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PLANS AND STATUS OF THE NASA-LEWIS RESEARCH CENTER WIND ENERGY PROJECT

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SUMMARY

As our nation's energy needs increase and our gas and oil dwindle, alternative energy sources must be investigated and developed where practical. Wind energy, being a clean nondepletable source of energy that has proven technically feasible in past efforts, is now being investigated as an alternative source of energy. In 1973 the National Science Foundation (NSF) was given the responsibility for planning and executing a sustained wind energy program. The objective of this program is to develop the technology needed to build reliable and cost-effective wind-energy conversion systems that have the potential for early and rapid commercial implementation. In January 1975 the wind energy program was transferred from NSF to the newly formed Energy Research and Development Administration (ERDA).

This report describes that portion of the national five-year wind energy program that is being managed by the NASA-Lewis Research Center for the ERDA. The Lewis Research Center's Wind Power Office, its organization and plans and status are briefly described. The three major elements of the wind energy project at Lewis are the experimental 100 kW wind-turbine generator; the first generation industry-built and user-operated wind turbine generators; and the supporting research and technology tasks which are each briefly described.

INTRODUCTION

Wind-energy systems have been used for centuries as sources of energy for man; the applications range from the pumping of water and grinding of grain to the generation of electricity. As early as 1910, Denmark had a total installed capacity equivalent to 200 MWe from wind systems. From 1930 to 1960 considerable interest existed in Europe (and in the United States in the 1940's) in developing large wind-driven generating systems as a source of electric power. However, interest in these systems declined because they were not cost competitive with fossil fuel systems of that era. These efforts were generally privately financed and suffered from the lack of a sustained research and development effort. Little of the technological development of the past two decades has been applied to wind-generator systems.

Because of the recent oil and gas shortages (referred to as the energy crisis), all potential energy sources are being investigated; this includes the clean nondepleting source of energy available in the winds. A joint NSF/NASA Solar Energy Panel recommended that wind power be developed.[1] A joint NSF/NASA sponsored three-day workshop was held in June 1973 to discuss wind-energy systems, past history and plans.[2] The conclusion of this workshop was that wind-energy systems could provide a practical energy source and should be developed as an energy source to help meet our nation's needs.

In 1973, responsibility for the national wind-energy program was assigned to the National Science Foundation as part of the RANN (Research Applied to National Needs) program. Agreement was reached between NSF and NASA that, under the overall program management of the NSF, the NASA-Lewis Research Center would provide project management for the large experimental wind generators and for the development of the supporting technology for these large wind systems.

In the fall of 1973 a major energy study entitled "The Nation's Energy Future" that was requested by the President was completed under the direction of the Chairman of the Atomic Energy Commission. This report recommended that approximately $30 million be spent over the next five years on research to expedite the development of technology needed to build reliable and cost-effective wind-generator systems.[3]

In January 1975, the wind energy program was transferred from NSF to the newly formed Energy Research and Development Administration (ERDA). This report describes that portion of the national five-year wind energy program that is being managed by the NASA-Lewis Research Center for the ERDA. The NASA-LeRC wind-energy project includes three major elements: (1) design and operation of a 100 kW experimental wind generator, (2) industry-designed and user-operated wind generators in the range of 50 to 3000 kW, and (3) supporting research and technology for large wind-energy systems. This report summarizes the plans and status of these three major elements of the NASA-LeRC wind-energy project through 1974.

WIND ENERGY PROJECT PLANS

Objectives

The major objective of the national wind-energy program is to develop the technology for practical cost-competitive wind-generator conversion systems that can be used for supplying significant amounts of energy to help meet the nation's energy needs.

To achieve this broad objective, a national wind-energy program has been developed. The NASA-LeRC has been assisting the NSF and now ERDA in the planning and execution of this program, particularly the design, fabrication, and testing of the major experimental wind-conversion systems. The specific objectives of that portion of the overall wind-energy program for which NASA is responsible are as follows:

(1) Identify cost-effective configurations and sizes of wind-conversion systems.

(2) Develop the technology needed to produce cost-effective, reliable wind-conversion systems.

(3) Design wind-conversion systems that are com-

patible with user applications, particularly utility networks.

(4) Build up industry capability in the design and fabrication of wind-conversion systems.

(5) Transfer the technology obtained from the program to stimulate the rapid commercial application of wind-conversion systems.

Project Organization

To meet the above specific objectives, the NASA has organized a Wind-Power Office. Figure 1 shows the organization of the Wind Power Office into three major elements to meet the objectives of the project plan. These three major elements are:

(1) Design, fabrication, and testing of a 100 kW experimental wind turbine generator (WTG)

(2) Industry design of optimized WTG systems for selected user operation

(3) Supporting research and technology for WTG systems

Figure 1 also indicates the industry involvement already underway in the project and the supporting efforts supplied by LeRC and other NASA centers. In particular LeRC is supplying project management and support in aerodynamics, control/instrumentation, structural dynamics, data reduction, machine design, facilities and test operations. Other NASA centers are supplying consulting services, such as: (1) Langley - aeroelasticity, (2) Ames - rotor dynamics, and (3) Marshall - meteorology. The industry involvement includes: the Lockheed Corporation for design and fabrication of the 125-foot diameter rotor blades for the 100 kW experimental WTG, General Electric with a subcontract to Hamilton Standard for one design study of WTG systems optimized for minimum cost, and Kamon Aerospace with assistance from North East Utilities for the other design study. Also as part of the supporting research and technology tasks, a 4.1 kW WTG with a 9.0 meter (30 ft) diameter rotor has been purchased from Aerowatt of Paris, France and is being tested by LeRC.

Throughout the design and fabrication phases of the wind-energy program, the government strongly desires user (particularly the utility industry) inputs to the program. These inputs will be solicited from advisory personnel at key design reviews throughout the program. It is necessary to have the users' inputs not only for the technical design of WTG systems but also to obtain proper technical and operational interfacing of the WTG systems with the users' operations.

Project Schedule

The specific plans and status of the three project elements are the subject of the remaining portion of this report. Before discussing these elements in detail, however, figure 2 shows how the NASA project elements interface with the national five-year wind-energy program. The top bar indicates the five-year NSF program elements which include: (1) mission studies (definition of applications, interface requirements, cost goals, potential of wind-energy systems, etc.); (2) wind characteristics (wind information needed to design systems and select sites); (3) research and technology of advanced systems; and (4) investigation of the environmental, legal, institutional and other aspects of wind-energy systems. The remaining bars summarize the NASA portion of the wind-energy program. The 100 kW experimental WTG which will serve as an early test bed for the program will become operational in July 1975. The first optimized WTG's by industry are planned to become operational in mid 1977. Two design-study contracts are already underway and are scheduled for completion by early summer of 1975. The fourth bar shows an effort underway to select user sites for the first industry-designed WTG systems. As part of the user operation portion of the project, a meeting at LeRC was held in December 1974 with about 30 utility companies to initiate action on selecting some of these sites. Also the first mission studies by NSF will be complete about the end of 1975 and the results of these studies will be considered in selecting the most promising applications and sites. The bottom bar shows a continuing supporting research and technology effort throughout the program. As part of this effort, a 30-foot diameter rotor 4.1 kW WTG is in operation by NASA-LeRC at a site near Sandusky, Ohio.

The dashed bar starting in the last quarter of 1978 indicates second generation WTG's. These may be completely new designs or modifications of the first industry designs. These second-generation systems will have the benefit of results from the additional NSF mission studies, the NASA 100 kW experimental system, the first industry WTG's and the supporting research and technology efforts.

Funding Levels

Table I shows the planned budgets for each of the three major project elements for FY '74 and FY '75 and the totals for FY '74 through FY '79. The total funding for the Plum Brook 100 kW experimental is \$835 K for the fabrication and assembly. Testing will proceed throughout the 5-year program with new and improved components being supplied from the SR&T element for testing.

The SR&T element is estimated at a total of \$8600 K with \$150 K for FY '74 and \$1070 K planned for FY '75. The \$150 K in FY '74 included the purchase of the 4.1 kW Aerowatt WTG, the 60 meter (200 ft) meteorological tower at Plum Brook, documentation of the Gorman-Hutter designed WTG[4-6] and modification of the MOSTAB helicopter rotor code for WTG rotor analysis.

The industry-built user-operated WTG element totals \$1100 K for FY '74 and FY '75. These funds were used for the two parallel design study contracts for designing WTG systems optimized for low cost in the range of 50 kW to 3 MW. The remaining \$16 265 K in funds is for the design and fabrication of several first generation WTG systems and the design of improved second generation machines.

The totals shown in Table I for FY '74 through FY '79 are estimates used for planning purposes and will depend on yearly program submissions and approvals, and on the funding available at that time.

100 KW EXPERIMENTAL WIND TURBINE GENERATOR

General

The objective of the experimental wind turbine generator is to provide, as soon as possible, engineering data for use as a base for the entire wind-energy program and to serve as a test bed for components and subsystems. To meet this objective, LeRC has designed and is constructing a wind-turbine generator large enough to assess the technology requirements and engineering problems of large wind-turbine generators yet small enough that construction and development costs do not exceed available budgets. In-house personnel have been used to apply current technology to initiate, immediately, a design for early construction and testing. This wind generator will also support research and technology by acting as a test-bed for various design concepts of blades, hub, pitch change mechanism, system controls, and generators.

To meet these requirements a 100 kW machine has been selected as the candidate size. This machine will be mounted on a tower 30 meters (100 ft) high and contain two large blades each 62 feet (18.3 m) long, which are capable of pitch change and full feather. The program from design to construction is to be 18 months in duration with operation to start July 1975. Performance testing will then be conducted over a 12-month period. This test program will both evaluate the performance of the machine and make design improvements. The performance evaluation of the machine will emphasize the following:

1. To collect engineering performance data for use as a base for program direction and design of other follow-on wind-turbine generators of all sizes. This data will include energy and power output at various wind speeds; performance data on control systems; and loads, stresses, and vibrations on components such as blades, hub, and tower.

2. To identify the components and subsystems whose costs and maintenance need to be reduced; to acquire a basis for making realistic cost estimates.

3. To acquire data and experience on erecting and servicing, and attended and unattended operation.

4. To provide a test bed for field testing new and improved components and subsystems for support research and technology of windmills of all sizes.

5. To evolve design concepts for alternate applications

The design of the 100 kW machine will utilize state-of-the-art technology where possible. Technology from other programs such as large helicopters will be applied particularly in the rotor design. Off-the-shelf components will be used where possible.

System Description

The 100 kW experimental WTG consists of a rotor turbine driving a transmission train and generator all of which are mounted on top of a tower. The power the WTG develops as a function of wind speed is shown in Fig. 4. The dashed line in Fig. 4 shows the increase in power available if the blade is set at the optimum pitch angle for each wind speed. The solid line is for a fixed blade angle. Also shown in Fig. 4 is a plot of the blade angle as a function of wind velocity for rated power output and zero power output.

The coefficient of power (C_p) for the 100 kW experimental WTG as a function of rotor tip speed to wind speed (λ) is plotted in Fig. 5 for a number of blade pitch angles. The coefficient of power (C_p) is defined as the ratio of rotor power extracted by the rotor to the power of the wind in the rotor disk area.

Table II lists the general specifications of the 100 kW experimental WTG. The rotor blades are located downwind of the tower. This arrangement provides maximum safety from blades' striking the tower and is also a more stabilized arrangement with respect to wind direction. Also in this arrangement the tower is subject to less dynamic interference, but the rotor blades see the effect of tower shadow.

Rotor Blades: The rotor has two all-metal blades each 18.75 meters (62.5 ft) long. Table III summarizes the blade specifications. The blades are designed to provide 133 kW of power at 7.92 meters per second (18 mph) wind speed when rotating at 40 rpm. They are twisted a total of 26.5° (nonlinear) and have an NACA 23 000 airfoil. The blades are presently being fabricated by the Lockheed Company and are scheduled for delivery in May of 1975. Figure 6 shows a sketch of the blade and some of the pertinent specifications. The blade templates and fixtures with some of the root material are at the Lockheed Company and shown in Fig. 7.

Hub: The hub connects the blades to the low-speed shaft. It also houses the mechanical gears, linkages, actuators, etc., necessary for pitch changing the blades (Fig. 8). Wind loads, both steady and gusting, and centrifugal loads are absorbed by the hub and transmitted to the low-speed shaft.

The hub is of the fixed type, that is the hub is bolted rigidly onto the main low-speed shaft with the blades fixed to the hub allowing only the pitch change degree of freedom. The fixed hub arrangement provides the potential for a low-cost hub but may contribute to increase blade root forces resulting from wind shear and tower shadow.

Pitch Change Mechanism: The pitch change mechanism consists of a hydraulic pump, a pressure control valve, actuator, and a gear or linkage for connecting a linear movement to a rotational movement of the blades. In the case of the fixed hub, the type of pitch change mechanism employed is that used in the aircraft industry on some early propellers. This is a torque actuator (in this case a rack-and-pinion type of actuator) that turns a master gear which in turn rotates the blades through a bevel gear mounted on the roots of the blades (Fig. 8). The advantage of this type of pitch change mechanism is that the entire system is self-contained within the hub and is not exposed to the elements. The hydraulic pump is mounted separately on the structure and the hydraulic fluid brought into the shaft via rotating seals.

Bed-Plate and Yaw Control: The 100 kW WTG is supported on a large-gear bearing assembly and bed plate which is capable of rotating (yawing) the entire machine on top of the tower. The yaw control is not designed to follow sudden changes in wind direction but rather the slow directional change that results from a weather front moving through the area. The yaw rate is 1/6 of a rpm and is operational even when the machine is not generating power. The bed-plate supports the rotor, the transmission train, alternator, and all shafts and bearings. Figure 9 shows a sketch of the yaw control and bed plate with all the components mounted on it. Those components are enclosed in a fiberglass cylinder for protection from the environment.

Transmission Train: From the hub, torque is transmitted to the alternator through a 45/1 ratio gearbox (Figs. 9 and 10). The hub transmits the high torque, low rpm to the gearbox via a low-speed shaft. Out of the gearbox a high-speed shaft transmits the low torque, high rpm to the alternator through a belt system.

The gearbox is a standard triple-reduction type of design. The primary difference between this gearbox and most triple reduction designs is the gear ratio is a step-up ratio rather than the more conventional step-down ratio. An oversized gearbox was selected because of the uncertainty of sizing a gearbox for a wind-turbine application. The gearbox has a rated output of 176 kW (236 hp) which is about 32 percent higher than the maximum power of 133 kW (178 hp) the rotor should ever supply to it.

Alternator: The alternator is an 1800 rpm synchronous two-bearing self-cooled type with a direct connected brushless exciter and regulator (Fig. 11). The regulator includes power, potential, and current transformers. The alternator is rated at 125 KVA, 0.8 power factor, 480 volts. It is a three-phase, 60 hertz, Y-connected machine and weighs approximately 646.4 kilograms (1425 lb).

Tower: The tower is 30 meters (100 ft) tall constructed of steel and of the pinned truss design, resting on a concrete foundation (Fig. 3). It must withstand the high wind and rotor thrust loads, both steady and cyclic, during the operation of the machine. It must also serve as a test bed by providing easy access to the machine for personnel to perform maintenance, etc.

The advantages of this type tower are the lower cost (due to existing usage by utilities) and the higher natural frequency (up to twice that of a guyed tubular tower). Its disadvantage is that it is not as pleasing in appearance as steel tubular or concrete constructed towers.

Controls: The wind turbine will generate approximately 100 kW of electricity at wind velocities of 7.9 meters per second (18 mph) and greater. Between 3.5 meters per second (8 mph) and 7.9 meters per second (18 mph) the electrical power will be generated as a function of the wind velocity. From 7.9 to 26 meters per second (18 to 60 mph) wind velocities, the machine generates 100 kW of electrical power; that is, the variable pitch blades rotate toward feather spilling the excess power. Below 3.5 meters per second (8 mph) and above 26 meters per second (60 mph) the turbine blades will be placed in the feathered position. Initially the alternator will be operated asynchronously into a load bank. Figure 12 shows the simplified block diagram for asynchronous generation. Later, the wind turbine will be connected to the local utility grid and operated synchronously as shown in the control block diagram of Fig. 13.

Site Description

The 100 kW wind turbine generator will be erected at the NASA-Plum Brook Facility near Sandusky, Ohio (Fig. 14). This facility contains 32 square kilometers (8000 acres) of land with large open areas. The site selected at Plum Brook is readily accessible to Lewis personnel, has a clear view of the S-SW prevailing winds in the summer and N-NW winds in the winter, is protected from vandalism and has existing utilities and buildings for normal test operation.

Wind data over the past 10 years is available for Plum Brook near the site selected. The time-duration curve for December 1971 to December 1972 is plotted in Fig. 15. Also, the data has been tabulated to determine the hours at or above a given wind speed by month (Table IV).

In examining the wind data and site it was determined that (1) the winds were high enough to fully test the machine, and (2) there are a significant number of hours when the wind speeds are above 8 mph for evaluating the machine. Its closeness to Lewis was particularly desirable for the first machine since this machine will be heavily instrumented and many changes are anticipated for testing various components. It was this latter feature in the program that most dictated accessibility. In an experimental program remote areas such as offshore islands and remote mountains where wind velocities are higher increase costs and cause delays because of the logistics of getting personnel and equipment to and from the site.

For economic demonstration the Plum Brook site is less than desirable. Its annual mean wind velocity is less than 4.4 meters per second (10 mph). The machine will generate 179 000 kW-hr/yr if available for operation throughout the year or have an annual plant factor of about 20 percent.

Prior to the erection of the 100 kW machine two additional structures have been erected (Fig. 16) at the site. The first is a meteorological tower (200 ft) high located southwest of the 100 kW machine. This tower (Fig. 17) supports the wind instruments for measuring the wind structure at the site. Wind speed and direction sensors are located at approximately 12, 30, 48, and 60 meters (40, 100, 160, and 200 ft). This provides for determining the characteristics of the wind available to the rotor disk. All wind information is being recorded on magnetic tape for data reduction and tabulation purposes. The data from the tower will also be used to determine the minimum amount of wind data necessary to obtain accurate velocity duration curves for each month and year.

The second structure that is at the site is a 4.1 kW WTG purchased from Aerowatt of Paris, France. This machine is discussed later in this report under the Supporting Research and Technology section.

Schedule

The 100 kW experimental WTG is well underway. All systems have been designed and all major items are being procured. Figure 18 shows a simplified schedule of the major systems. As can be seen in this figure, all major components will be delivered about the end of the first quarter of 1975 except for the tower which is scheduled for completion in June of 1975. The major components such as the hub, gearbox, generator, and shafts, etc. will be assembled and checked out in early spring prior to final assembly of the WTG at the site. Operation of the WTG is scheduled to begin in the summer of 1975.

Summary of Costs

Table V shows a cost breakdown for the 100 kW experimental machine. These costs are approximate and engineering costs and spares have not been included. The purpose of this table is to show, in the first column, approximately the cost of this WTG in terms of \$ per kilowatt. Table V shows that the cost is approximately \$5000 per kilowatt for the 100 kW machine with about 50 percent of the cost occurring in the rotor system and 25 percent in the tower and foundation. Obviously, these are areas that should receive attention for possible cost reduction.

The second column shows our present estimates for what it would cost to build follow-on WTG systems similar to the 100 kW experimental WTG. The major difference in the follow-on machines would be the elimination of test-bed features, the reduction of design margins of safety as a result of better analysis of the rotor and tower loads and an increased power rating by operating the machines at sites with higher average wind speeds.

An increased output to 150 kN could result from rating the machine at 9.24 meters per second (21 mph) instead of 7.92 meters per second (18 mph). The same metal blades would be used since they can handle the increased power output. The blades were primarily sized by the accident case of inadvertent feather and not by the rated power out. In the follow-on systems it is still evident that the major area to concentrate on for cost reduction is the rotor.

Based on the costs of the experimental 100 kW WTG and the estimated costs of $2000 per kilowatt for the several follow-on WTG systems, we expect the first industry-designed optimized WTG systems to be close to $1000 per kilowatt. From the above cost estimates it is reasonable to expect at this time that it should be possible to build later optimized WTG systems at less than $1000 per kilowatt. Figure 19 shows a comparison of cost for a WTG costing $1000 per kilowatt with a diesel generator. The important cost of a generator system is its cost of energy or mills per kilowatt-hour. For a WTG the mills per kilowatt-hour is a function of capital, maintenance, etc., and wind available at the site. For a diesel generator the mills per kilowatt-hour is also a function of the price of fuel oil. In Fig. 19 the two diagonal lines are for different capital costs of diesel generators and show the cost of power in mills per kilowatt-hour as a function of fuel oil cost per 3.79 liters (1.0 gal). The calculations include a 15 percent charge of money per year and assumes the diesel generator operates at a 75% load factor. Two cases for the WTG are shown both for WTG systems costing $1000 per kilowatt but one operating in a 4.4 meters per second (10 mph) average wind and the other in a 6.6 meters per second (15 mph) average. In summary, the figure shows that a WTG at a $1000 per kilowatt operating on a site with a 6.6 meters per second (15 mph) average wind can compete with a diesel generator if fuel costs 30 cents or more per 3.79 liters (1.0 gal). It must be noted that the diesel plant does have storage and the WTG does not. However, the wind energy available on a yearly basis is rather firm and the oil supply may not be. With oil available, the cost of the WTG with a storage system would have to be $1000 per kilowatt or lower to be competitive with a diesel generator whose fuel is 30 cents per 3.79 liters (1 gal).

This figure is not intended to show that a WTG should be selected over other forms of electric power generation. It does show that with reasonable success, however, the wind-energy program may produce WTG designs that will offer an alternative energy source for some applications in some locations.

FIRST GENERATION INDUSTRY-BUILT USER-OPERATED WIND TURBINE GENERATORS

Objective

The objective of the industry-built user-operated element of the NASA wind energy project is to involve industry and users in the design of optimized WTG systems that are capable of supplying electrical power into existing power networks at costs competitive with conventional power sources. It is planned to develop the necessary technology for these WTG systems that is needed for minimum costs and extended life so that rapid commercial implementation of WTG systems will result.

Also during the course of this effort, attention will be paid to evaluating the public reaction and/or acceptance of WTG systems. To meet these objectives a multiphased project is planned which includes the following phases:

(1) Design study contracts
(2) Evaluation
(3) Detail design and fabrication contracts
(4) Site selections
(5) Operation of WTG systems

Figure 20 summarizes these phases and the planned accomplishment for each phase. The planned schedule for these phases is shown in Fig. 21. The design and fabrication phases are primarily industry involvement and the site selection and WTG operation are primarily user involvement. This schedule shows that the first industry-built WTG systems should be in operation on selected user sites by the last quarter of 1977.

Design Study Contracts

The first phase of the industry-built user-operated WTG systems is the design study contracts. Two parallel 9-month contracts were awarded in mid-November for the preliminary designs of WTG systems optimized for minimum cost. The scope of the contracts were limited to horizontal axis machines. Figure 22 outlines the major tasks of these contracts in block diagram form. The contracts consist of four major tasks plus the final reports. The first task is the conceptual design of WTG systems. Each contractor is to evolve three promising concepts of WTG systems in the size range of 50 to 250 kW and three concepts of WTG systems in the size range of 500 to 3000 kW. At the conclusion of task 1 a single concept will be selected from each size range for minimum cost optimization and refinement. At the conclusion of the studies the minimum cost designs and sizes will be selected for preliminary design. In parallel with these tasks a fourth task will be conducted to determine the necessary interface requirements for operating a WTG on a utility network. The inputs from this task will influence the other three tasks. Applications other than utility operation may prove practical but at this early stage of the program it has been decided to concentrate on the utility applications. The NSF mission studies will most likely identify other applications for which WTG systems appear promising and these inputs will also be considered in selecting the first sites and applications.

Participation of users such as utilities will be encouraged at key design reviews during the design studies.

In summary, it is planned to obtain the following accomplishments from the design study contracts:

Preliminary designs of optimum WTG systems

Definition of utility interface requirements

Estimated costs of WTG electric power for limited production and mass production

Identification of technology required to reduce cost of electric power from WTG systems

As mentioned above, two parallel contracts of approximately $500 K each were awarded in mid-November for the design studies. These awards resulted from a competitive procurement from NASA-LeRC. One contract was awarded to the General Electric Company with a major subcontract to Hamilton Standard for rotor analysis. The General Electric Company has also contracted for the consulting services of Dr. Hutter during the contract. Dr. Hutter is a world recognized authority on the design of WTG systems. The second contract was awarded to Kaman Aerospace Corporation who has a subcontract to Mueller Engineering for towers and electrical equipment specifications. Kaman also has a working agreement with Northeast Utilities for assistance on defining the utility interface requirements for a WTG.

Evaluation Phase

At the conclusion of the design study contracts, a six-month evaluation phase will be conducted. First, the results of the design studies will be evaluated and a selection made (integration of designs if necessary) of preliminary designs for size(s) and number of WTG systems to be fabricated. User participation particularly from the utilities will be solicited to aid in this evaluation. After the preliminary designs are selected, contracts will be awarded for final design and fabrication following a competitive procurement cycle. The size(s) and number of WTG systems to be built will depend on the program funding available.

Detail Design and Fabrication Contracts

The contracts for detail design and fabrication are planned to begin in early 1976 (Fig. 21). The contracts are planned to be 18 months in duration with approximately 6 months for detail design and 12 months for fabrication. It is anticipated that procurement of the long lead items will begin before final design is complete to meet the schedule. These first generation WTG systems must utilize or extend existing technology in order to meet the planned schedules.

As can be seen on the overall schedule in Fig. 2, the detail design phase will have the benefit of the 100 kW experimental WTG operation; the results of the first NSF/ERDA mission studies; the design study contracts; and the SR&T efforts. These parallel efforts should result in well designed first-generation WTG systems with the potential for low energy cost and reliable operation.

Proposed Plan and Schedule for Site Selection and User Involvement

In parallel with the design and fabrication phases, a user involvement and site selection phase is planned for identifying and selecting the sites for the operation of first generation industry built WTG systems.

To initiate the site selection action, the NASA sent inquiries to all the utility companies in the United States briefly describing the wind energy program and asking if the utility companies were interested in possibly participating. A meeting was held at the LeRC on December 17, 1974, with approximately 40 representatives from 30 utility companies. At this meeting the wind energy program was described to the utility companies by NSF and NASA and a proposed plan presented on how to select sites and the degree of involvement by the utilities and the NASA.

The NSF and NASA indicated that they would provide the following:

1. The WTG including the tower and foundations

2. All necessary controls, instrumentation, and recording equipment

3. NASA and NASA-contractor personnel for project support and guidance throughout the 2-year WTG operation

4. NASA and NASA-contractor personnel to collect, evaluate, and publish reports of performance and operating data

The utilities were asked to consider providing the following:

1. Perform an initial site survey and submit the resulting information to NASA by April 1975.

2. If preliminary surveys are promising the utilities are to take at least 1 year of wind data at the potential WTG site. The utility company is to provide meteorological tower and instruments for this wind data and submit this data to NASA by July 1976 for site selection.

3. If the proposed site is selected for one of the first experimental WTG systems, the utilities are also to provide: personnel to interface with NASA and the NASA contractor; provide site preparation including an access road, control room, security fencing, and necessary electrical interface equipment; and provide personnel for operating the WTG for up to 2 years.

The utilities were informed that, obviously, they could propose sites individually or work with other utilities. However, the government strongly desires cooperation among the interested utility companies rather than competition. It was emphasized that the sites will be selected to maximize the information to the whole industry. In addition to maximizing the amount and variety of test information to be obtained from the first experimental WTG systems, the following site factors and variables are considerations for site selection:

Wind energy available at the site

Mode of power generation that the WTG will interface with (hydro, steam, diesel, etc.)

Size of utility company and network

Need for alternative energy sources (e.g., cost of electric power)

Geographical location and environment

Project visibility for public reaction

Preliminary Site Surveys: As shown in Fig. 21, the site selection plan was initiated in December 1974. It is planned that interested utilities will make preliminary surveys of their systems and submit the results of these surveys to NASA by April 1975 if they have promising sites.

Figure 23 summarizes the type of information that is desired from the preliminary site surveys. The information submitted to NASA is to contain background information about the utility company and the site characteristics including preliminary wind data.

Upon submittal, the preliminary site data will be evaluated by ERDA and NASA; these evaluations will be reviewed with the utilities. At this point the utilities may assess the potential of their proposed site(s) relative to others submitted and determine their level of further participation (e.g., 1 yr of wind data).

Site Selection Considerations: After the preliminary site surveys the ERDA and NASA will develop the final criteria to be used for making the site selections. These criteria will utilize in addition to the wind data the results of the preliminary site surveys and the results of the NSF/ERDA mission studies. The site selections will then be made by ERDA and NASA using the results of the mission studies, the sites proposed by the utility companies and any unanticipated site/user proposals. Again, the site selection will be made to maximize the amount and variety of test information from the first experimental WTG systems. One year of site wind data is preferred but sites with less wind data will be considered.

User/Industry Coordination Phase: Following the site selections, that are planned for the late summer of 1976, the selected user is being requested to assign a person to interface with NASA and the NASA WTG contractor. This person will work closely with the contractor during the fabrication phase and will provide necessary detailed site and interface information. Following completion of the WTG the users are expected to provide personnel for a cooperative effort during installation and checkout and to provide necessary personnel for 2 years of operation.

WTG Operation Phase: During the 2-year operation of the WTG the NASA contractor will be kept on board for routine inspections, any major problems that may arise, and for reporting of results. After the 2 years of operation, a decision on major modifications, possible relocation of the WTG, etc. will be made by ERDA/NASA. NASA and the NASA contractor will be responsible during the 2 years of operation to obtain, evaluate, and publish WTG data. It is planned to release quarterly reports the first year with a semiannual and final report the second year. The resulting reports will be distributed to all interested organizations.

SUPPORTING RESEARCH AND TECHNOLOGY INCLUDING ENERGY STORAGE

Objective

The objective of the Supporting Research and Technology (SR&T) project is to evolve the technology that is needed to reduce the capital and maintenance costs of wind turbine generator (WTG) systems, components, and subsystems and at the same time improve their performance, reliability, and service life. Included in the objective is the creation of new and promising concepts for both components and subsystems, as well as total systems, and the development of promising methods for energy storage so that WTG systems can supply energy dependably.

Investigations in this project are divided into the following three areas: (1) subsystem and component technology development, (2) experiments with small WTG systems, and (3) energy storage systems that are particularly applicable to WTG systems. The SR&T studies that are funded by ERDA directly will be monitored by LeRC and the results integrated into the overall project.

Component and Subsystem Technology Development

It is planned to investigate and evaluate those WTG subsystems and components which offer the most potential for reduced costs, increased reliability, improved performance, and lower maintenance. Except for the horizontal axis rotors, however, SR&T plans for the major WTG subsystems and components such as towers, power conversion, power transmission, and controls have not been definitely formulated at this time. The several parallel sources which are being utilized to identify those subsystems and components which should be further investigated are: (1) the 100 kW experimental WTG at Plum Brook, (2) the two parallel industry-designed WTG system studies currently being performed, and (3) the ERDA-funded SR&T tasks. The information resulting from these three sources will be evaluated to determine plans and investigations for improving WTG subsystems and components.

It is planned to test promising WTG subsystems and components in bench tests. The facilities for some of these tests are already set up as a result of the bench tests and assembly required for the 100 kW experimental WTG. Following the bench tests, the subsystems and components with definite promise will be assembled into the 100 kW experimental WTG for field testing. This WTG has been designed as a test-bed for the resulting SR&T improvements.

Horizontal Axis Rotors: The horizontal axis rotor systems have been the most efficient, well developed, and widely used WTG rotor systems to date. The 100 kW experimental WTG and both industry design WTG systems studies utilize horizontal axis rotors. The SR&T efforts in this area are directed at supporting the above tasks and following up on promising ideas from these tasks and from ERDA-funded horizontal axis rotor studies.

In 1975 three specific tasks are planned by Lewis in support of the horizontal axis rotors:

(1) The design and fabrication of composite material blades for the 100 kW experimental WTG: The purpose of this task is to obtain low-cost, lightweight reliable blades using composite materials. The request for proposals for this task is planned to be released in early 1975 with blade fabrication to be complete within 15 months of award of contract.

(2) The design and fabrication of a teetered hub for the rotor on the 100 kW WTG: An analysis has shown that the bending moments of the blade roots will be reduced if the hub is teetered instead of fixed.[8] To verify this analytical prediction, a teetered hub will be tested on the experimental 100 kW WTG. The detail design and fabrication is expected to be completed under contract and the hub ready for testing by mid-1976.

(3) The award of a contract to modify a high frequency analysis helicopter rotor computer code MOSTAB-HFA for WTG rotor analysis: This code includes high order rotor in-plane and flapping modes and the necessary equations for coupling the rotor and tower dynamics. A major part of the rotor SR&T effort is the development of the necessary analytical tools for predicting rotor performance. Lewis has funded two small contracts to modify an existing helicopter rotor code (MOSTAB) for WTG rotor analysis. This code, now referred to as MOSTAB-WT, has been modified to put the rotor in a vertical plane, include tower shadow, and include the effects of wind shear. The MOSTAB-WT only includes the first flapping mode at this time.

Vertical Axis Rotors: The technological characteristics of vertical axis rotor systems are poorly understood. At present several investigations of the Darrius rotor are underway at the NASA-Langley Research Center, Sandia Laboratories, and Canada's National Research Council. Additional studies will be funded in FY 1975 directly by NSF. These NSF studies will probably include other vertical axis concepts such as the Savonius rotor.

In FY 1975, LeRC will review the status of the technology of vertical axis rotor systems and identify the persons who are presently engaged in their investigations. Contacts will be established and maintained with these investigators. Upon completion of this review, a plan may be drawn up to identify those SR&T efforts that LeRC will undertake in the investigation of technology for vertical axis rotor systems.

Experiments with Small WTG Systems

Small WTG systems of less than 10 kW will be tested to assess total systems problems and to identify the better ideas for further development at the 100 kW scale. Tests are planned for small WTG systems in: (1) wind tunnels under carefully controlled conditions; (2) in the field at the NASA Plum Brook site; and (3) in actual applications.

Wind Tunnel Tests: It is planned to conduct wind-tunnel tests on small commercial WTG systems and on selected rotor models. These tests will be used to acquire data, under controlled conditions, on the performance and structural dynamic characteristics of WTG systems and their components for a wide range of wind speeds, directions, and wind gradient conditions. It is planned to use this data to verify the predictions of the analytical methods and to improve those methods if required.

In 1975 it is planned to initiate testing of models of the 100 kW experimental rotor, the rotors selected for the first industry-designed WTG systems, and rotors resulting from other ERDA funded studies. In addition several more commercial WTG systems will be tested to obtain baseline information for comparison of performance and for evaluation of new or different rotor systems.

Field Tests of WTG Systems: There is some question as to whether the analytical models are adequate for predicting the performance of WTG systems in the field, and whether the tunnel test results are valid in projecting what the field performance will be. To answer these questions, some small commercial WTG systems and some promising designs that emerge from other SR&T studies will be instrumented and tested in the field as well as in a wind tunnel by LeRC. The field tests will be done at the NASA Plum Brook site on a 22.8 meter (75 ft) tall WTG tower that was installed in December 1974. The results of the field tests will be compared with the analytical and wind tunnel results. From this comparison will emerge an assessment of the validity of using both the math models and the wind tunnel for predicting the field performance.

Figures 24 and 25 show the 22.8 meter (75 ft) WTG tower at Plum Brook and the 4.1 kW WTG that is presently under test. The 4.1 kW WTG was purchased through the Pennwalt Corporation of Texas from Aerowatt of Paris, France and has a 9.1 meter (30 ft) diameter rotor and delivers 4.1 kW at 7.5 meters per second (17 mph). This WTG uses a fly-ball type governor and operates at a nominal 50 hertz. The 30-foot diameter rotor is of a two-bladed design and represents the largest WTG rotor commercially available in the world today.

Experiments with Small WTG Systems in Actual Applications: Both LeRC and NSF are interested in identifying applications that are suitable for using small WTG systems such as power for individual homes, remote radio and TV relay stations, and navigation aids. The objective of these experiments is to acquire performance data, experience, and costs for the WTG systems that are used in actual applications.

One application for such experiments that is presently underway is that of supplying electrical energy to a remote relay station in the southwest Arizona desert. NASA-Lewis and NASA-Johnson Space Center (JSC) are cooperating in this experiment which is one task of the program STARPACH which JSC has with the Department of Health, Education and Welfare (HEW). STARPACH stands for Space Technology Applied to Rural Papago Advanced Health Care, and has as its objective the improvement of health care delivery to the Papago Indians in southwest Arizona. Essentially the health care delivery system consists of a mobile hospital van from which diagnostic and medical advice is given by television and voice communication. A remote relay station is an essential link between mobile hospital van in the field and the central hospital. This station requires about 1.5 kW of power and about 8 kW-hours per day of energy.

JSC has already equipped the relay station with a propane gas-generator system to supply the power. However, fuel must be supplied to the site every 10 days. JSC eventually wants the site to operate unattended. To achieve this goal, JSC has given serious consideration to the use of a small WTG system and requested that LeRC assist in the experiment. In FY '75 LeRC will supply the WTG and battery storage system and and JSC will supply the installation, operation, maintenance service, and all performance and cost data. From this experiment will result a better understanding of the costs and performance capability of WTG systems to supply power to remote relay stations.

Other experiments on the use of WTG systems to supply power to actual applications will be identified by ERDA and NASA. As they arise, they will be evaluated and conducted if the experiments are of value to the wind energy program.

Energy Storage Systems

The ERDA Mission Studies will identify the most attractive applications for WTG systems and the amount of energy storage required. In parallel with this effort it is planned to conduct investigations on energy storage methods as part of the NASA-LeRC wind energy project.

A study is already underway to identify which of the energy storage methods might be most suitable for use with a WTG system. Systems under study include:

Battery storage
Redox cells
Compressed air
Fly wheels
Hydrogen

It is planned to have in operation as soon as possible small prototype energy storage systems to operate with the 100 kW experimental WTG.

The project plans for the specific development of the technology for energy storage systems to be used with WTG systems are still being formulated at this time.

CONCLUDING REMARKS

In 1973 the National Science Foundation (NSF) was given the responsibility for planning and executing a sustained wind energy program. The objective of this program is to develop the technology needed to build reliable and cost-effective wind energy conversion systems that have the potential for early and rapid commercial implementation. In January of 1975 the wind energy program was transferred from NSF to the newly formed Energy Research and Development Administration (ERDA). The NASA-Lewis Research Center has been assisting the NSF and now ERDA in the planning and execution of this program particularly in the development of the technology for the wind energy conversion systems. This report has briefly described those areas of the national wind energy program that are being conducted by the NASA-Lewis Research Center.

The following comments are relevant to the utilization of wind energy as an energy source to help meet the nation's energy needs:

1. Preliminary information on costs, performance, and operation of a large WTG system will be available in 1975. The 100 kW experimental WTG will become operational in the summer of 1975. This machine will provide early WTG data for the wind energy program. In addition, this machine will serve as a test-bed for evaluating improved components resulting from the supporting research and technology efforts.

2. The preliminary designs of WTG systems optimized for low cost will be available in mid-1975. Early estimates indicate that the costs of these first industry-optimized machines should be in the range of $1000 to $2000 per kilowatt for machines from the 100 kW to MW size.

3. It appears that a significant number of sites are available for the early utilization of WTG systems in utility networks. In a survey of the U.S. electric utilities, 70 companies expressed interest in actively participating in the wind energy program. Approximately 30 of these companies have agreed to provide wind data, sites, control rooms, and personnel for WTG operation if they are selected to participate in evaluating a WTG on their network.

4. Although it is early in the wind energy program, it is promising that WTG systems appear to have the potential to be cost effective in a significant number of utility applications.

5. It is expected that mission studies to be conducted for ERDA in 1975 will identify a number of other attractive applications for WTG systems in addition to the utility applications.

REFERENCES

(1) National Science Foundation/National Aeronautics and Space Administration Solar Energy Panel, "Solar Energy as a National Energy Resource," 1972.

(2) J. M. Savino, ed., "Wind Energy Conversion Systems," National Science Foundation Report NSF/RA/W-73-006, 1973.

(3) D. L. Ray, "Nation's Energy Future - Review of Federal and Private Energy R&D Report to the President of the United States," Atomic Energy Commission Report WASH-1281, 1973.

(4) U. Hutter, "Operating Experience Obtained with a 100-kW Wind Power Plant," NASA TT-F-15,068, 1973.

(5) U. Hutter, "Influence of Wind Frequency on Rotational Speed Adjustments of Windmill Generators," NASA TT-F-15,184, 1973.

(6) U. Hutter, "The Development of Wind Power Installations for Electrical Power Generation in Germany," NASA TT-F-15,050, 1973.

(7) R. L. Puthoff and P. J. Sirocky, "Preliminary Design of a 100-kW Turbine Generator," presented at the International Solar Energy Society, Fort Collins, Colo., Aug. 21-23, 1974.

(8) Spera, David A., "Structural Analysis of Wind Turbine Rotors for NSF-NASA MoD-O Wind Power System," NASA TM X-3198, 1975.

TABLE I. - ESTIMATED NASA LeRC WIND ENERGY PROJECT FUNDING FOR FY 1974† THROUGH FY 1979

Major project elements	FY '74	FY '75	Totals†† FY '74 through FY '79
100 kW experimental WTG	715 K	120 K	835 K
Industry-built User/operated WTG systems	500 K	600 K	17 365 K
SR&T including energy storage	150 K	1070 K*	8 600 K
Totals	1365 K	1790 K	26 800 K

†FY is fiscal year which begins on July 1 of preceding calendar year.

*Estimated for FY '75.

††Totals submitted to NSF in Project Development Plan from NASA, assumes up to 10 WTG systems in operation ranging from 100 kW to 3 MW and the design of a 10 MW farm system.

TABLE II. - GENERAL SPECIFICATIONS OF 100 kW EXPERIMENTAL WTG

Power:	
Blade power (assuming 7° coning; 0° inclination), kW	133
Generator output, kW	100
Desired rotor power coefficient	0.375
Cut-in wind speed (first load applied), m/sec	3.52 (8 mph)
Rated wind speed (100 kW bus), m/sec	7.92 (18 mph)
Feather wind speed, m/sec	26.4 (60 mph)
Hurricane wind speed, m/sec	66 (150 mph)
Location to rotor with respect to tower	downwind
Direction of rotation (looking up-wind)	counterclockwise

TABLE III. - BLADE SPECIFICATIONS

Number of blades	2
Diameter, m	37.5 (125 ft)
Cone angle - fixed, deg	7
Effective diameter of circle swept by airfoils, m	37.2 (124 ft)
Inclination of axis of rotation relative to horizontal, deg	0
Effective circular area swept by airfoils, m^2	1071.9 (11 910 ft^2)
Area of one blade projection on swept circular area, m^2	16.1 (179 ft^2)
Slenderness ratio relative to blade radius	22
Airfoil area density, percent	3
Rotor rpm	40
Maximum thrust from the wind (two blades), newtons	44 482 (10 000 lbf)

TABLE IV. - HOURS AT OR ABOVE GIVEN WIND SPEED BY MONTH AND YEAR

FOR PLUM BROOK - JAN THROUGH DEC 1972

Wind speed, mph*	Cum hr/yr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	8268	619	641	585	679	742	720	742	741	718	742	714	625
1	8261	619	641	578	679	742	720	742	741	718	742	714	625
2	6150	619	635	576	677	740	720	740	731	713	742	714	583
3	8085	616	627	564	671	734	717	729	718	705	740	706	558
4	7837	606	604	552	663	708	687	700	661	652	733	682	529
5	7471	594	575	524	644	672	654	656	633	659	719	653	498
6	6934	570	531	486	610	629	608	588	564	627	682	592	447
7	6180	542	475	436	553	551	536	487	480	576	625	514	405
8	5318	512	425	378	482	499	457	374	381	483	526	436	365
9	4442	467	380	323	417	430	384	280	276	376	415	368	326
10	3644	430	323	274	351	354	322	180	203	289	312	311	295
11	3007	374	281	236	303	302	257	135	141	214	240	255	269
12	2535	330	236	215	263	257	214	99	101	153	194	223	245
13	2063	284	194	192	207	207	164	73	70	100	159	190	223
14	1665	240	159	163	176	165	121	53	56	72	112	166	202
15	1351	215	125	142	149	132	97	38	32	39	77	129	182
16	1122	199	104	125	122	95	70	24	22	29	60	102	170
17	919	181	91	98	105	75	56	16	15	17	42	80	143
18	756	163	82	82	80	59	38	14	9	13	35	61	120
19	636	140	76	67	64	49	28	10	3	11	24	57	107
20	520	129	63	45	50	42	22	7	2	8	16	41	95
21	409	115	47	31	33	32	18	5	1	7	9	31	80
22	304	98	36	17	22	24	12	2	0	5	6	23	59
23	248	86	29	6	16	16	12	2	0	4	5	23	49
24	199	73	22	5	10	14	8	1	0	2	2	20	42
25	142	58	11	3	4	11	7	1	0	0	2	12	33
26	101	48	7	2	2	9	2	1	0	0	1	8	21
27	76	42	3	1	2	7	1	0	0	0	1	5	14
28	45	27	1	0	1	5	0	0	0	0	1	3	7
29	26	15	1	0	1	2	0	0	0	0	0	3	4
30	17	13	0	0	1	0	0	0	0	0	0	1	2
31	7	6	0	0	1	0	0	0	0	0	0	0	0
32	2	2	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
99**	516	125	55	159	41	2	0	2	3	2	2	6	119

*0.44 m/sec is equivalent to 1 mph.

**Instrumentation failure.

TABLE V. - SUMMARY OF COSTS FOR 100 kW EXPERIMENTAL WTG AND SIMILAR FOLLOW-ON WTG SYSTEMS

	FIRST 100 kW EXPERIMENTAL WTG		FOLLOW-ON 150 kW WTG SYSTEMS	
ROTOR				
BLADES	160 K	50.4%	140 K	64%
HUB, PITCH/CHANGE	95 K		50 K	
MECHANICAL				
GEAR BOX	11.5 K	10.8%	11.5 K	10.5%
BEDPLATE, SHAFTS, ETC	43 K		20 K	
ELECTRICAL GENERATOR, CONTROLS	68 K	13.5%	25 K	8.5%
TOWER, FOUNDATION	128 K	25.3%	50 K	17%
TOTAL	$505 K		$296.5 K	
$/kW	~ $5000/kW		~$2000/kW	

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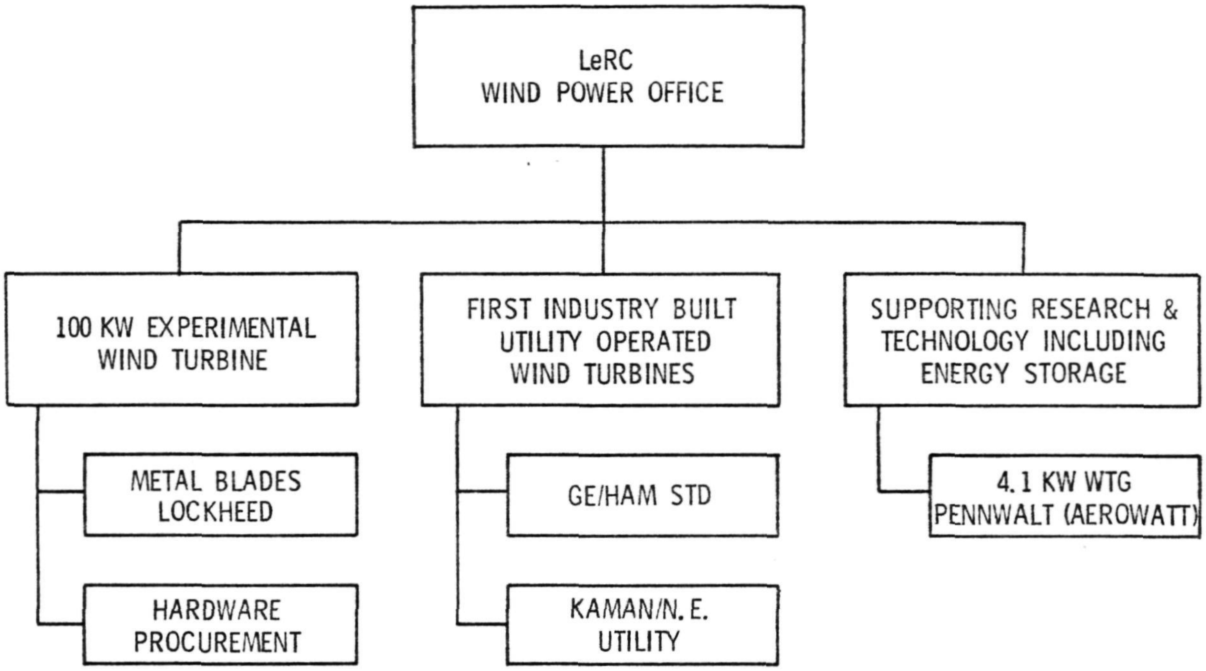

LeRC SUPPORTING AREAS:
AERODYNAMICS, CONTROLS/INSTRUMENTATION, STRUCTURAL DYNAMICS, DATA REDUCTION, MACHINE DESIGN, FACILITIES, TEST OPERATIONS

NASA CENTERS SUPPORTING AREAS:
LANGLEY - AEROELASTICITY
AMES - ROTOR DYNAMICS
MARSHALL - METEOROLOGICAL

Figure 1. - NASA LeRC wind energy project organization.

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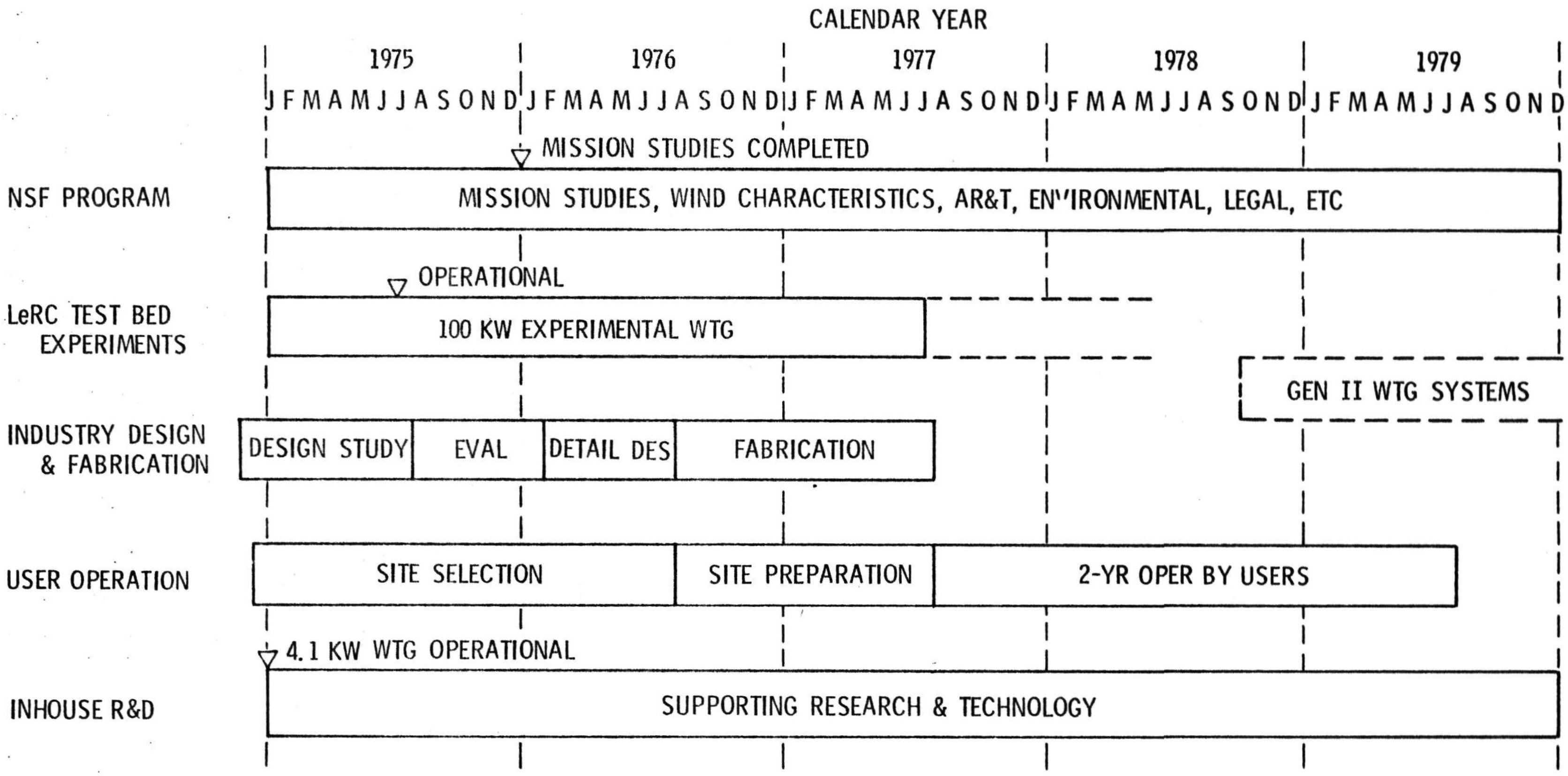

Figure 2. - Schedule of major wind-energy program elements.

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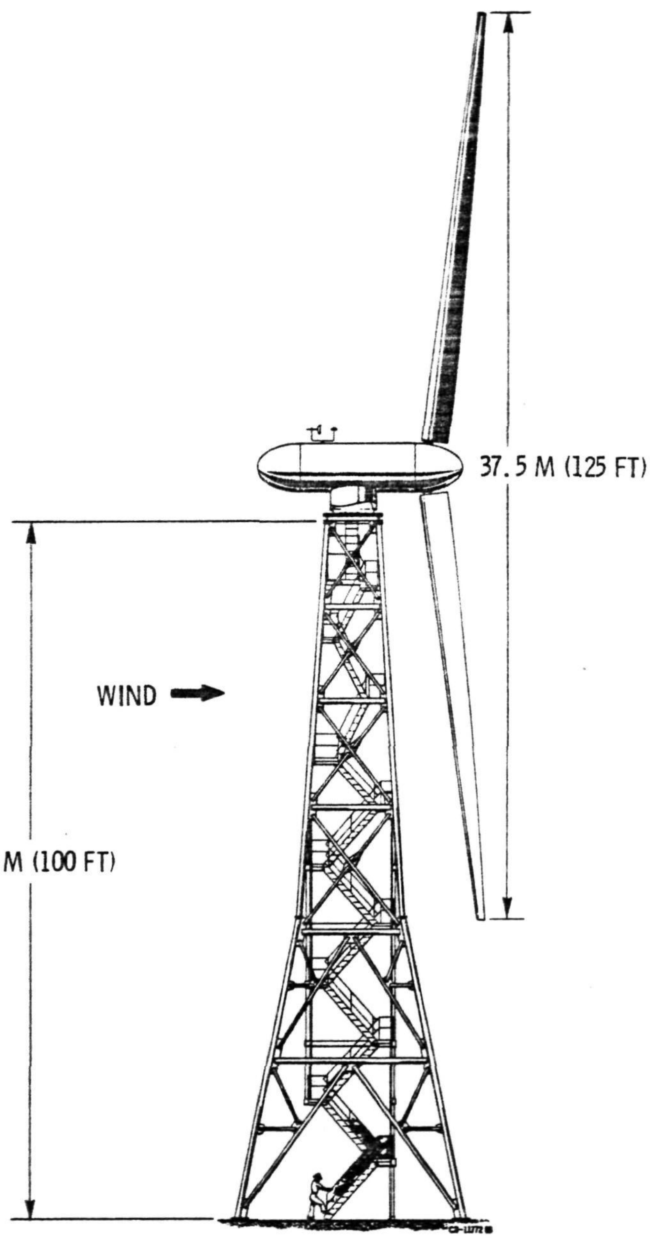

Figure 3. - 100-kilowatt experimental wind turbine generator.

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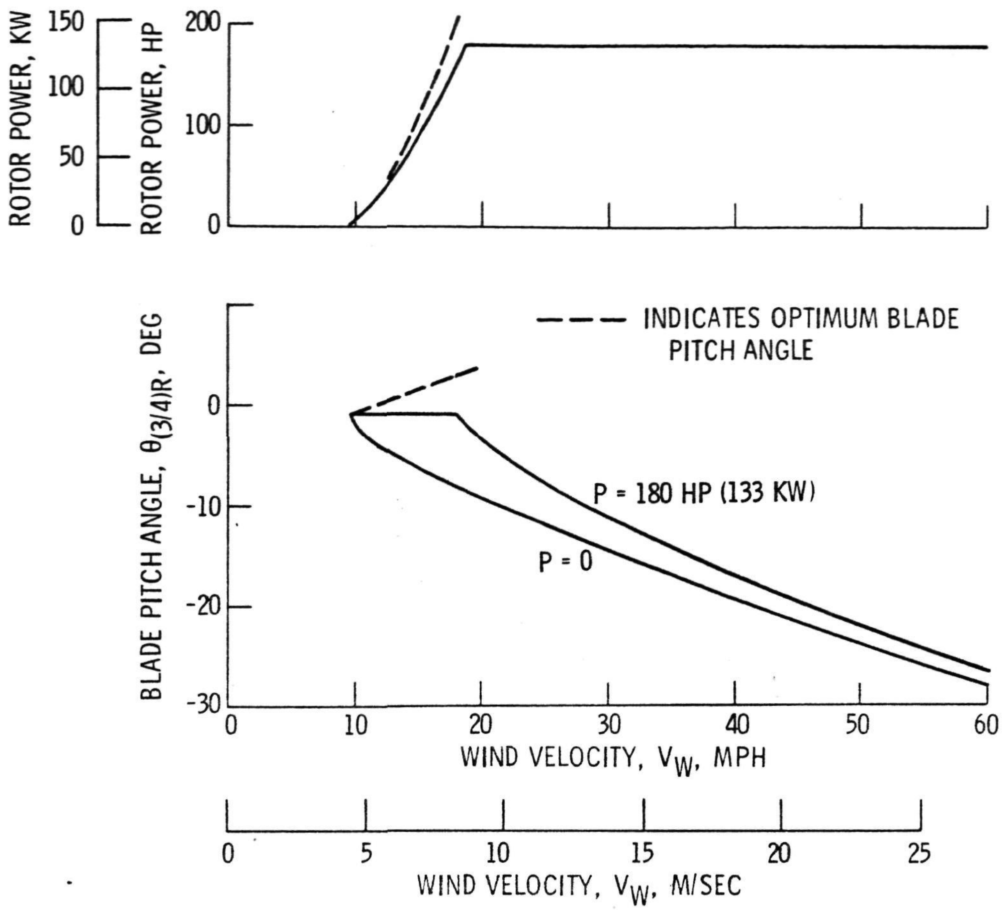

Figure 4. - 100-kilowatt experimental wind turbine generator.

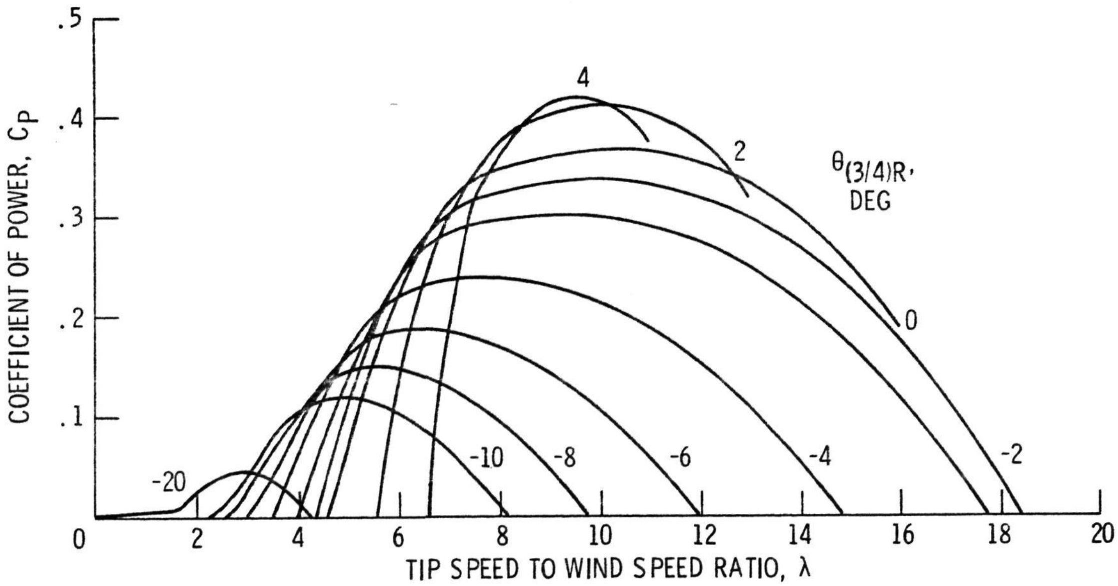

Figure 5. - Coefficient of power for 100-kilowatt experimental wind turbine generator.

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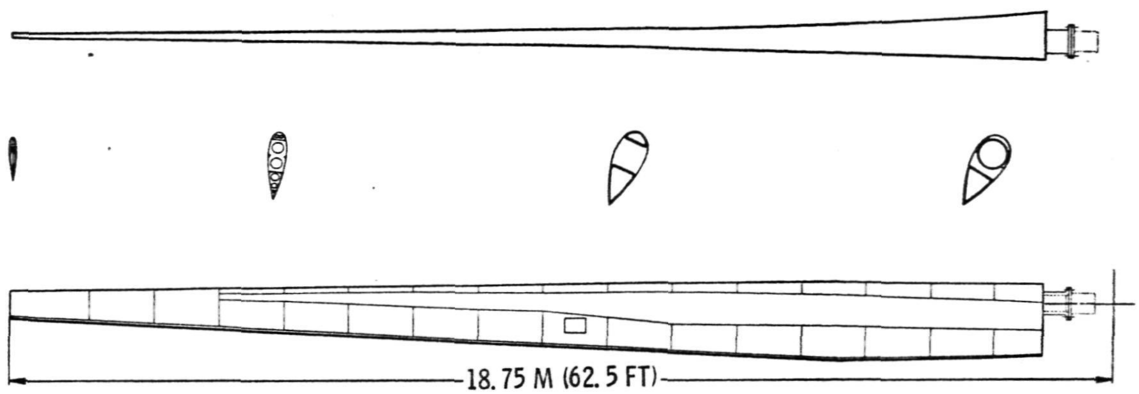

CD-11767-03

CONTRACTOR: LOCKHEED; BURBANK, CA

AIRFOIL: NACA 23 000 SERIES; TOTAL TWIST = 26.5° (NONLINEAR)

SIZE: 1.2 M (4 FT) CHORD AT ROOT END, 0.45 M (1.5 FT) AT TIP

APPROX WT = 907.2 KG (2000 LB)

DESIGN FEATURES
- 4130 STEEL ROOT END FITTING TO MATE WITH HUB
- "D" SPAR MAIN LOAD CARRYING MEMBER - 2024-T4 ALUMINUM
- MAIN RIBS SPACED 1.3 M (44 IN.) APART - ALUMINUM

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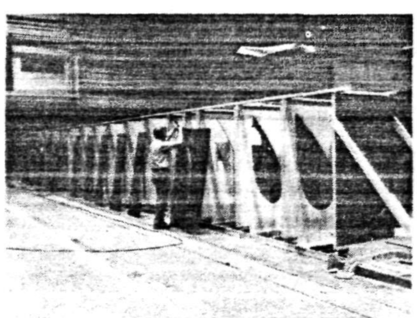
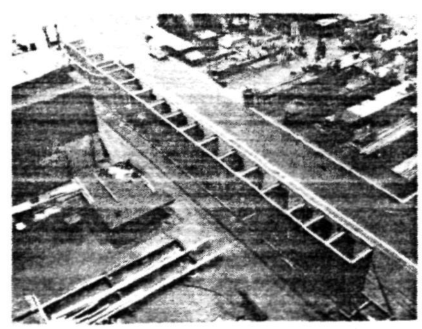
Figure 6. - Metal blade for the 100-kilowatt experimental wind turbine generator.



BLADE TEMPLATES



ASSEMBLY FIXTURE

BLADE ROOT END FORGINGS

Figure 7. - 100 KW experimental wind turbine metal blades - Lockheed.

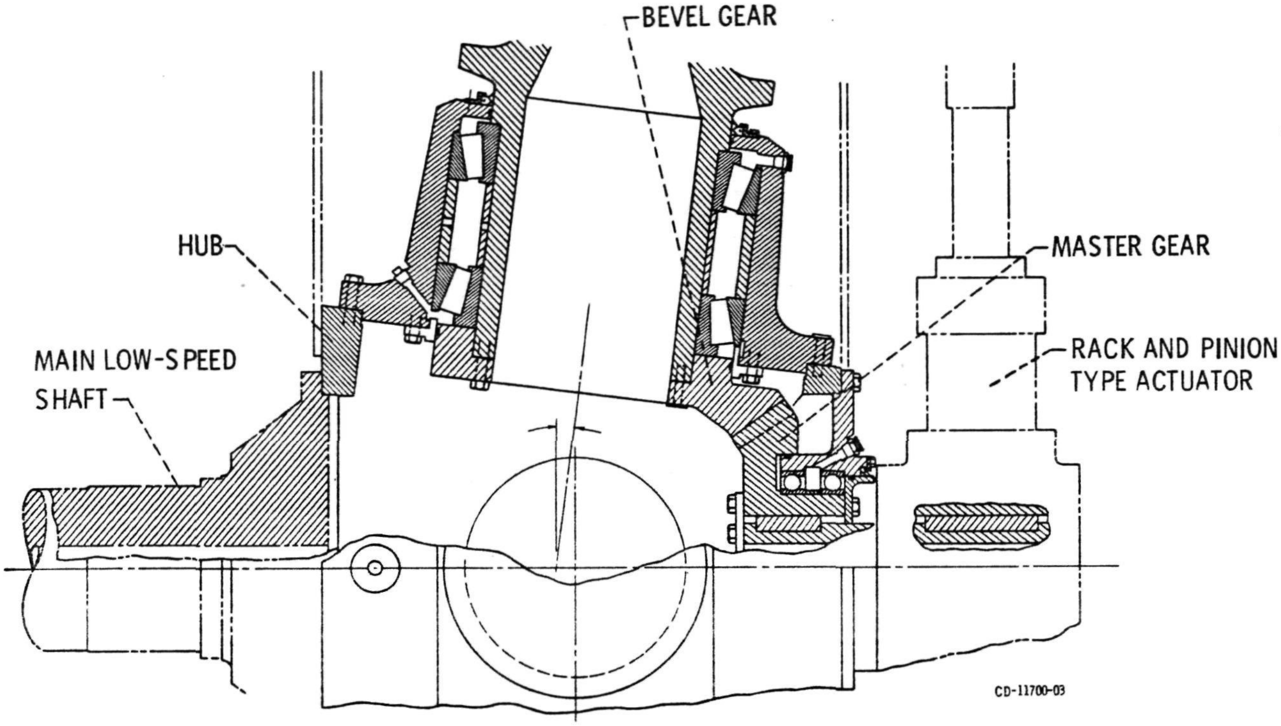


Figure 8. - Hub and pitch change assembly - fixed hub.

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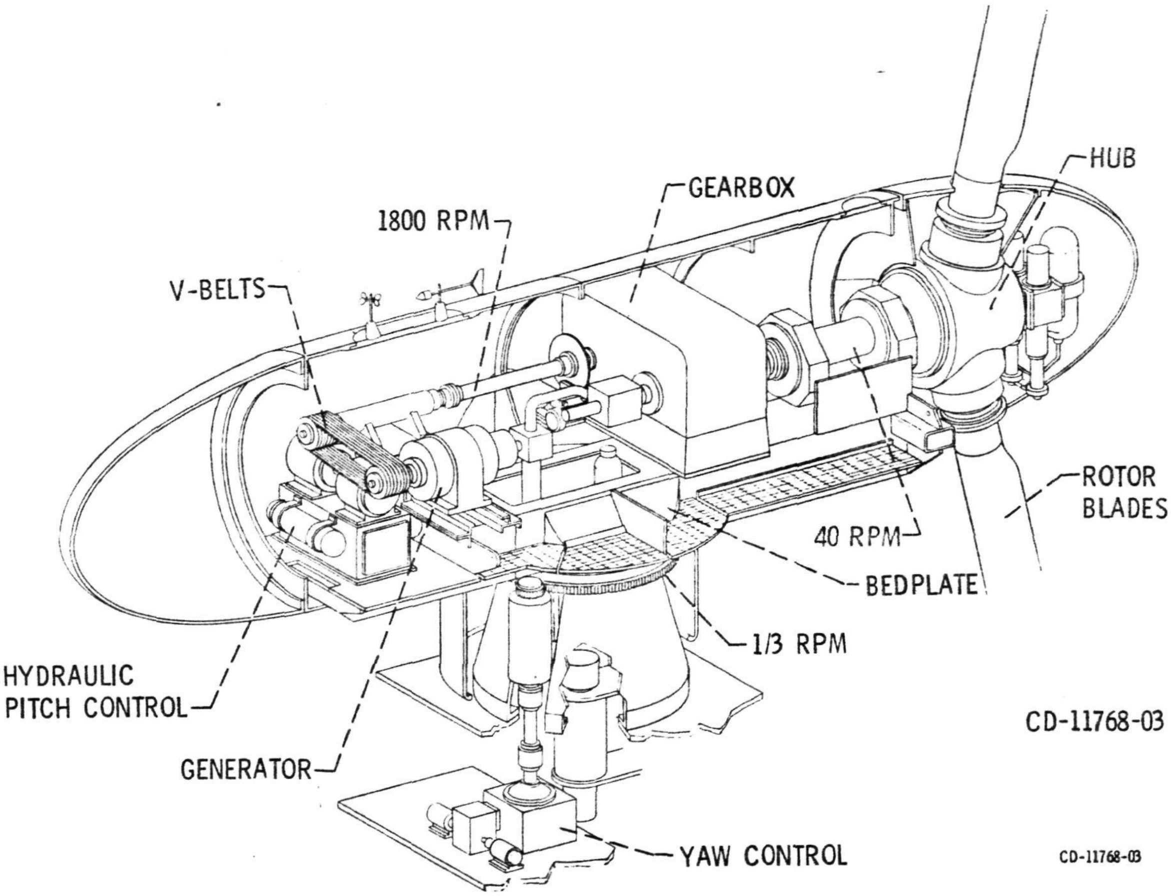
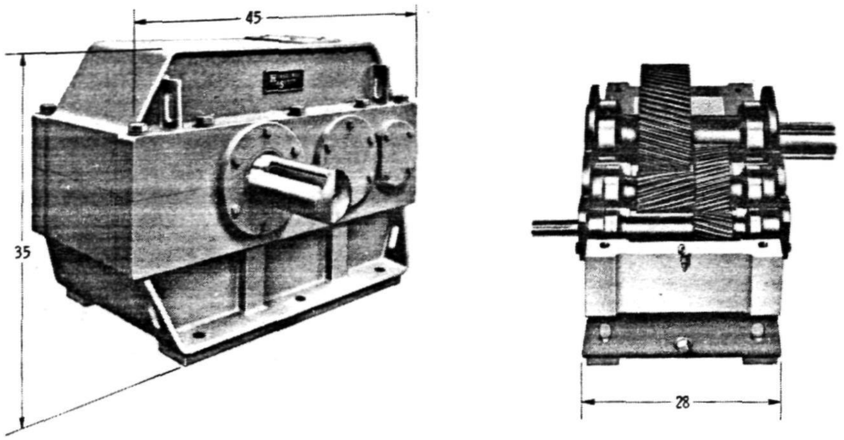
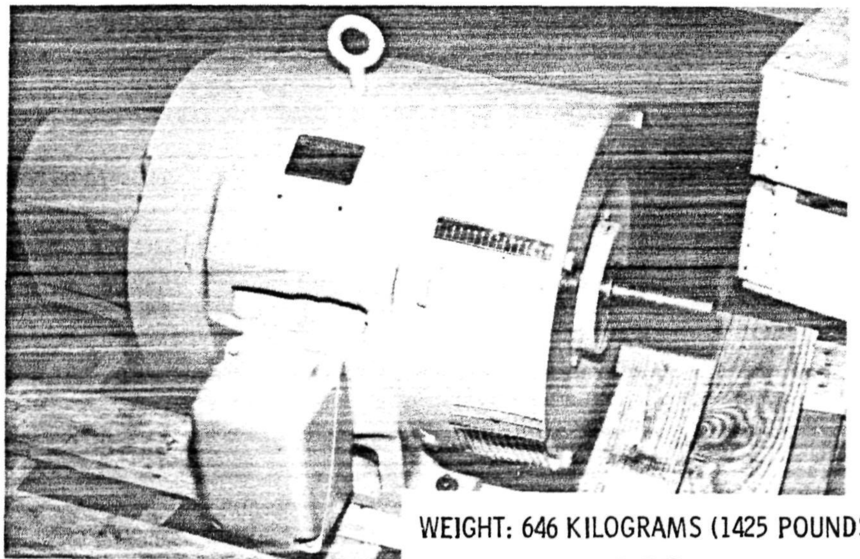


Figure 9. - 100-kilowatt wind turbine drive train assembly and yaw system.



RATIO - 45:1
RATING - 176 KW (236 HP) AT 1800 RPM
APPROX. MASS - 2180 KILOGRAMS (WEIGHT = 4800 POUNDS)
Figure 10. - Gearbox for experimental 100 KW wind turbine generator.



WEIGHT: 646 KILOGRAMS (1425 POUNDS)
APPROX. DIMENSIONS:
0.61 M DIAMETER (2 FT)
0.91 M LONG (3 FT)

Figure 11. - Synchronous generator for 100 KW experimental WTG.

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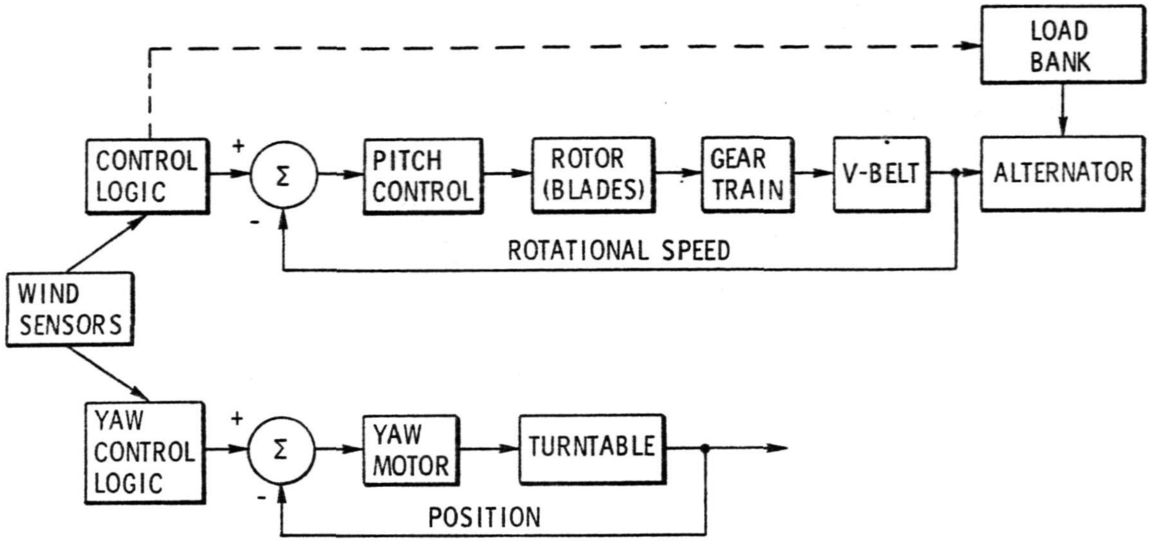

Figure 12. - Asynchronous (off-net) operation control block diagram for the 100-kilowatt experimental wind turbine generator.

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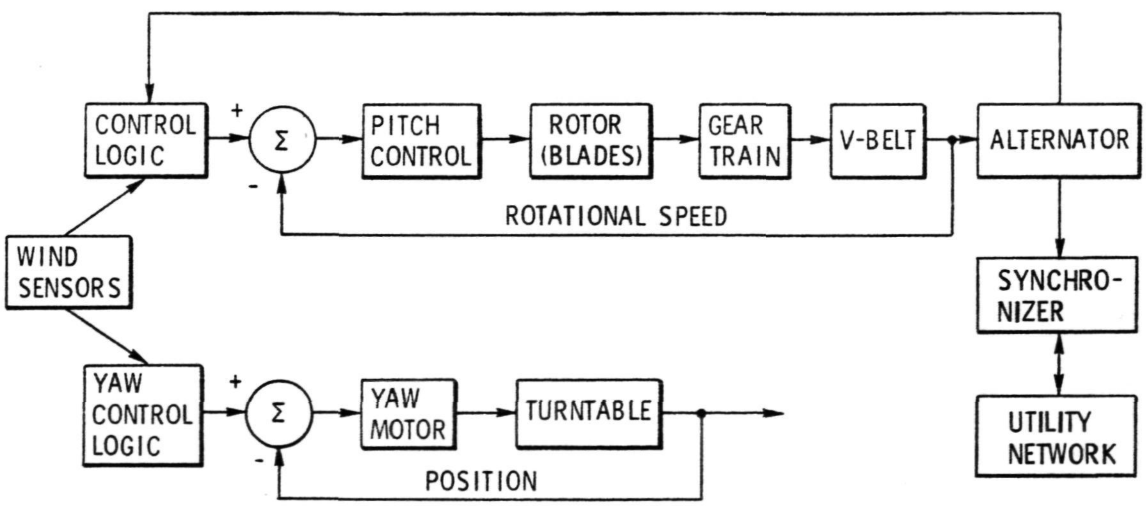

Figure 13. - Synchronous operation control block diagram for the 100-kilowatt experimental wind turbine generator.

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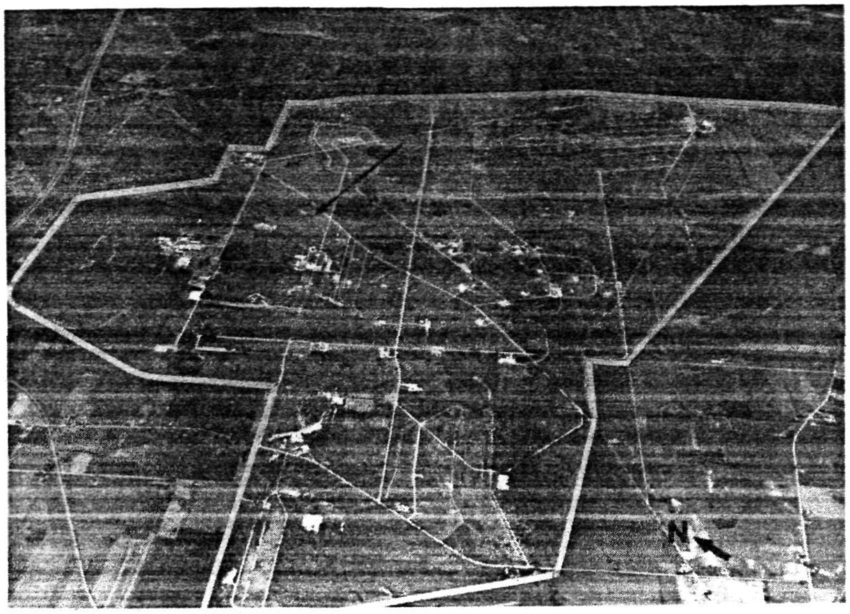

Figure 14. - Plum Brook wind turbine generator site.

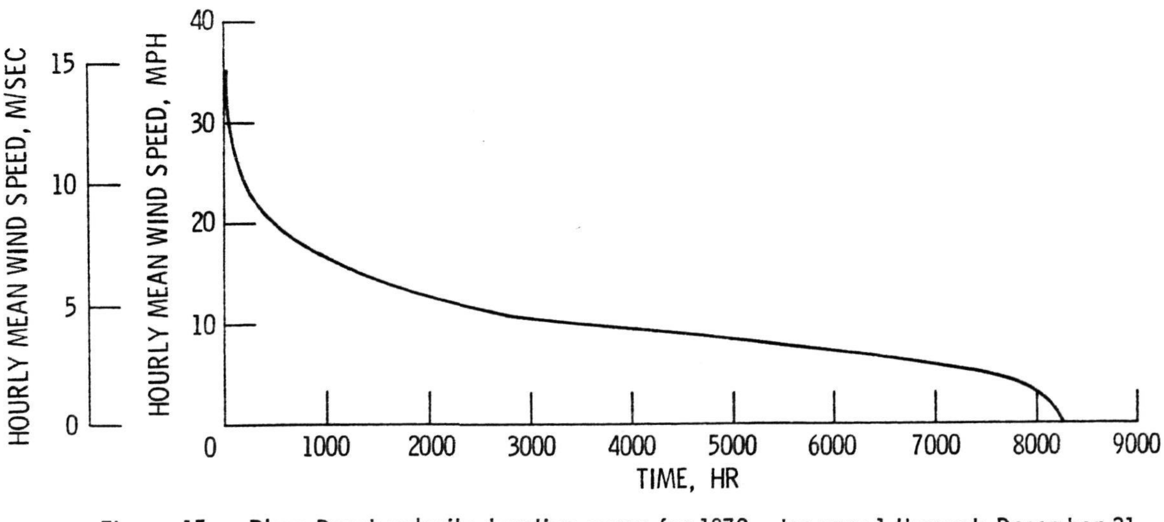

Figure 15. - Plum Brook velocity duration curve for 1972. January 1 through December 31, 1972 for 39-M (130-ft) height.

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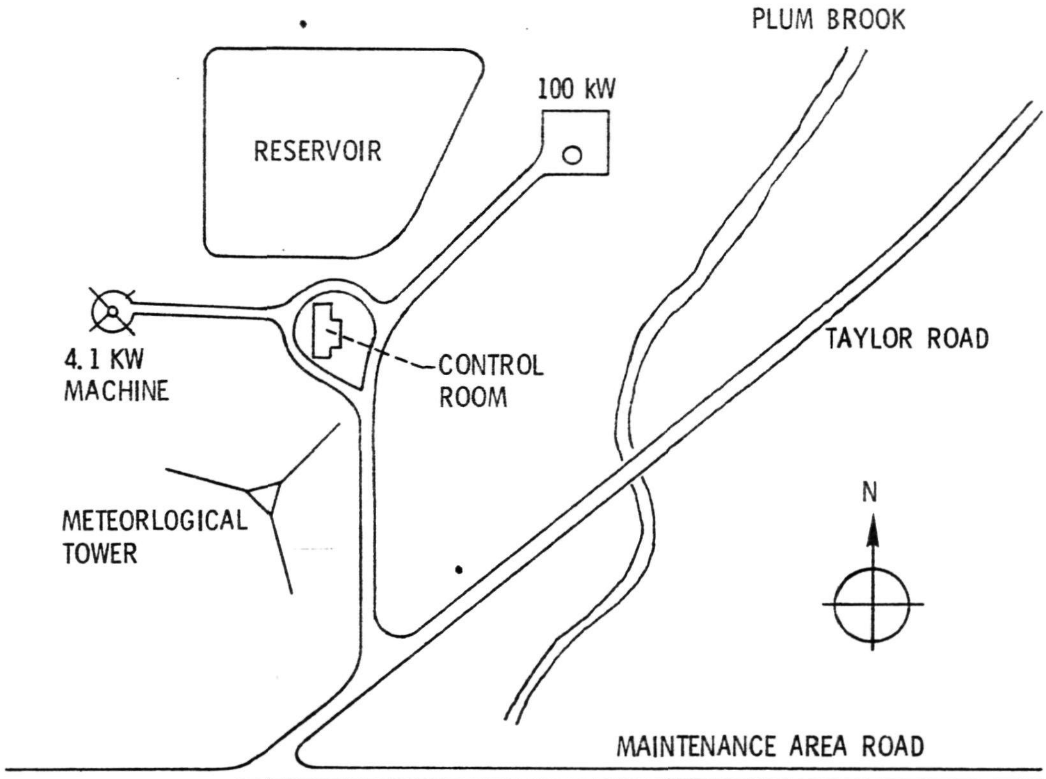

Figure 16. - Site layout.

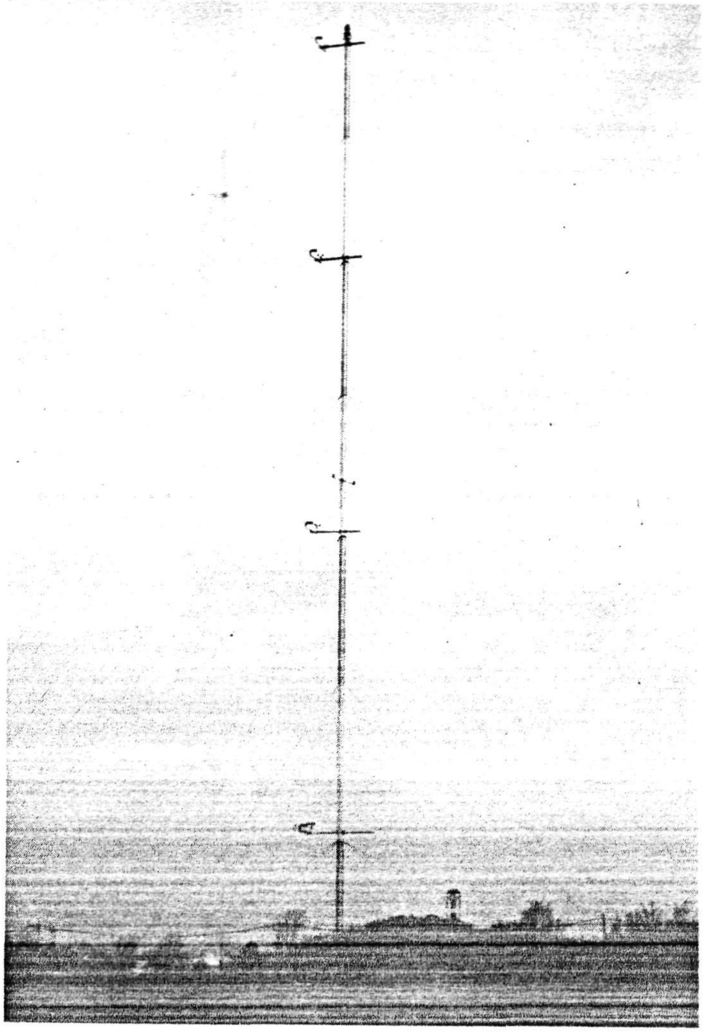

Figure 17. - 60 M (200 ft) meteorlogical tower at Plum Brook WTG site.

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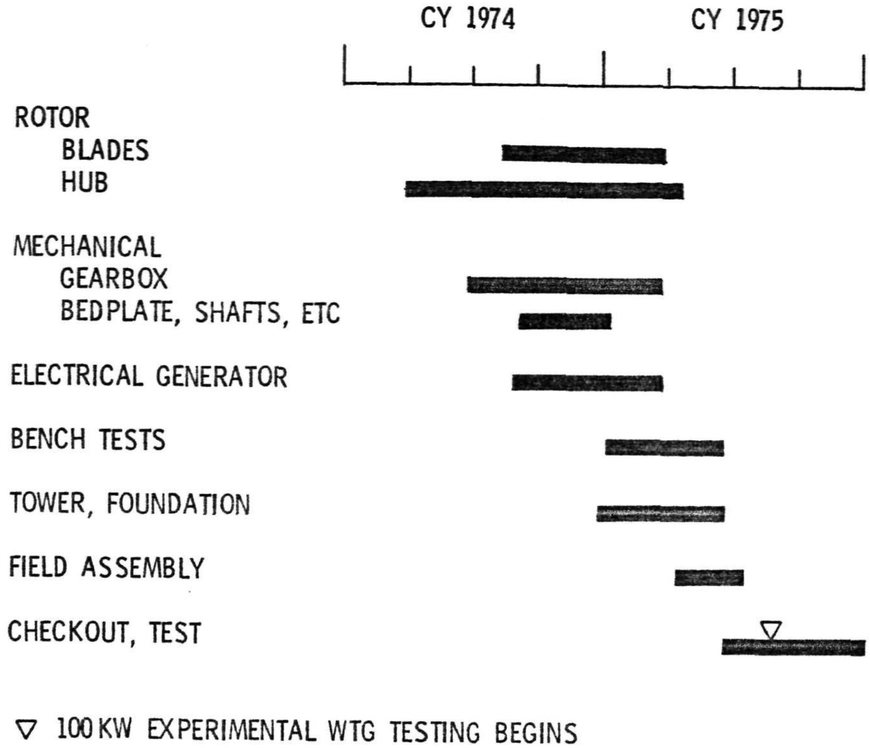

Figure 18. - Schedule for 100-kilowatt experimental wind turbine generator.

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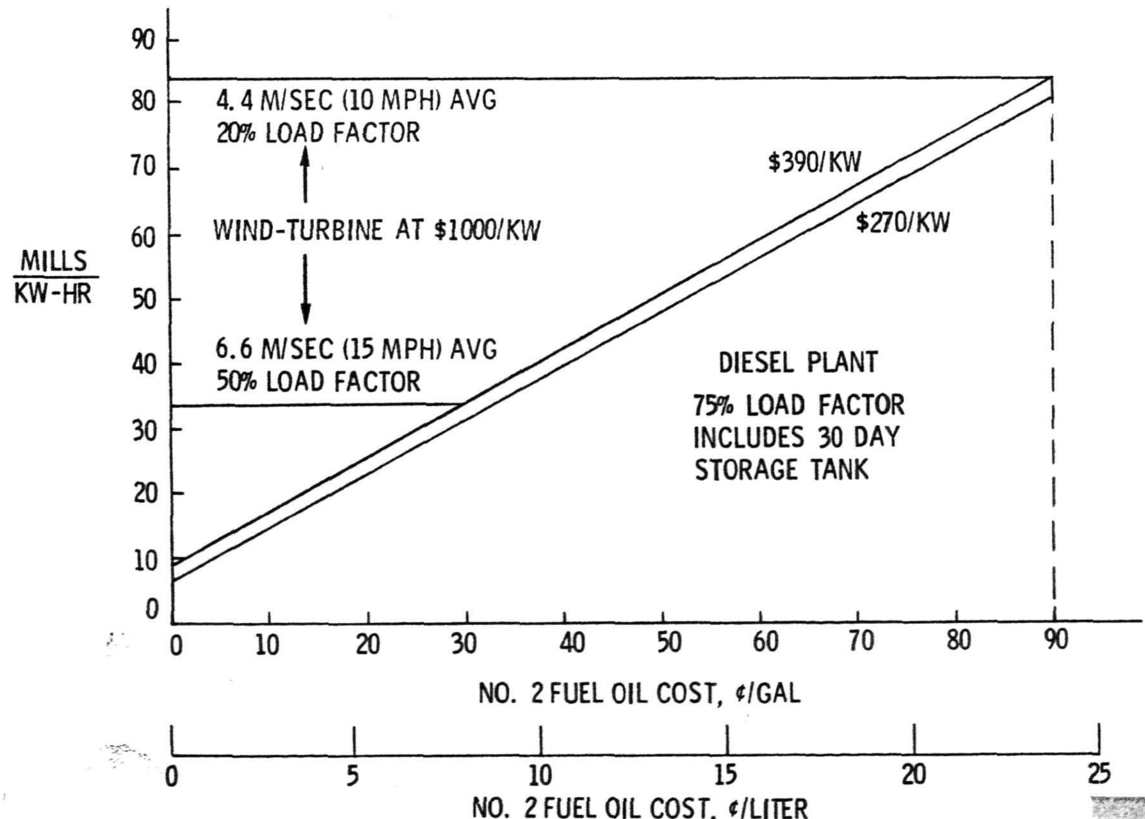

Figure 19. - Comparison of costs for wind-turbine/diesel generator.

PROJECT PHASES	PLANNED ACCOMPLISHMENT
DESIGN STUDY CONTRACTS	DETERMINE COST OPTIMUM (MINIMUM ¢/KW-HR) WTG SYSTEM, PRELIMINARY DESIGN
EVALUATION	SELECT FINAL DESIGN(S) OF A WTG UNIT
DETAIL DESIGN & FABRICATION CONTRACT	DETAIL DESIGN & FABRICATION OF SEVERAL WTG UNITS
SITE SELECTION	NO. OF REPRESENTATIVE SITES
WTG OPERATION	EVALUATION OF THE PERFORMANCE OF WTG UNITS IN TYPICAL USER ENVIRONMENTS

Figure 20. - Project phases and planned accomplishments for first industry built/utility operated wind turbine generator project.

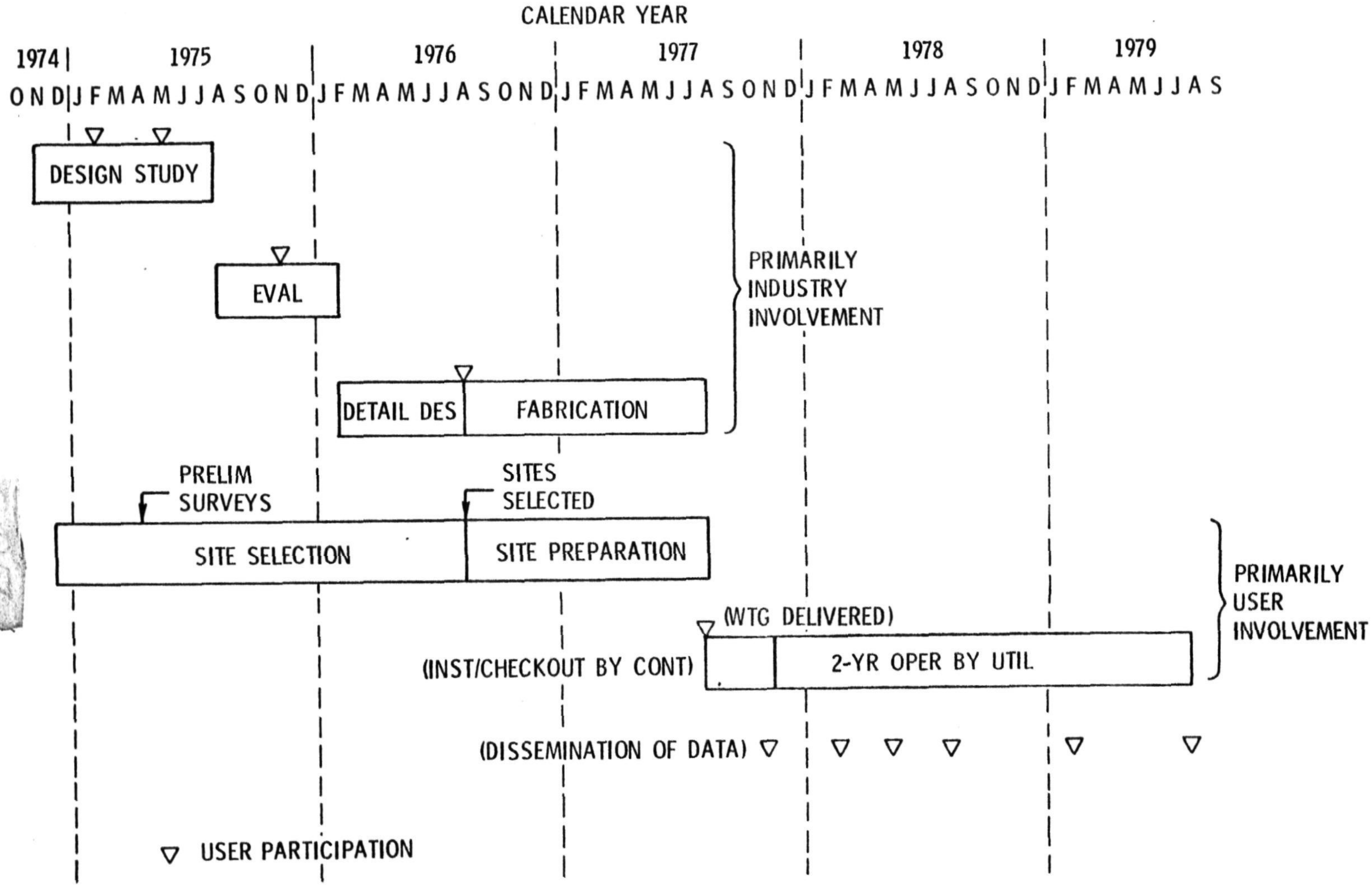

Figure 21. - Proposed schedule for first industry built/user operated wind turbine generator project.

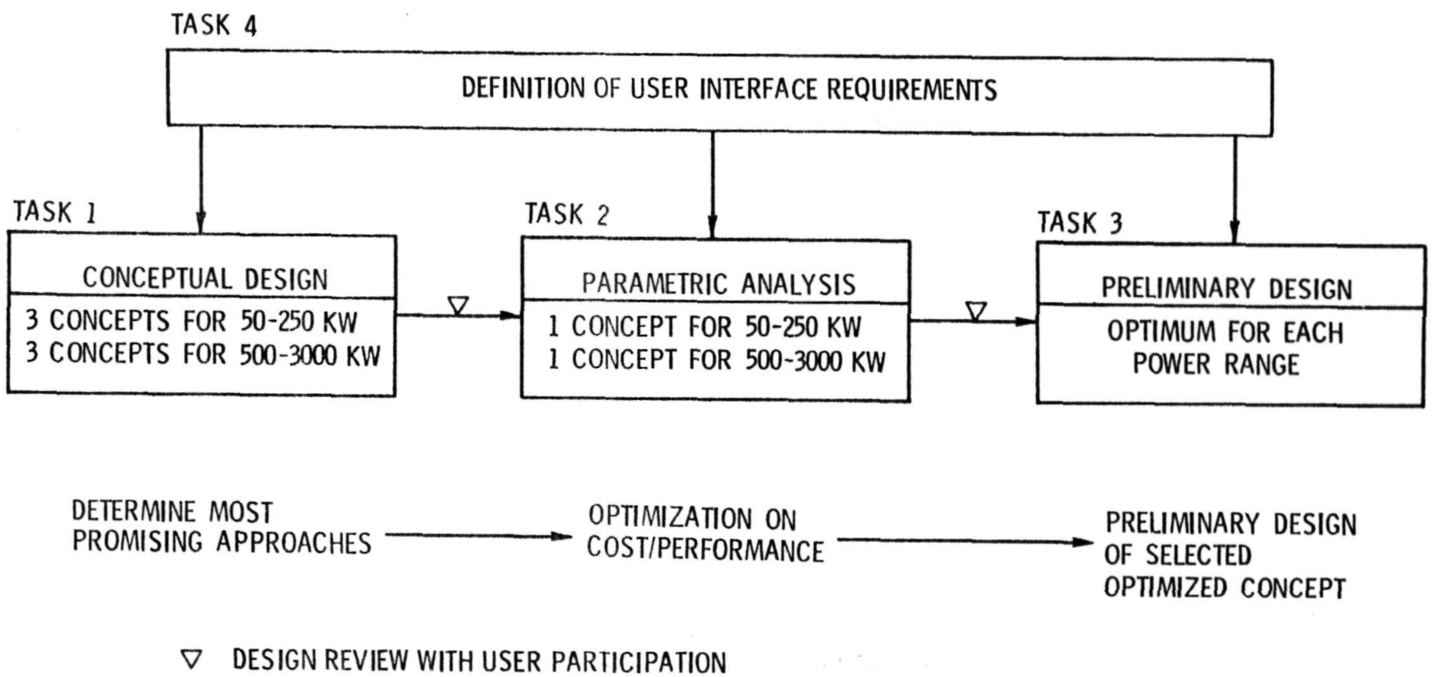

Figure 22. - Design study contract tasks for first industry built/user operated wind turbine generator project.

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- BACKGROUND INFORMATION ON UTILITY CO.
  - SIZE OF CO. (POWER CAPACITY, AREA SERVED, ETC)
  - TYPES OF POWER GENERATION (STEAM, NUCLEAR, HYDRO, DIESEL, ETC)
  - NEED FOR ALTERNATIVE SOURCES; COST OF ELECTRIC POWER
- SITE CHARACTERISTICS
  - LOCATION - INCLUDING PHOTOGRAPHS OF SITE, MAPS, CLIMATE, ETC
  - PRELIMINARY WIND DATA
  - COST, MODE OF POWER GENERATION, & GRID CHARACTERISTICS THAT WIND TURBINE GENERATOR WOULD INTERFACE WITH
  - SITE REQUIREMENTS PROVIDED BY UTILITY
    ACCESS ROAD
    CONTROL ROOM
    SECURITY FENCING
    ELECTRICAL INTERFACING EQUIPMENT
    TOWER & INSTRUMENTATION FOR WIND DATA
  - PROJECT VISIBILITY FOR PUBLIC REACTION
  - OTHER - ANY OTHER REASONS WHY THIS SITE SHOULD BE CONSIDERED FOR SELECTION

Figure 23. - Information desired from preliminary site surveys.

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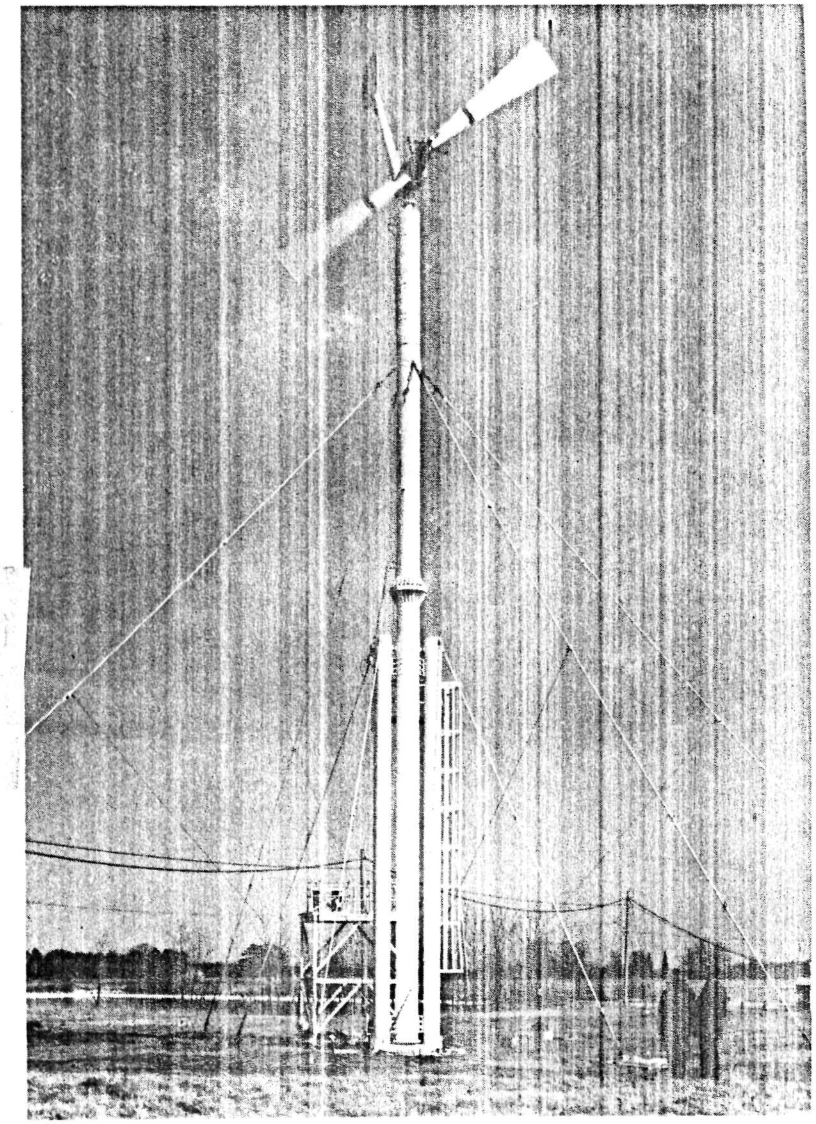

Figure 24. - 4.1 KW WTG in operation at Plum Brook site.

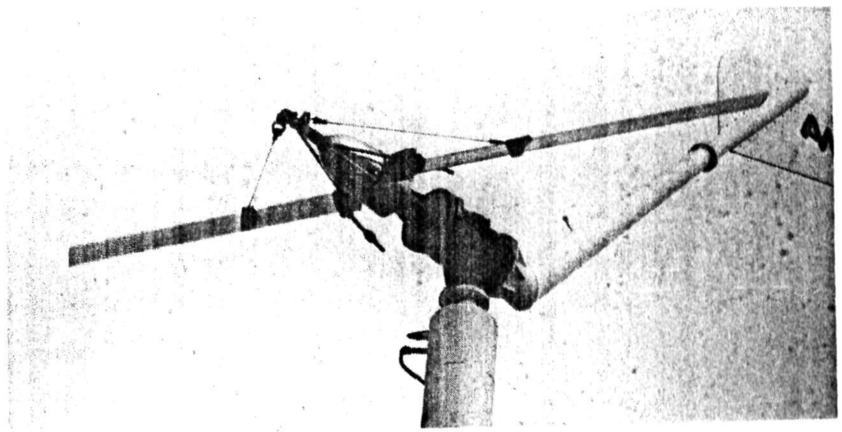

Figure 25. - Closeup of the 4.1 KW WTG.

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