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UC-60

GRUMMAN WS33 WIND SYSTEM

Phase II Executive Summary

Prototype Construction & Testing

November 1, 1980

F. M. Adler
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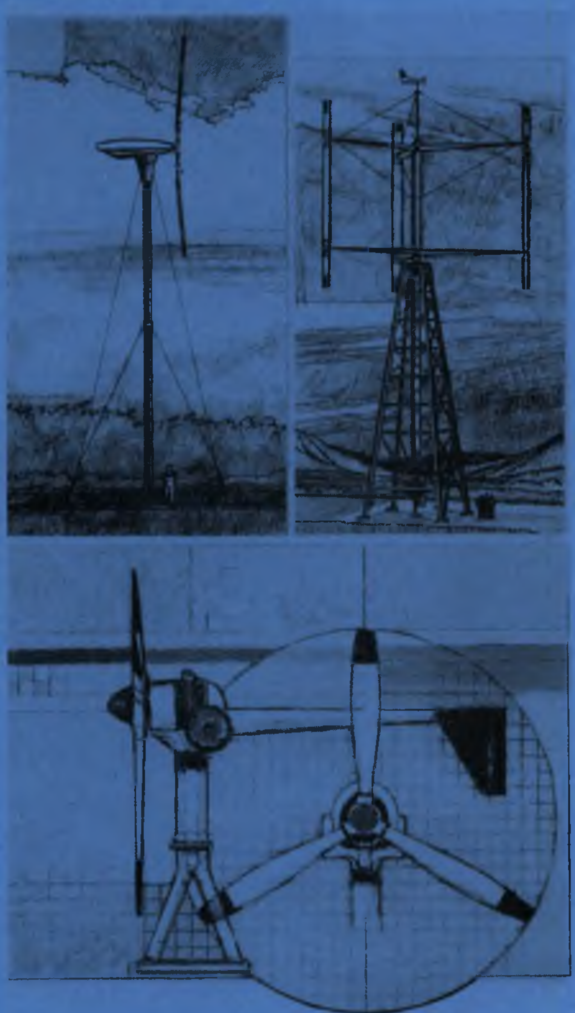

GRUMMAN ENERGY SYSTEMS, INC.
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Bohemia, New York 11716

Prepared for

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Rocky Flats Plant
Wind Systems Program
P.O. Box 464
Golden, Colorado 80402-464

Subcontract No. PF71787-F

As a Part of the

UNITED STATES DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGY DIVISION
FEDERAL WIND ENERGY PROGRAM

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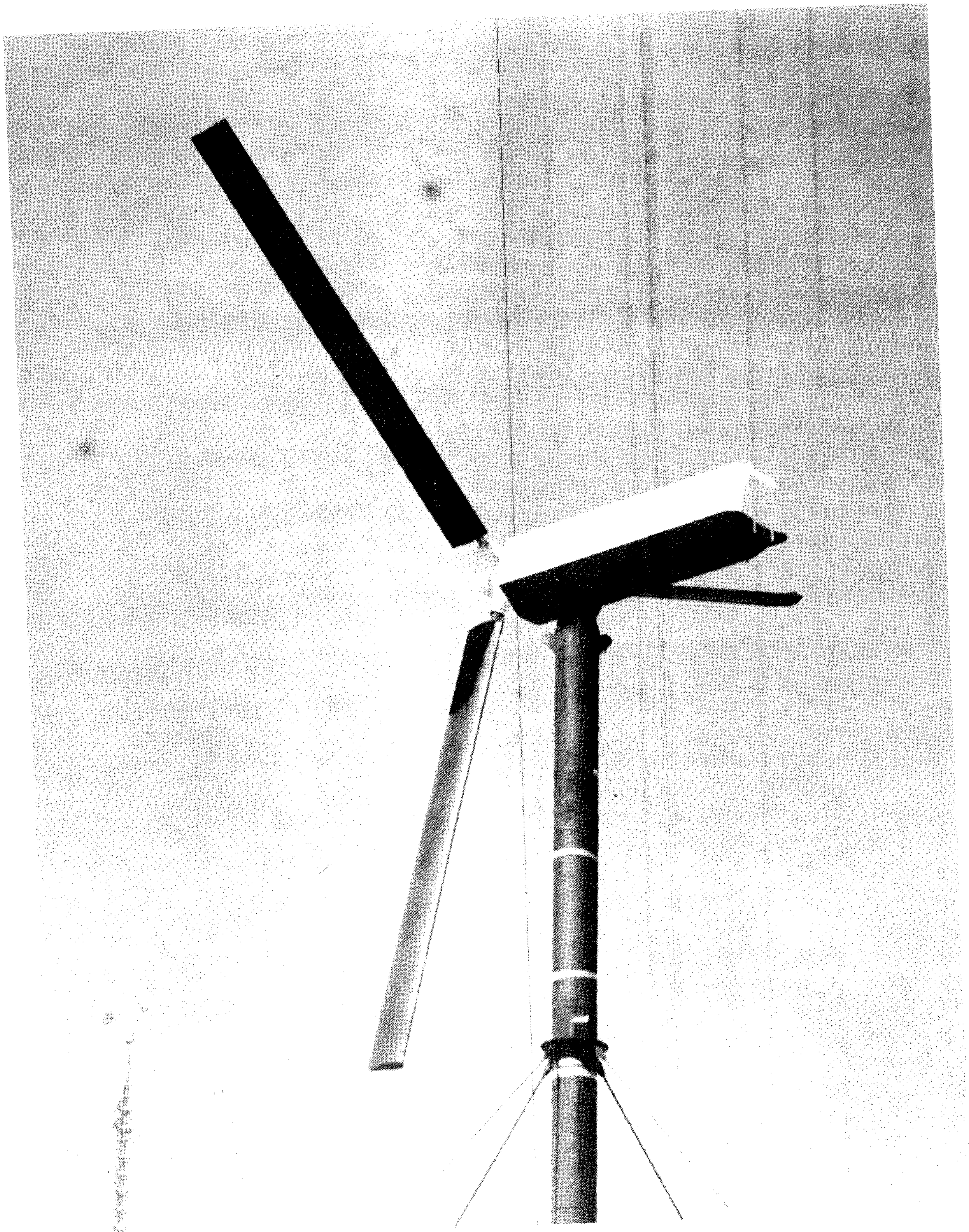
ABSTRACT

In January, 1978 Grumman Energy Systems, Inc. (GESI) was awarded contract No. PF71787-F, Development of an 8 kW Wind Turbine Generator. Administered by the Rocky Flats Wind Systems Program which is managed by the Rockwell International Corporation for the U.S. Department of Energy, the contract covered a two phase program to develop an 8 kW small wind energy conversion system (SWECS). Phase I involved design of the unit and was reported in a separate report. This report documents work in Phase II, Prototype Fabrication and Testing. The completed prototype unit was delivered to the Rocky Flats Wind Systems Test Center in December, 1979.



GRUMMAN WS33 WIND SYSTEM

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1.0 INTRODUCTION

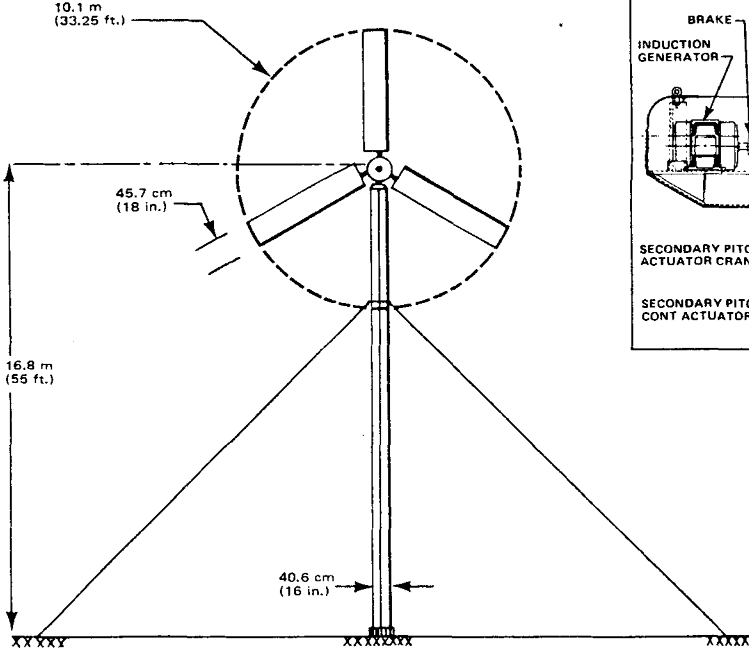
In March 1979, Grumman Energy Systems, Inc. commenced work on the second phase of Contract No. PF71787-F, "Development of an 8 kW Wind Turbine Generator." The Statement of Work called for fabrication and pre-delivery testing of one prototype unit and tower. Very few problems were encountered during this effort and the prototype unit was delivered to Rocky Flats in December, 1979. The configuration of the unit as delivered was virtually identical to that presented and approved at the Phase I Final Design Review, the only changes being those made to facilitate fabrication. This report discusses the configuration of the delivered unit and its fabrication and pre-delivery testing.

2.0 PROTOTYPE CONFIGURATION

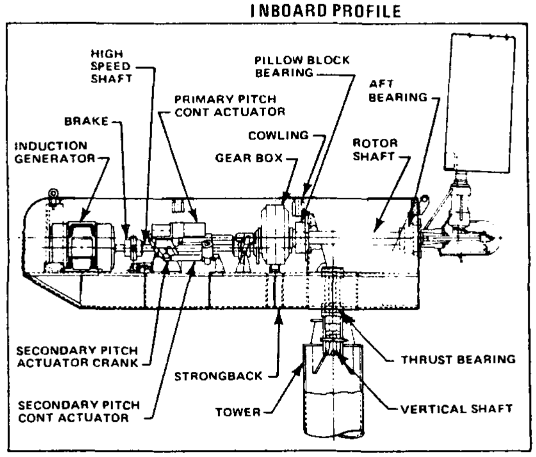
2.1 CONFIGURATION OVERVIEW

The Grumman WS 33 (see Figure 1) is a three bladed, down wind machine designed to interface directly with an electrical utility network. The initial design specification required an 8 kW production capability at 20 mph. The machine as finally designed and fabricated, however, is rated at 15 kW at 24 mph and peak power of 18 kW at 35 mph. Utility compatible electrical power is generated in winds between a cut-in speed of 9 mph (4.0 m/s) and a cut-out speed of 50 mph (22 m/s) by using the torque characteristics of the unit's induction generator combined with the rotor aerodynamics to maintain essentially constant speed. A blade pitch control system provides for positioning the rotor at a coarse pitch for start-up; fine pitch for normal running; and a feather position for shut-down. The pitch control system incorporates a primary actuator for normal operation with a back-up, secondary actuator for emergency operation. Operation of the machine is controlled by a self-monitoring, programmable logic microprocessor.

Figure 2 shows the general arrangement of the machine as presented and approved at the Phase I Final Design Review (FDR). During fabrication of the prototype, a small number of detail design modifications were incorporated to facilitate production. The unit, as delivered to Rocky Flats, is depicted in Figure 3.



INBOARD PROFILE

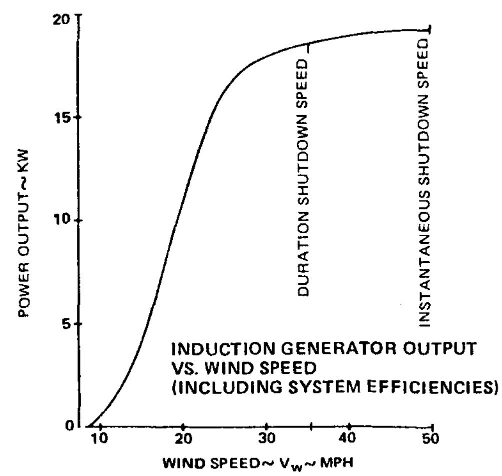


WINDSTREAM 33 CHARACTERISTICS

Induction Generator Rating	20 KW
Induction Generator Speed Range	1800-1860 R.P.M.
Gearbox Ratio	25.1 : 1
Rotor Speed	74.1 R.P.M.
Rotor Diameter	33.25 ft.
Rotor Solidity	0.0615
Blade Chord	1.5 ft.
Power Coefficient, Max (C_P MAX)	0.38*
Tip Speed Ratio at C_P MAX	5.25*
Wind Speed at C_P MAX	17.0 M.P.H.
System Efficiency at C_P MAX	83%
Output Power at V_W = 24 M.P.H.	15 KW*
Rotor Coning Angle	3 1/2°
Rotor/Nacelle Assembly Wt.	2,589 lb.
Drive Axis Height	55 ft.
Tower Section	16.0", O/DIA, 3/8" Wall.
Guy Base	80 ft.

*PREDICTED

Specifications subject to change without notice



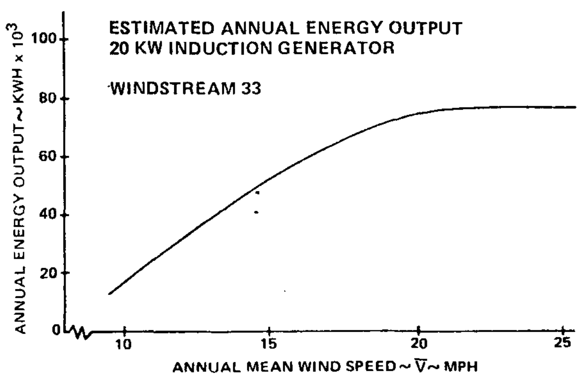


Figure 1 Grumman 8 kW Characteristics

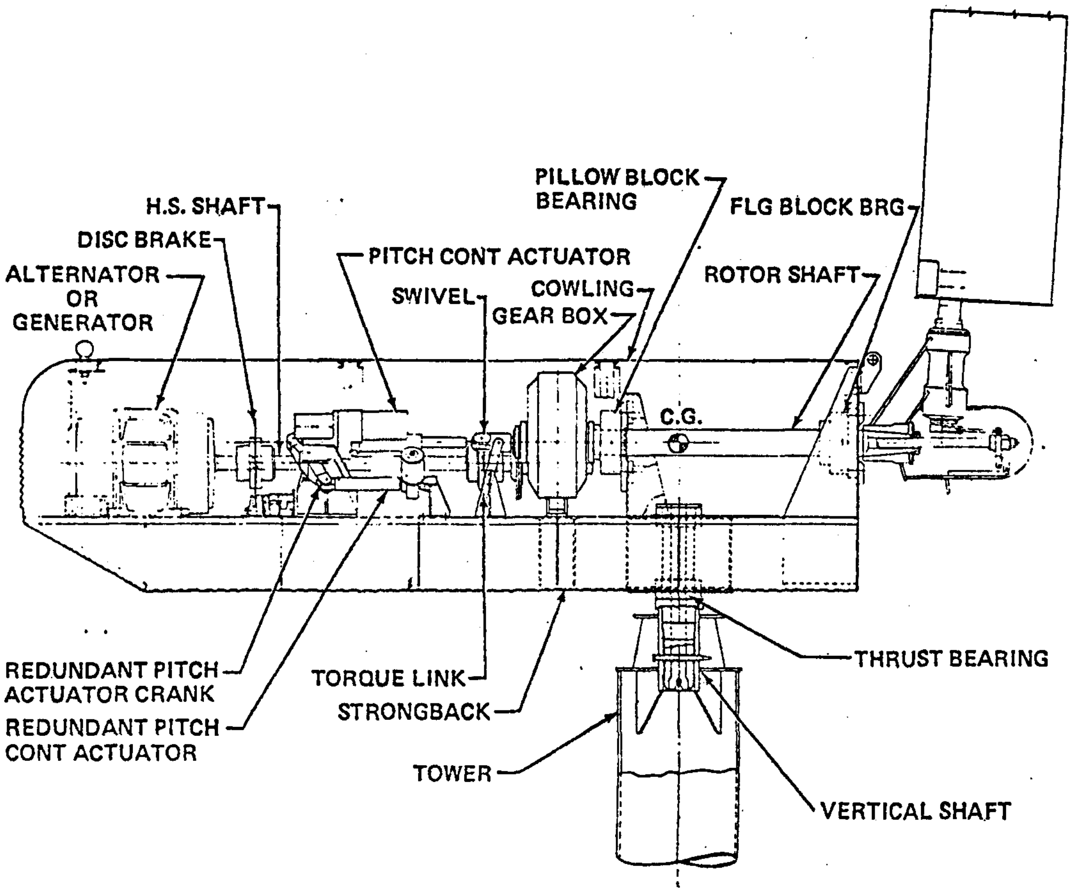


Figure 2 General Arrangement - Final Design Review Prototype System

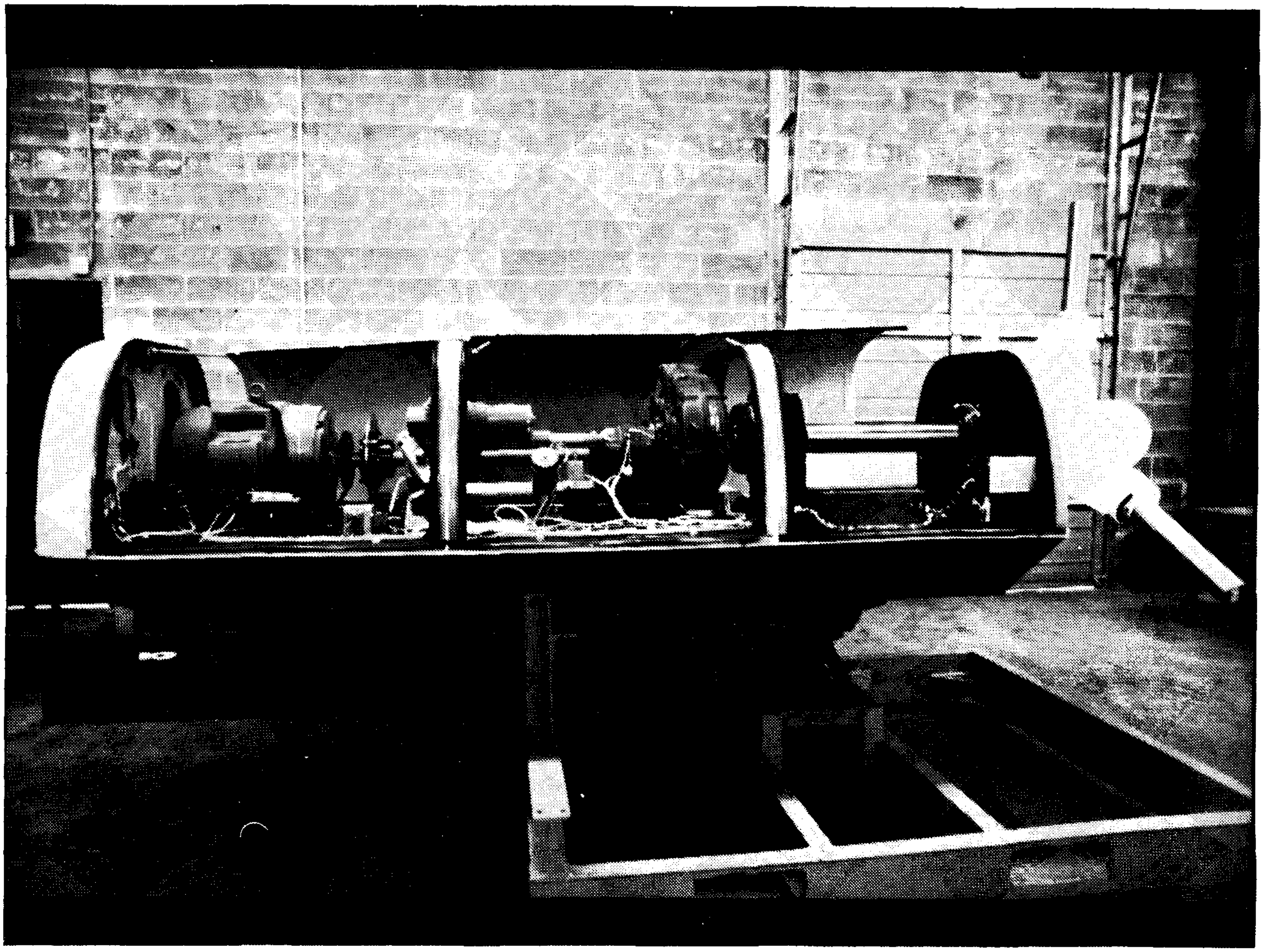


Figure 3 Prototype Configuration As Delivered to Rocky Flats

3.0 PROTOTYPE FABRICATION

3.1 SUMMARY

The 8 kW prototype was assembled and functionally tested at the Grumman Energy Systems, Inc. plant in Bohemia, New York and functionally tested prior to delivery to Grumman's Bethpage facility for installation and operational testing. Grumman obtained system components through a series of make or buy decisions based on considerations of cost and delivery. Some schedule delays were experienced, mostly attributable to vendor fabrication problems. In addition, deliveries of "off-the-shelf" hardware frequently did not meet the schedules originally quoted by the manufacturers. The impact of these delays on the prototype delivery schedule was held to a minimum by minor design changes and by machine shop capabilities when necessary. Assembly of the unit presented only minor problems normally associated with prototype fabrication.

Two design modifications were made to the tower during fabrication. The tower was originally designed as a seamless CORTEN tube. To reduce material costs, this design was modified to incorporate a tube made from rolled and welded CORTEN plate. The second change involved construction of an adapter to accommodate the tower foundation at Rocky Flats. Neither change impacted the delivery schedule.

3.2 SYSTEM COMPONENTS

3.2 1 Make or Buy Decisions

When approval was received to proceed with prototype construction, Grumman established a team to oversee and coordinate fabrication schedules. The team consisted of members from:

- Purchasing
- Manufacturing Methods
- Scheduling
- Engineering

The team reviewed the methodology of fabrication for each component and where items were direct-purchase parts, purchase orders were issued immediately. Where parts required sophisticated machining, Grumman's capabilities and schedules were measured against outside vendors' cost and delivery estimates. Make or buy decisions were made based on these findings.

The majority of the structural and mechanical components were subcontracted to local machine shops and sheet metal parts fabricators. Vendor performance was satisfactory, although some schedule delays were experienced in the manufacture of the strongback, hub and nacelle covers. These delays were, in general, associated with the use of soft tooling typical for prototype parts fabrication. In some instances, minor modifications were incorporated into the design to permit the use of alternative manufacturing methods. Delays were also minimized by selective use of in-house machine shop facilities.

3.2.2 Component Tracking and Liaison

Each component, whether manufactured outside or made in-house, was tracked to the purchase order schedule. This tracking was reviewed on a weekly basis until parts were within a week of delivery. Parts were then tracked to a daily schedule.

Components were also classified as to complexity. Items that were deemed complex were assigned a liaison engineer to insure that each process was completed correctly.

3.2.3 Component Inspection and Repair

When delivered, each component was inspected for specification compliance prior to being placed in stock. Any discrepancy was noted and routed to the appropriate engineer for disposition.

Assembly of the prototype was straightforward and presented no major problems. However, some difficulty was originally experienced with alignment of the generator and gearbox due to a slight distortion in the welded structure of the strongback. This was corrected by selective use of shims under the generator mounting.

3.4 FUNCTIONAL TESTING

All mechanical and electro-mechanical components were bench tested prior to installation in the unit. The gearbox input and output shaft alignment was checked by installing the gearbox in a "slave" nacelle consisting of a strongback, drive train and induction generator. The generator was run as a motor and the wobble motion of the gearbox measured. The first gearbox tested was excessively noisy and had a pronounced wobble which exceeded specified limits of $\pm$ 3/64. A second gearbox was then tested and proved to be acceptable. Power output of the generator at speeds above synchronous was checked against the manufacturer's specification on a dynamometer at the Grumman Aerospace Electrical Test facility.

Adjustment and functional testing of the complete system was performed during the final stages of the assembly process.

3.5 TOWER FABRICATION

The original design for the prototype tower called for its construction from seamless CORTEN steel tube, swaged from 18" to 16" diameter. However, during the course of construction, it was found that the purchase cost of a small amount of this material was excessive. The tower was therefore redesigned for fabrication from rolled and seam-welded steel plate.

The prototype tower was designed to interface with its foundation by means of a tower base flange with holes to match a pattern of bolts embedded in the concrete of the foundation. Subsequent to the manufacture of the tower, Rocky Flats made the decision to mount the tower on a universal foundation. An adapter was therefore made to permit the tower to be mated with the new bolt pattern.

4.0 PRE-DELIVERY TESTING

Prior to delivery of the 8 kW prototype to Rocky Flats, the machine was installed and checked out for two weeks on the tower at Grumman's Bethpage wind systems test facility. During this period, an acceleration survey of the nacelle was performed, at Rocky Flats' request, to determine the machine's response to blade passage excitation. It was found that acceleration and deflections were relatively small and would not have any significant effect on system loading.

After two weeks of satisfactory running, the unit was subjected to a hurricane (Hurricane David, September 6, 1979). After about forty minutes of running, in winds which occasionally exceeded fifty mph, the blades oscillated violently and then the unit shut down. Subsequent investigation showed damage to several items in the pitch control system. Further study showed the damage initiated at the secondary actuator tube due to tube lugs which were under strength. This part was replaced with a thicker walled tube which bench tests showed satisfactory. All units now use the thicker tube and have shown no further damage in this area. It appears that initiation of the failure occurred because elongation in the actuator attachment holes reduced control system stiffness resulting in control system flutter.

4.1 ACCELERATION SURVEY

Four accelerometers were mounted inside the nacelle to determine the accelerations, frequencies and displacements of the system in the three orthogonal axes.

Readings were taken of the peak accelerations and associated frequencies during routine system operation. These were averaged and are presented in Table I.

TABLE I

Frequencies, Accelerations & Peak Deflections

ACCELEROMETER DIRECTION AND LOCATION		FREQUENCY f_n (Hz)	ACCELERATION ($\pm$ g)	DEFLECTION ($\pm$ in)
Fore-Aft:	FWD	3.63	0.088	0.065
Vertical:	FWD	3.83	0.200	0.133
Lateral:	FWD	3.66	0.101	0.074
Lateral:	Aft	3.65	0.037	0.028

It can be seen that the readings were similar in all three directions. The frequency in each direction (3.63 to 3.83 Hz) matches the frequency of the blade passage past the tower at operating speed. Excitation of the nacelle is obviously caused by the cyclic offloading of the blade from tower shadow. Acceleration and deflections are relatively small and will not have a significant effect on the loading.

5.0 COST ANALYSIS

5.1 COST ANALYSIS UPDATE

Phase II activities did not lead to any major changes in hardware or production cost estimates. Therefore, the costs presented in the Phase I report are representative of the production costs in 1978 dollars. Updating these costs to 1980 dollars using inflation rates of 10% for 1979 and 10% for 1980 yields the following:

	1,000 Units Per Year	
	1978	1980
Production Cost	$11,010	$13,322
Transport, Dealer Fees (50%)	5,505	6,661
Installation	3,800	4,600
Installed Cost	$20,315	$24,583

The cost of this, or any other mechanism of equivalent size and complexity, is quite sensitive to production rates. In addition, several other factors weigh heavily on the ability of this industry to reach the production necessary to lower the costs. These are:

- Cost of money (Prime Rate)
- Skilled labor availability
- Critical component lead time
- Heavy machine time availability
- Facility start up costs

As these additional non-recurring costs and factors will be applied to any machine manufactured, optimizing the production rate to meet the demand will be critical.