NASA Contractor Report 189583

WEIGHT, CENTER OF GRAVITY AND MODAL TEST REPORT FOR NTF FAN BLADE SET NO. 3

Inger P. Friedman

DYNAMIC ENGINEERING INCORPORATED
Newport News, Virginia

Contract NAS1-18352
February 1992

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23665-5225

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure

1.0 INTRODUCTION

A complete set of fan blades for the National Transonic Facility (NTF) at the NASA Langley Research Center was recently fabricated by Dynamic Engineering Incorporated (DEI). These blades were the third complete set of blades fabricated for the NTF. The first set of blades was fabricated by NASA and installed in the tunnel in December 1981. This original set was destroyed in an accident in January 1989. The second set of blades were fabricated by NASA and installed in August 1989. This second set of blades is currently in use in the NTF. The third set of blades recently fabricated by DEI is a spare set. The blades were fabricated according to detailed procedures to meet design requirements necessary for operation in the NTF. In order to insure that the blades met these requirements, DEI performed a series of tests on each of the completed blades. These tests included weight and center of gravity measurements of each blade. In addition, a modal survey was conducted on each blade to define the dynamic characteristics.

The purpose of this report is to discuss the fan blade tests conducted by DEI and to present the results. The test set-ups and procedures are described in detail. The results obtained for each of the 27 blades are documented and comparisons are made between this set of blades and similar data for the two previous sets of NTF fan blades. This report necessarily summarizes the test results. A full data package for each blade has been provided separately to NASA.

2.0 WEIGHT AND CENTER OF GRAVITY MEASUREMENT

One set of tests consisted of weight and center of gravity (c.g.) measurements of the blades. This set of tests consisted of two parts: the initial c.g. measurement and the full-up c.g. measurement. The c.g. location of the blades were defined in terms of the X, Y and Z axes of the blade. A sketch of the blade defining the axes is shown in Figure 1. The X-axis lies along the centerline of the blade bores which is also the centerline of the pin. The leading edge of the blade faces the negative direction of both the X and Y-axes. The Z-axis passes through the center of the blade and is positive towards the tip. The c.g. location is referenced to the intersection point of the three axes.

Initially, the weight and c.g. measurements were performed for each blade alone, without any attachments. The blades were weighed with a 500 lb static load cell and then set into a balancing stand provided by NASA. Measurements in the X, Y and Z axes of the blade were obtained by orienting the blade in three different positions in the balance stand. The actual c.g. location of the blade was determined from the balance stand measurements and parameters defined by the test set-up. The initial weight and c.g. location were obtained for the entire set of 27 blades. These results were compared to documented results from identical tests performed on the first two sets of NTF blades. This comparison served as a check of the test procedures and as an initial check of the similarity between the blade sets.

The full-up c.g. measurements were performed on the blade assembly which included the blade, flight pin and fairings. The flight pin was installed in the blade using a specially designed pin insertion stand provided by NASA. The two fairings were then attached to the pin. The same flight pin and fairing set were used for every blade tested. This full-up assembly represents the blade configuration used in the tunnel. NASA requires that the Y-axis c.g. location of the blades lie within a specified range for safe operation in the NTF. In order to meet this requirement, ballast weights were installed in the blade web area to shift the Y-axis c.g. location of the blade if necessary. Due to the presence of the fairings, the blade set-up for Y-axis measurement in the balance stand was different from the set-up in the initial c.g. test. Otherwise, the procedures used to obtain the initial and full-up c.g. measurements with the balance stand were the same. The final X, Y and Z c.g. measurements were made with the ballast weights installed. The average and range of full-up blade weight and c.g. locations for this set of blades were compared with the previous blade sets to check the consistency of the blade sets.

2.1 Test Set-up and Procedures

The initial and full-up weight and center of gravity tests were performed according to procedures outlined by NASA. The specially designed blade test fixtures which had been used to test the two previous sets of blades were furnished by NASA. Other necessary items which were not available from NASA were provided by DEI.

2.1.1 Equipment

A complete list of the equipment used to perform the weight and c.g. measurement tests is shown below.

- Blade balance stand
- Two axis cross slide
- Right angle wheel block
- Y-axis scale block
- Counter balance boom
- Blade tip pointer
- Six inch scale
- Two transits

- Pin insertion stand
- Pin alignr/puller
- Chain come along
- Wooden pin tray
- Cross shaft assembly
- Dummy flight pin
- Hollow pin
- NTF flight pin
- Hub sleeves (2)
- Pin nuts and washers (2)
- Pin nut wrench
- Blade ballast weights
- "Brake free" lubricant
- Overhead hoist
- Lifting straps
- Blade holding cart
- Depth mike
- Rubber mallet
- 500 lb load cell and readout indicator
- 20 lb load cell and readout indicator
- Load cell stand for Z-axis measurement
- 5 lb tare weight

Photographs showing the blades and some of the test equipment are presented in Figure 2. The blades were stored in wooden carts when not being tested. The photograph in Figure 2 also shows one blade in the blade holding fixture underneath the overhead hoist and another blade in the balance stand. The counter balance boom can be seen hanging from the ceiling on the left.

2.1.2 Test Procedures

The test procedures used in performing the blade c.g. measurements were based on existing documentation from the tests previously conducted by NASA on the first two sets of blades. DEI reviewed the existing procedures and clarified and modified the test procedures as necessary with the assistance of NASA personnel. The updated procedures were documented in detailed step-by step instructions and approved by NASA. An explanation of the balance stand operation and a summarized version of the procedures are included in this section. The step-by-step detailed procedures covering both the initial and full-up c.g. tests are contained in Appendix A.

The primary test fixtures used in the c.g. measurement tests were the balance stand and the two transits. Before taking any measurements, the transits and the balance stand were leveled and aligned. One transit was positioned perpendicular to the balance stand rotation axis and the other was aligned with the rotation axis. The blade was supported in the balance stand by the cross shaft assembly fitted with the dummy pin (for the initial test) or the NTF flight pin (for the full-up test). As shown in Figure 3, the pin was inserted through the blade bores and the cross shaft.

The balance stand was used to measure c.g. offsets in the X, Y and Z blade axes by positioning the blade three different ways. To perform the initial and full-up X-axis measurements, the blade was positioned in the balance stand with the cross shaft sitting on the rotating wheels as shown in Figure 4. To perform the initial Y-axis measurement, the blade was simply lifted and rotated 90° on the balance stand so that the pin rested on the rotating wheels. In the full-up configuration, the fairings covered the flight pin, and therefore the blade set-up was different. The full-up Y-axis blade set-up, shown in Figure 5, required the use of the right angle wheel block. The right angle wheel block was used to change the axis of rotation. This block which was positioned between the balance stand and the cross shaft assembly locked the balance stand wheel rotation. The flight pin rested on rotating wheels contained in the block which allowed the blade to rotate freely about the pin centerline.

X and Y c.g. offset measurements were read at the blade tip from a six inch scale, as illustrated in Figure 6a. The scale was attached to the two axis cross slide and positioned so that the center of the scale was aligned with the center of the axis of rotation. This alignment was checked with the transit before each measurement. The pointer inserted in the blade tip was located at the blade centerline (along the Z-axis). If the X or Y-axis c.g. was located exactly at the origin, the tip pointer would be positioned exactly above the center of the scale (at the 3 inch mark on the 6 inch scale). An offset measured at the tip in a particular axis was proportional to the blade c.g. location in that axis. As mentioned earlier, the full-up Y-axis measurement required the use of the right angle wheel block to change the axis of rotation. In this configuration, a scale block, shown in Figure 6b, was needed to adjust the scale orientation and height.

The set-up for the Z-axis c.g. measurement required an additional test fixture, the counter balance boom. The blade was initially placed in the X-axis test position in the balance stand. The lower end of the balance boom was then attached to the top of the cross shaft. The blade/balance boom assembly was rotated on the wheels 90° so that the balance boom and blade Z-axis were horizontal. This blade orientation is illustrated in Figure 7. The free end of the balance boom rested on a 20 lb load cell. The Z-axis c.g. location was determined from the compressive force applied to the load cell by the balance boom and a tare weight which was sometimes needed to add additional counter weight.

The full-up blade assembly included the blade, the flight pin and the fairings. The flight pin was the actual pin used to mount the blades to the hub in the tunnel. The fairings were attached to the blade pins. Each blade installed in the tunnel will be assigned a specific flight pin and fairing set. For this set of tests, however, the same flight pin and fairing set were used for all the blades. Installation of the flight pin required the use of the pin insertion fixture and a come along. This procedure is pictured in Figure 8. The cross shaft was secured to the pin insertion stand to align the pin axis properly. A pin aligner attached to the front end of the flight pin was pulled through the blade bores by the chain come along guiding the flight pin behind it. The pin nuts and washers were then installed and set to a specified distance from each end of the blade.

For safe operation in the NTF, NASA requires that the fan blade Y-axis center of gravity be located on the negative side of the Y-axis within a specified range. This c.g. range equates to a full-up Y-axis offset value at the blade tip of $0.10" \leq \Delta y \leq 0.11"$. If the Y-axis offset of the full-up blade assembly did not lie within this range, ballast weights were added to the blade web area to shift the c.g. location. The total ballast weight needed to get a Y-axis offset reading of $0.10" \leq \Delta y \leq 0.11"$ had to be divisible by four so that the weights could be placed symmetrically around each leg of the web. The ballast weights were attached to the web legs with nuts and bolts as shown in the bottom of the photograph in Figure 9. The X-axis and Z-axis c.g. measurements in the full-up configuration were taken with the ballast weights installed.

The initial and full-up c.g. measurement procedures are outlined below in the order in which they were performed:

1. Weigh blade alone (without fairings, pin or ballast weights).

2. Perform initial c.g. measurement of blade alone.
   a. Insert cross assembly with dummy pin into blade.
   b. Position blade in balance stand for Y-axis measurement.
   c. Align scale with center of rotation and record Y-axis offset at tip pointer.
   d. Position blade in balance stand for X-axis measurement.
   e. Align scale with center of rotation and record X-axis offset at tip pointer.
   f. Attach balance boom to cross shaft and rotate assembly on balance stand to horizontal position for Z-axis measurement.
   g. Record load cell reading and tare weight.

3. Repeat procedures 1 and 2 for each blade.

4. Calculate initial c.g. location for each blade.

5. Weigh the NTF flight pin and fairings.

6. Perform full-up c.g. measurement of blade with flight pin, fairings and ballast weights.
   a. Install flight pin, nuts and washers.
   b. Attach fairings to flight pin.
   c. Position blade in balance stand for Y-axis measurement.
   d. Check scale alignment and record Y-axis offset at tip pointer.
   e. Add ballast weights until Y-axis offset is between $0.10'' \leq \Delta y \leq 0.11''$.
   f. Weigh ballast weights and install in blade web.
   g. Record new Y-axis offset.
   h. Position blade in balance stand for X-axis measurement.
   i. Check scale alignment and record X-axis offset at tip pointer.
   j. Attach balance boom to cross shaft and rotate assembly on balance stand to horizontal position for Z-axis measurement.
   k. Record load cell reading and tare weight.

7. Repeat procedure 6 for each blade.

8. Calculate full-up blade assembly c.g. location for each blade.

2.2 Center of Gravity Calculations

The blade center of gravity location was calculated from the X- and Y-axis offset measurements, load cell reading and tare weight in the Z-axis set-up, blade weight and constant test parameters. The equations used to calculate the c.g. location in the X, Y and Z axes are the following:

$$X_{cg} = \frac{-Z_{cg}\Delta x}{A}$$

$$Y_{cg} = \frac{-Z_{cg}\Delta y}{A}$$

$$Z_{cg} = \frac{W_{cb}L_1 + (W_t - W_{1c})\,L_2}{W_b}$$

The variables in these equations are: W_t the tare weight, W_{lc} the load cell reading, W_b the blade weight, Δx the X-axis blade tip offset measurement and Δy the Y-axis blade tip offset measurement. For the initial tests, W_b is the blade weight alone, but for the full-up tests W_b includes the weight of the blade, fairings and ballast weights.

The fixed parameters in these equations are : W_{cb} the weight of the balance boom, L_1 the distance of the boom c.g. to the axis of rotation, L_2 the distance from the load cell to the axis of rotation, and A the vertical distance from the pin centerline to the end of the tip pointer. These distances are shown in Figure 10. For the full-up configuration, the weight of the fairings (which is included in the total blade weight) is constant for all the blades. The values of the fixed parameters are the following:

W_{cb} = 91.55 lb
L_1 = 40.378 in
L_2 = 47.671 in
A = 49.975 in
Fairing set weight = 16.38 lb

Test flight pin weight = 106.55 lbs
(not used in c.g. calculation)

The sign convention for the c.g. location follows the blade axis system defined in Section 2.0 and in Figure 1.

2.3 Test Results

A procedure checklist was followed while testing each blade to maintain consistency and to record the required test data. Sample procedure checklists for the initial and full-up tests are included in Appendix B.

During the initial c.g. tests the following data were recorded: test date, blade weight, X-axis tip offset measurement, Y-axis tip offset measurement, Z-axis load cell reading and tare weight. These data from each blade tested are presented in Table 1. The X, Y and Z c.g. blade locations calculated from the test data are presented in Table 2. The average and range of the blade weight and c.g. locations for this blade set are the following:

INITIAL	AVERAGE	RANGE
Blade Weight (lb)	229.64	227.20 to 234.05
Xcg (in)	-.105	-.081 to -.137
Ycg (in)	.054	.018 to .088
Zcg (in)	15.87	15.70 to 16.00

These results are consistent with the initial weight and c.g. location results on the first two sets of blades. A comparison of the blade weight and c.g. location summary for all three blade sets is shown in Table 3.

The data recorded during the full-up c.g. tests were similar to the data recorded during the initial c.g. tests with the addition of the ballast weights. Y-axis tip offset measurements were recorded with and without the ballast weights. X-axis and Z-axis data were taken with the ballast weights installed. The full-up c.g. test data is presented in Table 4, and the c.g. locations calculated from this data are presented in Table 5. The average and range of the blade weight with ballast and the c.g. locations for the full-up blade configuration for this blade set are the following:

FULL-UP	AVERAGE	RANGE
Blade Weight w/ ballast (lb)	232.32	230.40 to 235.00
Xcg (in)	.166	.145 to .192
Ycg (in)	-.032	-.034 to -.031
Zcg (in)	15.09	15.02 to 15.18

The full-up c.g. test results are very consistent for the blade set as a whole. None of the blades showed any unusual characteristics. A comparison of the final c.g. location summary for the three NTF blade sets, presented in Table 6, shows good consistency between the blade sets as well.

2.4 Retest of NTF Fan Blades from Blade Set 2

During the time period in which DEI was conducting the tests on NTF Blade Set 3 several NTF blades were removed from the tunnel for routine inspection and minor repair work. These blades are from NTF Blade Set 2. The weight, c.g. measurement and modal testing of these blades had been performed at NASA in 1989. At the request of NASA, DEI remeasured the c.g. location of two of these blades, numbers 32 and 50. The new results were compared with the results obtained in 1989 to check the consistency of the present test procedures at DEI and to determine the effect of repairs on the results. The two blades were tested in the initial and full-up configurations. In the full-up configuration, each blade was fitted with its assigned NTF flight pin and fairing used in the tunnel, as was done in the 1989 tests. The current and 1989 results are shown below.

INITIAL C.G. MEASUREMENT - BLADE NO. 32

TEST	WEIGHT (LB) Blade only	Xcg (in)	Ycg (in)	Zcg (in)
1989	231.9	0.12*	0.026	15.99
1991	231.8	-0.085	0.054	15.99

*See text for explanation of sign error in 1989 data.

FULL-UP C.G. MEASUREMENT - BLADE NO. 32

TEST	WEIGHT (LB) Blade,fairings, ballast	Xcg (in)	Ycg (in)	Zcg (in)
1989	250.8	0.173	-0.031	15.18
1991	251.0	0.191	-0.011	15.12

INITIAL C.G. MEASUREMENT - BLADE NO. 50

TEST	WEIGHT (LB) Blade only	Xcg (in)	Ycg (in)	Zcg (in)
1989	227.4	0.107**	0.075	15.94
1991	227.4	-0.092	0.068	15.90

**See text for explanation of sign error in 1989 data.

FULL-UP C.G. MEASUREMENT - BLADE NO. 50

TEST	WEIGHT (LB) Blade,fairings, ballast	Xcg (in)	Ycg (in)	Zcg (in)
1989	248.4	0.191	-0.032	15.05
1991	248.1	0.188	-0.047	15.03

Considering the uncertainties inherent in the balance stand and the c.g. measurement technique, as well as possible changes to the blades from repair, the 1989 and 1991 results agree fairly well. The results for blade number 50 match the 1989 data slightly better than the results for blade number 32. From these repeat tests it was discovered that the X-axis sign convention used in the 1989 initial c.g. measurement tests was incorrect. Therefore, the initial Xcg values for the 1989 test should be negative. The good agreement between the tests verified that the c.g. measurement technique used for Blade Set 3 was accurate, and that the c.g. locations of blades 32 and 50 had not shifted significantly.

3.0 MODAL SURVEY

The second set of tests performed on the NTF blades was a modal survey to determine the dynamic characteristics of the blades. The modal data of interest were the natural frequencies of the blade vibration modes, the mode shapes and the damping associated with the primary modes. To prevent vibration and flutter problems, the blade natural frequencies must lie within certain ranges and must avoid disturbing frequencies which are present during operation in the tunnel. The primary modes of concern are the first and second bending modes and the first torsion mode. The dynamic requirements specified by the NTF for safe operation are the following: the first bending mode frequency should be approximately 60 Hz; the first torsion mode frequency should be greater than 90 Hz; and none of the modes should coincide with the 24 per rev frequency at the tunnel operating speeds.

The blades were mounted in a test fixture which was designed to represent the boundary conditions of the blade mounted to the hub in the NTF. The blades were tested without fairings or ballast weights. A random excitation force (0-500 Hz frequency band) applied to the blade with an electromagnetic shaker was used to excite the vibration modes. The shaker input force and the blade acceleration response were monitored with a load cell and an accelerometer mounted on the blade. The blade natural frequencies were identified from the frequency response functions which were generated from the force and acceleration records. Sine excitation was applied at the blade frequencies to map the mode shapes. The damping characteristics associated with a particular mode were determined from free decay response records.

3.1 Test Set-up and Procedures

A photograph of the test set-up with the blade mounted in the modal test fixture is shown in Figure 11. The wooden stand supported the shaker which was attached to the lower surface of the blade. The instrument racks held all the electronic equipment needed for the test.

3.1.1 Equipment

A complete list of the equipment used to perform the modal survey tests is shown below. Some of the test equipment was provided by NASA and some by DEI.

- Modal test fixture
- Pin nut wrench
- NTF flight pin
- Pin nuts and washers(2)
- Shim washers for modal fixture (2)
- Wood pin tray
- Come along
- Pin aligner/puller
- Torque wrenches (10 ft-lb and 50 ft-lb)
- Shaker support stand
- Ling Dynamic Systems Shaker (Model 203)
- ONO SOKKI FFT 2-channel Analyzer (Model CF350)
- Stereo Amplifier
- Fluke Digital Multimeter (Model 8842)
- HP Pen Plotter (Model 7550)
- Krohn-Hite Filter (Model 3343R or 3323)
- Kistler Accelerometer (2) (Model 818)
- Kistler Dual Mode Amplifier (2) (Model 5004)
- PCB Transducer (Model 208 A02)
- Tektronix Oscilloscope (Model 5110)
- Tektronix Dual Trace Amplifier (2) (Model 5A18N)
- Tektronix Time Base Amplifier (Model 5B10N)
- Tektronix Storage Oscilloscope (Model 5111)
- Tektronix Amplifier (2) (Model 5A15N)
- Wavetek Signal Generator
- Instrument rack
- BNC cables and BNC to microdot cables

3.1.2 Test Procedures

The test procedures followed for performing the modal survey were similar to those used in testing the two previous sets of blades. However, some changes were made in the test set-up and procedures to improve the accuracy and consistency of the results. The test procedures are explained in this section and outlined in the order in which they were performed in Appendix C.

Proper mounting of the blade in the modal test fixture was very important. The blade was held in position by the NTF flight pin which was inserted through the blade bores and the flight pin hole in the fixture. A close up of the test fixture is shown in Figure 12. The pin nuts and washers were installed and torqued to 10 ft-lbs. The blade web rested on the top surface of the fixture which was contoured to the web surface. A block which fits in the blade web area was used to clamp one side of the blade to represent the configuration on the hub. The clamp was torqued to 150 ft-lbs. The modal test fixture was bolted to the concrete floor to provide a rigid base. When mounted properly the blade fit securely in the fixture without any freeplay at the interface.

The significance of the interface between the blade and the test fixture on the identification of the modes became apparent after testing the first several blades. Initially, the blade modes were not easily identified from the frequency response functions (FRF). The peaks were not clearly defined, the frequencies shifted after unclamping and reclamping the blade, and some of the mode shapes were difficult to identify. In addition, there were noticeable differences in the FRFs of the first several blades. In some blades an additional mode was identified below the first bending mode which was similar to first bending but displayed a phase shift in the root area. The blades were also tested in an unclamped configuration. In this configuration the clamp was removed and the blade positioned so that there was no contact between the blade web and the top of the modal fixture. The blades were tested in this unclamped configuration in 1989 after having difficulty identifying the first bending mode in some of the blades in the clamped configuration and finding poor data repeatability. During the current tests, however, it became apparent that it was not possible to achieve consistent boundary conditions in the unclamped configuration. Because the blade web contours are slightly different from blade to blade, some of the blades were in contact with the modal fixture. The differences in this boundary condition had a significant effect on the frequencies.

In an effort to improve the results and the repeatability of the test set-up a different flight pin was tried in the modal fixture. It was discovered that the diameter of the first test pin used (4.865") was actually under tolerance. An actual spare NTF flight pin was found to be larger in diameter (4.872") than the first test pin and therefore provided a tighter fit of the blade in the modal fixture. The blades which had been tested with the first test pin were rechecked with the spare NTF flight pin. In all cases the FRFs demonstrated more clearly defined modes, and the results were more consistent from blade to blade. In addition, the frequencies increased by 10 to 20 percent. These improved results indicated that the quality and consistency of the FRFs were significantly affected by the blade boundary conditions. The smaller pin did not provide a uniform tight fit of the blade in the modal fixture thereby allowing freeplay at the root. As a result of this finding the decision was made, with NASA consent, to test all of the blades with the spare NTF flight pin in the clamped configuration only. This test set-up assured accurate and consistent results.

The positions of the shaker, load cell and accelerometer are shown in Figure 13. The shaker was suspended from the support stand and attached to the lower surface of the blade near the leading edge tip (approximately 4 inches aft of the leading edge and 2 inches from the tip). A flexible stinger was used to connect the shaker to the blade. A load cell was mounted at the shaker/blade attachment point to monitor the shaker input force. The random signal input to the shaker was generated by the FFT Analyzer and amplified by the stereo amplifier. An accelerometer was attached to the upper surface of the blade near the leading edge corner. This location was found to give the best acceleration responses for identifying the blade modes.

The blade modes were excited with a 0-500 Hz bandwidth random excitation force. The input force and the acceleration response were monitored on the 2-channel analyzer. The frequency response function was generated from the force and acceleration and averaged 32 times. A typical FRF magnitude plot is shown in Figure 14. The peaks on the plot correspond to the blade vibration modes. The frequency at the tip of a peak is the frequency corresponding to that particular mode. FRFs were generated and plotted for each blade to identify the blade frequencies.

Having identified the blade frequencies, the mode shape corresponding to each frequency was determined. Each mode was excited separately using sine excitation at the identified frequency. Two accelerometers were used to identify the mode shape: a reference accelerometer and a roving accelerometer. The relative magnitude and phase between the two responses were examined at different locations on the blade to locate node lines and map out the mode shape.

The damping value corresponding to a particular mode was determined from the free decay acceleration response. Each mode was excited with the sine excitation and the acceleration response monitored on the FFT analyzer. After turning off the excitation, the free decay response of the blade was recorded. The damping coefficient was calculated from these responses using the logarithmic decrement method.

3.2 Test Results

A modal survey was performed on each of the 27 blades. Five modes were identified within the 0-400 Hz frequency range. Modes above 400 Hz were of no concern because they lie outside of the excitable frequency range at the tunnel operating speeds. The primary modes of interest for dynamic design requirements were the first and second bending modes and the first torsion mode. Two higher modes were also identified: a combined bending/torsion mode and the third bending mode. The damping values were determined for the three primary modes.

The magnitude plot of the frequency response function for blade number 60 is shown in Figure 15. The frequencies identified from this FRF are 62.5 Hz, 121.25 Hz, 221.25 Hz, 280.0 Hz and 387.5 Hz. The mode shapes corresponding to these frequencies are presented in Figures 16 thru 20. The mode shapes are illustrated by node lines and plus or minus signs to indicate phase changes. The 62.5 Hz mode, shown in Figure 16, is the first bending mode. The 121.25 Hz mode, shown in Figure 17, is the second bending mode. A phase change occurs across the node line which lies across the blade. The third mode, at 221.25 Hz (Figure 18), is the first torsion mode. The node line lies diagonally across the blade rather than vertically at the centerline. This behavior is likely due to the twist of the blades and the test fixture mounting. The mode identified at 280.0 Hz (Figure 19) is a combined bending/torsion mode, and the mode identified at 387.5 Hz (Figure 20) is the third bending mode. The free decay responses for the first three modes are shown in Figures 21 thru 23. The damping value for the first bending mode is .051, .072 for the second bending mode, and .036 for the torsion mode.

Table 7 presents the five blade mode frequencies identified for each of the 27 blades. The damping values corresponding to the first three modes are shown in Table 8. The average frequency and frequency range of each mode for Blade Set 3 as a whole are the following:

MODE DESCRIPTION	FREQUENCY RANGE (HZ)	AVERAGE (HZ)
1st Bending	58.75 - 65.00	61.5
2nd Bending	118.75 - 123.75	120.7
1st Torsion	206.25 - 227.50	216.7
Bending/Torsion	267.50 - 280.00	273.2
3rd Bending	376.25 - 413.75	392.7

The modal survey results for Blade Set 3 indicate that all the blades meet the dynamic requirements necessary for safe operation in the NTF. An interference diagram of the blade frequencies and the tunnel disturbing frequencies is presented in Figure 24. The tunnel normally operates at speeds between 360 RPM and 600 RPM. The predominant disturbing frequency present during tunnel operation is 24 per rev. One per rev and 4 per rev disturbances are also present at lower energy levels. This plot shows that the first bending frequency is well above the 1 per rev and 4 per rev frequencies. The second bending mode does not coincide with the 24 per rev frequency anywhere within the operating range. The torsion mode is well above 90 Hz, and it does not cross the 24 per rev line at the predominant operating speeds of 360 RPM and 600 RPM.

The narrow frequency bands indicate that the dynamic characteristics of the blades are consistent within the blade set. Blade frequency differences from one blade to another were relatively small. The mode shapes mapped out for each blade were also very similar. The mode shapes illustrated for blade number 60 in Figures 16 thru 20 are representative of the mode shapes for all the blades. Repeat tests performed on several blades showed good repeatability of the results.

A comparison of the average blade frequencies identified for the three NTF Fan Blade Sets is shown below. There are some similarities between the blade sets but also several noticeable differences.

MODE NO.	MODE DESCRIPTION	AVERAGE FREQUENCY		
		SET 1	SET 2	SET 3
1	1st Bending	57.3	66.1	61.5
2	Bending/Torsion	74.4	80.9	----
3	2nd Bending	118.7	158.1	120.7
4	1st Torsion	188.7	195.3	216.7

All three blade sets exhibited a first bending mode at approximately the same frequency. The second bending mode frequency of the first and third sets are very close, but the second set exhibited a considerably higher frequency. In 1989, when the second blade set was tested, this discrepancy was not resolved or explained. A bending/torsion mode was identified in both the first and second blade sets but not in the third blade set. These differences in the modal survey results for the three blade sets are primarily due to inconsistencies in the blade mounting technique used for the three tests. As discussed in section 3.1.2, the boundary conditions of the blade in the test fixture were found to significantly affect the quality and repeatability of the frequency response functions from which the modes were identified. The three blade sets were tested with different flight pins which varied in diameter. The bending/torsion mode identified in Blade Sets 1 and 2 was most likely a function of the blade root boundary conditions. Blade Set 2 exhibited inconsistencies even in the first bending mode, which could not be identified for some of the blades. The modal survey results for Blade Set 3 as a whole are very consistent and repeatable as a result of proper blade mounting to obtain good quality frequency response functions.

3.3 Retest of NTF Fan Blades from Blade Set 2

At NASA's request, modal surveys were conducted on blade numbers 32 and 50 from Blade Set 2. These blades were removed from the NTF for routine inspection. The original modal tests on these blades had been conducted in 1989. In the current test, the blades were fitted in the modal test fixture with their assigned NTF flight pins, although a different pin had been used in 1989. The modal survey results from the two tests on these blades, shown below, exhibit the same differences discussed in the previous section.

MODE	BLADE 32 1989	BLADE 32 1991	BLADE 50 1989	BLADE 50 1991
1st Bending	71.25	62.50	66.25	63.75
Bending/Torsion	----	----	86.25	----
2nd Bending	156.25	122.50	155.00	121.25
1st Torsion	196.25	215.00	191.25	221.25

The discrepancy between the results is a function of the boundary conditions in the test fixture. The frequency of the second bending mode dropped from the unexplainably high frequency of 155 Hz to 121 Hz, which is consistent with the results from Set 1 as well as Set 3.

4.0 CONCLUDING REMARKS

DEI conducted a series of tests on NTF Blade Set 3 to insure that the blades met the design requirements necessary for operation in the NTF. The first set of tests included weight and center of gravity measurements of each blade. The initial c.g. measurements were taken for the blade alone. The final c.g. measurements were taken for the blade in the full-up assembly configuration with flight pin and fairings installed. Ballast weights were added to the blade web area to achieve the required Y-axis c.g. location. The second set of tests consisted of a modal survey of each blade to determine the blade dynamic characteristics. The blade natural frequencies, mode shapes and damping characteristics were identified from these tests.

The results of these tests indicate that the blades in Blade Set 3 meet the requirements for operation in the NTF. The blade characteristics are consistent within the entire blade set. There is little variation in weight and c.g. location from blade to blade. In addition, the average and range of weight and c.g. location for Blade Set 3 is very similar to those previously measured for Blade Sets 1 and 2. The dynamic characteristics identified from the modal survey tests meet the NTF dynamic requirements. These results are also consistent and repeatable within the blade set. The boundary conditions of the blade in the test fixture were found to have a significant affect on the blade modes. The variation of this boundary condition in testing the three blade sets was the primary cause of the differences in the frequencies and modes of the blade sets.

APPENDIX A

DETAILED PROCEDURES FOR NTF BLADE C.G. MEASUREMENT

A. Transit and Test Stand Alignment and Leveling

1. Place transit approximately 28 feet from the test stand, perpendicular to the test stand rotation axis.

2. Level transit stand.

3. Place a 1 inch drill rod across wheels and check the stand to see that it is parallel with the transit. Make adjustment using leveling screws on stand. "Bondo" can be used around leveling screws to stick it to the floor so the test stand will not move if it is bumped.

4. Place a second transit in line with the test stand rotation axis. Scribe crosshairs through center of rod end. With a small V-block (approx. 1.25" x 1.25") scribe a centerline through center of the V. Lightly spring clamp the rotating wheels on one end (to hold in position). Place rod on wheels, scribed end towards transit scope, and place V block on opposite end of rod. Align scope with crosshairs and plumb centerline of V block. Adjust position of transit to align scope with the rod axis.

   A scribed line aligned with the centerline axis and a benchmark on the wall can be used to recheck the transit alignment and test stand positioning.

5. Using established centerline swing scope down and position scale to 3" (the center of the 6" scale).

B. Preparation of Blade for Test Stand - Initial C.G. Measurement

The initial C.G. measurement is performed on the blade alone, i.e., without the fairings and the flight pin. The blade is supported in the test stand by the cross assembly.

1. Check for cleanliness and lubrication of all parts prior to assembly.

2. Check blade machined surfaces for resin coating problems.

3. Check balance wheels and clean with alcohol if necessary.

4. Lift the blade from the box using straps through the pin sleeves and position into the blade holding cart.

5. Attach the load cell to the overhead hoist and zero the readout with strap attached.

6. Lift the blade out of the holding cart with the strap and record blade weight.

7. Hang the cross shaft pin on the overhead crane using an eye bolt inserted into the lifting plate at the center of cross shaft. Lift the shaft to the same height as the blade pin sleeve.

8. Slide the cross shaft pin in position with the blade - dowel hole facing blade.

9. Place sleeves in both bores of the blade. Check for cleanliness.

10. Using the shop cart and wooden cylinder holder elevate the dummy blade pin to the proper height. Pin will be parallel with the floor. The short side of this pin must be on the leading edge side.

11. Insert the dummy pin gently into the blade bore using a strap wrench to rotate as the pin is pushed into the blade. Make sure pin is clean.

12. Push pin into the blade until 8.75 inches is left sticking out on the trailing edge end.

13. Alignment is correct when the alignment dowel can be inserted (rotate cylindrical pin until dowel can be inserted).

14. Check that the cross assembly is centered between the bores. Use shims to make adjustments.

C. Blade Positioning in Test Stand for Initial C.G. Measurement

At this point you must decide which axis you are preparing for: -z requires the addition of the balance boom; x-y doesn't.

X-axis and Y-axis C.G. measurement

1. Set blade in test stand.

    a. For Y-axis measurement the dummy blade pin (passing through pin sleeves in bores) sits on the rotating wheels.

    b. For X-axis measurement the cross shaft pin sits on the rotating wheels.

2. Disconnect crane and remove eye bolt and lifting plate and anything else not pertaining to the test itself.

3. The transit should be in position perpendicular to the test stand rotation axis.

4. Check that the center of the pin along the axis to be measured (dummy pin for

X-axis measurement and cross shaft pin for Y-axis measurement) and the benchmarks on the stand and the wall line up. The center of the pin can be targeted using the threaded pin center finders.

5. Insert the blade tip pointer and position tip approximately .01" above scale.

6. Move transit scope in line with test stand rotation axis and check alignment.

7. Read the pointer scale measurement from the scope and check it up close by eye. Record the scale reading. This measurement is used to determine the C.G. offset.

<u>Z-axis C.G. Measurement</u>

The Z-axis measurement requires the addition of the balance boom and the load cell.

1. Position transit perpendicular to test stand rotation axis and level it. Align scope with test stand and wall benchmarks.

2. Install the balance boom using the special bolts (2). The balance boom can be installed with the blade on the table (DEI preferred method) or after the blade is in the test stand.

3. Place the blade assembly with balance boom in the test stand positioned so that the cross shaft pin sits on the rotating wheels (X-axis set-up).

4. Align the center of the dummy pin with the scope, then rotate the blade 90° on the test stand and check that the tip pointer hole is close to the centerline of the scope.

5. Place a load cell (20 lb) on a stand positioned so that the load cell pointer lines up on the crosshair marked on the balance boom. The load cell will be approximately 47.67 inches from the test stand. The balance boom is positioned horizontally with the free end resting on the load cell when level.

6. Read the compressive loading on the load cell indicator box. If necessary, place tare weights on the boom directly above the load cell to obtain a compressive load of at least 5 lbs. Record the compression load and the tare weight.

D. Assembly of Flight Pin for Full-Up C.G. Measurement

The flight pin is the actual pin which is used to mount the blades to the hub in the tunnel. This pin is inserted through the blade bores using the pin insertion stand.

1. Lift the blade from the box using straps through the pin sleeves and position into the blade holding cart.

2. Insert cross shaft into blade repeating procedures B.7 -B.9.

3. Insert the hollow pin into the blade bore.

4. Position blade (leading edge first) in the "pin insertion" stand.

5. Strap cross shaft to stand.

6. Attach "bullet" to proper flight pin.

7. Lubricate pin with recommended substance as necessary.

8. Extend come along chain through blade mounting hole.

9. Pull the flight pin into the assembly.

10. Place the outboard nut and washer (-2) on the flight pin exposing approximately three threads.

11. Pull flight pin until installed nut/washer bottoms.

12. Place special lift device on top of cross shaft and install special bolts.

13. Attach assembly to overhead crane and release straps. Remove assembly.

14. Remove "bullet" from flight pin.

15. Install -1 nut and washer.

16. Check exposed portion of flight pin.

17. Set distance from end of pin to blade as follows -1 end = 1.195 in./-2 end = 2.445 in. Set one end first, then if the distance on the other end is greater or less than it should be, split the difference between the two ends.

18. Install fairings on blade.

19. Attach the load cell to the overhead hoist and zero the readout.

20. Lift the blade out of the holding cart and record the full-up blade assembly weight.

21. Assembly is ready to be installed in test stand.

E. Full-up C.G. Measurement and Balancing

Y-axis C.G. Measurement
The Y-axis C.G. measurement requires the use of the right angle wheel system to change the test stand rotation axis 90°. The offset at the tip pointer is measured off the Y-axis scale block.

1. Set the blade in the test stand positioned so that the cross shaft pin sits on the rotating wheels.

2. Lift cross shaft pin just high enough to slide the right angle wheel block underneath the pin. The flight pin should sit on the rotating wheels of the right angle wheel block.

3. Install fairings on blade.

4. Attach the target to the bare end of the flight pin.

5. Set the Y-axis scale block on the 2-axis slide table.

6. Using the transit, align the target, the scribed line on the right angle wheel block, the centerline of the scale block, and the benchmarks on the test stand.

7. Record Δy at tip pointer.

8. Add ballast weights to obtain $0.1" \leq \Delta y \leq 0.11"$.

   a. To determine the proper ballast, stack weights in the center of the web along the edge, along with the four 2½" long bolts, nuts and washers.
   b. Weigh and record ballast weight.
   c. The total ballast weight needed should be divided into groups of four and should be placed symmetrically around each leg of web.
   d. Install ballast weights on blades, with heaviest weight on the outside, next largest on the inside and the rest in the middle.
   e. Record new Δy.

X-axis and Z-axis C.G. Measurement
The ballast weights remain in place for the X-axis and Z-axis c.g. measurements.

1. Lift blade assembly and remove right angle wheel block.

2. Set up blade for X-axis measurement using the procedures described for the initial C.G. measurement.

3. Record Δx at tip pointer.

4. Install balance boom and set up blade for Z-axis measurement using the procedures described for the initial C.G. measurement.

5. Record load cell reading and tare weight.

APPENDIX B-1

NTF BLADE WEIGHT AND INITIAL C.G. MEASUREMENT PROCEDURE CHECKLIST AND DATA SHEET

BLADE NUMBER: _______ TEST DATE:___________

____ 1. Check cleanliness and lubrication of all blade assembly parts and balance wheels.

____ 2. Visually inspect blade.

3. Weigh the blade:

____ Check load cell & rebalance/calibrate as required

____ Blade removed from box with strap through pin sleeve

____ Place blade in holding cart

____ Attach load cell to overhead hoist and zero the readout with a strap and shackle attached

____ Lift blade out of box with the strap & record load cell reading

Blade Weight = __________ lbs

____ Install blade into holding cart. Remove the load cell.

4. Install cross assembly with dummy pin onto the blade:

____ Install sleeves into blade bores

____ Lift the cross shaft from the eyebolt in the center

____ Insert cross shaft into blade

____ Install dummy pin - short end on L.E. side of the blade

____ Insert dowel pin

____ Center cross assembly between bores with shims

5. Set blade in test stand for Y-axis C.G. measurement:

____ Dummy pin sitting on rotating wheels

____ L.E. on negative side of scale

____ Remove eyebolt & plate

____ 6. Check transit and blade alignment

____ 7. Insert blade tip pointer positioned .01" above scale

____ 8. Measure Y-axis offset at tip pointer and record

Δy = _____ in

____ 9. Lift and rotate blade 90° for X-axis C.G. measurement:
____ Install eyebolt lifting plate
____ Cross shaft sitting on rotating wheels
____ LE on negative side of scale
____ Remove eyebolt & plate

____ 10. Check transit and blade alignment

____ 11. Measure X-axis offset at tip pointer and record

Δx = _____ in

____ 12. Position transit perpendicular to test stand rotation axis. Level it and align it with test stand.

13. Hoist balance boom and attach to cross assembly.
____ Crosshair on balance boom facing down
____ Cross shaft pin sitting on rotating wheels
____ LE on negative side of scale

____ 14. Align center of dummy pin with scope. Rotate blade 90° and check that tip pointer hole is near scope centerline

15. Position load cell at crosshair on balance boom
____ Zero load cell reading
____ Check that balance boom is level

16. Obtain tare weight and load cell reading:
____ Add tare weights until load cell reading > 5 lbs
____ Record tare weight and load cell reading

Tare weight = ______ lbs **Load cell = ______ lbs**

Test performed by:______________________________
Test date:______________
Start time:_________ End time:_________

APPENDIX B-2

NTF BLADE FULL-UP C.G. MEASUREMENT PROCEDURE CHECKLIST AND DATA SHEET

BLADE NUMBER: _______ TEST DATE: ___________

____ 1. Check cleanliness and lubrication of all blade assembly parts and balance wheels.

____ 2. Visually inspect blade.

3. Weigh the blade:
- ____ Check load cell & rebalance/calibrate as required
- ____ Blade removed from box with strap through pin sleeve
- ____ Place blade in holding cart
- ____ Attach load cell to overhead hoist and zero the readout with a strap and shackle attached
- ____ Lift blade out of box with strap & record load cell reading

Blade weight = ___________ lbs
Install blade into holding cart. Remove load cell.

4. Install cross assembly with hollow pin into blade:
- ____ Install sleeves into blade bores
- ____ Insert cross shaft into blade
- ____ Insert hollow pin into blade bores

5. Install flight pin:
- ____ Blade in pin insertion stand LE first
- ____ Cross shaft strapped to stand
- ____ Bullet attached to flight pin
- ____ Flight pin lubricated
- ____ Flight pin pulled through and outboard nut/washer on
- ____ Bullet removed and other nut/washer installed

____ 6. Set distance from end of pin to blade
-1 end=1.195 in, -2 end=2.445 in

____ 7. Install fairings on blade

8. Weigh full-up blade assembly
- ____ Load cell zeroed out
- ____ Record load cell reading

Full-up Blade Assembly weight = __________ lbs

9. Set blade in test stand for Y-axis C.G. measurement
   - ___ Cross shaft pin sitting on rotating wheels
   - ___ LE on negative side of scale
   - ___ Right angle block positioned under cross assembly
   - ___ Eyebolt and plate removed

___ 10. Align transit, Y-axis scale block and center of flight pin

___ 11. Insert blade tip pointer positioned .01" above scale block

___ 12. Measure Y-axis offset at tip pointer and record

Δy = ____________ in

13. Add ballast weights until $0.10 \leq \Delta y \leq 0.11$
   - ___ (13. Add ballast weights until $0.10 \leq \Delta y \leq 0.11$)
   - ___ Bolts, nuts and washers included with weights
   - ___ Total weight divided into groups of four
   - ___ Ballast weights installed on each leg of web
   - ___ Heaviest weight on outside, next largest on inside and rest in middle

Ballast weight = ___________ lb

$\Delta y_{corrected}$ = ___________ in

14. Set up blade for X-axis C.G. measurement
   - ___ Right angle block removed
   - ___ Cross shaft sitting on wheels

___ 15. Check transit and blade alignment

___ 16. Measure X-axis offset at tip pointer and record

Δx = ___________ in

___ 17. Position balance boom above blade

18. Attach balance boom to cross assembly
   - ___ Crosshair on balance boom facing down

___ 19. Position transit perpendicular to test stand rotation axis. Level it and align it with test stand.

____ 20. Align scope with balance boom centerline. Check that tip pointer is near scope centerline.

21. Position load cell at crosshair on balance boom
____ Zero load cell reading
____ Check that balance boom is level

22. Obtain tare weight and load cell reading:
____ Add tare weights until load cell reading > 5 lbs
____ Record tare weight and load cell reading

Tare weight =_______ lbs **Load cell = __________ lbs**

Test performed by:________________________________
Test date:______________
Start time:______ End time:_________

APPENDIX C

NTF BLADE MODAL TESTING PROCEDURES

1. Mount the blade on the modal test fixture with the NTF flight pin.
   a. Apply 10 ft-lb torque to pin nuts.
   b. Center clamp block in blade web and torque clamp nut to 150 ft-lb.

2. Set up the shaker to apply a force to the blade at the tip leading edge corner. (approximately 4" aft of LE and 2" from tip on lower surface)
   a. Connect the shaker to the blade using a flexible stinger.
   b. Install the PCB load cell at the shaker/blade attachment point to monitor the input force.

3. Attach an accelerometer to the blade on the upper surface tip LE corner.

4. Apply a periodic random force (0-500 Hz bandwidth) to the blade with the shaker, using a signal generated from the analyzer.

5. Monitor the input force and acceleration response on the 2-channel analyzer.

6. Generate the frequency response function (FRF) (32-64 averages) from the force and acceleration records.

7. Identify the frequencies of the blade modes from the FRF peaks.

8. Plot the FRF magnitude and phase and store on a disk.

9. Identify the mode shapes.
   a. Map out a grid on the blade.
   b. Apply a sine excitation at each identified frequency.
   c. Using a roving accelerometer compare amplitude and phase at different locations on the blade with respect to a reference accelerometer.
   d. Locate the node lines.

10. Measure the damping of the first four modes.
    a. Apply a sine excitation to the blade to excite one mode at a time.
    b. Filter the free decay acceleration response within a bandwidth that includes the blade modes.
    c. Turn off the excitation and record the free decay response.
    d. Plot the free decay response and store on disk.
    e. Calculate the damping coefficient from the free decay response using the logarithmic decrement method.

11. Repeat procedures 1 through 9 for all the blades.

TABLE 1. NTF FAN BLADES INITIAL C.G. TEST DATA

TEST DATE	BLADE NUMBER	BLADE WEIGHT (LBS)	Y-AXIS	X-AXIS	Z-AXIS	
			ΔY (IN)	ΔX (IN)	TARE WEIGHT (LBS)	LOAD CELL (LBS)
8-20-91	56	227.20	-0.150	0.430	5.00	6.62
8-22-91	57	228.65	-0.135	0.355	5.00	6.26
8-12-91	58	227.95	-0.150	0.255	5.00	6.78
8-12-91	59	230.75	-0.166	0.365	5.00	6.55
8-9-91	60	230.80	-0.059	0.365	5.00	6.30
8-14-91	61	227.95	-0.155	0.320	5.00	6.10
8-12-91	62	228.15	-0.110	0.340	5.00	6.43
8-13-91	63	230.10	-0.105	0.355	5.00	5.31
8-13-91	64	230.15	-0.210	0.255	5.00	5.69
8-22-91	65	229.25	-0.125	0.320	5.00	6.10
8-14-91	67	228.20	-0.150	0.309	5.00	6.32
8-14-91	68	227.55	-0.190	0.360	5.00	6.65
8-16-91	69	229.70	-0.155	0.320	5.00	5.47
8-14-91	70	230.20	-0.125	0.395	5.00	5.35

TABLE 1. CONTINUED

TEST DATE	BLADE NUMBER	BLADE WEIGHT (LBS)	Y-AXIS	X-AXIS	Z-AXIS	
			ΔY (IN)	ΔX (IN)	TARE WEIGHT (LBS)	LOAD CELL (LBS)
8-14-91	71	228.75	-0.055	0.300	5.00	6.17
8-15-91	72	229.00	-0.190	0.315	5.00	6.08
8-21-91	73	230.45	-0.220	0.330	5.00	5.59
8-19-91	74	231.90	-0.205	0.330	5.00	5.62
8-21-91	75	229.65	-0.260	0.345	5.00	5.64
8-21-91	76	232.50	-0.250	0.320	5.00	5.63
8-19-91	77	227.90	-0.270	0.325	5.00	6.65
8-20-91	78	227.60	-0.120	0.395	5.00	6.69
8-22-91	79	228.65	-0.275	0.330	5.00	6.26
8-23-91	81	233.60	-0.120	0.360	5.00	5.42
8-23-91	82	234.05	-0.205	0.365	5.00	5.41
8-23-91	83	231.00	-0.250	0.307	5.00	6.48
8-21-91	84	228.55	-0.235	0.285	5.00	6.31

TABLE 2. NTF FAN BLADES INITIAL C.G. LOCATION

BLADE NUMBER	BLADE WEIGHT (lb)	Xcg (in)	Ycg (in)	Zcg (in)
56	227.20	-0.137	0.048	15.930
57	228.65	-0.113	0.043	15.904
58	227.95	-0.081	0.048	15.844
59	230.75	-0.115	0.052	15.700
60	230.80	-0.115	0.019	15.748
61	227.95	-0.102	0.050	15.987
62	228.15	-0.108	0.035	15.904
63	230.10	-0.114	0.034	16.001
64	230.15	-0.081	0.067	15.919
65	229.25	-0.102	0.040	15.896
67	228.20	-0.098	0.048	15.923
68	227.55	-0.115	0.060	15.900
69	229.70	-0.102	0.050	15.996
70	230.20	-0.126	0.040	15.986
71	228.75	-0.096	0.018	15.916
72	229.00	-0.100	0.061	15.918
73	230.45	-0.105	0.070	15.919
74	231.90	-0.104	0.065	15.813
75	229.65	-0.110	0.083	15.964
76	232.50	-0.101	0.079	15.700
77	227.90	-0.103	0.086	15.875
78	227.60	-0.126	0.038	15.888
79	228.65	-0.105	0.088	15.904
81	233.60	-0.113	0.038	15.739
82	234.05	-0.115	0.064	15.711
83	231.00	-0.096	0.079	15.697
84	228.55	-0.091	0.075	15.901
AVG	**229.64**	**-.105**	**0.054**	**15.874**

TABLE 3. SUMMARY OF INITIAL C.G. TEST RESULTS FOR NTF BLADE SETS 1, 2, AND 3

BLADE SET	BLADE WEIGHT (lb)	Xcg (in)	Ycg (in)	Zcg (in)
1	227.70 +2.9 -2.1	-.138 +.051 -.062	.008 -.033 +.032	16.278 +.146 -.092
2	228.67 +5.75 -4.67	.139 +.059 -.05	.048 +.051 -.034	15.955 +.242 -.314
3	229.64 +4.41 -2.44	-.105 +.024 -.032	.054 +.034 -.036	15.874 +.127 -.177

NOTE: Sign convention of Xcg for blade set 2 was incorrect.

TABLE 4. NTF FAN BLADES FULL–UP C.G. TEST DATA

TEST DATE	BLADE NO.	BLADE WGT W/BALLAST (LBS)	ΔY WITHOUT BALLAST (IN)	ΔY WITH BALLAST (IN)	BALLAST WEIGHT (LBS)	ΔX WITH BALLAST (IN)	TARE WEIGHT (LBS)	LOAD CELL (LBS)
8-28-91	56	230.40	-.255	.110		-.480	5.0	4.31
8-29-91	57	231.15	-.225	.107	2.921	-.570	5.0	4.21
8-29-91	58	230.85	-.275	.100	3.235	-.590	5.0	4.57
8-30-91	59	231.60	-.315	.108	3.677	-.515	5.0	4.27
8-30-91	60	231.00	-.225	.110	2.879	-.485	5.0	4.19
9-5-91	61	231.10	-.275	.103	3.307	-.502	5.0	3.92
9-5-91	62	230.75	-.250	.110	2.956	-.535	5.0	4.34
9-4-91	63	232.90	-.230	.110	3.091	-.535	5.0	3.17
9-4-91	64	233.60	-.315	.102	3.66	-.625	5.0	3.37
9-4-91	65	231.70	-.235	.102	2.862	-.572	5.0	4.08
9-6-91	67	231.65	-.275	.110	3.633	-.560	5.0	3.97
9-10-91	68	230.85	-.305	.100	3.488	-.525	5.0	4.35
9-5-91	69	233.05	-.290	.100	3.342	-.575	5.0	3.23
9-10-91	70	233.25	-.265	.105	3.203	-.485	5.0	3.21
9-11-91	71	231.05	-.185	.107	2.546	-.565	5.0	4.30
9-16-91	72	232.66	-.310	.107	3.712	-.550	5.0	3.82
9-12-91	73	234.40	-.335	.107	3.956	-.585	5.0	3.21
9-17-91	74	234.20	-.330	.105	3.984	-.550	5.0	3.25
9-16-91	75	233.90	-.395	.110	4.464	-.575	5.0	3.12
9-18-91	76	234.35	-.360	.105	4.127	-.560	5.0	3.15

TABLE 4. CONTINUED

TEST DATE	BLADE NO.	BLADE WGT W/BALLAST (LBS)	ΔY WITHOUT BALLAST (IN)	ΔY WITH BALLAST (IN)	BALLAST WEIGHT (LBS)	ΔX WITH BALLAST (IN)	TARE WEIGHT (LBS)	LOAD CELL (LBS)
9-12-91	77	231.90	-.385	.102	4.023	-.575	5.0	4.25
9-13-91	78	230.40	-.220	.110	2.897	-.490	5.0	4.78
9-13-91	79	232.85	-.415	.110	4.572	-.570	5.0	3.70
9-17-91	81	233.95	-.255	.103	3.203	-.527	5.0	3.31
9-17-91	82	235.00	-.315	.102	3.657	-.535	5.0	3.11
9-19-91	83	232.35	-.380	.105	4.239	-.595	5.0	4.10
9-19-91	84	232.00	-.330	.110	3.866	-.635	5.0	3.89

TABLE 5. NTF FAN BLADES FULL–UP C.G. LOCATIONS

BLADE NUMBER	BLADE WEIGHT W/BALLAST (lb)	Xcg (in)	Ycg (in)	Zcg (in)
56	230.40	0.145	-0.033	15.113
57	231.15	0.172	-0.032	15.087
58	230.85	0.178	-0.030	15.036
59	231.60	0.155	-0.033	15.047
60	231.00	0.147	-0.033	15.099
61	231.10	0.152	-0.031	15.145
62	230.75	0.162	-0.033	15.086
63	232.90	0.162	-0.033	15.179
64	233.60	0.189	-0.031	15.098
65	231.70	0.173	-0.031	15.078
67	231.65	0.169	-0.033	15.102
68	230.85	0.158	-0.030	15.078
69	233.05	0.174	-0.030	15.159
70	233.25	0.147	-0.032	15.151
71	231.05	0.170	-0.032	15.075
72	232.60	0.166	-0.032	15.073
73	234.40	0.177	-0.032	15.081
74	234.20	0.166	-0.032	15.085
75	233.90	0.174	-0.033	15.128
76	234.35	0.169	-0.032	15.096
77	231.90	0.173	-0.031	15.033
78	230.40	0.147	-0.033	15.022
79	232.85	0.172	-0.033	15.081
81	233.95	0.159	-0.031	15.089
82	235.00	0.161	-0.031	15.064
83	232.35	0.179	-0.032	15.035
84	232.00	0.192	-0.033	15.096

TABLE 6. SUMMARY OF FINAL C.G. TEST RESULTS FOR NTF FAN BLADE SETS 1, 2, AND 3

BLADE SET	BLADE WEIGHT W/ BALLAST (lb)	Xcg (in)	Ycg (in)	Zcg (in)
1	234.61 +2.74 -2.31	.159 +.053 -.038	-.028 +.016 -.005	15.120 +.087 -.079
2	231.55 +6.06 -3.12	.163 +.059 -.033	-.032 +.002 -.002	15.105 +.187 -.171
3	232.32 +2.68 -1.92	.166 +.026 -.021	-.032 +.001 -.002	15.089 +.09 -.067

TABLE 7. NTF FAN BLADE MODAL SURVEY RESULTS BLADE FREQUENCIES

BLADE NUMBER	FIRST BENDING	SECOND BENDING	FIRST TORSION	BENDING/ TORSION	THIRD BENDING
56	61.25	121.25	215.00	273.75	405.00
57	61.25	123.75	218.75	275.00	382.50
58	62.50	121.25	218.75	270.00	376.25
59	62.50	118.75	218.75	268.75	376.25
60	62.50	121.50	221.25	280.00	378.50
61	63.75	121.25	221.25	275.00	385.00
62	62.50	118.75	213.75	272.50	413.75
63	61.25	123.75	218.75	277.50	391.25
64	61.25	121.25	215.00	275.00	408.75
65	61.25	121.25	217.50	273.75	386.25
67	62.50	118.75	217.50	272.50	411.25
68	61.25	118.75	208.75	272.50	376.25
69	61.25	118.75	213.75	275.00	383.75
70	58.75	121.25	215.00	275.00	396.25
71	62.50	121.25	218.75	277.50	412.50
72	58.75	121.25	213.75	278.75	410.00
73	62.50	121.25	217.50	270.00	381.25
74	60.00	121.25	213.75	278.75	402.50
75	61.25	120.00	217.50	275.00	377.50
76	58.75	118.75	206.25	271.25	401.25
77	62.50	121.25	220.00	268.75	382.50
78	58.75	120.00	207.50	266.25	396.25
79	58.75	120.00	213.75	267.50	408.75
81	61.25	121.25	216.25	267.50	386.25
82	61.25	122.50	218.75	273.75	386.25
83	65.00	120.00	226.25	271.25	386.25
84	65.00	120.00	227.50	273.75	391.25

TABLE 8. NTF FAN BLADE MODAL SURVEY RESULTS DAMPING COEFFICIENTS

BLADE NUMBER	FIRST BENDING	SECOND BENDING	FIRST TORSION
56	.059	.072	.034
57	.055	.065	.033
58	.063	.066	.039
59	.056	.069	.036
60	.051	.072	.036
61	.061	.059	.038
62	.053	.044	.038
63	.056	.059	.038
64	.053	.055	.040
65	.054	.052	.035
67	.057	.063	.039
68	.050	.067	.041
69	.052	.079	.042
70	.049	.063	.043
71	.059	.071	.030
72	.049	.061	.029
73	.060	.076	.045
74	.053	.050	.036
75	.050	.060	.034
76	.049	.050	.039
77	.055	.063	.044
78	.050	.057	.039
79	.053	.074	.045
81	.049	.056	.035
82	.064	.058	.035
83	.066	.058	.034
84	.059	.056	.039

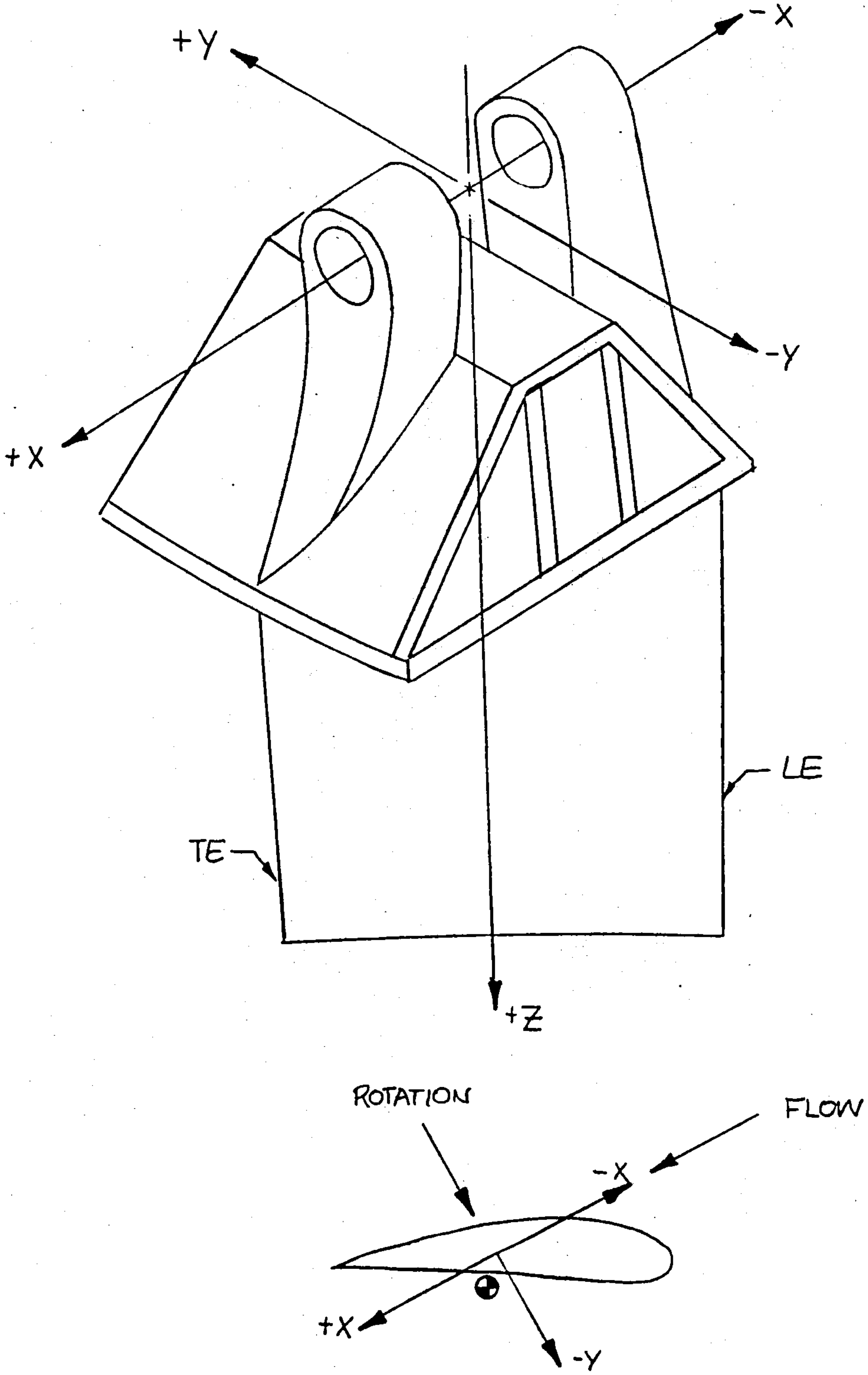


Figure 1. NTF Fan Blade Axis System.

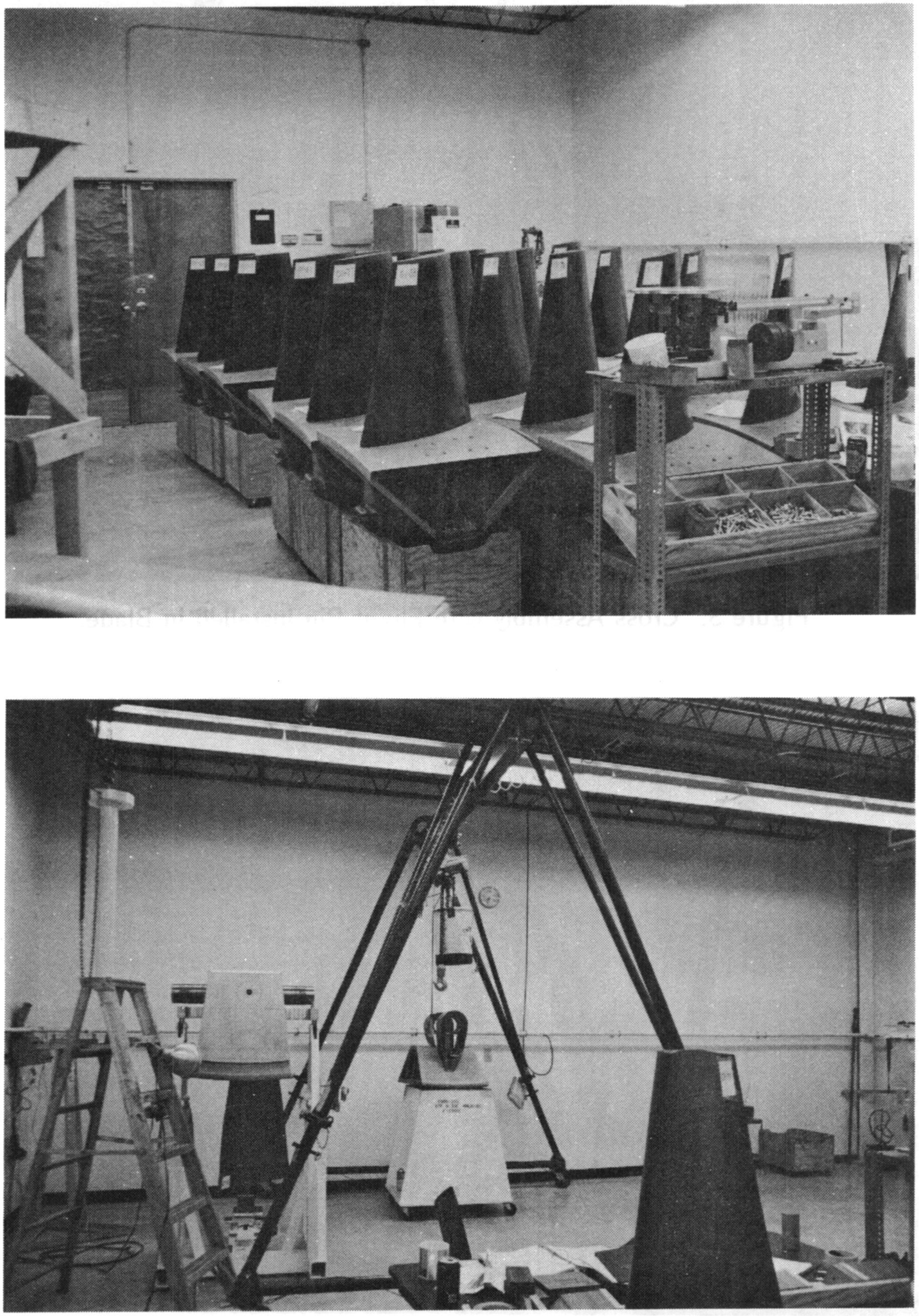


Figure 2. Photographs of the Test Setup.

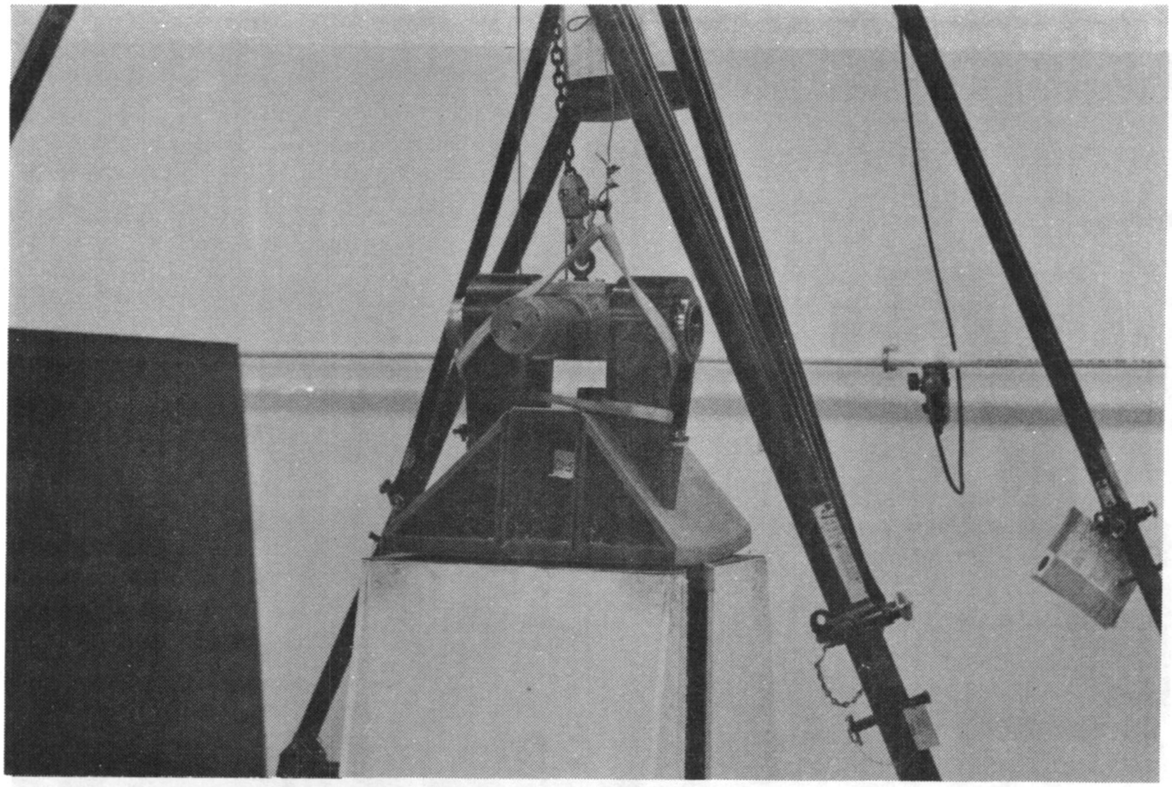


Figure 3. Cross Assembly with Flight Pin Installed in Blade.

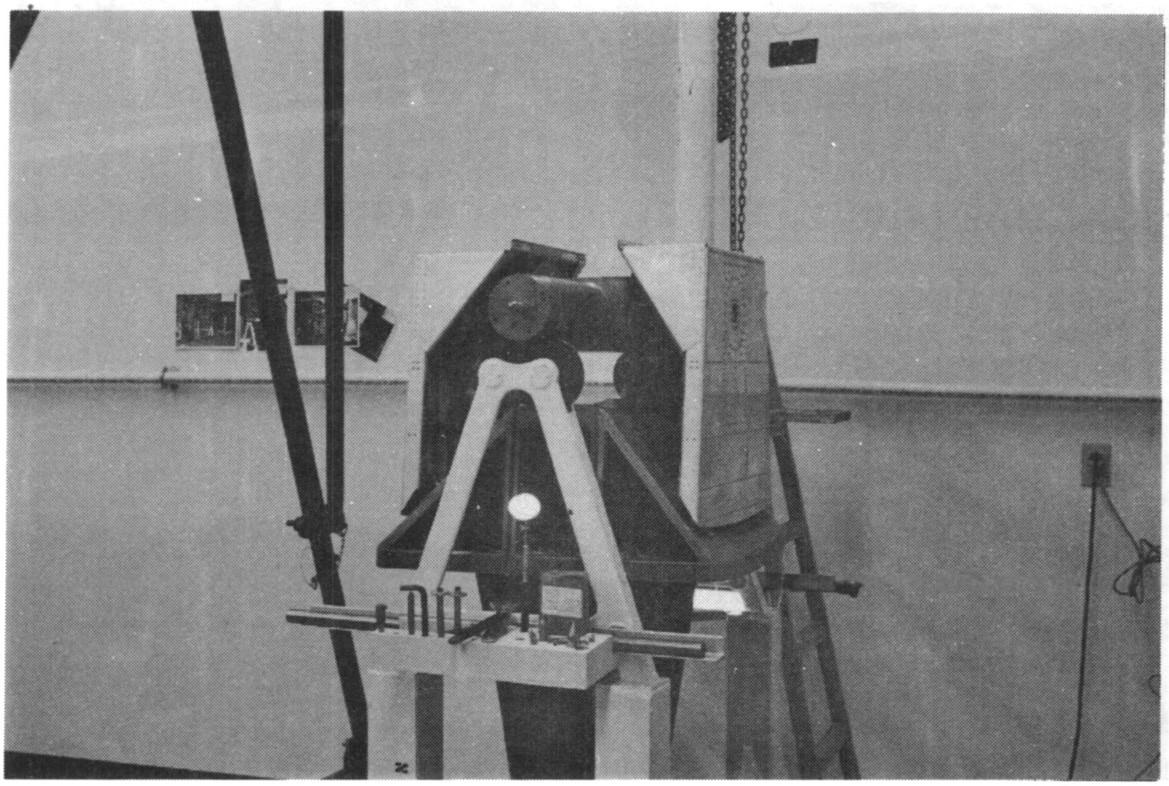


Figure 4. Blade Position for Full–Up X–Axis C.G. Measurement.

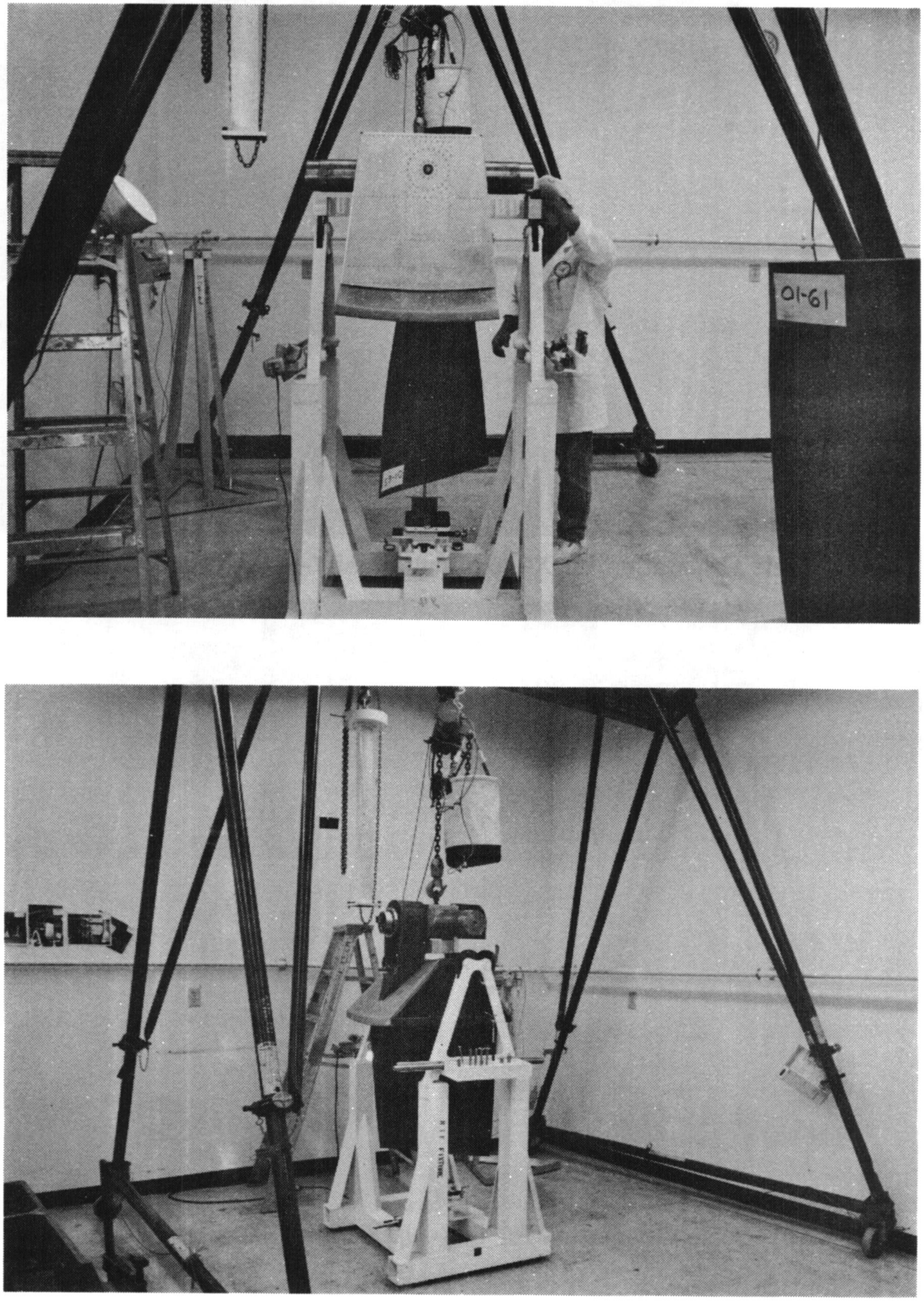
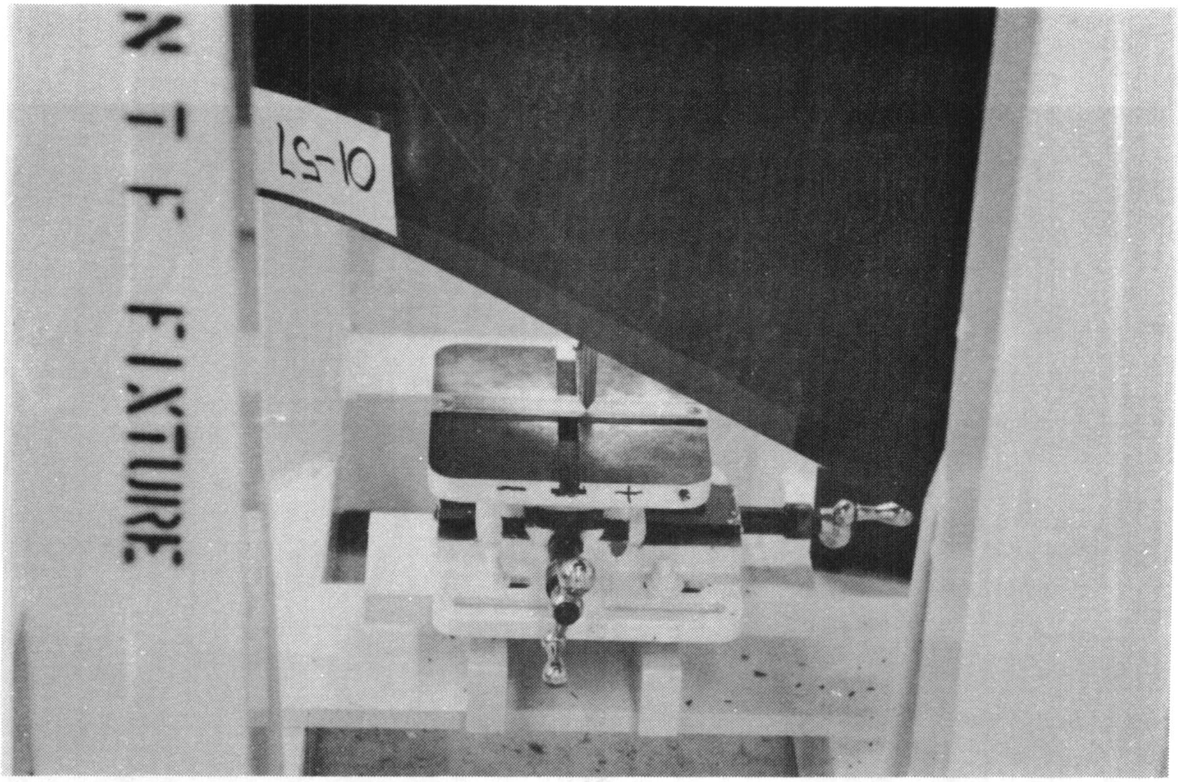
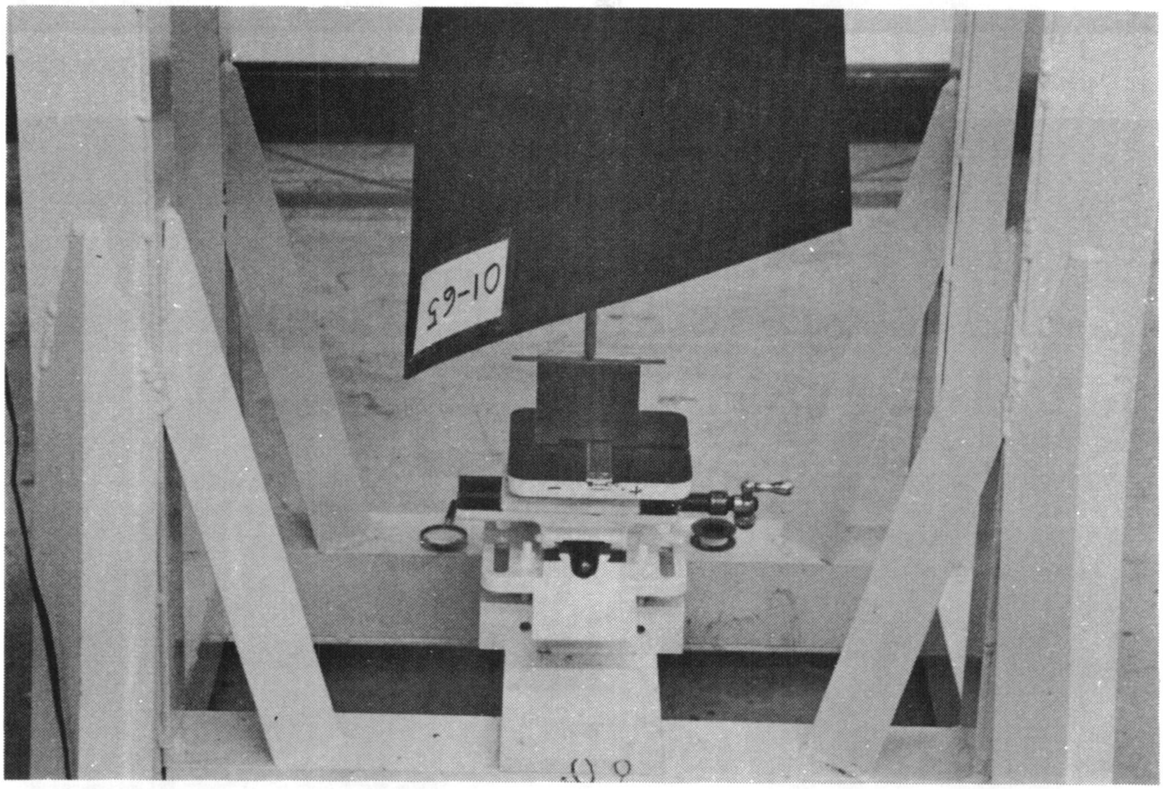


Figure 5. Blade Position for Full–Up Y–Axis C.G. Measurement.



a) Scale Orientation for X–Axis and Initial Y–Axis Measurement.



b) Scale Orientation for Full–Up Y–Axis Measurement.

Figure 6. Scale Orientation for Blade Tip Offset Measurement.

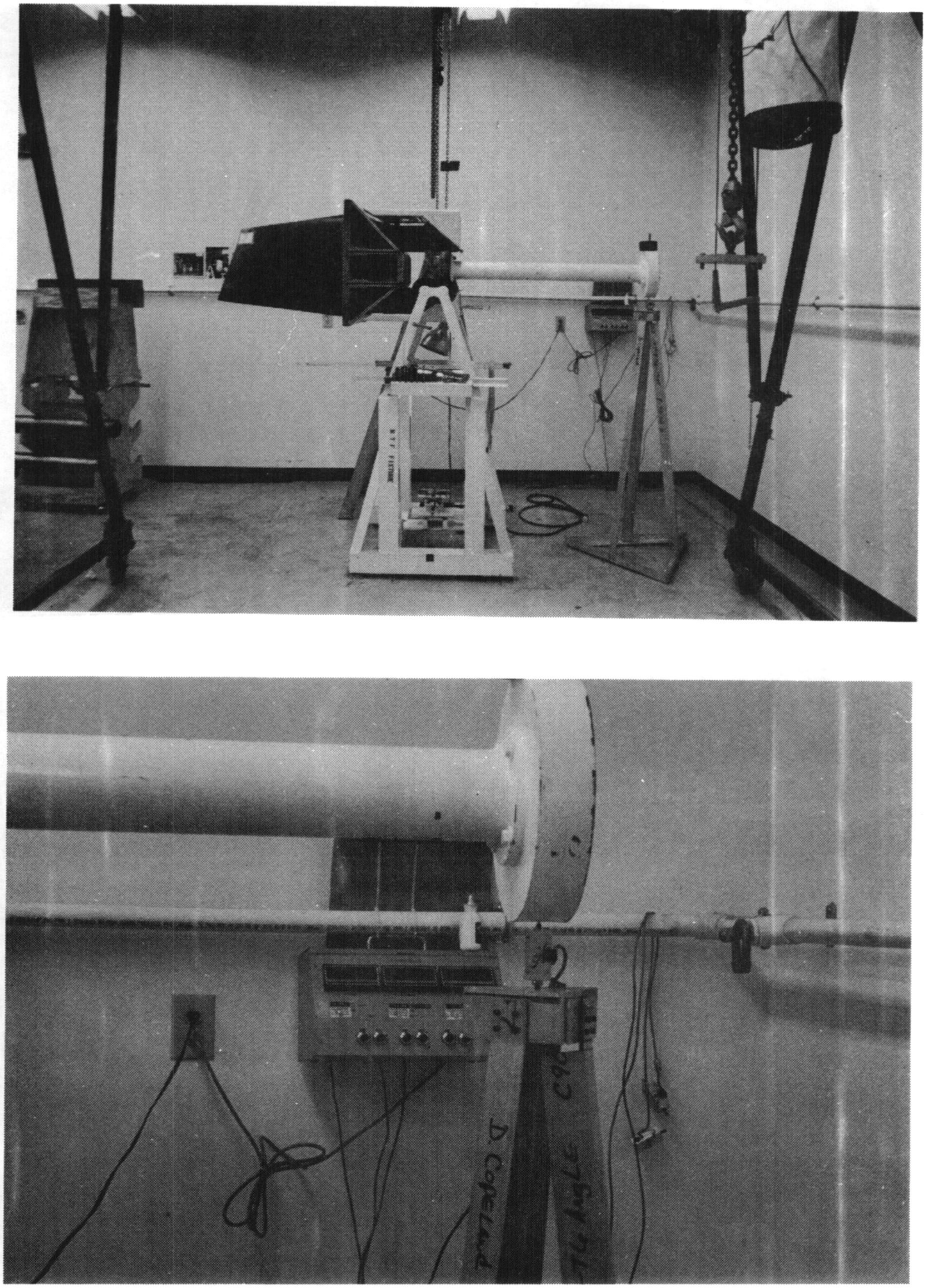


Figure 7. Photographs of Test Setup for Z–Axis Measurement.

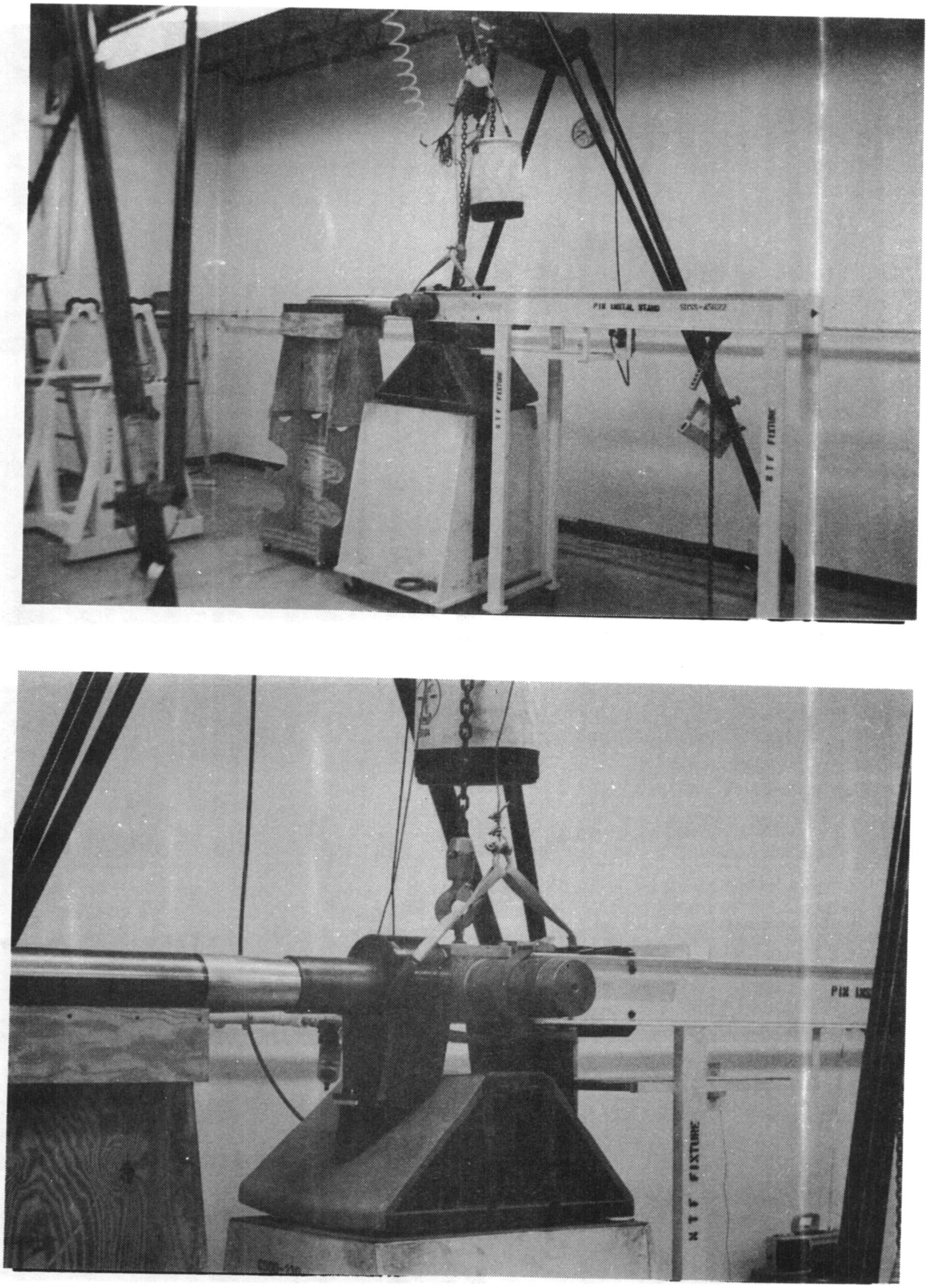


Figure 8. Photographs of Flight Pin Installation.

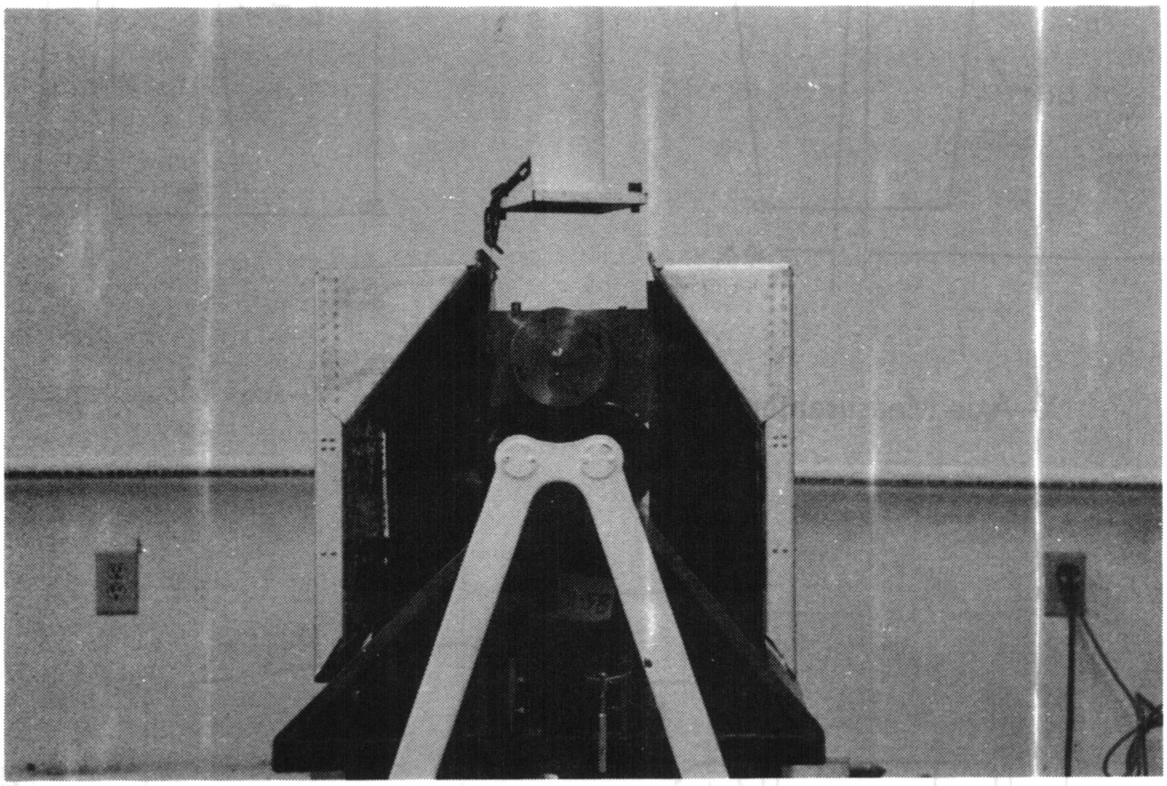
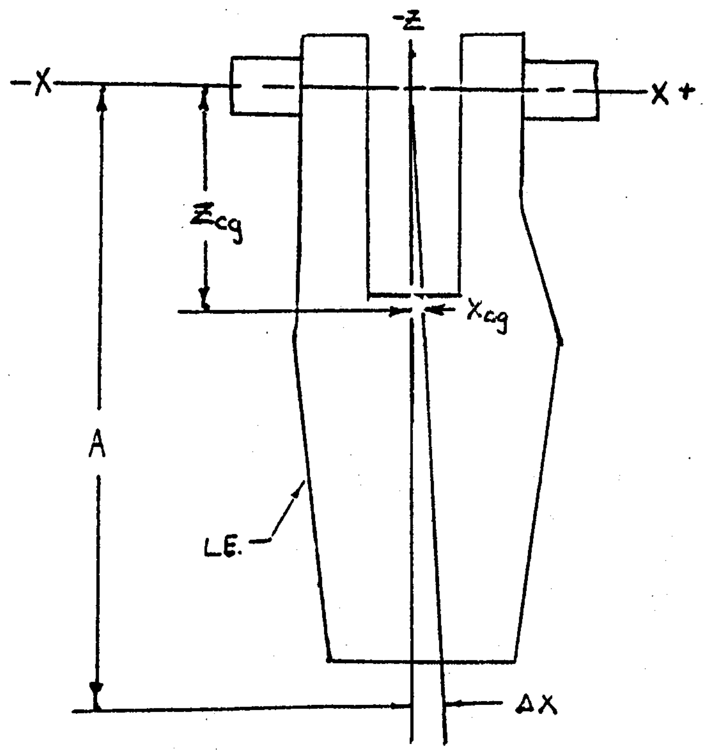
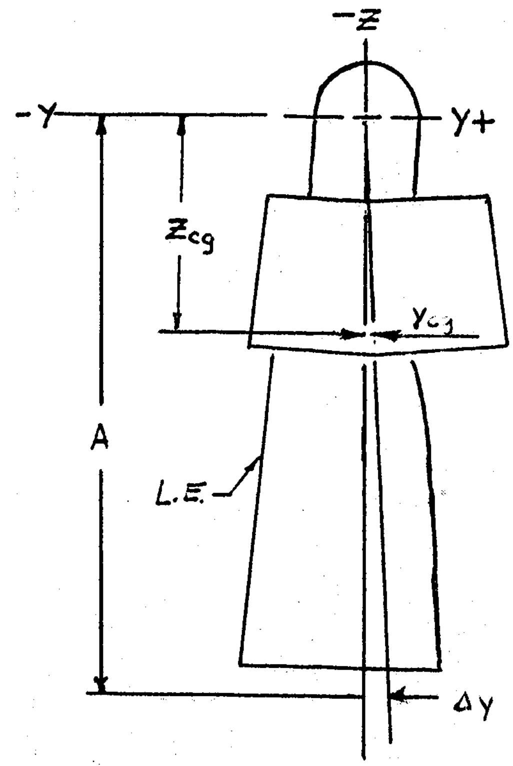


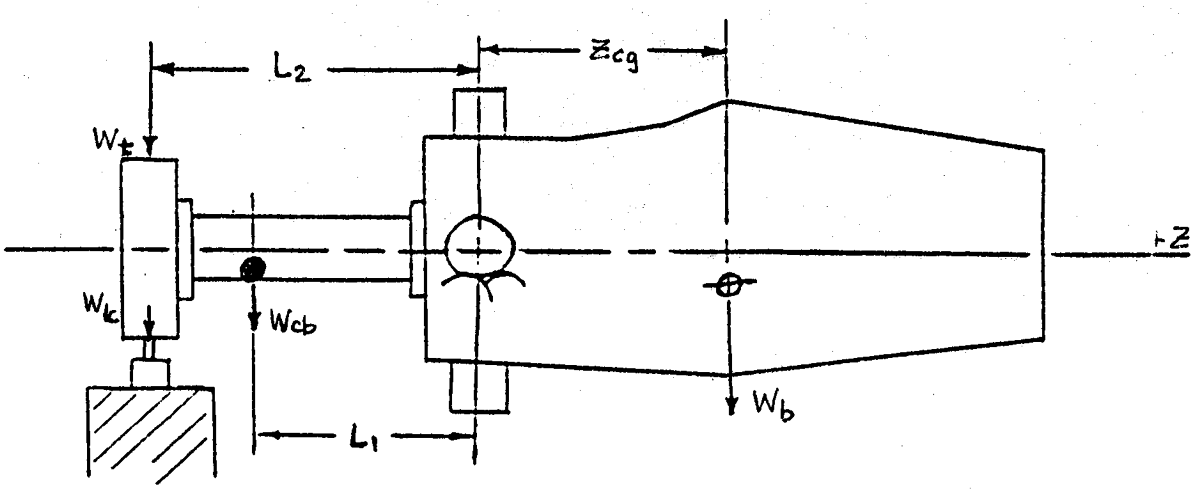
Figure 9. Ballast Weights Installed in Blade Web Area.



X–Axis Measurement

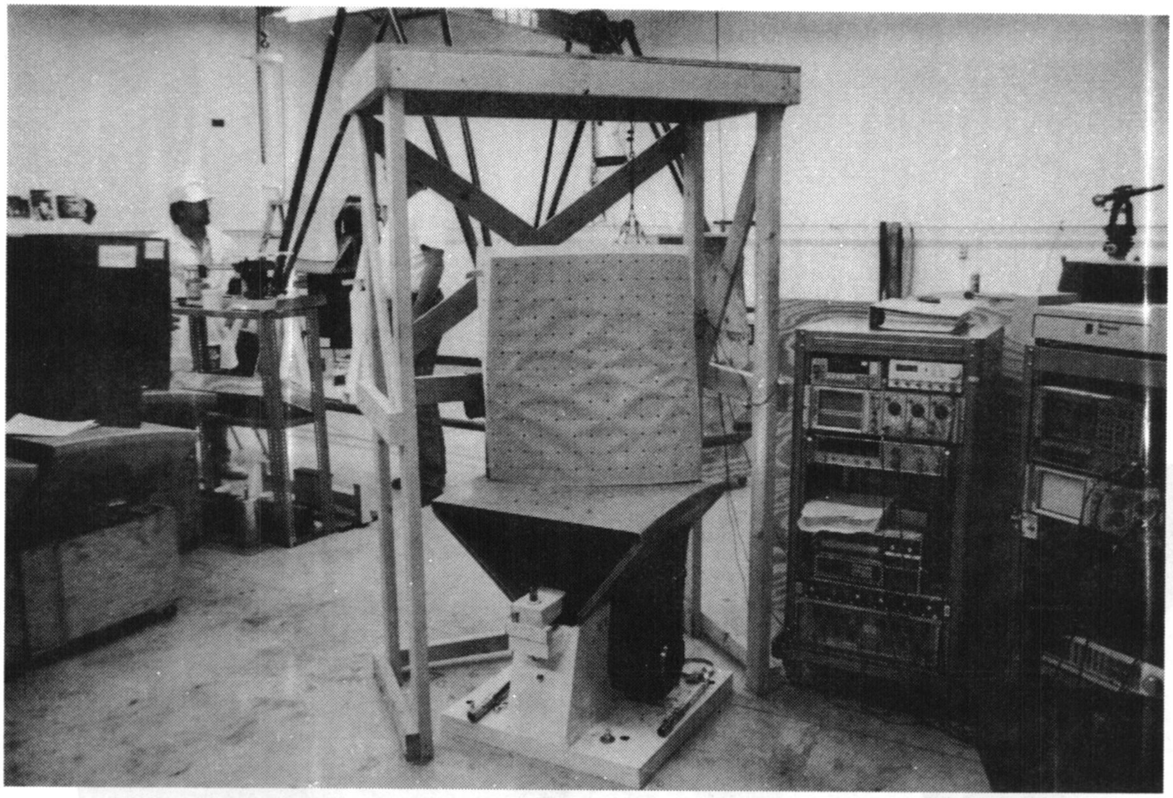


Y–Axis Measurement



Z–Axis Measurement

Figure 10. Definition of Variables and Fixed Parameters for C.G. Calculations.



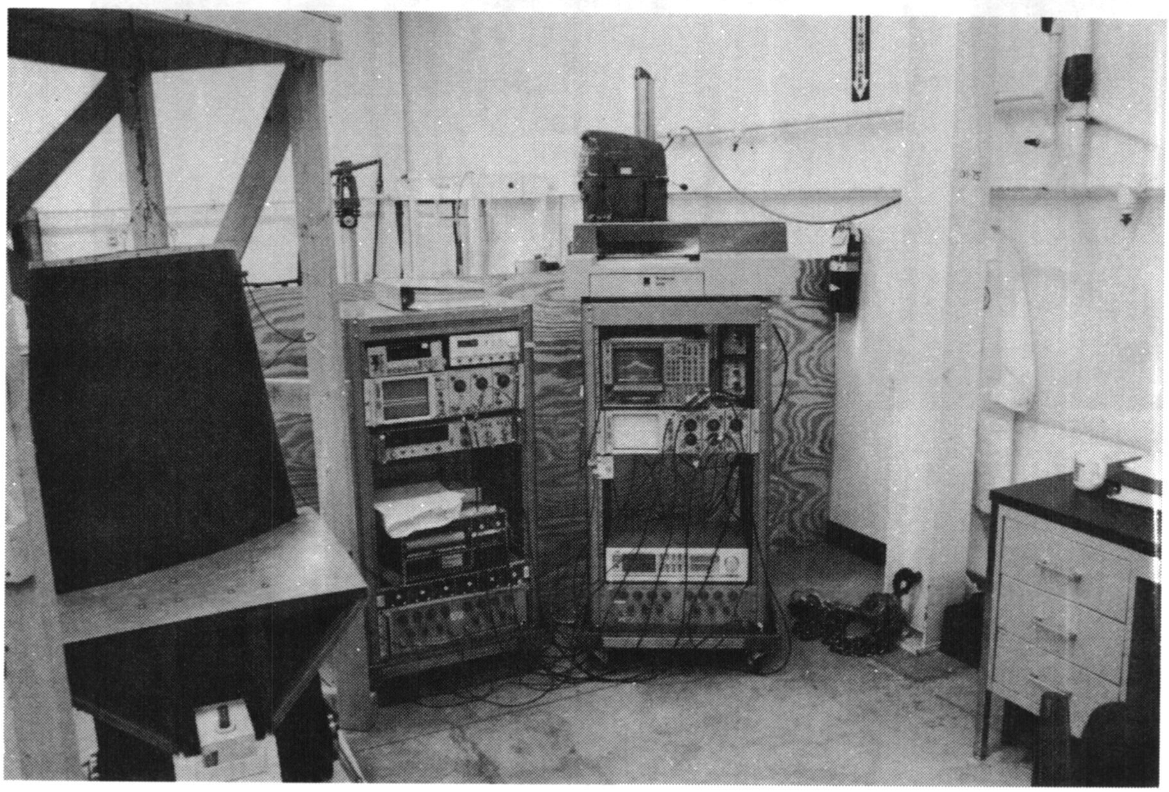


Figure 11. Photographs of Test Setup for Modal Survey.

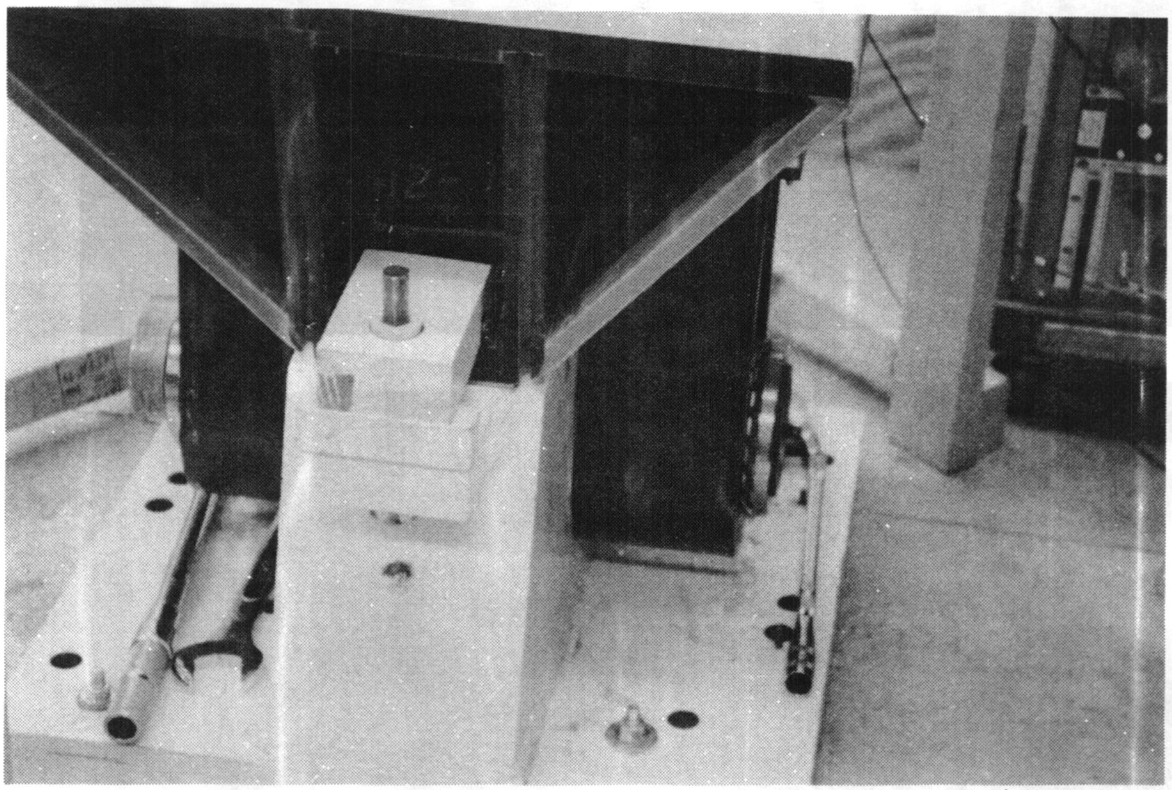
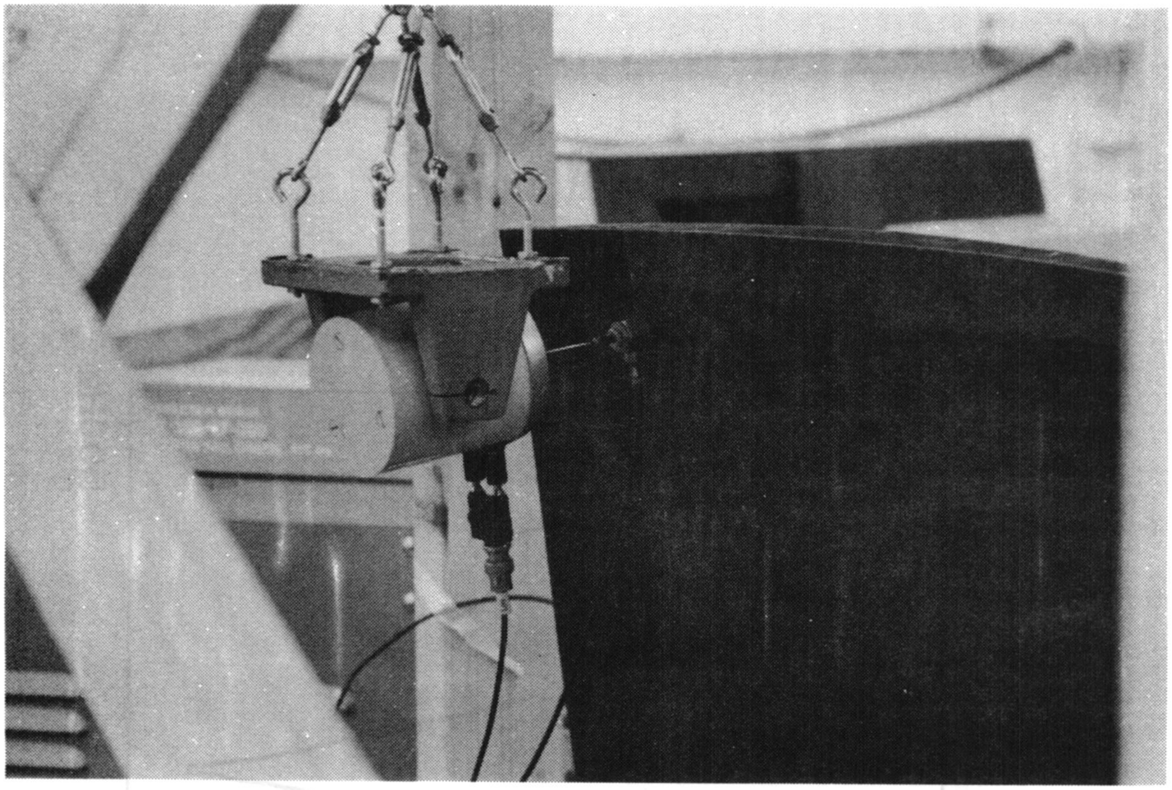
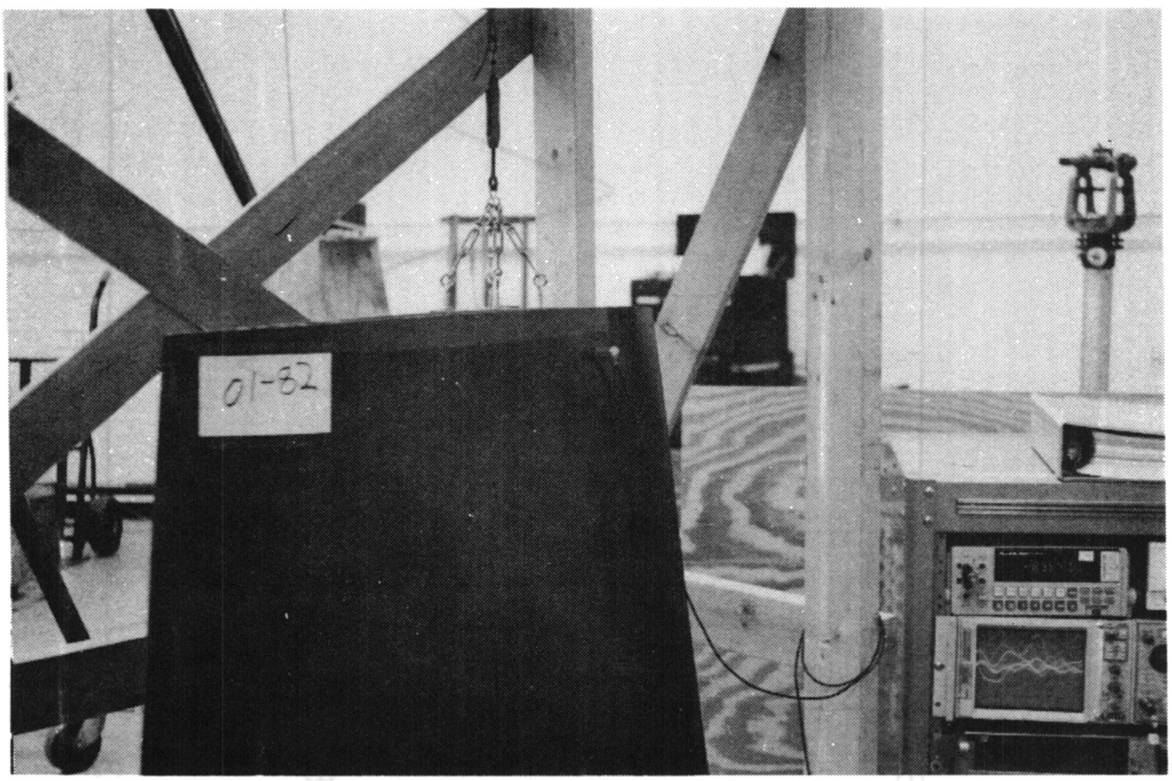


Figure 12. Blade Mounted in Modal Test Fixture.



a) Shaker Position and Load Cell Attachment to Blade.



b) Accelerometer Mounted on Blade.

Figure 13. Shaker, Load Cell, and Accelerometer Positioning.

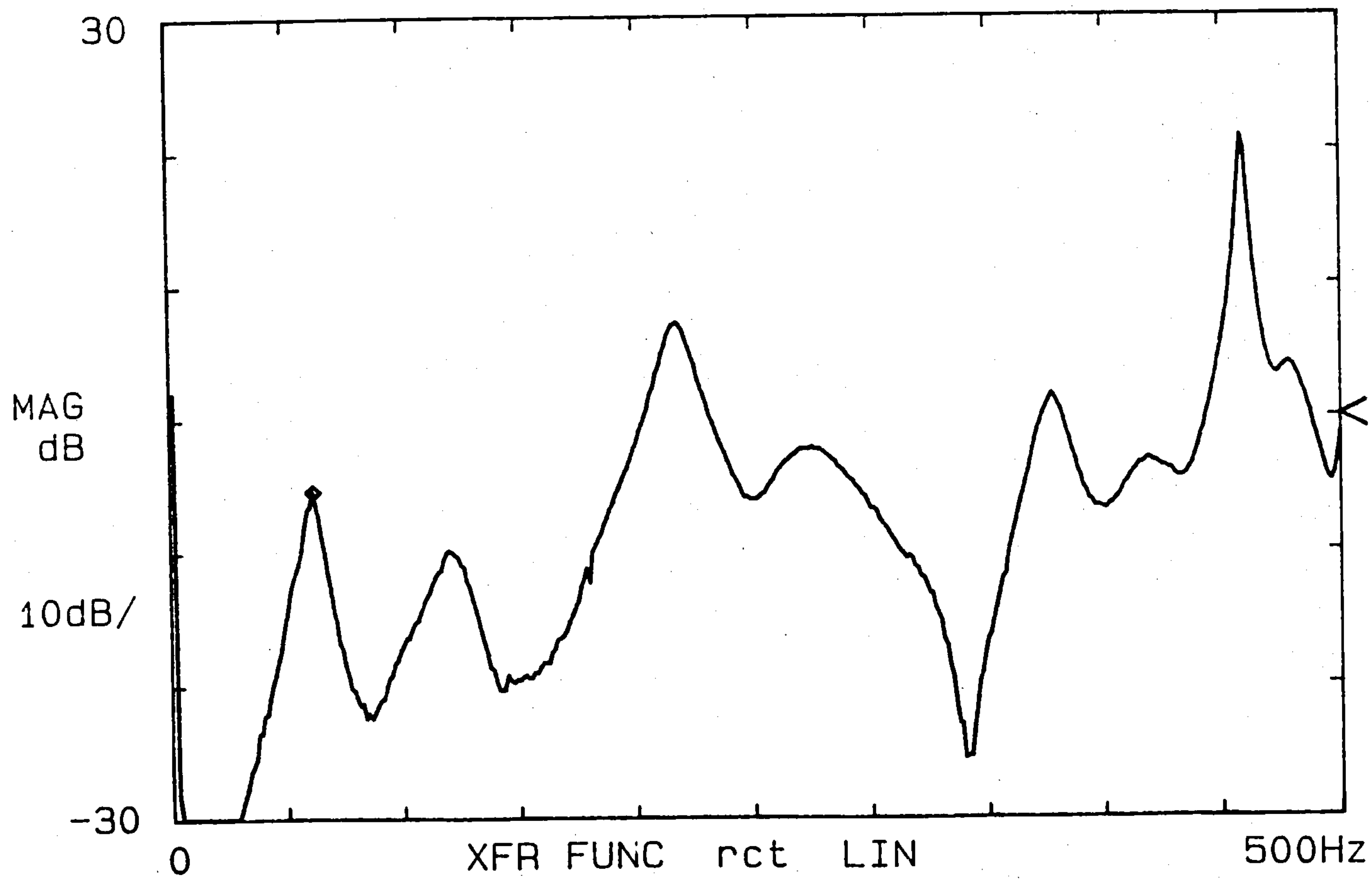


Figure 14. Sample Frequency Response Function Plot for NTF Blade.

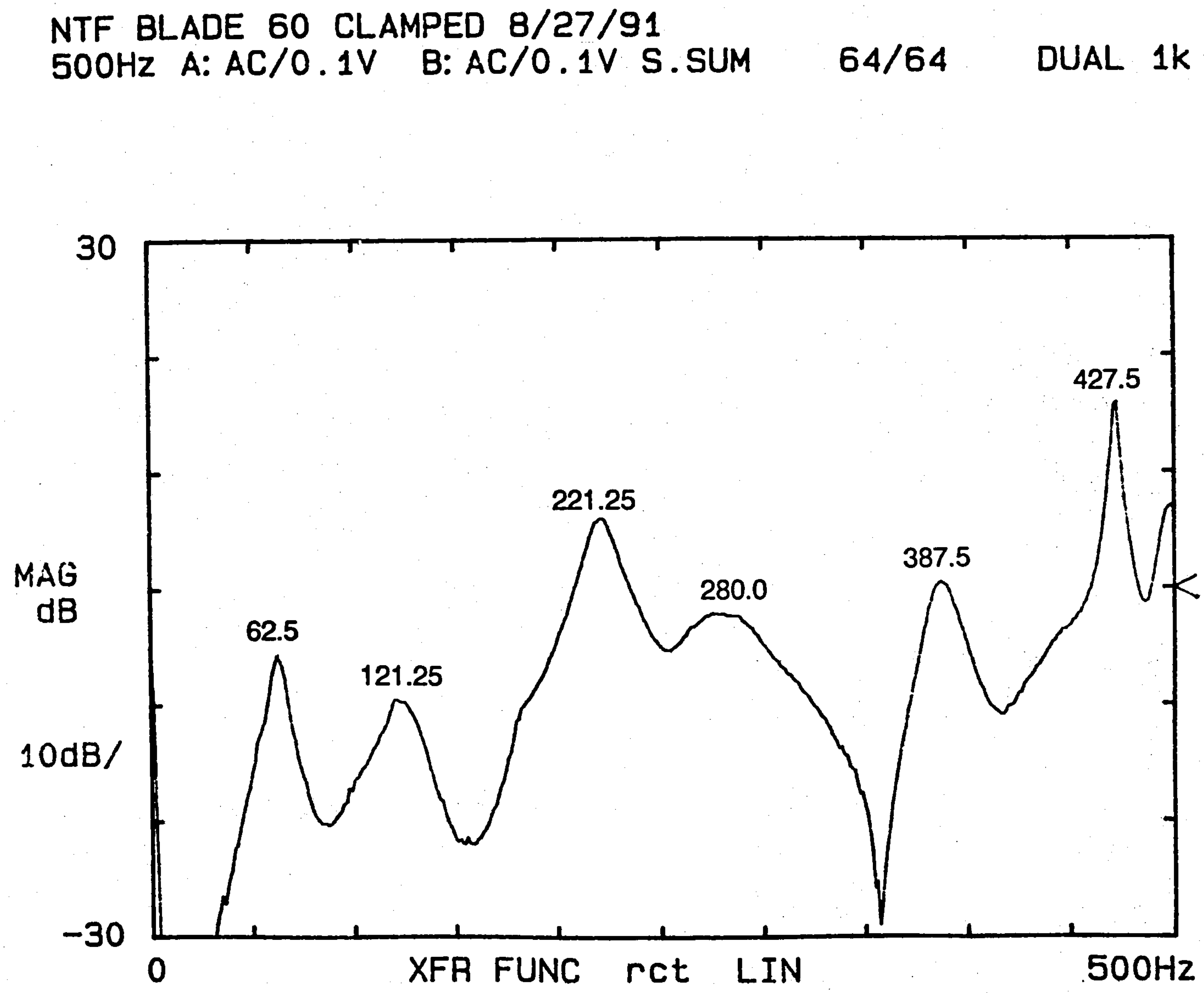


Figure 15. FRF Magnitude Plot for Blade No. 60.

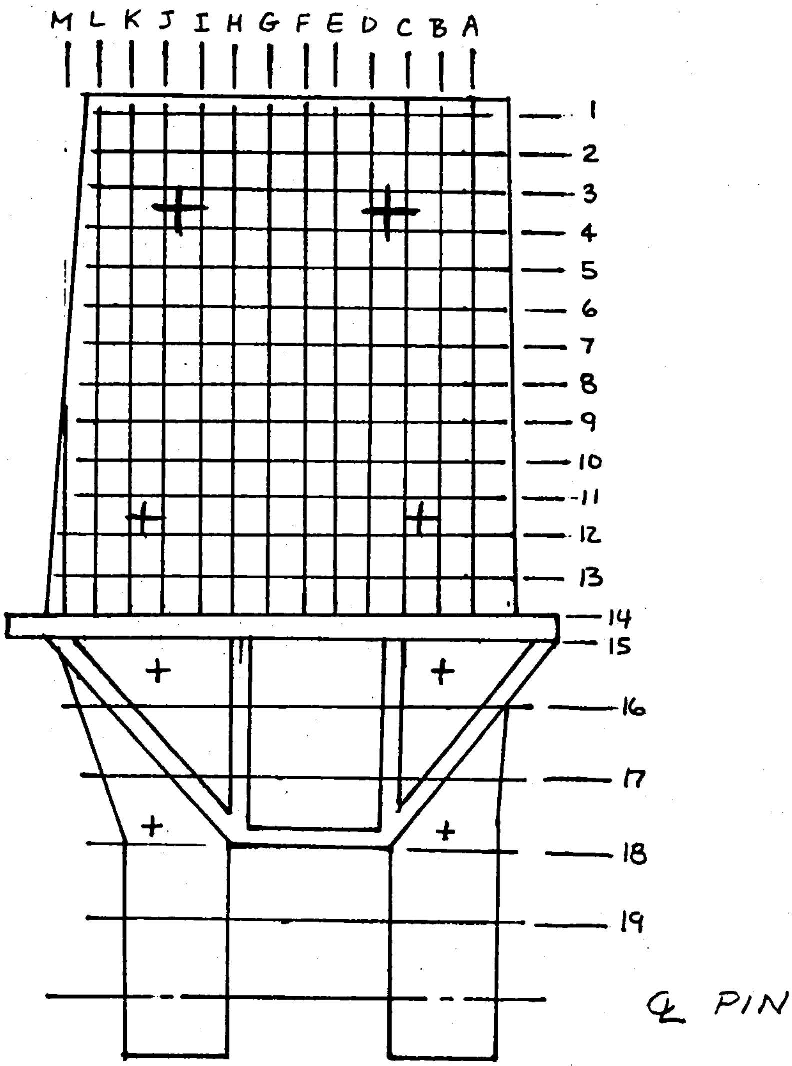


Figure 16. First Bending Mode, 62.5 Hz, Blade No. 60.

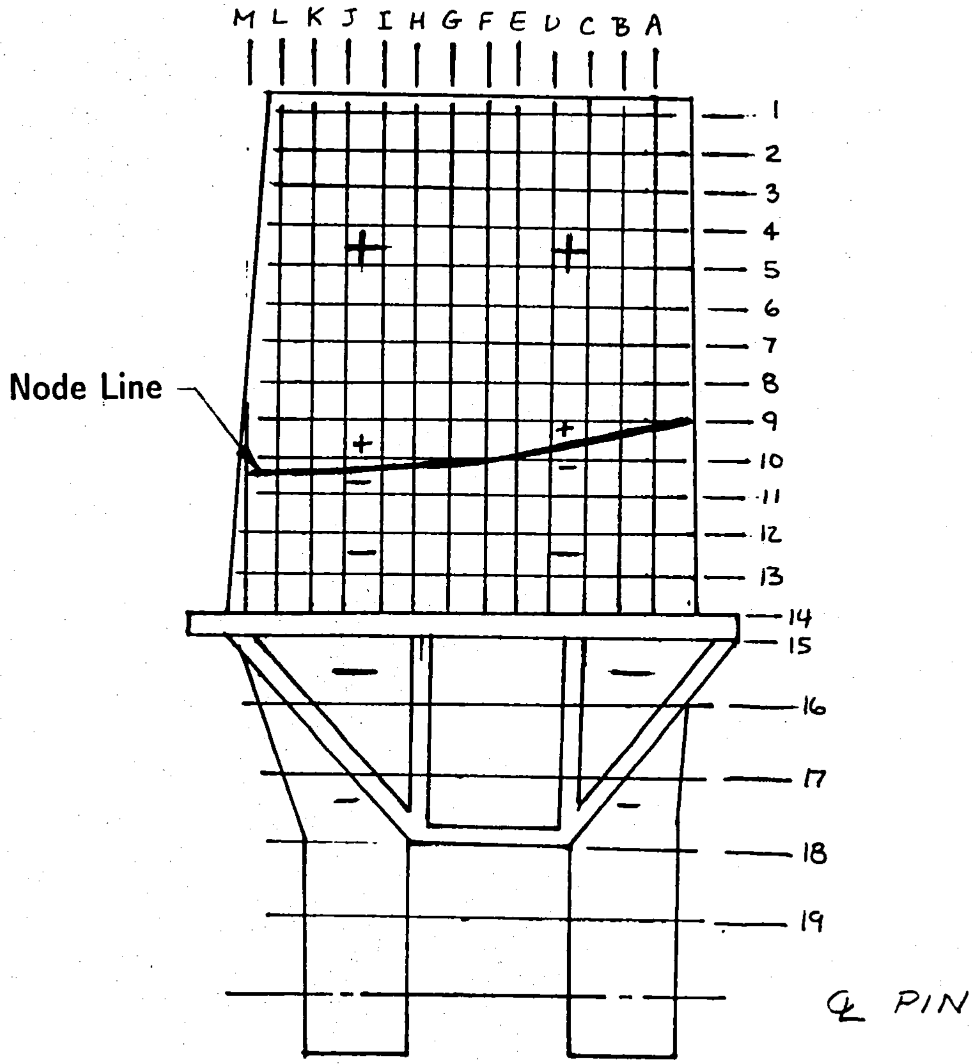


Figure 17. Second Bending Mode, 121.25 Hz, Blade No. 60.

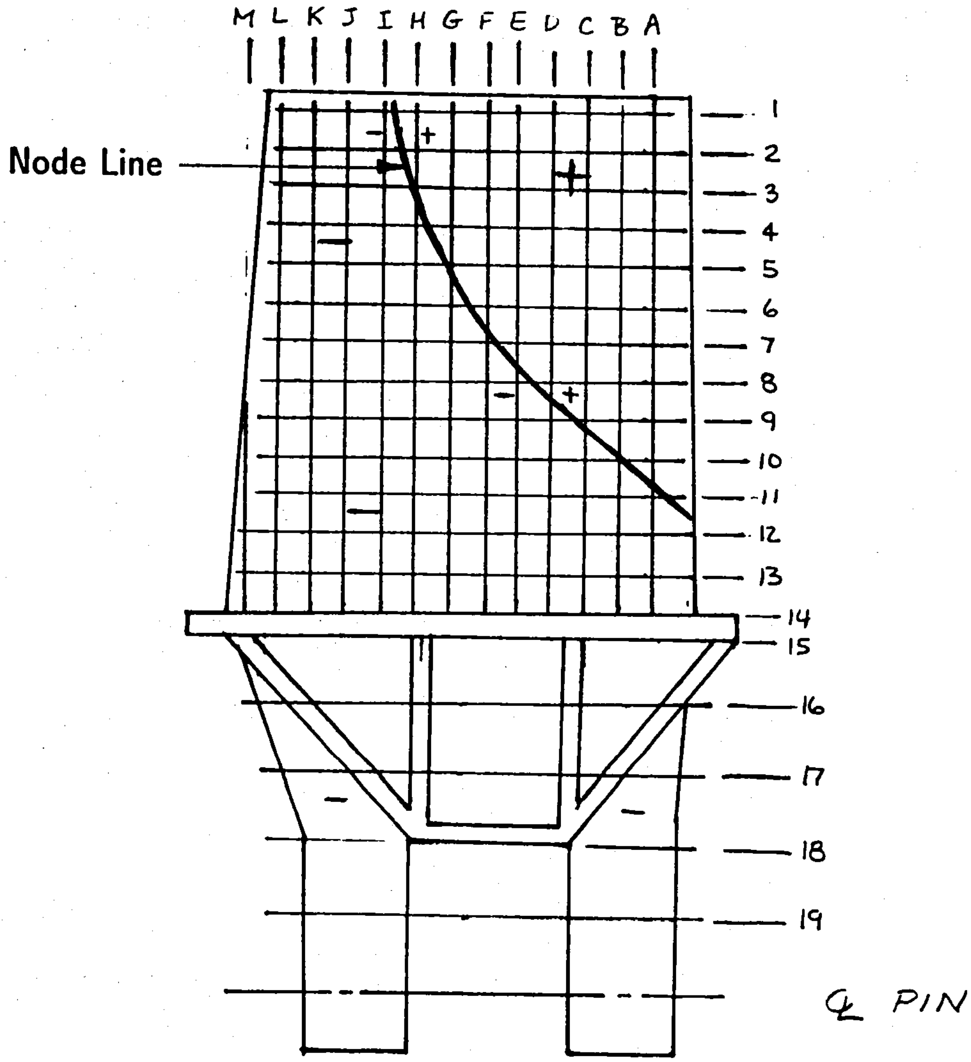


Figure 18. First Torsion Mode, 221.25 Hz, Blade No. 60.

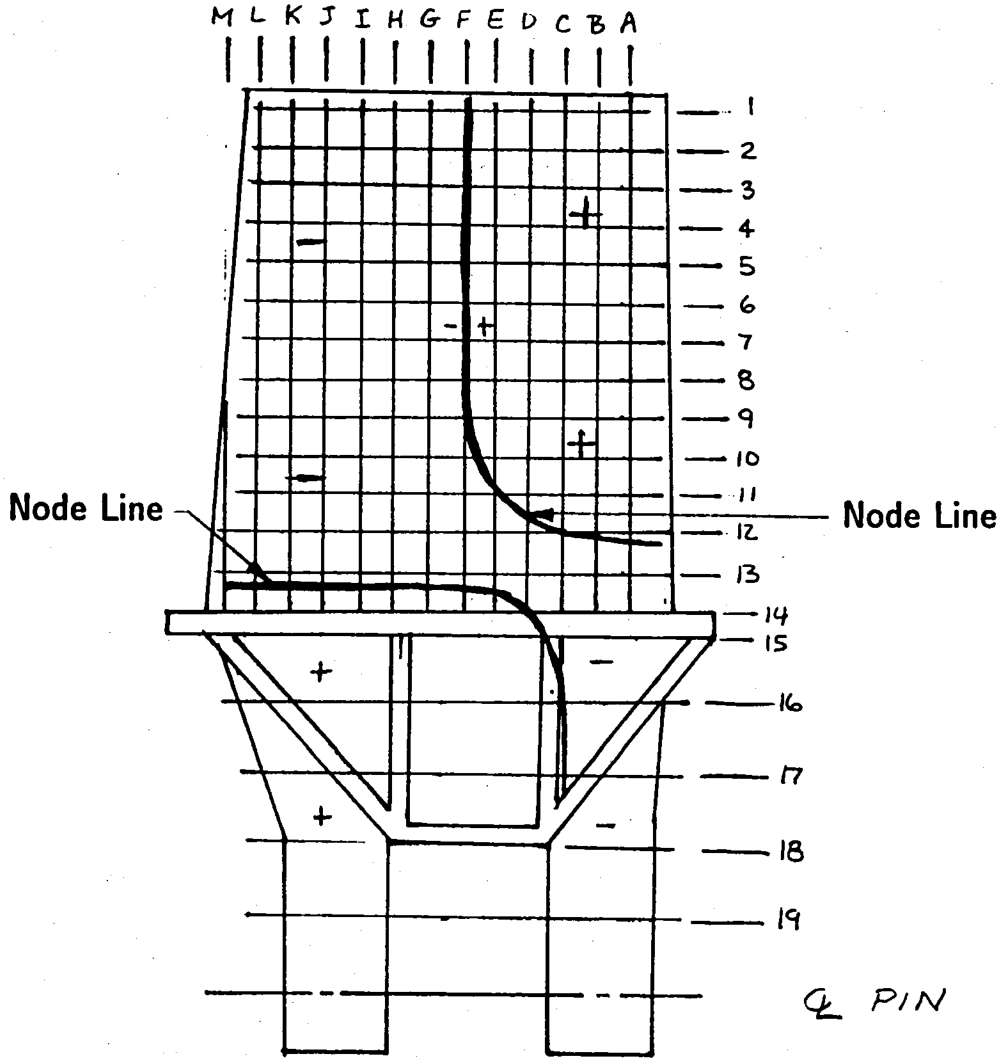


Figure 19. Bending/Torsion Mode, 280.0 Hz, Blade No. 60.

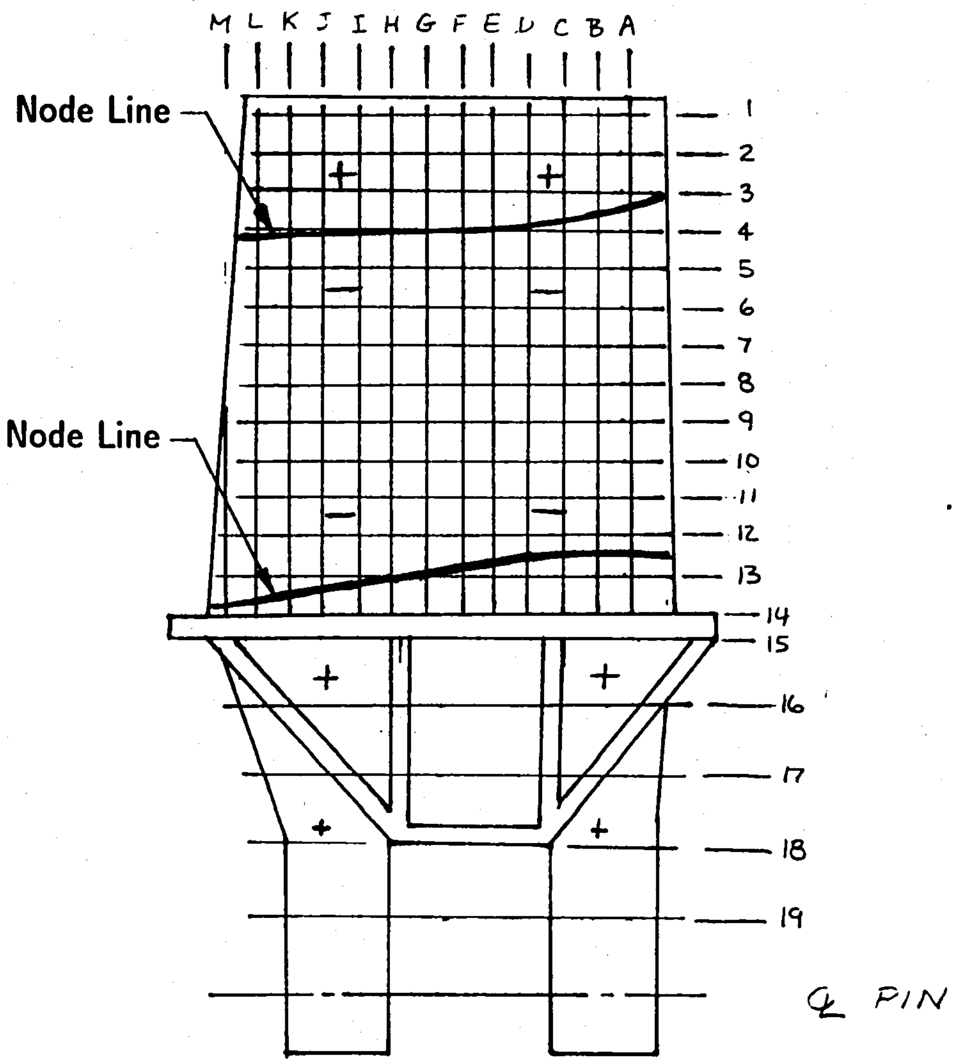


Figure 20. Third Bending Mode, 387.5 Hz, Blade No. 60.

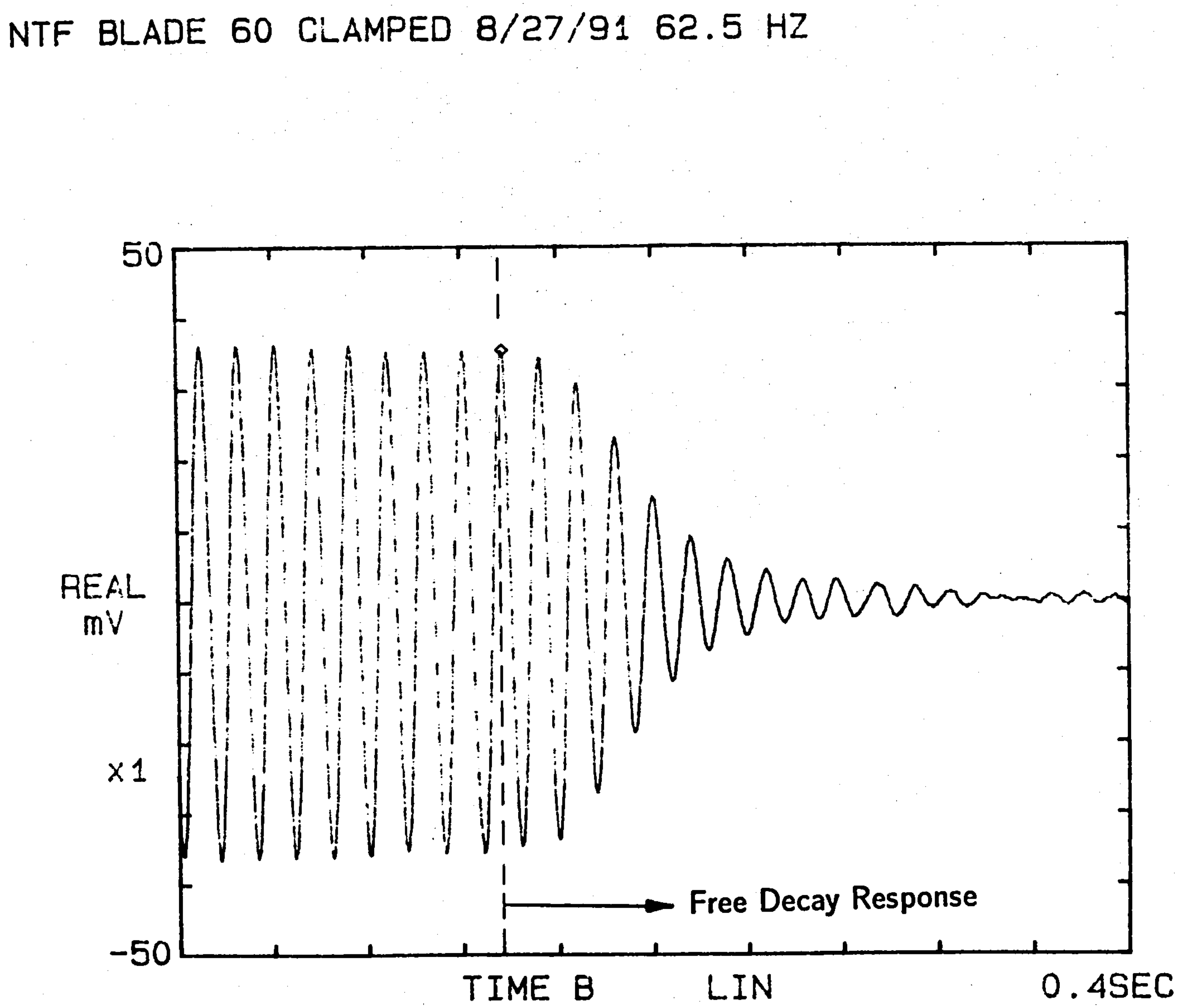


Figure 21. Free Decay Acceleration Response for First Bending Mode.

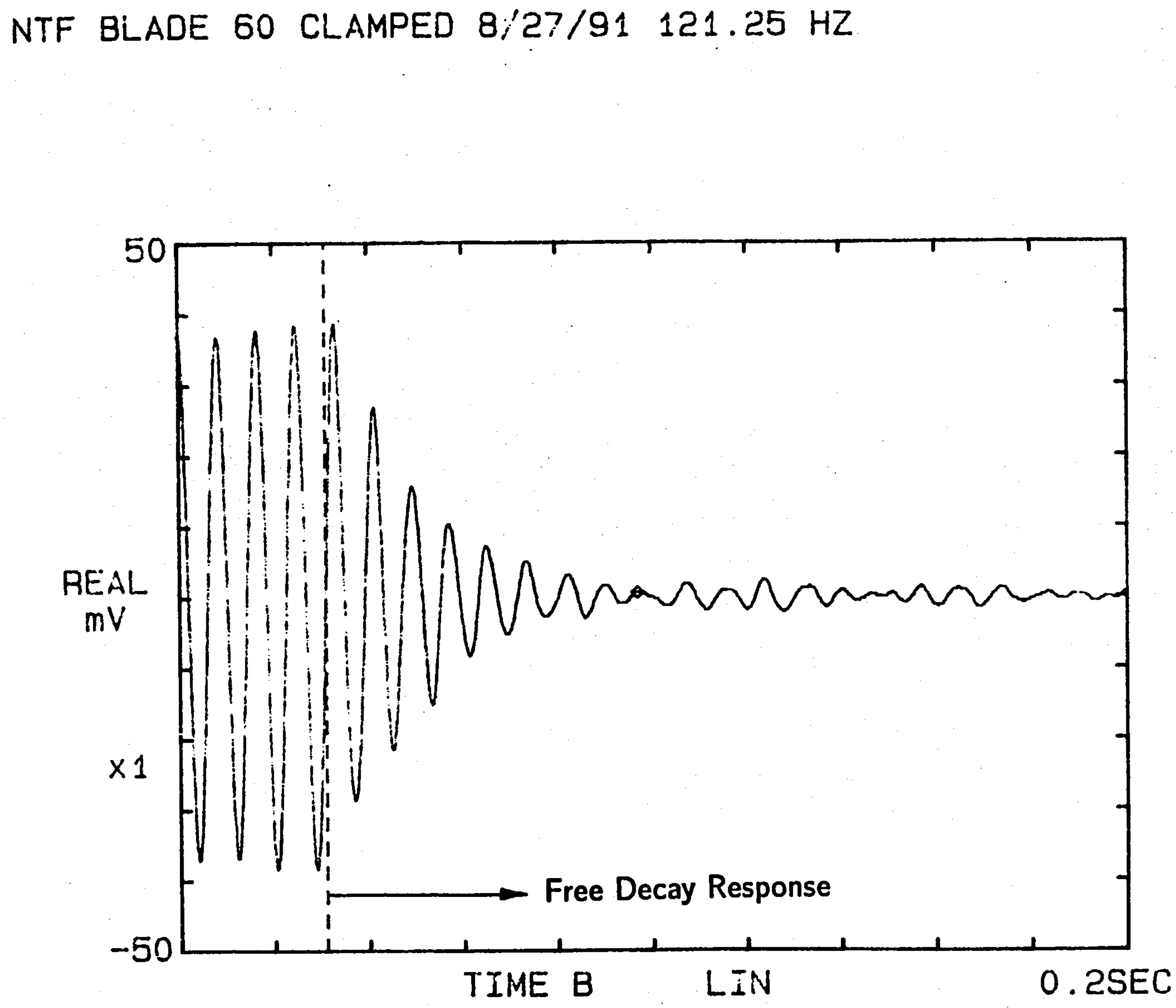


Figure 22. Free Decay Acceleration Response for Second Bending Mode.

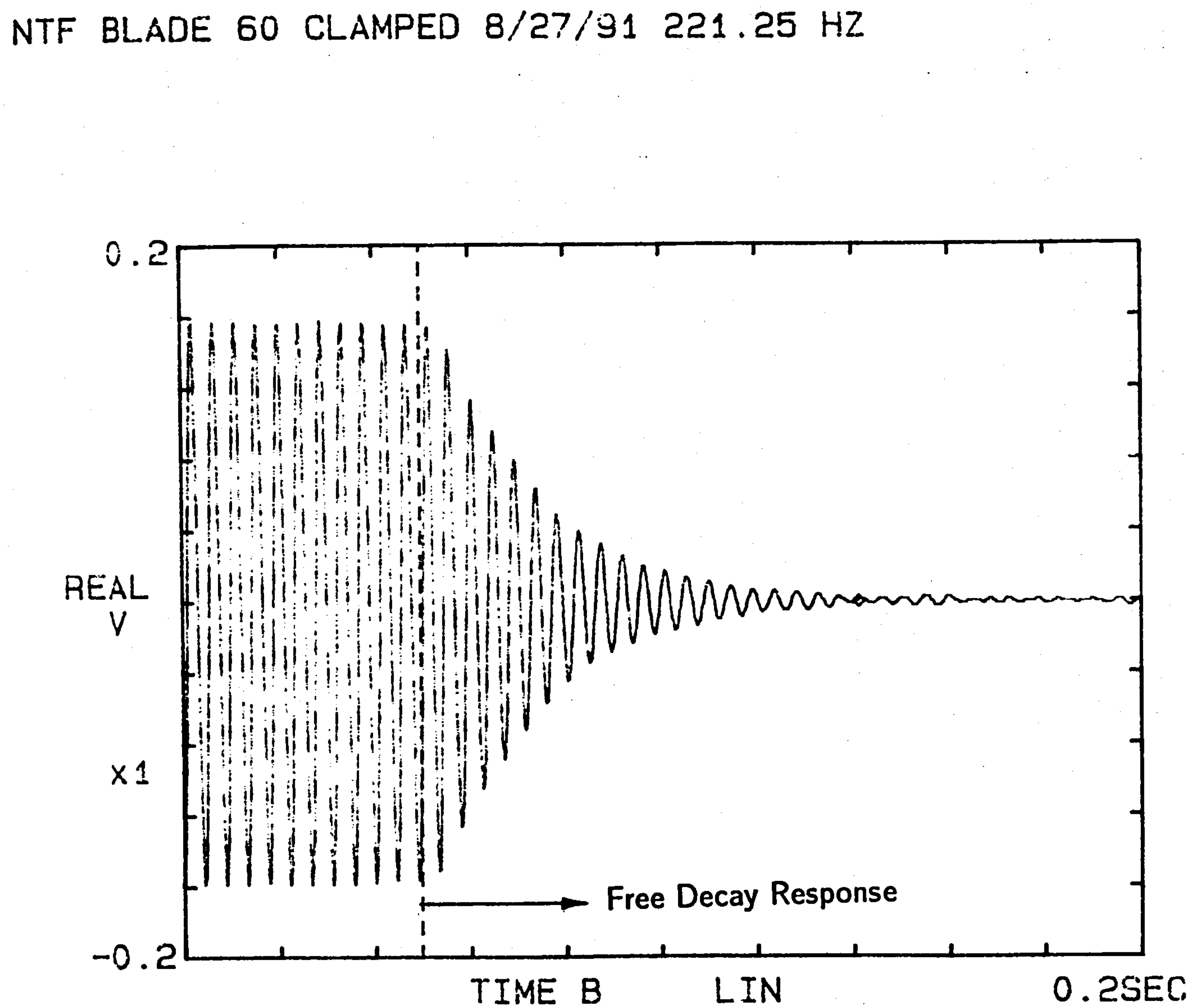


Figure 23. Free Decay Acceleration Response for First Torsion Mode.

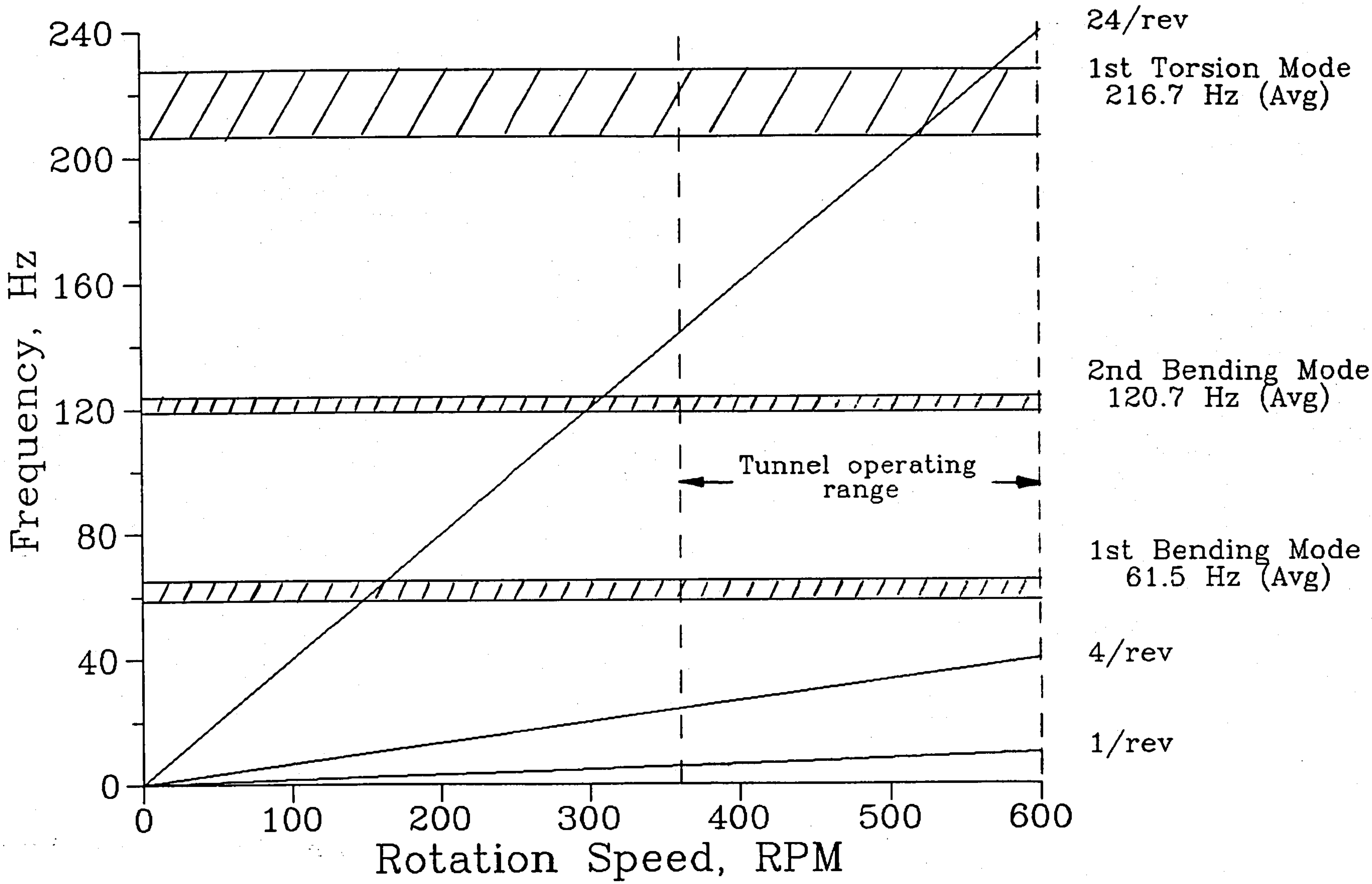


Figure 24. Interference Diagram for NTF Fan Blade Dynamics.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1992	Contractor Report

4. TITLE AND SUBTITLE

Weight, Center of Gravity and Modal Test Report for NTF Fan Blade Set No. 3

5. FUNDING NUMBERS

NAS1-18352

505-59-85-01

6. AUTHOR(S)

Inger P. Friedman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Dynamic Engineering Incorporated
703 Middle Ground Boulevard
Newport News, VA 23606

8. PERFORMING ORGANIZATION REPORT NUMBER

DEI Report No. D-425

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

NASA Langley Research Center
Hampton, VA 23665-5225

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

NASA CR-189583

11. SUPPLEMENTARY NOTES

Langley Technical Monitor: Mark S. Wampler
Final Report

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Unlimited - Unclassified
Subject Category - 39

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A complete set of fan blades for the National Transonic Facility (NTF) at the NASA Langley Research Center was recently fabricated by Dynamic Engineering Incorporated (DEI). These blades were the third complete set of blades fabricated for the NTF. The first set of blades was fabricated by NASA and installed in the tunnel in December 1981. This original set was destroyed in a mishap in January 1989. The second set of blades is currently in use in the NTF. The third set of blades recently fabricated by DEI is a spare set. The blades were fabricated according to detailed procedures to meet design requirements necessary for operation in the NTF. In order to insure that the blades met these requirements, DEI performed a series of tests on each of the completed blades. In addition,a modal surcey was conducted on each blade to define the dynamic characteristics.

This report is to discuss the fan blades tests conducted by DEI and presents the test results. The test set-ups and procedures are described in detail. The results obtained for each of the 27 blades are documented and comparisons are made between this set of blades and similar data for the two previous sets of NTF fan blades. This report summarized the test results.

14. SUBJECT TERMS

NTF fan blades; Weight analysis; Vibration testing

15. NUMBER OF PAGES 66

16. PRICE CODE A04

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL