RFP-3232/1
UC-60

UTRC 8KW WIND SYSTEM

Phase II-Fabrication and Test Executive Summary

February 4, 1981

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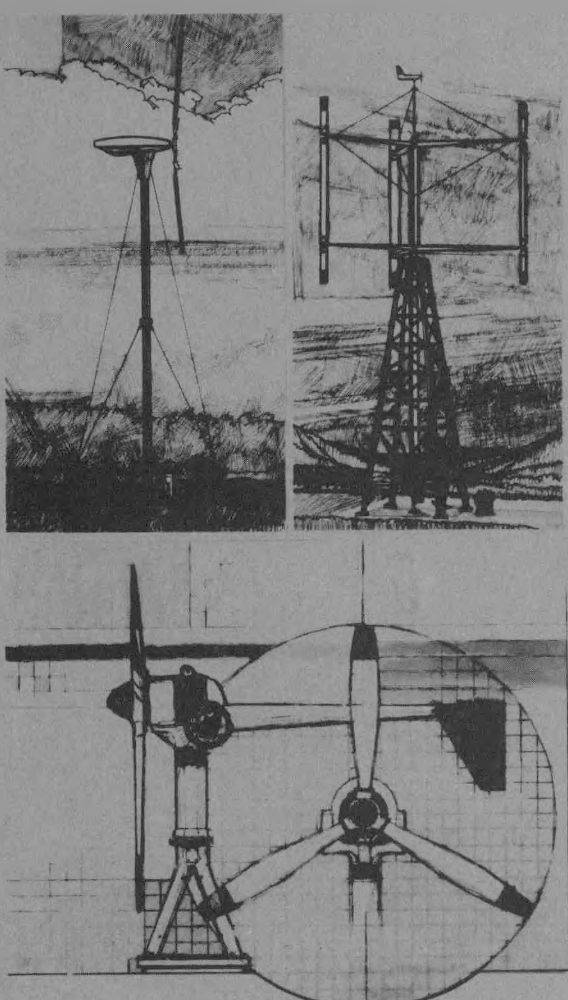

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For
Rockwell International Corporation
Energy Systems Group
Rocky Flats Plant
Wind Systems Program
P.O. Box 464
Golden, Colorado 80401

Subcontract PF68186F

As part of the
UNITED STATES DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGY DIVISION
FEDERAL WIND ENERGY PROGRAM

Contract No. DE-ACO4-76DPO3533

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EXECUTIVE SUMMARY

INTRODUCTION

This report contains a summary of the results of Phase II of the United Technologies Research Center's (UTRC) contract to design, fabricate, and test an 8 kW Wind Turbine Generator (WTG) under the Department of Energy's (DOE) small wind energy conversion system program. The UTRC system was conceived under an earlier DOE study, and the current contract, through Rockwell International, is to carry the WTG concept through hardware development and field evaluation at Rocky Flats, CO.

Phase I of this contract consisted of the system design along with experimental programs and analytical studies in support of the design. The rotor system that evolved from the design phase utilizes the Composite Bearingless Rotor (CBR) concept that was developed for helicopter applications. The rotor blade is comprised of two distinct parts: (a) the blade, or aerodynamic portion which is fabricated from fiberglass, and (b) the inner portion of the rotor, called the flexbeam, which provides the freedom for the rotor blade to deflect in bending and also to twist to achieve blade pitch variation. The mechanism that twists the blades is another important feature of the UTRC concept - a passive control system consisting of pendulums sensitive to centrifugal force. The use of CBR rotor concept, coupled with the passive pendulum control system, provides a rotor system that is simple and potentially low cost to manufacture.

The final design that evolved from Phase I is a horizontal axis, two-bladed, down-wind free-yaw rotor with a diameter of 9.45 m (31 ft) and a steel tower with 16.8-m (55-ft) height that is supported by guy wires. Based upon this design, a hardware development program was conducted which culminated with fabrication of a full-scale prototype, shown in Fig. 1. Field testing of the prototype was completed in Phase II and successfully demonstrated the various features of the UTRC 8 kW wind turbine. Test evaluation is presently continuing at Rocky Flats, CO, and preliminary results indicate that the WTG is performing well in all aspects.

Fig. 1 UTRC Wind Turbine

FULL-SCALE FABRICATION

Based upon the final design drawings of the Phase I study, the hardware for a full-scale wind turbine was fabricated and then assembled into the prototype to be used for field testing and evaluation. Fabrication of the full-scale prototype consisted of hardware development in five main areas: rotor blade, flexbeam, pendulum, generator head components, and tower.

Blade

A subcontract was awarded to Morrison Molded Fiberglass Co. to pultrude a 381-mm (15-in.)-chord blade for the aerodynamic lifting portion of the rotor. A cross section of the blade is shown in Fig. 2. The blade design includes mass balancing forward of the midchord to minimize the chance of classical flutter, and a solid leading edge for erosion and impact protection. E-glass was selected as the blade material due to its low cost and availability.

Flexbeam

The flexbeam, which accounts for the inner portion of the rotor, is composed of a hand layed-up composite material that is 2.54-m (100-in.) long and has a 140 x 14-mm (5.5 x 0.55-in.) cross section. A single flexbeam is used which is bolted to the rotor hub at the center of the flexbeam. The flexbeam is cured in a pre-twisted and preconed position to maintain edgewise stiffness and also reduce steady stresses during normal operation. Graphite epoxy is used as the composite material for the flexbeam and was selected over other composites due to its high modulus and strength.

Pendulums

Hub mounted pendulums are used, which are connected to the blades through steel flexstraps, and adjust blade pitch under the actions of centrifugal force as rotor speed increases. The blade pitch angle is positioned for optimum aerodynamic performance at a selected wind speed. Plain carbon steel weights were selected as the material for the pendulum weights. A heat treated martensitic stainless steel, AISI 410, was selected as the material for the flexstrap, which connects the pendulum to the flexbeam. The joint between the flexstrap and pendulum utilizes bronze bushings and teflon washers to minimize wear. A photograph of the pendulum-flexbeam assembly is shown in Fig. 3.

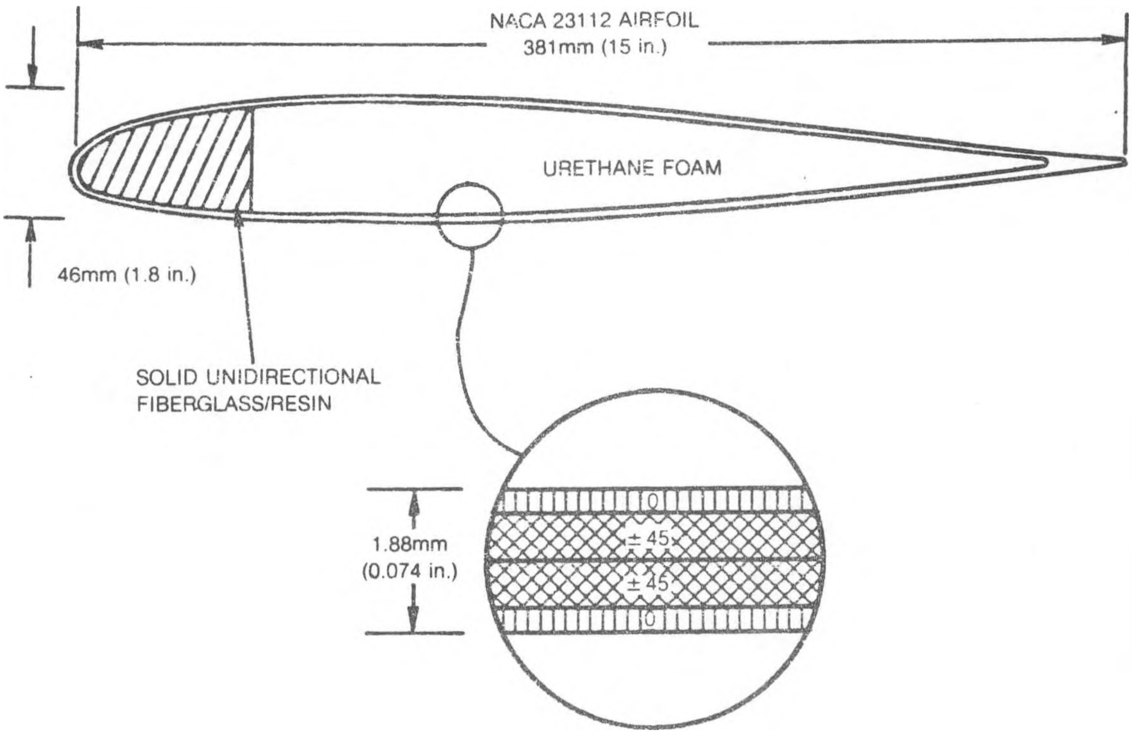

Fig. 2 Airfoil Section Showing Fiberglass Layup of Blade Skin

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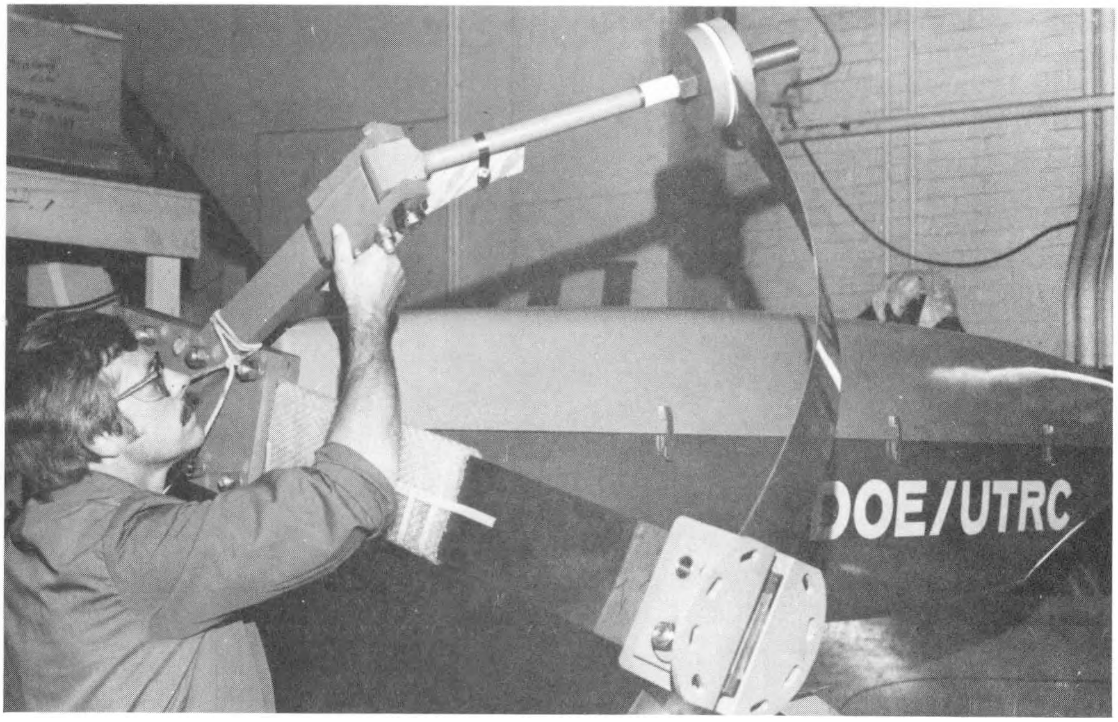

Fig. 3 Pendulum and Flexbeam Assembly

Generator Head Components

The generator head components, schematically shown in Fig. 4, consist of (1) the rotor drive shaft, supported at either end by self-aligning FMC spherical roller bearings, (2) a flexible coupling connecting the shaft, (3) the 17 to 1 FMC gearbox, and (4) a face mounted Baldor 15 kW induction generator. The components are mounted on a steel weldment which is mechanically connected to a steel yaw shaft that is held in the tower cavity by FMC spherical roller bearings. The entire assembly is enclosed in the molded fiberglass shroud which is designed for easy removability. An automotive disc brake is included for the prototype system but is expected to be replaced by an electric brake in a production system.

Tower

The tower is composed of two flanged sections of Schedule 10 254-mm (10-in.)-diam steel pipe, each approximately 7.9-m (26-ft) long. This is a low cost scheme both from the standpoint of fabrication time and material cost. Three cables of 25-mm (1-in.)-diam improved plow steel with simple thimbles and clamps are attached to the upper flange. A similar guy system of 19-mm (0.75-in.)-diam cable is attached at the midstation. The guys are attached to the ground anchors by means of turnbuckles, one for each wire. The turnbuckles are located above the ground level at a point where it is convenient for manual adjustment. An erection pivot at the base of the tower is composed of a 102-mm (4-in.)-diam bar welded to the base and tangent to the pipe. The tower assembly is shown schematically in Fig. 5.

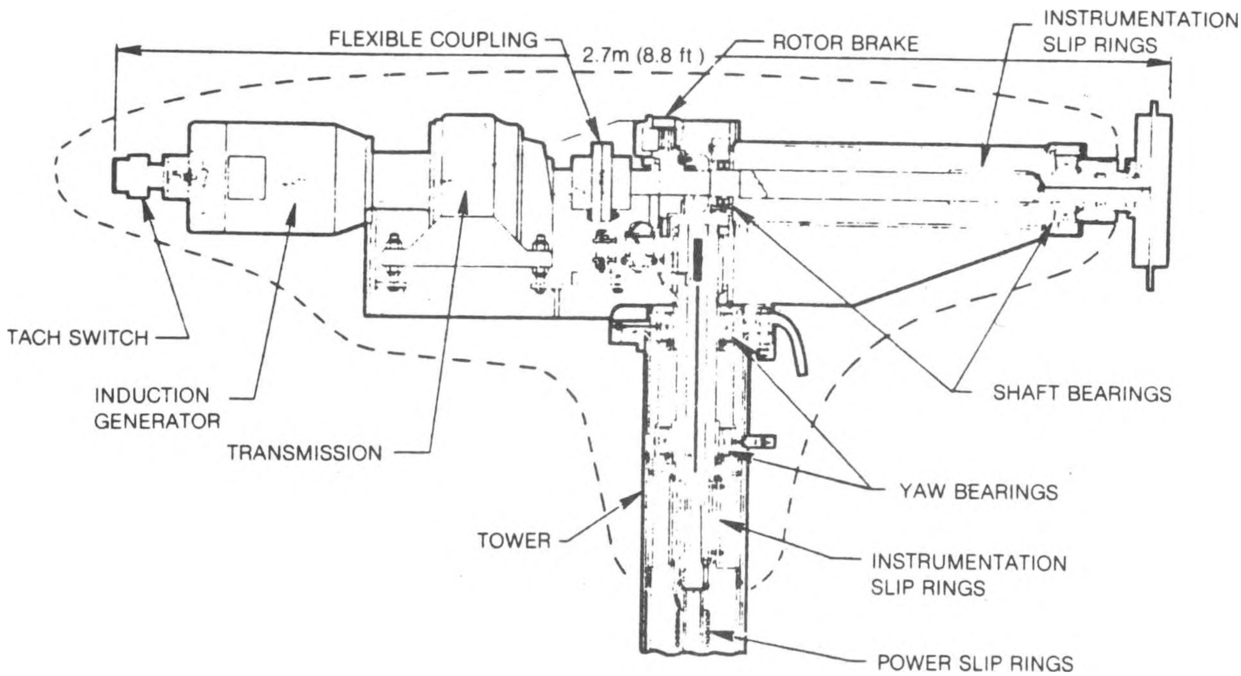

Fig. 4 Major Wind System Components

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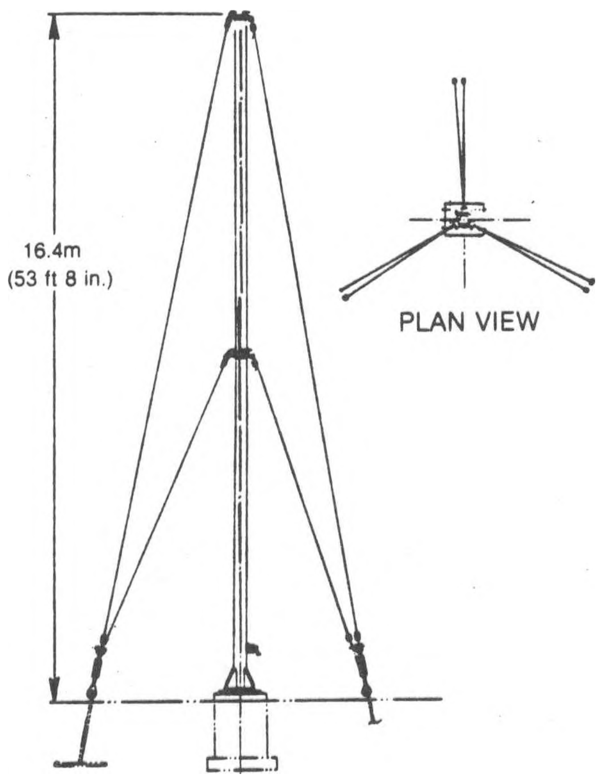

Fig. 5 Schematic of Tower Assembly

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EAST HARTFORD PROTOTYPE TESTS

Following fabrication of the full-scale prototype, testing was conducted in East Hartford, Connecticut to evaluate performance and general operating characteristics.

Performance

Performance data were taken over a one week period in January 1980 and a sample of data is shown in Fig. 6 along with the predicted output. Peak system power output is about 14 kW at 12 m/s (27 mph).

Blade Stresses

The flexbeam on the prototype blade was instrumented to record flatwise, edgewise, and torsional stresses. Blade stresses for several wind power conditions are presented as time histories in Fig. 7. For all test conditions, blade bending stresses remained low, well below the flexural strength allowable for graphite/epoxy which is approximately 1034 MPa (150 kpsi).

High Speed Stall

To confirm the high speed stall concept, tests were conducted with the generator uncoupled from the grid to demonstrate the reduction in velocity ratio, VR (ratio of rotor tip speed to wind speed) as wind speed increases. These results are shown in Fig. 8. The data show that velocity ratio continues to fall with increasing wind speed and that the minimum tip speed reached is 85 m/s (279 ft/s) at 9 m/s (20 mph) wind speed. Beyond this speed the rotor blades experience deeper stall and the velocity ratio is reduced further. This method of surviving high wind speeds provides sufficient rpm to maintain adequate centrifugal stiffening to resist the high aerodynamic blade loading and yet does not allow the rotor speed to increase unchecked, thus preventing an eventual edgewise resonant condition.

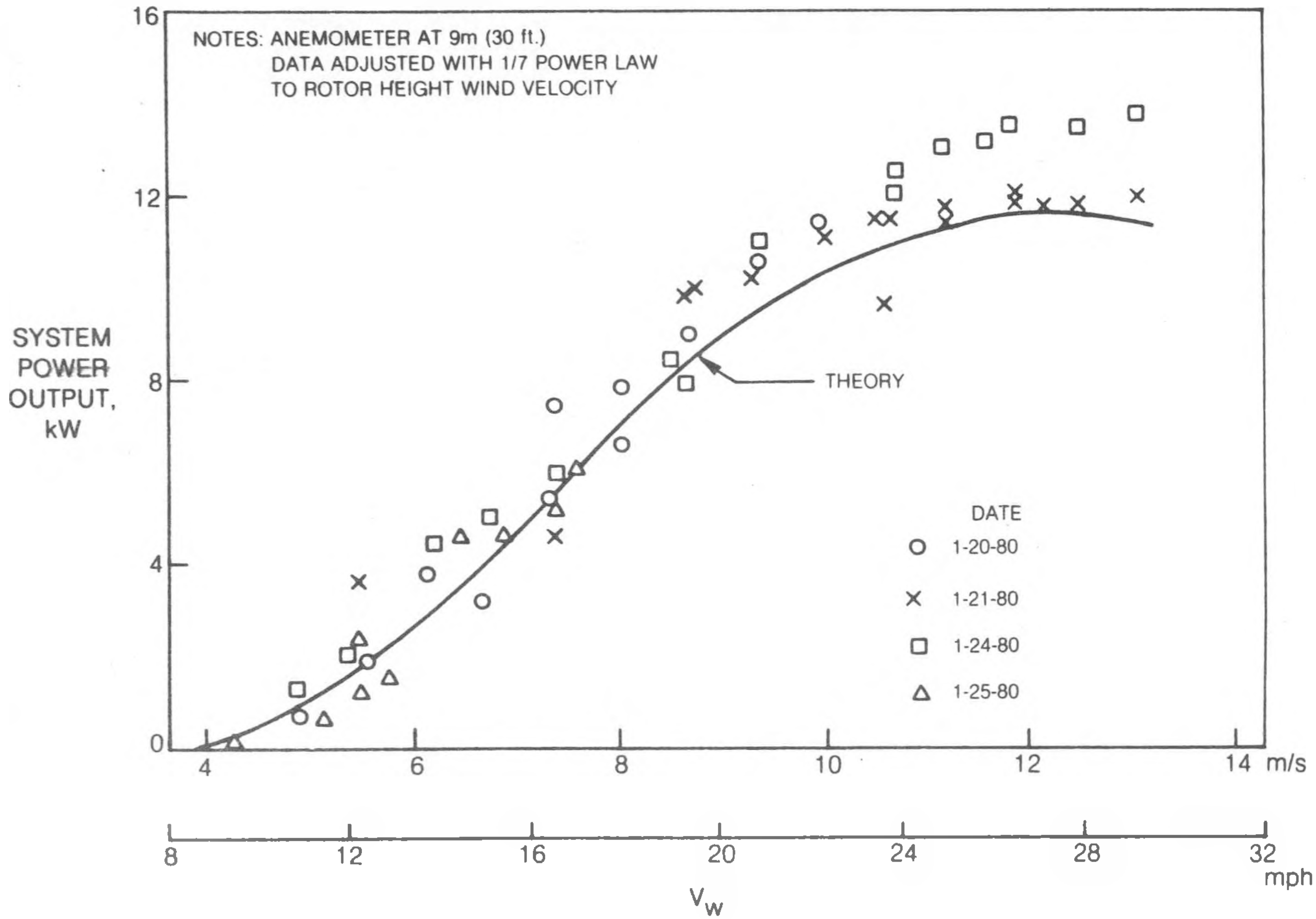

Fig. 6 Power Output

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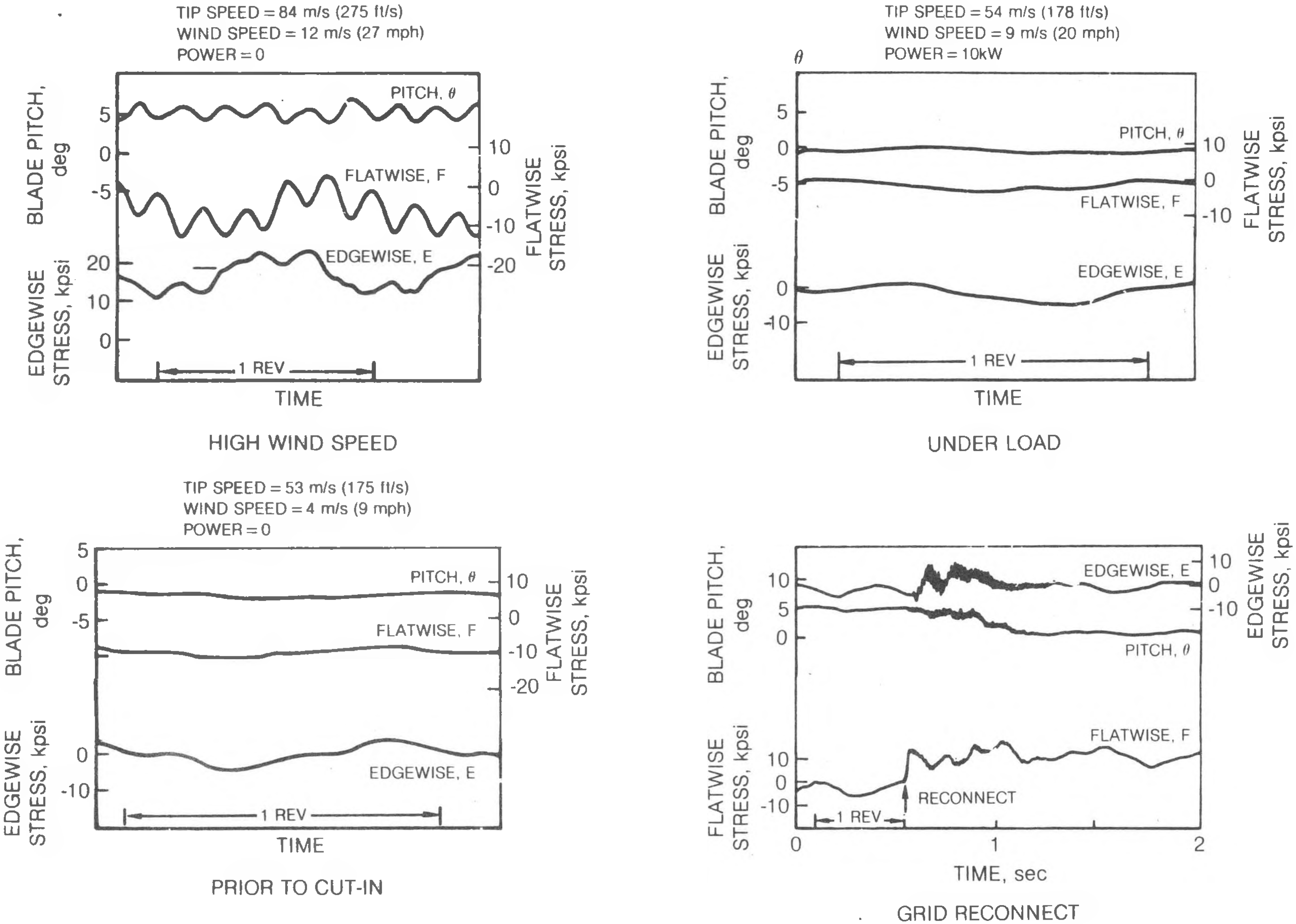

Fig. 7 Blade Pitch and Flexbeam Stresses for Several Wind Conditions

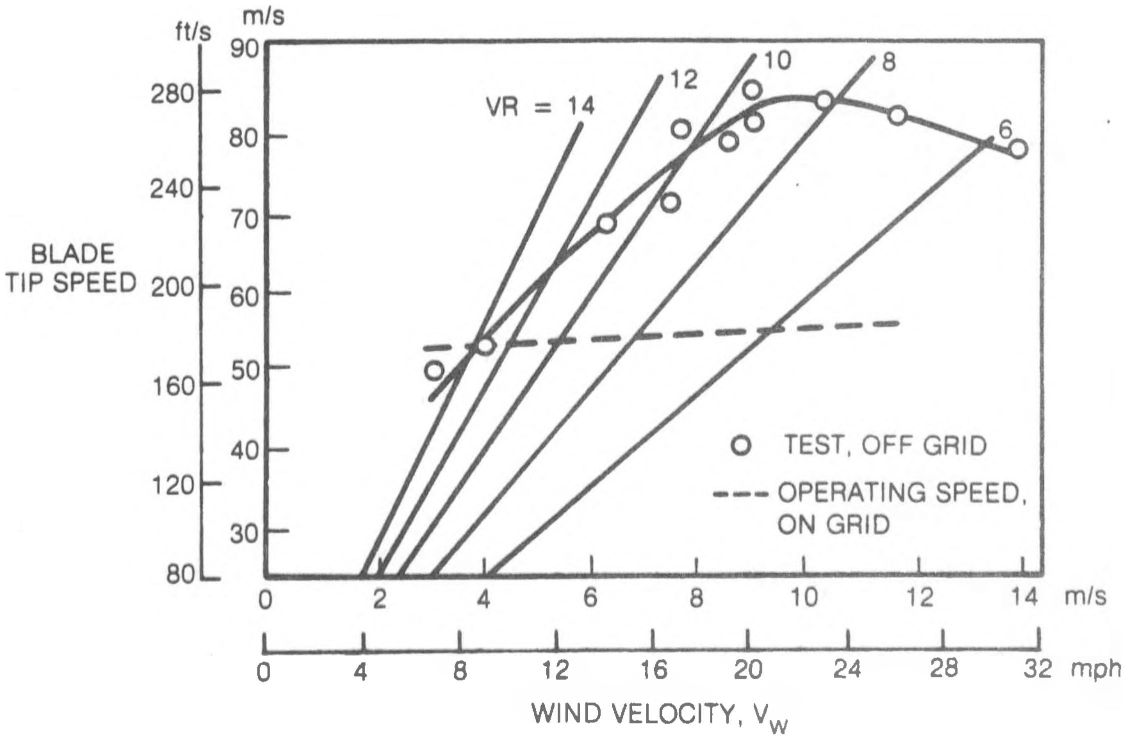

Fig. 8 Blade Tip Speed Variation with Wind Speed

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CONCLUDING REMARKS

The various features of the UTRC Bearingless Wind Turbine, which were conceived and wind tunnel tested during the earlier ERDA contracts and the first year of this program, were successfully demonstrated in full-scale during the field testing reported. The specific operating characteristics which were verified are: the passive self-starting feature, the proper blade pitch schedule to place the blade at its pitch setting for high performance, the automatic pitch increase to place the blade at its stall angle to limit rotor speed in the event of decoupling from the grid, and the passive yaw feature which provides for the continuous self-alignment to wind direction changes.

Except for two minor start-up yaw problems which were revealed early in the test program and subsequently corrected, the system has performed as expected. It has been demonstrated that, except for an rpm switch to connect and disconnect the induction generator from the grid, a simple passive mechanical pendulum device, along with free yaw, provides all the necessary controls to allow the system to perform all operating requirements from start-up, power generation, wind direction alignment, and high speed survivability.