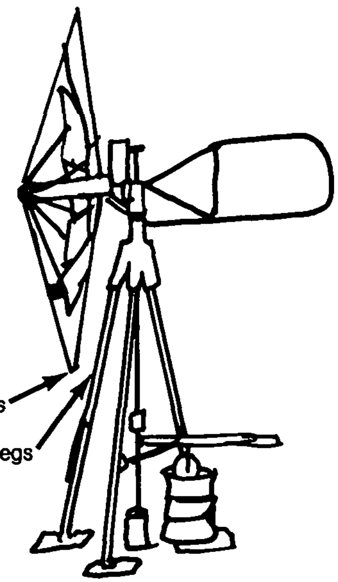


FIGURE 24. WINDMILL IS UP:
ATTACHING THE PUMP ROD, HANDLE, & COUNTER BALANCE DRUM

all control the amount of weight required.

2) Adjust the eccentric wheel flange to fit the desired stroke and work load of the windmill. From our experience, it is better to keep the windmill pumping with a short stroke (low water yield per stroke) than a long stroke which would make the windmill harder to start. Once the windmill is in motion it can accelerate more rapidly to respond to sudden, short-lived gusts—a common condition in our area.

You may feel that we should take more advantage of the higher wind speeds than suggested by the slow and steady approach recommended here. (Available power in the wind is proportional to the cube of wind speed—if wind speed doubles, available power goes up eight times.) In our area there is little steady wind; for example 1-3 minutes of 8 mph wind is followed by short gusts of 15-30 seconds at 15 mph. Experience here proved that adjustment for slow water pump yield for a longer time resulted in both a higher daily output and in longer lasting moving parts. Again, however, it is a question of the type of wind and maintenance facilities in your area. (A general rule is that the more consistent the wind speed, the more you maximize the pump stroke.) Note that moving the flange 1 inch from the center of the eccentric wheel will add 2 inches of movement to the pump rod.

3) Tighten the nuts on top of the pump rod in the exact position desired. Before doing this, make certain that you have enough freedom of movement for the pump piston, by checking to see if the pump rod can be moved 1" above and 2" below the stroke length for which the eccentric wheel is set. The pump rod is secured by tightening the two nuts against each other—both above the "collar" nut on the end of the eccentric wheel shaft. (NOTE: These nuts should not be tightened *around* the eccentric wheel shaft because this will tend to prevent the windmill from pivoting easily on its vertical axis, and could also unscrew the pump rod connections.)

4) The shear block on the pump rod should now be tested. Provide a load of about 1000 pounds on the pump rod with a log or rocks. Next, turn the windmill blades by hand to force the pump rod to lift this weight. Tighten the four bolts which clamp the shear block parts together, until the pump rod can lift this weight without slipping out of the shear block. Test again by adding 200 pounds more weight—the rod should separate from the shear block at this load. Re-set the rod and tighten the nuts again to this point.

5) Check all nuts and bolts and other connections, especially those on the blade sockets and guy wires. Both the radial guy wires and the outer guy wires must be tight. No more than 1½" of deflection should result from a moderate pull at the mid-points of these guy wires. Also, tighten the pump handle linkage nuts to prevent the bolts from turning.

6) Last, climb up the tower with about 1 pint (½ liter) of grease. Put some grease on every exposed nut and bolt (U-bolts included) except the bolt heads in the rubber drive tire. Avoid getting grease anywhere near the rubber tire and eccentric wheel rim. Be careful—parts of the windmill will get rather slippery! This grease is to protect the metal parts from rust.

You've done it. It's time to lay down on your back, prop your head up and ponder this magical source of energy called the wind. For casual and continued reading, go on to the next section about operation and maintenance. It is a short section because there isn't much to worry about.

Operation & Maintenance

It may appear unnecessary to provide rules for the operation of a device which runs on a natural energy source. And certainly you don't 'operate' this windmill, but there are a few things to be said about the **control** of the machine. These include stopping it and letting it run free (disengaged from the pump).

Stopping the Windmill

You will need to stop the windmill for inspection, maintenance, and any necessary repairs.

Stopping the windmill should be done slowly. Pull down on the brake rod gently, allowing the elastic section to absorb any bumps caused by the rough surface of the rubber tire. Some people prefer a simple hook for attaching the brake rod to the tripod legs; other people prefer to tie the brake rod. The pull down pressure is not expected to be more than 40 pounds, so attaching the brake rod securely to the tripod legs should not be a problem. If you are in an area in which the windmill will be turning completely around often, you will need to periodically check that the brake rod does not become wrapped around the pump rod. In two years this occurred only once, in an area of great turbulence. This is a minor, but difficult problem to correct, so we just live with it.

Disconnecting the Drive Mechanism

Disconnecting the drive mechanism from the pump is another way of controlling the machine. It allows you to repair the pump while the windmill continues to move.

Simply raise the pump rod above the maximum position of the eccentric wheel. This can be easily done by adding weight to the counter balance drum, which will allow the windmill to run free.

Manual Operation

The pump can be operated by hand if there is no wind or the windmill is intentionally stopped. Disconnect the drive mechanism (described above), stop the windmill at the top of the pump stroke, and disconnect the main pump rod at the handle linkage. By inserting a piece of wood approximately 2'' dia. X 5' into the end of the pump handle, you can manually operate the pump. This is the size of the hoe handles, the main village agricultural implement in this part of Tanzania.

Maintenance

Every Two Weeks

Maintenance of the windmill involves an inspection every 2 weeks of all the bolts and moving parts. Check the blades closely to be sure that they are not loose. You should oil the pump rod linkage, using 30-weight or heavier oil.

Every Two Months

About every 2 months you should grease the bearings of the hub wheel, eccentric wheel, rocker arm and the tripod center pipe. Avoid getting grease onto the hub wheel or eccentric wheel—grease on either of these parts will cause the eccentric wheel to slip, particularly if a long pumping stroke has been selected. You must cover all exposed threaded parts with grease, to prevent rust.

Each Year

About once a year, check (and if necessary, re-set) the shear block tension as described in FINAL ADJUSTMENTS. The drive tire should need replacement after 1-3 years (for our area, one year's wind produces about 60,000 miles of tire wear, but the load on the tire is far less than that on an auto or truck tire).

A list of equipment and spare parts for operation & maintenance of this windmill over a 10-year period in Tanzania includes:

20 spare bolts (5/8'' dia.) for all the moving pivot linkages
a scrap innertube for the brake rod linkages
3 sets of ¼'' X 1½'' bolts for mounting the drive tire
1 gallon of 30-weight oil
5 gallons of grease
3 spare rubber tire sections for the drive tire
105 feet of guy wire
an adjustable 12'' wrench
a pliers
a hammer
a grease gun

Alterations, Pumps, and Other Uses

Alterations

There are many possible ways of making this windmill cheaper, especially if you don't have to meet the many conditions unique to Tanzania. (Problems: turbulent thermal winds, difficult transport and communications, deep boreholes; Advantages: good basic metal fabrication facilities and ministry administrative support, emphasis on self-reliance.) If conditions favor instead a more standard windmill application, it would easily be possible to construct this windmill for one-half the cost and amount of materials.

Alterations might include using wood for the tower, and a simple crank drive mechanism instead of the eccentric wheel design shown in the manual. The tail could be made of wood and leather hide (see Figure 26). The blades could be made of wooden poles (2'' dia.) and heavy cloth (varnished for protection) or goatskins. (This is the accepted 500 year-old design of the sail windmill from Crete. The Intermediate Technology Development Group has produced a fine manual on this design as modified for use in Ethiopia. A Dutch language version of the original design is also available. See ADDITIONAL READING section.)

These alterations are shown in Figures 25 through 26. Remaining in original form are the tripod and superstructure frame (except the main shaft). Figure 27 shows another possible eccentric wheel design.

Crank Drive Mechanism

The eccentric wheel mechanism has been included in the design of this windmill to enable an increase in the power, in order to operate a reciprocating pump in a deep bore hole. Almost all large water-pumping windmills designed to pump water from deep bore holes have a set of gears. These gears change the ratio of wind rotor rotations to pump rod strokes—to a ratio of greater than 1:1. The eccentric wheel drive has proven to be a relatively cheap substitute for a set of gears, providing a 3:2 ratio. However, construction of this eccentric wheel should certainly not be included in areas where a crank drive (with a 1:1 ratio) will do the job. (See description with Figure 25.)

For shallower pumping needs (75 feet or less) the use of gears is normally not necessary, and a direct drive such as the crank drive shown in Figure 25 is usually sufficient. We have not used the crank drive in Arusha region because the water table typically is found at a depth of about 250 feet.

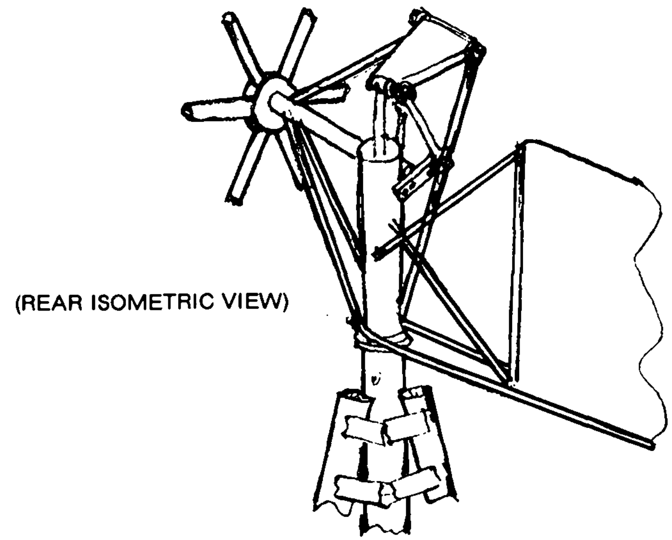


FIGURE 25. CRANK DRIVE MECHANISM

In this crank drive mechanism, the hub wheel and main shaft are locked together as one unit, so that they turn together. The main shaft rotates inside a pipe housing. The supports for the main shaft are welded instead to this housing pipe. The pipe is welded to one side of the tail center pipe, near the top. The main shaft passes all the way through the housing pipe, and is fitted with a crank at the end. The crank has a connecting rod attached, to move the rocker arm up and down. (In this drawing there are three different holes where the connecting rod can be attached. This allows adjustment of the pump stroke.).

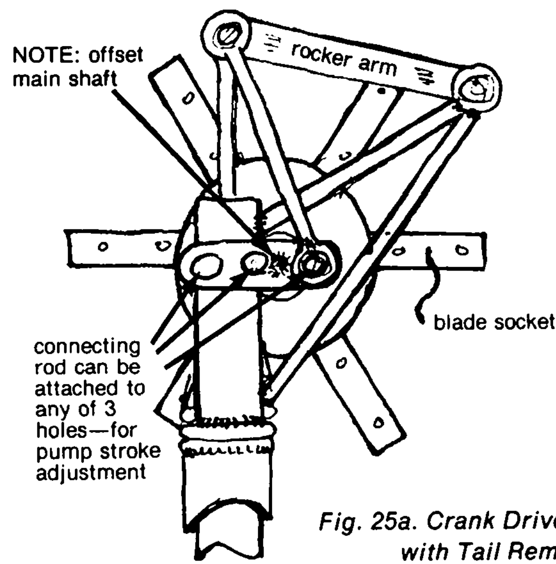


Fig. 25a. Crank Drive: Rear View with Tail Removed

Sail Cloth or Animal Hide Blades

In this design, cloth or animal hide is used to replace the sheet metal blades and tail of the windmill. A modification on the traditional sail cloth windmill can allow the sails to turn slowly away from the wind as the wind speed increases. Called "feathering," this enables the windmill to start up easily at low wind speed and still operate efficiently at full wind speed.* The sails will also "feather" under conditions of high or sudden winds. This protects the windmill from damage. A unique "governing" mechanism is shown in Figure a, which uses a piece of rubber or spring to "feather" the blades.

Another advantage of cloth sails is that they can be removed during storms, leaving only a skeleton structure. In some parts of the world typhoons might damage the windmill if the blades cannot be removed.

*This concept is used in a different, fan-bladed cloth and bamboo spoke design developed by Jean Sahores of France—see ADDITIONAL READING.

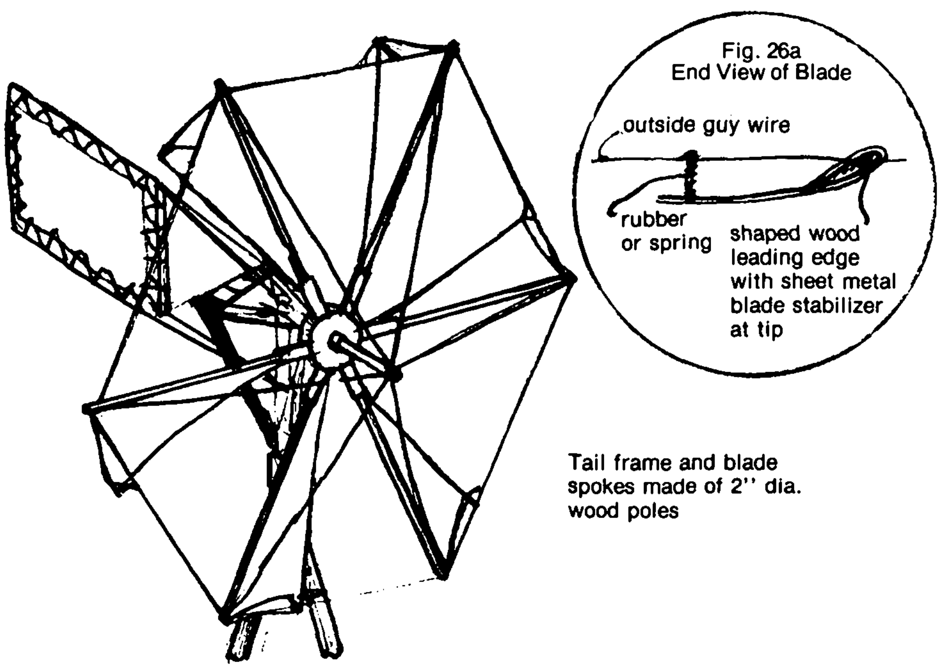


FIGURE 26. CLOTH OR HIDE BLADE AND TAIL CONSTRUCTION

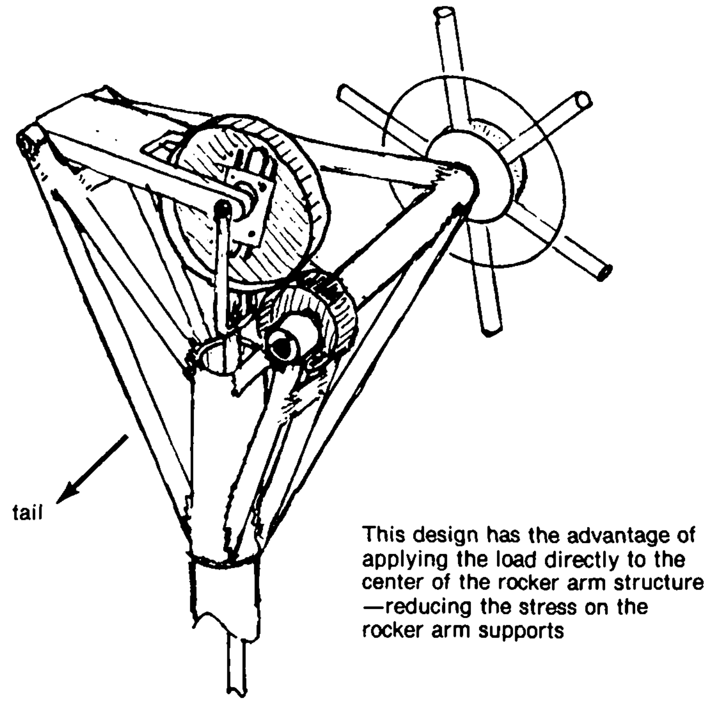


FIGURE 27. ALTERNATIVE ECCENTRIC WHEEL DESIGN

Other Possible Alterations

Aerodynamic analysis suggests that the windmill might operate more efficiently if the following alterations were made (these have not yet been tested at the time of printing):

a) Blade spokes placed in *front* of the blades, rather than *behind* them. This would probably require increasing the number of U-bolt attachments between the spokes and blades.

b) The *radius of curvature* of the blade would be approximately 4 feet, not 6 feet (see drawing on page 28).

c) Blade angle at the tip would be 22 degrees; at the base (near the hub) it would be 38 degrees (see drawing on page 30).

The above changes should result in a tip-speed ratio of 1.5.

(Notes from Dick Stanley, who is grateful especially for the help of Hans Bleijs, coordinator of the sub-committee on micro-projects at Eindhoven University of Technology, Eindhoven, The Netherlands.)

Borehole Pump

Shown here is a new type of heavy duty water pump which is designed for deep borehole pumping—lifting water from a depth of 300 feet (90m). This design is rather unique and fits the windmill well. The design enables you to make a very sturdy deep borehole pump without the use of a lathe, and with only simple welding equipment (to mount the check valves) and standard metal pipe. (The design is now being modified to function as a double-acting pump, and we'll be writing about that when it has been sufficiently tested.)

The pump is a reciprocating type. It is based on the observation that it is easier to polish the outside surface of a piston pipe than to polish the inside surface of a cylinder pipe. The seal is merely packing material (leather) stuffed into a 3'' socket and compacted by attaching a 3'' nipple to the upper end. The lower end of the socket screws down on the 3'' cylinder pipe. The action of this pump is similar to the motion of hydraulic cylinders (used on everything from a bulldozer to a heavy-duty automobile jack).

Because in this design the pump rod and the delivery tube are the same moving pipe, an attachment to deliver the water through a motionless pipe is needed (shown in Figure 29). A piece of 1'' or 1½'' diameter flexible plastic pipe, coiled around the delivery tube/pump rod, absorbs the up and down motion. This 8-foot length of plastic pipe is firmly attached to the foundation at one end and to the opening in the delivery tube/pump rod at the other. Thus it provides a fixed delivery point for the water, and can be fitted with standard pipes and/or empty into a storage tank.

The mechanism is capable of operating at high pressures and can be maintained and repaired easily. Another nice feature is that it uses the weight of the delivery tube and pump rod on the down stroke to force the water out, thus achieving a counter-balancing system not found in normal piston pumps.

The yield of this pump is about the same as a regular piston pump, but its ease of construction and potential for long life under rough conditions make it better than the regular design. It has been tested at an 85-foot head for about one year and the results are impressive.

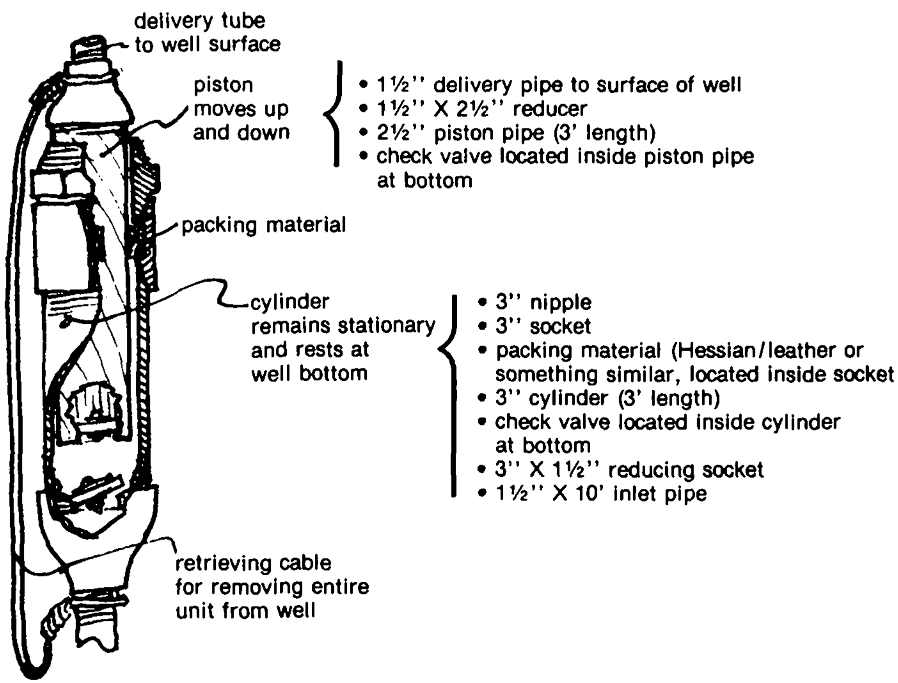


FIGURE 28. WORKING MECHANISM OF PISTON RAM PUMP

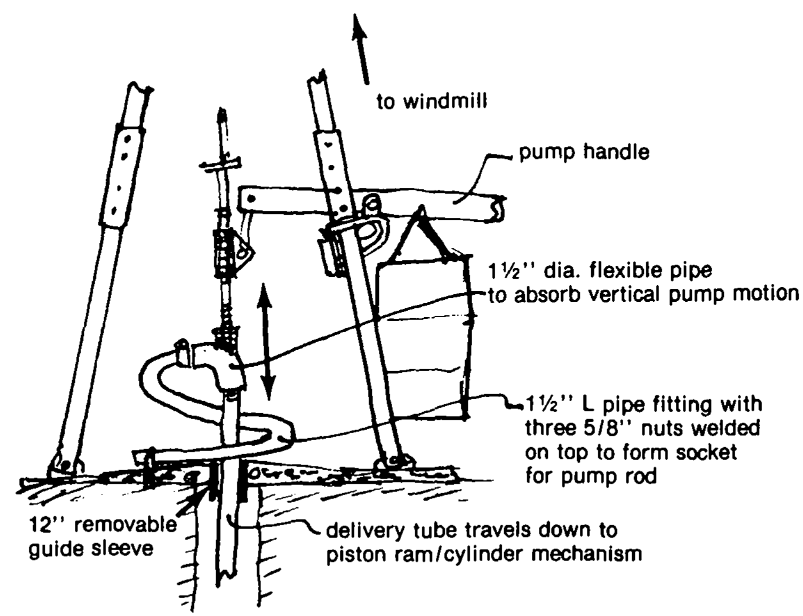


FIGURE 29. DELIVERY END OF PISTON RAM PUMP (shown connected to windmill)

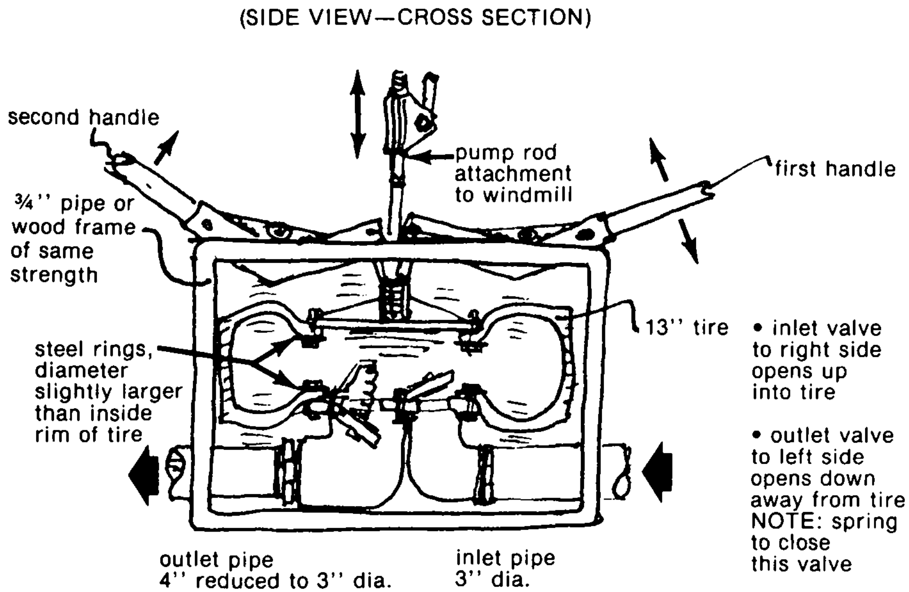


FIGURE 30. DIAPHRAGM PUMP FOR HIGH VOLUME, LOW LIFT IRRIGATION USES

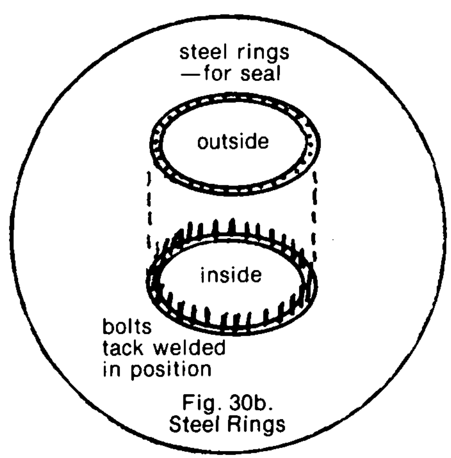


Fig. 30b. Steel Rings

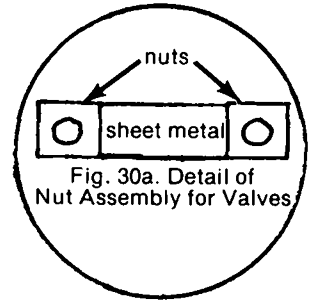


Fig. 30a. Detail of Nut Assembly for Valves

Irrigation Pump

A second type of water pump that can be used with the windmill is for low lift, high volume irrigation pumping for small agricultural plots, including rice fields. Using a popular pump design, first observed at the University of Nairobi, we produced a simple diaphragm pump out of a 13" auto tire (shown in Figures 30 & 31). This pump can lift 10,000 U.S. gallons (38,000 liters) of water per hour a height of 6' (2m) using the energy of a 15 mph (7m/sec) wind. The crank drive mechanism shown in Fig. 25 would be appropriate to operate this low-lift pump—and it would also be cheaper and easier to make than the eccentric wheel system.

The design shown here has only been tested in the workshop, and is not a final version. However, it would take little additional experimentation to find a suitable design for your area; we would like to learn of any such attempts.

The biggest single problem with this pump is making a good seal between the rim of the tire and the disks which serve as the plunger and valve surfaces (the top and bottom disks respectively). In our design, these disks were made of ¼" steel plate and attached to the tire with a series of ¼" X 1½" bolts, spaced 1" apart around the rim. The bolts were welded to rings (also made of ¼" plate) which are placed on the inside of the tire rim. The bolts are tack welded into holes in the rings which match the bolt holes in the disks. This provides a sturdy flat surface for sealing the pump. If wood is used for the disks, the same metal ring reinforcement should be applied.

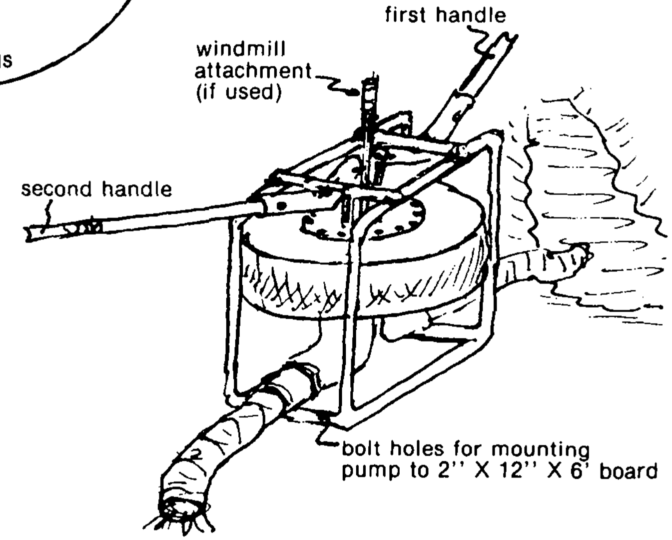


FIGURE 31. DIAPHRAGM PUMP IN ACTION

The valves are attached to the bottom metal plate before the plates are attached to the tire, and after the pipe elbows (for the inlet and outlet pipes) are welded in place.

The nuts which secure the valves are spot-welded together, using a small, thin strip of sheet metal between the nuts, as shown in Figure 30a. This keeps the nuts aligned and prevents them from turning as the corresponding bolts are tightened from the outside. If the pump were made any smaller (e.g., with smaller inlet and outlet pipes), this would prove a bit more difficult to do.

A spring on the outlet valve (held in place by a small piece of metal welded to the sheet metal/nuts unit for that valve) is included to insure that this valve will close. This is needed especially during the early moments of pumping, before the back pressure from the delivery tube is sufficient to force the valve closed.

I would be interested in learning of your experiences with this design, and I am willing to share ideas on it (Dick Stanley).

Other Pumps

Basic design principles for deep and shallow well simple pumps is contained in *Hand Pumps for Village Wells* (1975, 14 pages, $1.50 from VITA, 3706 Rhode Island Ave., Mt. Rainier, Maryland 20822, USA). These pumps can be made with a variety of materials ranging from steel water pipe to PVC pipe; less efficient pumps can even be made of wood.

Wells

A recommended book on wells is the *Water Wells Manual* (1969, 156 pages, $8.00 from Whole Earth Truck Store, 558 Santa Cruz Ave., Menlo Park, California 94025, USA). It requires a good knowledge of English but no formal training in water supply. The book provides "instruction and guidance to field personnel engaged in the construction, maintenance, and operation of small diameter (up to 4"), relatively shallow wells used primarily for individual and small community water supplies."

Other Uses: Rotary Power

An application of the basic windmill for rotary power is shown above. An easy power transfer to rotary motion is achieved by using a simple table and shaft with a friction drive. This unit is easily controlled using a simple lever which lifts the rotary table off the drive wheel. The lever is foot or hand operated and mounted at ground level. Braking could be done by locking the shaft.

A wide variety of options exist with this design, including: rotary centrifugal pumps, workshop machinery and grain grinding equipment.

A rotary table mechanism is much easier to make than the eccentric wheel/rocker arm design, and is worth serious consideration if rotary power is your need.

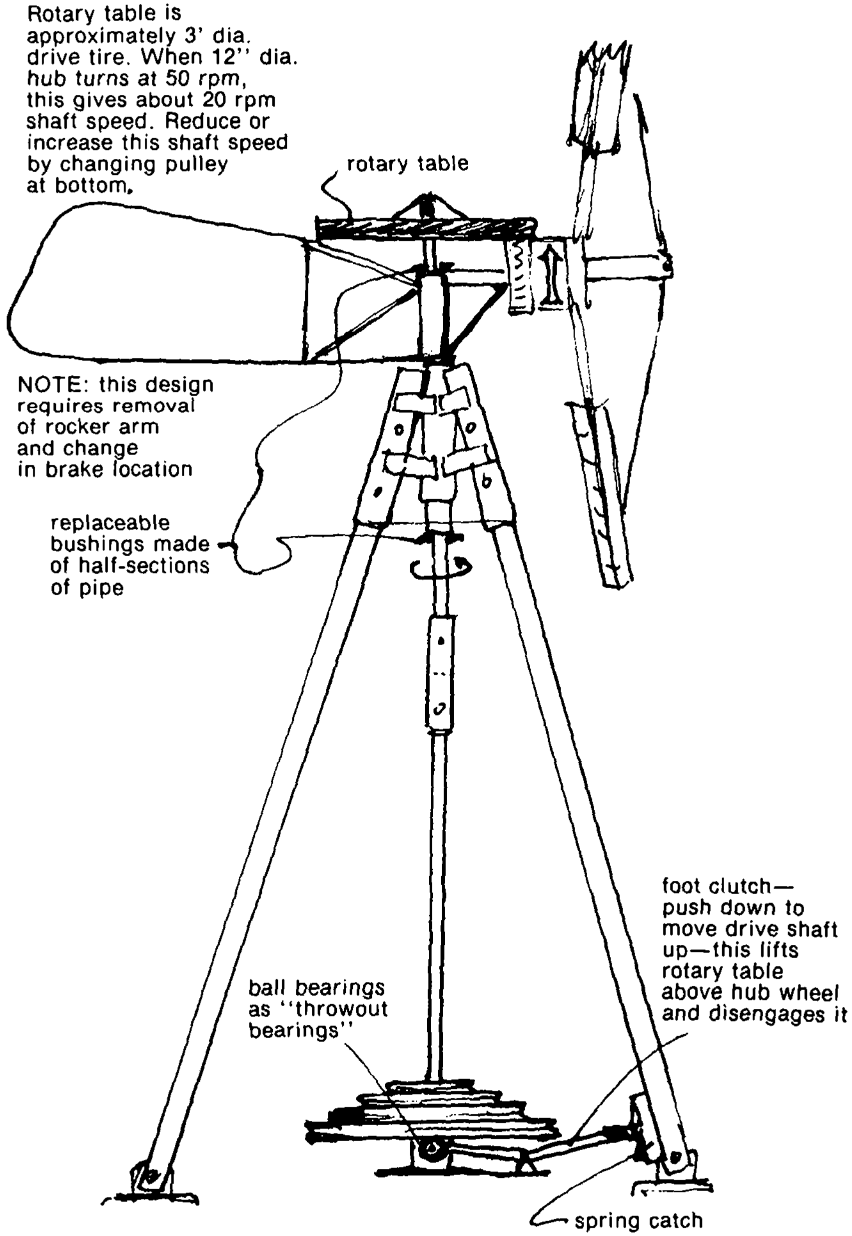


FIGURE 32. ROTARY DRIVE FOR GRAIN GRINDING, POWER TO WORKSHOP TOOLS, ETC.

Useful Data & Design Formulas

The following formulas and charts can be useful in the design or adaptation of a windmill to fit your particular environment. Where examples are needed, we have used data from the Arusha windmill.

First of all, the basic sets of equations are:

Power in the Wind

Power in the wind = Velocity^3 X Area

Velocity = wind speed

Area = area swept by the windmill blades when turning (πr^2, where r = radius of wind rotor)

If we use actual units of power, wind speed, and area, we get:

Power = .0012 X V^3 X A

where Power is measured in foot-pounds per second (ft-lbs./sec)

V (wind speed) is measured in feet per second (ft/sec)

A (area) is measured in square feet (ft^2)

If we want to measure power in **horsepower**, instead of ft.-lbs./sec, we need to know that:

1 horsepower = 550 ft-lbs./sec

Therefore,

$$\text{Horsepower} = \frac{.0012 \text{ X } V^3 \text{ X A}}{550}$$

$$\text{Horsepower} = .0000022 \text{ X } V^3 \text{ X A}$$

With any known wind speed and rotor diameter, we can now figure the amount of horsepower in the wind passing through the machine. Only a part of this power can be captured by a windmill. The theoretical limit of the power that can be extracted by a windmill is 59% of the power in the wind. Considering the friction losses and other inefficiences in the windmill, we can expect the windmill to capture only 10-30% of the energy in the wind.

Power Obtained by the Windmill

If we take the formula for horsepower and include an efficiency factor E (a measurement of the efficiency of our windmill in converting wind power into pumping power), we can get a realistic figure for the actual power we will obtain at a particular wind speed:

$$\text{Horsepower} = .0000022 \text{ X } (KV)^3 \text{ X A X E}$$

where V = wind speed

K = a constant to adjust the units of V (if V is in mph, K = 1.47; if V is in ft/sec, K = 1.0)

A = swept area of the windmill, measured in ft^2 ($=\pi r^2$ where r = radius of windmill rotor)

E = efficiency factor (for practical purposes, our design has an efficiency factor of about .25)

Thus the horsepower of the 16.5 ft. diameter Arusha windmill, in a 20 mph wind =

$$.0000022 \text{ X } (1.47 \text{ X } 20)^3 \text{ X } (\pi \text{ X } 8.25^2) \text{ X } .25 = 3.0 \text{ HP}$$

Note: For metric units the formula for horsepower is:

Horsepower = .000236 X $(KV)^3$ X A X E

where V is measured in meters/sec

K = 3.28

A is measured in m^2

It is worth noting, however, that for the wind conditions in Tanzania, the efficiency is not as important as the low-speed "torque" of the wind rotor. This is because the windmill works only for a short time before it slows down, changes direction, and starts up again—capturing the energy of the wind gusting from a new direction. The Arusha windmill was designed for this start-up ability rather than for continuous high-speed efficiency.

What is "torque"? Torque is a twisting force, measured by the amount of *force applied at a certain distance from the main hub shaft—the center of* rotation. The units of measurement are inch-pounds.

$$\text{Torque} = \frac{3300 \text{ X D X HP}}{(U/V)\text{tip X KV}}$$

where D = diameter of the windmill rotor in feet

HP = horsepower

U = speed of the blade at the outer tip (= $2\pi rN/60$)

where r = radius of rotor

N = revolutions per minute (rpm)

V = velocity = wind speed in ft/sec

$(U/V)\text{tip} = \frac{\text{blade speed at the tip}}{\text{wind speed}}$

= about 2 for the Arusha windmill

K = a constant to adjust V, same as in horsepower formula

$$\left(\begin{array}{l}\text{if V is in mph, K = 1.47} \\ \text{if V is in ft/sec, K = 1.00} \\ \text{if V is in meters/sec, K = 3.28}\end{array}\right)$$

continued →

Thus, the torque of the Arusha windmill in a 20 mph wind =

$$\frac{3300 \times 16.5 \times 3.0}{2 \times 1.47 \times 20} = 2{,}778 \text{ inch-pounds}$$

The starting power of a windmill is of greatest interest, and this is called the 'static torque.' This is typically 1/3 of the 'dynamic torque' (calculated above). Windmills usually have to lift a full load of water as they start up, and this usually makes them slow starting. However, by coincidence the natural inefficiency of the pump leather seal allows some slip in the pump which partially compensates for the starting problem by reducing the starting load.

Matching Power to Water Yield

How can we measure the amount of power from the windmill required to pump water? Below is a standard table for calculating the water yield that matches the horsepower being produced by a windmill (Table 2). If we know what the wind speed is (see final section), the formulas already given allow us to calculate the horsepower available for any windmill size. Table 2 allows us to calculate the horsepower required to pump a given amount of water per hour to a given height. All of this information combined will allow us to go back and calculate the size of the windmill required to pump the water needed, under normal wind conditions.

	FLOW RATE	100	200	300	400
HEIGHT	50	.05	.10	.16	.24
	100	.09	.20	.33	.47
	200	.18	.40	.66	.94
	400	.36	.80	1.3	1.9
	600	.54	1.2	1.9	2.8
	800	.72	1.6	2.6	3.8
	1000	.90	2.0	3.3	4.7

← HORSE POWER

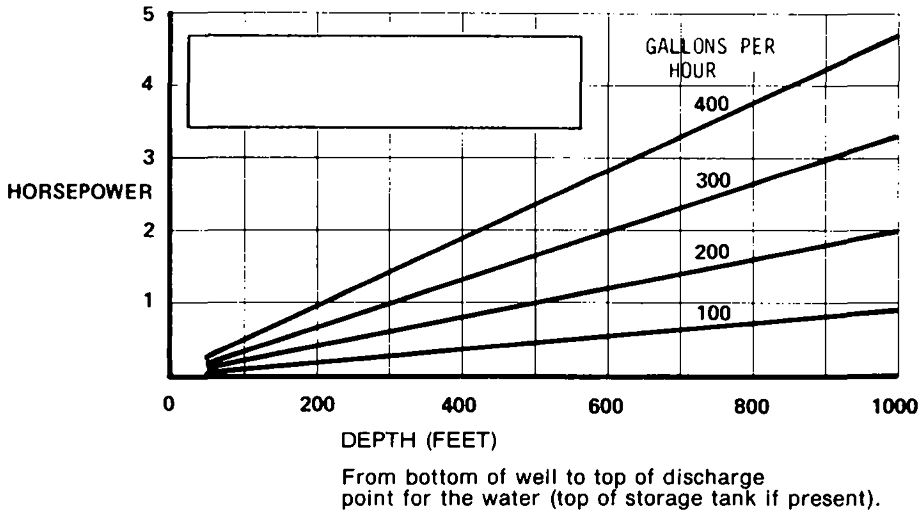


Table 2. Horsepower, Depth of Well, Flow Rate

For our area, a 400-foot well yielding 400 gallons of water per hour would meet the livestock and domestic needs for a rural village. Using either of the charts of Table 2, we see that 400 gallons per hour at a 400 foot depth requires about 1.9 horsepower. From earlier calculations, we have found that the windmill was producing 3.0 horsepower in a 20 mph wind. Thus, as long as the wind is blowing at 20 mph we have more than enough horsepower to lift the water we need.

In the Arusha region, however, 15 mph winds would be more typical, with a 10 to 15 hour duration each day. At 15 mph, the Arusha windmill would produce about 1.25 HP. From Table 2, we see that about 300 gallons of water per hour could be pumped from our 400-foot well.

The horsepower a windmill produces at a given wind speed depends on the diameter of the wind rotor. You cannot change the wind patterns in your area; you can only calculate how much power you can expect to get using different wind rotor diameters. The Arusha windmill design presented in this manual is a fixed 16-foot diameter design. Thus, if you need more horsepower for your pumping tasks you will have to build more than one windmill. And if you need less horsepower, be sure that you do in fact have as much wind energy available as we do in Arusha region. *Arusha region has a greater than average amount of wind energy available.*

You may find that you need very little horsepower in a low-lift application. For example, the 16-foot diameter Arusha windmill will lift 10,000 gallons (38,000 liters) per hour from a depth of 6' (2 meters). At 5 mph wind speed, the Arusha windmill would lift 400 gallons of water per hour from this depth. You may need much less water than this—if so, it would be better to build a low-cost, smaller diameter sail windmill more appropriately sized to the pumping task you have. You can use the formulas we have presented here to determine approximately how big your windmill should be.

Wind Measurement

The above calculations can be done reliably if you know what the wind speed tends to be in your area. However, there is very little reliable data usually available concerning wind speed, except at airports, in any country.

In Arusha region, we did have some data from other sources. The records were poorly kept, however, and the measuring stations were 125 to 200 miles apart! To get really good data, it would be necessary to spend $5000 per wind station and measure data for 5 years; and then the data would fail to show the significance of changing winds and occasional gusts.

Our answer to this lack of data has been to use the windmill itself as a measure of wind speed. The whole unit costs only about $300, and if the wind is found to be insufficient, the upper part of the windmill can be removed and taken to a more promising site. The tripod is then left behind, where it is useful in removing the water pump (operated by some other power source) for repairs.

If you can't afford to buy and maintain an anemometer, you can make one that will give you some idea of how much wind is available (see Figure 33). Some kind of rounded, light-weight (but solid) plastic cups are needed. If these cannot be found, the next best thing to use are cone-shaped cups, which you may have to make yourself. The counter on this anemometer could be a US$2.00 plastic bicycle odometer (used to measure the distance a bicycle travels).

The rotational speed of the anemometer is proportional to wind speed, which means that the number appearing on the counter in any time period will be proportional to the average wind speed. The device can be put on top of a pole and placed at the height intended for the windmill rotor. The count can be recorded every day or every few hours. If there is a regular time of day when the wind always blows, you may want to measure this separately.

The only difficulty is to match the numbers on the counter with a known measure of wind speed. The easiest way would be to run it next to a borrowed commercial anemometer, and simply compare the results. The production of a number of these low-cost anemometers would be a great help in a regional wind power development project. Since you probably can't borrow a commercial anemometer, you can instead attach your home-built anemometer to a pole tied to a car or truck, when there is no wind. Using the car's odometer (mileage indicator) and a watch with a second hand, you can made several test drives at a steady speed. This will give you a good estimate of the proper relationship between the numbers on the counter and the wind speed. You can also do this with the car's speedometer. For example, you drive a steady 15 miles per hour for 5 minutes. The counter reads 1240. Multiply this by 60/5 to get the expected count for one hour at 15 mph (1240 X 60/5 = 14880). Therefore, one hour of 15 mph wind would produce something close to 14880 on the counter. If you are using a bicycle odometer with 1/10 mile as the smallest unit (when used with a bicycle) it will require about 80 revolutions to add one unit. Thus you might get only 15 units on the counter after driving 5 minutes at 15 mph. In this case, 180 units on the counter would represent 1 hour of 15 mph wind.

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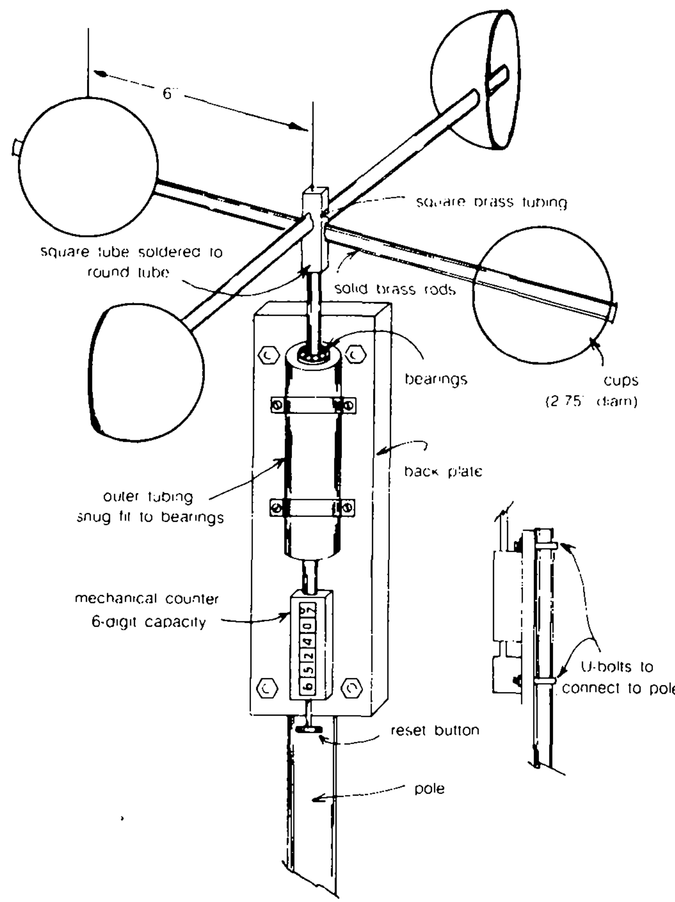

Figure 33. A Home-Built Cup Anemometer
For Measuring Average Wind Speeds

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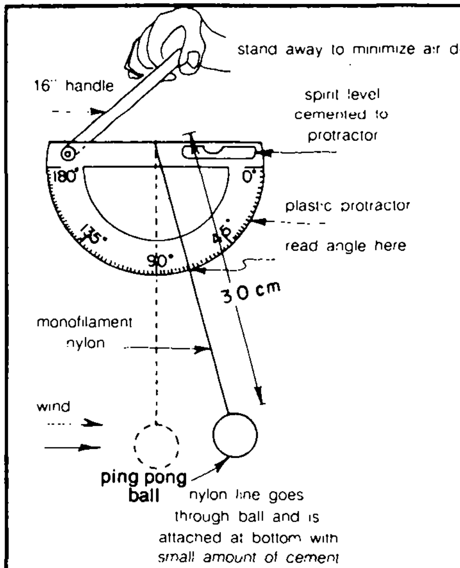
Another way to measure wind is to use the hand-held gauge shown in Figure 34. The angle at which the ping pong ball hangs can be used to compute the wind speed. For example, if the wind pushes the ball back to 60°, the corresponding wind speed is about 14.9 mph.

An even simpler way to estimate the amount of wind energy available is to observe the effects of wind on the environment. Table 3 shows the Beaufort Scale, which matches natural evidence of wind speed to a measured scale. This will give you an estimate of the wind speed at any particular moment.



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

Figure 34. A Simple Hand-Held Wind Gauge with Calibration Data (based on C.L. Strong, **Scientific American**, October 1971).

Table 3. Qualitative Description of Windspeed

Wind Speed (mph)	Wind Effect
0–1	Calm; smoke rises vertically.
2–3	Direction of wind shown by smoke drift but not by wind vanes.
4–7	Wind felt on face; leaves rustle; ordinary vane moved by wind.
8–12	Leaves and twigs in constant motion; wind extends light flag.
13–18	Raises dust, loose paper; small branches are moved.
19–24	Small trees in leaf begin to sway; crested wavelets form on inland waters.
25–31	Large branches in motion; whistling heard in telegraph wires, umbrellas used with difficulty.
32–38	Whole trees in motion; inconvenience felt in walking against wind.

What we need next is some long term evidence of wind energy, such as trees bent in response to continual wind over a long period of time, sand or dirt deposits left by the wind, or differences in plant growth in windy areas.

Tower Height

There are two ways in which tower height contributes to the wind energy available: 1) by lifting the windmill above and away from houses, trees, and other obstacles that cause turbulence at ground level, and 2) by allowing the windmill to operate in the stronger winds that exist at higher elevations.

Over an open plain, wind speed increases with tower height as shown in Table 4, below.

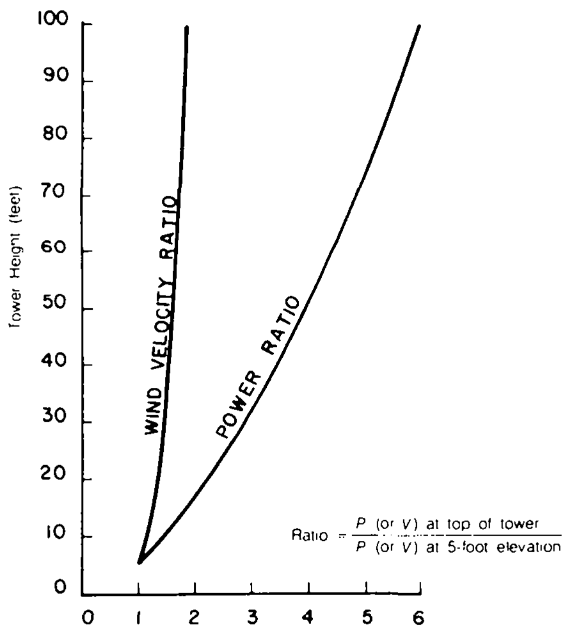


Table 4. Increase in Wind Velocity and Power with Increasing Height (open plain, based on 5-foot height reference point)

Because the power available increases proportionally to the cube of the wind speed, a small increase in wind speed has a great effect on the windmill's ability to pump water. For example, the 30% increase in effective wind speed on top of a 20-foot tower compared to a 5-foot tower would mean a 120% increase in power available. If the tower were extended to 30 feet, the power gain would be 190% (or 30% more power than for the 20-foot tower). Of course, towers cost money, and at some point it is not worth building up any further. Shown in this manual are 20-foot and 26-foot towers which have been tested and are quite adequate for conditions in the plains of Arusha. An option for an untested 30-foot tower is given also. Above that height, the tower would have to be constructed using larger diameter pipe and cross bracing.

The local shape of the land affects wind speed greatly. In hilly areas, moving the machine 100 feet can have a dramatic impact on the amount of wind energy captured. This is another reason why expensive data-gathering techniques are of questionable value. Windmills should be located away from all obstacles that might create turbulence.

In plains regions, the wind usually does not vary much from spot to spot. Once such an area has been determined to have sufficient wind for water-pumping, one can safely build many windmills. Some of the Greek islands, for example, have what appear to be entire forests of windmills turning in the wind.

Because a large number of windmills can be used in the same general area, the concept of efficiency does not have the same meaning for windmills as it has for other devices that use a limited fuel or power source. It is often better to have several relatively inefficient but very low-cost windmills, rather than one efficient but expensive windmill: the power source is free.

Table 2 is from Jack Park's **Simplified Windpower Systems for Experimenters**, a highly recommended reference book (see review on page 52).

Figures 33 and 34, and Tables 3 and 4 are from **Other Homes and Garbage**, by Leckie, Masters, Whitehouse and Young, 1975.

Glossary

abundant—very plentiful; more than sufficient.

access hole—a hole in one part that allows you to get inside to change or lubricate another part.

adequate—sufficient; enough.

aligned—to be in a straight line.

alignment—arrangement in a straight line.

alterations—changes.

anchor pins—pieces of metal which are placed in the concrete foundation and connect the windmill tower legs to the foundation.

anemometer—a device for measuring wind speed.

axes—more than one axis.

axis—a straight line on which an object rotates.

axle—a rod on which a wheel turns.

back pressure—pressure in the opposite direction to the flow of water.

barren—without much plant life.

bearing housing—a pipe that holds the bearings in position.

bore hole—a hole in the ground made by drilling, for a pump.

boring—drilling.

brace—support.

brazed—joined by melting metal.

burrs—tiny rough pieces of metal.

butt weld—to weld end to end.

car jack—a device which can lift the heavy weight of a car a short distance off the ground.

casting—a process of shaping metal in which the metal is melted and poured into a mold.

center punch—a tool with a hard pointed end which can be hit with a hammer to make a dent in metal.

clamp—hold together firmly.

clearance—open space between two parts.

constraints—limitations, boundaries.

convert—change into.

corrugated—having parallel grooves and ridges.

corrugation—one of the parallel grooves or ridges of corrugated sheet metal.

counter balance—a system in which one weight balances another, making both easier to move.

cross bar—a bar or pipe which connects two other pipes.

cross braces—supports which go across the main supports.

cross bracing—a set of supports that go across and strengthen the main supports.

cross section—a view of a part as if that part were cut in half.

cup anemometer—a device for measuring wind, that catches the wind with cup-shaped parts that turn on a shaft.

data—information.

deflection—movement away from the normal position.

dia.—diameter.

diaphragm pump—a pump that operates as a flexible wall collapses and expands.

dies—tools used in cutting threads on steel rod to make bolts.

drill press—a workshop machine for making holes at a precise angle (usually 90°) in metal or wood.

drive mechanism—the part of a windmill that operates the pump; in this windmill either the eccentric wheel or crank alteration.

duration—the time that a thing continues.

eccentric wheel—a wheel in which the axle is not at the center point; in this windmill, as the wheel turns, the axle moves up and down.

enlarge—make bigger; make larger.

fabrication—construction; manufacture.

feathering—a system in which the blades on a windmill are designed to change their angle to the wind as the wind speed changes.

fittings—small parts used to join, adjust, or adapt other parts.

flange—a collar on a wheel to hold it in place and give it strength; specifically, a collar on the eccentric wheel of this windmill.

flux (brazing)—a substance used to help metals fuse together.

foundry—the process of melting and molding metals.

friction-drive—a power system in which power is transferred from one part to another by forcing the two parts to rub together.

friction losses—power (energy) losses due to the rubbing of parts against each other, creating small amounts of heat.

galvanized—metal covered with zinc to protect it from rust.

governing mechanism—a device which changes the angle of the blades to the wind as the wind speed changes, allowing the windmill to operate more efficiently.

grease (verb)—to lubricate; to put grease on something.

grease nipples—small metal fittings through which grease can be pumped; for example, to lubricate bearings inside a pipe housing.

grinding wheel—a workshop tool that has a wheel with a hard, rough surface, used to smooth or remove small amounts of metal from a tool or part; also, the wheel portion of this tool.

gusset—a triangular metal brace for reinforcing a corner or angle.

gust—a sudden, strong rush of air.

gusting—blowing in sudden, strong rushes of air.

guy wires—cables that strengthen the blades and keep them in position.

gyroscopic force—a force which makes a spinning wheel tend to stay in its original plane of rotation.

hacksaw—a hand saw for cutting metal.

housing—a frame, or pipe for containing and supporting some part or mechanism.

hub extension—a piece of pipe which sticks out from the front of the hub and provides a place to attach guy wires to strengthen the blades.

inertial forces—for this windmill, forces which tend to make the windmill remain stopped if it is already stopped, or tend to make it keep moving in a particular direction if it is already moving in that direction.

insert—to put inside something.

isometric view—a method of drawing figures in which three dimensions are shown not in perspective, but all dimensions are shortened to give the impression of proper relative size.

jack (car or automobile)—a device which can lift the heavy weight of a car a short distance off the ground.

linkage—a part that connects two other parts.

load—the weight to be lifted by the windmill pump rod.

load bearing surface—the surface supporting the entire weight of the windmill superstructure and the pump system.

lubrication—application of grease to make slippery or smooth.

maximize—to make something operate at the highest possible level.

mechanical governor—see "governing mechanism".

metal-working lathe—a workshop machine which can cut circular shapes out of metal.

milling—the grinding, cutting or processing of metal.

modified—changed slightly.

nipple—a piece of metal with a small opening through which water or grease can be forced.

obstacle—barrier; something that gets in the way.

odometer—a simple counting device that records the distance a vehicle has traveled.

optimum—best.

options—choices, possibilities.

parallel alignment—two axes lined up exactly parallel to each other.

perpendicular—at a 90° angle.

pipe fittings—small pieces of threaded pipe used to connect two longer pieces.

pitch adjustment—adjustment of the angle at which the blades are attached.

pivot—turn on an axis.

plunger—the part of a diaphragm pump that moves up and down.

pop riveting—connecting two pieces of metal by forcing through and flattening metal pins.

precise—exact.

pump rod—the steel rod going from the top of the windmill to the top of the pump; it moves up and down.

pump stroke—the distance the pump piston travels between its highest and lowest points.

punch—to knock a hole in a piece of metal using a hammer and a sharp tool.

radial guy wires—guy wires connecting the blade tips to the hub extension, to strengthen the blades.

radius of curvature—the curve required in a part is as if the part were following the edge of a circle with the radius given.

reciprocating pump—a pump in which the movement of a piston up and down forces the water up.

remote areas—areas difficult to get to from outside.

rigid—stiff.

rocker arm—a support mechanism which turns on a shaft at one end and moves up and down at the other end.

rotary motion—turning, rotating.

rotary power—power provided by a turning shaft.

sealed ball bearings—ball bearings in which lubrication is not required.

seasoned hardwood—hardwood that has been cut and allowed to dry for a long time.

segment—piece of something.

shear block—two pieces of wood which clamp two pieces of pump rod; under normal conditions this connects the pump rod pieces, but under greater stress one of the pieces will pull out of the block.

sheet metal forming—shaping sheet metal to whatever form is desired.

shim—a thin piece of metal used for filling space or leveling.

smear—spread around.

snug—close fit.

socket—a piece or part into which something fits.

spacer—a piece of metal used to fill space so that two pieces will come together at the right point, or clear each other.

speedometer—a device in a car which measures the speed at which the car is traveling.

spot braze—to braze in small spots.

spot weld—to weld in small spots.

stops—drops of weld or indentations in a bearing housing to prevent the bearing from sliding in or out.

stress—force acting on a part that tends to strain or alter its shape.

strut—a brace; a support which resists pressure in the direction of its length.

superstructure—a structure built on top of another.

swept area—the circle made by the blades of a windmill as they turn.

tabs—small pieces of metal that are bent for some purpose.

tack weld—to weld temporarily with a small amount of material.

tap—to cut threads on the inside of a hole in a nut, pipe, or piece of metal.

terrain (rough)—land that is difficult to move through.

thermal winds—winds caused by the heating of the ground by the sun.

threading equipment—tools that can cut threads into metal rod to make bolts, and cut threads inside holes in pipes or pieces of metal.

torque—the force that acts to produce rotation; a twisting force.
triangular—having three straight sides.
tripod—a support having three legs.
turbulence—irregular motion of air.
turnbuckle—a simple steel device made of two eye-bolts screwed into a piece of steel housing; when the housing is turned, wires attached to the eye-bolts are either tightened or loosened; used in this windmill to adjust the tightness of the radial guywires.

U-bolt—a U-shaped bolt with threads and nuts at both ends.
unevenness—roughness, irregularity.

varnished—covered with a paint-like substance made of resins dissolved in oil; for protection from damage by the weather.
vertical axis—an axis that follows a line straight up and down.

wear ring—one of two pieces of steel rod bent to form a ring and rub against each other as the windmill pivots in the wind.
welding rod—a special rod of metal that is melted during the welding process when two pieces of metal are joined.
wind rotor—the turning wheel and blades of the windmill.

English/Metric Conversion

Metric	**English**
Length	Length
1 mm = .039 inch (.003 foot)	1 inch = 2.54 cm (25.4 mm)
1 cm = .39 inch (.033 foot)	1 foot = 30.5 cm (.305 meter)
1 meter = 39.4 inches (3.28 feet)	1 mile = 1.60 kilometer
1 kilometer = 0.62 mile	
Area	Area
1 square cm = .155 square inch	1 square inch = 6.45 square cm
1 square meter = 10.8 square feet	1 square foot = .093 square meter
1 hectare = 2.47 acres	1 acre = 0.4 hectare
Volume	Volume
1 cubic cm = .061 cubic inch	1 cubic inch = 16.4 cubic cm
1 cubic meter = 35.3 cubic feet	1 cubic foot = .028 cubic meter
1 liter = .264 U.S. gallon	1 U.S. gallon = 3.78 liters
Weight	Weight
1 gram = .035 ounce (avoirdupois)	1 ounce (avoirdupois) = 28.3 grams
1 kilogram = 2.2 pounds	1 pound = 0.45 kilogram
Temperature	Temperature
°C. = 5/9 X (°F. - 32°)	°F. = (9/5 X °C.) + 32°
Example: How many °C. = **77 °F?**	
5/9 X (77 °F. - 32°) = **25 °C.**	
Energy	Energy
100 calories = .396 BTU	1 BTU (British Thermal Unit) = 252 calories
100 watts = .134 horsepower	1 horsepower = 746 watts (.746 kw)
1 kilowatt-hour = 3413 BTU	
Common Abbreviations	Common Abbreviations
millimeter (mm)	inch ('')
centimeter (cm)	foot (ft. or ')
meter (m)	ounce (oz.)
kilometer (km)	pound (lb.)
gram (gm)	horsepower (hp)
kilogram (kg)	British Thermal Unit (BTU)
Speed	Speed
1 mile per hour (mph) = 0.45 m/sec	1 m/sec = 2.24 miles per hour (mph)

Additional Reading

This section was reprinted from the APPROPRIATE TECHNOLOGY SOURCEBOOK (also available from the AT Project). Some addresses for the books (from VITA, WETS, Mother Earth News, BRACE, and ITDG) are provided at the end of the section.

Wind machines can be used to pump water or to generate electricity. It is also possible to use them to drive machinery directly; the giant Dutch windmills reached up to 14 horsepower and were used to grind grain into flour in addition to pumping water (see **Windmills and Watermills**, *reviewed on page 159 for more on these Dutch windmills and direct use of wind power to drive equipment).*

The word "windmill" in a strictly technical sense refers only to a type of machine that drives a mill to grind flour. In fact, however, the word is often used as a general term for wind machines of all kinds. "Windgenerator" is only used to describe a machine that generates electricity.

There are many different designs for wind machines. Water pumping windmills usually have a slowly turning wheel with many blades. Windgenerators usually have 2 or 3 narrow blades which turn at a very high speed. For windgenerators, gearing is still needed to multiply the number of revolutions per minute (rpm) up to the range required by a generator. For example, a windgenerator may be charging the batteries at 200 rpm, but only if the gearing has multiplied this to at least 800 rpm at the generator. There are many practical ways to do this "gearing up"; sometimes this dramatically affects the entire design of the windgenerator.

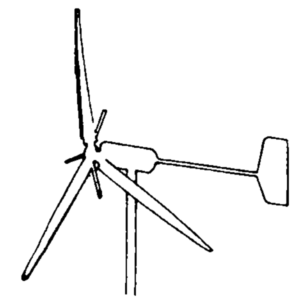
The amount of power available from the wind depends of course on the wind speed. It is a peculiarity of wind power that the energy available increases as the cube of the wind velocity. This means that there is 8 times as much energy in wind moving at 20 mph as there is in wind moving at 10 mph. There are a number of important consequences of this peculiarity; one is that the designer and builder must provide some method of protecting the windmill from the tremendous forces of high winds. There are 3 common methods for this: a "feathering" system for moderately strong winds, in which the angle of the blades is changed so that more of the wind is allowed to pass through the rotor without affecting it; a system which causes the wind rotor to turn sideways out of the wind at still higher wind velocities; and a brake and tying down system for very high winds. In countries that have severe tropical storms sail windmills may be a good choice; the sails can easily be removed, leaving only a skeleton that is not as easily damaged by the wind.

Two other consequences of the power peculiarities of wind as speed increases greatly affect the final positioning of the windmill. Wind speed is generally faster above ground level; for this reason, and to avoid turbulence caused by trees, houses, or other obstacles, windmills are usually placed on top of 20- to 40-foot towers. The wind speed is very much affected by the local geography; this makes site selection important. The top of a small hill will usually have much more wind energy available than the bottom of a hill. (See reviews of **Other Homes and Garbage** *and* **Build It Yourself Science Lab** *for additional information on wind measuring devices to aid in site selection—pages 42 and 53.)*

The wind power available is also determined by the "swept area" of the blades. A 10-foot diameter rotor will sweep an area 4 times as large as that swept by a 5-foot diameter rotor; the larger rotor should be able to capture about 4 times as much power from the wind. As rotors get larger, however, balancing becomes more difficult and vibrations become more of a problem.

The first part of this section is on water pumping windmills, which can be used to provide water for grazing animals or for irrigation of small plots (about 2 acres or 1 hectare). Five of the following entries give complete construction information for water pumping windmills that can be built of locally available materials in most developing countries.

The small-scale generation of electricity using windgenerators is the second major focus of this section. Probably about 500 watts is the practical maximum output to expect from a home-built windgenerator; however, some sophisticated designs are beginning to appear for home-built machines with 2 or 3 times this capacity. This is one of the most active areas of experimentation in alternate sources of energy; the years 1974-1976 saw the publication of most of the best books on the subject, and there is every reason to believe that there will be more to come.



A windgenerator with 3 wooden blades.

Is There A Place For the Windmill in the Less-Developed Countries?, paper, 21 pages, M. Merriam, 1972, free on request from the East-West Technology and Development Institute, East-West Center, 1777 East-West Road, Honolulu, Hawaii 96822.

This is an excellent paper—important reading for anyone seriously considering the use of windmills in developing countries. The author lists the most important considerations in choosing to build a windmill, including the most favorable circumstances for a variety of power needs. Four prevailing types of windmills are briefly examined (the Dutch, American multi-vane, propellor, and Savonius Rotor), and the power and other characteristics of each design are briefly compared. There are several tables, drawings, and appendices with supporting information.

Island applications are particularly recommended. The author includes a series of questions that should be useful in determining whether to build a windmill at all in a rural area. He argues that conventional economic analysis is often too complicated and uncertain and fails to take into account important considerations from the villagers' point of view.

"In places where the average wind velocity exceeds 12 mph, and especially in places where it exceeds 15 mph, windmills should be considered for use as decentralized sources of mechanical and electrical power. Their economic attractiveness is limited to situations where central station power is not available and liquid petroleum fuels are expensive or unsuitable...The greatest problem is that each installation must be engineered to the characteristics of the load and the local wind. The expertise to do this kind of installation engineering is not widely available in the less developed countries.

"The types of loads to which windmills have traditionally been applied and to which they could reasonably be applied now are : 1) pumping water for human or animal consumption, for crop irrigation, for drainage of land; 2) mechanical power for operating machines of the flour milling or small-scale industry type, and 3) generating small amounts of electricity to charge storage batteries, in order to operate radios and other electrical appliances...The amount of electricity required to operate radios...is not large and its value is high."

A Survey of the Possible Use of Windpower in Thailand and the Philippines, book, 74 pages plus appendix, W. Heronemus, 1974, on request from Agency for International Development, Washington DC 20523, USA; or $6.00 from NTIS (Accession No. PB-245 609/3WE, N'74; foreign orders add $2.50 handling charge).

This remarkable book is not the kind of report one has come to expect from a USAID contract. It is easy to read, and the author's emphasis, at least for water-pumping windmills, is on the use of local materials and locally available skills. It answers favorably the question "could windpower be used by the peasant farmer in Thailand or the Philippines to improve the quality of his life?"

"Numbers of six-sail wind machines are currently in use in the salt works around the northern shore of the Gulf of Thailand. The machines are of about 6 meters diameter and use bamboo spars, rope and wire to form a wheel which carries 6 triangular sails, each woven from rush or split bamboo." These machines drive the paddles of the traditional water-ladder low-lift pumps. The author recognizes that while efficiency could be greatly improved, the current machines are "admirably sized to the task they are to perform" and the primary limiting factor is not in the machines but in the land available for salt evaporation.

For use in irrigation, the author makes some stimulating suggestions for improvements in the sail windmill design and for local adaptation of a wooden, 16-bladed fan mill. "The blades would be of molded plywood, made between matched concrete molds in the existing Bangkok plywood factories...Each laminated blade would be inserted into a wood spoke and the spokes would in turn be brought to an iron banded wood hub. The entire wheel would be a timber (plus glue) product, producible by native artisans possessing the same skills and tools required to build the water ladders."

Most of the report is focussed on Thailand, but the contents are of general interest to people in any area where there is a need for low-lift pumps for irrigation. Photos of the sail windmill and water ladder are included.

Considerations for the Use of Wind Power for Borehole Pumping, leaflet, 15 pages, AT Unit Report, 1976, send nominal sum for postage to Appropriate Technology Unit, Christian Relief and Development Association, P.O. Box 5674, Addis Ababa, Ethiopia.

An introduction to the basic considerations for the use of multi-bladed windmills for water pumping. Explains the importance of site selection, rotor design, and the other major components along with the criteria that affect these choices. No plans or detailed information given.

Food from Windmills, book, 75 pages, Peter Fraenkel, 1975, £2.50 or US$5.00 surface mail from ITDG.

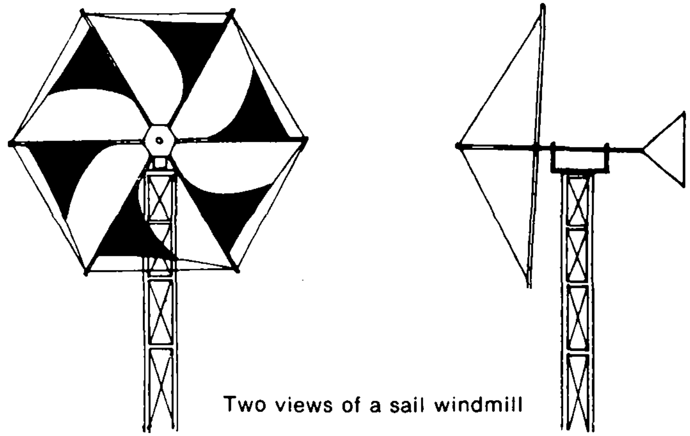
MATERIALS: *pvc pipe, angle iron, steel water pipe, commercial piston pump, steel bar; styrofoam block and half oil drum for float.*

PRODUCTION: *some welding and metal-cutting.*

This book is to be recommended to anyone doing work on the design of low-cost windmills for irrigation. It thoroughly covers the work of the American Presbyterian Mission on adapting the Cretan sail windmill for use in an isolated area of Ethiopia.

The report contains drawings and photos of the necessary components. Much of the text discusses the design, problems, and resulting modifications.

Through the increasingly honored soft-technology approach of 'racing' one design against another (rather than getting involved with expensive monitoring devices), the Mission was able to come up with a windmill that would pump at



Two views of a sail windmill

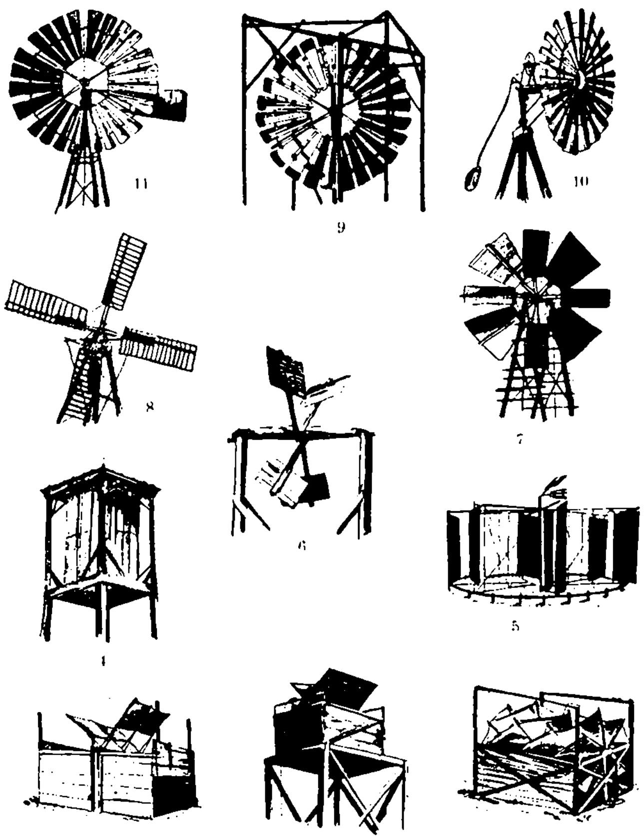
almost twice the rate of a commercial American Dempster multi-blade windmill. (This was partly because the sail windmill, due to its relatively light weight, was constructed so as to sweep a larger cross-sectional area. The sail windmill also outperformed 3 Savonius rotor windmills.) The most impressive design had the following characteristics: 16-foot diameter rotor when rigged with four sails, operating at a static head of 9 feet, would pump 1300 gallons of water per hour in a 14.5 mph wind.

The application of this windmill is interesting. Pumping is directly from a river that has a water level variation of 2 meters; a float is used as part of the intake.

The experiments have resulted in a design which has 8 arms. The number of sails actually used depends on the wind at the time. The owner/operators put up the sails in the morning and adjust them while the mill is in use; when work is finished in the fields, the sails are removed for safe-keeping (which also protects the mill from damage in case of a sudden storm and high winds). Thus these windmills are not taking full advantage of the 24-hour availability of wind, though in these circumstances the windmills are in operation during the peak wind velocity period.

A 3-legged tower is about 15 feet high, built of angle iron, and needing no foundation other than impacted soil. 1½" pvc plastic pipe draws water from the float, which is made of a styrofoam (polystyrene) block fitted into half an oil barrel for protection. There is a foot-valve at the bottom of the pipe to keep the prime. 3" diameter commercial piston pumps are used. The crank shaft and connecting rod are made of steel bar and water pipe; some of these bearings are hardwood. The sails were made of donated Dacron sail cloth, which was both strong and resistant to the deterioration that comes from continuous exposure to strong sunlight. Cotton is claimed to be not generally strong and long-lasting enough; the kind of cloth sail used in Crete is not identified. Some experimentation was done with detachable aluminum sails, made from surplus roof cappings; these were claimed to be "readily available and cheaper than Dacron in most areas...more durable than locally-available textile."

By August 1975, 19 windmills of various types were being used by villagers, and another 5 were operating on the mission grounds. The 11-foot design has a cost estimate of US$250-350, almost all of which goes for the steel, the pvc pipe, and the commercially-purchased pump. This is about 1/3 the cost of a delivered factory-produced model of similar capacity. Costs might be significantly reduced in areas with a supply of strong bamboo and wood materials.



The homemade windmills of Nebraska

The Homemade Windmills of Nebraska, book, 78 pages, E. Barbour, 1898 (reprinted 1976), $3 from Farallones Institute, 15290 Coleman Valley Road, Occidental, California 95465, USA.

Sketches are provided of more than 60 different windmills. They appear roughly in order of efficiency, and the text explains the advantages and disadvantages of each. The books was written with the express purpose of providing good models to copy, so that builders would benefit from the experiences of others.

This is a remarkable little book. Our first reaction was to ignore it—there have been some significant advances in windmill design since 1898. But choice of windmill design involves cost as well as efficiency, and a lot of these windmills could be built for almost nothing—using only local materials. This is a great idea book: many of these designs could be adapted to use bamboo poles and woven bamboo mats for the blades or sails, along with wooden bearings and power transmission arms. In fact, if combined with simple low-lift pumps, a water-pumping windmill could be put together for an extraordinarily small cash outlay in many developing countries. The designs are so simple that any carpenter could put one together just by looking at an existing machine. This is exactly how they spread all over the state of Nebraska in the United States.

The majority of the machines do not have the capability of turning to accept wind from any direction; they were designed for areas with a prevailing wind from a dependable direction. However, some of the machines do rotate to face the wind, and others are vertical-axis machines for which wind direction is not important. J. Baldwin of the CoEvolution Quarterly says this book may result in more working machines than any other. After seeing this book, we think he's right.

"Labor, it is found, is contributed freely to such work, at times when more important work is practically at a standstill." Many of the farmers "put them to work in various ways to save hand labor, such as running the grindstone, the churn, the feed grinder, the corn sheller, the wood saw, and other farm machinery." It is also interesting to note that many of the farmers were wealthy and didn't purchase a shop-made mill (which was more efficient) because they could build a heavier duty, cheaper mill themselves.

The text is full of 'case studies' of the farmers and their mills.

Highly recommended.

Low-Cost Windmill for Developing Nations, booklet with dimensional drawings, 40 pages, H. Bossel for VITA, French edition also available, $2.00 from VITA.

MATERIALS: rear axle and differential of a small car, sheet metal, pipe, steel ribbon/rod/angle iron/channel, and wood.

PRODUCTION: some welding, steel drilling, and sheet metal cutting.

"Construction details for a low-cost windmill are presented. The windmill produces one horsepower in a wind of 6.4 m/sec (14.3 mph), or two horsepower in a wind of 8.1 m/sec (18.0 mph). No precision work or machining is required, and the design can be adapted to fit different materials or construction skills. The rotor blades feather automatically in high winds to prevent damage. A full-scale prototype has been built and tested successfully."

Performance data is included. The windmill is best used to transmit mechanical energy, but also can be connected to a generator.

Sahores Windmill Pump, booklet, 80 pages, J. Sahores, 1975, $6 from Commission on the Churches' Participation in Development, World Council of Churches, 150 Route de Ferney, 1211 Geneva 20, Switzerland.

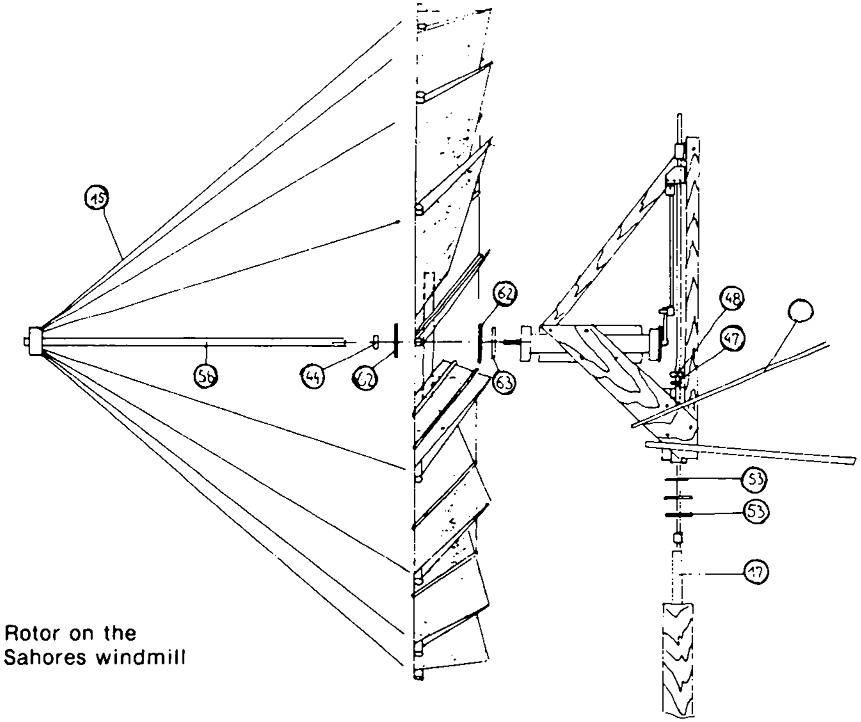
MATERIALS: bamboo or wood, cloth, nylon strings, inner tube, axle, crankshaft and bearing supports made of iron and steel

PRODUCTION: some welding and metal work for axle and crankshaft

French language edition only; however, the step-by-step construction plans are so detailed that the unit has been built without a translation of the text.

A group of French engineers has developed a light, simple windmill, mainly using bamboo sticks, cloth and string, which sets in motion a standard water pump (design not included). Only the welded transmission mechanism needs some sophistication for manufacture. This windmill incorporates the primary elements of the American multi-bladed windmill, at perhaps 5% of the cost! One of the most imaginative examples of appropriate technology we've seen.

There are three innovations of particular note: 1) the 3 meter diameter wheel



Rotor on the Sahores windmill

is made of bamboo (or wood) with cloth sails in the shape of the American multi-blade design; its light weight and automatic feathering mechanism mean that the tower can consist only of a pole with 4 cord or steel guy wires rather than a large, expensive (usually steel) structure. 2) The automatic feathering system consists of pieces of inner tube attached so that the blades open more as the wind becomes stronger, thus protecting the windmill from damage while also allowing it to make use of light winds. 3) A counterweight system is employed which enables the pumping action to be adjusted by the owner, for operation at windspeeds from 2 m/sec up to strong winds.

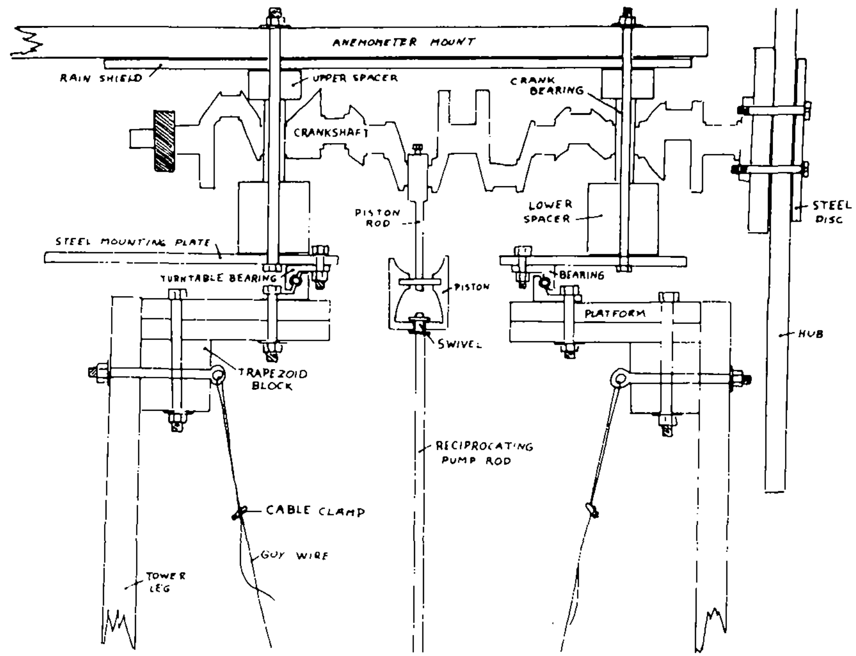
The cost of materials in France was approximately US$85 (this included a purchased pump). The first prototypes have been working for 3 years. 20 of these machines were built in 1974-75 and are being tested in Africa.

Highly recommended.

A Water-Pumping Windmill That Works, article with plans, 7 pages, New Alchemy Institute, in Journal No. 2, 1974, $6.00 from WETS.

Dimensional drawings with English measurements, text, and assembly information. A complete parts list is provided.

"This windmill consists of three cloth sails attached to three tubular steel masts which are fastened to a triangular plywood hub. The center of the hub is bolted to the end of an automobile crankshaft, which spins in bearings mounted



The turntable: an automobile crankshaft and piston are used to convert the rotating motion of the windmill rotor to the up-and-down motion of the pump rod.

on top of a steel ball-bearing turntable. The bearing turntable unit, which allows the windmill to rotate so that the sails are always perpendicular to the wind, is mounted at the top of an eight-legged tower which is firmly guyed and braced. A piston rod connected to the crankshaft transfers power through a reciprocating vertical steel pipe which runs from the top to the bottom of the tower where it operates a high capacity piston-type water pump. This windmill is designed to remain operational and to withstand storm conditions...Water-pumping trials showed a yield of 250 gallons per hour in a 6 mph wind with 18 ft. diameter blades applying power to a 3" diameter pump through a 3½" stroke." The designers recommend a greater stroke or larger diameter piston so that the full potential of the windmill will be reached.

A version of this sail-wing windmill using a bullock cartwheel and bamboo poles for the rotor has been built in Madurai, India (described on page 101 of the Energy Primer). The ball-bearing turntable is "the only component that cannot be assembled in an Indian village. A machine shop is required."

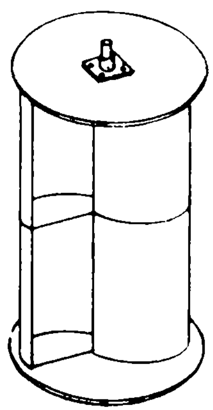
A very promising design.

Wind Power Poster, 1 large sheet, both sides, $3 from Windworks, Box 329, Route 3, Mukwonago, Wisconsin 53149, USA.

Good introductory material on wind power is presented, in the form of a wall poster. Includes single sketches of 17 different windmill designs, giving an idea of what has been tried and the relative sizes of the machines. Shows theoretical potential power and actual performance for each in kilowatts. Formulas and graphs for: available power, some design characteristics, and electrical appliance consumption. Text briefly introduces important considerations for the use of wind power. Annotated references. Summary in French and German.

How to Construct a Cheap Wind Machine for Pumping Water, leaflet, 13 pages, Brace Research Institute, 1965 (revised 1973), $1.25 from BRACE.

MATERIALS: 2 oil drums in good condition, 2 self-aligning ball bearings (flange type), wood frame, plywood, 80 feet of 1/8" galvanized steel wire, 6 turnbuckles, 1¼" water pipe for rotor shaft, one ½" bore ball bearing, 15 feet of plastic pipe.
PRODUCTION: some welding, no critical machining is necessary.



This device is a Savonius Rotor, adapted to water pumping for irrigation where windspeeds are 8-12 mph or more, and water level is not more than 10-15 feet below ground.

Brace has tested the unit to find out its potential for low-cost water pumping. "From the tests the following conclusions can be drawn: the Savonius Rotor, although not as efficient as a windmill of comparable size, lends itself to water-pumping for irrigation due to its low initial cost, simplicity of materials and construction, and low maintenance cost...The only important points to be observed in erecting such a machine is the proper choice of the site and careful assessment of the average wind speeds. From this information, the proper pump size and stroke can be chosen from the graphs at the back of this pamphlet." Another graph is included which gives the output at various wind speeds. One pump designed to operate at 10 mph and lift water 15 feet will have an output of 181 imperial gallons per hour at that wind speed.

The Rotor has been designed in this form for moderate wind speeds and water-lifting up to 30 feet. Brace reports that a fair amount of "experimentation was needed to determine the best location of the pump relative to both the source and the discharge." Design of a simple diaphragm pump is also included.

This leaflet is complete. Shop and plumbing terms are often used. (See also **Wind and Windspinners** in this section.)

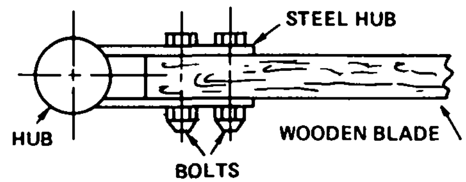
Performance Test of a Savonius Rotor, technical report with charts and graphs of the test results, 17 pages, M. Simonds and A. Bodek for Brace Research Institute, 1964, $2.00 from BRACE.

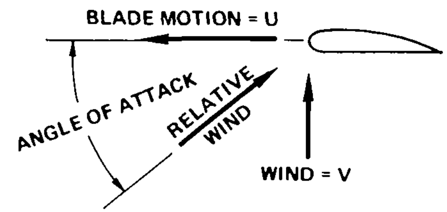
Performance tests were carried out using an 18 sq. ft. rotor on an open site. "*It is concluded that a Savonius Rotor pumping system operates quite satisfactorily and is indeed a practical design of windmill.* It is, however, only about half as efficient as the conventional fan mill" which costs 4 or more times as much. Two rotors would thus have the same output as a conventional fan mill, but the total cost would be less than half that of the conventional machine.

"The system seems best suited for pumping in cases where the well-depth does not exceed 20 ft....the windmill should be designed to look after itself safely in storms."

This is clearly an important report for anyone who plans to experiment with or build any large numbers of Savonius Rotors. Torque, power co-efficients, and tip speed ratios are examined. (see also **Wind and Windspinners**.)

Simplified Wind Power Systems for Experimenters, book, 80 pages, Jack Park, 1975, $6 from Helion, Box 4301, Sylmar, California 91342 USA; or WETS.





This book represents another attempt to demystify technology. It is a response to the fact that "most of the information (currently) available requires engineering training or is not complete enough...It is hoped that (in this book) the reduction of complex mathematics into simple graphs and arithmetic problems will allow a greater segment of the innovative public to use the fundamentals an engineer has. To make this book as useful as possible, a page has been devoted to graph reading, and numerous examples are used to illustrate each step in the windmill design process."

Over 50 illustrations and photos of all kinds of windmachines, and an equal number of simple graphs and minor drawings. It not only gives an excellent overview of the possibilities for small windpower installations; it also comes very close to Park's goal of providing "the reader with the engineering tools necessary to accomplish a respectable job of designing and planning the construction of windmills."

Major topics are power required, wind energy available, windmill efficiency, airfoils, windmill augmentation, structural design, and mechanical design. Very little is actually said about pumping water, electrical systems or direct mechanical conversion; you'll have to go elsewhere for this essential information. But as to the design of the windmill itself, this is the book to have.

Hats off to Jack Park. A significant contribution to the effort to take knowledge of technology out of the sole control of the experts and make it accessible to the public.

Helion also publishes two wind power technical memos: WTM 1—Aerodynamic Layout of Windwheel Blades (a technical method for optimum layout), 10 pages, $1. WTM 2—Hybrid Windmill Notes (a summary of Helion's findings on Darrieus rotor/Savonius rotor vertical-axis hybrid windmills), 8 pages, $2. Plans for an aluminum-bladed 2-5 kw windgenerator, $10.

Proceedings of the United Nations Conference on New Sources of Energy—1961, Volume 7 on wind power, 408 pages, $16.00 from United Nations, Sales Section, Room LX-2300, New York, NY 10017 USA.

The seven-volume **Proceedings** were originally printed in 1964, and reprinted in 1974. They are obviously expensive and hard to find; as of this printing they are still available from the above address. Some major libraries have copies.

The relevant material in volume 7 (the only volume dealing with wind power) is as follows:

a) Studies of wind behavior and investigation of suitable sites for wind-driven plants (15 articles).

b) The design of windpower plants (11 articles).

c) The testing of windpower plants (4 articles).

d) Recent developments and potential improvements in windpower utilization (13 articles), including:

"Small Radio, Powered by a Wind-Driven Bicycle Dynamo," by Stam, Tabak, and van Vlaardingen, 5 pages.

"Adaptation of Windmill Designs, with Special Regard to the Needs of the Less Industrialized Areas," by Stam, 9 pages.

"Windmill Types Considered Suitable for Large-Scale Use in India," by Nilakantan, Ramakrishnan, and Venkiteshwaran, 7 pages.

Wind Energy Bibliography, booklet, 66 pages, Ben Wolff, 1974, $3 from Windworks, Box 329, Route 3, Mukwonago, Wisconsin 53149 USA; or WETS.

One of the best wind energy bibliographies available. Topic headings are wind (behavior, measurement), windmills (historic perspectives, developing countries, large scale installations, electrical generators, vertical axis, shrouded and fan type, commercial), aerodynamics, electrical, towers, storage (batteries, compressed air, flywheels), conversion, hydrogen, catalogues. 350+ listings of articles, books, and papers—some of them undoubtedly obscure and hard to find. No annotations, addresses, or prices given (except for 12 annotated general entries).

Most of the materials in the category "windmills—developing countries" are old Brace Research Institute papers.

In addition to the wind energy bibliography and the wind power poster, to experimenters in developing countries Windworks offers full plans of their 25-foot sail windmill. These are $25.00 for one set of plans (we haven't seen them). More information on Windworks' early experiments with various windmills can be found on the back of the wind power poster (reviewed in this section) and in **Energy Book #1** (see page 133); includes some photos and comments.

Energy from the Wind, annotated bibliography, 180 pages, B. Burke and R. Meroney, 1975, $7.50 in USA, $8.00 for foreign orders from Publications, Engineering Research Center, Foothills Campus, Colorado State University, Fort Collins, Colorado, 80521, USA.

"The basis for this bibliography is a systematic search of the major abstracting and indexing tools from 1950 to 1974...In an effort to prepare a comprehensive bibliography useful to many people with varied interests in windpower, all references discovered have been included, regardless of their scope or emphasis. They range from popular review to a technical aerodynamic study, from do-it-yourself homebuilt projects for house or farm to large scale commercial production for power networks." Some annotations are provided. No address or price information is given for the 760 references listed. An annual update service is planned.

We gave this bibliography a test: we looked for everything we knew had been published about homebuilt windgenerators. We did find just about every pre-1975 publication listed. However, most of the best books on homebuilt windgenerators were published in 1975 and 1976. The best of this material on homebuilt windgenerators is already covered in the **Sourcebook**, but you might find **Energy from the Wind** a valuable source of information on other aspects of wind energy.

Wind Power Digest, quarterly journal, 50 pages average length, $6.00 for 4 issues or $2.00 for a single issue, from Wind Power Digest, 54468 CR 31, Bristol, Indiana 46507, USA.

Wind Power Digest is a new and welcome journal on small-scale wind power systems, in non-technical language. It is not a scientific journal but rather a forum for discussion by people experimenting with small wind power systems or simply interested in the subject. Most of the contributors and readers are North Americans.

Contents include how-we-did-it articles by people who use windmills or windgenerators as regular sources of power, ideas from experimenters and notes on new developments from among this informal network, experiences with various home-built and commercially-available windmachines, reviews of new publications and plans for home-built windmachines, brief summaries of developments by the large scientific institutions, and occasional reprints from other sources. The focus is on North American applications of wind power.

This journal will be of interest to groups experimenting with wind power in developing countries. However, little of the contents so far are relevant to appropriate village-level technology. The editors are planning to add an appropriate technology section focusing on wind power uses other than generating electricity—a welcome addition.

A good example of what a national-level subject-oriented appropriate technology journal can be—a communication device among a decentralized network of ordinary people and small groups of experimenters. The plain language, concentration on small-scale systems, and the kind of audience addressed make this an important voice in the effort to demystify wind power technology.

Addresses

BRACE—Brace Research Institute. This group has developed some of the most innovative village and small community equipment. Their particular focus is on water supply for arid regions. For their publications write to Publications Dept., Brace Research Institute, MacDonald College of McGill University, Ste. Anne de Bellevue, Quebec H0A 1C0, Canada.

ITDG—Intermediate Technology Development Group. They are doing a large amount of research and development, and have been actively helping in the establishment of national intermediate technology centers in a number of developing countries. They have the largest publications list on intermediate technology. For their publications write to: Intermediate Technology Publications, 9 King St., Covent Garden, London WC2E 8HN, England. (The main office of the organization has also just moved to this address.)

Mother Earth News—Their book-selling address is Mother's Bookshelf, Box 70, Hendersonville, North Carolina 28739, USA.

VITA—Volunteers in Technical Assistance. They have some volunteers in the field, and a much larger network of people who handle technical problems by mail. Their **Village Technology Handbook** and other plans are excellent. They accept UNESCO coupons in payment. Publications, Volunteers in Technical Assistance, 3706 Rhode Island Ave., Mt. Rainier, Maryland 20822, USA.

WETS—Whole Earth Truck Store, 558 Santa Cruz Ave., Menlo Park, California 94025, USA. They have a book price list, updated every 6 months, available for $1.00. For overseas orders, they add 10% to cover postage and insurance.

Two key books on appropriate village technology:

Village Technology Handbook, 387 pages, 1970, $9.00 (free if you live in the Third World and cannot afford it), English, Spanish, and French editions available, from VITA, 3706 Rhode Island Ave., Mt. Rainier, Maryland, 20822, USA.

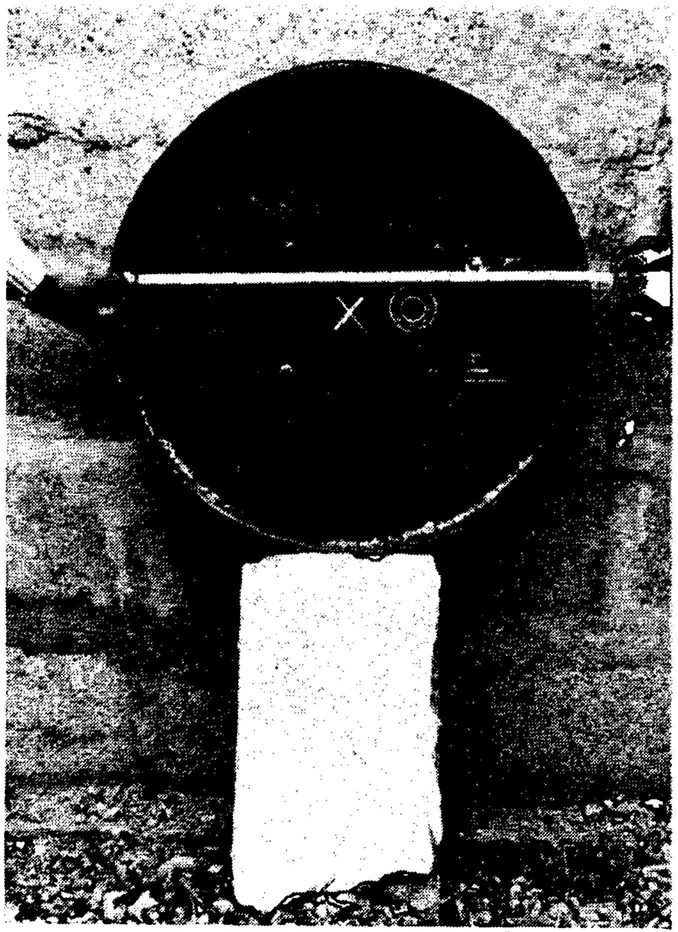
This handbook describes techniques and devices which can be made and used in villages. Subjects covered include: developing water resources, water lifting, water storage, water purification, water power, health and sanitation, agricultural equipment, food processing and preservation, and construction.

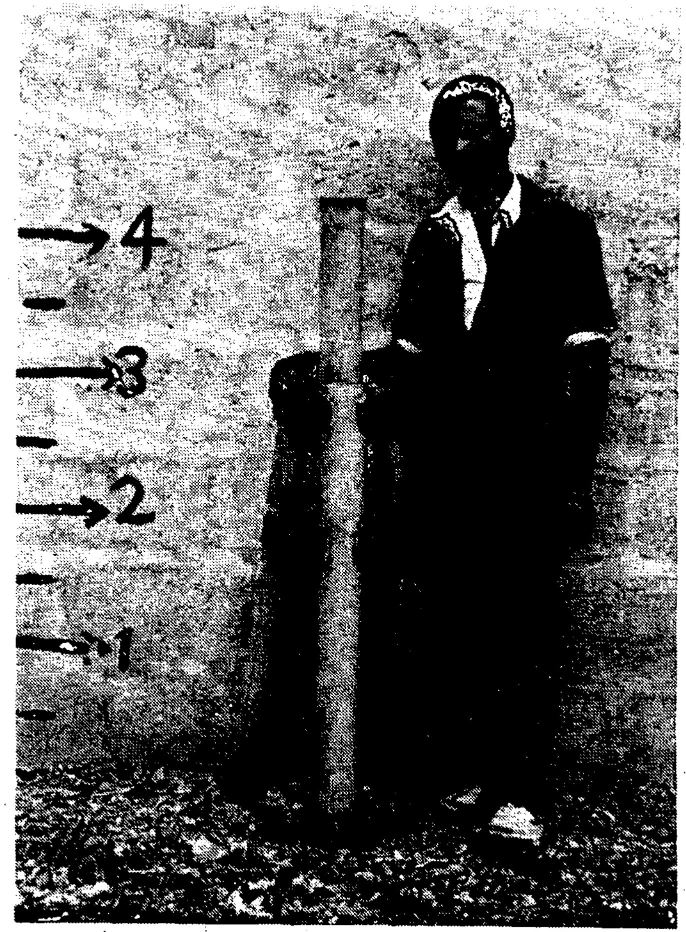
A very valuable practical book, currently being used throughout the world.

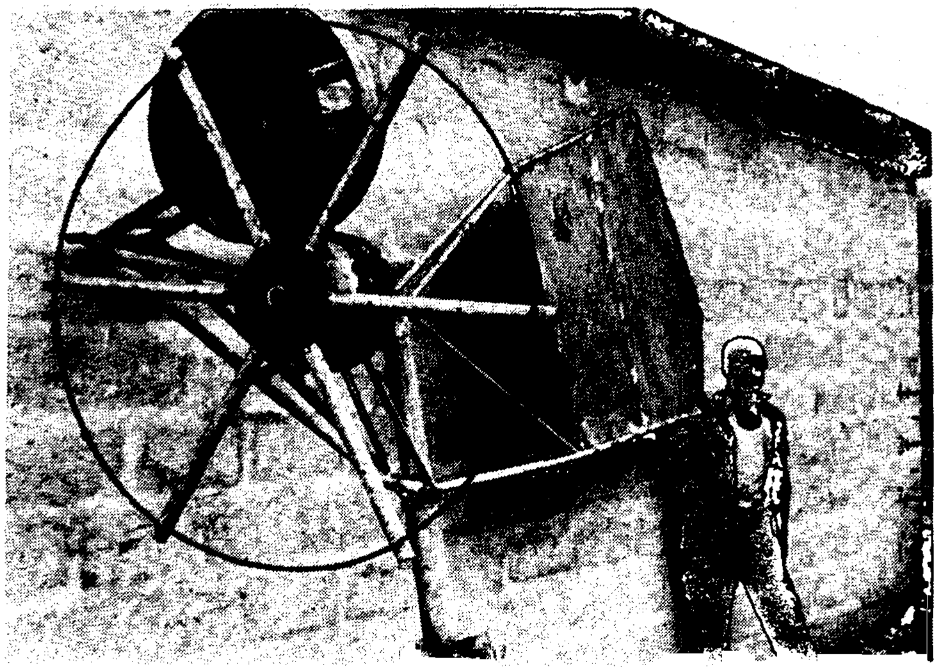
Appropriate Technology Sourcebook, 304 pages, November 1976, $4.00 ($2.00 to local groups in the Third World), from Appropriate Technology Project, Volunteers in Asia, Box 4543, Stanford, California 94305, USA.

This is the key to an entire library of practical information on small-scale technologies that can be built and used by the reader. The 250 illustrations and 385 lengthy reviews give the reader a very good idea of the content of each publication before purchasing. It's the next best thing to having all the books in front of you to select from. Price and address are given for each publication along with materials and tools used. The ADDITIONAL READING section of this Arusha windmill manual is a reprint of the AT SOURCEBOOK section on water-pumping windmills.

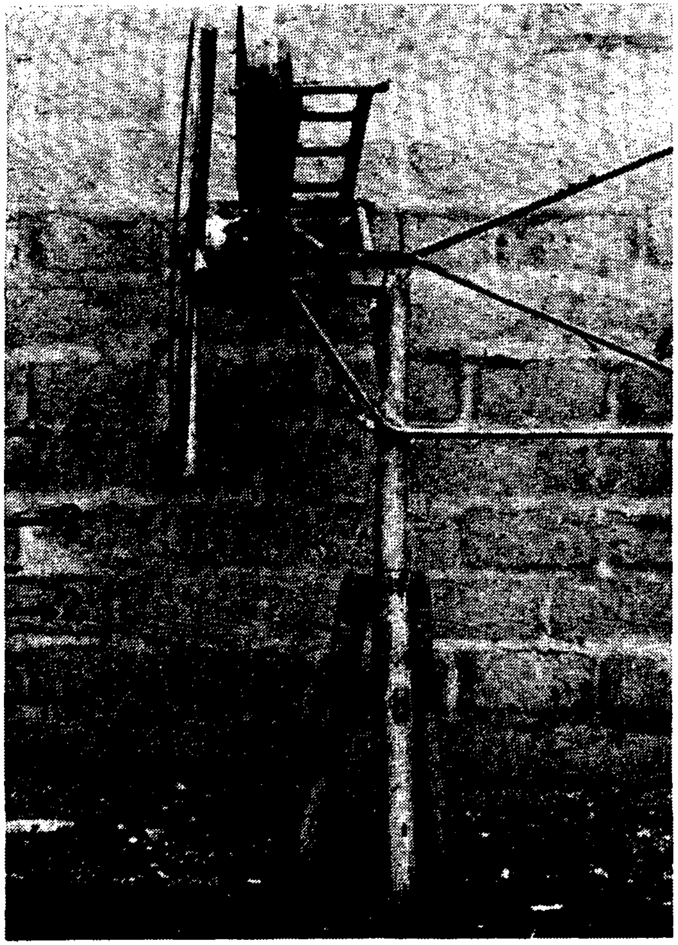
This book has had two editions and five printings, and is now being used in more than 100 countries.



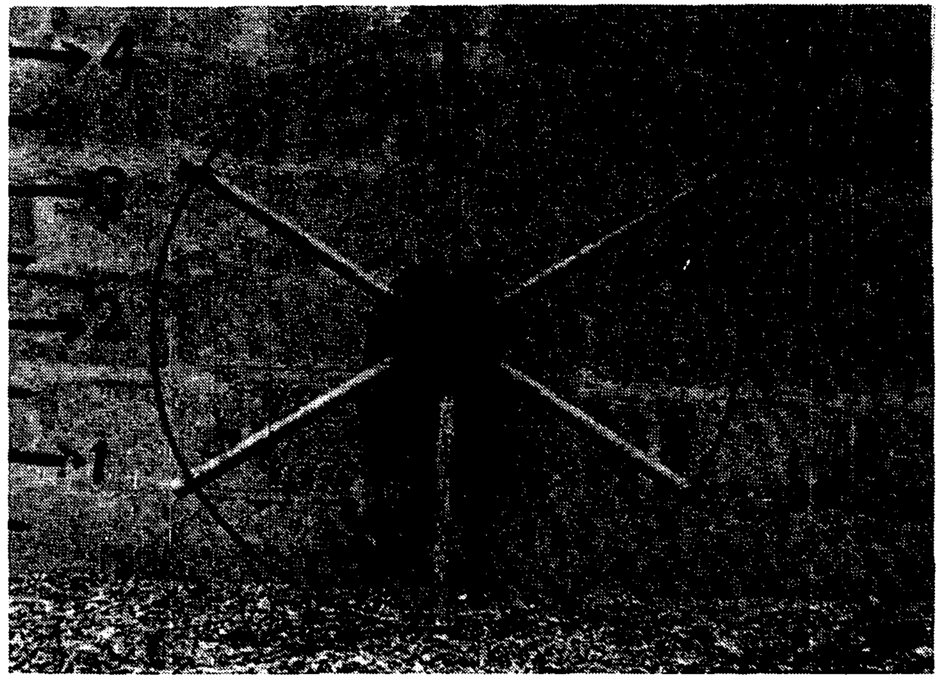


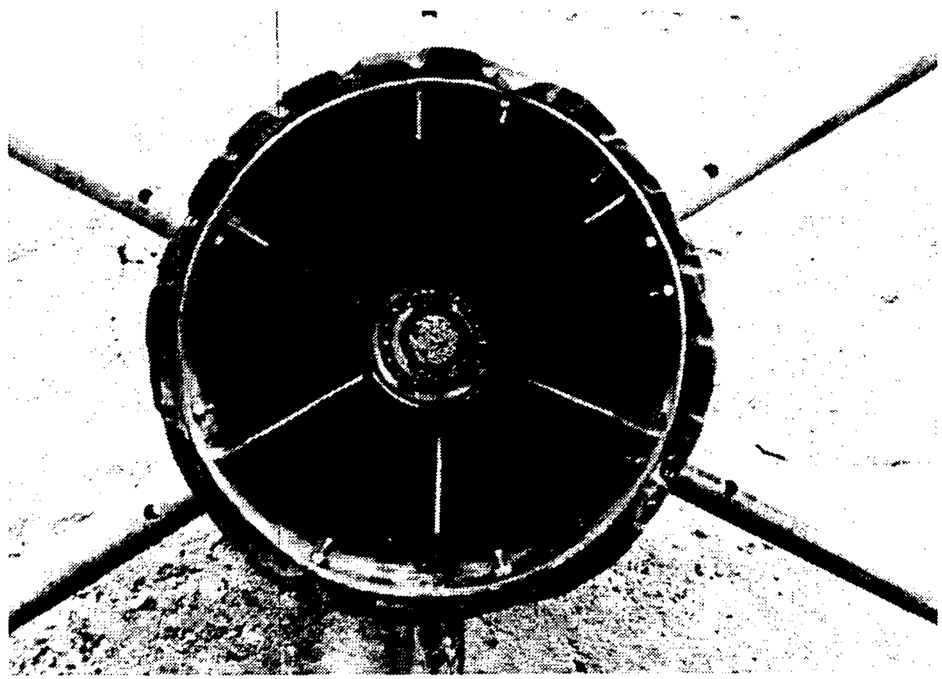


Top left: eccentric wheel with adjustable flange
Bottom left: top of windmill after trial assembly
Right: tripod

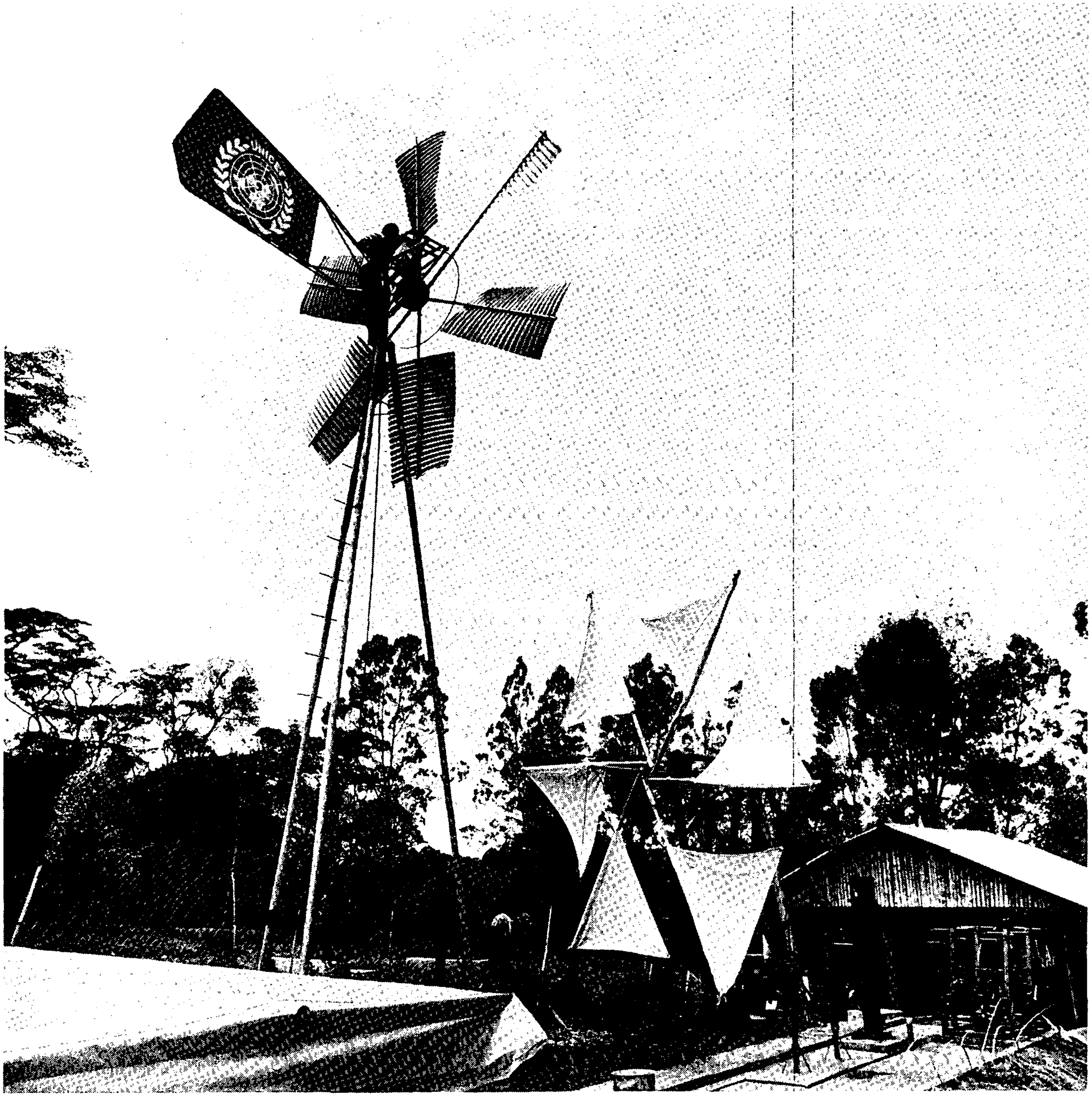


Top right: hub wheel assembly, front view
Bottom right: hub wheel, rear view, showing 6 gussets and drive tire
Left: top of windmill after trial assembly





Left: blade and blade spoke
Middle: irrigation pump
Right: irrigation pump being tested



The Arusa windmill and a sail cloth windmill at the UNICEF village technology unit display in Nairobi, Kenya. (Photo credit: UNICEF, by Thorning)