DOE/NASA/1004-78/14
NASA TM-79034

AN OPERATING 200-kW HORIZONTAL AXIS WIND TURBINE

Charles L. Hunnicutt
Lockheed Aircraft Service Co.

and

Bradford Linscott and Robert A. Wolf
National Aeronautics and Space Administration
Lewis Research Center

Work performed for
U.S. DEPARTMENT OF ENERGY
Office of Energy Technology
Division of Distributed Solar Technology

TECHNICAL PAPER presented at the
Twenty-third National SAMPE Symposium and Exhibition
Anaheim, California, May 2-4, 1978

NOTICE

DOE/NASA/1004-78/14
NASA TM-79034

AN OPERATING 200-kW HORIZONTAL AXIS WIND TURBINE

Charles L. Hunnicutt
Lockheed Aircraft Service Co.
Ontario, California

and

Bradford Linscott and Robert A. Wolf
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Prepared for
U. S. DEPARTMENT OF ENERGY
Office of Energy Technology
Division of Distributed Solar Technology
Washington, D. C. 20545
Under Interagency Agreement E(49-26)-1004

Twenty-third National SAMPE
Symposium and Exhibition
Anaheim, California, May 2-4, 1978

SUMMARY

This report describes design features and certain operating features peculiar to the Mod-OA wind turbine located in Clayton, NM. A description of the Mod-OA wind turbine is provided. Certain operational aspects of the wind turbine are discussed. The structural design, fabrication and testing of the rotor blades is emphasized. Early test data, on blade loads, are presented and analyzed. Finally, the Mobile Data Acquisition System and how it functions with the wind turbine is described.

INTRODUCTION

The Mod-OA wind turbine generator -- the modern version of the windmill -- is generating electrical power for use by the people of Clayton, New Mexico. Output from the 200-kilowatt machine will be enough to meet the power requirements of about 60 families. The thirty years that the Mod-OA system will be operating will greatly reduce the energy demand upon natural sources.

DESCRIPTION OF THE 200-KW WIND TURBINE SYSTEM

The 200-KW wind turbine is a two-bladed, horizontal-axis, rotor system driving a synchronous electric generator through a step-up gear box located within a nacelle. The nacelle is mounted on top of a 100-foot tower as shown in figure 1, with the rotor located downwind from the tower. The 200-kilowatts rated power output of the wind turbine is achieved at a turbine rotor speed of 40 rpm and a rated wind speed of 18.3 mph. The rated wind speed is defined as the lowest wind speed at which full power is achieved. The wind turbine power output, as a function of wind speed, is regulated by varying the pitch angle of the blades.. At wind speed below cut-in and above cut-out the rotor blades are placed in a feathered position and no power is produced. The cut-in wind speed, defined as the lowest wind speed at which power can be generated, is 6.9 mph. The cut-out wind speed, defined as the lowest wind speed at which wind turbine operation would result in excessive blade stress, is 34.2 mph. All of these wind speeds are measured at a 30-foot elevation.

In the gear box, the shaft rpm is increased from 40 to 1800 rpm. A high-speed shaft connects the gear box to the 200 kW alternator. The drive train assembly is enclosed in a fiber-glass nacelle for environmental protection. The nacelle and rotor assembly are positioned at the top of a tower to provide the necessary blade tip to ground clearance. The hoist provides access to the tower. The onsite controls and electrical switchgear are housed in the control building at the base of the tower.

3. OPERATION

The yaw drive permits rotation of nacelle/blades to maintain proper alignment with the wind. Rotation is achieved by driving a large bull gear with two pinion gears as shown in figure 2. The two pinion gears, which are preloaded against each other to increase torsional stiffness, are driven by separate motors and yaw drives. If necessary, yaw control can be achieved by using only one unit. The yaw rate, which is 1/6 rpm, is operational whenever the wind speed exceeds the cut-in wind speed of the wind turbine.

The torsional stiffness of the rotating machinery is further increased by activating the three yaw disk brakes shown in figure 2. Even during the yawing motion, some brake pressure is applied to damp out any torsional oscillations by maintaining a drag force. Once the machine has aligned itself to the wind, this brake pressure is increased to the maximum.

The function of the fluid coupling on the high-speed shaft is to damp out the power oscillations resulting from the continuously varying wind velocity that the baldes must withstand due to the tower shadow and the wind shear effects.

3.1 BLADE PITCH CHANGE MECHANISM

The pitch change mechanism consists of a hydraulic pump, a pressure control valve, a rack and pinion actuator, and gears for rotational movement of the blades. This type of pitch change mechanism is similar to that used in the aircraft industry on variable pitch propellers. A pair of racks is moved linearly back and forth by hydraulic pressure. This pair of racks rotates a pinion that turns a master gear, which in turn rotates the baldes through bevel gears bolted to the blade spindle. The hydraulic supply is mounted separately inside the front of the nacelle (see figure 2). Hydraulic fluid is brought into the main shaft through rotating seals and transmitted to the rack and pinion actuator mounted on the rotor hub (see figure 2). The maximum rate of pitch change is 8 degrees per second. At wind velocities above 23 mph the rotor blades increase pitch, thus spilling the wind and ensuring that the electrical power developed does not exceed 200 kW. Below 6 and above 60 mph the turbine blades will be placed in a feathered position and the machine shut down.

4. STRUCTURAL DESIGN/APPLICATION

4.1 BLADE DESIGN

Strength and stiffness criteria were developed by NASA from a statistical evaluation of many wind turbines throughout the world. Although the adequacy of these criteria to define ultimate strength has been shown to some degree during operation of the Mod-0 wind turbine, the Mod-OA is loacted at a different site, in a different environment, and is intended to operated for long periods of time, continuously integrated into an electrical power supply system (varying loading). The Mod-0A will test the fatigue endurance of a wind turbine of this type long before comparable data are accumulated on the Mod-0. The major concern is the assurance of longevity under the total operating environment.

Differences in structural deisgn between the Mod-0 and Mod-0A wind turbine blades resulted from recommendations made by Lockheed, during an analytical appraisal of Mod-0 operational load measurements in the interest of increasing longevity, and from recommendations of a NASA safety group.

4.2 BLADE FABRICATION

In many aspects, the baldes are similar to an airplane wing: they contain a leading and trailing edge, formers, stringers, ribs, webs, and skin. However, the length of each blade (62.5 feet), the taper, twist, and contour parameters it must maintain coupled with the balance, weight, and flex requirements for symmetrical blades, make them unique. All components were tested for chemical and physical properties to ensure against impurities. In addition to the required test certifications, a copy of the actual test results accompanied each certification.

Before assembly was started, the balde fixture, figure 3, was boresighted and adjusted to ensure contour, taper, and rigidity at all stations. The same check was performed at least three times a week during actual balde assembly.

The brake-formed leading edge, assembled in sections, serves as the base for installation of the D-spars, formers, stringers and ribs. Once installed in the blade test fixture, the leading edge is drawn tight against aluminum sheets fastened to the jig frame on one side and ribs on the other. Stability is ensured by use of turnbuckles and a strap that is secured to the cement floor.

Before any adjustment of the leading edge skin is attempted, each skin is aligned to chord lines marked on the jig and then boresighted adjustments are made as required and the first skin segment of the leading edge is trimmed and spliced together with the second skin segment, etc., until the leading edge is one complete assembly. D-spars and ribs are added and secured to the leading edge by Hi Loc fasteners. Formers over D-spars, and stringers on both sides of the leading edge and the formers, give additional support to the blade. Thick aluminum skins, varying from 3/16-inch just aft of the blade root to 3/64-inch at bladetip, are attached to the ribs which run the length of the blade. Except for the steel blade root fitting, all components are constructed of heat-treated 2024T3 aluminum.

All structural components are wet-sealed at assembly, and frequent inspections are made to ensure an airtight condition exists. Five hollow tubes, one in the apex of the leading edge at the blade root, one centered on ribs at the root segment; and three attached at the blade tip, permit weights to be added or removed to maintain symmetrical balance between each set of blades. In addition, throughout the entire length of the balde (approximately every 22 inches) weighted tubes and solid bars are installed in the leading edge to maintain section and segment structural balance.

Strain gages, installed in the balde root and in the wind blade mid-section, enable monitoring of flap bending, in-plane bending, and torsion moments during operation. The gages are epoxy-sealed and all wires secured to a terminal board and then, by clamps, to the ribs and blade root.

Each blade was tested for (a) deflection and vibration, (b) weight and balance, (c) strain gage accuracy, and (d) X-rayed for defects. Each set of baldes was given deflection and vibration, weight and balance, and symmetry checks. Figure 4 shows checks being made on a set of blades.

4.3 STRAIN GAGE

The design loads were calculated by a fully coupled analysis program which calculates loads at 44 blade stations. Only two stations per blade are instrumented for monitoring. The gages at the two stations, will measure load magnitudes and frequencies, but they will not always be at critical locations. Since gage locations must remain fixed, they were positioned to provide a warning that potentially damaging leads are being approached.

5. AEROELASTIC STABILITY

Several dynamic analyses were performed on the wind turbine blades coupled with the tower: blade response frequencies, flutter and divergence characteristics, and whirl mode stability. The analyses showed the system to be free from aeroelastic problems. Panel flutter was precluded by selection of skin thickness and spar rib spacing.

5.1 FLUTTER AND DIVERGENCE

The analyses included the effects of rotor shaft and blade feathering constraints, rotor speed, collective blade angle, wind (speed and direction), and control system flexibility. Using NASA furnished tower data, analyses were performed for the cantilever, antisymmetric (cyclic), and symmetric (collective) conditions.

The stiffness and inertia data used in the analyses were supplied by NASA-LeRC.

5.2 TESTS

Nonrotating tests were conducted on the first blade in September 1977 at Lockheed Aircraft Service, Ontario, California. A setup that incorporated a blade mounted on a simulated rotor hub (figure 4) was used to verify blade-frequency response characteristics. Electromechanical shaker(s) were used. Frequency sweeps from 1.5 to 40 Hz were made to identify natural frequencies. Fixed and roving vibration pickups were placed at sufficient locations and directions to identify various modes. Tests were conducted at two pitch settings.

Measured frequencies were compared with those used in analyses. Correlation was excellent.

5.3 SHIPPING

Blades were shipped in a NASA trailer built especially for that purpose. The trailer is 65 feet long and just high enough to clear the highest point of the blade (see figure 5).

6. DESCRIPTION OF MOD-OA AND EARLY ANALYSIS OF TEST DATA

Construction work on the 200 kW Mod-OA wind turbine was completed in Clayton, N.M. during the last week of November 1977. Figure 1 shows the Mod-OA during final assemply of the nacelle and rotor blades on the tower. A large mobile crane was used to hoist the nacelle and blades from ground level to the top of the tower. The tower structure is primarily comprised of tubular members. The tubular members were chosen over other sturctural shapes in an effort to reduce the tower shadow on the downwind side of the tower (reference 1).

Figure 2 shows the machinery and equipment assembled inside the nacelle of the Mod-OA wind turbine. Although many parts of the Mod-OA are identical to the Mod-O wind turbine (reference 2), several modifications were incorporated on the Mod-OA as a result of the DOE/NASA test program on the Mod-O wind turbine (references 3 and 4).

Some of the modifications incorporated on Mod-OA are shown in figure 2. These include the dual yaw drive and the yaw brake. The Mod-OA required a gear box having a higher power rating than Mod-O to allow Mod-OA to produce 200 kW of power. An alternator rated at 200 kW was also installed in the Mod-OA nacelle. A fluid coupling, not shown in figure 2, was installed on the 1800 rpm shaft.

The dual yaw drive and yaw brake concept was tested on the Mod-O wind turbine (reference 4). Test results show that a significant reduction in blade bending moments could be expected as a result of the dual yaw drive and yaw brake modification. The fluid coupling was also tested on Mod-O. Test data indicates that the fluid coupling, installed in the high speed drive shaft, reduces power oscillations during operation on a utility network.

First rotation of the Mod-OA rotor blades was accomplished in Clayton, N.M. on November 30, 1977. The wind turbine uses a microprocessor control for startup and shutdown and to automatically synchronize its power with an electric utility network. The Mod-OA was automatically synchronized to the electrical network in the city of Clayton, N.M. on December 11, 1977. The Mod-OA was operated on the utility network in the attended automatic mode for the first 24-hour period on December 14 through 15, 1977.

The DOE/NASA Portable Instrument Vehicle was used to take the data shown in figure 6. This data was taken on December 15, 1977. The wind turbine was generating power to the utility and operating in an automatic control mode. Personnel from the NASA/LeRC Wind Energy Project Office monitored the wind turbine during this time to assure proper operation.

Figure 6 shows the blade flapwise and chordwise bending moments as a function of time. Each cycle of bending moment data occurs over 360 degrees of rotor rotation. Thirty cycles of the bending moment data taken from the center of the data shown in figure 6 was analyzed. The bending moments were averaged over the 30 cycles selected. The blade pitch angle, measured at the blade 0.75 radius, is shown in figure 6. The blade pitch angle remained at about -5 degrees over the time span considered, with the alternator speed verified at 1800 rpm. The wind velocity, measured at the nacelle, was about constant at 25 mph during the 30 cycles of loads data considered. The alternator power, shown in figure 6, varied from 210 kW maximum to 170 kW minimum over the time period considered.

Table I shows the average values for the Mod-OA blade bending moments taken from the data shown in figure 6. For the purpose of comparing blade loads, the blade bending moments, measured during operation of the Mod-O wind turbine, are presented in table I. The Mod-O blade loads were taken with the tower stairway removed and a mechanical lock was installed between the tower and nacelle (reference 4).

From table I, the peak to peak blade flapwise bending moment measured on Mod-OA is about 43% smaller than the blade bending moment measured on the Mod-O wind turbine. The reduction in Mod-OA blade flapwise loads is attributed to the tubular tower sturcture. The Mod-OA tower sturcture is evidently allowing a larger airflow through the tower than occurs through the Mod-O wind turbine tower.

The chordwise blade bending moment trace, shown in figure 6, displays a fairly smooth sinusoidal wave form. This smooth wave form indicates that the chordwise blade bending moments are primarily due to the balde weight. The Mod-O blade cyclic chordwise bending moment, due to weight, is equal to ±38,000 ft-lbs. This value agrees quite closely with the cyclic value of ±40,000 ft-lbs measured during operation on the Mod-O wind turbine, shown in table I. The Mod-OA blade cyclic chordwise bending moment, due to weight, is equal to 45,350 ft-lbs. This value agrees closely with the cyclic value of ±48,800 ft-lbs measured on the baldes during Mod-OA operation, shown in table I.

7. DESCRIPTION OF THE DOE/NASA MOBILE DATA ACQUISITION SYSTEM

Data for evaluating the operation and performance of the Mod-OA wind turbine generator was obtained through the use of the DOE/NASA Mobile Data Acquisition System (MDAS). The MDAS consists of three independent remote multiplexer units (RMUs) and a portable instrument vehicle (PIV). To obtain data from Mod-OA, the first RMU was installed on the wind turbine hub, the second on the bedplate and the third in the control house at the base of the wind turbine tower. Each RMU contains the necessary electronics for signal conditioning and multiplexing data signals onto one or two coaxial cables for transmission to the PIV. The PIV is self-propelled and provides a controlled environment for data acquisition, recording, reduction and on-line display equipment. The MDAS is completely independent of the control electronics needed for proper operation of the Mod-OA. Consequently, the MDAS can be removed from the Mod-OA and transported to other wind turbine sites for additional data gathering.

7.1 REMOTE MULTIPLEXER UNIT

Each RMU enclosure is an aluminum case designed to protect the interior electronic circuitry from water or dust by conforming to NEMA-12 standards. The hinged access door has a rubber seal and all electrical connections to the interior of the enclosure are through MS weatherproof connectors. Each RMU is designed to operate over the temperature range of -35°C to +55°C (-30°F to +130°F), humidity range from 0 to 100 percent and vibration range of ±15G's along any axis.

Each RMU can accommodate up to 32 data channels, with each channel having a 4-pole, low-pass active Butterworth filter providing a bandwidth of 40 Hz and adjustable measurement ranges. All channels can be individually configured to signal condition data from either sensors with resistance outputs (e.g. -- strain gage) or sensors with voltage outputs. Twenty of the 32 channels have the added option to signal condition data from copper constantan thermocouples.

Each conditioned data channel is frequency modulated onto a cneter frequency and summed with other modulated channels into one of two frequency modulated multiplexes of sixteen channels each. The center frequencies are spaced 500 Hz apart, from 1000 Hz to 8500 Hz, and each data channel will produce a center frequency deviation of ±125 Hz. A reference frequency is also summed into each multiplex for use when the data is processed. The multiplex summing amplifiers are capable of transmitting the multiplexed data over 610 M (2000 ft) of coaxial cable to the PIV.

7.2 PORTABLE INSTRUMENT VEHICLE

The portable instrument vehicle shown in figure 7 contains the necessary equipment for processing data at a wind turbine site. The vehicle is self-propelled and constructed to permit transportation from site to site over public highways without special permits or approvals. The vehicle is outfitted with an air ride suspension on both front and rear axles to limit road-induced vibratation and shock to the data processing equipment. Two heating and cooling units installed on the rear of the vehicle maintain the interior temperature at a nominal 21°C (70°F) over an exterior temperature range of -28°C to 50°C (-20°F to 120°F).

The six frequency modulated multiplexes, two from each RMU, enter the PIV and are connected to the input patch panel in the analog processing cabinet (Figure 8). Each multiplex can be patched to one track of a fourteen-track tape recorder/reproducer and simultaneously patched to a group of frequency modulation discriminators. The analog tape recorder operates at a speed of 0.024 M/S (15/16 in/S) and records all six multiplexes plus IRIG B time signal for data playback at a later time. The discriminators is provided for each multiplex and the output of each discriminator is connected to the output patch panel.

From the output patch panel, each electrical analog can be patched one of sixteen strip chart recorder channels, a spectrum analyzer or an analog digital converter. The strip chart recorders provide real time monitoring of high frequency data. The spectrum analyzer computes the frequency spectrum of an input signal over the frequency range of 0.1 to 25.6 Hz in 0.1 Hz steps. The analog to digital converter samples an input signal and converts the sample to a twelve bit binary word with a conversion rate of 25 kHz for entry into the digital processing cabinets (figure 9).

Each converted binary word is passed from the converter to a data compressor for testing against as many as three predefined algorithms. If the binary word passes the algorithm test, the word is passed to a digital computer for further processing. If the word fails to pass the test, the word is not passed and algorithm testing on the next binary word begins. Algorithms available for use include pass if within a plus or minus limit, pass if outside a plus or minus limit, pass if the magnitude has changed by more than a specified value from the last passed binary word and pass every N^{th} word where N can be any value between 0 and 8000. By proper selection the algorithms, the amount of data requiring further processing can be reduced and still achieve the data requirements for accuracy.

The digital computer that receives the passed binary words performs two functions with the words. If selected by the MDAS operator, the binary words representing samples from a specific data channel are converted to engineering units (e.g., degrees C) and displayed in real time on a CRT. Up to 20 data channels may be converted and displayed at the same time. In addition, all binary words received from the compressor are recorded on digital magnetic tape. Time of the year is also recorded on the digital tape to aid in retrieving data from the tape at a later time. The digital tape is the official data record of the wind turbine and is permanently stored for future study and analysis.

Data recorded on digital tape can be retrieved by the digital processing system and plotted versus time. The MDAS operator specifies the parameter to be plotted (up to six may be plotted on one set of axes) and the time over which the plot is to be made. The digital processing system then searches the magnetic tape and generates a plot similar to that shown in figure 10. The parameter plotted in figure 4 is the flap bending moment on blade number one measured at station 40 for one minute. The "E.U." on the vertical axis is an abbreviation for engineering units, which for the case of blade loads is ft. lbs. The vertical axis scale, therefore represents values from -3,000 to +130,000 ft. lbs.

8. CONCLUSIONS

The DOE NASA experimental effort to develop the Mod-0 wind turbine has led to an improved operating wind turbine called Mod-0A.

The Mod-0A rotor blades were designed and fabricated to carry higher loads than the Mod-0 rotor blades. Early operational data shows that Mod-0A blade loads are well within the operational design loads envelope. Blade flapwise bending moments measured on Mod-0A are 43 percent smaller than similar moments measured on the Mod-0 blades.

Tubular members were used to construct the Mod-0A tower structure in an effort to minimize the downwind tower shadow. As a result of the blade flapwise bending moments, measured on Mod-0A, it is concluded that the downwind tower shadow is smaller for the Mod-0A tower than the Mod-0 tower.

A Mobile Data Acquisition System was developed for the Mod-0A wind turbines. On site tests show that this system effectively receives, processes and records the Mod-0A performance and operating characteristics.

REFERENCES

1. Savino, J.M.; and Wagner, L.H.: Wind Tunnel Measurements of the Tower Shadow on Models of the ERDA/NASA 1000-kW Wind Turbine Tower. NASA TM X-73548, 1976..

2. Puthoff, R.L.: Fabrication and Assembly of the ERDA/NASA 100-Kilowatt Experimental Wind Turbine. NASA TM X-3990, 1976.

3. Glasgow, J.C.; and Linscott, B.S.: Early Operation Experience on the ERDA/NASA 100-kW Wind Turbine. NASA TM X-71601, 1976.

4. Linscott, B.S.; Glasgow, J.C.; Anderson, W.D.; Donham, R.E.: Experimental Data and Theoretical Analysis of an Operating 100-kW Wind Turbine. Paper presented at the 12th Intersociety Energy Convention Engineering Conference, Washington, D.C., Aug. 1977.

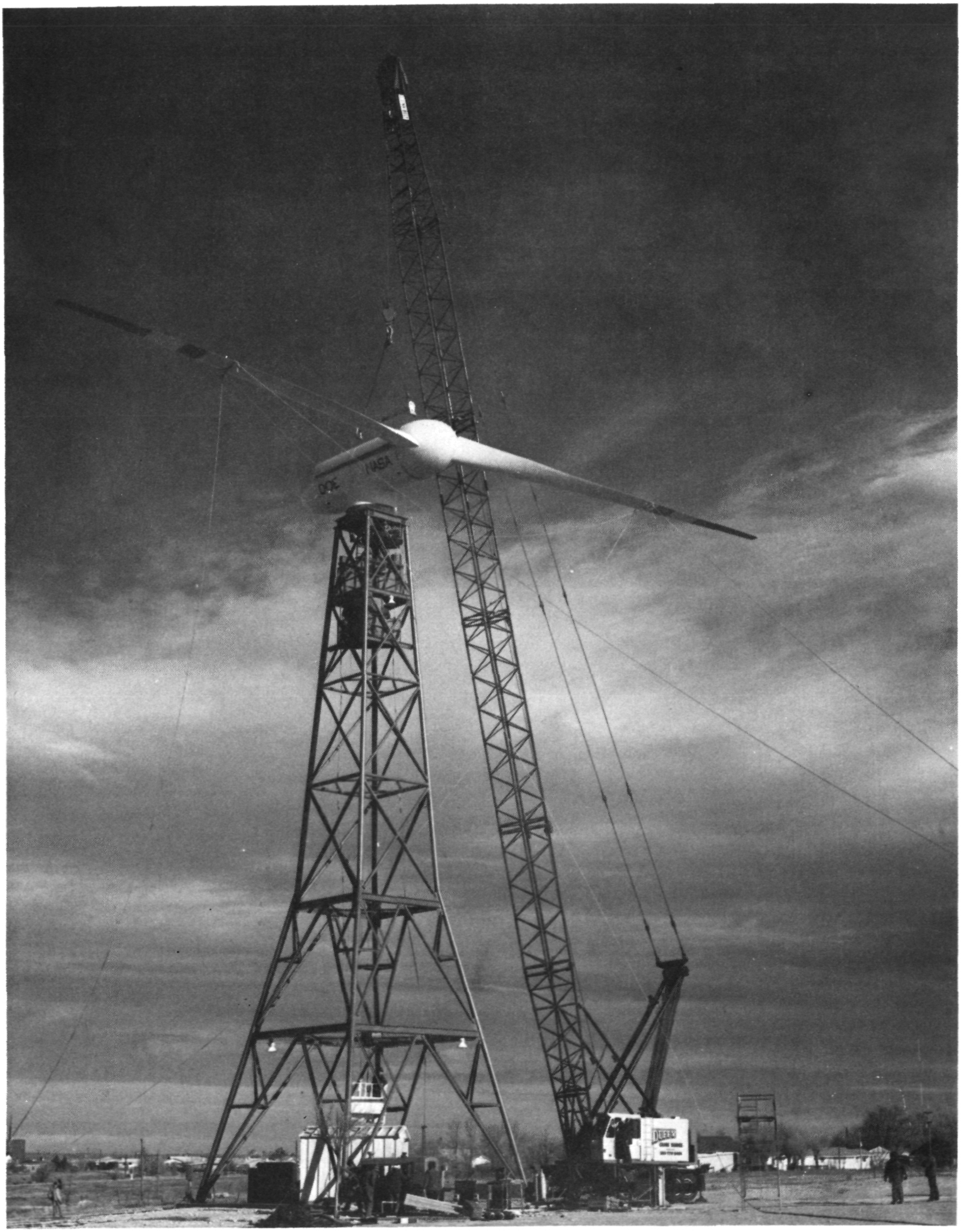

Figure 1. 200 kW Mod-OA Wind Turbine System

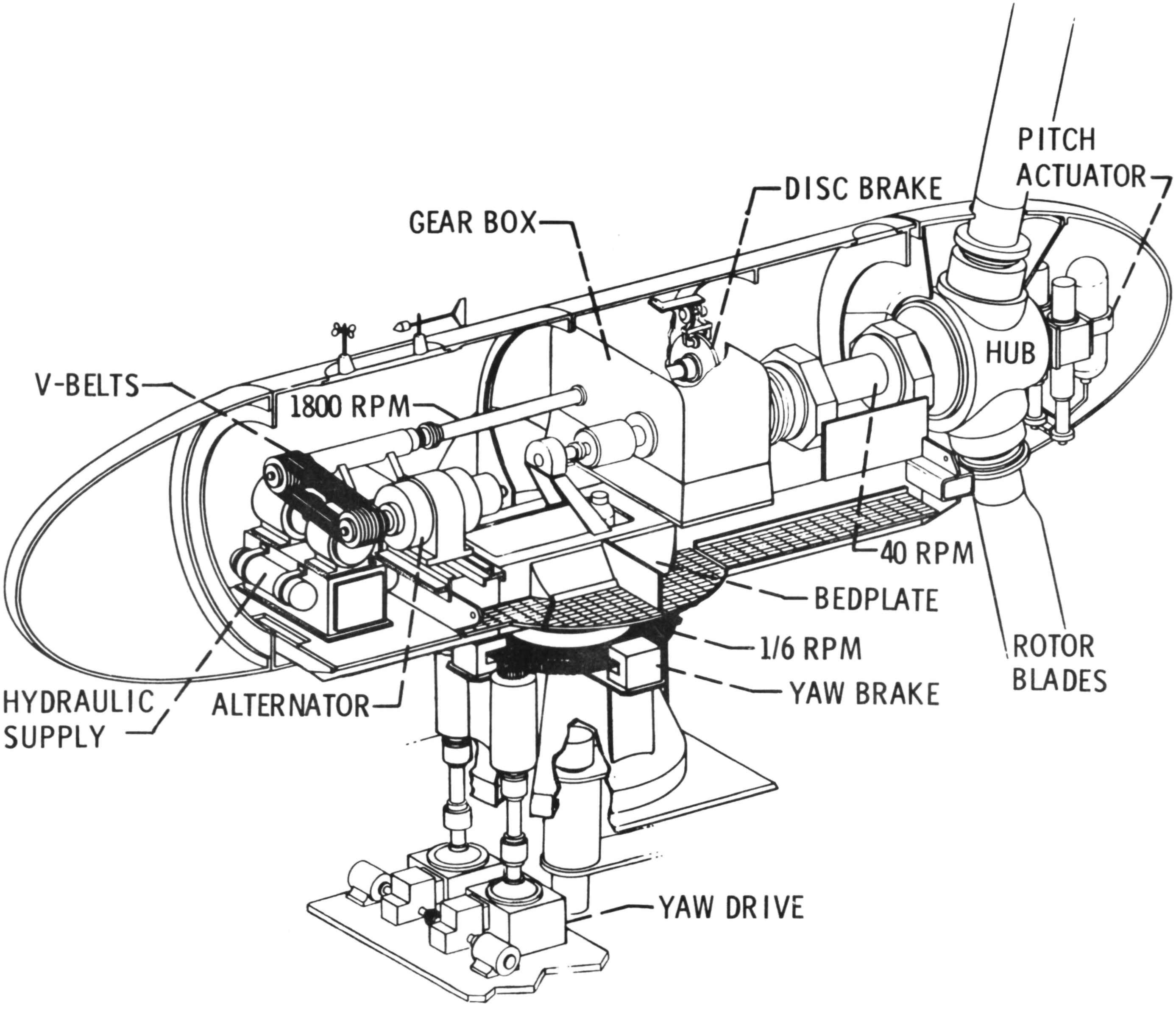

Figure 2. 200 kW Mod-OA Wind Turbine Nacelle and Interior Equipment

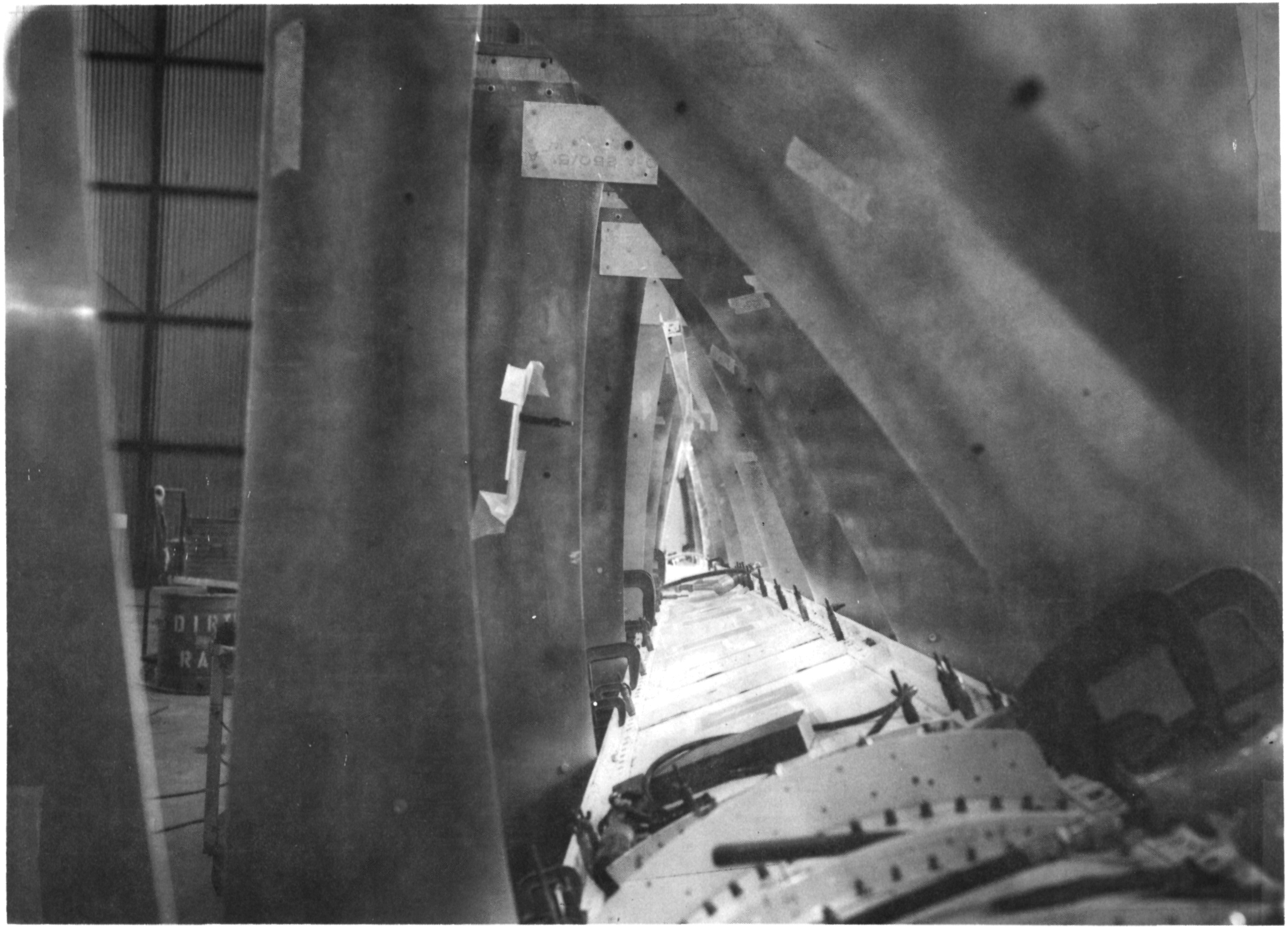

Figure 3. Blade Fixture Jig Showing Length, Twist and Contour Check Points (Sheet 1 of 2)

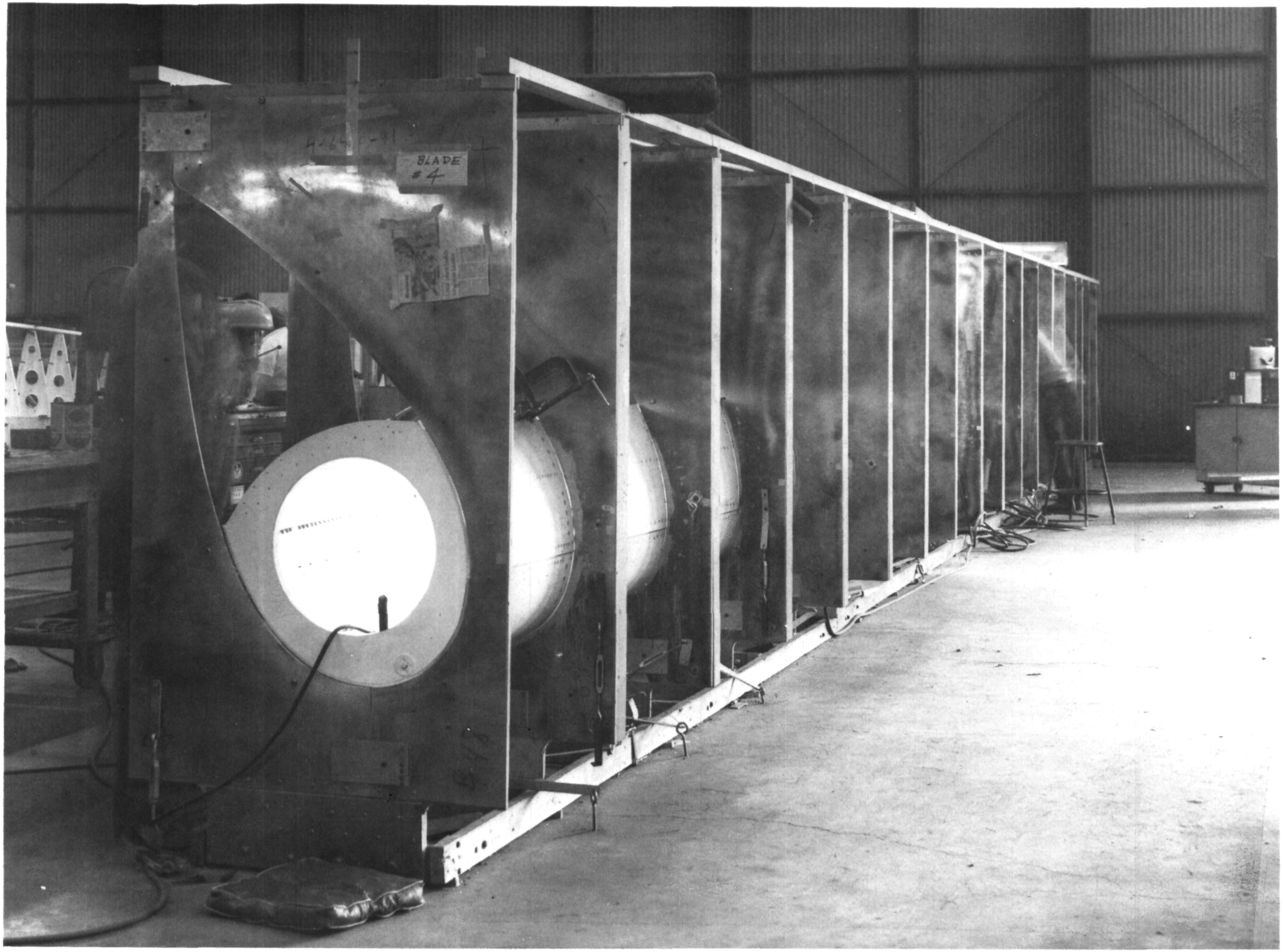

Figure 3. Blade Fixture Jig Showing Length, Twist and Contour Check Points (Sheet 2 of 2)

Figure 4. Vibration, Weight and Balance, and Symmetry Check

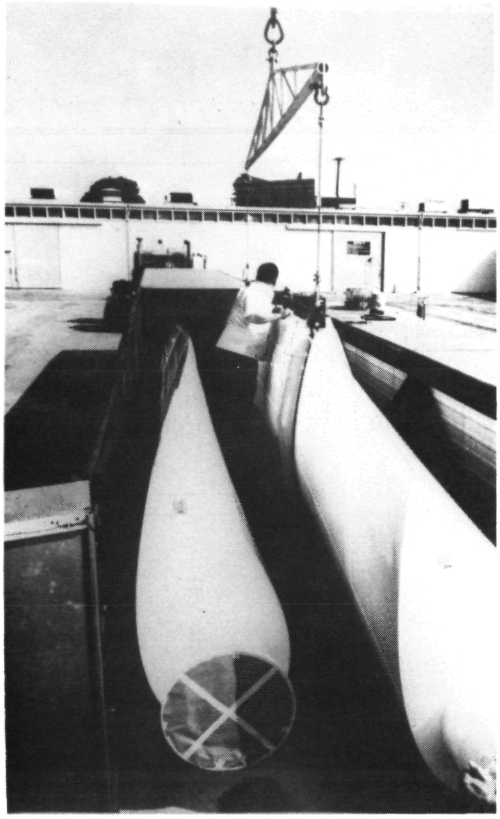

Figure 5. Transporting Blades on NASA Trailer

Table I. Blade Bending Moments Measured During Operation of MOD-OA and MOD-O

	BLADE BENDING MOMENT (FT-LBS) AT STATION 40					
	FLAPWISE			INPLANE		
	PEAK TO PEAK	MEAN	CYCLIC	PEAK TO PEAK	MEAN	CYCLIC
[1]MOD-O	64,500.	-7,750.	±32,250.	80,000.	-18,000.	±40,000.
MOD-OA	36,500.	-18,250.	±18,250.	97,760.	-18,560.	±48,800.

[1]No stairway and nacelle locked in yaw

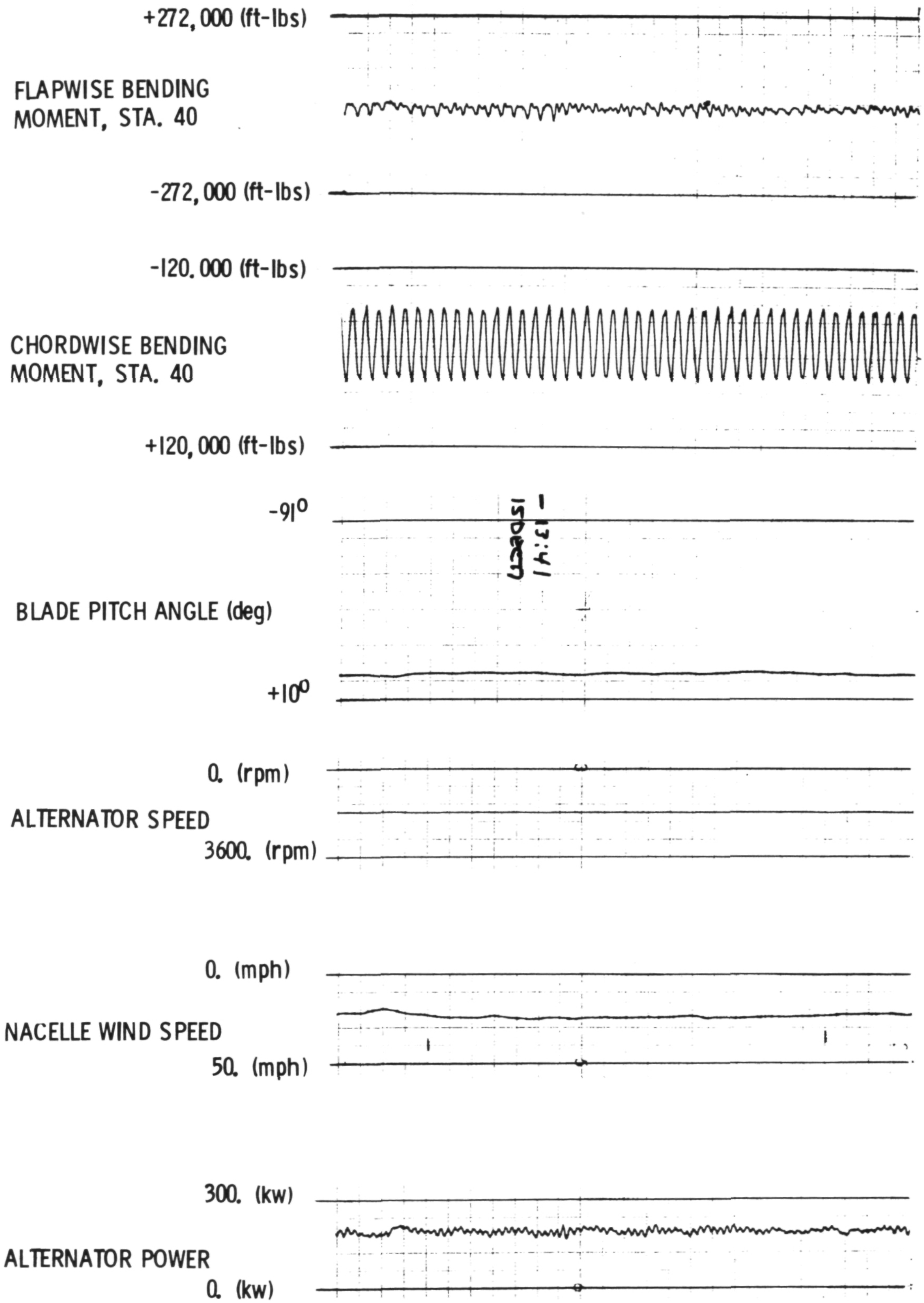

Figure 6 200kW MOD-OA Wind Turbine Test Data,
Rotor Speed at 40 rpm, 200 kW Power

Figure 7. The DOE (Formerly ERDA)/NASA Portable Instrument Vehicle

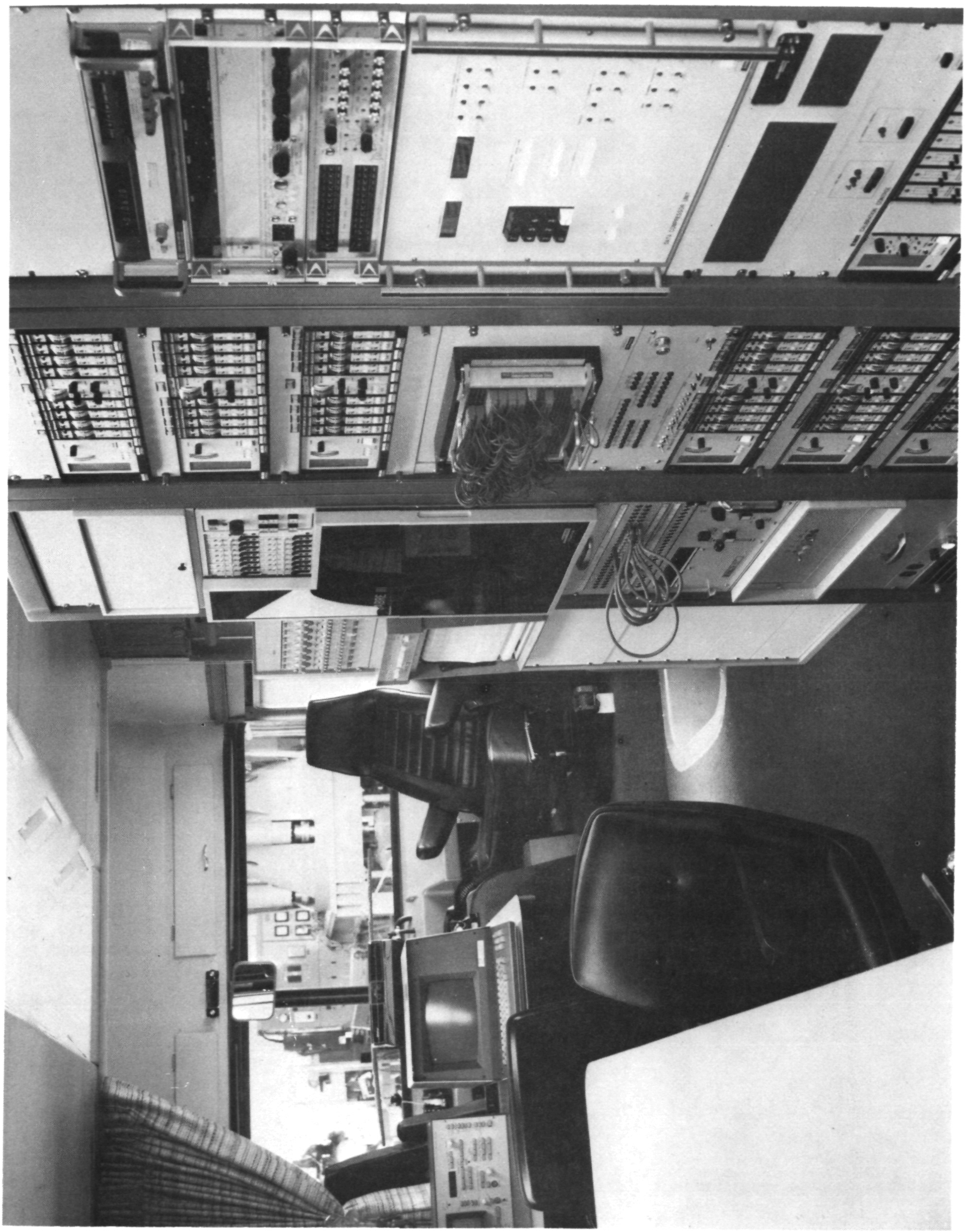

Figure 8. Analog Processing Cabinets and Front of PIV

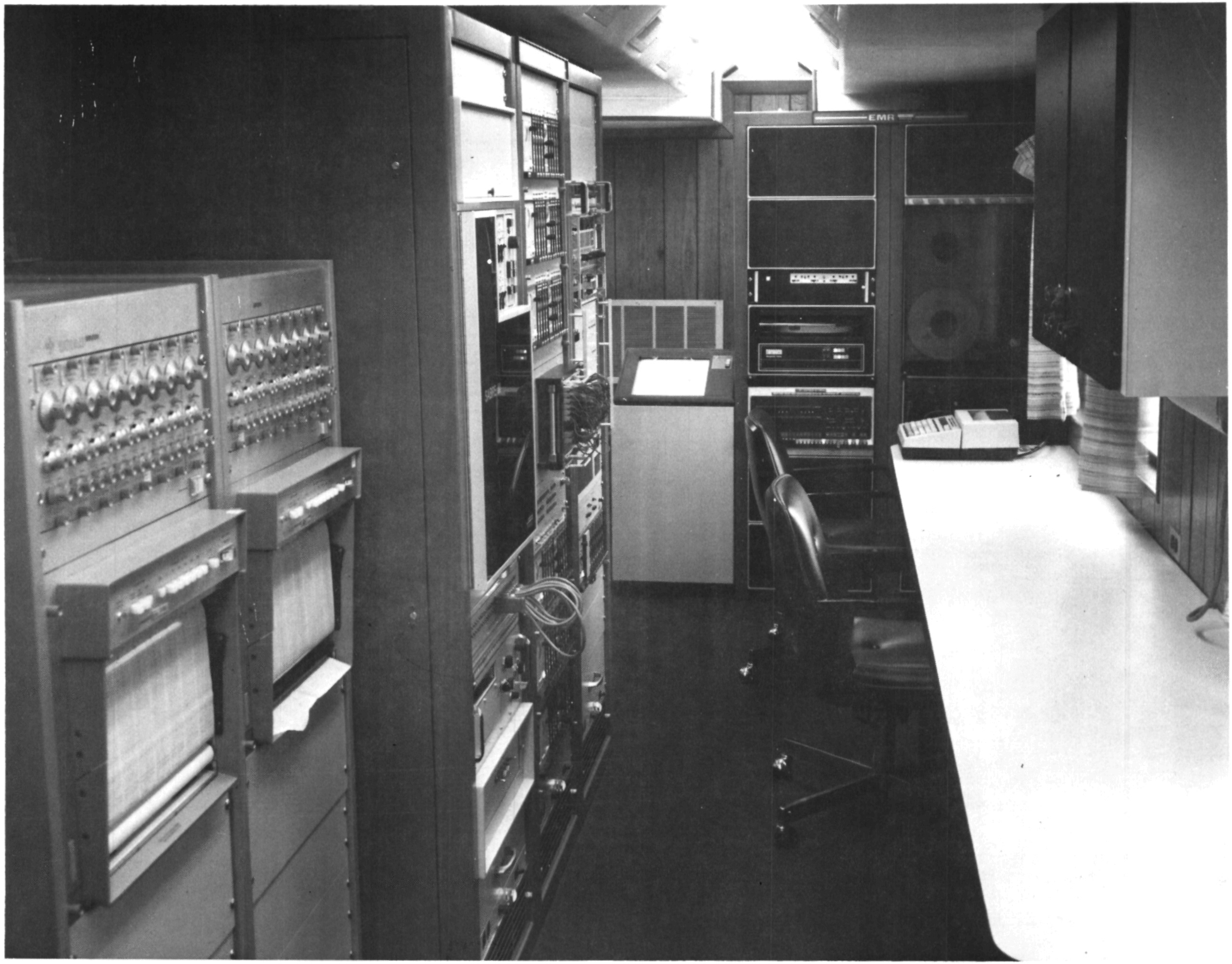

Figure 9. Digital Processing Cabinets and Rear of PIV

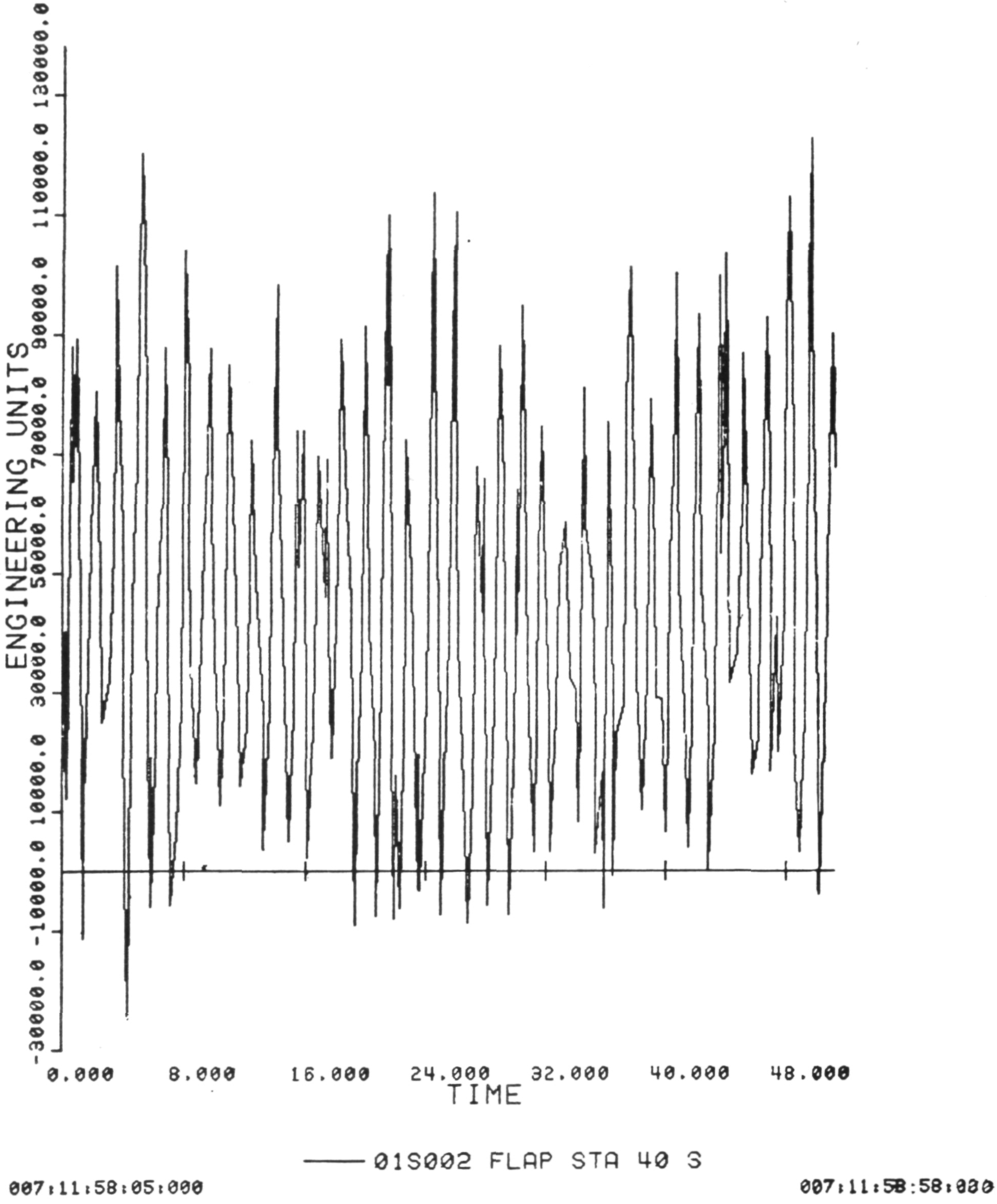

Figure 10. Sample MDAS Plot — Flap Bending of Blade Number One at Station 40

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-79034		

4\. Title and Subtitle
AN OPERATING 200-kW HORIZONTAL AXIS WIND TURBINE

5\. Report Date

6\. Performing Organization Code

7. Author(s)
Charles L. Hunnicutt, Lockheed Aircraft Service Co.; and
Bradford Linscott and Robert A. Wolf, Lewis Research Center

8\. Performing Organization Report No.
E-9833

10\. Work Unit No.

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

11\. Contract or Grant No.

13\. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
U.S. Department of Energy
Division of Distributed Solar Technology
Washington, D.C. 20545

14\. Sponsoring Agency ~~Code~~ Report No.
DOE/NASA/1004-78/14

15. Supplementary Notes
Prepared under Interagency Agreement E(49-26)-1004. Presented at Twenty-third National SAMPE Symposium and Exhibition, Anaheim, California, May 2-4, 1978.

16. Abstract
The Mod-OA wind turbine blades, manufactured by Lockheed Aircraft Service Company (LAS), Ontario, California, are now operating in Clayton, New Mexico. These blades, rotated for the first time on November 30, 1977, establish the Mod-OA as the first wind-driven generator in 35 years to be continually tied into an electrical power system which services a community. Two additional sets of Mod-OA blades will become operational by the end of 1978. Sites will be on the Island of Culebra, Puerto Rico, and Block Island, Rhode Island. Tower-mounted equipment and blade structural design and fabrication is the subject of this publication.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Wind turbine	Unclassified - unlimited
Wind energy	STAR Category 49
Windmill	DOE Category UC-60

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161