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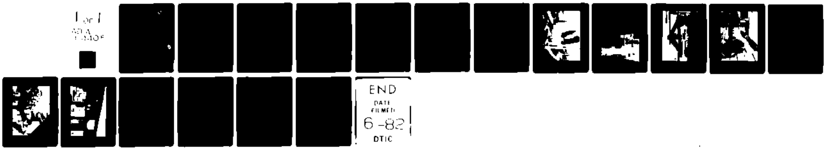

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NATIONAL TRANSONIC FACILITY (NTF) PROTOTYPE FAN BLADE FATIGUE TEST

E. H. Dean, A. J. Gustafson, D. M. Saylor

March 1982

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The Applied Technology Laboratory conducted fatigue tests on a composite fan blade designed for use in the new NTF wind tunnel being constructed at NASA-Langley. The tests were performed by the Structures Technical Area using the root end fatigue machine (REFM), which was modified for ground-air-ground testing. Simulated centrifugal and aerodynamic (bending) load tests were performed. The fan blade successfully withstood 6000 cycles at 360 rpm and 600 rpm load conditions for the cyclic rate tests. These tests simulated the starting and stopping cycles of the fan. Static load tests to 57,000 pounds

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design load were also successfully performed on the blade specimen.

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INTRODUCTION

The NASA-Langley Research Center is currently constructing a major research wind tunnel designated the National Transonic Facility (NTF) for acquiring aerodynamic data in the transonic speed range. The wind tunnel will operate at Mach numbers from 1.0 to 1.2, pressures from 8.3 to 130 psia, flow stream temperatures from +175° to -300°F, and Reynolds numbers up to 120 million. The gaseous medium in the tunnel will be dry air or nitrogen at cryogenic temperatures for simulation of full-scale aerodynamic parameters.

As part of the construction effort, NASA designed a single-stage compressor that provides the aerodynamic power for the NTF. This system consists of 25 fan blades attached to the periphery of a center disc and constructed of composite materials. The fan will rotate at speeds up to 600 rpm and is exposed to the temperature environment of the tunnel flow stream. Figure 1 shows a single fan blade of the system.

Recognizing the capabilities of the Applied Technology Laboratory's root end fatigue machine (REFM), NASA-Langley Research Center requested that the Structures Technical Area of ATL perform cyclic load and simulated aerodynamic (bending) load tests on the single fan blade specimen of Figure 1. These tests were to simulate the start and stop cycles of the fan and were necessary to assure that the fan blades could operate safely in the NTF environment. Static load tests were also performed on the blade specimen.

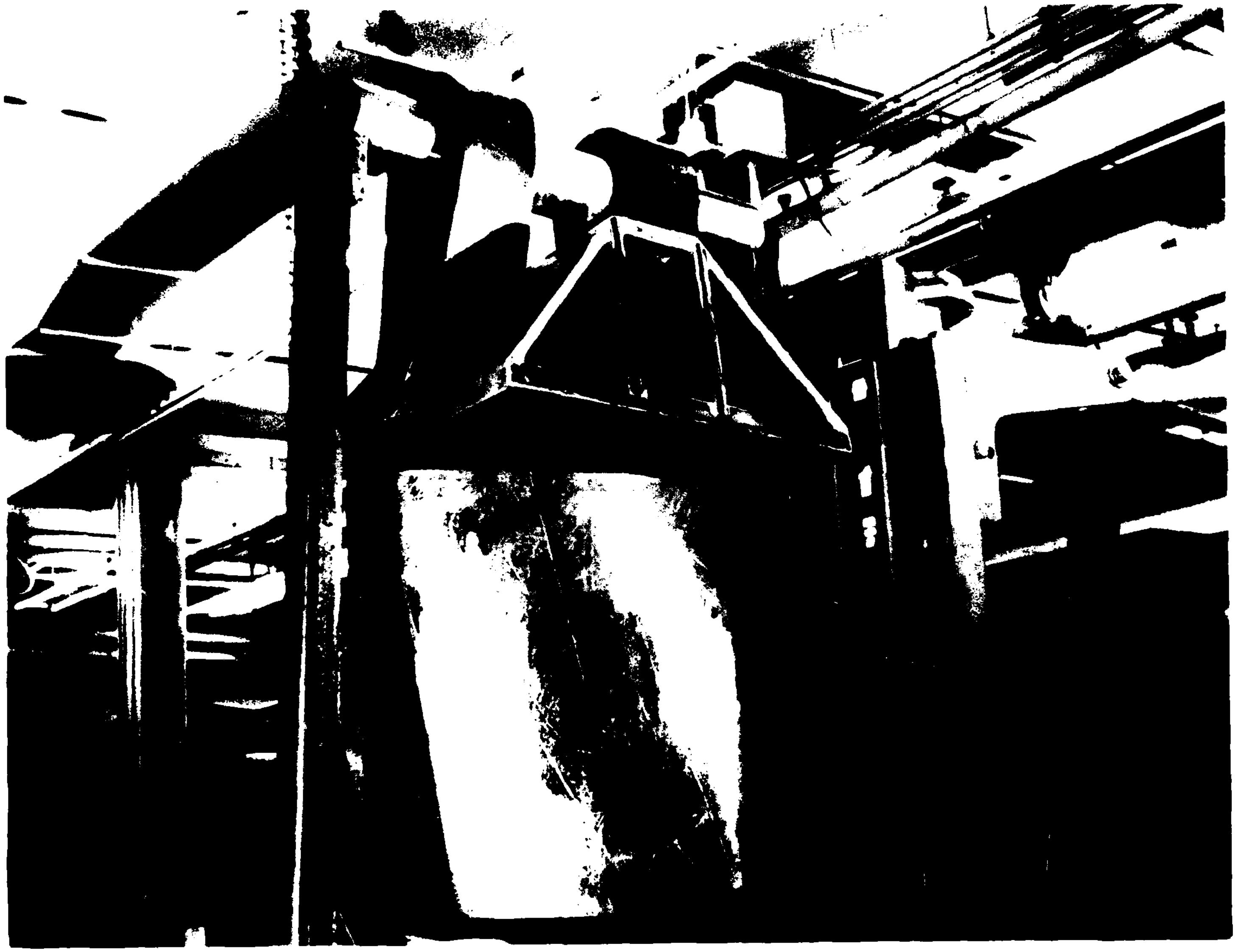

Figure 1. National Transonic Facility main drive fan blade.

TEST APPARATUS AND HARDWARE

The REFM is a large steel load frame 33-1/2 feet long by 4 feet high by 6-2/3 feet wide fitted with a hydraulic actuator for applying transverse loads to the test article and with an air bag actuator for applying tensile loads to the test article (see Figures 2, 3, and 4). The REFM was modified to allow simultaneous application of the transverse load and the tensile load while maintaining a constant ratio between these loads. This modification was made by adding electrically controlled valves in the air supply to the air bag and by making appropriate software changes in the control computer.

The NTF blade is an all-composite structure 52.1 inches long with a 27-inch chord; it weighs 120.5 pounds. The weight of the production version blade will be slightly different from that of the test blade. The root end fitting is made of two wraparound pin connectors (see Figure 1). The tip end is designed to be frangible for blade protection in the presence of small amounts of debris. The majority of the blade structure is E glass with epoxy resin.

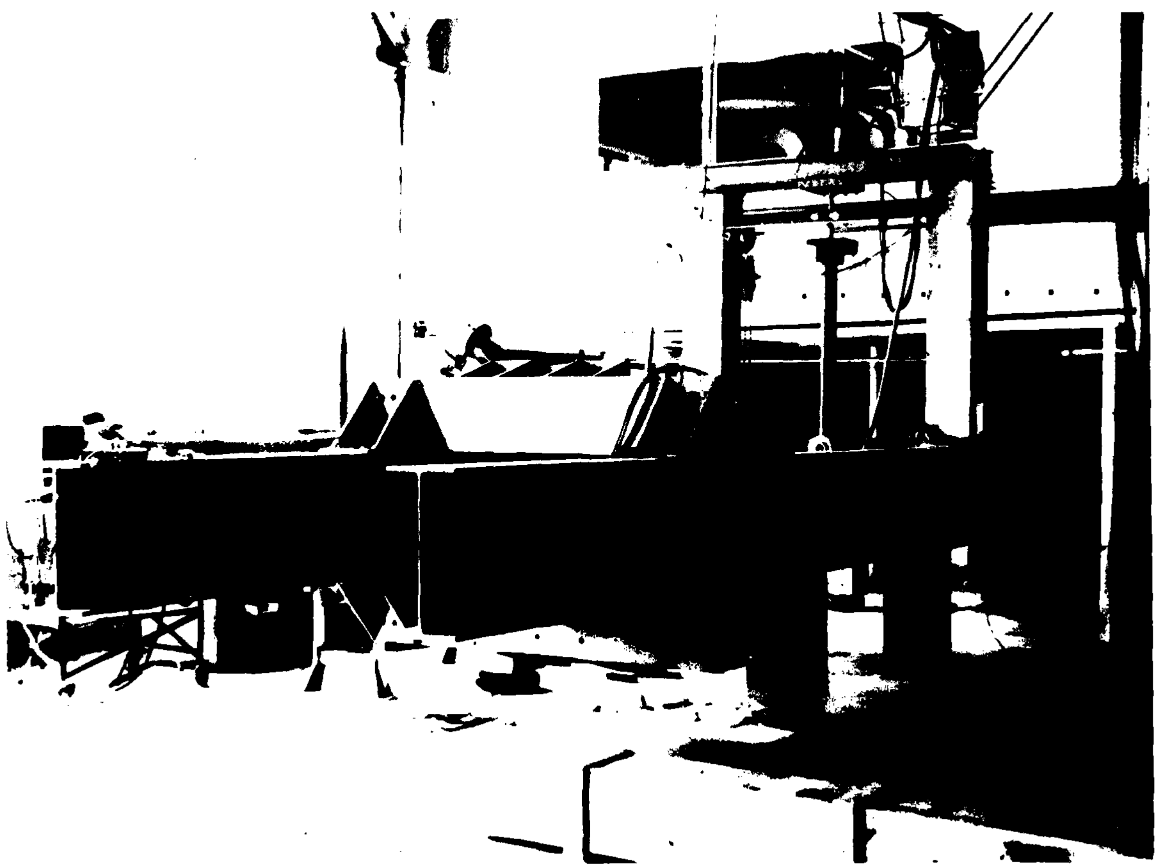

Figure 2. Applied Technology Laboratory's root end fatigue machine.

Figure 3. View of root end fatigue machine showing centrifugal force air bag.

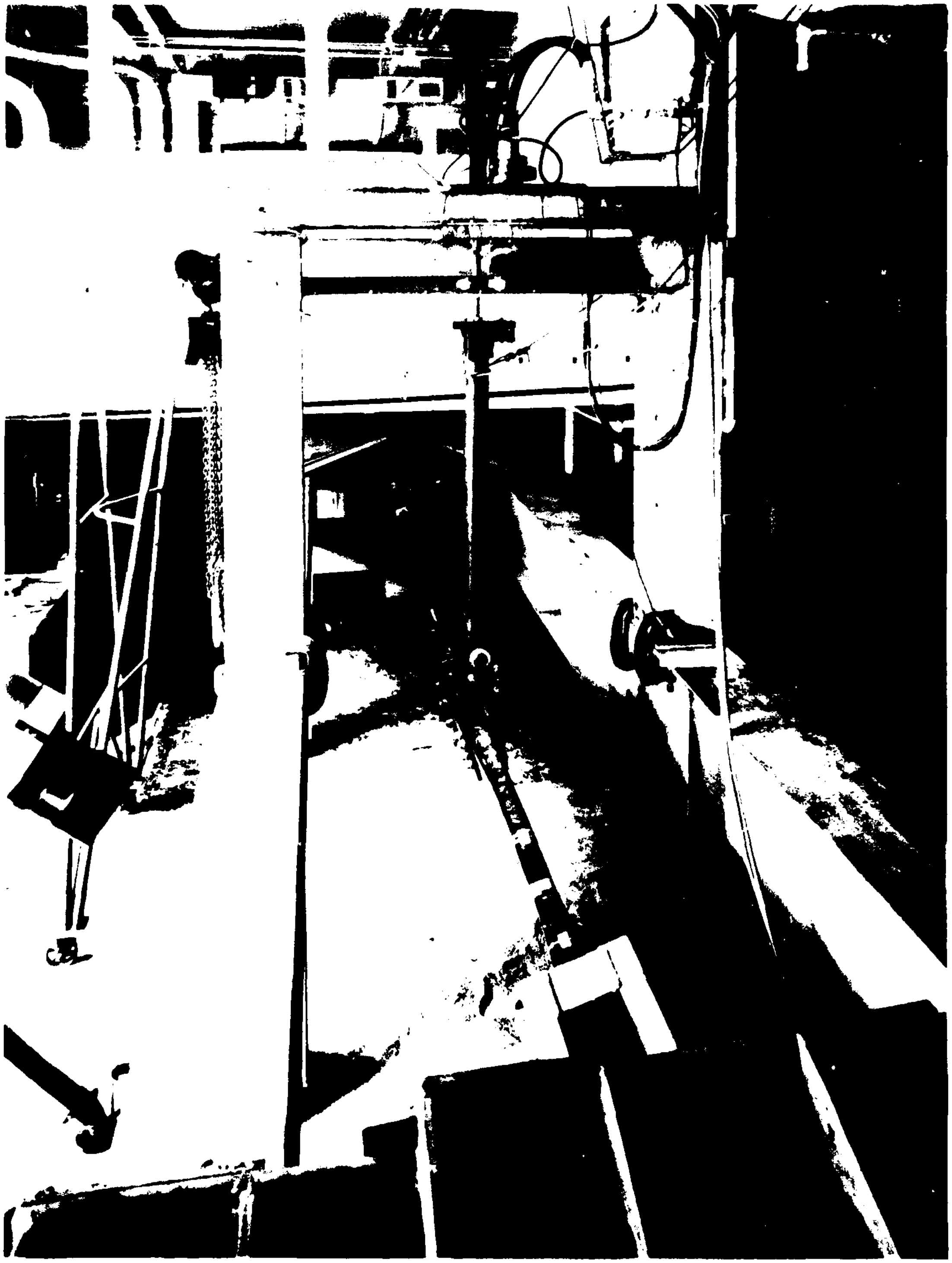

Figure 4. View of root end fatigue machine showing hydraulic actuator.

DATA ACQUISITION AND CONTROL

GENERAL

The fan blade test specimen was delivered to the Applied Technology Laboratory and installed in the REFM (see Figure 5). The specimen was controlled and engineering data were recorded using two PDP-11 minicomputers which are part of the Structures Technical Area Automatic Data Acquisition and Control System (ADACS) (see Figure 6). The ADACS can handle up to 50 channels of engineering data from transducers such as strain gages, load cells, and displacement sensors. It can also control two servo-hydraulic actuators in amplitude, frequency, and phase relation. One limitation is that both actuators must operate at the same frequency.

During static load testing, loads were applied manually by the operator, who determined the proper load condition by reading the load with a digital multimeter. Data were recorded and printed at each load level.

Fatigue testing was accomplished by computer control. Load conditions were input by the operator, and the computer then controlled the test. Data were recorded on cassette tape upon signal from the control computer to the data acquisition computer at the positive and negative peaks of every cycle. The test produced 35 cassettes of data. These data were later transferred to a hard disk file at the Acoustic Laboratory Facility at NASA-Langley Research Center.

Prior to testing the fan blade specimen, calibration was performed. 2 B

CALIBRATION

A channel definition table (CDT) was prepared by the program NEWCDT. The CDT was recorded on tape by NEWCDT for input during calibration of the control and data acquisition system data inputs. Information in the CDT included:

1. Channel type number.
2. Units per full-scale value of 10 volts.
3. Value of the calibration voltage.
4. Units per volt.
5. Bridge resistance in ohms.
6. Calibration resistance in ohms.
7. A phrase describing each channel.

Two types of data were input to the computer during calibration. All strain gage inputs were conditioned by a bridge balance unit within the computer console. Other inputs, such as load and displacement signals, were conditioned by external signal conditioners to meet voltage levels required by the analog to

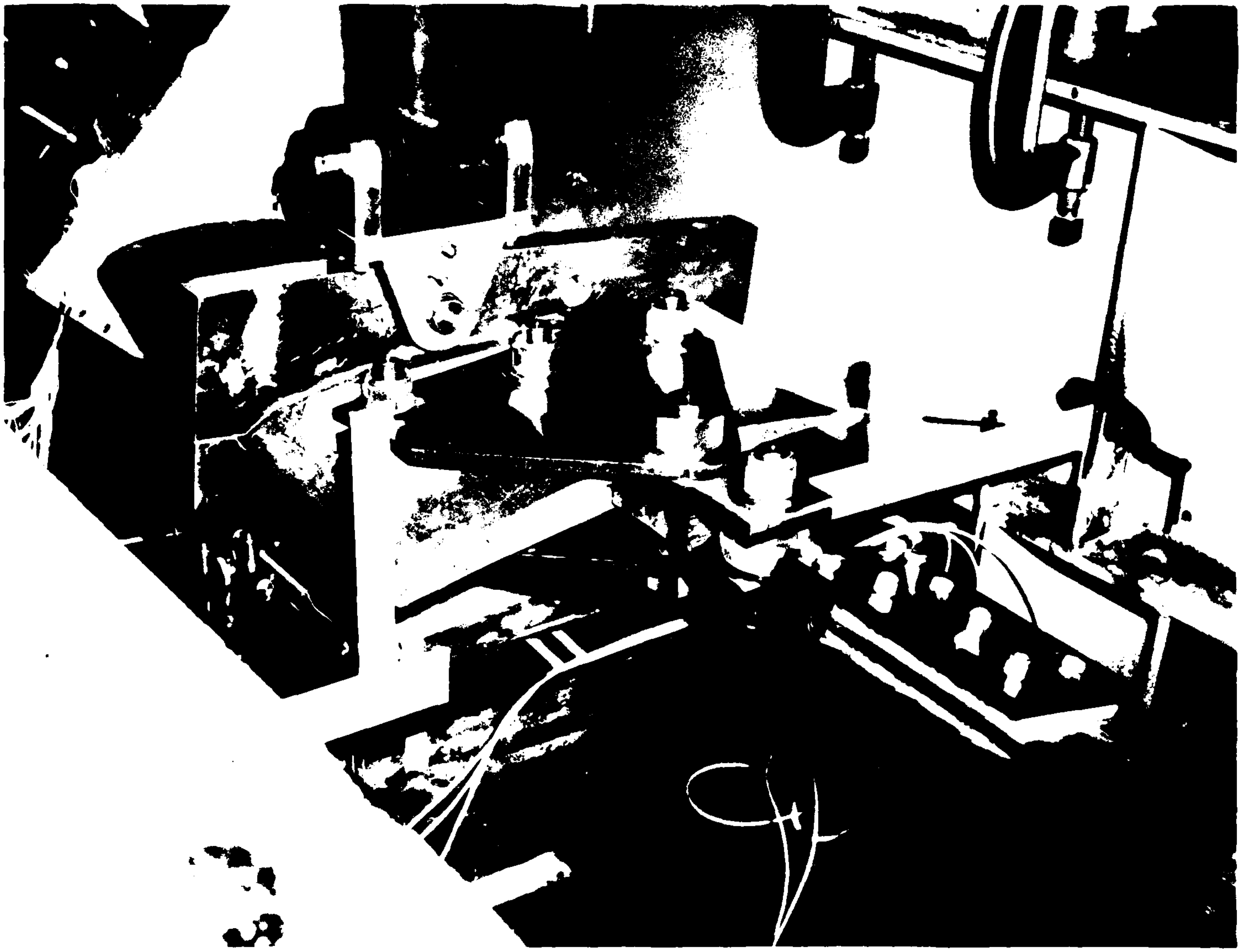

Figure 5. National Transonic Facility main drive fan blade mounted in root end fatigue machine.

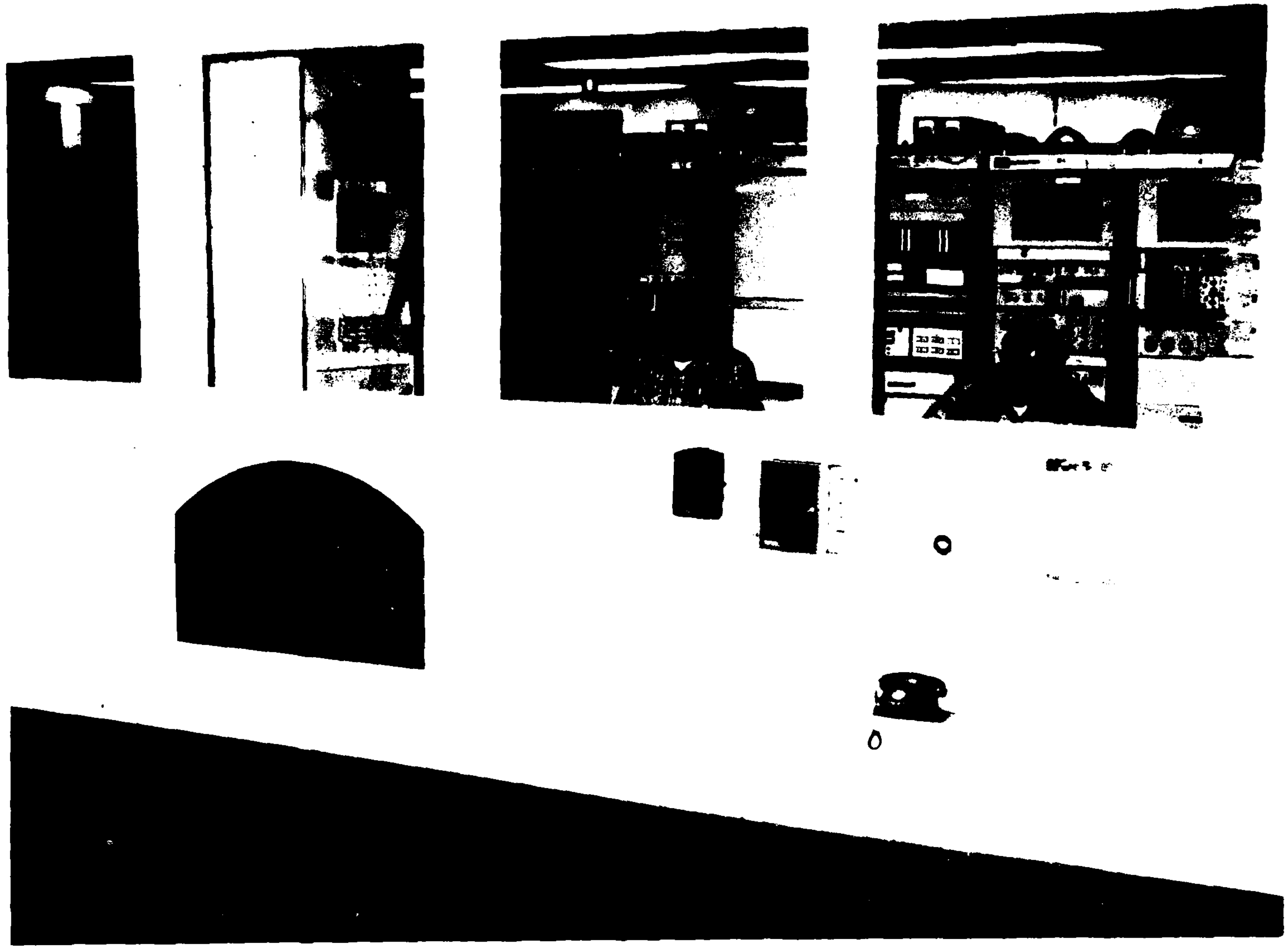

Figure 6. Acquisition control room and PDP minicomputers used for test control and data acquisition.

digital (A/D) converter. Both signals were digitized by the A/D converter for input to the computer.

All channels except those of the strain gage were calibrated by shorting the input of each conditioner, digitizing the resulting signal, and saving the results as each channel's zero offset. This value was subtracted from all subsequent readings. Secondly, a known voltage was similarly input and the results were saved as each channel's calibration constant.

Strain gage channels were calibrated by switching a 220K ohm resistor in parallel with one of the arms of the bridge circuit. The value of strain this resistor represented was used to calculate the full-scale strain for each channel. This value was then compared to the desired full-scale strain specified in the CDT. The computer printed a list of required bridge voltages that would give the required full-scale value. The operator was then prompted to adjust each channel until the channel met specifications. When all adjustments had been made, another calibration was performed and the full-scale strain values for each channel were calculated and saved for use in data reduction.

DATA ACQUISITION

Data for the NTF blade test were acquired using the following equipment:

1. A PDP-11 minicomputer with 32K words of memory - Digital Equipment Corp.

2. A TA-11 digital cassette recorder - Digital Equipment Corp.

3. An operating system - MTS Systems Inc.

4. AQNTF - A BASIC program modified for this test from the previously used MULTAQ.

5. A bridge balance unit - B&F.

6. An 11-bit analog-to-digital converter - Data Technology.

Three types of data were input to the computer during the tests. The first type of transducer input was load and displacement measurements from the aerodynamic actuator and load from the centrifugal actuator. These signals were conditioned by MTS signal conditioners, attenuated by a voltage divider, and then amplified by a gain of 2000 in the A/D converter. The second type of transducer was direct current differential transformers used for displacement measurements of the end of the blade specimen. These signals were attenuated and then amplified by a gain of 2000. The third type of transducer was single-arm strain gages that were connected to a B&F bridge balance unit. Precision 350-ohm resistors were used to complete a full bridge. The bridge outputs were connected directly to an amplifier with a gain of 2000.

The A/D converter was used to digitize all of the data. Each channel was converted to a binary number in the range of -2047 to +2047. This provides a resolution of 1 part in 2047 for all data recorded during the test. For example, the centrifugal load that was calibrated for 100,000-pound full-scale measurements had a resolution of 50 pounds.

The BASIC computer program AQNTF (modified slightly from MULTAQ) was used for data acquisition. This program permitted automatic calibration of all data channels, recording of data on digital cassettes, and printout of data in engineering units. Data were recorded and printed out immediately during the static load tests. Fatigue test data were recorded upon receipt of an interrupt signal from the control computer.

COMPUTER CONTROL

The NTF blade fatigue test was conducted using a PDP-11/05 minicomputer and the rotor blade root end test machine. The machine was modified for this test to permit remote control of the centrifugal load. This was accomplished by inserting an electrically controlled solenoid valve in the air bag supply line. The air bag applied the centrifugal load to the NTF blade. CONNTF (a computer program) was written for this test and provided the following features:

1. Input of test requirements: Test requirements were input by the operator from the terminal keyboard. Required data were the maximum and minimum values for centrifugal load, aerodynamic displacement. The required data were then stored on a tape file to preclude the necessity of inputting the data from the keyboard each time the test was restarted.

2. Calibration of data channels: The data channels connected to the control computer were calibrated as described on page 10 of this report. Interactive question and answer dialogue was provided during the calibration. A CDT file name was requested and the operator was prompted to check that the Milliverter switches were set properly. The full-scale values for each channel, as well as the zero offsets, were printed on the terminal for operator evaluation. When the operator was satisfied that he had completed a good calibration, the program returned to a menu that allowed the operator to begin testing when ready.

3. Operation of the fatigue test: Before a test could be started, the computer program requested several operator inputs. Some of these were required and some were optional, since they were used for test documentation only. The requested inputs were:

Optional

1. Operator's name
2. Date
3. Time
4. Is air pressure set to desired value?
5. Is hydraulic pressure on?
6. Span pot setting

7. Centrifugal load range

8. Aerodynamic load range

Required

9. Starting cycle count

10. Stopping cycle count

The computer then printed the message "PRESS ENTER TO START TEST" and went into a loop waiting for the operator to press the enter key on the terminal keyboard.

When the test was started, the computer closed a relay that pressurized the centrifugal load air bag. The computer then started to measure the centrifugal load and compare it to the desired value as entered from the test requirements file. When the desired value was reached, the computer caused the data acquisition computer to take a scan of all channels. It also caused the air bag to be vented to atmosphere and permitted the centrifugal load to drop toward zero. The voltage generated by the centrifugal load cell was attenuated by a variable resistor and used to drive the aerodynamic actuator in phase with the centrifugal load.

As the centrifugal load dropped toward zero, the computer again measured the load continuously. When the load reached the specified minimum value, the computer again closed a relay that caused the air bag to pressurize and the centrifugal load to increase. This cycle continued until an abnormal condition stopped the test, the operator stopped the test, or the required cycle count was reached.

REPORT OF TEST

A static load deflection test was conducted first, followed by a fatigue test. All data taken were analyzed and processed by NASA engineers present during testing.

STATIC TEST

The simulated aerodynamic load was incremented in steps of 2,000 pounds up to 12,500 pounds (last step was 2,500 pounds) and deflections were taken on increasing load and decreasing load. The same process was followed for the simulated centrifugal force load to a value of 57,000 pounds in 10,000-pound steps (last step was 7,000 pounds).

FATIGUE TEST

The fatigue test was performed in the REFM by simultaneously applying the simulated aerodynamic and centrifugal loads in a fixed ratio. These loads are listed in Table 1. The blade successfully withstood 6000 cycles at loads that develop at fan speeds of 360 rpm and 600 rpm.

TABLE 1. FATIGUE TEST LOADS

Fan Speed (rpm)	Centrifugal Force (lb)	Aerodynamic Force (lb)
360	20,500	12,500
600	57,000	5,000

With the exception of minor resin cracks, there was no damage to the fan blade throughout the test; however, a bearing pad screw on the blade failed in shear and jammed between the bearing pad and the adapter plate. This extra friction was sensed as an aerodynamic overload by the control computer, and the test was shut down. The bearing pad was repaired and the test proceeded without further incident.

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