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A Curriculum Guide for Windmills

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A CURRICULUM GUIDE

for

WINDMILLS

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by

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I would like to thank my wife and children for their patience and understanding during my many hours of work necessary to complete this paper. I would also like to thank Mrs. Sharon Karibian, my school librarian, for her help and encouragement in this effort.

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Chapter 1

INTRODUCTION

Ninety-five percent of the fuel used in the world of today is called fossil fuels. These fuels are coal, oil, and natural gas which were developed over the millions of years from fossilized remains of prehistroic animals and plants. These fossil fuels are all stored deep in the earth, are limited in amount, and are not easily renewable.

Man has become dependent on fossil fuels to do work, to provide warmth, to move people, and to move goods from one place to another. The amount of fuel used by man daily has doubled every twenty years since the year 1900. Man's use of fossil fuels is greater than his production of fossil fuels. There is a need for a new energy source that is inexpensive, clean, and easily renewable. Many people believe that wind power is a possible solution to this problem.

PURPOSE

Due to the current energy crisis of today many people are looking toward windmills as a cheap, unlimited supply of energy. Unfortunately there is not a single curriculum guide available in the Industrial Arts Department in Chesapeake on wind energy or windmills. It is my purpose to provide such a guide.

HISTORY

For centuries man has been aware of the power of the winds. The amount of energy developed in a hurricane or a tornado is greater than that developed in a hydrogen bomb explosion, but there is no technology known to man today capable of converting the energy of these great winds into a usable form.

Man sometimes forgets that wind energy is a form of solar energy. It is the sun that heats the Earth, and the Earth in turn heats the air. The sunshine imparts a little heat to the atmosphere as it passes through, but warm land or water heat the overlying air by conduction. Because of the varying terrain and because of clouds, the Earth is heated unevenly. This in turn causes the movement of air as nature tries to equalize pressures and winds are formed. These winds are a form of kinetic energy and range from near calm to hurricane force.

Through the years man has tried to harness the great power of the wind. His first attempts began as early as 2500 B.C., when the ancient Egyptians used the wind to power their ships at sea. As man's knowledge of the patterns of the Prevailing Westerlies and Trade Winds increased, merchant ship captains and explorers explored the Earth and increased trade and knowledge during the 11th through the 18th century.

The history of man's development is the history of man's discovery of new resources of energy which he used to do better and more efficient work. Around 400 A.D., in Islam during the reign of Caliph Omar I, man developed a machine of a class known as prime mover, and he called that machine a windmill.

Historians suggest that the ancient prayer wheel, copied in todays pinwheel toys, was the inspiration for the first windmills. This idea of harnessing the power of the wind did not spread rapidly, but in 950 A.D. the Persians used windmills in a desert area that was hot and dry with strong prevailing winds. The windmills were used to pump water for irrigation, to harvest crops, and to grind grain. Later the Dutch used windmills to reclaim land from the sea and to operate the mills and factories.

Before Columbus discovered America, Europeans used windmills as air brakes for heavy loads that had to be lowered, and even suggested their use for driving fighting tanks or lobbing beehives into besieged cities.

A great variety of windmills were built in Holland in 1592. One was the classic Dutch type with a horizontal drive shaft and huge blades, often covered with cloth.

Other windmills used a vertical shaft like the Norse waterwheels, with turbinelike blades, including a design remarkably like the currently popular Savonius rotor.

When the first Dutch settlers settled in New York, Manhattan Island featured rows of Dutch windmills. The last of these windmills burned only fifty years ago. A pair of Dutch mills were also built on a bluff that is now part of the Golden Gate Park in San Francisco, where they pumped water in pre-earthquake days and were reactivated in 1973 after the energy crisis.

Long before the windmills of New York the first American windmill was built at Windmill Point, not far from Jamestown, Virginia. In the mid-nineteen hundreds the American windmills were radically changed by a millwright named Daniel Holladay, who designed a "self-governing" windmill in Connecticut. This inspired a succession of futher inventions and led to the production of millions of windmills in an industrial revolution that lasted until the 1930's, when the Rural Electrification Administration made it unnecessary to rely on wind power for electric lights and power.

An estimated 6.5 million windmills were in use between 1880 and 1930. Cattlemen, homesteaders and rail-roads used mills to pump water and grind grain. In the late 19th century windmills supplied about one fourth of the power needs in the United States.

The discovery of electricity and the development of the battery and generator led to the adoptation of windmills to produce electricity. In 1894 explorer Fridtjof Nansen of Norway built himself a wind-drawn dynamo in the Artic and had electric lights. Admiral Richard Byrd, the noted explorer, also used a Jacobs wind generator which was so dependable that decades later his son found it still working and brought its propeller back as a momento.

The basic American made electric windmill is the Jacobs windmill built by Jacobs Wind Electric Company in the 1930's. This windmill is a three blade rotor with a matching generator of 2500 watts at 32 volts or 3000 watts at 110 volts. In 1975 the cost of installing the Jacobs Windmill with batteries was about $800 per kilowatt, but the average yearly repair cost was only $100 per year. The operating and maintenance cost were largely limited to the replacement of batteries. These figures were gained from records kept on more than a thousand plants over a ten year period. The Jacobs Wind Electric Company discontinued making windmills in 1957 because the rural electrification program greatly reduced the demand of windmills.

In 1931 G.J.M. Darrius patented an unusual device named the Darrieus Vertical Axis Rotor. The reason for the circular shape can be understood by imagining a square instead of a hoop rotating on a shaft. The sides of the square are airfoils, and the cords of the shaft are simply brace members. This device will rotate in the wind, however, at any significant wind speed the centrifiugal force will cause the vertical airfoil members to bend outward unless they are heavily braced. The solution to this problem was to design the blades into the shape of the catenary. Sometimes the machine is fitted with three blades instead of two to increase the solidity. The only fault with the Darrieus rotor is that it is not self-starting. Today there are four laboratories experimenting with the Darrieus rotor. They are the Low Speed Aerodynamics Labroratory, National Research Council, Ottawa, Canada; Sandia Laboratory, Albuquergue, New Mexico; Langley Research Center, Hampton, Virginia; and the Research and Design Institute, Providence, Rhode Island.

The Savonius Rotor is the best known version of the vertical axis rotor. Built in 1929 by S.J. Savonius, the Savonius Rotor is constructed in the S-shaped design with a shaft down the center of the "S". It looks like an oil drum cut lengthwise in half with one half turned around to create the letter "S". Some crude Savonius rotors have been successfully built from split oil drums. The Savonius has also been used successfully as an ocean current meter, where it can accurately measure ocean current speed as low as 0.5 knots.

The Savonius rotor is a self-starting rotor in wind from any direction, but it has a very low velocity ratio. Because of this low velocity ratio, the Savonius rotor has received very little attention as a windmill prototype.

Even with all of these types of windmills, the coming of cheap electricity and cheap small engines ended the reign of windmills. Electricity was more convenient and cheaper than the maintenance of a windmill. Only where the power lines were absent did the windmills remain.

Before the energy crisis there was a general fading out of the windmill as a power source, but England, France, Russia, Demark and the United States continued experimenting with large windmills to produce electrical power. Today NASA Lewis Laboratory of Cleveland, Ohio, the main branch of the government for large windmill research, has plans for building a one megawatt windmill in the near future and in the little community of Tvind, on the Danish west coast, the largest electrical windmill in the world was completed in 1975. One of the many highlights of the bicentennial year, 1976, was the erection of a large windmill at Windmill Point, Virginia the site of the first American windmill. There are also restored windmills in Rhode Island, Williamsburg, Virginia, and Winnemucca, Nevada. With the advent of the energy crisis windmills are again becoming of interest to man.

Chapter 2

RELATED LITERATURE

Warning of our dwindling fuel supplies, the rapid increase in power cost, the fear of nuclear catastrophe, and the continuing drive for a pollution-free environment are spurring the interest in windpower energy generation. Studies and articles cover every aspect of wind energy from discussions on the development of winds to the speculation of climatic changes; from futuristic inventions and applications of wind energy to applications and specifications of wind energy generation. Most studies indicate that though wind-powered generation cannot supply all of our electrical power, it may be a partial answer to the problem.

Government and private interest groups are spending millions of dollars to develop practical wind-powered systems. The problem simply stated is "At what point does a wind machine make economic sense?" It has been discovered that a rotor blade sixteen feet in diameter is needed to extract only two kilowatts of energy from a 20 miles per hour wind. Therefore agencies such as the Department of Energy (DOE), and the National Aeronautic and Space Administration (NASA) are experimenting with huge windmills that will extract 100 to 300 kilowatts per hour. Many authors agree that the major drawback to a windmill is the ability to produce a constant electrical output regardless of variations in windspeed. Victor D. Chase suggests that this can be accomplished by hooking the windmill to an existing utility power grid. Then power can be fed into the grid by the windmill when the wind is right; and power can be drawn from the grid when the wind is down. This process is also made possible by modern windmills using variable pitch and constant speed rotors. A failing of Mr. Chase's plan is that the utility company owning the grid would not like to provide power for the system when the wind is down.

Another suggestion is to build large windmills in areas where constant winds are available and as Mr. Chase puts it, "farm" the wind as crops are farmed. An alternate plan of William E. Heronemus, professor of engineering at the University of Massachusetts, proposed to build floating windmills and moor them a hundred miles off the Atlantic coast where the off-shore winds are more powerful than the land winds.

Heronemus' studies estimate that a difference of three hundred to five hundred watts of electricity can be harvested from the off-shore winds than land winds. In 1976 Senator Edward Kennedy introduced an amendment on off shore wind power to Congress. Congress is now conducting a feasibility study, but results have been dilatory. Today's economic difficulties will prove detrimental to this program.

Giant windmills are being built by the Department of Energy in Vermont, North Carolina, and California. These windmills will extract over one and one quarter megawatts of electricity. Large windmills are being built because they prove to be more efficient, but the size adds to the production cost and uses more land area. All of these factors make wind energy unattractive. Floyd Hickok stresses in his book, Handbook of Solar and Wind Energy, that non-fossil fuels such as the sun and wind are everywhere, free, and inexhaustable and that they only require invention and proper technology to make them useful to man.

Although many scientist feel that wind energy is the answer to our energy problem, a few scientist have reservations in the area of extracting to much energy from the wind. Dr. M.R. Gustavson believes that if more than ten percent of the wind's kinetic energy is extracted the climate of the Earth would be changed or at least would suffer from the energy loss. Dr. Gustavson stresses the need for caution in the use of windmills and expresses the need of specific governmental guidelines in the amount of windmills and the placement of windmills in certain land areas.

Interest in windmills is not limited to the United States. Many countries are involved in using the awesome power of the winds to stretch the dwindling source of fossil fuels. Canada, England, France, Sweden, Switzerland,

and Russia are all studying and building windmills. In Tvind, Denmark, the largest windmill in the world was built in 1975. This windmill was built by untrained volunteers to save the cost of heating oil for the community of eight hundred people.

Windmills, which once dotted the minwestern plains of the United States fifty years ago, are returning. Wind speed variation, power storage, structural integrity, support towers, initial cost, aesthetics, and noise are the main problems facing windmill designers of today. The need for greater efficiency and safety has eliminated the old Dutch windmill. Today's windmills will have slender metal or composity blades, aerodynamically contoured, turning at higher speed and needing breezes of ten to fifteen miles per hour to produce an adequate amount of electricity.

SUMMARY

The energy crisis of the late 1970's has increased man's interest in the use of windmills as electric generators. Wind energy, being a by-product of solar energy, is free, easily renewable, and pollution free. All of these factors make wind energy a perfect alternative source of electric power.

Many articles and books are being written illustrating how windmills can be built for use in private homes, farms. factories, and even hotels to help save on the cost of

heating oil and electricity. Studies have been made and are still being made on the effects of windmills on the economy and on the environment. It has not been made clear if the extraction of the kinetic energy of the wind will cause damage to the climate of the world.

In general windmills are looked upon favorably by most scientists and engineers. Modern technology is producing a more efficient wind extraction machine. With imporved efficiency, windmills will become a greater factor in the solution of our current energy crisis.

Chapter 3

OBJECTIVES

The students will be able to:

1. correctly discuss the history of the development of windmills.
2. name and locate, on a global map, the major winds of the Earth.
3. accurately name winds by their speed according to the Beaufort Wind Scale.
4. accurately name and describe the three major types of windmills.
5. accurately name the parts of the windmill.
6. describe the conversion process of windenergy chinging to electric energy.
7. discuss the feasibility of using windmills and their placement in different land areas.
8. build a workable windmill.

SCOPE

airfoil blade

Beauford Wind Scale

Darrieus Rotor

Department of Energy

Egyptians

Floyd Hickok

fossil fuels

fuel cell

gears

Gustavson, M.R.

inverter

Jacobs Windmill

kilowatt

kinetic energy

National Aeronautic and Space Administration

pin wheels

pollution

Prevailing Westerlies

Princeton Auto Rotation Vane

pump rods

rectifier

Savonius Rotor

site survey

solar energy

starter bucket

tail vane

tower

Trade Winds

Tvind, Denmark

William E. Heronemus

wind engineer

wind energy conversion systems

TOPIC OUTLINE

I. Introduction to Windmills

II. History of Windmills

III. Names of Winds

IV. Use of Windmills

V. Types of Windmills

VI. Location of Windmills

VII. Size of Windmills

VIII. Parts of Windmills

Chapter 4

SCOPE AND SEQUENCE

I. Introduction to Windmills

- A. Fossil Fuels
- B. Pollution
- C. Solar Energy

II. History of Windmills

- A. Egyptians
- B. Dutch
- C. American
- D. Floyd Hickok

III. Name of Winds

- A. Beauford Wind Scale
- B. Prevailing Westerlies
- C. Trade Winds

IV. Use of Winds

- A. Kinetic energy
- B. Wind engineer
- C. Kilowatt

V. Types of Windmills

- A. Jacobs Windmill
- B. Darieus Rotor
- C. Princeton Auto Rotation Vane
- D. Savonius Rotor

VI. Location of Windmills

- A. National Aeronautic and Space Administration
- B. Site Survey
- C. Wind engineer

VII. Size of Windmills

- A. Department of Energy
- B. Starter Bucket
- C. Tower
- D. Wind energy conversion system

VIII. Parts of Windmills

A. Airfoil blade
B. Fuel cell
C. Gears
D. Inverter
E. Pin wheels
F. Pump rods
G. Pectifier
H. Tail vane
I. Tower

LESSON PLAN

Topic: Names of the Winds

Objective: The students will be able to identify the different winds on the Beauford Wind Scale.

Lesson Procedure:

Discuss the following types of winds and their wind speed.

a. calm
b. light air
c. light breeze
d. gentle breeze
e. moderate breeze
f. fresh breeze
g. strong breeze
h. moderate gale
i. fresh gale
j. strong gale
k. whole gale
l. strom
m. hurricane

Class Activity:

Given a weather map with different wind speeds on it the student will lable the names of the winds with the speeds of the winds.

Special Equipment:

Handout of weather maps.

Evaluation:

Match the name of the wind with the correct speed.

A	B
light air	74 and above
hurricane	1 - 3 nauts
strong breeze	37-38 nauts
storm	13-18 nauts
moderate gale	64-73 nauts
fresh gale	19-24 nauts

LESSON PLAN

Topic: Parts of a Windmill

Objective: The students will be able to name and identify the parts of the windmill as discussed in the classroom with 90% accuracy.

Lesson Procedure:

Discuss and show illustrations of the following parts of a windmill:

a. fuel cell
b. gears
c. airfoil
d. pumprod
e. tail vane
f. inverter
g. rectifier
h. tower

Class Activities:

1. Have students name the parts of a sketched windmill on the board.
2. Pass out a handout with different types of windmills and have the students identify various parts of the windmill.

Lesson Assignment:

Have students complete the class activity handhout.

Special Equipment:

1. batteries
2. gear
3. tail vane
4. pump rod
5. airfoil blade

Evaluation:

Lay out the parts of a windmill on a table and have the students identify specified parts.

LESSON PLAN

Topic: Location of Windmills

Objective: After having studied the topics on the National Aeronautics, site survey and wind engineering, the students will be able to select and plan the proper site for a windmill to be located.

Lesson Procedures:

1. Discuss the National Aeronautic and Space Administration.
2. Discuss the process of site surveying.
3. Discuss the job of an wind engineer.
4. Show filmstrip on Wind Engineer.

Class Activity:

Select five areas that windmills could possible be located and discuss there feasibility as good locations.

Lesson Assignment:

From the five possible areas that have been listed, select the one that you feel is the best location and explain your reasons using information about wind engineers and the National Aeronautics and Space Administration.

Special Equipment:

None

Evaluation:

Review students assigments.

LESSON PLAN

Topic: Types of Windmills

Objective: The students will be able to identify the different types of windmills and their rotors.

Lesson Procedure:

1. Show filmstrip on the different types of windmills and their rotors.
2. Pass out handouts on the different types of rotors and explain each.

Class Activity:

Make and design a display or bulletin board on windmills.

Lesson Assignment:

Write a two page paper on one of the types of windmills mentioned in class.

Special Equipment:

None

Evaluation:

Check written papers on windmills.

Plans

for

Building

a

Windmill

Windmills can produce electric power absolutely free using wind power as the total energy source. The only drawback to the use of windmills in that a windmill can cost from $7,000 to $8,000, before installation.

Here is a windmill that can be built for approximately $300, if all the parts are bought new, or for about $100 by a very enterprising person who is willing to search for parts in the workshop and neighborhood.

The windcharger, as it is called, can supply a major part of the electricity requirements for a modest house or cabin or about 100 kilowatt-hours per month in an area with 10-mile per hour average windspeed.

The windcharger is a 12-ft.-diameter horizontal-axis sailwing. The sailwing construction for the three rotor blades is simple enough for a home workshop, and sailwings afford a rotor effeciency comparable to any other currently available high efficiency rotor designs. The sailwing blade assembly consists of a rigid leading edge, a tip and base section. The trailing edge of the blade is formed by a tensioned steel cable connected between the tip and base sections.

The sail is made of silicon-impregnated Dacron sail-cloth. It is cut so that the trailing edge forms a catenary arc when in place on the blade assembly. The trailing-edge cable pulls the sail taut and the catenary shape insures that the sail tensions across the blade are equal all along the length of the blade. Since the fabric is flexible, the blade is able to change shape in response to windspeed. If the sail is correctly tensioned the blade automatically assumes a shape and pitch angle that is best for most wind-load conditions. The trailing-edge cable is tensioned so that at windspeeds above operating range the sail stalls and becomes ineficient and, therefore, self-limiting.

The main rotor, transmission and alternator are mounted on a carriage that is fabricated from a 2-inch square steel tube to which are welded angle-iron mountings. A 2-inch steel tube welded to the carriage functions as a lolly shaft. It rides in a 2½-inch I.D. steel tube (fitted with two Oilite bearings and a thrust bearing) mounted on the tower. The lolly shaft and bearings enable the carriage to rotate through a full 360° axis so that the blades can turn to face downwind.

To start construction use graph paper to make a scale-up template of the leading-edge rib. Six templates will be needed. Two for the rib-forming blocks, three for the blade assemby jig and one for the initial rib bank. Be careful that the tooling holes, rivet holes and blade spar (center) hole are accurately located. Trace a 5/8-inch wide strip (in the pattern shown on the diagram) around one of the rib templates to allow for the shape of the rib blanks (the strip is the mounting flange).

Cement two of the rib templates (without the flange) to a piece of 3/4-inch plywood. Following the outline of the template, cut out two plywood rib-forming blocks with a band saw or saber saw. Drill 3/16-inch holes for the spar center and jig locating holes. The 3/32-in. radius (for bending the flange) and 5° relief can be made with a wood rasp. Cement the rib template with the 5/8-in. border (the flange pattern) to a piece of .025-in. 6061T-4 aluminum sheet. Cut out a rib blank and drill the spar center, jig-locating hole and rivet holes. Use this cut and drilled aluminum rib blank as a template to make eight more rib blanks (there are three of the ribs in each blade).

The ribs are formed by sandwiching a rib blank between the two forming blocks. Maintain proper placement of the blank by inserting 3/16-in. bolts through the jig-locating hole and the spar center hole in the forming blocks and rib blank. Hold the sandwich together by clamping it in a large vise. Use a rubber mallet to knock the 5/8-in. flange flat against one side of the forming block. The direction is indicated by where the rib is to be placed in the blade. Next, use a lead solder bar to shape the flange. The soft solder bar, when pounded onto the flattened flange, conforms to the shape of the forming block and forces the rib flange to lay down and smooth out. (Between rib-forming operations flatten the solder bar on a hard surface with a hammer to ready it for the next rib.)

Remove the finished rib from the forming-block sandwich and cut the rear end to accomodate the spar. The rib mounting plates are cut from 1x1x1/8-in. aluminum angle iron. Drill 5/32-in. rivet holes on the rib and spar sides of the angle in the pattern shown.

The cable stays (for holding the trailing-edge cable) are fabricated from two pieces of 1x1x1/8-in. aluminum angle epoxied and riveted together. Clean two 8-ft. lengths of aluminum angle with a strong detergent and water and then rub bright with dry steel wool pads. Clamp and bond the two lengths together with epoxy. Aircraft-quality epoxy such as 3M brand 2216B/A is recommended. Cut stays to length. Use a drill press and a 2-in. hole saw to make the sutout for the spar. Drill the rivet holes and the cable hole in the cable stay. Rivet each cable stay as shown. Their triangular shape can be cut with a hack saw or on a table saw using a finetooth finishing blade. The base and tip cable stays are braced with ½-in. aluminum round stock with ends flattened for fastening. Drill bolt holes in the base cable stay to accommodate the aluminum band that holds the sail in place. Rivet and epoxy the mounting plates to all the leading edge ribs. Do the same to the cable stays. A cable stay, a leading-edge rib and two mounting plates riveted together form the blade tip assembly.

in the skin, spar and ribs. Epoxy and rivet into place. Loosen clamps in 12-in. sections. After the epoxy has cured trim off excess aluminum and file sharp edges smooth.

The sails are cut from 4-oz. silicon-impregnated Dacron sailcloth. The pattern must be followed accurately to obtain the critical catenary arc required for the trailing edge.

The trailing edge of the blade is rigged with an 1/8-in. flexible steel cable. Thread the cable through the cable holes in stays. Slip 1/8-in. I.D. vinyl tubing over the cable between the stays. Put a press-on lead sleeve on the end of the cable at the tip stay and pull the sail over the blade skeleton. The open end of the sail can then be attached to the base cable stay with a wraparound 1-in. aluminum strip made from the same material as the blade skin. It is clamped in place with No. 6 nuts and bolts. Tensioning the sail requires two people and a table. One person stands on the table and holds the blade vertically with the trailing-edge cable hanging clear off the table. Hang a 70-lb. weight on the cable. The second person can crimp a lead press-on sleeve on the tensioned cable. Trim off the excess. You could also tension after the blade is mounted but it is harder to get the correct amount of pull.

The carriage is made from a piece of 2x2-in. steel tube, angle iron and a 2-in. steel pipe. All joints are welded.

The transmission system is assembled directly in the carriage. Bolt 4 pillow blocks (bearings) to the carriage.

Install the main shaft and the jack shaft in the pillow blocks and mount the three transmission sprockets on the shafts. The alternator is mounted to brackets under the main drive tube. The exact dimensions of these brackets depend upon the brand and type of alternator used.

The power takeoff is through two brass slip rings mounted on the lolly shaft. The slip-ring assembly is made from a 4-in. length of lucite or acrylic plastic 2-in. I.D. ($\frac{1}{4}$-in. wall)tube that is epoxied to the lolly shaft. Over that tube position and epoxy two 1-in. long, $2\frac{1}{2}$-in. I.D. ($\frac{1}{4}$-in. wall) brass bearings. Use flat washers to attach wires from the alternator to the bolts. The $\frac{1}{2}$-in.-wide carbon brushes are mounted in $\frac{1}{2}$-in square tube holders.

The lolly support tube is a 3-ft. length of $2\frac{1}{2}$-in. I.D. ($\frac{1}{4}$-in. wall) steel tube. A 2-in. I.D. Oilite flange bearing is epoxied in the top of the tube. A second straight-sided oilite bearing is mounted in the tube and held in place by a nut and bolt through both walls of the support tube and bearing.

The blade hub consists of three angle irons welded to a Dodge weld-on hub. Each blade is bolted to a hub angle with $\frac{1}{2}$-in. hardened bolts.

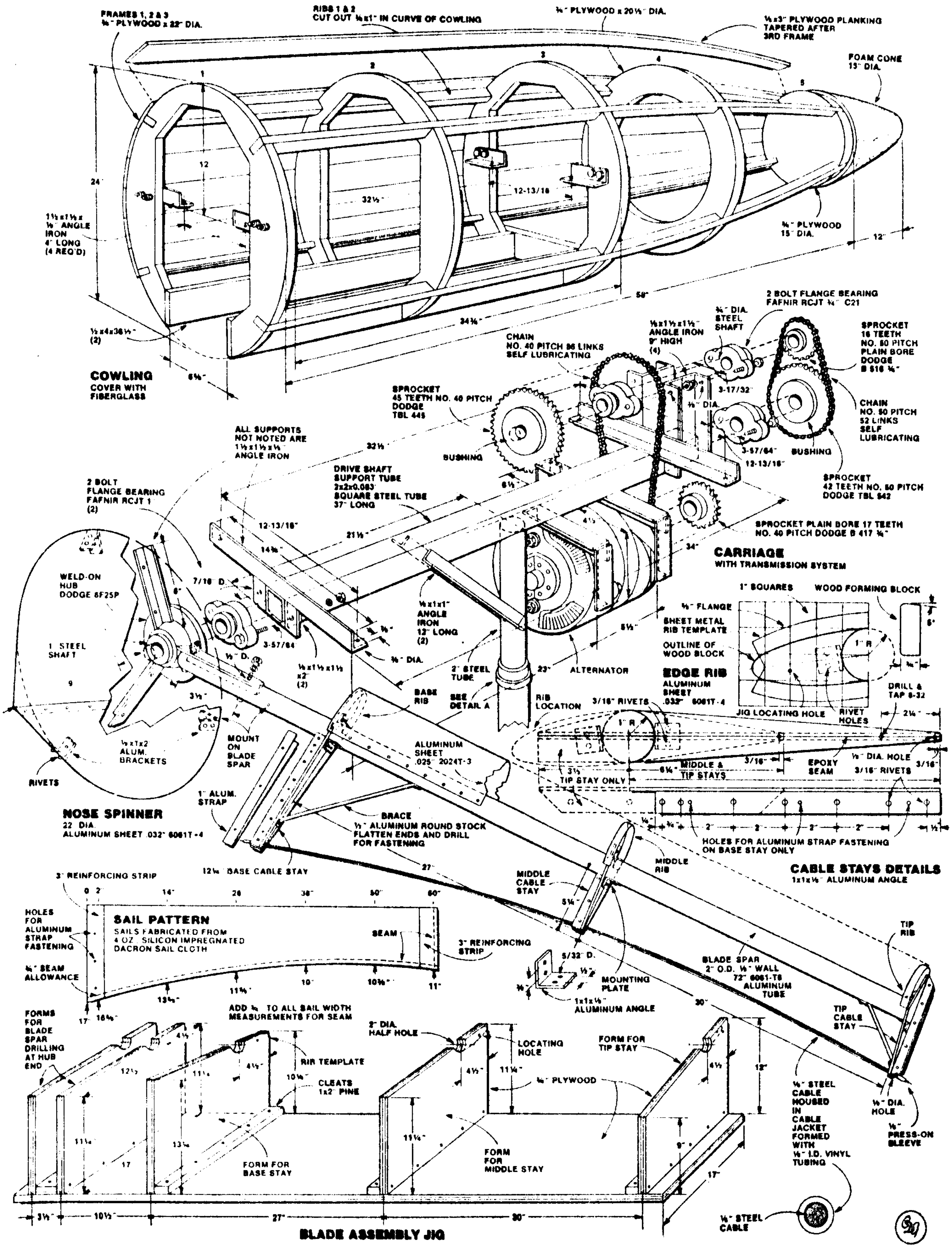
The cowling braces are made from five 3/4-in. plywood pieces cut as shown. The cowl skeleton is covered with tapered strips of 1/8-in.-thick plywood. The nose is carved

The blade-assembly jig is made from 3/4-in. plywood. The assembly jig ensures finished blade uniformity plus correct blade pitch angles. Bolt the leading-edge ribs to the assembly jig through the jig-locating holes in the ribs. Lay the rear cable stays in place. Slip the blade spar into the jig and locate the rivet holes on the spar. Withdraw the spar and drill the rivet holes (and the horizontal blade-mounting holes at the base). Reinsert the blade spar into the assembly jig and rivet and epoxy the mounting plates to the spar.

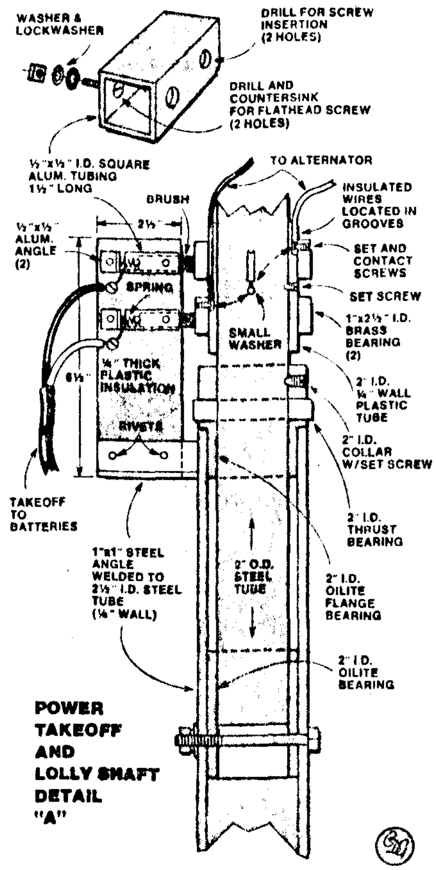
The leading-edge skins are formed from a 60x11-in. piece of .025-in. 2024T-3 aluminum sheet. Locate and scribe a lengthwise centerline on the aluminum skin. Line this along the edge of a worktable. Clamp the skin between the table and a 2x4 with C-clamps and rubber-mallet the aluminum into a right angle. Unclamp the skin and carefully continue bending the aluminum over to form a U-shape. This can be made easier by placing the skin on the floor. Lay a long board on the top so that the board covers the leading edge along its entire length. Put your knees on the board and apply pressure to bend the aluminum over to form the U-shape skin.

The next step is to attach the formed leading-edge skin to the blade skeleton. Use C-clamps to hold everything in place. Starting at the tip of the blade, drill rivet holes from a Styrofoam block which is epoxied to the front bulkhead. apply a layer of fiberglass and paint.

After everything is assembled the windcharger can be safely mounted to a tower.



FRAMES 1, 2 & 3 ¾" PLYWOOD x 22" DIA.
RIBS 1 & 2 CUT OUT ¾x1" IN CURVE OF COWLING
¾" PLYWOOD x 20½" DIA.
¼x3" PLYWOOD PLANKING TAPERED AFTER 3RD FRAME
FOAM CONE 15" DIA.
¾" PLYWOOD 15" DIA.
1½x1½x ¼" ANGLE IRON 4" LONG (4 REQ'D)
½x4x36½" (2)
COWLING
COVER WITH FIBERGLASS
2 BOLT FLANGE BEARING FAFNIR RCJT ¾" C21
¾" DIA. STEEL SHAFT
½x1½x1½" ANGLE IRON 9" HIGH (4)
CHAIN NO. 40 PITCH 86 LINKS SELF LUBRICATING
SPROCKET 16 TEETH NO. 50 PITCH PLAIN BORE DODGE B 516 ¾"
SPROCKET 45 TEETH NO. 40 PITCH DODGE TBL 445
CHAIN NO. 50 PITCH 52 LINKS SELF LUBRICATING
ALL SUPPORTS NOT NOTED ARE 1½x1½x¼" ANGLE IRON
BUSHING
DRIVE SHAFT SUPPORT TUBE 2x2x0.083" SQUARE STEEL TUBE 37" LONG
SPROCKET 42 TEETH NO. 50 PITCH DODGE TBL 542
2 BOLT FLANGE BEARING FAFNIR RCJT 1 (2)
SPROCKET PLAIN BORE 17 TEETH NO. 40 PITCH DODGE B 417 ¾"
CARRIAGE
WITH TRANSMISSION SYSTEM
WELD-ON HUB DODGE 8F25P
¼x1x1" ANGLE IRON 12" LONG (2)
1" STEEL SHAFT
½x1½x1½ x2" (2)
2" STEEL TUBE
ALTERNATOR
1" SQUARES
WOOD FORMING BLOCK
½" FLANGE
SHEET METAL RIB TEMPLATE
OUTLINE OF WOOD BLOCK
EDGE RIB
ALUMINUM SHEET .032" 6061T-4
BASE RIB
SEE DETAIL A
RIB LOCATION
3/16" RIVETS
JIG LOCATING HOLE
RIVET HOLES
DRILL & TAP 8-32
ALUMINUM SHEET .025" 2024T-3
½x1x2 ALUM. BRACKETS
MOUNT ON BLADE SPAR
RIVETS
EPOXY SEAM
⅛" DIA. HOLE
3/16" RIVETS
MIDDLE & TIP STAYS
TIP STAY ONLY
NOSE SPINNER
22" DIA.
ALUMINUM SHEET .032" 6061T-4
1" ALUM. STRAP
BRACE
½" ALUMINUM ROUND STOCK FLATTEN ENDS AND DRILL FOR FASTENING
HOLES FOR ALUMINUM STRAP FASTENING ON BASE STAY ONLY
12¼" BASE CABLE STAY
MIDDLE RIB
MIDDLE CABLE STAY
CABLE STAYS DETAILS
1x1x⅛" ALUMINUM ANGLE
3" REINFORCING STRIP
SAIL PATTERN
SAILS FABRICATED FROM 4 OZ. SILICON IMPREGNATED DACRON SAIL CLOTH
HOLES FOR ALUMINUM STRAP FASTENING
SEAM
¼" SEAM ALLOWANCE
ADD ¼" TO ALL SAIL WIDTH MEASUREMENTS FOR SEAM
MOUNTING PLATE
1x1x⅛" ALUMINUM ANGLE
BLADE SPAR 2" O.D. ⅛" WALL 72" 6061-T6 ALUMINUM TUBE
TIP RIB
TIP CABLE STAY
FORMS FOR BLADE SPAR DRILLING AT HUB END
2" DIA. HALF HOLE
LOCATING HOLE
FORM FOR TIP STAY
RIB TEMPLATE
CLEATS 1x2" PINE
¾" PLYWOOD
FORM FOR BASE STAY
FORM FOR MIDDLE STAY
⅛" STEEL CABLE HOUSED IN CABLE JACKET FORMED WITH ⅛" I.D. VINYL TUBING
⅛" DIA. HOLE
⅛" PRESS-ON SLEEVE
⅛" STEEL CABLE
BLADE ASSEMBLY JIG



POWER TAKEOFF AND LOLLY SHAFT DETAIL "A"

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