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TECHNICAL AND MANAGEMENT SUPPORT FOR THE DEVELOPMENT
OF SMALL WIND SYSTEMS

Annual Report for October 1, 1977—September 30, 1978

MASTER

February 1979

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

Rockwell International
Energy Systems Group
Canoga Park, California

U.S. Department of Energy

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**TECHNICAL AND MANAGEMENT SUPPORT
FOR THE
DEVELOPMENT OF SMALL WIND SYSTEMS**

**Annual Report for the Period
October 1, 1977 - September 30, 1978**

February 1979

**Prepared by the
DOE Rocky Flats Wind Systems Program**

**Operated by the
Rockwell International
Energy Systems Group**

**As part of the
U.S. DEPARTMENT OF ENERGY
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ABSTRACT

The FY 1978 Annual Report of the Rocky Flats Wind Systems Program describes the objectives, approach, and achievements of the program and each of its task areas during the period October 1, 1977 - September 30, 1978. During this period, additional testing of ten small wind energy conversion systems (SWECS) was conducted and the Test Center was expanded to accommodate up to 30 SWECS. Work on nine design and analysis projects for advanced prototypes in three size ranges progressed through a series of design reviews, with prototype delivery scheduled to begin in mid-1979. Supporting activities included a Systems Engineering project which analyzed the cost of SWECS components and fabrication, a task effort in technical support to standards development, and the dissemination of information. Planning for a SWECS field evaluation program and two new task areas involving special studies and supporting research and technology (SRT) was conducted.

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EXECUTIVE SUMMARY

Program Objectives and Organization

The Rocky Flats Wind Systems Program, managed for the U.S. Department of Energy (DOE) by the Rockwell International Energy Systems Group, provides technical support to the DOE Federal Wind Energy Program for the development of Small Wind Energy Conversion Systems (SWECS).

The primary objectives of the Rocky Flats (RF) program during FY 1978 were to stimulate the development of SWECS by the private sector and accelerate the utilization of these systems by the public. The strategy employed to achieve these objectives was to perform testing, system development, and systems engineering efforts designed to improve the reliability and decrease the cost of SWECS. To carry out this strategy, the program was organized under eight task areas, as follows:

- Task 0 - Program Management
- Task 1 - Test Center Establishment
- Task 2 - Test Center Operations
- Task 3 - Systems Engineering
- Task 4 - Technology Development
- Task 5 - Standards
- Task 6 - Information Dissemination
- Task 7 - Planning

Program Achievements During FY 1978

TASK 0 - PROGRAM MANAGEMENT

Early in FY 1978 the RF Program was organized under the eight task areas described in this report. Monthly administrative reports were provided to DOE regarding progress under these task areas, quarterly reviews were presented and liaison was maintained with the DOE Wind Systems Branch and the DOE Rocky Flats Area Office.

Specific directions from DOE to expand the scope of the RF Program resulted in the identification of new tasks, including Field Evaluation, Special Studies, and Supporting Research and Technology. The program was reorganized late in FY 1978 into 11 task areas to accommodate the additional efforts.

TASK 1 - TEST CENTER DEVELOPMENT

During FY 1976, DOE authorized the establishment of the Small Wind Systems Test Center (WSTC). Since that time the primary activities have been establishing the site, installing towers and wind turbines, and initiating testing and data collection. During FY 78, the emphasis was on testing commercially available machines under natural wind conditions. Other testing capabilities being developed include: component tests, system tests, and environmental tests.

The test center is located on the northwest corner of the Rocky Flats plant site approximately 15 miles northwest of Denver, Colorado, between Golden and Boulder. Since the test center site is on a large flat plains area facing a mountain pass, the wind regime provides a large variety of conditions, from gentle breezes to hurricane-force wind storms. The high wind conditions predominate from the northwest, and, therefore, the WTG tower arrangement was laid out with the rows oriented perpendicular to that direction. Roadways and general construction have been kept to a minimum, in line with a general policy of preserving the natural state of the area as much as possible.

Wind turbine generator towers, associated data acquisition systems, and WTG power output control equipment for 12 sites have been installed, and are operational. Three sites were added during FY 1978. Fifteen additional towers and control sheds will be installed during early FY 1979.

Figure 1
Rocky Flats Small Wind Systems
Test Center Location

Figure 2

Layout of Rocky Flats Small Wind Systems Test Center - Sept. 30, 1978

Wind speed and direction data were also taken at each WTG tower site. The anemometers are generally located on booms approximately 1-1/2 to 2-rotor diameters below the WTG hub height, and provide input to the data collection system.

The data acquisition system was made fully operational during FY 78. It consists of a signal generation and conditioning subsystem, an analog to digital conversion subsystem, a central computer used for overall system control, data acquisition, and permanent data storage. The electrical analog signals generated from sensors mounted on each WTG are routed to microprocessors housed in an instrumentation and power control shed located at the base of each WTG tower. This microprocessor converts the analog signal to a digital signal, performs preliminary calculations, and temporarily stores the digitalized information. The Central Control and Storage computer interrogates each microprocessor at the test site on a scheduled basis, acquires the data, and permanently stores it on digital tape for subsequent analysis.

The WTG power control and storage subsystem consists of a microprocessor control unit and a resistor bank located in the shed at the base of each tower. In addition, there is a 120 V central power storage bank which consists of 60 deep discharge 2 V batteries with a capacity of 1760 ampere hours.

TASK 2 - TEST CENTER OPERATIONS

A major objective of the activities at Rocky Flats is to test small wind energy systems over a wide range of actual environmental conditions. The data collected from this testing will:

- o Provide consumer information for potential buyers of small wind systems.
- o Provide detailed engineering data for use by developers, manufacturers, and researchers of small wind systems.

Quantitative as well as qualitative data were collected during FY 1978. The qualitative data included information on the condition in which a machine was received from the manufacturer, usefulness of operating manuals, installation difficulties which were encountered, and operational experience. During the testing process, Rocky Flats personnel interfaced directly with the manufacturers of machines under test to discuss problems encountered and provide them with current operational data. In several instances, this interface resulted in the redesign and retrofiting of WTG's under test.

The collection of quantitative technical data was implemented by gathering both long-term and intensive testing data. Machines and towers installed and operated as of September 30, 1978, are listed in Table I.

Actual test experience with these systems varied from machine to machine. Problems have ranged from cracks in tail vane assemblies to loss of blades. As a direct result of test center experience at Rocky Flats, two manufacturers have redesigned portions of their systems. One other manufacturer has made modifications to its machine based on input from Rocky Flats as well as from other owners. Thus, it can be seen that test center experiences have already had a positive effect on the industry, with the result being improved hardware.

Long-Term Data

Long-Term Data results from continuous testing 365 days a year. The data collected were restricted to two areas of interest: (1) basic machine performance (rotor rpm, generator voltage and amperage, etc.); and (2) the general wind characteristics (velocity, direction) in which the machine operated during the test period.

TABLE I

Commercial SWECS Being Tested At Rocky Flats
(September 30, 1978)

<u>Position</u>	<u>Tower</u>	<u>WTG</u>
(See Figure 3)		
1.1	Dunlite 12m (40-ft)	Dunlite 2 kW
1.2	Aermotor 12m (40-ft)	Altos 1.5 kW*
1.3	Octahedral 40-ft 12m	North Wind Eagle 3 kW
1.4	Concrete pole 12m (40-ft)	Kedco 1.2 kW
1.5	Rohn 25g 12m (40-ft)	Sencenbaugh 1 kW
1.6	Wood pole 12m (40-ft)	---
2.1	Swing tower 17m (55-ft)	---
2.2	Concrete pole 17m (55-ft)	Grumman 15 kW
2.3	Rohn SSv 17m (55-ft)	Zephyr 15 kW
2.4	Rohn 80g 17m (55-ft)	American Wind Turbine 2 kW*
2.5	Steel post 17m (55-ft)	Elektro 6 kW
2.6	Rohn SSv 17m (55-ft)	---
Stock Tank	Sparco	Sparco*
	Scheduled for Installation in Early FY 1979	Millville 10 kW Aeropower 1 kW Pinson Cyclo- turbine 2 kW Mehrkam (40 kW)

*Installed during FY 1978.

Intensive Testing Data

Detailed information was also obtained relative to structural and/or performance characteristics of wind system components during periods of high winds and/or unusual environmental conditions. The high volume of data collected during intensive testing periods was obtained from strain gages, accelerometers, and thermocouples. Measurements were made in such critical components as blades, rotor shafts, gearboxes, and towers. While considerable intensive testing data were collected during FY 1978, the ability to analyze these data was just being established at the end of the fiscal year.

SWECS tested at Rocky Flats are classified into three broad categories. The first category is the "commercially-available" machine. If the manufacturer has sold and delivered at least three units, and of these three, at least one has been installed and made operational, the machine is considered to be commercially-available. The second type is the "commercial prototype." This category requires that development has proceeded to the stage where at least one machine has been built and has been operated but is not in production. The third category will encompass those machines being developed under government contract. These machines include the 1-2 kW High Reliability, 8 kW, and 40 kW developmental machines. During FY 1978, Rocky Flats tested machines in the first category (commercially available). Candidates for the second category (commercial prototypes), were under consideration at the end of the year. Testing in the third category of machines will commence in the latter part of FY 1979.

TASK 3 - SYSTEMS ENGINEERING

As part of the overall small wind systems development program, a need was identified to define those areas requiring further study and development which would improve small wind systems performance, reliability and longevity, and decrease system cost. The results of these analyses

will be used to guide and prioritize future subcontracted R&D efforts at Rocky Flats.

A study was initiated to examine the wind turbine generators under test at Rocky Flats. The study concentrated on determining the characteristics of the components of each machine, including size, weight, material, fabrication methods, and cost.

This task also provided support to Test Center Operations and Technology Development activities on an "as-required" basis. This included support to the establishment of data collection procedures at the test site, the performance of data analyses, and support to the review of Technology Development subcontract activities. The areas of technical expertise included aerodynamics, aeroelasticity, wind characteristics/meteorology, mechanical, and electrical engineering.

TASK 4 - TECHNOLOGY DEVELOPMENT

Under the Technology Development task element of the Rocky Flats Program, outside organizations were funded to develop advanced SWECS to achieve reduced wind-generated energy costs. Three projects are currently underway to design and build prototype 1-2 kW, 8 kW, and 40 kW WTGs for test at Rocky Flats (see Table II).

Needs had been identified for low cost SWECS of approximately 8 kW output for home or farm use. Also, numerous applications exist in deep well irrigation, general farm/ranch applications, and for small isolated communities and industries for a machine of 40 kW output. Low system cost is particularly vital in each of these cases. The third major need was for a high-reliability system, developing approximately 1-2 kW, for remote locations where the cost of installing and maintaining conventional power systems is high. Possible applications in this category are communications repeater stations, pipeline galvanic protection, remote seismic monitoring stations, and offshore navigational aids.

TABLE II

Specifications of Advanced SWECS Under Development

Contractor	kW @ 20 mph*	Configuration	Rotor Size	WTG Weight (lbs)	Tower Weight (lbs)
<u>1-2 kW (High Reliability) Systems</u>					
Enertech	2.3	2-blade horizontal axis downwind	16.4 ft dia.	350	300
North Wind	2.0	3-blade horizontal axis upwind	16.4 ft dia.	325	300
Aerospace Systems, Inc.	1.0	3-blade vertical axis cyclo-turbine	15 ft dia. x 8 ft high	508	N/A
<u>8 kW Systems</u>					
Windworks	8.0	3-blade horizontal axis downwind	31 ft dia.	1600	2362
United Technologies Research Center	9.0	2-blade horizontal axis downwind	31 ft dia.	1855	2619
Alcoa	11.0	3-blade vertical axis Darrieus	33 x 34 ft	10,480	---
Grumman	11.0	3-blade horizontal axis downwind	33.25 ft dia.	2540	N/A
<u>40 kW Systems</u>					
Kaman Aerospace Corp.	40.0	2-blade horizontal axis downwind	64 ft dia.	4900	4000
McDonnell Aircraft Corp.	40.0	3-blade vertical-axis giro-mill	32.5 ft x 65 ft	N/A	N/A

*Measured at hub height.

Contracts were awarded in 1977 for the 1-2 kW and the 8 kW projects. Two 40 kW contracts were awarded in late FY 1978. Multiple awards were made, with small business participation in both the 8 kW and High Reliability Programs. The prototypes fabricated under the projects will be tested at Rocky Flats beginning in FY 1979.

TASK 5 - STANDARDS

The objective of this task is to provide technical support for the formation of consensus standards by private industry and their acceptance in the manufacture, product testing, and reporting of data on small wind systems. The development of these standards will aid in the acceptance of small wind systems by consumers, by the financial and insurance industries, and by utilities with which SWECS will be interconnected.

During FY 1978, a workshop was held to obtain inputs from the technical community regarding standards for testing, data reduction, and reporting. A plan for RF support to standards development was drafted, which identified the American Wind Energy Association (AWEA) as private industry's focal point for the development of SWECS consensus standards.

TASK 6 - INFORMATION DISSEMINATION

Work under this task involved the dissemination of technical and consumer information produced by the entire Rocky Flats Wind Systems Program to potential users, SWECS manufacturers/suppliers, and other DOE agencies and programs. This effort was designed to increase awareness of the potential uses of small wind systems. A general objective of this task was to develop at Rocky Flats a contact point and information center for all available small wind systems data.

Four reports were completed during FY 1978. One report was available from the National Technical Information Service (NTIS). The other three were awaiting DOE printing at the end of the fiscal year. In addition, four reports were in preparation at the end of the year, including the FY 1979 Program Summary, the First Semiannual Report from the WSTC and two Phase I design reports from Technology Development subcontractors.

Information was provided to consumers through correspondence, the exhibition of displays at conventions and fairs, and regular guided tours of the Test Center. Brochures and special information packages were prepared and disseminated in response to inquiries.

Over 500 items were added to the SWECS library. The library was used extensively by RF personnel and in the answering of written or phoned consumer inquiries.

TASK 7 - PLANNING

The expansion of the RF program has involved the preparation of comprehensive long-range and operational plans for achieving program objectives. A workshop was conducted in late FY 1978 to obtain planning inputs from the wind energy community for development of the Supporting Research and Technology (SRT) and Special Studies sections of this program plan.

Program Plans for FY 1979

FY 1979 will see an expansion of the advanced small machine development and test program managed by Rocky Flats. At the test site, atmospheric testing already underway will be supplemented by vibration testing of SWECS and subassemblies, dynamometer testing of the SWECS generator/gearbox assembly, controlled testing, and environmental chamber testing.

The first series of 1-2 kW, 8 kW, and 40 kW advanced machines will be delivered to Rocky Flats for testing in mid and late 1979. Requests for Proposals (RFP's) for 15 kW and 4 kW design competitions were expected to be issued early in 1979. It is anticipated that additional machines will be obtained through competitive design procurements as development needs and requirements are defined by marketing and application studies and the results of ongoing tests at Rocky Flats. Additions to the test site are already underway with an expansion of the data acquisition system and the number of test pads required to accommodate the new machines.

A major effort in SWECS Supporting Research and Technology will be initiated by Rocky Flats in FY 1979. A series of competitive procurements will be used to subcontract research on SWECS dynamics, mechanical and electrical characteristics, aerodynamics, and various components which have a significant influence on SWECS costs.

To enable the collection of data and operational experience under widely different environmental conditions, a Field Evaluation program is being planned. The major objectives of this program are (1) to aid in establishing institutional and technical procedures for interconnecting small wind systems with utilities and accelerating the establishment of a standard rate structure for such applications, and (2) to stimulate the small wind systems industry. The program would involve the installation and testing of commercially-available and prototype wind turbines at selected user sites. Details on this program will be widely advertised in FY 1979.

SWECS market studies, institutional studies, and a study of the operational aspects of interconnecting large numbers of dispersed SWECS with utility systems will begin in FY 1979 under the new RF Special Studies task. Technical support to standards development will begin with an analysis of the impact of standards, which will define the types of standards which would benefit the industry, consumers, various institutions, and utilities.

A comprehensive information dissemination plan will be developed to promote the use of small wind systems and provide pertinent product information generated by the Test Center and the planned field evaluation program. Annually updated guides to available systems, updated user's guides (designed for use with small WECS siting handbooks prepared by Battelle-Pacific Northwest Labs) and information and data packages for various classes of small wind turbines and related products will be made available to manufacturers, consumers, researchers, and others.

In coming years, the focus of the Rocky Flats Wind Systems Program will be on the development of cost-competitive hardware, the development of a solid technology base and a sound SWECS industry, the resolution of barriers to SWECS commercialization, and the dissemination of information vital to promoting the use of small wind systems.

1.0 INTRODUCTION

Operated by Rockwell International, the Rocky Flats Wind Systems Program provides technical and management support to the Department of Energy (DOE) for the development, testing, and commercialization of small wind systems (machines with an output of less than 100 kW) designed primarily for farm, home, and rural use.

The Federal Wind Energy Program (FWEP), under which the Rocky Flats (RF) program is funded, is designed to support the earliest possible commercialization of wind power to help meet national energy requirements. At RF, this goal is being pursued by simultaneously developing advanced small wind systems, addressing the technical, economic and institutional requirements for their use, and stimulating their commercial utilization. This document summarizes the RF Wind Systems Program activities during FY 1978 toward achieving these objectives for the small wind systems component of the FWEP.

Widespread utilization of small wind energy conversion systems (SWECS) is dependent upon these systems achieving energy costs competitive with the cost of power obtained from conventional sources. But the achievement of competitive costs (by whatever means) will not in itself assure widespread SWECS use if consumer and institutional acceptance has not been achieved. A close coupling of SWECS testing and development activities with research projects oriented toward potential uses for wind power is required to develop the SWECS industry and create an institutional and consumer environment conducive to SWECS commercialization.

2.0 PROGRAM OBJECTIVES AND ORGANIZATION

The RF Wind Systems Program objectives are:

- o Stimulate the development and manufacture of SWECS by the private sector.
- o Accelerate the utilization of SWECS by the public.
- o Provide program support to the FWEP as required.

The program ground rules which were established to avoid duplication of effort and insure compatibility with other DOE programs are as follows:

- o RF involvement will be in small wind systems, generally not exceeding 100 kW output.
- o At least 50% of the program funds will be expended outside RF in subcontracts and/or purchase orders with strong emphasis on small business participation.
- o RF will not produce commercial machines for sale. The RF DOE facility is operated and managed by the Energy Systems Group of Rockwell International under cognizance of the DOE/Rocky Flats Area Office (RFAO). As a government facility, RF will not compete with industry.
- o RF will be involved in all aspects of small wind systems hardware (machines, towers, electrical controls/interface, mechanical/ hydraulic systems, etc.) as well as studies to support SWECS development and use. Energy storage systems will not be developed under this program unless they are uniquely related to wind energy.
- o RF will participate with related DOE programs such as the one being conducted by USDA. Results of USDA field activities to demonstrate the feasibility of various agricultural applications will be factored into the technology development programs being managed by RF.

During FY 1978, eight task areas were identified to meet the RF Program objectives. Implementation of these tasks was assigned to a Program Manager and Functional Managers, as shown in Figure 1. The Wind Systems Program is managed under a matrix-type management system whereby program requirements are assured 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.

The function of each task area during FY 1978 is described briefly below:

TASK AREA	FUNCTIONS
TASK 0 - PROGRAM MANAGEMENT	Provided program management functions through a matrix-type organization structure. Interfaced with and reported to DOE/WSB and RFAO.
TASK 1 - TEST CENTER ESTABLISHMENT	Provided facilities and testing capability required for Test Center Operations (Task 2).
TASK 2 - TEST CENTER OPERATIONS	Tested commercially available systems. Provided machine reports and data for dissemination to consumers, manufacturers, and others.
TASK 3 - SYSTEMS ENGINEERING	Provided specialized technical support to other task areas.
TASK 4 - TECHNOLOGY DEVELOPMENT	Worked to develop advanced SWECS of various sizes.
TASK 5 - STANDARDS	Assisted private industry in planning efforts to develop consensus standards; obtained technical inputs from Test Center Operations, Technology Development, and other task areas.
TASK 6 - INFORMATION DISSEMINATION	Processed and distributed all technical and program reports, wind machine data, articles and other materials produced under other task areas. Coordinated workshops, answered correspondence, and prepared and disseminated special information packages.

TASK AREA	FUNCTIONS
TASK 7 - PLANNING	<p>Provided long-term and operational planning for RF program activities. Prepared planning documents for transmittal to DOE.</p>

3.0 PROGRAM PROGRESS

3.1 PROGRAM MANAGEMENT

3.1.1 Objective

The objective of this task is to provide the general management functions necessary to achieve rapid commercialization of SWECS in support of the Federal Wind Energy Program. These management functions included planning, budgeting, staffing, directing, and tracking all activities identified in this plan as necessary in accelerating the commercialization of SWECS.

The numerous companies, personnel, disciplines, and tasks involved in the program were organized and utilized in a manner which insured achievement of program objectives within constraints of budgets and schedules.

3.1.2 Approach

Program Management was carried out using the matrix organization shown in Figure 3. The following management tasks were performed:

- o Organization of task activities and responsibilities to insure a timely and cost-effective achievement of program objectives.
- o Directing and controlling all program activities to assure adherence to the scope of work. This included awarding and managing subcontracts as required, conducting technical liaison with the DOE Wind Systems Branch, administrative/liason with RFAO, and providing regular monthly administrative reports and other management tools required by DOE.

- o Staffing the program within prescribed budget limitations with qualified and capable personnel to insure the effective performance of assigned work.
- o Day-to-day coordination and monitoring of program activities.

3.1.3 Achievements

Several additional activities were added to the scope of the program in 1978. With the support of industry, Rocky Flats has taken the leadership role in planning and developing a national field evaluation of SWECS. Pending DOE approval, the program will initiate actual hardware purchases and site selection in FY 1979. Extensive discussions with industry also resulted in initiation of activities relative to conducting needed market analyses and application studies. While contract awards will not be made until 1979, definition of these special studies was begun in 1978. The data becoming available from the national SWECS Test Center and the various wind system development contracts indicated that some technology areas could benefit from concurrent, supportive research work. Consequently, a new task called Supporting Research and Technology was defined in 1978 with contracts to be awarded in 1979. The organizational changes made to incorporate these new endeavors are shown on the organization chart provided in Section 5.0.

The evolutionary aspects of 1978 events prompt some additional conclusions regarding the Rocky Flats role relative to all other FWEP participants. In working with and funding expanded activities of the American Wind Energy Association (AWEA), RF has established a communication forum and clearing center for program and budget planning within the SWECS community. This has facilitated RF's working with DOE Headquarters in the planning/management of the federal SWECS budget. Expanded leadership and guidance activities have also been manifested in the increased channeling of international participants through Rocky Flats.

Since the commercialization of SWECS requires the involvement of participants regardless of differing needs or national boundaries, it is anticipated that continued progress in these areas through 1979 will bring the FWEP substantially closer to realizing its primary program objectives.

Figure 3
Rocky Flats SWECS Program Organization During FY 1978

3.2 TEST CENTER ESTABLISHMENT

3.2.1 Objectives

The RF Small Wind Systems Test Center (WSTC) is designed to provide a facility for testing commercially-available SWECS as well as prototypes developed by governmental or private funding. The original objectives for establishing the center were to:

- o Provide consumer information for potential buyers of SWECS.
- o Provide a broad, accurate engineering data base for use by the engineer and developer of SWECS.

While these basic objectives have remained unchanged, additional uses of data from SWECS -- by utilities, manufacturers, financial and insurance organizations, and others -- are now recognized.

3.2.2 Approach

The capability for atmospheric testing of SWECS was achieved in FY 1978. Work is now underway or planned to provide additional testing capabilities, including:

- o Vibration Testing of SWECS and Subassemblies.
- o Dynamometer Testing of SWECS Generator/Gearbox.
- o Controlled Testing of SWECS.
- o Environmental Chamber Testing of SWECS and Subassemblies.

The test facility provides appropriate power management and SWECS loading requirements with an onsite energy storage capacity, public utility interties, and a microprocessor-controlled resistive load application.

Position	SWECS
1.1	Dunlite (2 kW)
1.2	Altos (1.5 kW)
1.3	North Wind Eagle (3 kW)
1.4	Kedco (1.2 kW)
1.5	Sencenbaugh (1 kW)
2.2	Grumman (15 kW)
2.3	Zephyr (15 kW)
2.4	American Wind Turbine (2 kW)
2.5	Elektro (6 kW)
Stock Tank	Sparco (Water Pumper)

Figure 4. Rocky Flats Small Wind Systems Test Center

Automated data acquisition, management analysis, and presentation (plotting, etc.) are an integral part of the testing activity and are accomplished by two interrelated systems:

ECDAS - A digital data acquisition system

ADAS - An analog data acquisition system

3.2.3 Achievements

Test Site Development

A national Small Wind Systems Test Center (WSTC) has been established. The center consists of 12 individual test sites, two meteorological towers, a data acquisition system, a power distribution network, and support facilities.

The individual test sites consist of a support pad (foundation), a tower, and a utility shed. The utility sheds contain data and power junction boxes from which data and power may be directed to various locations on the Test Center. Also contained in each shed is a microprocessor which provides for:

- o Preprogrammed SWECS loads.
- o First stage of data acquisition, analogue to digital conversion, and temporary storage.

An anemometer to measure wind speed and direction is also installed at each test site.

The data acquisition system consists of the microprocessor located in each shed, the interconnecting data bus, and a NOVA 3/12 computer. The computer provides the main function of overall data system control and permanent digital data recording. Limited analog data collection capability also exists. Planning is currently underway to expand both the digital and analog systems.

The entire data acquisition system is powered from a Motor-Generator (MG) set and battery storage system. The battery system is charged by the SWECS under test with the public utility as the backup.

At the end of FY 1978, construction was underway to expand the number of test sites to 30. Also underway was the planning of:

- o Additional testing capability to include vibration testing, dynamometer testing, and acoustic testing.
- o An expanded M-G/Battery system.
- o An expanded digital and analog data acquisition system.
- o An expanded power bus.
- o A WSTC building.

Instrumentation/Calibration

Calibration of all instruments is performed before testing. The objective of the calibration effort is to provide reliable data with an assignable accuracy. The desired accuracy is plus or minus 3% overall and for every parameter being measured.

Software Development

Microprocessor Software

The two main functions of the microprocessor are data collection and load control. A third necessary function is communications with the NOVA Computer.

The microprocessors loop continually, collecting data from up to 16 analog channels. Each new value for any channel is added to the sum of previous values until the NOVA asks the micro for data. Then the values in the micros "ready" buffers are sent to the NOVA,

and the values in the "sum" buffers are divided by the number of samples. The "means" thus found are moved into the "ready" buffers. The sum buffers are zeroed out, and the micro goes back to sampling and summing.

The data which the micros collect from their SWECS include:

- Generator Current
- Generator Voltage
- Wind Speed
- Wind Direction
- Rotor RPM
- Yaw Azimuth
- Blade Pitch Angle (if applicable)
- Tail Fold Angle (if applicable)

The load on the SWECS can be controlled by the microprocessor by its switching of eight resistors, which are sized in a binary progression. That is, each resistor draws twice as much power as its predecessor. This allows the load on the SWECS to be adjusted within 0.5% of the rated output of the SWECS. Several algorithms for load control are being developed, including: constant voltage, ramp voltage within limits, constant tip/speed ratio, functions of wind velocity, and constant rpm.

NOVA Software

The NOVA software consists of several tasks which run in the "foreground," several programs which run in the "background," and several files, kept on disk, which contain constants, data, and status.

The foreground tasks actually perform the data collection functions. The background programs are used to communicate with the foreground and to maintain the files.

SWECS Procurement and Installation

Eleven wind turbines were under test at the WSTC at the end of FY 1978. A list of those machines is presented in Table I. Commercially available machines on order at the end of the year are also listed.

In addition, RF has initiated and monitored three programs to design and build prototype High Reliability (1-2 kW), 8 kW, and 40 kW SWECS. A total of nine machines are being developed (see Section 3.5). Each prototype will be tested at the WSTC beginning in the fall of 1979.

Planning

Several major activities are in various stages of planning and implementation at the WSTC as discussed in the following sections.

Site Expansion

Work is currently underway to expand the WSTC by constructing test sites in Rows 3 and 4. Row 3 is designed for testing SWECS having a power rating of up to 40 kW and Row 4 is designated for testing SWECS up to 100 kW. In order to obtain maximum flexibility of testing, the concept of Universal Test Pad (UTP) construction has been pursued. These pads are designed to accept a variety of SWECS and tower configurations.

By October of 1979, as many as 30 wind turbine generators will be up and operational. These generators will be supplying energy in a variety of forms, including 3-phase 480 V ac power, single-phase 110 V ac power, 120 V dc, 24 V ac, and 12 V dc. Total energy output could be as much as 750 kW of power. These machines will be loaded in a variety of ways, including resistive loads, local battery banks, and utility interconnection. Plans are being pursued to provide a power distribution

Figure 5
Planned Extended Computerized Data Acquisition System

network with the sufficient versatility to allow handling of the power generated as well as providing appropriate loading conditions for the various machines.

Also in planning are efforts associated with establishing a power grid onsite. Such a power grid would accept a broad variety of ac voltages and provide power for use at the WSTC, use under prespecified controlled load conditions, and feedback to the local utility.

The specific objectives to be addressed are:

- 1) establishment of the technical requirements for tying SWECS together to form a grid
- 2) provide data relative to the quality of power available from SWECS grid
- 3) provide data relative to the availability and level of power available from a distributed SWECS grid
- 4) obtain experience relative to the interfacing of a SWECS grid and a utility grid
- 5) help define safety considerations associated with a SWECS grid and its interface with a utility grid.

Expanded Data Acquisition System (EDACS)

When normal operations of the current data acquisition system were established, an evaluation of its performance was made in light of near-term and long-term needs. The system limitations were identified.

To overcome these limitations, several system modification alternatives were considered. These alternatives were evaluated and a new system configuration designed. The configuration is presented in Figure 5 and described in the paragraphs below.

The primary purpose of the ECDAS is to collect and analyze data from 35 remote sites. Thirty-two of the sites are SWECS and three sites are wind characteristic towers (WCT).

For reliability and system flexibility, the proposed system will be a hierarchially-distributed system. It is configured with a central computer with three (expandable to four) satellite computers. Each satellite computer will connect to 12 (expandable to 16) data acquisition systems. The central computer and satellite computers will communicate over a high speed, 19K bits/second (minimum) data link. The distance between the central computer and the satellite computers would be 5000 ft or less.

The normal data collection mode is to collect data once per second for each site. The system has the capability of operating unattended over a 3-day weekend.

The central computer and satellite computer will have the capability of adding digital I/O for interfacing with external devices. The satellite computers will have printer/keyboard devices and the central computer will have CRT terminals and a printer/plotter.

3.3 TEST CENTER OPERATION

3.3.1 Objectives

Under this task area, SWECS were tested using the facilities developed under Task 1.

The overall objectives of testing are to:

- o Provide credible information for potential buyers of SWECS.

- o Provide a broad, accurate engineering data base for use by the engineer and developer of SWECS.
- o Develop and define SWECS testing techniques.
- o Provide support activities for:
 - Data acquisition, management, and analysis.
 - Maintenance of SWECS under test and the test facility.

3.3.2 Approach

Testing emphasis during FY 1978 was on the exposure of a SWECS to actual atmospheric conditions and the measurement of its performance. This emphasis was a direct result of the need to provide immediate information to consumers about the performance of commercially-available wind machines.

Atmospheric testing of a SWECS involved appropriate instrumentation of the machine to collect data on its overall performance. The instrumented SWECS was then mounted on a tower at a test site. The SWECS/tower was exposed to the elements during the entire period of testing (see Figure 6).

The collection of data associated with atmospheric testing occurred in two broad categories: (1) Long-Term Data Collection (LTDC), and (2) Intensive Testing Data Collection (ITDC).

All SWECS tested at the WSTC underwent long-term testing. The specific duration of long-term testing was dictated by several factors, but the planned maximum test duration is 2 years. This time frame allows for exposure of the SWECS to two full "wind seasons (late fall and winter)." In addition, this duration:

- 1) assures an adequate number of data points to define a power curve

Figure 6
Typical SWECS Atmospheric Test Configuration

- 2) maximizes the probability of exposure to the entire wind regime available (0-120 mph)
- 3) maximizes the probability of exposure to at least one wind storm of $V > 85$ mph.

If these conditions are satisfied prior to a 2-year period, testing may be terminated. The length of the testing period is also influenced by the objectives of the testing program for a specific machine.

Intensive testing was planned for selected SWECS. The nature of the tests to be conducted during intensive testing will be determined on a case-by-case basis and will depend upon such considerations as:

- 1) Will the data collected be of general interest and use to manufacturers?
- 2) Will the data collected be of specific use to consumers?
- 3) Will the data collected provide a base for future SWECS development?

3.3.3 Achievements

During FY 1978 atmospheric testing data collection was performed on commercially available wind turbines, including nine electrical output systems and one mechanical output water pumper (See Table I). Long-term data collection was performed for all these systems. Intensive data collection was performed in those cases where specific machine characteristics indicated that useful and interesting data would be obtained. A description of each machine tested is provided in Appendix A.

A detailed account of test results for each machine during FY 1978 is contained in the First Semiannual Report, Rocky Flats Small Wind Systems Test Center Activities, Volume II. Generic information on test operations is provided below.

3.3.3.1 Long-Term Data Collection

The primary parameters defined by RF to be descriptive of the machine performance are:

- 1) generator voltage
- 2) generator current, amps
- 3) rotor speed, rpm
- 4) machine yaw angle, degrees.

For a detailed description of the instrumentation sensors currently being used, see the First Semiannual Report, Rocky Flats Small Wind Systems Test Center Activities, Volume I.

3.3.3.2 Intensive Test Data Collection

The intensive testing parameters measured include:

- 1) strains - measured in both fixed and rotating frames
- 2) accelerations - measured in both fixed and rotating frames
- 3) forces/moments - measured in both fixed and rotating frames
- 4) operating temperatures of critical components.

For a detailed description of the sensors currently being used, see the First Semiannual Report, Rocky Flats Small Wind Systems Test Center Activities, Volume I.

3.3.3.3 SWECS Atmospheric Testing

Actual atmospheric testing of the SWECS began after appropriate checks were made of the installation of instrumented SWECS, the hookup of power and data lines, the operation of hardware/software systems, the validity of calibrations, and overall machine operation.

LTDC was performed on a 24 hours per day, 7 days a week basis. Daily checks of each SWECS were made for purposes of checking operational status, filling appropriate logs, and checking calibrations and data collection.

During high wind periods, a test engineer and data acquisition engineer were always present at the site to observe wind and SWECS conditions and to assure that the data acquisition system was functioning.

3.3.3.4 Data Analysis and Interpretation

Long-Term Data Analysis

The Long-Term Data Collection System acquired a substantial amount of data on a routine basis. Software to analyze, compile, and store this data in a highly compressed form is under development at this time.

The primary method of analysis of long-term data used during FY 1978 at the WSTC is known as the "Method of Bins." This method has been described in detail in a report by Akins (1978). The method of bins can best be described with an example. To generate a curve of SWECS power as a function of wind speed (from a time history of power and wind speed such as the LTDC records) consider wind speed the independent and power the dependent variable. Wind speed is broken down into a number of intervals, or "bins," of 1 m per second width. For every occurrence of wind speed within a given bin, the power associated with that wind speed was accumulated into an average for that bin. At the end of the sorting and averaging, the number of events in each bin was normalized to yield the wind speed probability density function. The average power in each bin represented the power that would be extracted by the SWECS from a wind within the given interval. For example, given ten data points as shown in Table III, the method of bins gave the results shown in Figure 8. The standard deviation of all the power values accumulated in a given bin was also calculated for each bin. The standard deviation can be

Figure 7
Data Lines Schematic

expected to be a function of the WTG response time and the wind turbulence characteristics as well as the data sampling and averaging times.

The method of bins analysis was run on all data taken with the LTDC System. The analysis was performed with the following pairs of variables:

- 1) Power vs. wind speed.
- 2) RPM vs. wind speed.

TABLE III

Method of Bins Accumulation (See Figure 8)

<u>Wind Speed</u>	<u>Sum of Power</u>	<u>Number of Occurrences</u>	<u>Mean</u>
1	3	2	1.5
2	7	2	3.5
3	20	3	6.7
4	8	1	8
5	23	2	11.5

Intensive Testing Data Analysis

Intensive test data were collected but not analyzed during FY 1978. By its very nature, intensive data are not amenable to a highly structured analysis system such as that used on the long-term data. Therefore, a series of utility software routines will be generated to allow test engineers to specify a flexible variety of analyses tailored to each SWECS. Among these routines will be the ability to calculate:

- 1) mean, maximum, minimum, standard deviation, and probability density function of any time series;
- 2) energy spectrum and autocorrelation of any time series;
- 3) cross-spectrum and cross-correlation between any two simultaneous time series;
- 4) transfer function between any pair of time series.

Plotting and tabulation routines will also be available. Specialized equipment such as a modal analyzer will be used for specific analyses to complement and supplement the above analyses.

- 3) C_p vs. Tip/speed ratio.
- 4) The difference between rotor and wind azimuth vs. wind speed.
- 5) The difference between rotor and tail azimuth vs. wind speed (where applicable).
- 6) Blade pitch angle vs. wind speed (where applicable).

The standard deviation within each bin was also calculated for each dependent variable.

The results of the above analyses plus the probability density function for every measured variable were stored in permanent files on computer mass storage. A typical analysis covered a 1/2-hour measurement

Figure 8. Power as a Function of Wind Speed

period. A series of utility subroutines will be developed to allow scanning of files, combining a number of files, comparing files, etc., to develop a long-term view of a machine's performance.

In addition to a method of bins analysis of all of the long-term data, a number of calculations of cumulative totals were made. At a minimum, the total energy produced by the WTG, the total hours of running, and the total number of rotor revolutions were calculated from the long-term data.

A second method of data analysis, called frequency-matching, will compare with the method of bins. Frequency-matching involves the matching of equal cumulative probabilities of occurrence of two variables, such as power and wind speed. The probability density functions calculated and stored in each method of bins analysis will be available for this type of analysis whenever desired.

Data Interpretation and Theoretical Modeling

The meaningful interpretation of long-term and intensive testing must rely heavily upon comparisons with theoretical models of SWECS performance. By the same token, development and improvement of theoretical models must rely heavily upon comparisons with reliable data. Thus, the goals of model development and data interpretation are inseparable and must be pursued simultaneously. Toward this end, RF has begun acquisition of a number of theoretical models covering subjects ranging from aerodynamic, to structural, to control system analyses.

The aerodynamic performance program written by Wilson, Lissaman, and Walker (1976) was made operational on the time-sharing computer terminal RF has with the Bureau of Reclamation in Denver. This program uses strip theory to predict steady-state performance of a propeller-type WTG.

The Bureau of Reclamation computer service supports the Structural Analysis Program (SAP)4 and SAP5. These programs will be available for analysis of towers and WTG components at the WSTC.

A variety of programs are being developed by other organizations under contract to the Department of Energy, Wind Systems Branch. Included are control systems models, simplified structural and aerodynamic programs, and aerodynamic and optimization codes for Darrieus rotors. These programs will be used at Rocky Flats as they become available.

3.4 SYSTEMS ENGINEERING

3.4.1 Objective

The objective of this task was to examine current small wind systems and identify those component design modifications or improvements which can significantly lower the overall system cost or result in markedly improved performance, reliability, or longevity. Attention was also given to the materials and methods of construction used in component fabrication to determine their effect on these factors. The results of these studies were used to guide and prioritize subcontracted R&D efforts of the RF Program.

3.4.2 Approach

A subcontractor began an examination of small wind systems which are currently in production and which are in the advanced prototype stage. Foreign as well as United States manufactured systems are being analyzed during this study.

Manufacturer's engineering drawings, specifications, and whenever possible, cost and performance data were used in this evaluation. In addition, actual hardware were examined at the RF Test Center.

Contact with manufacturers was undertaken with their consent when additional fabrication data was needed. Manufacturers also provided information on manufacturing costs, quality control procedures, and product testing facilities.

The analysis examined component designs, identifying deficiencies as well as over-designed parts. Component parts were studied to determine if maximum use was made of standard readily available, high volume parts such as bearings, flanges, shafts, fasteners, etc. The materials used in component construction were compared with those suggested by normal practice. The compatibility of adjoining materials was examined in light of possible galvanic corrosion, galling, and thermal expansion problems which could affect the integrity or performance of the component.

Methods used in the manufacture of specially built components were reviewed for adaptability to high volume production. Alternate means of fabrication which appear to offer cost advantages were being considered. Quality control of the fabrication and assembly operations and also the product testing procedures were also examined.

3.4.3 Accomplishments

A contract was issued to J. P. Sayler and Associates in June 1978, for the analysis of six wind turbines which were then available for inspection. The following tasks were completed during the last quarter of FY 1978.

- 1) Physical examination of the wind turbine hardware.
- 2) Review of the available manufacturer's engineering drawings, specifications, costs, and performance data.
- 3) Evaluation of component design, identifying deficiencies, and over-designed parts.

- 4) Evaluation of manufacturing methods employed by the manufacturer and their adaptability to high volume production.
- 5) Evaluation of the quality of components and assemblies.

The contractor will complete the following three tasks in FY 79:

- 1) Estimate production costs for the 10th, 100th, 1,000th, and 10,000th unit based on large quantity, parts/material purchases, and the use of appropriate learning curves for fabrication and assembly labor hours.
- 2) Conduct parametric analyses to determine a realistic projection of costs for future SWECS developments based on such factors as system weight, rotor diameter, power output, and system type.
- 3) Write a final report documenting the results of the study. The report will provide recommendations for additional development work in the design, material, or methods used in the fabrication of components which might be effective in reducing SWECS costs and improve reliability and/or performance.

3.5 TECHNOLOGY DEVELOPMENT

3.5.1 Objectives

The primary objective of this task is to develop reliable SWECS in a number of size ranges to meet a variety of applications needs at costs competitive with conventional energy sources. Another objective is to develop supportive technology for use by designers and manufacturers in providing these wind systems.

3.5.2 Approach

Commercially-available SWECS are too high-priced to generate energy at a cost competitive with conventionally fueled sources. In addition, there are a number of high potential applications for which suitably sized wind systems do not exist. Finally, experience to date has shown much need for improving reliability before SWECS will have widespread appeal. A need exists, therefore, to develop dependable and cost-effective wind systems in a number of size ranges.

Initial efforts to meet this need have involved a systems approach. Requests for Proposals (RFPs) were issued to design and build prototypes for evaluation at the Rocky Flats Small Wind System Test Center in three system sizes. One would produce 1-2 kW in a 9 m/s (20 mph) wind and be designed for high-reliability operation at remote sites. This system would have 24 V dc output. A second would produce 8 kW in a 9 m/s (20 mph) wind and be designed primarily for tie-in with a utility for small farm and other rural applications. An option to the design would provide for stand-alone operation utilizing dc power. The third size wind system would generate 40 kW in a 9 m/s (20 mph) wind in two general output configurations, mechanical and electrical. In the case of electrical output, the system would be designed for tie-in with a utility and also for stand-alone applications requiring a 60 Hz power source. These 40 kW systems would be capable of meeting some irrigation, small industry, or isolated

community energy needs. General design specifications and goals for all three system sizes are listed in Table IV.

Multiple contracts were awarded to develop each size system: Three for the 1-2 kW, four for the 8 kW, and two for the 40 kW. Four of the nine awards went to small businesses. Each contract is being performed in two phases covering (1) design of the system based on extensive trade-off studies and technical analyses, and (2) prototype construction. Emphasis is being placed on meeting system cost goals as well as wind, environmental, and lifetime design criteria.

Information on the design analyses conducted and prototype fabrication and testing will be made available to researchers, designers, and manufacturers to aid in improving the state-of-the-technology. Involvement of private industry in the development of prototype SWECS will provide this industry with proven machine designs ready for the final design revisions, which can result in marketable hardware.

In addition to the systems development efforts, a contract was underway with the University of Massachusetts to continue their investigation of the feasibility of using wind energy for space heating. This work was started under contract with the National Science Foundation (NSF) in 1975 and was subsequently transferred to the DOE wind program for administration by Rockwell.

3.5.3 Achievements

During the past year, one SWECS development contract has completed the design phase and five others are nearly to this point. A protest on the 40 kW procurement caused a delay in awarding these two contracts until late in the fiscal year, so the projects are just getting underway. Work on the Alcoa 8 kW contract is on hold pending a decision on how best to proceed. Prototypes of the 1-2 kW, 8 kW, and 40 kW systems are scheduled for delivery at Rocky Flats during 1979 and early 1980.

Design work by the contractors developing the various systems will be discussed in paragraphs below. Summaries of design characteristics for each size wind system are presented in Tables V, VI, and VII. More complete design characteristics are given in Appendix B, wherein changes at each design review which has been completed (Preliminary, Critical, and Final) can be identified. All data shown should be considered tentative, pending completion of each contract. Figures show artists' renditions of the designs. These are based on early stages of each design and do not reflect subsequent modifications. However, basic design features and appearance are fairly accurately indicated.

3.5.3.3 1-2 kW High-Reliability SWECS

The three 1-2 kW size systems reflect the widest range of design approaches. Enertech's downwind horizontal-axis machine uses blade pitch control, while the North Wind Power upwind horizontal-axis design features a fixed-pitch rotor which tilts back to a horizontal position, parallel to the tail boom, in high winds. In the ASI/Pinson vertical axis design, each blade cyclically oscillates over a small angular range throughout each rotor revolution, as opposed to a Darrieus design where the blades are rigidly fixed to the rotor shaft.

These machines are being designed for unattended operation and to survive in extremely harsh wind and environmental conditions, such as gusting winds to 165 mph, temperatures to -94°F, ice, and hail. These conditions are expected at remote television and radio repeater/relay stations, galvanic protection stations for oil/gas pipelines, and some remote cabins or small homes. During Phase I, analyses and trade-off studies were conducted to size the machines. Alternate designs were evaluated in the 1-2 kW size range for the required 24-volt battery charging capability. As a result of these analyses, Enertech and North Wind selected 2 kW designs, while ASI selected a 1 kW. In each case, the contractor has justified his selection in terms of performance, reliability, and cost factors. Each contractor also performed extensive

TABLE IV: SWECS DESIGN SPECIFICATIONS AND COST GOALS

Program	Minimum kW Output @ 20 mph*	System Life	Output Power Type	System Includes	System Cost Goal - 1000th Unit FOB (Factory)
HIGH RELIABILITY	1-2	25 Years	24 V dc for Charging Batteries	All Components Except Tower	\$1500/kW**
8 kW	8	25 Years	120/240 V ac 60 Hz Utility Tie-In	All Components Including Tower Except Synchronous Inverter	\$750/kW**
40 kW	40	25 Years	440 V ac 60 Hz for Utility Tie-In and Stand Alone; Separate version for Mechanical Shaft Output	All Components Including Tower	\$500/kW**

*Measured at hub height.

**Based on kW output in 9 m/s (20 mph) wind (1977 dollars).

TABLE V: HIGH-RELIABILITY (1-2 kW) FEATURES (Tentative)

CONTRACTOR	Output kW @ 20 mph*	Rotor Diameter/ Size	Generator	Speed Increaser	Blade Design	Operating Wind Range	Overspeed Control	Configuration/ Features
ENERTECH	2	16.4 ft	Alternator	1:11.6	Linear Taper Zero Twist Wood	7-40 mph	Stall	2-Blade, Downwind, Horizontal Axis, Variable Pitch
NORTH WIND	2	16.4 ft	Alternator, Direct Drive	None	Linear Taper Zero Twist Wood	10-60 mph	Rotor Tilt-back	3-Blade, Up-wind, Horizontal Axis, Fixed Pitch
ASI/PINSON	1	8 ft X 15 ft (Diameter)	Alternator	1:9	Constant Chord Zero Twist Al Built-up	5-40 mph	Stall	3-Blade, Vertical Axis, Cyclicly Variable Pitch

*Measured at hub height.

ASI/Pinson

Enertech

Northwind

Figure 9
High Reliability Wind Systems

reliability analyses. Failure modes and effects were identified along with estimates of failure rates for individual components and subsystems. These estimates were combined to arrive at projections of overall system reliability. Meeting the reliability requirement has played a major role in design evolution, with the result that all three contractors were authorized to construct pre-prototype machines in order to assess the feasibility of design features and modes of operation.

Some key aspects of each design are described below, to show how changes have occurred as a result of trade-off studies. No projected cost figures are reported because of (1) the difficulty in accurately predicting estimates for the 1000th machine at this time and (2) the tentative state of the designs.

Enertech 2 kW System

The contract with Enertech was awarded January 3, 1978. During FY 1978, the design phase has progressed through the Preliminary and Critical Design Review, and as of October 1, 1978, the final design was being completed. The program schedule calls for the first prototype unit to undergo field testing at Enertech during the spring of 1979 and for more extensive testing at Rocky Flats to begin during the summer of that year.

The original Enertech design underwent two major design changes in the rotor and hub and in the electrical system during Phase I, although the basic machine concept remains the same. The two-bladed downwind rotor will be 5 m (16.4 ft) in diameter. The blades are made of a wood laminate (leading edge of white ash with trailing edge of western red cedar), linearly tapered from a 23 cm (9.0 in.) chord at the root to a 18 cm (7.0 in.) chord at the tip, with a 4° twist. This construction method was chosen in order to achieve proper location for the blade center of gravity. The original hub concept incorporated flyweights, constrained by metal straps, to pitch the blades to aerodynamic stall as

the windspeed (and rotor rpm) increased. At PDR, this design was shown to be excessively bulky and expensive. The first major design change was to replace the metal straps with one torsion-tension tube per blade to provide the restraint and spring function required.

The second major change occurred in the electrical system design. The original concept consisted of a low speed, permanent magnet alternator, which did not require the use of a gearbox. As the design definition progressed, Enertech determined that this concept, while innovative and promising for the future, could not be developed in a timely manner with their overall machine concept. The present design consists of a flux-switching, wound-rotor alternator whose three-phase output is rectified to dc for battery charging. The particular alternator chosen has a dual output capability made possible by mounting two separate sections on a common shaft (complete with separate rectifiers and controls). Each section is capable of delivering one kilowatt of power at the rated conditions, greatly enhancing the system's overall reliability.

The system's blades and hub are connected directly to the input shaft of a step-up gearbox, which in turn drives the alternator. A fiberglass shroud (or nacelle) encloses the machine to present a pleasing appearance. The system is mounted on a standard, three-legged, telecommunications-type tower which will include a guywire system. The tower can be easily installed without a crane.

North Wind 2 kW System

The contract with North Wind was awarded January 4, 1978. During FY 1978, the design phase progressed through the Preliminary Design Review (PDR) and at year's end, North Wind was defining the specific configuration for an upcoming Critical Design Review. An extensive effort was required to achieve a workable theoretical representation of the machine control concept. In early 1979, North Wind plans to fabricate and begin field testing of their first prototype unit. This unit will be delivered in the summer to Rocky Flats for more extensive testing.

The original North Wind design has remained basically unchanged during Phase I. The three-bladed upwind rotor will be 5 m (16.4 ft) in diameter. The blades are constructed of sitka spruce, and are linearly tapered from the 33% radius (20 cm (8.0 in.) chord) to the tip (8.0 cm (3.2 in.) chord) with a 12° twist. The blades are connected to a simplified hub which constrains the blades to a fixed pitch position. The machine maintains relatively constant rotor rpm and system output control through a pitch-back of the complete rotor assembly. In low speed winds (below 20 mph), the rotor is in the "down" configuration and is oriented into the wind by the tail, as a conventional upwind machine would be. As the windspeed increases, the rotor begins to tilt back to prevent overload conditions. This tilt back is constrained by a spring so that a constant 2 kW output is maintained until 40 mph. Above 40 mph, the rotor continues to tilt back until it reaches a horizontal (or helicopter) orientation at a wind speed of 60 mph. It remains in this orientation in windspeeds above 60 mph. When the windspeed decreases, the spring mechanism returns the rotor to a more vertical orientation for the desired output (at each windspeed condition). Through a series of tests on a preprototype unit, North Wind is attempting to verify the operation of the machine concept.

The electrical output will be provided by a low speed, Lundell-type alternator, whose three-phase output will be rectified and controlled for battery charging. This alternator is directly attached to the rotor shaft. North Wind is conducting an in-house effort to develop this alternator concept, since there was no low speed alternator available in a 24-volt configuration. The alternator development includes fabrication and test evaluation of preprototype alternator units to verify the predicted performance.

The support tower for the North Wind system will be a standard, three-legged, telecommunications-type tower including guywire cables.

Aerospace Systems, Inc. (ASI) 1 kW System

The contract with ASI was awarded January 26, 1978. During FY 1978, the design phase has progressed through the Preliminary and Critical Design Reviews and at the end of the fiscal year, the final design was being defined. The program schedule calls for the first prototype unit to undergo field testing at ASI during the spring of 1979 and for more extensive testing at Rocky Flats to begin during the latter part of the summer of that year.

The original ASI design concept (based on the Pinson C2E Cycloturbine design), remained unchanged during Phase I. However, the rotor size increased to 2.4 m x 4.6 m (8 ft x 15 ft) in order to provide the 1 kW output in a 9 m/s wind. Several other changes have also been made in order to enhance reliability. The rotor supports struts will be fabricated from extruded aluminum airfoil sections. The three constant chord, 8-ft long rotor blades will be fabricated out of aluminum, with extruded D-spar leading edge sections and thin-skin afterbodies. The blade pitch is controlled by control rods which are actuated by a tilt-cam assembly. A vertical vane on the tilt-cam assembly orients the cam (with respect to the wind direction) and actuates the desired cyclical pitch, providing the basic rpm control. As the windspeed changes, the loading on a horizontal wing (part of the tilt-cam assembly) translates an up/down motion to the tilt-cam. When the windspeed increases to 40 mph, the tilt-cam induces a high collective pitch to the blades, shutting the machine down (i.e. the aerodynamically stalling blades). Therefore, the tilt-cam system integrates both rpm and shutdown controls in one mechanism.

The rotational output of the rotor is stepped-up through a gearbox to provide the high-speed input required by the alternator. This alternator is a commercially available three-phase flux-switching type. Its conventional design will be modified slightly to enhance reliability. In the ASI design, the voltage regulation circuitry is located near the base of the tower, in the same enclosure which houses the battery bank.

Lightning and surge protection equipment is located both on the tower and in close proximity to the electrical controls.

The support tower is an Octahedron design. Detailed analysis of the ASI design has indicated potential dynamic interaction problems with towers in general, so that the dynamic characteristics of a given tower design for a given tower height must be well known. ASI is pursuing further analysis and tests to verify the adequacy of the Octahedron tower design for their application.

3.5.3.4 8 kW SWECS

All three horizontal axis 8 kW wind systems have downwind rotors. Blade pitch control varies, however, ranging from a flexible beam which twists in the UTRC machine to more traditional mechanical linkages for the Windworks and Grumman designs. Alcoa's vertical axis design is the only Darrieus machine among the nine development contracts.

Significant changes have occurred in all 8 kW designs as a result of trade-off studies conducted by the contractors. The FOB cost goal of \$750/kW was the main factor influencing redesign of the systems. Projected cost data are omitted because of the difficulty in predicting 1000th unit costs and the tentative status of the designs; however, it appears that this goal may be difficult to meet. Final cost estimates are due upon completion of each contract. To date, the potential for significant reductions over initial estimates is high.

Windworks 8 kW System

The contract with Windworks was awarded September 21, 1977. During FY 1978, the design phase has progressed through the Preliminary and Critical Design Reviews and at year's end, the final design was being completed. The program schedule calls for the prototype to undergo field testing at Windworks during the summer of 1979 and for the more extensive testing at Rocky Flats to begin in the autumn of that year.

TABLE VI: 8 kW WTG FEATURES (Tentative)

CONTRACTOR	Output kW @ 20 mph*	Rotor Diameter/ Size	Generator	Speed Increaser	Blade Design	Operating Wind Range	Overspeed Control	Configuration/ Features
WINDWORKS	8	33 ft	Direct Drive Alternator	None	Constant Chord Zero Twist Al Extrusion Tapered, Twisted Fiber- glass Tip	7-45 mph	Feather	3-Blade, Downwind, Horizontal Axis, Variable Pitch
UTRC	9	31 ft	Induction	1:17 Gearbox	Constant Chord Zero Twist Fiberglass	7.5-50 mph	Stall	2-Blade, Downwind, Horizontal Axis, Variable Pitch
ALCOA	11	33.7 ft x 33 ft (Diameter)	Induction	1:24 Gearbox	Constant Chord Zero Twist Al Extrusion	12-65 mph	Stop and Lock	3-Blade, Vertical Axis, Darrieus
GRUMMAN	10	33 1/4 ft	Induction	1:20 Gearbox	Constant Chord Zero Twist Al Extrusion	7-35 mph	Feather	3-Blade, Downwind, Horizontal Axis, Variable Pitch

*Measured at hub height.

Grumman

United Technologies
Research Center

Windworks

Alcoa

Figure 10
8 kW Wind Systems

The original Windworks design was modified somewhat during Phase I; however, the overall concept was not changed. The three-bladed downwind rotor will be 10 m (33 ft) in diameter. Each blade will have two sections: an extruded aluminum, constant 200 mm (8 in.) chord, zero twist section extending to about 75% of the radius, and a 1.25 m (4 ft) long fiberglass tip section which is tapered and very slightly twisted. Use of the fiberglass tip will increase rotor performance, reduce overall blade weight, and possibly result in quieter operation. Another feature of the rotor will be the use of hinges to allow the blades to flap out of the rotational plane, easing bending forces on the blades.

The rotor will be connected directly to a low-speed alternator, eliminating the need for a transmission. The permanent-magnet, low-speed alternator is being designed by Windworks and will produce variable voltage, variable frequency alternating current. The alternator output will be rectified to 200 V dc, which could be used directly for certain applications, or be interfaced with a utility/ac load by use of a synchronous inverter.

In the original design, Windworks planned to use blades made of a composite containing metal and foam. These blades would have been rigidly attached to the rotor hub. This blade construction approach appeared to be a major factor in driving up the system cost, causing Windworks to look for less expensive alternatives. It was found that by using an extruded aluminum blade, hinged at the hub so as to allow it some freedom to flap, the blade cost could be reduced considerably, while the hub cost was not too adversely affected. A further blade refinement was made when the outboard 1.25 m (4 ft) of the aluminum extrusion was replaced with a fiberglass section. This decreased the blade weight and allowed this part of the blade, from which about half of the rotor power is obtained, to be made of an airfoil section with a more aerodynamically optimum shape.

The three blades will be simultaneously controlled in pitch by a mechanical linkage, powered by a hydraulic cylinder/piston, which is opposed by spring pressure to return the blades to a feathered position when no hydraulic pressure is present. This hydraulic system is pressurized from a pump driven by the main rotor shaft. A governor, also driven by the main rotor shaft, regulates the flow of hydraulic fluid from the pump, thus varying the blade pitch and keeping the rotor at constant speed (140 rpm) in winds over 9 m/s (20 mph).

The rotor of the Windworks' design is equipped with a failsafe shutdown mechanism. A valve is incorporated to quickly dump the hydraulic fluid into a reservoir if one of three conditions arise. The first is high wind gusts which are sensed by an air pressure transducer located near the nose of the nacelle. The second is excessive vibration, indicated by a vibration sensor. The third is manual shutdown from the base of the tower.

The support tower will be made of schedule 40 steel pipe normally used in well casings. This three-section tower will be attached to a pivoting base and will be held in position by three guy cables. The tower can be raised and lowered without the use of a crane. An optional A-frame structure and a winch will provide this capability.

8 kW System - United Technologies Research Center (UTRC) Design

A contract with UTRC was awarded on October 5, 1977. At the end of FY 1978, the UTRC design was through the Final Design Review, completing Phase I of the program. Fabrication of the prototype was underway and it is anticipated that the field tests and checkout of the prototype at UTRC would be complete by early spring 1979. The system will be shipped to Rocky Flats for extended field testing beginning in the summer.

The design concept originally proposed by UTRC features a two-bladed downwind rotor 8.5 m (28 ft) in diameter which would drive an

alternator through a step-up belt drive. The blades have neither twist nor taper and originally were to be comprised of a composite spar and leading edge, surrounded by a urethane or epoxy foam which would form the skin of the airfoil (blade composition has since been altered, as described below). The spar is attached at the root to a graphite/epoxy flexbeam, which is the unique feature of the UTRC design. This flexbeam will be constructed in a manner that will allow the torsional, bending, and tensile properties to be tailored to the loads imposed by the wind and dynamic forces acting on the blades. Pendulum flyweights are arranged to elastically twist the flexbeam over a range of 20° and hence change the blade pitch. Additional pitch change is not necessary with the UTRC design because rotor overspeed is controlled by stalling the blades rather than by feathering them.

For power generation, UTRC considered the use of a direct drive, permanent magnet alternator as well as a conventional brushless alternator, driven through a gearbox or a two-stage, belt-driven transmission. Both would require rectification and synchronous inversion for tie-in with a utility. UTRC also investigated the use of a 15 kW induction motor as the generator, to be driven at 1800 rpm through a two-stage gearbox. After comparing costs of the various approaches, UTRC decided on the induction generator approach. The wind system must be tied directly to a utility or auxiliary power system and will not function in the absence of external power, a safety feature of the induction generator. For stand-alone applications, a conventional dc generator (about 20-30 hp) can be substituted for the induction generator. Output of this configuration will be 240 V dc.

In order to optimize annual electrical energy production by their system, UTRC recommends that the gear ratio of the transmission be different for a low-to-moderate wind regime. A two-stage 1:17 ratio gearbox is proposed for use in most areas of the U.S., where the mean annual wind speed is 4-5.5 m/s (9-12 mph). This system would produce about 13,000 to 28,000 kWh annually, depending upon the actual mean wind

speed. For those higher wind regimes where the mean annual wind speed is 5.5-7 m/s (12-16 mph), a 1:14 gearbox can be substituted. The annual system output would then be increased to about 28,000 to 48,000 kWh.

During development of the design, UTRC increased the rotor diameter to 9.5 m (31 ft). However, cost of the originally proposed composite blades became high, necessitating review of other possible approaches. As a result, UTRC decided to use a fiberglass blade made by the pultrusion/filament winding process. In this process, fiberglass in filament or tape form is coated with epoxy resin and then wrapped around a stationary mandrel located within a die, which provides the external contour of the blade. The formed blade is continually pulled through the die and off the mandrel, both of which are heated to allow rapid curing of the epoxy resin. It appears that this process, when used in large quantity production, will produce blades at prices competitive with extruded aluminum blades (which were eliminated from consideration by UTRC because of their greater weight). It is also possible that in the future the graphite/epoxy flexbeams could be better and less expensively made using the pultrusion/winding process, but on the prototype this part will be made by hand lay-up, followed by isostatic pressing.

The support tower is a 250 mm (10 in.) diameter steel pipe, stabilized by three guy cables attached to the top of the tower and three cables at about the halfway point. The tower is designed to be raised and lowered by a winch, without the need for crane service.

Grumman 8 kW System

A contract with the Grumman Energy Systems, Inc. was awarded on January 3, 1978. During FY 1978, the Preliminary Design was completed and currently the detailed design is in preparation. Final design completion is scheduled for early in 1979, with prototype delivery around midyear.

Initially, Grumman proposed a three-bladed downwind rotor configuration utilizing extruded aluminum alloy blades having a chord of 0.6 m (24 in.) with zero taper and zero twist. This rotor was heavy, and to accommodate it the power train design also became heavy and expensive. Extensive trade-off studies were performed with the objective of reducing rotor weight and consequently, that of other system components as well. These studies resulted in reducing the blade chord to 0.46 m (18 in.).

In addition, by introducing coning in the rotor, a considerable size reduction was realized in the design of the blade stubs because thrust loads could be partially offset by centrifugal loads. This resulted in reduced sizing and weight of the main shaft, bearings, and supporting frame (strong-back). To maximize power output at 9 m/s wind speed, the rotor diameter was increased to 10.1 m (33 1/4 ft) which resulted in a system output increase from 8 to 11 kW. The overall improvement as a result of these design changes was a predicted 15% reduction in component weight and 38% increase in power generation at 9 m/s wind speed.

The power generation system originally proposed by Grumman consisted of a self-excited alternator, rectifier and dc-ac inverter to produce 120/240 volts ac power. However, after comparing this approach with an induction generator option, Grumman decided to choose the latter because of lower system cost. This savings reflects simplification in the control system resulting from constant rpm operation controlled by the line frequency.

Optimization of the system for annual energy production led Grumman independently to the same conclusion that UTRC arrived at regarding improving performance at lower wind speeds. This result was presented in slightly different terms, in that the rotor C_p was optimized for winds around 7.6 m/s (17 mph) instead of 9 m/s (20 mph). The consequence of this decision was to reduce output in 9 m/s winds from 11 kW to 9.5 kW, and to increase the transmission step-up from 1:20 to 1:25.

Initial plans were to use a 16.8 m (55 ft) high concrete tower for the system. However, after conducting structure and dynamic analyses, Grumman found that the concrete tower was not adequate for the new machine. Based on a preliminary analyses of concrete, steel truss, and galvanized steel pipe tower design approaches, a guyed Cor-Ten steel pipe tower has been identified by Grumman as the most cost effective configuration.

Alcoa 8 kW System

The Aluminum Company of America (Alcoa) was awarded a contract on November 15, 1977 to develop an 8 kW Darrieus SWECS. During FY 1978, the design phase of the contract progressed through the Preliminary and Critical Design Reviews. It was then concluded that Alcoa's original design approach of placing the blades at the upper end of a long rotating shaft (see Figure 10) in order to meet RF's request for locating the rotor swept area at a height of 16.8 m (55 ft) led to an excessively heavy and costly machine. An alternative approach would be to place the rotor closer to the ground, increasing its size as necessary to maintain the system energy output for a given wind regime. This would introduce some restrictions with regard to locating Darrieus wind systems because of the need for a highly exposed site. At the end of FY 1978, design and programmatic options were under detailed consideration.

Alcoa conducted trade-off studies on a number of system configurations. Among those considered were the system shown in Figure 11, guyed rotors placed on fixed towers and unguyed rotors cantelivered up from fixed towers. A three-bladed guyed design, utilizing a single tube shaft with bearings at either end, was selected as the most cost effective approach for meeting the design requirements (with the rotor swept area centered at 16.8 m).

If the rotor were to be located closer to the ground, considerable weight savings could be realized by both shortening the rotor shaft and reducing its wall thickness and diameter. In addition, the guy wire system could be made lighter. However, to maintain the systems' energy output in a given wind regime, the rotor swept area would need to be increased to compensate for the lower velocity airflow closer to the ground.

Alternate approaches considered for providing the proper shaft rpm at the induction generator included friction drive off a flywheel attached at the base of the rotor shaft and a gearbox speed increaser. The gearbox was believed to be the most cost-effective and reliable configuration.

3.5.3.5 40 kW SWECS

Both design approaches (one vertical and one horizontal axis) under development will be capable of producing either electrical or mechanical power. Kaman opted for a downwind horizontal axis configuration which can be built in two versions to achieve both power output formats. McDonnell, on the other hand, is developing the vertical axis Giromill concept which was studied under a previous contract with the FWEP. The blades are pitched cyclically during each rotor revolution, but following a different schedule and over a greater range than in the case of the ASI/Pinson design. Because its vertical axis configuration provides a convenient way of transmitting shaft motion to ground level, the basic machine design can be readily converted from electrical to mechanical output.

There is less to report on progress of the 40 kW designs than in the case of the smaller SWECS, owing to the late contract starts. Whether the \$500/kW cost goal can be met has yet to be determined. Final cost estimates will be presented at project completion.

TABLE VII: 40 kW SWECS FEATURES (Tentative)

CONTRACTOR	Output kW @ 20 mph*	Rotor Diameter/ Size	Generator	Speed Increaser	Blade Design	Operation Wind Range	Overspeed Control	Configuration/ Features
KAMAN	40	64 ft	Synchronous	1:24	Linear Taper Linear Twist Fiberglass and Foam	10-70 mph	Feather	2-Blade, Downwind, Horizontal Axis, Variable Pitch
McDONNELL	40	32.5 ft x 65 ft (Diameter)	Synchrnous	1:60	Constant Chord Zero Twist Al Built-up	Not Yet Defined	Blades Allowed to Weather Vane	3-Blade, Vertical Axis, Cyclicly Variable Pitch

*Measured at hub height.

McDonnell

Kaman

Figure 11
40 kW Wind Systems

Kaman Aerospace Corporation 40 kW

The contract with Kaman was awarded July 7, 1978. During the balance of FY 1978, the initial design was developed with efforts concentrating on trade-off studies, parametric analyses and establishment of design loads criteria. Completion of the Final Design Review is scheduled for early in 1979, with delivery of both electrical and mechanical output prototypes by late summer.

The downwind 64-ft diameter rotor will incorporate two fiberglass blades fabricated by an automated transverse filament tape (TFT) process. In this construction technique, the blade spar is wrapped around a mandrel with a material whose fibers run predominantly parallel to the spar axis. Additional weaves of $\pm 45^\circ$ fibers provide torsional strength. This construction technique readily lends itself to twisted and tapered blades. The trailing edge would be built up using fiberglass and foam and might also be constructed by the automated process.

Blade pitch will range from -90° to $+5^\circ$ with a failsafe emergency feathering subsystem employed to protect the machine in winds above 16.8 m/s (60 mph). The power train uses a gearbox having a 1:26 step-up ratio to drive a generator at 1800 rpm. For the mechanical output configuration, a rotating shaft is brought through the yaw bearing and routed to ground level along one of the simplified truss tower legs.

McDonnell Aircraft Company 40 kW

The contract with McDonnell was awarded September 15, 1978. Because of this late start, there is no progress to report. Design finalization is scheduled for mid-1979 with prototype delivery in early 1980. One wind system will be fabricated. It will include a changeover kit to convert the output type from electrical to mechanical.

3.5.3.6 University of Massachusetts

This project was initiated by the FWEP in 1975 to determine the feasibility of using wind power for space heating in colder climates. Contract monitoring responsibility was transmitted to RF during 1977. The objectives of the contract continue to be the development of performance and economic data which can be used to design heating systems for specific sites and buildings, using any commercially available wind turbine.

During FY 1978 the Wind Furnace, a 10 m (32.5 ft) diameter, 25 kW wind system was operated in a fully automatic mode (see Figure 12). Performance data from the Wind Furnace and the solar flat-plate collectors, which combine with it to supply heat to an experimental house called the Solar Habitat, have been collected and analyzed. Even with the extensive system downtime (due mainly to problems with the instrumentation), the Wind Furnace was able to supply about 50% of the load during the 1977-1978 heating season, which was a rather severe winter for the Northeast. This performance data also compared very favorably with that predicted during the design of the system, thus providing an important confirmation of the U Mass-modified Wilson-Lissaman performance program.

To provide more versatility in the Wind Furnace and to increase its usefulness as an experimental wind system, U MASS has designed and built a microprocessor controller. This device will allow blade pitch, generator field current, and system yaw to be controlled at varying rates and the system performance will be evaluated for a number of these operation modes.

In order to more accurately characterize the wind regime that exists in the near vicinity of the Wind Furnace, an array of anemometer towers has been installed. This array, consisting of five anemometers (one per tower) is arranged in line with the Wind Furnace. Four towers

Figure 12 University of Massachusetts Wind Furnace I

are located upwind into the north-northwest direction (which is the predominant wind direction), and one tower is downwind in the south-southeast direction. In addition to characterizing the near field wind regime, this array will more importantly be used to collect data for quantifying wind gusts as they pass through the array and into the wind rotor. This data will also be related to blade stresses induced by these gusts, as measured by strain gauges located on one of the blades.

Improvements in the thermal efficiency of the house heating system were made by insulating the 3.8 m³ (1000 gal) hot water storage tank (made of concrete) with urethane and lining it with polyethylene. Another system modification which may improve the overall system efficiency was the installation of a preheat tank in series with the regular gas-fired hot water heater. The water in this preheat tank will be heated by wind and/or solar through a heat exchanger fed from the large thermal storage tank.

Studies of various blade configurations were made and a 5.3 m (17.5 ft) wooden model of a linear taper, linear twist (LTLT) blade was constructed. The studies showed that this blade design was nearly as aerodynamically efficient as a more optimally twisted and tapered blade but was expected to be less expensive to manufacture. The performance predictions of this LTLT blade were computed using the Wilson-Lissaman program.

A dynamic analysis of the U MASS 18.3 m (60 ft) guyed support tower for the Wind Furnace was performed which resulted in dynamic equations of motion for the tower and guys. These equations were solved by computer to obtain the first five tower bending modes, frequencies, and periods.

It had been thought earlier that, for providing hot water for residential heating, mechanical agitation of the water might be a more cost-effective method than using electrical immersion heaters. This mechanical heating could be achieved using a water churn which would be

driven either by: (1) a shaft which would pass down the center of the tower, through a right angle drive in the foundation, and then enter the basement of the Solar Habitat, or (2) installing the churn in the nacelle, replacing the electric generator, and piping the water up and down the tower from the storage tank. Laboratory bench tests were performed on two sizes of mechanically-driven water churns. These tests indicated that the power absorbed in the churn was a cubic function of the input shaft speed. The economic analysis of this method of generating hot water has not been completed.

Another economic study was completed in which U MASS extended a previously developed computer analysis to include the use of a system such as the Wind Furnace as a means of supplying electrical energy to the user, as well as providing heating. This study suggested that some systems could perform both of these functions at costs which would be competitive with conventional energy systems.

The Wind Furnace and tower were lowered for maintenance and repair in early July 1978. During this process, the operator lost control of the crane and dropped the tower and the turbine approximately 2 m (6 ft) onto the corner of a receiving cradle. One blade struck the ground and was broken in two places. The nacelle was partially crushed and a large hole was made around the service door. The fiberglass coating on the lightning rod was also cracked. A spare blade was used to replace the broken one and the other damage was easily repaired. The turbine and tower were reinstalled on July 27, 1978.

The contract has been extended through July 31, 1979. Further evaluation of the general automatic operation of the wind turbine will be made as well as short term tests such as the measurements of blade strains and rotor torques under various winds. Tower shadow effects on blade strains as a function of various tower diameters will also be studied. Wind measurements will be used to verify an analytical model for relating power output to variations in wind speed (e.g. gusts). The

development of an economic analysis model will provide graphical design charts and simplified analytical methods for estimating the technical feasibility and economic potential (in terms of break even cost) of using wind energy for heating at locations throughout the United States.

3.5.3.7 Future Plans

Systems Development

While the systems currently under development are being designed to reliably produce cost-competitive energy, the need continues to develop additional dependable cost-effective wind systems in other size ranges. For each new system to be developed, multiple contracts are planned for award as a result of competitive procurements. Two-phase programs will be conducted, similar to the current efforts. Phase I will determine a design based on trade-off studies and technical analyses. Under Phase II, a prototype will be constructed. Emphasis will be placed on meeting energy cost goals as well as wind, environmental, and lifetime design criteria.

Two general sizes of machines are planned for competitive procurement during FY 1979. One would have a design output of approximately 15 kW and the capability of generating 45,000 to 55,000 kWh annually in a wind regime having an average velocity of 5.4 m/s (12 mph). The other would be smaller, being approximately 4 kW in size and capable of generating 10,000-20,000 kWh annually in the same wind regime. Both sizes of systems would be designed to generate 120/240 V ac, 60 Hz tied in with a utility. Long range planning will include assessing the need for SWECS larger than 40 kW.

3.6 STANDARDS

3.6.1 Objective

The objective of this task is to provide technical support for the formation of standards to be used in the manufacture and testing of and data reporting for small wind systems. When adopted on a consensus basis by private industry, standards will aid in the SWECS commercialization process by increasing public and institutional confidence in and understanding of the safety, reliability, and performance of SWECS hardware which is entering the marketplace.

3.6.2 Approach

This task involves the identification and provision of actions, schedules, and funding required to support private industry in the development of voluntary consensus standards.

Drawing on its experience with SWECS development and testing, RF is responsible for the planning, technical guidance and management of the standards technical support efforts, which will be conducted in three phases.

The first phase of this task is the gathering of the information necessary for the preparation of a comprehensive planning document for the standards development process. Writing and coordinating the plan will be accomplished using this information.

Phase two will consist of assessing the cost, schedule, and technical impacts of specific SWECS-related standards on the utilization of SWECS. Included as part of this assessment will be a prioritization of specific standards and recommendations for proceeding with the task.

Phase three of this task will be the actual process of providing technical data and support for the development of SWECS standards through voluntary consensus procedures in the private sector. Involvement of other organizations prominent in wind industry such as the American Wind Energy Association (AWEA), NASA, and Battelle-Pacific Northwest Laboratories will be essential to ensure that unrealistic or inappropriate standards which would endanger SWECS commercialization are not promulgated. Involvement of a nationally recognized standards development organization such as the American Society of Testing and Materials (ASTM) will also be considered to ensure the establishment of credible and recognized consensus standards.

3.6.3 Achievements

3.6.3.1 Program Plan for Technical Support to SWECS Standards Development

A comprehensive plan was written and submitted to DOE/WSB for review and approval in July 1978. The plan assigned the responsibility for administering federal involvement in national consensus standards development to the Rocky Flats Wind Systems Program. The document provides the planning information required for technical support for the development of standards. The text identifies the actions, schedules, and funding required of DOE/WSB to provide technical support to private industry.

3.6.3.2 Technical Support to Standards Development

The American Wind Energy Association (AWEA) was contracted to provide technical information on three specific categories of standards. These are:

- 1) Testing procedures, data reduction, and reporting.
- 2) Wind energy related terminology.
- 3) Identification of existing standards which might be applicable to siting, installation, and safety.

The contract for the testing and reporting component was issued in June 1978. Preliminary survey efforts were conducted in July and August to identify affected groups/organizations and then specific data needs. Additional information was gathered to determine the test methods and data reduction procedures in current use and a workshop was held in August 1978, to obtain recommendations from prominent persons in the SWECS industry who are knowledgeable in SWECS testing. A draft report documentating results of the surveys and the workshop was prepared by AWEA. Included in this report are recommendations for developing and presenting SWECS rating information in a graphic form rather than the rated kilowatt capacity at rated wind speed system currently used.

Many specialized areas of knowledge are applied to the design and operation of SWECS. Each of these requires the use of specific terms. SWECS technology is also developing a unique terminology. A standard set of terms for SWECS (including power, rating, components, and design features) is required to assist in developing and documenting standards. In August 1978, a Task Order was issued to AWEA to develop a glossary of SWECS-related terms. Completion of this effort was scheduled for the first quarter of FY 79.

A review of the applicability of existing standards was also performed in FY 1978. AWEA surveyed the standards compiled by the National Bureau of Standards. The review was conducted using key words (for example: "airfoil," "dynamics," "wind") to identify current standards which might be applicable to SWECS. The purpose of this effort was to reduce future SWECS standards development efforts and identify potential redundancies and conflicts. Completion of this effort was scheduled for the first quarter of FY 79.

3.6.3.3 Technical Support to Tax Credit and Demonstration Program

A workshop on eligibility criteria for wind systems tax credits and demonstration programs was conducted in January 1978 by AWEA. Two

internal planning reports were written and submitted to Rocky Flats documenting the conclusions reached at the workshop and providing recommendations for the development of eligibility criteria. These two reports were entitled "Eligibility Criteria for Wind Systems Tax Credits (February 1978)" and "Eligibility Criteria for Demonstration Programs (15 March 1978)."

3.7 INFORMATION DISSEMINATION

3.7.1 Objectives

The overall objective of the Information Dissemination task is to make information and data on SWECS readily available to the public and private sectors. This overall objective requires a series of supporting objectives, including: (1) the development of a comprehensive information dissemination plan; (2) the processing, development, and dissemination of information materials; and (3) the development of a contact point for SWECS information at Rocky Flats. Quality control for all RF publications is a supporting objective of this task.

Information and data on SWECS are generally not available, and the general lack of knowledge concerning SWECS technology can deter or delay its near-term use. As the national center for SWECS testing and development, Rocky Flats produces information for consumers, manufacturers, researchers, utilities, finance insurance/institutions, government agencies, and other audiences crucial to SWECS development, acceptance, and use.

3.7.2 Approach

The approach used during FY 1978 to achieve this objective included three basic subtasks, as listed below.

1) Processing RF and Subcontractor Reports

All reports which were completed in draft form were distributed for internal RF/DOE and external review. Review comments were incorporated and the reports were edited for accuracy, clarity, and form. Final versions of reports were printed in limited quantities at RF for distribution to a list of over 100 manufacturers, researchers, and government organizations

and were also distributed in response to urgent inquiries from consumers and others, pending general printing by the DOE Technical Information Center.

2) Direct Contact with Consumers

Direct contact with existing and potential SWECS users was accomplished through the preparation and exhibition of displays, the conduct of tours at the WSTC and the answering of telephone and written inquiries regarding wind energy, SWECS, and the RF program. Preparation for active distribution of information during FY 1979 was begun by compiling two separate mailing lists: one for those interested in general and program information, and the other for those interested in SWECS data.

3) Compilation of a SWECS Information Base

All reports received through the general Wind Energy distribution list (UC-60) and other materials ordered at Rocky Flats or received from the wind energy community are being catalogued in a SWECS library at Rocky Flats. These materials are used by RF personnel and are available for onsite reference by the public. They are also referenced in answering public inquiries.

3.7.3 Achievements

RF activities in information dissemination were highlighted by the completion of the first program reports, continued dissemination of information to consumers (through mailings, test site tours, and the showing of displays at fairs and conventions) and the continuation of ancilliary activities such as the SWECS library and the presentation of

technical papers by RF personnel. Activities in these three areas are highlighted below.

Reports

Four reports were completed during FY 1978, and distributed by Rocky Flats to manufacturers, various government agencies, and consumers. One of these reports received general UC-60 distribution through the DOE Technical Information Center (TIC) and was made available to the public through the National Technical Information Service (NTIS). The other three were awaiting TIC printing at the close of the fiscal year. In addition, several reports were in draft form on September 30, 1978, and were scheduled for completion early in CY 1979.

Reports completed included:

- 1) An Index of Manufacturers, Researchers, and Distributors Currently Involved in the Development of Wind Energy Conversion Systems (Available from NTIS)
- 2) Technical and Management Support for the Development of Wind Systems for Farm, Remote, and Rural Use (Annual Report for the Period October 1976 - September 1977)

This annual report details progress during FY 1977, the first full year of the Rocky Flats Wind Systems Program.

- 3) Wind Power for Farms, Homes, and Small Industry

This report was edited at RF after completion by the contractor, Nielsen Engineering and Research, Inc. It is designed to provide consumers with the information necessary to assess the feasibility of wind

power at a specific site and select and operate a small wind energy conversion system. The report is scheduled for update in FY 1979. This update will include additional editing and reorganization to increase its usefulness to consumers.

4) Guide to Commercially-Available Wind Machines

The Index (see above) was used as a basis for this report, which provides information on commercially-available and soon-to-be-available prototypes marketed in the United States as of June 30, 1978. The report includes a short introductory section on wind machine design and operation and features detailed specification sheets on 66 electrical and mechanical output systems. Addresses of manufacturers and distributors of wind machines, towers, inverters, batteries, and wind measurement equipment are also included. The Guide was also scheduled for update in FY 1979.

5) Monthly Data Reports to Manufacturers

Preliminary data collected from SWECS were transmitted to the manufacturers of each system.

Reports in preparation at the end of FY 1978 included:

1) FY 1979 Program Summary

Scheduled for completion in early FY 1979, the RF Program Summary is designed to provide basic information on the RF Program to virtually every

audience. Information on the FY 1979 task reorganization and expansion at RF is included. RF subcontracts are described in an appendix.

2) First Semiannual Report - Rocky Flats Small Wind Systems Test Center Activities (Volumes I and II)

Also scheduled for completion in early FY 1979, this report describes the national Small Wind Systems Test Center (WSTC) and presents experimental data collected at the WSTC to June 30, 1978. Volume I of the report contains information on the philosophy of testing at RF, the WSTC facilities, test procedures, and data collection and analysis.

Volume II contains descriptions of nine SWECS tested at the WSTC, provides performance curves for those SWECS from which useful data were available and presents (in an appendix) detailed reports on the six SWECS which experienced failures during FY 1978.

3) Phase I Reports - Technology Development Contractors

United Technologies Research Center (8 kW) and Aerospace Systems, Inc. (1-2 kW) were in the process of preparing Phase I design and analysis reports for submittal in early FY 1979. These reports will be processed and transmitted to the RF distribution and TIC during 1979.

4) Test, Data Reduction, and Reporting Procedures

This report, prepared by the American Wind Energy Association under contract to RF, will provide the

basis for voluntary consensus standards for SWECS testing and data reporting. It is scheduled for completion by mid 1979.

Information Provided to Consumers

1) Correspondence and the Distribution of Information Packages

Over 600 written and telephone inquiries were processed by the RF during FY 1978. Specific inquiries regarding wind energy and SWECS evaluation, selection, and use were addressed on a case-by-case basis. More general inquiries were responded to with an informative cover letter and the following materials:

- o RF Brochure - A two-color brochure entitled To Catch the Wind displaying a general history of wind power use and describing the RF Program.
- o A Checklist of Commercially-Available Small Wind Systems, June 30, 1978.
- o Selected References on Wind Energy Conversion Systems

Other materials, including a DOE-prepared report bibliography and copies of technical papers, were also disseminated. Additional materials are planned for development and use during FY 1979.

An important by-product of this activity has been the compilation of a large list of individuals and organizations who are specifically interested in small wind energy conversion systems.

2) Preparing and Exhibiting Portable Displays

A second large manned display (augmenting a unit prepared in FY 1977) was prepared, together with two display modules designed to "stand alone" in exhibition space. These displays were used at energy-related conferences and fairs during FY 1978 (see Figure 13). Display locations were selected on the basis of maximum exposure to potential SWECS users (for example, state fairs attended by farmers and homeowners) and their potential for exposing industry representatives, researchers, and government policy makers to the concept and potential of wind power use and the DOE Federal Wind Energy Program's Activities. Over four million potential exposures were achieved through exhibits at the following functions:

<u>Location</u>	<u>Event</u>	<u>Date</u>
Washington, DC	AAAS Conference	2/78
Washington, DC	5th Energy Tech. Conference	2/78
Amarillo, TX	American Wind Energy Assoc. Conference	3/78
El Paso, TX	International Solar Energy Conference	4/78
Alamosa, CO	Colorado Symposium on Energy Alternatives	4/78
Golden, CO	Engineering Days	4/78
Debuque, IA	Solar Energy Conference	4/78
Denver, CO	Sun Day	5/78
Lansing, MI	Michigan State U., Energy Expo	6/78
Casper, WY	Central Wyoming Fair & Rodeo	7/78
Billings, MT	Yellowstone Exhibit	8/78
San Diego, CA	Int. Solar Energy Conf.	8/78
Pueblo, CO	Colorado State Fair	8/78

<u>Location</u>	<u>Event</u>	<u>Date</u>
Denver, CO	Int. Solar Eng. Society Conference	8/78
Boise, ID	Western Idaho Fair	8/78
Topeka, KS	Sunflower State Fair	9/78
Lincoln, NE	Nebraska State Fair	9/78
Oklahoma City, OK	Oklahoma State Fair	9/78

3) WSTC Tours

Guided tours of the WSTC were regularly scheduled for Fridays from 10:00 a.m. - 12:00 noon. About 1,000 visitors were received during FY 1978, including representatives from 42 foreign countries.

SWECS Information Base Compilation

An average of ten items per week were added to the SWECS Library at Rocky Flats during FY 1978. The library contains over 1,000 reports, reference books, technical papers, and journals pertaining to the following subject categories:

- general wind energy/solar energy
- wind machine design
- wind characteristics
- innovative wind energy systems
- structural dynamics
- aerodynamics and aeroelasticity
- electrical engineering
- mechanical engineering
- computer science
- institutional/legal issues
- bibliography

UNITED STATES DEPARTMENT OF ENERGY DEVELOPMENT AND TESTING OF WIND SYSTEMS

Figure 13

Large Portable Display Exhibited at Fairs and Conferences

All materials received as of October 12, 1977, were catalogued in a computer-generated index. Materials received after that date have been catalogued on cards for incorporation in a revised index to be completed in mid FY 1979. This index will be updated on a continued basis thereafter.

The library was used extensively by RF personnel during FY 1978. While several public visitors were received and benefited greatly from the library, space limitations do not permit heavy public use at this time.

Planning for FY 1979

Rocky Flats will take a more active role in information dissemination during the next fiscal year. Whereas prior activities have primarily involved responding to consumer, industry, and government inquiries, RF will begin, during FY 1979, to identify the information needs of primary audiences and develop and disseminate information to meet those needs.

The steps required to develop a comprehensive information dissemination plan were documented and submitted to the DOE Wind Systems Branch in August 1978. At that time it was proposed that the American Wind Energy Association develop the plan and recommend strategies for its implementation consistent with overall DOE information dissemination policies.

Additional activities for FY 1979 include the development of a monthly RF newsletter; the preparation of new brochures and special information packages; updating of the Index, Guide, and Wind Power for Farms, Homes, and Small Industry; further expansion of the SWECS library, and the development of procedures for public access; and the building or refurbishing of five portable exhibition displays.

3.8 PLANNING

3.8.1 Objective

The objective of this task is to develop long-range and fiscal year operational planning documents to promote the orderly conduct of SWECS development activities.

3.8.2 Approach

The development of planning documents will be based on the results of efforts concentrated in four subtask areas, which are:

- o Gather and evaluate information from all sectors involved in SWECS development and use (government, industry, consumer, etc.) in order to determine the needs which must be satisfied to further the orderly accelerated growth and public acceptance of SWECS. In addition, a comprehensive assessment of the impacts (both positive and negative) which would result from the resolution (or nonresolution) of these identified needs will be made.
- o Define approaches and alternatives for resolving critical needs which are appropriate for RF to pursue and the primary actions required.
- o Formulate advance planning documents detailing recommended strategies, together with supporting rationale, resource requirements, and schedules which integrate these strategies into the RF Program and the overall FWEF. (Coordination and tentative approval of these advance planning documents from DOE will be required prior to their incorporation into fiscal year RF Program Plans.)

- o Integrate those advanced program tasks which were given tentative approval with ongoing tasks to update the fiscal year Program Plan. This plan will be submitted to DOE for formal approval.

3.8.3 Achievements

3.8.3.1 Long-Range Plan

Work was initiated on the development of a plan for achieving the program goal of widespread use of SWECS. As it is anticipated that a number of years will be required for this goal to be met, the long-range plan covers the 5-year period through 1984.

Under this plan the main obstacles to the widespread use of wind power will be identified and assessed, including the availability of wind machines of the required size and cost, and the level of awareness of the various applications and potential cost advantages of wind power. Numerous inputs are needed detailing customer requirements so that the needed hardware can be developed. Similarly, methods for demonstrating the applications of wind power will be addressed. Interactions between various agencies needed to assure a steady and smooth task progress will be identified so that adequate pre-planning can be made each year.

3.8.3.2 Advanced Planning Information

In June 1979, The American Wind Energy Association (AWEA) was contracted to provide Rocky Flats with an advanced planning document titled "Technical Development and Implementation Strategy for the SWECS Program." The objective of this effort was to assemble information for future strategy planning, and AWEA was chosen because of its capability to readily gather the viewpoints and biases of the SWECS industry. This information is necessary and considered essential for the development of future strategies and planning related to the Rocky Flats Wind Systems

Program. In performing this task, AWEA identified the needs of affected groups and developed recommended approaches to meet these needs. A draft of a proposed 3-to-5-year Action Plan was completed and transmitted to Rocky Flats in September 1978.

3.8.3.3 FY 1979 Program Summary

In August 1978, an FY 1979 Program Summary was submitted to DOE/WSB for review and approval. The summary document was given approval contingent on the interaction of the results of the forthcoming Planning Workshop (see below). Due to the conduct of the Planning Workshop, completion of the Program Summary was delayed until early FY 1979.

3.8.3.4 Planning Workshop

A Planning Workshop was held in September 1978, at Hyannis, Massachusetts, to identify and prioritize FY 79/80 projects for SWECS supporting Research Technology (SRT) and Special Studies. The workshop was attended by representatives of Rockwell International, Rocky Flats, SWECS development contractors, AWEA, solicited DOE/Wind Systems Branch contractors and DOE management. The information obtained from this workshop was analyzed for applicability to near-term SWECS development needs and/or commercialization activities.

Selected projects/studies were then incorporated into the FY 1979 Rocky Flats Wind Energy Program Plan, under Task Elements V (Supporting Research and Technology) and VII (Special Studies).

3.8.3.5 FY 1979 Program Plan

The FY 1979 Rocky Flats Wind Systems Program Plan was formulated during the months of August and September. A draft plan was ready in late September but was delayed because of the requirement to develop and document the new Supporting Research and Technology and Special Studies

task elements authorized by the DOE Wind Systems Branch. Completion of the draft was therefore delayed and was not scheduled for submittal for DOE/WSB review and approval until the Rocky Flats Wind Systems Program Quarterly Review in early November 1979.

4.0 PLANNED ACTIVITIES*

4.1 FIELD EVALUATION

4.1.1 Objectives

During FY 1978 a Field Evaluation Program was designed to accelerate the commercialization process for SWECS. The program goal is to accelerate near-term resolution of existing technical and institutional constraints on wind energy use. Institutional and technical constraints to utility interconnections, limited public awareness, and the need for sufficient industry supply and user demand remain as barriers to any large-scale utilization of wind energy. The overall objective of the Field Evaluation Program is to advance the federal wind program efforts to identify and remove these barriers as well as to provide stimulation to the various segments of the SWECS industry.

The Field Evaluation Program will be carried out in two phases. Phase I will be the field evaluation of commercially-available SWECS in states and territories of the U.S. Phase II will undertake, at a later date, the field evaluation of new and improved designs that have been determined to have commercial potential. This discussion outlines the objectives and requirements for the execution of Phase I.

The primary objectives of the Field Evaluation Program Phase I are to:

- o Establish procedures for SWECS interconnected with or supplemental to a utility grid and accelerate the process for establishing cost of service for these applications.
- o Assist and support state and local governments in the reduction of institutional barriers to the use of SWECS in the private sector.

*NOTE: Details of programs described in the section are subject to DOE approval and may change at any time.

- o Prepare user information on the performance and reliability of commercially available SWECS and the procedures and costs for interconnecting SWECS with utility networks.

The secondary objectives of the Field Evaluation Program Phase I are:

- o Obtain typical operating experience data on SWECS with a variety of real load and environments to be used by manufacturers for future design and development efforts.
- o Provide stimulation to the SWECS industry that will maintain current manufacturing and distribution capacities and aid in the establishment of a viable field repair sector of the industry.

Phase I of the Field Evaluation Program will entail the selection of users in the states and territories of the U.S., based on technical criteria. These users will be awarded a wind system for field evaluation. The sites to be considered in the initial user selection process are those where the wind system would be supplemental to or interconnected with a utility grid. Experience from the selected sites will be used in the assessment of the technical and institutional interfaces between dispersed SWECS and utility networks.

Data will be collected at each site on the performance and failure modes of the Wind Turbine Generators (WTG's), on available wind power, on load power requirements, and on technical/institutional procedures for installation and siting of the machines. These data will be provided to manufacturers for design and development efforts, to utilities and state utility regulatory commissions for establishment of procedures and rates, to DOE to guide research and development efforts, to state energy offices planning for wind programs, and to potential SWECS users.

Commercially-available WTG's will be purchased from SWECS manufacturers and distributors, and matched to selected user applications by program personnel. The suppliers or their designated representatives will perform field installation and repair of WTG's under contract to this program. The selected users will be responsible for trouble reporting, for retrieval and mailing of data cassettes, and for routine maintenance of the wind system.

Five Program elements have been defined in order to carry out Phase I.

- o User Selection - establish qualified users/sites within the states and territories.
- o SWECS Selection and Procurement - select commercially available WTG's, towers, and ancillary equipment. Selection criteria have been developed to achieve an optimum mix of machine sizes and suppliers.
- o Instrumentation Development and Data Analysis - a standard instrumentation package will be designed for data collection at each site. The data at each site will be recorded on tape cassettes and processed for computer data analysis.
- o Installation and Repair - the WTG suppliers, or their designated representatives, will provide for site preparation, installation, and field repairs under contract to Rockwell International. Manufacturers will be required to maintain a spares inventory. Scheduling of field operations and failure analyses will be performed by program personnel.
- o Institutional Interface Analysis and Reporting - assessment of the technical and institutional barriers to dispersed SWECS interconnected to utility networks will be carried out. Data collected at user sites and the Rocky Flats Test Center will be

aggregated for the use by utilities, utility regulatory commissions, manufacturers, state energy offices, and potential SWECS users. Analyses will be performed for the impacts of current and potential procedures and rate structures on the widespread use of SWECS interconnected to utility networks. All analyses will be generated, when possible, in coordination with utilities and utility industry organizations such as EPRI, the National Association of Regulatory Commissions, and National Rural Electric Cooperative Association.

4.1.2 Achievements

Definition of the Field Evaluation Program began in January 1977. Several briefings were presented to DOE-WSB culminating in the preparation and submission of a Program Definition document on June 9th. Revisions incorporated subsequent to review resulted in document approval on August 18th.

A Program Plan was in preparation prior to receipt of approval of the program definition. It subsequently has been revised to include comments received and has been incorporated into the Wind Systems Program Plan.

A PERT network has been drawn of the entire Field Evaluation Program. Segments of the network were run on the computer with the entire run scheduled for early October.

Effort was also expended in compiling listings of qualified WTG manufacturers, specifications, and delivery capabilities. While criteria for manufacturer qualification has been established, specific criteria for quantity selection and application/site matching were under development.

The instrumentation package has been conceptualized utilizing inputs obtained from various sources, including Battelle-Pacific Northwest Laboratories and various utility companies. The concept will utilize the minimum instrumentation necessary to determine the wind available at the sites and the power inputs and outputs. Steps were taken to procure components, design packaging, and subsequently to fabricate and test a "breadboard" package at Rocky Flats.

In the area of Institutional Interface, efforts have concentrated on identifying state and federal agencies and utility industry organizations who will impact program activities or who will be impacted by these activities. The United States Department of Agriculture, Rural Electrification Association, National Rural Electric Cooperative Association, Department of Energy, Electric Regulatory Administration, and National Regulatory Research Institute have expressed an interest in joint program efforts and negotiations are underway. A directory of state energy offices and a file of current utility rates and procedures has been developed for future program use.

In addition, through award of a subcontract, media through which the program will be announced were identified.

4.2 SUPPORTING RESEARCH AND TECHNOLOGY

4.2.1 Objectives

Development of economical and reliable wind energy systems requires technology advances in such areas as materials, fabrication methods, and hardware components.

Rocky Flats' experience with the SWECS development contracts has shown there is a need for technical data and analytical techniques which designers can use in developing new, cost-effective systems. For example, the ability to accurately predict wind loads would result in less overdesign and thus lower system weight and cost.

In addition, certain new-generation hardware components show potential for making SWECS more cost-effective and reliable. However, adequate development of these components has not occurred either within the industry or as a result of systems development contracts.

4.2.2 Approach

To address these needs, programs will be initiated which focus on providing analytical tools and specific types of systems and component performance data for use by SWECS designers. Development of some hardware components, materials, and construction methods which show promise of contributing to more cost-effective and reliable wind systems will also be supported. Some efforts will be conducted at Rocky Flats, but the bulk of the work will be performed by contractors selected as the result of competitive procurements. Selection of projects will be based on data from the Rocky Flats WSTC and systems development contracts, as well as input from AWEA, the wind industry, and direction from the Federal Wind Energy Program.

4.3 SPECIAL STUDIES

4.3.1 Objectives

The developing SWECS industry has neither the resources nor the expertise to assess national SWECS potential, define SWECS markets, study SWECS applications and address issues posed by the entrance of SWECS technology into the complex social and institutional environment which exists in the U.S. Such efforts are needed to:

- o Accelerate the consumer utilization and institutional acceptance of SWECS.
- o Define the SWECS characteristics which will result in optimum penetration of the energy market.

The RF program's extensive efforts in SWECS testing and development and the proposed Field Evaluation Program will form a baseline for Special Studies to provide this information during FY 1979, FY 1980, and FY 1981.

Special Studies conducted under the RF program will define and assess SWECS national potential, market potential, applications, and institutional implications and will determine the SWECS characteristics required for optimum market penetration.

4.3.2 Approach

Whenever possible, Special Studies will be subcontracted to private industry on a competitive basis. Projects have been developed under the following subtask areas:

- o Mission Analysis - Define overall national potential for SWECS and develop strategies for private industry and government to realize this potential.

- o Market Studies - Locate and quantify SWECS markets and provide private industry with marketing strategies.
- o Applications Studies - Address the technical, operational, and economic aspects of high-potential SWECS applications defined by RF market studies.
- o Institutional Studies - Identify and resolve the institutional issues associated with SWECS use, including the legal, social, and environmental barriers and requirements for SWECS commercialization.

Close coordination with the Field Evaluation program and other RF task areas will be maintained.

5.0 PROGRAM REORGANIZATION FOR FY 1979

Eleven task areas have been identified to meet the RF Program objectives during FY 1979. The contribution of each task area to the RF effort is described below. A diagram of the RF Program organization for FY 1979 is provided in Figure 14.

TASK AREA	CONTRIBUTION
Task I - Program Management	Provides program management functions through a matrix-type organization structure. Interfaces with and reports to DOE/WSB and RFAO.
Task II - Test Center Development	Provides facilities and testing capability required for Test Center Operations (Task III).
Task III - Test Center Operations	Tests commercially-available systems and tests prototypes developed under Task IV (Systems Development). Provides machine reports and data for dissemination to consumers, manufacturers, and others.
Task IV - Systems Development	Develops advanced SWECS of various sizes. Provides prototypes for testing to Test Center Operations and subsequently to Field Evaluation. Transmits reports to Information Dissemination for peer review, editing, and distribution.
Task V - Supporting Research and Technology (SRT)	Performs research in specialized technical areas to increase SWECS reliability and performance per unit cost. Transmits reports to Information Dissemination for peer review and subsequent distribution.

TASK AREA	CONTRIBUTION
Task VI - Field Evaluation	Installs, instruments, and tests commercially-available systems and tested RF-developed systems at selected user sites. Provides performance data and procedural information gained from operational experience. Transmits reports to Information Dissemination on utility interface requirements, state and local siting requirements, and other institutional issues.
Task VII - Special Studies	Performs mission analysis, market studies, and institutional studies to determine the potential of and address barriers to SWECS commercialization. Defines SWECS characteristics required for optimum use. Transmits reports to Information Dissemination for peer review and subsequent distribution.
Task VIII - Technical Support	Provides specialized technical support to other task areas.
Task IX - Planning	Provides long-term and operational planning for RF program activities. Prepares planning documents for transmittal to DOE.
Task X - Standards	Assists private industry in the development of consensus standards; obtains technical inputs from Test Center Operations, Systems, Special Studies, and other task areas.
Task XI - Information Dissemination	Processes and distributes all technical and program reports, wind machine data, articles, and other materials.

TASK AREA	CONTRIBUTION
Task XI (Cont'd)	<p>produced under other task areas. Coordinates workshops, answers correspondence, and prepares and disseminates special information packages.</p>

Figure 14

Planned FY 1979 Rocky Flats Wind Systems Program Organization

APPENDIX A

SWECS Tested During FY 1978

A-1 AMERICAN WIND TURBINE (AWT)

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: AWP-16

Design Output: 2.0 kW @ 9.0 m/s
(21.4 mph)

Output Type: 220 V ac, 3Ø

Rotor Diameter: 4.88 m (16 ft)

Rotor Configuration: Horizontal-axis,
multi-bladed bicycle wheel; fixed
pitch; upwind.

Rotor Speed Control: Mechanical
foldable tail; automatic.

Test Center Equipment

Tower: Rohn 80

Hub Height: 16.8 m (55 ft)

Anemometer: R. M. Young Propvane,
Model 8002.

Machine Description

The AWT is a lightweight machine manufactured by American Wind Turbine Co., Stillwater, OK; and is designed for use with an electrical water pump. The alternator is rim-belt driven by a multi-bladed rotor, 4.88 m in diameter, with a 30:1 ratio. The rotor is constructed of formed aluminum airfoils supported by stainless steel spokes and inner and outer rims.

Rotor overspeed control is achieved by utilizing increasing wind pressure on the rotor to gradually swing the rotor and alternatore assembly out of the oncoming wind. The return spring aligns the tail as the wind speed decreases.

A-2 ALTOS (formerly Amerenalt)

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: 8B

Design Output: 1.5 kW @ 12.5 m/s
(28 mph)

Output Type: 24 V dc

Rotor Diameter: 2.4 m (8 ft)

Rotor Configuration: Horizontal-axis;
bicycle multi-bladed; fixed pitch;
upwind.

Rotor Speed Control: Mechanical;
foldable tail; automatic or manual.

Test Center Equipment

Tower: Aermotor

Hub Height: 12.2 m (40 ft)

Anemometer: R. M. Young Propvane,
Model 8002

Machine Description

The Altos (formerly Amerenalt), is a lightweight machine manufactured by Altos Corporation, Boulder, Colorado. The main generator housing is welded steel. The alternator is coupled through a 11:1 cycloidal gearbox and is driven by a multi-bladed rotor, 2.4 m in diameter. The rotor is constructed of form aluminum Clark Y airfoils supported by stainless steel spokes and inner and outer rims.

Rotor overspeed control is provided by utilizing increasing wind pressure on the rotor to swing the rotor and alternator assembly (which is offset from the tail assembly) out of the oncoming wind. The return spring automatically reopens the tail as the wind speed decreases.

A-3 DUNLITE

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: 81/002550

Design Output: 2.0 kW @ 11 m/s
(25 mph)

Output Type: 110 V dc

Rotor Diameter: 4.10 m (13.5 ft)

Rotor Configuration: Horizontal-axis
propeller-type; variable pitch;
upwind.

Rotor Speed Control: Mechanical;
blade feathering; centrifugally-
operated.

Test Center Equipment

Tower: Davey-Dunlite

Hub Height: 12.2 m (45 ft)

Anemometer: R. M. Young Propvane,
Model 8002

Machine Description

The Dunlite is manufactured by Dunlite Electrical Company, a division of Pye Industrial Sales, Australia, and is distributed in the United States. The alternator is coupled through a 5:1 helical gearbox and is driven by a three-bladed propeller 4.10 m in diameter. The blades are made from galvanized steel sheets.

Propeller overspeed control is provided by the automatic feathering action of the blades. As speed of the blade increases, the centrifugal force on the governor weight on each of the blades overcomes the tension of a central spring and shock absorber unit and moves the blade to a coarser pitch. As the wind speed decreases, the propeller speed will slow, thus reducing the centrifugal force on the governor weights. This relaxes the central spring and returns the blades to maximum speed position.

A-4 ELEKTRO

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: WV50G

Design Output: 6.0 kW @ 11.7 m/s
(26.1 mph)

Output Type: 110 V dc

Rotor Diameter: 5.0 m (16.4 ft)

Rotor Configuration: Horizontal-axis,
propeller-type; variable pitch;
upwind.

Rotor Speed Control: Mechanical
blade feathering, centrifugally-
operated. Foldable tail, auto-
matic or manual.

Test Center Equipment

Tower: Steel post

Hub Height: 16.8 m (55 ft)

Anemometer: R. M. Young Propvane,
Model 8002.

Machine Description

The Elektro is manufactured by Elektro GmbH, Switzerland, and is distributed in the United States. The alternator is coupled through a 4:1 gearbox and is driven by a three-bladed propeller 5.0 m in diameter. The blades are manufactured from spruce or redwood, depending on availability.

Propeller overspeed control is provided by the automatic feathering action of the blades. Each blade is equipped with a centrifugal weight, in a blade holder, which is preloaded by a spring. As the rotational speed of the blade increases, the centrifugal force exceeds the spring force and changes the pitch of the blade. An automatic control system protects the rotor from overspeeding, protects the machine from storms, and prevents

the batteries from overcharging. The control box is located at the base of the tower and uses a servomotor to furl the tail so that the machine can operate in any intermediate position between total shutdown and full output. This servomotor is activated if the main current flow reaches an overload of 5% to 10% or if the wind speed becomes so excessive that the wind pressure switch is activated.

Reset is also automatic. A time switch is activated twice a day and automatically resets the generator for operation.

A-5 GRUMMAN

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: Windstream 25

Design Output: 15 kW @ 11.6 m/s
(26 mph)

Output Type: 110 V dc

Rotor Diameter: 7.62 m (25 ft)

Rotor Configuration: Horizontal-axis;
three-bladed; variable pitch;
downwind. Solidity-14%.

Rotor Speed Control: Blade Pitch
Control.

Test Center Equipment

Tower: Reinforced concrete pole

Hub Height: 16.8 m (55 ft)

Anemometer: R. M. Young Propvane
Model 8002

Machine Description

The Grumman Windstream 25 was designed as a stand-alone system for charging large battery banks. However, at the present time some are supplementing utilities through synchronous inverters.

No uncommon features have been incorporated in the design. For example, the rotor is controlled by blade pitch. There are three extruded aluminum blades. It is a downwind machine and the generator is driven through a standard shaft-mount reducer-type gearbox. The machine has been designed with conservative safety factors wherever possible.

Grumman Corporation has recommended a 13.7 m (45 ft) concrete tower for most of its machines. At the WSTC, it was decided to erect the Windstream on a 15.2 (50 ft) tower, raising the hub height to 16.8 m.

A-6 KEDCO

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: 1200

Design Output: 1200 watts @ 9.3-
9.8 m/s (20.8-21.9 mph)

Output Type: 12 V dc

Rotor Diameter: 3.6 m (12 ft)

Rotor Configuration: Horizontal-axis;
three-bladed; downwind. Solidity-13%

Rotor Speed Control: Centrifugal
Blade Pitch.

Test Center Equipment

Tower: Reinforced Concrete

Hub Height: 12.2 m (40 ft)

Anemometer: R. M. Young Propvane
Model 8002

Machine Description

The Kedco is a lightweight machine made by Kedco, Inc., Englewood, CA. The blade design incorporates an aircraft-type aluminum construction. The remaining structural components are welded steel. The main frame (strongback) is tubular, with main shaft bearings fitted into the tube. This design yields a very efficient, lightweight, and relatively stiff structure.

10.0 NORTH WIND (EAGLE)

10.1 DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: Eagle 3kW-110

Design Output: 3kW @ 12.2 m/sec
(27 mph)

Output Type: 110 V dc

Rotor Diameter: 4.14 m (13.6 ft)

Rotor Configuration: Horizontal-axis,
three-bladed; Up-wind.

Rotor Speed Control: Centrifugal
Blade Pitch.

Test Center Equipment

Tower: 40 ft Rohn SSV, Sections,
12 ft Top Stub Tower

Hub Height: 16.76 m (55 ft)

Anemometer: R.M. Young Propvane,
Model 8002

Machine Description

A direct drive, shunt wound, dc generator is driven by a three-bladed variable blade-pitch rotor. The blades are pitched by centrifugal forces. In this rotor the centrifugal weights are the blades themselves. The blades are retained by springs and translate along the pitch axis under centrifugal force. As they translate, a linkage system pitches the blades.

A-8 SENCENBAUGH

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: 1000-14

Design Output: 1.0 kW @ 10.3 m/s
(23 mph)

Output Type: 14 V dc

Rotor Diameter: 3.65 m (12 ft)

Rotor Configuration: Horizontal-axis,
propeller-type, fixed pitch; upwind.

Rotor Speed Control: Mechanical
foldable tail; automatic or manual.

Test Center Equipment

Tower: Rohn 25G

Hub Height: 12.2 m (40 ft)

Anemometer: R. M. Young Propvane,
Model 8002

Machine Description

The Sencenbaugh is a lightweight machine manufactured by Sencenbaugh Wind Electric, Palo Alto, CA. The blades are manufactured from Sitka spruce, with a bonded copper leading edge and a polyurethane finish. The main generator casting is 356T6 aluminum alloy. The alternator is coupled through a 3:1 helical gear-box and is driven by a three-bladed propeller 3.65 m in diameter.

Overspeed control is provided by using the increasing wind pressure of the propeller (and the resultant propeller thrust) to swing the alternator assembly (which is offset from the bearing support column) out of the oncoming wind. The foldable tail automatically reopens as wind speed decreases due to gravitational forces on the tail assembly. Tail offset and inclination with respect to the rotor may be varied, thus changing the cut-in and cut-out speeds of the machine.

A-9 ZEPHYR

DESCRIPTION OF MACHINE

Manufacturer's Specifications

Model: 15 kW

Design Output: 15 kVA @ 14 m/s
(31.3 mph)

Output Type: Variable frequency ac

Rotor Diameter: 9 m/sec (20 ft)

Rotor Configuration: Three-bladed;
fixed pitch; downwind. Solidity-
8%.

Rotor Speed Control: Positive Yaw
Drive.

Test Center Equipment

Tower: Zephyr Stub Tower on top
of Rohn SSV, Section 7 & 8, NH.

Hub Height: 16.7 m (55 ft)

Anemometer: R. M. Young Propvane

Machine Description

There are a total of four Zephyr Wind Dynamos in existence. Zephyr has incorporated many modern wind system design features into the system, such as the downwind rotor and a positive yaw drive controller, but the most innovative concept incorporated is the permanent magnet, direct drive alternator. The alternator is approximately 0.74 m (2.4 ft) in diameter and only 0.20 m (2.9 in.) wide. The magnets are fixed to the outer rim and, consequently, the relative circumferential speeds of the magnets are high. A direct drive generator develops its rated power at a low rotational speed, eliminating the speed-up transmission that is usually needed for a machine of this size.

APPENDIX B
Characteristics Summaries
for
SWECS Under Development

SWECS DESIGN CHARACTERISTICS

Work Location:

121 Middlesex Turnpike
Burlington, Massachusetts

Subcontractors:

Pinson Energy Corporation
Natural Power, Inc.

Aerospace Systems, Inc.

Principal Investigator: John Zvara
RF Program Monitor: Warren S. Bollmeier
Contract Administrator: James Roberts

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	1.2 @ 20	1 @ 20	1 @ 20	
Axis: Vertical/Horizontal	Vertical	Vertical	Vertical	
Rotor Location, Upwind/Downwind	NA	NA	NA	
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	12' X 8'	12' X 8'	15' X 8'	
Number of Blades	3-4	3	3	
Centerline Hub Height (ft)	40'	40'	40'	
Method of Power Regulation	Variable Pitch	Variable Pitch	Variable Pitch	
Type of Output Voltage & ϕ	24 Vac/3 ϕ	24 Vac/3 ϕ	24 Vac/3 ϕ	
Total System Weight (lbs)	464	464	508	
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	0.41	0.45	0.4	
Cut-in Wind Velocity (mph)	5	5	5	
Cut-out Wind Velocity (mph)	NS*	40	40	
Survival Wind Velocity (mph)	165	165	190	
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution — adjusted to sea level)				
@ 12 mph	NS	NS	1698	
@ 15 mph	NS	NS	2813	
@ 18 mph	NS	NS	3778	
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)	96	96	120	
Coning Angle (Deg)	NA	NA	NA	
Rotor/Hub Weight (lbs)	174	174	(Approx.)	
Blades				
Airfoil	NACA 4415	NACA 4415	NACA 0015	
Material	Aluminum	Aluminum	Aluminum	
Length (ft)	8	8	8	
Weight (lbs)	13	13	21	
Type of Hub				
Material	Aluminum	Aluminum	Aluminum	
Weight (lbs)	75 (2 hubs and shaft)	75 (2 hubs and shaft)	24/each	
CONTROL SYSTEM	Variable Pitch with Vane CAM	Tilt-CAM	Tilt-CAM	
Pitch Control Method				
Shutdown Provisions	NS	Tilt-CAM	Tilt-CAM	
TRANSMISSION/SPEED CHANGER				
Type	Timing Belt	Gear Box	Gear Box	
Ratio	$\approx 9:1$	$\approx 9:1$	15:1	
Weight (lbs)	NS	NS	60	
BEARINGS (Main)		Seal-West-SFC	Sealmaster-SFC	
Type	NS	2	2	
Material	NS	NS	Steel	
Weight (lbs)	NS	NS	8/each	

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR	NPI Flux-Switch Alternator	Same	Same	
Type:				
Output Power (kW) @ Rated RPM:	1-2 @ NS	1 @	1 @	
Maximum Output Power (kW):	1-2	1	1	
Weight (lbs):	35	35	35	
TOWER				
Type of Construction/Features:	Octahedron	Same	Same	
Materials:	Steel	Same	Same	
Height (ft):	34	34	34	
Weight (lbs):	NS	NS	NS	
Access:	NS	NS	NS	
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NS	NS	NS	
Form of Voltage:	NS	NS	NS	
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u> Total	NS			
Tower	NS			
Above Tower	464	464	508	
Rotor	174	174	290	
Blades Only	39	39	63	
<u>System Weight (lbs)/ft² : (ft² / lbs):</u> Total	NS: NS	NS: NS	NS: NS	
No Tower	4.83: .207	4.83: .207	4.23: .236	
<u>kWh/System Weight (lbs):</u> 12 mph site	NS	NS	NS	
15 mph site	NS	NS	NS	
18 mph site	NS	NS	NS	
<u>kWh/WTG Weight (lbs), (No Tower):</u> 12 mph site	NS	NS	3.34	
15 mph site	NS	NS	5.54	
18 mph site	NS		7.44	
<u>kWh/Rotor Swept Area (ft²):</u> 12 mph site	NS	NS	14.15	
15 mph site	NS	NS	23.44	
18 mph site	NS	NS	31.48	

SWECS DESIGN CHARACTERISTICS

Work Location:

P.O. Box 420

Norwich, Vt. 05055

Energetech Corporation

Principal Investigator:

William Drake

RF Program Monitor:

Warren Bollmeier

Contract Administrator:

James Roberts

Subcontractors:

Kaman Aerospace Corporation

Maremont Corporation

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	1.2 @ 20	2.3 @ 20	2 @ 20	
Axis- Vertical/Horizontal	Horizontal	Horizontal	Horizontal	
Rotor Location, Upwind/Downwind	Downwind	Downwind	Downwind	
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	12	16.4	16.4	
Number of Blades	2	2	2	
Centerline Hub Height (ft)	40	42.5	42.5	
Method of Power Regulation	Pitch to Stall w/ Rotor RPM	Same	Same	
Type of Output Voltage & ϕ	24 Vac/3 ϕ	24 Vac/3 ϕ	24 Vac/3 ϕ	
Total System Weight (lbs)	170	369	350	
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	0.37	0.37	0.30 (Svstem)	
Cut-in Wind Velocity (mph)	7	7	7	
Cut-out Wind Velocity (mph)	56	NA	NA	
Survival Wind Velocity (mph)	165	165	165	
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution -- adjusted to sea level)				
@ 12 mph	NS*	NS	5760	
@ 15 mph	NS	NS	8520	
@ 18 mph	NS	NS	11796	
ROTOR (Including Blades/Hub)	113	211.1	211.1	
Rotor Swept Area (ft ²)	0	0	0	
Coning Angle (Deg)	43	195	109	
Rotor/Hub Weight (lbs)	Clark Y-Modified	NACA 4415	NACA 23015	
Blades				
Airfoil	CLARK Y-MODIFIED	NACA 4415	NACA 23015	
Material	Wood	Sitka Spruce	White Ash/Red Cedar	
Length (ft)	NS	NS	NS	
Weight (lbs)	15	22.5	22	
Type of Hub	Centrifigally Pitching (Metal Straps/Fly Weights)	Same	Centrifigally Pitching (Torque/Tension Tubes)	
Material	Steel	Steel	Steel	
Weight (lbs)	13	150	65	
CONTROL SYSTEM	Centrifigal Pitch to Stall	Same	Same	
Pitch Control Method				
Shutdown Provisions	Same	Same	Same	
TRANSMISSION/SPEED CHANGER				
Type	NA	NA	Two-Stage Helical Gear	
Ratio	NA	NA	10.9:1	
Weight (lbs)	NA	NA	82	
BEARINGS (Main)				
Type	NS	NS	NS	
Material	NS	NS	NS	
Weight (lbs)	NS	NS	NS	

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR				
Type:	Permanent Magnet Alternator (Zephyr)	Same	Maremont (2 Part, 3 ϕ , Flux Switch) Alternator	
Output Power (kW) @ Rated RPM:	1-2 @ NS	2.3 @ 225	2.4 @ 2300	
Maximum Output Power (kW):	1-2	5.0	4.5	
Weight (lbs):	75	125	65	
TOWER				
Type of Construction/Features:	ROHN 45-G	ROHN 45-6SR	ROHN 45-6SR Double-Braced Top Section	
Materials:	Steel	Steel	Steel	
Height (ft):	40	40	40	
Weight (lbs):	NS	300	825	
Access:	NS	NS	NS	
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NA	NA	NA	
Form of Voltage:	NA	NA	NA	
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u>				
Total	NS	290.8	562.5	
Tower	NS	130.4	412.5	
Above Tower	170	160.4	175.0	
Rotor	43	84.8	54.5	
Blades Only	30	19.6	22	
<u>System Weight (lbs)/ft² : (ft² /lbs):</u>				
Total	NS:NS	3.17: .316	5.56: .180	
No Tower	1.50: .665	1.75: .572	1.66: .603	
<u>kWh/System Weight (lbs):</u>				
12 mph site	NS	NS	4.90	
15 mph site	NS	NS	7.25	
18 mph site	NS	NS	10.03	
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site	NS	NS	16.46	
15 mph site	NS	NS	24.34	
18 mph site	NS	NS	33.70	
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site	NS	NS	27.29	
15 mph site	NS	NS	40.36	
18 mph site	NS	NS	55.88	

SWECS DESIGN CHARACTERISTICS

Work Location:

P.O. Box 315

Warren, Vt 05674

Subcontractors:

Speigel/Zamecnik

Magnetic Products, Inc.

Northwind Power Company

Principal Investigator:

Don Mayer

RF Program Monitor:

Warren Bollmeier

Contract Administrator:

Don Cullen

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	1-2 @ 20	2.0 @ 20	2.0 @ 20	
Axis- Vertical/Horizontal	Horizontal	Horizontal	Horizontal	
Rotor Location, Upwind/Downwind	Upwind	Upwind	Upwind	
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	10	16.4	16.4	
Number of Blades	3	3		
Centerline Hub Height (ft)	40	40	40	
Method of Power Regulation	Rotor Tilt-Back	Rotor Tilt-Back	Rotor Tilt-Back	
Type of Output Voltage & ϕ	24 DC/1 ϕ	24 Vac/3 ϕ	24 Vac/3 ϕ	
Total System Weight (lbs)	NS*	325	530	
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	0.38	0.38	0.38	
Cut-in Wind Velocity (mph)	10	10	9	
Cut-out Wind Velocity (mph)	55	60	60	
Survival Wind Velocity (mph)	165	165	165	
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution — adjusted to sea level)				
@ 12 mph	NS	NS	5641	
@ 15 mph	NS	NS	8322	
@ 18 mph	NS	NS	10897	
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)	78.5	211.1	211.1	
Coning Angle (Deg)	0	0	0	
Rotor/Hub Weight (lbs)	NS	66	75	
Blades				
Airfoil	GU-75-5 (11) 8	N60	N60	
Material	Wood	Sitka Spruce	Sitka Spruce	
Length (ft)	NS	7	7	
Weight (lbs)	NS	6	10	
Type of Hub	Fixed	Fixed	Fixed	
Material	Steel	Steel	Steel	
Weight (lbs)	NS	48	45	
CONTROL SYSTEM				
Pitch Control Method	Rotor Tilt-Back	Rotor Tilt-Back	Rotor Tilt-Back	
Shutdown Provisions	Rotor Tilt-Back	Rotor Tilt-Back	Rotor Tilt-Back	
TRANSMISSION/SPEED CHANGER				
Type	NA	NA	NA	
Ratio	NA	NA	NA	
Weight (lbs)	NA	NA	NA	
BEARINGS (Main)				
Type	NS	NS	Ball (2)	
Material	NS	NS	Steel	
Weight (lbs)	NS	NS	2/each	

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR	Direct Drive Permanent Magnet	Direct Drive Alternator (Lundell)	Direct Drive Alternator (Lundell)	
Type:				
Output Power (kW) @ Rated RPM:	1-2 @ NS	2 @ 240	2 @ 250	
Maximum Output Power (kW):	NS	2	2	
Weight (lbs):	NS	NS	210	
TOWER				
Type of Construction/Features:	ROHN 45-G	ROHN 45-GSR	ROHN 45-GSR	
Materials:	Steel	Steel	Steel	
Height (ft):	40	40	40	
Weight (lbs):	NS	300	300?	
Access:	NS	NS	NS	
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NA	NA	NA	
Form of Voltage:	NA	NA	NA	
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u>				
Total	NS	312.5	415	
Tower	NS	150	150	
Above Tower	NS	162.5	265	
Rotor	NS	33	37.5	
Blades Only	NS	10	22.5	
<u>System Weight (lbs)/ft² : (ft² /lbs):</u>				
Total	NS:NS	3.15:.317	3.93:.254	
No Tower	NS:NS	1.53:.649	2.51:.398	
<u>kWh/System Weight (lbs):</u>				
12 mph site	NS	NS	6.79	
15 mph site	NS	NS		
18 mph site	NS	NS	13.24	
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site	NS	NS	10.64	
15 mph site	NS	NS	15.70	
18 mph site	NS	NS	20.73	
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site	NS	NS	26.72	
15 mph site	NS	NS	39.42	
18 mph site	NS	NS	52.05	

SWECS DESIGN CHARACTERISTICS

Work Location:

4175 Veterans Memorial Highway
Ronkonkoma, N.Y. 11777

Subcontractors:

Grumman Energy System

Principal Investigator: Frank Adler
RF Program Monitor: James Gerwitz
Contract Administrator: James Roberts

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	8 kW @ 20	11 kW @ 20 RPM		
Axis- Vertical/Horizontal	Horizontal	Same		
Rotor Location, Upwind/Downwind	Downwind	Same		
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	NS	33.2 ft.		
Number of Blades	3	3		
Centerline Hub Height (ft)	NS	55 ft.		
Method of Power Regulation	Full Span Pitch	Full Span Pitch		
Type of Output Voltage & ϕ	110/220 Vac; 3 ϕ	110/220 Vac; 3 ϕ		
Total System Weight (lbs)	NS	5161 lbs.		
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	0.42	0.41		
Cut-in Wind Velocity (mph)	7 mph	7 mph		
Cut-out Wind Velocity (mph)	60 mph	60 mph		
Survival Wind Velocity (mph)	165 mph	165 mph		
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution — adjusted to sea level)				
@ 12 mph	NS*	NS		
@ 15 mph	NS	NS		
@ 18 mph	NS	NS		
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)	NS	868 ft ²		
Coning Angle (Deg)	NS	6°		
Rotor/Hub Weight (lbs)	NS	1314 lbs.		
Blades				
Airfoil	NACA 644-421	Same		
Material	Extruded Aluminum	Same		
Length (ft)	NS	NS		
Weight (lbs)	NS	NS		
Type of Hub				
Material	Steel Weldment	Same		
Weight (lbs)	NS	NS		
CONTROL SYSTEM				
Pitch Control Method	NS	Motor-Driven Act		
Shutdown Provisions	CENTRAL-OPERATED LATCHES ON LEAF AND THE BLADES	Redundant Actuators		
TRANSMISSION/SPEED CHANGER				
Type	SHAFT-DRIVE THRU A FIXED RATIO GEAR-BOX TO ALTERNATOR	Same		
Ratio	20:1	Same		
Weight (lbs)	NS	410 lbs.		
BEARINGS (Main)				
Type	NS	NS		
Material	NS	NS		
Weight (lbs)	NS	96 lbs		

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR				
Type:	Variable Frequency AC Alternator	Same	Induction Generator	
Output Power (kW) @ Rated RPM:	10 kW @ NS	13.8 kW @ 99	11.1 kW @ 75.2	
Maximum Output Power (kW):	10 kW	13.8 kW	20 kW	
Weight (lbs):	NS	310 lbs.	330 lbs.	
TOWER				
Type of Construction/Features:	Guyed Pole	Same	Fixed Base Guyed Pipe	
Materials:	Concrete	Same	Cor-Ten	
Height (ft):	55 ft.	Same	55 ft.	
Weight (lbs):	NS	NS	2621 lbs.	
Access:	Gin Pole Erection, Fixed Base	Same	Same	
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NS	NS	NS	
Form of Voltage:	NS	NS	NS	
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u>				
Total	NS	5161	5210	
Tower	NS	NS	2621	
Above Tower	NS	NS	2589	
Rotor		119	1000	
Blades Only		NS	564	
<u>System Weight (lbs)/ft² : (ft² /lbs):</u>				
Total	NS:(NS)	5.9:(NS)	6.0:(1.66)	
No Tower	NS:(NS)	NS:(NS)	2.98:(3.35)	
<u>kWh/System Weight (lbs):</u>				
12 mph site	NS	NS	7.43	
15 mph site	NS	NS	11.50	
18 mph site	NS	NS	14.01	
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site	NS	NS	14.95	
15 mph site	NS	NS	23.14	
18 mph site	NS	NS	28.2	
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site	NS	44.58	44.58	
15 mph site	NS	69.00	69.00	
18 mph site	NS	84.1	84.1	

SWECS DESIGN CHARACTERISTICS

Work Location:

Alcoa Laboratory

Alcoa Center, Pennsylvania 15069

Subcontractors:

Alcoa

Principal Investigator:

Thomas Stewart.

RF Program Monitor:

Rodger L. Moment

Contract Administrator:

Don Cullen

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	8 kW @ 20 mph	11 kW @ 20 mph	11.2 kW @ 20 mph	
Axis- Vertical/Horizontal	Vertical	Vertical	Vertical	
Rotor Location, Upwind/Downwind	Darrieus	Darrieus	Darrieus	
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	30ft. x 30ft.	30 ft. X 33.7 ft.	33 ft. X 33.7 ft.	
Number of Blades	2-3	3	3	
Centerline Hub Height (ft)	N/A	N/A	N/A	
Method of Power Regulation	NS	NS	Induction Generator	
Type of Output Voltage & ϕ	NS	110 AC, ϕ NS	460 Vac, 3 ϕ	
Total System Weight (lbs)	NS	14,000 lbs.	14,578 lbs.	
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	NS	0.39	NS	
Cut-in Wind velocity (mph)	12-14 mph	12 mph	NS	
Cut-out Wind Velocity (mph)	65 mph	65 mph	NS	
Survival Wind Velocity (mph)	165 mph	165 mph	165 mph	
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft. , based upon NASA Wind Distribution -- adjusted to sea level)				
@ 12 mph	NS*	NS	Sandia 31,000	
@ 15 mph	NS	NS	55,000	
@ 18 mph	NS	NS	81,000	
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)	NS	NS	670 ft ²	
Coning Angle (Deg)	NS	NS	0°	
Rotor/Hub Weight (lbs)	NS	814 lbs.	1679 lbs.	
Blades				
Airfoil	NACA 0015 Symmetric	Same	Same	
Material	Extruded Alum.	Same	Same	
Length (ft)	N/A	N/A	N/A	
Weight (lbs)	NS	814 lbs.	1679 lbs.	
Type of Hub				
Material	N/A	N/A	N/A	
Weight (lbs)	N/A	N/A	N/A	
CONTROL SYSTEM				
Pitch Control Method	No Pitch Control. Machine Started By Motor, Powered By Outside Source	Same	Same	
Shutdown Provisions	Brake	Brake	Brake	
TRANSMISSION/SPEED CHANGER				
Type	Vertical Shaft-Drive Thru Flywheel To Induction Generator	Vertical Shaft-Drive Thru A Gear-Train → Gear-Box	Browning Helical Shaft Mount Reducer, Gear Box + Belt, Or In-Line Option	
Ratio	NS	17:1 → 28:1	1:24.7	
Weight (lbs)	NS	NS	417 lbs.	
BEARINGS (Main)				
Type	NS	Ball/Roller Bearing (6) Roller Bearing (2)	Spherical Roller Thrust- 1 Upper 1 Lower	
Material	NS	NS	Steel	
Weight (lbs)	NS	NS	113 lbs.	

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR	Induction Generator/ Motor	Same	Same.	
Type:				
Output Power (kW) @ Rated RPM:	≥ 8 kW @ NS	15 kW @ NS	25 kW @ 18000 RPM	
Maximum Output Power (kW):	≥ 8 kW @ NS	15 kW @ NS	25 kW @ NS	
Weight (lbs):	NS	NS	303 lbs.	
TOWER	Guyed Double Tube/ Cantilever Double Tube With Tower	Guyed Double Tube Guyed Single Tube	Guyed Rotating Single-Tube	
Type of Construction/Features:				
Materials:	NS	Steel	Steel	
Height (ft):	55 ft.	Same	Same	
Weight (lbs):	NS	9361→6280	11,577	
Access:	NS	NS	NS	
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NS	NS	NS	
Form of Voltage:	NS	NS	NS	
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u>				
Total	NS	NS	1325	
Tower	NS	NS	585	
Above Tower	NS	NS	740	
Rotor	NS	NS	863	
Blades Only	NS		78.5	
<u>System Weight (lbs)/ft² : (ft² /lbs):</u>				
Total	NS:NS	NS:NS	21.77:(.046)	
No Tower	NS:NS	NS:NS	14.17:(.071)	
<u>kWh/System Weight (lbs):</u>				
12 mph site	NS	NS	2.126	
15 mph site	NS	NS	3.773	
18 mph site	NS	NS	5.556	
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site	NS	NS	3.265	
15 mph site	NS	NS	5.792	
18 mph site	NS	NS	8.530	
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site	NS	NS	46.269	
15 mph site	NS	NS	82.089	
18 mph site	NS	NS	120.895	

SWECS DESIGN CHARACTERISTICS

Work Location:

Silverlane

East Hartford, Connecticut 06108

United Technologies Research Center

Principal Investigator: M.C. Cheney

RF Program Monitor: Joseph Boland

Contract Administrator: J. Kisker

Subcontractors:

Goldsworthy Engineering
Industrial Design Consultants
Hamilton Standard

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	8 @ 20	8 @ 20	11 @ 20	9 @ 20 mph
Axis: Vertical/Horizontal	Horizontal	Same	Same	Same
Rotor Location, Upwind/Downwind	Downwind	Same	Same	Same
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	28	28	31	31
Number of Blades	2	2	2	2
Centerline Hub Height (ft)	66	Same	Same	Same
Method of Power Regulation	NS	NS	NS	Ind. Gen/Utility Line
Type of Output Voltage & ϕ	120/240 AC, 1 ϕ	NS	440 Vac, 3 ϕ	220 VAC, SING. or 3 ϕ 240 VDC
Total System Weight (lbs)	NS	NS	4959	4322
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	NS	0.3 to 0.45	0.43	0.43
Cut-in Wind Velocity (mph)	NS	NS	9.0	7.5
Cut-out Wind Velocity (mph)	70	70	50	50
Survival Wind Velocity (mph)	165	165	165	165
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution — adjusted to sea level)				
@ 12 mph	NS	NS	NS	28,741
@ 15 mph	NS	NS	NS	40,689
@ 18 mph	NS	NS	NS	46,828
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)	616	616	750	750
Coning Angle (Deg)	NS	NS	NS	10°
Rotor/Hub Weight (lbs)	NS	NS	NS	382
Blades				
Airfoil	NS	NACA 23,112	NACA 23,112	NACA 23,112
Material	FIBER REINFORCED COMPOSITE (FRP)	REINFORCED, FORMED FOAM	E-GLASS (FRP) STEEL, GRAPHITE/EPOXY	FRP (E-Glass)
Length (ft)	11	11	12	12
Weight (lbs)	NS	NS	100	150
Type of Hub				
Material	NS	NS	NS	Graphite/Epoxy/Steel
Weight (lbs)	NS	NS	NS	232
CONTROL SYSTEM ¹				
Pitch Control Method	Fly Weight/Flex Beam	Same	Same	Fly Weights/Flex Beam
Shutdown Provisions	Manual Yaw Brake	Auto Disc Brake	Manual Disc Brake	Rotor Disc Brake
TRANSMISSION/SPEED CHANGER				
Type	1 Stage Belt Drive	2 Stage Belt Drive	2 Stage Gear	2 Stage Gear
Ratio	NS	NS	14:1, 17:1	1:17
Weight (lbs)	NS	NS	NS	300
BEARINGS (Main)				
Type	NS	NS	Taper Roller	Spherical Roller
Material	NS	NS	Steel	Steel
Weight (lbs)	NS	NS	NS	138

¹ Overspeed Control : Stall

	PROPOSED	PDR	CDR	FDR
GENERATOR				
Type:	AC Brushless	AC Brushless	Induction	Induction or DC
Output Power (kW) @ Rated RPM:	8 @ NS	10 KVA @ 1714	11 @ 1800	15 @ 1800 (AC) NS @ 1800 (DC)
Maximum Output Power (kW):	NS	NS	15	15
Weight (lbs):	NS	135	NS	295
TOWER				
Type of Construction/Features:	Guyed Pole	Guyed Pole	Guyed Pole	Same
Materials:	Steel	Same	Same	Same
Height (ft):	55	Same	Same	Same
Weight (lbs):	NS	NS	NS	NS
Access:	NS	NS	NS	NS
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NS	NS	NS	NS
Form of Voltage:	NS	NS	NS	NS
MISCELLANEOUS INFORMATION				
	NS	NS	NS	NS
VALUE INDICATORS (1st/1000th Units)				
	NS	NS	NS	NS
<u>System Weight (lbs)/kW:</u>				
Total	NS/NS	NS/NS	NS/NS	480.2
Tower	NS	NS	NS	274.1
Above Tower	NS	NS	NS	206.1
Rotor	NS	NS	NS	42.4
Blades Only	NS	NS	NS	16.6
<u>System Weight (lbs)/ft² : (ft² / lbs):</u>				
Total	NS:NS	NS:NS	NS:NS	5.76:(0.17)
No Tower	NS:NS	NS:NS	NS:NS	2.47:(0.4)
<u>kWh/System Weight (lbs):</u>				
12 mph site	NS	NS	NS	6.7
15 mph site	NS	NS	NS	8.8
18 mph site	NS	NS	NS	10.4
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site	NS/NS	NS/NS	NS/NS	15.6
15 mph site	NS	NS	NS	20.5
18 mph site	NS	NS	NS	24.3
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site	NS	NS	NS	38.6
15 mph site	NS	NS	NS	50.6
18 mph site	NS	NS	NS	60.0

SWECS DESIGN CHARACTERISTICS

Work Location :

Box 44A Route 3
Mukwonago, Wisconsin 53149

Windworks, Inc.

Principal Investigator: Hans Meyer
RF Program Monitor: Joe Boland
Contract Administrator: James Hill

Subcontractors:

Generac
AMF-Head

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	8 @ 20	8 @ 20	8 @ 20	8 @ 20
Axis- Vertical/Horizontal	Horizontal	Same	Same	Horizontal
Rotor Location, Upwind/Downwind	Downwind	Same	Same	Downwind
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	29.5	31	31	33
Number of Blades	3	3	3	3
Centerline Hub Height (ft)	55	55	55	55
Method of Power Regulation	Gemini	NS	NS	Gemini Sync. Inv.
Type of Output Voltage & ϕ	240 Vac, 1 ϕ	NS, 3 ϕ	120/240 Vac, 1 ϕ	220 Vac, 1 ϕ
Total System Weight (lbs)	3634	3541	3952	3476
PERFORMANCE PARAMETERS				
C_p @ Rated Wind Velocity	0.45	0.45	0.42	0.4 @ 20 mph
Cut-in Wind Velocity (mph)	7	7	7	7
Cut-out Wind Velocity (mph)	NS	NS	NS	45
Survival Wind Velocity (mph)	165	165	165	165
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution — adjusted to sea level)				
@ 12 mph	NS*	NS	NS	24,000
@ 15 mph	NS	NS	NS	34,000
@ 18 mph	NS	NS	NS	40,000
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)		750	750	850
Coning Angle (Deg)	NS	NS	NS	4° Nom.
Rotor/Hub Weight (lbs)	NS	NS	NS	425
Blades				
Airfoil	AI L/D Ratio	Same	Wortman FX61-184	Wortman FX61-184
Material	Comb. Composite	Same	Alum, FRP Tip	Alum W/FRP Tip
Length (ft)				13
Weight (lbs)	225	225	240	220
Type of Hub				
Material	NS	Tensaloy	Same	Alum Alloy
Weight (lbs)	310	78	185	185
CONTROL SYSTEM				
Pitch Control Method	SELF-POWERED, SPRING LOADED, HYD. LIMITED RPM, 4 MODE FEATHERED BLADE			Hyd/Spring
Shutdown Provisions	Two Auto, 1 Manual	Same	Same	Feather, Brake
TRANSMISSION/SPEED CHANGER				
Type	NA (Direct Drive)	Same	Same	NA (Direct Dr.)
Ratio	NA (Direct Drive)	Same	Same	NA
Weight (lbs)	NA (Direct Drive)	Same	Same	NA
BEARINGS (Main)				
Type	NS	NS	NS	Roller
Material	NS	NS	NS	Steel
Weight (lbs)	16	16	16.5	16

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR	Direct Drive PM Alternator	Same	Same	Direct Drive Perm Mag Alt.
Type:				
Output Power (kW) @ Rated RPM:	8 @ 110~130	8 @ 110~130	NS @ NS	8 @ 140
Maximum Output Power (kW):	NS	NS	NS	8 Plus
Weight (lbs):	202	202	NS	600
TOWER		8" SCH 40 Well Casings		
Type of Construction/Features:	Guyed Pole		Same	Same
Materials:	Steel	Same	Same	Steel
Height (ft):	55	55	55	55
Weight (lbs):	2202	2202	2362	1860
Access:	Tower Pivots	Same	Same	Tower Pivots to GND
AUX. ELECTRICAL EQUIPMENT REQ'D	Gemini 8 kW	NS 8	NS 8	Gemini AC or DC
Power Output to User:				
Form of Voltage:	1 Ø AC	3 Ø AC	1 Ø AC	60 HZ 220 VAC, 1 Ø
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u>				
Total				434
Tower				233
Above Tower				202
Rotor				53
Blades Only				28
<u>System Weight (lbs)/ft² : (ft² /lbs):</u>				
Total				4.1:0.24
No Tower				1.9:0.52
<u>kWh/System Weight (lbs):</u>				
12 mph site				6.9
15 mph site				9.8
18 mph site				11.5
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site				14.9
15 mph site				21.0
18 mph site				24.8
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site				28.4
15 mph site				40.2
18 mph site				47.4

SWECS DESIGN CHARACTERISTICS

Work Location:

Old Windsor Road

Bloomfield, Connecticut 06002

Subcontractors:

Kaman Aerospace

Principal Investigator:

H. Howes

RF Program Monitor:

Eugene Bange

Contract Administrator:

Don Cullen

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	40 kW @ 20 mph	40 kW @ 20 mph		
Axis: Vertical/Horizontal	Horizontal	Horizontal		
Rotor Location, Upwind/Downwind	Downwind	Downwind		
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	60 ft.	64 ft.		
Number of Blades	2	2		
Centerline Hub Height (ft)	75 ft.	75 ft.		
Method of Power Regulation	Variable Pitch	Variable Pitch		
Type of Output Voltage & ϕ	480 Vac, 3 ϕ	480 Vac, 3 ϕ		
Total System Weight (lbs)	8900	8900		
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	0.44	0.37		
Cut-in Wind Velocity (mph)	10	13		
Cut-out Wind Velocity (mph)	70	60		
Survival Wind Velocity (mph)	125 + 1.5 S.F.	125 + 1.5 S.F.		
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution -- adjusted to sea level)				
@ 12 mph	NS*	Est. 112,128 kWh		
@ 15 mph	NS	168,192 kWh		
@ 18 mph	NS	203,232 kWh		
ROTOR (Including Blades/Hub)				
	TFT SPAR FIBERGLASS SKINS	TFT SPAR FIBERGLASS SKINS		
Rotor Swept Area (ft ²)	2827 ft ²	3217 ft ²		
Coning Angle (Deg)	10°	6°		
Rotor/Hub Weight (lbs)	NS	1600 lbs.		
Blades				
Airfoil	230 XX	23,036		
Material				
Length (ft)	29.5 ft.	31.5 ft.		
Weight (lbs)	NS	690		
Type of Hub	Rigid	Rigid		
Material	Forged Steel	Forged Steel		
Weight (lbs)	NS	220 lbs.		
CONTROL SYSTEM				
Pitch Control Method	Full Span Pitch	Full Span Pitch		
Shutdown Provisions	Auto-Feather	Auto-Feather		
TRANSMISSION/SPEED CHANGER				
Type	2 Stage Planetary	2 Stage Planetary		
Ratio	1:24	1:26		
Weight (lbs)	NS	NS		
BEARINGS (Main)				
Type	NS	NS		
Material	NS	NS		
Weight (lbs)	NS	NS		

*Not Supplied

	PROPOSED	PDR	CDR	FDR
GENERATOR				
Type:	Synch	Induction for Proto, Synch for 3 Designs		
Output Power (kW) @ Rated RPM:	40 kW @ 76 RPM	40 kW @ 69 RPM		
Maximum Output Power (kW):	NS	49 kW		
Weight (lbs):	NS	NS		
TOWER				
Type of Construction/Features:	Truss	Simplified Truss		
Materials:	Channel	3 Tubes		
Height (ft):	75 ft.	75 ft.		
Weight (lbs):	NS	4000 lbs.		
Access:	Hinged, Base for Erection, Ladder	Hinged, Base for Erection, Ladder		
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	NS	NS		
Form of Voltage:	NS	NS		
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u>				
Total	222.5	222.5		
Tower	100.0	100.0		
Above Tower	122.5	122.5		
Rotor	40.0	40.0		
Blades Only	34.5	34.5		
<u>System Weight (lbs)/ft² : (ft² /lbs):</u>				
Total	3.15:(3.18)	2.77:(3.61)		
No Tower	1.73:(5.77)	1.53:(6.57)		
<u>kWh/System Weight (lbs):</u>				
12 mph site	NS	12.6		
15 mph site	NS	18.9		
18 mph site	NS	22.8		
<u>kWh/WTG Weight (lbs), (No Tower):</u>				
12 mph site	NS	22.89		
15 mph site	NS	34.3		
18 mph site	NS	41.5		
<u>kWh/Rotor Swept Area (ft²):</u>				
12 mph site	NS	34.8		
15 mph site	NS	52.3		
18 mph site	NS	63.2		

SWECS DESIGN CHARACTERISTICS

Work Location:

P.O. Box 516

St. Louis, Missouri 63166

Subcontractors:

Valley Industries

McDonnell Aircraft Company

Principal Investigator: John Anderson

RF Program Monitor: Eugene Bange

Contract Administrator: James Roberts

	PROPOSED	PDR	CDR	FDR
GENERAL CONFIGURATION				
Output Power (kW) @ Rated Wind $\bar{V}$	40 kW @ 20 mph			
Axis- Vertical/Horizontal	Vertical-Giromill			
Rotor Location, Upwind/Downwind	N/A			
Rotor/Cone Diameter (ft) (Width & Height - Vert. axis)	65 ft. X 32.5 ft.			
Number of Blades	3			
Centerline Hub Height (ft)	75 ft.			
Method of Power Regulation	Variable Pitch			
Type of Output Voltage & ϕ	480 v, 3 ϕ			
Total System Weight (lbs)	TBD			
PERFORMANCE PARAMETERS				
Cp @ Rated Wind Velocity	0.53			
Cut-in Wind Velocity (mph)	TBD			
Cut-out Wind Velocity (mph)	60 mph			
Survival Wind Velocity (mph)	125 mph W/1.5 S.F.			
ANNUAL OUTPUT (kWh)				
(For average wind velocity measured @ 30ft., based upon NASA Wind Distribution — adjusted to sea level)				
@ 12 mph	112,700			
@ 15 mph	163,800			
@ 18 mph	203,400			
ROTOR (Including Blades/Hub)				
Rotor Swept Area (ft ²)	2112.5 ft ²			
Coning Angle (Deg)	N/A			
Rotor/Hub Weight (lbs)	TBD			
Blades				
Airfoil	NACA 0018			
Material	Aluminum			
Length (ft)	32.5 ft.			
Weight (lbs)	TBD			
Type of Hub				
Material	Rotating Tower 36" Steel Tube			
Weight (lbs)	TBD			
CONTROL SYSTEM				
Pitch Control Method	Modulated Blades			
Shutdown Provisions	Auto-Feathering			
TRANSMISSION/SPEED CHANGER				
Type	TBD			
Ratio	TBD			
Weight (lbs)	TBD			
BEARINGS (Main)				
Type	TBD			
Material	TBD			
Weight (lbs)	TBD			

	PROPOSED	PDR	CDR	FDR
GENERATOR				
Type:	TBD			
Output Power (kW) @ Rated RPM:	40 kW @ 30 RPM			
Maximum Output Power (kW):	50 kW +			
Weight (lbs):	TBD			
TOWER	Truss Type (Stationary) Tube Type (Rotating)			
Type of Construction/Features:				
Materials:	TBD			
Height (ft):	≈69'			
Weight (lbs):	TBD			
Access:	Ladder			
AUX. ELECTRICAL EQUIPMENT REQ'D				
Power Output to User:	TBD			
Form of Voltage:	TBD			
MISCELLANEOUS INFORMATION				
VALUE INDICATORS (1st/1000th Units)				
<u>System Weight (lbs)/kW:</u> Total	TBD			
Tower	TBD			
Above Tower	TBD			
Rotor	TBD			
Blades Only	TBD			
<u>System Weight (lbs)/ft² : (ft² /lbs):</u> Total	TBD:TBD			
No Tower	TBD:TBD			
<u>kWh/System Weight (lbs):</u> 12 mph site	TBD			
15 mph site	TBD			
18 mph site	TBD			
<u>kWh/WTG Weight (lbs), (No Tower):</u> 12 mph site	TBD			
15 mph site	TBD			
18 mph site	TBD			
<u>kWh/Rotor Swept Area (ft²):</u> 12 mph site	53.35			
15 mph site	77.5			
18 mph site	96.3			

APPENDIX C

Wind Systems Performance Plots

Wind Systems Performance Plots

There is a complex interrelationship between design windspeed, design output, rotor diameter, generator size, and annual energy production from a wind machine. In order to provide a simplified tool for estimating machine SWECS specifications, a series of plots have been generated which incorporate these numerous factors. These plots are useful for obtaining approximate values of design output power, rotor diameter, and design wind velocity for a given annual energy output requirement. As such, they permit rough sizing of a wind machine. Rotor diameters from 3 to 46 m (10 to 150 ft) are included, as well as design outputs from 1 to 100 kW.

Annual energy outputs were calculated using the plot of:

$$\frac{\text{Average Power Output}}{\text{Design Power}} \quad \text{vs} \quad \frac{\text{Annual Mean Wind Speed}}{\text{Design Wind Speed}}$$

published in the report, The Effect of Generalized Wind Characteristics on Annual Power Estimates from Wind Turbine Generators, by William C. Cliff (PNL-2436, October 1977). This plot was developed by Dr. Cliff to provide rough estimates of average wind turbine power output.*

The three plots presented here are for wind machines operating in a 5.4 m/s (12 mph) average velocity wind distribution. The power vs rotor diameter relationship was calculated using:

$$P = 0.05472 A \times C_p \times V_r^3$$

where:

A = rotor area in square meters

V_r = rated (design) wind velocity in mph

C_p = system power coefficient

*Battelle assumes: Very low cut-in (low enough to be unimportant); constant power from design to cutout wind speed

In performing the calculations, a system efficient of 60% was assumed, which results in a system power coefficient of 0.35.

An example of how the plots can be used is as follows. Assume that it is desired to have a wind machine that produces 50,000 kWh/yr in a wind regime of $\bar{V} = 5.4$ m/s. From Figure 2, it can be seen that a number of machines will do, ranging from 9 kW at 5.4 m/s (12 mph) to 17.5 kW at 9 m/s (20 mph). Machines falling between these two sizes can be sized using the graph. Other sizes which would be rated either above 9 m/s or below 5.4 m/s could be identified, but the graphs do not cover these ranges. In addition to rated output to rated wind velocity, one can also determine that the 9 kW machine (in this case) would have a rotor diameter around 18.6 m (61 ft), while the 17.5 kW machine would have a rotor closer to 12.2 m (40 ft) in diameter.

While the above example assumes that the desired annual energy production is given, the plots can also be used starting with any of the other parameters. For instance, given a rotor diameter, a machine's design output, wind speed, and annual energy production can be estimated. Or starting from a rated output, the rated wind speed, associated rotor diameter, and annual energy generation could be approximated.

It should be emphasized that a fixed wind distribution was used in preparing these plots and combined with other assumptions regarding machine performance, the result is data which should only be used in making rough sizing estimates for SWECS. For specific machines, the actual performance data must be combined with the correct wind distribution curve for a specific site in order to arrive at annual energy production.

SMALLER SWECS (Up to 14 kW)
Rated (Design) Output (kW) / Rotor Diameter (Ft) / kWh per Year

Figure C-1

LARGER SWECS (5-40 kW)
Rated (Design) Output (kW) / Rotor Diameter (Ft) / kWh per Year

Figure C-2

LARGE SWECS (40-100 kW)
Rated (Design) Output Power (kW) / Rotor Diameter (Ft)

Figure C-3

APPENDIX D

Report Bibliography

The entries in this bibliography include publications generated by Rocky Flats and its contractors.

Massachusetts, University of, Amherst. Investigation of the Feasibility of Using Wind Power for Space Heating in Colder Climates. (Third quarterly progress report covering the final design and mfg. phase of the project, September-December 1975). W. E. Heronemus, December 1975, 165 pp. Contract No. NSF-AER-75-00603. (ERDA/NSF/00603-75/T1) Available from NTIS

Nielsen Engineering and Research, Inc. Wind Power for Farms, Homes, and Small Industry. J. Park and D. Schwind, September 1977. 230 pp. Contract No. E(04-3)-1270. (RFP-2841/1270/78/4) Available from NTIS

Rocky Flats Plant. First Semiannual Report, Rocky Flats Small Wind Systems Test Center Activities, Volume I, Description of the National Small Wind Systems Test Center (RFP-2920/3533-78/6-1); Volume II, Experimental Data Collected From Small Wind Energy Conversion Systems (RFP-2920/3533-78/6-2), September 28, 1978.

Rocky Flats Plant. Technical and Management Support for the Development of Wind Systems for Farm, Remote, and Rural Use, Annual Report for the Period October 1976-September 1977, October 1977. 125 pp. (RFP-2721/3533/78/2). Available from NTIS

Rocky Flats Plant. An Index of Manufacturers, Research, and Distributors Currently Involved in the Development of Wind Energy Conversion Systems. American Wind Energy Association. February 1978. 72 pp. (DOE/RF/3533-78/1). Available from NTIS

Rocky Flats Plant. A Guide to Commercially-Available Wind Machines, prepared with the assistance of the American Wind Energy Association, April 3, 1978. 121 pp. (RFP-2836/3533/78/3). Available from NTIS

Rocky Flats Plant. FY 1979 Program Summary, Technical, and Management Support for the Development of Small Wind Systems. October 1, 1978. 31 pages. (RFP-2882/3533-79/1).

When indicated above, reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.