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TECHNICAL AND MANAGEMENT SUPPORT FOR THE DEVELOPMENT
OF WIND SYSTEMS FOR FARM, REMOTE AND RURAL USE

Annual Report, October 1976—September 1977

October 1977

Work Performed Under Contract No. EY-76-C-04-3533

Wind Systems Program
Rocky Flats Plant
Rockwell International
Golden, Colorado

MASTER

U.S. Department of Energy

Solar Energy

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Wind Systems Program
Rocky Flats Plant
Rockwell International

950 3416

October 1977

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Prepared for the United States Department of Energy
Division of Solar Technology
Wind Systems Branch
Contract E(20-2)-3533

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EXECUTIVE SUMMARY

This annual report details progress during FY1977, the first full year of the Rocky Flats program entitled "Technical and Management Support for the Development of Wind Systems for Farm, Remote and Rural Use." The primary program goal is to stimulate the manufacture and sale of small wind energy conversion systems (SWECS) by private sector industry and to increase use of SWECS by the general public. This goal will be met by reducing the cost of energy produced by wind turbine generators (WTG's). Energy costs can be reduced by decreasing system capital cost, by improving performance and/or by improving system reliability and lifetime.

The approach of the Rocky Flats program has been four-fold:

1. Establishment of a national SWECS Test Center to determine the state-of-the-art in existing SWECS and identify areas wherein improvements can be made.
2. Development of SWECS hardware to meet specific objectives and goals as identified by results of SWECS testing and applications studies.
3. Information dissemination to appraise SWECS manufacturers, designers and users of the results of the RF program.
4. Long range planning for stimulating utilization of SWECS in accordance with the overall DOE Wind Energy Program.

The RF Wind Systems group has identified and pursued eight specific tasks to achieve the objectives of the program:

- Task 0 - Program Management
- I - Test Center Establishment
 - II - Test Center Operations
 - III - Systems Analysis
 - IV - Technology Development
 - V - Standards Development
 - VI - Information Dissemination
 - VII - Long Range Planning

During FY1977, the Test Center has been established and a total of eight WTG's have been mounted on towers for testing. At year end, five were undergoing tests, two had been returned to the manufacturers for retrofit of design improvement, and one had been destroyed in a wind storm. In addition, two WTG's were being assembled and prepared for testing and one machine was on order.

Specific design improvements have been identified and implemented on two WTG's as a direct result of RF testing.

The high-speed data acquisition system at the test center is not yet operational, though the hardware and software are both nearing completion. The system, when completed, will be capable of continuous monitoring of the performance of all the machines at the site as well as intensive testing for measurement of engineering data on any given WTG.

Several subtasks have been identified within the Technology Development task. Most important are the programs for development of 1kW High-Reliability, 8kW and 40kW WTG's. At least two contracts will be let for development of SWECS in each of the three size ranges. During FY1977, RFP's were sent out, proposals were evaluated and several contracts negotiated. At end-of-year, two contracts had been announced for 8kW WTG development. They are with Windworks, Inc. of Mukwanago, Wisconsin and United Technologies Research Center of East Hartford, Connecticut.

At the time of printing additional 8KW WTG contracts had been announced with Grumman Energy Systems, Inc. of Ronkokoma, New York, and ALCOA of New Kensington, Pennsylvania. Contracts for development of 1KW High Reliability WTG's had been announced with Enertech Corporation of Norwich, Vermont, Northwind Power Company of Warren, Vermont and Aerospace Systems, Inc., of Burlington, Massachussetts.

In all of the WTG development contracts plans call for a two phase development. The first phase consists of design and analysis of the system. During the second phase a prototype will be constructed and shipped to Rocky Flats for testing. An important aspect of the developments is a cost goal for each machine. The 40kW machines have a goal of \$500/kW (including tower but excluding installation), the 8kW WTG's have a goal of \$750/kW. The High-Reliability WTG's have as a primary goal the capability of operating unattended for one year in a severe environment. A secondary cost goal of \$1500/kW has also been established.

Efforts under Task V (Standards Development) have resulted in an informal survey of the wind energy community's opinions on the direction Standards Development should take. During two workshops a consensus of attendees has been reached that an organization such as the American Wind Energy Association (AWEA), with assistance of Rockwell International and the DOE, should pursue establishment of standards for WTG performance evaluation, product standards and standardized data reporting nomenclature and format. Thus the background work is essentially complete at this time and future efforts will be determined in discussion with AWEA, DOE, and other organizations.

Information dissemination has resulted in distribution of approximately 25,000 brochures, with a potential exposure of nearly 200,000 persons, construction of a traveling display, and continuous interface with local and national news media.

Information dissemination has been advanced by a standards workshop, establishment of a wind power library at Rocky Flats, and work on "A Guide to Commercially Available Wind Machines," an index of wind energy manufacturers, distributors and researchers, and a user's guide to SWECS.

1.0 INTRODUCTION

Small wind energy systems offer great potential as an economic, renewable energy resource that can supply a significant portion of the nation's energy requirements. Development of the technological and institutional framework to expedite utilization of this resource is a prime goal of the U. S. Department of Energy (DOE), Wind Energy Systems Branch.

Rockwell International, operator of the DOE Rocky Flats Plant near Golden, Colorado, has been authorized by DOE to manage and direct a program for the development of small wind energy conversion systems (SWECS). The program is entitled "Technical and Management Support for the Development of Wind Systems for Farm, Remote and Rural Use." This report summarizes technical progress of the first full year FY1977 of the Rocky Flats (RF) program. Progress of both in-house efforts and subcontracted development is reported.

This first year of the RF program has seen rapid growth and acceleration in all areas of the program. The year has been primarily one of planning and establishment, however, significant technical progress has already been achieved in the program. In addition to technical progress this report relates details of the establishment of the RF program, its current status and, in light of the rapid acceleration, some indications of future plans and activities.

1.1 Objectives

The overall objective of the RF program is to stimulate manufacture of SWECS by the private sector and utilization of these systems by the public. This requires understanding of applications and requirements, then translating to equipment specifications for subcontracted development.

This commercialization must be done as rapidly as practical and in a fashion that will assist the small businesses which currently comprise the backbone of the industry.

Reducing the cost of wind energy is the principal specific objective of the program. The capital-intensive cost of wind systems hardware represents a substantial investment for potential users. Although the fuel (i.e., the wind) is free, and maintenance requirements/costs are generally minimal, the amortized costs of the hardware result in per unit energy costs which are usually not competitive with alternate sources, such as public utility companies (or require long break-even times) so that the investments in hardware are not economically attractive at the present time. At this time, wind systems are generally economically competitive only in remote sites (which are not serviced by public utilities), and/or in high wind areas which have high costs for other energy sources.

Another important objective is a reduction in uncertainty of performance and cost due to unknown reliability and associated system cost. Reliability improvements are particularly significant for applications in remote areas where maintenance is extremely difficult and costly.

Other objectives of the Federal program which are not the prime responsibility of the RF program but which may affect the RF effort are as follows:

1. Development of large WECS (output greater than 100kW or its equivalent).
2. Determination of the potential of wind energy on a national, regional, and local basis.

3. Determination of wind characteristics and siting strategies including effects of local site and terrain, system sensitivity, predictability and variability of winds, and gust and storm loadings.
4. Solution of user interface problems including institutional constraints, demand-supply matching, electrical and failure mode interfaces, and energy storage requirements.
5. Evaluation of legal, environmental and aesthetic uncertainties and overall technological and social impacts.

RF makes every effort to remain cognizant of progress by other DOE programs towards meeting the above objectives and subsequently incorporate the appropriate technology into this program, or revise the RF program to solve specific SWECS problem areas.

Specific objectives of the RF program are to:

1. Determine technical/cost objectives from input received from other DOE programs and from RF generated requirements for non-farm, rural and remote applications.
2. Sponsor and manage subcontractor Research and Development (R&D) programs to develop the technology and hardware to meet technical/cost objectives.
3. Disseminate performance, engineering and reliability data to public users, R&D and manufacturing organizations and to other DOE programs.
4. Plan and support a combined DOE/RF/industry effort to provide product and test standards.

1.2 Approach

To meet the general objectives of this program, a multi-element parallel effort is being used. The four basic elements consist of:

1. Establishing and operating a national Wind Systems Test Center, testing SWECS representative of those currently available, and determining the state of the technology.
2. Performing the necessary research and development to provide the basic technology for an orderly, efficient evolution of economical and reliable SWECS. Improved design and analysis techniques, more effective fabrication methods, higher efficiency and more reliable components, test evaluation of advanced hardware, etc., are a portion of the needs envisioned as a part of the basic technology development. This effort will be an ongoing one controlled by progress from within the element and directed by results of the other elements.
3. Developing SWECS in accordance with specific technical/economical requirements. Programs will be scheduled as required for the specific applications. Requirements for these applications will be provided by DOE/WSB, and as indicated by the results of studies to be conducted under this program.
4. Developing a long-range plan for stimulating utilization of SWECS which will guide the RF program in accordance with the overall DOE wind energy plan.

1.3 Ground Rules

Several program ground rules have been established to guide the program and to ensure compatability with other DOE programs. These ground rules are as follows:

1. RF is involved in small systems, typically generating under 100kW or equivalent energy.
2. Fifty percent or more of the program funds are expended outside RF for subcontracted research and development, materials, services, equipment procurement, etc.
3. Emphasis is placed upon a strong small business policy to encourage and support participation of the individuals and small companies that comprise the current U.S. technology.
4. RF is not commercially involved in wind systems, i.e., machines will not be produced for sale. The RF facility is operated by the Atomics International Division of Rockwell International under management of the DOE Rocky Flats Area Office (RFAO). Rockwell International (RI) provides a systems management function for the DOE/Wind System Branch (WSB). As a DOE facility, production for public use is not permitted and RI/RF has made a further commitment not to pursue such activity.
5. RF has initially emphasized development of Wind Turbine Generators (WTGs) but will be involved in all aspects of small wind systems - including towers, electrical controls/interfaces, mechanical/hydraulic systems and related equipment which utilize wind power. Energy storage systems will not be developed under this program unless they are uniquely related to wind energy.
6. RF is jointly participating with a related DOE program being conducted by the United States Department of Agriculture (USDA). Together, the USDA and RF programs comprise the DOE program element entitled "Farm and Rural Use Systems". For farm and rural applications, USDA has basic responsibility for defining technical/economic objectives and determining market potential. RF will develop the necessary technology and/or hardware to meet the USDA objectives.

Development/prototype testing will be conducted at RF. Agriculture field tests will be conducted by USDA. Coordination between RF and USDA will be conducted by DOE/WSB. DOE will provide RF with technical/cost objectives as indicated by USDA results. When advised by DOE/WSB, RF will revise this Program Plan to address USDA needs. For SWECS applications which are neither farm nor rural, RF may become involved in field evaluation and demonstration test projects.

The remainder of this report discusses progress in all of the program tasks. The tasks are organized according to the Program Development Plan submitted to DOE/WSB for FY1977. The major task areas addressed are:

- Task 0 - Program Management
- Task I - Test Center Establishment
- Task II - Test Center Operation
- Task III - Systems Analysis
- Task IV - Technology Development
- Task V - Standards Development
- Task VI - Information Dissemination
- Task VII - Long Range Planning

2.0 PROGRESS BY TASK AREAS

2.1 Program Management (Task 0)

2.1.1 Objective

The objective of this task is to provide the general management functions of planning, organizing, staffing, directing and controlling the overall program activities, including conducting technical and administrative liaison with the customer.

2.1.2 Approach

In accordance with RF policy, this program is managed under a matrix type management system whereby the program requirements are ensured of accomplishment through a program management team that provides overall direction of the program, working through functional line management that is responsible for work performance.

Program direction and control is exercised by the Program Manager. This is accomplished by defining program requirements and objectives to the line organization in terms of program plans, budgets, schedules, and through performance measurement.

Responsibility for the management of the project is assigned to a Program Organization headed by a Program Manager. The Program Organization through the Program Manager:

- A. Represents Rocky Flats in all program matters with DOE. Technical and programatic reporting will be directly to the Wind Energy Systems Branch. Financial and administrative matters will be handled through normal RFAO and ALO channels.

- B. Prepares and maintains the Program Plan which defines the technical schedule and financial requirements and constraints of the overall program and the major tasks or work packages thereunder.
- C. Issues work orders and budgets to all functional organizations and other participants in the program.
- D. Evaluates performance against the Program Plan and directs alternative actions as required.
- E. Presents the status of the program to Rocky Flats Management and others as required using the prescribed Input-Output and other program status charts.

All functional organizations provide support to the program as defined and requested by the program organization and concurred in by the functional organizations.

Program Management responsibility for this program is assigned to the Wind Systems Branch of RF Research and Development.

The RF major portion of the Wind Systems Program office effort is devoted to two major areas:

1. Operation of the test center, including planning, testing, data reduction/analysis/reporting, etc.
2. Planning, issuing, monitoring, and reporting upon subcontracted programs for development of highly specialized technology areas such as material/component/system development, preparation and upgrading of analytical/design techniques, etc.

Figure 2.1.1 depicts the program organization and shows the principal participating organizations within RF and their representatives. The

Figure 2.1.1 Rocky Flats Program Organization

organization of the Wind Systems Branch at RF and its representatives are shown in Figure 2.1.2. During FY77 the staff of the Wind Systems group grew from six members in September, 1976 to 13 members in October, 1977. It is projected that the group will increase to the staff of 20 shown in the chart by January, 1978.

2.1.3 Reporting

The output of this task consists of the following on a regular basis:

Monthly Administrative letter reports containing financial and status summaries for the month.

Annual Technical Progress Reports documenting program activities and results for the year.

Technical reports on specific areas or portions of the program which document the complete and final technical accomplishments of in-house RF activities. (Technical reports will also be required for each subcontracted R&D project under Task IV - Technology Development).

Technical support by RF personnel to DOE/WSB. Six months of man level support was provided during FY1977 by RF personnel. Additional technical/management support to DOE/WSB was provided using personnel supplied under RI subcontract.

This annual progress report is the first report, other than the Monthly Administrative letters, to be distributed.

* ON BOARD JANUARY 1, 1980 18 1978

Figure 2.1.2 RF Wind Systems Branch Organization Chart

2.2 Test Center Establishment (Task I)

2.2.1 Objective

Establishment and operation of a national test center for SWECS at Rocky Flats has high priority in the RF program. The establishment and operation tasks are discussed in this section and in Section 2.3 respectively.

The objective of the test center establishment task is to provide the engineering design, planning, construction and inspection necessary to establish a test facility for SWECS. Included are the procurement and installation of test towers, instrumentation, electrical controls and other equipment necessary to obtain and measure power and engineering data from wind systems. Operational Safety Analyses are also required to ensure safe operation of the test center to protect workers and visitors to the site.

2.2.2 Site Establishment

Following the program go ahead in May 1976, 400 acres of the Rocky Flats Buffer Zone were set aside as the test center. Figure 2.2.1 points out the site location and Figure 2.2.2 the site plan. This area was divided into five tower rows with the rows perpendicular to the prevailing westerly wind. An Environmental Assessment Report was initiated in May and completed in August. This completion allowed construction to begin.

The first row of towers has six locations spaced 137m (450 feet) between towers. The maximum tower height is 12m (40 feet) to accommodate small Wind Turbine Generators (WTG's) of less than 6kW output. The second row of towers is 213m (700 feet) east of row one and allows for six towers 15-17m (50 to 55 feet) in height and spaced 137m (450 feet) apart. WTG's for these towers are limited to approximately 11m (35 feet) diameter. The third row has space for five towers 274m (900 feet) apart. Heights are currently planned in the 20 to 21m (65 to 70 feet) range. The

Figure 2.2.2 Test Center Site Plan

fourth row has space for four towers and the fifth row only two. Tower heights are to be determined as larger WTG's become available.

Two 40 meter meteorological towers were part of the initial plan with one located just west of the north end of row one and the other between row one and two near the south end of the rows. These towers and their instrumentation are discussed in detail in a later section.

Two trailers housing the data collection system and offices are located near the north end of row two. Electric utility power is brought in underground to these two trailers.

The initial construction projects were aimed at establishing the site to allow shakedown testing of the available machines. This was accomplished by awarding contracts for the two meteorological towers, fabricating and installing a 15m (50 foot) folding tower, installing five WTG towers, and drilling a demonstration water well.

2.2.3 Tower Erection

A contract for the installation of the two 40 meter meteorological towers (WCT1 and WCT2) was awarded in July and completed in December 1976. WCT1 is instrumented at the 10 and 40m levels with wind speed, wind direction and temperature sensors. WCT2 is instrumented at the 10 and 40 meter levels with wind speed and wind direction sensors only.

The first WTG tower to be installed at the site was a steel tower at location 2.1 (see Fig. 2.2.3). This tower pivots near its center allowing the WTG to be brought down to a service platform for maintenance. This tower is 17m (55 feet) high and the installation was completed in November 1976.

A contract was awarded in July 1976 for the installation of six WTG towers and completed in January 1977. These towers were placed at

locations 1.1, 1.4, 2.2, 2.3, 2.4 and 2.6. An instrument shed was also placed at each of the twelve tower locations in rows one and two.

In March of 1977 another contract was awarded for the installation of five more towers. These were located at 1.2, 1.3, 1.5, 1.6 and 2.5.

Figure 2.2.3 shows the following towers in place:

Location

- 1.1 A self-supporting 12m (40 foot) Dunlite three leg truss tower.
- 1.2 An Aeromotor 12m (40 feet) truss tower with 4 legs. This is the standard tower built for a 5m (16 foot) Aeromotor water pumping wind mill.
- 1.3 A 12m (40 foot) Octahedron self-supporting tower. Adapters were also purchased to allow installation of Jacobs, Elektro 6kW or Kedco 1200 WTG's on the Octohedron tower.
- 1.4 A 12m (40 foot) hollow spun cast reinforced concrete tower (self-supporting).
- 1.5 Foundation and guy anchors were installed to accommodate either a Rohn 25G or Rohn 45G guyed tower. The Rohn 25G was installed.
- 1.6 A standard power line wood pole in a concrete base. A top collar with flange was bolted and epoxied to the top of this 12m (40 foot) pole. The pole is guyed.
- 2.2 This tower is similar to that in position 1.4 but is 15m (50 feet) high.

- 2.3 A Rohn SSV self-supporting tower. It consists of two 6m (20 foot) sections (8NH and 7NH). A 35mm (1-3/8") plate is bolted to the top section allowing adaptation to different pole configuration to extend the height up to 17m (55 ft). This tower can withstand a 31KN (7000 pound) thrust at the 17m (55 foot) level.
- 2.4 The tower is a standard Rohn 80 guyed tower. The height is 12m (40 feet) with three guys attached at the 12m level. A top plate on this tower allows for adaptation to several configurations in order to install different WTGs. This tower is able to withstand a 31KN (7000 pound) thrust at the 17m (55 foot) level.
- 2.5 A 17m (55 feet), 12 sided steel post. It is a standard high tension power pole without the crossarms. The pole has lugs for guying if necessary and can withstand a thrust of 31KN (7000 pounds) with a minimum deflection of 2-1/2 percent of the pole length.
- 2.6 A Rohn SSV self-supporting tower 12m (40 feet) high. It consists of two 6m (20 ft) sections (7NW and 6NW). This tower is similar to that at location 2.3 except it is smaller in size. It also is adaptable to extensions to bring its height to 17m (55 feet) and can withstand a 31KN (7000 pound) thrust.
- 3.1 A tower to be installed in early 1978 will be used as a test stand. The tower comes in 5m (15 foot) sections and is pumped up by air and locked in place. Its extended height is 21m (70 feet) and its minimum lowered height is 2.6m (8 feet). This tower can withstand a maximum thrust of 25KN (5,500 pounds) at the top.

Rohn 80G (40 ft.)

Steel Post (55 ft.)

Rohn SSV (40 ft.)

Figure 2.2.3 WTG Towers

Folding Tower (55 ft.)

Hollow Cast Concrete (55 ft.)

Rohn SSV (40 ft.)

Figure 2.2.3 WTG Towers (continued)

Hollow Cast Concrete (40 ft.)

Rohn 25G (40 ft.)

Wood Pole (40 ft.)

Figure 2.2.3 WTG Towers (continued)

Dunlite (40 ft.)

Octahedral (40 ft.)

Aeromotor (40 ft.)

Figure 2.2.3 WTG Towers (continued)

All towers have an R. M. Young Propvane anemometer mounted on the end of a boom projected westward (into the prevailing wind) from a point near the top of the tower. This makes it possible to measure windspeed and direction near the rotor of each machine.

2.2.4 Machine Installation

The wind turbine generators which have been installed are shown in Figure 2.2.4.

The Aerowatt was installed on the swing tower (location 2.1) the first week in December 1976. The Dunlite was installed at location 1.1 in January. Its blades were installed early in February 1977.

The Grumman Windstream 25 (Loc. 2.2), Kedco 1200 (Loc. 1.4), Elektro (Loc. 2.4) and Jacobs (Loc. 2.6) were installed the first two weeks in February.

The small Zephyr Tetrahelix WTG was installed in June. This was installed on WCT1 meteorological tower for charging its data logger batteries.

The Zephyr was installed at location 2.3 in August and the Sencenbaugh at location 1.5 in September.

At year end, two WTG's had been delivered but not installed. An Amerenalt is to be installed at location 1.2 and the 5m (16 foot) blade diameter American Wind Turbine is to be installed at location 2.5.

A Pinson Cycloturbine was on order and will be installed at location 2.6. The Jacobs will then be moved to location 1.3.

Aerowatt (4.1 kW)

Grumman (15 kW)

Zephyr (15 kW)

Electro (6 kW)

Dunlite (2 kW)

Kedco (1.2 kW)

Figure 2.2.4 WTG Photographs

Jacobs (3 kW)

Sencenbaugh (1 kW)

Tetrahelix

Figure 2.2.4 WTG Photographs (continued)

2.2.5 Data Acquisition System

2.2.5.1 Overview

The data collection system at the Small Wind Systems Test Center is being designed to simultaneously collect data on all WTG's. The data will be consolidated onto magnetic tape for future analysis. Also, data are similarly collected from the Meteorological Data Collection System.

The two types of WTG data which will be collected are: Long Term test data, and Intensive test data.

Long term testing will include continuous monitoring of power and performance related variables, including wind speed and direction and WTG voltage, current, yaw angle and rotor RPM. The data will be recorded at one second or greater intervals. Intensive test data will be related to dynamic performance, such as vibrations and response to gustiness. The exact data elements will vary from WTG to WTG and from test to test. Intensive data will be sampled at a much higher rate than used in Long Term testing, but over a period of hours, rather than days and months.

Figure 2.2.5 shows schematically the configuration of the data collection hardware. Microprocessors, one at each WTG, will monitor the long term data and convert the analog signals to digital values. The microprocessors also can control the load on the WTG using a multi-resistor load bank. At regular intervals the Nova computer will poll each microprocessor. The data will then be transmitted to the Nova, and copied onto magnetic tape.

For intensive testing, the Neff A/D Converter/Signal Conditioner will be physically moved to the WTG being tested, and connected to the appropriate transducers. The Nova computer will control the Neff A/D converter using the same data bus (but different lines) used to interrogate the microprocessors.

Figure 2.2.5 Schematic of the Test Center Data Acquisition System

A Telemetry System will be used to collect data from the rotating components of WTGs which cannot be equipped with slip rings.

Eight Digital to Analog Converters will be used to drive an 8-channel strip chart recorder to display selected data, either before or after analysis.

2.2.5.2 Components

The Computer is a Data General Nova 3/12. Presently it has 32K words of memory; another 32K is on order and is scheduled for shipment on November 9, 1977.

Peripherals include a 10 million byte disk drive, two 9 track, 800 bpi, 75 ips tape drives, a paper tape reader, a Tektronics 4012 graphics cathode ray tube display with hard copy printer and a teletype. Digital Input/ Output boards are used to communicate with the microprocessors and telemetry system.

The microprocessors are Control Logic M series, which use the Intel 8080 microprocessor. Each one has 2K bytes Programmable Read-Only Memory and 4K bytes Random Access Memory. A 16-channel Analog/Digital converter and digital I/O boards make up the peripherals.

Five main packages are to make up the software for the SWECS Test Center. They are:

- 1) Long Term Data Collection
- 2) Intensive Data Collection
- 3) Microprocessor Collection and Load Control
- 4) Long Term Data Analysis
- 5) Intensive Data Analysis

The Long Term Data Collection Software will act as the main controller for itself and the intensive data collection package. Its primary function, however is to poll the microprocessors at regular intervals to obtain their data, and write it on magnetic tape. The current status of each microprocessor (e.g. running, polling freq., load control method, etc.) will be maintained in a status table.

The Intensive Data Collection Software will communicate with the Neff A/D converter and the telemetry system. It uses a dynamic-polling-frequency technique which allows adjusting the frequency at which each data element is sampled. To reduce the amount of data saved on magnetic tape, some elements need not be sampled as rapidly as others. For example, a channel measuring a vibration must be sampled much faster than one measuring a temperature, because the period of the vibration might be measured in milliseconds, whereas the period of the temperature might be minutes or hours.

The microprocessors will be programmed to convert the several analog channels into digital data as rapidly as possible. These values will be summed until the Nova requests the micro's data, at which time the average is computed and sent to the Nova.

Several load control algorithms can be stored in each microprocessor, and can be switched upon command from the Nova, to simulate different WTG loading conditions.

The data collected by the long term data collection system will be analyzed using several statistical techniques, the two most popular of which are known as the Method of Rins and Frequency Matching. Others may be developed as a better understanding of the data is gained. The results that are obtained from these analyses will be plotted to correlate parameters such as:

- 1) Power vs. wind velocity.
- 2) Coefficient of power vs. tip speed ratio.
- 3) The variance in the data used to determine these curves.

The exact techniques for analyzing intensive test data have not yet been established. Relationships of interest, which we should be able to extract from these data include:

- 1) Effect of tower shadow on blade vibration and stress.
- 2) Response of the pitch control mechanism to gusts and/or loading.
- 3) Resonant frequencies of WTG and tower components and combinations.

2.2.5.4 Status

Following is a summary of the status of each of the above described items.

Many operational problems have been encountered in operating the computer which have delayed the test schedule approximately three months.

Several mechanical fixes have occurred. On October 12, 1977, loose wires were repaired in a connector in the disk, and no serious problems have been experienced since. An earlier, documented problem with the Data General operating system was corrected by Data General. Microprocessors have been installed at 7 WTG towers, and installation is proceeding at 3 more. Resistive load banks and solid state switches have been installed at the same 7 WTG towers where microprocessors are installed.

The Neff A/D converter and signal conditioner has been received. Its installation awaits the writing of software to control it. Present schedule calls for installation by 23 November, 77. The telemetry system is due at Rocky Flats on 11 Nov., 1977.

The hardware for the analog display system is on hand and is scheduled to be rackmounted by 24 Oct.

The long term data collection software is about 50% complete and is scheduled to be operational by Nov. 17. Intensive Data Collection Software is about 40% complete. Further progress must await completion of the Long Term Software. Intensive testing software completion is scheduled for Dec. 31, 1977.

The microprocessor and load control software is about 70% complete. Its final debugging awaits progress on Long Term Testing Software. Its completion is scheduled for Nov. 30.

Long Term Data Analysis software is about 60% complete. Completion is scheduled for Nov. 12.

Intensive data analysis software has not been started. Completion of the first generation is scheduled for March 13, 1978.

2.2.5.5 Data Acquisition System

In order to obtain some meaningful data before the sophisticated computer-controlled system is operational, an interim system has been installed. An Esterline Angus Programmable Data Logger with magnetic tape output has been connected to the data bus, which has in turn been directly connected to transducers at several WTG's.

Some data have been collected but this system suffers from the noise problem inherent in all analog systems with long lines. Efforts are underway to eliminate or reduce the noise to acceptable levels, which will benefit the use of the data bus when it is converted back to digital transmission.

Programs already written to analyze Long Term Data are being modified to accept the data from the data logger. First analysis, using Method of Bins, is scheduled for Oct. 25, 1977.

2.2.5.6 Vidar Data Acquisition

A Vidar scanning voltmeter with paper tape output was used to collect data on the Dunlite, Elektro, Grumman and Kedco. A program to analyze and plot the data, using Method of Bins and Frequency Matching techniques was written for the plant's IBM 360/65 computer.

The limitation of this system was paper tape capacity. Recording time was limited to approximately 10 minutes, a period too short to obtain statistically meaningful results.

Examination of the ten minute data records revealed the wind does not cover the entire range of the WTG's operating regime. That is, if the average wind is about 20 mph, little or no data are collected at 10 or 30 mph. Thus the middle of the resulting curve may be smooth and statistically significant, but the ends are ragged, and not repeatable. There are no current plans to analyze or report this data because of the shortness of the records that can be obtained.

2.2.6 Meteorological Tower Data System

Two 40 meter meteorological towers have been erected at the test site to provide detailed wind and temperature data. The tower locations are shown in Figure 2.2.2. While the anemometers on the machine towers are used to measure the wind incident on any given WTG, the meteorological towers are used to measure vertical profiles of wind speed and direction and temperature. The system is designed for continuous recording and will be used to provide long term wind statistics for the test site.

At the present time Tower 1 (refer again to Figure 2.2.2) has wind and temperature sensors at the 10 and 40 meter levels. Tower 2 has wind sensors only at the 10 and 40 meter levels. Instruments will also be installed at the 20 and 30 meter levels on Tower 1 during the coming year to give better definition of the vertical structure of the wind at the test site.

The windspeed sensors are Climet cup anemometers with a distance constant less than 2m and accuracy of $\pm 1\%$ or .07 m/s, whichever is greater. The instruments are of the light chopper type and operate from a 12 v battery.

The wind direction sensors are Climet wind vanes with a distance constant less than 1m and a damping ratio of 0.4. They have a DC output proportioned to wind direction (0° to 360° continuous). Air temperature is sensed using a thermistor temperature sensor (Thermistor Composite YSI No. 44018). Accuracy of the complete sensor, interface and ADC card is better than or equal to $\pm 0.3^\circ\text{C}$.

Outputs from the meteorological sensors are sampled by microprocessors at the base of each tower. The microprocessors accumulate average, standard deviation and peak values until they are polled by a radio telemetry unit controlled by the Nova computer. The data are transmitted from the microprocessor to the Nova, converted to engineering units, and recorded on magnetic tape and hard copy printer if desired. The rates at which the sensors are sampled and the microprocessors are polled are controlled by operator command to the Nova computer. The sensor sample rate can be individually specified up to a maximum rate of seven samples/second for each sensor. All towers are polled at the same rate up to a maximum of approximately one polling per minute. At the present time this polling rate is limited by the software rather than hardware. Thus, if necessary, the polling rate can be increased by changing the software package (to suppress hard-copy printing).

To date the meteorological tower system has operated on an intermittent basis only. Difficulties with the Nova system (discussed in Section 2.2.5) have been the major reason the meteorological data system has not operated continuously. Thus a continuous long term record is not yet available from the towers. The instruments have been monitored during downslope wind storms, and the data will be analyzed for peak gust and gust factor information.

2.2.7 Irrigation Project

A 365m (1200 foot) deep well was completed in September of 1977. The well is cased with 17cm (6-5/8 in.) outside diameter pipe to the bottom. An 1100w (1-1/2 HP), 480 v A.C., 3 phase, submersible pump was set at 230m (750 feet). This pump will deliver 30 to 38 ℓ (8 to 10 gallons) of water per minute at the well head.

Near the well a 53m (173 foot) section, raincat center-pivot irrigation sprinkling system was installed in December, 1976. The unit operates on 480 v A.C. and delivers 113 ℓ (30 gallons) per minute at 345KPa (50 psi) pressure through 11 sprinkler heads.

A 12m (38 foot) diameter open stock tank was installed in July which holds 90,000 ℓ (24,000 gallons) of water as a reservoir for the center pivot system. A ground level pump supplies water to the center pivot system from the stock tank.

A large battery storage trailer was installed in September. The batteries are to be charged by the WTG's via a D.C. bus which is tied to each wind generator shed. The storage capacity is 1640 amp hours at 120 volt. The batteries supply DC current to a 10kW motor generator set located next to the battery trailer. The motor generator (MG) then supplies 480 Vac power to the well pump and irrigation system. The M.G. set also has the capability of being operated directly from the larger WTG's.

2.2.8 Consulting Support From Windworks, Inc.

In August, 1976 RF entered into a contract with Windworks, Inc., of Mukwonago, Wisconsin, to provide consulting services. Windworks prepared several suggestions of the scope of their work, and on Feb. 9, 1977, were authorized to proceed with Stage I work entitled "Radial Wind Velocity Profile Determination".

The work included measuring the longitudinal wind velocity near a WTG using an anemometer mounted so it could be moved up and down along a boom behind the wind turbine. A second anemometer was mounted at the top of the boom, at 5m (15 ft) radius, to provide a reference wind velocity. Rocky Flats loaned Windworks a Brush 8-channel Strip Chart Recorder to facilitate their data collection.

A second stage of study was subsequently authorized which included mounting two anemometers on booms outside the "affected slipstream" but in the same plane as the WTG rotor. The object was to correlate wind speed with system performance, and to define the existence of "Quasi-steady" conditions.

A report containing the results of both phases of work is contained in Appendix A.

2.3 Test Center Operation (Task II)

2.3.1 Introduction

The main objectives of the test center operations are the following:

- (i) To buy and test WTGs representative of commercially available U. S. machines, and to also test commonly used foreign machines. Test data will be provided to potential buyers to assist their selection/decision process. Data supplied to manufacturers/suppliers will allow improvements in their equipment. Data will also be utilized at RF to establish the current state of the technology (e.g., which components and designs are reliable/efficient and which are not) and to direct planning for subsequent technology development.
- (ii) To provide a test service for organizations to test machines that are not commercially available or which have not been selected for test under (i) above. This service will be provided, at cost, to organizations as RF resources and scheduling allow.

During FY 1977, emphasis was placed on completing the design of the test program, instrumenting the operating WTG's and collecting preliminary performance data on four WTG's.

The computer data acquisition system is not yet operating and the interim data logger results have not yet been calculated and compiled. Therefore, test results to date are in the form of qualitative observations of machine behavior and detection of the many "bugs" inherent in these new systems. The significance of these "bugs" cannot be ignored, either in the time and attention required of Rocky Flats personnel in curing them

or in the level of frustration and disappointment they would present to a consumer. Detailed descriptions of the problems encountered with the test machines are presented in this section. RF personnel have already had lengthy and productive interactions with manufacturers to solve many of the problems.

As discussed briefly in the previous section, there are two types of testing planned at Rocky Flats. First is the "long term" test program and second is the "Intensive Testing Program".

The major products of the long term testing program will be as follows (for each WTG tested):

- (1) Performance data
- (2) Reliability data

Additional (possibly more important) products will be the detection of potentially weak areas in the over-all systems, e.g. structural weaknesses, control weaknesses, etc. This information will provide basic performance data of interest to users and a basis for the "Intensive Testing Program"

Under the long term program the following procedure is followed:

- (1) WTG assembly, during which the assembly manual is evaluated
- (2) Erection and electrical hookup as described and recommended in WTG manual.
- (3) Data collection of the following parameters
 - a) Free stream wind velocity using a R. M. Young model 8002 propvane anemometer.

- b) Free stream wind direction using a R. M. Young model 8002 propvane direction indicator.
- c) WTG rotor speed using a "No Slip" positive drive system and a Servo-Tek tachometer, model SB-757A-2.
- d) Rotor yaw angle using a positive drive system and a precision potentiometer.

The yaw angle of the rotor with respect to the wind direction is important to performance measurement since some WTG's rely on control of this angle to control the rotor speed.

WTG's chosen by the R. F. test personnel will be subjected to more in-depth testing where the following parameters might be studied.

- a) Maximum power generated using "optimum loading"
- b) Vibration monitoring and identification
- c) Pitch system operation and optimization (some machines may produce more power with "tuning" of the pitch system).
- d) WTG response to wind gusts.
- e) Any potential weak link in the overall system.

This information should aid the manufacturer in establishing a lower cost, more reliable system.

2.3.2 Test Center Activity and Machine Experience

In this section a brief description of WTG's operating at RF and experience with each system will be described. The support structures (towers) are described in the "Test Center Establishment" section of this report.

(1) Aerowatt

rated power	-	4.1 kw @ 7.5 m/sec
diameter		9.2 m (30 ft 2 in)
blades		Two, Constant Chord, Zero Twist. Aluminum.
orientation	-	Upwind
control	-	Synchronous Centrifugal blade pitch
test site		
position	-	2.1

This machine was erected on December 1, 1976. It had operated without problems for approximately three months when on February 22, 1977, it failed (for details see the Aerowatt Failure Report in Appendix B). While operating, the WTG maintained a constant 50 Hz output with high precision.

Since the Aerowatt was operated so briefly at Rocky Flats test, experience is limited. However, a report on the operating characteristics of the machine has been published by the NASA Lewis Research Center (reference "Installation and Initial Operation of a 4100 watt Wind Turbine" by Henry B. Tryon and Timothy Richards, Lewis Research Center, Cleveland, Ohio 44135, December 1975, Report #NASA TMX-71831.)

(2) Dunlite

rated power	-	2 KW @ 11.2 m/sec
diameter	-	4.1 meters
Blades	-	Three, twisted, constant chord, sheet metal
orientation	-	Upwind rotor
Control	-	Centrifugal blade pitch
Test site		
position	-	1.1

The Dunlite was erected on January 21, 1977. It was operated intermittently, for approximately four months, until all the electrical connections were completed. The machine has operated continuously since May 25, 1977.

Only limited performance data have been collected since the data collection systems have not been completed. The obvious observations about the machine are that it starts in a low wind speed (approximately 2.7 m/sec) and will operate in the highest wind speeds encountered at RF since June 8, 1977 (approximately 40 m/sec). Maintenance repair has been limited to replacing the tail vane which cracked.

(3) Kedco

Rated power	-	1.2 kw @ 9.8 m/sec
diameter	-	3.65 m
blades	-	three, tapered & twisted, sheet aluminum
orientation	-	downwind rotor
control	-	centrifugal blade pitch
test site		
position	-	2.4

Operation of the Kedco WTG has been plagued by numerous small problems caused both by design deficiencies and RF installation errors. Breakage of a feathering cable resulted in a runaway condition and damage to the WTG. A replacement machine has also broken the feathering cable and has been sent to the factory for retrofitting of a new feathering control system. A detailed narrative of the experiences with the Kedco is given in the following paragraphs.

The Kedco was erected on February 10, 1977. During February, the feathering cables were difficult to operate and the blades tend to go into stall when the running mode cable was activated, e.g., they would

go into a 0° attitude instead of the 22° which is its approximate running mode. The feathering trigger assembly, which has attached to it the vibration sensing lead weight and feathering control roller bearing, was inspected and found to be bent. This caused the difficulty in activating the feathering cable. The trigger rod was straightened and remounted on the wind generator. The blade stall problem was corrected by repositioning the hub assembly on its shaft. While the wind was averaging 28 mph and was peaking to 47 mph, the trigger cocking cable was pulled allowing the blades to rotate into their run position. The blades rotated for approximately 30 seconds when the feathering cable broke and wrapped around the feathering trigger shaft. At this point, the machine was in a runaway mode that lasted approximately two minutes. A large amount of vibration was observed. The machine then feathered automatically. The blade counter weights were found to be bent parallel to the blade shafts.

A new Kedco unit was subsequently received from the supplier. Instrumentation (tachometer and yaw transducer) was installed and the machine was reinstalled on tower 1.4.

During subsequent checkout operations, the manual feathering cable was again broken. The machine was taken down to repair the problem and Kedco, Inc. was contacted. Per Kedco's recommendation, the WTG has been returned to the factory for replacing a bearing and to incorporate improved feathering and transmission mechanisms which are now incorporated in production models.

(4) Grumman

Rated power	-	15 kw @ 11.6 m/sec
diameter	-	6 meter
blades	-	Three constant chord zero twist, extruded Aluminum
Orientation	-	downwind rotor

Control	-	microprocesor/servo blade pitch
Test site location	-	2.2

The Grumman Windstream 25 at Rocky Flats was the first unit produced by Grumman and as such has had some prototype design deficiencies which may not be present in subsequent machines. The machine was stiff in yaw and the pitch control system failed when slipping brushes were burned out. The machine is being shipped to Grumman for replacement with a new machine incorporating many changes to eliminate the problems detected at Rocky Flats and in other installations. A detailed chronological narrative of the RF experiences with the Grumman Windstream is given in the following paragraphs.

The Grumman was erected on February 4, 1977, however the electrical equipment located in the control shed, necessary to operate the WTG, was not completed until April 1.

During operation, the following problems were noted:

- (1) at low wind speeds, the machine would not yaw to orient with the wind direction and sometimes rotated backwards and/or with the blades upwind.
- (2) at low rpms (below 30 rpm), grating noise was detected in one blade which stopped at higher angular velocities.
- (3) The gear box noise seemed excessive.

The Grumman was removed from its tower on June 10, 1977. Grumman installed larger hub bolts and a new pitch control board. A new yaw bearing was installed by RF to allow the machine to yaw more freely. Extensive instrumentation was also installed.

Inspection of the blades indicated no reason for the noise previously referred to. One possible explanation is that there may have been enough play at the blade-hub interface to have allowed the blade to shift back and forth during rotation. The gearbox oil was changed to a Mobil Synthetic (SHC 629) 90W oil.

The Grumman was reinstalled on August 16. The pitch control system was checked out and seemed to operate properly. However, four days later the pitch control system would not respond to manual controls, nor would it operate properly under automatic control. After correspondence with Grumman the problem was determined to be in the pitch control slipping assembly. Two of the power transmission brushes were burned out, possibly caused by a malfunctioning limit switch in the pitching servo.

It was decided by Grumman and Rocky Flats, to replace this machine with a newer model of the same type for the following reasons:

- (1) This machine was the first one made, a prototype, with many typical prototype problems.
- (2) New innovations incorporated in the more recently manufactured Windstreams made this one obsolete.

The Windstream has been removed from the test site and is being returned to Grumman.

(5) Jacobs

Rated power	-	3.0 KW @ 9.8 m/sec
diameter	-	4.1 meters (13.6 feet)
Blades	-	Three-twisted, tapered, fiberglass covered wood
Orientation	-	Upwind rotor

Control - Centrifugal blade pitch and
manual tail feather
Test location - 2.6

The reconditioned Jacobs was erected February 18, 1977. Final electrical hook-up was completed two days later and was operated without load for a short time.

On February 22, during a wind storm averaging 38 mph and peaking to 52 mph, one blade on the Jacobs came off its shaft. One of the tail rails was also slightly bent. The Jacobs was operating under no load at the time of the failure. The sequence of events appeared to have been as follows: The knuckle-joint rod on one of the blades, which both holds the blade and allows it to rotate between the run and feather modes, had pulled out of its hub socket. The rod is held in the socket with an allen set screw with only a friction hold. The rod was subsequently found to be manufactured of extremely hard steel compared to the allen set screw. The blade then flew away from the hub with enough centrifugal force to overextend the blade retention spring. The spring remained distended and the blade remained attached to the hub via this spring. The excess vibration caused by the loose blade may have caused a link in the tail chain to break. It was found that the tail stop chain had been improperly installed on the wrong side of the chain yoke. (Installation directions do not state the side which should be used.) This incorrect installation may have caused the tail rail to bend. The exact cause cannot be determined. The tower casting broke either during the high vibration period or after the tail chain broke, which caused the tail to fold very fast. One of the tail rails was also slightly bent. North Wind Power Company representatives participated in March in the analysis of the failed components and supplied replacement parts. The Jacobs was reinstalled on tower 2.6 on May 4, 1977. With a wind of 15 mph, the machine would produce only 6 volts. The Jacobs was removed

from the tower after investigation showed that the field had an open circuit due to a defective solder joint. Repairs were completed and the machine was reinstalled on May 18. Additional work was required to modify the wiring on the machine so that the voltage regulator would function properly. The system was checked when winds were sufficient on May 26.

On June 23, the hub and rotor assembly rotated off the machine. The blades were a total loss, but the hub appeared undamaged. The rotor was turning at less than 100 rpm prior to the incident. On June 29, inspection of the inside of the hub shaft showed that the woodruff key groove had not been bored deep enough in the hub and there was a distinct mark at the end of the key groove. As the hub nut was tightened, it locked the hub against the woodruff key and not against the tapered generator shaft. A new hub and three blades arrived on July 21. The new hub was an exact duplicate of the first hub. A call to Northwind confirmed that the key way in the hub was not deep enough. A new key way was bored from front to back in the hub, approximately 30° away from original key way. The hub and blades were placed on the Jacobs on July 26. On July 27, the control box was removed for repairs. The field circuit was not being controlled properly, and a failed transistor was replaced. On July 28, the control box voltage regulator section was inoperative. A blown fuse was replaced, but the control box would operate only in the "Regulator Off" mode. In this mode, the field is shorted to the negative terminal, which puts on the full field and the generator will put out 200 volts or more). The control box was removed again for repairs.

A new control box was purchased from North Wind and installed on September 20. It was found that the voltage was regulated properly whenever the machine is loaded. If no load is applied a high voltage is developed. The Jacobs has been operating continuously since the correction of this last problem.

(6) Elektro 6

Rated power	-	6 KW @ 11.6 m/sec
Blade diameter	-	5 m
Blades	-	Three-twisted, constant chord, wood
Orientation	-	Upwind rotor
Control	-	Centrifugal blade pitch and automatic tail feather
Test site location	-	2.4

The Swiss made Elektro 6 was erected on January 21, 1977. A representative of Enertech Corporation arrived on March 1, to inspect the Dunlite and the Elektro. It was found the Elektro would not operate without 110V battery banks since the tail motor was a 110V motor instead of the 24V motor originally indicated on the prints. A 110V battery bank was connected temporarily, and the tail cable motor operated properly. The system seemed ready, but there was no wind. The Elektro was allowed to run on the morning of March 3, charging batteries at 8 amps. At approximately 2:30 p.m. the tail motor override was operated, resulting in damage of the screw shaft. The tower retaining nut of the screw shaft unscrewed and fell to the ground. The spot weld also broke, as well as the crank nut.

The initial observation was that the screw shaft bent, gouging the threads. The fix was to repair the shaft and to install it with extra set screws. On March 10 the control box was reinstalled and operated twice prior to hookup to the tail cable. After hooking up the tail cable, the machine was allowed to run for approximately 10 minutes. The wind was peaking to 30 mph, and the control box was registering 32 amps. The batteries were fully charged. The control box evidently sensed the

high amperage and commanded the tail motor to pull the tail in approximately 45° . The tail motor actuated, but the control box failed to command it to stop, and about six inches of threads were stripped from the screw shaft. The tail control box was shipped back to the distributor. A new control box was received on April 1 and was installed on April 4.

Adjustments were made on the tail motor to ensure proper operation of the tail chain. In light winds of 8-13 mph the tail was rotated to the "start" position. Unfortunately on April 26, the tail assembly worm gear stripped again. To permit continued testing of the remainder of the system Rockwell maintenance personnel then machined another gear of larger diameter bar stock with American threads. This worm gear was installed and the system has subsequently worked well.

During June-July the Elektro was run intermittently because its battery bank was small and the Elektro charges the batteries at excessive rates. Since a larger battery bank has been installed, the Elektro has run continuously.

The machine will be taken down during November to receive the standard instrumentation. Until that date only partial data collection will occur.

(7) Zephyr

Rated power	-	15 kw @ 15.6 m/sec
Blade diameter	-	6.1 m
Blades	-	Three-twisted, tapered Kevlar covered foam
Orientation	-	Downwind rotor
Control	-	Yaw position automatic
Test site		
Location	-	2.3

The Zephyr was erected on August 25, 1977 and the electrical hook-ups completed on September 8. At that time the machine was operated briefly. During this brief test a rectifier in the load control circuit was blown. Also, a number of vibrations were noticed during the test. Willard Gillette of Zephyr feels that the major once-per-revolution vibration was due to unbalanced aerodynamic loads on the blades. Other vibrations are expected and due to the nature of the generator.

Willard Gillette also suggested that the machine be loaded with resistors using the AC output rather than the present DC rectification and resistance loading.

To correct the aerodynamic imbalance problem the blade loads will be measured using strain gages. Then the blade pitch angles will be adjusted to balance those loads.

The machine was taken down on October 17, to install this instrumentation.

(8) Sencenbaugh

Rated power	-	1.0 kw @ 8.9 m/s
blade diameter	-	3.7 m
Blades	-	3 twisted & tapered wood
Orientation	-	Upwind rotor
Control	-	Thrust activated yaw
Test site		
Location	-	1.6

The Sencenbaugh was erected on September 22, 1977. The electrical hook-up was completed on October 7, and the machine has been operating continuously since that date. No significant test experience has been accumulated at Rocky Flats on the Sencenbaugh WTG.

2.4 Technology Development (Task IV)

2.4.1 Objective

A principal thrust of the RF program is development of the technology required to reduce wind-produced energy costs and to improve SWECS performance/reliability. This is a broad and encompassing task and involves a wide variety of subtasks.

Before describing the development subtasks in process, the following point should be noted. Performance improvement is not a goal in itself. The "fuel" for wind machines is free. Wind-generated power costs derive from obtaining and maintaining the hardware. With the goal of minimizing per-unit energy costs, it is conceivable that low cost, low(er)-technology machines could be preferable to more sophisticated high-technology ones. In some instances, comparatively high costs for wind power may still be competitive with conventional fuel sources. Remote mountain or sea locations are examples where these conditions might apply, and in these instances, a premium might be placed on performance and reliability, rather than minimum power cost.

A comprehensive technology development plan must therefore address all significant applications, and consider both "high" and "low" technology machines. The RF program currently accomplishes this by development of a wide variety of machines for a variety of high-potential applications.

2.4.2 High-Reliability, 8kW and 40kW WTG Development

Based on a survey of commercially available SWECS*, data on irrigation requirements**, and estimates of residential and remote application

*For description see Section 2.6, Guide to Commercially Available Wind Energy Conversion Systems, of this report.

**Communication from USDA-ARS research center, Bushland, TX.

power requirements*, a need was identified for three types and sizes of wind energy conversion systems. Hence, efforts have concentrated on initiating development programs for 8kW, 40kW and High-Reliability systems. Results from activities in these programs will be used to plan future development activities, such as design of specific system components, or entirely new SWECS of other sizes.

There are many similarities between the development programs for the 8kW, 40kW and High-Reliability systems. The following sections describe each of these three programs in more detail.

An announcement of intention to issue Request For Proposals was published in the February 17, 1977, issue of "Commerce Business Daily" (CBD). All three programs were briefly described, but because of a printing error, a corrected announcement was re-published in the March 2, issue. Because it was felt that many individuals, organizations or companies who could be interested in submitting proposals might not be familiar with CBD, a letter announcement was also mailed out. This letter included a slightly expanded description of all three programs, and was sent to names on a list obtained from the American Wind Energy Association.

Each program is structured as a two-phase effort. Phase I consists of design and analysis of the system, including estimates of what production cost would be in quantities of 1000 per year. Numerous analyses and trade-offs shall be used to select the design, that will best meet the program goals. During Phase II, a prototype of the system designed in Phase I will be built and shipped to the Rocky Flats Test Center for testing and evaluation. Final drawings of the system as well as an updated estimate of production costs will also be provided.

Multiple awards are planned for all three programs. One of each of the 8kW and 1kW High-Reliability awards is set aside for small businesses.

*Input from consultation with U. S. Coast Guard, U. S. Air Force, U. S. Navy.

During FY1977, one contract was awarded - an 8kW program to Windworks Inc. of Mukwonago, Wisconsin. Additional 8kW contracts as well as those for the 40kW and 1kW High-Reliability programs are still being negotiated.

2.4.2.1 40kW WTG Development Program

A WTG with an output of 40kW appears adequate to meet a number of application requirements. For example, in the high plains region of Texas alone, there are approximately 85,000 water pumping systems used for irrigation*. Approximately 92% of these operate in wells, with lifts predominantly between 125 and 400 ft. From 93 to 98% of the energy used to pump this water is from natural gas, fueling internal combustion engines operating at constant speed and connected through a mechanical drive to turbine pumps. There are two problems being encountered by owners of these pumping systems. First, the natural gas used is unregulated intra-state gas, with prices ranging to over \$2.00 per thousand cubic feet. Second, the water table is dropping from 1 to 4 feet per year, which means more energy is required each year to pump the same quantity of water. Both this region of Texas and other areas using a high level of irrigation lie in a portion of the United States which is comparatively "rich" in wind energy resources. Therefore the possibility exists for utilizing the wind as an alternative energy source for water pumping applications. It has been estimated that 40kW of power would suffice for approximately 50% of the installations just described**. A WTG with mechanical power output would allow tie-in with existing systems, allowing wind power to supplement the internal combustion engines.

*All irrigation data obtained from "1976 Pump Irrigation Energy Survey" published by the Texas Department of Agriculture, John C. White, Commissioner.

**Personal communication from Dr. R. N. Clark, USDA-ARS Research Center, Bushland, TX.

Other potential applications for a 40kW size WTG, but with electrical power output, might lie in small remote villages or industries, such as can be found in Alaska*. Such a machine could also meet the power needs of a number of homes, or, if a number of machines were interconnected into a small independent utility grid, provide the energy needs of isolated communities in the mountains, on islands, or along coastal regions. In addition, a 40kW electrical output WTG, like its counterpart with mechanical output, could be used in water pumping and irrigation applications.

Aside from literature which has been distributed by a foreign WTG manufacturer for a 55kW electrical output machine**, no information is available on a SWECS in this size range. Other WTGs commercially available have outputs under 15kW and costs ranging upwards from \$1000/kW for a complete system, with \$3000/kW to \$7000/kW [based on power output in a 9 m/s (20 mph) wind] being typical.

As a result of the identified potential need for a 40kW WTG system, and the high cost of wind power (compared to conventional energy sources at 1977 prices), the decision was made to fund development of such a system, with potential for low cost production in large quantities being a prime goal of the design. The system specifications are listed in Table 2.4.1.

*Personal communication from W. C. McConkey, Dept. Commerce & Economic Development, State of Alaska, Anchorage, AK.

**NOAH Energie Systeme GMPH, Bonn, Germany.

TABLE 2.4.1
40kW WTG SPECIFICATIONS

Item	Electrical	Mechanical
<u>Output</u>		
Power Mode	40kW minimum in 9 m/s wind 60 Hz	same Horizontal shaft at constant speed: 440, 880 or 1760 RPM.
Options	1. 3 phase, 480 volt + 5% for tie-in with utility grid 2. 3 phase, 480 volt + 5% for stand-alone operation 3. 3 phase, 240 volt + 5% for stand-alone operation 4. 3 phase, 480 volt + 5% for tie-in of two or more WTGs.	Shaft speed to vary no more than + 1% for windspeed of 9 m/s
<u>Wind Range</u>		
Cut-in	Minimize with respect to economics of power production and system cost.	
Cut-out	27 m/s (60 mph) minimum. Selection of a lower speed to better meet program objectives to be justified.	
Peak gust protection	56 m/s (125 mph) minimum with a 1.5 safety factor.	
<u>Controls</u>		
Start/Stop	Automatic	
Braking/control	Automatic for rotor overspeed; back-up mechanical brake.	
Operation	Automatic cut-in and cut-out.	
Output	As required to provide proper power mode.	
<u>Environment</u>		
Basic Machine	-40°C to + 60°C (-40°F to + 140°F), icing, hail, lightning, dust, coastal environment.	
Special Machines	Arctic (lower temp. limit -51°C (-60°F), heavy icing, direct salt spray, severe dust-sand conditions	

TABLE 2.4.1 (Continued)

Cost Goal

Basic Machines (including tower) not including foundations or installation	\$500/kW, based on output in a 9 m/s wind, for production of 1000 units per year
Special Machines	Plus specific costs related to machine configuration changes.

The rated windspeed of 9 m/s (20 mph) was chosen as a compromise between that windspeed which a good site might experience during a large percentage of the year (say 70% of the time) and a higher windspeed, typical of that which currently available machines are rated at, but which might be attained only 20% or less of the time during a year. For a WTG system with high efficiency, a rotor diameter of approximately 18m (59 ft) would be required for 40kW output in a 9 m/s wind. This is an increase in rotor diameter by a factor of approximately 2, over rotors on current WTGs, and was felt to represent a reasonable size increase in the state-of-the-art in blade manufacture.

To minimize the cost of produced energy, the WTG should extract power over as wide a range of windspeeds as possible. At many locations in the plains region of the United States, winds up to (and occasionally over) 125 mph occur often enough that any machine installed in this geographic area could expect to experience them numerous times within its lifetime. Also, temperature and other environmental extremes (sand, salt spray, ice, etc.) will vary depending on location of the installation. Therefore, a basic design was specified, with modifications being specified when the machine would be used in severe climates of one kind or another.

Two different WTG designs, for electrical and mechanical power output, were requested. The electrical applications fall into three basic categories:

- 1) Tie-in with an existing utility grid
- 2) Stand-alone operation
- 3) Interconnection of two or more WTGs to establish a small independent utility grid.

All the requisite hardware is to be designed for each of these applications.

The mechanical system was to provide a constant speed output at either 440, 880 or 1760 RPM. Turbine well pumps operate at 1760 RPM, and thus the WTG output would be easily connected to the existing mechanical system.

Future programs for possibly procuring a number of pre-production units are being considered, with the goal of establishing field evaluation of the WTG in various wind regimes on a number of applications.

2.4.2.2 8kW System for Residential Use

On February 24, 1977 an announcement was sent to Commerce Business Daily asking for written expressions of interest in a Request For Proposals (RFP) dealing with the technical development of an 8kW wind system.

About 220 respondents indicated in writing that they would like to receive a copy of the RFP. Of these original inquiries, 21 followed up by submitting a proposal. The closing date for receipt of these proposals was May 9, 1977.

Technical and management reviews of the proposals were presented to a Source Selection Board (SSB). Negotiations were subsequently conducted with Windworks, Inc. and a contract was signed in mid-September. Negotiations were also completed, but no contracts are as yet signed with other companies and contract awards are pending.* A schedule of expected progress is given in Table 2.4.2.

The four competing designs of an 8kW wind system will attempt to produce prototypes capable of full output at 9 m/s (20 mph). They will be designed to withstand, but not supply power, in wind gusts up to 75 m/s (165 mph). Severe environmental conditions will be taken into consideration in the design of these systems so they can survive widespread use. A summary of design requirements is given in Table 2.4.3.

*At the time of printing additional contracts, as noted in the Executive Summary, had been announced.

The primary application for the system will be to supply 120/240 volt, A.C. power needed for residential use. However, the contractors will also design the systems so that this can be used as a stand-alone power supply or be used in conjunction with an isolated power supply such as a diesel-generator.

Above all, the designs will carefully consider the economic aspects of mass production in attempting to produce a system, comprised of wind turbine generator and tower, that can be sold at a price of \$750/kW.

TABLE 2.4.2
SCHEDULE OF EXPECTED PROGRESS
ON 8kW SYSTEMS

Sept. - Nov., 1977	-	Contracts awards.
Jan. - Feb., 1978	-	Preliminary design reviews during which the Contractors designs are critiqued by Rocky Flats personnel.
April - May, 1978	-	Critical design reviews between Contractors and Rocky Flats.
June - July, 1978	-	Final design reviews.
Jan. - Oct., 1979	-	Completed prototype systems are installed at Rocky Flats for field testing.
April, 1980	-	Test results incorporated into Contractor's final reports.

TABLE 2.4.3
TABLE OF DESIGN REQUIREMENTS
FOR 8kW SYSTEM

System Lifetime	-	Service life of at least 25 years with a maximum downtime of 1% for causes other than insufficient wind.
Environmental Extremes	-	System must survive temperatures between -50°C and +60°C, impact from 25mm diameter hail, ice build-up to 60mm, blowing sand, dust and snow, and corrosive industrial and marine atmospheres (smog and salt water spray).
Aesthetics	-	The system must be designed with public acceptance in mind. Attractive appearance and elimination of excessive noise and other detrimental factors will be design considerations.
Maintainability	-	The system design will provide for safe, easy maintenance by allowing ready access to components that require occasional servicing. Applicable safety codes will be followed in the design of electric wiring and enclosures, ladders, hoisting gear, etc.
Availability of Parts	-	To the greatest extent possible, the design will use commercially available parts, especially in those components where periodic replacement may be required.

System Controls

- Reliable, automatic devices will control system start-up, normal running and shut-down. For those periods when maintenance is necessary, a positive braking system will be provided.

Manufacturability

- The design will give strong consideration to high volume production requirements. Selection of materials for construction will be given careful attention as they affect the cost, availability, expected lifetime, ease of fabrication, freedom from maintenance, strength, weight, appearance, etc.

2.4.2.3 1kW High Reliability WTG Development Program

An increasing number of applications for small wind energy systems involve rural and remote needs. Examples of such applications are power for remote communications repeater stations, galvanic protection to buried pipelines, remote seismic monitoring stations, pumping water into remote stock watering tanks (and also power for deicing the tanks in winter), and off-shore navigational aids. A system with an electrical output of about 1kW would meet the requirements for most of these applications, provided the system could operate reliably over a wide range of geographic locations*.

The requirements on a wind energy conversion system in a remote or rural location can vary substantially from those in a residential or industrial location.

In a typical remote application, the costs of traveling to the site and performance of necessary maintenance might equal or exceed the total system cost. Therefore, it is extremely important that the system generate the power reliably under extreme weather conditions in order to be cost-effective. To simplify transport and installation of the system, components and/or subsystems should be light and easy to assemble. Once the Wind Turbine Generator (WTG) is installed and operational, routine maintenance would be required on the order of once per year. Since some failures might occur, the system will be designed for ease of repair. Because of the needs for high reliability and minimal maintenance, a rugged but simple design is desired.

As a result of the possible applications identified for a 1kW High-Reliability System in rural and remote areas, the decision was made to fund development of such a system. The system specifications are listed in Table 2.4.4.

*Communications with and input from Air Force, Navy, and Coast Guard personnel.

The emphasis on reliability is clear. A mean time between failure of 10 years was chosen, because the system would have a very good chance (>90%) of surviving one years service without a failure. When a crew travels to the site to perform routine maintenance, a minimum of work will be required. However, certain parts that may experience high wear can be easily replaced. While the expected "system life is 25 years", the blades may be replaced at 3, 5, or 10 year intervals, for example. In the 1kW system, the blades are expected to be a low cost item, i.e. under \$100 a set.

The most harsh requirements on this system will be the environmental requirements. Temperature extremes represent the variation between an Alaskan or Arctic winter (-70°C) to typical desert conditions ($+60^{\circ}\text{C}$). Mountain top locations can be extremely harsh, especially with respect to wind and icing conditions. While specific data are not available for a large number of locations, estimates of wind velocities in mountain passes are in the 130-150 mph range. Coastal locations where hurricanes are possible could experience winds in excess of 150 mph*. The 165 mph survival windspeed places design requirements not only on the machine, but also on its tower. With this stringent requirement, the 1kW High Reliability Machine should be adequately designed for the severe wind conditions at typical mountain sites. Since navigational aids are located on off-shore buoys, the salt water requirement was set.

Evaluation of the proposals submitted to Rocky Flats is complete and negotiations are continuing with selected firms. One to three prototype units will be supplied by each contractor for testing at Rocky Flats. An approximate schedule for performance on this program allows 8 months for the Phase I design and analysis effort. Phase II, fabrication, testing, and delivery of the prototype unit(s) to the Rocky Flats Test center will take approximately another 6-9 months. At the end of the

*Data obtained by National Hurricane Center in Florida.

program, data will have been collected on the performance of the prototype(s), and complete drawings for fabrication shall be provided to Rocky Flats.

TABLE 2.4.4
1kW HIGH RELIABILITY WTG SPECIFICATIONS

Item

Reliability	The goal is to design for the utmost reliability. The mean time between failures shall be no less than 10 years.
-------------	---

Maintainability	The design goal shall be a maximum of one scheduled maintenance day per year.
-----------------	---

Power Output	1kW (minimum) generated at a windspeed of 9 m/sec; 120 $\pm$ 15 volts DC, with voltage regulation to control charging of a 120 volt battery system.
--------------	--

Wind Range

Cut-In	Minimize with respect to power production and system cost.
--------	--

Cut-Out	Maximize with respect to power production and system cost.
---------	--

Survival	54 m/sec minimum for steady winds, gusts to 75 m/sec.
----------	---

Environment

Basic Machine	-70°C to 60°C, rain, ice (to 60mm), hail (to 40mm), salt water spray, dust (with 45 m/sec wind), corrosive atmosphere, and lightning.
---------------	---

Controls

Rotor Speed	Optional
-------------	----------

Yaw	Optional
-----	----------

<u>System Life Goal</u>	25 years (minimum)
Target Capital Cost Goal (not including tower)	\$1500/kW (maximum)

<

2.4.3 University of Massachusetts Wind Furnace Program

The Wind Furnace program at the University of Massachusetts, which received an initial grant from the National Science Foundation (NSF) in 1975 and was renewed by NSF and ERDA with program management responsibility assigned to RI. RI subsequently issued a new contract which expires on June 30, 1978. The broad goal of the project is to determine feasibility of the use of wind power in home heating.

During the past year a major milestone was reached when, in early November 1976, the wind turbine generator was erected on the 18m (60 ft) support tower. This wind turbine is part of a combined wind/solar system that is capable of providing the bulk of the heat for a well-insulated home located at the base of the tower.

The wind turbine consists of a 25kW generator driven through a two step speed increaser by a 10m (32.5 ft) diameter, three-bladed, downwind rotor. The electric power is fed into resistance heaters which are immersed in a 7.6m³ (2000 gal.) water storage tank in the basement. A heat exchanger transfers this stored heat to the house hot water circulating system. This entire system, including the solar flat plate collector system, is instrumented so that a thorough analysis of the system performance can be made.

A series of rather minor problems with the rotor control system prevented the Wind Furnace from extensive operation during the winter of '76-77. These problems have been overcome and the system is being readied for the coming winter. Additional instrumentation and anemometry equipment is being installed in the near vicinity of the wind turbine in order to provide a better correlation of system performance to windspeed.

Laboratory bench testing conducted this past summer indicated that a mechanical water churn, driven directly by the wind turbine, would be a more cost effective means of producing hot water than by using the electric immersion heater. The current contract will adapt this churn to the wind turbine itself, in place of the electric generator.

Additional studies are planned which are directed toward improving the economics of the basic Wind Furnace design. One study will determine the most cost effective compromise between aerodynamic shape, tip speed ratio and manufacturability of the rotor blade, which is a major cost driver of the system. The approximate life cycle costs of the wind furnace will be determined and this will be compared with solar and conventional heating systems. Another part of the economic modeling study will optimize the design of the residential wind furnace for various sites and heating loads and wind regimes. The final portion of the economic study will be to simulate an advanced design of the Wind Furnace, incorporating the cost saving features that have been identified since the original design. The results of such a study would hopefully be of interest to industrial firms that might want to enter the wind furnace market.

Because the future market for a wind furnace system would require a variety of sizes to satisfy the particular requirements, the dynamic analysis of the rotor/tower combination will be performed for a range of rotor diameters and tower heights. Such a study will identify any undesirable combination of WTG/tower and provide a future manufacturer with a program by which he can confidently predict the safe operation of the support structure.

In order to broaden the range of use of the Wind Furnace, the control system will be studied with the intent of allowing excess wind derived energy to be utilized in ways other than for heating. It is felt that the cost effectiveness of the wind system may be improved by using it to supply electric power for motors and other electric appliances during periods when all of the energy is not needed for space or water heating.

Finally, as part of the University participation in this program, the Solar Habitat will continue to remain available to public tours in an effort to stimulate interest in wind energy as a source of home heating.

2.4.4 Oklahoma State University WTG Program

The technical monitoring responsibility for a National Science Foundation grant (No. NSF-AER 73-07951) to Oklahoma State University was assigned to Rockwell International at Rocky Flats on December 17, 1976. The administrative responsibility for this grant remains with NSF. This grant was to have expired on April 30, 1977; however, a no-cost extension until October 31, 1977 was granted by NSF.

Three major objectives were sought under this grant. The first was to bring the existing Chalk turbine to a point of commercial exploitation through the incorporation of automatic systems for the rotor directional control and for the regulation of output voltage. The second objective was to design, build and test a 9m (30 ft) diameter scaled-up version of the Chalk turbine in an effort to expand this turbine towards large system applications. The final objective was to effectively disseminate the technical information obtained from this program through workshops and reports.

The automation goal has been met with the development of the spring-loaded, folding tail vane which controls the rotor direction and provides high wind protection for the system. The work on the field modulated generator has demonstrated another method of controlling the output

voltage to a constant frequency while using variable frequency input. The cost and efficiency of the field modulated generator appear to be the major impediments to commercialization of this device.

The second objective should be accomplished by the time of contract completion. The scaled-up Chalk turbine is undergoing field tests at the Stillwater airport test site. The 6 month contract extension was to allow time for this system to be completed and tested. Preliminary test data have indicated a rotor coefficient of performance of 0.30 to 0.35. Confirmation of this value, along with a description of other performance characteristics of this larger system will be given in the final project completion report.

The last objective will be completed with the final workshop to be held at Oklahoma State University on October 28, 1977 and the assembly of the final completion report a month later.

2.5 Standards Development (Task V)

2.5.1 Objective

The objective of this task is to formulate standards to be used in the manufacture, product testing, and data reporting for wind energy conversion systems (WECS). The development of these standards will aid in the rapid commercialization and widespread use of WECS by increasing public confidence in the safety, reliability, and performance of the increasing numbers and variety of systems which are entering the market place.

2.5.2 Approach for FY 1977 and Expected Accomplishments

This task is viewed as a joint effort among industry, academic, and government agencies. Rocky Flats has coordinated with various organizations, such as DOE, the American Wind Energy Association (AWEA), American Society for Testing and Materials (ASTM), and National Bureau of Standards (NBS), to discuss and resolve issues on standards. Specific workshops were held during the AWEA conference at Boulder, Colorado in May and during Wind Workshop III at Washington, DC in September. The goal of these workshops was to assimilate the views and opinions of all interested parties and to discuss alternate approaches to standards development, including testing procedures, performance data, nomenclature, and product standards. As work on standards proceeds, the following items will be developed:

1. Standard testing procedures for small wind systems describing the variables to be examined as well as the techniques to be used.
2. Standard reporting methods and terminology describing how the test data is to be presented.
3. Identification of all existing standards which are appropriate to this field.

2.5.3 Status

I. AWEA Conference

A Standards Workshop convened during the AWEA conference, held in Boulder, Colorado, in May. The attendees were invited persons from universities, industry, government agencies, Rockwell International and others. The initial discussions covered terminology for WECS. The group then split into two separate workshops: One on product standards and the other on testing standards.

A. Product Standards Workshop

During this workshop the attendees felt that there was a need for a scheme by which machines could be compared. In particular, there was discussion as to how machine performance could be defined and presented. There was a strong reaction against the type of standards that would specify requirements for certain performance levels. The bulk of the discussions centered on the definitions of performances (such as kW output versus windspeed, cut-in and cut-out windspeeds, electrical performance, mechanical performance, system life, Kwh output for a year, etc.) and safety standards. The following were the Workshop's recommendations:

- 1) The standards should be drawn up under the auspices of the relevant professional society, in this case AWEA.
- 2) A list of definitions of performance should be drawn up, reviewed, and published.
- 3) AWEA should coordinate this effort.
- 4) A list should be compiled of the applicable safety standards and a study conducted of the manufacturer's responsibilities.

B. Test Standards Workshop

The consensus of the test standards workshop was that the consumer is interested in the initial cost, energy cost, reliability, and safety of wind systems, and that test standards should be developed to help provide this information to the consumer. The following is a summary of the issues that were discussed during the workshop:

- 1) When describing WECS performance the following parameters need to be measured:

- a) load(s)
- b) wind direction, velocity and turbulence

While there was much discussion, there was no consensus as to how to measure the wind, or exactly how to analyze the data taken. Rocky Flats will continue to try a number of approaches to determine the methods which work best.

- 2) Battelle Pacific Northwest Laboratories mentioned plans to publish guidelines for wind characterization and will furnish Rocky Flats with a preliminary "field test program", which can be used to gather and analyze wind and WECS data.
- 3) The work on test standards should continue with:
 - a) A full-time person to write draft test standards for wind characterization and WECS testing.
 - b) A review and revision of these draft standards before the Wind Workshop III in September 1977.
 - c) A test standards workshop to be convened during Wind Workshop III.
- 4) Rocky Flats should investigate possible funding of standards development activities.

II. AWEA Interim Study on Standards

After the May AWEA Conference, a number of political and ERDA program decisions were made that affect Standards Development. Congress has addressed the possibility of an Income Tax Credit for Wind Energy Conversion Systems. DOE/WSB has investigated options for SWECS Demonstration Programs. The immediate impetus for standards development shifted towards the development of "Interim Performance Criteria for SWECS" that could be used to qualify SWECS for potential government-sponsored demonstration programs. As a consequence of these decisions, AWEA was asked to study the standards development process, with special emphasis on the requirements for a National Income Tax Credit Specification and for a Plan for the Development of Interim Performance Criteria for SWECS. The results of this interim study were to be presented at the Wind Workshop III.

The following six tasks were investigated:

1. Overview - including the need for standards, the present situation, and the AWEA's ideas concerning standards development areas.
2. Terminology - including existing WECS terminology, what needs to be done, and how the work should be accomplished.
3. Data Sheet - including the uses of a data sheet with an example, or model data sheet.
4. Testing Procedures - including what we need to know about testing, present testing procedures, and what needs to be tested.
5. Standards Development - including a brief history of the voluntary consensus standards system in the United States, major standards-making bodies, their techniques and procedures for setting standards, as well as their role in standards development. An outline of a plan for preparing both performance and specification standards was to be included.

6. Income Tax Credit Specification - a draft version will be prepared for discussion and comments.

2.5.4 Future Activities

Much of the background information gathering has been completed as has a polling of the wind energy community's opinions on the manner in which standards should be formulated. RF will coordinate input from DOE/WSB as to the future direction and emphasis in standards development.

2.6 Information Dissemination (Task VI)

2.6.1 Objective

The objective of this task is to disseminate technical information produced within the entire Rocky Flats wind program so that it may be effectively utilized by potential users and manufacturers/suppliers of SWECS as well as other U.S. Government agencies and programs. Increased public awareness concerning small wind systems and potential for their utilization is also a prime objective. General information on wind energy will, therefore, also be made available to the public.

Activities undertaken to achieve these objectives include:

- 1) Conducting a workshop on developing standards.
- 2) Drafting of a Guide to Commercially Available Wind Energy Conversion Systems.
- 3) Compilation of an Index of individuals and organizations actively involved with some aspect of wind systems.
- 4) Drafting a guide for potential users of SWECS in farm, home or small industry applications.
- 5) Creation of travelling displays for use at conferences, state fairs and other display opportunities.
- 6) Formation of a library containing a wide range of books, reports, journals and other sources of information pertaining to SWECS and other topics pertinent to wind energy.
- 7) Preparation and release of information to the news media concerning wind energy program activities at Rocky Flats.

The following sections will detail activities in each of the above area and availability of the various reports.

2.6.2 A Guide to Commercially Available Wind Energy Conversion Systems

A contract was awarded to the American Wind Energy Association (AWEA) to compile a volume that would list all commercially available wind energy

conversion systems, along with basic information about them. Figure 2.6.1 shows the data sheet format that was used. Manufacturers and distributors of WECS were contacted by mail and phone and asked to supply this information for each model of each machine that they handle. Both electricity-generating and direct water-pumping systems were included.

In addition to the data sheets, the guide includes a brief introduction, including definitions of the terms used on the data sheets, and lists of manufacturers and distributors of WECS hardware, anemometry equipment, towers, batteries and inverters. An appendix is included which lists selected references on wind energy and WECS. Every attempt was made to make the Guide complete, though it is recognized that there may be products that are omitted because of a lack of published information about them.

Verification of all information included with the Guide will be made prior to publication. As a result, the Guide is not expected to be available to the public until sometime in 1978.

2.6.3 Compilation of an Index

Early in the Rocky Flats wind program activities it became apparent that many individuals and organizations are, or have been, active in the field of wind energy. Limited compilations of names of such people have been assembled by private organizations. However, details of the extent of interest or activities are often not included.

A contract was awarded to AWEA to assemble a comprehensive list of people and companies active in wind energy, broken down into three categories:

1. Manufacturers
2. Distributors
3. Researchers

MAIN OFFICE

ORGANIZATION:

ADDRESS:

CONTACT:

TELEPHONE:

BRANCH OFFICE

ORGANIZATION:

ADDRESS:

CONTACT:

TELEPHONE:

time employees in the wind energy field

Involved in the wind energy industry for years

Organization is a ☐ manufacturer; ☐ distributor; ☐ researcher;
 ☐ other:

MANUFACTURER SECTION

Type of W.E.C.S.: ☐ horizontal axis; ☐ vertical axis;
 ☐ other:

System classified as ☐ production; ☐ prototype (in production months)

Rotor diameter: ft
 blades

Unit begins to generate @ mph

Unit designed to withstand mph

Unit generates: ☐ ac; ☐ dc; ☐ other:

Rated output: Watts @ mph

Suggested price: \$

Sold under warranty or guarantee:

☐ no; ☐ yes

System in operation for years

Adaptable to other applications:

☐ no; ☐ yes:

Figure 2.6.1 Sample Questionnaire Used in Compiling the Index

ORGANIZATION:

DISTRIBUTOR SECTION

Systems distributed:

☐ Jacobs	☐ Elektro	☐ Amerenalt
☐ Kedco	☐ Dunlite	☐ Wincharger
☐ A.W.T.	☐ Edmonds	☐ Aeropower
☐ D.A.F.	☐ Winpower	☐ Scencenbaugh
☐ Zephyr	☐ Lubing	☐ Other:

Services provided: ☐ site selection; ☐ installation; ☐ repair; ☐ other:

RESEARCHER SECTION

Research areas:

☐ W.E.C.S.	☐ inverters
☐ Meteorological data systems	☐ Towers
☐ W.E.C.S. components	
☐ Other:	

Working under contract or grant:

☐ no; ☐ yes: from

Information available to the public:

☐ no; ☐ yes: from
for

Work overview:

COMMENTS

Figure 2.6.1 Sample Questionnaire Used in Compiling the Index
(continued)

A questionnaire was drafted, approved by the OMB, and copies sent out to approximately 2,500 individuals on a list accumulated over the years by AWEA. (The complete questionnaire is included in Appendix C of this report.) This mailing also drew upon lists assembled by various companies or published in conjunction with workshop proceedings. Only 325 questionnaires were returned, but these have been compiled into an Index, divided into the three categories listed above. Final publication of the Index is planned for sometime during 1978, after all reviews have been completed.

2.6.4 User's Guide

On July 8, 1977, Nielsen Engineering and Research, Inc. (NEAR) began work under contract to ERDA to write a handbook entitled "Buyer's Guide to Small Wind Energy Conversion Systems". The contract also called for an introductory brochure, or pamphlet, on wind energy conversion systems. Written for potential users of SWECS, the handbook would address such areas as power requirements, power availability, wind energy conversion devices, economic factors, legal aspects and installation, maintenance safety and environmental aspects of WECS ownership. Potential users of small (1-35kW) WECS would be able to use the handbook to provide assistance in evaluating their energy needs and assessing the value and utility of such systems to them.

Administration of the contract was transferred from ERDA/WSB to the ERDA area office at Rocky Flats (RFAO) on February 1, 1977, with the technical monitoring role to be handled by the wind energy program at Rocky Flats.

A first draft of the Guide, titled "Wind Power for Farms, Homes and Small Industry" was submitted for review prior to transfer of the program administration to Rocky Flats. It consisted of a detailed description of all aspects of wind energy conversion system acquisition, written in simplified terms so that someone not previously familiar with the calculations would be able to follow the various steps. An outline is presented

covering each item that should be considered, from the initial idea that wind power might be desirable to have, to the decision of what land and size installation is best suited for a particular need.

A revised draft which incorporates reviewer's comments has been submitted for additional review. The final decision as to type of publication will be made by ERDA/WSB. It is expected that the report will be available to the public in 1978.

2.6.5 Wind Energy Library

A library of wind power books, periodicals, reports and bibliographies is maintained at Rocky Flats to facilitate communication between researchers and individuals interested in wind power. The library presently contains approximately 300 volumes and is growing rapidly as efforts in wind power development expand. Materials in the library are available to all visitors to Rocky Flats (although items cannot be taken from the library). Many of the items in the library can be purchased through NTIS, National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia (VA) 22161.

A computerized index is maintained and updated monthly (as needed) to access all volumes. Subject, author, document type, corporate source, publication date and report number indices are available that catalogue all the library materials.

The library receives all documents on the Department of Energy, Wind Systems Branch (UC-60) distribution as well as acquisitions from surveys of open literature, conference proceedings and the many energy abstracts services available from public and private sources.

2.6.6 Public Displays

A traveling exhibit highlighting historical and some current concepts for the use of wind energy was fabricated and displayed during the year with excellent success. This manned, animated display was supplemented with program brochures, information sheets and follow up contracts.

Five major events were scheduled during the administrative year. The first, the American Association for the Advancement of Science (AAAS) national meeting was held in Denver in February. An estimated 5000 AAAS members and members of the general public visited the exhibit during the four day conference.

The American Wind Energy Association's workshop and convention was held in Boulder, Colorado in May, 1977. Rocky Flats personnel assisted the conference organizers with administrative and logistics support (printing of posters, agendas, equipment support, etc.) as well as the fully manned exhibit. Over 500 pamphlets describing the program were distributed at that meeting.

As in previous years, the exhibit traveled to the Colorado State Fair held in Pueblo, Colorado, in August. Over 150,000 area ranchers and farmers had access to the display during the ten-day Fair. Approximately 15,000 brochures and information sheets were distributed.

The Better Thermal Utilization (BTU) conference sponsored by the New England Solar Energy Association in Hartford, Connecticut also drew sizable crowds. Nearly 10,000 brochures and information sheets were distributed, and significant discussions were a constant activity of those manning the booth.

The final conference for the year was Wind Workshop III held in Washington, D.C. in late September.

The exhibit has also been used in conjunction with local activities as well as in support of major activities and scientific forums.

Locally, community and school science fairs were held in January, February, and April. The display of elements of the display were incorporated into presentations to approximately 800 elementary school age students in small groups.

The exhibit has also been loaned to a local group involved in establishing the Denver Metropolitan Science Museum. Information Services personnel manned the exhibit in order to help generate interest and support for the Museum. An estimated 20 - 25,000 people were exposed to the information while it was displayed in major shopping centers in the Denver metro area.

In addition to the large traveling exhibit, graphic and photographic displays were also made available to local scout troops, civic clubs, etc. An estimated 2000 persons viewed these unmanned materials.

Total estimated public exposures to the Wind Energy exhibits for the year include about 25,000 actual information brochures and information sheets distributed, and a potential exposure of nearly 200,000 persons.

2.6.7 Media Activity and Interface

The Information Services Department has, through the Wind Systems Branch and DOE Public Information Office, maintained a consistent flow of information to the news media. Press releases have been issued where appropriate, and information requests from the press and general public honored as received.

The RF contract award was announced in May, 1976 with simultaneous Rockwell/ERDA press releases. This initiated a continuing activity on the part of the local news media with occasional national coverage. Information Services provided stills and descriptive texts to ERDA

public information offices and directly to local and national media (e.g. Time magazine, New York Times, Los Angeles Times, CBS - Chicago and San Francisco, etc.)

The February, 1977 AAAS and the May, 1977 AWEA conferences stimulated local, regional and national coverage. Both Rockwell and ERDA personnel and news media information releases received considerable coverage and exposure.

The award of the first 8kW development contract was also formally released by both ERDA (at the Wind Workshop III conference) and by Rockwell locally. Further contract releases are being made by award winners through Rocky Flats Information Services and ERDA (DOE).

In addition to formal releases and information requests, status reports and items of interest are published periodically in the Rockwell News (Rocky Flats and Corporate editions) which is circulated to media, civic and local government leaders. These insertions tend to initiate further press inquiries as well as stimulate public interest.

The Test Center has also been featured in a series of employment and public service advertisements (funded by Rockwell International). These display ads have included notation of public tour availability and have stimulated general public awareness of the program.

2.7 Long Range Plan (Task VII)

2.7.1 Objective

The objective of this task is to develop a plan for achieving the program goal of widespread use of wind energy conversion systems. As it is anticipated that a number of years will be required for this goal to be met, the long range plan covers the six-year period through 1982.

2.7.2 Approach

The main obstacles to widespread use of wind power are identified--availability of wind machines of the required size at a satisfactorily low cost, and awareness by potential users of the various applications and cost advantages of wind power. Numerous inputs are needed detailing customer requirements so that the needed hardware can be developed. Similarly, the question is addressed of how to demonstrate applications for wind power. Interactions between various agencies needed to assure a steady and smooth progress in the various tasks is identified, so that adequate pre-planning can be made each year.

2.7.3 Output

A report containing the following items has been submitted to DOE/WSB for review:

1. A list of inputs needed to identify required development program.
2. A list of activities, concerning the testing of machines at RF, development of new wind turbine machines and their demonstration of usefulness in various geographic locations and applications.
3. A list of organizations expected to be involved with providing needed input and
4. A schedule for accomplishing basic tasks.

APPENDIX A

"FREE STREAM SMALL WECS TESTING"

Rocky Flats
Small Wind Energy Conversion Systems
Test Program

Contract # PF 58104-A

1 December 1977

Windworks, Inc.
Route 3, Box 44A
Mukwonago, WI 53149

1.0 ABSTRACT

This report presents results from recent free stream wind turbine generator testing carried out at Windworks under contract with Rockwell International's Rocky Flats Small Wind Energy Conversion Systems (SWECS) Testing Program. Rockwell International, under a contract with the U. S. Department of Energy, provides technical and management support for the development of SWECS. The anemometry locations allowed for axial flow wind measurements, first, at varying radial stations behind the rotor, and second, outside the rotor's wake in the plane of rotation. "Quasi-steady state" events, which correlate to steady state theoretical prediction, are shown to exist for short periods of time in the free stream and are in close agreement with analytical predictions. Major system performance functions analyzed were the rotor wake velocity profile, the machine power curve, and rotor axial thrust. Data obtained from tests were examined with a one second interval point selection and with a "quasi-steady state" event selection process. Statistical comparisons of mean and standard deviations for the two methods are presented.

2.0 INTRODUCTION

The determination of small WECS performance and system loads is critical in the process of refining design procedures, which are ultimately aimed at lower unit costs. The use of free stream, or natural wind, testing program to analyze a machine's operating characteristics is an inviting approach, in light of the alternatives. However, a major disadvantage of free stream testing is the lack of steady flow. Generally wind tunnel and vehicle mounted testing programs have been used to gain steady flows for wind machine testing.

Steady flows are desired because, to date, system performance and load calculations are performed using steady state models. Our program was initiated to determine if specific instances of steady flow could be identified in the free stream. To accomplish this, a definition for a "quasi-steady" event i.e. a point in time when the wind turbine reaches equilibrium in the free stream, was developed.

Data were also reduced sequentially, taking one sample every second. Comparison of the data taken with both techniques and a comparison with theoretical predictions indicate that both methods provide accurate information concerning the system's operational characteristics. The advantage of the "quasi-steady" approach is that only a few points need to be identified, possibly a manual process, while interval data collection and reduction is a process better suited to computer data handling systems.

3.0 TEST SYSTEM

3.1 WIND SYSTEM

These tests were conducted using a Jacobs 110VDC/2500 watt wind generator mounted with a "blade actuated" hub (Allied type) manufactured by North Wind Power Company and Jacobs-style blades refinished with fiberglass and resin. The wind generator was mounted on a 72 foot octahedron module tower at the Windworks site outside Mukwonago, WI. Throughout the tests a constant resistive load of 10.5 Ω was employed.

3.2 INSTRUMENTATION

The Jacobs machine was fitted with a belt driven tachometer connected to the main shaft which produced a voltage signal proportional to RPM.

Power measurements were made by recording voltage from the machine and with the Gemini digital wattmeter. Calculations of power using the $P = VI = \frac{V^2}{R} = V^2/R$ relationship for a fixed resistive load were checked against power readings from the wattmeter. Power values reported in this paper are for usable electrical power delivered to a load corresponding to system coefficient of performance C_S .

An axial thrust sensor was installed with twin boom anemometry assembly. The axial thrust strain gauge bridge was installed on a spring assembly mounted on the rear of the Jacobs end bell casting. The standard Jacobs ball bearing was replaced with a roller bearing that allowed 2.5mm (.10") end play in the main shaft. The bridge mounting was designed so that the load was constant between support points, thereby eliminating positioning errors. Strain gauge calibration was performed for loads from 0 to 300 pounds (0 to 1330 Newtons). Dynamometer load tests were conducted to insure that the main shaft was free from magnetic centering.

A potentiometer mounted on the stub column, provided a determination of yaw rates. The interest in yaw motion was to find the maximum yaw rates associated with the Jacobs machine. The maximum yaw rate recorded was 0.6 rad./sec.

3.3 ANEMOMETRY

3.3.1 Vertical Boom

A boom was constructed that bolted directly to the Jacobs generator. Attached to the boom were two (2) anemometers, one fixed one rotor diameter out from the axis of rotation, and

the other mounted on a motorized sliding cart (See Figure 1). The anemometers used were the Gill Propeller type with a .82m (2.7 feet) distance constant. The 4-bladed polystyrene propellers are 19 cm in diameter and have a 30 cm pitch. The motorized cart on the anemometer mast could be positioned from .3 to 4.0m (1 to 13 feet) out from the axis of rotation. Both anemometers were placed at a constant distance of .60m (2.0 feet) behind the plane of the windmill's rotor and the anemometer propellers were parallel. This allowed for measurements of the wind speed only perpendicular to the plane of the rotor. Distances for the moveable anemometer are given in terms of r/R where R is the rotor's radius and r is the distance from the axis of rotation.

The vertical boom anemometry allowed the mapping of the axial velocity component in the wake of the rotor and a determination of the wake boundary. Free stream wind speeds were obtained by using the single reference anemometer at 4.3 meters.

3.3.2 Twin Boom Anemometry Array

Subsequent to the vertical boom testing, the Jacobs generator was fitted with two (2) anemometers projecting outside the rotor's swept area and in the plane of rotation. From the vertical boom testing it was determined that the rotor influence area in the plane of the rotor did not extend radially beyond 2.6m (8.5 feet).

The anemometer mounting constrained measurements to only the axial velocity component in the free stream. The anemometers on the twin booms were positioned 2.90m (9.5 feet) from the centerline of rotation at 45° above and below the horizontal. (See Figure 2).

This anemometry mounting technique was chosen as the most appropriate method for determining the flow velocities at the rotor, especially for the determination of "quasi-steady" state events because the rotor was bracketed. Identical readings from both anemometers implied that the rotor was being influenced by a "Quasi-steady" stream across the total swept area.

3.4 DATA RECORDING SYSTEM

Data were recorded with a Gould Brush 481, 8 channel hot pen strip chart recorder.

3.5 DATA REDUCTION

Strip chart data were manually reduced to tabular form. The two methods of data reduction used were (1) one second interval points and (2) the selection of "quasi-steady" state events.

The one second interval data were taken for test periods ranging from 30 seconds to a few minutes. Since the intent of the investigation was to find and document "quasi-steady" events, little data were taken during the more turbulent high velocity winds.

"Quasi-steady" points are defined so as to approximate a steady state test condition. A steady state condition occurs when the wind turbine is operated in a steady wind i.e. laminar flow until all transients have been damped out. This condition is approximated by defining a "quasi-steady" event as the instant in time before which the system parameters (rpm, yaw

rate, volts, current, and power) have been constant and the wind velocity was within ± 0.5 m/sec. (± 1 mph) for at least the previous three seconds. An example of "quasi-steady" state is shown in Figure 3.

Data obtained from the strip chart recordings were analyzed for mean and standard deviation where appropriate. Figures 4 through 7 present the mean and a line showing ± 1 standard deviation.

4.0 TWIN BOOM ANEMOMETRY

Comparison of the two wind velocities taken from the twin boom tests showed them to be well within the first standard deviation at all wind speeds considered. The variation in height between the two anemometers caused a slight difference but this was so small that it was masked by the turbulence in the flow.

5.0 ROTOR WAKE VELOCITY PROFILE

5.1 Using the 4.3 meter anemometer boom with its sliding anemometer the axial velocity behind the rotor from a radial position r/R of .2 to 2.0 was plotted. The ratio of the velocity behind the rotor to the free stream velocity (measured at 4.3 m) equals the velocity reduction term "b" used by Lissaman and Wilson¹ ($b = 1 - 2a$ where "a" equals the axial interference factor). Since this term is paramount in the aerodynamic evaluation of a rotor, its direct measurement provides a touchstone for the theoretical evaluation.

¹ Wilson, R. E., Lissaman, P. B. S., Walker, S. N.: "Aerodynamic Performance of Wind Turbines". June 1976

The velocity profile behind the rotor, determined from testing is shown in Figure 4.

The "b" terms of 0.5 for the outer one meter (3 ft.) of the Jacob's rotor accurately illustrate the effects of using a low L/D airfoil with a poor surface condition. Optimum performance would be reflected by a "b" term of 0.33^1 .

The deterioration of section performance for the inner annuli is a result of using a blade with limited twist and very little plan form taper. It can be seen that the inner third of the Jacob's blades are stalled under typical operating conditions. Stalled operation is characterized by a higher standard deviation in the flow stoppage term. The irregularities are a result of the turbulence induced in the wake as the blades pass the anemometer. This can be expected with any untwisted or slightly twisted blade such as the Jacobs.

A distinction between "quasi-steady" state data and one second interval data is not shown here because no difference was observed.

The axial interference coefficient obtained from the strip theory analysis of the Jacobs rotor are also plotted in Figure 4 for a tip speed ratio of 5.5. This information is also presented in Table 1.

TABLE 1

"b" Factors From Strip Theory
 $b = 1 - 2a$
 $X = \text{Tip Speed Ratio}$

	$X = 4$	$X = 5$	$X = 5.5$	$X = 6$
	$C_p = .262$	$C_p = .312$	$C_p = .327$	$C_p = .332$
.9	.624	.563	.532	.500
.7	.661	.587	.552	.516
.5	.638	.555	.511	.472
.3	.812	.648	.517	.462

6.0 MACHINE PERFORMANCE

6.1 RPM

A graph of RPM vs. Wind Speed is shown in Figure 5. Tip speed ratios are represented as lines of constant slope. These operating characteristics are specific for the 10.5 Ω resistive load. Other loads will cause slight variations in performance parameters. A tip speed ratio of 5.5 is maintained over most of the fixed pitch operating range.

At lower wind speeds, below 4m/sec, the tip speed ratio increases because the field is not sufficiently energized. The Jacobs, as it was set up for our testing, would start in a wind speed of about four meters a second, therefore, data generated below 4m/sec was taken only after the machine began operation in higher velocity flows.

6.2 RPM in the Control Regime

The RPM control obtained by the "blade actuated" hub can also be seen in Figure 5. Above 10 or 11 m/sec the tip speed ratio decreases as the machine operates at a slightly increasing RPM. The control mechanism requires this slight increase in RPM to feather the blades. For our tests the Allied springs were set to feather at a lower than normal condition so that feathering regime could be more fully explored. Adjustment of initial spring tensions provides this flexibility.

6.3 Axial Thrust

In Stage 2 of the test program an axial thrust sensor was installed as explained in the Instrumentation section. Figure

6 compares the axial thrust versus wind speed for the "quasi-steady" points and for the one second interval data was obtained while the flow was relatively steady and therefore does not contain the excursions one would expect from very turbulent flow. Some of the data at higher wind speeds show variations due to gusts but these points do not represent the worse case loads one would anticipate at these wind speeds.

Experimental data were compared to theoretical results. One set of momentum calculations was made using empirical results obtained from wake flow measurements. The flow reduction ("b" terms) obtained give an accurate picture of the momentum exchange at the various radial stations (See Figure 5). Thrust loads can be obtained by integrating the momentum interchange over the entire area, annulus by annulus, using the equation:

$$T = \frac{1}{2} \rho V^2 \int_0^R 4a(1-a) \cdot 2\pi r dr$$

Another set of axial thrust calculations was performed using a five annulus strip theory as in the performance calculations, (See Table 1). Both methods gave results within a few percent of each other because the axial interference terms in both calculations were nearly identical.

Within the operating regime there is good correlation between the experimental and theoretical results. The response associated with the axial thrust sensor is much faster than the response associated with an RPM change. The axial thrust measurement therefore follow wind speed changes more closely than parameters which require an RPM change. A relatively

good correlation with theoretical results for axial thrust can be obtained because the calculations are not as dependent on the airfoil drag as power and torque are.

At wind speeds above 9 meters per second, the Jacobs wind generator is in a control regime. The average thrust is limited as the blades feather, but the variation in thrust loads becomes much greater. This can be seen clearly in Figure 6. The overspeed control system in these tests is the blade-actuated governor manufactured by North Wind Power Company. This hub uses the blade as a centrifugal weight to initiate feathering. As the RPM increases due to increased wind speeds, the blades move out radially and are feathered by means of a spider. The feathering angle is controlled by RPM and therefore rapid changes in the wind speed cannot be accounted for. This gust condition increases the blade loads until the system's RPM increases and the blades are placed in a new equilibrium position. The loads experienced by the blades are a function of the airfoil's angle of attack changes and the increased relative wind velocity, which means that the blades encountered the largest load fluctuations at the higher wind speeds.

6.4.1 Power Vs. Wind Speed

A plot of power vs. wind speed for one second interval and "quasi-steady" data is shown in Figure 7. Little difference can be seen between the two types of data over the range in which they both appear. The data presented in this report were taken from relatively stable winds. Data taken under gusty wind conditions may indicate power and blade load variations due to a higher level of turbulence.

The standard deviations associated with these power curves is larger than those associated with axial thrust. This is due mainly to the Jacobs' long response time. Primarily, the rotor and armature inertia limit the acceleration of the armature which in turn governs the voltage change and therefore power output. The inductance of the shunt wound generator further increases the lag term.

A theoretical analysis of the Jacobs rotor was done, as for axial thrust, using a tip speed ratio of 5.5. This was done using a 5 annulus strip theory² using Clark Y airfoil data, 11% thick. A calculated C_p of .327 is obtained which, when coupled with the generator efficiency of 75%, gives a system coefficient of performance, C_s , of .245. The generator efficiency, determined from dynamometer tests with fixed resistive loads, is presented in Figure 8.

The theoretical analysis of the Jacobs blades is complicated by a lack of accurate predictions of the airfoil polars, given the low operating Reynolds number, the effects of surface roughness, and a relatively thick trailing edge. Of primary concern is the coefficient of drag (C_D) term since it is most effected by blad surface and operating conditions, while being paramount in the analysis of performance.

- 6.4.2 One preliminary result that was noted but not fully investigated was a power reduction due to turbulence. This reduction in power output was seen through a different data reduction technique. A period of thirty seconds was taken from a sample

² Wilson, R. E., Lissaman, P. B. S., Walker, S. N.: "Aerodynamic Performance of Wind Turbines". June 1976.

of turbulent data. Points were taken every second for wind speed and power and were then integrated numerically over time to give average wind speed and power. The average power was then compared to the value obtained from the power curve at the average wind speed (Figure 9). Four sections of data were reduced in this manner and each showed a reduction in actual power of 15 to 20 percent. We feel this is due to the increased level of turbulence. This seems inconsistent because no reduction was seen between the power curves for "quasi-steady" and one second data. Insufficient data were reduced in this manner to make definite statements. If this is a result of turbulent flow and/or blade design, it could have a large effect on economic analysis, siting, and design. This effect is now being investigated by de Kinderen et al³ along with reductions associated with cross flows.

7.0 CONCLUSION

It was anticipated that the anemometry in both stages of the work would allow for the accurate correlation of the wind stream/machine interaction. The event sensitive "quasi-steady" state sampling, was felt necessary for the verification of the aerodynamic calculations, since the aerodynamic model used steady flow. Free stream testing must rely on either long term averaging or individual "quasi-steady" events to determine the wind/machine interaction for comparison with steady state calculations. Our preliminary conclusions are,

³ der Kinderen, W. J. G. J., Van Meed, J. J. E. A., Smolders, P. T.: "Effects of Wind Fluctuations on Windmill Behaviour". Wind Engineering, Vol. 1, No. 2, 1977.

(1) "quasi-steady" state events do occur in the free stream, (2) the performance parameters measured at these events can be meaningfully compared to steady state theoretical predictions, and (3) both data reduction techniques, quasi-steady and one second, are valid. The definition of "quasi-steady" state flow used in a free stream testing program is paramount in the event selection process. The time duration needed for system stabilization is a machine specific parameter, which should be the basis for a "quasi-steady" state definition.

Theoretically, the identification of wind velocities that correspond to machine power levels is done assuming a steady wind flow, as in a wind tunnel. The actual performance of a windmill and the stresses induced while the machine is in the free stream airflow will vary from this ideal condition. The actual amount of variation will depend on the amount of turbulence in the flow and the particular machine's design. At this point site selection becomes important. Not only can the added turbulence of a poor site lower the energy production of a system, but it can also increase the cyclic stresses in the machine, demanding more maintenance and reducing system life.

Analytically, the inability to theoretically handle the complex equations for non-steady state operation, forces engineers to view system performance and loads primarily in the steady state. Theoretical power curves are a good example of the steady state flow analysis commonly used. The on-going work to develop analytical methods to better understand non-steady state windmill operation is a significant step in the refinement of the design procedure. To facilitate this analytical analysis, experiments should be conducted to measure the stresses induced on a rotor system in turbulent flows and to quantify the energy deficit incurred.

FIGURE 1

Instrumented Jacobs with a Single
Anemometer Boom

FIGURE 2

Instrumented Jacobs with a Twin
Anemometer Boom

Figure 3 - Example of Quasi-steady Flow

FIGURE 4

Wake Velocity Profile

Figure 5

Rotor RPM as a Function of Windspeed

Figure 6
Axial Thrust vs. Wind Speed

Figure 7
Power vs. Wind Speed

Figure 8
Dynamometer Test Jacobs 110/2500 Efficiency vs. rpm

$$\text{Average Wind Speed} = \frac{6.8 + 7.4}{2} = 7.1 \text{ m/s}$$

$$\text{Predicted Power} = .83 \text{ kw (from Figure 7)}$$

$$\text{Average Power from Chart} = .653 \text{ kw}$$

$$\frac{.653}{.83} \rightarrow 79\% \text{ of predicted power}$$

Figure 9
Turbulence Power Loss

APPENDIX B

AEROWATT FAILURE ANALYSIS

On December 1, 1976, the Aerowatt, model 4100FP7 wind turbine generator, originally purchased and tested for about two years by NASA at their Plum Brook Station, was installed at the Rocky Flats test center. A pivoting support tower of similar design, but shorter than the tower at Plum Brook, was used at Rocky Flats. Prior to being placed on the tower, the Aerowatt was examined by Robert Dodge of the Automatic Power Division of Pennwalt Corporation which is the United States distributors of the Aerowatt family of wind systems.

The Aerowatt had operated continually for about two weeks at Rocky Flats when the decision was made to place it out of commission temporarily while the electrical power conductors were placed in conduit rather than being allowed to lie on the ground. This work, along with installation of an instrument shed at the base of the tower and relocation of the Aerowatt's resistor bank, resulted in a two month delay in placing the Aerowatt back in operation.

The system performed well from its restart on February 17, 1977 until its failure on February 23. The winter's major downslope windstorm began to develop during February 22, a day which saw two smaller wind systems receive damage. The Aerowatt was observed to be operating normally by the last person to leave the site on the afternoon of the 22nd and again by two plant guards who checked the test site at 2:26 a.m. on February 23rd.

At about 6:30 a.m., television news team, accompanied by personnel from Rocky Flats Information Services, arrived on site with the purpose of filming the operation of some wind systems against a sunrise background. Instead, they discovered the fallen Aerowatt.

An investigating team was assigned to determine the likely cause of failure and they began by having plant photography take a series of on-scene photographs of the damage sustained by the Aerowatt, the support tower and the nearby work platform. The Aerowatt was carefully moved indoors where it was slowly disassembled, while another series of photographs was taken, showing the internal damage. Samples of fractured areas were submitted for chemical and metallographic analysis and the wind data from a nearby meteorological tower were tabulated for the period during which the failure occurred.

A full analysis of these data is contained in a report which will be sent to the manufacturer and distributor. The summary of the investigating team report, outlining the most likely failure mechanism, is as follows:

The wind conditions during the hours before the failure consisted of steadily increasing wind velocities whose maximum gusts peaked at 39 m/sec (87 mph) around 7 p.m. The velocity then decreased slowly during the night except for a short period around 3 a.m. when a sharp increase to 34 m/sec (76 mph) in gust velocity was recorded. By the time the news team arrived at 6:30 a.m. the peak gusts were down to 21 m/sec (48 mph) the lowest value of the night.

It is believed that a crack, which was initiated long before the failure and had propagated well through the chord length of one of the two blades, weakened the blade to the point of catastrophic failure during a high velocity gust. Metallographic examination of the fractured surface of the blade showed that this fracture began as a fatigue crack at the leading edge of the blade's root. A heavily oxidized intergranular crack had progressed more than half way through the chord before the sudden fracture of the remaining chord section.

It is hypothesized that the initial fatigue crack occurred during the testing of the Aerowatt at Plum Brook Station. Early during this testing one of the guy cables, which reinforced the blade by attaching it at the 1/3 radius point to an extended hub nose, came loose and the Aerowatt operated for a day or two before this cable was reinstalled. From this point until failure, stress corrosion cracking was the probable mechanism for the propagation of the pre-crack across the chord. The heavily oxidized nature of the crack lends support to the belief that the crack existed to a fair extent well before the time of final failure.

At the time of blade failure, the Aerowatt was probably operating in the stalled condition, producing no torque but continuing to rotate at 60-100 rpm. This was a design characteristic of the system as noted by NASA and Rocky Flats test personnel. The rotor speed control of the Aerowatt was done by pitching the blades toward the stall position rather than by feathering them. This has the effect of allowing very high thrust forces to act on the blades during high winds and explains the importance of the guy cables.

After the blade fractured it was prevented by the guy cable from leaving the rotor. Instead, as evidenced by scratches and dents, this blade became entangled with the remaining blade. It was envisioned that the rotor made several turns with both blades intertwined, causing severe cyclic loads to be transmitted through the hub to the large aluminum casting which attached the system to the tower.

The cyclic loading of this casting proved too great and several cracks developed at weak points (such as bolt holes). These cracks progressed catastrophically, resulting in failure of the tower/Aerowatt attachment. The Aerowatt was then toppled from the tower by the wind, falling toward the east-south east, the direction towards which the wind was blowing.

During its fall from the tower, the blades struck the support tower in several places, indicating that they may have still been rotating. The intact blade slid along one of the large tower guy cables, causing deep cable marks on the blade. At about mid-fall this blade became caught between the guy cable and the ladder cage on the work platform located adjacent to the support tower. In order to continue falling, the intact blade had to bend and the small guy cable attaching this blade to the hub nose broke at a clevis. The Aerowatt then impacted the ground, narrowly missing the newly installed instrument shed at the base of the tower.

The force of ground impact resulted in extensive damage to the entire tail (vane) structure. More importantly, some internal components such as the generator, hub and pitch controlling mechanism were also badly damaged. It was determined at this point in the investigation that the Aerowatt was a near total loss, largely because of the severe internal damage, and that no further thought would be given to rebuilding the system.

Several lessons should be learned from the Aerowatt failure. For safety of nearby personnel, an area at the base of the test towers should be restricted for use by test site personnel only, and then extreme caution should be exercised when working beneath the wind turbines, especially during strong winds. Designers and manufacturers of wind systems should consider the consequences of a blade coming loose from the hub. If the remainder of the system is designed with enough back-up strength total damage to the system could be restricted to the broken blade. Sharp cross section transitions at blade attachment points that will cause stress concentrations should be avoided whenever possible. Finally, potential users of wind systems should carefully consider the hazards due to falling objects when deciding on the location of the support tower.

Appendix C

AWEA Questionnaire

INSERT TO QUESTIONNAIRE, OMB NO. 38-S770006

ADDITIONAL INFORMATION

This questionnaire is authorized by the Energy Reorganization Act of 1974. Your response is entirely voluntary.

Although the questionnaire is designed to elicit general information pertaining to firms engaged in the wind energy conversion industry, it is recognized that the size or organizational structure of any particular respondent could result in the submission of information which is essentially personal. All information supplied in responses to the questionnaire will be compiled in the published survey results, which will be available to both other firms in the industry and potential users of the products or services you offer. Failure to furnish requested information will result in a corresponding incompleteness of the data concerning your activities. A more detailed statement of the purpose of this questionnaire is included in the section entitled "INTRODUCTION" on page C-4 of the form.

FORM APPROVED
G.A.B. NO. 08-077-200

A

QUESTIONNAIRE

**FOR MANUFACTURERS, DISTRIBUTORS AND
RESEARCHERS CURRENTLY INVOLVED IN
WIND ENERGY CONVERSION SYSTEMS
DEVELOPMENT
PREPARED FOR**

AND

Rockwell International

**BY THE
AMERICAN WIND ENERGY ASSOCIATION
1919 - 14th St.
SUITE 401
BOULDER, COLORADO 80302**

INTRODUCTION

The American Wind Energy Association under contract with the Energy Research and Development Administration and Rockwell International, Atomic International Division, Rocky Flats Plant, Golden, Colorado is compiling an index of manufacturers, distributors and researchers currently involved in the wind energy conversion industry. This index, when completed, will serve two purposes. One, to help further the exchange of information within the industry, and two, provide information to prospective wind energy conversion system owners on the availability of systems and services.

Your name has come to our attention as one of those that are currently involved in the wind energy conversion industry. We ask that you spend a few minutes and complete the enclosed questionnaire and return it to us in the envelope supplied. We encourage your comments or questions and space has been provided at the end of this questionnaire for them.

We are attempting to gather a great deal of information about manufacturers, distributors and researchers with this questionnaire and realize you may not wish to answer certain questions. If this should be the case we ask that you answer as many as you can and return the questionnaire to us.

The final index will be available in the spring of 1977. If you would like to receive a copy or if you would like to know more about the American Wind Energy Association or the wind energy system testing program underway at the Rockwell International operated Rocky Flats plant please let us know.

We greatly appreciate your participation and hope this information will facilitate the use of wind energy systems once again in this country.

American Wind Energy Association
Index Study
1919-14th St. Suite 401
Boulder, Colorado 80302

American Wind Energy Association Index Questionnaire

1. Name of individual or organization completing this questionnaire?
 - a. Name
 - b. Address
 - c. City, State, Zip
 - d. Telephone
2. Location of branch offices?
 - a. Name
 - b. Address
 - c. City, State, Zip
 - d. Telephone
3. How many people do you employ in the wind energy field on a full time basis?
 - a. 0-5
 - b. 6-10
 - c. 11-25
 - d. 26 or more
4. Length of time involved in the wind energy industry?
 - a. 0-3 years
 - b. 4-10 years
 - c. 11-25 years
 - d. 26 years or more
5. Type of organization?
 - a. Manufacturer
 - b. Distributor
 - c. Researcher
 - d. Other, please explain

6. Are you aware of the testing and evaluation program on small wind energy conversion systems currently underway at ERDA's Rocky Flats Plant operated by Rockwell International Corporation, and would you like to receive information on the program?
- a. Yes
 - b. No

NOTE The remainder of the questionnaire is divided into three sections, please go to the section(s) that most represent(s) your work and continue.

MANUFACTURERS SECTION

1. What type of WECS do you manufacture?
 - a. Horizontal axis
 - b. Vertical axis
 - c. Other, please explain
 2. Would you classify your system(s) as?
 - a. Prototype units
 - b. Production units
 3. If prototype, how soon do you expect to be in production?
 - a. 1-6 months
 - b. 7-10 months
 - c. 19-36 months
 - d. 37 months or longer
 4. Rotor diameter of your system(s)?
 - a. 1-6 ft.
 - b. 7-12 ft.
 - c. 13-20 ft.
 - d. 21 ft. or more
 5. Number of blades in your system(s)?
-

6. Speed at which unit(s) begin to generate?

_____mph

7. Maximum windspeed unit(s) are designed to withstand?

_____mph

8. Does your system(s) generate?

- a. AC
- b. DC
- c. Other, please explain

9. Rated output of system(s) you manufacture?

- a. _____ watts at _____ windspeed
- b. _____ watts at _____ windspeed

10. Suggested price of system(s) you manufacture?

- a.
- b.

11. Is the system(s) you manufacture sold under a warranty or guarantee?

- a. Yes
- b. No

12. Length of time you have had system(s) in operation?

- a. 0-3 years
- b. 4-10 years
- c. 11-25 years
- d. 26 years or more

13. Are your system(s) adaptable to other applications?

- a. Yes
- b. No

DISTRIBUTOR SECTION

1. What type of systems do you distribute?

a. Electro	h. A W T
b. Dunlite	i. Edmonds
c. Jacobs	j. D A F
d. Amerenalt	k. Aeropower
e. Kedco	l. Scencenbaugh
F. Wincharger	m. Winpower
G. Zephyr	n. Lubing
	o. other

2. Does your organization provide site selection services?

- a. Yes
- b. No

3. Does your organization provide installation and repair services?

- a. Yes
- b. No

RESEARCH SECTION

1. Area in which you are conducting research?

- a. Wind energy conversion systems
- b. Meteorological data systems
- c. Components of WECS (e.g. rotors)
- d. Inverters
- e. Towers
- f. Other, please explain

2. If you are working under contract or grant please specify from where?

3. Give a brief overview of your work.

4. Do you provide information to the public on the work you are doing.

a. Yes

b. No

5. If yes, where is it available and at what cost?

This space is provided for your comments or questions.

We thank you for taking the time to fill out this questionnaire.

Sincerely,

American Wind Energy Association