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DYNAMIC RESPONSE CHARACTERISTICS OF TWO TRANSPORT MODELS TESTED IN THE NATIONAL TRANSONIC FACILITY

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Table

Figure

Figure

SUMMARY

This paper documents recent experiences with measuring the dynamic response characteristics of a commercial transport and a military transport model during full scale Reynolds number tests in the National Transonic Facility. Both models were limited in angle of attack while testing at full scale Reynolds number and cruise Mach number due to pitch or stall buffet response. Roll buffet (wing buzz) was observed for both models at certain Mach numbers while testing at high Reynolds number. Roll buffet was more severe and more repeatable for the military transport model at cruise Mach number. Miniature strain-gage type accelerometers were used for the first time for obtaining dynamic data as a part of the continuing development of miniature dynamic measurements instrumentation for cryogenic applications. This paper presents the results of vibration measurements obtained for both the commercial and military transport models, and documents the experience gained in the use of miniature strain gage type accelerometers.

INTRODUCTION

Recent testing of a commercial transport model in the National Transonic Facility (NTF), (see ref. 1) has demonstrated that severe buffeting (pitch and/or roll oscillations) can occur while testing at full scale Reynolds number and associated high dynamic pressures. Such buffeting or dynamic response phenomena can severely limit the test envelope and pose high risk to the facility if model failure should result due to dynamic overload. At present, a real time model protection and dynamic and aeroelastic response measurements and monitoring system capability is being developed for the NTF. One element of the model protection system development activity is to monitor and obtain model vibration data in the NTF for use in system checkout and model dynamic response simulation. Recently, a commercial and a military transport model were instrumented and monitored during full scale Reynolds number testing in the NTF for this purpose. In addition to monitoring the dynamic signals from the strain gage force balance (see ref. 2), two miniature strain gage type accelerometers (ENTRAN 125 series, see appendix A) were installed in the wings of the Douglas/Pathfinder commercial transport model (fig. 1) and two in the nose section of the High Wing Transport model, (fig. 2).

In the case of the commercial transport, the accelerometers were placed in the wings for possible use in limiting dynamic loads if unacceptably severe buffeting was encountered. Since this was the largest transport model (wing span) to be tested in the NTF, concern over high vibration loads was warranted. Unfortunately, there was no available space for accelerometer installation in the wings of the military transport model. Since the High Wing Transport model had experienced large yaw vibrations while testing at cryogenic temperatures during a previous tunnel entry in 1991, two accelerometers were installed in the nose to monitor pitch and yaw vibration. The large yaw vibrations experienced by the High Wing Transport model during the 1991 test were believed to be due to yaw vibration of the model support system (see ref. 3).

The objectives of this paper are to present and characterize dynamic data obtained from testing the two transport models, to present observations relative to the models dynamic behavior under various test conditions, and to document experience with the previously untried miniature strain gage type accelerometer in the cryogenic test environment.

MODELS DESCRIPTION

The commercial and military transport models monitored for dynamic response during full scale Reynolds number tests in the NTF are described in this section.

Douglas/Pathfinder Model

This model utilized an extended Pathfinder I fuselage and a Douglas commercial transport wing, and was tested in the wing body configuration only. The model is shown installed in the NTF in figure 1. The model was supported by a standard tapered sting and utilized an NTF 113 force balance. This model has the largest wing span (61.43 inches) of any models previously tested in the NTF. The wing was constructed of 18 Ni Grade 200 maraging steel while most of the fuselage is constructed of Nitronic 40 stainless steel, with the exception of the fuselage extension section which is constructed of 18 Ni maraging grade 200 steel. The 2.426 percent scale model weighs approximately 265 lb, is 60.5 inches in length, and has 232 pressure orifices.

High Wing Transport Model

The High Wing Transport model installed in the NTF is shown in figure 2. The 2.78 percent scale model has a wing span of approximately 55 inches, is 53.08 inches long and weighs approximately 460 lb. This is the heaviest model by far of any models previously tested in the NTF. The model has approximately 220 pressure orifices, and is constructed of A286 stainless steel. The model utilized a standard NTF 113 force balance and was supported on a standard NTF tapered sting.

SPECIAL INSTRUMENTATION

Accelerometers

The accelerometers used for these tests are miniature ENTRAN EGA-125 series strain gage type accelerometers having a dynamic range of ± 100 g. These accelerometers had not been used previously in cryogenic tests at NTF but were subjected to immersion in liquid nitrogen by the manufacturer and checked for functionability (see appendix A for description and calibration). The accelerometers are quite small (0.140 in. $\times$ 0.140 in. cross section by 0.27 in. high) which make them adaptable for use in wind tunnel models where volume is limited, e.g. installation in thin wings. Since the acceleration measurement axis is normal to the longitudinal axis, this type of accelerometer is easily installed in small trenches machined in thin wings.

The transport model wind tunnel tests provided an opportunity to test the accelerometers for cryogenic applications. Four accelerometers were procured and subjected to a dynamic calibration test sequence which is shown in figure A-1. This test sequence temperature profile is representative of an operational cycle in the NTF, i.e. cooldown, soak (test), and warmup. The calibrations are given in figures A-2 and A-3 in terms of sensitivity as a function of temperature. It can be seen from the figures that the sensitivity changes are quasi linear with temperature for both the cooldown and warmup portions of the cycle. The results of calibration were very encouraging in that the accelerometers survived the test and sensitivities were unchanged at room temperature after cryogenic cycling.

Model Installation

Douglas/Pathfinder model.- The accelerometers used for the Douglas/Pathfinder model were installed in machined slots in the wing. The left wing accelerometer was located at wing body station 18 in. (outboard of fuselage center-line) while the right wing accelerometer was located farther outboard at wing body station 22.5 in. These locations gave good measurements for the wing vibration modes of interest, with the exception of the 2nd wing bending asymmetric mode at 67 Hz, where the left wing accelerometer was located very near a node point.

The accelerometers were encased in plastic tubing and bonded in place with the wiring being routed through tubing which was installed by the model manufacturer especially for these tests. This provides for a clean installation and avoids having to route and bond the accelerometer wires in trenches machined in the wing which can result in wire breakage due to installation, thermal cycling and/or mechanical loading.

High Wing Transport Model.- Since no provisions were made initially for installation of accelerometers in the High Wing Transport model, two of the units were installed in the nose section.

Unfortunately, the only available space for installation was on the angle of attack (AOA) sensing unit which is heated. The AOA sits forward of the electronic scanning pressure measurement (ESP) modules which are also heated. The accelerometers were encased in plastic tubing, bonded to a bracket on the top surface of the AOA unit, and oriented to measure accelerations in the pitch and yaw directions. A thermocouple was installed on the AOA unit near the accelerometers in order to monitor temperature. Unfortunately, this thermocouple was unavailable during the latter part of the test so a thermocouple located near the ESP module was used to estimate temperature changes for the accelerometers.

RESULTS AND DISCUSSION

Presentation and discussion of dynamic response data for the two transport models are provided in this section. Both models were tested in the air mode (low Reynolds number) and in the cryogenic mode (flight or full scale Reynolds number) for various Mach numbers and a variety of configurations (aileron deflection angles, etc.). Although dynamic data were recorded for both models for many high Reynolds number run conditions, only a few examples of the data are provided for discussion purposes.

Douglas/Pathfinder Model

In general the dynamic response of the Douglas/Pathfinder model was characterized by roll and pitch oscillations encountered at various Reynolds number and Mach number conditions, with angle of attack being limited to about 5° or less at high Reynolds number, high Mach number, and high dynamic pressure conditions. The most severe oscillations were observed at Mach 0.8 at a Reynolds number of 30 million based on the mean aerodynamic chord.

An example frequency spectrum for the Douglas/Pathfinder model accelerometers response is provided in figure 3. The data provide an excellent dynamic signature of the model, i.e. the fundamental structural mode frequencies (shown on the frequency scale) correspond to the peak values in the spectra and compare well with the modal frequencies provided in table B-1, except for the response peak at 270 Hz which happens to be the operating frequency of the pitch system pump. It should be noted that the amplitudes shown on the frequency spectra plots provided herein are RMS values of the time domain response. In general, peak values of the response can be approximated by multiplying the peak value shown on the spectrum by $\sqrt{2}$ if the time domain signal is a pure sinusoid. If however, the time domain signal is random in character, e.g. narrow band random, a more conservative approximation is to multiply the spectrum peak amplitude by a factor of 3.

The first example data for run 198, at Mach 0.80, 30 million Reynolds number and dynamic pressure of 1900 psi are given in figure 4. Significant pitch oscillations were encountered at 4.5° angle of attack, apparently due to pitch or stall buffet response. The magnitudes of the balance loads associated with these vibrations were large enough to trip the tunnel safety interlock which brought the model to the home position (0 angle of attack). The NTF has the capability for rapidly reducing model loads through the wind tunnel interlock trip system. The interlocks provide the capability to simultaneously trip the tunnel drive system, fail safe the inlet guide vanes upstream of the fan to rapidly reduce dynamic pressure, and bring the model pitch system to a preprogrammed home position (usually zero angle of attack) at a rate of about 3 degrees per sec. References to tripping the tunnel safety interlock in this paper refers to actuating this system. Most trips for the models discussed in this paper used only the pitch to home capability, either manually or automatically actuated. Pitch oscillations at high angles of attack and high dynamic pressures are common occurrences in wind tunnel testing, with amplitude generally dependent upon dynamic pressure. Unfortunately the gains for run 198 were set too high on the normal force and pitching moment channels which resulted in signal saturation. The peak displacement amplitude associated with the 6.5 Hz oscillation was approximately 0.5 in. peak to peak. Note from figure 4 that the pitching moment was greater than 10,000 in-lbs which is approaching the full scale design value of 13,000 in-lbs for the NTF-113 balance.

By far the most interesting dynamic response condition for this model was run 211 at the same Mach number and Reynolds number (Note: for run 198, the wing fuselage configuration was tested whereas for run 211 the configuration was wing/fuselage, with flap track fairings, nacelle/pylon and asymmetric aileron settings). Significant vibrations were encountered during run 211 (Mach 0.80) at $\alpha \simeq 4.5°$. The frequency spectra given in figure 5 for the accelerometers located in the wings show a strong response in roll (19–20 Hz), as well as oscillation components of 1st sting bending (6.25 Hz); and low level wing bending mode responses at 47 Hz, 144 Hz and 183 Hz. The videotape for this run showed a complex motion associated with pitching, yawing and rolling motion, which is composed primarily of the 6.5 Hz (1st sting bending) and 20 Hz (roll) mode as evidenced by the frequency spectra for various balance channels shown in figure 5. A further examination of this motion in the time domain is provided in figures 6 and 7. Unfortunately the signals were saturated on the pitching moment and rolling moment channels as indicated in figure 6. It can be seen in figure 6 that the outboard accelerometer experienced >10 g, with the balance pitching moment exceeding 2000 in-lb, roll moment exceeding 5000 in-lb, and yaw moment peaks at approximately 8000 in-lb. This high loading condition on the balance was sufficient to trip the pitch system interlock, which was triggered either manually by a test engineer or automatically by the Critical Point Analyzer (CPA). The CPA scales and sums normalized signals from the Balance Dynamic Display Unit (BDDU), which monitors the six strain gage balance output channels, and provides visual and audible alarms if preset limit loads are exceeded. See reference 2 for a detailed discussion of these systems. The amplitude associated with the 20 Hz roll/yaw mode at the wing tip for run 211 is estimated to be in excess of 1.0 in. peak to peak based on the outboard accelerometer response. Since the mode of vibration is primarily rigid body, the stress levels associated with the inertial and aerodynamic loadings were most likely low compared to the structure allowables (see ref. 1).

In summary, significant vibrations in pitch and roll were encountered for the Douglas/Pathfinder model. In general, oscillations appeared to be more severe while running at Mach 0.8 at 30 million Reynolds number. The mechanism for exciting the model is not known but is likely due to flow separation over the wing lifting surfaces resulting in either roll or pitch buffet dynamic response (see ref. 1).

High Wing Transport Model

The High Wing Transport model dynamic response was also characterized by roll and pitch oscillations particularly at full scale Reynolds number (40 million based on mean aerodynamic chord) and Mach 0.77. The model was much more prone to roll buffet (buzz), than the Douglas/Pathfinder Model particularly at Mach 0.77. The dynamic behavior in pitch was similar to the Douglas/Pathfinder model in that the pitch oscillations were primarily associated with the 1st sting bending mode at about 6.5 Hz, which limited angle of attack to about 5.3° at the higher Mach numbers. However, the model did not experience large oscillations in the yaw plane which had been observed in an earlier test (1991) after the tunnel had been cold soaked for 1 to 2 days. The oscillations observed in the earlier test were believed to be associated with the model support system vibration (see ref. 3).

Since the earlier test of the High Wing Transport model in 1991, a new material "Vespel" has been installed on the pitch system arc sector bearing pads (pucks). This material has a low friction coefficient which allows the bearing clearances to be set at zero (at room temperature) which in turn reduces the "slop" or looseness of the arc sector. The tightening of clearances on the bearings appears to have contributed to attenuation of the vibrations observed in earlier tests of the model. See reference 3 for a discussion of the effects of bearing or puck clearance on yaw vibration response.

The High Wing Transport model vibration modes and frequencies are provided in table B-II. Comparison of the natural modes and frequencies of the two models (tables B-I and B-II) shows the High Wing Transport model frequencies to be slightly lower for sting bending and considerably higher for wing bending modes, as expected. However, note that the predominantly rigid body roll modes measured for both models are very nearly the same, i.e. 20–23 Hz. This particular mode appears to be common to all the large transport models that have been tested in NTF (see e.g., ref. 1) and seems to be the mode most often excited at full scale Reynolds number conditions, with the exception of pitch buffet at high angles of attack. This roll mode involves the interaction of the roll inertia of the model with the balance roll spring. The pitch buffet mode is predominantly the first sting bending mode response at high angles of attack, apparently due to flow separation with amplitude generally proportional to dynamic pressure and is referred to as pitch or stall buffet for discussion purposes.

For the High Wing Transport model test, the accelerometers were located in the nose section very near the center line, such that rolling motions and wing elastic mode response could not be measured as was done for the Douglas/Pathfinder model. Dynamic data from the accelerometers and the force balance are provided to characterize the response and amplitude at different test conditions.

Frequency spectra are provided in figures 8 and 9 for the accelerometer and force balance response for a run at Mach 0.74 and angle of attack of approximately 4.9°. These data were taken at or near a time when the tunnel interlock was tripped either manually or automatically due to pitch buffet. The predominant frequencies of the response are 6.5 Hz (1st sting bending), 13 Hz (model pitching on balance) and 20 Hz (roll/yaw mode). Time domain data for this run are provided in figure 10 for the two accelerometers, normal force and pitching moment. Unfortunately normal force and pitching moment channels were saturated such that dynamic amplitude is known to have exceeded 500 lb normal force and 4000 in-lb pitching moment. This was one of the early encounters of pitch buffet for this model while running in the cryogenic mode, with dynamic motions considered to be well within structural limits.

A more interesting set of data are provided in figures 11 through 16, taken from run numbers 72 and 77 which clearly illustrate the roll buffet (buzz) oscillation that was consistently encountered while running at Mach 0.77 at full scale Reynolds number. The frequency spectra provided in figure 11 for the two accelerometers and roll and yaw moment show the dominant response to be at 20 Hz which is the roll buffet mode consisting of predominantly roll motion with some pitch and yaw motion present. The associated time domain response for the roll and yaw moment is provided in figures 12 and 13. Note that for this run the roll response is a pure sinusoid at constant frequency (indicating roll lock-in) with a peak value of about 8640 in-lb, while the yaw moment is narrow band with a peak value of about 5530 in-lb (see fig. 13). These compare with full scale design values of 8989 in-lb and 6480 in-lb for the roll and yaw moment channels respectively for the NTF 113 balance. Similar plots are provided in figures 14 through 16 for run 77 at Mach 0.77 which resulted in an interlock trip on the pitch system at an angle of attack of approximately 4.3°.

In general, roll buffet (wing buzz) was encountered on every run at Mach 0.77 (including inverted runs) at full scale Reynolds number. The point of onset and lock-in (constant frequency) was a function of angle of attack and usually began to occur at about 4 degrees angle of attack.

Accelerometer Performance

Upon installation and checkout in the Douglas/Pathfinder model, the accelerometers were found to be quite noisy with the device resonance frequency of 1500 Hz showing up very strong in the acquired signals. A low pass filter was used to filter out the high frequency noise. The two accelerometers installed in the Douglas/Pathfinder model seemed to work well during the test in air and at cryogenic temperatures. After the Douglas/Pathfinder test completion, one of the units was installed in the High Wing Transport for further testing while the other unit was subjected to a post-test dynamic calibration (see fig. A-1). However, the unit sent out for calibration showed a very large DC bias and was returned to the manufacturer for evaluation.

During installation in the High Wing Transport model, one of the units, which had been setting on the shelf after initial calibration, was found to have an open bridge. This unit was dropped during initial installation in the Douglas/Pathfinder but subsequently checked out O.K. and put on the shelf for the High Wing Transport test. This unit was also returned to the manufacturer. The two remaining units were used for the High Wing Transport test and a post-test calibration was performed. One of these units was found to have a large DC bias (~ 5 volts) which rendered it unacceptable for further use. The fourth unit was successfully calibrated with the changes in sensitivity versus temperature comparing very well with that shown in the upper graph of figure A-3. The failure of 3 out of 4 of the miniature accelerometers suggests that for the present design, the devices are not viable for extended use in the NTF cryogenic environment.

CONCLUDING REMARKS

Dynamic response data from the Douglas/Pathfinder and High Wing Transport models tested in the NTF are presented and discussed in this paper. The dynamic behavior of both models was characterized by roll and pitch buffet oscillations while testing at full scale Reynolds number and high Mach numbers. The High Wing Transport model was more prone to roll buffet (buzz) particularly at Mach 0.77 and full scale Reynolds number. Both models were limited to around 5.5° angle of attack or less when testing at high dynamic pressures. Such oscillations are not unique to the NTF but are more severe, due to the high dynamic pressures, when testing cryogenically at full scale Reynolds number. The mechanism for exciting the models is not known but most likely is associated with flow separation (buffet), and similar oscillations have been observed on other transport models previously tested in the NTF.

Large yaw plane oscillations observed for the High Wing Transport model during an earlier entry in 1991, when the tunnel was cold soaked for 1 to 2 days, were not observed for this test under similar test conditions. The absence of large yaw vibrations for this test may be due to the use of a new bearing surface material for the arc sector pucks which allows for zero clearance between the arc sector and bearing pads.

As a part of development of cryogenic dynamic instrumentation for use in NTF models, miniature strain gage type accelerometers were installed in both models. Although the accelerometers survived the dynamic calibration and appear to have repeatable sensitivity changes with temperature, the operational experience to date (3 out of 4 failures) raises a number of questions as to their viability for extended use in the NTF environment.

REFERENCES

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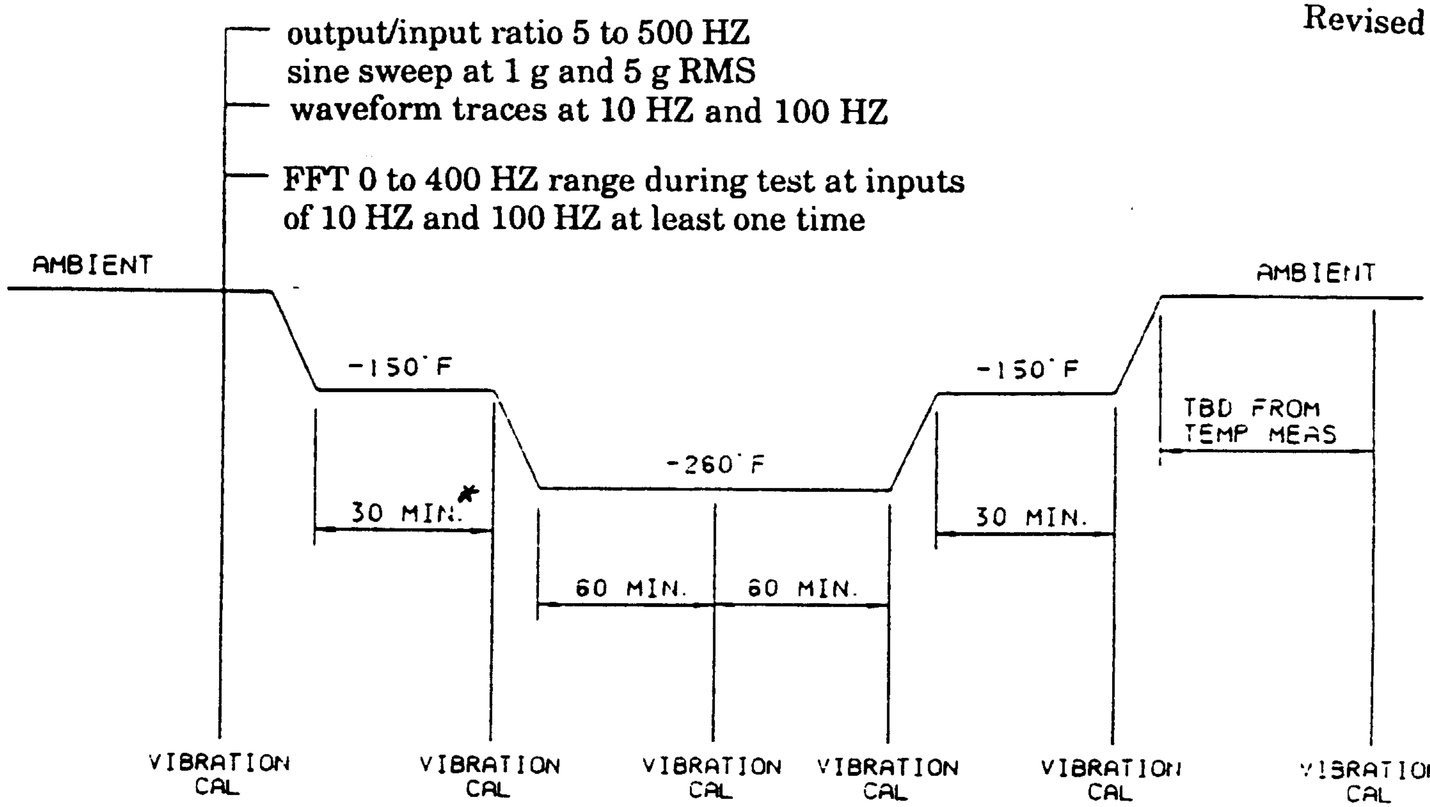
2. Ferris, Alice T.; and White, William C.: Monitoring Dynamic Loads on Wind Tunnel Force Balances, ISA Paper 89-0021, 1989.
3. Young, C. P., Jr.; Popernack, T. G. and Gloss, B. B.: National Transonic Facility Model and Model Support Vibration Problems. AIAA Paper No. 90-1416 presented at the 16th Aerodynamic Ground Testing Conference, June 18–20, 1990, Seattle, Washington.

APPENDIX A

DESCRIPTION, CALIBRATION SEQUENCE AND SENSITIVITIES FOR ENTRAN 125 SERIES ACCELEROMETERS

Specifications for the ENTRAN 125 series miniature accelerometers used for the tests described in this paper are available from the manufacturer. The accelerometers are very small, 0.14 in. by 0.14 in. cross section and 0.27 in. high. The accelerometers are strain-gage type with semi-conductor circuitry. The devices used for these tests did not employ a temperature compensating module and had a dynamic range of ± 100 g. The accelerometer calibration test sequence is shown in figure A-1 which is designed to represent a typical operational cycle in the NTF. The accelerometer sensitivities obtained at low temperatures are provided in figures A-2 and A-3. Note that the measured changes in sensitivity of all the devices were quasi linear with temperature during cool-down and warm-up cycles.



* Can cool down faster as long as it is assured that accelerometer gets to desired temperature for testing

Figure A-1 - Vibration Calibration Test Sequence for Entran-125 Series Accelerometers

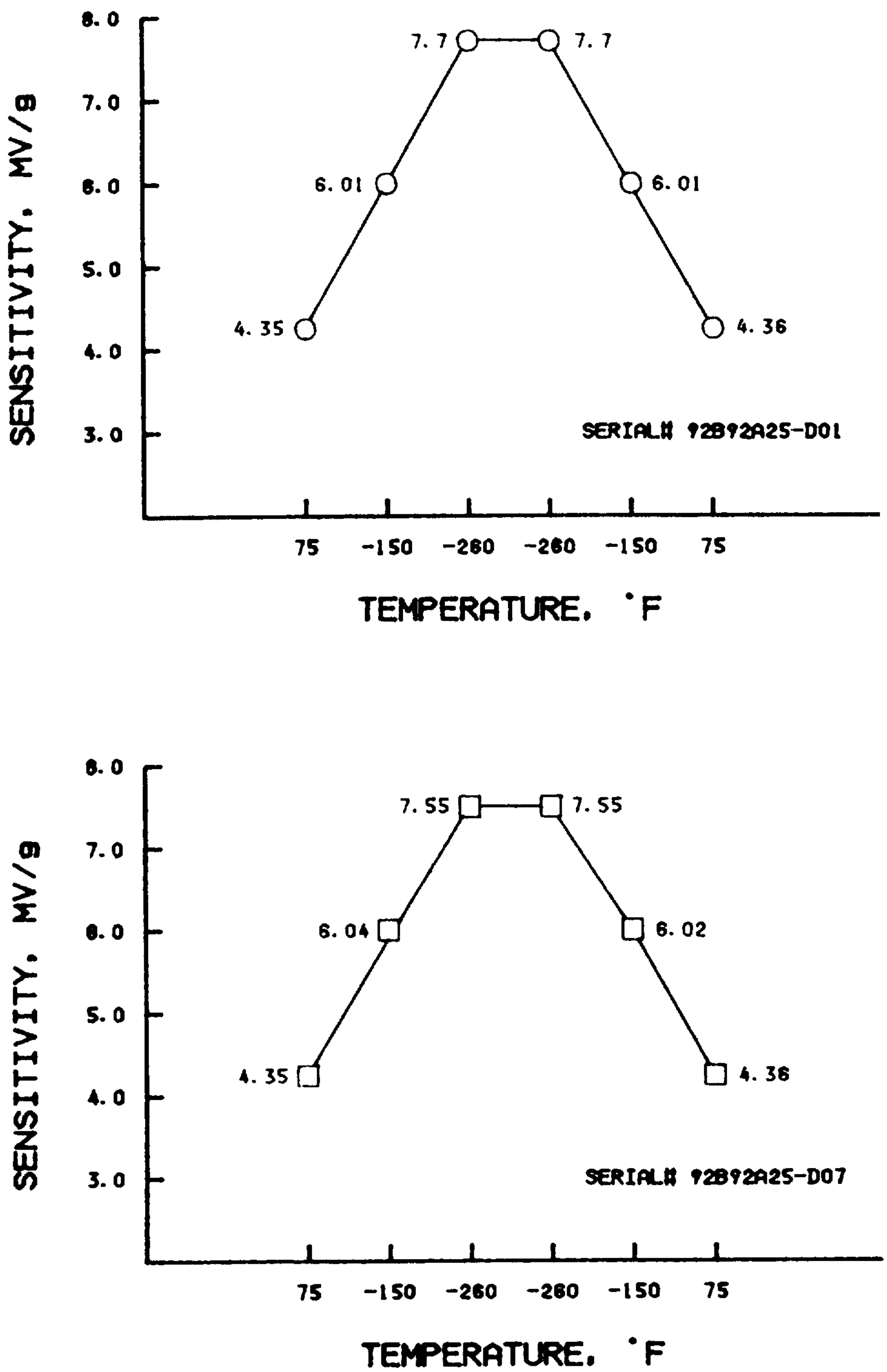
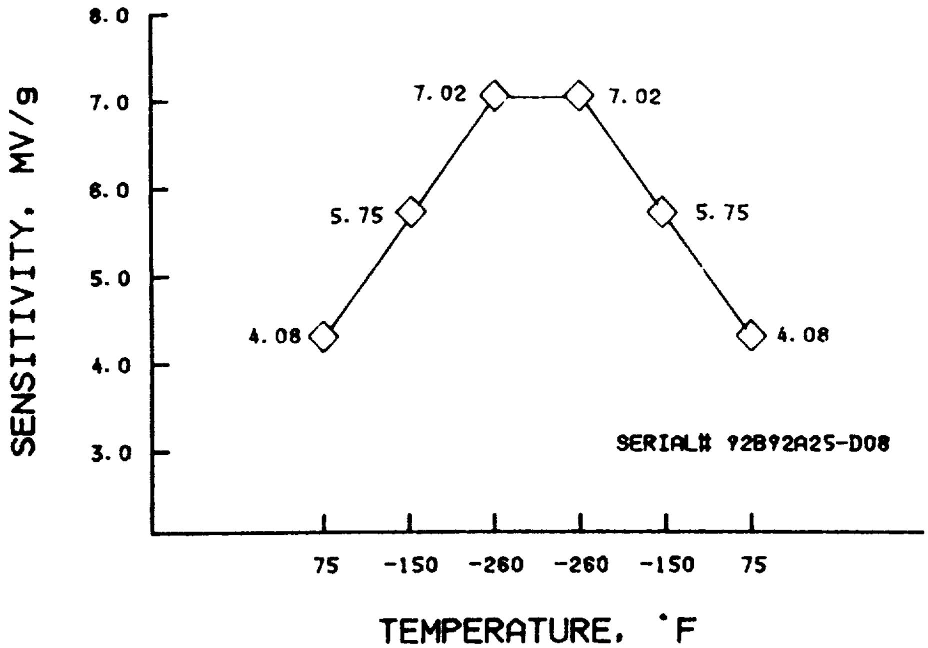


FIGURE A-2. ACCELEROMETER SENSITIVITIES AT CRYOGENIC TEMPERATURES. ENTRAN EGA-125 WITHOUT COMPENSATION MODULE, 100g DYNAMIC RANGE.



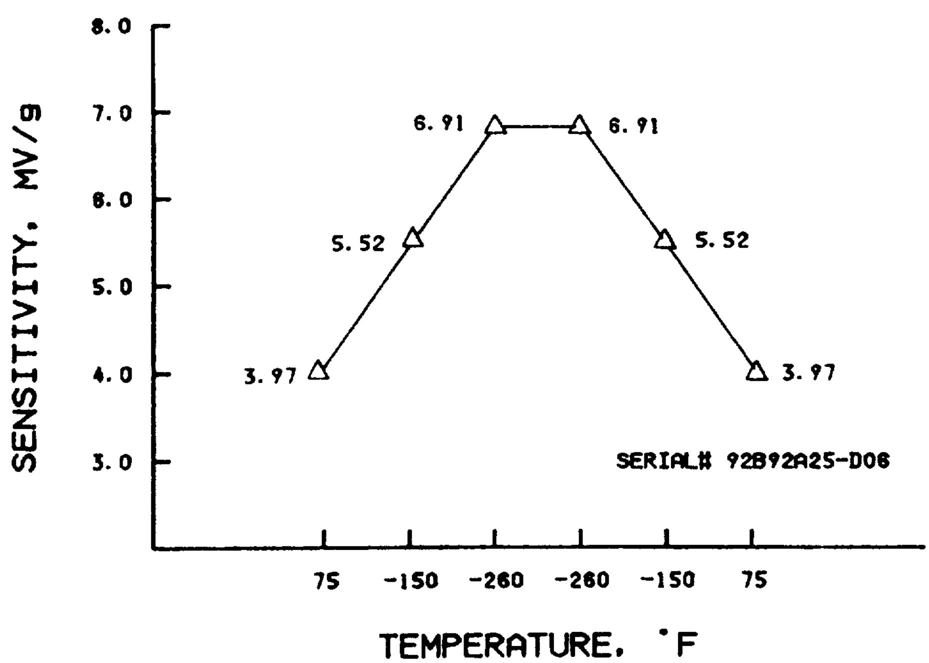


FIGURE A-3. ACCELEROMETER SENSITIVITIES AT CRYOGENIC TEMPERATURES. ENTRAN EGA-125 WITHOUT COMPENSATION MODULE, 100g DYNAMIC RANGE.

APPENDIX B

NATURAL MODE CHARACTERISTICS

Modal test data are presented in this appendix. Natural vibration mode shapes and frequencies were obtained via a modal survey or wind-off vibration test. These data are normally obtained for most NTF model systems and are needed to evaluate, identify and analyze the model system dynamic response during testing. Also these data are used to strategically locate instrumentation to properly monitor vibration modes, particularly for the wing.

The modal survey for the Douglas/Pathfinder model was performed after installation in the wind tunnel test section. The High Wing Transport vibration test was conducted in the model assembly bay, which is representative of the actual wind tunnel installation. The natural vibration data were acquired with a Modal Analyzer System which provides a tabulated set of mode shapes, frequencies and damping data, and displays of the animated mode shapes. A summary of mode frequencies and brief description of mode shapes is provided in tables B-I and B-II for the Douglas/Pathfinder and High Wing Transport models respectively.

The first sting bending mode frequencies (pitch plane) for the High Wing Transport and Douglas/Pathfinder model systems range from 7.2 to 7.5 Hz. The High Wing Transport first bending mode is slightly lower due to the model being heavier than the Douglas/Pathfinder model. Both models have roll/yaw (predominantly roll) modes at 20–23 Hz. This mode is basically a rigid-body mode involving the model roll inertia and the force balance torsional (roll) spring. The roll or roll/yaw mode shape and frequency seems to be common to all large transport models tested in the NTF (see e.g. ref. 1). This mode is often times excited when testing at full scale Reynolds number and seems to be associated with flow separation over the wing (ref. 1). The other mode(s) typically excited at large angles of attack due to pitch or stall buffet are the first sting bending mode and the model pitching on the balance (see section on Discussion of Results).

Table B-I. Douglas/Pathfinder Measured Mode Shapes and Frequencies

Mode	Frequency, Hz	Description
1	6.4	Sting yaw
2	7.5	Sting pitch
3	11.7	Yaw, sting/balance
4	18.5	Pitch, sting/balance
5	23	Roll, balance
6	47	Wing bending, tip torsion (sym.)
7	66.7	Wing bending, tip torsion (asym.)
8	143.6	2nd wind bending (sym.)
9	177.2	2nd wing bending (asym.)

Table B-II

High Wing Transport Mode Shapes and Frequencies

	Frequency, Hz		
MODE	WITH NACELLE	WITHOUT NACELLE	DESCRIPTION
1	7.22 Hz	7.458 Hz	1st Bending
2	11.934	12.225	Bal. Beam Yaw
3	13.087	13.128	Bal. Beam Pitch
4	20.02	21.810	Bal. Beam Roll

WING MODES

MODE	WITH NACELLE	WITHOUT NACELLE	DESCRIPTION
1	72.651 Hz	75.838 Hz	Sym. Wing Bending
2	101.977	-	Nac. 26 Winglet Y 29
3	109.288	115.239	2nd Wing Bending
4	144.723	-	Nac. 26 Winglet Z 29
5	166.884	-	Winglets
6	212.105	-	Nac. 27 (Z) Winglets 28
7	216.748	-	Nac. 27 & 28 in Phase
8	221.789	210.467/ 239.574	Winglets
9	244.42	-	Nac. 27 & 23 out of Phase

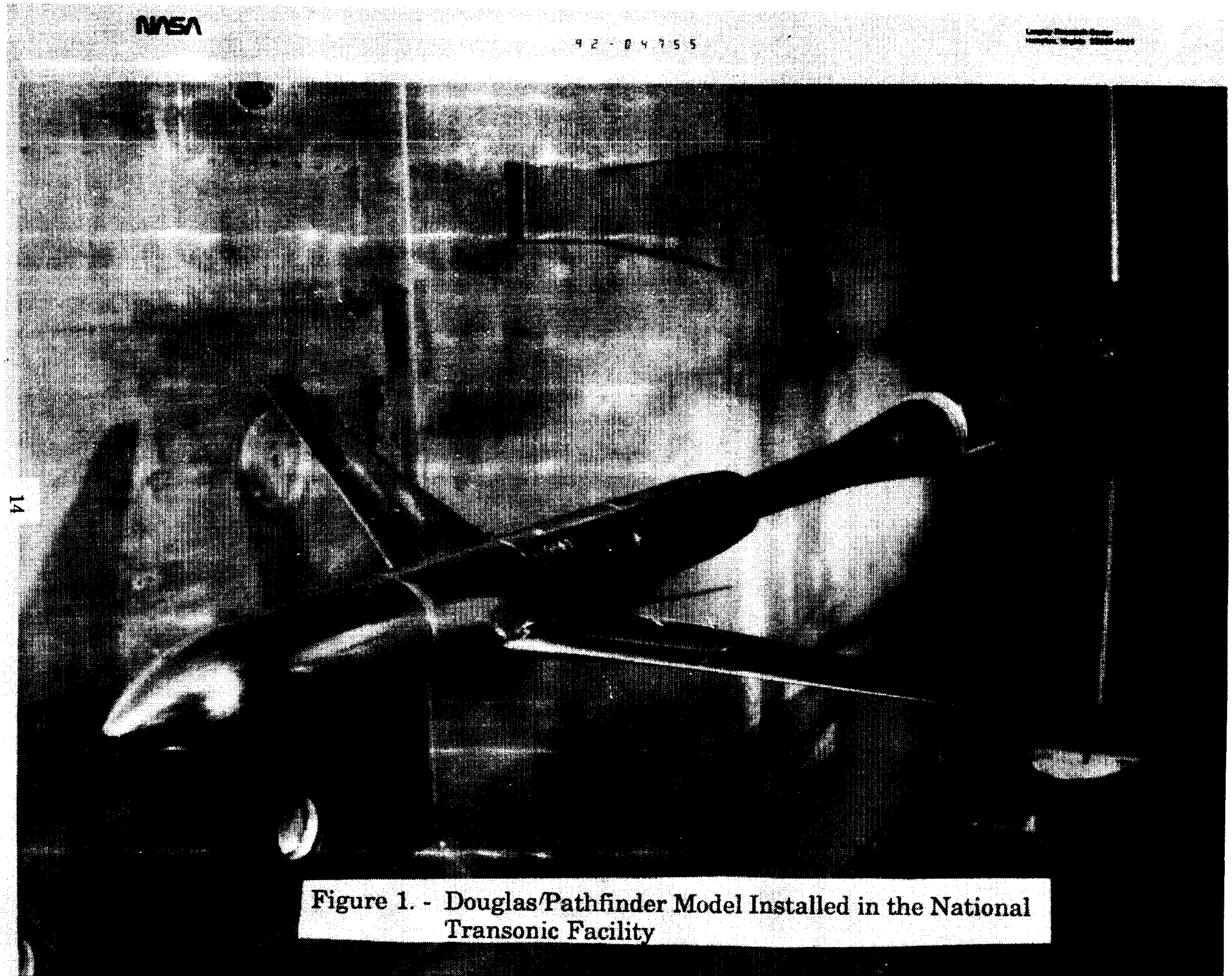


Figure 1. - Douglas/Pathfinder Model Installed in the National Transonic Facility

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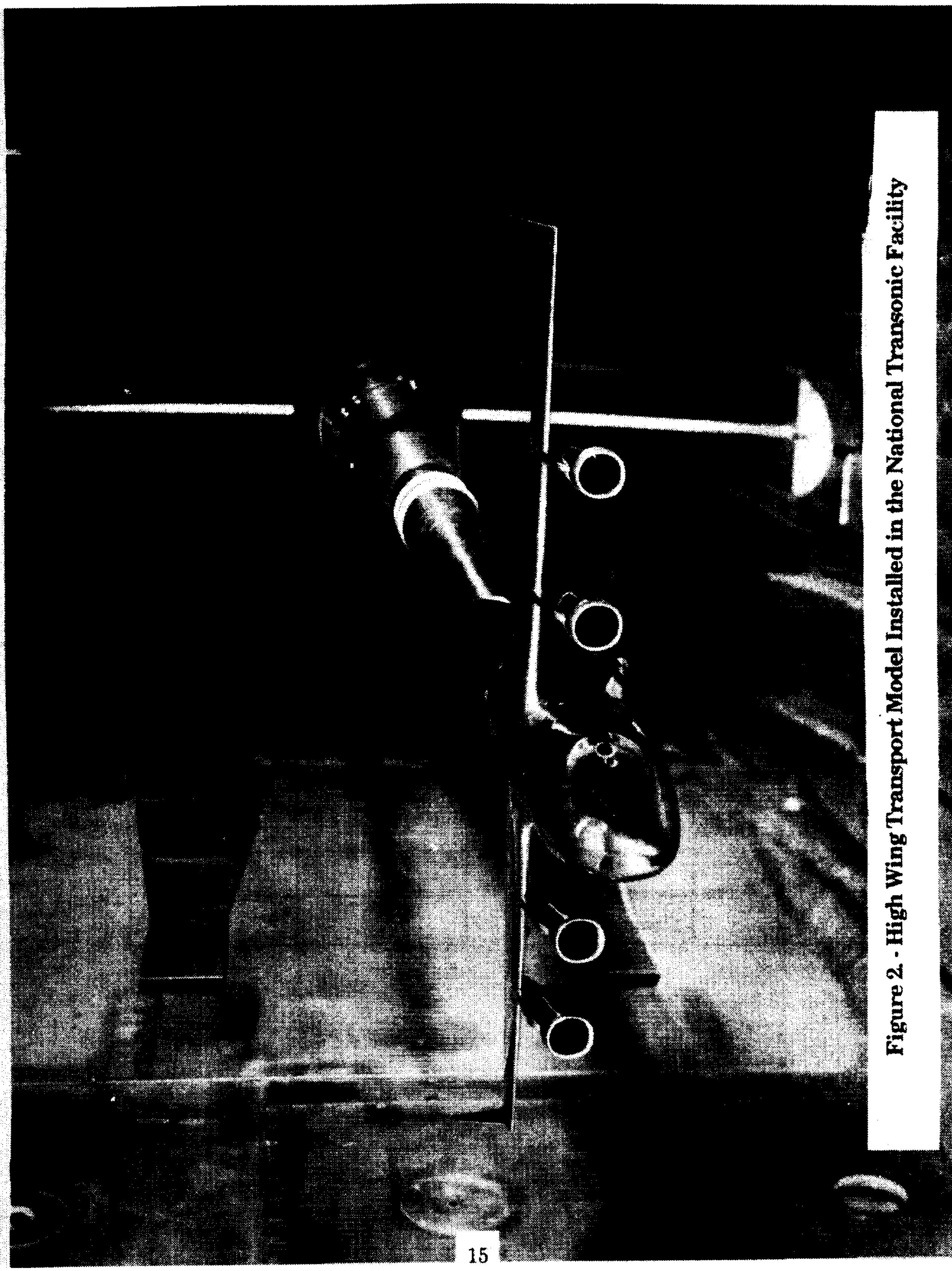

Figure 2. - High Wing Transport Model Installed in the National Transonic Facility

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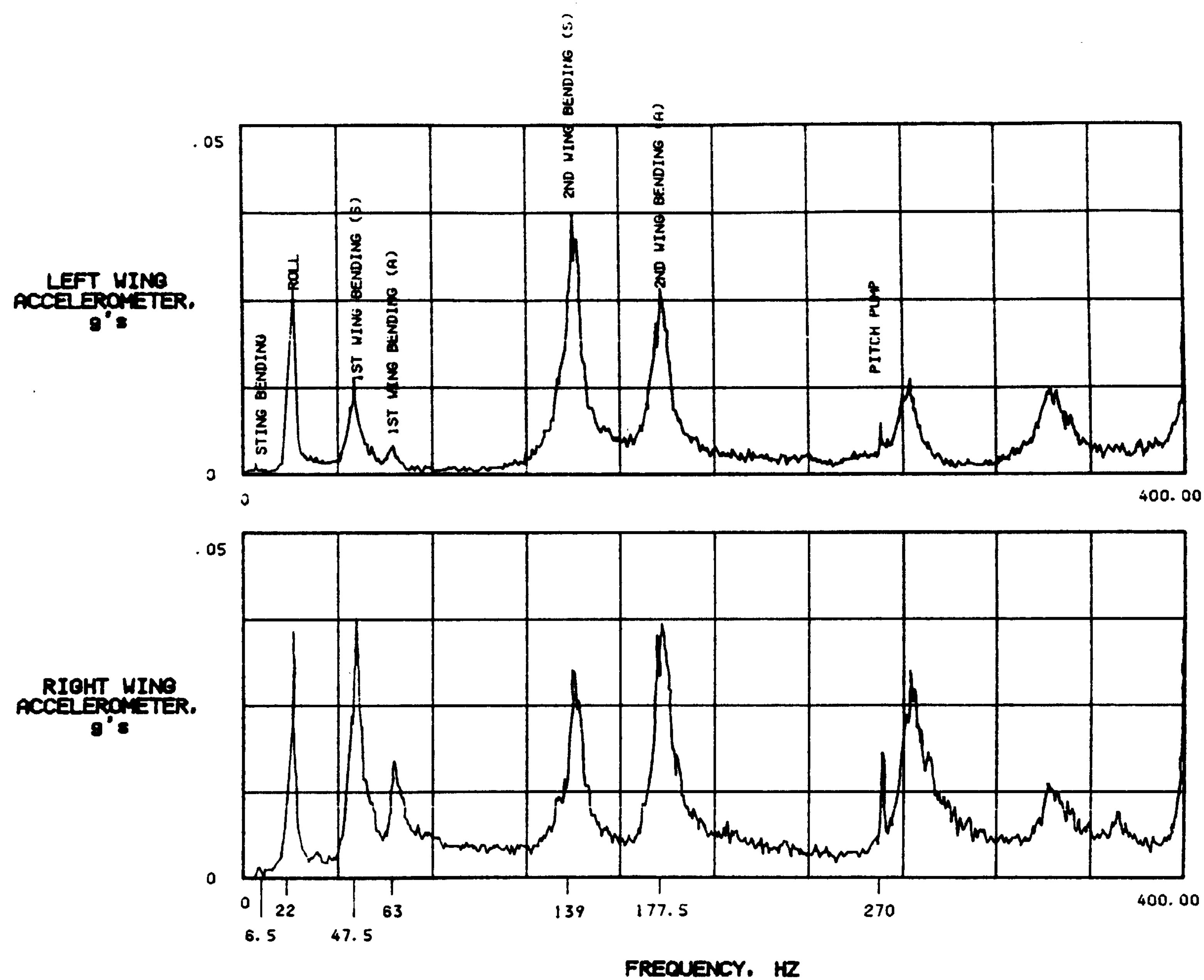

FIGURE 3. EXAMPLE FREQUENCY SPECTRA FOR ACCELEROMETER INSTALLED IN DOUGLAS/PATHFINDER MODEL WING

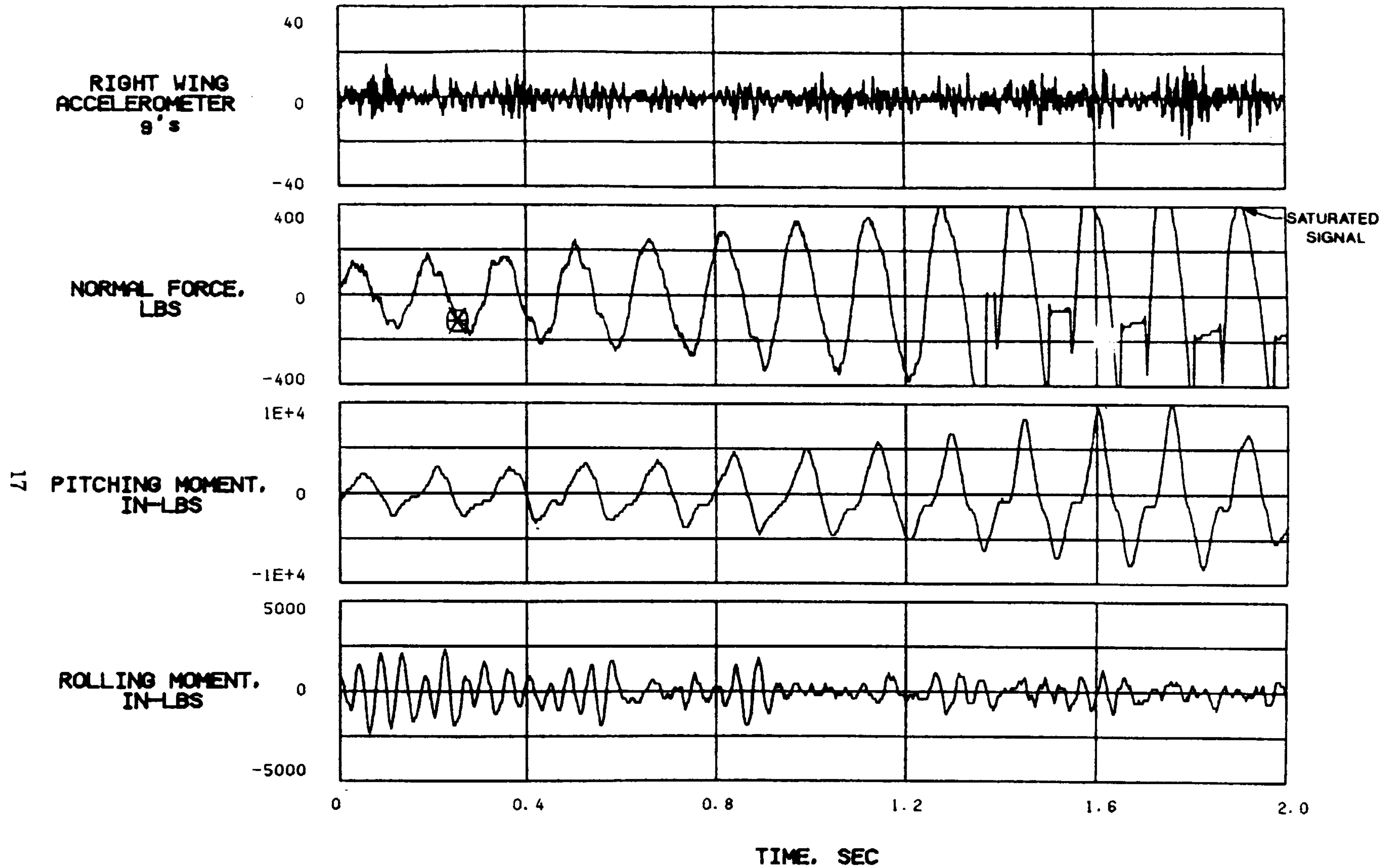

FIGURE 4. TIME HISTORIES OF DOUGLAS/PATHFINDER MODEL, RUN 198, MACH 0.8, $\alpha \simeq 4.7°$ - JUST PRIOR TO TRIP DUE TO PITCH BUFFET

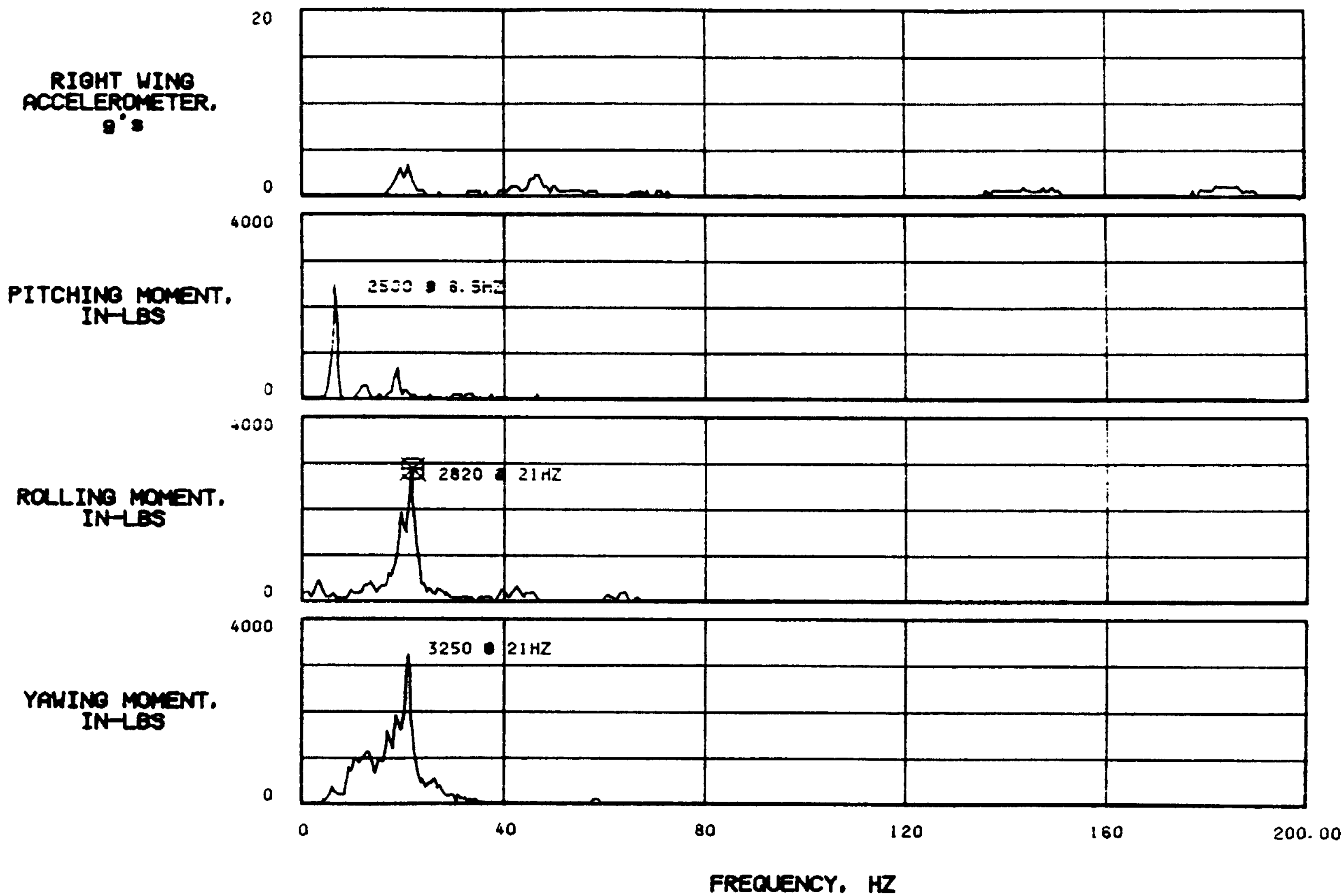

FIGURE 5. FREQUENCY SPECTRA FOR SELECTED ACCELEROMETER AND FORCE BALANCE CHANNELS - DOUGLAS/PATHFINDER MODEL, RUN 211, MACH 0.8, $\alpha \simeq 4.3°$ - TRIP CONDITION

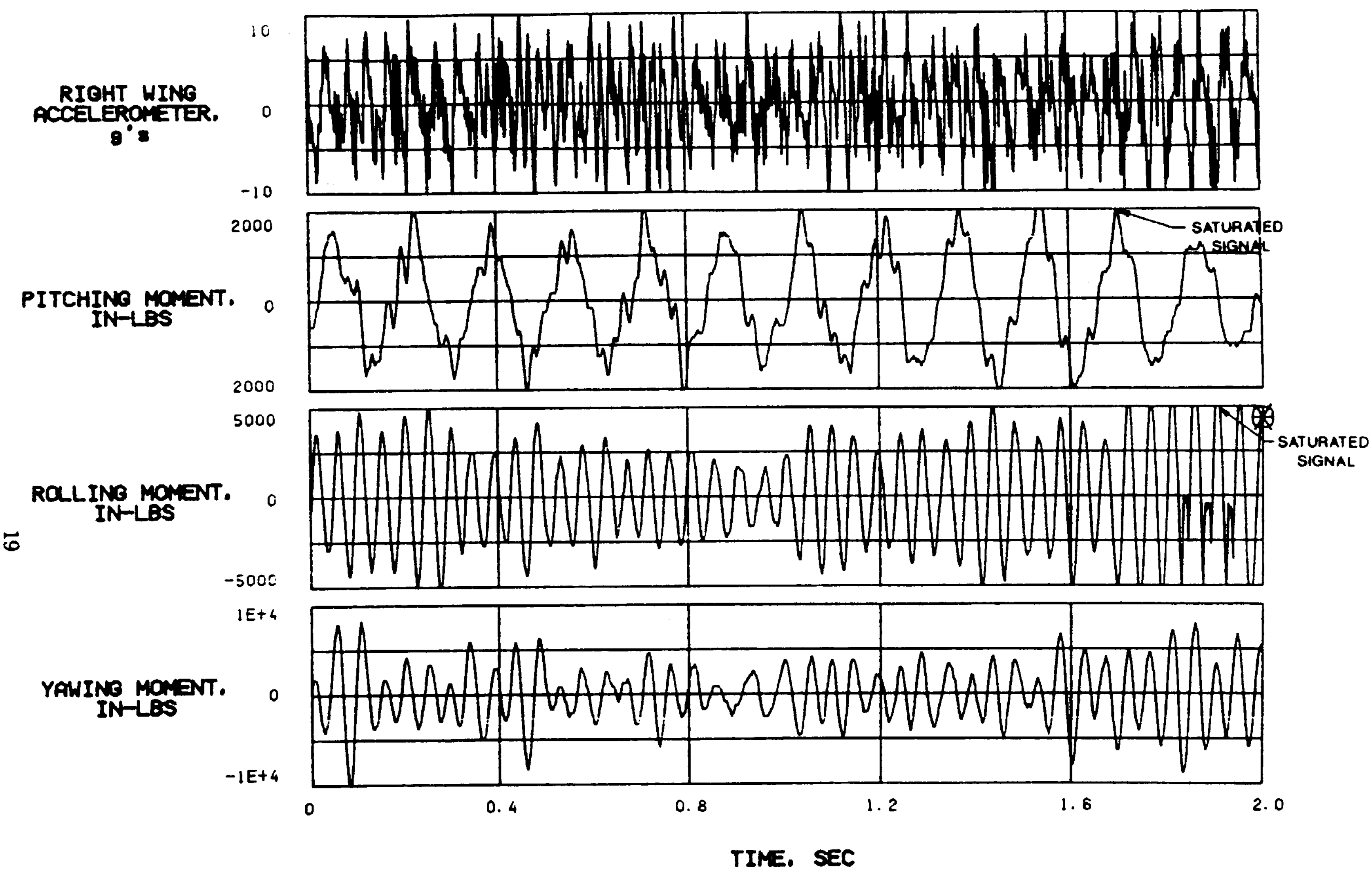

FIGURE 6. DYNAMIC RESPONSE TIME HISTORIES FOR DOUGLAS/PATHFINDER MODEL, RUN 211, MACH 0.8, $\alpha \simeq 4.3°$ - TRIP CONDITION

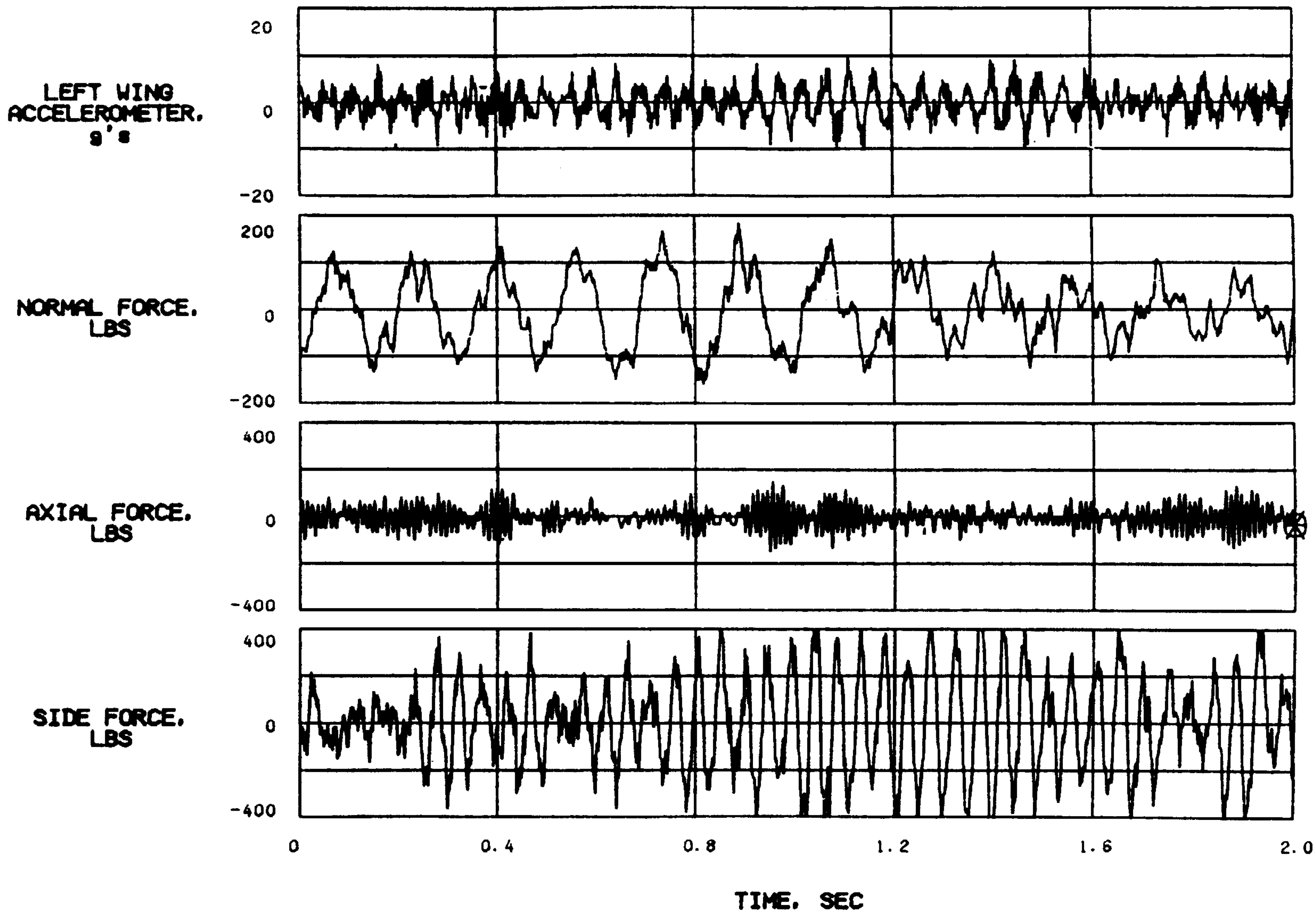

FIGURE 7. DYNAMIC RESPONSE TIME HISTORIES FOR DOUGLAS/PATHFINDER MODEL, RUN 211, MACH 0.8, $\alpha \approx 4.3°$ - TRIP CONDITION

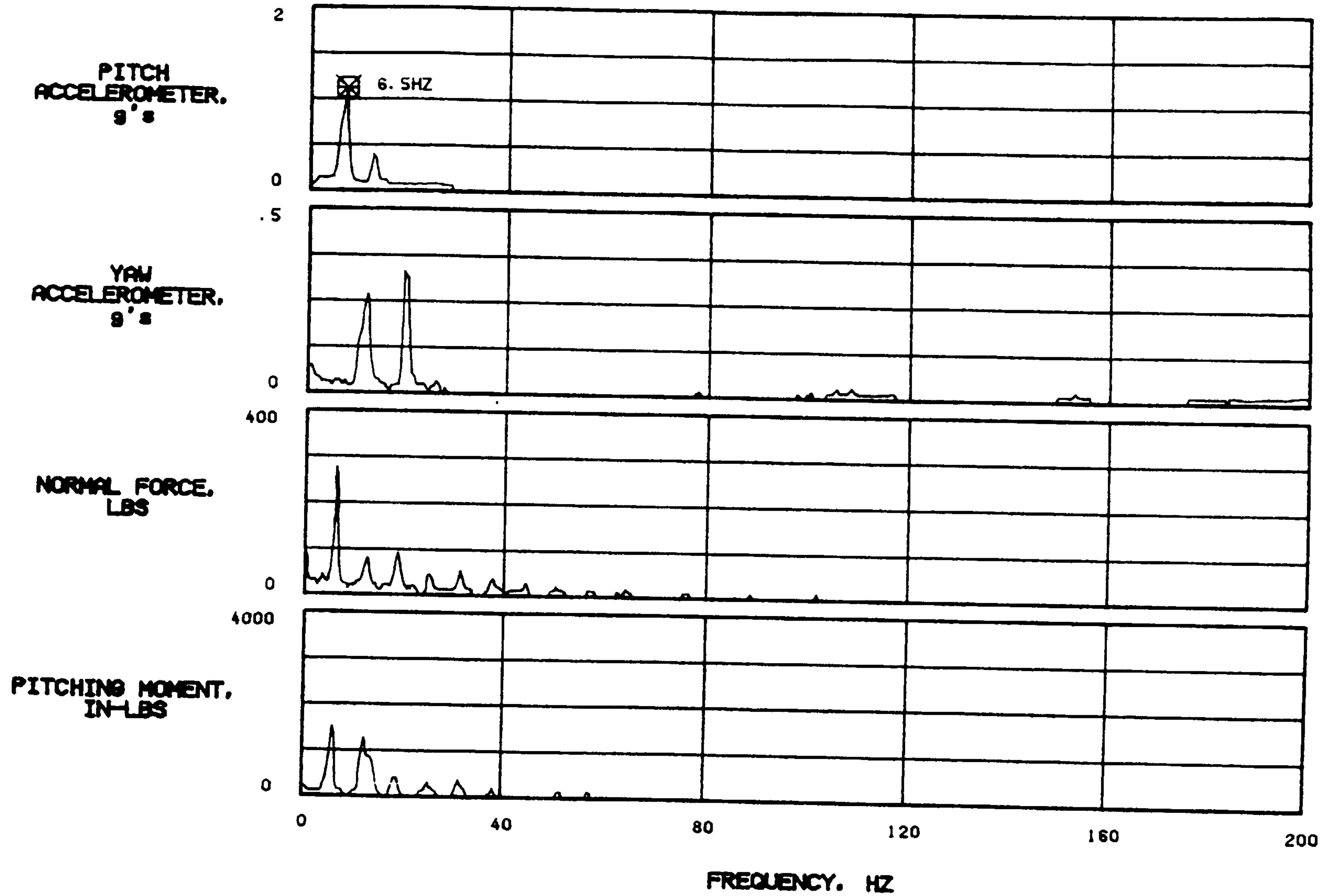

FIGURE 8. FREQUENCY SPECTRA FOR HIGH WING TRANSPORT MODEL, RUN 66, MACH 0.74, $\alpha \simeq 4.9°$ - TRIP CONDITION DUE TO PITCH BUFFET

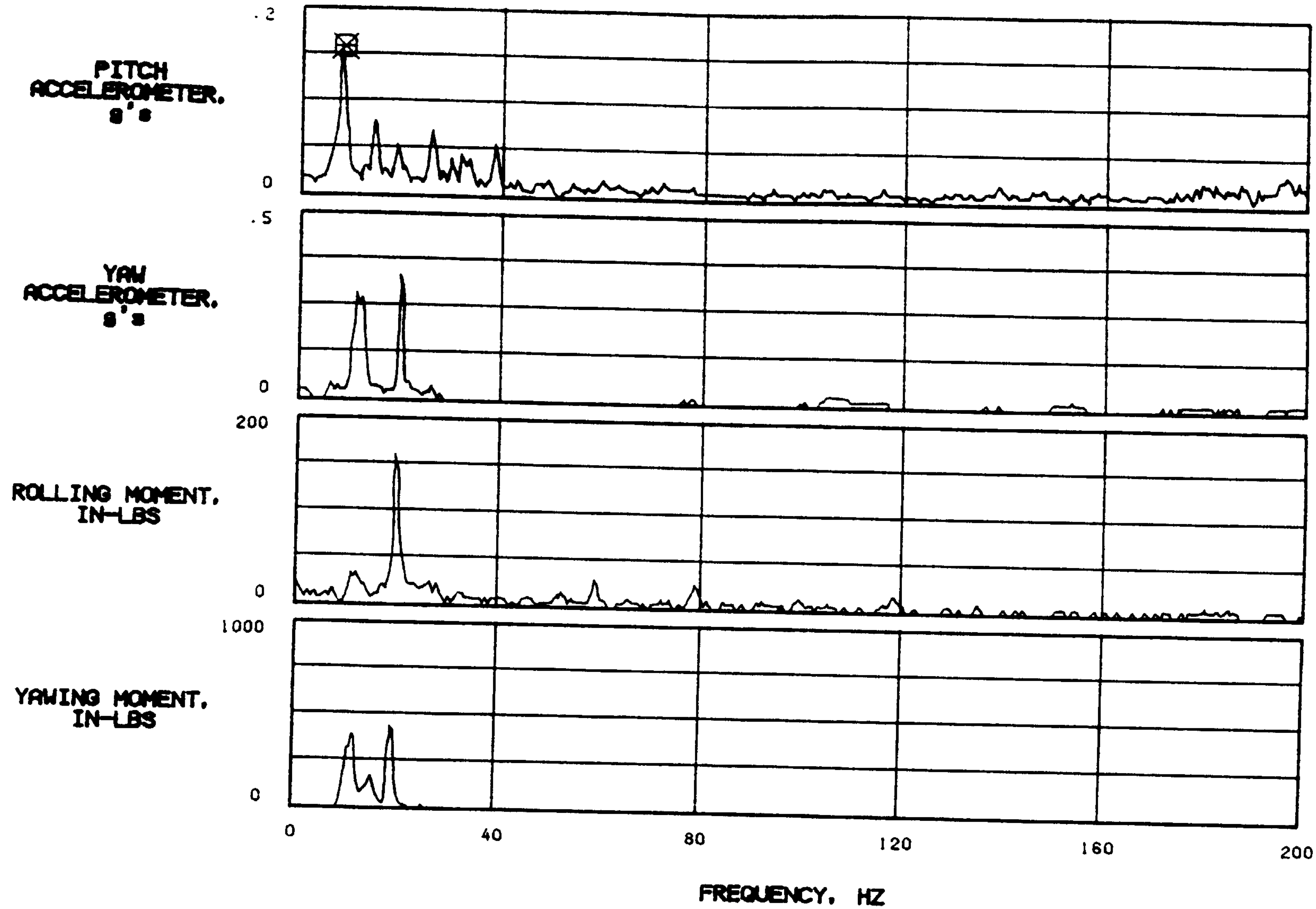

FIGURE 9. FREQUENCY SPECTRA FOR HIGH WING TRANSPORT MODEL, RUN 66, MACH 0.74, $\alpha \simeq 4.9°$ - TRIP CONDITION DUE TO PITCH BUFFET

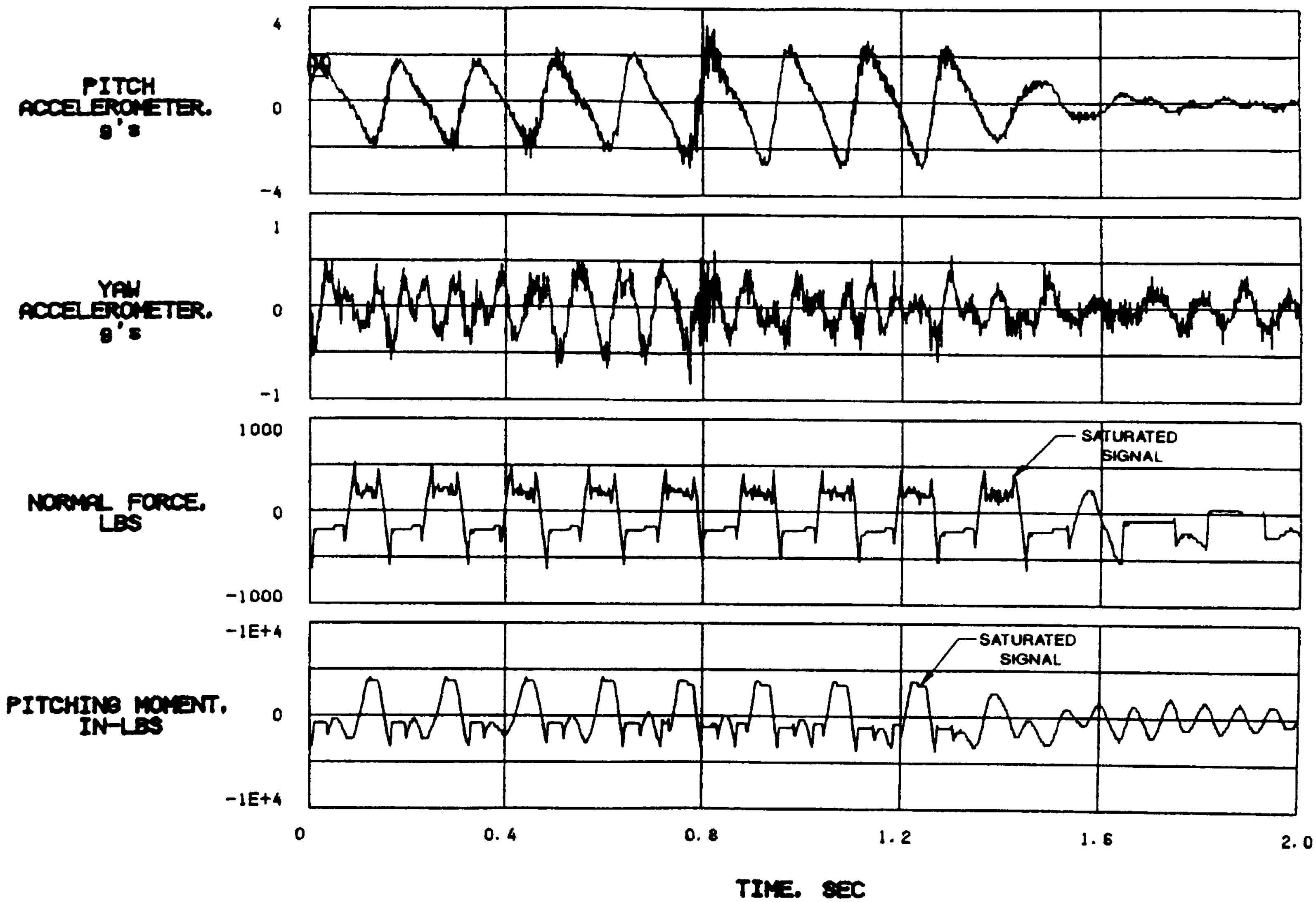

FIGURE 10. DYNAMIC RESPONSE TIME HISTORIES FOR HIGH WING TRANSPORT MODEL, RUN 66, MACH 0.74, $\alpha \simeq 4.9°$ - TRIP CONDITION DUE TO PITCH BUFFET

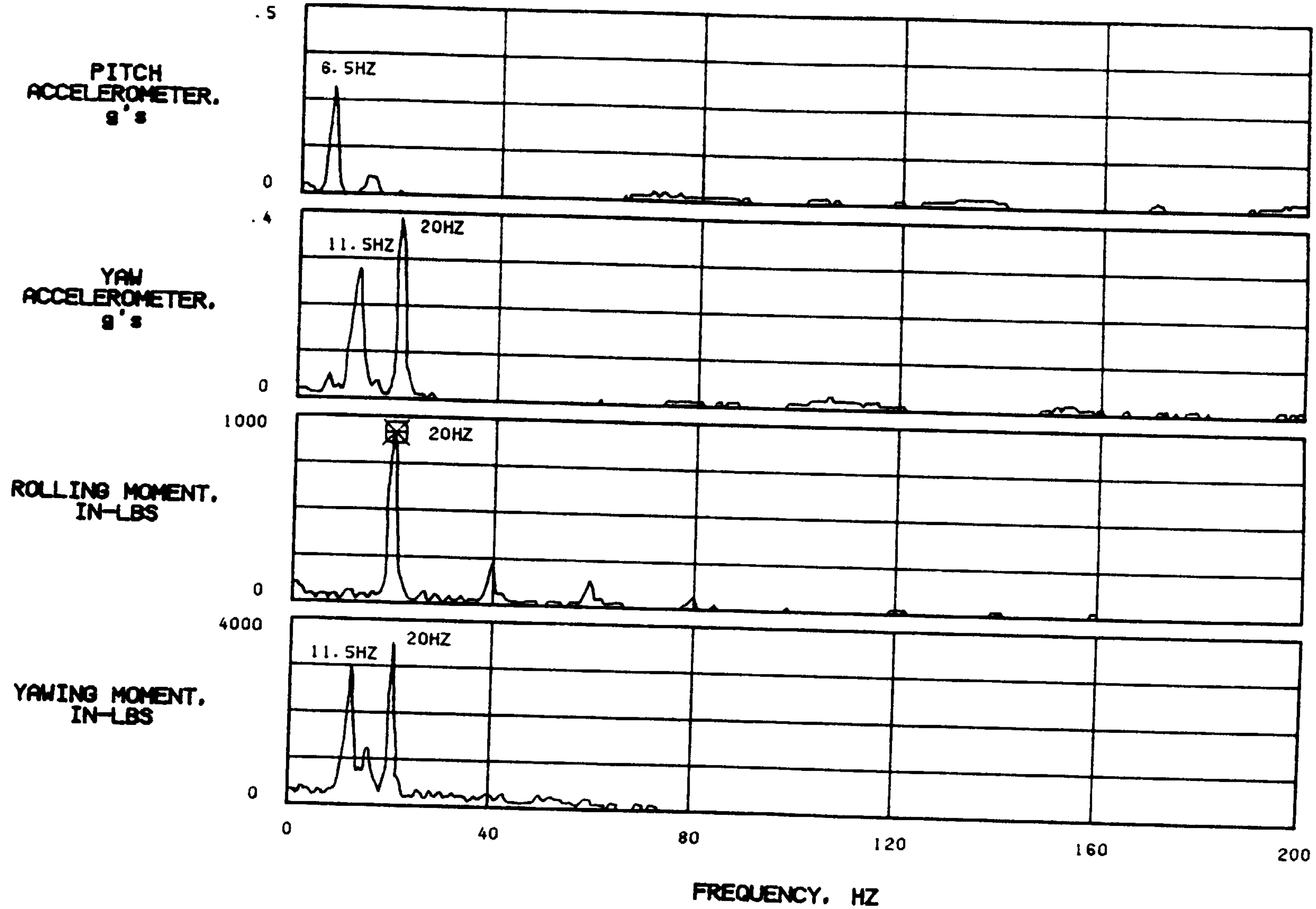

FIGURE 11. FREQUENCY SPECTRA FOR HIGH WING TRANSPORT MODEL, RUN 72, MACH 0.77 - ROLL BUFFET (BUZZ) CONDITION

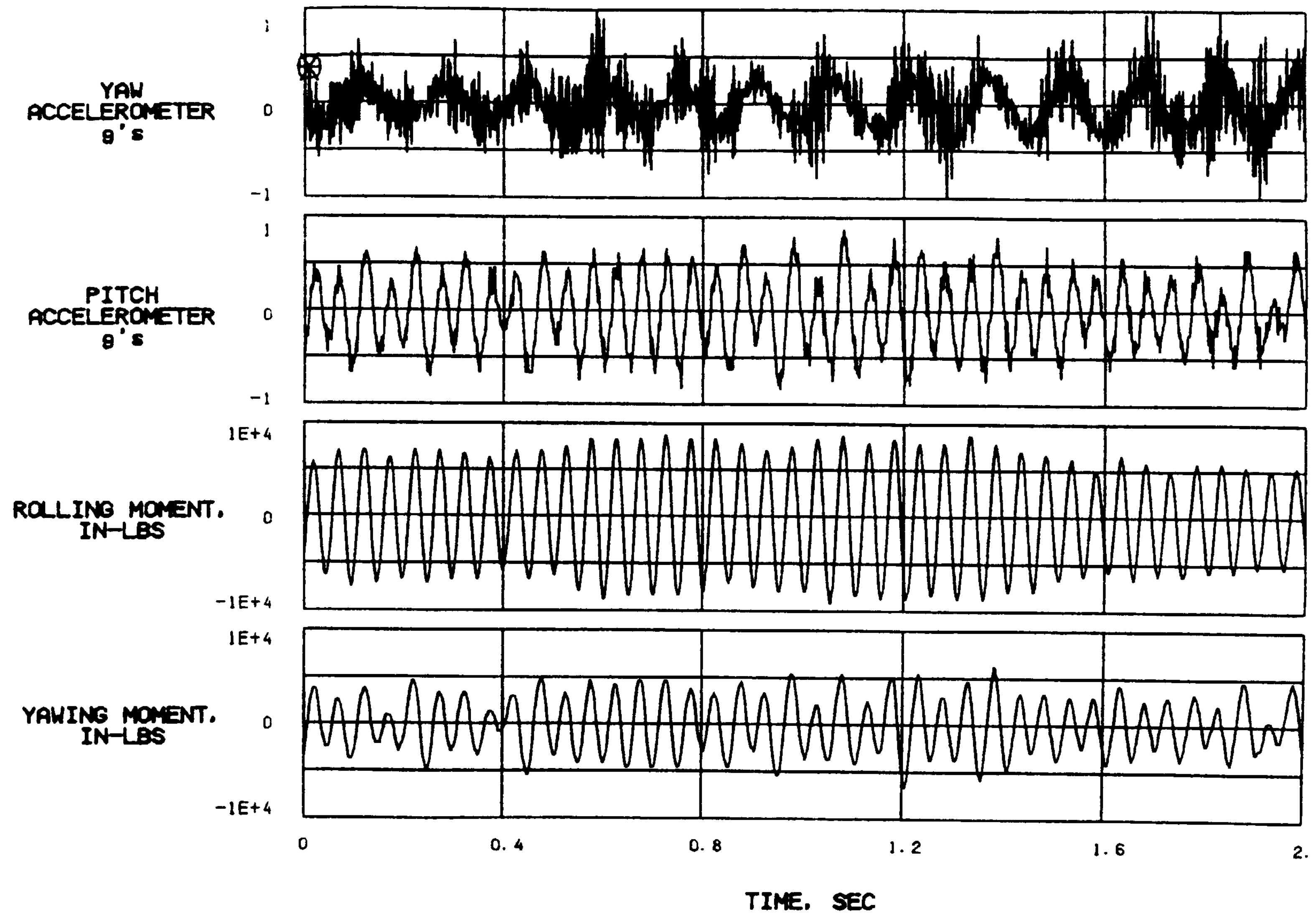

FIGURE 12. DYNAMIC RESPONSE TIME HISTORIES FOR HIGH WING TRANSPORT MODEL ILLUSTRATING ROLL BUFFET RESPONSE, RUN 72, MACH 0.77

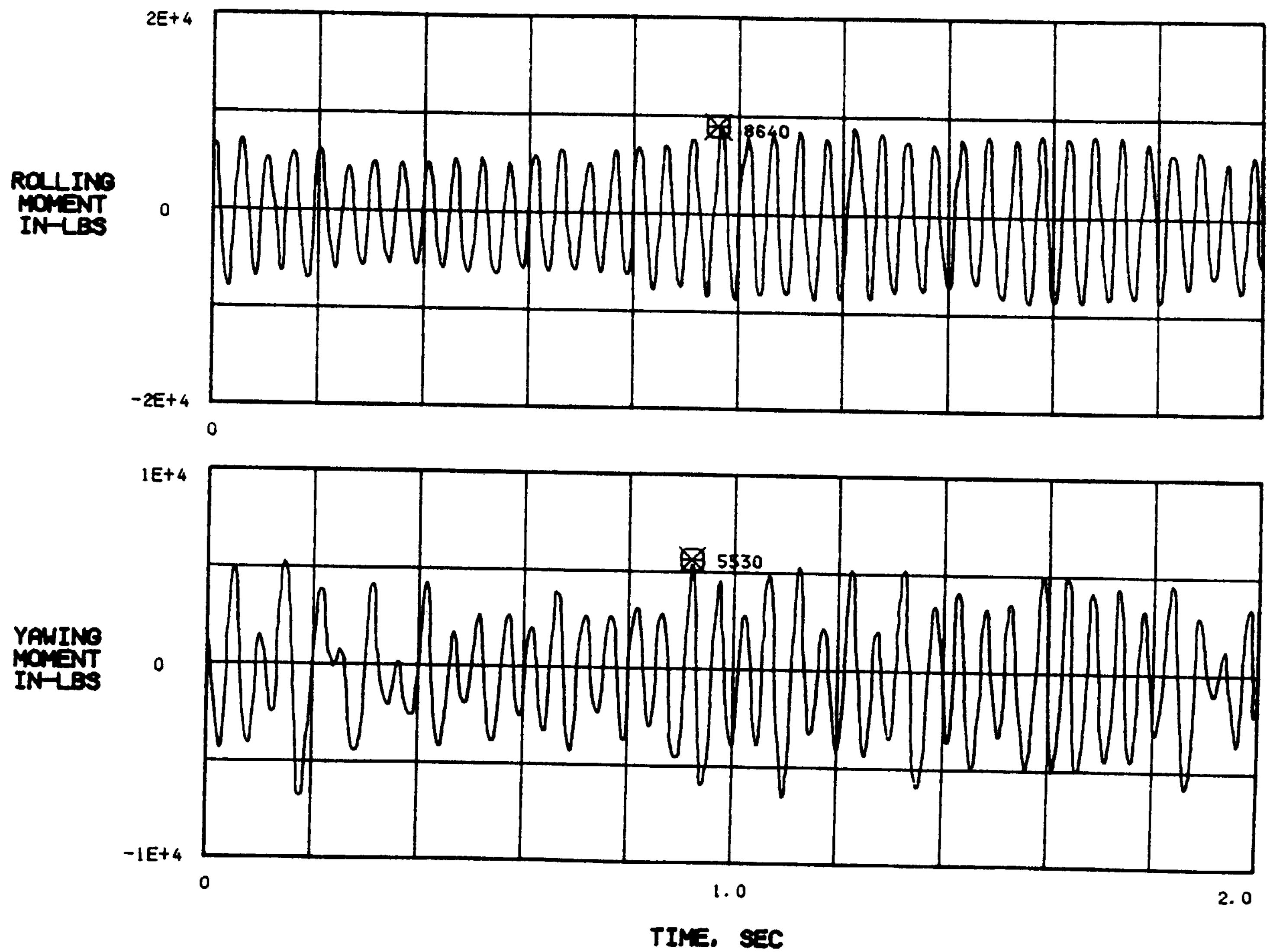

FIGURE 13. BALANCE ROLLING MOMENT AND YAWING MOMENT TIME HISTORIES FOR HIGH WING TRANSPORT MODEL, ILLUSTRATING ROLL BUFFET CONDITION, RUN 72, MACH 0.77

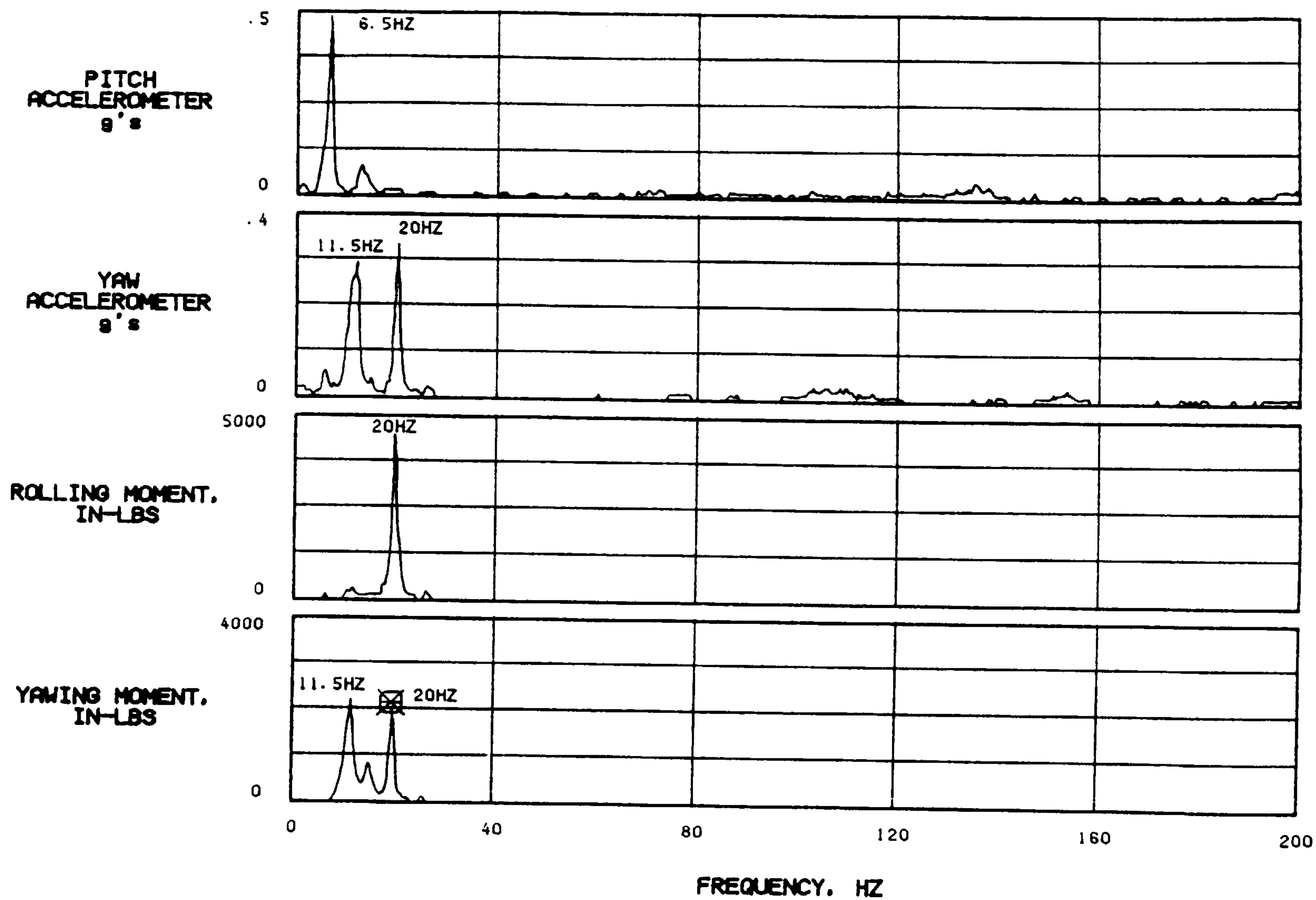

FIGURE 14. FREQUENCY SPECTRA FOR HIGH WING TRANSPORT MODEL - RUN 77, MACH 0.77, $\alpha \simeq 4.3°$ - TRIP CONDITION

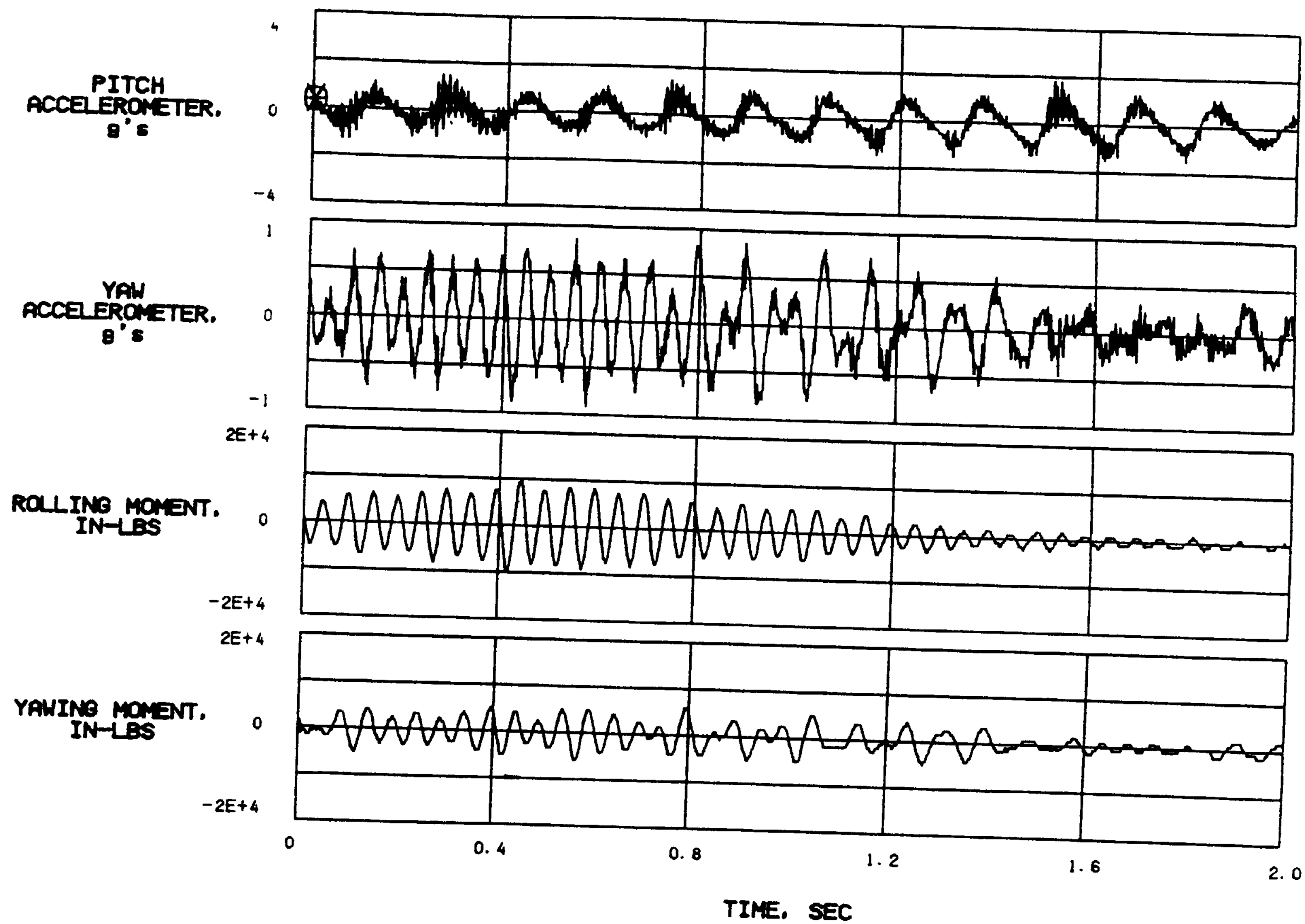

FIGURE 15. DYNAMIC RESPONSE TIME HISTORIES FOR HIGH WING TRANSPORT MODEL ILLUSTRATING ROLL BUFFET, RUN 77, MACH 0.77, $\alpha \simeq 4.3°$ - TRIP CONDITION (PITCH TO HOME)

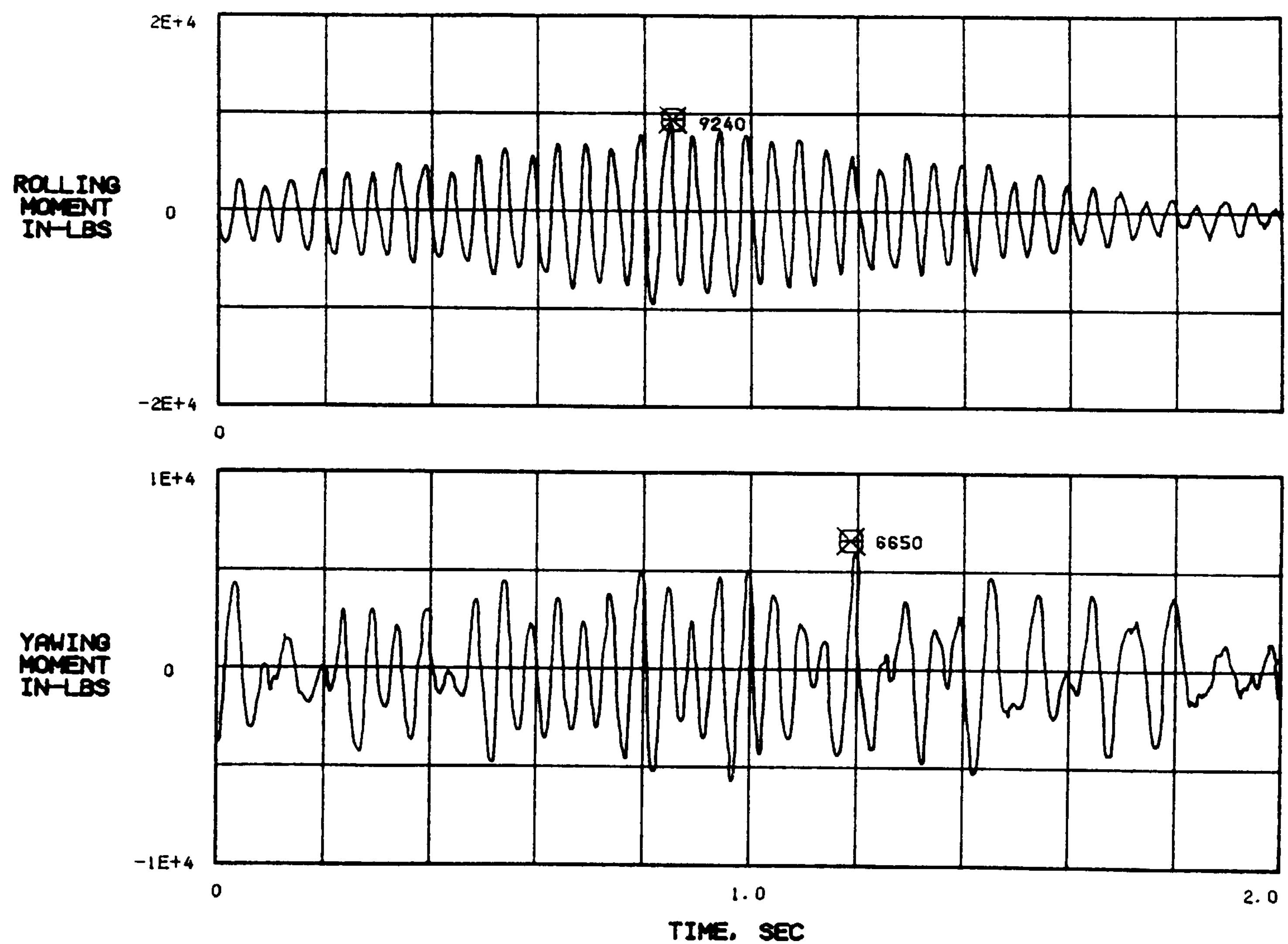

FIGURE 16. DYNAMIC RESPONSE TIME HISTORIES FOR HIGH WING TRANSPORT MODEL, ROLL AND YAW MOMENT, RUN 77, MACH 0.77, $\alpha \simeq 4.3°$ - TRIP CONDITION

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13. ABSTRACT *(Maximum 200 words)*

This paper documents recent experiences with measuring the dynamic response characteristics of a commercial transport and a military transport model during full scale Reynolds number tests in the National Transonic Facility. Both models were limited in angle of attack while testing at full scale Reynolds number and cruise Mach number due to pitch or stall buffet response. Roll buffet (wing buzz) was observed for both models at certain Mach numbers while testing at high Reynolds number. Roll buffet was more severe and more repeatable for the military transport model at cruise Mach number. Miniature strain-gage type accelerometers were used for the first time for obtaining dynamic data as a part of the continuing development of miniature dynamic measurements instrumentation for cryogenic applications. This paper presents the results of vibration measurements obtained for both the commercial and military transport models, and documents the experience gained in the use of miniature strain gage type accelerometers.

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