ALCOA WIND TURBINES

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OVERVIEW

The Alcoa wind energy program, initiated in 1975, began with the fabrication of turbine blades, and two years later broadened its scope to the design and fabrication of complete systems of Darrieus-type vertical-axis wind turbine.

Alcoa's interest in blade fabrication is natural, as the extrusion process is uniquely suited to the production of all-aluminum blades with constant chord. Since A. G. Craig, Jr. is going to present "Fabrication of Extruded Vertical Axis Turbine Blades" in the same Workshop, the discussion on blades here will be brief.

1. Alcoa served as a subcontractor to Kaman Aerospace in the fabrication of the original 21-inch chord blades for Sandia's 17-m research Darrieus turbine.[1] The blade is of a helicopter blade design and each blade has five sections with two or them forming V-shaped struts as supports.

2. Alcoa fabricated the 6-inch chord blades for Sandia's 5-m research turbine[2], and the same blade has been used for many other machines including the Dynergy 5-m and Clarkson College's silo-mounted turbines.

3. Alcoa extruded the new 24-inch chord blades and formed them at the site for the Sandia 17-m. The blades are continuous 80-foot long pieces without joints or struts.[3] The same blade will be used for the Low Cost 17-m machine funded by the U.S. Department of Energy.

4. Alcoa has extruded a 14-inch chord blade for a 60 kW turbine and a 29-inch chord blade for a turbine with a rated power in excess of one quarter MW.

5. Blades with chord up to 58 inches, large enough for MW size machines, are under study.

6. In addition to blades for Darrieus turbines, Alcoa has also supplied a 24-inch chord blade with the cross section of an unsymmetrical airfoil to Grumman Aerospace for the Wind Stream 25, a horizontal axis wind turbine with a rated power of 15 kW.

In the area of complete systems, a family of five Darrieus turbines named ALVAWT (Alcoa Vertical-Axis Wind Turbine) are in demonstration runs within a year. All systems are designed to operate as constant rpm devices to be interfaced with utility grids to produce AC 3-phase at 60 Hz.

In figure 1, the schematic of the basic ALVAWT models are shown. The number system adopted designates the rotor size, with the first two digits* indicating the rotor height in feet, the second two digits the rotor diameter in feet, and the last two digits the chord of the blade in inches. All models show the 2-bladed rotor with single torque tube supported on top with three tiedown cables.

The development of the second and the fourth turbines, 453011 and 835524, is funded by the U.S. Department of Energy. Number 453011 is also known as the 8 kW VAWT in the Rockwell International's Rocky Flats program, and 835524 is also known as the Low Cost 17-m, which has received technical input from Sandia. The Low Cost 17-m represents the central effort at Alcoa to date, and the other models in the ALVAWT are simply either scale-down or scale-up versions of this machine. A detailed description of the Low Cost 17-m is given in the following section.

A variation of the 271806 may also be of interest as it materialized as the result of a joint venture initiated by Clarkson College of Potsdam, New York.[4] This turbine, installed at Clarkson College, has many unique features; it is mounted high on the side of a silo with no cable support; it has a continuously varying ratio speed increaser; and it is equipped with the flexibility of either a 15-foot height/diameter ratio of 1.0 or an 18-foot height/diameter ratio of 1.5 rotor, with each rotor having either two or three 6-inch blades. The system is a research vehicle designed for rural application where silos are readily available. Its free-standing design also suggests the possibility that it could be installed on top of tall buildings.

The 634214 is a machine in an overlapping size which can be considered as a small system for rural or residential use,

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*The exception is the fifth or the largest model which needs three digits.

but in the meantime possessing all the characteristics of a utility machine. It is still small enough to be shipped by conventional trucks and installed easily. Several units have been planned for delivery, with the first one scheduled to be installed in western Pennsylvania in the fall of 1979.

The largest model in the ALVAWT family is the 1238229 which is an enlarged version of the Low Cost 17-m using the 29-inch chord blades. If installed today, it would be the largest VAWT in the world. This machine is intended for utility application at high wind sites. It could be rated at 1/2 MW for a site with an annual mean wind speed of 8.05 m/s (18 mph). A prototype is scheduled to be installed for testing at the Alcoa Technical Center in Alcoa Center, Pa., in early 1980.

The performance specifications, prepared with the aid of Sandia's mathematical model PAREP,[5] are presented in Table 1.

Table 1
ALVAWT PERFORMANCE SPECIFICATIONS
(Annual Mean Wind Speed 15 mph)

Model	Rated Power kW	Rated Wind Speed m/s (mph)	Turbine Speed rpm	Generator hp	Annual Energy Output MW-Hr
271806	8	15.2 (34)	164	10	14
453011	26	14.8 (33)	96	30	52
634214	55	14.8 (33)	72	75	109
835524	114	13.9 (31)	52	150	246
1238229	280	13.0 (29)	34	400	625

In addition to the five basic models, Alcoa Laboratories is also studying a MW unit. It has been recognized that large Darrieus VAWT systems can be installed economically.[6,7] However, a fair amount of research and development is believed to be needed before MW units can be readily fabricated.

THE LOW COST 17-m

As part of the Federal Wind Energy Program to accelerate the development, commercialization and utilization of reliable and economically viable wind energy conversion systems, the program "Design and Fabrication of a Low-Cost Darrieus Vertical-Axis Wind Turbine System" was initiated in 1978. The resultant turbine is 17 meters in rotor diameter, producing 100 kW AC electrical power and compatible with a utility grid. The Sandia 17-m was used as the background machine from which design information was drawn, and the U.S. Department of Energy provided technical support to the program through Sandia Laboratories. The new machine is referred to as the "Low Cost 17-m", or 835524 if the Alcoa number system is used.

A major objective of this program is to obtain realistic fabrication cost data, based on current technology, with the goal of minimizing costs of energy generated. Another objective of this program is to provide a low-cost system design suitable for continued production and/or to serve as a base line for further cost reduction efforts.

The program has two distinct phases: Phase I was a seven-month design phase. Its objective was to produce detailed design layouts and drawings for fabrication and is now complete. Phase II is a fabrication and installation phase to utilize the design completed in Phase I. Four units have been authorized for demonstration by the U.S. Department of Energy, with the first unit to be located at the small Wind System Test Center at Rocky Flats, CO. Work on Phase II is expected to begin shortly.

System Definition

The Low Cost 17-m is similar to the Sandia 17-m research turbine with certain configurational changes aimed at cost reduction. By concentrating the modifications on an existing design, emphasis was focused on component cost reduction rather than selection of optimal configuration or operating modes.

The Low Cost 17-m has two blades. Each blade has a uniform cross-section of a 610 mm (24 in.) chord NACA 0015 airfoil (Fig. 2). For practical fabrication reasons the nominal blade shape is the straight-circular straight approximation to the troposkien as in the case of the Sandia 17-m. However, a height/diamer ratio of approximately 1.5 has been selected to give the new machine 50% more swept area. The blade for the new machine is the same as the current Sandia 17-m and no strut is required.

The torque tube or tower is a single, spiral-welded steel tube of 762 mm (30 in.) diameter supported at the top bearing by three tiedown cables and at the bottom bearing by a simple steel frame resting on a concrete foundation. The blades are attached to the torque tube by means of truss-like connectors with the lower ends of the blades located 3.048m (10 ft) above ground. The two blades and the torque tube form the rotor which is the rotating part of the system.

For comparison, the geometrical configuration parameters of the Low Cost and the Sandia 17-m are presented in Table 2.

Table 2 Configuration Parameters

	Low Cost 17-m	Sandia 17-m
Rotor Diameter	17 m (55 ft)	17 m (55 ft)
Rotor Height	25.15 m (82.5 ft)	17 m (55 ft)
Ground Clearance	3.048 m (10 ft)	4.27 m (14 ft)
No. of Blades	Two	Two or Three
Blade Cross Section	NACA 0015	NACA 0012 (O),* NACA 0015 (N) **
Blade Chord	610 mm (24 in.)	533 mm (21 in.,O),* 610 mm (24 in.,N) **
Blade Length	30.48 m (100 ft)	24 m (79 ft)
Nominal Blade Shape	Straight-Circular-Straight	Straight-Circular-Straight
No. of Struts	None	Two per Blade (V-Shaped,O),* None (N)**
Rotor Type	Single Tube	Single Tube
Tube Size	762 mm (30 in.) O.D. 5.6 mm (0.219 in.) wall	0.5 m (20 in.) O.D. 25.4 mm (1 in.) wall
Rotor Support	Guyed on Top	Guyed on Top
No. of Cables	Three	Four
Cable Size	22.2 mm (0.875 in.)	25.4 mm (1 in.)
Cable Angle	35°	35°
Cable Length	50 m (164 ft)	39.3 m (129 ft)
Overall Height	28.9 m (94.9 ft)	28.65 m (94 ft)

* O = Original blade (Kaman)
**N = New blade (Alcoa)

The total weight of the system, excluding the concrete foundation for the main structure and footings for the tie-down cables, is approximately under 12,272 kg (27,000 lb). It is believed that further reduction in weight is possible when fabrication techniques are refined in Phase II of the project. As a comparison, the Sandia 17-m has a total weight of 16,800 kg (37,000 lb).

The system has a simple drive train which is defined as the series of components to transmit and to convert the aerodynamic torque from the rotor to electrical power delivered to the utility grid. It begins with the rotor which is connected by a low-speed shaft to a speed increaser, and the speed increaser is connected by a high-speed shaft to a relatively high-speed induction motor. The induction motor is directly connected to a utility line and maintains the drive train at a nearly constant speed, corresponding to its synchronous speed. The induction motor acts as a generator when wind-produced torques from the rotor minus all losses in the drive train are positive. The same unit acts as a motor to start the turbine from rest. The drive train

is provided with a braking system mounted on the high-speed shaft to stop the turbine when the induction motor/generator is decoupled from the utility line. The schematic of the drive train is shown in Fig. 3.

The nominal rotational speed of the turbine is selected as 51.5 rpm corresponding to the selection of a rated electric power of 100 kW for the system. The rated power would be realized when the wind speed reaches 13.86 m/s (31 mph) measured 9.1 m (30 ft) from the ground. The induction motor chosen for the system is a 150 hp, 1800 rpm unit with a generator slip of 1.1%. The nominal rotational speed of the turbine and the synchronous speed of the induction motor determine the fixed ratio (35.068) of the speed increaser. In the starting mode, the induction motor is capable of providing sufficient torque to overcome losses in the system in order to accelerate the rotor to 51.5 rpm in less than 15 seconds.

System Operations

Two kinds of operation of the system have been identified. The first kind is the normal operation which is defined as the normal power generation of the turbine between a cut-in wind speed of 5.81 m/s (13 mph) and a shut-down wind speed of 26.8 m/s (60 mph) at a turbine speed of 51.5 rpm. Since wind is fluctuating by nature, the wind speeds selected for cut-in and shut-down are averages over pre-set time intervals.

The second kind is the emergency shut-down operation triggered by certain anomalies which might lead to the runaway condition. The turbine structure is designed with adequate strength against an arbitrarily-determined runaway condition of a combined situation of a turbine speed of 75 rpm and a wind speed of 33.5 m/s (80 mph). For the turbine to accelerate from its nominal speed of 51.5 rpm to 75 rpm, a five-second interval exists allowing the system to activate the emergency brake.

A controller is designed to provide both fail-safe automatic operation or manual operation of the system. Either mode is selectable by means of panel-mounted selector switches.

In automatic mode the controller, sensing wind speed via an anemometer, will automatically start the turbine when the cut-in wind speed is passed. Conversely, when wind speed falls below the cut-in speed, the controller will automatically shut down the turbine. The controller will also shut down the turbine when the shut-down speed is reached.

In manual mode the turbine may be started independently of the anemometer by sequential operation of the brake release and turbine start push buttons. The anemometer will, however, provide for shut-down wind speed protection as in automatic mode.

In order to avoid possible damage to the system, many safety features have been incorporated via the controller. The system will be shut down if any one of the following abnormal conditions is encountered: excessive vibration, overspeed, loss of line, ground gault, and computer program failure.

The most cost effective way of implementing this controller, providing for the protection and proper sequencing of the brakes, starter and other subsystems, has been determined to be a micro-computer. A schematic of the control diagram is shown in Fig. 4.

To summarize, parameters associated with the operations are presented in Table 3 for the Low Cost 17-m and the Sandia 17-m.

Table 3· Operation Parameters

	Low Cost 17-m	Sandia 17-m (Original)
Rated Electric Power	100 kW	60 kW (3-Blade)
		50 kW (2-Blade)
Generator Capacity	112 kW (150 hp)	60 kW
Rated Wind Speed	13.86 m/s (31 mph)	14.3 m/s (32 mph)
Cut-In Wind Speed	5.8 m/s (13 mph)	—
Shut-Down Wind Speed	26.8 m/s (60 mph)	26.8 m/s (60 mph)
Nominal Turbine rpm	51.5	52.0
Designed Max.Allowable Turbine rpm	75.0	75.0
Nominal Turbine Torque	21 130 N·m (15,585 ft-lb)	13 558 N·m (10,000 ft-lb)
Nominal Brake Torque	59 656 N·m (44,000 ft-lb)	67 790 N·m (50,000 ft-lb)
Emergency Brake Torque	59 656 N·m (44,000 ft-lb)	67 790 N·m (50,000 ft-lb)

All wind speeds in Table 3 are measured 9.1 m (30 ft) from the ground.

General Design Criteria

The major turbine and drive train components are designed for a productive life of approximately 30 years. All portions of the system can withstand weather extremes typical of the U.S. and protection is provided from the weather for all delicate components. The main structure is designed to survive a maximum wind speed of 67.1 m/s measured at 9.1 m above ground (150 mph, 30 ft). The system is also more than adequate to survive earth-quake loads for seismic zone 3.

Performance Analysis

The sole function of a wind turbine is to convert kinetic energy in the ambient air stream into usable energy. As such, the performance analysis of the wind turbine system is, in essence, the determination of the power coefficient, C_p, under a wide range of wind conditions, and the determination of the total electric energy output per year depending on site characteristics. These calculations were carried out with the aid of computer programs developed by Sandia Laboratories.

For the calculation of C_p, the program "PAREP" was again supplied. For the Low Cost 17-m operating at its normal turbine rotational speed of 51.5 rpm, the C_p plotted against λ , the rotor tip speed/ambient wind speed, is presented in Fig. 5.

The electric power output versus ambient wind speed measured at the center of the rotor is shown in Fig. 6. The peak of the curve represents the rated power of the turbine system. The wind speed at the center of the rotor is in general higher than that measured 9.1 m (30 ft) from the ground due to the added height.

The total energy output of a turbine system is a strong function of its site. In order to assess the total energy output in a year, the wind distribution data at the site must be known. The Sandia program, VERS 16, was used for the total energy output calculations using typical annual wind duration curves as shown in Fig. 7.

The total energy production per year of the Low Cost 17-m for an annual mean wind speed of 6.71 m/s (15 mph) was computed as 235,000 kW·h/yr. As a comparison, the 3-bladed Sandia 17-m at the same site would produce a total energy output of 160,000 kW·h.

Cost Estimate

As mentioned earlier, the major objective of this program is to obtain realistic fabrication cost data based on current technology. However, costs are known to be sensitive to volume of production. One can readily see that it is highly unlikely that the same manufacturing process would be applied to a production of a few demonstration units as to a production of, say, one hundred units. To go one step further, the 100th unit cost of a production of 100 units within a certain period of time on a continuous base may again differ considerably from the 100th unit cost in a single order of 100 units. It is apparent that by constructing different scenarios, one may come up with just as many different cost estimates.

For the case of the Low Cost 17-m, the assumption made is that the unit cost is defined as the average cost per unit based on a production of 100 units per year on a continuous schedule of approximately two units per week. The facility is a new "Greenfield" plant optimized for the production for intermediate sized vertical-axis wind turbines typified by the Low Cost 17-m based on a manufacturing process recommended by Alcoa's Allied Products Department after reviewing the design completed in Phase I. The numbers generated in this scenario would be considered highly probable rather than optimal. It should be emphasized that all figures are based on 1978 October dollars and must be adjusted for inflation to whatever time period that production will be required or costs are to be compared to other alternatives.

The "Greenfield" plant is sized at approximately 25,000 sq. ft. and staffed with six people in administration, engineering and sales, and twelve management, clerical, and support people as part of the overhead.

For direct cost estimates, it has been assumed that adequate labor will be available at an average cost of $5.00 per work hour and that a 30% payroll benefits package will apply. Those figures are approximately median in the sixteen subsidiaries that compose the Alcoa Allied Products Department. Furthermore, a single-shift, five day schedule in a fifty week work year has been assumed.

Preliminary production plans show a need for 615 person hours for fabrication and assembly, which suggest a need for 32 direct production workers and, with allowances for vacations and holidays, an annual payroll of $433,000 for 61,500 hours of productive work. Projections of annual material and component purchases total $3,842,000. The component cost and direct labor per unit are shown in Table 4.

Table 4. Direct Material and Labor Cost

	Person Hours	Material Cost
Rotor Components	345	$ 12,800
Base Assembly/Mechanical/ Electrical Subsystems	262	$ 24,495
Miscellaneous Components	8	$ 1,125
	615	$ 38,420
Direct Labor Cost		$ 4,330
Direct Material/Labor Cost		$ 42,750

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Adding corporate and production overhead, the total production cost of 100 units per year is given in Table 5.

Table 5. Total Production Cost - 100 Units/Year

Direct Materials Purchased	$ 3,842,000
Direct Labor and Benefits	433,000
Production Overhead	536,000
Corporate Overhead	472,000
Total	**$ 5,283,000**

Assuming a gross margin goal that will result in a 25% return on capital in use, and capital requirements of $1,180,000, the annual profit goal is $295,000. Therefore, total revenue is projected at $5,578,000 and an average selling price of approximately $56,000 per unit is dictated.

Site preparation, including three tiedown footings and a base foundation, is estimated to cost approximately $5,000 if ground conditions are "average." Delivery costs, with average shipping distances of approximately 250 miles, would add another $500 to the cost; and unloading, assembly, erection, hookup and checkout of the system should cost an additional $15,000-$19,000.

The total installed cost would, therefore, be $76,500-$80,500 depending on the site related cost. With experience, design refinement, increased confidence levels and backward integration into more production operations (as opposed to purchased components), an additional cost reduction of approximately $11,000 is believed possible in an established business enterprise.

Therefore, the total installed cost of the Low Cost 17-m, ready for delivery of three-phase 60 Hz AC electricity at 460 volts, should be in the $65,500-$80,500 range in 100 unit annual production quantities.[8]

The cost of energy to the owner is calculated based on the following formula:

$$COE = \frac{\left(\begin{array}{c}\text{Total installed}\\\text{cost}\end{array}\right) \times \left(\begin{array}{c}\text{Annual charge}\\\text{rate}\end{array}\right) + \left(\frac{O\&M}{yr}\right) \times \left(\begin{array}{c}\text{Levelization}\\\text{factor}\end{array}\right)}{\text{Total electric energy output/yr} \times \text{Availability factor}}$$

In the calculations, three annual charge rates, 12, 15 and 18%, have been assumed to cover the spread to different owners because of interest rate difference, tax structure, or other reasons. The O & M per year is chosen as $773.00 which is the number used by Sandia for the Sandia 17-m. The levelization factor is taken as 2.0. In the denominator, the figures 235,000 kW·h and 0.9 are used as the total electric energy output per year and the availability factor, respectively. The results, therefore, represent the cost of energy at a site with a 6.71 m/s (15 mph) annual mean wind speed.

Table 6. Cost of Energy

Total Installed Cost	Annual Charge Rate	$/kW·h
$ 65,500	12%	0.044
80,500		0.053
65,500	15%	0.054
80,500		0.064
65,500	18%	0.063
80,500		0.076

Numbers in Table 6 suggest that the competitiveness of wind energy becomes highly dependent on the annual charge rate and the availability and cost of alternative forms of energy. This indicates that for the same site one type of owner may favor wind energy while another type may not.

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DISCUSSION

Q. What aluminum material was used in the extrusion, and also what protection system, if any, was used?

A. The extrusion material can either be 6063 or 6061. We have done both. As far as protection is concerned, I believe the Sandia blades are painted. We haven't done anything in this regard, and we haven't really addressed the problem. If it's necessary, say if the blade is to be used in a corrosion environment, then we will provide the proper finish. The blades may even be Teflon coated, if there is concern about ice. We have a lot of capabilities in the area of surface finishing.

Q. Are you prepared to supply one of these units at the price of $100,000?

A. Yes, on this particular design we will deliver the first four units to DOE. The next one will then be available. In fact, our subsidiary is very anxious to start. They really believe it is a viable commercial item at that price.

Q. Have you included land requirements and loan costs?

A. Loan costs, yes, but not land requirements.

Q. Can you discuss the flexibility that is incorporated into the drivetrain?

A. The main point is to have the torque ripple stay within a certain limit.
Ours is less than 20 percent. The result is based on a theoretical model
developed by Sandia. The drivetrain is softened up in order to do that by
having an adjustable low speed shaft, etc.

Q. What is the slip of your induction generators?

A. The slip was 1.1 percent, which means the unit is operating between 1,780
and 1,820 rpm.

Q. One of the things discussed was thrust bearings. A thrust bearing is carry-
ing the total weight of the turbine in your installation. The thrust bearing
can be a difficult problem since it carries the total weight and is involved
in starting, stopping and lubrication. What do you do?

A. That was a problem we have given a lot of thought to. We have a lower bear-
ing supported by a steel frame, and the load is transmitted to the frame.
With this type of design with guy wires, the lower thrust bearing carries
the weight of the rotor plus the vertical component of the tension from the
guy wires. The bearings will be running in oil. We have done our calcula-
tions and selected the bearing to meet the requirements. The bearing should
be adequate according to its specification.

Q. What is the Alcoa business purpose? Are you to sell vertical axis machines
and extruded blades or just what?

A. Our business purpose is two-fold. We are interested in selling blades be-
cause that is a mill product. We are in that business. We are also inter-
ested in energy conservation and production, and more and more it looks
like this is a diversified business.

Q. For the 24-inch extrusion, where is the Alcoa press, and what does a recur-
ring extrusion die cost if a design is different than what you have?

A. There are four 14,000 ton presses in the western world. Alcoa owns two of
them. Both are located at Lafayette, Indiana. The die cost for the 24-
inch or 29-inch blade is approximately $20,000. The reason that the prices
are similar is because they fit into the same sized cylinder. It should be
noted that tooling cost relates to the chord of the blade and not to its
length. That is an important consideration for making the blade inexpen-
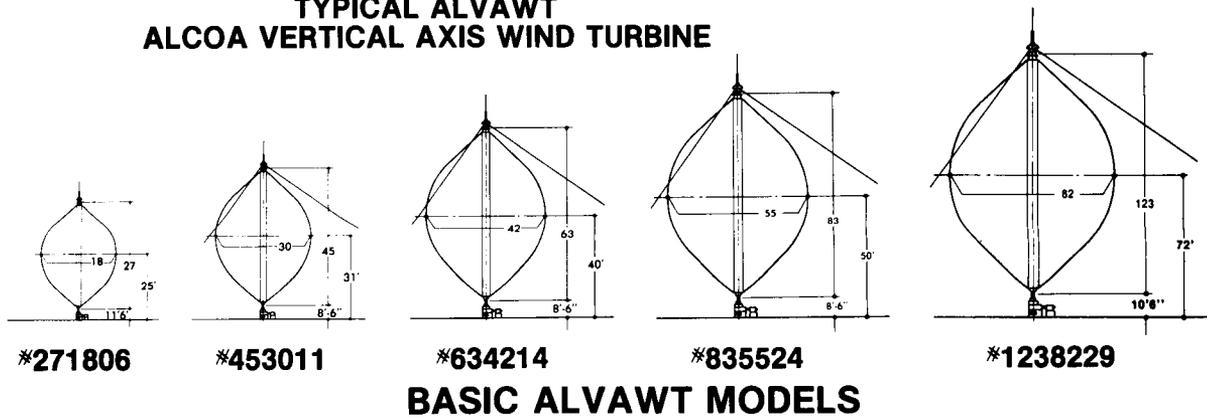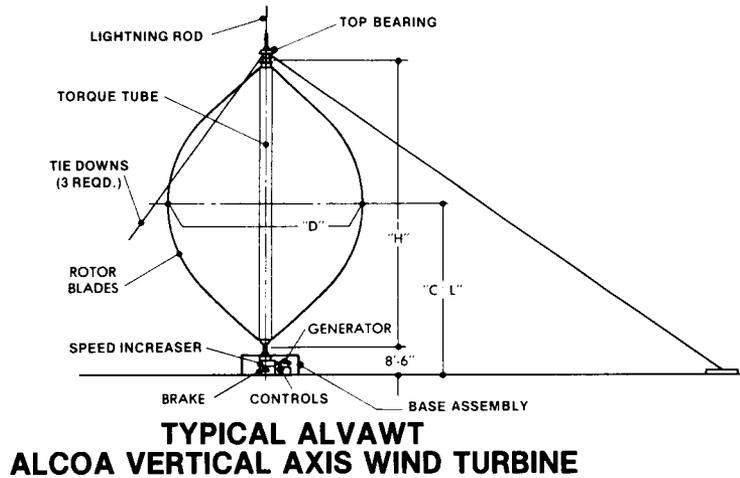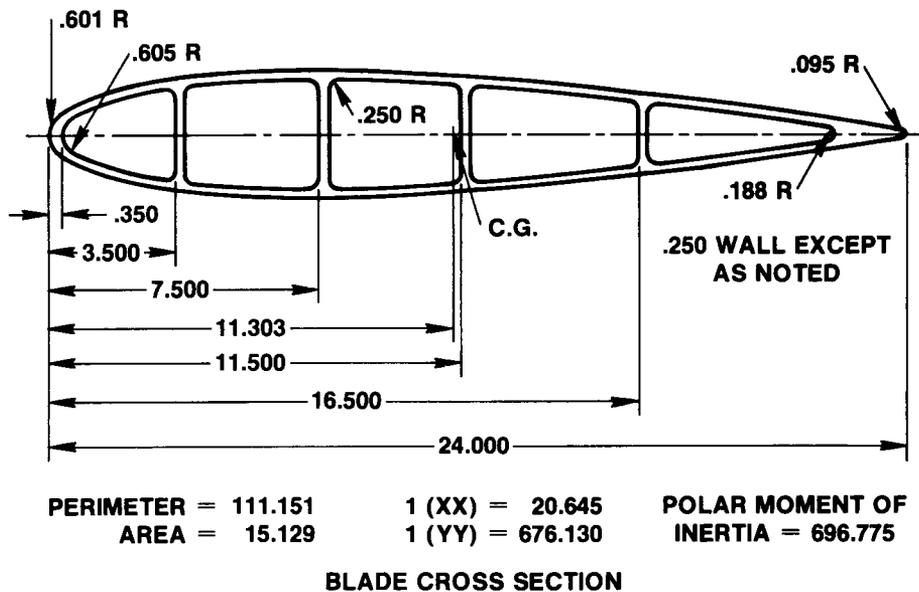sively.

TYPICAL ALVAWT
ALCOA VERTICAL AXIS WIND TURBINE

#271806 #453011 #634214 #835524 #1238229

BASIC ALVAWT MODELS

Figure 1

PERIMETER = 111.151   1 (XX) =   20.645   POLAR MOMENT OF
     AREA = 15.129   1 (YY) = 676.130   INERTIA = 696.775

BLADE CROSS SECTION

THE EXTRUDED 24-INCH CHORD ALUMINUM BLADE

Figure 2

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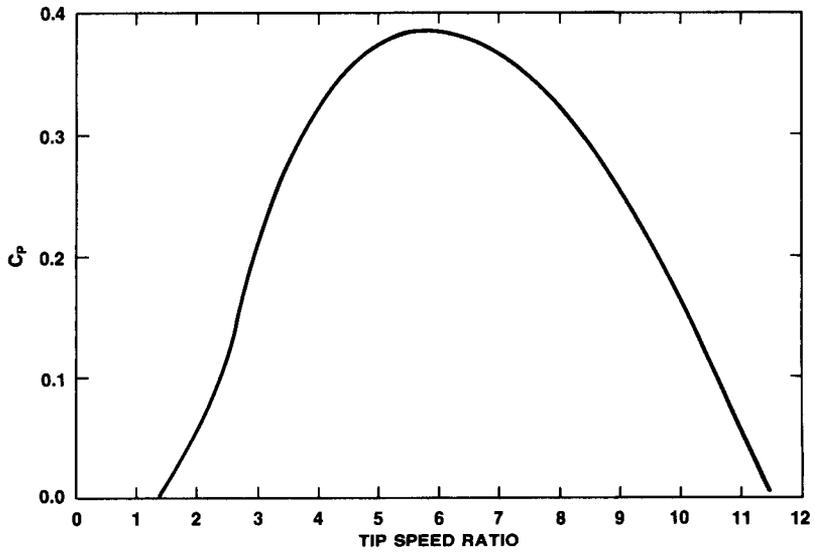ROTOR SHAFT EXTENSION

GENERATOR/MOTOR

ROTOR/SPEED
INCREASER
COUPLING
ASSEMBLY

EMERGENCY/
PARKING
BRAKE

SPEED INCREASER/
GENERATOR-MOTOR
COUPLING

SERVICE
BRAKE

SPEED INCREASER
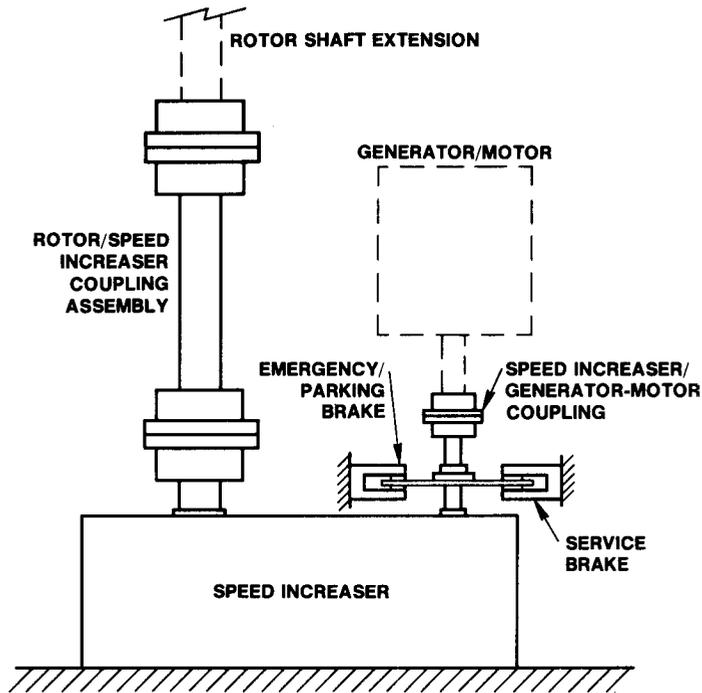
DRIVE TRAIN SCHEMATIC

Figure 3

ROTOR

UTILITY
SERVICE

SPEED
INCREASER

PARKING
BRAKE

SOL
SERVICE
BRAKE

SOL

M/G

MOTOR
STARTER

MAIN
SWITCH

OFF

CONTROLLER

AUTO
MAN
POWER ON
ALARM RESET
BRAKE RELEASE
TURBINE START
SERVICE BRAKE
PRESSURE SW.
PARKING BRAKE
PRESSURE SW.
MOTOR SPEED
TACHOMETER
WIND SENSOR
VIBRATION SENSOR
SET MAX. WIND
SPEED
SET MIN. WIND
SPEED
SET MAX. WIND
AVG. TIME
SET MIN. WIND
AVG. TIME
SET ACCEL.
TIME
SET MAX. MOTOR
SPEED

ALARM RELAY CONTACTS (CUSTOMER USE)

SPARE OUTPUTS

CPU RUN

GEN. FAULT

WIND > MAX. SET

WIND < MIN. SET

GEN. OVERSPEED

ACCELERATION FAILURE

BRAKE FAULT

EXCESS VIBRATION

SCHEMATIC OF CONTROL

Figure 4

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TURBINE RPM = 51.5

Figure 5

TURBINE RPM = 51.5

Figure 6

170

WIND SPEED, MPH

50

40

30

20

10

0

0   1000   2000   3000   4000   5000   6000   7000   8000   9000

HOURS

REFERENCE HEIGHT - 30 FT.

V_{MED} = 18 MPH
V_{MED} = 15 MPH
V_{MED} = 12 MPH
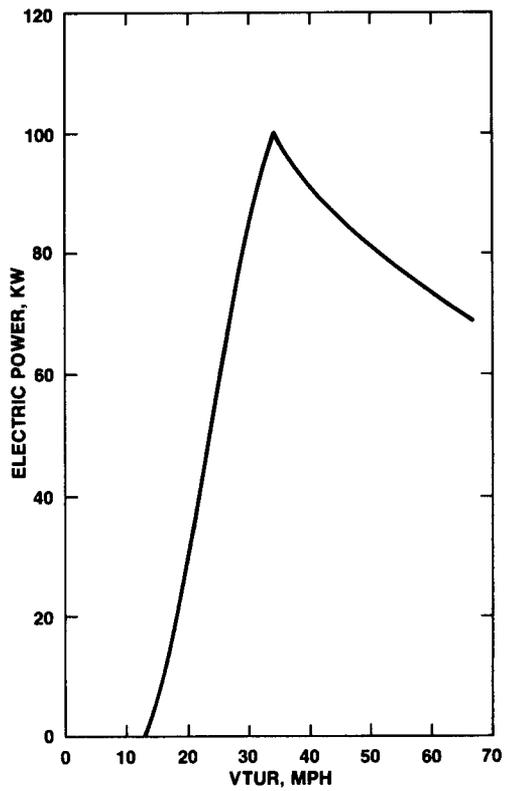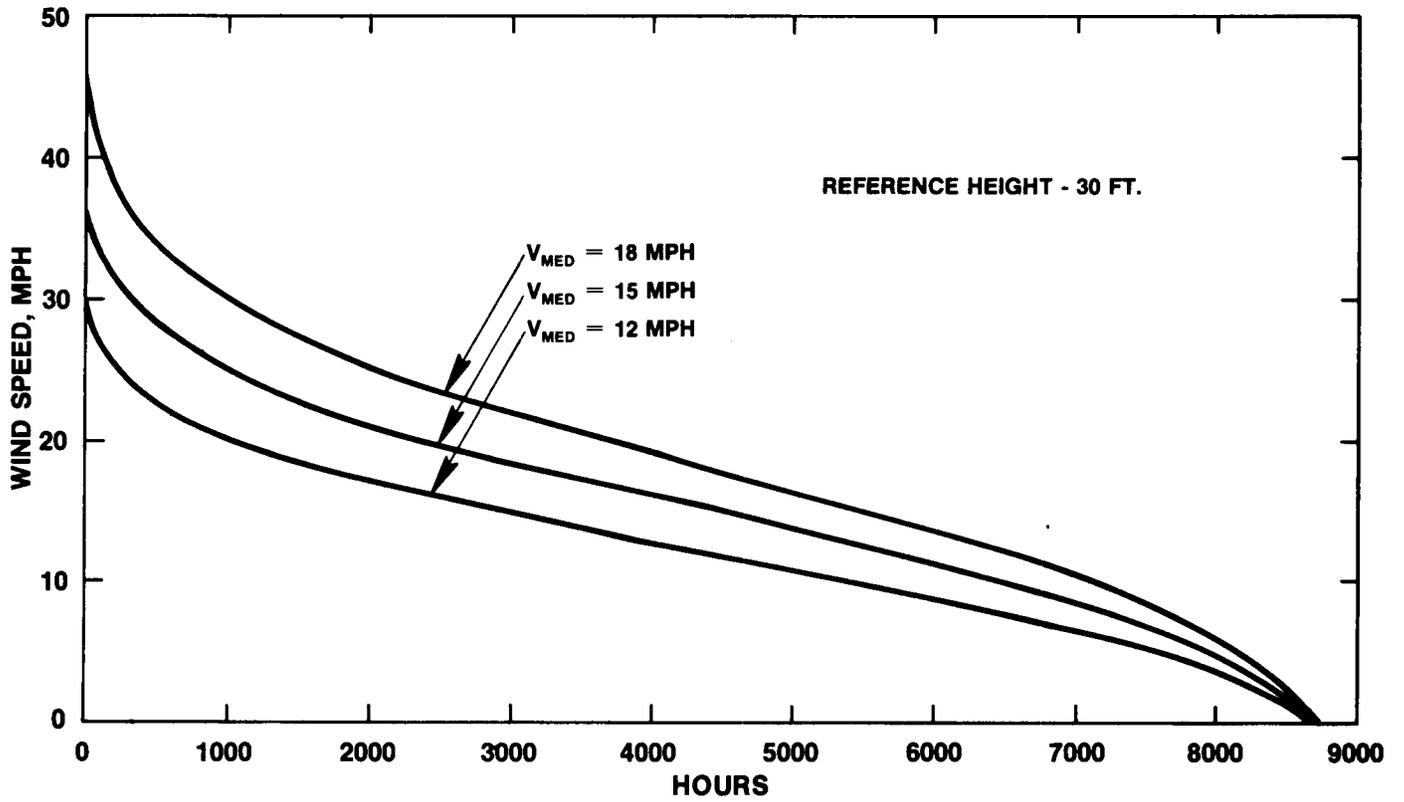
ANNUAL WIND SPEED DURATION CURVES

Figure 7