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GROUND SHAKE TEST OF THE BOEING MODEL 360 HELICOPTER AIRFRAME

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Contract NAS1-17497

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

FOREWORD

Boeing Helicopters, together with other U.S. helicopter manufacturers, is engaged in a finite element applications program designed to emplace in the United States a superior capability to utilize finite element analysis models in support of helicopter airframe structural design. The Boeing effort is being performed under U.S. Government Contract NAS1-17497. The contract is monitored by NASA Langley Research Center, Structures Directorate.

This report reviews the test plan and presents results for a shake test of the Boeing Model 360 helicopter. Results of this test will serve as the basis for validation of a finite element vibration model of the helicopter being formed under a different task of this contract.

Key NASA and Boeing personnel in the program are listed below:

NASA Langley

P. H. Clark, Contracting Officer

J. W. Owens, Contract Specialist

J. H. Cline, Technical Representative

R. G. Kvaternik, Leader, Rotorcraft Structural Dynamics Group

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1.0 Introduction

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INTRODUCTION

The NASA Langley Research Center is sponsoring a rotorcraft structural dynamics program with the overall objective to establish in the United States a superior capability to utilize finite element analysis models for calculations to support industrial design of helicopter airframe structures. Viewed as a whole, the program is planned to include efforts by NASA, universities, and the U.S. helicopter industry. In the initial phase of the program, teams from the major U.S. manufacturers of helicopter airframes will apply extant finite element analysis methods to calculate static internal loads and vibrations of helicopter airframes of both metal and composite construction, conduct laboratory measurements of the structural behavior of these airframes, and perform correlations between analysis and measurements to build up a basis upon which to evaluate the results of the applications. To maintain the necessary scientific observation and control, emphasis throughout these activities will be on advance planning, documentation of methods and procedures, and thorough discussion of results and experiences, all with industry-wide critique to allow maximum technology transfer between companies. The finite element models formed in this phase will then serve as the basis for the development, application, and evaluation of both improved modeling techniques and advanced analytical and computational techniques, all aimed at strengthening and enhancing the technology base which supports industrial design of helicopter airframe structures. Here again, procedures for mutual critique have been established, and these procedures call for a thorough discussion among the program participants of each method prior to the applications and of the results and experiences after the applications. The aforementioned rotorcraft structural dynamics program has been given the acronym DAMVIBS (Design Analysis Methods for VIBrationS).

This report presents the results of an effort under the DAMVIBS program by Boeing Helicopters to plan, perform and discuss a ground shake test of the Boeing Model 360 helicopter airframe.

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2.0 Description of Boeing Model 360 Helicopter

DESCRIPTION OF BOEING MODEL 360 HELICOPTER

The Model 360 prototype is a tandem rotor helicopter with a rear loading ramp designed for aerial transport of passengers and/or cargo. The airframe is basically an all-composite airframe using modularized construction techniques. Design gross weight is 30,500 pounds. The rotor system is a four-bladed counter-rotating design with a normal speed of 269 RPM. Primary power is provided by two T55-L-11 turbo-shaft engines mounted inside of the aft pylon. The landing gear configuration is a retractable design with a single forward gear and dual aft gear. Normal crew is a pilot, copilot and crew chief.

DESCRIPTION OF BOEING MODEL 360 HELICOPTER

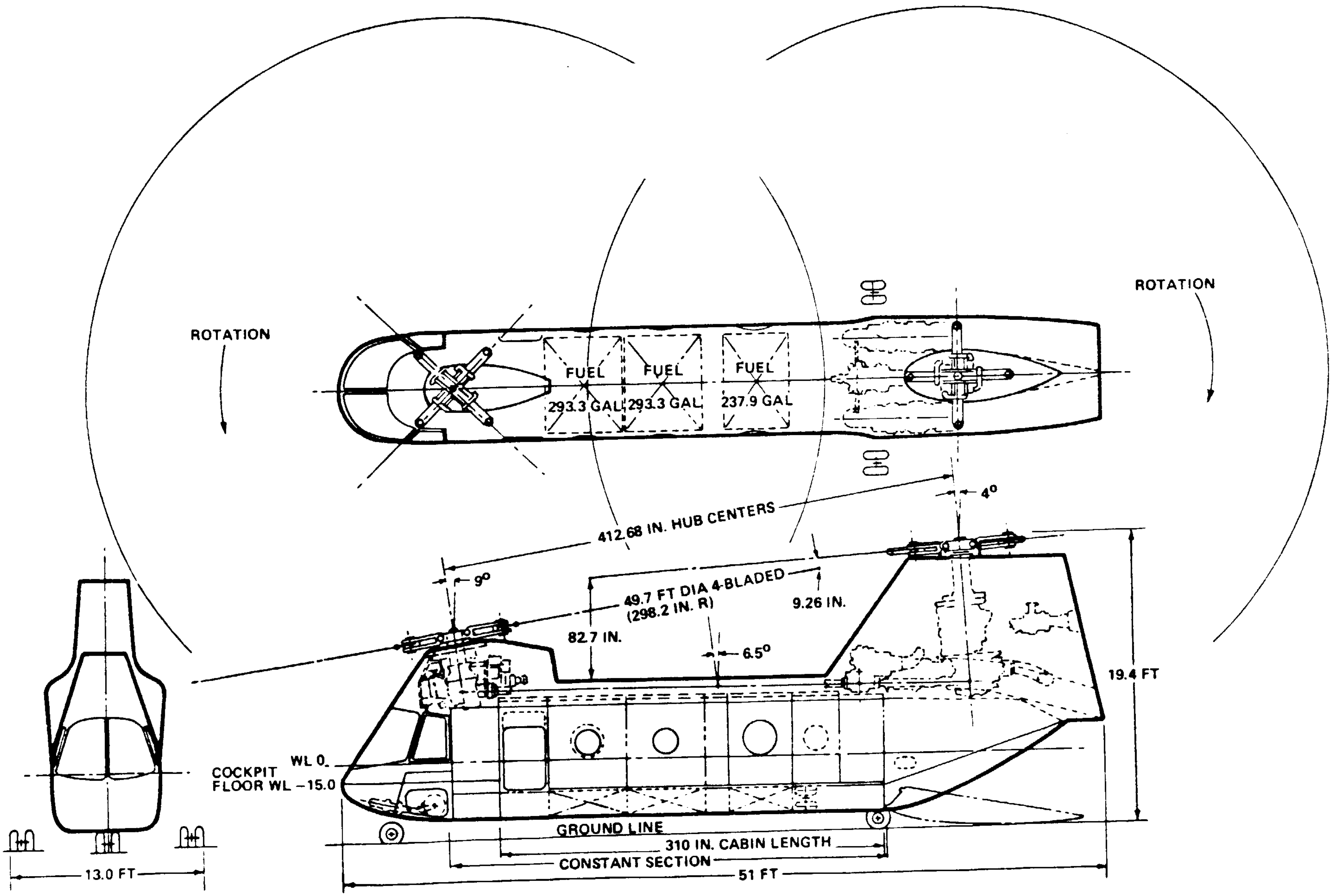
MODEL 360 OVERALL DIMENSIONS AND GENERAL ARRANGEMENT

The accompanying three-view drawing shows the general arrangement and typical overall dimensions for the Model 360 prototype. Overall length exclusive of the rotors is 51 feet. The center to center rotor dimension is 34.39 feet and the rotor diameter is 49.7 feet. Including the rotors and landing gear, the overall length and width are 83.3 and 13 feet, respectively.

Two Lycoming T55-L-11 engines drive 90° angle gearboxes and cross shafts into a combining transmission. The combining transmission, in turn, drives interconnect shafts to the forward and aft rotor transmissions. The overall gear ratio is 64.045 which reduces the power turbine speed to the normal rotor speed of 269 RPM.

The airframe is of all composite construction with a low frontal area. The cockpit contains dual pilot/copilot stations and all accompanying controls and instruments. The main cabin is a constant section with a forward left-hand escape hatch, a forward right-hand cabin door and an aft ramp. An aft pylon structure bridges the ramp and supports the aft transmission and rotor, the engines and an auxiliary power unit. Fuel is contained in three crashworthy cells below the cabin floor.

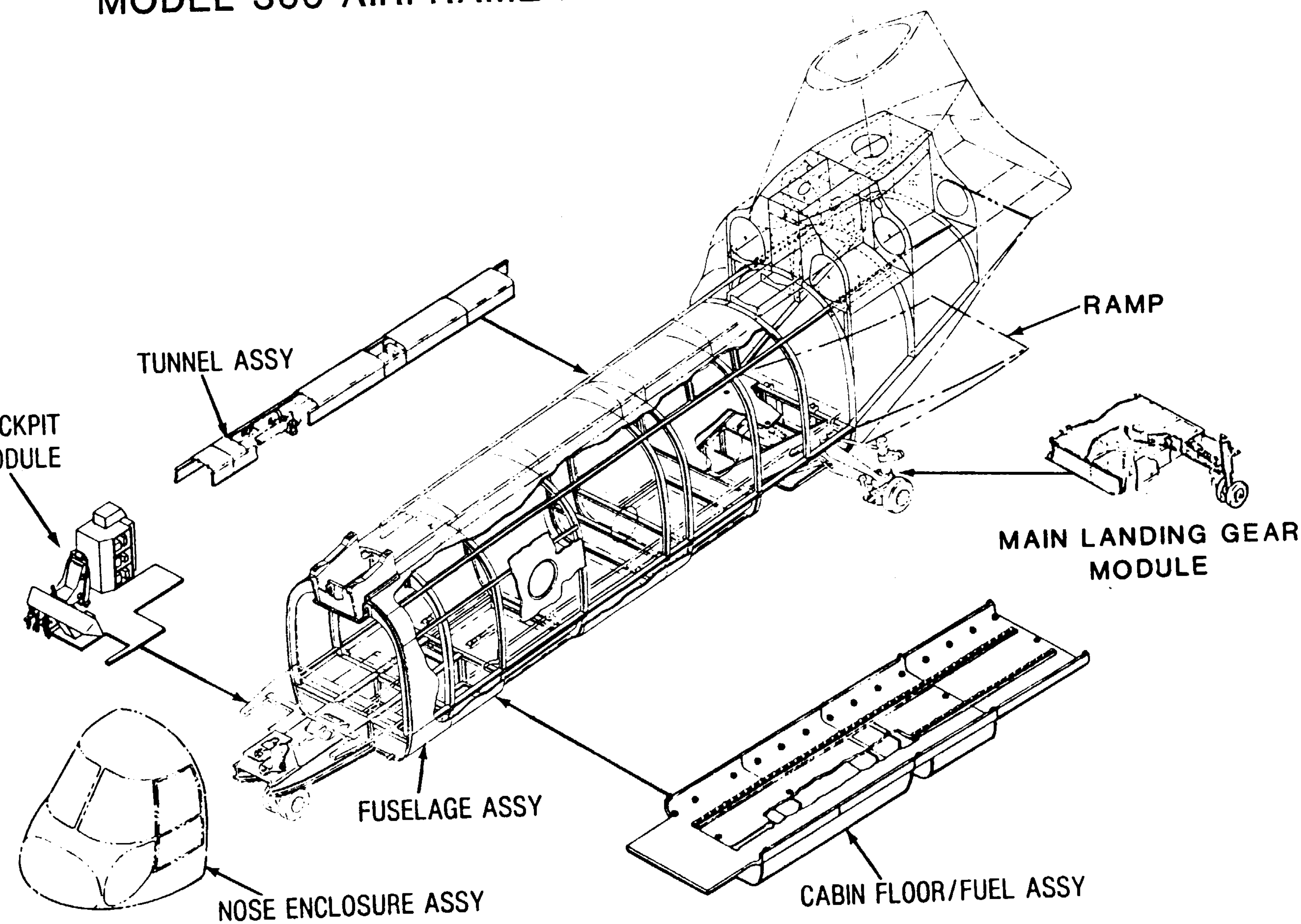
MODEL 360 OVERALL DIMENSIONS AND GENERAL ARRANGEMENT



MODEL 360 AIRFRAME AND SUBSYSTEM MODULES

The Model 360 airframe consists of seven subsystem modules as illustrated in this figure. These subsystems include the tunnel, cockpit module, nose enclosure, fuselage, ramp, main landing gear module and cabin floor/fuel assembly. The tunnel, ramp and nose enclosure are considered to be nonstructural since they are designed to neither contribute to the overall stiffness nor support any major components. The cockpit module and cabin floor/fuel assembly, on the other hand, support significant masses. The dynamic behavior of both of these subsystem modules is controlled by supporting the modules on mass-tuned, anti-resonant isolators.

MODEL 360 AIRFRAME AND SUBSYSTEM MODULES

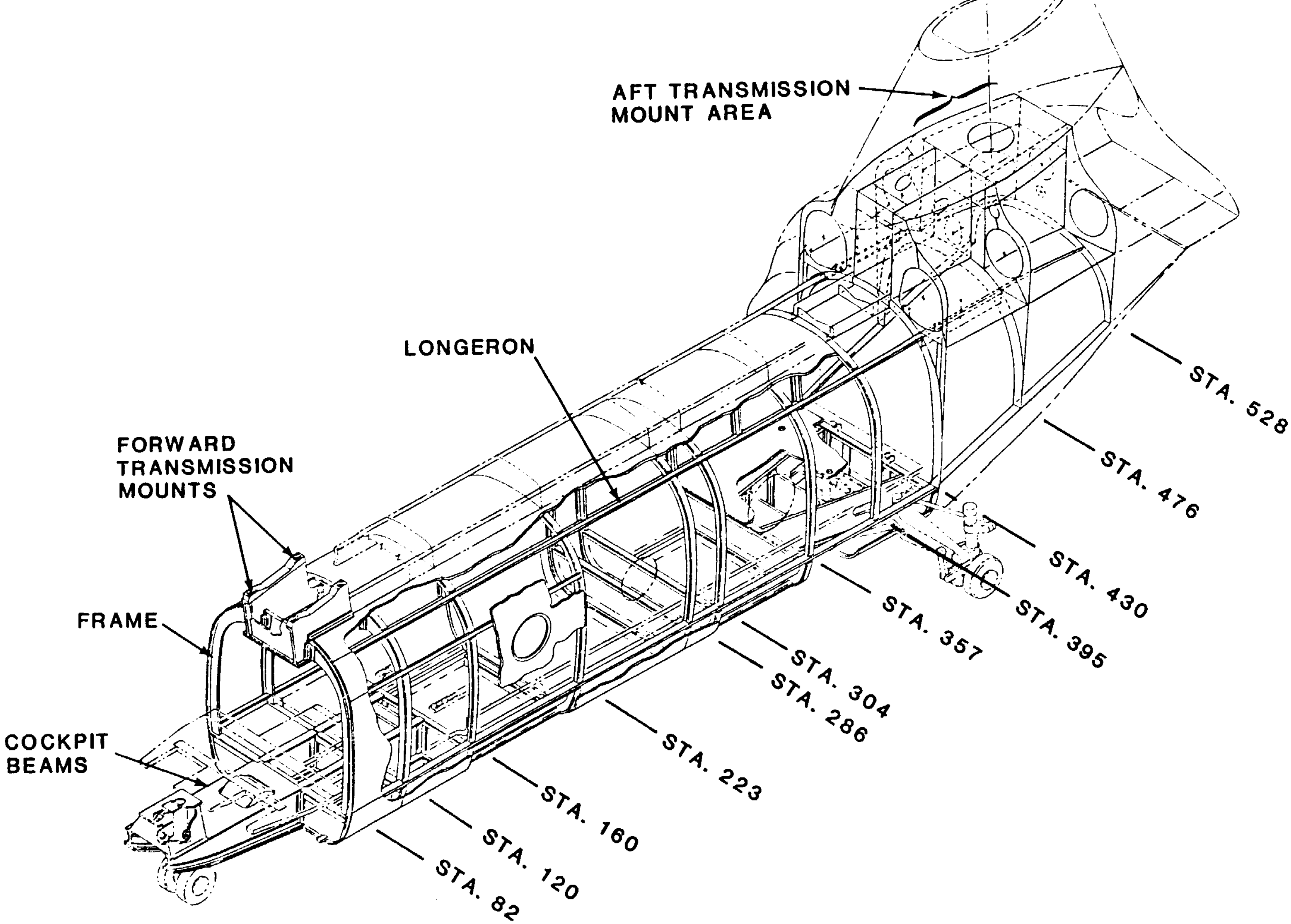


MODEL 360 PRIMARY STRUCTURE

The Model 360 has an all composite semi-monocoque fuselage with a primary structure of frames, longerons and stressed, honeycomb-sandwich, skin panels and bulkheads. Frames are located only where major concentrated loads enter the aircraft, leading to skin panel sizes which vary from approximately 2 foot by 6 foot to 6 foot by 6 foot. At major frames in the cabin section, deep webs in the frame below the floor line aid in distribution of loads. Four main longerons are sized to carry overall fuselage vertical and lateral bending loads. All major components are mixed modulus construction to meet strength and stiffness requirements.

Butt-line beams bridge the two major frames at Stations 82 and 120 to support the forward transmission. The two beams which support the cockpit are cantilevered forward of Station 82 and bridge the two frames (Stations 120 and 160) aft of Station 82. A large double-box structure bridging the frames at Stations 430, 476 and 528 supports the aft transmission (transmission mounted between Stations 476 and 528) and transfers the rotor loads to the lower fuselage structure. Assembly of the major modules is achieved by a bonded/bolted joining of the subassemblies. Bolts are used to provide pressure during the adhesive cure and are sized to carry the design limit loads as a redundant load path.

MODEL 360 PRIMARY STRUCTURE



MODEL 360 FUSELAGE ASSEMBLY

A photograph of the partially completed fuselage assembly is shown on the following page. Visible in the photograph are the access for the forward left-hand escape hatch, a portion of the cockpit beams and the partially completed forward transmission support structure.

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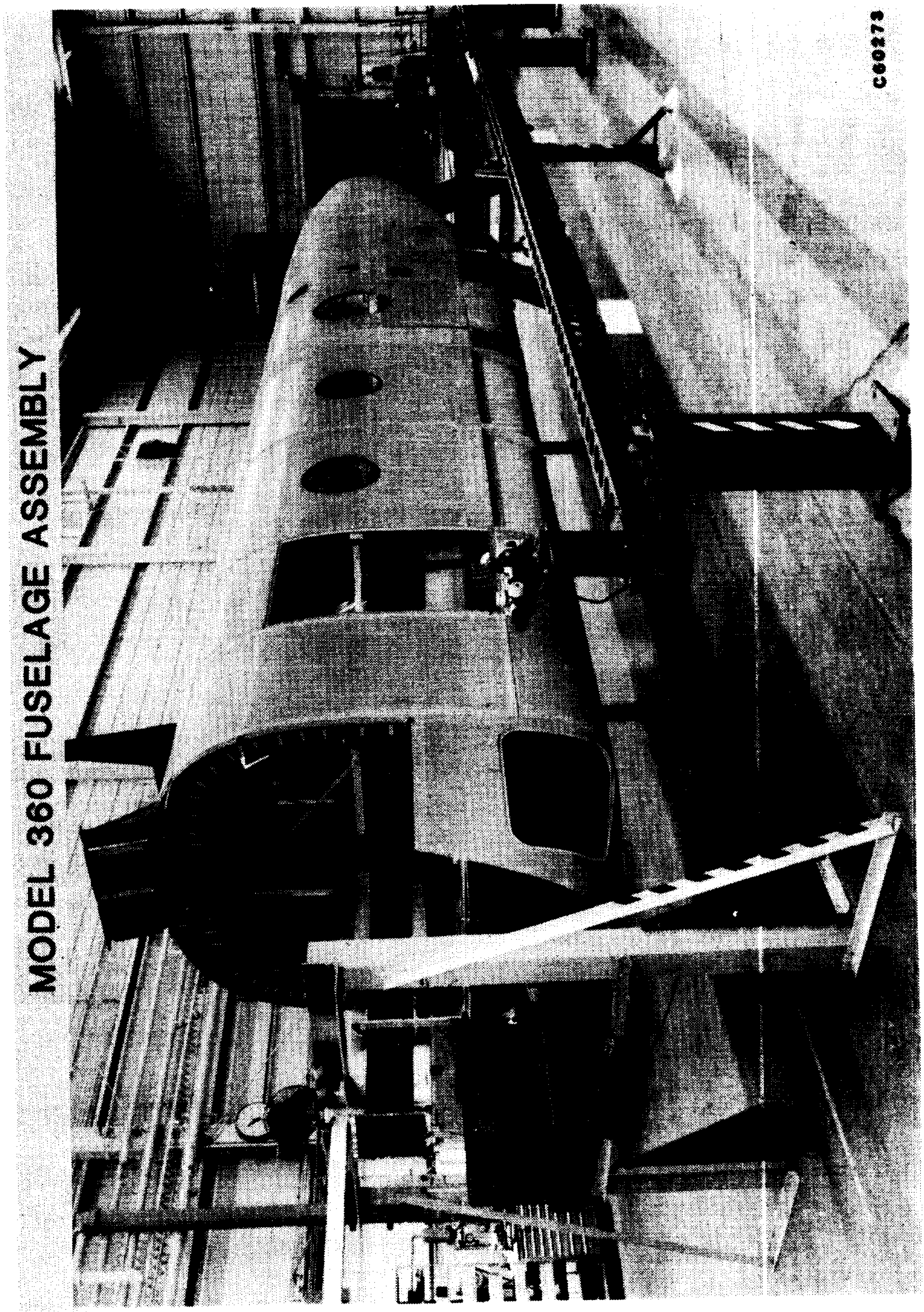

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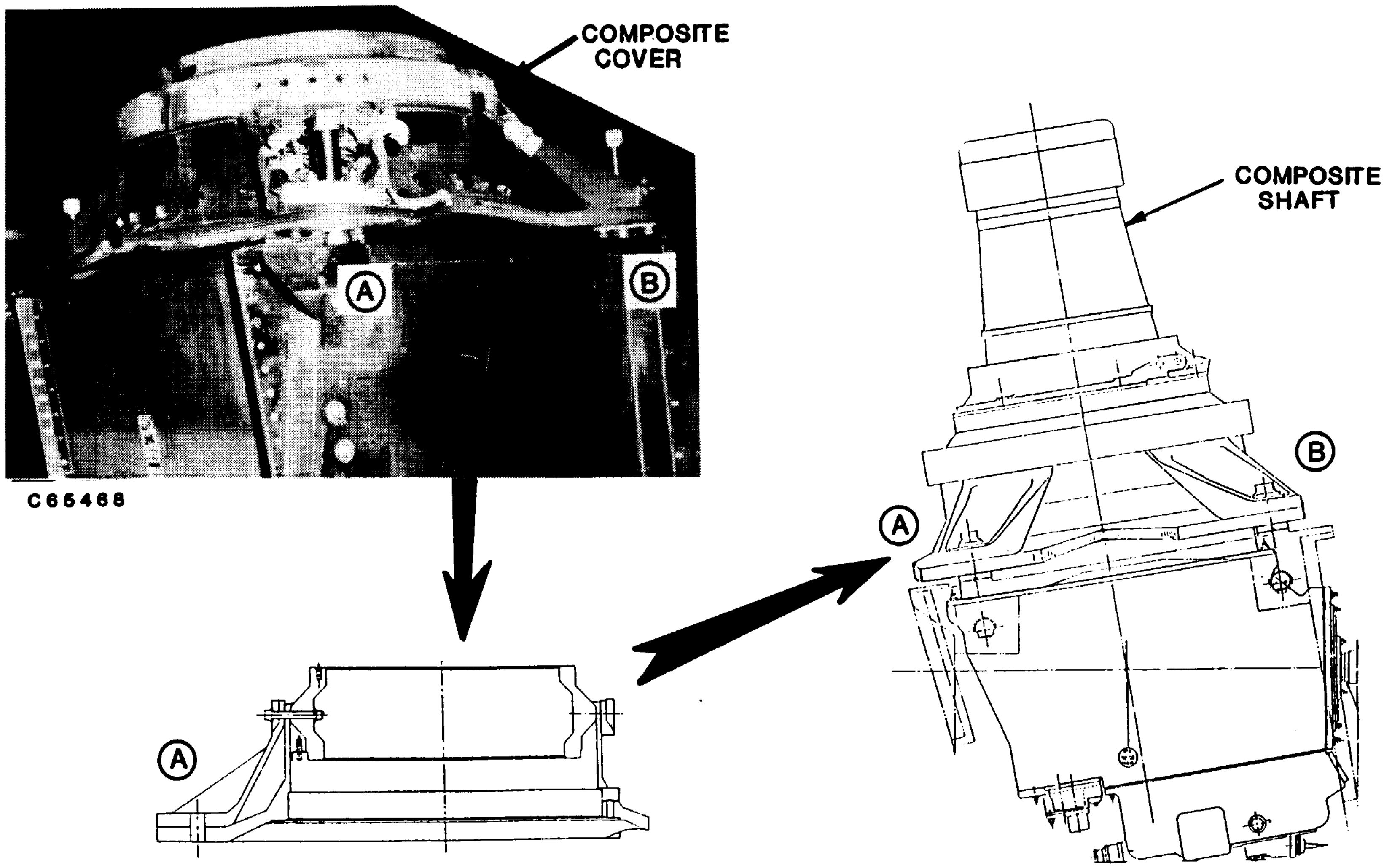
MODEL 360 FORWARD TRANSMISSION AND ROTOR SHAFT

As shown in this illustration, the Model 360 utilizes a composite rotor shaft and transmission cover. The rotor shaft is cantilevered from the transmission with the load path to the airframe being through the transmission upper cover. Mechanically, the transmission is a modified CH-47C transmission.

MODEL 360 FORWARD TRANSMISSION AND ROTOR SHAFT



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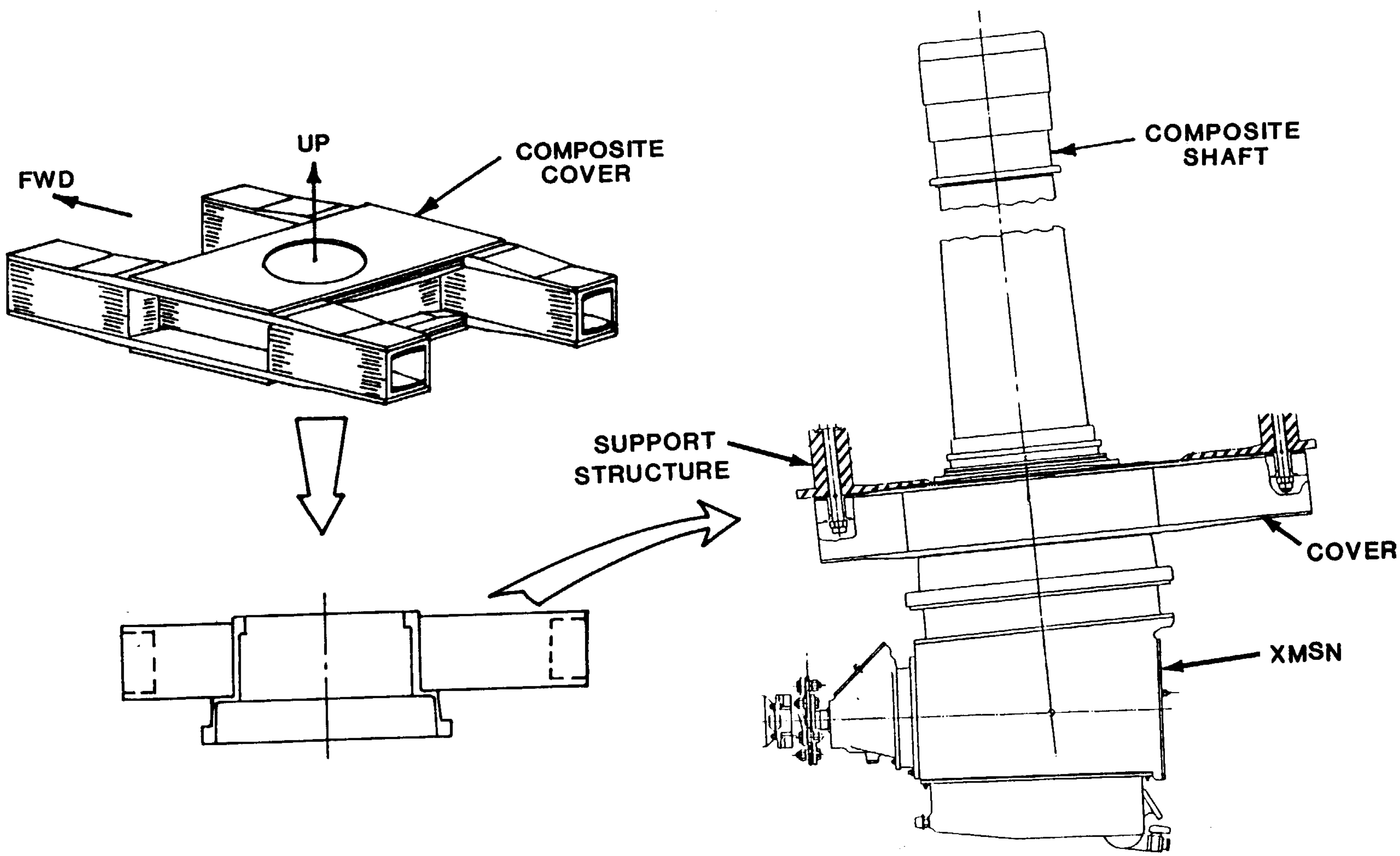
MODEL 360 AFT TRANSMISSION AND ROTOR SHAFT

Functionally, the aft rotor installation is the same as the forward installation. In both cases, the rotor shaft is cantilevered from the transmission cover. However, as shown in this illustration, the configuration of the aft transmission cover is totally different. In addition, the structural attachment points are located above, rather than below, the transmission. The aft rotor shaft is also approximately three times longer than the forward rotor shaft.

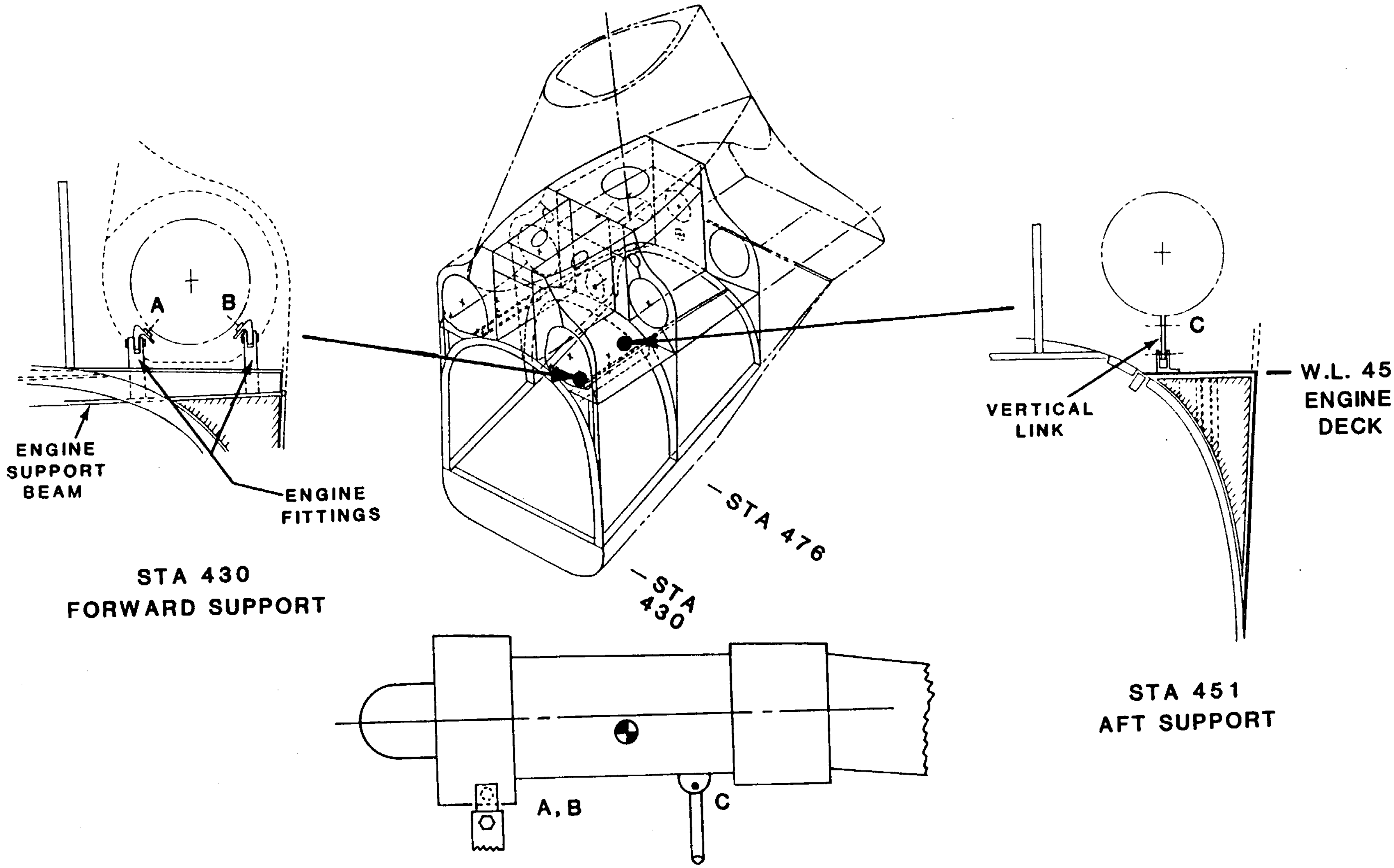
MODEL 360 AFT TRANSMISSION AND ROTOR SHAFT



MODEL 360 ENGINE SUPPORT STRUCTURE

The engines are mounted on the aft fuselage on either side of the aft pylon structure and are fully enclosed within the pylon aerodynamic fairing. The forward engine support fittings are attached to a lateral beam (extending the full width of the airframe) at Frame 430. The aft support fittings are attached to the engine deck at Station 451. At the forward engine support, two attachment points provide longitudinal, lateral and vertical load paths to the primary structure. At the aft support, a vertical link pivoted at both engine and airframe attachments provides only a vertical load path.

MODEL 360 ENGINE SUPPORT STRUCTURE

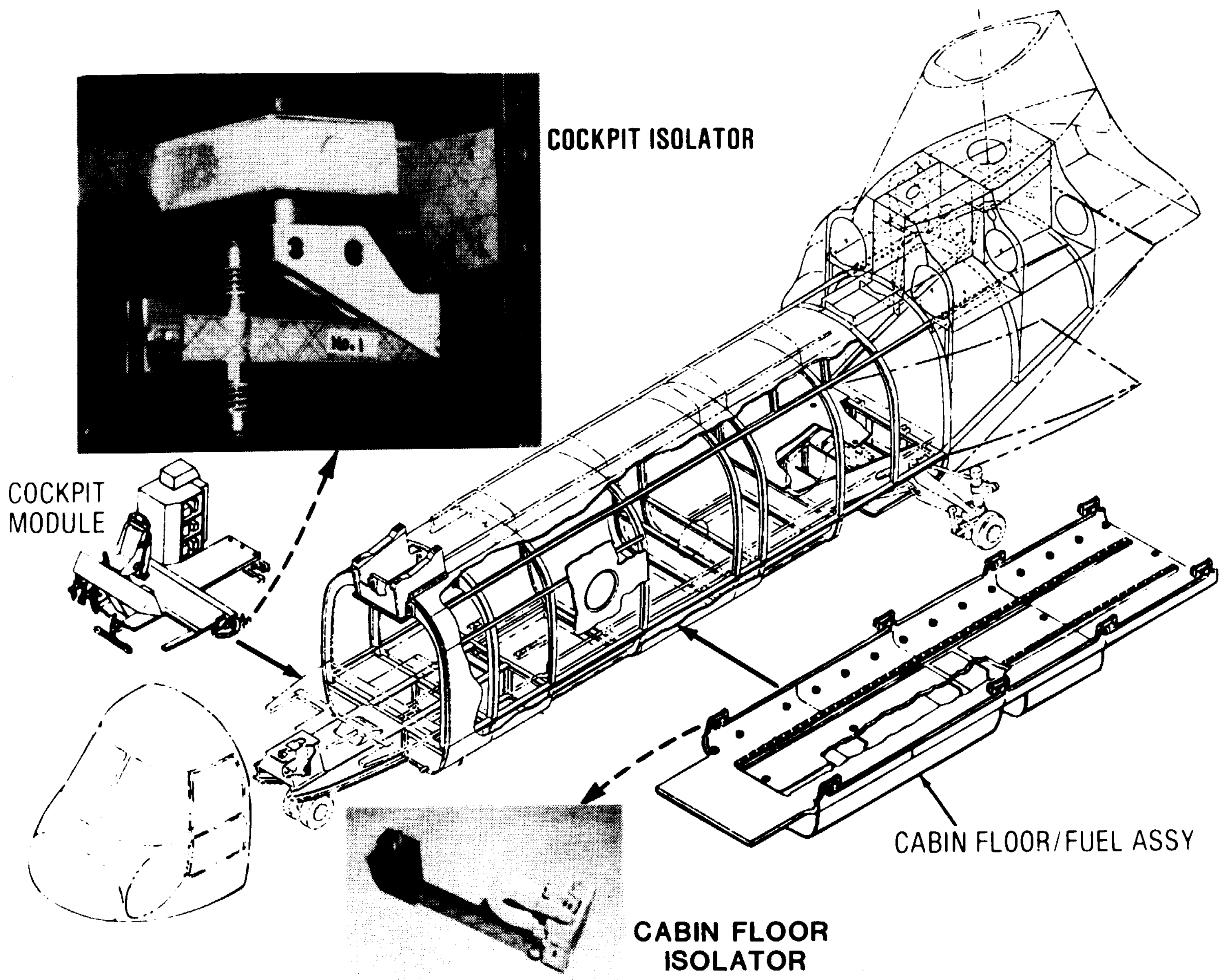


ISOLATED COCKPIT AND FLOOR/FUEL MODULES

The cockpit module and the cabin floor/fuel module are both isolated from the airframe by mass-tuned anti-resonant isolators. The anti-resonant isolation is stiff at low frequencies and dynamically soft at the tuned isolation frequency.

The cockpit isolators are tuned to minimize cockpit vibration at both 4/rev (blade passage frequency) and 8/rev. At 4/rev, the isolators act in the vertical, lateral, pitch and roll axes. Isolation at 8/rev is in the vertical direction only. The floor/fuel isolators are single frequency units designed to provide only 4/rev vertical isolation.

ISOLATED COCKPIT AND FLOOR/FUEL MODULES



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3.0 Test Objective and Approach

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TEST OBJECTIVE AND APPROACH

The primary objective of the shake test is to provide measured airframe vibration response which will be used to evaluate a NASTRAN Finite Element Vibration Model of the Boeing Model 360 helicopter airframe. To this end, detailed frequency response and mode shape data will be obtained for a variety of conditions including:

- Independent excitation at both rotor hubs.
- All flight hub force and moment directions except torque.
- Frequency range from 4 to 40 Hz.

TEST OBJECTIVE AND APPROACH

OBJECTIVE

- PROVIDE MEASURED AIRFRAME VIBRATION RESPONSE TO EVALUATE THE NASTRAN FINITE ELEMENT VIBRATION MODEL.

APPROACH

- OBTAIN DETAILED FREQUENCY RESPONSE AND MODE SHAPES UNDER CONDITIONS WHICH EXERCISE MAJOR ELEMENTS OF THE MODEL.

  —EXCITATION AT BOTH FORWARD AND AFT HUBS

  —ALL FLIGHT HUB FORCE DIRECTIONS EXCEPT TORQUE

  —FREQUENCY RANGE FROM 4 TO 40 Hz

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4.0 Test Guides

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4.1 Actual Versus Planned Guides - Summary

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TEST GUIDES

ACTUAL VERSUS PLANNED GUIDES - SUMMARY

An initial test plan was written and presented at a Government/industry conference. During the course of the test, several deviations from the initial plan were required. A more detailed description of the initial plan and deviations from it are contained in the following section.

Principal deviations from the initial guides were as follows:

1. Planned uses of 100% rotor mass was not implemented. Based on preliminary results from a coupled rotor/fuselage analysis, only 70% of blade flapping mass was used.

2. Swing test of aft rotor transmission was not performed due to schedule constraints.

3. Vibratory loads were adjusted based on observed aircraft response. Forward pitch excitation was terminated at 35 Hz due to internal engine response.

4. A multiple support point system was used to provide a floating shaker support point which permitted better control of shaker position.

5. A side-by-side shaker arrangement was used for vertical excitation in lieu of a tandem configuration to obtain symmetric drive point motions in the presence of coupled vertical/pitch response.

6. Based on initial testing, two measurement locations were modified and three additional locations provided.

TEST GUIDES

ACTUAL VERSUS PLANNED GUIDES – SUMMARY

- HUB WEIGHT REDUCED FROM 100% TO 70% FLAPPING MASS ON BASIS OF COUPLED ROTOR/FUSELAGE ANALYSIS.
- AFT XMSN SWING TEST NOT IMPLEMENTED DUE TO SCHEDULE.
- VIBRATORY LOADING CONDITIONS MODIFIED ON BASIS OF OBSERVED RESPONSE.
- MULTIPLE SUPPORT POINT SYSTEM USED TO PROVIDE FLOATING SHAKER SUPPORT POINT FOR BETTER POSITIONING.
- SIDE-BY-SIDE VERTICAL SHAKER CONFIGURATION USED IN LIEU OF TANDEM CONFIGURATION TO OBTAIN SYMMETRIC DRIVE POINT MOTION IN PRESENCE OF COUPLED PITCH RESPONSE.
- TWO MEASUREMENT LOCATIONS MODIFIED AND THREE ADDITIONAL LOCATIONS PROVIDED ON BASIS OF INITIAL TESTING.

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4.2 General Measurement Requirements

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TEST GUIDES

GENERAL MEASUREMENT REQUIREMENTS

The requirements outlined on the accompanying page summarize the major steps to be accomplished in executing the task. These topics and related subjects will be addressed in this section.

TEST GUIDES

GENERAL MEASUREMENT REQUIREMENTS

- DEFINE AIRCRAFT CONFIGURATION
- SUSPEND THE AIRFRAME TO SIMULATE FREE-BODY RESPONSE
- APPLY VIBRATORY LOADS TO AIRFRAME
- MEASURE AND RECORD INDUCED AIRFRAME RESPONSE
- PROCESS MEASURED RESPONSE DATA
- PREPARE PLOTS OF PROCESSED DATA

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4.3 Test Specimen

TEST GUIDES

TEST SPECIMEN - CONFIGURATION

The test specimen will be the Boeing Model 360 (M360) prototype all-composite airframe. The airframe will be in a stripped condition; i.e., only the basic structure will be utilized. Landing gear, the nose enclosure, ramp, doors, windows, hatches, fairings, avionics, controls, and other nonstructural items will not be installed. Isolation systems for the cockpit and cabin floor/fuel modules will be locked out. Ballast will be installed on cockpit and cabin floor/fuel modules (no fuel) to induce significant inertial loading into the structure.

Planned use of 100% static rotor mass was not implemented. Based on preliminary coupled rotor/fuselage analysis, only 70% of the blade flapping mass was included in the hub weight.

TEST GUIDES

TEST SPECIMEN - CONFIGURATION

- **TEST HUB FIXTURE EQUAL TO 100% ROTOR MASS**

  PLANNED USE OF 100% ROTOR MASS NOT IMPLEMENTED, WEIGHT REDUCED TO REFLECT ONLY 70% BLADE FLAPPING MASS.

- **STRIPPED AIRFRAME: LANDING GEAR, NOSE ENCLOSURE, RAMP, DOORS, WINDOWS, HATCHES, FAIRINGS, AVIONICS, CONTROLS AND OTHER NON-STRUCTURAL ITEMS WILL NOT BE INSTALLED**
- **COCKPIT AND CABIN FLOOR/FUEL MODULE ISOLATION SYSTEMS INACTIVE (LOCKED OUT)**
- **COCKPIT AND CABIN FLOOR/FUEL MODULES (NO FUEL) BALLASTED TO OBTAIN MEANINGFUL INERTIA LOADS ON PRIMARY STRUCTURE**

TEST GUIDES

TEST SPECIMEN - STATIC MEASUREMENTS

Static measurements will be performed to obtain the test specimen gross weight and center of gravity. The actual weight and moments of inertia will also be obtained for major weight items, such as, the hub test fixtures, rotor transmissions and shafts, and any dummy weight assemblies.

Planned swing test of aft rotor transmission not implemented due to schedule constraints.

TEST GUIDES

TEST SPECIMEN - STATIC MEASUREMENTS

DURING PREPARATION OF THE AIRFRAME, THE FOLLOWING STATIC MEASUREMENTS WILL BE OBTAINED:

- **TEST SPECIMEN WEIGHT AND CENTER OF GRAVITY**
- **ACTUAL WEIGHT OF HUB TEST FIXURES, ROTOR TRANSMISSIONS AND SHAFTS, AND ANY DUMMY WEIGHT ASSEMBLIES**
- **MOMENT OF INERTIA (SWING TEST) OF HUB FIXTURES AND ROTOR TRANSMISSIONS**

PLANNED SWING TEST OF AFT ROTOR TRANSMISSION NOT IMPLEMENTED

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4.4 Shake Test Facility

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TEST GUIDES

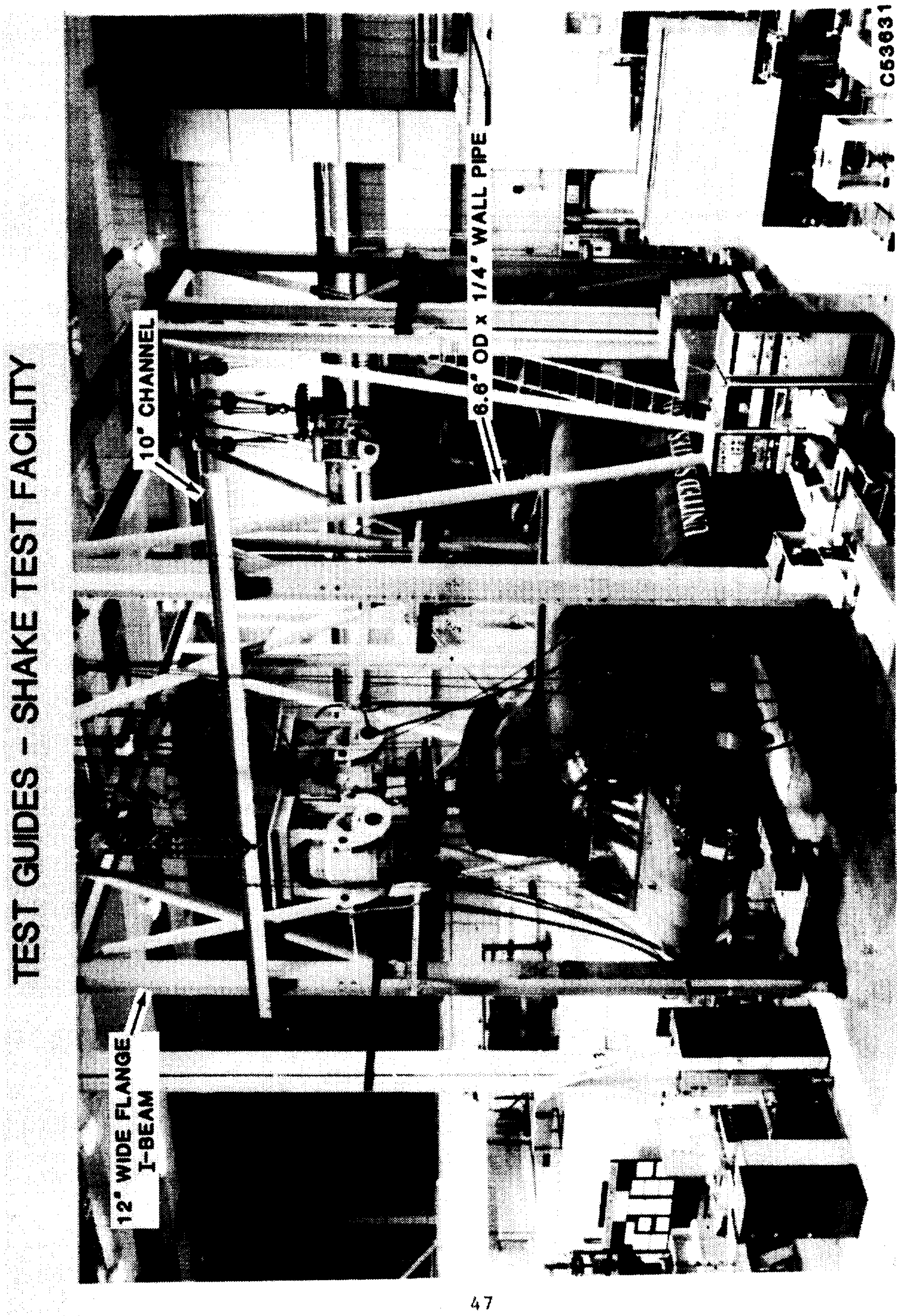
SHAKE TEST FACILITY

The accompanying photograph shows a CH-47D test aircraft suspended in the test rig. The shake test facility consists of a gantry fabricated from steel "erector set" I-beams with the following overall dimensions:

Length ----------------------	51 feet
Width -----------------------	22 feet
Height ----------------------	35 feet

Size of the major structural members are indicated for reference purposes. Total weight of the fixture is approximately 18.5 tons.

The aircraft is suspended from the rotor heads by a chain hoist, spring bank, wire rope assembly and a lifting eye. The spring banks, together with the overall pendulum length of the suspension, comprise a low-frequency suspension system which isolates the gantry from the aircraft.


TEST GUIDES - SHAKE TEST FACILITY
10" CHANNEL
6.6" OD x 1/4" WALL PIPE
12" WIDE FLANGE
I-BEAM
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4.5 Vibratory Loading Conditions

TEST GUIDES

CONTRACT VIBRATORY LOADING GOALS

The desired loading conditions outlined in the contract statement of work are summarized on the accompanying sheet. Observations relating to certain of these goals are as follows:

- With regard to hub torsional excitation, which may or may not be significant, correct implementation requires that the drive system be both free to rotate and preloaded between the engines and the rotors to remove system backlash. Satisfying these conditions does not appear feasible. It is noted also that NASTRAN structural models do not generally include the drive system degrees of freedom.

- The magnitudes of operational exciting levels at different rotor harmonics vary significantly. An exciting force value based on the operational level at the predominant blade passage frequency may excite excessive response at other frequencies.

- In the case of the M360, it is observed that the minimum desired test frequency (.2/rev) is in the region of the usual aircraft and shaker suspension frequencies. Further, the frequency is approximately 1/5 of the lowest expected modal frequency. Response data this far below the lowest mode does not appear to have any practical value.

TEST GUIDES

CONTRACT VIBRATORY LOADING GOALS

- **EXCITING FORCES APPLIED AT THE ROTOR HUBS**
- **ENCOMPASS ALL SIGNIFICANT ACTUAL HUB FORCES AND MOMENTS**
- **WITHIN EQUIPMENT CAPABILITY, STRIVE TO ACHIEVE LOADS UP TO ESTIMATED OPERATIONAL LEVELS**
- **FREQUENCY RANGE FROM 0.2/REV TO 8.8/REV (0.9 TO 39.5 Hz FOR MODEL 360)**

TEST GUIDES

VIBRATORY LOADING CONDITIONS

Planned loading conditions and deviations are presented on the accompanying chart. The rational behind each of the selected conditions is summarized below:

1) Frequency range - The minimum frequency is based on a consideration of the lowest estimated modal frequency and the operational limit of the vibration analysis equipment (quoted limit of the analyzer is 2.5 Hz) and accelerometers.

   Forward rotor pitch excitation terminated at 35 Hz to avoid audible internal engine response.

2) Force Shaping - This is considered to be the best approach to the problem of obtaining adequate response at the blade passage frequency while avoiding excessive response of low frequency fundamental modes.

3) Shaker Configuration and Load Levels - All forces and moments are included except hub torque. At the very least, meaningful data with torque excitation cannot be obtained without added complexity in both the test and analytical model. Magnitude of the loads at the blade passage frequency is based on previous shake test experience and estimated loads at the blade passage frequency.

   Force levels adjusted where it was judged necessary to either increase or reduce the observed aircraft response.

4) Load Level Variation - In airframes of conventional construction, non-linear response is observed with variation in force level. This non-linearity is attributed to clearance dimensions, working of riveted/bolted joints, and behavior of buckled skins. With composite construction, the latter two items are largely absent.

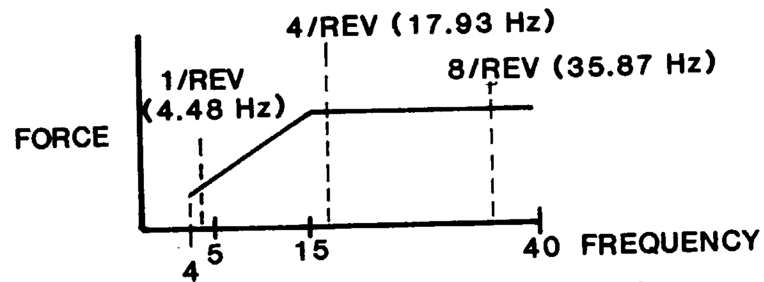
TEST GUIDES

VIBRATORY LOADING CONDITIONS

- **FREQUENCY RANGE: 4 TO 40 Hz (0.89 TO 8.92 PER REV)**

  FORWARD PITCH EXCITATION TERMINATED AT 35 Hz

- **FORCE SHAPING: RAMP 4 TO 15 Hz, CONSTANT 15 TO 40 Hz**



- **SHAKER CONFIGURATIONS AND LOAD LEVELS (EXCITATION APPLIED SINGLY):**

EXCITATION	FORCE OR MOMENT: FORWARD HEAD PLANNED	FORWARD HEAD ACTUAL	AFT HEAD PLANNED	AFT HEAD ACTUAL
VERTICAL (LB)	200 TO 800	200 TO 800	200 TO 800	150 TO 600
LATERAL (LB)	125 TO 500	200 TO 600	125 TO 500	100 TO 400
LONGITUDINAL (LB)	125 TO 500	200 TO 600	125 TO 500	100 TO 400
PITCH (FT-LB)	266 TO 1066	266 TO 667	266 TO 1066	266 TO 1066
ROLL (FT-LB)	266 TO 1066	266 TO 1066	266 TO 1066	266 TO 1066

- **LOAD LEVEL VARIATION (NON-LINEAR EFFECT): LIMITED RESPONSE DATA (LOCATIONS) AT 50% BASIC LOAD LEVEL FOR VERTICAL AND LONGITUDINAL HUB EXCITATION**

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4.6 Aircraft Suspension

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AIRCRAFT SUSPENSION

This figure shows the details of the suspension system which isolates the airframe from the support structure to simulate a free body condition. The chain hoists are used to raise the aircraft into the rig and control the attitude. The M360 rotor shaft axes are tilted forward (9 degrees forward, 4 degrees aft) and the aircraft will be suspended in a nose-up attitude to place both rotor shafts as near vertical as possible. This is desirable to facilitate shaker alignment.

A metal spring suspension is used to avoid creep problems experienced with bungee cord. The spring bank is composed of a holder and a number of coil tension springs. The number of springs is selected to obtain the softest suspension consistent with the spring capacity and aircraft gross weight. Vertical and pitch mode frequencies are controlled by the suspension stiffness. Lateral, longitudinal, roll and yaw mode frequencies are determined principally by the overall length of the suspension system. Typical measured rigid body frequencies for an aircraft similar to the M360 are as follows:

Vertical	1.60 Hz	Pitch	1.65 Hz
Lateral	0.20 Hz	Roll	0.70 Hz
Longitudinal	0.30 Hz	Yaw	0.30 Hz

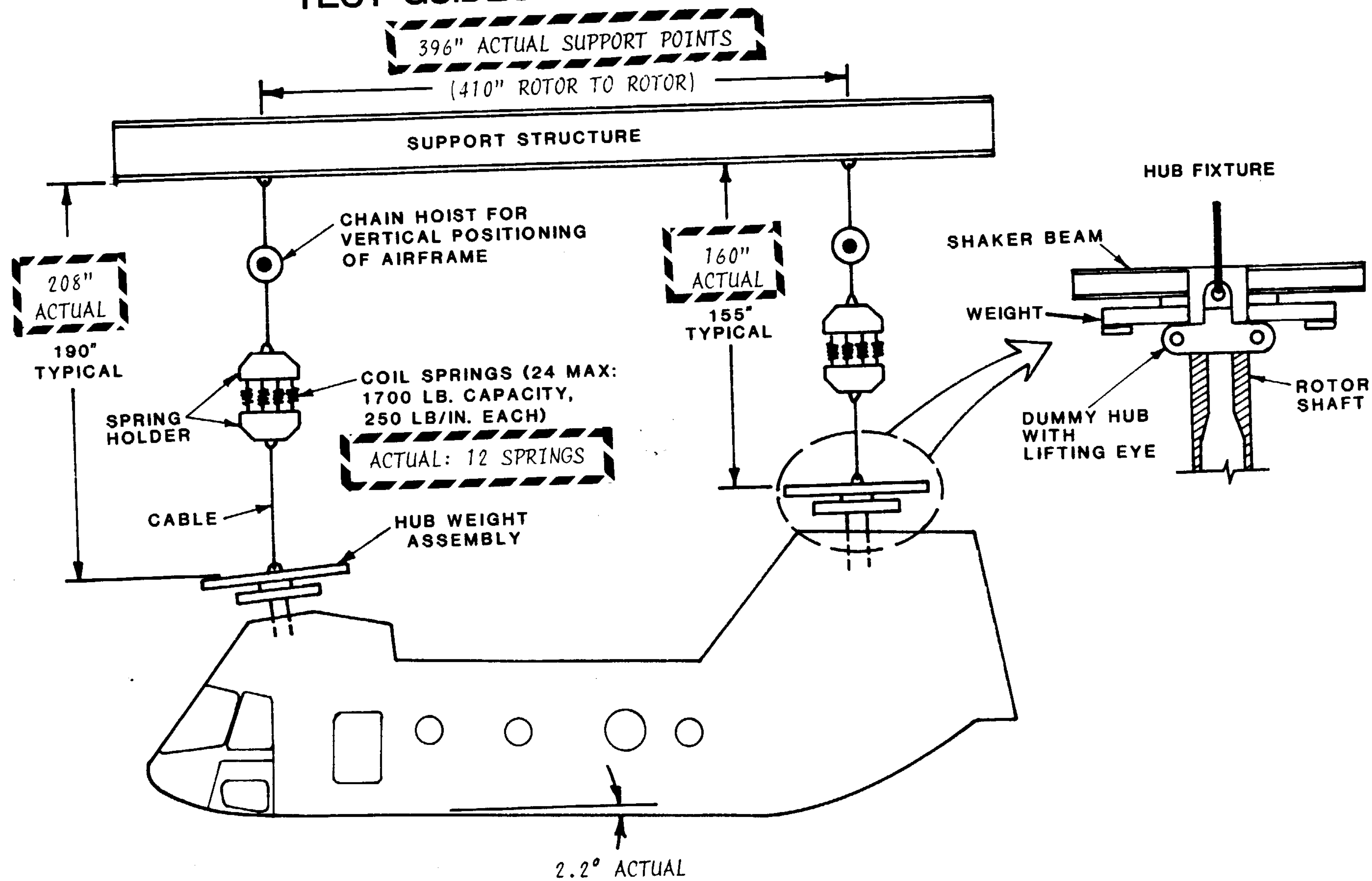
Locating dimensions and rigid body frequencies will be determined for the M360 for reference purposes.

Actual rigid body frequencies were:

Vertical	*1.66 Hz*	*Pitch*	*2.08 Hz*
Lateral	*0.19*	*Roll*	*0.75*
Longitudinal	*0.24*	*Yaw*	*0.32*

A dummy hub with an integral lifting eye will be used in the test. This is necessary to permit the use of an existing hub fixture which also provides the required shaker attachment points.

TEST GUIDES - AIRCRAFT SUSPENSION



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4.7 Method of Excitation

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TEST GUIDES

METHOD OF EXCITATION

The necessary shaker operating features are summarized on the accompanying chart. A detailed description of the shaker installations and associated controls is presented in subsequent figures.

TEST GUIDES

METHOD OF EXCITATION

THE SHAKER INSTALLATIONS WILL PROVIDE THE FOLLOWING FEATURES:

- **A SINGLE LOAD PATH TO THE AIRFRAME**
- **A METHOD FOR OBTAINING AND MAINTAINING ALIGNMENT**
- **CONTROL OF THE APPLIED LOAD**
- **MEASUREMENT OF APPLIED LOAD AT THE AIRFRAME INTERFACE**
- **PERMIT VERTICAL, LATERAL, LONGITUDINAL, PITCH AND ROLL EXCITATION AT THE HUB**

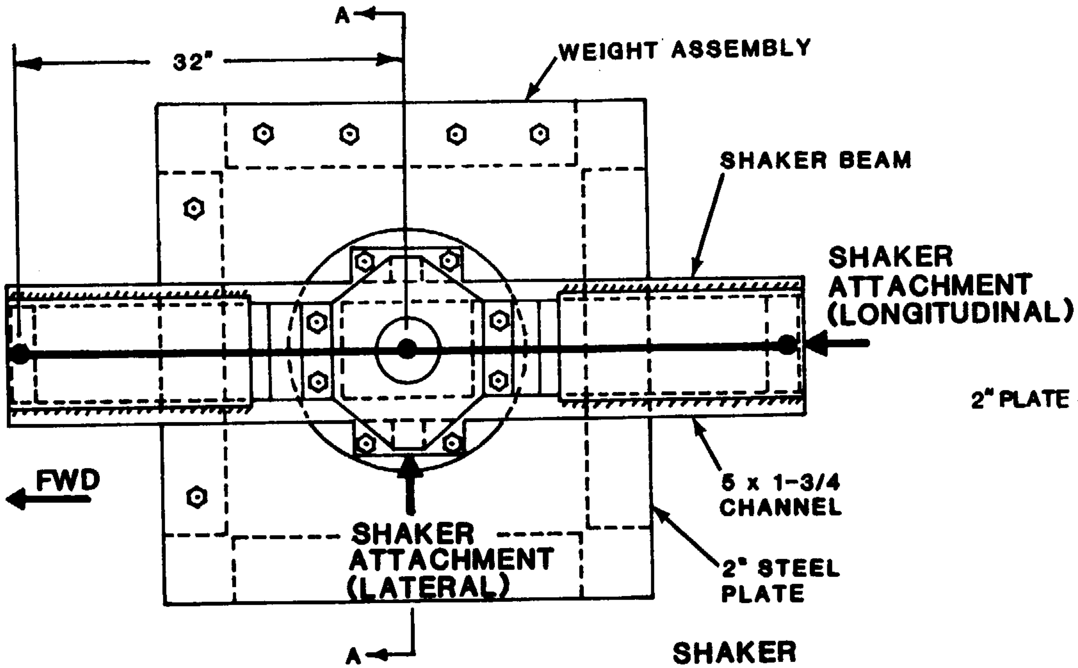
METHOD OF EXCITATION - HUB FIXTURE

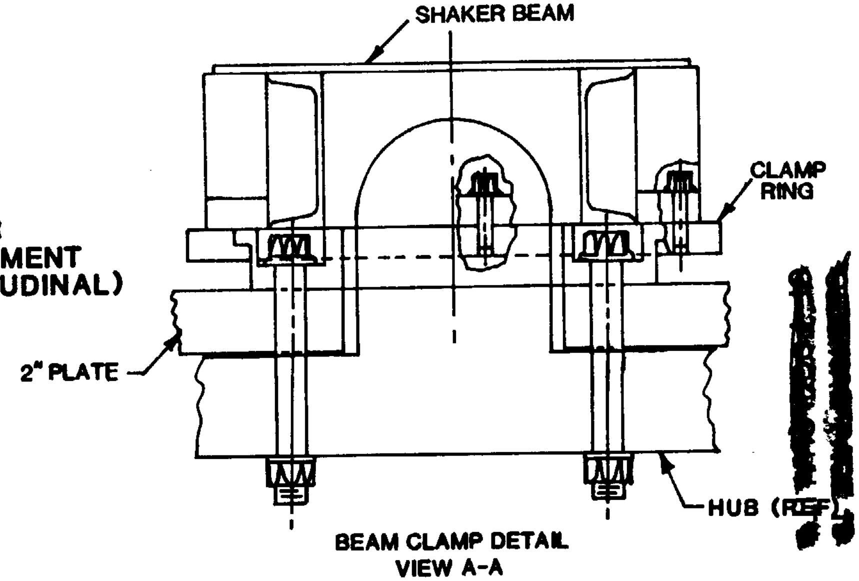
The hub fixture, which is composed of a weight assembly and a shaker beam to which the shakers are attached, is illustrated in this figure. The beam is oriented in the fore and aft position as shown in this figure for vertical/pitch, lateral and longitudinal excitation. Rather than rotating the hub, a clamp ring between the beam and the weight assembly permits rotation of the beam to the lateral position for roll excitation. The lateral beam position also provides an alternate position for vertical excitation.

Actual orientation of the beam was fore and aft for pitch, lateral and longitudinal excitation. Lateral orientation was used for vertical and roll.

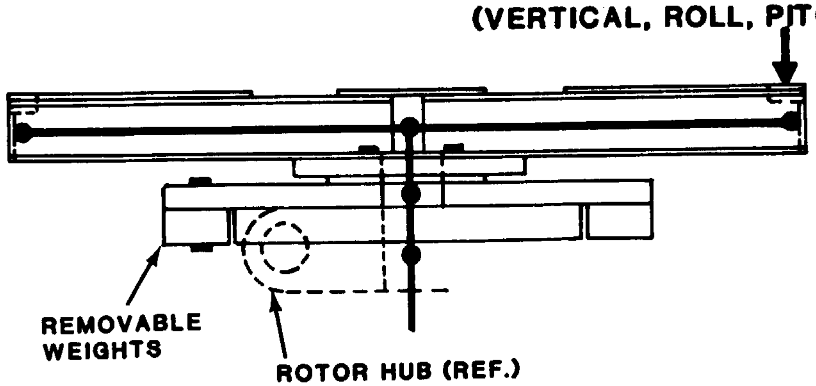
TEST GUIDES

METHOD OF EXCITATION – HUB FIXTURE





BEAM CLAMP DETAIL
VIEW A-A



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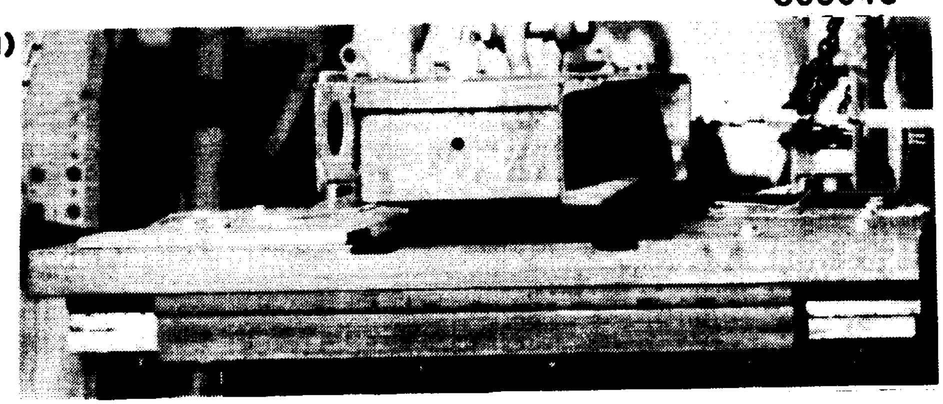

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METHOD OF EXCITATION - PLANNED SHAKER INSTALLATION

Electrodynamic shakers are suspended from the shake test gantry in a cradle assembly which provides reaction mass and facilitates shaker alignment. Dual vertical shakers operating in a master/slave mode are driven in phase or out of phase to provide vertical, pitch, or roll excitation. Force and frequency output of the shakers is controlled by a closed-loop system consisting of a shaker force transducer and a programmable digital control unit.

The following schematic illustrates the vertical/pitch and typical inplane (longitudinal) shaker installations. The dual shaker roll installation is obtained by rotating the shaker beam 90° and relocating the shakers accordingly. For the lateral installation, only the shaker is relocated with the drive link attached to the side of the shaker beam. From the sketch it is observed that:

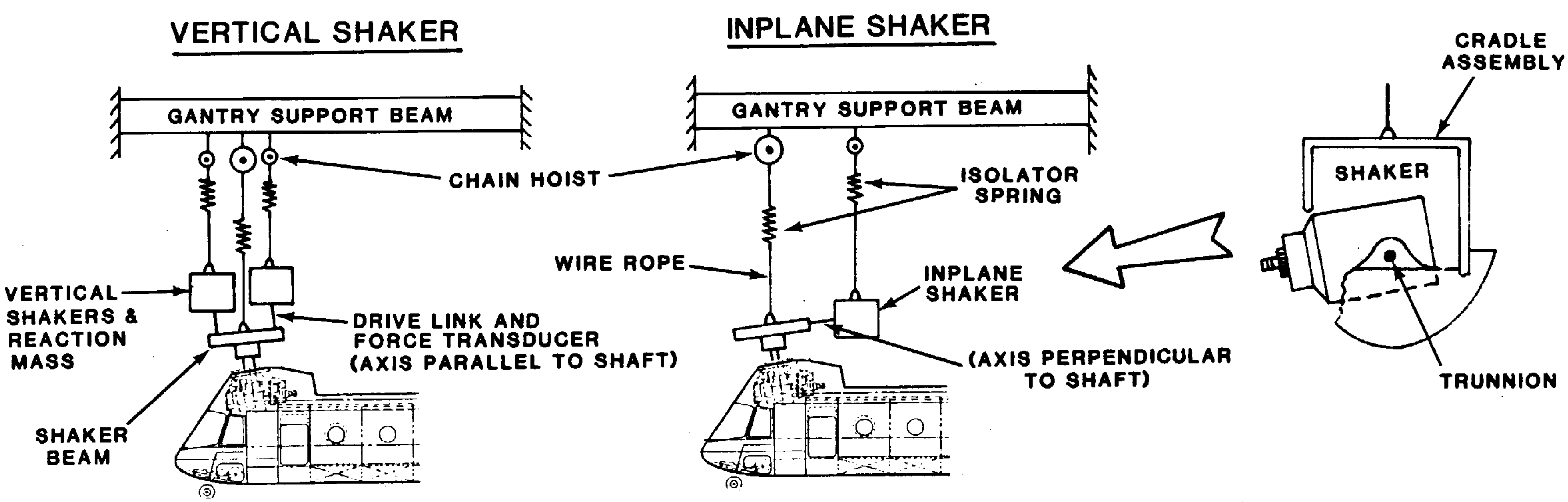
1) In the vertical direction, the soft suspension of both the aircraft and shaker isolates the shaker from the aircraft except through the drive link. In the horizontal plane, effective isolation of the shaker is provided by the low frequency pendulum modes of the aircraft and shaker on the suspension cables. Typical shaker suspension frequencies (including the effect of elastic horizontal guys discussed in a subsequent figure) are as follows:

Vertical	----- 1.5 Hz	Pitch	----- 1.2 to 1.7 Hz
Lateral	----- .25 to .3 Hz	Roll	----- 1.2 to 1.7 Hz
Longitudinal	----- .25 to .3 Hz		

2) In the vertical direction, the exciting forces are applied parallel to the axis of the rotor shaft. In the horizontal direction, the force is applied perpendicular to the rotor shaft axis.

TEST GUIDES

METHOD OF EXCITATION – PLANNED SHAKER INSTALLATION



- SERVO CONTROL OF SHAKER FORCE AND FREQUENCY
- DUAL VERTICAL SHAKERS IN OR OUT OF PHASE PROVIDE VERTICAL, PITCH AND ROLL EXCITATION. SINGLE SHAKERS PROVIDE LATERAL AND LONGITUDINAL EXCITATION
- AIRCRAFT AND SHAKER ISOLATION PROVIDE A SINGLE SHAKER LOAD PATH THROUGH THE DRIVE LINK AND FORCE TRANSDUCER

METHOD OF EXCITATION - PLANNED SHAKER INSTALLATION

Additional details of the shaker installation are illustrated in the accompanying figure. The features of principal interest are as follows:

1) The chain hoist is used to position the shaker vertically and the horizontal position is obtained by adjusting the guy wires. (Not all locations reouire guy wires and no more than two guy wires are necessary.) Angular variation from horizontal is obtained by tilting the shaker about the trunnion axis. Note that both the guy wires and the vertical support are isolated from the support structure.

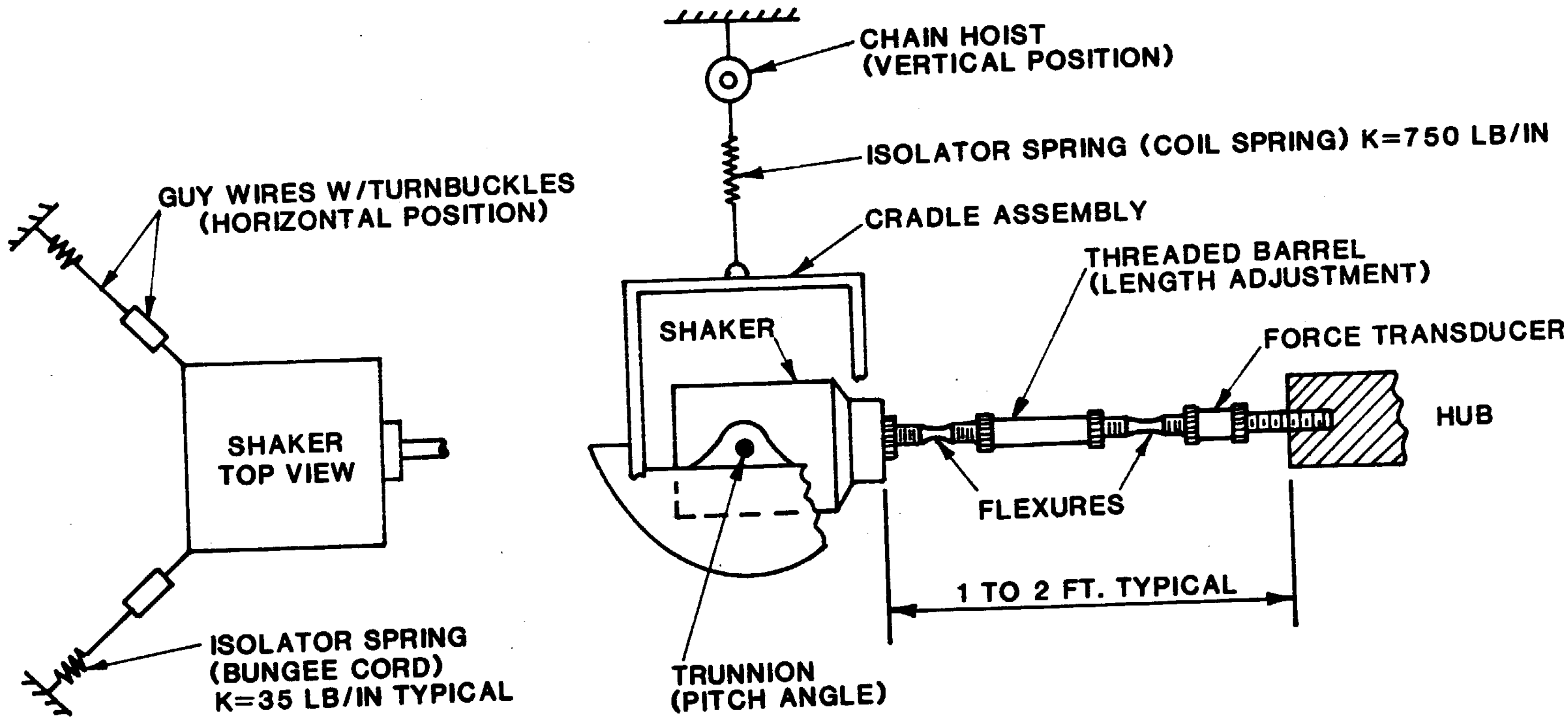
2) Small adjustments in the drive link length for final positioning are obtained by means of the threaded barrel. (Barrels with different basic lengths are used for different installations.)

3) A double flexure arrangement (flexures at 90°) is incorporated in the drive link to minimize side loading.

4) Since bungee cord tends to creep, metal coil isolator springs are used in the heavily loaded main shaker support to maintain a stable position.

TEST GUIDES

METHOD OF EXCITATION – PLANNED SHAKER INSTALLATION



- INSTALLATION PROVIDES A SUITABLE MEANS OF ALIGNMENT
- DYNAMIC SIDE LOADING OF THE SHAKER IS MINIMIZED BY DUAL DRIVE LINK FLEXURES

METHOD OF EXCITATION - CHANGES IN SHAKER INSTALLATION

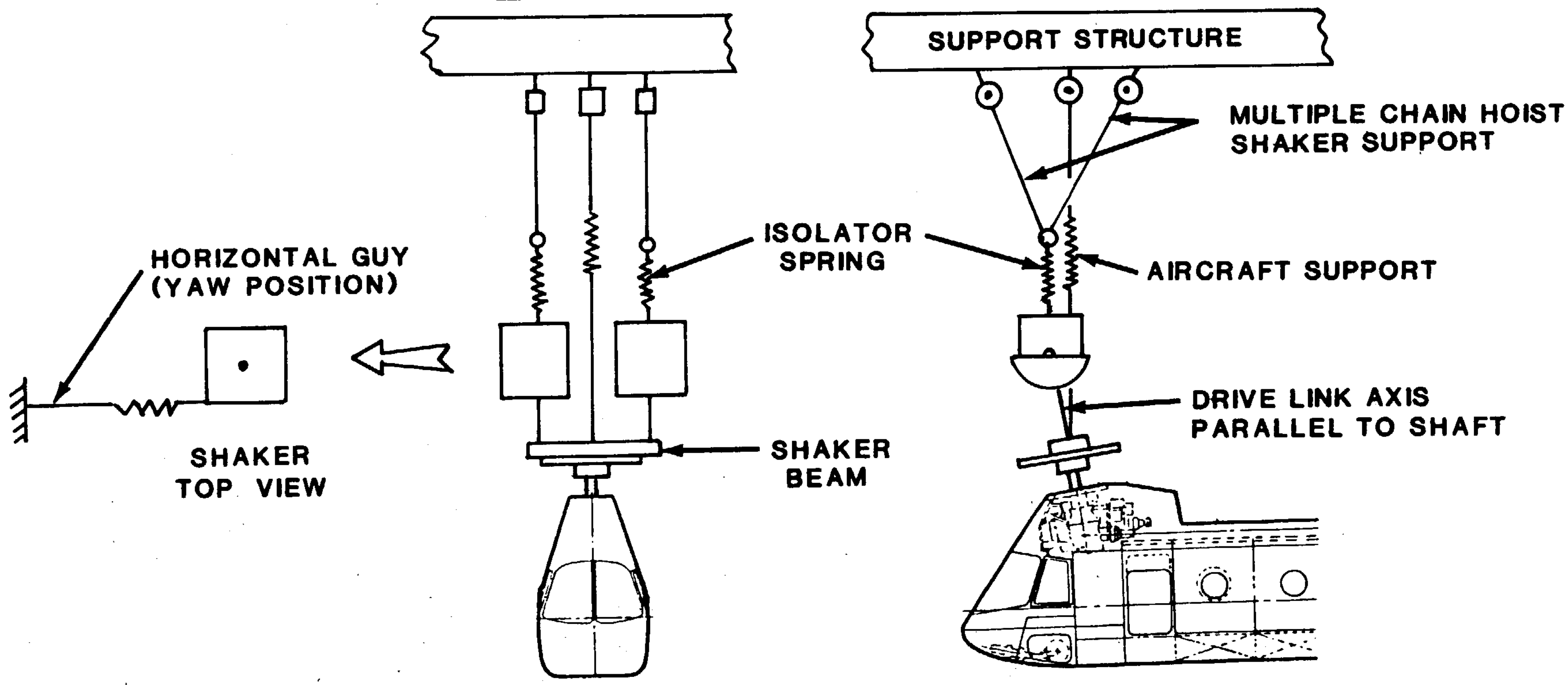
A major change in the typical shaker installation was the introduction of a multiple chain hoist arrangement above the shaker isolator as illustrated in the accompanying schematic for the vertical/roll shaker configuration. Two, and in some cases three, chain hoists were used. This arrangement provided a floating support point which made it possible to position the shaker in the horizontal plane without the use of guy wires as originally planned. When hanging freely, some of the shakers were slightly displaced in yaw. This was corrected with a single, lightly loaded, elastic guy wire.

The second change was the use of the optional vertical/roll configuration (laterally oriented shaker beam) for vertical excitation in lieu of the vertical/pitch configuration (fore and aft beam orientation). Vertical responses typically involve significant pitch motion. With the laterally oriented beam configuration, the drive point response in the presence of a pitch motion is the same at both shakers which was felt to be a preferred condition.

TEST GUIDES

METHOD OF EXCITATION - CHANGES IN SHAKER INSTALLATION

VERTICAL/ROLL SHAKER



- MULTIPLE CHAIN HOIST ARRANGEMENT PROVIDES FLOATING SUPPORT POINT AND REQUIRES GUY WIRE ONLY TO CONTROL YAW POSITION
- LATERAL SHAKER BEAM ORIENTATION USED FOR VERTICAL EXCITATION.

TEST GUIDES

METHOD OF EXCITATION - DRIVE LINK DETAIL

The shaker, hub fixture and a typical interconnecting drive link are shown in this photograph. Note that the flexures are oriented at 90° relative to each other to minimize side loading of the shaker armature.

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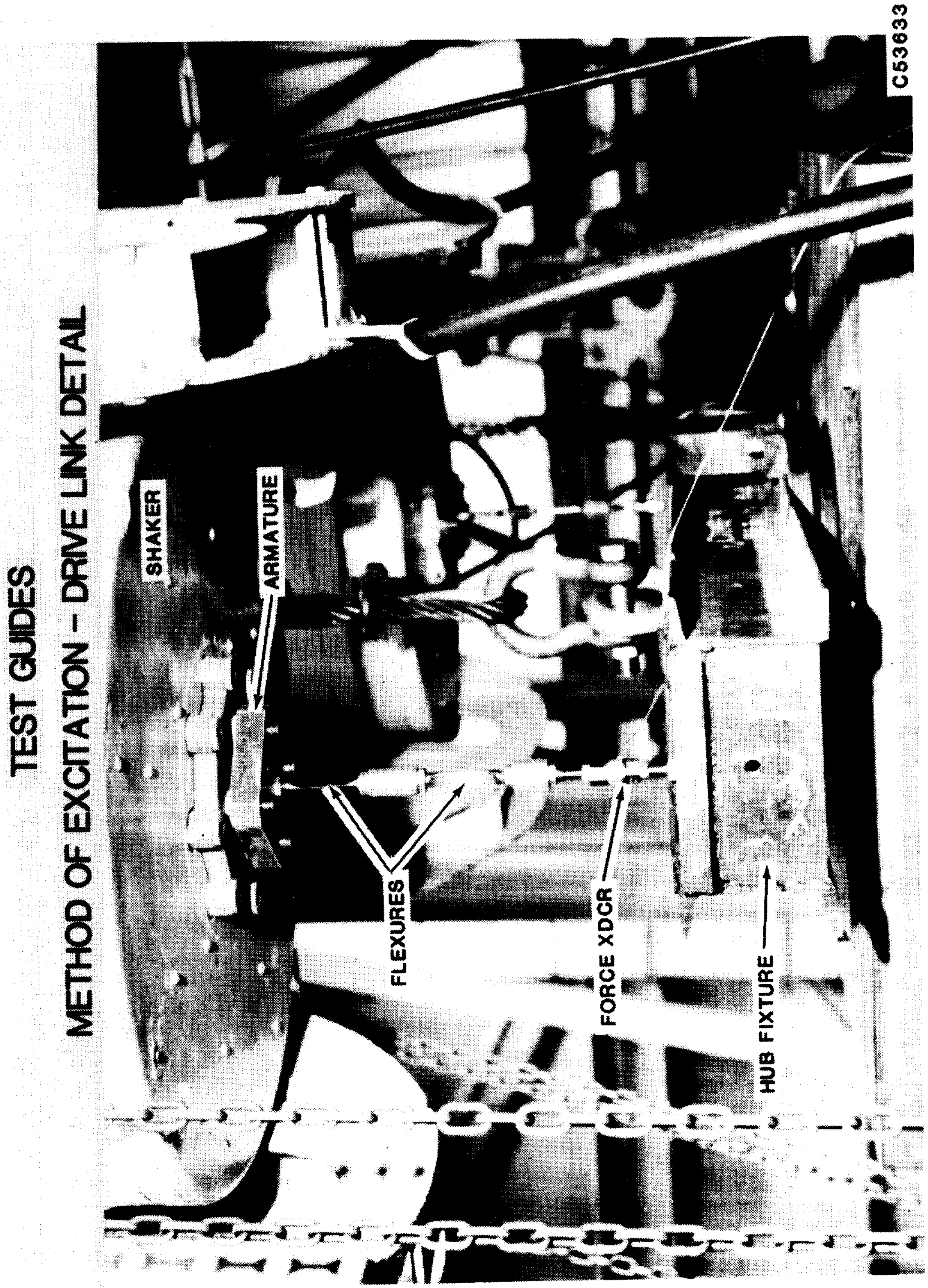

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TEST GUIDES - METHOD OF EXCITATION

VERTICAL/ROLL SHAKER INSTALLATION

The dual shaker vertical/roll installation is typified by this photograph of the forward rotor installation. In this configuration, the beam on the top of the hub fixture is aligned in the lateral direction in order to obtain either a vertical force or roll moment. Evident in the photograph are the shaker suspension springs (isolator springs), yaw guy wires, shaker, drive link, and hub fixture. Also visible is the aircraft forward rotor suspension spring. While not evident in the photograph, the drive links are inclined in a longitudinal direction (perpendicular to plane of the paper) so that they are parallel to the axis of the rotor shaft.

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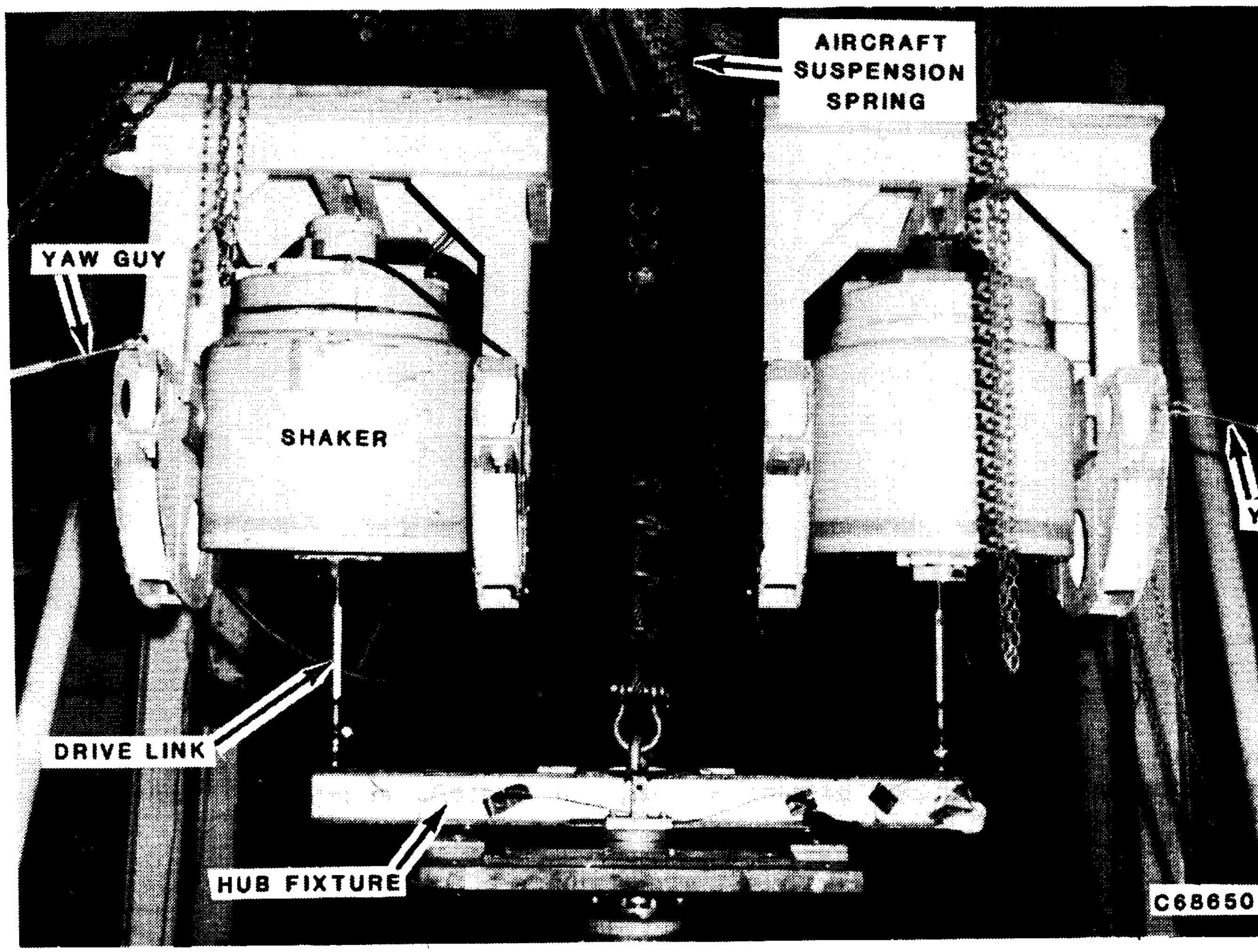
TEST GUIDES – METHOD OF EXCITATION
VERTICAL/ROLL SHAKER INSTALLATION



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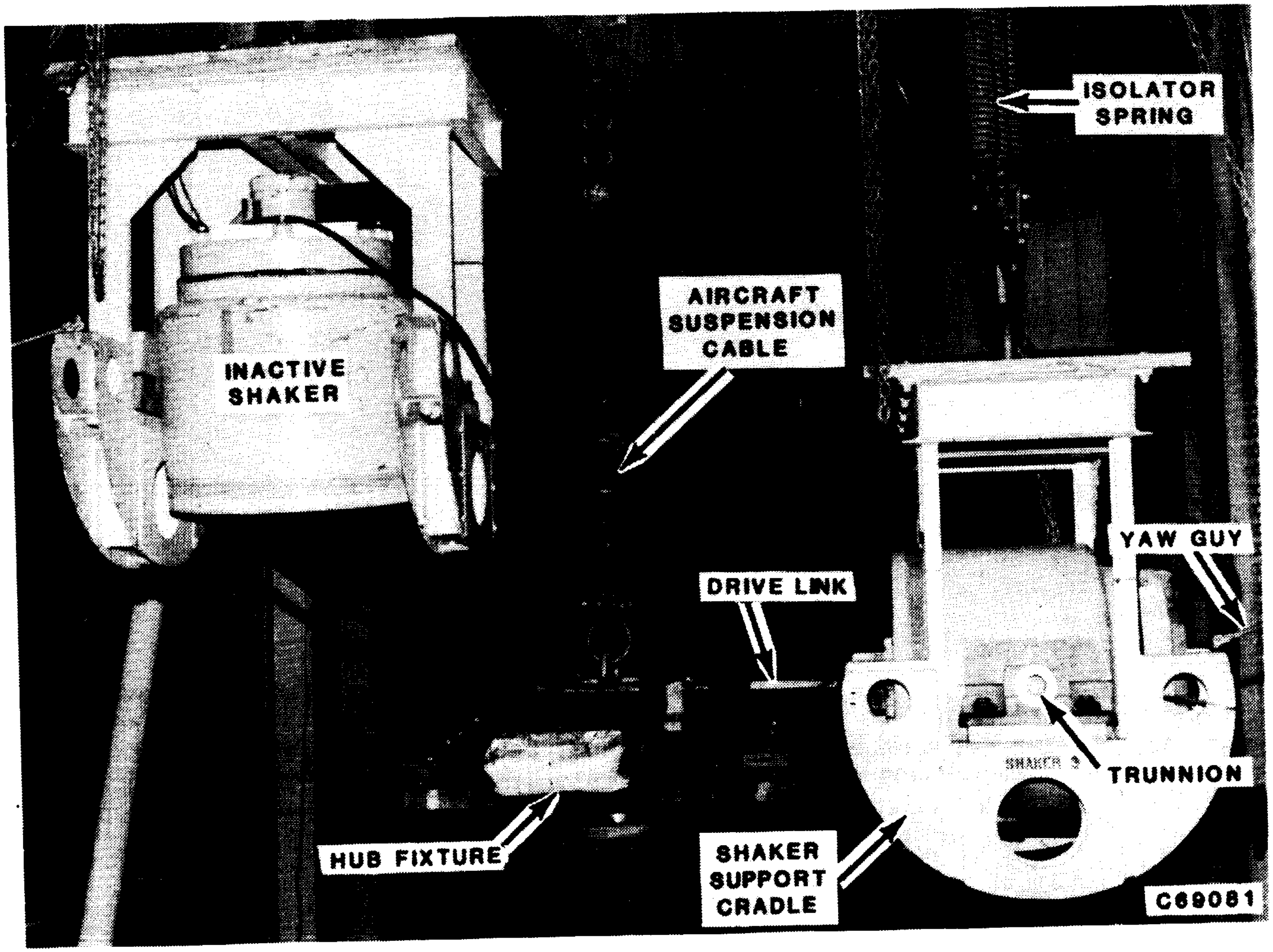
BLACK AND WHITE PHOTOGRAPH

TEST GUIDES - METHOD OF EXCITATION

LATERAL SHAKER INSTALLATION

A lateral shaker installation typical of both the forward and aft rotor heads is shown in this photograph. Additional details of the shaker and support cradle are visible in this view.

TEST GUIDES – METHOD OF EXCITATION
LATERAL SHAKER INSTALLATION

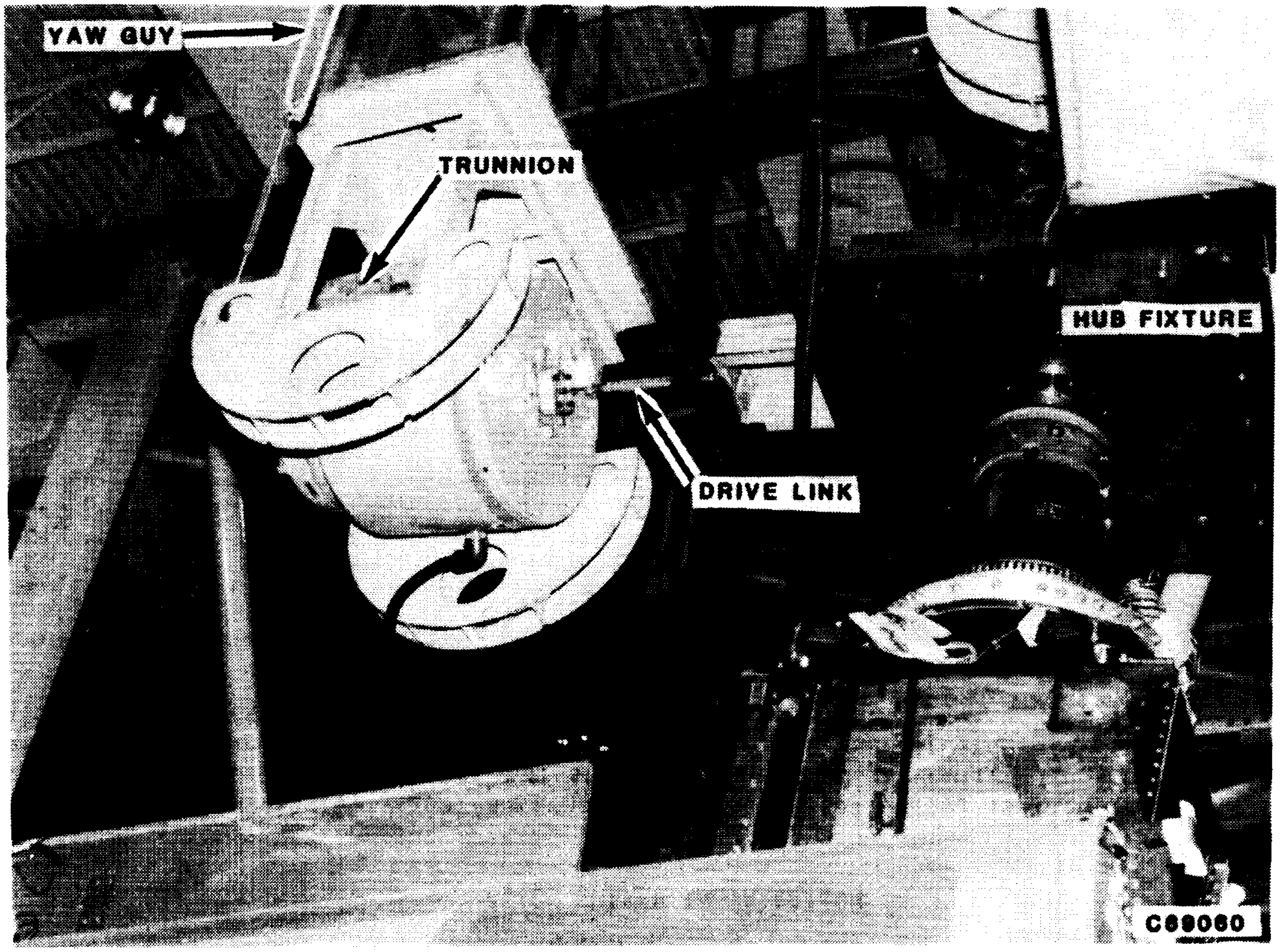


TEST GUIDES - METHOD OF EXCITATION

LONGITUDINAL SHAKER INSTALLATION

This photograph shows a forward rotor longitudinal installation which is typical. Details of the shaker assembly and hub fixture are visible from a different perspective than the previous photograph. The shaker is slightly inclined about the horizontal trunnion axis so that the drive link is perpendicular to the rotor shaft axis. The installation on the aft rotor is identical except that the shaker faces aft rather than forward.

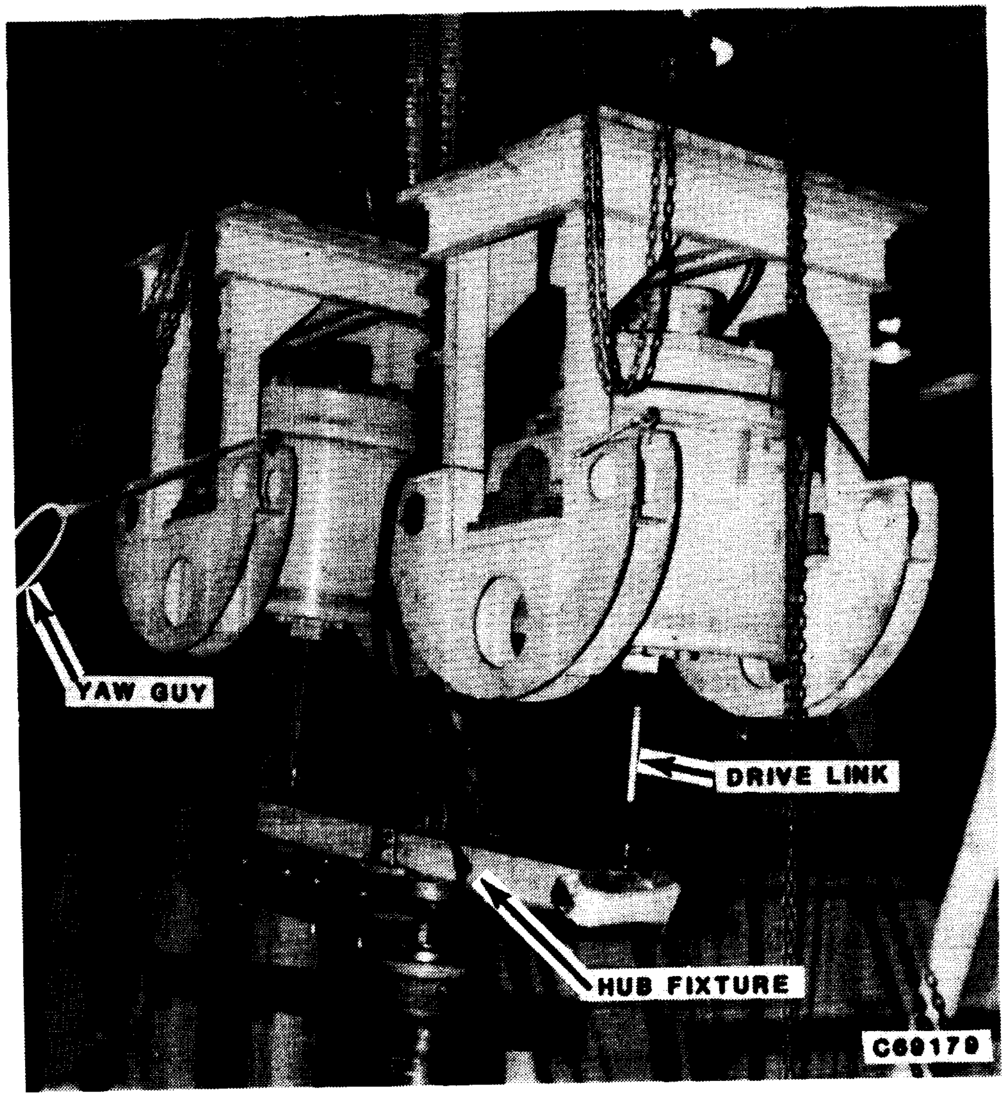
TEST GUIDES - METHOD OF EXCITATION
LONGITUDINAL SHAKER INSTALLATION



PITCH SHAKER INSTALLATION

The dual shaker pitch installation (alternate vertical installation) is illustrated in this photograph. Note the angular position of the shaker in the cradle required to align the shaker along the axis of the rotor shaft. The installation shown is at the forward rotor; however, the installation for the aft rotor is identical in all essential details.

TEST GUIDES – METHOD OF EXCITATION
PITCH SHAKER INSTALLATION

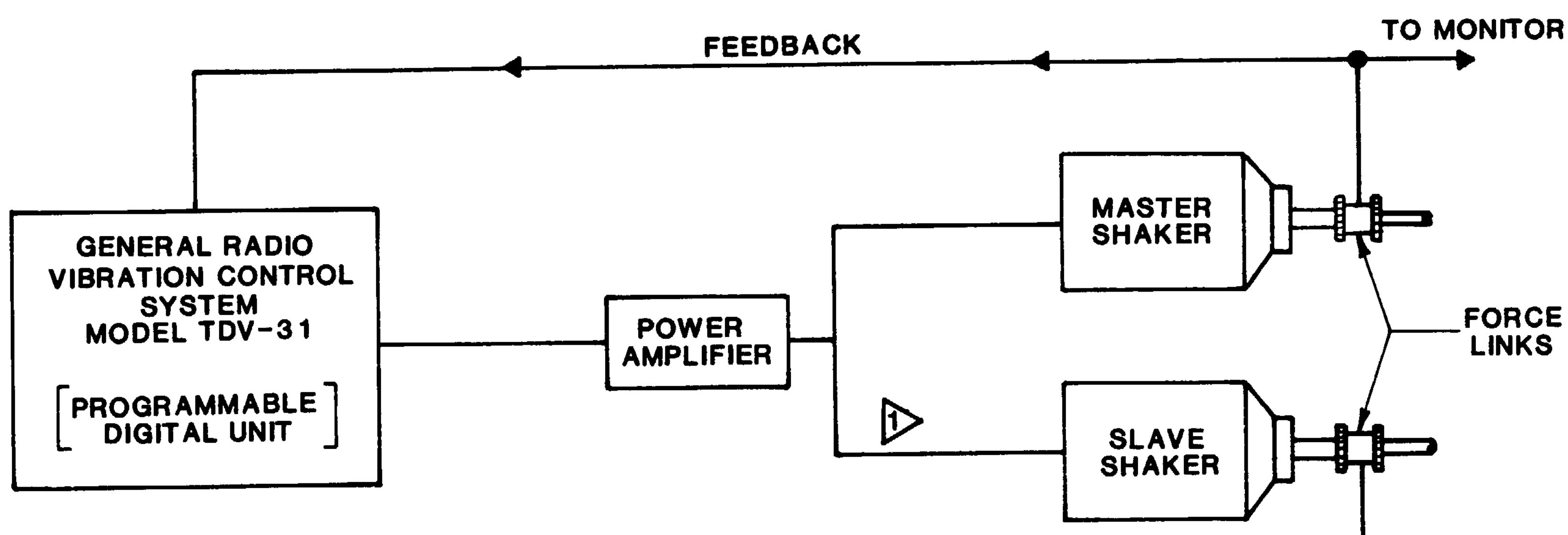


METHOD OF EXCITATION - SHAKER CONTROL SYSTEM

The accompanying block diagram illustrates the method of shaker control. A programmable digital control unit is used to generate the shaker drive signal. Frequency sweep limits, sweep rate, and load may be specified. As indicated previously, dual shakers operating in a master/slave relationship are driven in phase or out-of-phase to provide vertical, pitch or roll excitation. In the dual shaker configuration, the slave shaker is operating open loop and receives the same input signal corrections as the master unit. Phase of the slave shaker is controlled only by polarity.

TEST GUIDES

METHOD OF EXCITATION – SHAKER CONTROL SYSTEM



1 REVERSE WINDING POLARITY FOR OUT OF PHASE OPERATION

- DIGITAL CONTROL UNIT PROVIDES CONTROL OF SWEEP LIMITS, SWEEP RATE AND LOAD SHAPING

TEST GUIDES - METHOD OF EXCITATION

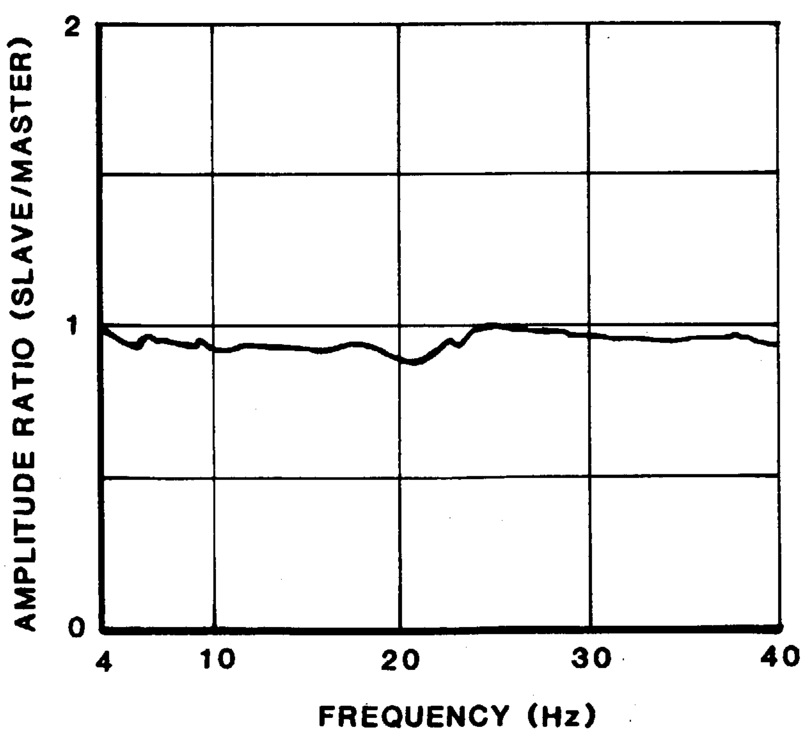
TYPICAL DUAL SHAKER AMPLITUDE RATIO AND PHASE

As stated previously, the slave shaker operates open loop in the dual shaker arrangement. Typical amplitude response ratio and phase between the master and slave units are shown in the figure. For the case illustrated, a moment was being applied and the slave shaker is 180° out of phase. Some small variation in force level between the units is evident; however, the phase angle error is extremely small.

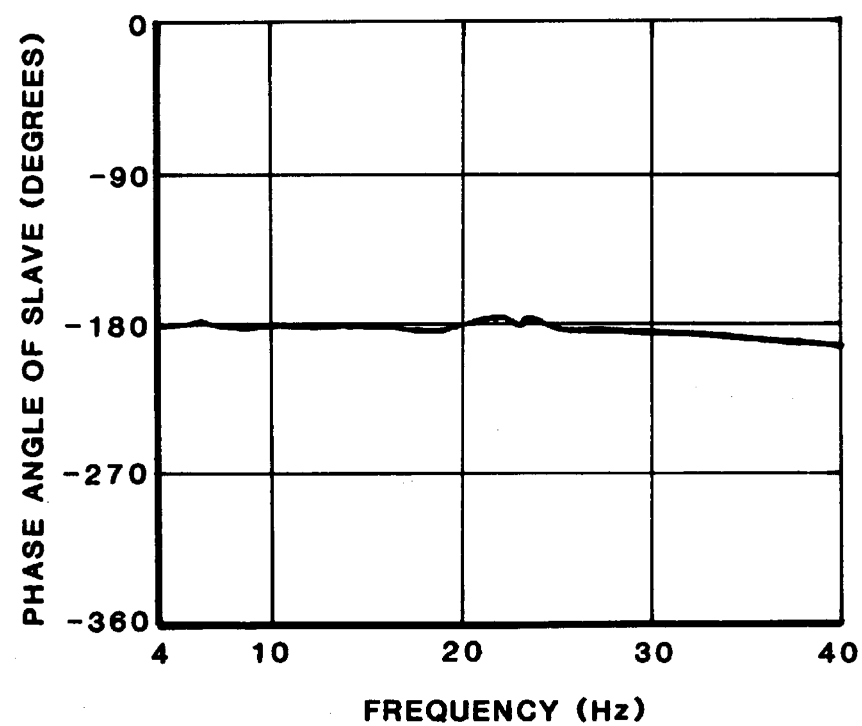
TEST GUIDES – METHOD OF EXCITATION
TYPICAL DUAL SHAKER AMPLITUDE RATIO AND PHASE

MODEL 360 DATA - FORWARD ROLL EXCITATION

AMPLITUDE RATIO



PHASE



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4.8 Vibration Recording and Analysis System

TEST GUIDES

VIBRATION RECORDING AND ANALYSIS SYSTEM

A block diagram of the vibration analysis system is shown in the accompanying figure. This system permits simultaneous processing and recording of only four channels of data, one of which must be a reference shaker input force. For dual shaker operation, output from the slave shaker must be treated as response data in order to obtain its amplitude and phase.

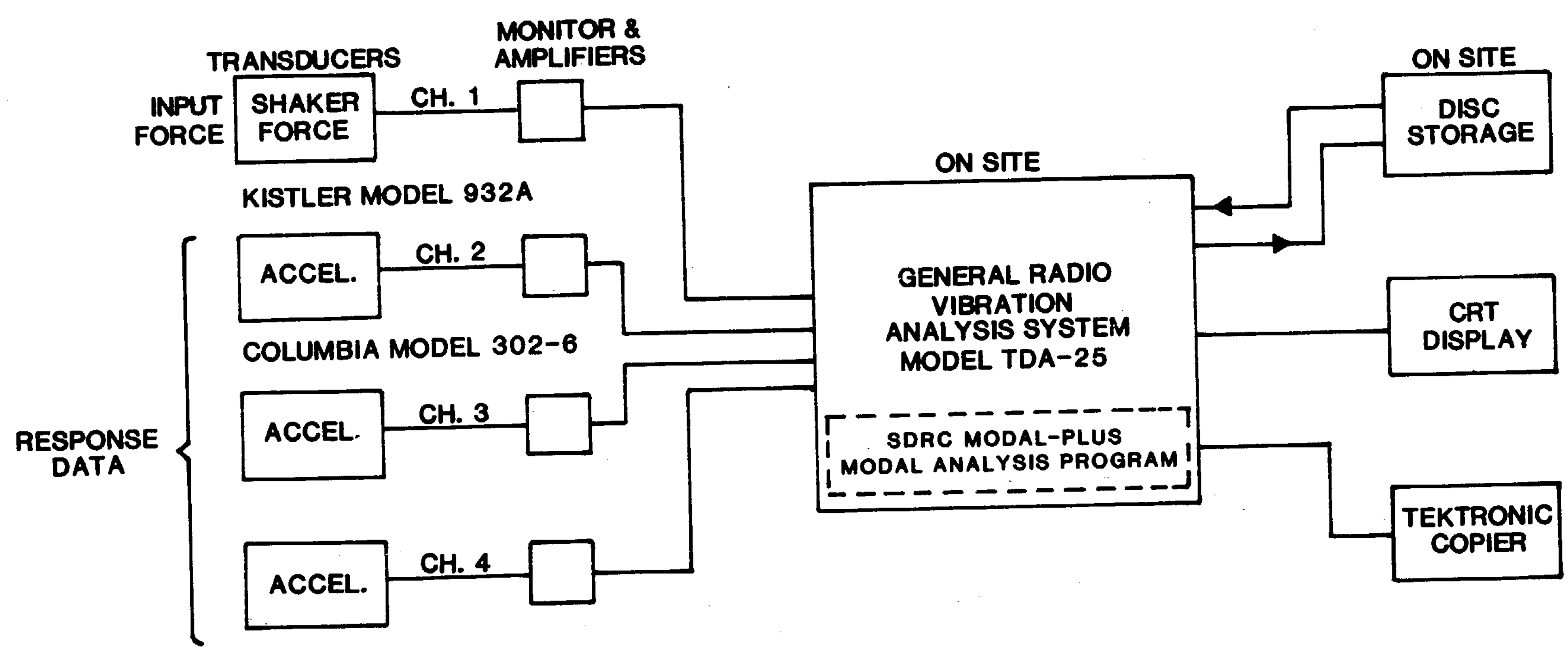
The basic software associated with the analyzer is the Modal-Plus modal analysis program prepared by Structural Dynamics Research Corporation. This program is essentially designed to operate with random excitation. To obtain sufficient energy in the low frequency range, sinusoidal cycling is used in lieu of random excitation. Approximately four logarithmic sweep cycles (4 to 40 Hz, 40 to 4, 4 to 40, 40 to 4) and a minimum total cycling time of approximately five minutes is necessary for the computer to perform an accurate analysis.

Actual data acquisition process used six sweep cycles and 4 minute 30 second cycling time.

The quoted operating range of the analyzer is 2.5 to 10,000 hz. It has been observed, however, that the performance (compared to other methods of analysis) begins to deteriorate below approximately 5 Hz. The accelerometers, on the other hand, display satisfactory characteristics down to 2.5 Hz. On average, the system is felt to be adequate for this program down to 4 Hz.

TEST GUIDES

VIBRATION RECORDING AND ANALYSIS SYSTEM



- **MAXIMUM FOUR CHANNELS SIMULTANEOUSLY**
- **FIVE MINUTES DATA ACQUISITION TIME (SINUSOIDAL CYCLING 4 TO 40 Hz)**

  ACTUAL DATA ACQUISITION TIME WAS 4 MIN. 30 SEC.

- **SYSTEM FREQUENCY RESPONSE FLAT FROM 4 TO 10,000 Hz**

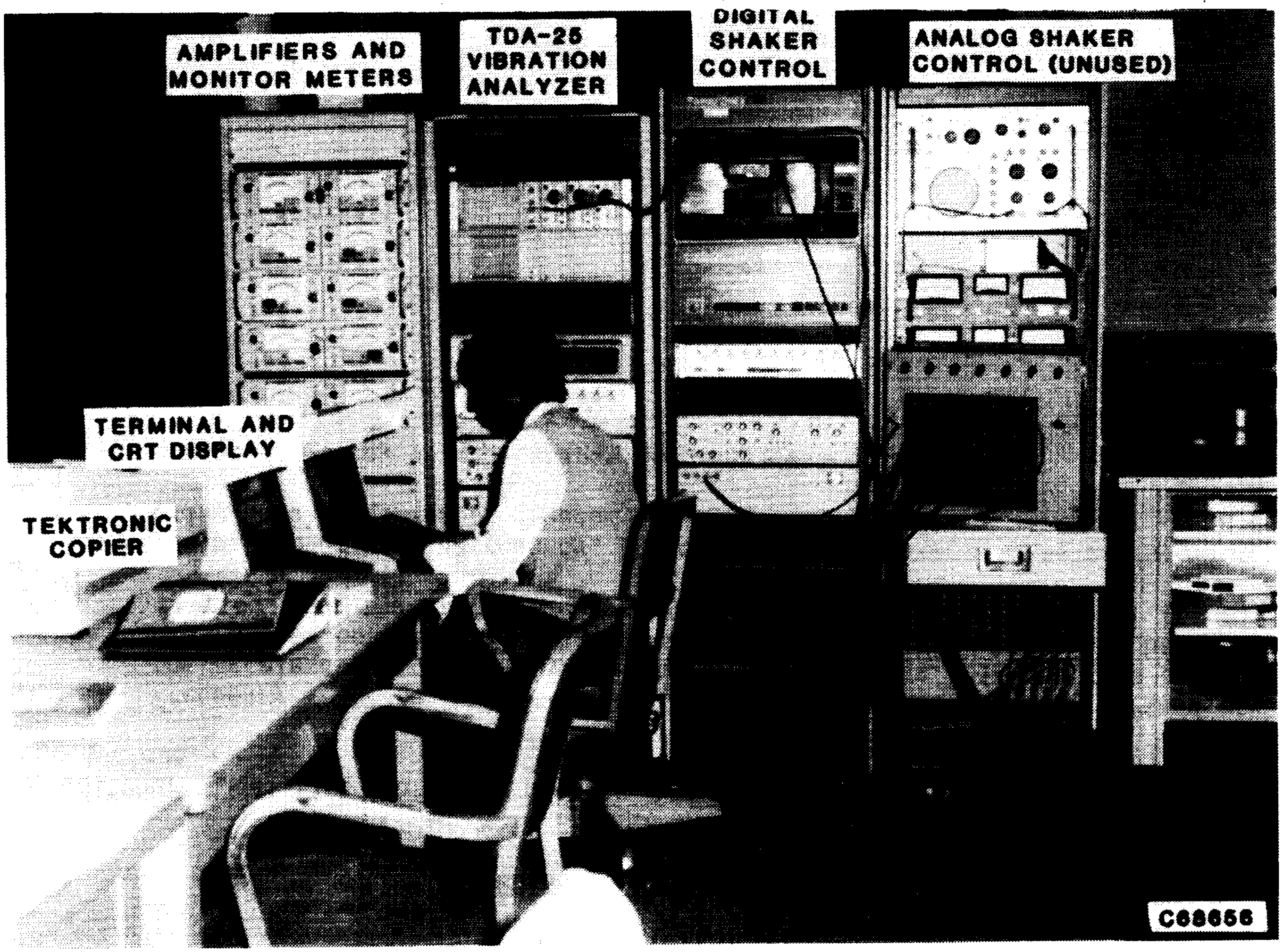
TEST GUIDES

VIBRATION RECORDING AND ANALYSIS SYSTEM - CONTROL STATION

The operator's control station is shown in this photograph with all major equipment identified. The station contains all of the shaker operating controls and all of the signal conditioning, analysis, monitoring and display equipment shown in the previous block diagram.

TEST GUIDES

VIBRATION RECORDING AND ANALYSIS SYSTEM – CONTROL STATION



VIBRATION RECORDING AND ANALYSIS SYSTEM - ANALYZER SOFTWARE

The analyzer Modal-Plus software package provides several important modal analysis features. These include:

a) Frequency response presented as a transfer function which is defined as the acceleration divided by the master shaker force. In the case of the dual shaker configurations (vertical, pitch and roll), it should be kept in mind that the master shaker force is only one half the total force.

b) Estimation of modal frequency, phase and damping from a transfer function using a multi-degree of freedom curve fitting technique.

c) Animated display of mode shapes from any desired perspective.

TEST GUIDES

VIBRATION RECORDING AND ANALYSIS SYSTEM – ANALYZER SOFTWARE

FUNCTIONS OF PRINCIPAL INTEREST PROVIDED BY THE MODAL-PLUS SOFTWARE INCLUDE THE FOLLOWING:

- FREQUENCY RESPONSE IN TRANSFER FUNCTION FORM (ACCELERATION DIVIDED BY MASTER SHAKER FORCE). PLOTS MAGNITUDE AND PHASE OR REAL AND IMAGINARY COMPONENTS

- ESTIMATES MODAL PARAMETER DATA FROM TRANSFER FUNCTION USING MULTI-DEGREE OF FREEDOM CURVE FITTING TECHNIQUE

- DISPLAYS ANIMATED MODE SHAPES

TEST GUIDES - VIBRATION RECORDING AND ANALYSIS SYSTEM

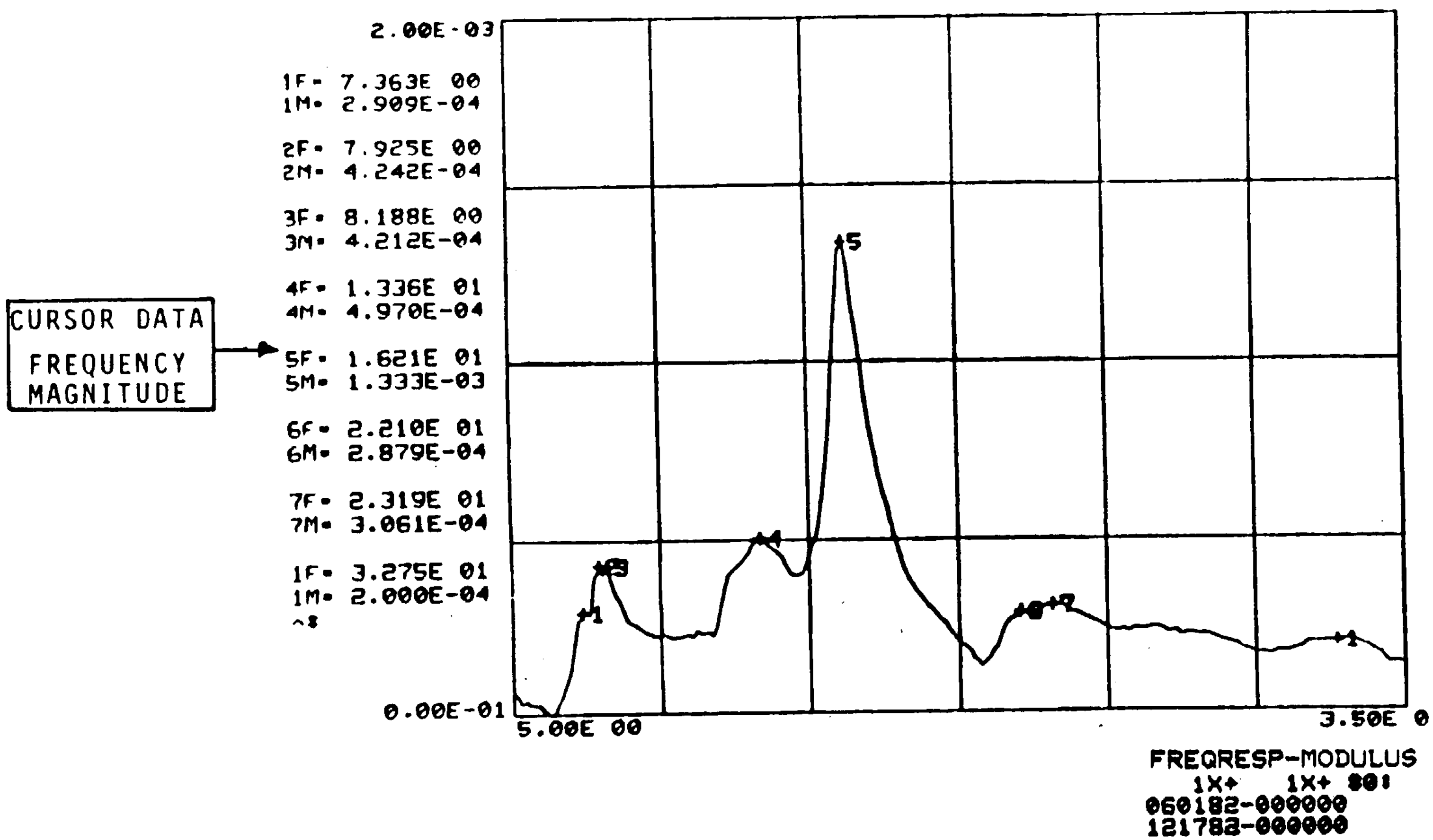
SAMPLE TRANSFER FUNCTION PLOT

Frequency response data provided by the vibration analysis system is presented as a transfer function which is defined as the acceleration divided by the reference input force. In the case of the dual shaker configurations (vertical, pitch, and roll), the master shaker force is used as the reference.

A sample transfer function, showing the magnitude of the response in g's/lb versus frequency, is shown on the following page. Both the magnitude and frequency are plotted on linear scales. The frequency and magnitude at the resonance points are obtained on the CRT display by positioning horizontal and vertical cursor lines at each of the peaks. The computer then identifies each of the resonance points by number and tabulates the frequency and magnitude on the plot.

TEST GUIDES – VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE TRANSFER FUNCTION PLOT



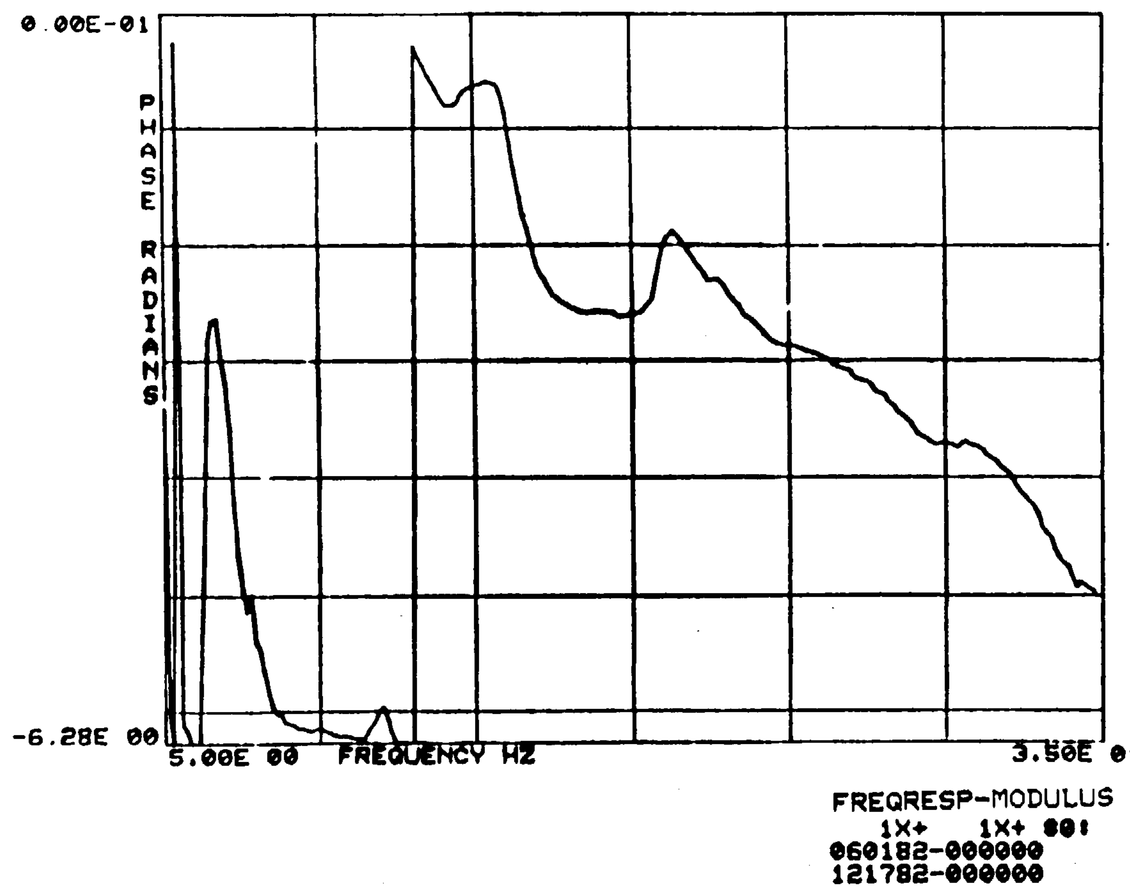
TEST GUIDES - VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE PHASE PLOT

The phase angle relative to the reference input force for the transfer function shown in the preceding plot is illustrated on the accompanying page. Phase in radians is plotted against frequency.

TEST GUIDES – VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE PHASE PLOT



TEST GUIDES - VIBRATION RECORDING AND ANALYSIS SYSTEM

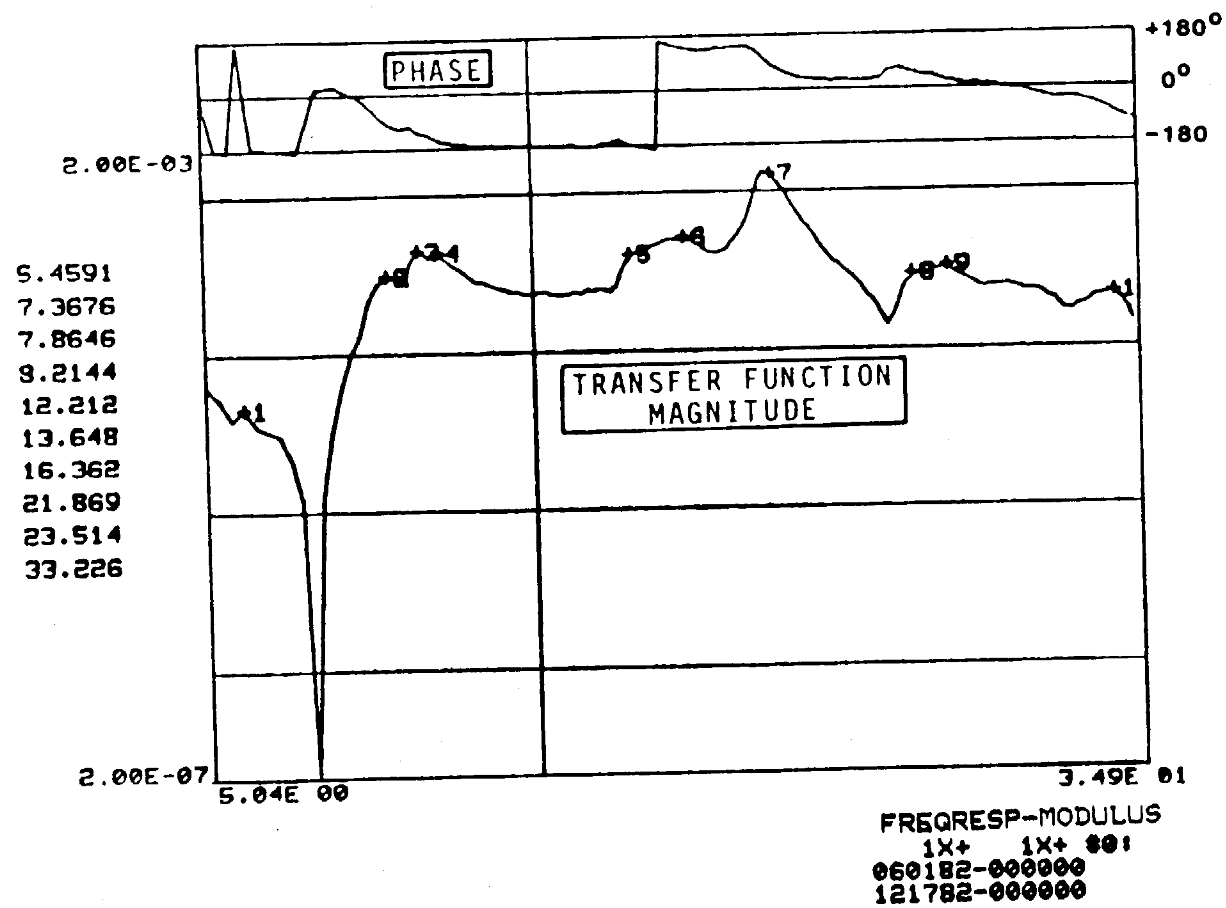
SAMPLE TRANSFER FUNCTION BODE PLOT

The transfer function magnitude and phase plotted against log scales (BODE plot) are shown in this sample. Advantages of this format are:

- Expanded plot in the low frequency range due to the logarithmic scale
- magnitude and phase on a single plot.

TEST GUIDES – VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE TRANSFER FUNCTION BODE PLOT



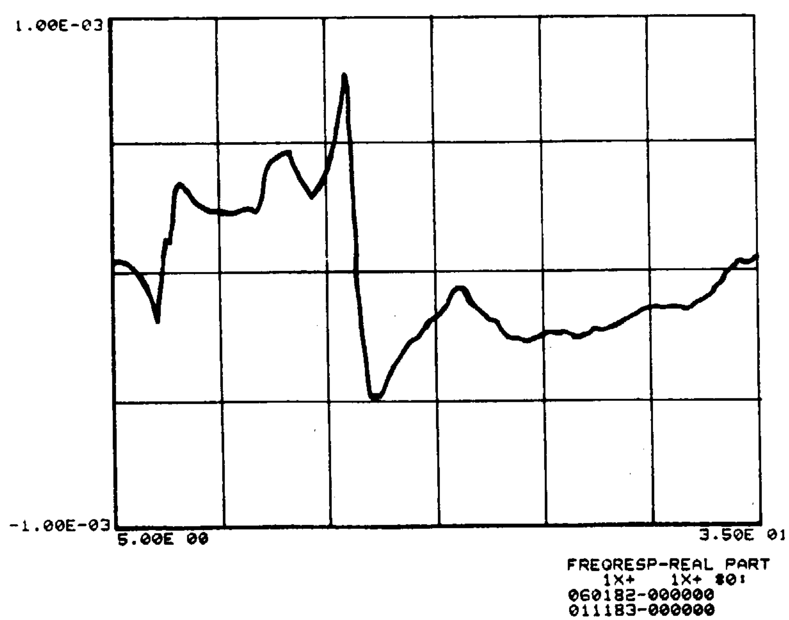
TEST GUIDES - VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE TRANSFER FUNCTION REAL AND IMAGINARY PLOTS

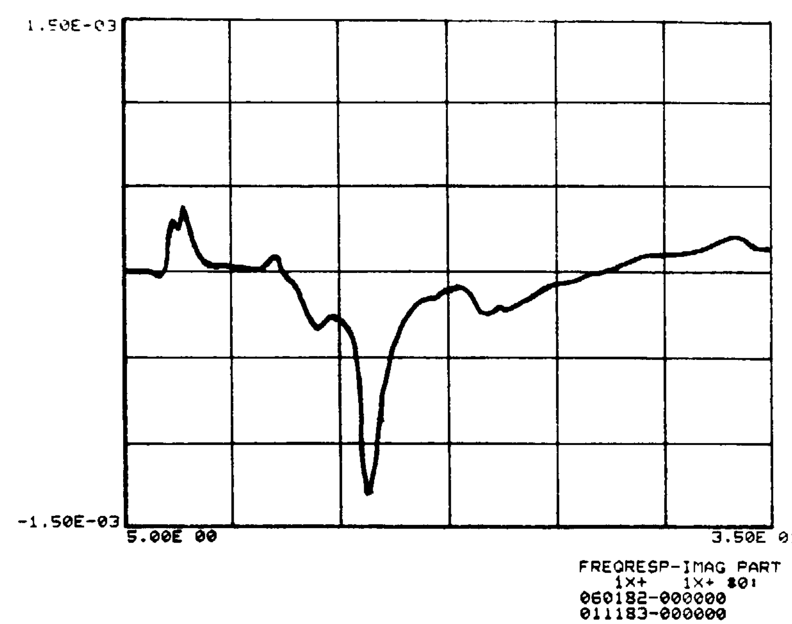
Plots of the real and imaginary components of the transfer function are an alternative to amplitude and phase plots.

TEST GUIDES – VIBRATION RECORDING AND ANALYSIS SYSTEM
SAMPLE TRANSFER FUNCTION REAL AND IMAGINARY PLOTS

REAL



IMAGINARY



SAMPLE OF ESTIMATED MODAL PARAMETERS

A sample tabulation of the estimated modal parameters and a plot of the calculated frequency response (both amplitude and phase) obtained from a multi-degree of freedom curve fit of test response data are shown in the following figure.

The tabulated parameters obtained from the analysis include the modal frequency, damping ratio, amplitude and phase. The last two columns indicate the location and direction of the reference force and the response, respectively. The (+) sign indicates signal polarity.

In order to perform the analysis, the operator must specify the frequency band, number of natural frequencies, and the approximate value of the natural frequencies. If the resulting curve fit does not appear adequate, the operator may specify additional frequencies or modify the previous values. At the upper and lower limits of the frequency range, significant deviation between test and calculated values can occur due to the contribution of modes beyond the range of the analysis.

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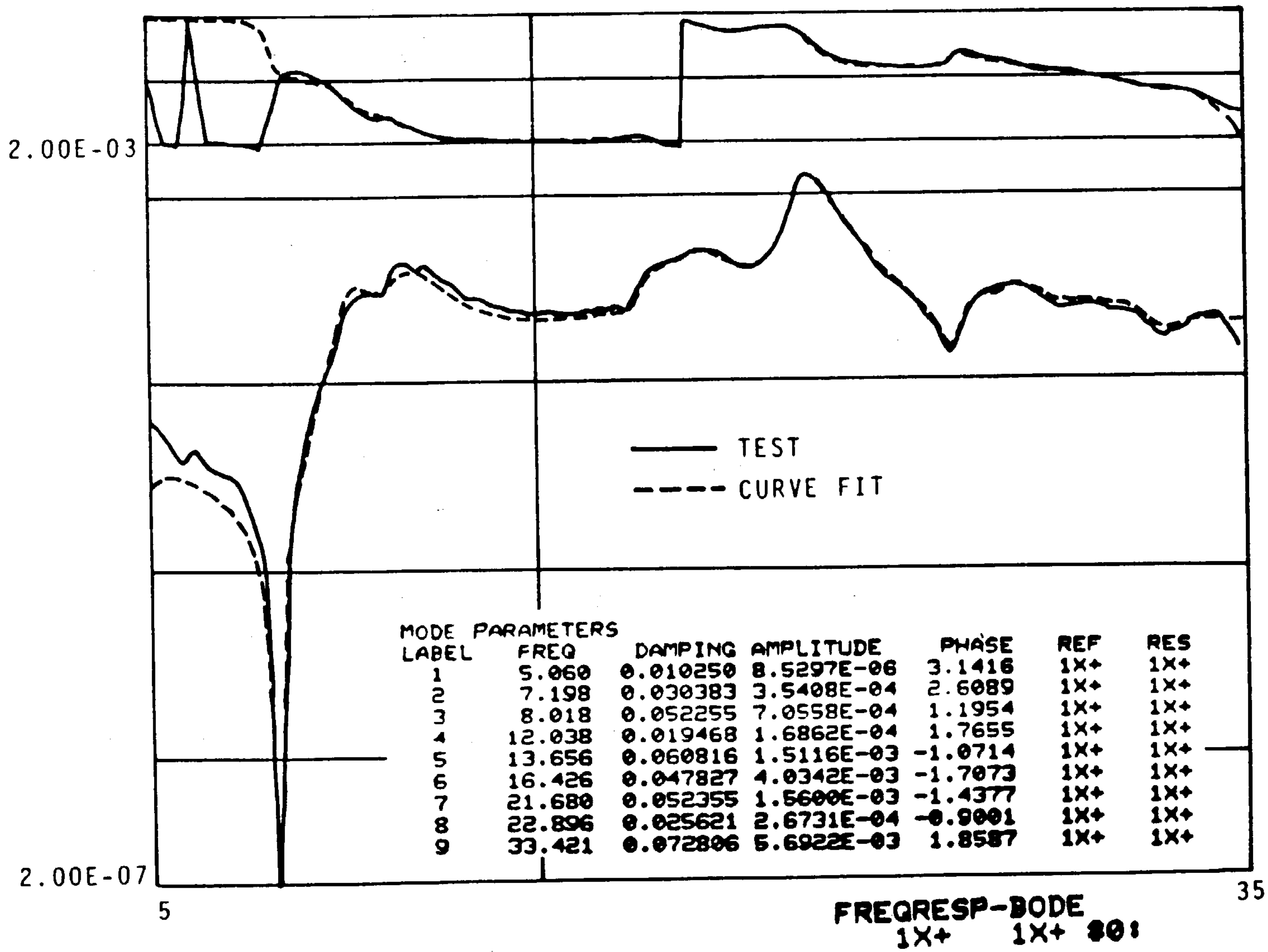
TEST GUIDES – VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE OF ESTIMATED MODAL PARAMETERS



MODE PARAMETERS

MODE LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	5.060	0.010250	8.5297E-06	3.1416	1X+	1X+
2	7.198	0.030383	3.5408E-04	2.6089	1X+	1X+
3	8.018	0.052255	7.0558E-04	1.1954	1X+	1X+
4	12.038	0.019468	1.6862E-04	1.7655	1X+	1X+
5	13.656	0.060816	1.5116E-03	-1.0714	1X+	1X+
6	16.426	0.047827	4.0342E-03	-1.7073	1X+	1X+
7	21.680	0.052355	1.5600E-03	-1.4377	1X+	1X+
8	22.896	0.025621	2.6731E-04	-0.9001	1X+	1X+
9	33.421	0.072806	5.6922E-03	1.8587	1X+	1X+

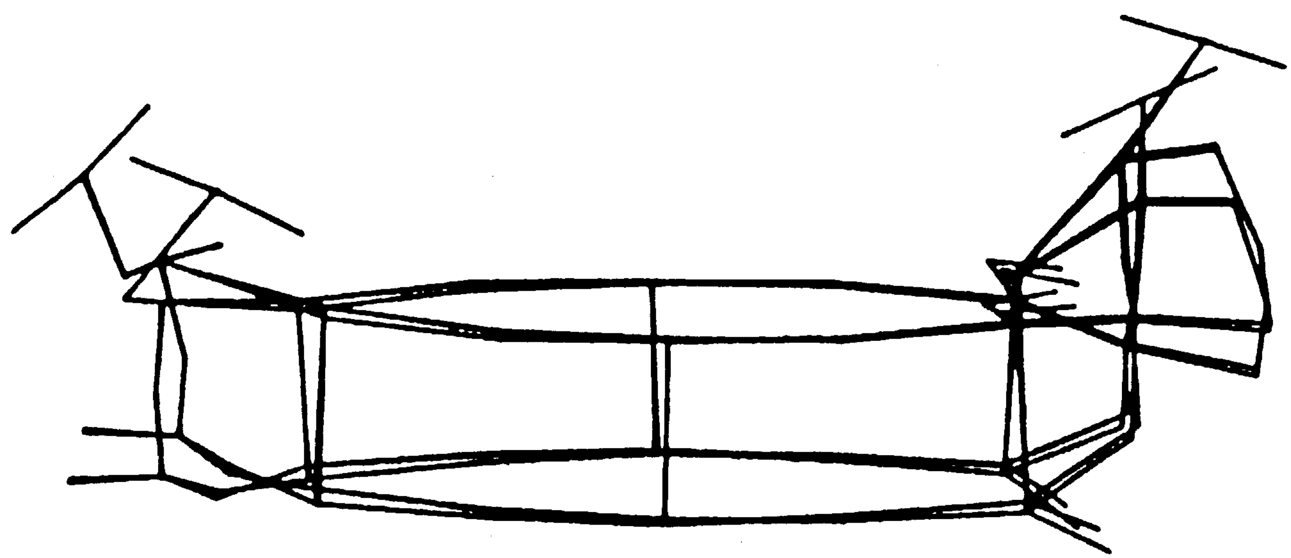
TEST GUIDES - VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE FORCED RESPONSE MODE SHAPE PLOT

This figure illustrates a typical forced response mode shape generated by the vibration analysis system.

TEST GUIDES – VIBRATION RECORDING AND ANALYSIS SYSTEM

SAMPLE FORCED RESPONSE MODE SHAPE PLOT



NASH02,FWD PITCH SHK,TOT RESP

4: 1X+ REAL,F= 18.500 HZ (0.0, -1.0, 0.0, 0.0)=VIEW

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4.9 Vibratory Measurements and Procedures

TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

PLANNED AIRFRAME MEASUREMENT LOCATIONS

Planned airframe accelerometer locations are summarized in the following figure. Vertical, lateral, and longitudinal measurements (in the aircraft axis system) will be obtained at all locations. In order to permit correlation with analytical results, provisions will be made to include all of the measurement locations as grid points in the NASTRAN model. The location numbers indicated here are identification numbers for the vibration analysis system computer. Software restrictions prevent the use of typical NASTRAN grid point codes.

Final test locations may differ somewhat from the locations shown here. Any necessary changes will be a reflection of such practical considerations as:

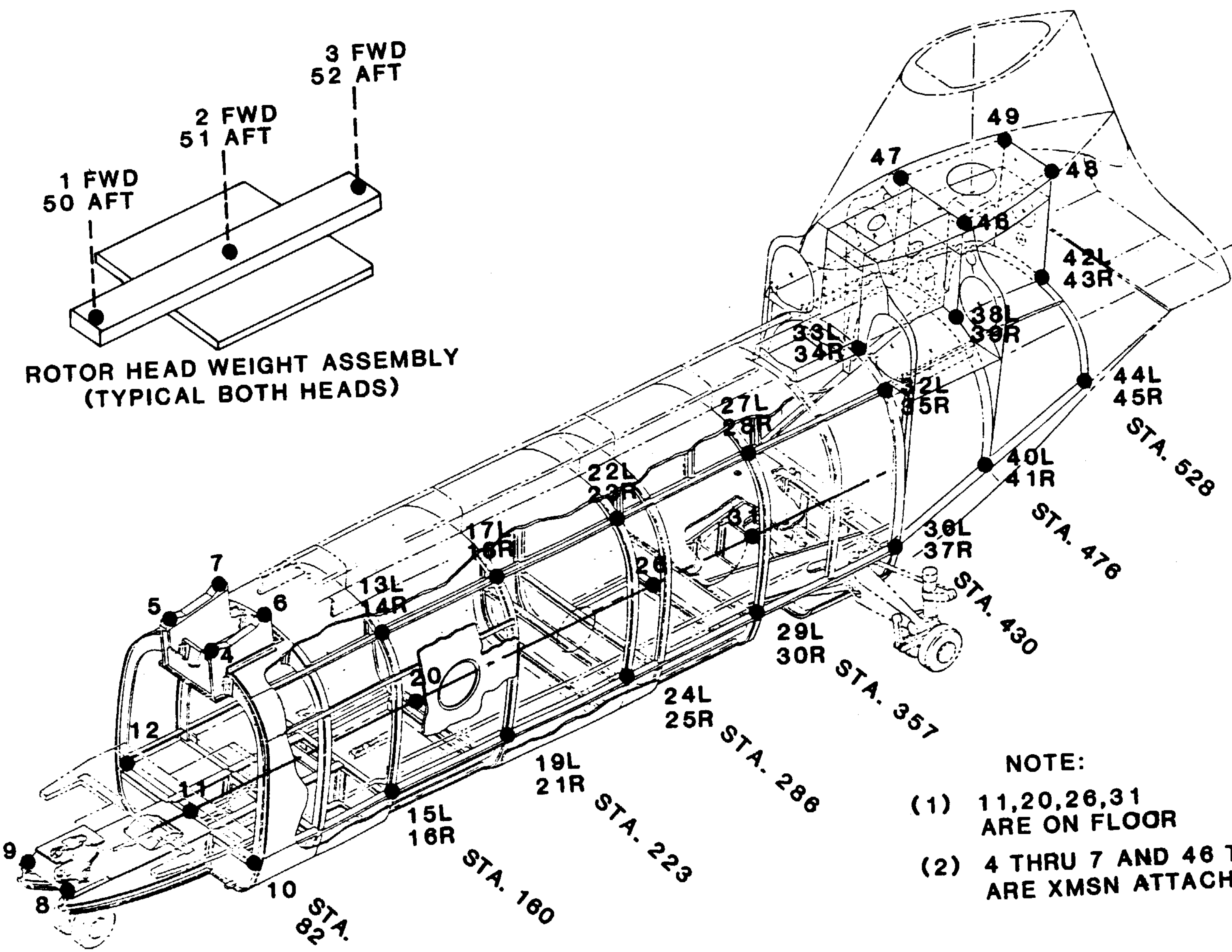
a) accessibility

b) suitable mounting surface

c) network of points which provides a reasonable skeletal outline of the major structure.

TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

PLANNED AIRFRAME MEASUREMENT LOCATIONS



NOTE:

(1) 11,20,26,31 ARE ON FLOOR

(2) 4 THRU 7 AND 46 THRU 49 ARE XMSN ATTACHMENTS

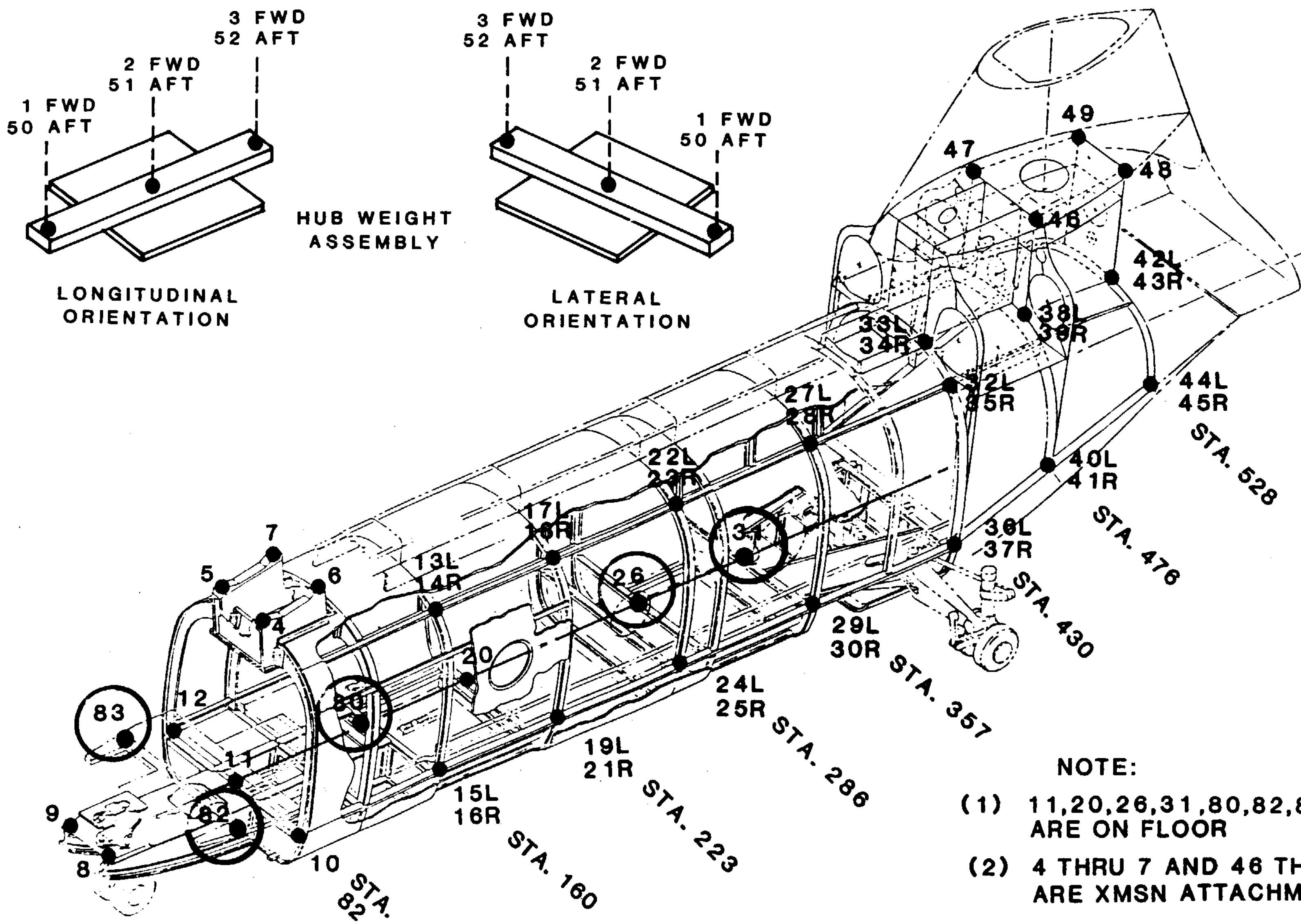
TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

ACTUAL AIRFRAME MEASUREMENT LOCATIONS

The actual airframe measurement locations differed only slightly from the planned locations. On the cabin floor, location 80 was added and two of the original locations (26 and 31) were modified to obtain a better distribution relative to ballast boxes placed on the floor. In the cockpit, two locations (82 and 83) were added to provide more detail. The figure also shows additional information for the hub weight assembly to reflect measurement locations with the shaker beam oriented laterally.

C-2

TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES
ACTUAL AIRFRAME MEASUREMENT LOCATIONS



NOTE:

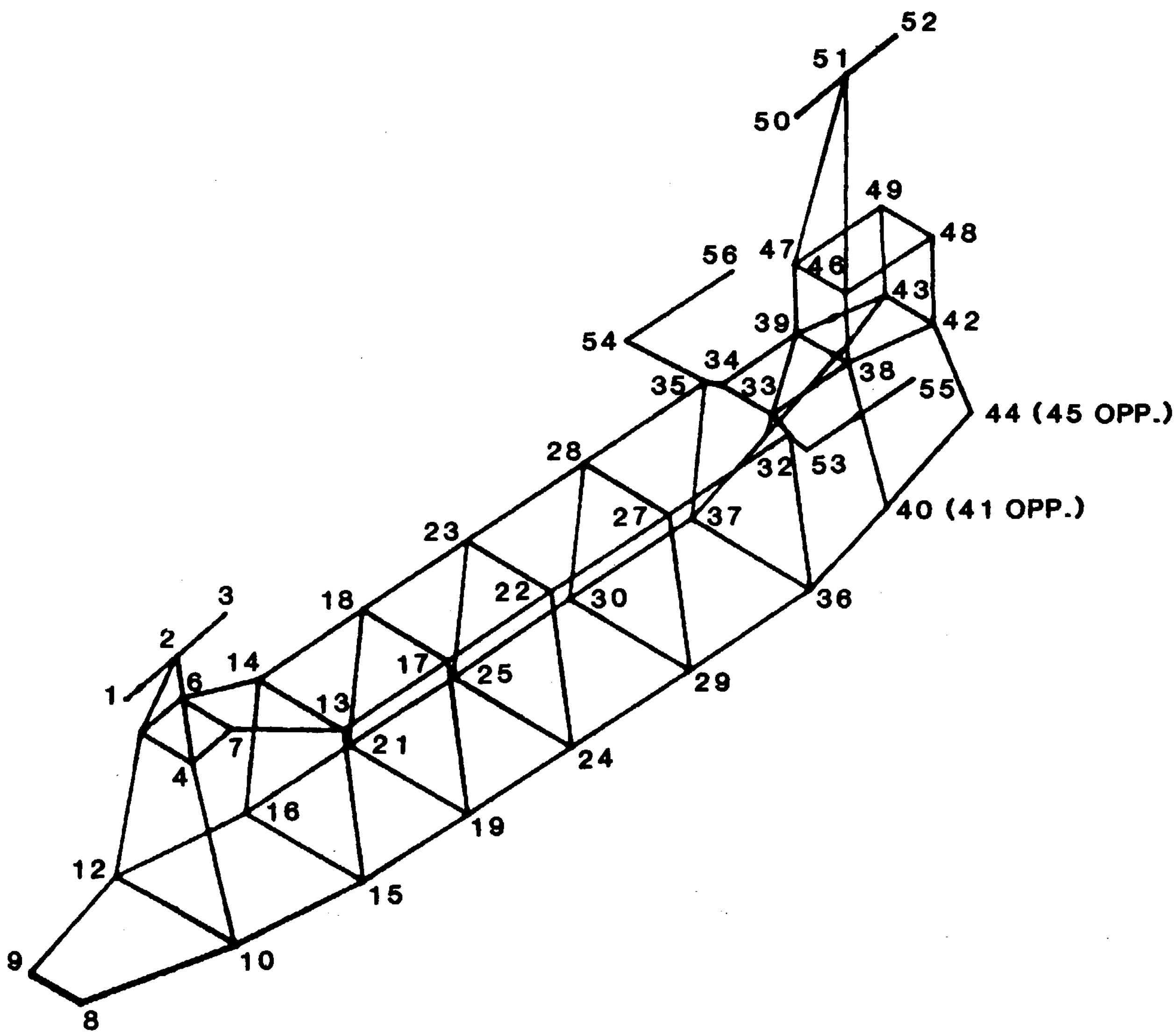
(1) 11,20,26,31,80,82,83 ARE ON FLOOR

(2) 4 THRU 7 AND 46 THRU 49 ARE XMSN ATTACHMENTS

MEASUREMENT LOCATION TRACE - ISOMETRIC

The following chart shows an isometric trace (produced by the vibration analysis system) of the airframe and engine measurement locations presented in the two previous charts. Observe that the selected locations produce a rudimentary 3-dimensional outline of the primary structure. An isometric view such as this is used to display modal response.

TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES
MEASUREMENT LOCATION TRACE - ISOMETRIC



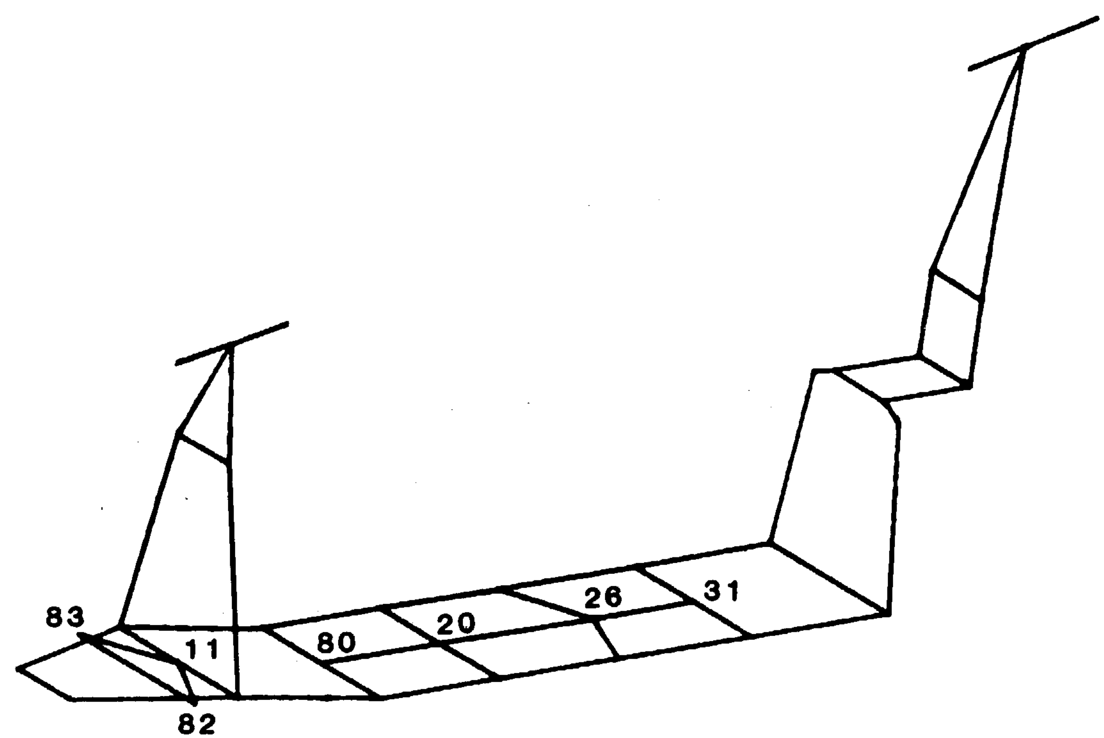
TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

MEASUREMENT LOCATION TRACE - ISOLATED FLOOR PANELS

The accompanying figure is a different version of the preceding isometric which shows the measurement locations on the normally isolated cockpit and cabin floor/fuel modules.

TEST GUIDES – VIBRATORY MEASUREMENTS AND PROCEDURES

MEASUREMENT LOCATION TRACE – ISOLATED FLOOR PANELS

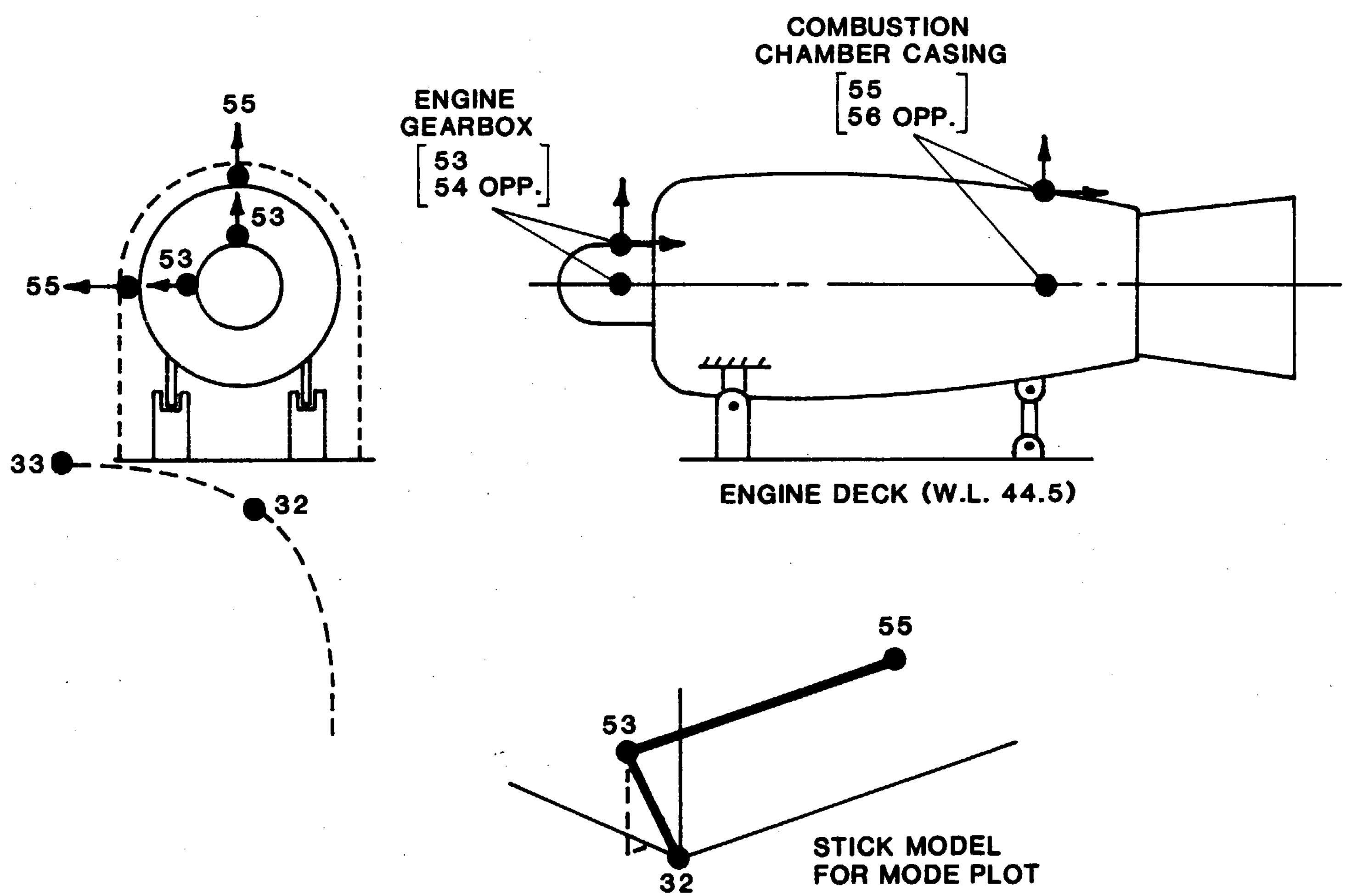


TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

ENGINE MEASUREMENT LOCATIONS

A set of accelerometer locations is desired which will permit a stick model representation of the engines for purposes of mode plotting. The number of locations suitable as accelerometer mounting positions is somewhat limited. A set of locations was selected which properly defined all of the rigid-body motions, except longitudinal. Due to the vertical offset from the centerline, both of the longitudinal accelerometers will be influenced, to some extent, by pitch motions. In the NASTRAN model, grid points corresponding to the accelerometer positions will be provided to facilitate analytical correlation.

TEST GUIDES – VIBRATORY MEASUREMENTS AND PROCEDURES
ENGINE MEASUREMENT LOCATIONS



MEASUREMENT COORDINATES AND SHAKER PHASING

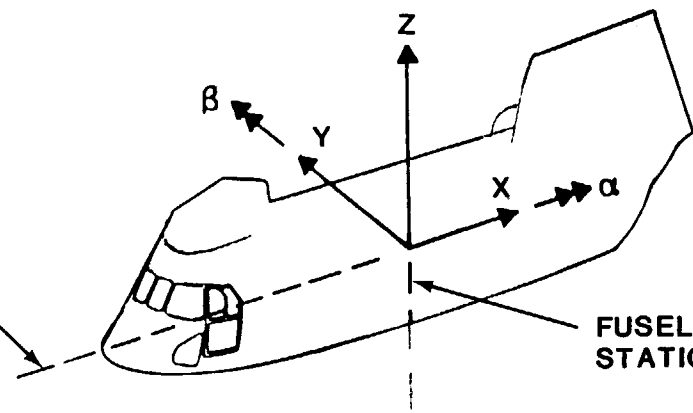
The accelerometer measurement coordinates which are parallel to the fuselage waterlines and station lines are illustrated in the figure. For future reference in performing analytical correlations, the polarity of the shakers is presented for each of the ten exciter configurations.

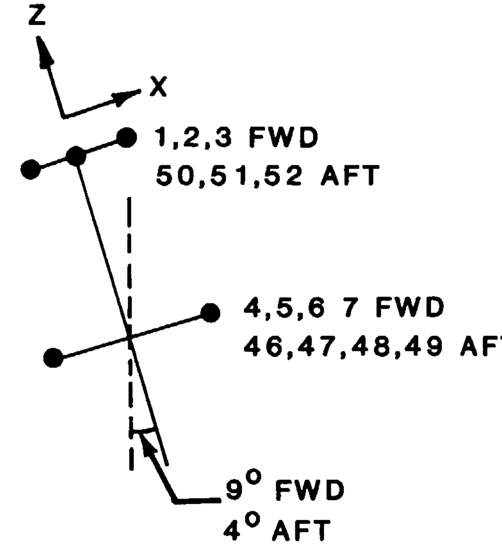
The sensitive axis directions of accelerometers mounted on the rotor heads and the transmission support points were aligned with the shaft axes system.

In the data analysis process, a compressive load in the force transducer is assumed to be a positive force. Taking vertical excitation as an example, the shaker is suspended above the hub and a compressive force produces a downward load on the aircraft. The polarity of the master shaker force is therefore in the negative (-Z) direction.

TEST GUIDES – VIBRATORY MEASUREMENTS AND PROCEDURES

MEASUREMENT COORDINATES AND SHAKER PHASING





ACTUAL HUB/TRANSMISSION COORDINATE SYSTEM

	EXCITATION	MASTER SHAKER POLARITY (REF.)	SLAVE SHAKER POLARITY
FORWARD	LONGITUDINAL	-X	—
	LATERAL	+Y	—
	VERTICAL	-Z	-Z
	ROLL	$+\alpha$	$+\alpha$
	PITCH	$+\beta$	$+\beta$
AFT	LONGITUDINAL	+X	—
	LATERAL	+Y	—
	VERTICAL	-Z	-Z
	ROLL	$+\alpha$	$+\alpha$
	PITCH	$-\beta$	$-\beta$

NOTES: 1. PITCH/ROLL MOMENTS (IN-LB) = MASTER SHAKER FORCE x 64.

2. VERTICAL SHAKERS PARALLEL TO ROTOR SHAFT AXIS. LONGITUDINAL AND LATERAL SHAKERS PERPENDICULAR TO SHAFT AXIS.

ACCELERATION MEASUREMENTS

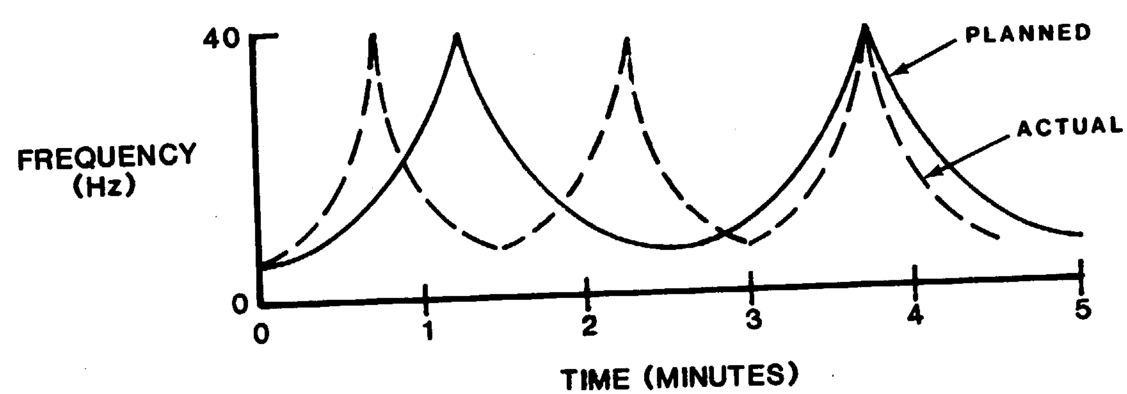
Acceleration data for all of the specified measurement locations will be obtained using a single tri-axial probe. Input force (master shaker for dual shaker configurations) will be recorded simultaneously as the phase reference. Prior to the start of testing, the adequacy of the planned cyclic frequency sweep function will be verified.

TEST GUIDES – VIBRATORY MEASUREMENTS AND PROCEDURES

ACCELERATION MEASUREMENTS

- A SINGLE TRI-AXIAL ACCELERATION PROBE
- ACCELERATION DATA AND INPUT FORCE SIMULTANEOUSLY RECORDED
- DATA ACQUIRED FOR ALL SPECIFIED MEASUREMENT LOCATIONS
- ADEQUACY OF PLANNED CYCLIC FREQUENCY SWEEP WILL BE VERIFIED

LOG FREQUENCY VARIATION



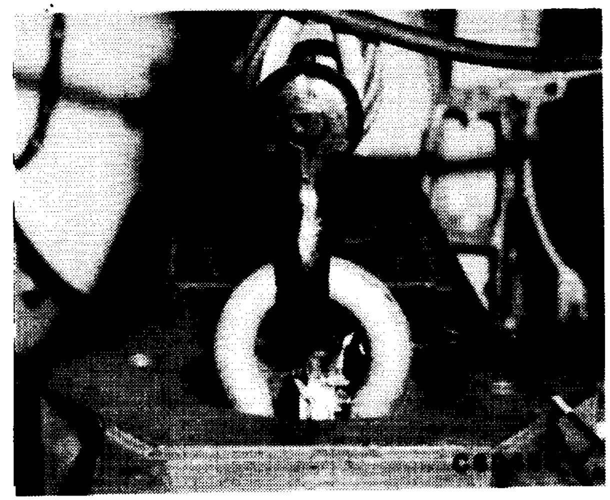
TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

TYPICAL ACCELEROMETER INSTALLATIONS

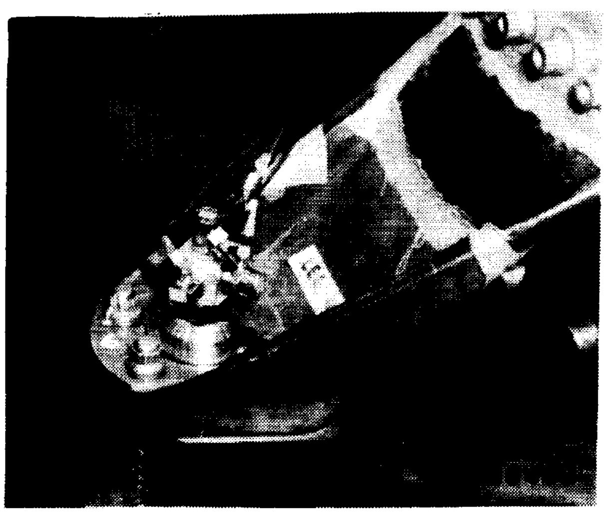
Typical installations of the tri-axial accelerometer probe are illustrated in these photographs. With the exception of the rotor hubs and the transmission support points, where measurements are made in the shaft axis system, placement of the accelerometers is designed to obtain measurements in the aircraft axis system. On contoured surfaces, the accelerometers are mounted on an appropriately contoured block. On vertical surfaces, an aluminum block is bonded at the desired location to provide a horizontal mounting surface for the probe. At all locations, the probe is held in place using a zinc chromate sealant. This material is sticky (yet firm) and allows rapid deployment of the probe.

TEST GUIDES – VIBRATORY MEASUREMENTS AND PROCEDURES
TYPICAL ACCELEROMETER INSTALLATIONS

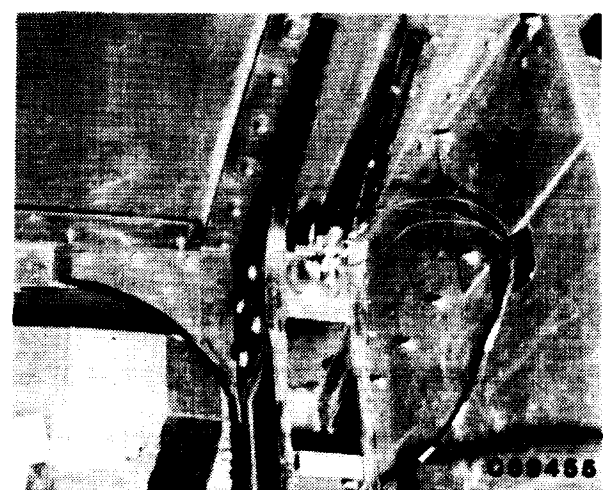
CONTOURED SURFACE



ROTOR HUB



FORWARD TRANSMISSION



AFT TRANSMISSION

TEST GUIDES - VIBRATORY MEASUREMENTS AND PROCEDURES

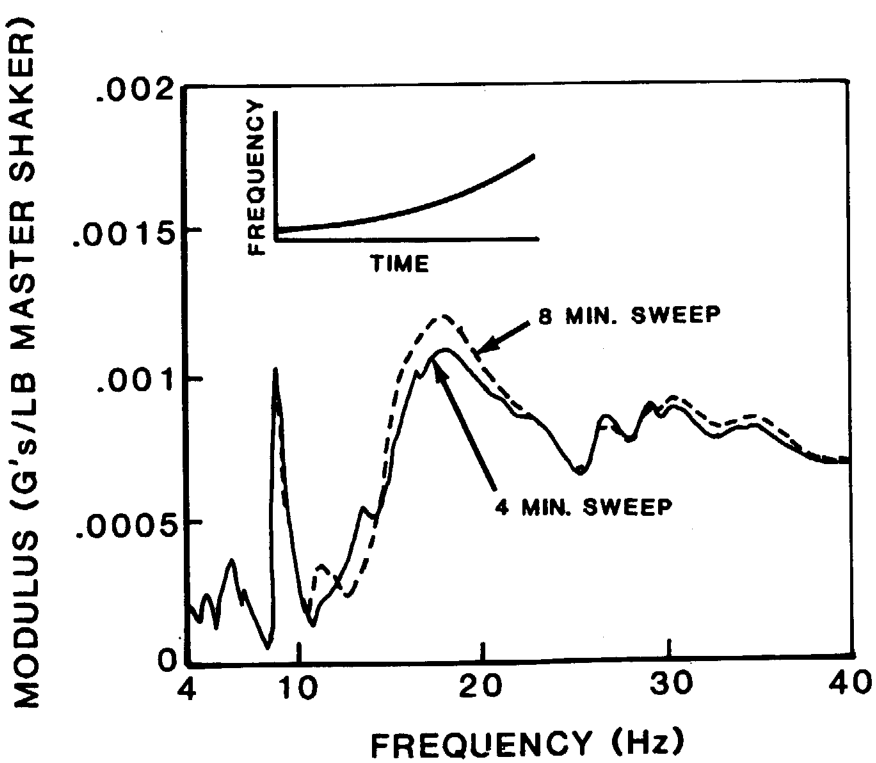
ACCELERATION MEASUREMENT WITH CYCLIC FREQUENCY SWEEP

The chart illustrates frequency response results (transfer function) obtained by both a conventional method using a log frequency sweep in conjunction with a narrow bandwidth digital filter and the Modal-Plus program with a cyclic log frequency sweep. For the conventional analysis, there are moderate differences between results obtained with a 4 minute and 8 minute sweep. Results obtained with the Modal-Plus program display excellent agreement with the conventional analysis using an 8 minute sweep.

TEST GUIDES – VIBRATORY MEASUREMENTS AND PROCEDURES
ACCELERATION MEASUREMENT WITH CYCLIC FREQUENCY SWEEP

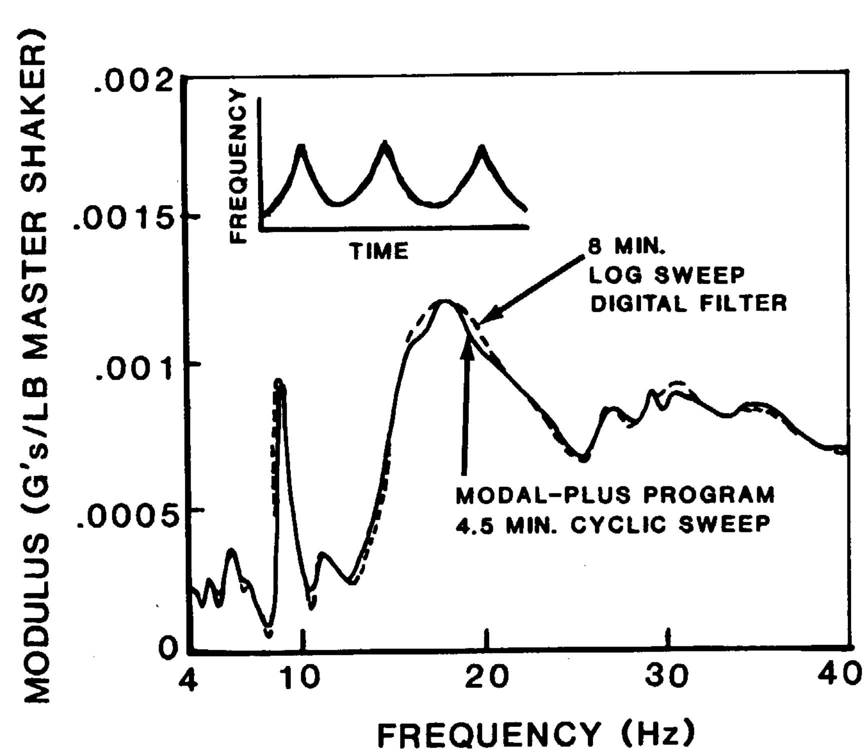
CONVENTIONAL ANALYSIS

- LOG FREQUENCY SWEEP WITH DIGITAL FILTER



MODAL–PLUS PROGRAM

- CYCLIC LOG FREQUENCY SWEEP WITH MODAL–PLUS PROGRAM



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4.10 Presentation of Results

TEST GUIDES

PRESENTATION OF RESULTS

The required and planned presentation of results are summarized on the accompanying chart. The only type of results required are plots of acceleration amplitude and phase (or equivalent) versus frequency for constant amplitude of applied load. In lieu of this, it is planned to present plots of the transfer function amplitude and phase. Since the transfer function is defined as acceleration divided by force, the transfer function plot is an acceleration plot for a unit applied load. In addition to the response data, it is also planned to present results of a modal parameter analysis for a limited number of locations and forced response mode shapes at estimated natural frequencies.

TEST GUIDES

PRESENTATION OF RESULTS

REQUIRED:

- **THE REQUIRED TYPE OF RESULTS ARE PLOTS OF ACCELERATION AMPLITUDE AND PHASE (OR EQUIVALENT) VERSUS FREQUENCY FOR CONSTANT AMPLITUDE OF APPLIED LOAD**

PLANNED:

- **PLOTS OF TRANSFER FUNCTION AMPLITUDE AND PHASE VERSUS FREQUENCY**
- **MODAL PARAMETER ANALYSIS (FREQUENCY AND DAMPING) FOR LIMITED NUMBER OF LOCATIONS**
- **FORCED RESPONSE MODE SHAPES AT ESTIMATED NATURAL FREQUENCIES**

TEST GUIDES - PRESENTATION OF RESULTS

FREQUENCY RESPONSE

Test results for later correlation with analytical predications will be presented as plots of the transfer function magnitude (or modulus) and phase as a function of frequency. The transfer function is defined here as the acceleration divided by the force at the master shaker (only master shaker force is used regardless of whether the configuration is dual or single shaker). In addition to providing data for direct correlation, the frequency response plots also provide a means of estimating the natural frequencies.

For each of the ten planned shaker configurations, response plots will be shown in three axes (x, y, z directions) for six agreed upon aircraft locations. These locations will be scattered throughout the aircraft and include:

1) rotor hubs

2) cockpit

3) cabin

4) aft fuselage

5) engines

In order to insure valid data, on-line plots of the transfer function magnitude (no phase) for all locations and directions will be prepared.

To illustrate possible nonlinear effects due to exciting force level, response data will be shown for the vertical and longitudinal shaker configurations at 50 and 100% of the basic force. Response will be presented for the hub (drive point) and one airframe location. Since rotor shaft bearing clearance is a potential source of nonlinearity, loads along the shaft axis (vertical) and normal to the shaft axis (longitudinal) have been selected.

TEST GUIDES – PRESENTATION OF RESULTS
FREQUENCY RESPONSE

- RESULTS WILL BE PRESENTED AS PLOTS OF TRANSFER FUNCTION MAGNITUDE AND PHASE VERSUS FREQUENCY WHERE THE TRANSFER FUNCTION IS DEFINED AS:

  ACCELERATION/MASTER SHAKER FORCE

- DATA FOR SIX AGREED UPON AIRCRAFT LOCATIONS WILL BE SHOWN IN THREE AXES (X, Y, Z DIRECTIONS) FOR EACH OF THE SHAKER CONFIGURATIONS

- RESPONSE DATA AT TWO LOCATIONS (HUB AND ONE AIRFRAME) WILL BE SHOWN FOR VERTICAL AND LONGITUDINAL SHAKER CONFIGURATIONS TO ILLUSTRATE POSSIBLE NON-LINEAR EFFECT OF FORCE LEVEL

TEST GUIDES - PRESENTATION OF RESULTS

SAMPLE FREQUENCY RESPONSE

The typical planned format for presentation of frequency response data is illustrated in the accompanying figure. Transfer function magnitude and phase in three axes (x, y, z direction) are shown for one aircraft location. A total of sixty eight (68) sheets will be required to present the planned data.

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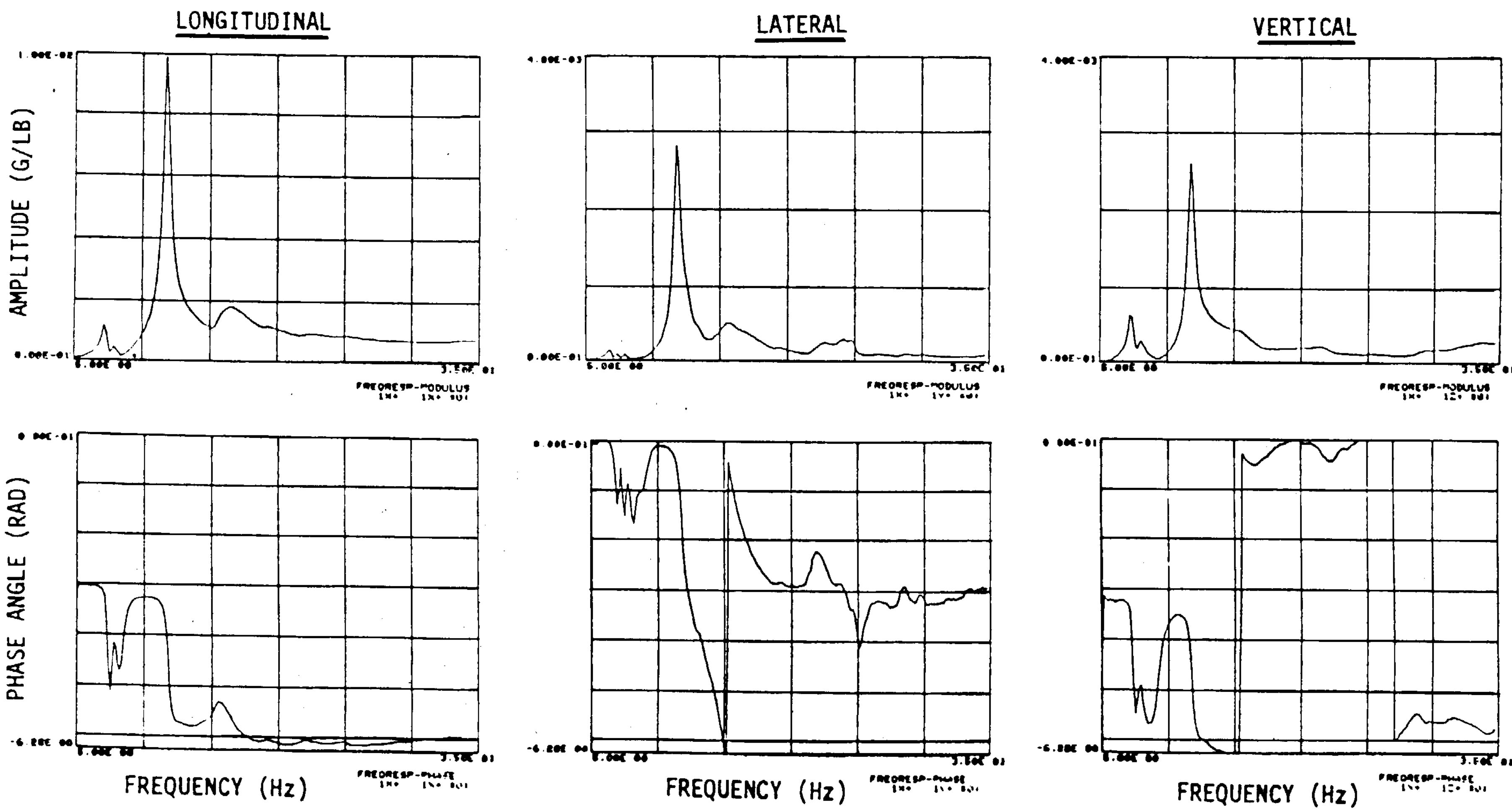
TEST GUIDES - PRESENTATION OF RESULTS
SAMPLE FREQUENCY RESPONSE

SIXTY EIGHT (68) SHEETS REQUIRED

EXCITATION: FWD HUB LONGITUDINAL RESPONSE: FWD HUB (LOC.2)



TEST GUIDES - PRESENTATION OF RESULTS

MODAL PARAMETER ESTIMATES

Modal parameter estimates, based on the hub drive point response (Test Locations 2 and 51) in the direction of the applied load, will be obtained using the analysis system multi-degree of freedom curve fitting capability. The principal purpose of this analysis is to obtain estimates of the modal damping for guidance in performing forced response calculations using a NASTRAN analytical model. In addition, the analysis also provides an estimate of the natural frequencies.

TEST GUIDES – PRESENTATION OF RESULTS
MODAL PARAMETER ESTIMATES

- ESTIMATES BASED ON CURVE FIT OF ROTOR HUB DRIVE POINT RESPONSE IN THE DIRECTION OF APPLIED LOAD WILL BE SHOWN
- MODAL PARAMETER ANALYSIS PROVIDES ESTIMATE OF MODAL DAMPING FOR GUIDANCE IN PERFORMING ANALYTICAL FORCED RESPONSE CORRELATION
- MODAL PARAMETER ANALYSIS ALSO PROVIDES ESTIMATE OF MODAL FREQUENCIES

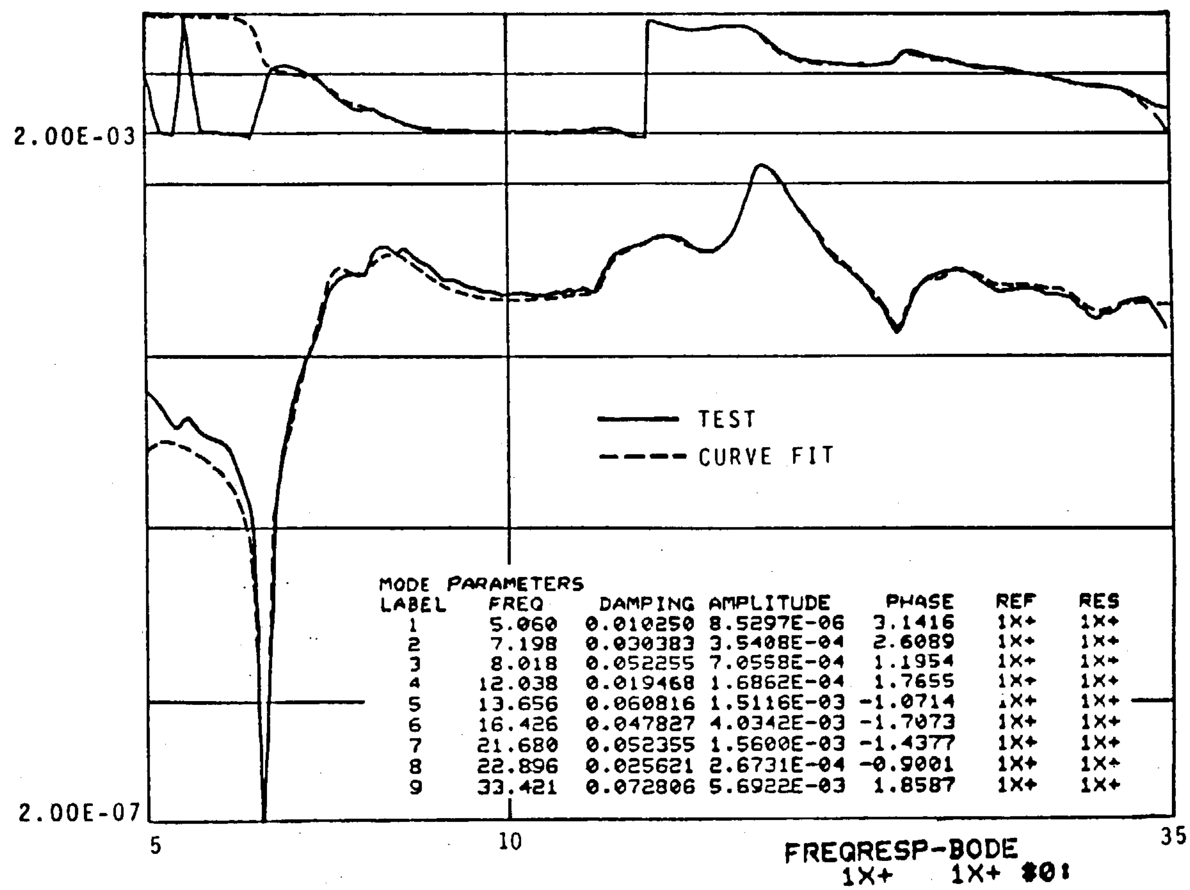
TEST GUIDES - PRESENTATION OF RESULTS

SAMPLE MODAL PARAMETER ESTIMATE

The planned presentation format for the modal parameter estimates is shown in this figure. The plot shows the test data and the results of the analyzer curve fit. Results of the analysis presented in the tabulation include the modal frequency, damping ratio, amplitude and phase. The last two columns indicate the reference force (master shaker is identified as 1x) and the response parameter location (1) and direction (x). The (+) sign indicates the signal polarity used in the analysis.

TEST GUIDES – PRESENTATION OF RESULTS
SAMPLE MODAL PARAMETER ESTIMATE

TEN (10) SHEETS REQUIRED



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	5.060	0.010250	8.5297E-06	3.1416	1X+	1X+
2	7.198	0.030383	3.5408E-04	2.6089	1X+	1X+
3	8.018	0.052255	7.0558E-04	1.1954	1X+	1X+
4	12.038	0.019468	1.6862E-04	1.7655	1X+	1X+
5	13.656	0.060816	1.5116E-03	-1.0714	1X+	1X+
6	16.426	0.047827	4.0342E-03	-1.7073	1X+	1X+
7	21.680	0.052355	1.5600E-03	-1.4377	1X+	1X+
8	22.896	0.025621	2.6731E-04	-0.9001	1X+	1X+
9	33.421	0.072806	5.6922E-03	1.8587	1X+	1X+

TEST GUIDES - PRESENTATION OF RESULTS

FORCED RESPONSE MODE SHAPES

Based on direct examination of the frequency response data and results of the modal parameter analysis, the approximate airframe modal frequencies will be estimated. Forced response mode shapes will be presented at the significant resonant frequencies for the shaker configuration which produces the greatest overall response. Shapes will be normalized to the maximum deflection.

It is recognized that these forced response mode shapes are not the so-called, "natural mode shapes". They do, however, serve several useful purposes; namely,

1. They provide some insight into the general characteristic of the natural modes,

2. Aid in assessing the general validity of test results, and

3. Contribute to an understanding of the differences between test and calculated forced response.

Estimates of the natural frequencies and the modal purity of the associated shape can be enhanced by a number of analytical procedures. These procedures, however, are time-consuming and beyond the specified scope of this program.

TEST GUIDES – PRESENTATION OF RESULTS
FORCED RESPONSE MODE SHAPES

- NORMALIZED FORCED RESPONSE MODE SHAPES WILL BE PRESENTED FOR SIGNIFICANT RESONANT FREQUENCIES
- FORCED RESPONSE MODE SHAPES SERVE SEVERAL USEFUL PURPOSES
  - — PROVIDE INSIGHT INTO CHARACTER OF NATURAL MODES
  - — AID IN EVALUATING TEST RESULTS
  - — CONTRIBUTE TO AN UNDERSTANDING OF FORCED RESPONSE

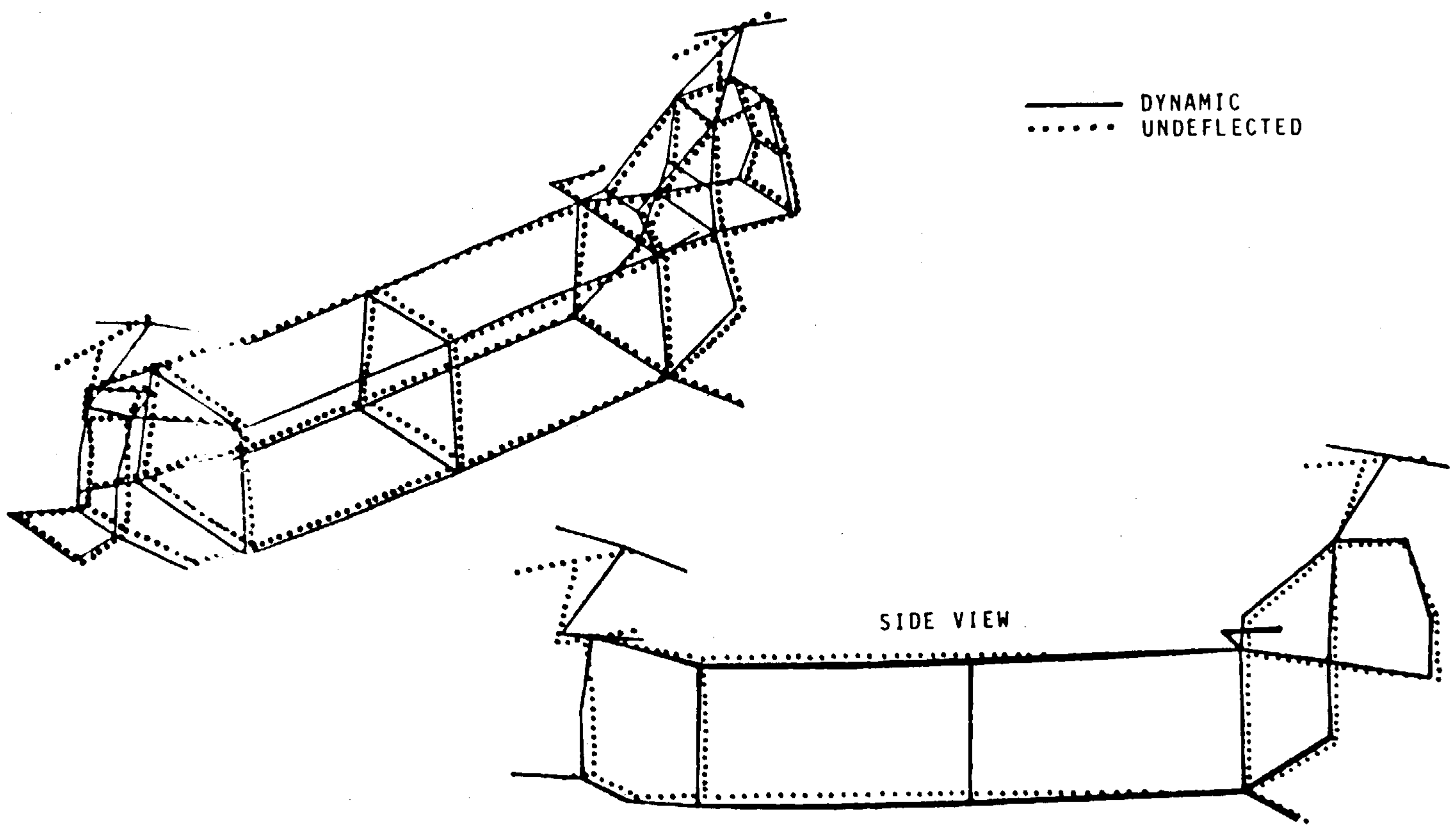
TEST GUIDES - PRESENTATION OF RESULTS

SAMPLE FORCED RESPONSE MODE SHAPE

A typical forced response mode shape is illustrated by the accompanying sample plot. Selected side, top, and end views are available in addition to an isometric. It is estimated that a total of approximately twenty (20) sheets will be required to present the planned data.

TEST GUIDES – PRESENTATION OF RESULTS
SAMPLE FORCED RESPONSE MODE SHAPES

APPROXIMATELY TWENTY (20) SHEETS REQUIRED



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5.0 Test Results

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5.1 Test Details

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TEST RESULTS

TEST DETAILS - MODEL 360 TEST VEHICLE

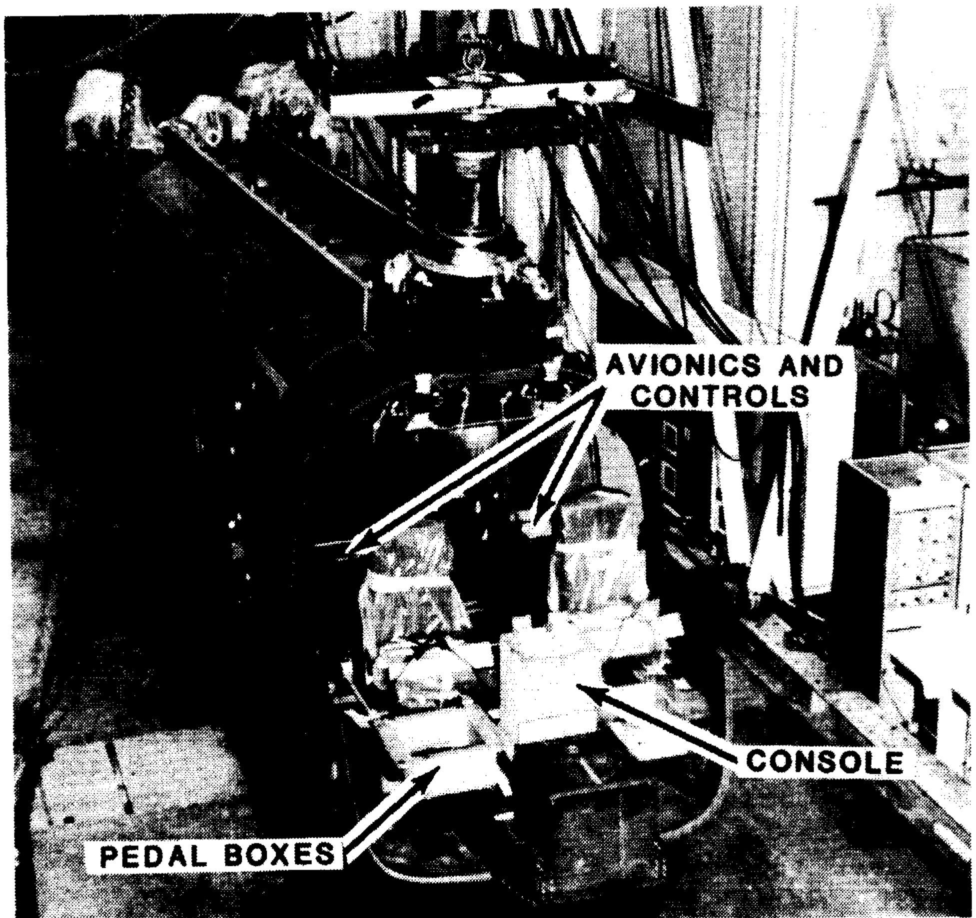
The accompanying photograph shows the Model 360 prototype in the test fixture. Visible dummy components in the cockpit are identified. These items consisted of 3/4 inch plywood containers which were ballasted to obtain the correct component weight and approximate center of gravity. Measured rigid-body frequencies of the test vehicle on the suspension system were as follows:

RIGID BODY FREQUENCIES (Hz)

Vertical	1.66
Lateral	0.19
Longitudinal	0.24
Pitch	2.08
Roll	0.75
Yaw	0.32

TEST RESULTS

TEST DETAILS - MODEL 360 TEST VEHICLE



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RIGID-BODY FREQUENCIES	
VERTICAL	1.66 Hz
LATERAL	0.19
LONGITUDINAL	0.24
PITCH	2.08
ROLL	0.75
YAW	0.32

TEST RESULTS

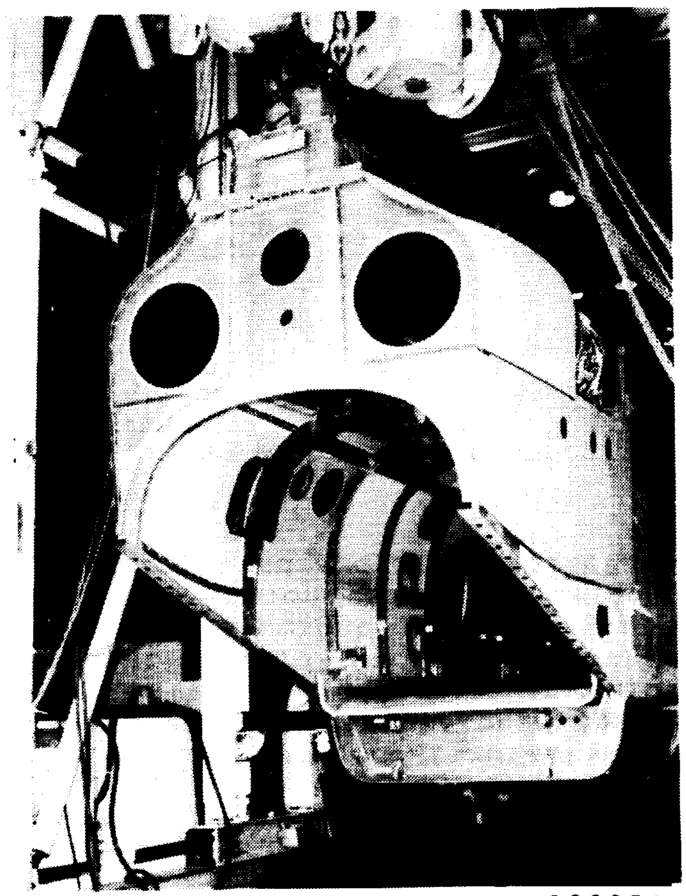
TEST DETAILS - MODEL 360 TEST VEHICLE

Additional details of the test vehicle are shown in these photographs. The photograph on the left shows the aft fuselage and pylon. Also visible are internal details of the center cabin. The upper aft pylon structure and the cantilevered aft rotor shaft are shown on the right.

<u>NOTE</u>: This photograph was taken during a Boeing test which preceded the NASA shake test and a dummy aft transmission and rotor shaft were installed.

TEST RESULTS

TEST DETAILS – MODEL 360 TEST VEHICLE



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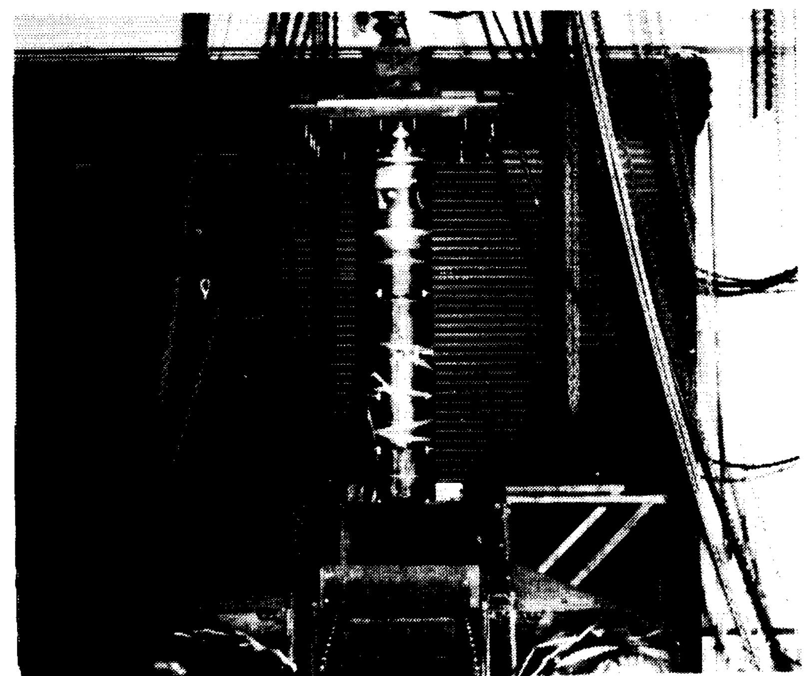
AFT FUSELAGE AND PYLON



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AFT PYLON AND ROTOR SHAFT

TEST RESULTS

TEST DETAILS - WEIGHT STATEMENT

An earlier test configuration which employed a dummy aft transmission and rotor shaft was hung and weighed during a Boeing test which preceded the NASA-sponsored shake testing. A tabular calculation is shown which yields a calculated hung weight of 10,652 pounds versus an actual weight of 10,780 pounds for this configuration. A weight of 18,285 pounds was obtained for the current test configuration by calculation using the earlier hung weight adjusted for the actual weight of items removed and/or installed.

TEST RESULTS

TEST DETAILS – WEIGHT STATEMENT

PRIMARY STRUCTURE	3029.
SECONDARY STRUCTURE & EQUIPMENT	1515.2
FORWARD TRANSMISSION ASSEMBLY	861.5
DUMMY AFT XMSN AND ROTOR SHAFT	1689.
COMBINING TRANSMISSION (MIXBOX)	248.
ENGINES AND ENGINE TRANSMISSIONS	1838.
FORWARD HUB ASSEMBLY	1471.5
CALCULATED HUNG WEIGHT	10652.2 LB.
ACTUAL HUNG WEIGHT	10780. LB.
LESS DUMMY AFT XMSN & ROTOR SHAFT	-1689.
AFT XMSN AND ROTOR SHAFT	1108.
AFT HUB ASSEMBLY	1465.5
COCKPIT BALLAST (INCLUDING SEATS)	1521.
CABIN BALLAST	5100.
TEST WEIGHT	18285.5 LB.

INSTALLED SECONDARY STRUCTURE & EQUIPMENT	
FLOOR ASSEMBLY	643.
FUEL CELLS	350.
FUEL SYSTEM (PARTIAL)	123.1
FLOOR INSTALLATION RIGGING	26.3
COCKPIT & CABIN ISOLATION UNITS	191.
WINDOWS (4)	19.5
RAMP HINGE & ACTUATOR FITTINGS	32.2
COCKPIT FLOOR PANEL	68.
FWD LANDING GEAR SKIN PANELS	24.
JACK PADS	10.9
MISC. SUPPORT PROVISIONS	22.2
STRAIN GAGE WIRING	5.
	1515.2 LB.

TEST RESULTS

TEST DETAILS - INTERNAL BALLAST

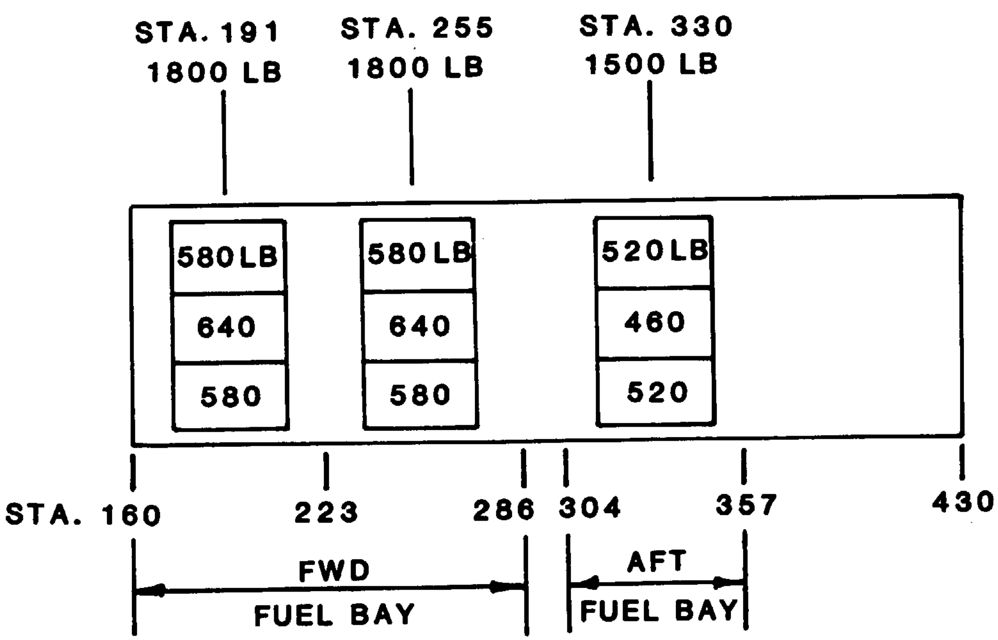
The amount and location of ballast in the center cabin was as shown. Ordinarily, fuel is carried in two box-like enclosures attached to the bottom of the floor. For the shake test, ballast was located on the floor directly above the normal fuel location. Weight of the ballast was equal to the nominal full fuel load. Ballast consisted of lead bars contained in heavy (3/4 inch) plywood boxes. The center box was bolted to the two outboard boxes which, in turn, were secured to the floor tiedown fittings with turnbuckles.

TEST RESULTS

TEST DETAILS – INTERNAL BALLAST

TOTAL BALLAST = 5100 LB

(BALLAST = FULL FUEL LOAD)



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TEST RESULTS

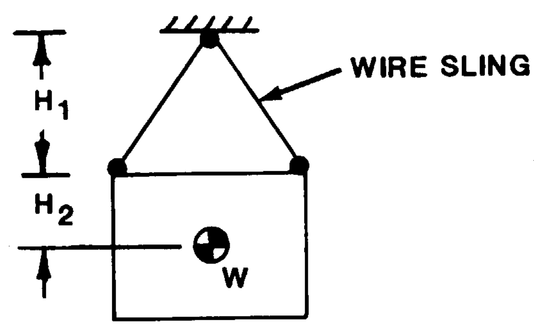
TEST DETAILS - COMPONENT SWING TESTING

As specified in the test guides, a swing test was attempted on the forward transmission, the hub fixture (weight assembly) and an engine to obtain moments of inertia. The combination of available lift points, size and shape precluded direct determination of the center of gravity by teetering or triangulation. Similarly, without provisions to support the specimens in the required attitude, it was not possible to use the torsional pendulum method for determining the inertia. In summary, implementation of the usual methods required an unplanned degree of sophistication. As an alternative, the pendulum frequencies were obtained for two different pendulum lengths using existing lift points and a wire sling. Using the sling dimensions and the two frequencies, both the C. G. and moment of inertia were calculated. Compared to anticipated results (C. G. in particular) the results do not appear sufficiently accurate to be useful.

TEST RESULTS

TEST DETAILS – COMPONENT SWING TESTING

- SWING TEST PERFORMED FOR FORWARD TRANSMISSION, HUB WEIGHT & ENGINE TO OBTAIN MOMENT OF INERTIA
- AVAILABLE LIFT POINTS REQUIRED A SLING FOR ADEQUATE SUPPORT



- SIZE AND SHAPE PRECLUDE DIRECT DETERMINATION OF CENTER OF GRAVITY. C.G. AND INERTIA CALCULATED USING FREQUENCIES FOR TWO PENDULUM LENGTHS ($H_1 + H_2$)
- RESULTS OBTAINED DO NOT APPEAR SUFFICIENTLY ACCURATE TO BE USEFUL

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5.2 Non-Linear Effect of Force

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TEST RESULTS

NON-LINEAR EFFECT OF FORCE

Comparison plots showing the non-linear effect of the exciting force magnitude are shown in the accompanying plots. Forward hub and Sta. 286 L/H cabin are presented for forward hub vertical and longitudinal excitation. Response at the aft hub and Sta. 286 L/H cabin are shown for aft hub vertical and longitudinal excitation.

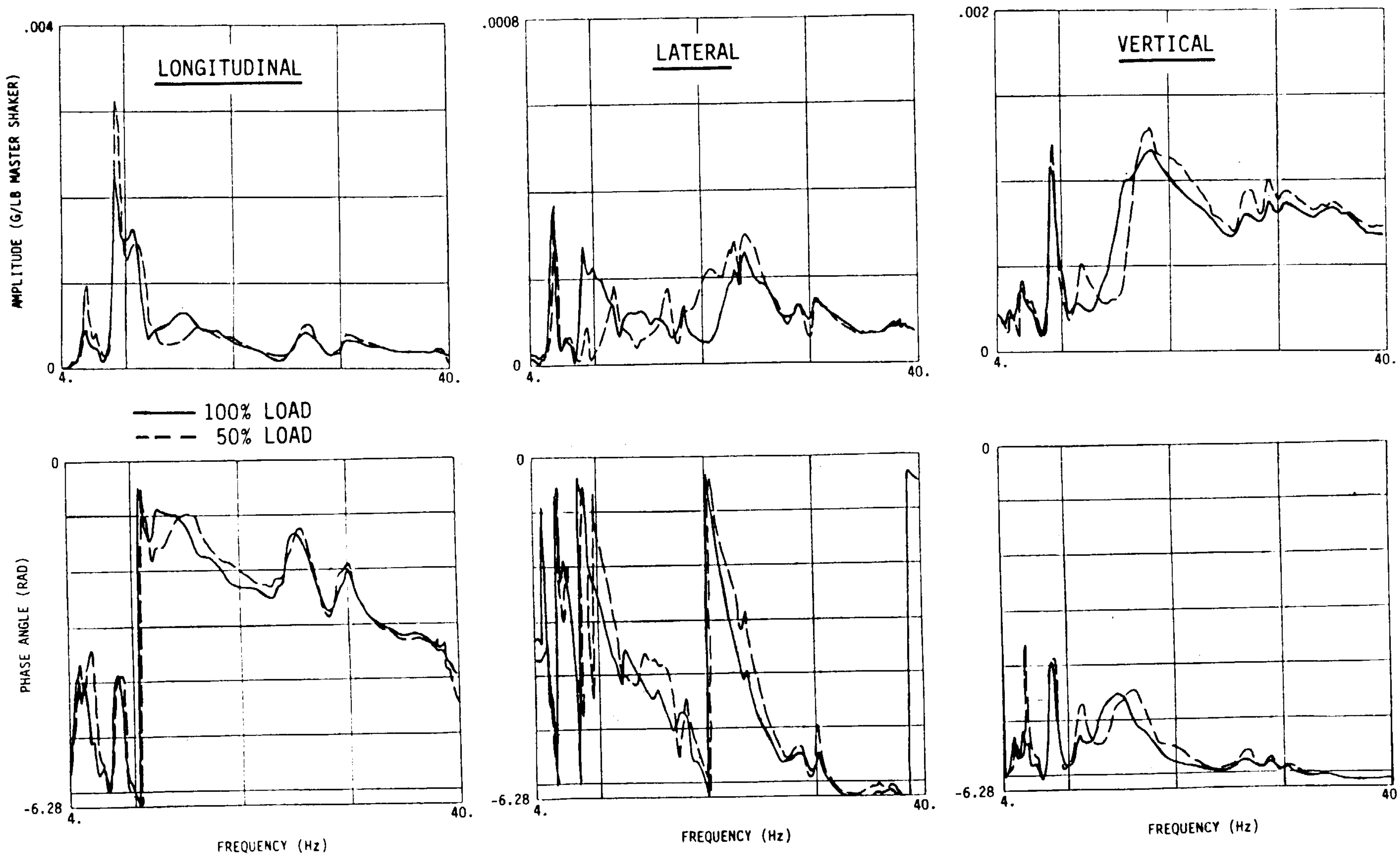
Examination of the amplitude response plots shows a tendency for the frequency of the peak responses to shift downward with increasing force level. The largest observed shift of a significant peak appears to be on the order of 1 Hz. The frequency shift is neither uniform across the spectrum nor consistent at any specific frequency. In addition to the down shift in frequency, the transfer function magnitude (G's/lb) in the peak response area tends to be reduced by increasing force level.

Changes are also evident in the phase data; however, the changes seem consistent with the changes in the response magnitude.

TEST RESULTS

NON-LINEAR EFFECT OF FORCE – FORWARD VERTICAL EXCITATION

RESPONSE: FORWARD HUB (LOC. 2)



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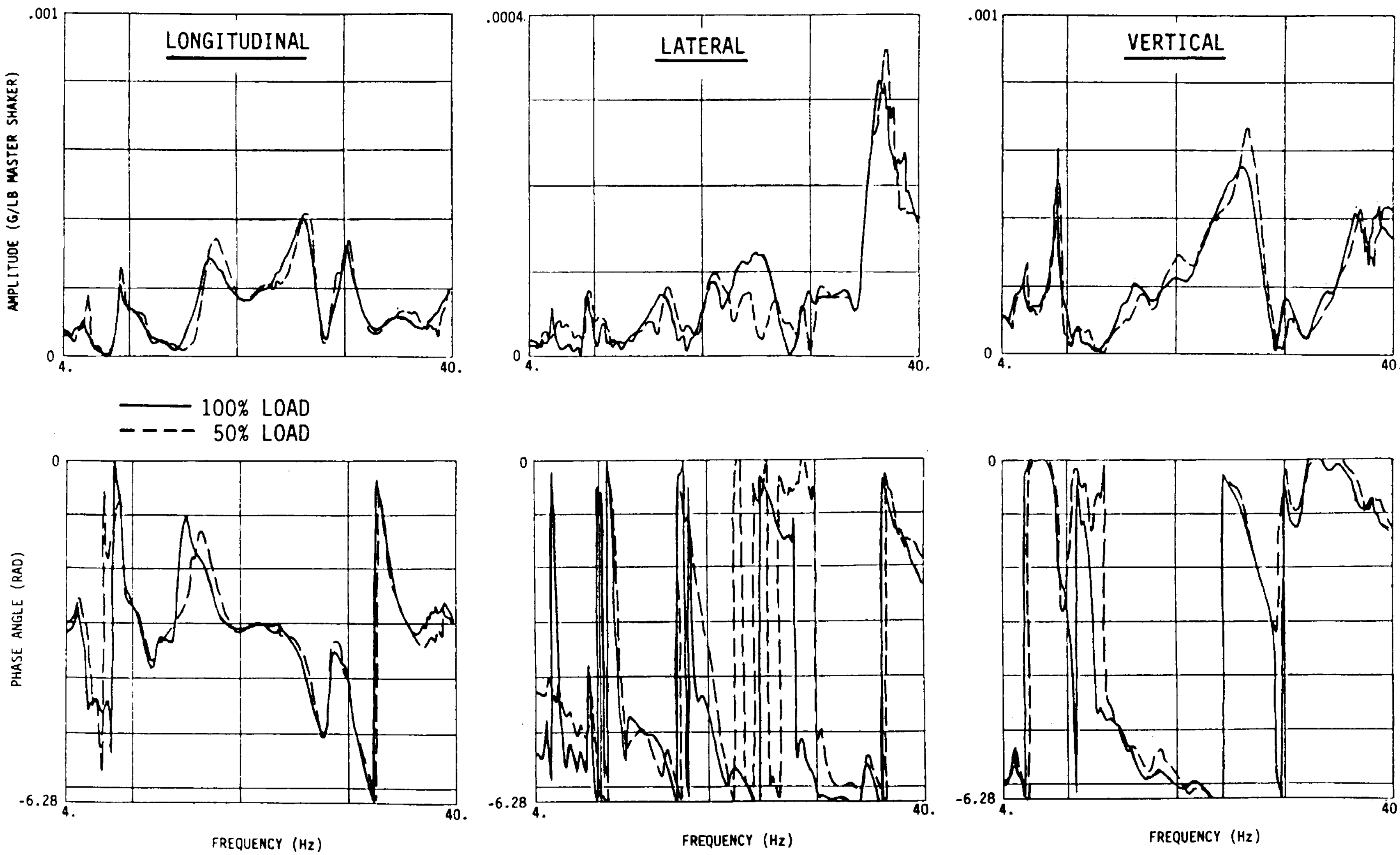
TEST RESULTS

NON-LINEAR EFFECT OF FORCE – FORWARD VERTICAL EXCITATION

RESPONSE: STA. 286 L/H CABIN (LOC. 24)



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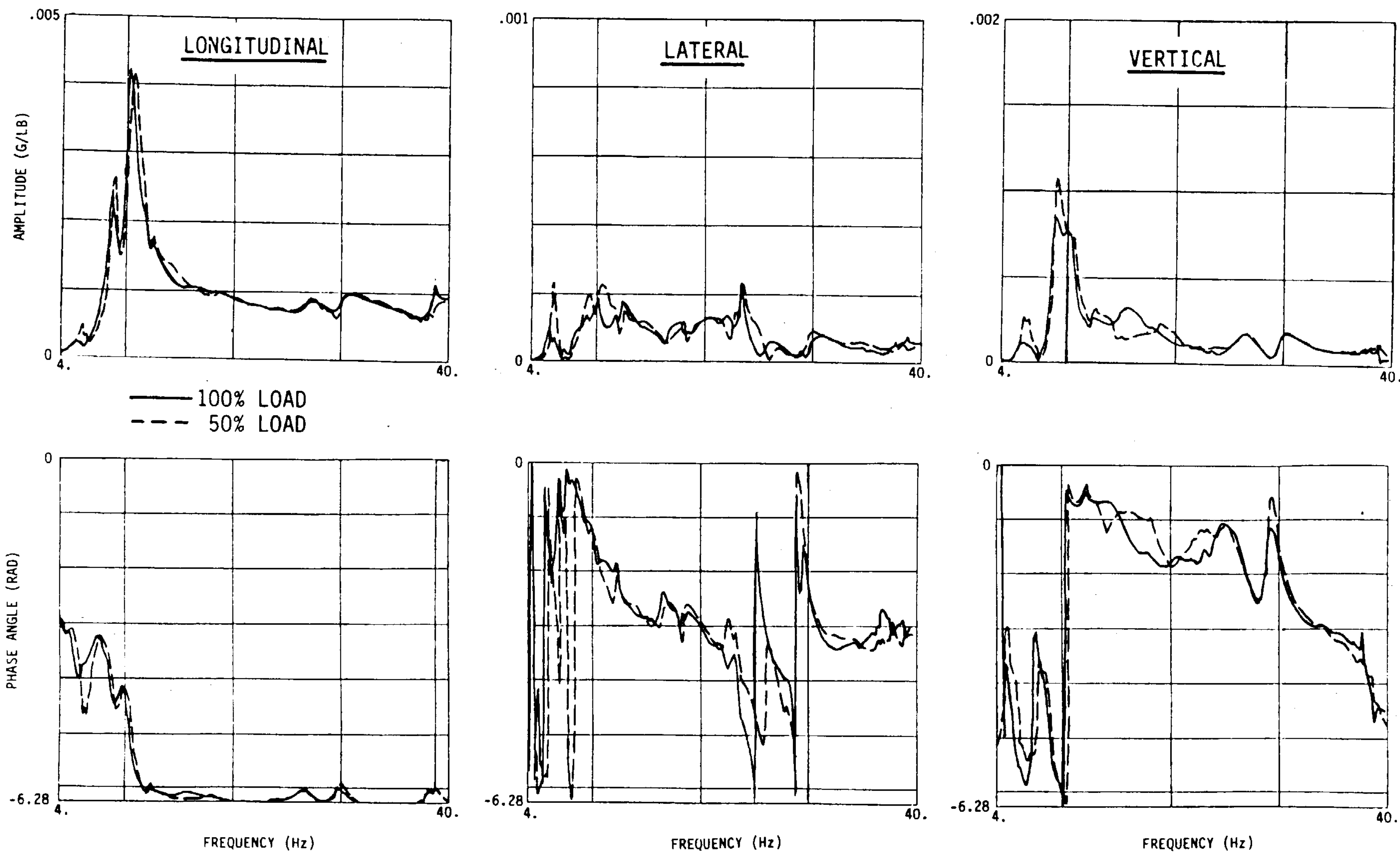
TEST RESULTS

NON-LINEAR EFFECT OF FORCE – FORWARD LONGITUDINAL EXCITATION

RESPONSE: FORWARD HUB (LOC. 2)



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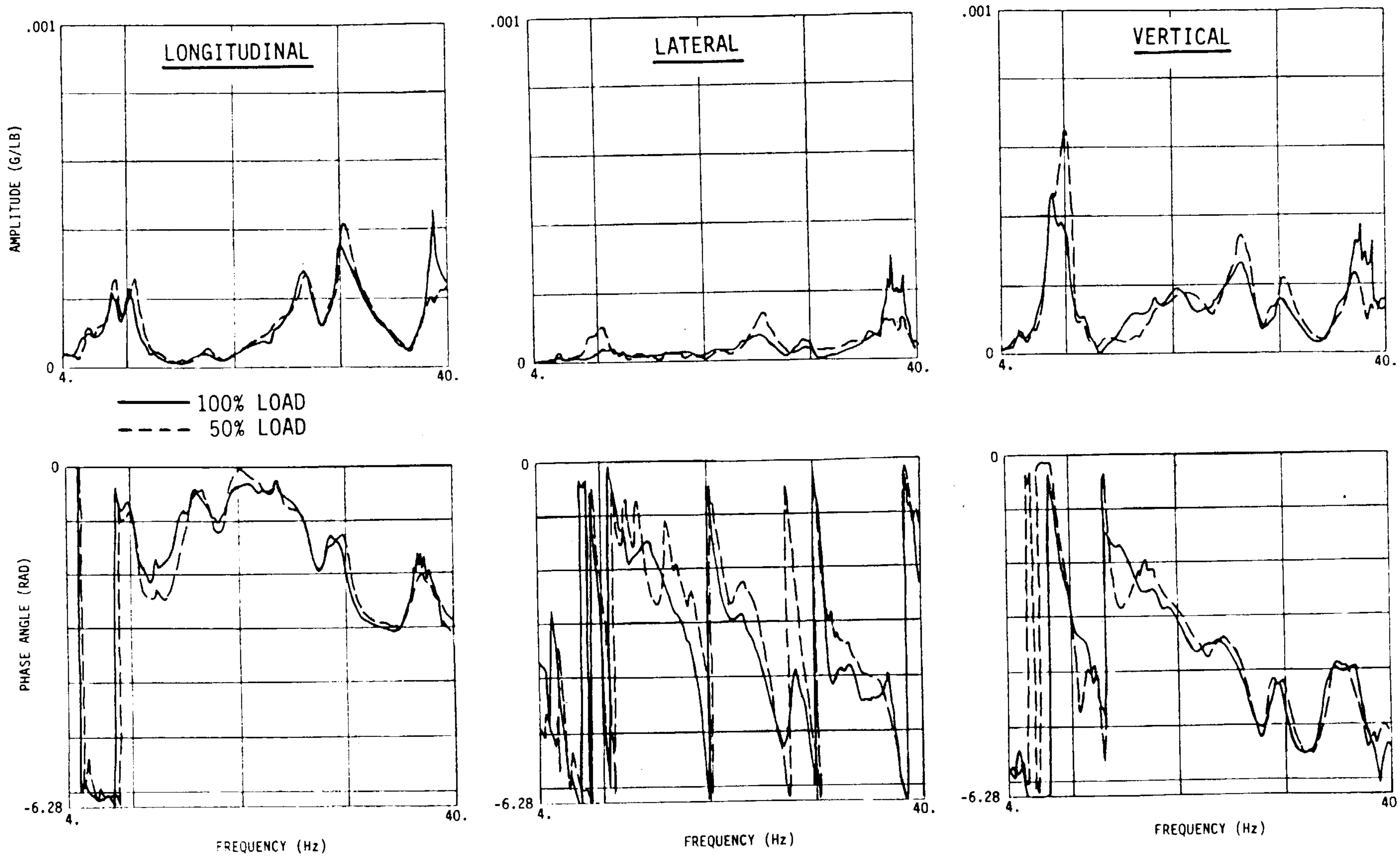
TEST RESULTS

NON-LINEAR EFFECT OF FORCE – FORWARD LONGITUDINAL EXCITATION

RESPONSE: STA. 286 L/H CABIN (LOC. 24)



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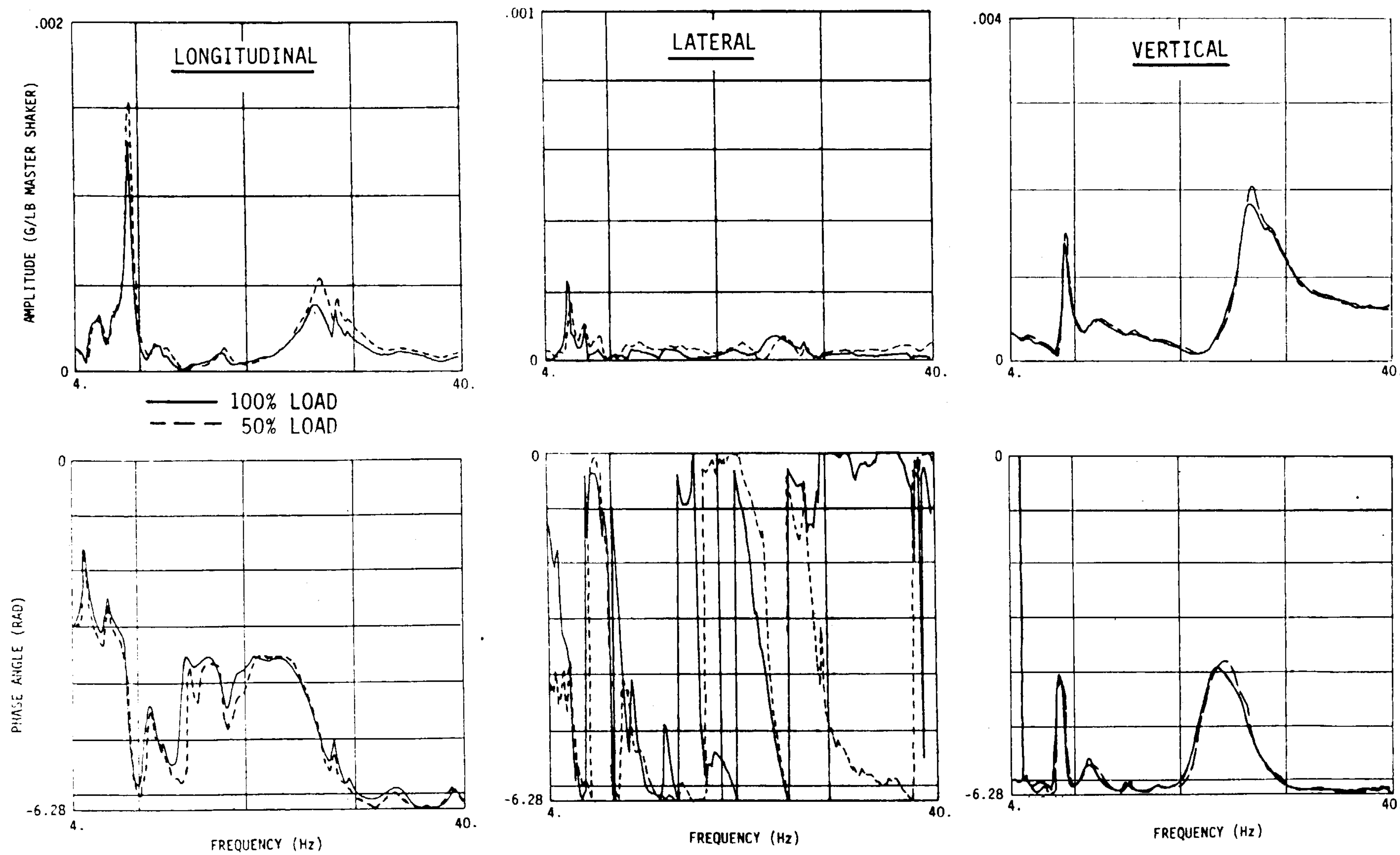
TEST RESULTS

NON-LINEAR EFFECT OF FORCE – AFT VERTICAL EXCITATION

RESPONSE: AFT HUB (LOC. 51)



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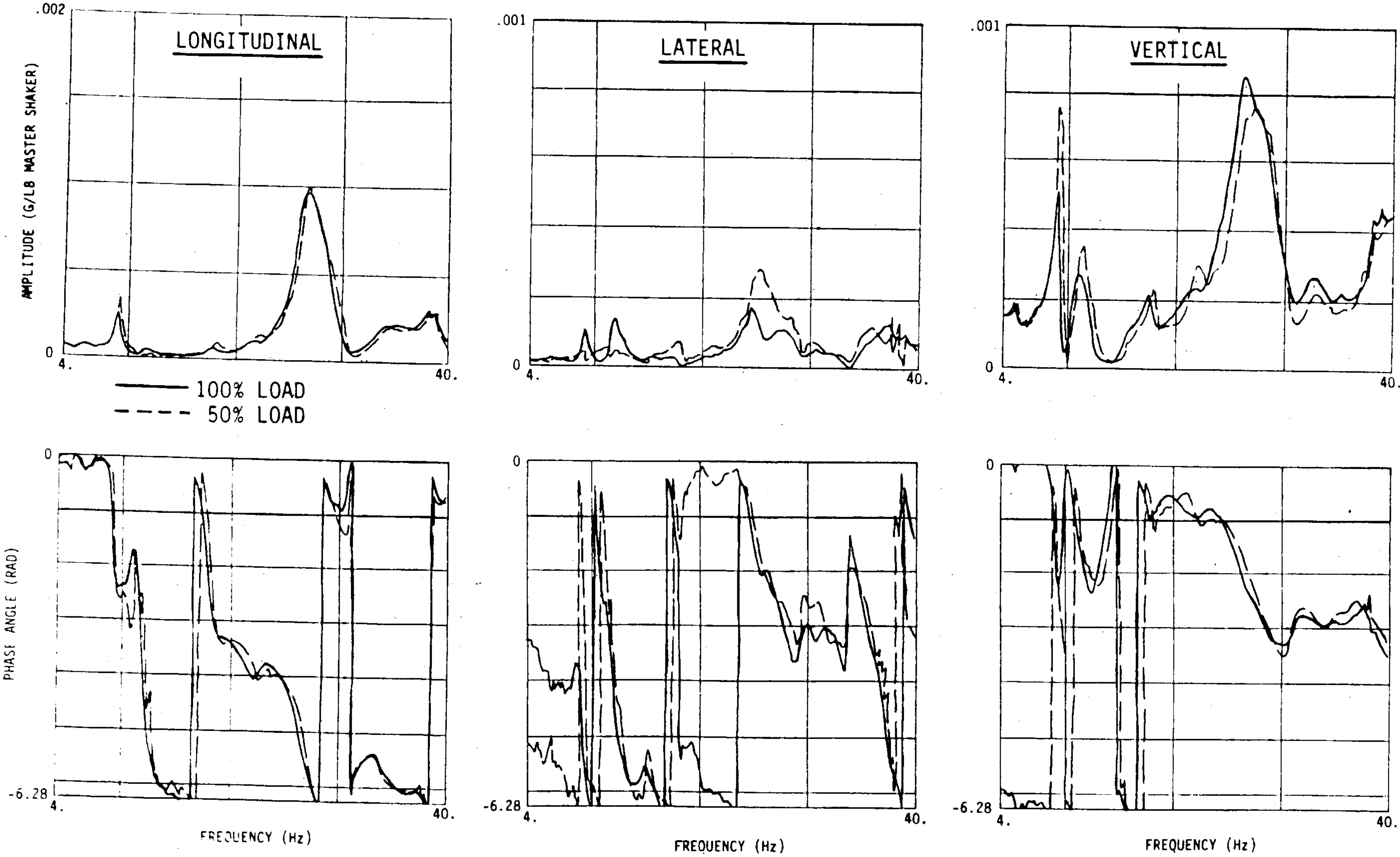
TEST RESULTS

NON-LINEAR EFFECT OF FORCE – AFT VERTICAL EXCITATION

RESPONSE: STA. 286 L/H CABIN (LOC. 24)



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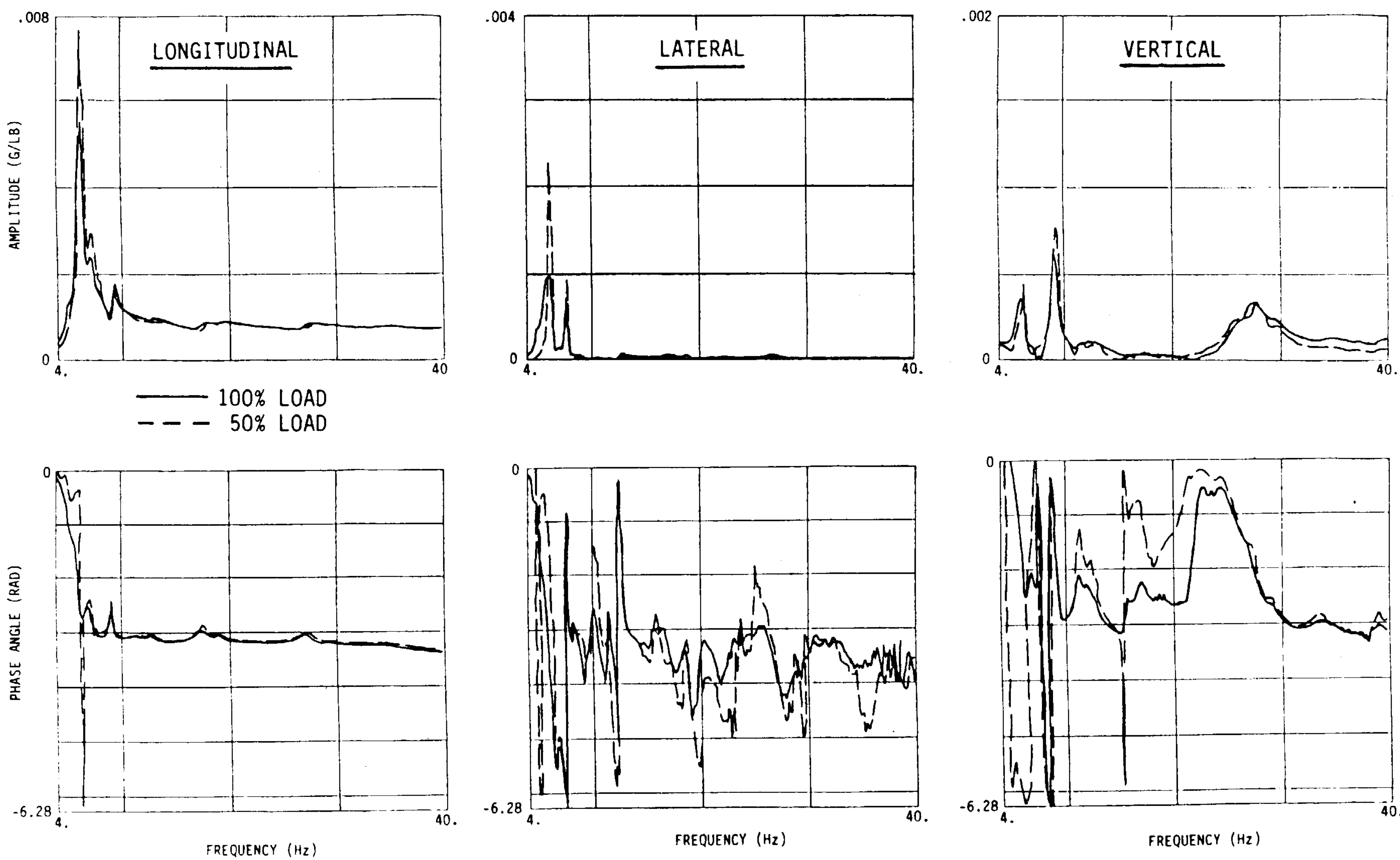
TEST RESULTS

NON-LINEAR EFFECT OF FORCE - AFT LONGITUDINAL EXCITATION

RESPONSE: AFT HUB (LOC. 51)



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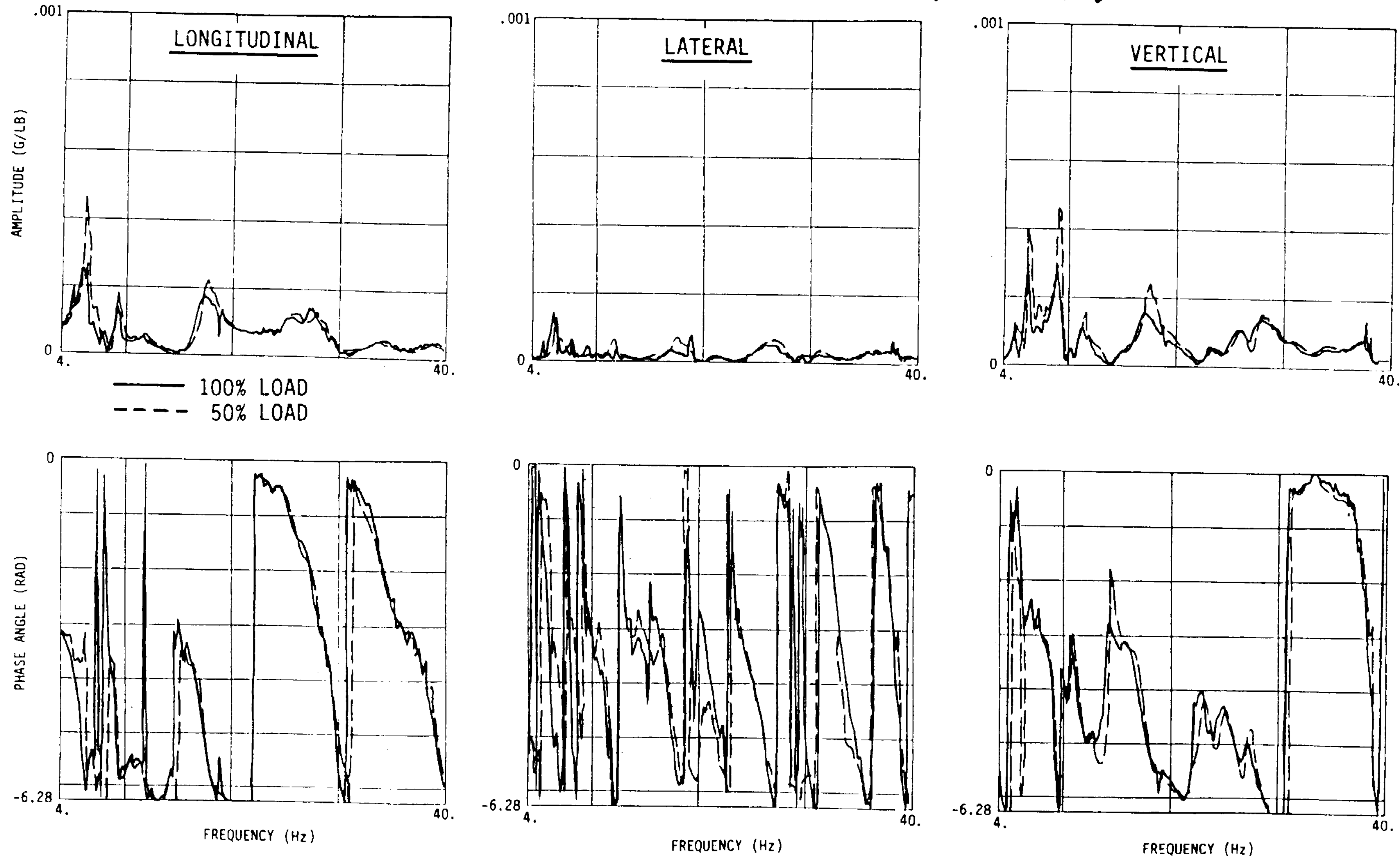
TEST RESULTS
NON-LINEAR EFFECT OF FORCE – AFT LONGITUDINAL EXCITATION
RESPONSE: STA. 286 L/H CABIN (LOC. 24)



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5.3 Modal Parameter Estimates

TEST RESULTS

MODAL PARAMETER ESTIMATES

Modal parameter estimates based on forward and aft hub response (Test Locations 2 and 51) were obtained using the analysis system multi-degree of freedom curve fitting capability. The purpose of this analysis was to obtain estimates of the modal damping for guidance in performing analytical forced response calculations at a later date. The curve fitting procedure was performed for the following cases:

Excitation	Hub Response At Shaker Location
Vertical	Vertical
Lateral	Lateral
Longitudinal	Longitudinal
Pitch	Longitudinal
Roll	Lateral

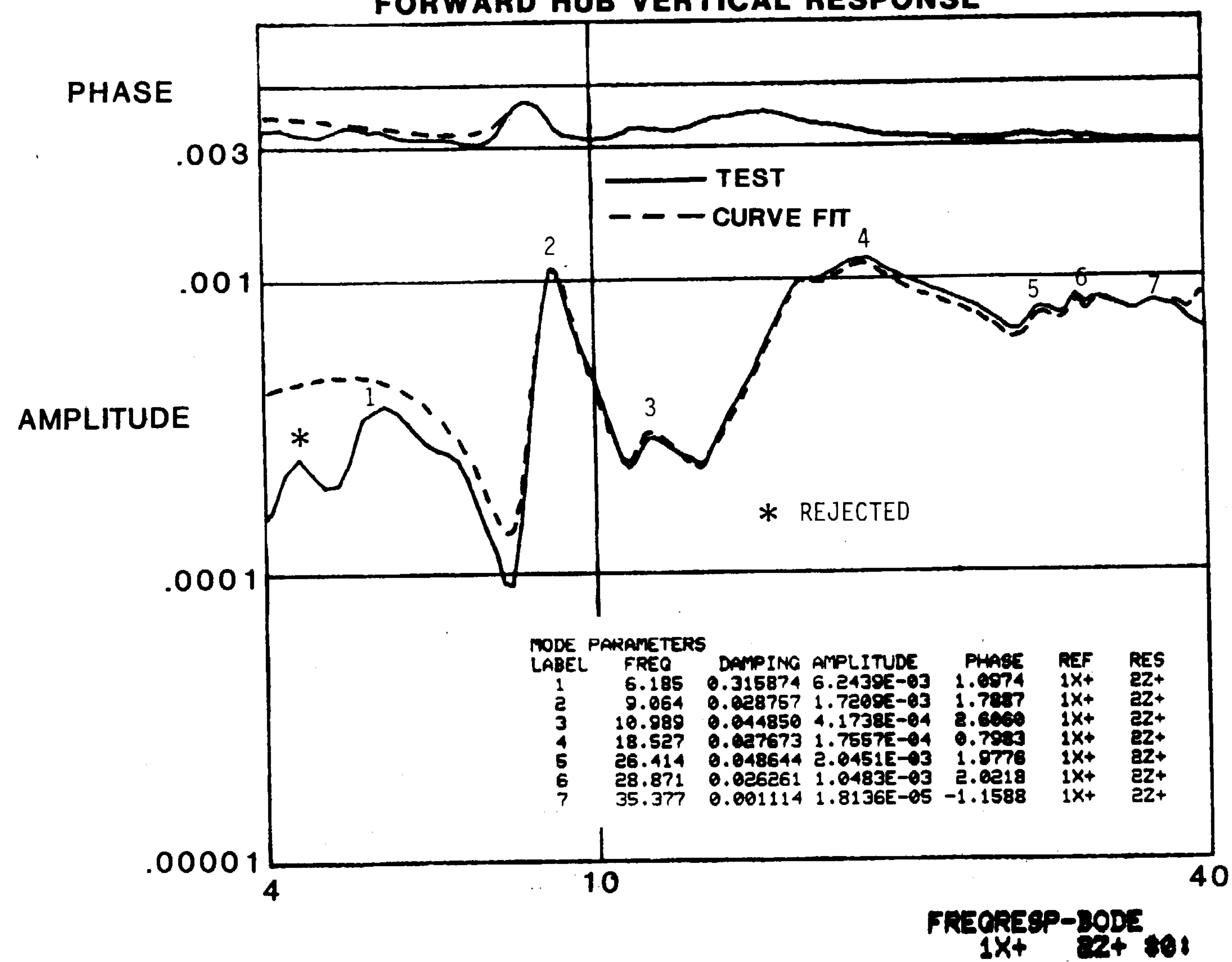
Results of the analysis are presented on the following pages. With minor exceptions, both the frequency and amplitude match are extremely good. The tabulated data indicates the constituent frequencies, damping, amplitude and phase of the curve fitted response. Interestingly, a number of significant response peaks are matched without requiring knowledge of a natural frequency in the vicinity (for example, forward lateral excitation). In most of these cases, a trial frequency at the peak has been rejected by the analysis.

Most of the well defined peaks show damping values in the range of 2 to 6 percent critical. A notable exception occurs with forward rotor lateral excitation where nearly 14 percent damping is obtained at 25 Hz. A reasonable average appears to be on the order of 2 to 3 percent.

TEST RESULTS

MODAL PARAMETER ESTIMATES - FORWARD VERTICAL EXCITATION

FORWARD HUB VERTICAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	6.185	0.315874	6.2439E-03	1.0974	1X+	2Z+
2	9.064	0.028757	1.7209E-03	1.7887	1X+	2Z+
3	10.989	0.044850	4.1738E-04	2.6060	1X+	2Z+
4	18.527	0.027673	1.7557E-04	0.7983	1X+	2Z+
5	26.414	0.048644	2.0451E-03	1.9776	1X+	2Z+
6	28.871	0.026261	1.0483E-03	2.0218	1X+	2Z+
7	35.377	0.001114	1.8136E-05	-1.1588	1X+	2Z+

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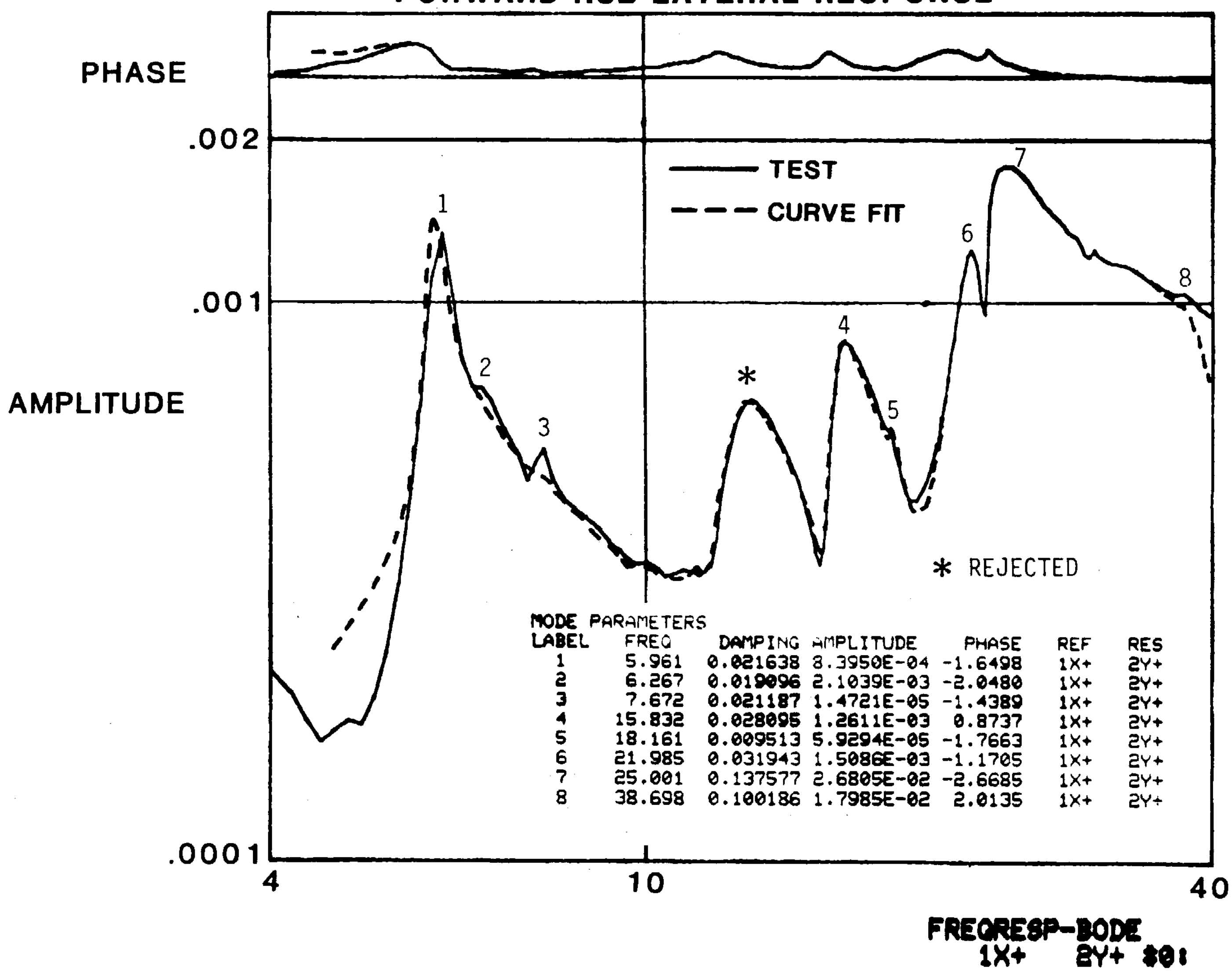
TEST RESULTS

MODAL PARAMETER ESTIMATES – FORWARD LATERAL EXCITATION

FORWARD HUB LATERAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	5.961	0.021638	8.3950E-04	-1.6498	1X+	2Y+
2	6.267	0.019096	2.1039E-03	-2.0480	1X+	2Y+
3	7.672	0.021187	1.4721E-05	-1.4389	1X+	2Y+
4	15.832	0.028095	1.2611E-03	0.8737	1X+	2Y+
5	18.161	0.009513	5.9294E-05	-1.7663	1X+	2Y+
6	21.985	0.031943	1.5086E-03	-1.1705	1X+	2Y+
7	25.001	0.137577	2.6805E-02	-2.6685	1X+	2Y+
8	38.698	0.100186	1.7985E-02	2.0135	1X+	2Y+

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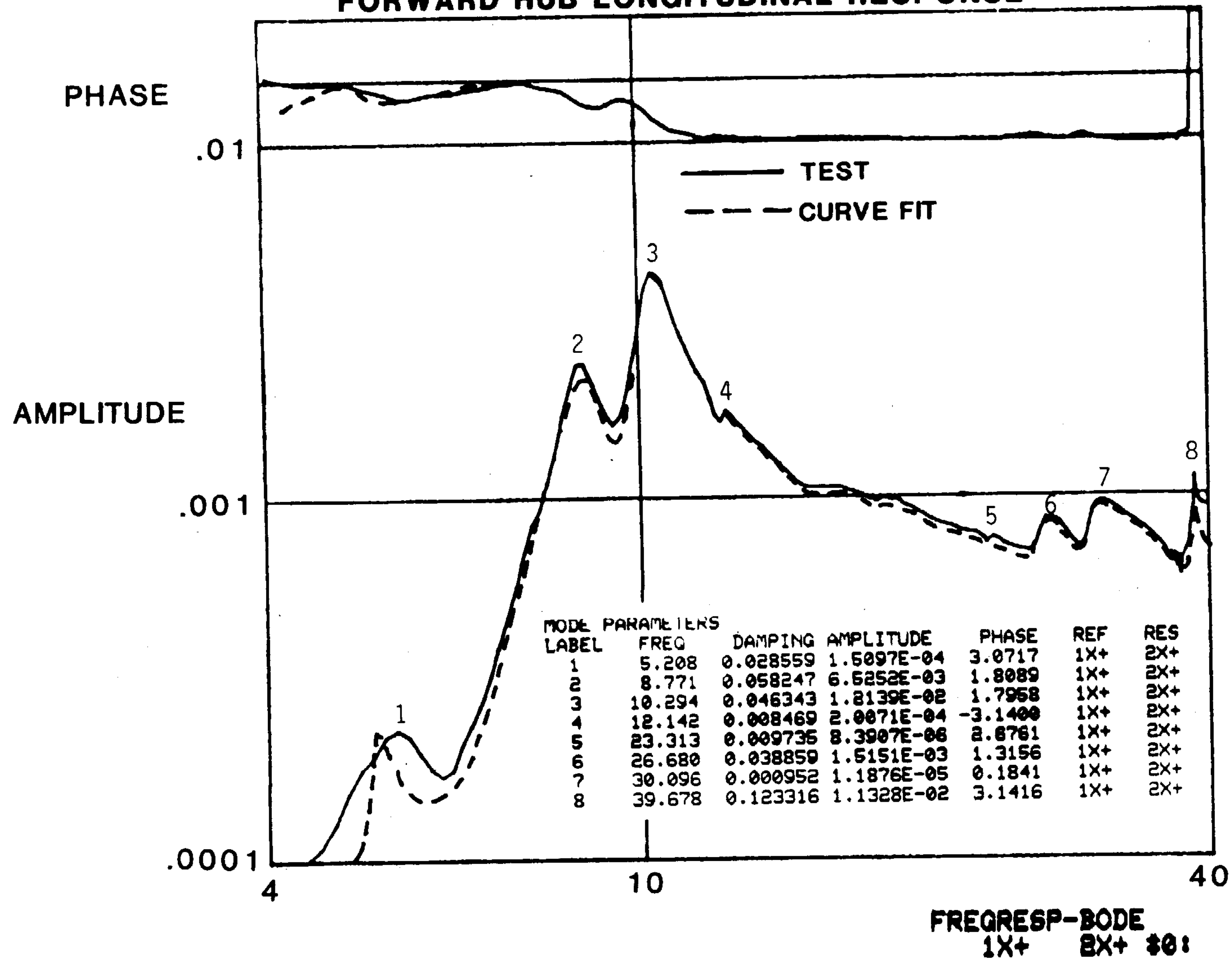
TEST RESULTS

MODAL PARAMETER ESTIMATES - FORWARD LONGITUDINAL EXCITATION

FORWARD HUB LONGITUDINAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	5.208	0.028559	1.5097E-04	3.0717	1X+	2X+
2	8.771	0.058247	6.5252E-03	1.8089	1X+	2X+
3	10.294	0.046343	1.8139E-02	1.7958	1X+	2X+
4	12.142	0.008469	2.0071E-04	-3.1400	1X+	2X+
5	23.313	0.009736	8.3907E-06	2.8761	1X+	2X+
6	26.680	0.038859	1.5151E-03	1.3156	1X+	2X+
7	30.096	0.000952	1.1876E-05	0.1841	1X+	2X+
8	39.678	0.123316	1.1328E-02	3.1416	1X+	2X+

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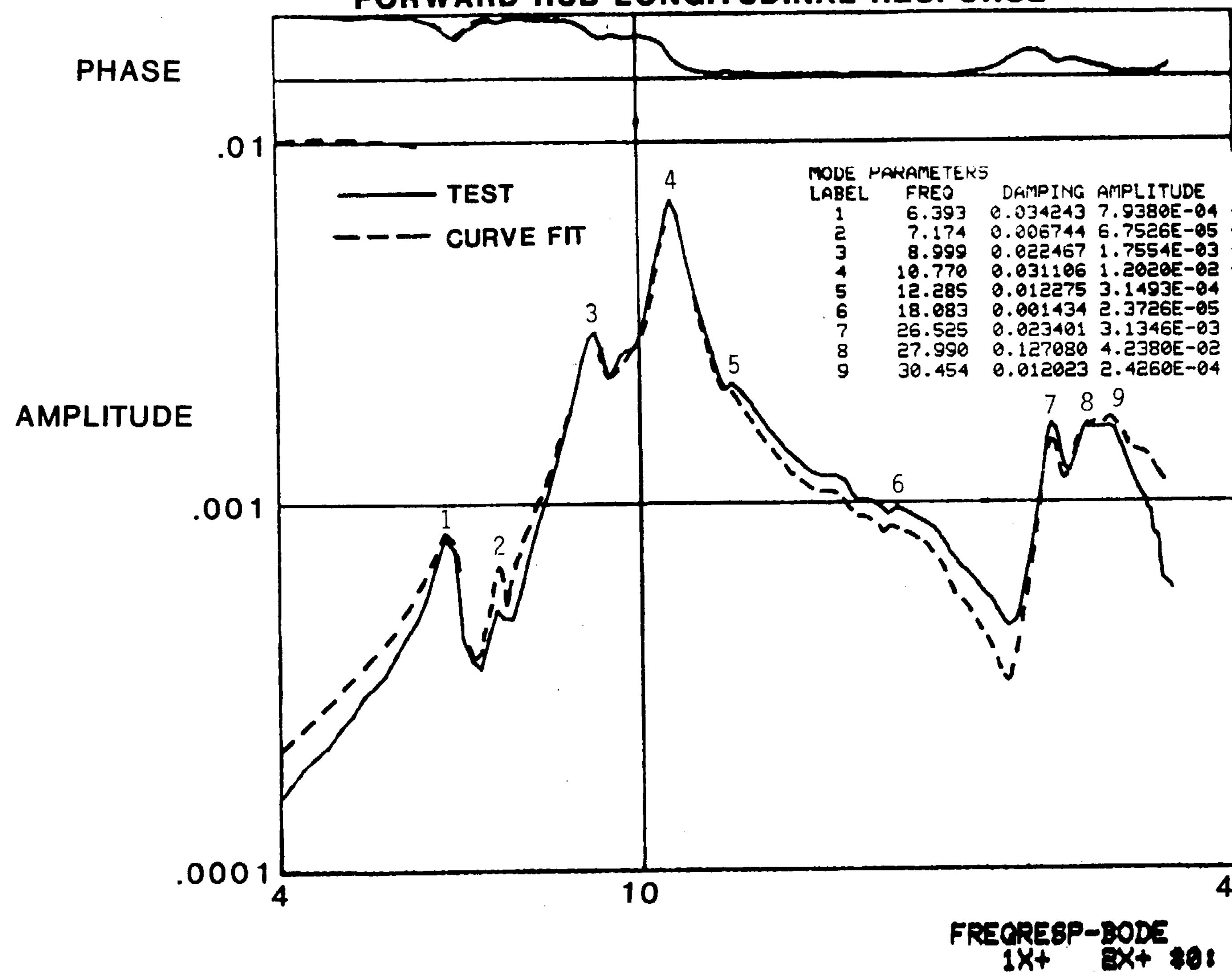
TEST RESULTS

MODAL PARAMETER ESTIMATES – FORWARD PITCH EXCITATION

FORWARD HUB LONGITUDINAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	6.393	0.034243	7.9380E-04	-1.3885	1X+	2X+
2	7.174	0.006744	6.7526E-05	-1.3839	1X+	2X+
3	8.999	0.022467	1.7554E-03	-1.4149	1X+	2X+
4	10.770	0.031106	1.2020E-02	-1.6495	1X+	2X+
5	12.285	0.012275	3.1493E-04	-0.5121	1X+	2X+
6	18.083	0.001434	2.3726E-05	0.1788	1X+	2X+
7	26.525	0.023401	3.1346E-03	-2.5574	1X+	2X+
8	27.990	0.127080	4.2380E-02	-1.0976	1X+	2X+
9	30.454	0.012023	2.4260E-04	-2.3337	1X+	2X+

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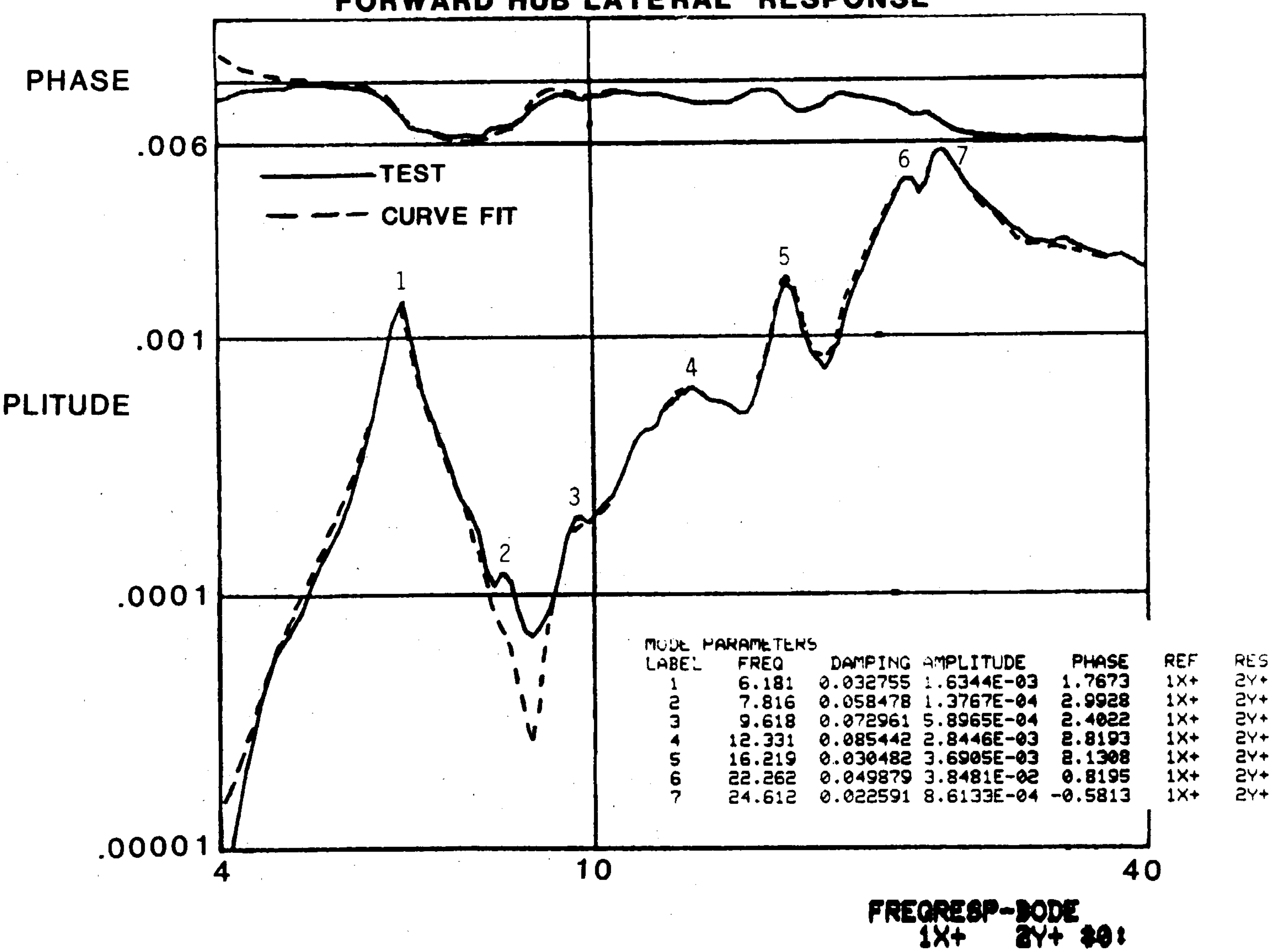
TEST RESULTS

MODAL PARAMETER ESTIMATES - FORWARD ROLL EXCITATION

FORWARD HUB LATERAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	6.181	0.032755	1.6344E-03	1.7673	1X+	2Y+
2	7.816	0.058478	1.3767E-04	2.9928	1X+	2Y+
3	9.618	0.072961	5.8965E-04	2.4022	1X+	2Y+
4	12.331	0.085442	2.8446E-03	2.8193	1X+	2Y+
5	16.219	0.030482	3.6905E-03	2.1308	1X+	2Y+
6	22.262	0.049879	3.8481E-02	0.8195	1X+	2Y+
7	24.612	0.022591	8.6133E-04	-0.5813	1X+	2Y+

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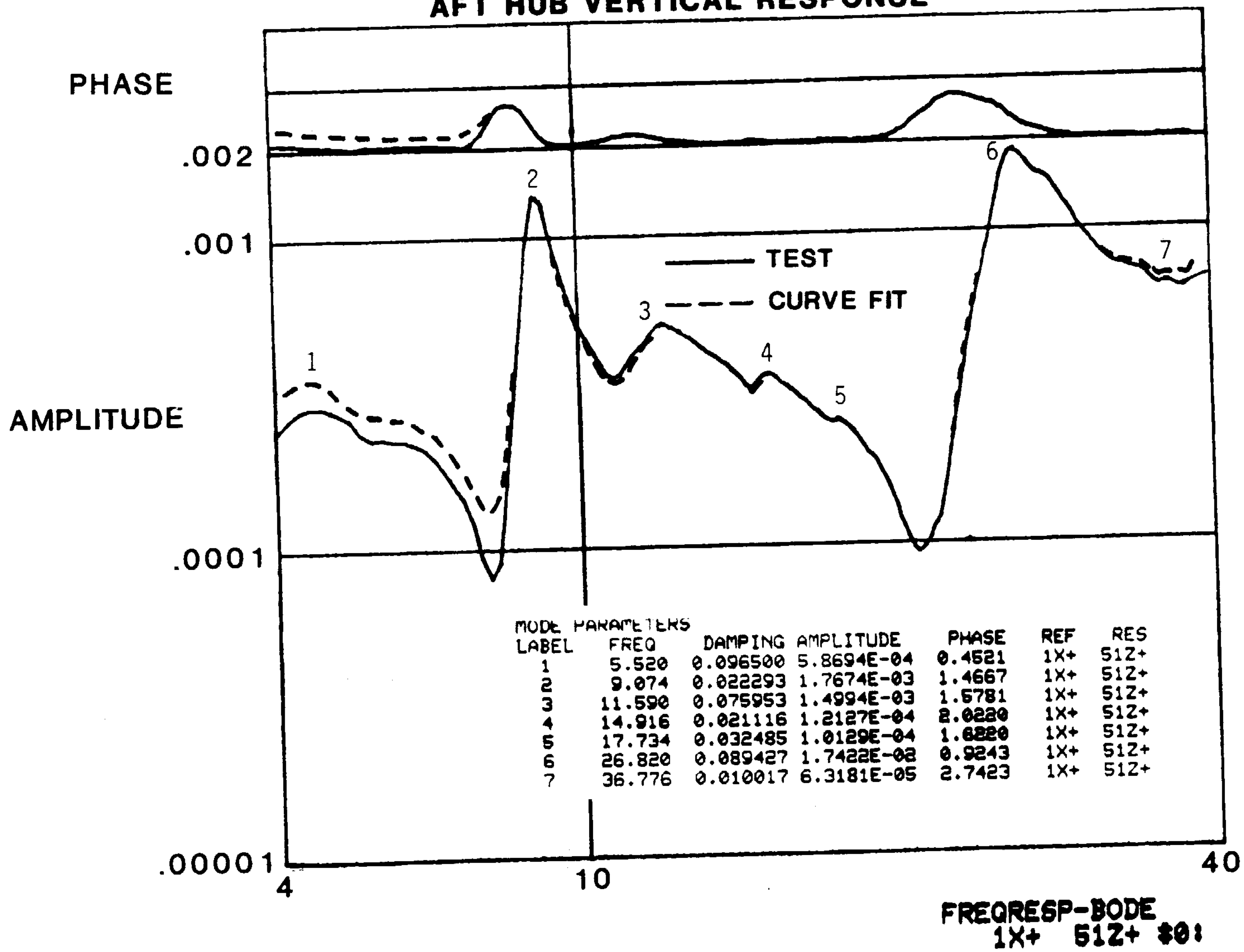
TEST RESULTS

MODAL PARAMETER ESTIMATES – AFT VERTICAL EXCITATION

AFT HUB VERTICAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	5.520	0.096500	5.8694E-04	0.4521	1X+	51Z+
2	9.074	0.022293	1.7674E-03	1.4667	1X+	51Z+
3	11.590	0.075953	1.4994E-03	1.5781	1X+	51Z+
4	14.916	0.021116	1.2127E-04	2.0220	1X+	51Z+
5	17.734	0.032485	1.0129E-04	1.6820	1X+	51Z+
6	26.820	0.089427	1.7422E-02	0.9243	1X+	51Z+
7	36.776	0.010017	6.3181E-05	2.7423	1X+	51Z+

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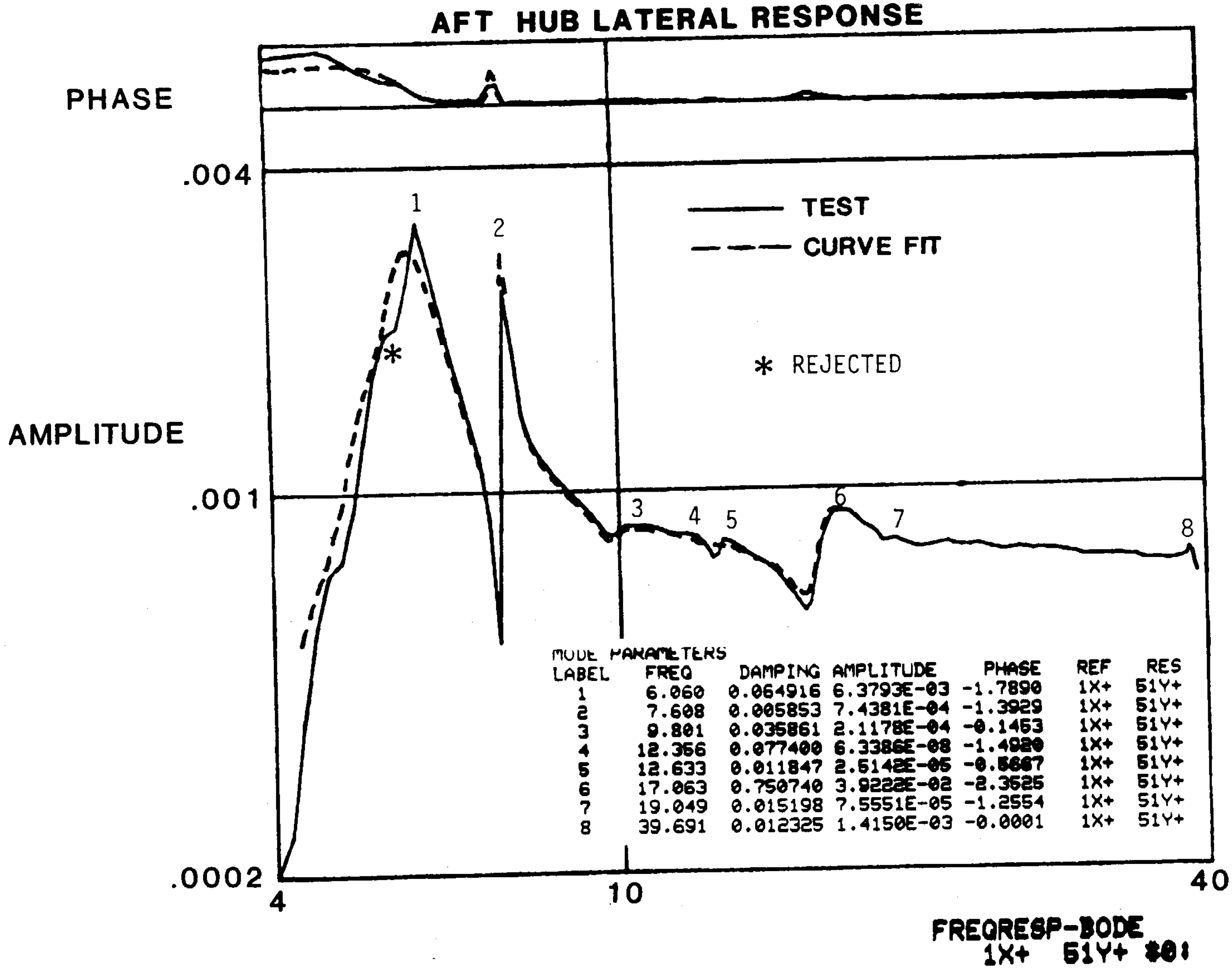
TEST RESULTS

MODAL PARAMETER ESTIMATES – AFT LATERAL EXCITATION



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	6.060	0.064916	6.3793E-03	-1.7890	1X+	51Y+
2	7.608	0.005853	7.4381E-04	-1.3929	1X+	51Y+
3	9.801	0.035861	2.1178E-04	-0.1453	1X+	51Y+
4	12.366	0.077400	6.3386E-08	-1.4920	1X+	51Y+
5	12.633	0.011847	2.5142E-05	-0.5667	1X+	51Y+
6	17.063	0.750740	3.9222E-02	-2.3625	1X+	51Y+
7	19.049	0.015198	7.5551E-05	-1.2554	1X+	51Y+
8	39.691	0.012325	1.4150E-03	-0.0001	1X+	51Y+

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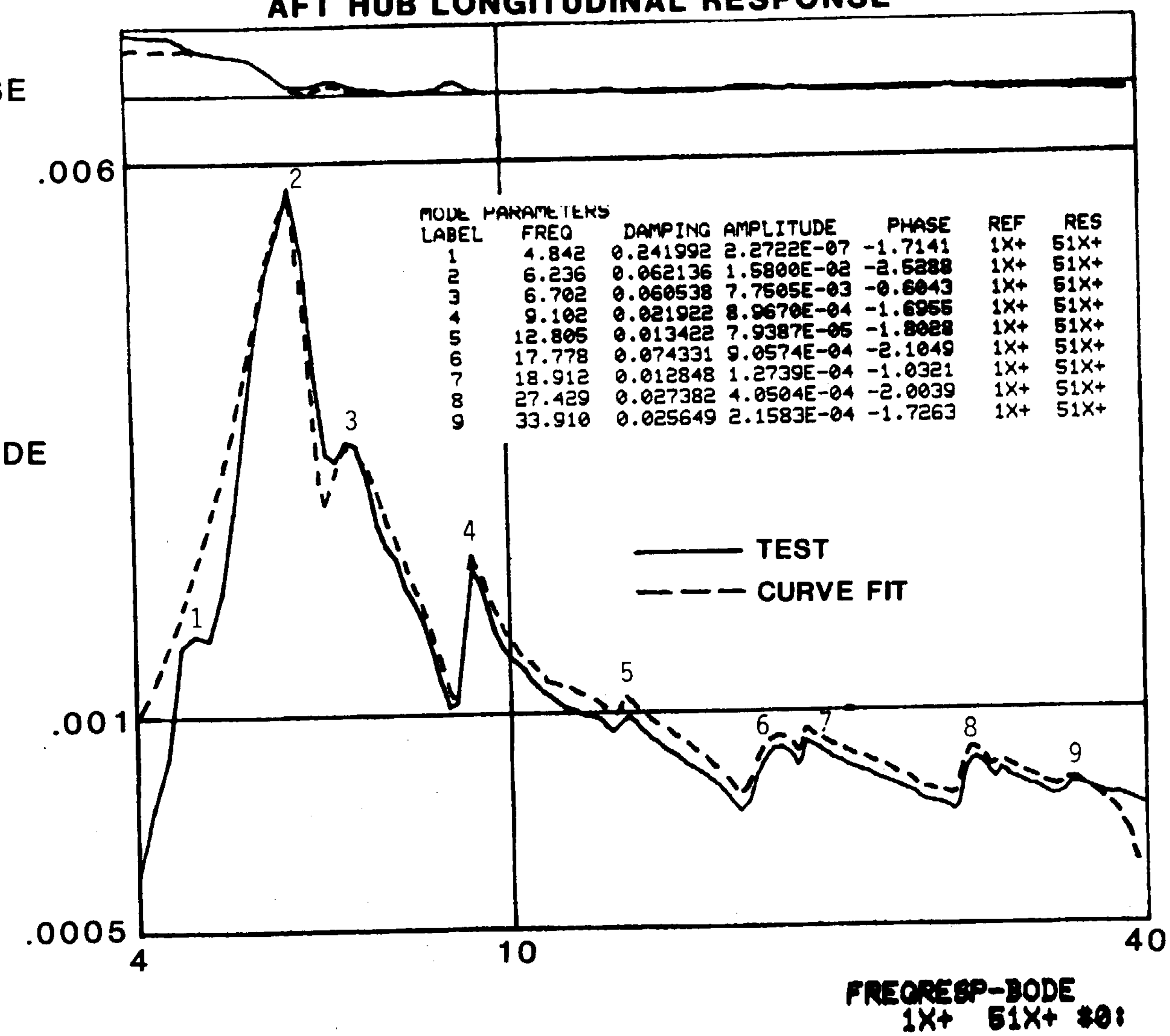
TEST RESULTS

MODAL PARAMETER ESTIMATES - AFT LONGITUDINAL EXCITATION

AFT HUB LONGITUDINAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	4.842	0.241992	2.2722E-07	-1.7141	1X+	51X+
2	6.236	0.062136	1.5800E-02	-2.5288	1X+	51X+
3	6.702	0.060538	7.7505E-03	-0.6043	1X+	51X+
4	9.102	0.021922	8.9670E-04	-1.6956	1X+	51X+
5	12.805	0.013422	7.9387E-05	-1.8028	1X+	51X+
6	17.778	0.074331	9.0574E-04	-2.1049	1X+	51X+
7	18.912	0.012848	1.2739E-04	-1.0321	1X+	51X+
8	27.429	0.027382	4.0504E-04	-2.0039	1X+	51X+
9	33.910	0.025649	2.1583E-04	-1.7263	1X+	51X+

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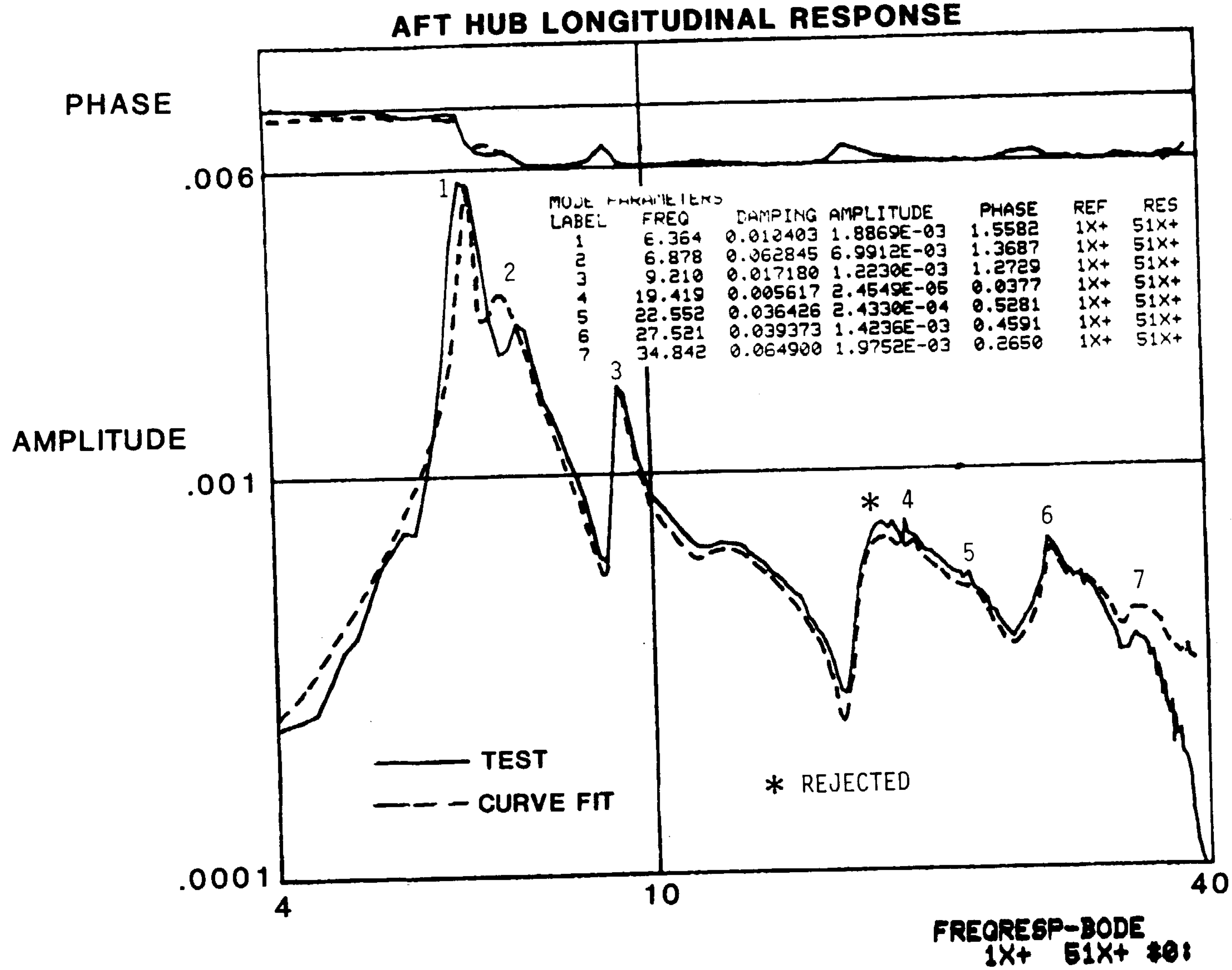
TEST RESULTS

MODAL PARAMETER ESTIMATES – AFT PITCH EXCITATION

AFT HUB LONGITUDINAL RESPONSE



MODE PARAMETERS

MODE LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	6.364	0.012403	1.8869E-03	1.5582	1X+	51X+
2	6.878	0.062845	6.9912E-03	1.3687	1X+	51X+
3	9.210	0.017180	1.2230E-03	1.2729	1X+	51X+
4	19.419	0.005617	2.4549E-06	0.0377	1X+	51X+
5	22.552	0.036426	2.4330E-04	0.5281	1X+	51X+
6	27.521	0.039373	1.4236E-03	0.4591	1X+	51X+
7	34.842	0.064900	1.9752E-03	0.2650	1X+	51X+

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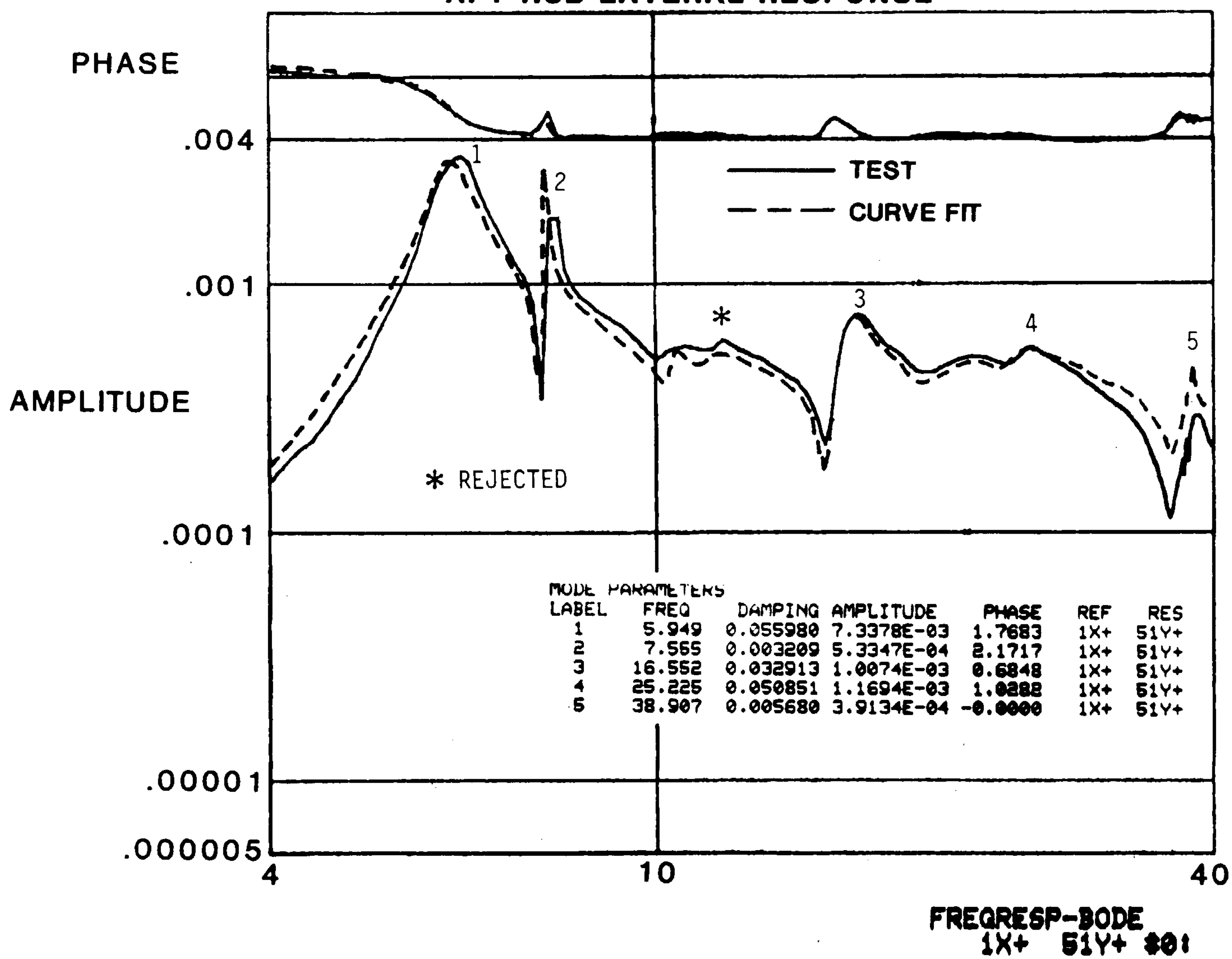
TEST RESULTS

MODAL PARAMETER ESTIMATES – AFT ROLL EXCITATION

AFT HUB LATERAL RESPONSE



MODE PARAMETERS

LABEL	FREQ	DAMPING	AMPLITUDE	PHASE	REF	RES
1	5.949	0.055980	7.3378E-03	1.7683	1X+	51Y+
2	7.565	0.003209	5.3347E-04	2.1717	1X+	51Y+
3	16.552	0.032913	1.0074E-03	0.6848	1X+	51Y+
4	25.225	0.050851	1.1694E-03	1.0288	1X+	51Y+
5	38.907	0.005680	3.9134E-04	-0.0000	1X+	51Y+

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5.4 Discussion of Frequency Response

TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

FORWARD ROTOR VERTICAL EXCITATION

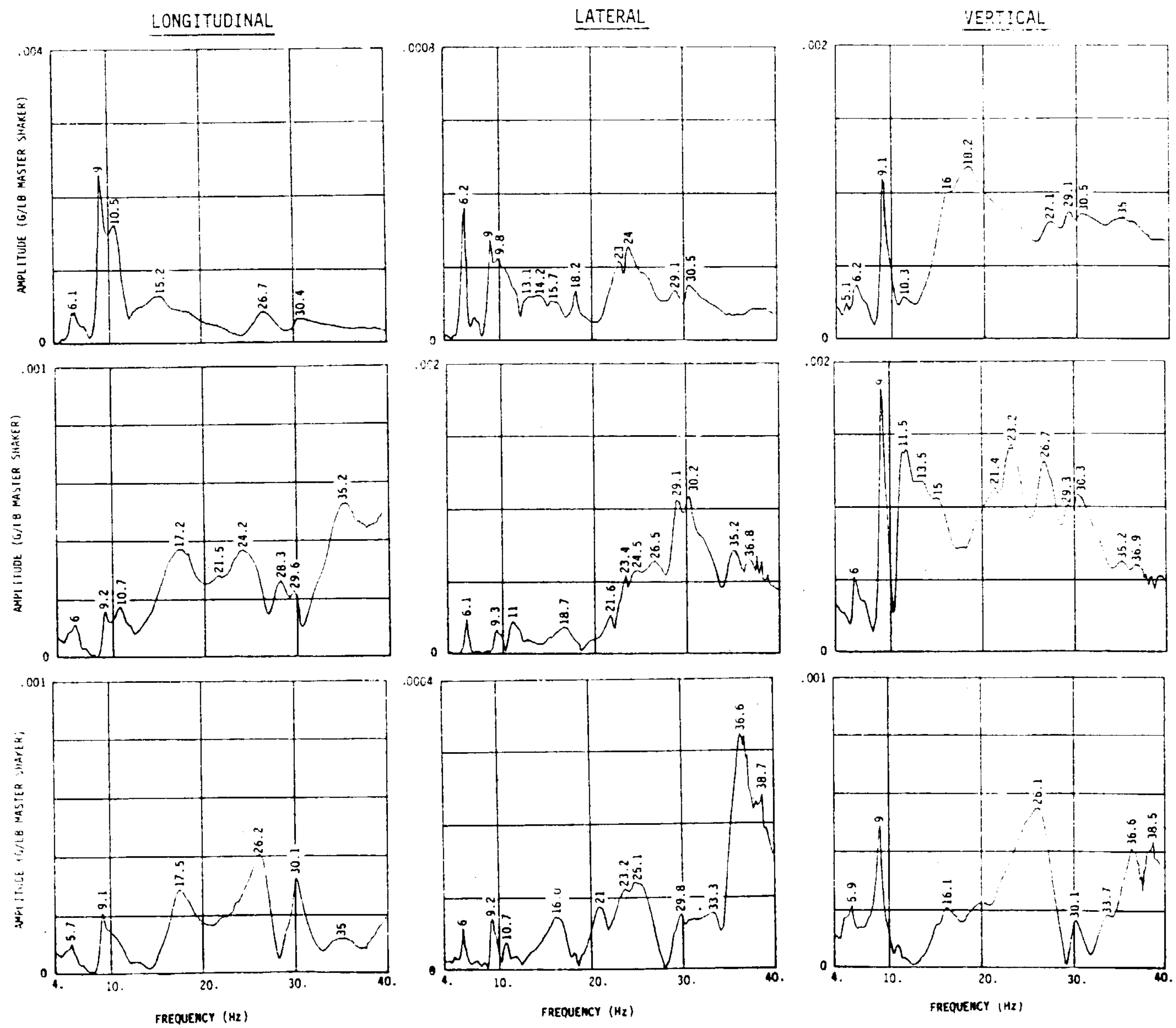
All locations and all axes show a multiplicity of response peaks. The single most dominant response is in the area of 9 Hz where a significant peak occurs in practically all of the vertical and longitudinal data. The second most recurring frequency seems to be in the vicinity of 26 to 27 Hz. As would be expected with vertical excitation, the magnitude of the lateral response is generally lower than the vertical and longitudinal.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR VERTICAL EXCITATION

FORWARD ROTOR HUB
(LOC. 2)

STA. 10 R/H
FORWARD COCKPIT
(LOC. 9)

STA. 286 L/H
CABIN STRUCTURE
(LOC. 24)



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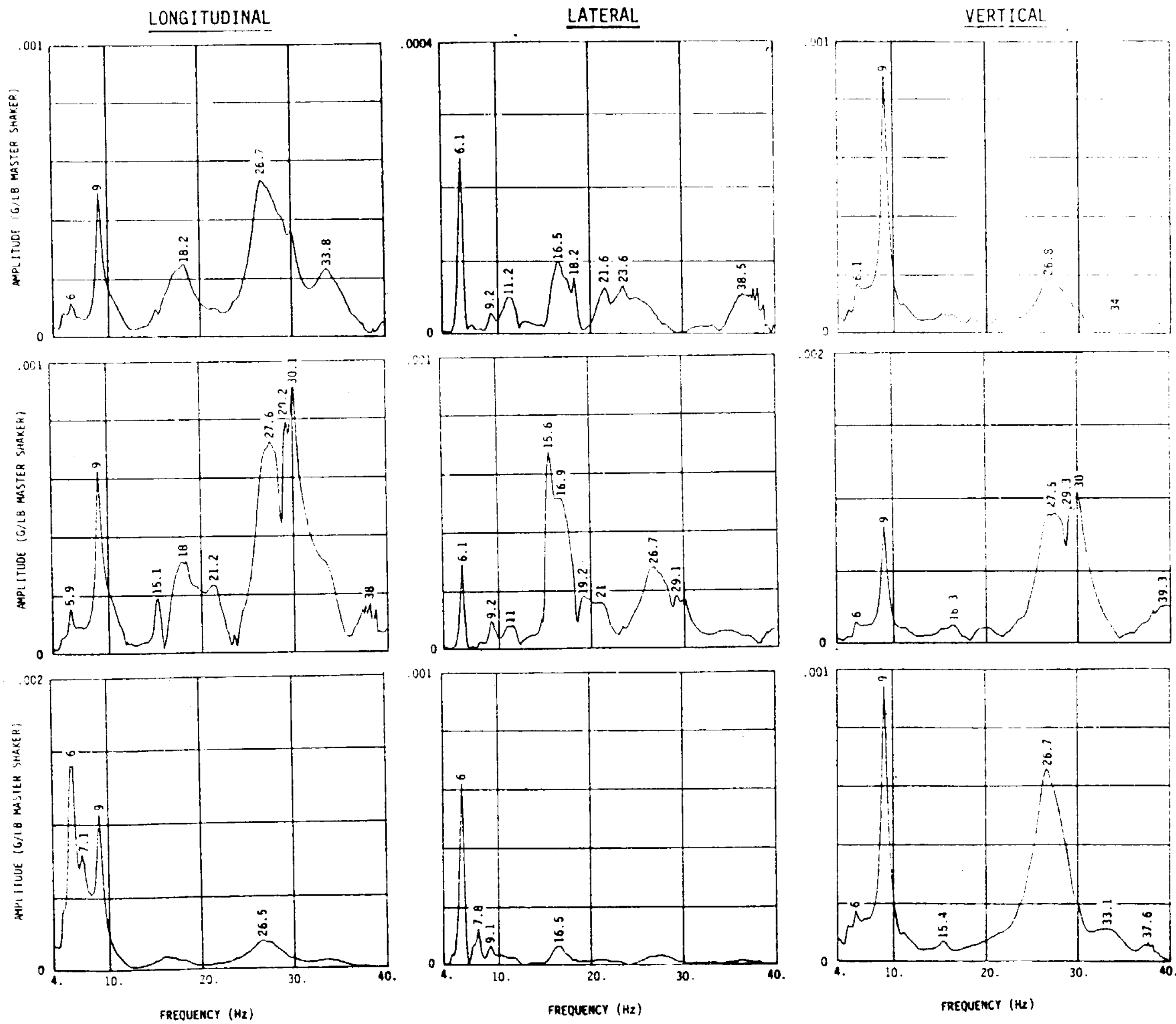
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR VERTICAL EXCITATION

STA. 480 L/H
AFT XMSN
(LOC. 46)

STA. 458 L/H
ENGINE CASE
(LOC. 55)

AFT ROTOR HUB
(LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

FORWARD ROTOR LATERAL EXCITATION

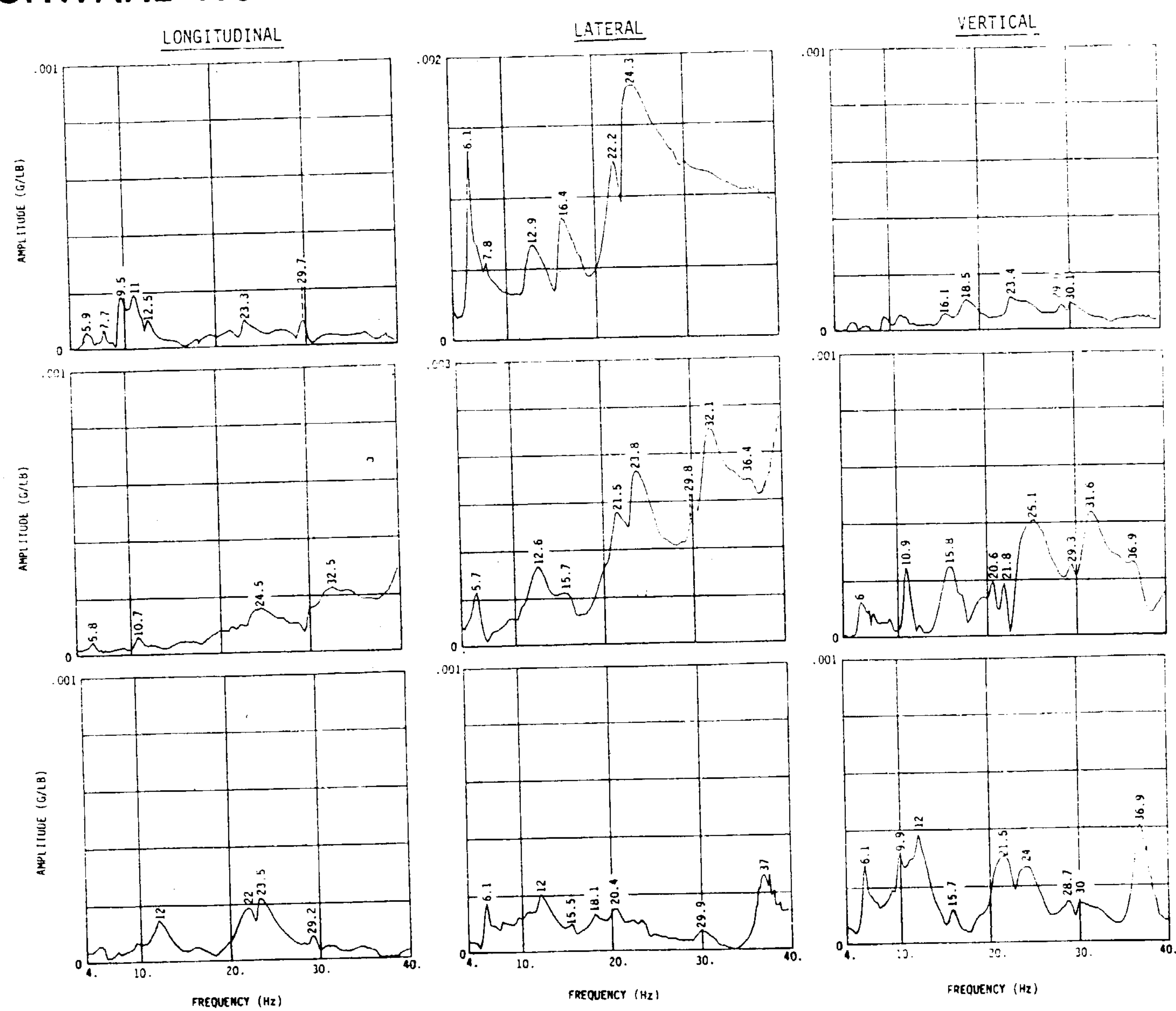
The lateral axis is most responsive and the longitudinal axis (except for the engine) displays the lowest level response. Again, a large number of peaks are evident indicating possibly 10 or more natural frequencies. The most dominant recurring frequencies seem to be in the vicinity of 6, 16, and 24 Hz.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR LATERAL EXCITATION

FORWARD ROTOR HUB
(LOC. 2)

STA. 10 R/H
FORWARD COCKPIT
(LOC. 9)

STA. 286 L/H
CABIN STRUCTURE
(LOC. 24)



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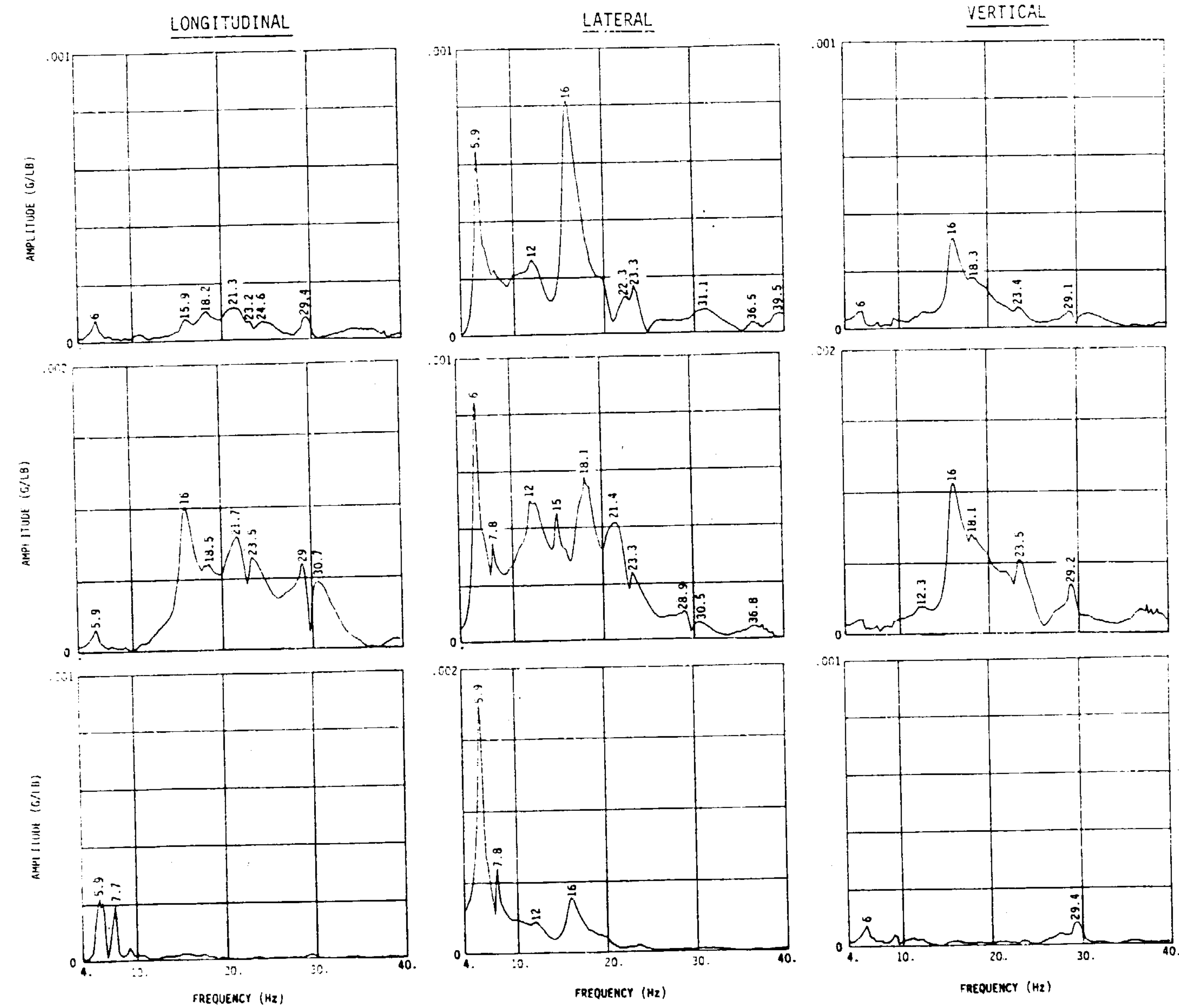
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR LATERAL EXCITATION

STA. 480 L/H
AFT XMSN
(LOC. 46)

STA. 458 L/H
ENGINE CASE
(LOC. 55)

AFT ROTOR HUB
(LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

FORWARD ROTOR LONGITUDINAL EXCITATION

The two most responsive frequencies here are at approximately 8.6 and 10.3 Hz. Significant recurring peaks are also evident at 26 to 27 Hz and 30 Hz.

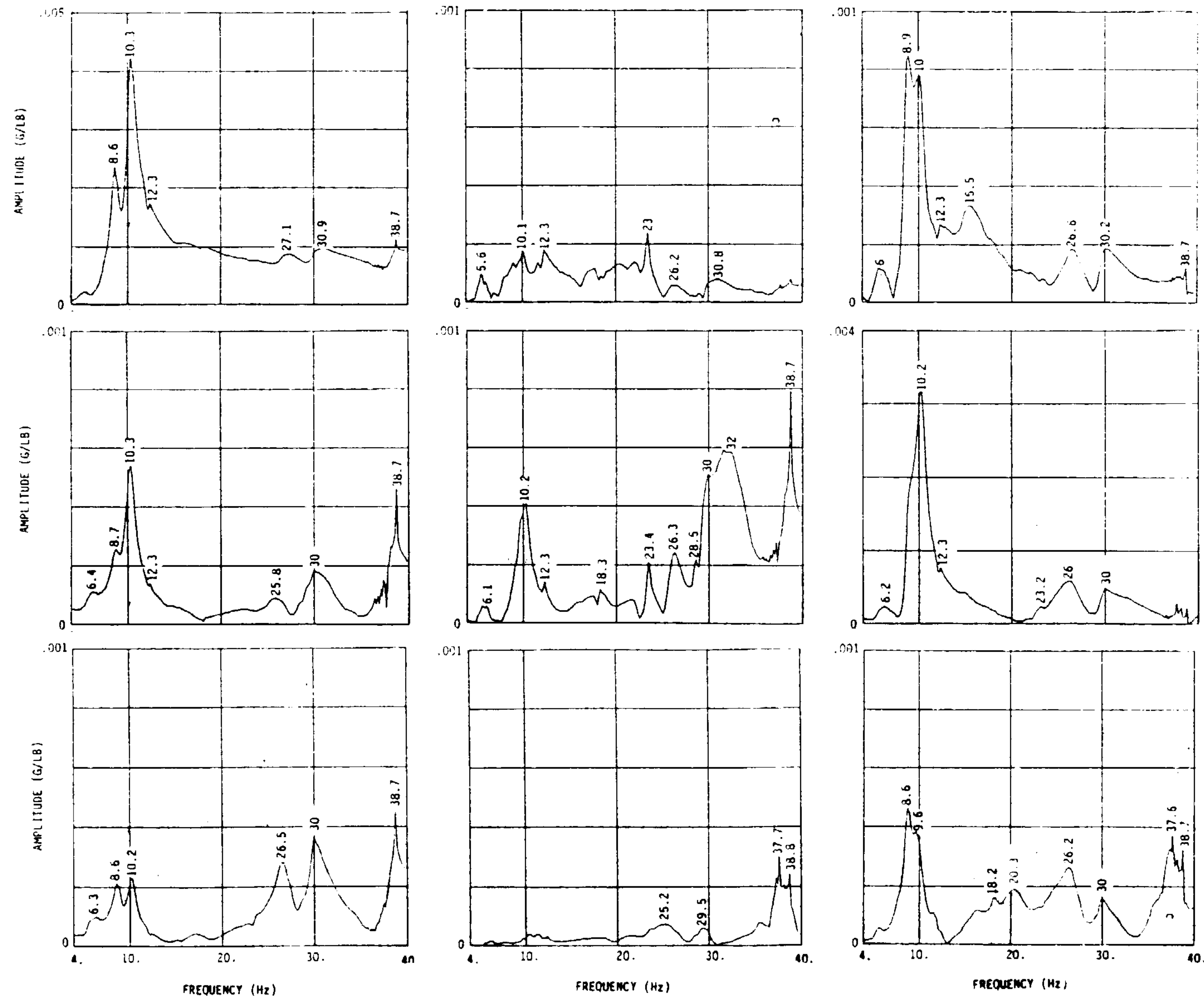
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR LONGITUDINAL EXCITATION

LONGITUDINAL | LATERAL | VERTICAL

FORWARD ROTOR HUB (LOC. 2)

STA. 10 R/H FORWARD COCKPIT (LOC. 9)

STA. 286 L/H CABIN STRUCTURE (LOC. 24)



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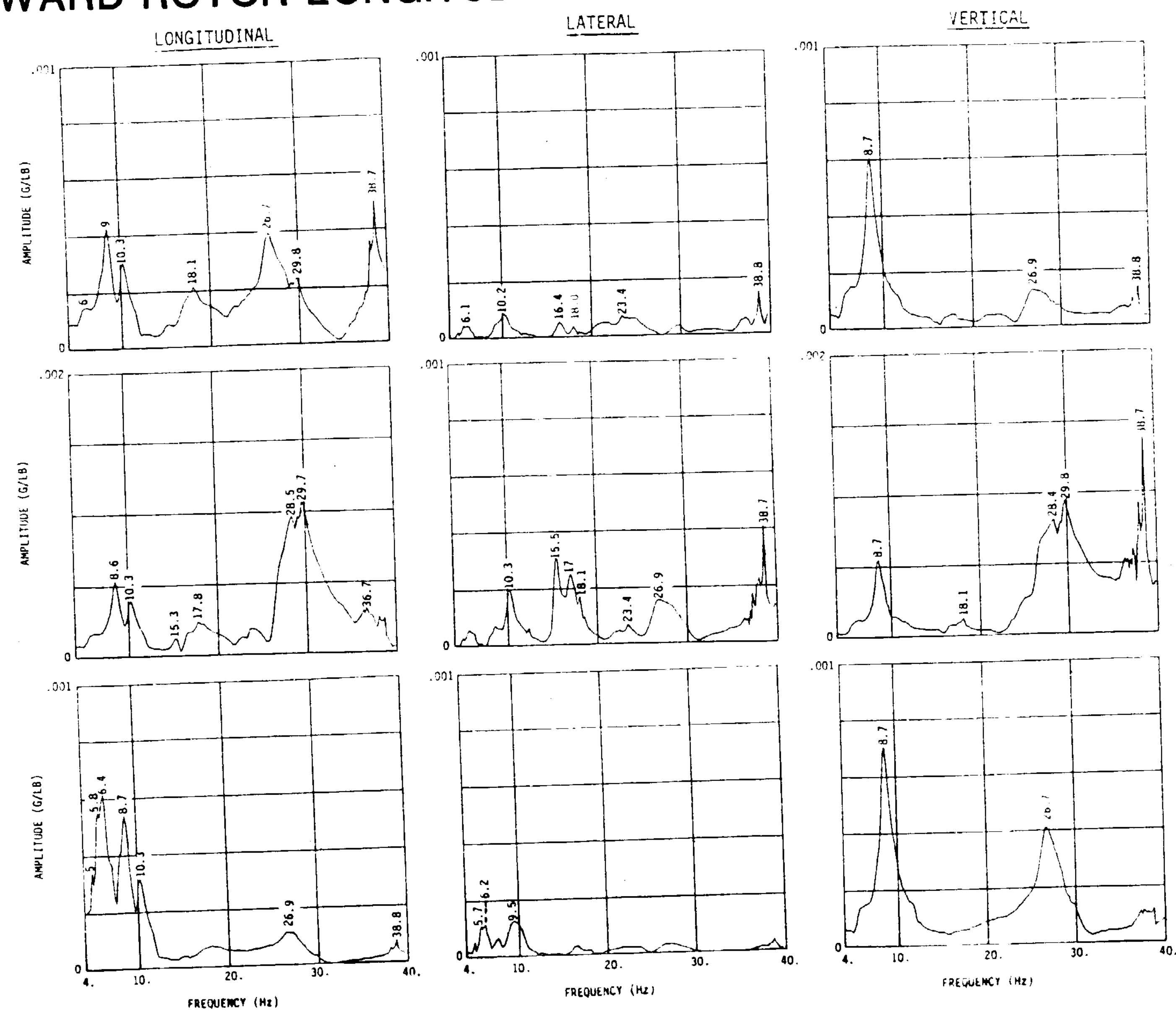
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR LONGITUDINAL EXCITATION

STA. 480 L/H
AFT XMSN
(LOC. 46)

STA. 458 L/H
ENGINE CASE
(LOC. 55)

AFT ROTOR HUB
(LOC. 51)

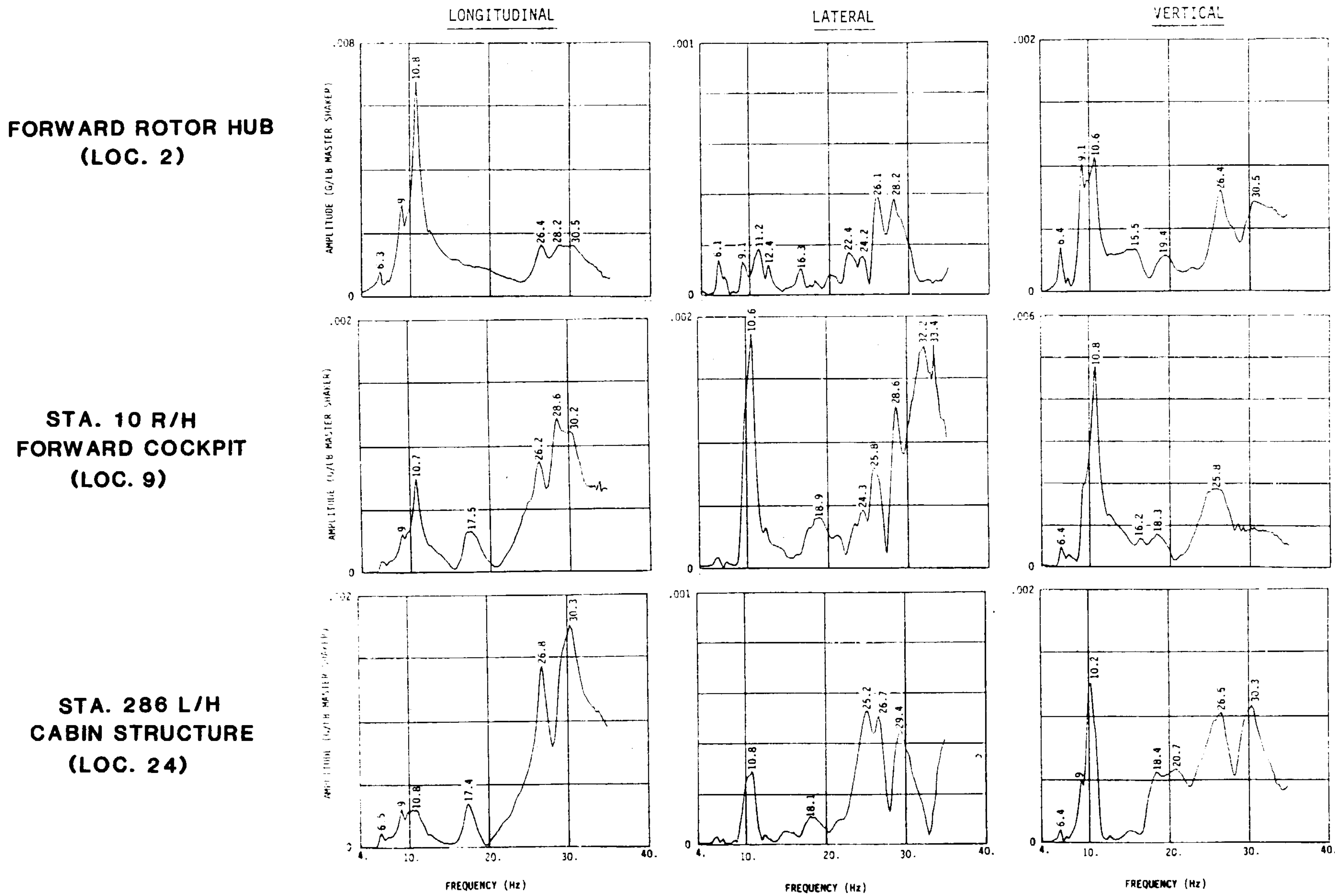


TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

FORWARD ROTOR PITCH EXCITATION

In terms of magnitude, the two most significant responses are at 10.8 and 28.8 Hz. Additional recurring major responses are at approximately 26.9 and 30.3 Hz.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR PITCH EXCITATION



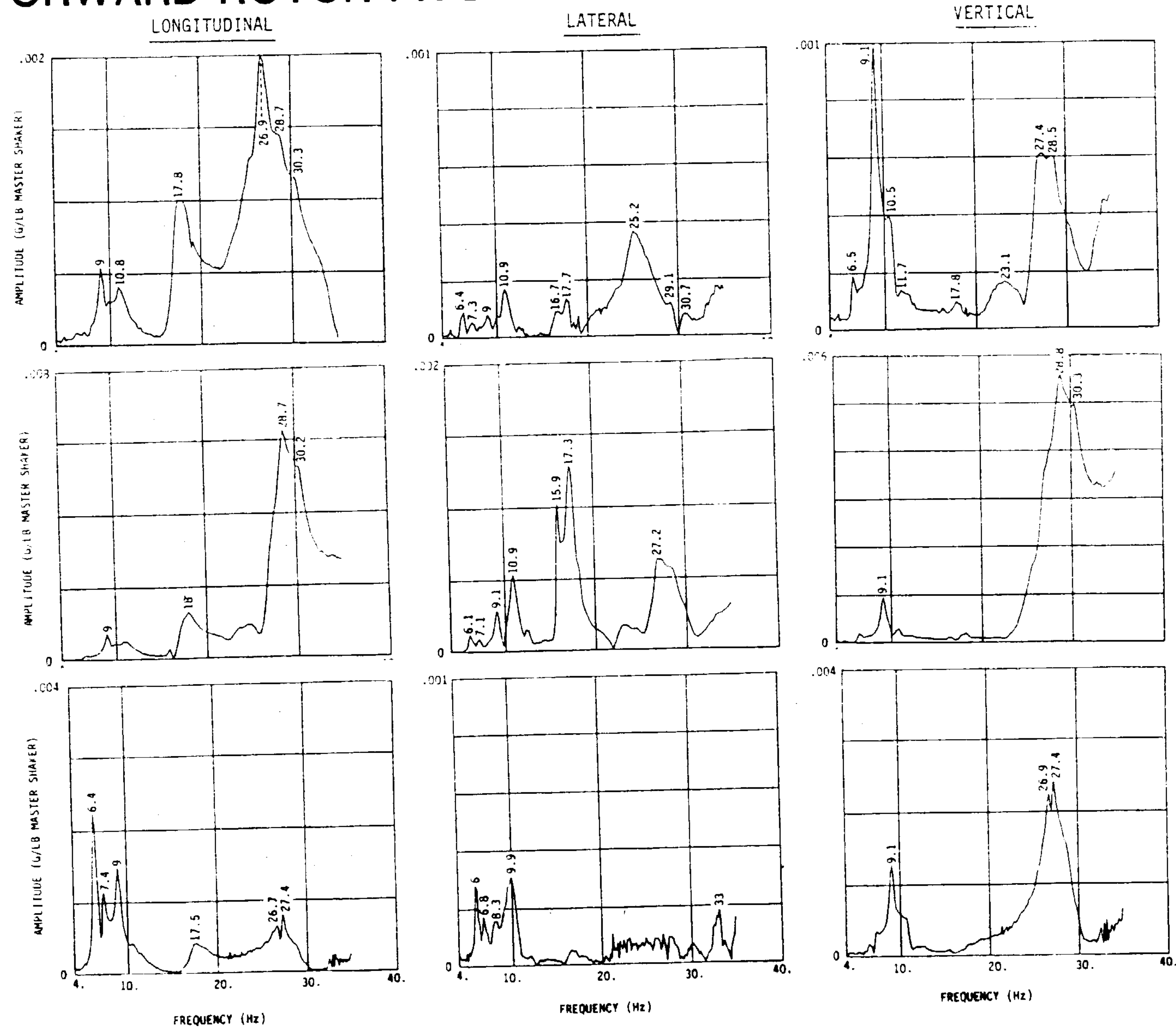
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE

FORWARD ROTOR PITCH EXCITATION

STA. 480 L/H
AFT XMSN
(LOC. 46)

STA. 458 L/H
ENGINE CASE
(LOC. 55)

AFT ROTOR HUB
(LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

FORWARD ROTOR ROLL EXCITATION

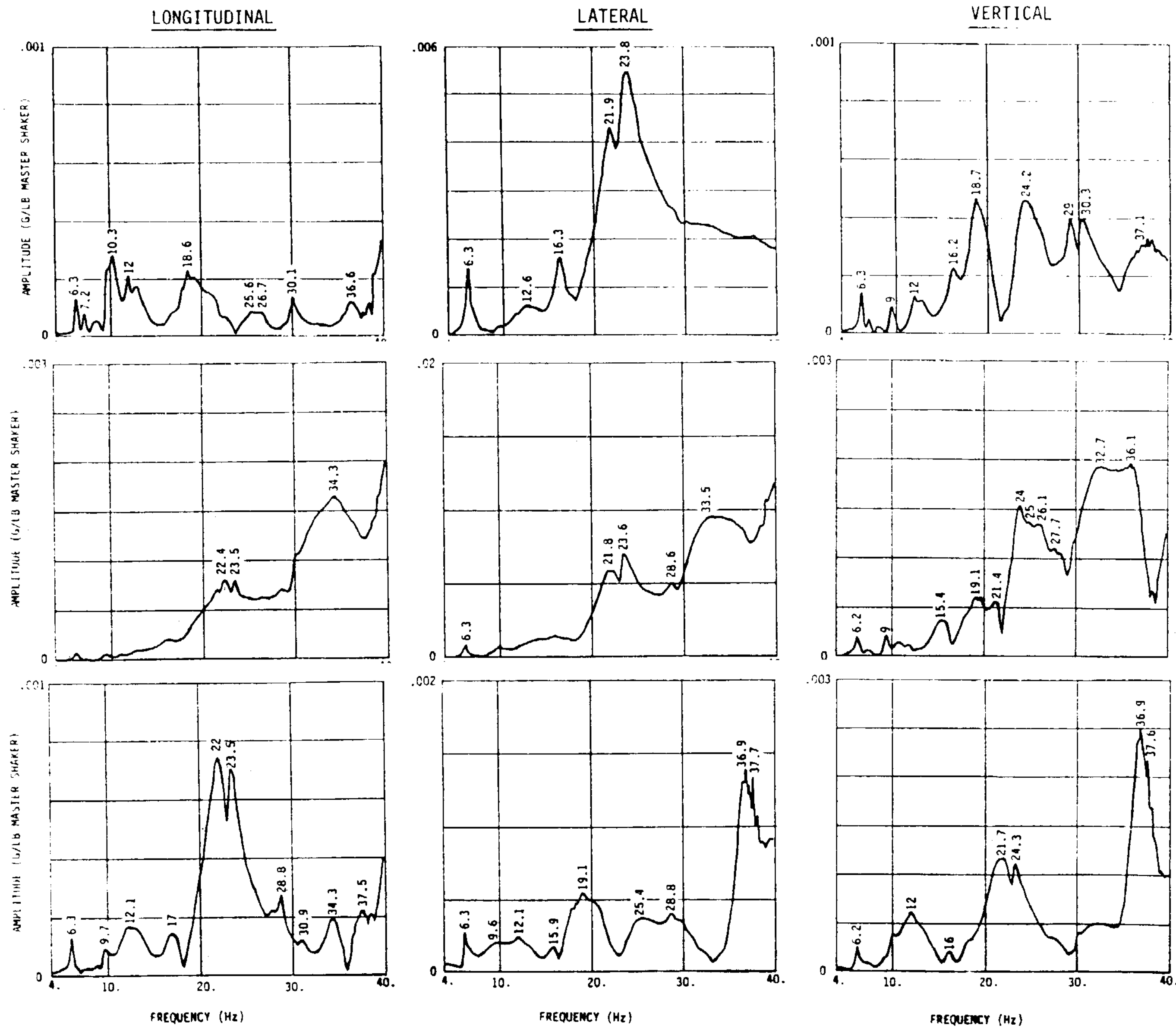
The single most responsive peak occurs at 23.8 Hz in the lateral direction on the hub. A second strong lateral hub response at 21.9 Hz also displays a large amplitude peak in the vertical and lateral directions on the engine. In the aft portion of the aircraft (Sta. 480, Sta. 458 engine case and the aft hub) strong recurring responses are present at approximately 6.3 and 16.4 Hz.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
FORWARD ROTOR ROLL EXCITATION

FORWARD ROTOR HUB (LOC. 2)

STA. 10 R/H FORWARD COCKPIT (LOC. 9)

STA. 286 L/H CABIN STRUCTURE (LOC. 24)



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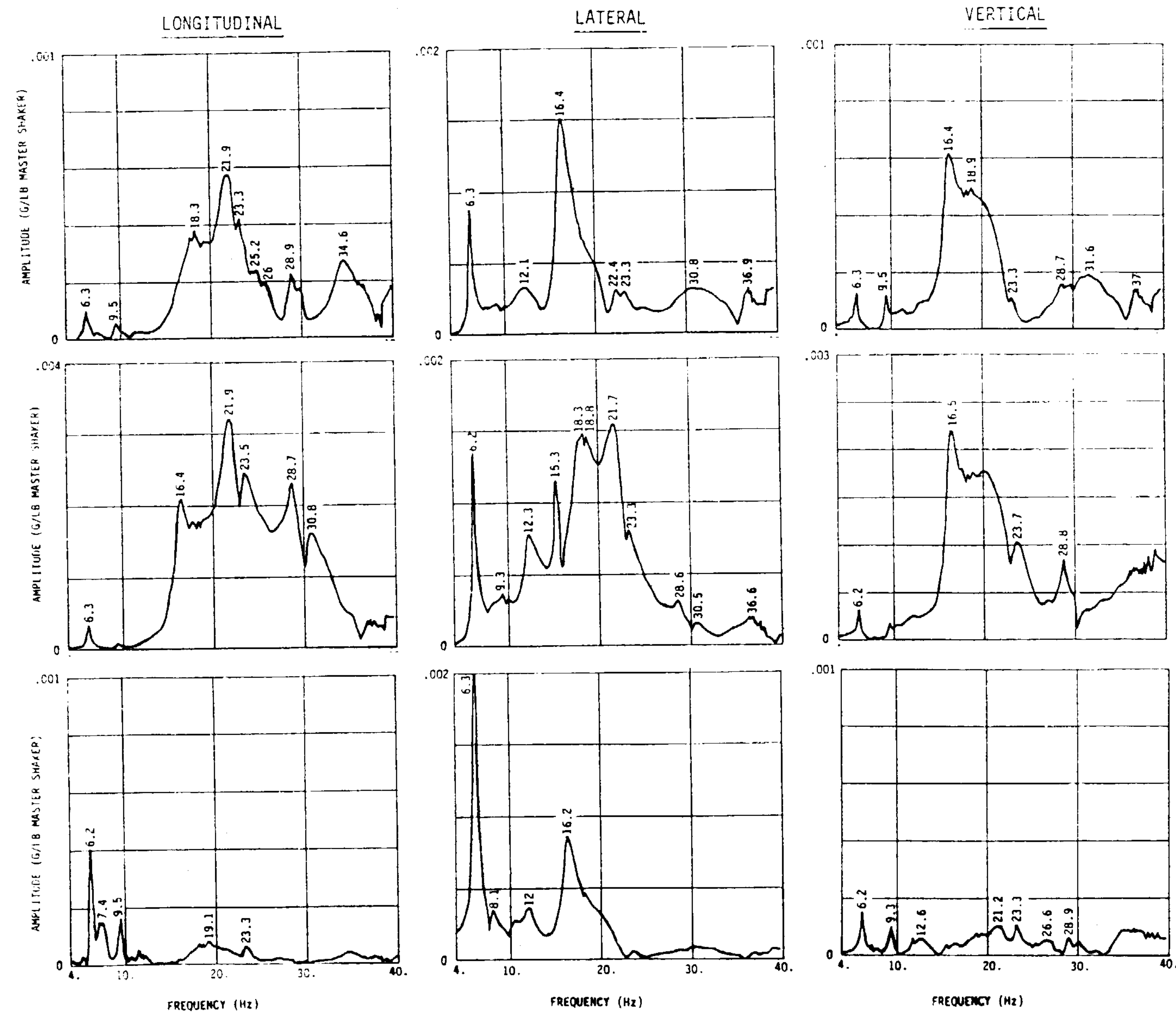
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE FORWARD ROTOR ROLL EXCITATION

STA. 480 L/H
AFT XMSN
(LOC. 46)

STA. 458 L/H
ENGINE CASE
(LOC. 55)

AFT ROTOR HUB
(LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

AFT ROTOR VERTICAL EXCITATION

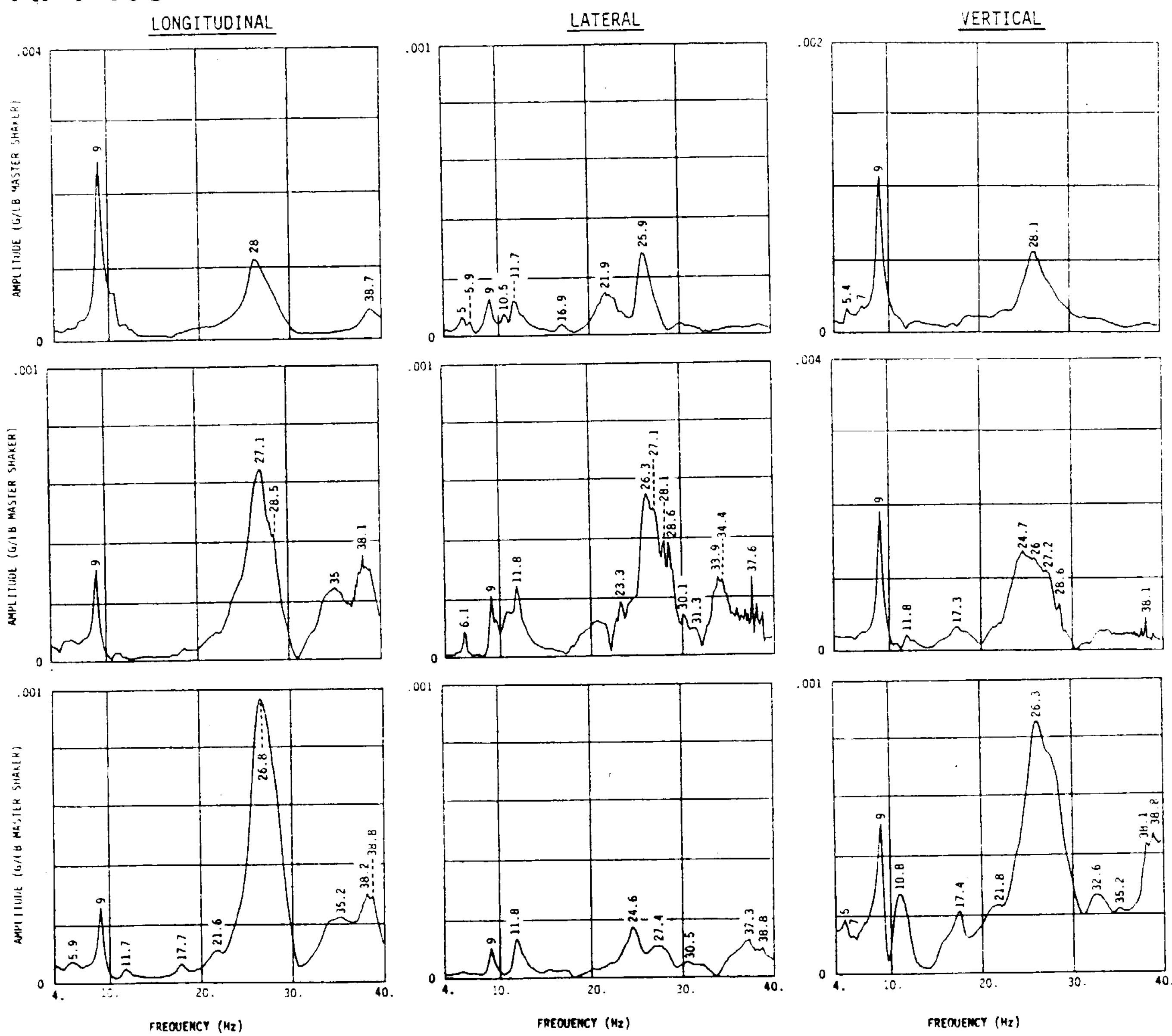
Disregarding the out-of-plane lateral axis, the response to aft vertical excitation is generally less active than that observed for forward rotor excitation. The two most dominant and recurring responses are at 9 Hz and approximately 26.6 Hz.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR VERTICAL EXCITATION

FORWARD ROTOR HUB
(LOC. 2)

STA. 10 R/H
FORWARD COCKPIT
(LOC. 9)

STA. 286 L/H
CABIN STRUCTURE
(LOC. 24)



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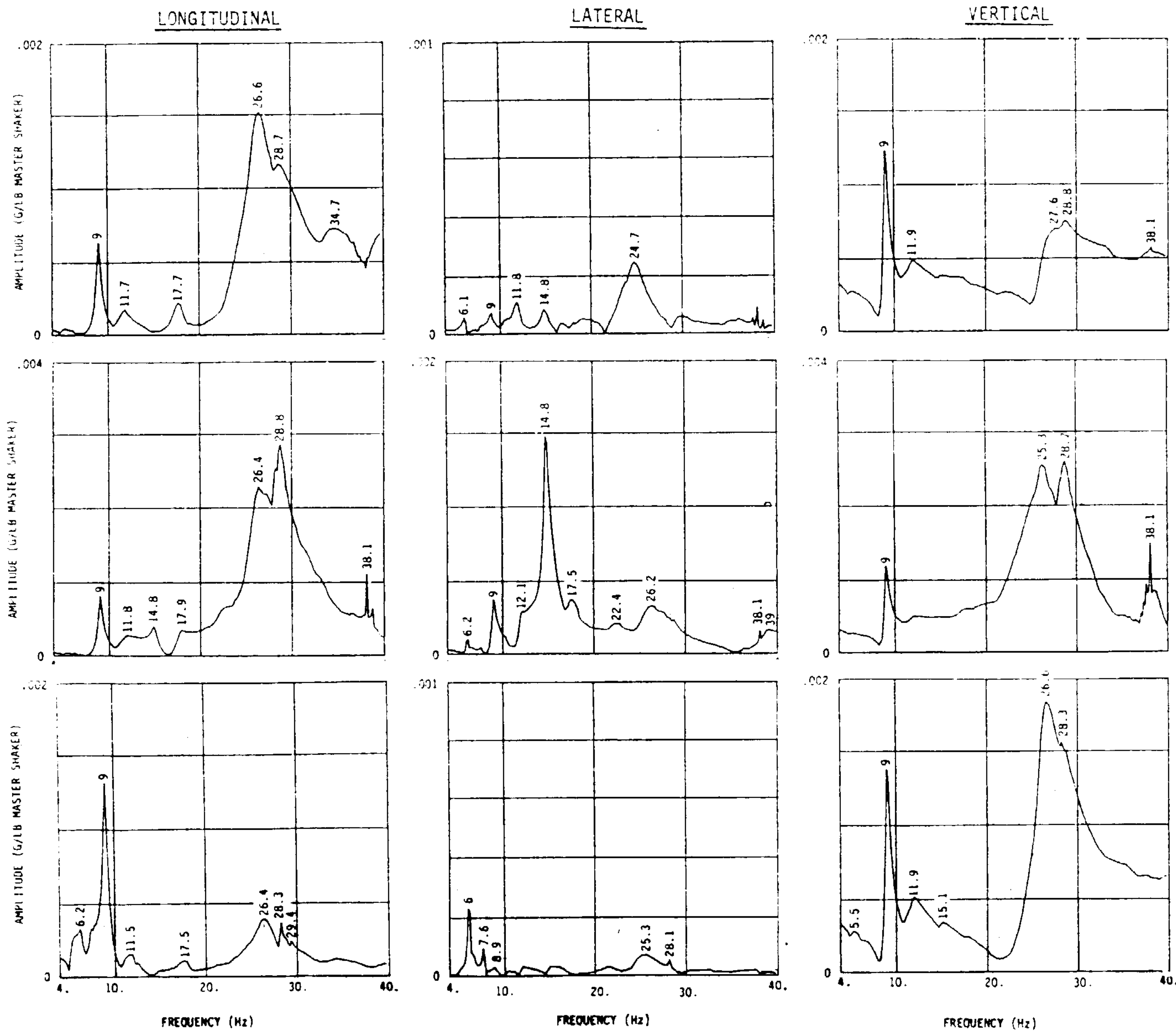
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR VERTICAL EXCITATION

STA. 480 L/H AFT XMSN (LOC. 46)

STA. 458 L/H ENGINE CASE (LOC. 55)

AFT ROTOR HUB (LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

AFT ROTOR LATERAL EXCITATION

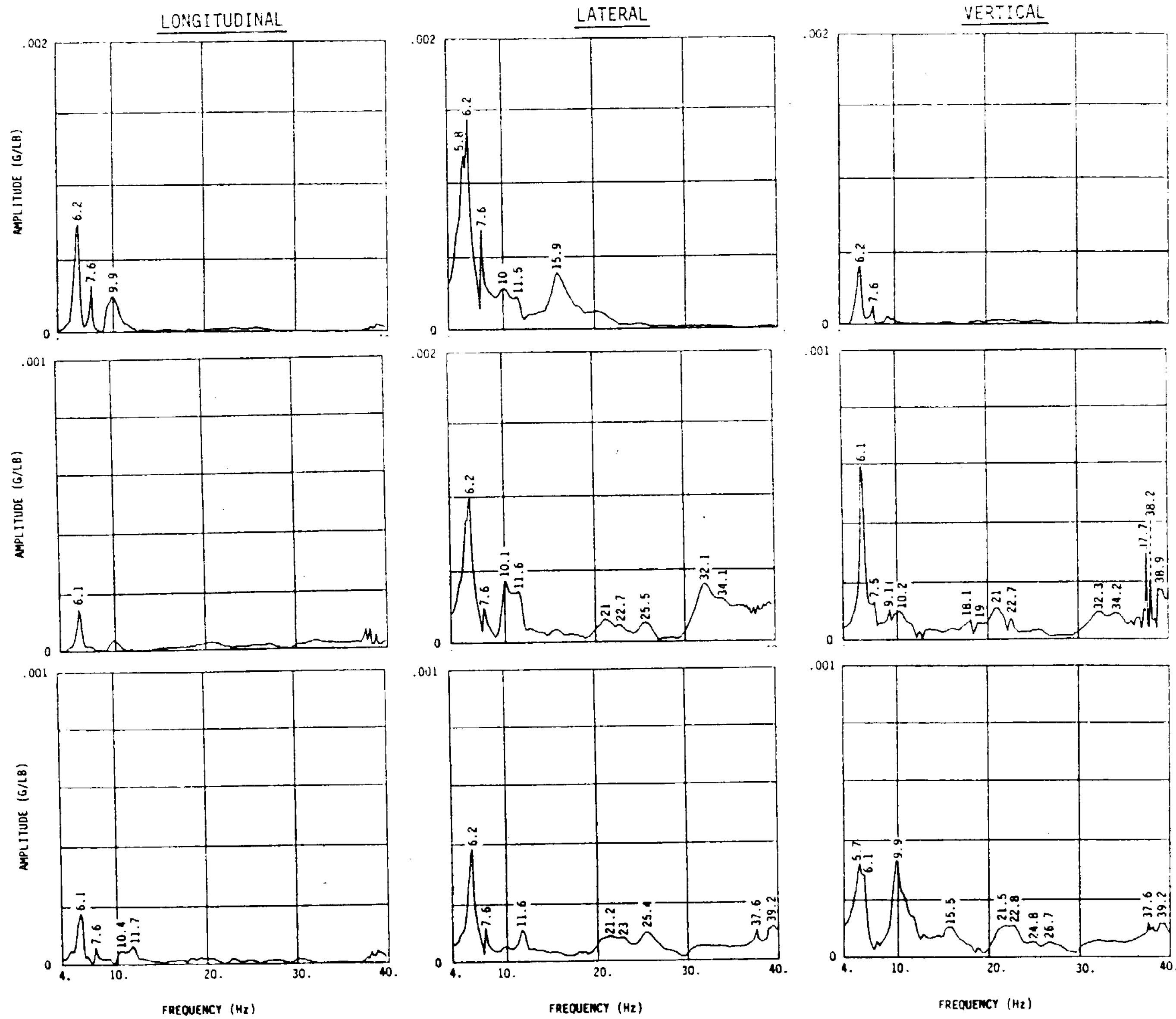
Again, response with aft rotor excitation displays less activity than that for forward excitation. The dominant response occurs at 6.2 Hz. Strong recurring peaks are also evident at 7.6 and approximately 16 Hz. The 16 Hz peak appears strongest in the Sta. 458 engine case response.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR LATERAL EXCITATION

FORWARD ROTOR HUB
(LOC. 2)

STA. 10 R/H
FORWARD COCKPIT
(LOC. 9)

STA. 286 L/H
CABIN STRUCTURE
(LOC. 24)



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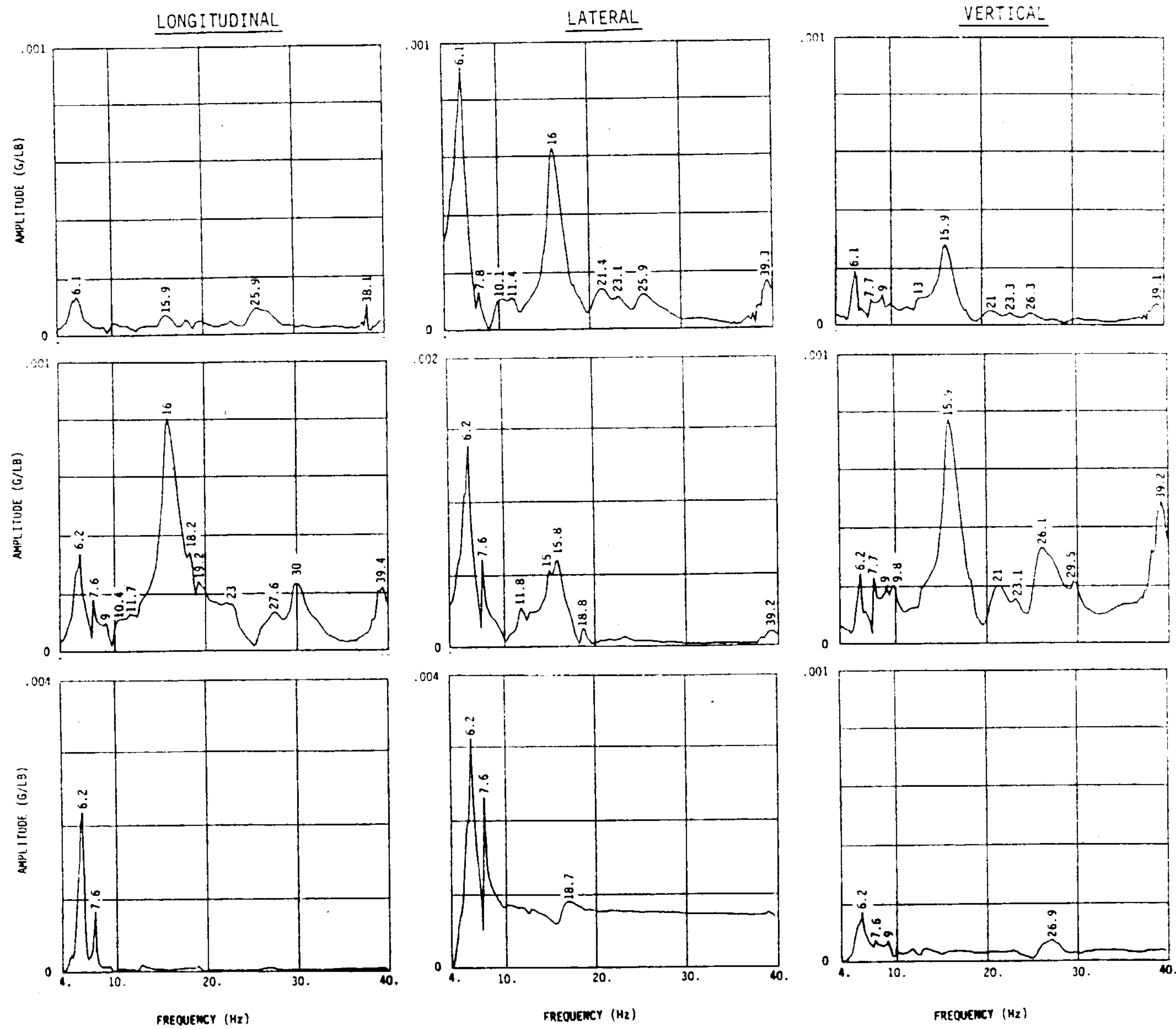
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR LATERAL EXCITATION

STA. 480 L/H
AFT XMSN
(LOC. 46)

STA. 458 L/H
ENGINE CASE
(LOC. 55)

AFT ROTOR HUB
(LOC. 51)



TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

AFT ROTOR LONGITUDINAL EXCITATION

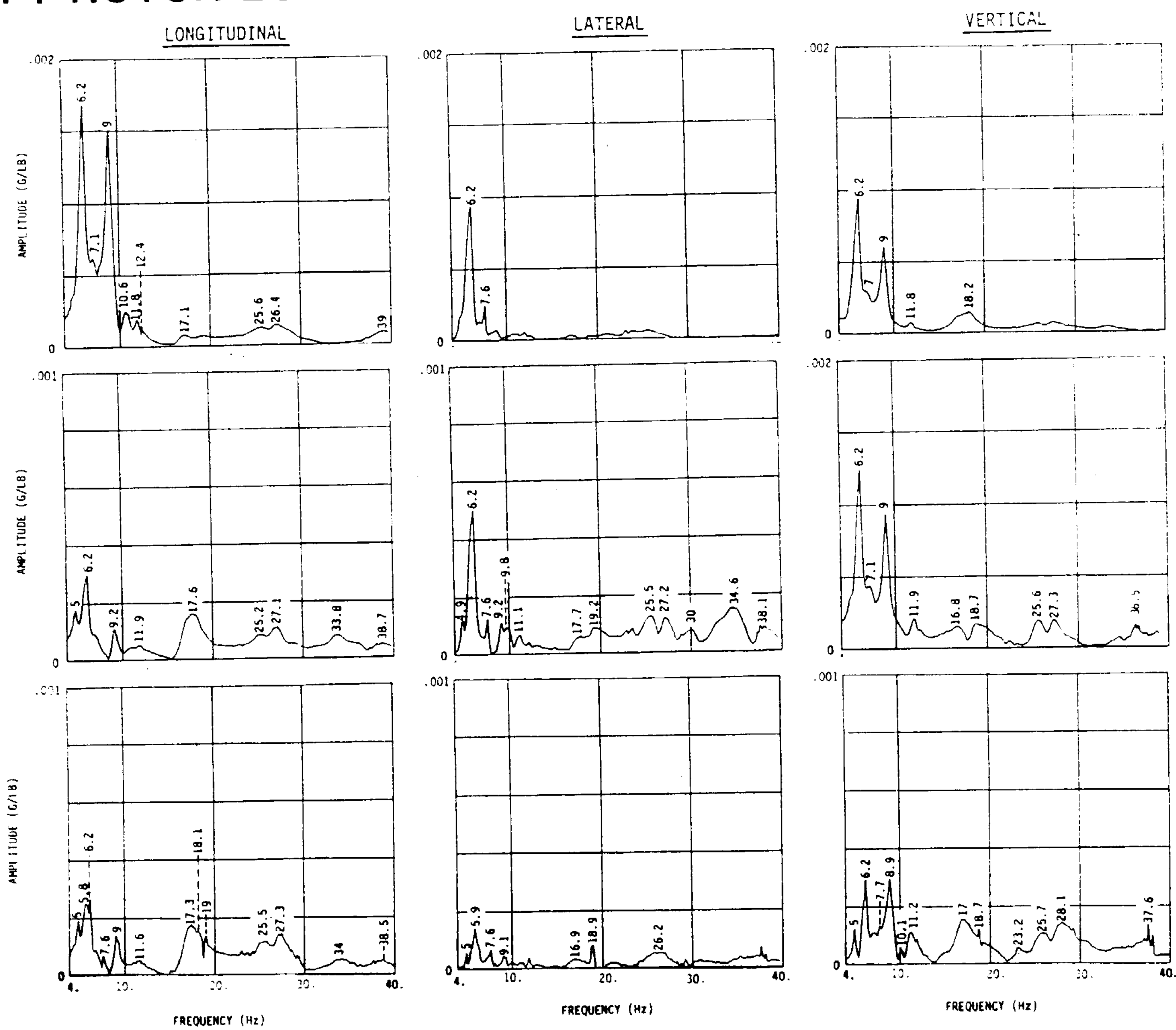
Except for consistent peaks at 6.2 and 9 Hz, the responses in the forward portion of the aircraft (forward hub, Sta. 10 and Sta. 286) are quite low. Recurring response peaks in the aft section (Sta. 480, Sta 458 engine case and the aft hub) appear at approximately 6.2, 9, and 12 Hz.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR LONGITUDINAL EXCITATION

FORWARD ROTOR HUB
(LOC. 2)

STA. 10 R/H
FORWARD COCKPIT
(LOC. 9)

STA. 286 L/H
CABIN STRUCTURE
(LOC. 24)



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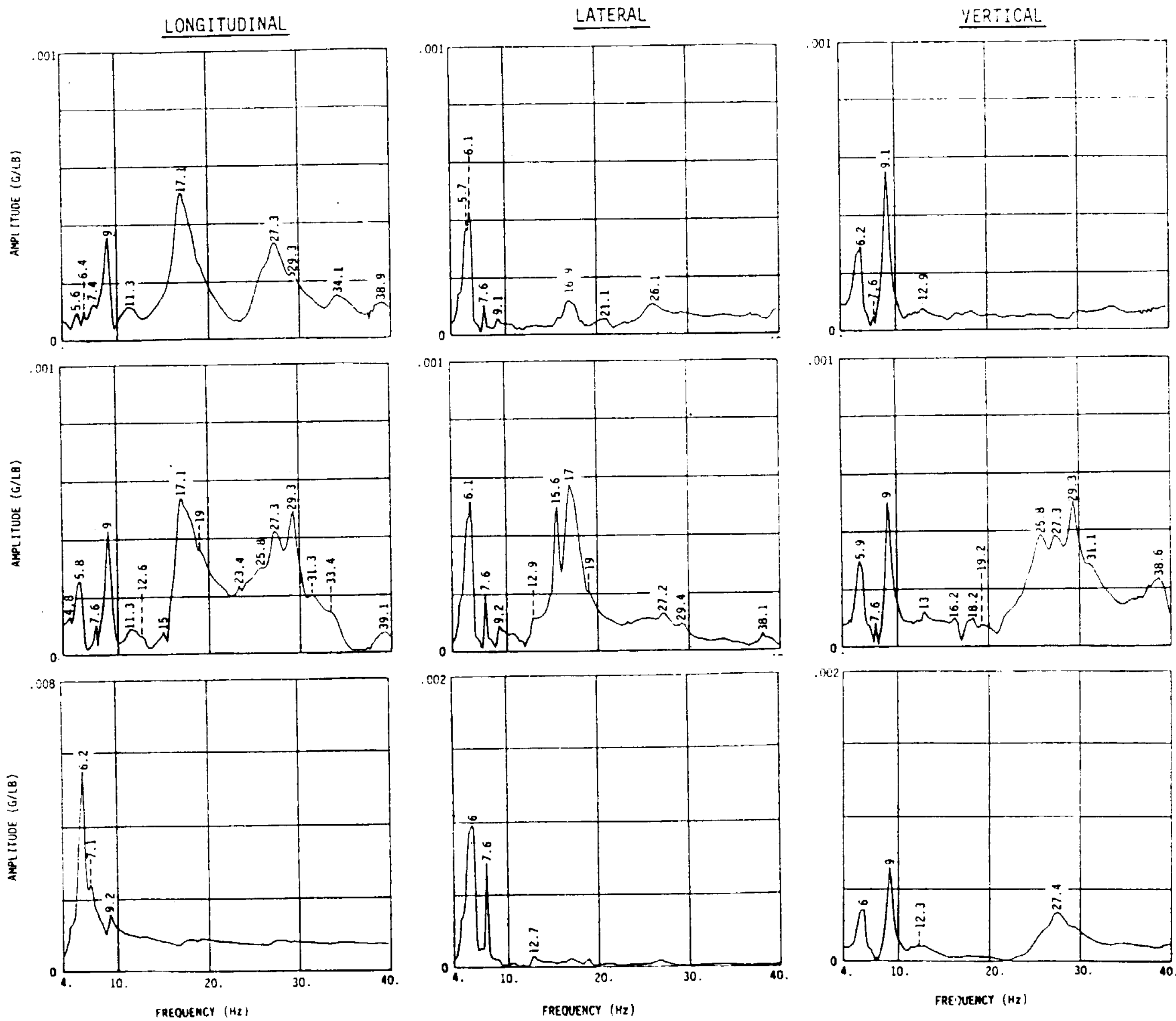
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR LONGITUDINAL EXCITATION

STA. 480 L/H AFT XMSN (LOC. 46)

STA. 458 L/H ENGINE CASE (LOC. 55)

AFT ROTOR HUB (LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

AFT ROTOR PITCH EXCITATION

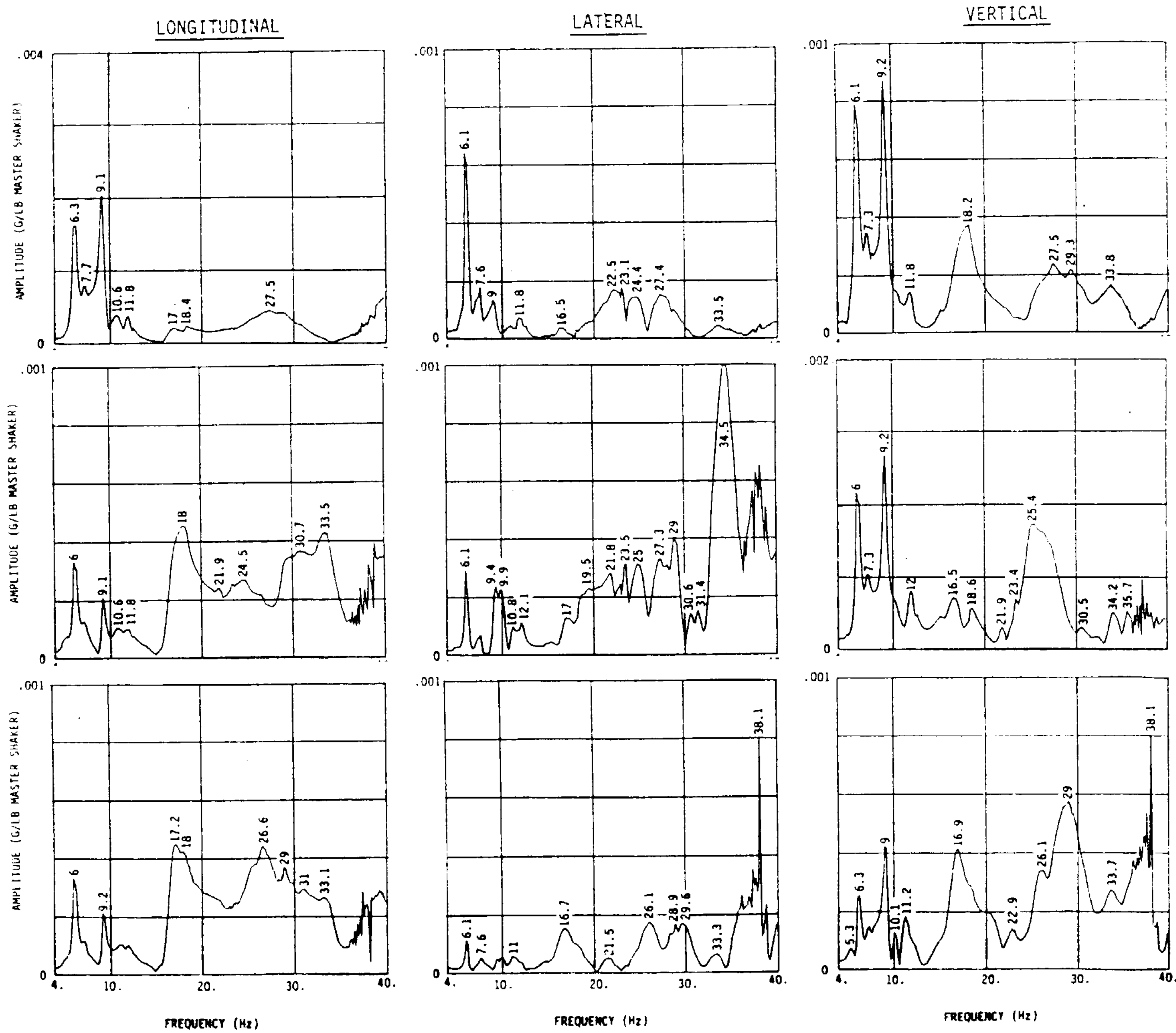
Ignoring the out-of-plane lateral, the most consistently appearing peaks are near 6 and 9 Hz. A recurring peak is also present in the 17 to 18 Hz range. A number of peaks are also present in the 25 to 30 Hz range. The strongest of these occurs near 29 Hz in the engine longitudinal and vertical responses. A relatively noisy response near 38 Hz is present in some of the data. To a lesser extent, this sort of response is also evident in some of the previous data. This characteristic is believed due to an impact condition; i.e. a mass vibrating within a clearance dimension.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR PITCH EXCITATION

FORWARD ROTOR HUB (LOC. 2)

STA. 10 R/H FORWARD COCKPIT (LOC. 9)

STA. 286 L/H CABIN STRUCTURE (LOC. 24)



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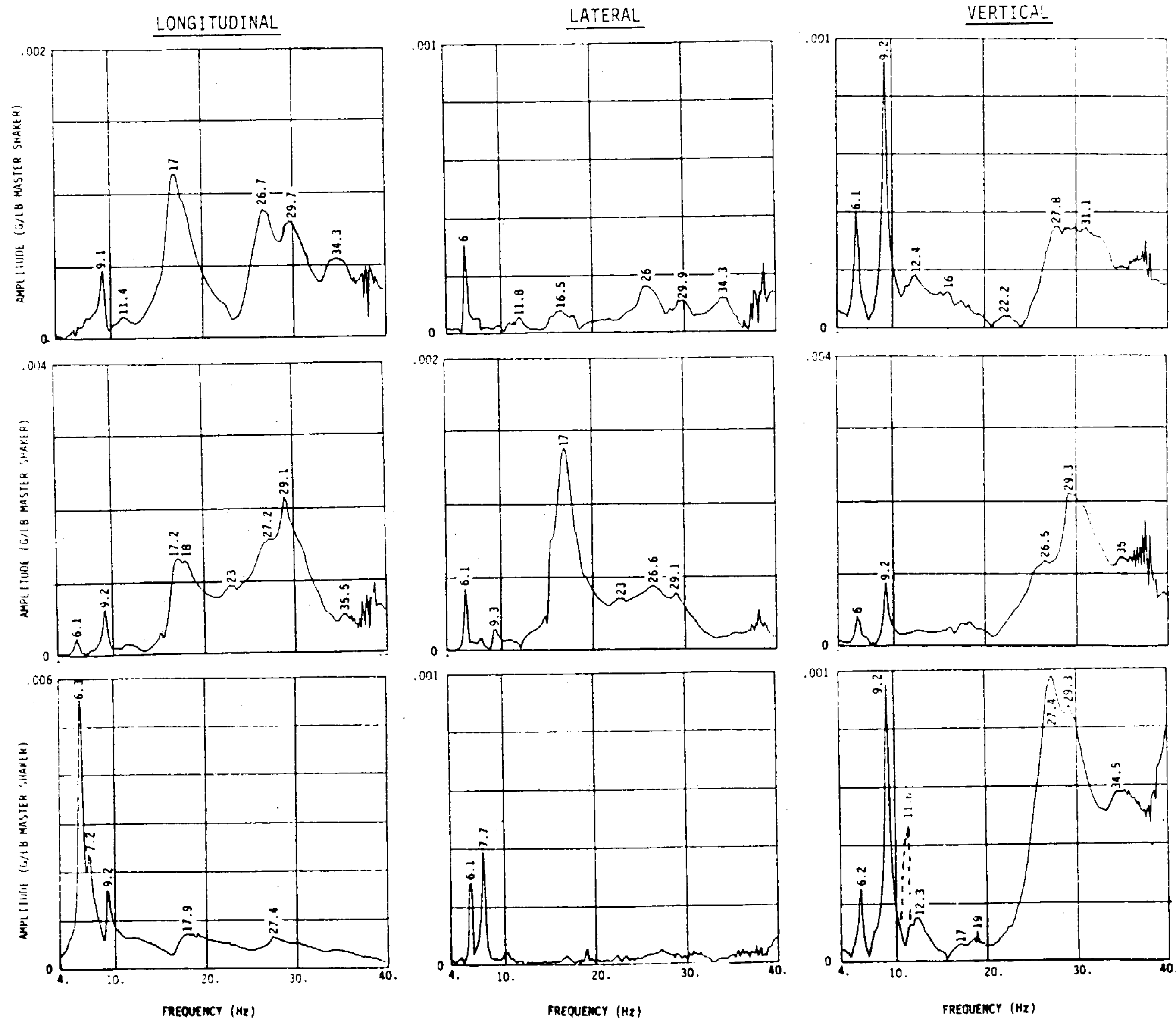
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE AFT ROTOR PITCH EXCITATION

STA. 480 L/H AFT XMSN (LOC. 46)

STA. 458 L/H ENGINE CASE (LOC. 55)

AFT ROTOR HUB (LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

AFT ROTOR ROLL EXCITATION

In the primary lateral direction, the most consistent responses occur near 6.1, 7.7 and 16 Hz. A noisy high level response centered near 38 Hz is present in most of the data. This was also observed to a lesser extent with aft pitch excitation.

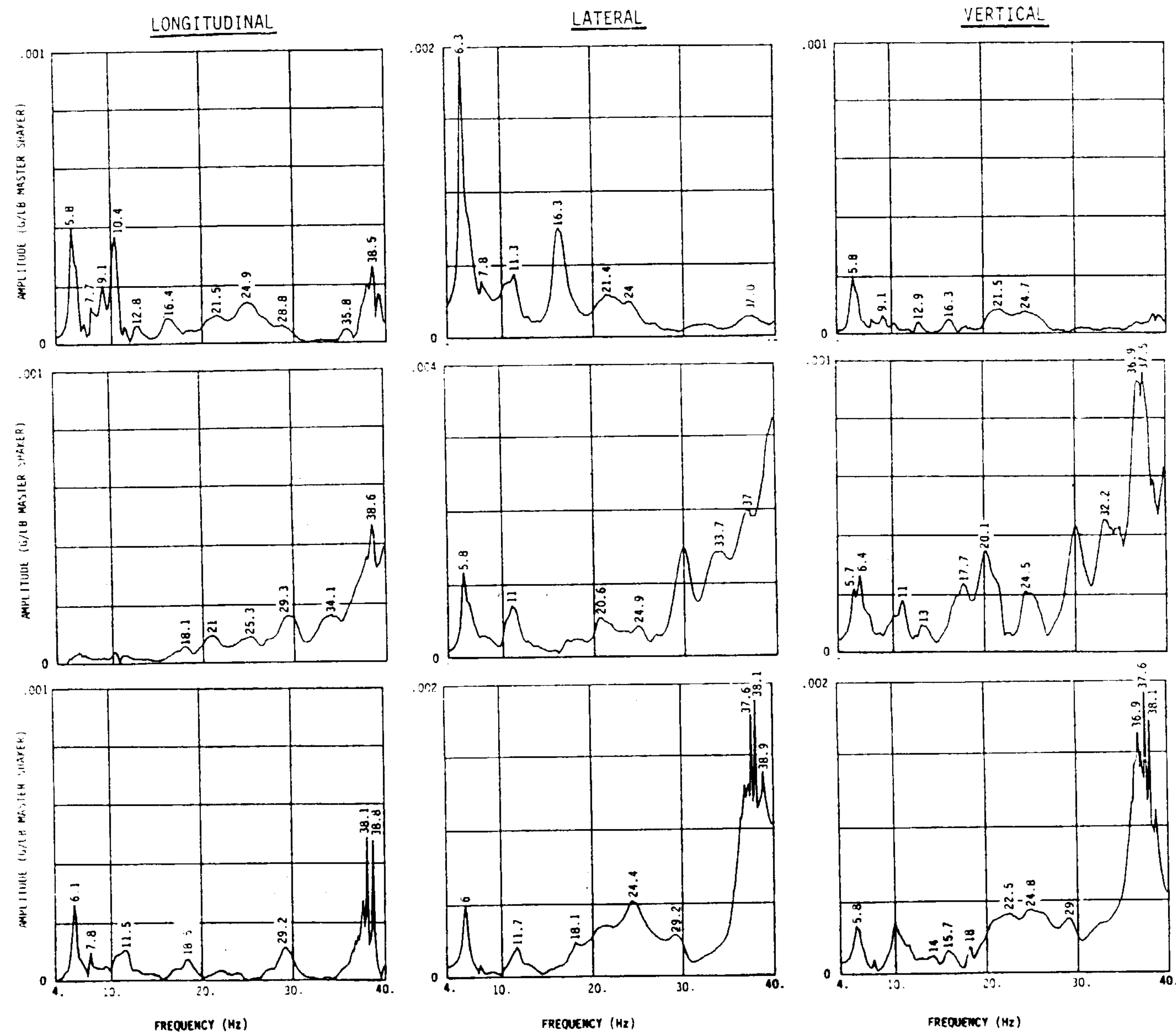
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE

AFT ROTOR ROLL EXCITATION

FORWARD ROTOR HUB
(LOC. 2)

STA. 10 R/H
FORWARD COCKPIT
(LOC. 9)

STA. 286 L/H
CABIN STRUCTURE
(LOC. 24)



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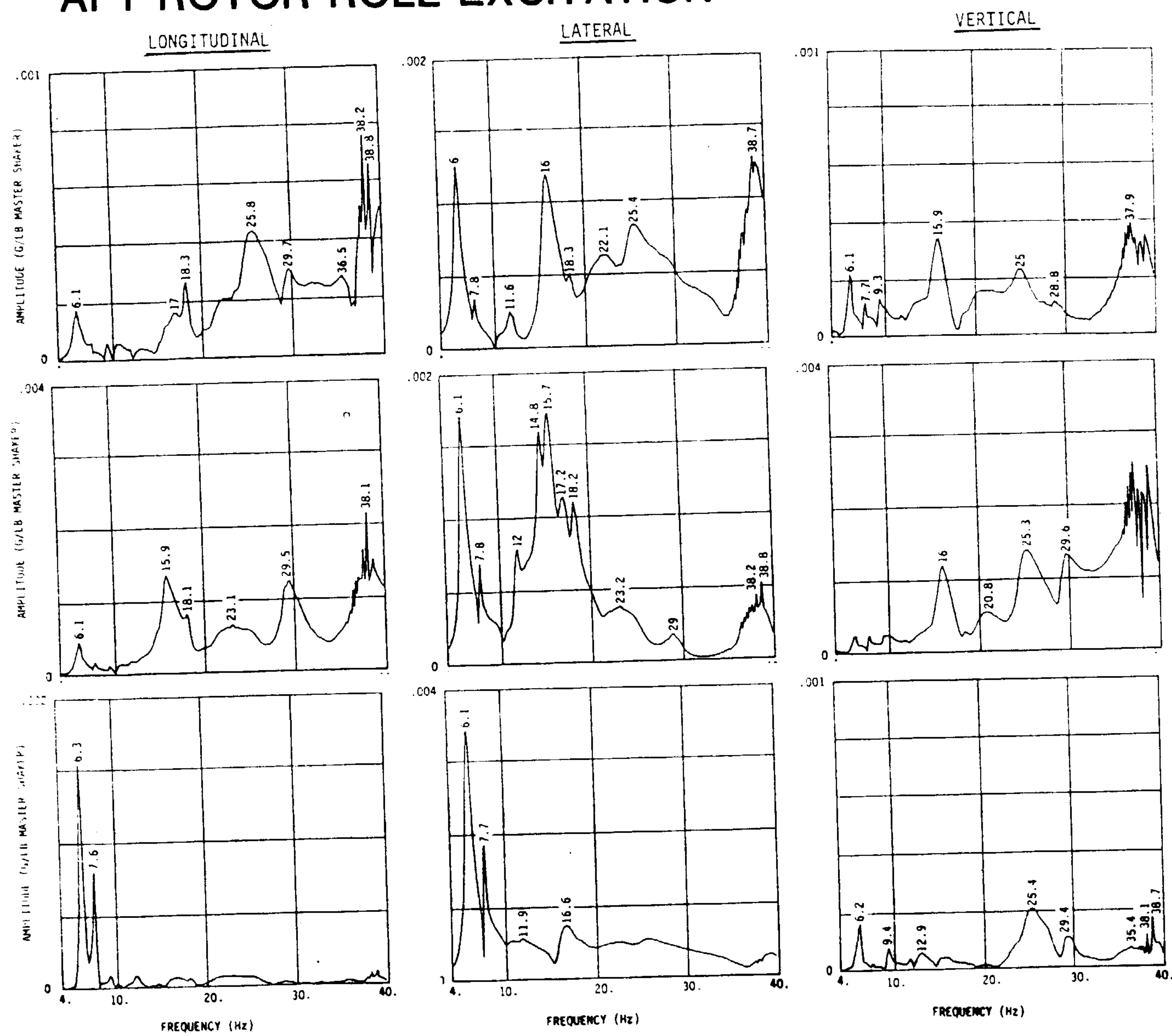
TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
AFT ROTOR ROLL EXCITATION

STA. 480 L/H AFT XMSN (LOC. 46)

STA. 458 L/H ENGINE CASE (LOC. 55)

AFT ROTOR HUB (LOC. 51)



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TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

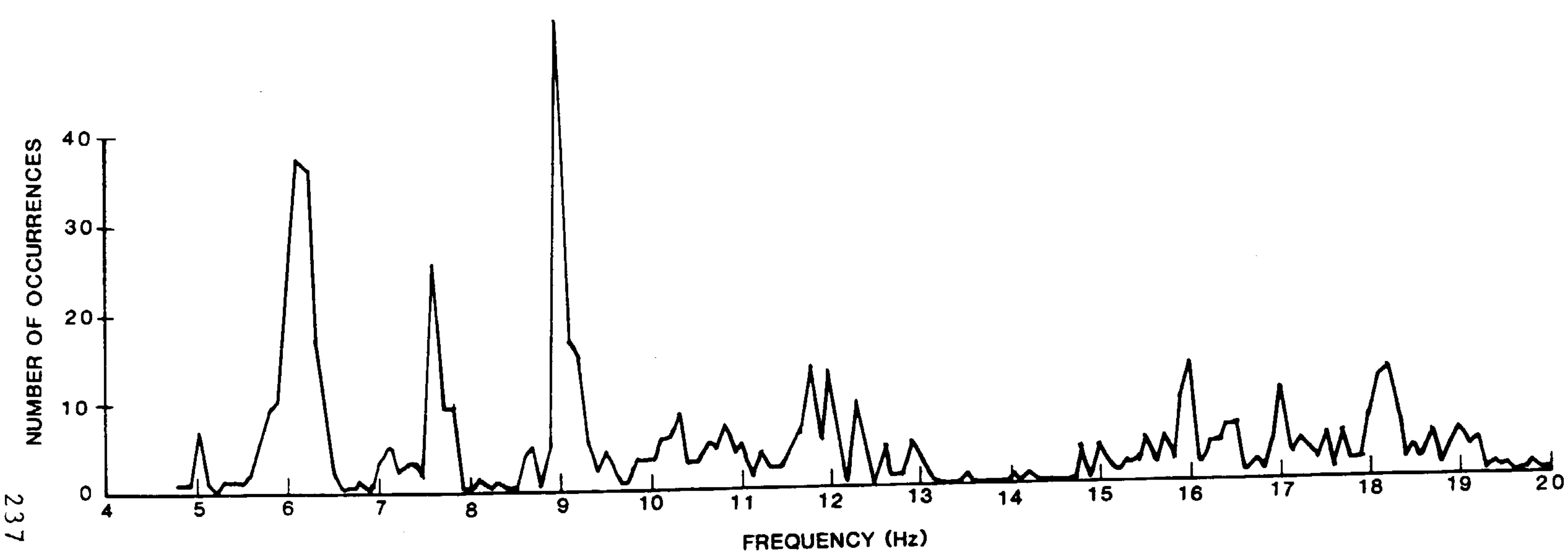
DISTRIBUTION OF RESONANCE POINTS

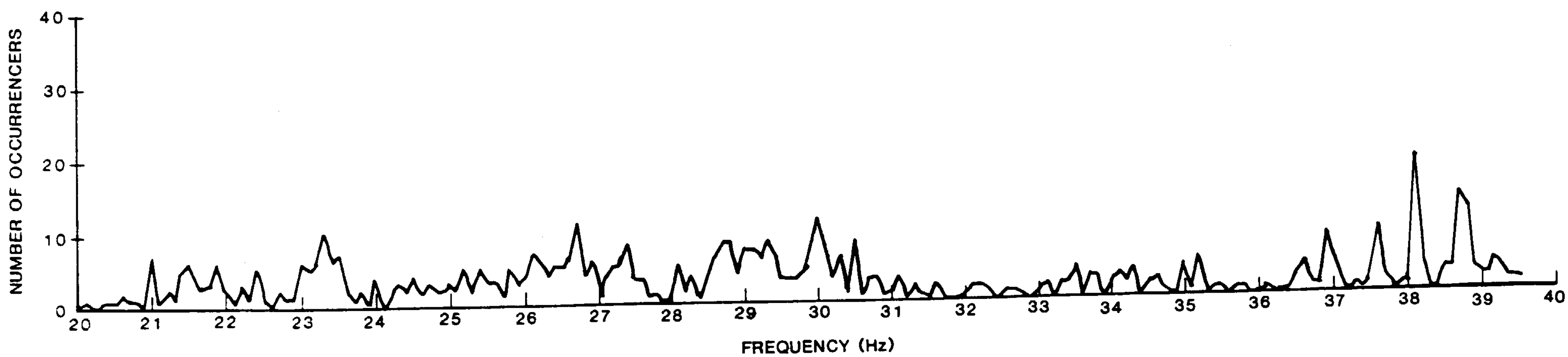
The accompanying chart is based on the preceding frequency response plots and shows a plot of the peak frequencies and the number of times that a given frequency appears. It is evident from the chart that there is considerable scatter in the frequency at which a mode appears. This makes it difficult (if not impossible) to precisely define the natural frequencies. Further, where modes are in close proximity, it may not be possible to distinguish between the modes. Often, it is necessary to add or remove weight at a critical location to separate modes for purposes of identification.

C-3

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE

DISTRIBUTION OF RESPONSE PEAKS





TEST RESULTS - DISCUSSION OF FREQUENCY RESPONSE

ESTIMATED NATURAL FREQUENCIES

A summary of the estimated natural frequencies is presented below. The shaker configuration which appears to provide the best excitation is noted. Estimated natural frequencies are based on the following considerations:

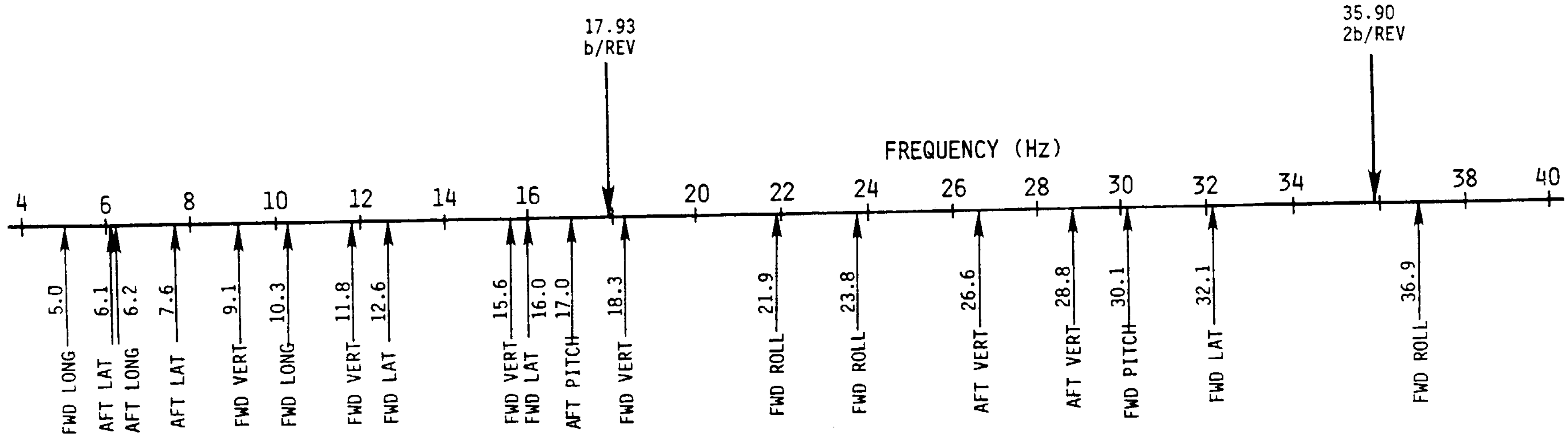
a) The distribution of resonance points shown in the previous chart.

b) The frequency for the shaker excitation with the largest response was generally favored (longitudinal and lateral were favored over pitch and roll where there was a choice).

c) Some prior knowledge of the general model frequencies and characteristics.

d) Examination of a limited amount of additional data and test observations.

TEST RESULTS – DISCUSSION OF FREQUENCY RESPONSE
ESTIMATED NATURAL FREQUENCIES



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5.5 Forced Response Mode Shapes

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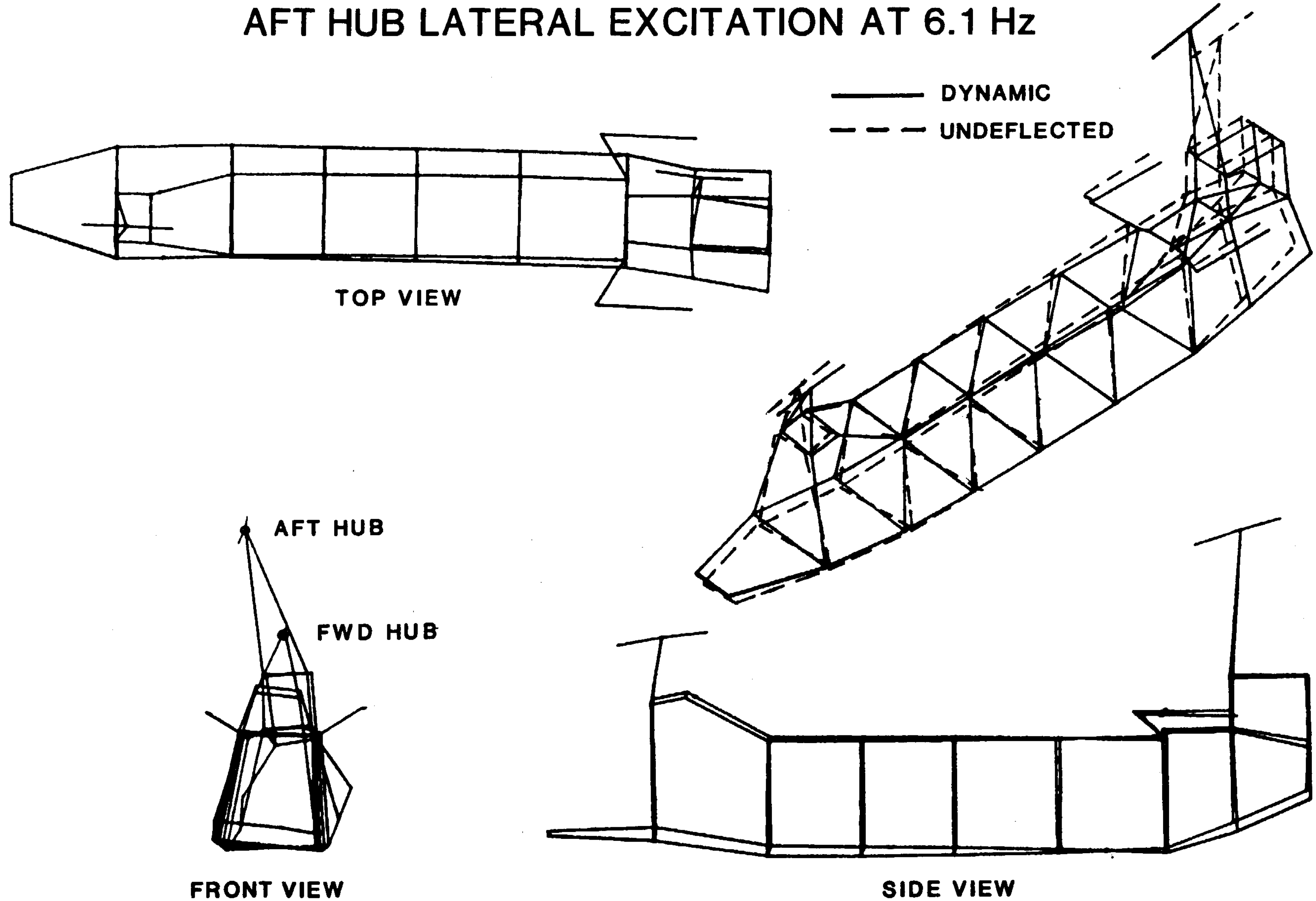
TEST RESULTS - FORCED RESPONSE MODE SHAPES

AFT HUB LATERAL EXCITATION AT 6.1 Hz

This mode is the fundamental torsion mode with the rotor hubs moving in opposition to each other. A large pylon lateral/roll motion is balanced by a nearly rigid body rotation of the fuselage center section and the forward rotor. Because of the large relative pylon motions, this mode is generally referred to as the "aft pylon lateral mode."

TEST RESULTS – FORCED RESPONSE MODE SHAPES
AFT HUB LATERAL EXCITATION AT 6.1 Hz

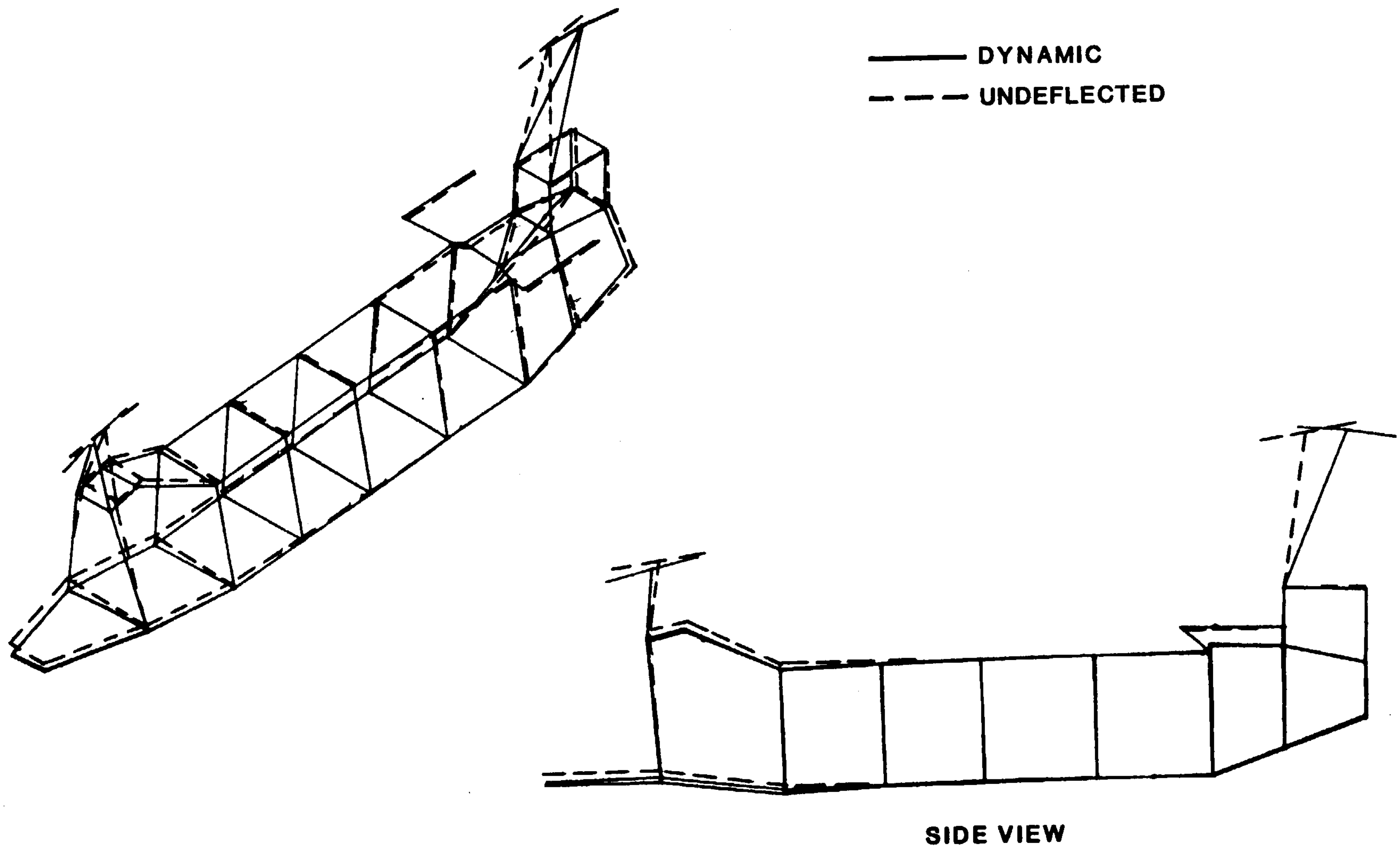


TEST RESULTS - FORCED RESPONSE MODE SHAPES

AFT HUB LONGITUDINAL EXCITATION AT 6.2 Hz

This mode is the fundamental bending mode with the hub motions opposing each other. The mode is referred to as the "aft pylon longitudinal mode" for obvious reasons. A large amplitude pylon pitching motion is opposed by an essentially rigid motion of the forward fuselage.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
AFT HUB LONGITUDINAL EXCITATION AT 6.2 Hz

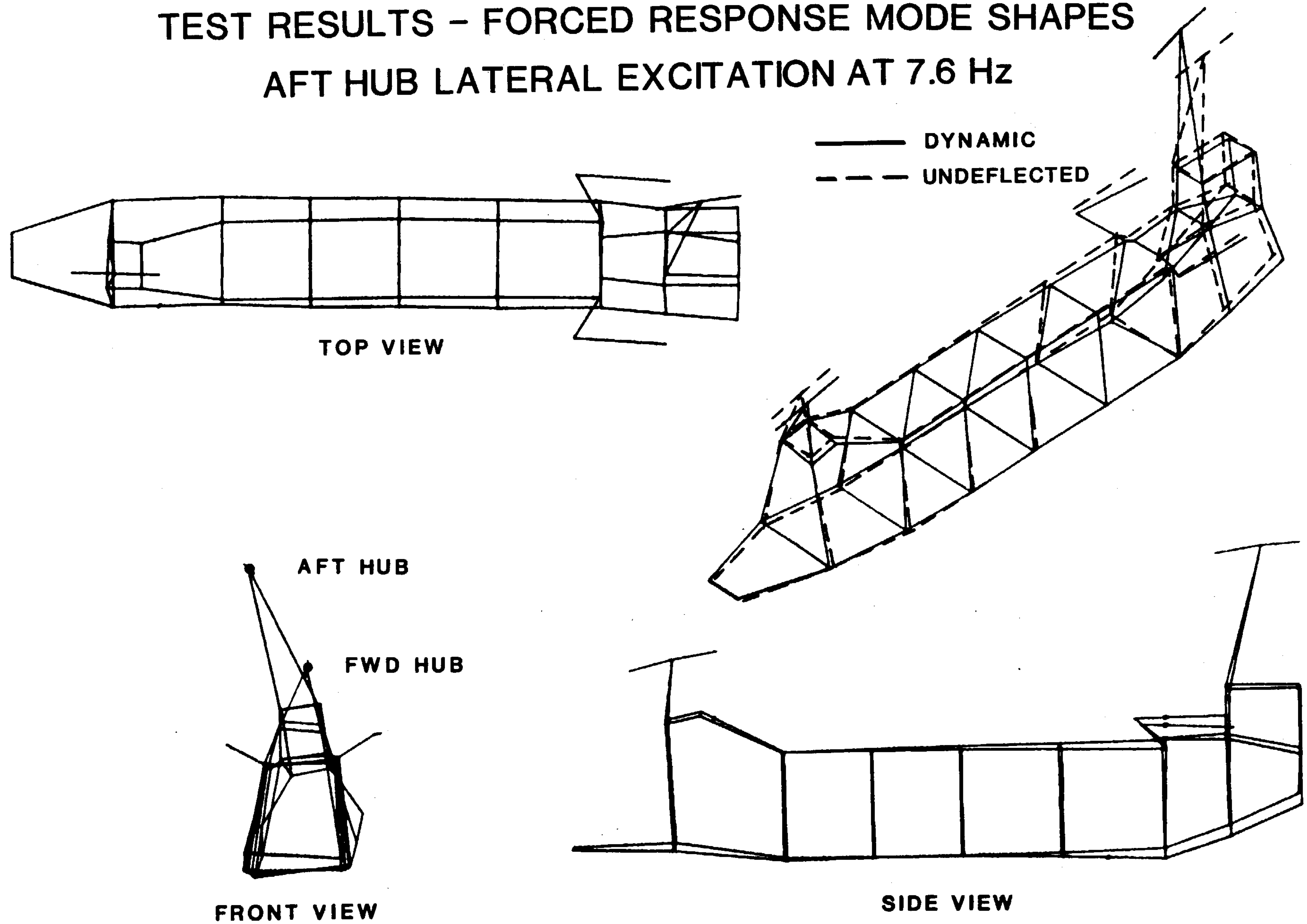


TEST RESULTS - FORCED RESPONSE MODE SHAPES

AFT HUB LATERAL EXCITATION AT 7.6 Hz

There is little question that there is a mode near this frequency; however, differences between the shape at this frequency and the previous lateral mode at 6.1 Hz are not obvious. At most, there is a small difference in the relative motion between the aft hub and the lower structure and engines.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
AFT HUB LATERAL EXCITATION AT 7.6 Hz

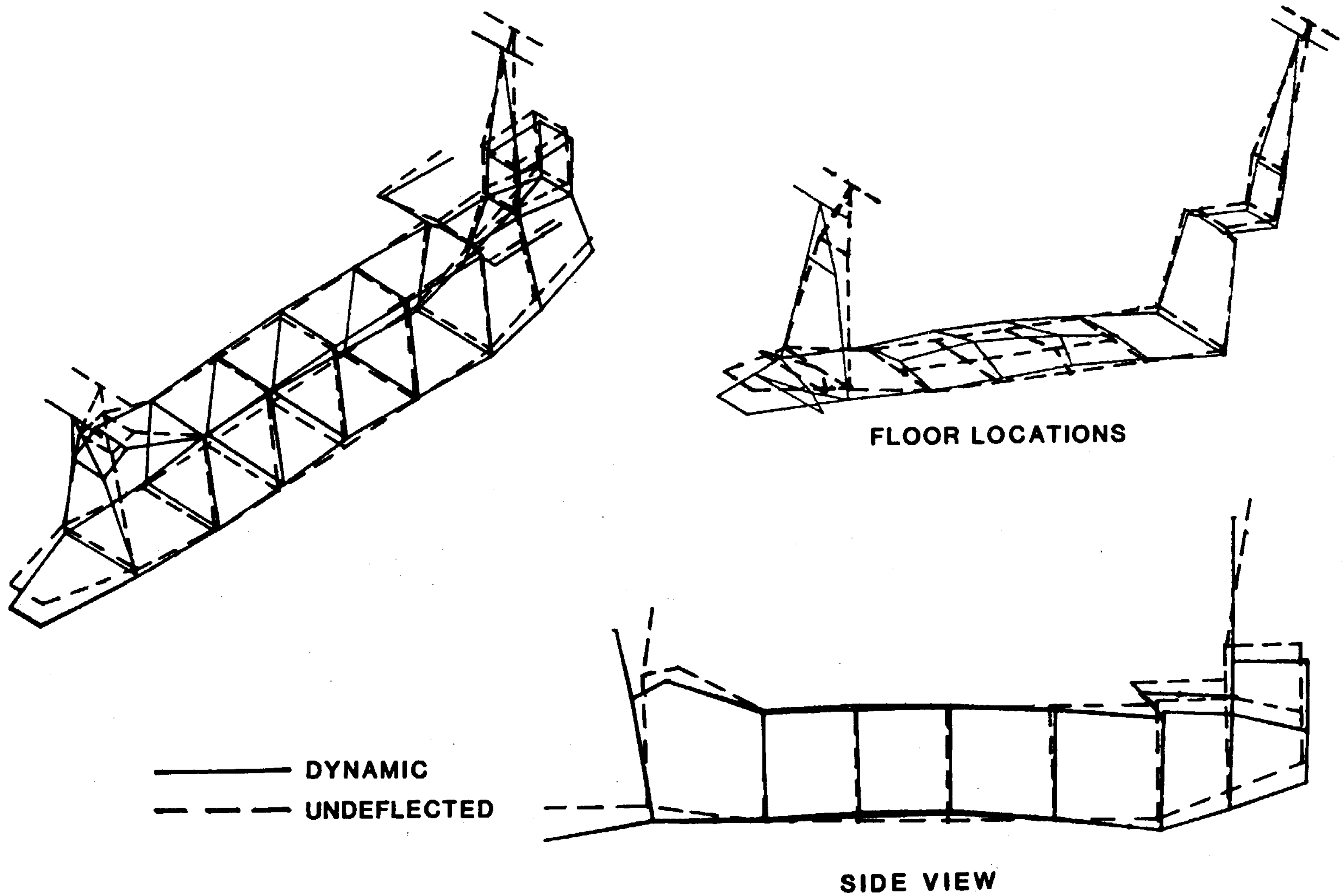


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB VERTICAL EXCITATION AT 9.1 HZ

The response shape at this frequency is a second bending mode with the hub motions in phase. Note that a small vertical motion of the cabin floor relative to the structure is also present.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB VERTICAL EXCITATION AT 9.1 Hz

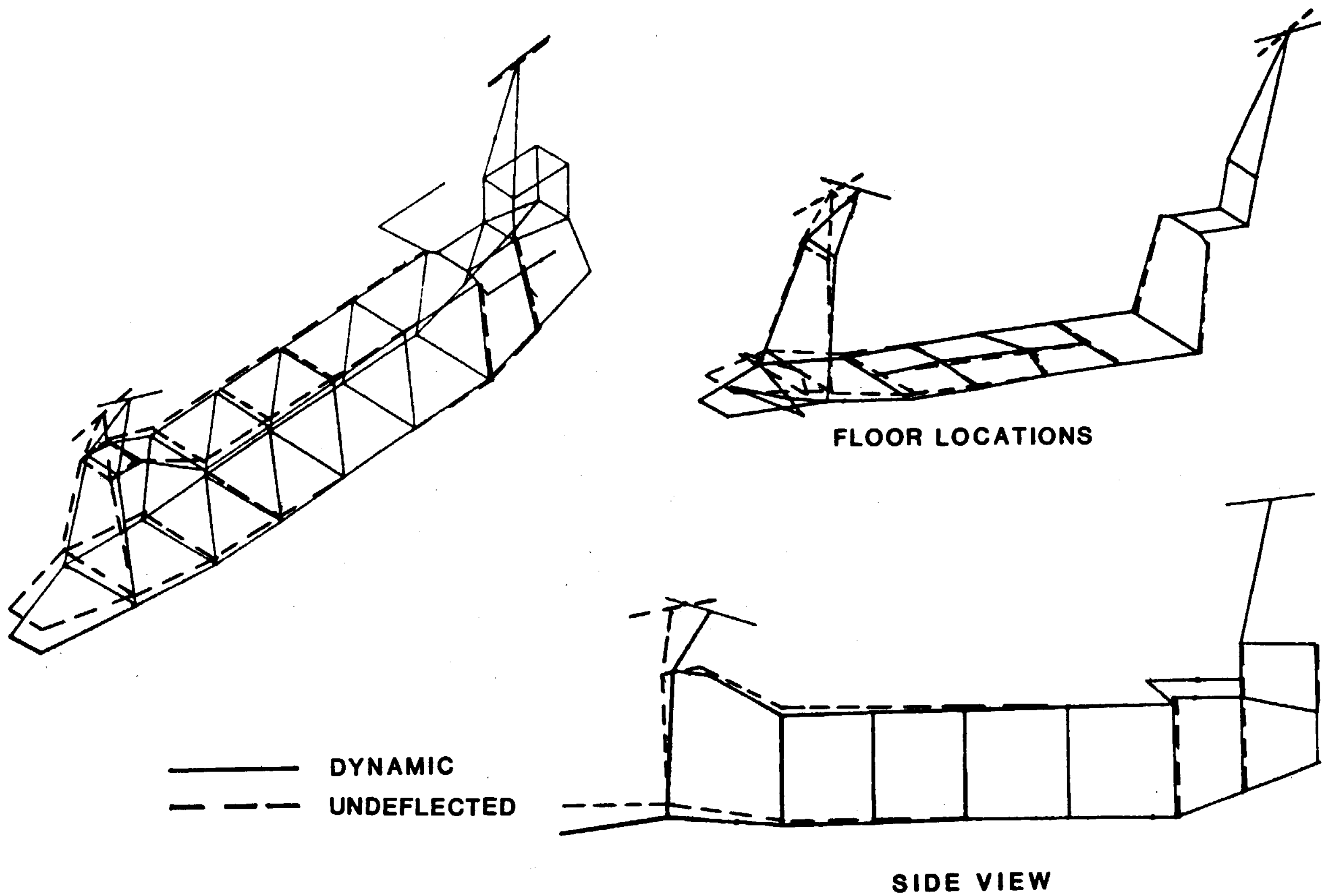


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB LONGITUDINAL EXCITATION AT 10.3 HZ

The motion here is nearly an uncoupled pitching motion of the forward transmission which is balanced by a vertical motion of the cockpit. The shape suggests that there may be deformation of the frame (elongation) at the forward transmission support.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB LONGITUDINAL EXCITATION AT 10.3 Hz

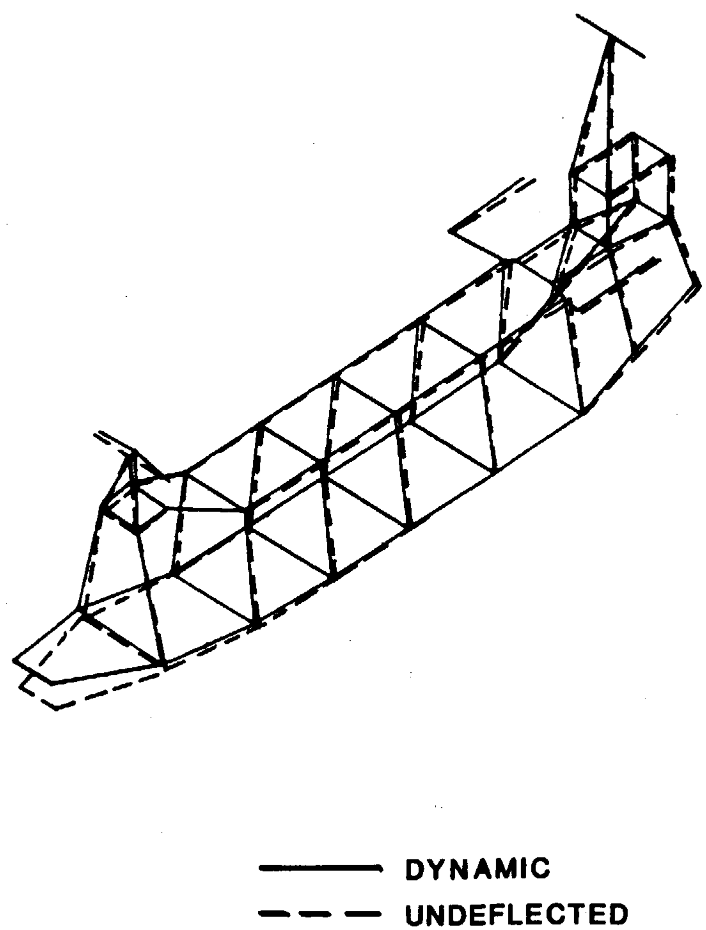


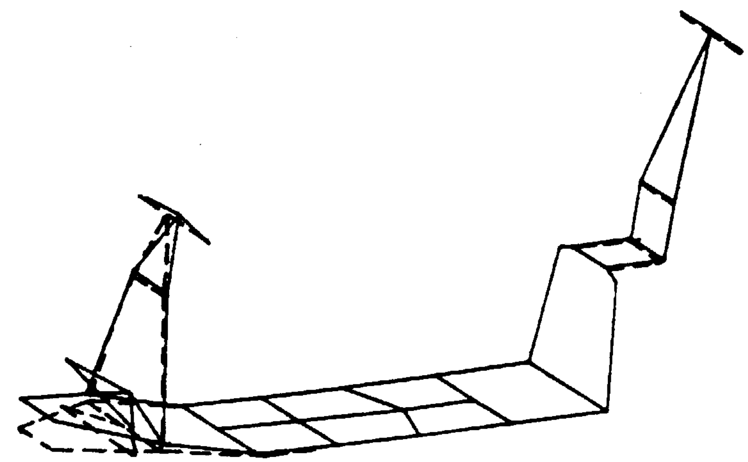
TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB VERTICAL EXCITATION AT 11.8 Hz

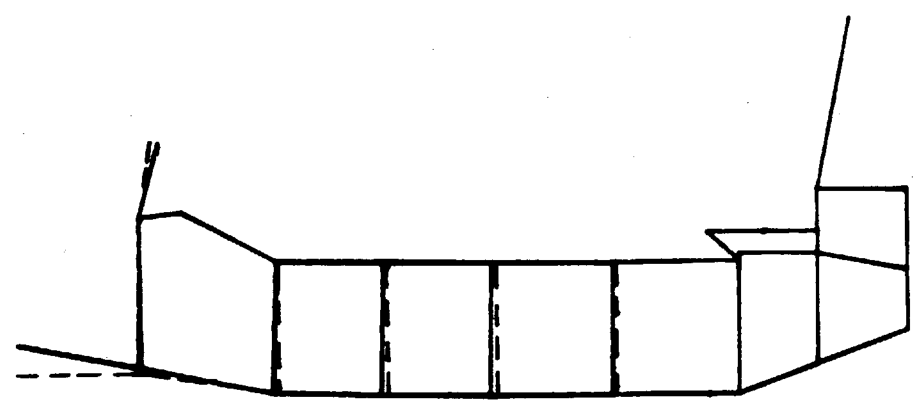
In this case, the motion is a local cockpit response. The cockpit structure is moving vertically with an inphase vertical-roll motion of the floor module relative to the structure. There is no evident inertial balance suggesting motion of a mass that was not instrumented.

TEST RESULTS – FORCED RESPONSE MODE SHAPES FORWARD HUB VERTICAL EXCITATION AT 11.8 Hz





FLOOR LOCATIONS



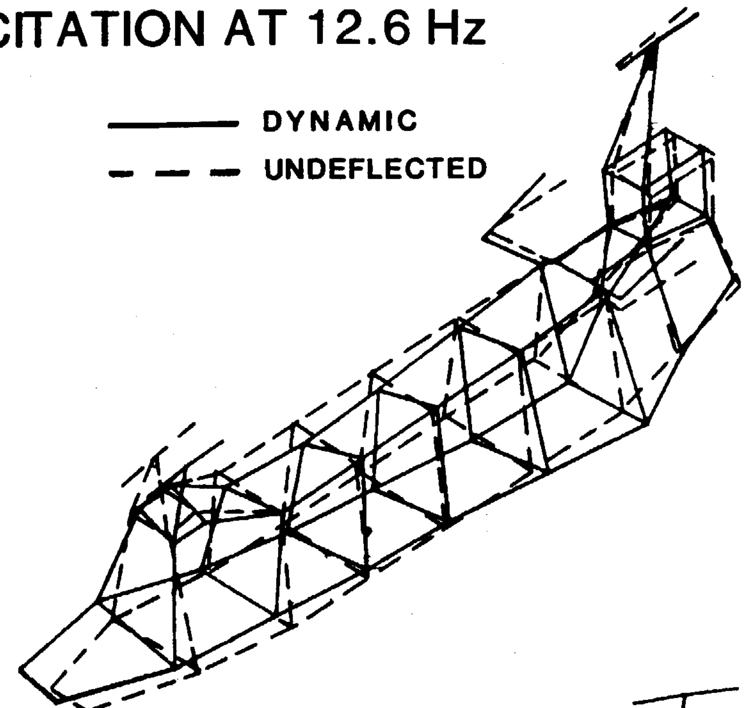
SIDE VIEW

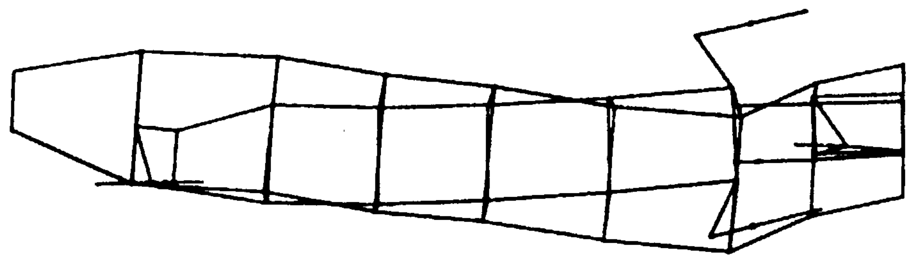
TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB LATERAL EXCITATION AT 12.6 Hz

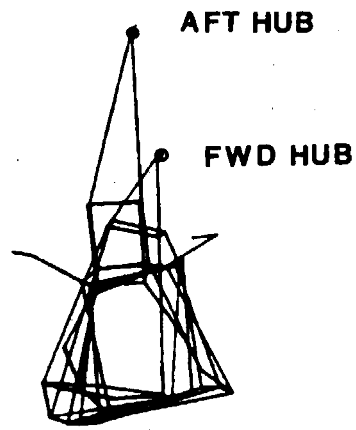
The motions in this mode are a mixture of first and second torsion characteristics. The fuselage is twisted clockwise at the front and counterclockwise at the rear. However, the hub motions are in phase.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB LATERAL EXCITATION AT 12.6 Hz

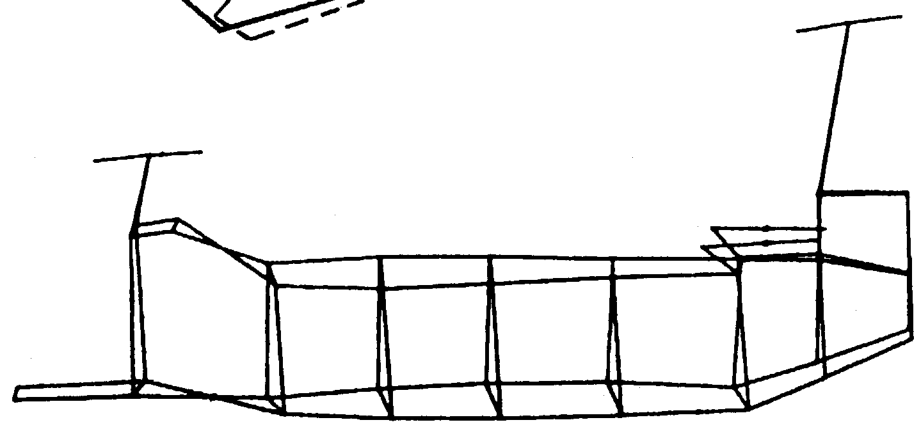




TOP VIEW



FRONT VIEW

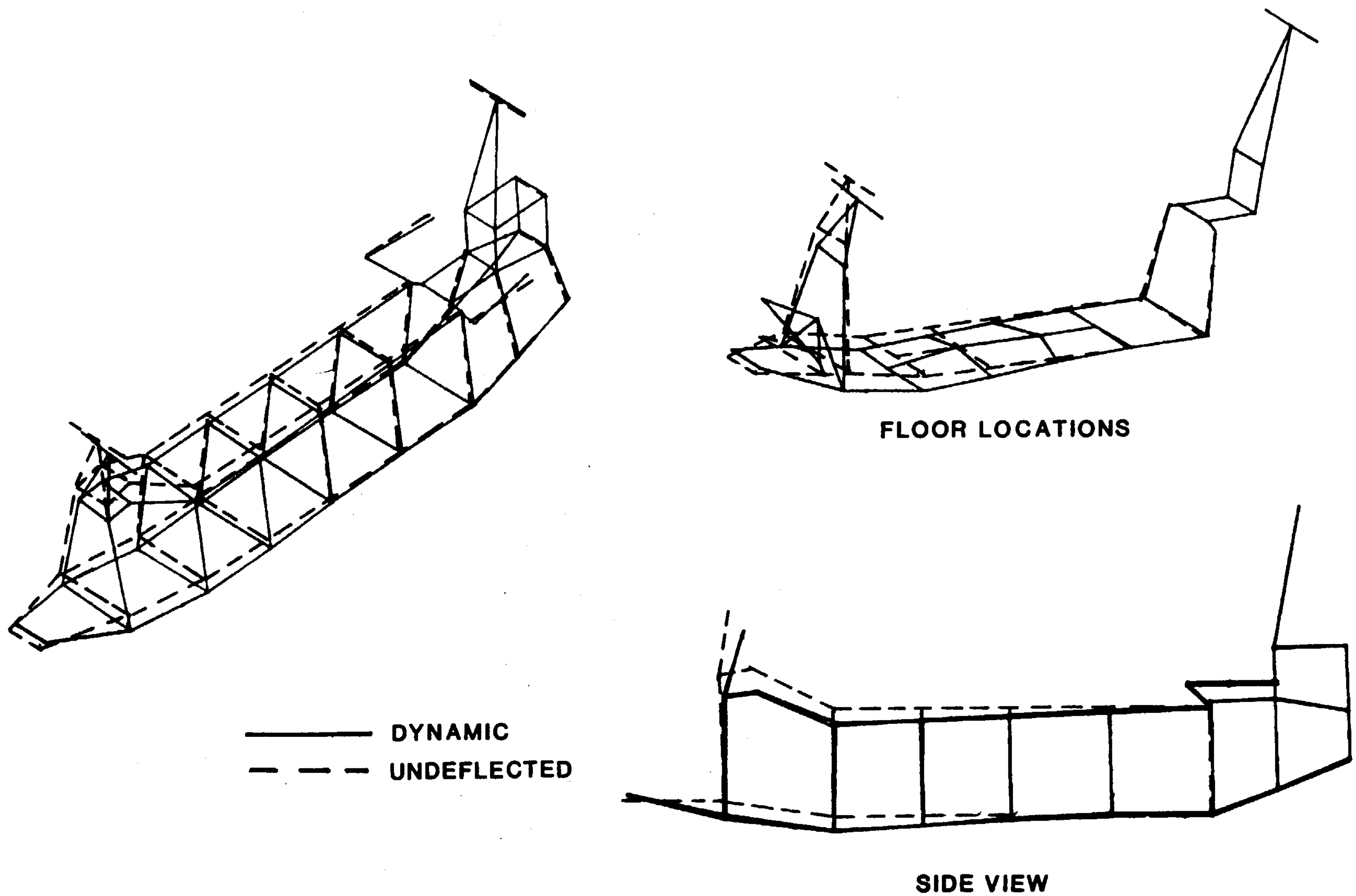


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB VERTICAL EXCITATION AT 15.6 Hz

In this mode the cockpit floor module is moving vertically relative to the support structure. Motion of the floor is balanced inertially by the out of phase vertical motion of the forward fuselage. Note that the motion of the cockpit module at this frequency is similar to that previously observed at 11.8 Hz.

TEST RESULTS – FORCED RESPONSE MODE SHAPES FORWARD HUB VERTICAL EXCITATION AT 15.6 Hz

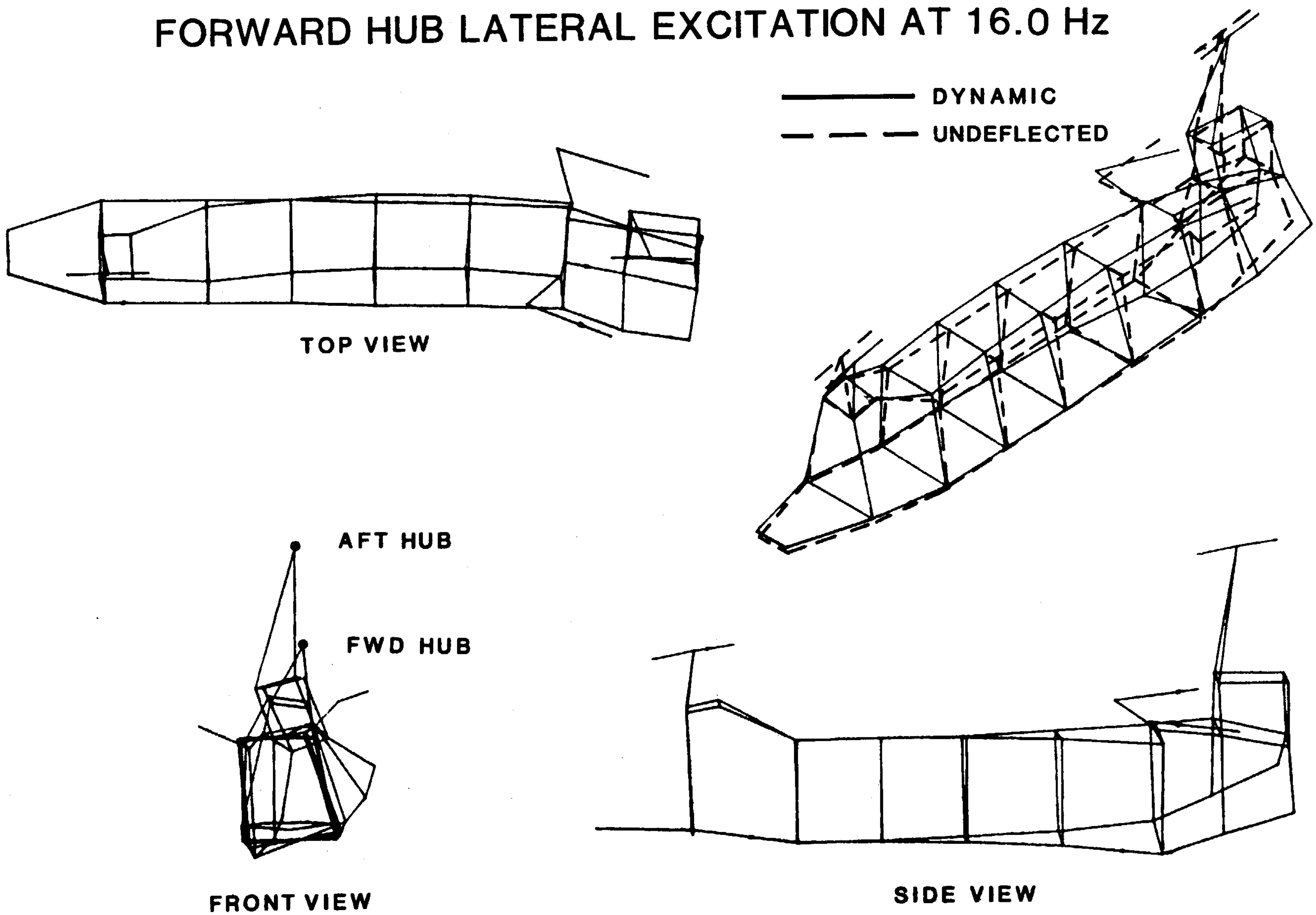


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB LATERAL EXCITATION AT 16 Hz

The motions at this frequency are characterized by in-phase lateral motion at the hubs together with a combination of frame racking and torsion. Lateral racking of the frames is evident at the forward end of the cabin and gradually transitions to something more nearly resembling torsion at the aft end. Significant symmetric yawing of the engines is also present.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB LATERAL EXCITATION AT 16.0 Hz

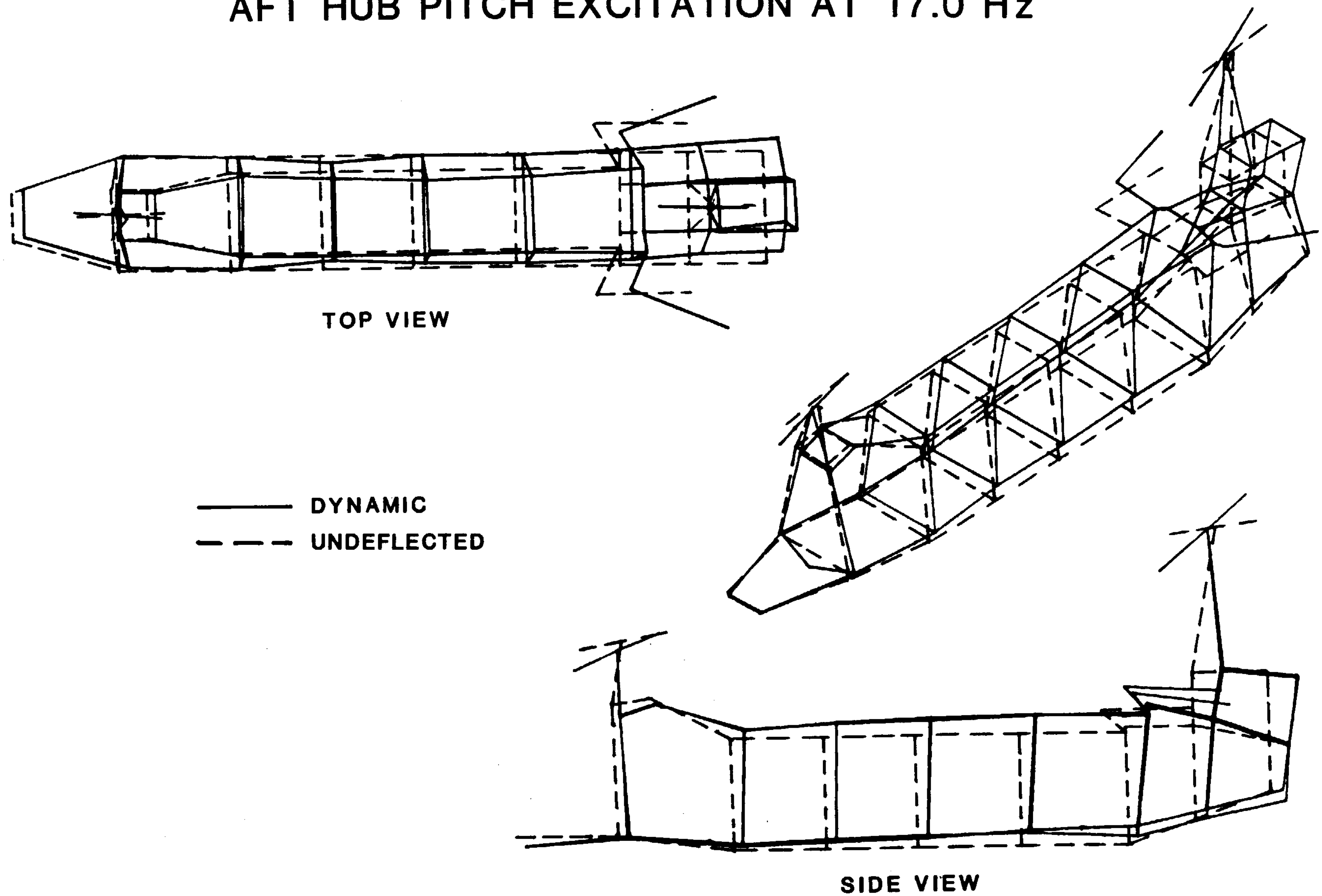


TEST RESULTS - FORCED RESPONSE MODE SHAPES

AFT HUB PITCH EXCITATION AT 17 Hz

The shape here is characterized by a vertical bending motion of the aft fuselage and pylon structure with an out-of phase pitch motion of the aft hub mass. More interesting is the symmetric engine yaw motion and the lateral breathing at the forward end of the cabin section.

TEST RESULTS – FORCED RESPONSE MODE SHAPES AFT HUB PITCH EXCITATION AT 17.0 Hz

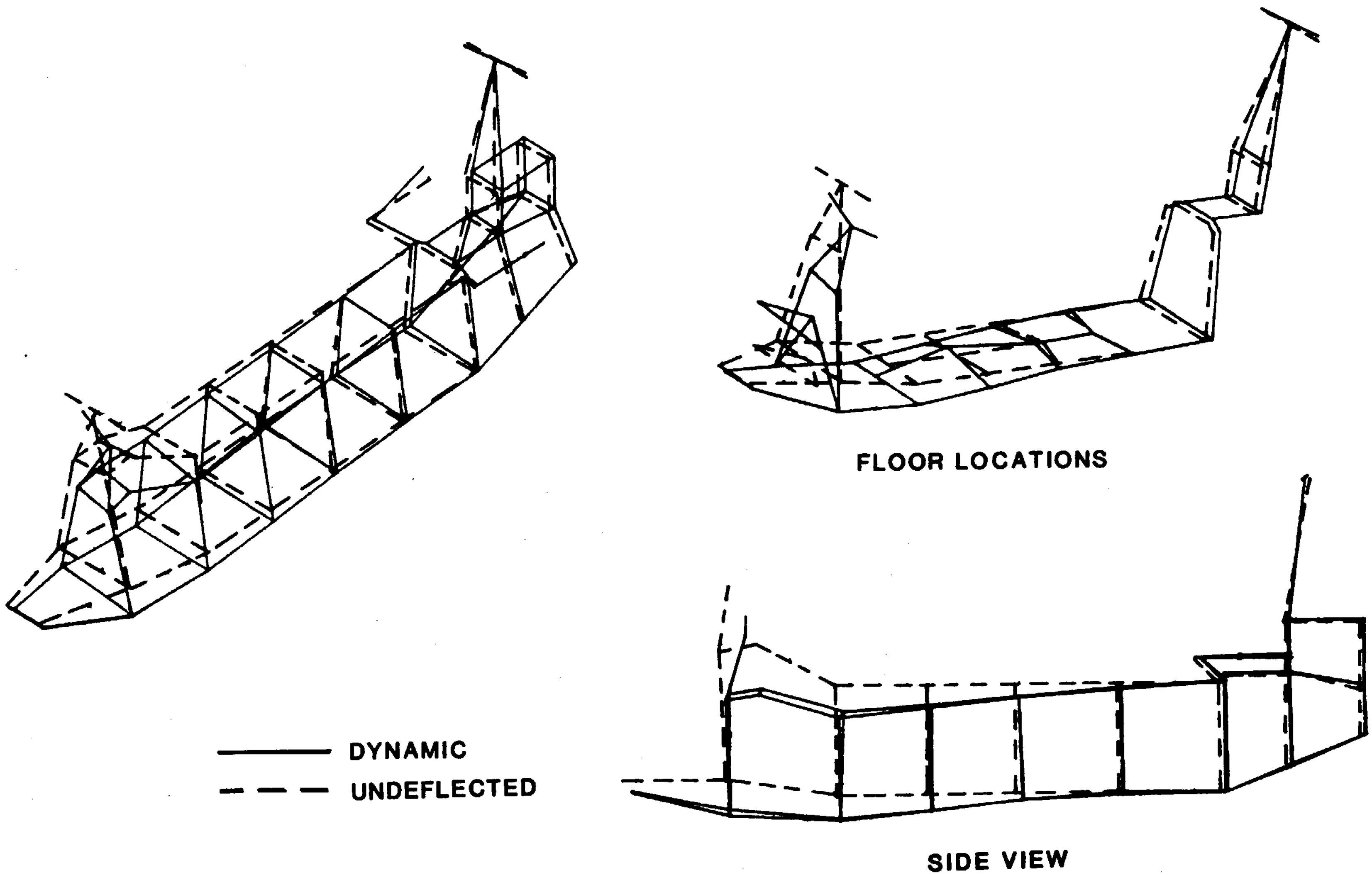


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB VERTICAL EXCITATION AT 18.3 Hz

With some minor exceptions, the shape at this frequency is nearly the same as that previously observed at 15.6 Hz. Relative motion between the cockpit floor module and the support structure seems greater, and no rolling is evident. In addition, relative motion between the cabin floor module and its support structure is evident.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB VERTICAL EXCITATION AT 18.3 Hz

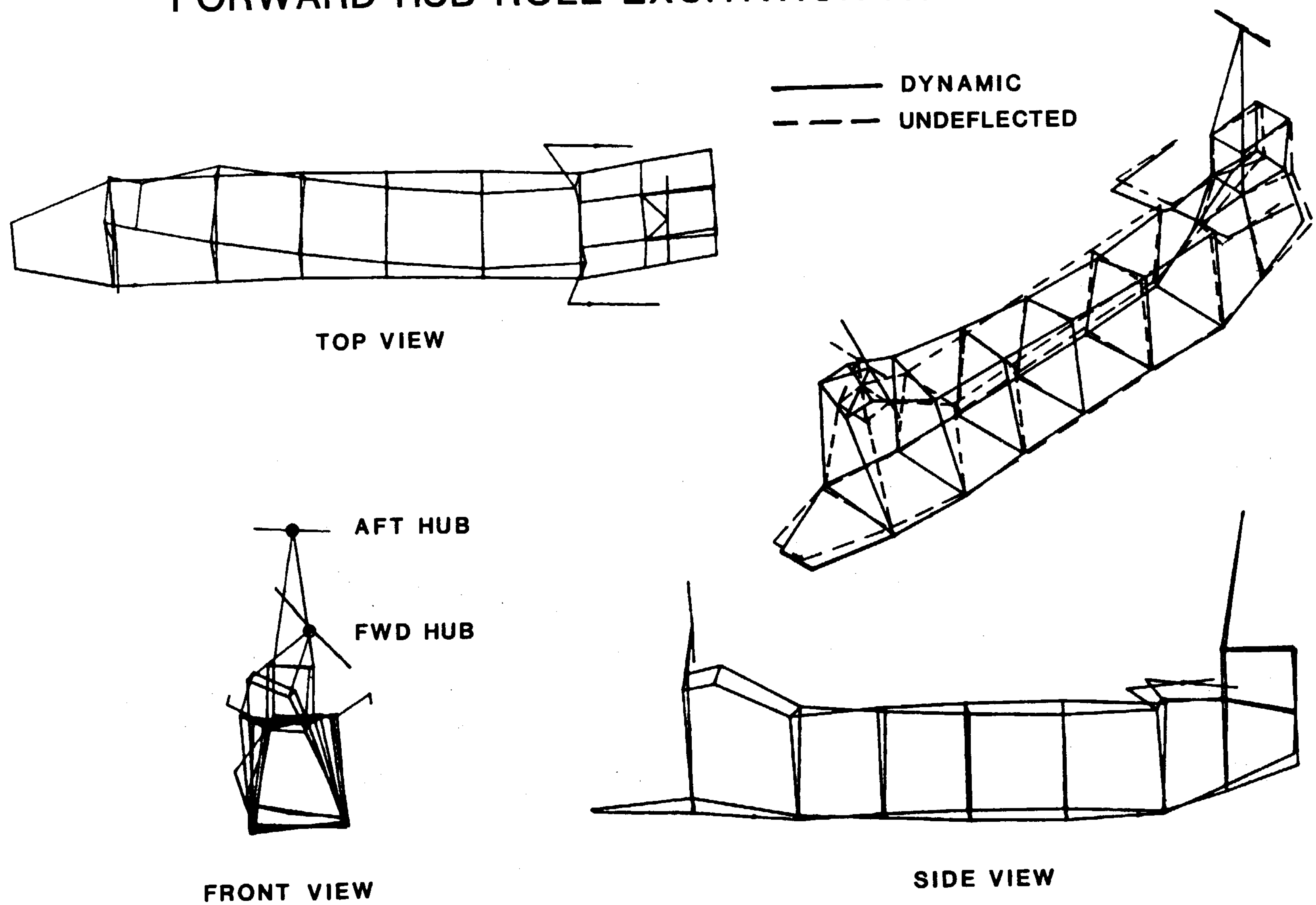


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB ROLL EXCITATION AT 21.9 Hz

A complex frame racking motion is present at this frequency. At the upper longerons there is a large lateral displacement with no corresponding motion at the lower longeron. Small vertical motions on the left and right side are out of phase.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB ROLL EXCITATION AT 21.9 Hz

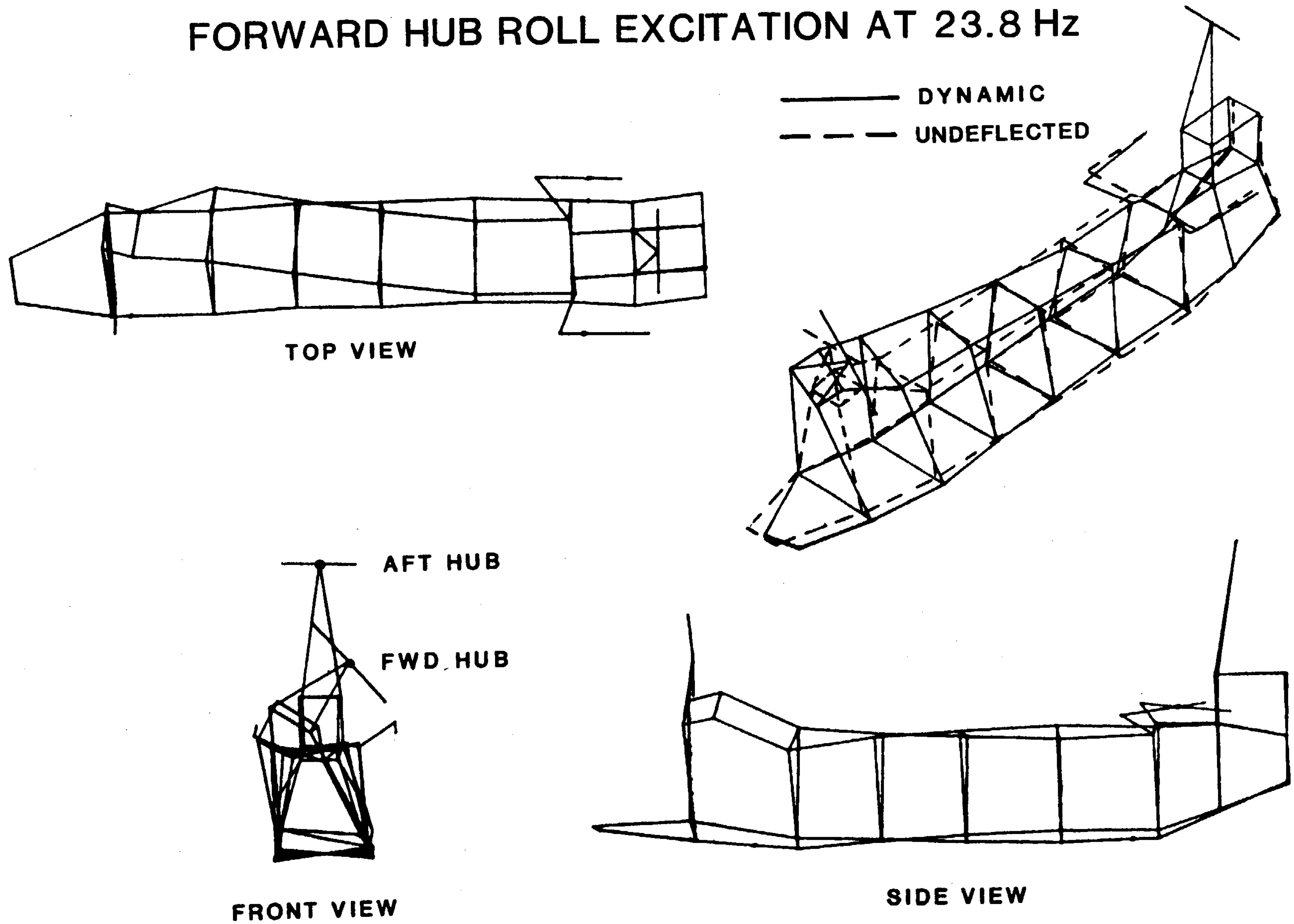


TEST RESULTS - FORCED RESPONSE MODE SHAPES

FORWARD HUB ROLL EXCITATION AT 23.8 Hz

The shape at this frequency is virtually the same as that noted at 21.9 Hz. The only difference seems to be the relative magnitude of the upper longeron lateral displacement.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
FORWARD HUB ROLL EXCITATION AT 23.8 Hz

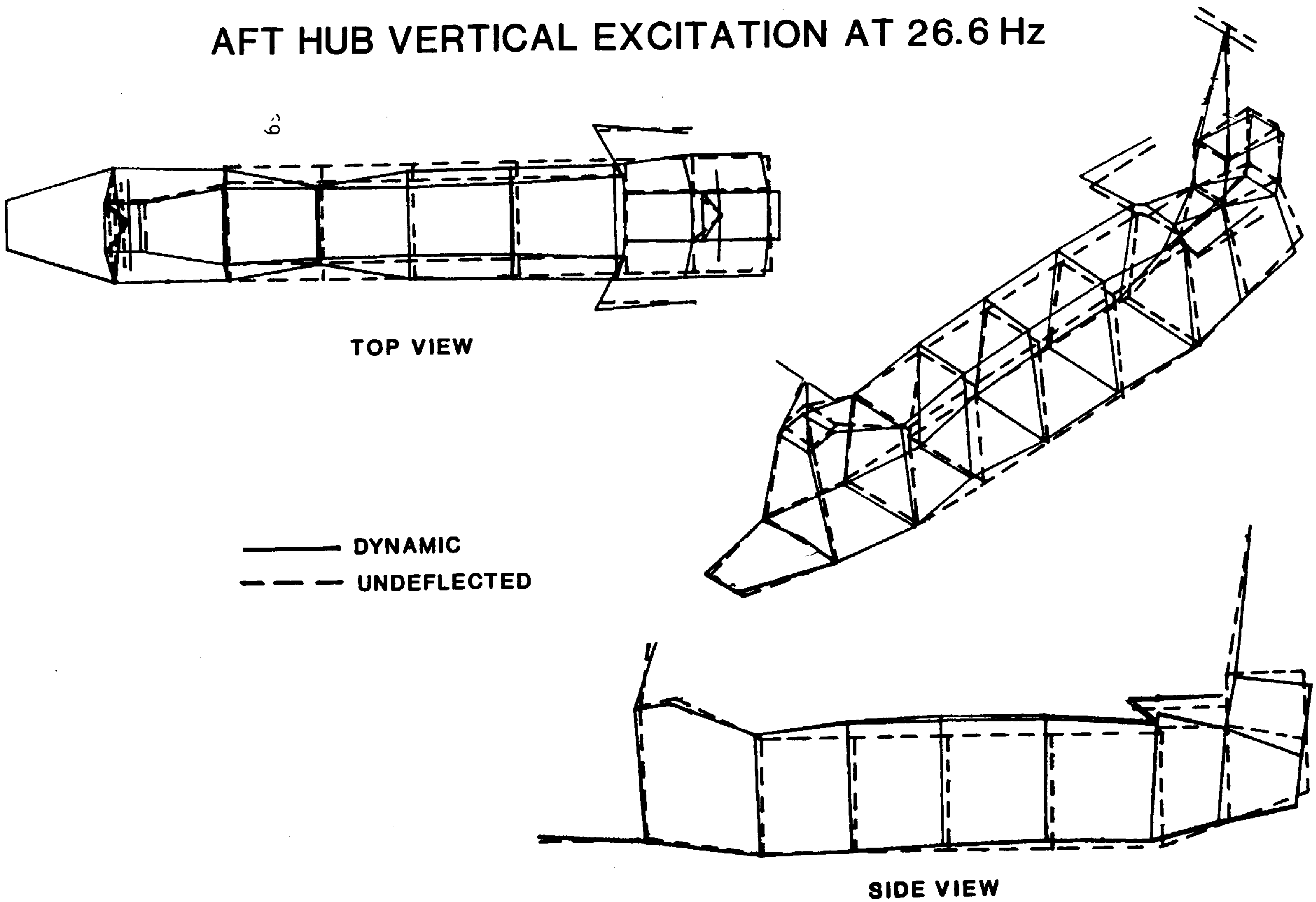


TEST RESULTS - FORCED RESPONSE MODE SHAPES

AFT HUB VERTICAL EXCITATION AT 26.6 Hz

The principal feature of the response is the breathing motion of one frame at the lower longeron. A similar motion was noted in the response at 17 Hz with aft pitch excitation.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
AFT HUB VERTICAL EXCITATION AT 26.6 Hz

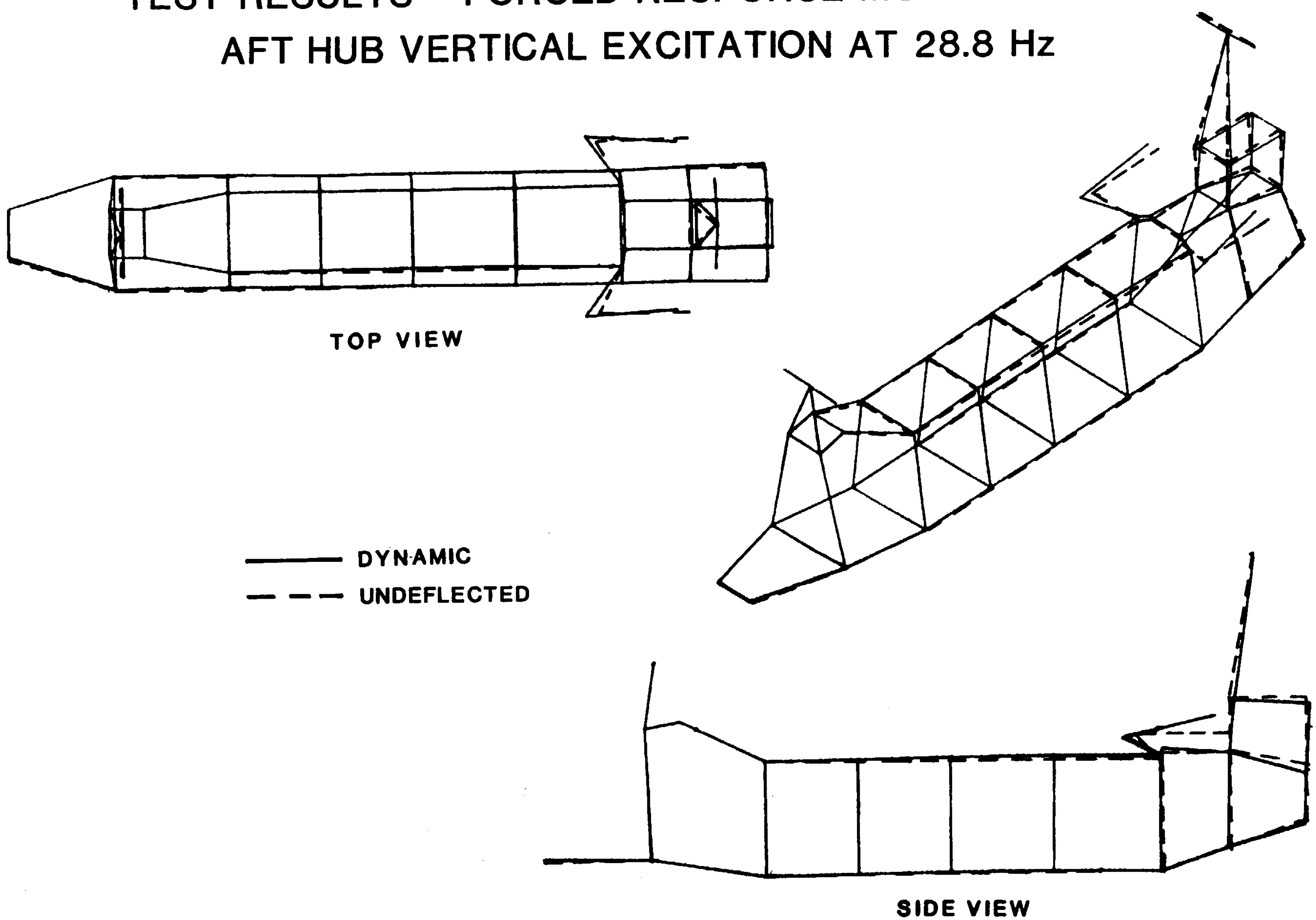


TEST RESULTS - FORCED RESPONSE MODE SHAPES

AFT HUB VERTICAL EXCITATION AT 28.8 Hz

The motion at this frequency is that of a virtually uncoupled symmetric engine pitch mode.

TEST RESULTS – FORCED RESPONSE MODE SHAPES
AFT HUB VERTICAL EXCITATION AT 28.8 Hz



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6.0 Conclusions

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CONCLUSIONS

A successful shake test program was conducted following the original test guides with only minor deviations. In summary:

1. The quantity and quality of the data obtained was sufficient to satisfy the program goal of providing data for evaluation of the M360 NASTRAN model.
2. Modal parameter estimates, based on curve fitting of the hub response, indicate an average damping of 2 to 3%.
3. Both the frequency and magnitude at resonance were non-linear with force. The frequency and amplitude at the resonance peak decreased at higher force levels. Maximum frequency change was approximately 1 Hz for a 50% change in force level.

CONCLUSIONS

- QUANTITY AND QUALITY OF SHAKE TEST DATA OBTAINED WAS SUFFICIENT TO SATISFY THE PROGRAM OBJECTIVE
- MODAL PARAMETER ESTIMATES INDICATE A REASONABLE AVERAGE DAMPING VALUE TO BE ON THE ORDER OF 2% TO 3% CRITICAL
- RESPONSE WAS NON-LINEAR WITH FORCE LEVEL. BOTH THE FREQUENCY AND THE MAGNITUDE AT RESONANCE TEND TO DECREASE AT HIGHER FORCE LEVELS. MAXIMUM FREQUENCY CHANGE WAS APPROXIMATELY 1 Hz

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APPENDIX A

FREQUENCY RESPONSE DATA

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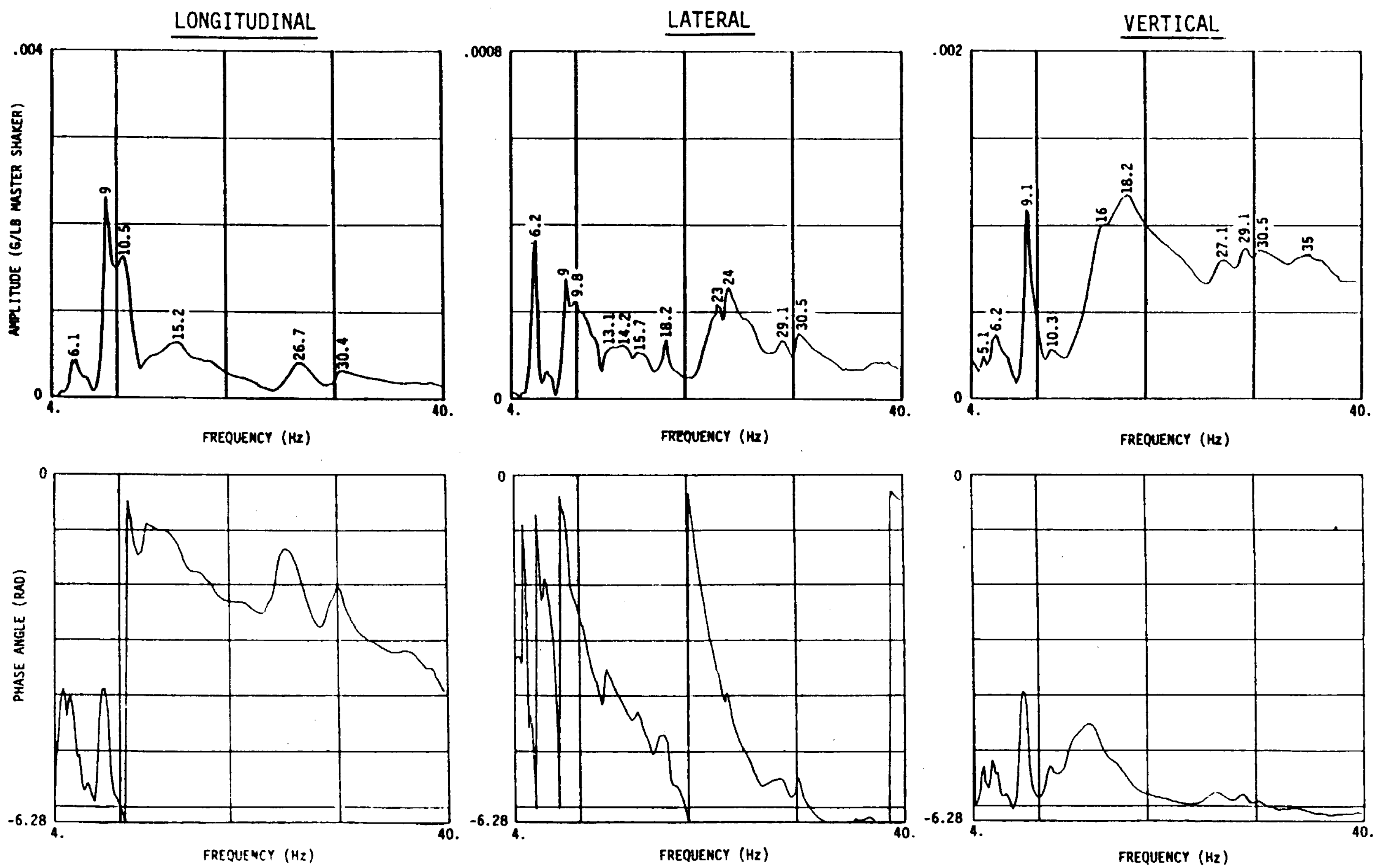
FREQUENCY RESPONSE – FORWARD VERTICAL EXCITATION
RESPONSE: FORWARD HUB (LOC. 2)



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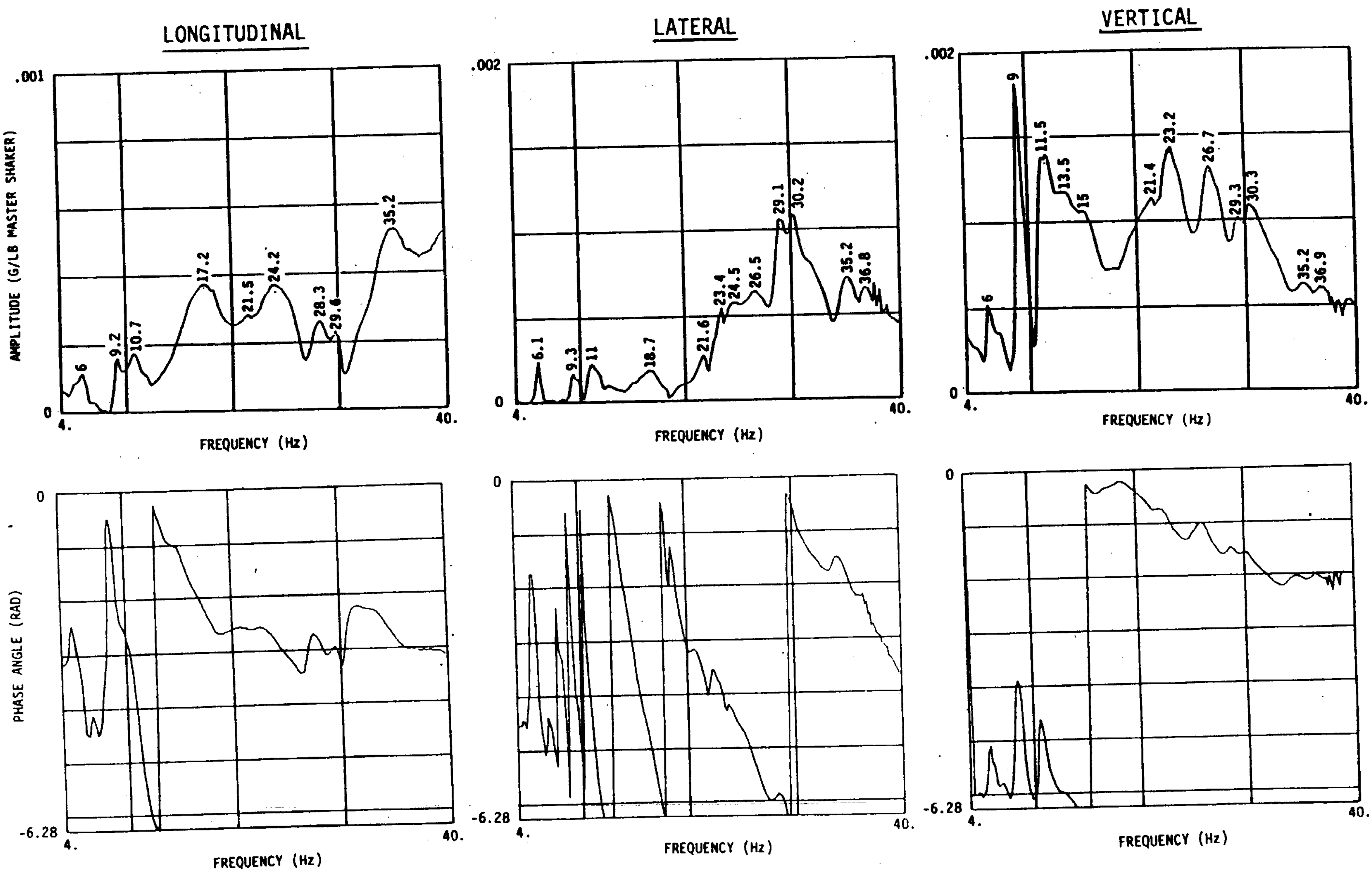
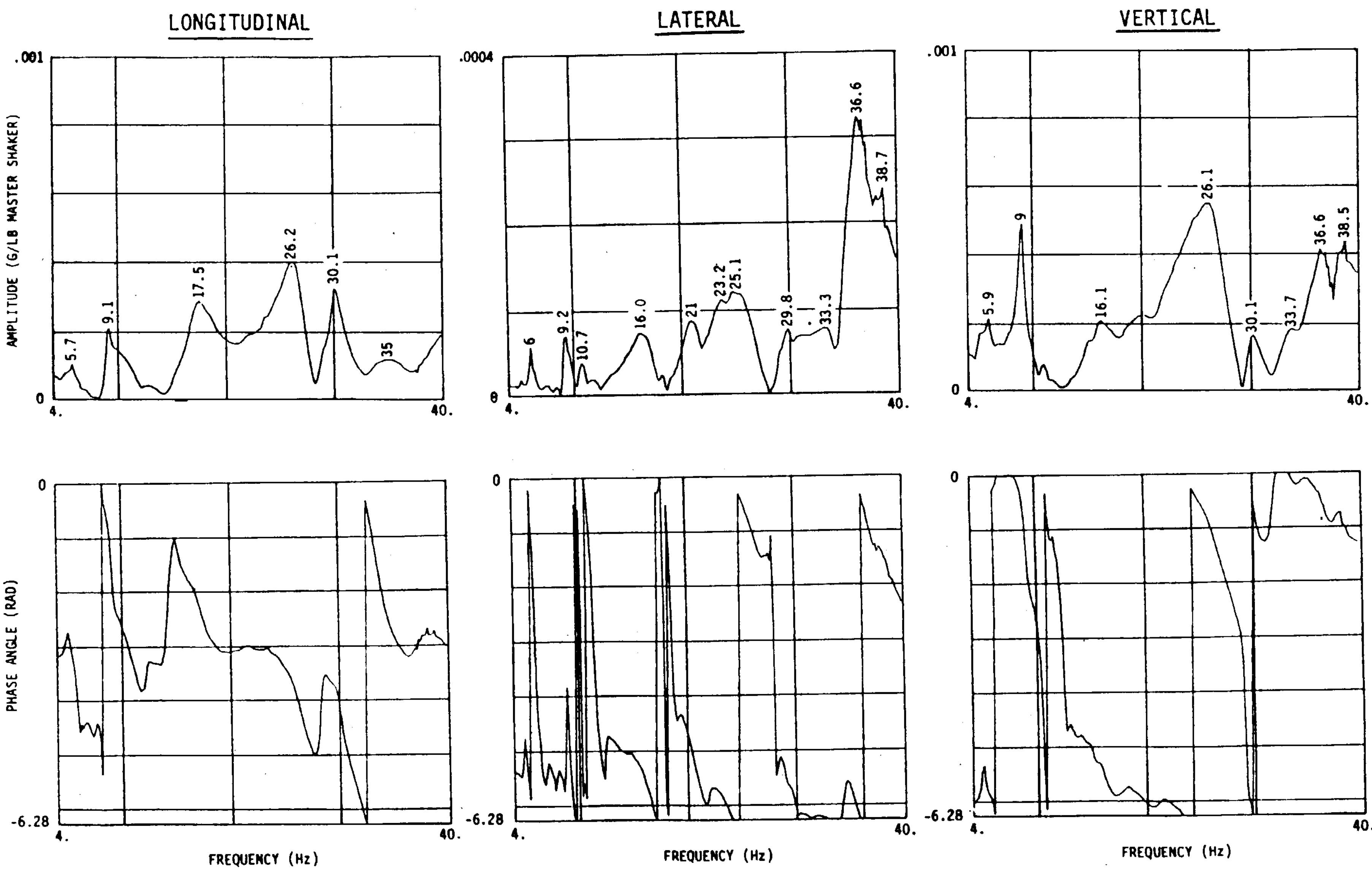
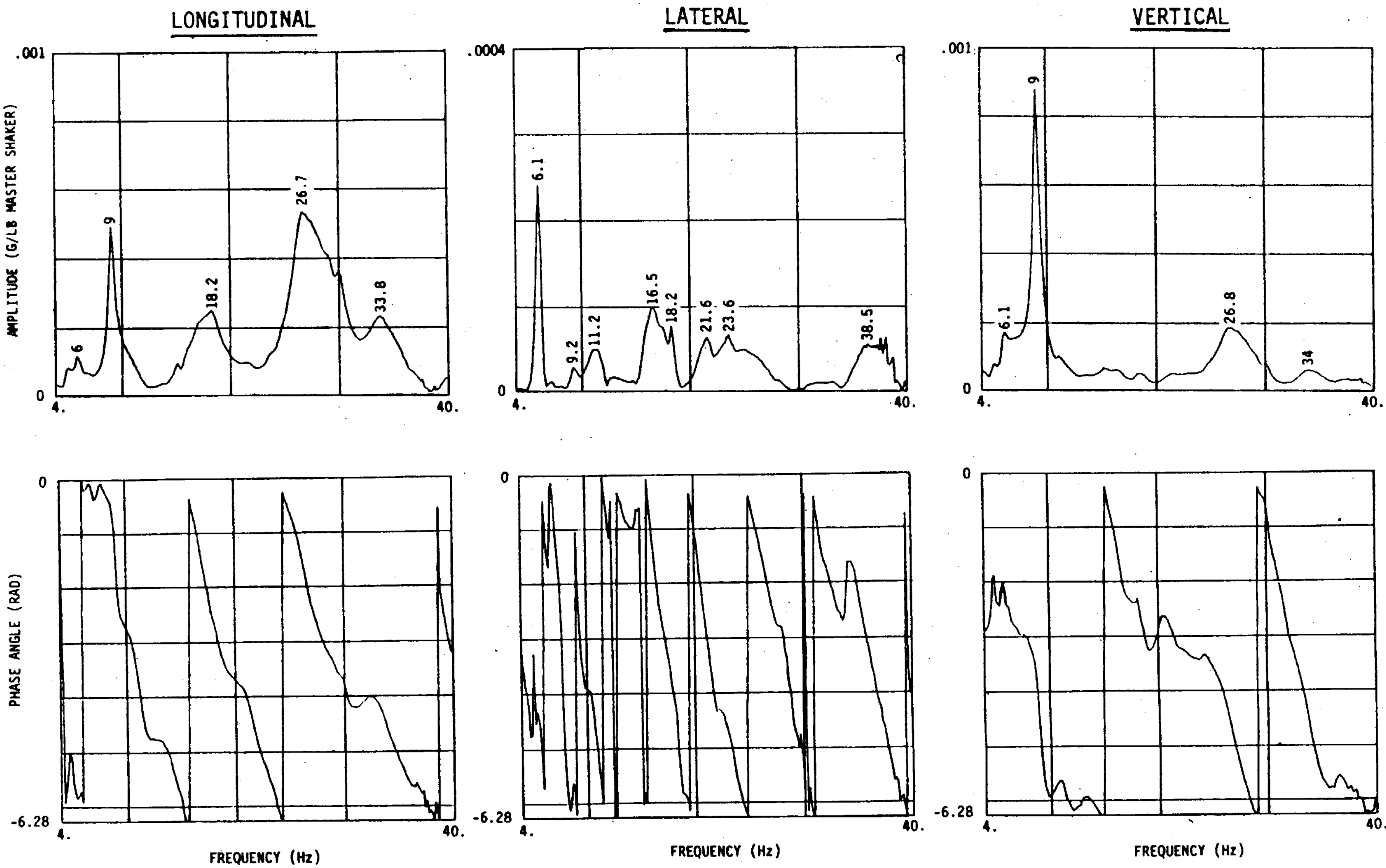
FREQUENCY RESPONSE – FORWARD VERTICAL EXCITATION
RESPONSE: STA. 10 R/H FORWARD COCKPIT (LOC. 9)



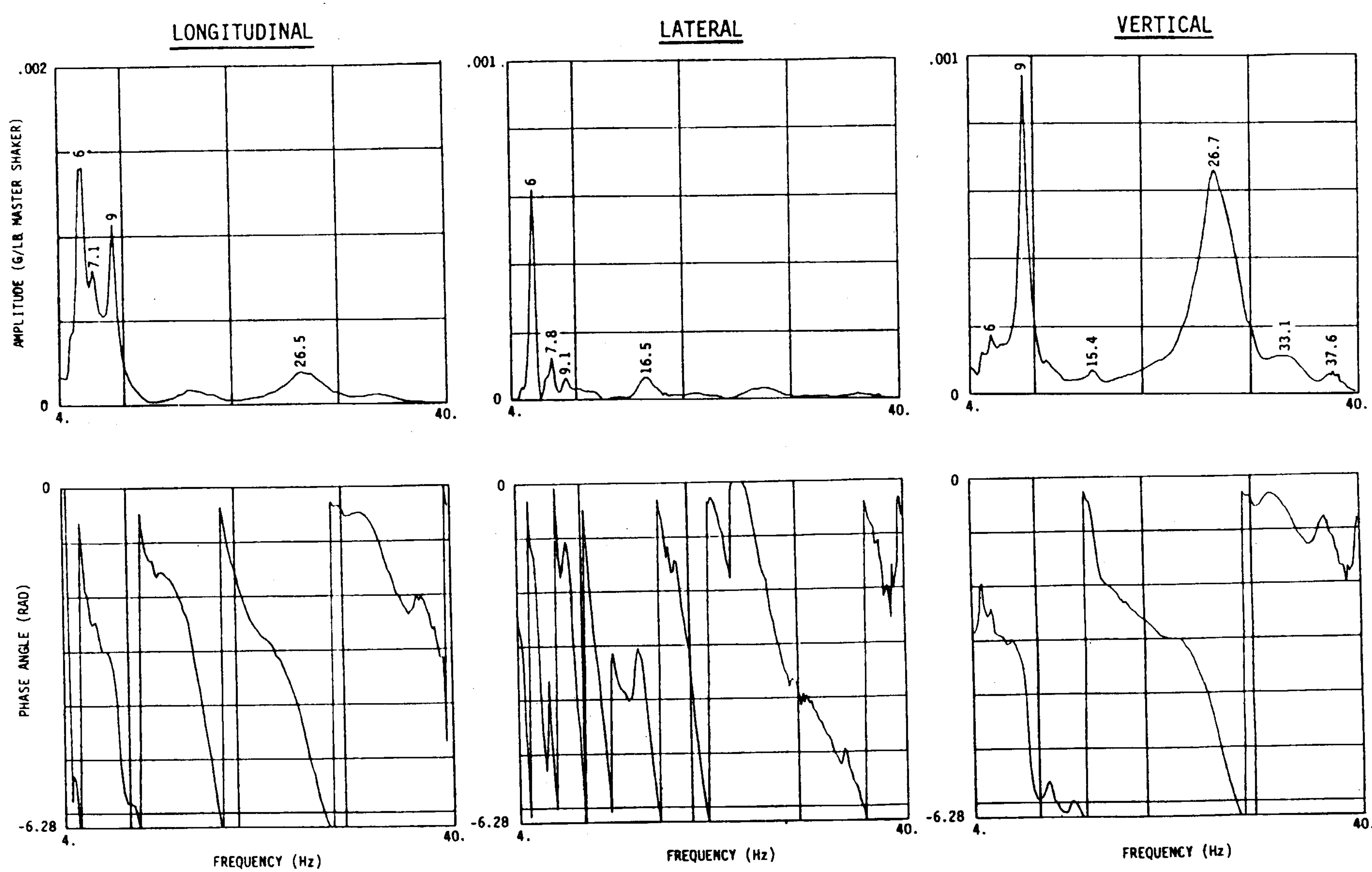
FREQUENCY RESPONSE – FORWARD VERTICAL EXCITATION
RESPONSE: STA. 286 L/H CABIN (LOC. 24)



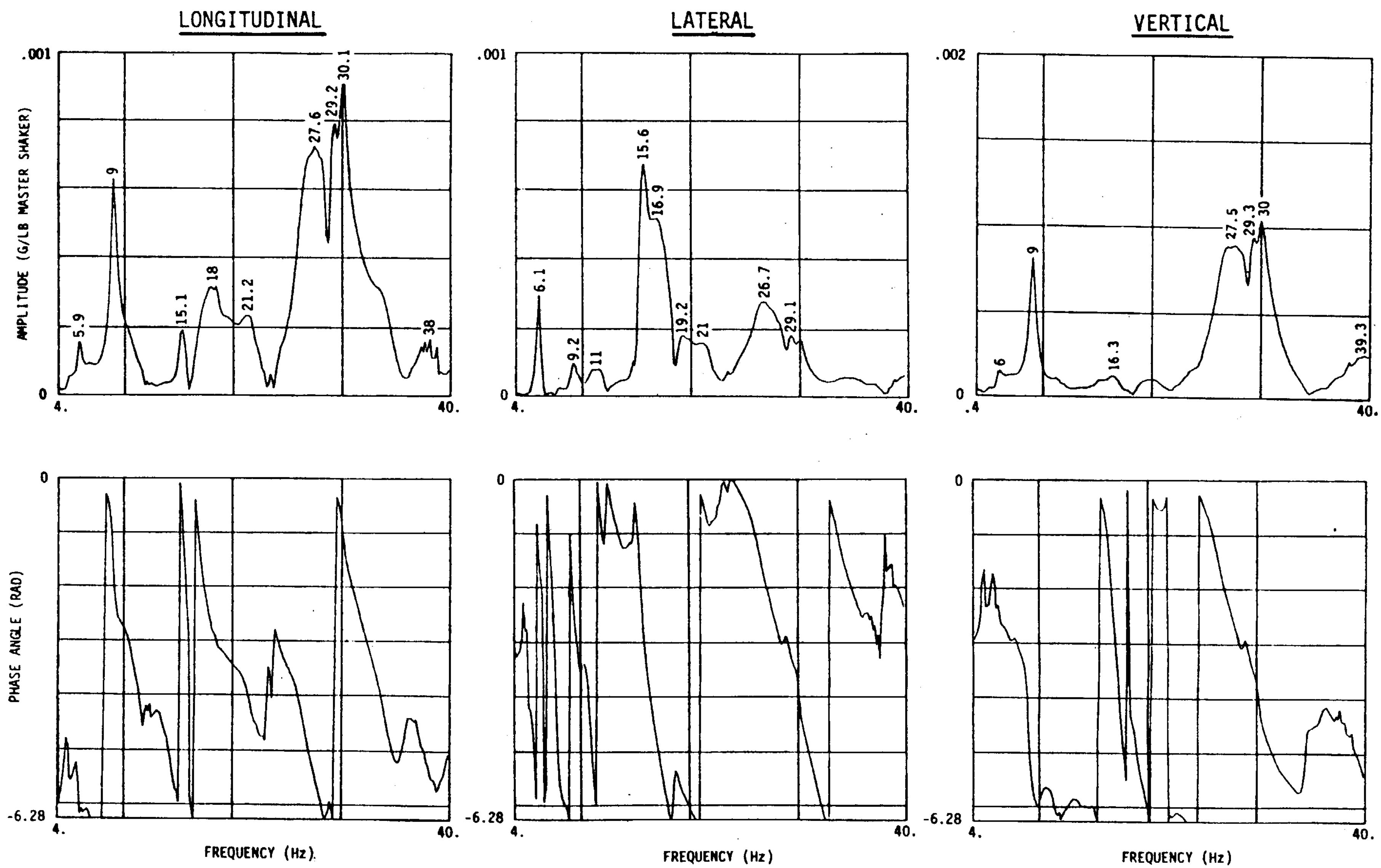
FREQUENCY RESPONSE – FORWARD VERTICAL EXCITATION
RESPONSE: STA. 480 L/H AFT XMSN (LOC. 46)



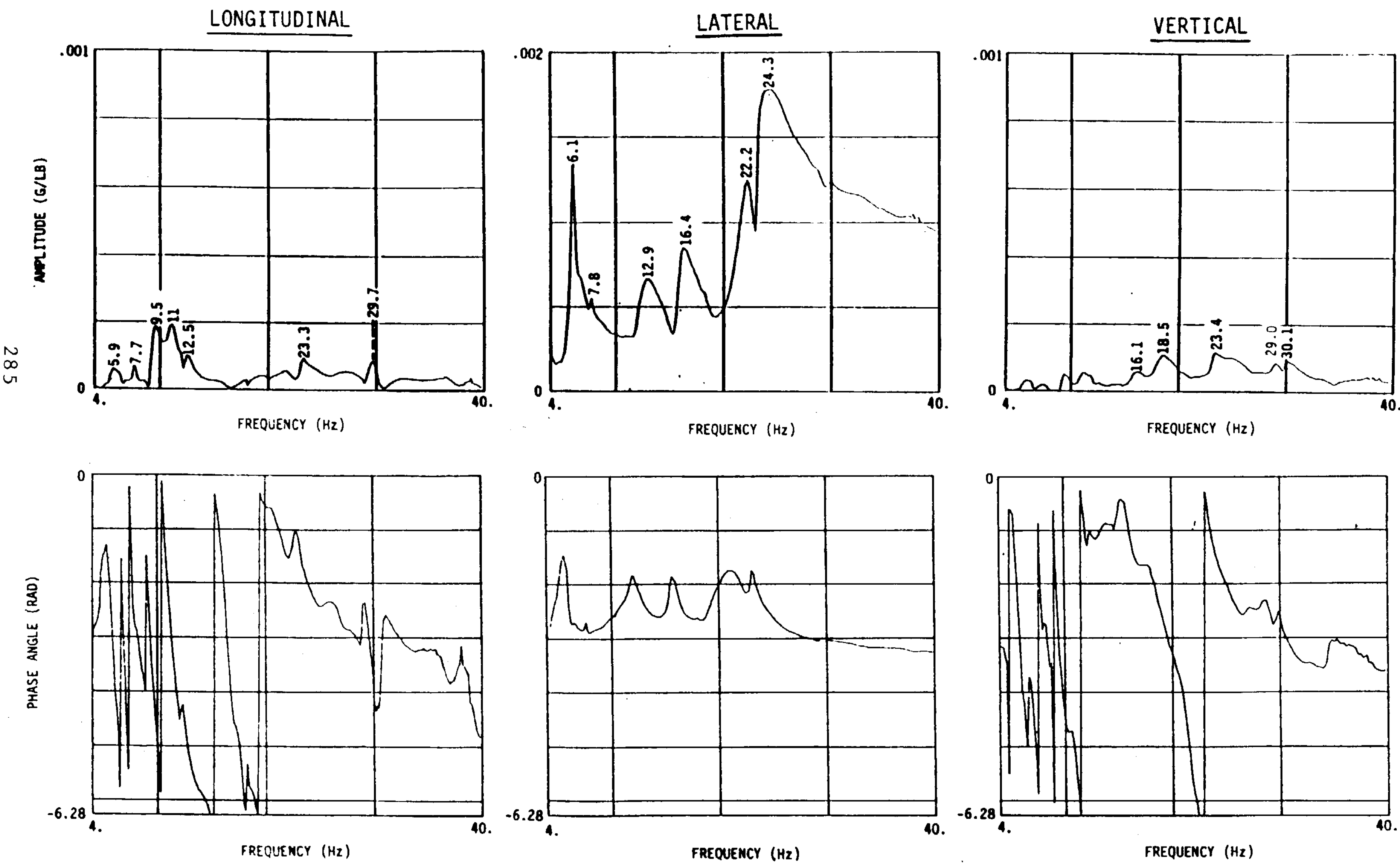
FREQUENCY RESPONSE – FORWARD VERTICAL EXCITATION
RESPONSE: AFT HUB (LOC. 51)



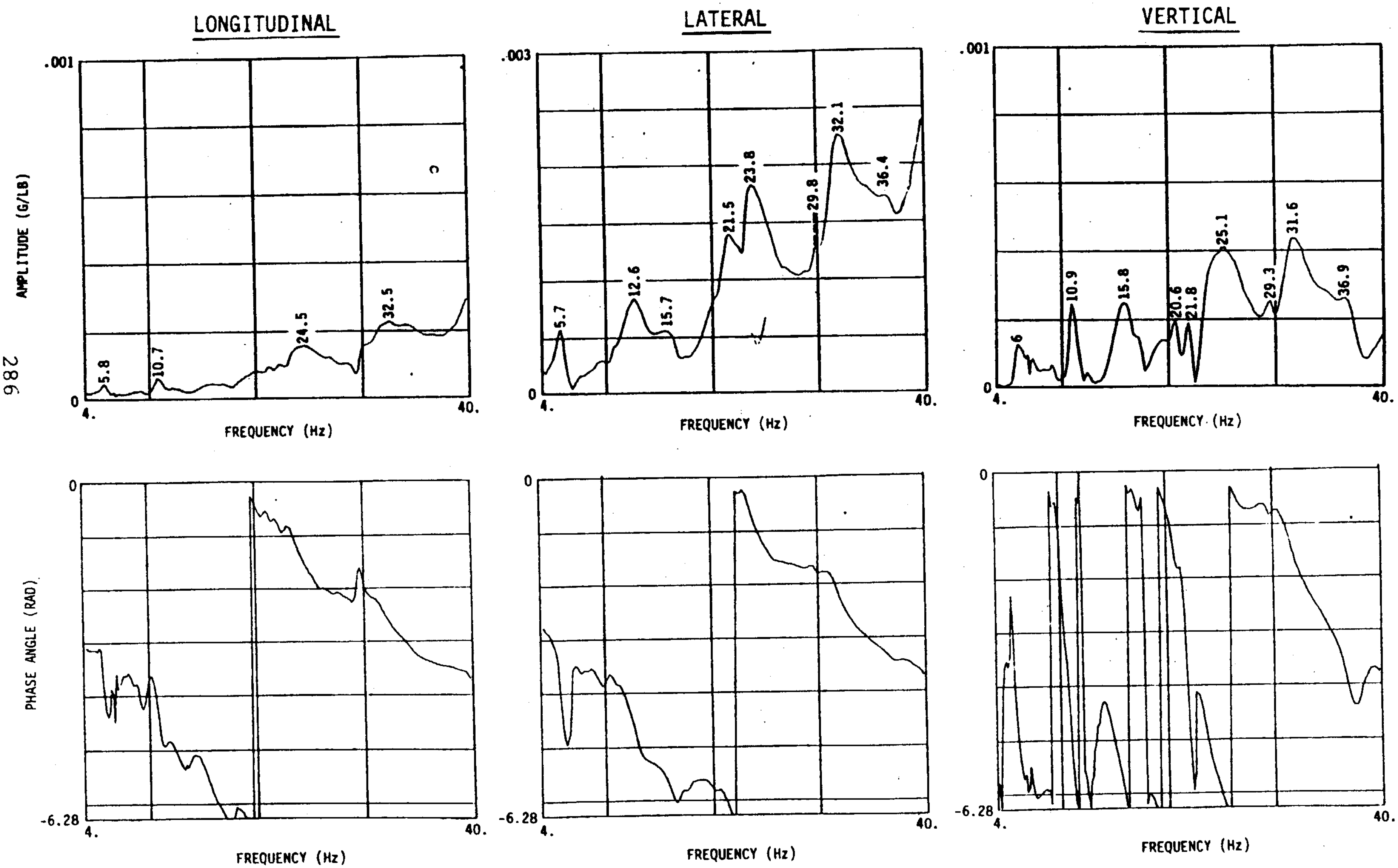
FREQUENCY RESPONSE - FORWARD VERTICAL EXCITATION
RESPONSE: STA. 458 L/H ENGINE (LOC. 55)



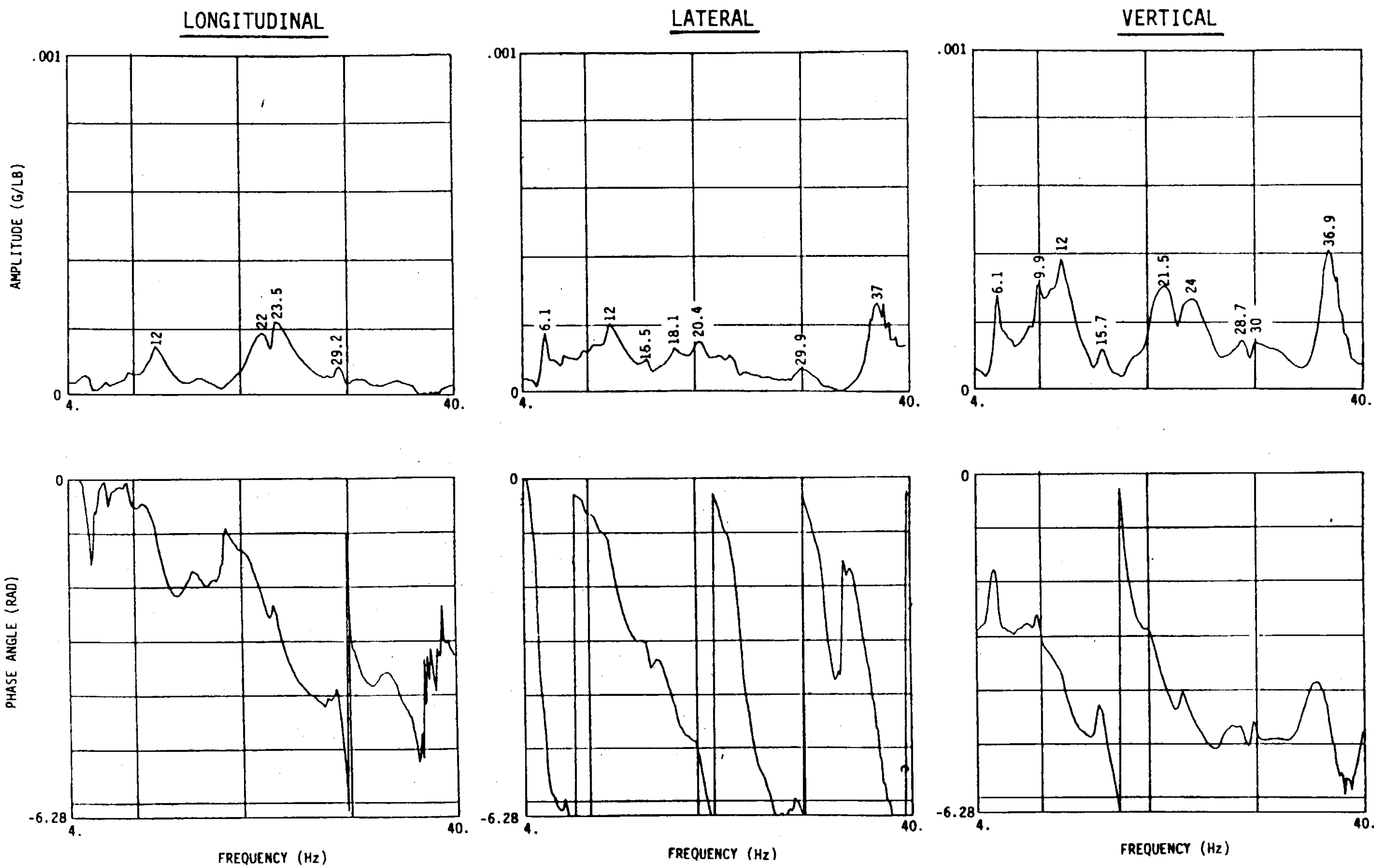
FREQUENCY RESPONSE – FORWARD LATERAL EXCITATION
RESPONSE: FORWARD HUB (LOC. 2)



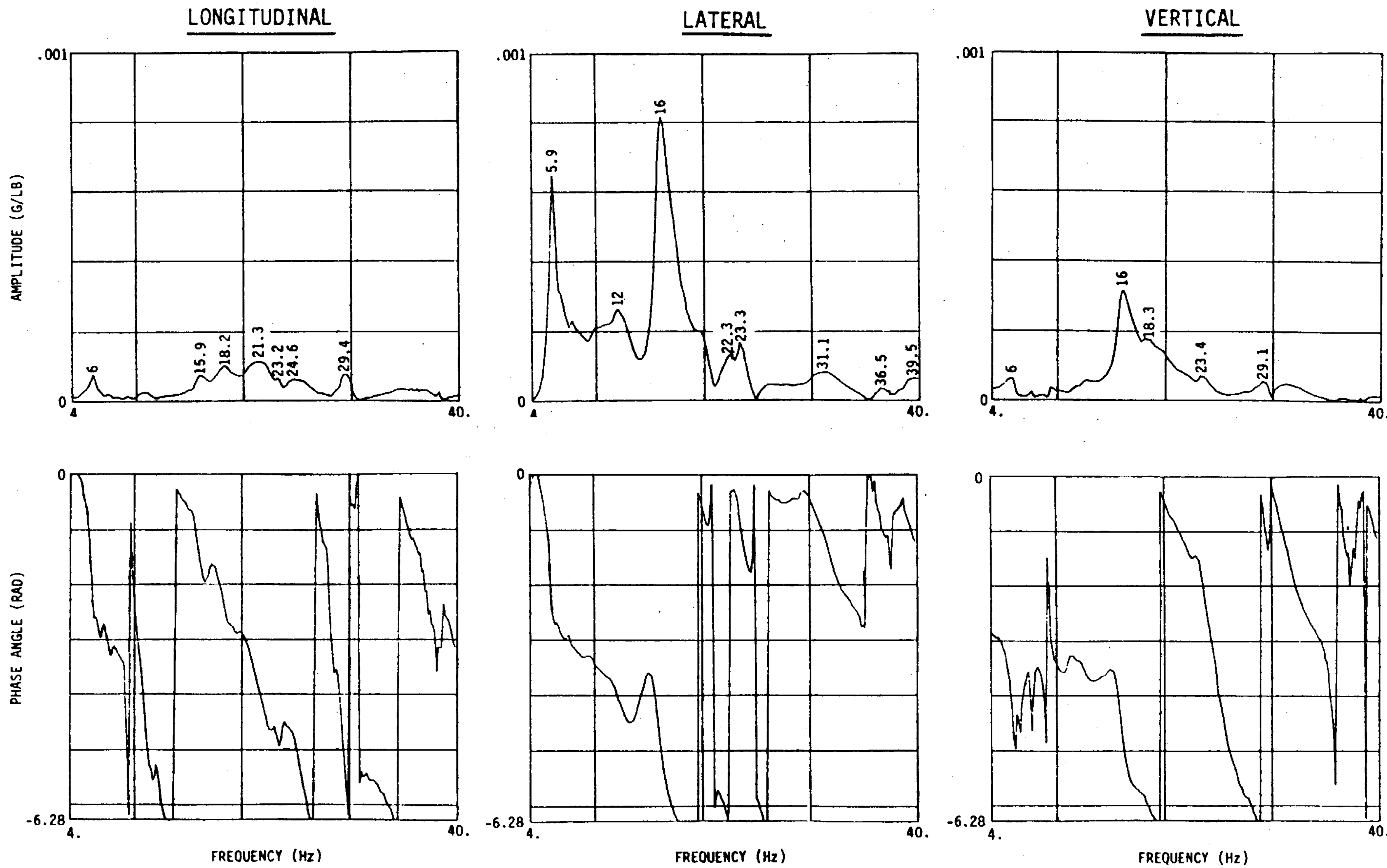
FREQUENCY RESPONSE – FORWARD LATERAL EXCITATION
RESPONSE: STA. 10 R/H FORWARD COCKPIT (LOC. 9)



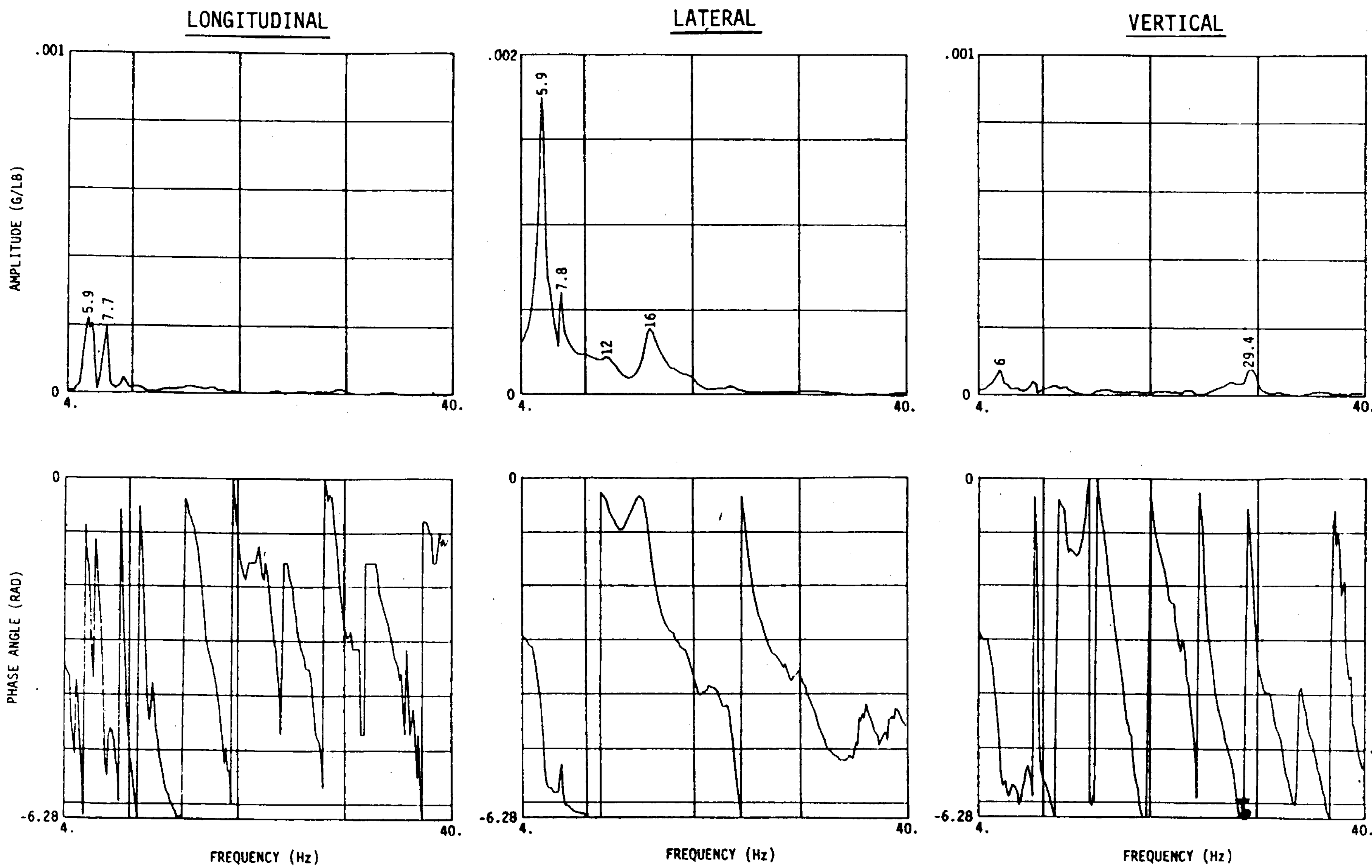
FREQUENCY RESPONSE – FORWARD LATERAL EXCITATION
RESPONSE: STA. 286 L/H CABIN (LOC. 24)



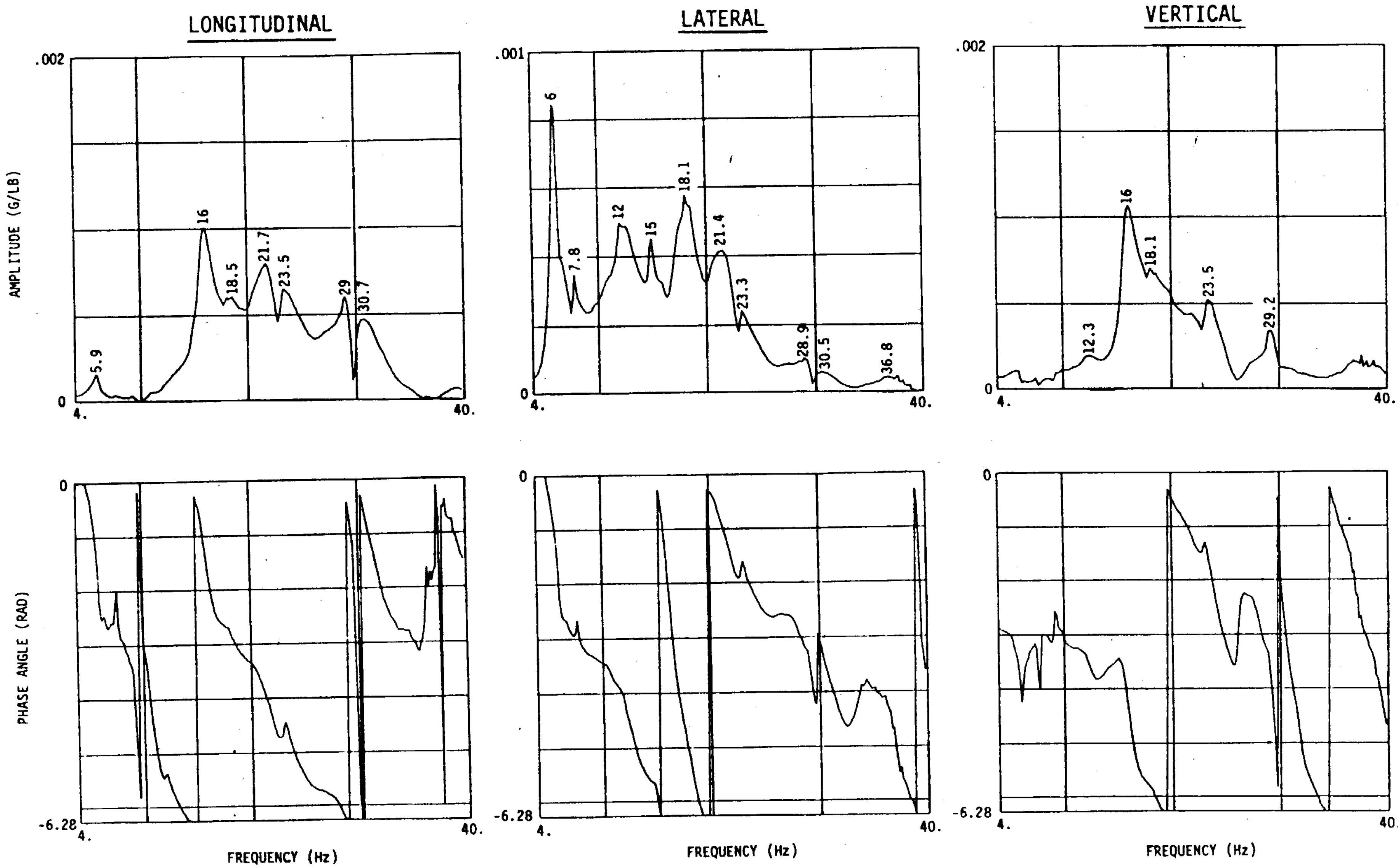
FREQUENCY RESPONSE – FORWARD LATERAL EXCITATION
RESPONSE: STA. 480 L/H AFT XMSN (LOC. 46)



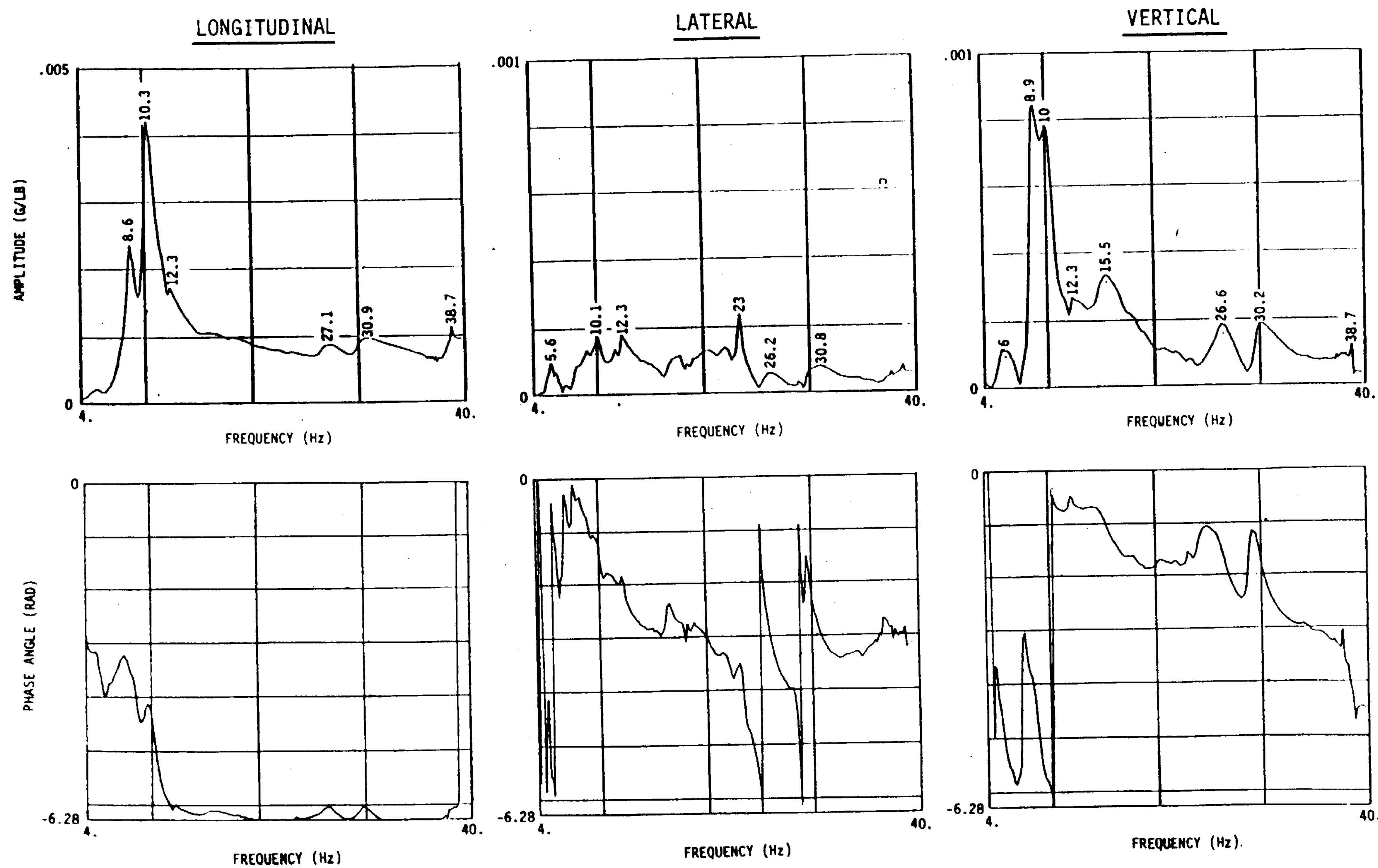
FREQUENCY RESPONSE – FORWARD LATERAL EXCITATION
RESPONSE: AFT HUB (LOC. 51)



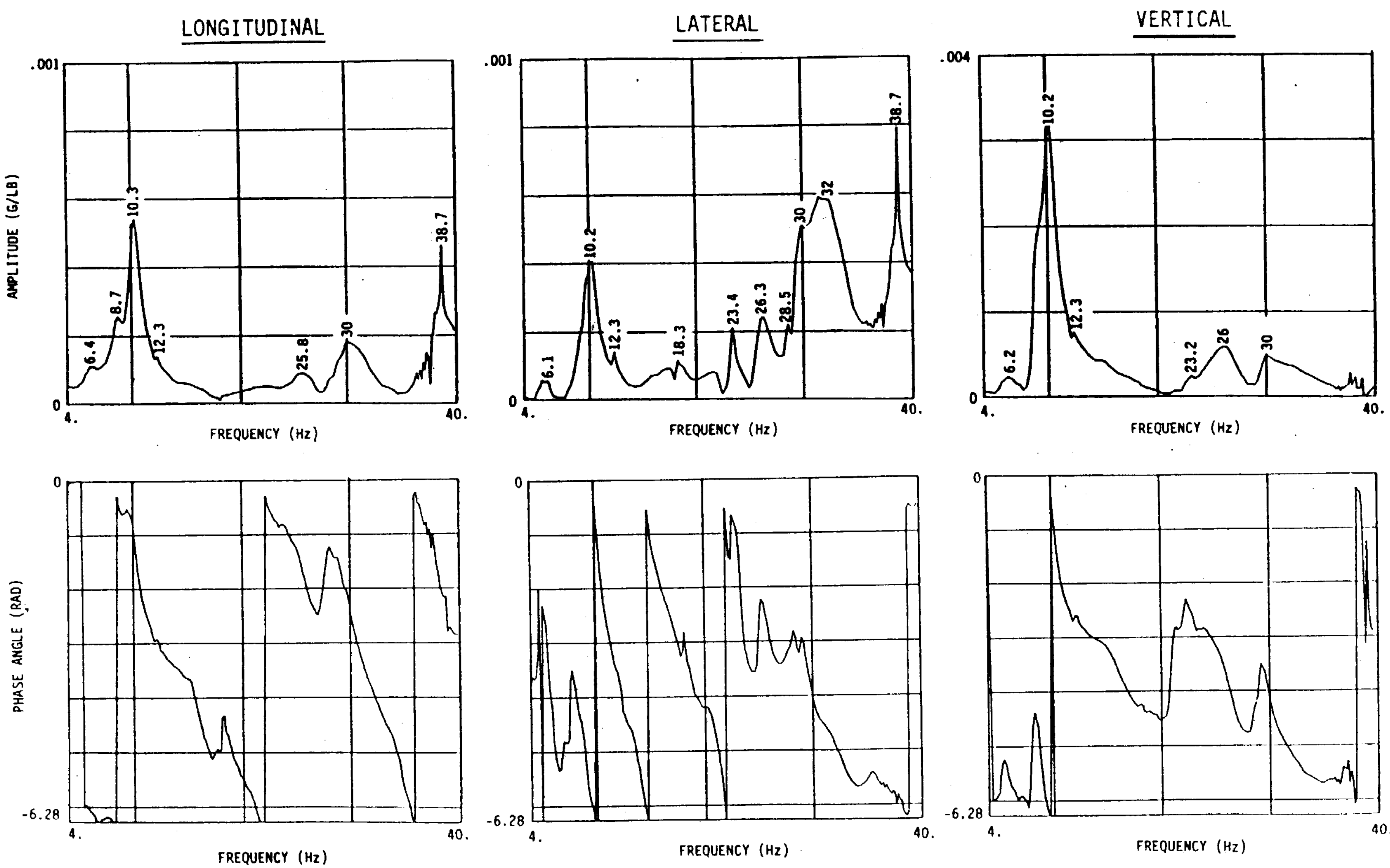
FREQUENCY RESPONSE – FORWARD LATERAL EXCITATION
RESPONSE: STA. 458 L/H ENGINE (LOC. 55)



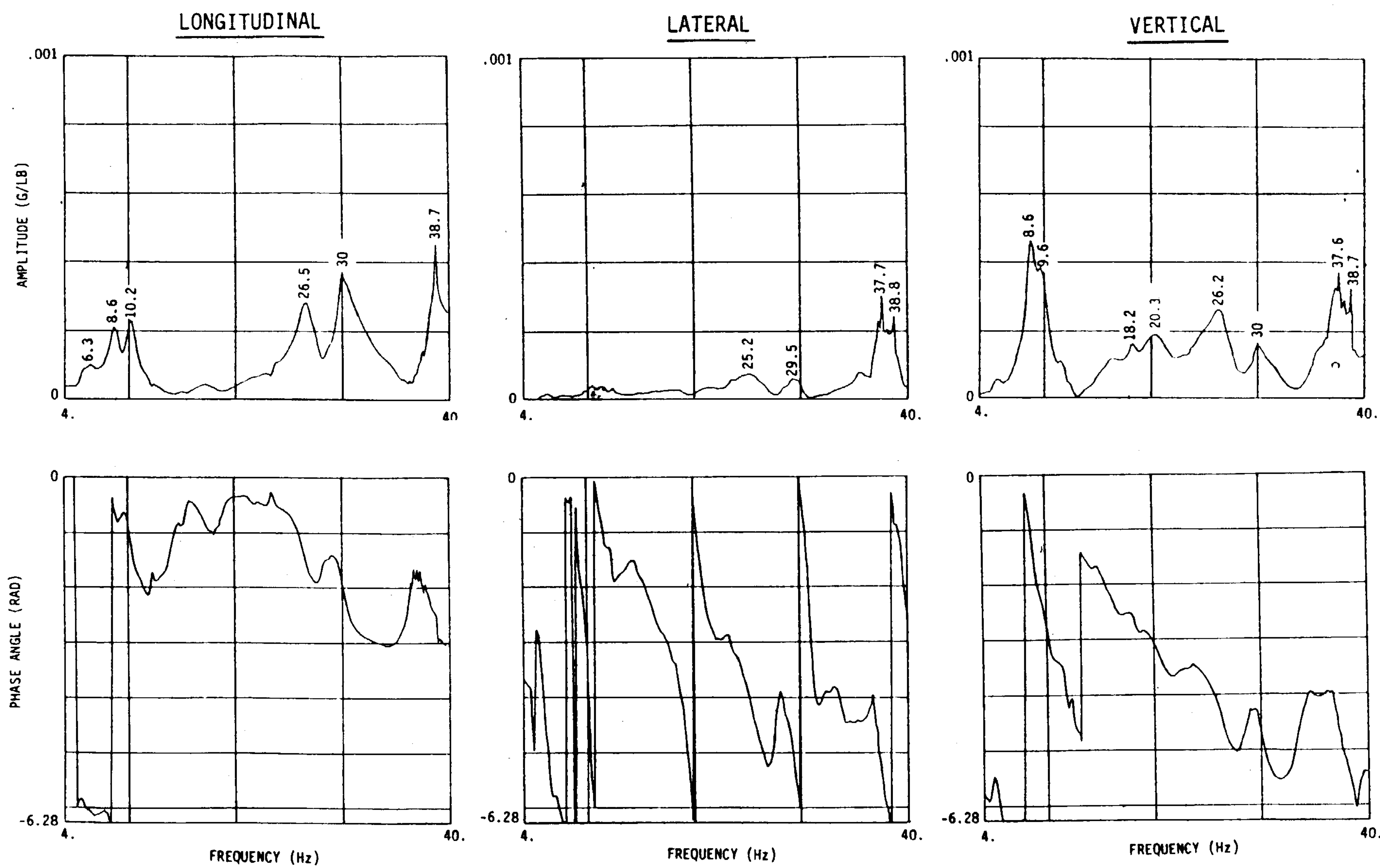
FREQUENCY RESPONSE – FORWARD LONGITUDINAL EXCITATION
RESPONSE: FORWARD HUB (LOC. 2)



FREQUENCY RESPONSE – FORWARD LONGITUDINAL EXCITATION
RESPONSE: STA. 10 R/H FORWARD COCKPIT (LOC. 9)



FREQUENCY RESPONSE – FORWARD LONGITUDINAL EXCITATION
RESPONSE: STA. 286 L/H CABIN (LOC. 24)



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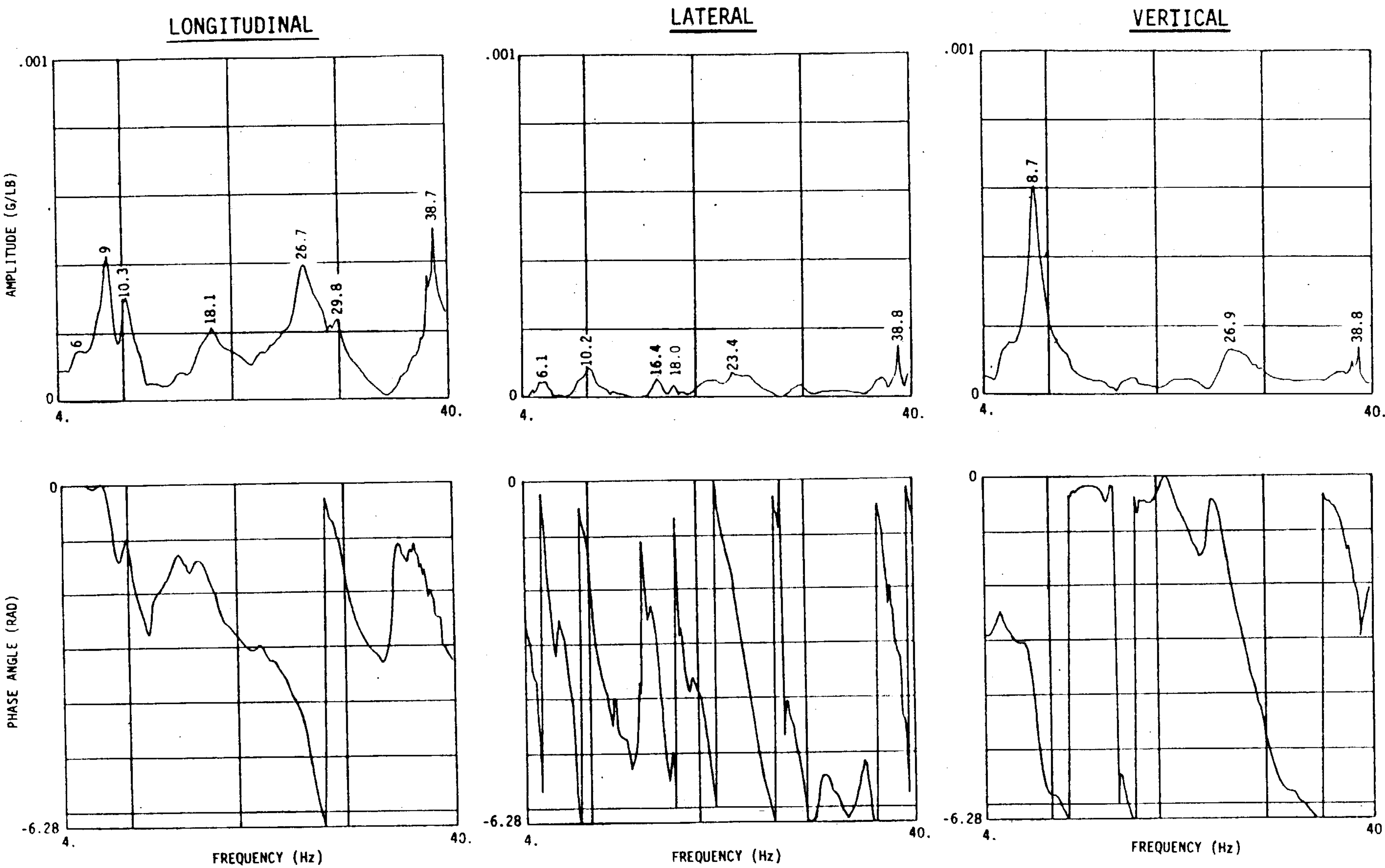
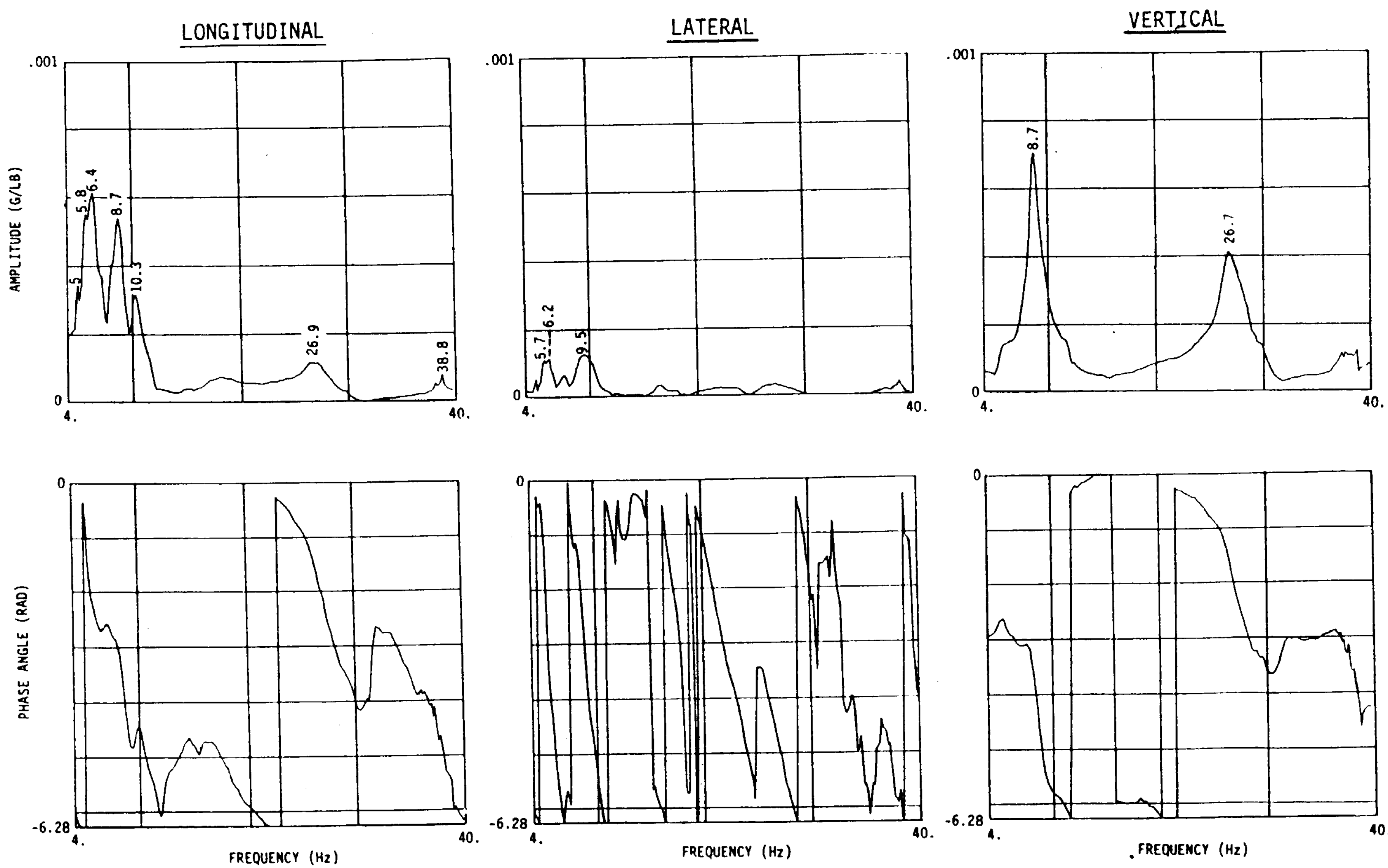
RESPONSE: STA. 480 L/H AFT XMSN (LOC. 46)



FREQUENCY RESPONSE – FORWARD LONGITUDINAL EXCITATION
RESPONSE: AFT HUB (LOC. 51)



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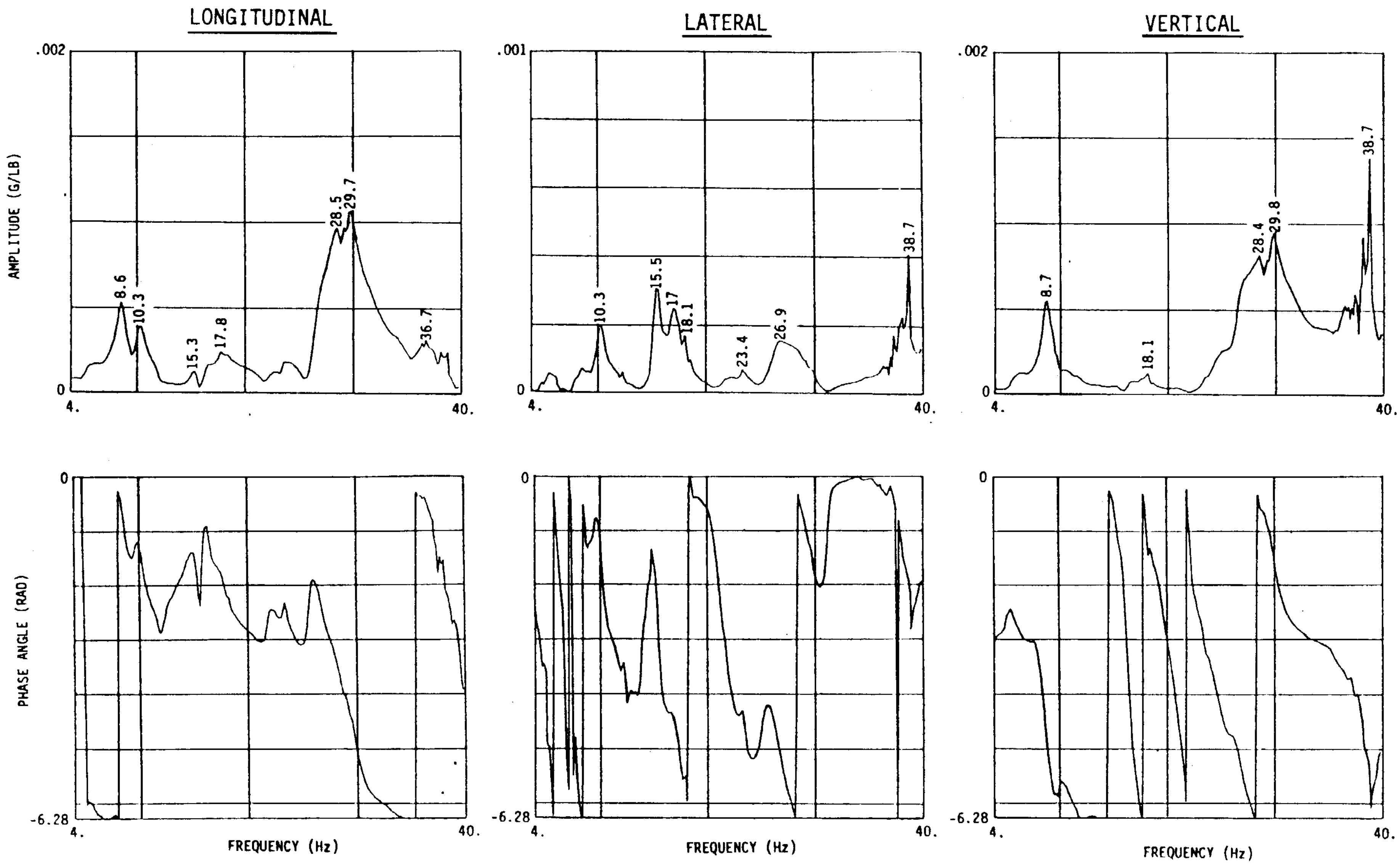
RESPONSE: STA. 458 L/H ENGINE (LOC. 55)



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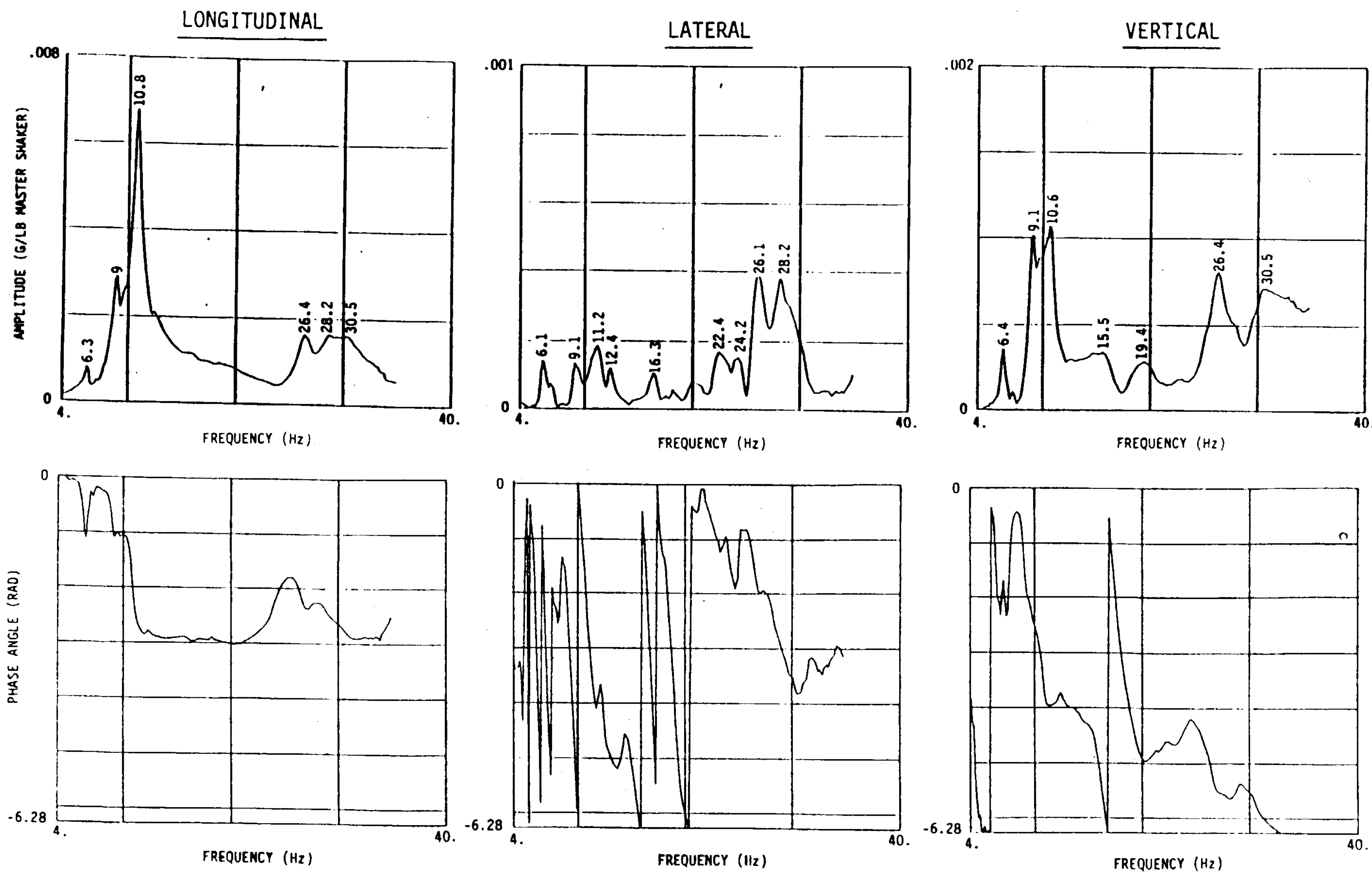
RESPONSE: FORWARD HUB (LOC. 2)



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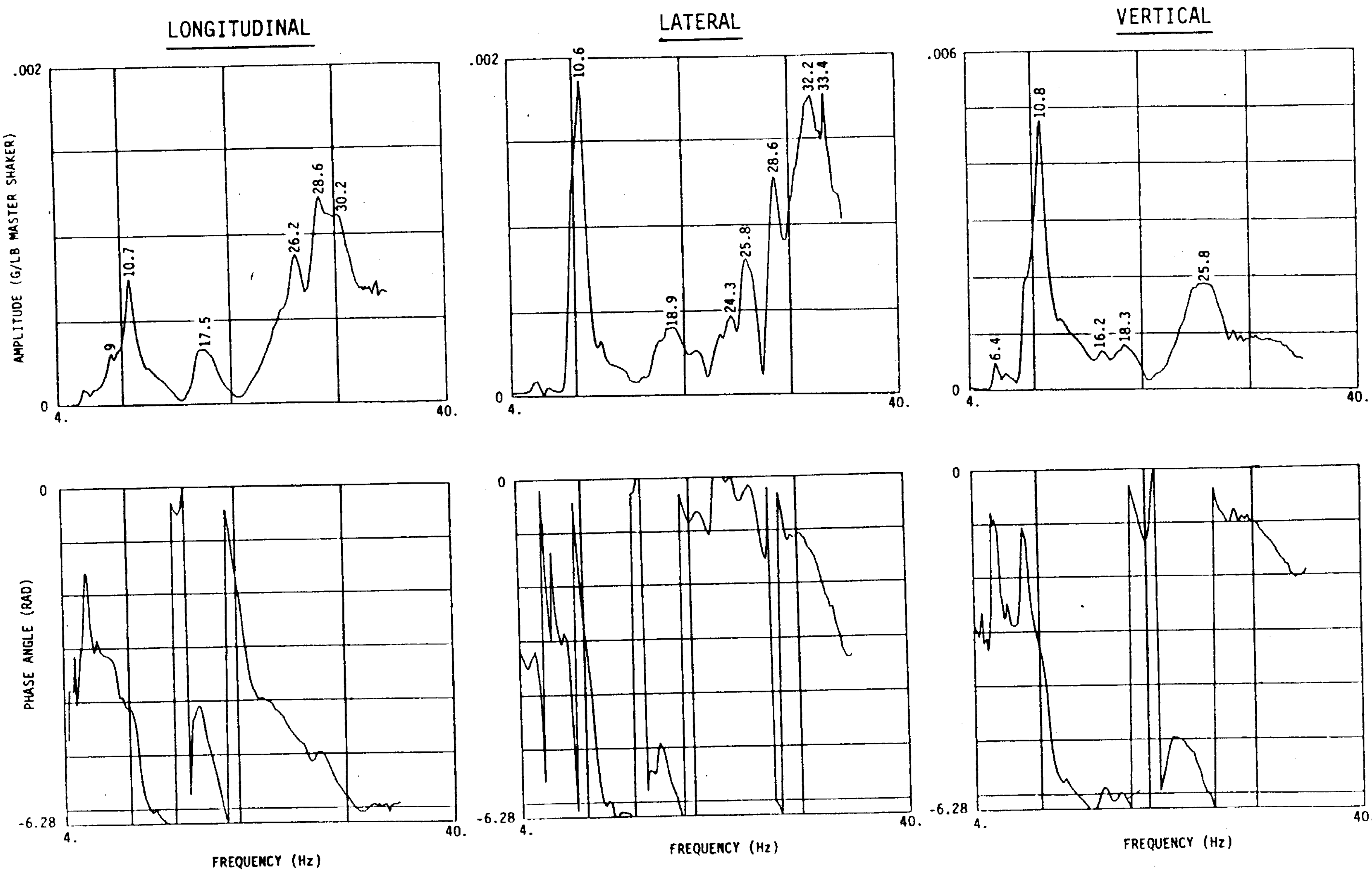

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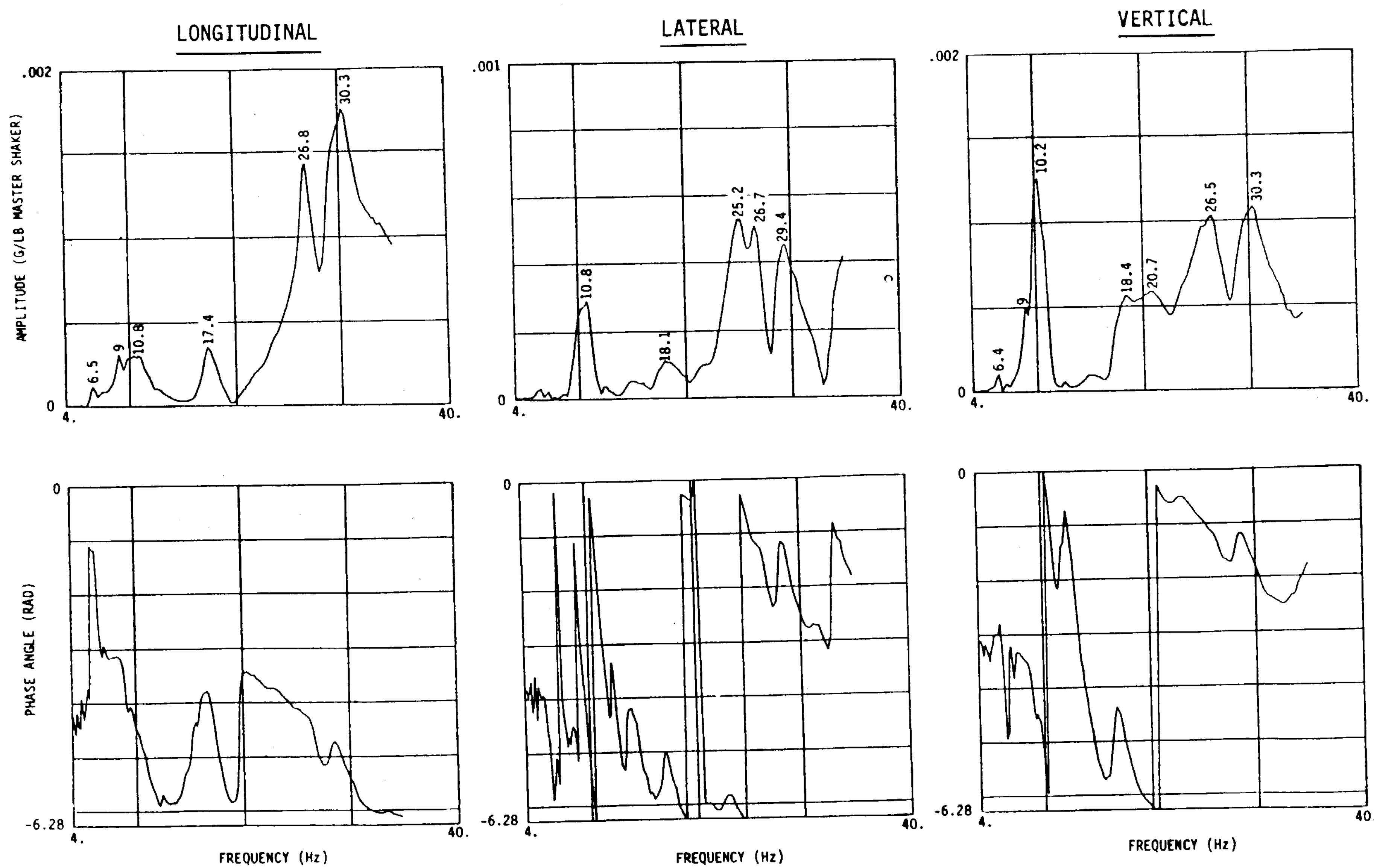
RESPONSE: STA. 286 L/H CABIN (LOC. 24)



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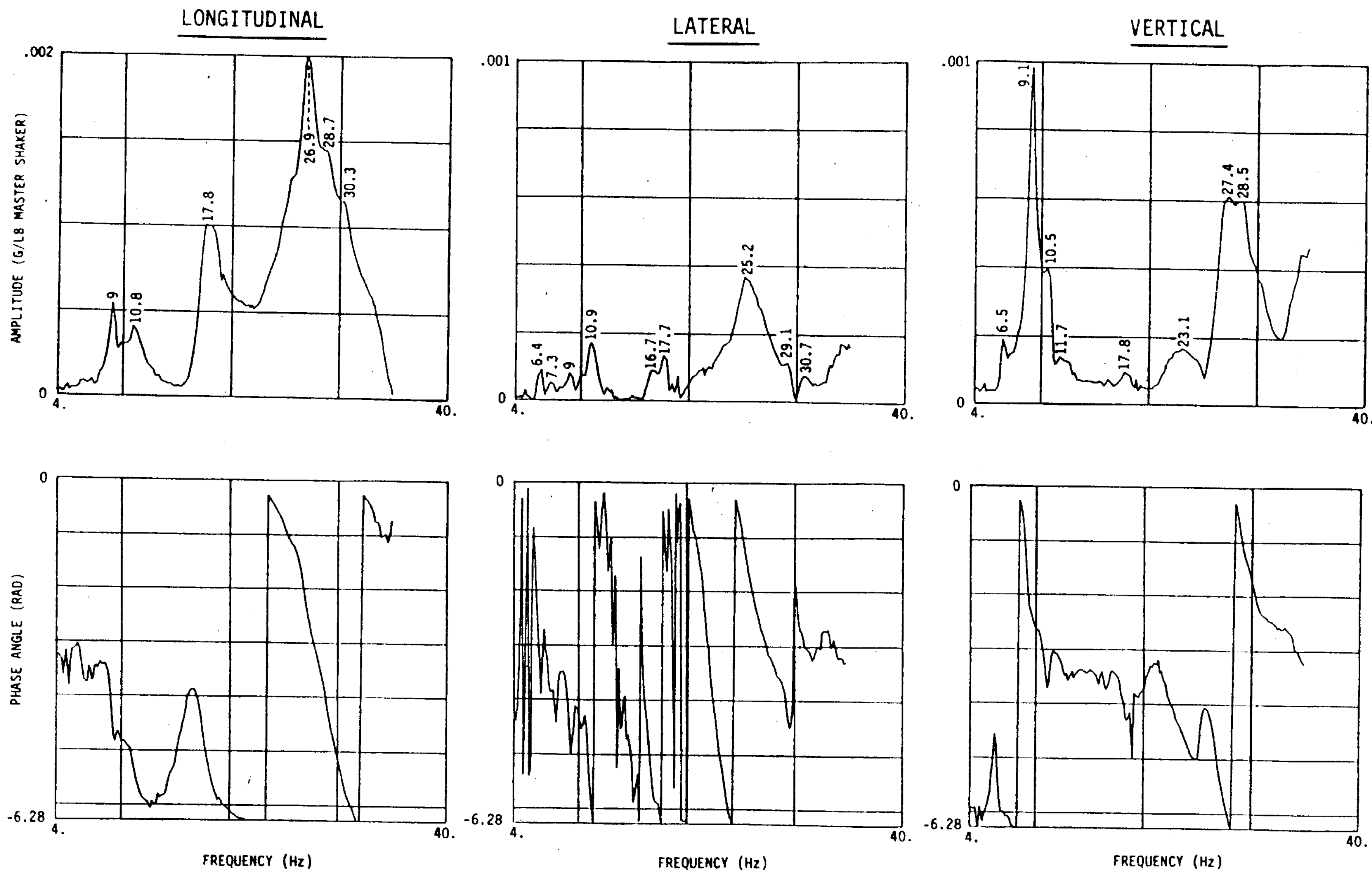
RESPONSE: STA. 480 L/H AFT XMSN (LOC. 46)



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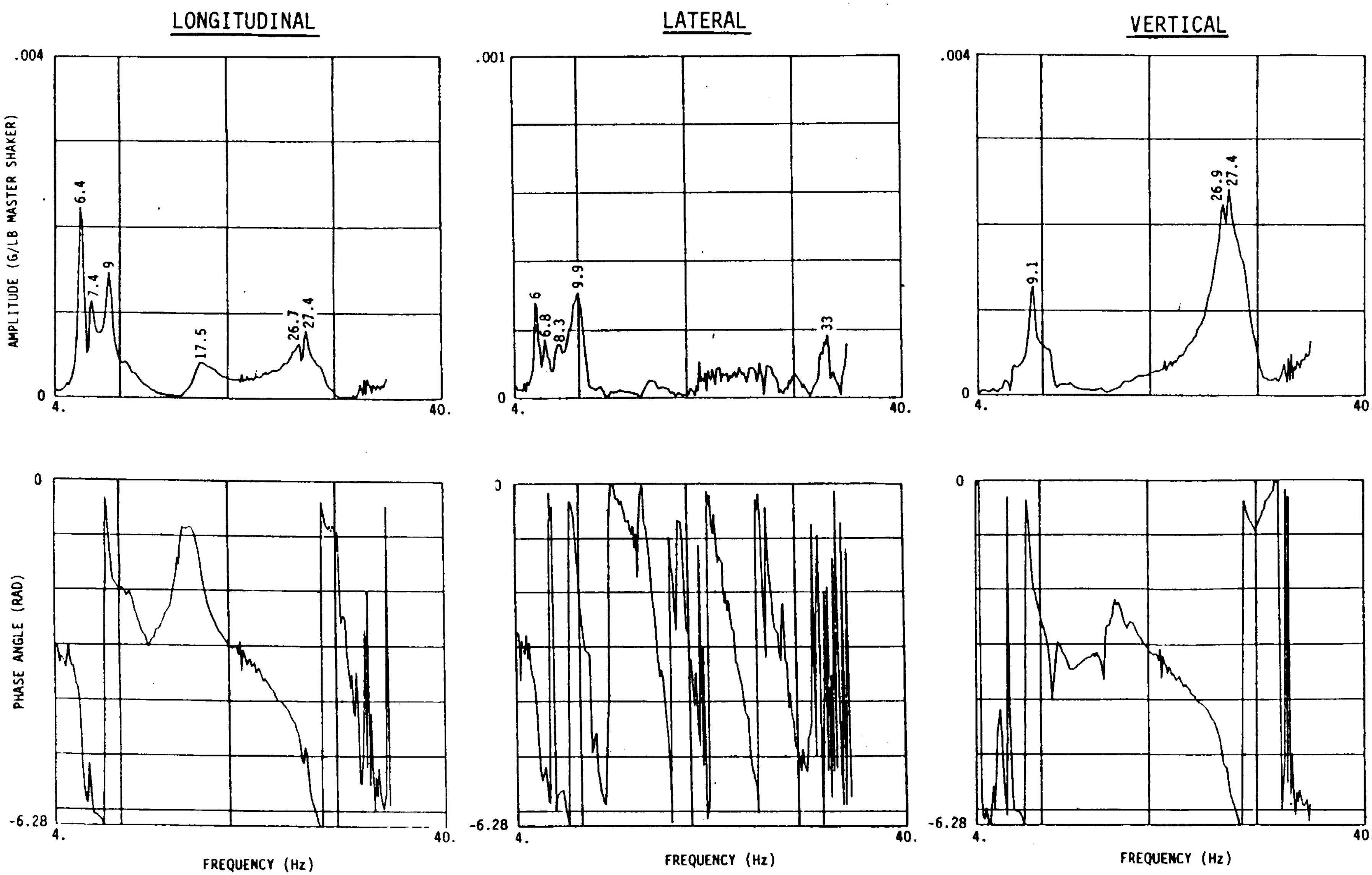
RESPONSE: AFT HUB (LOC. 51)



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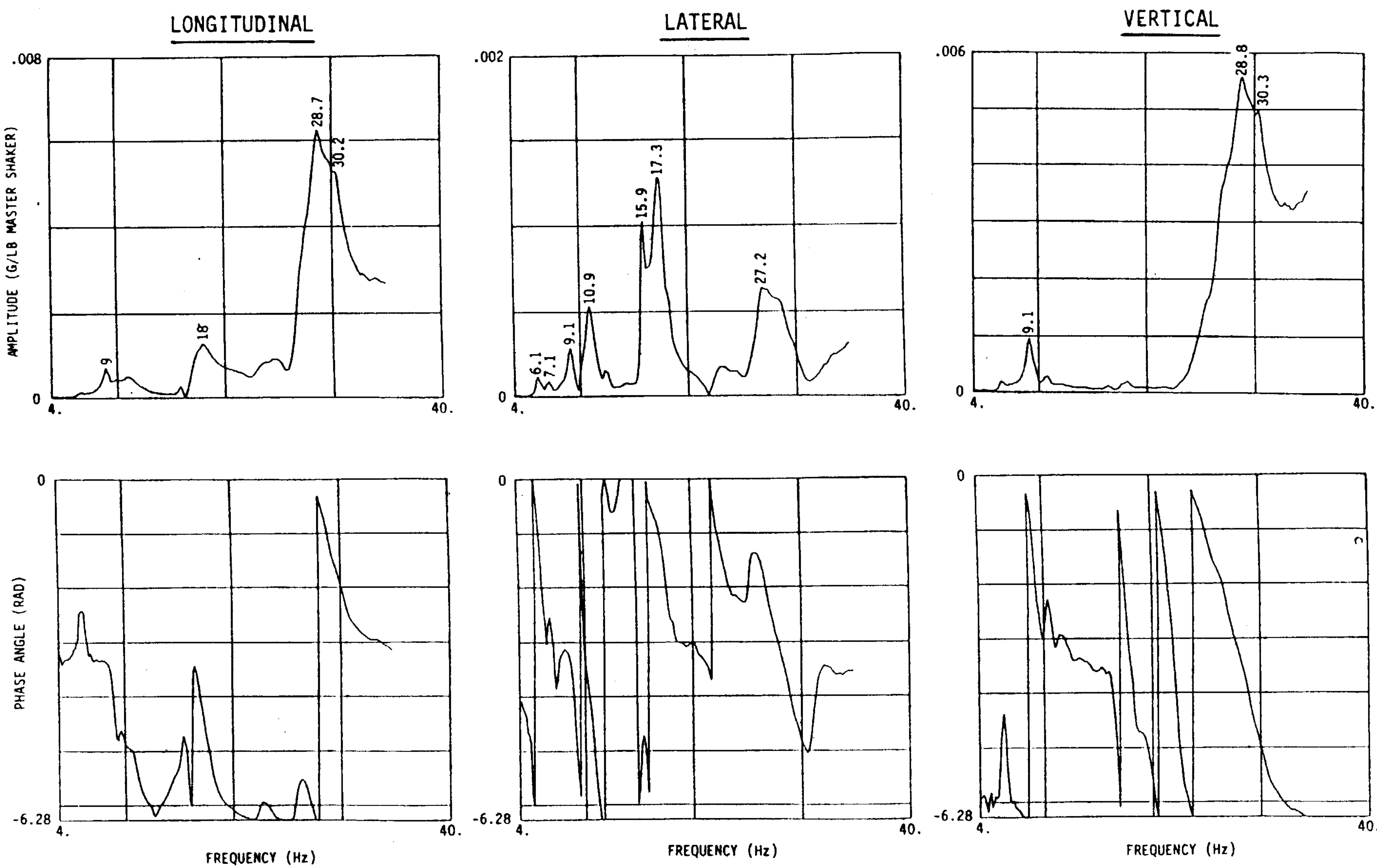

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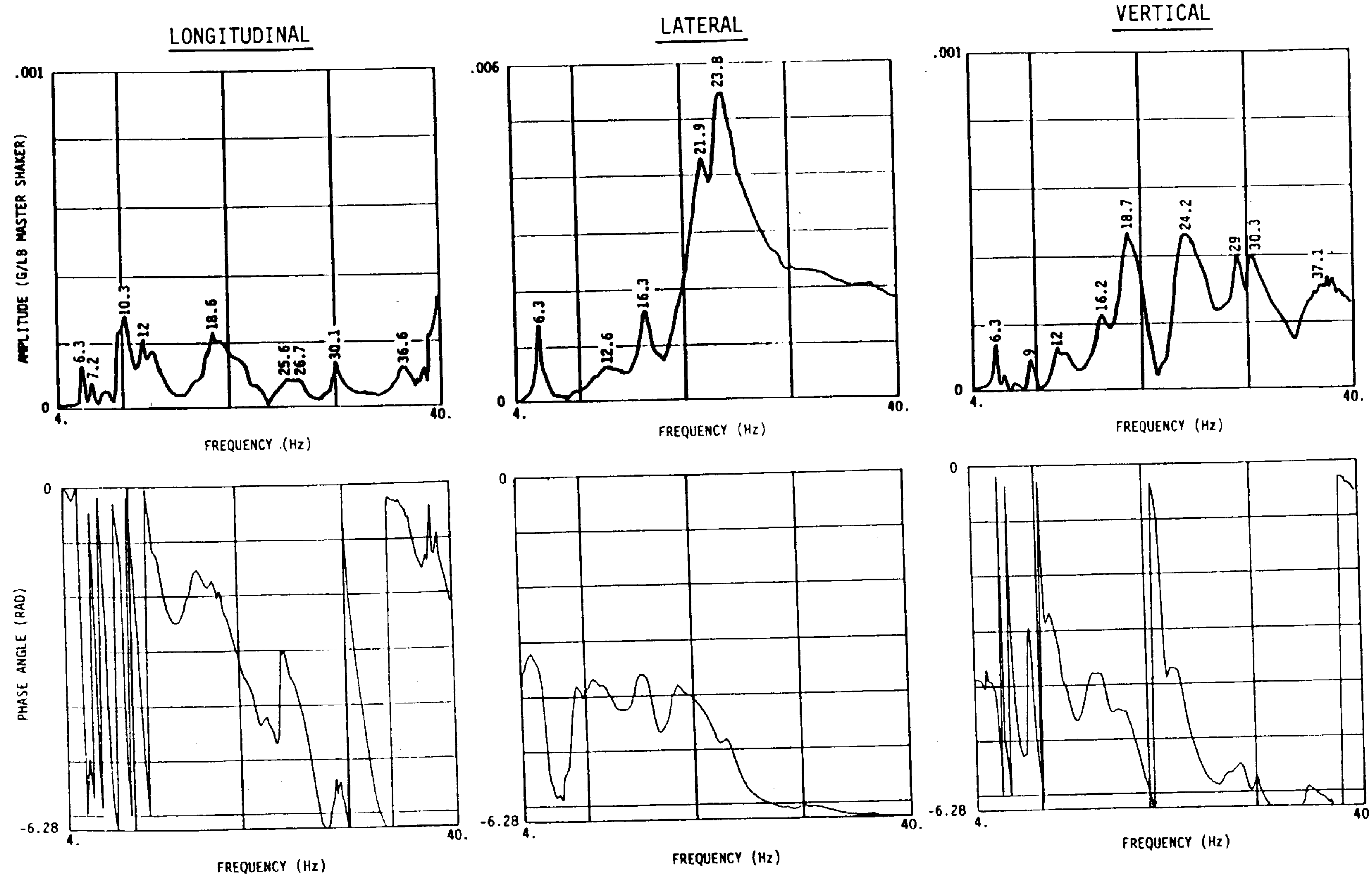
RESPONSE: FORWARD HUB (LOC. 2)



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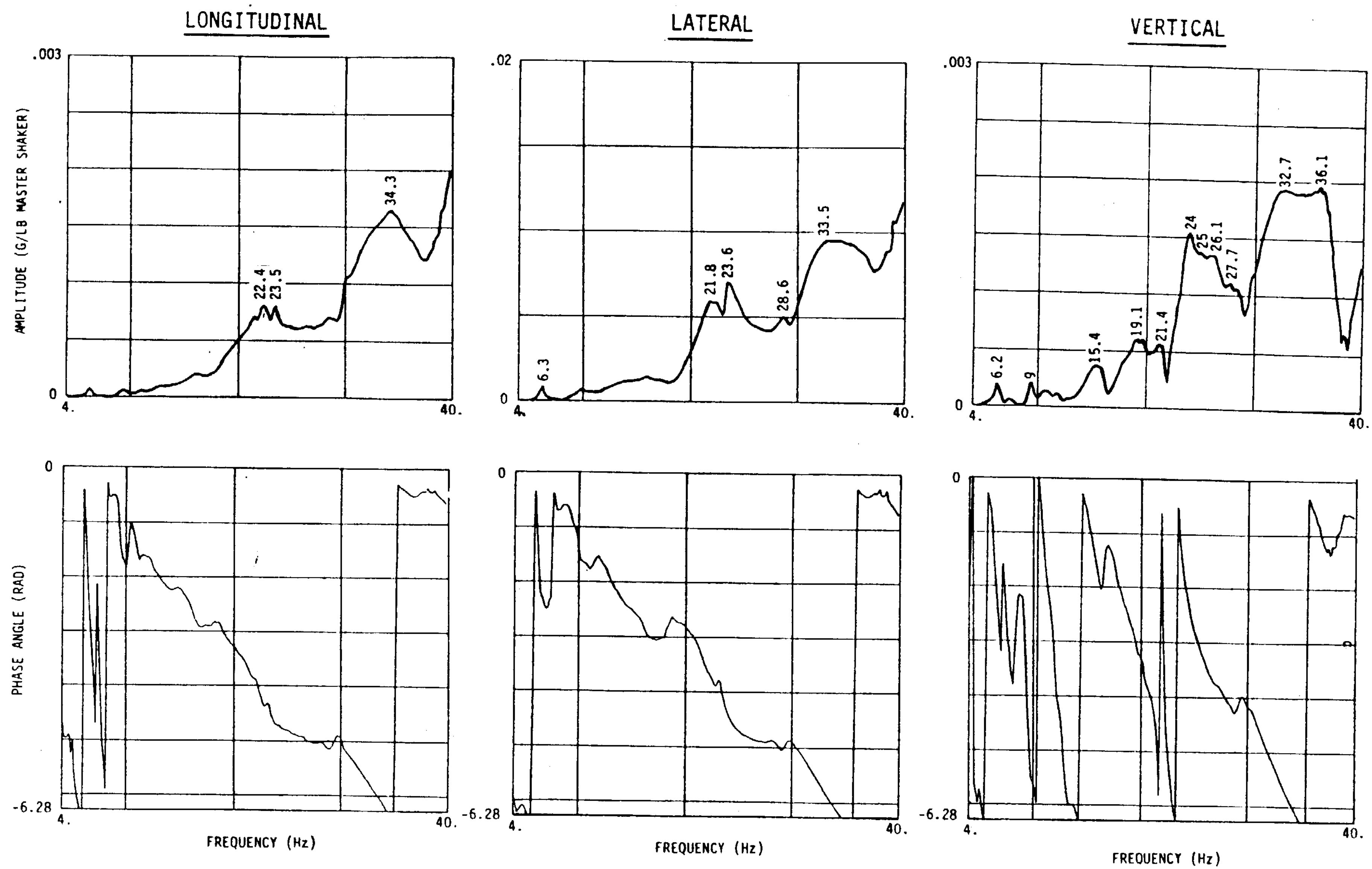

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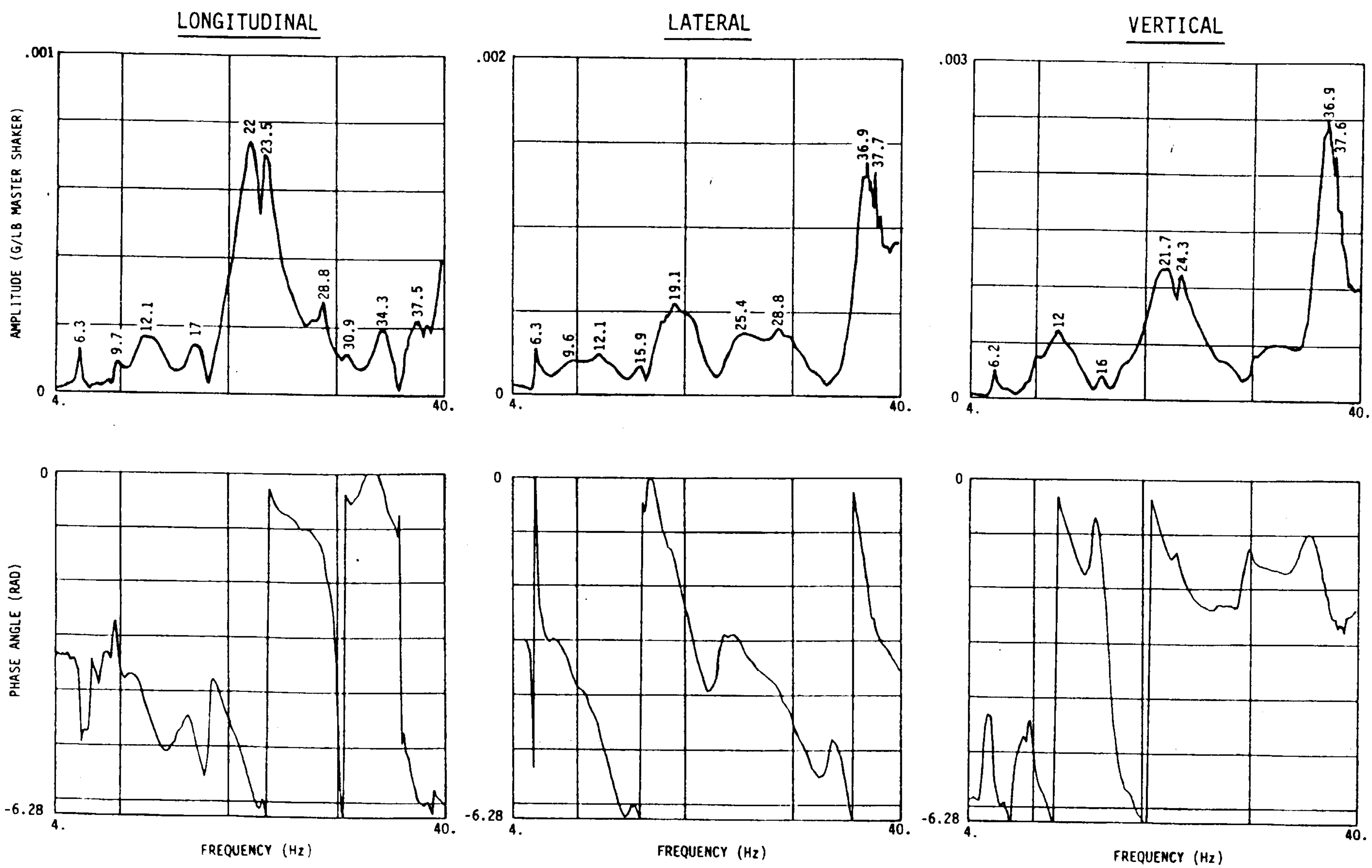

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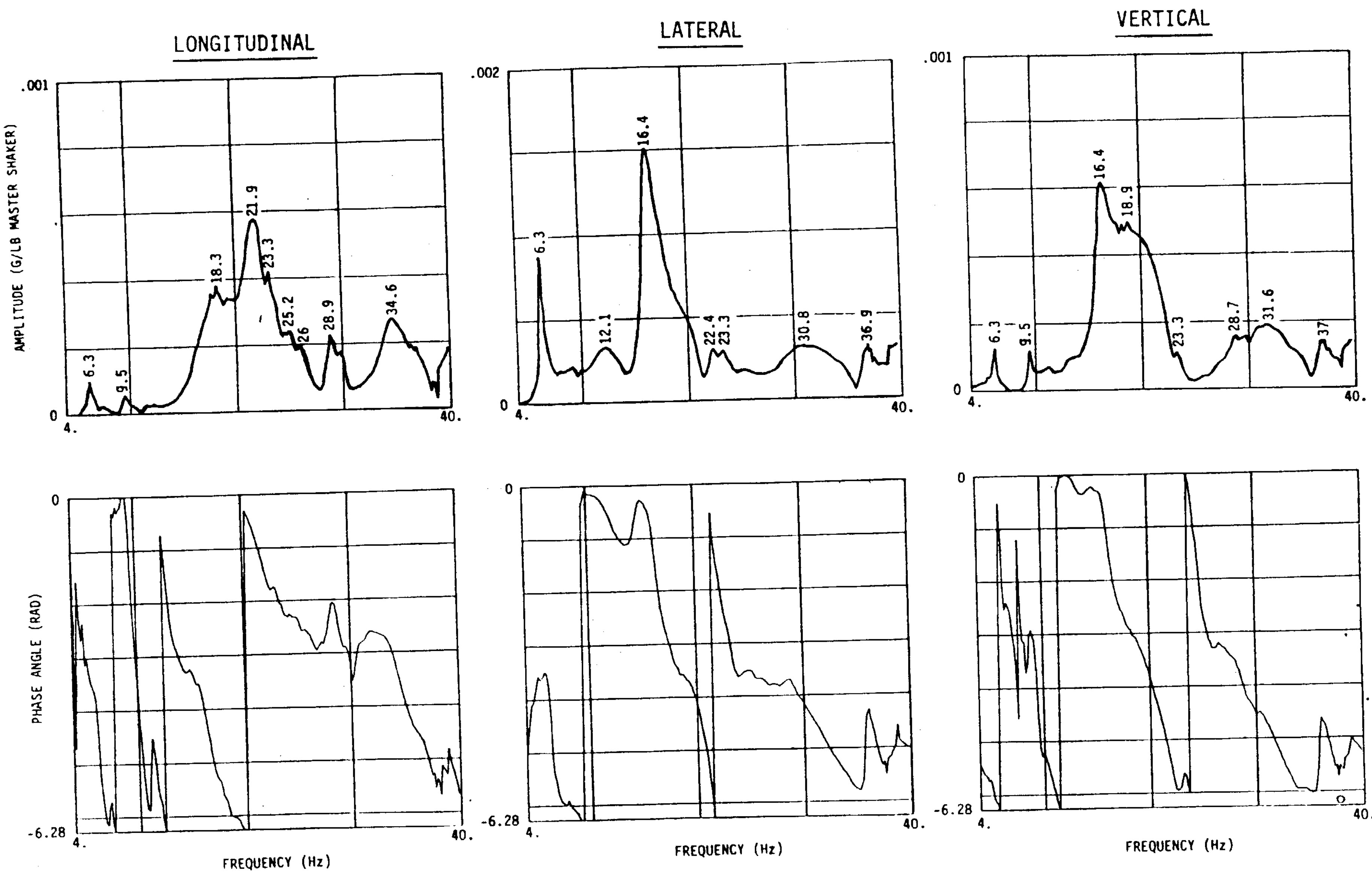

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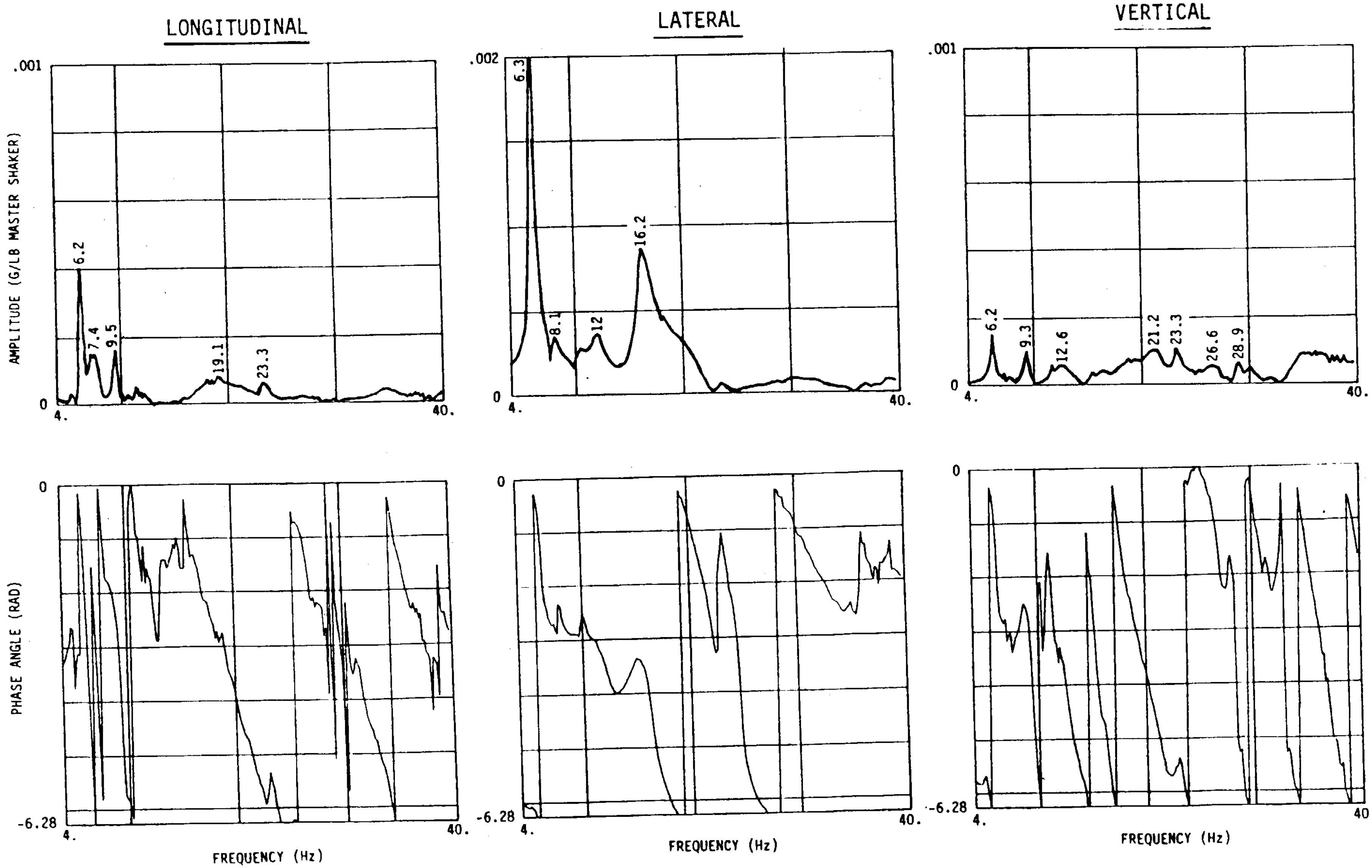

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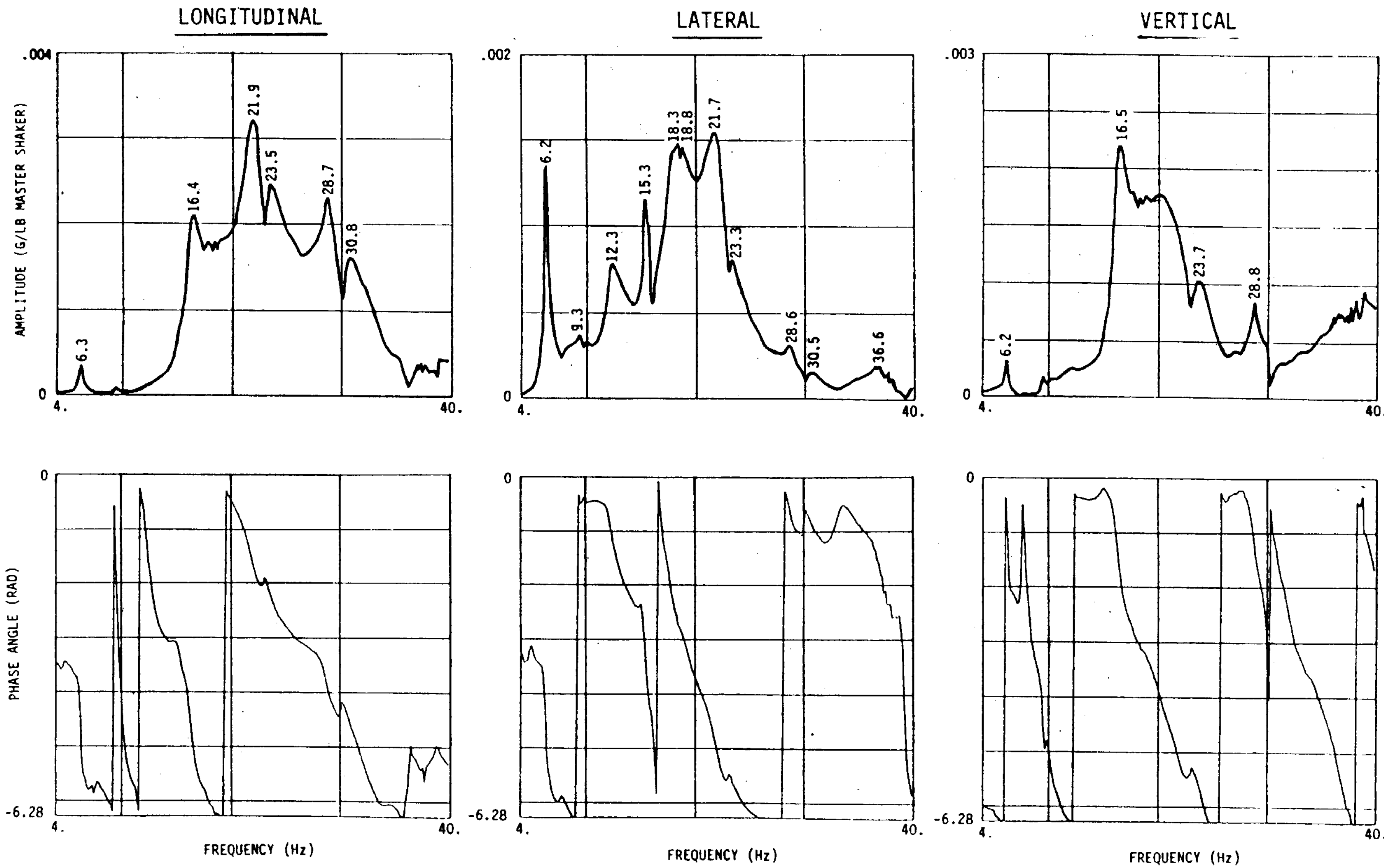

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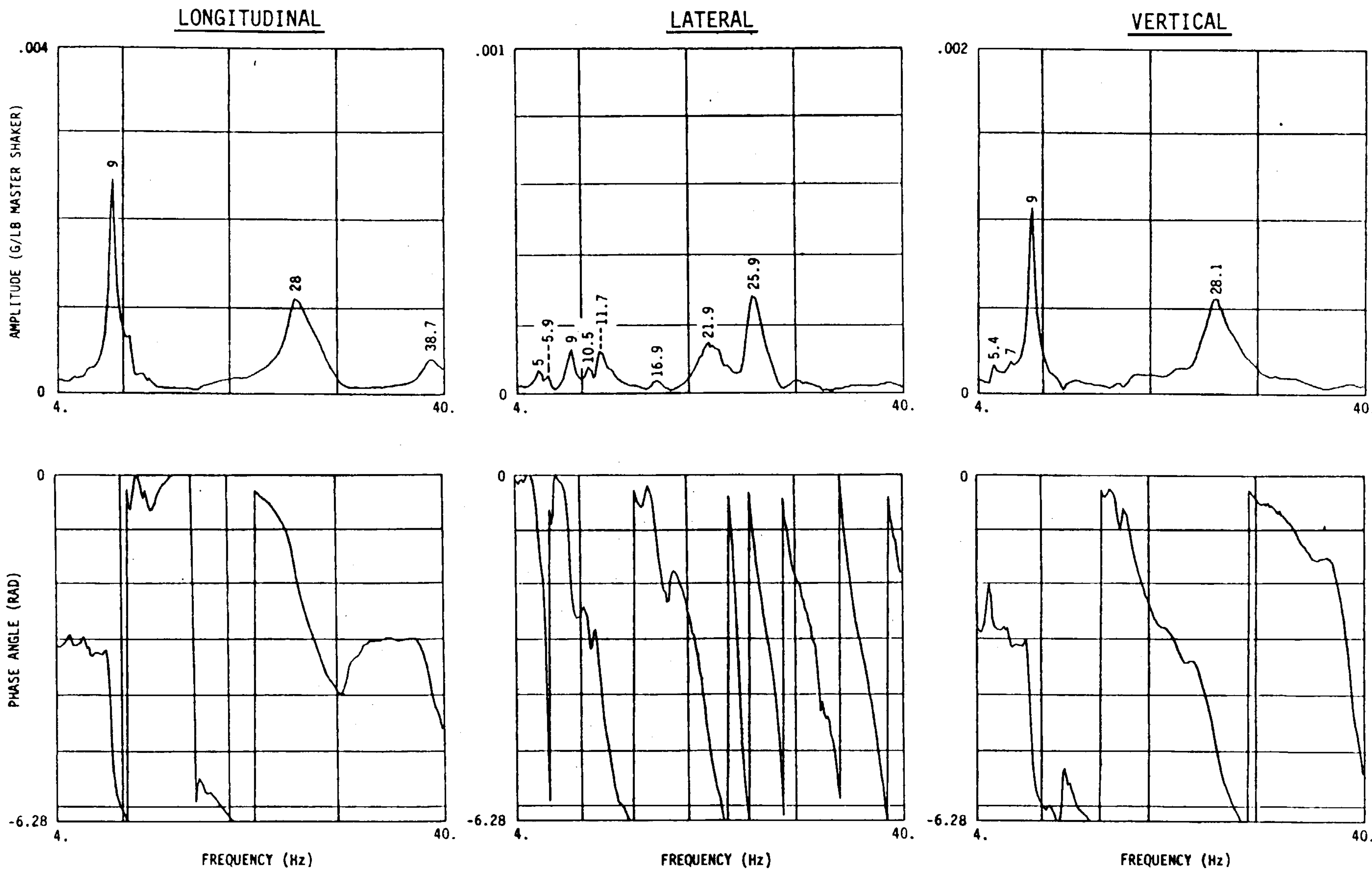
RESPONSE: FORWARD HUB (LOC. 2)



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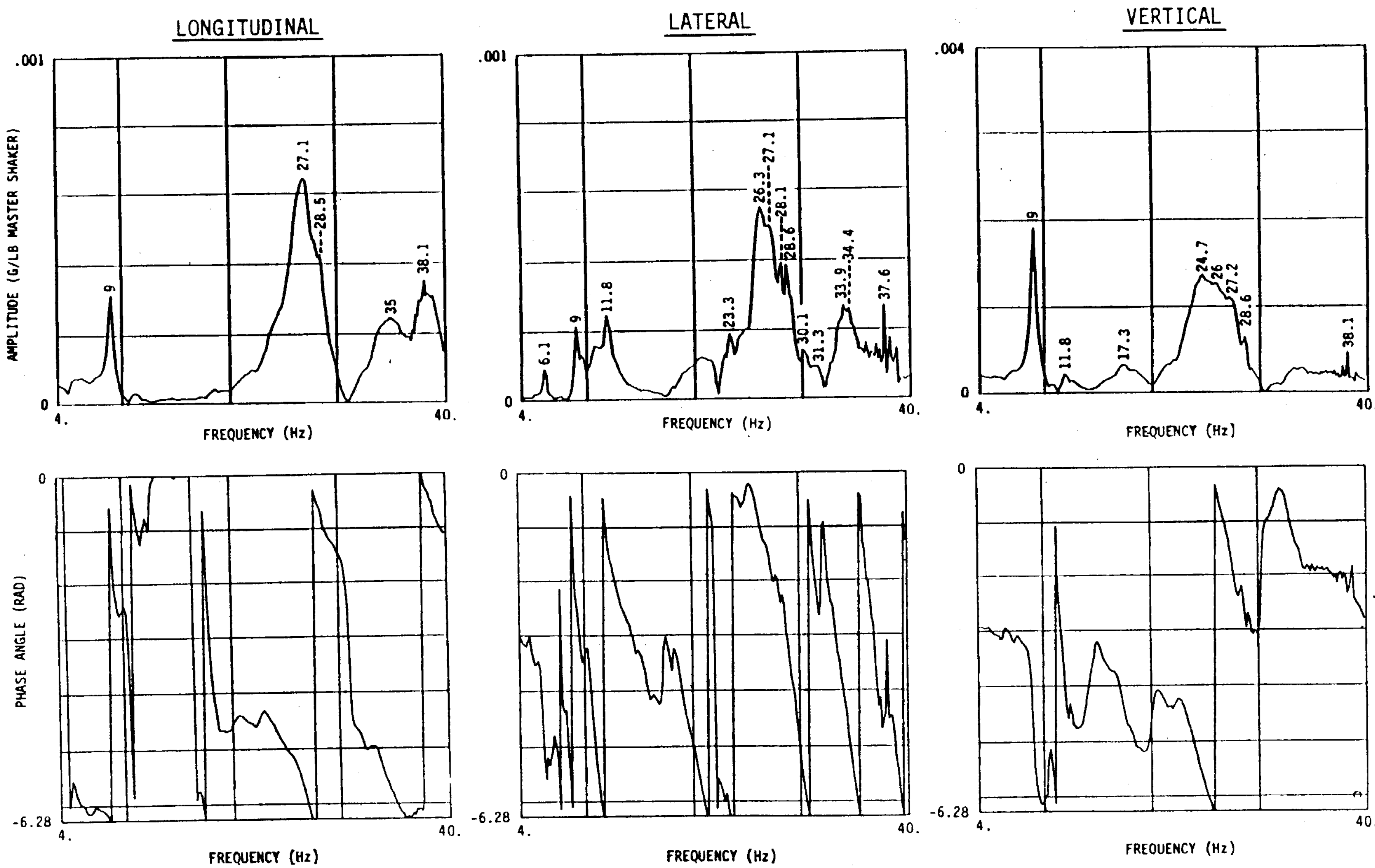
RESPONSE: STA. 10 R/H FORWARD COCKPIT (LOC. 9)



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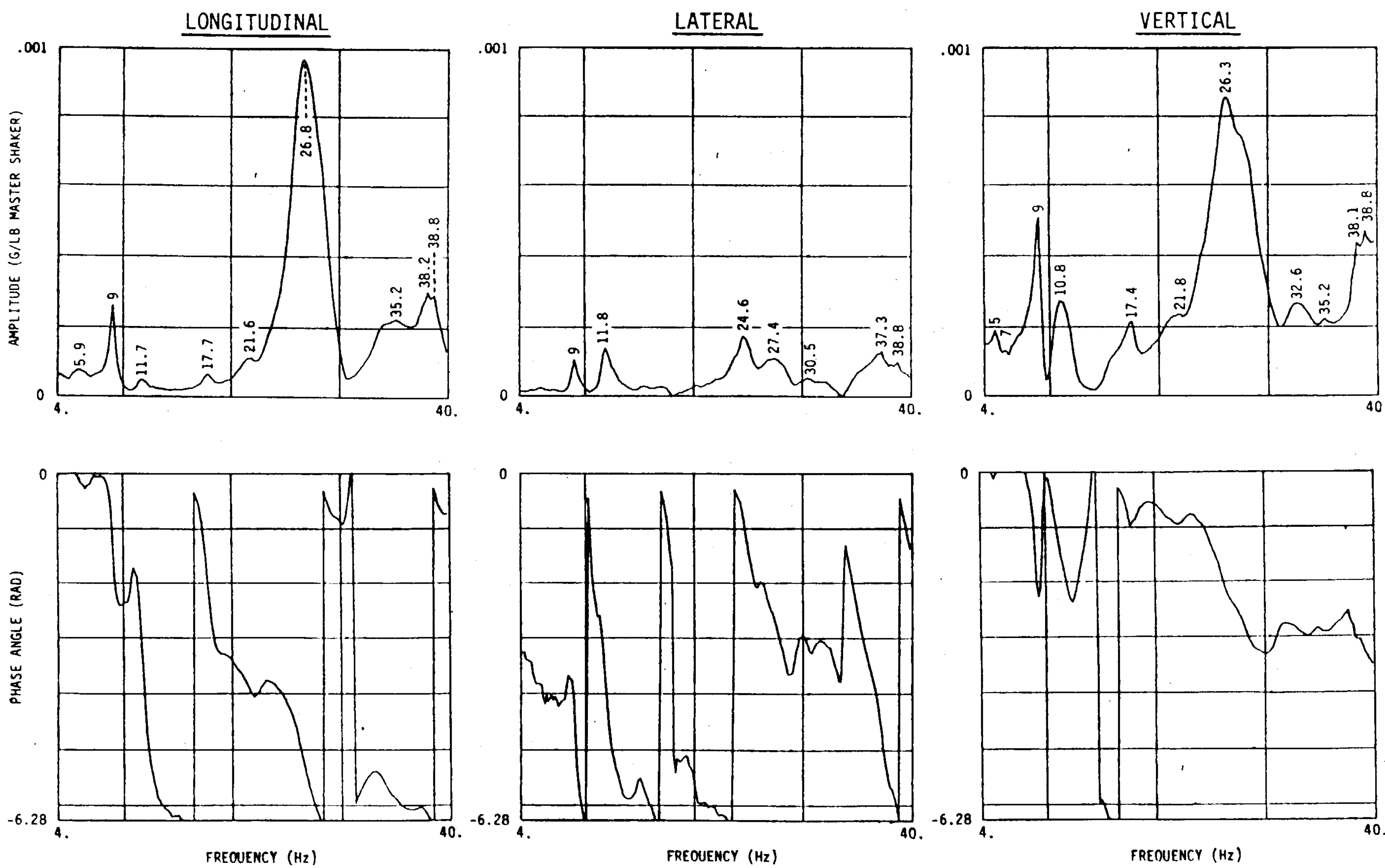

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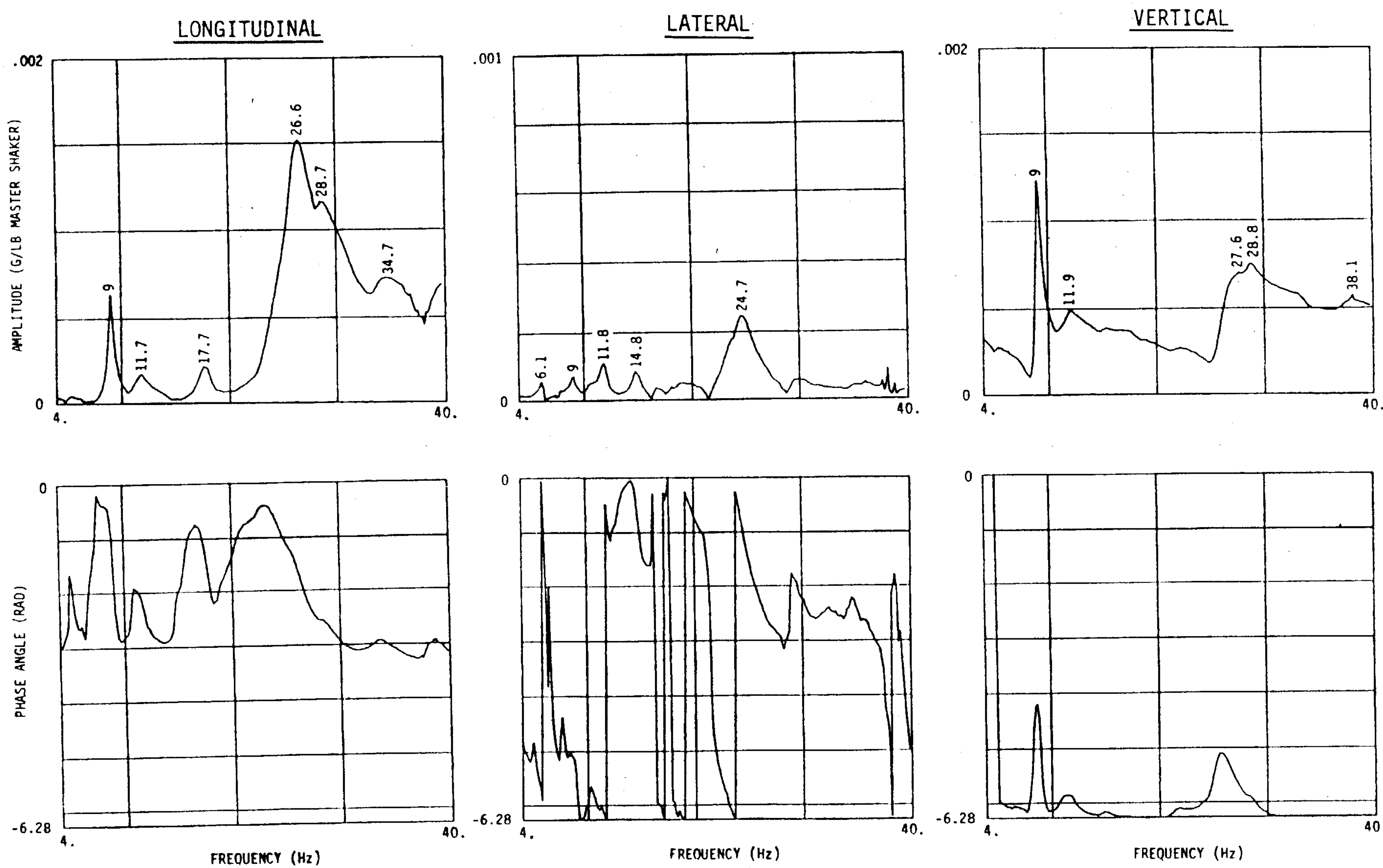

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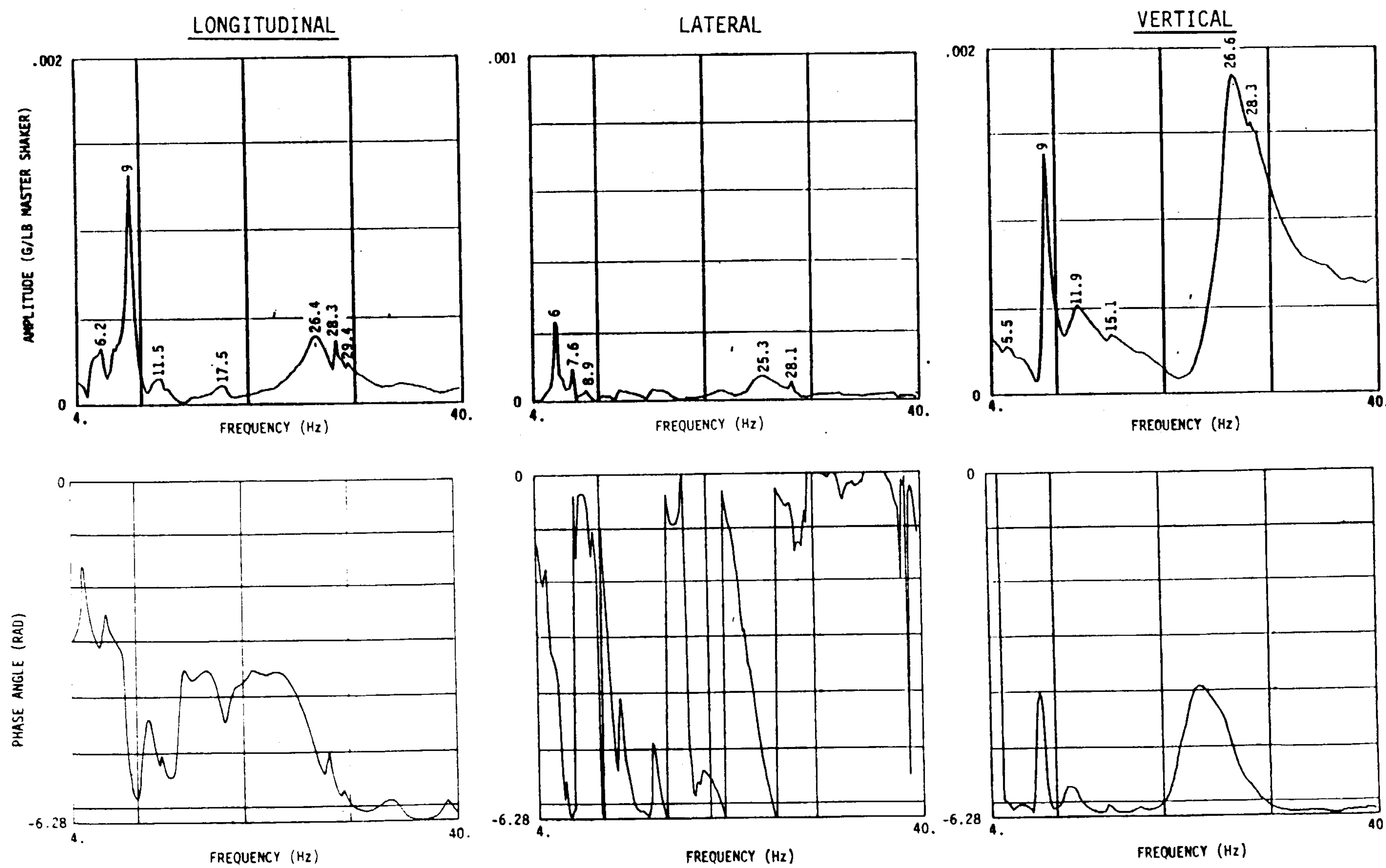

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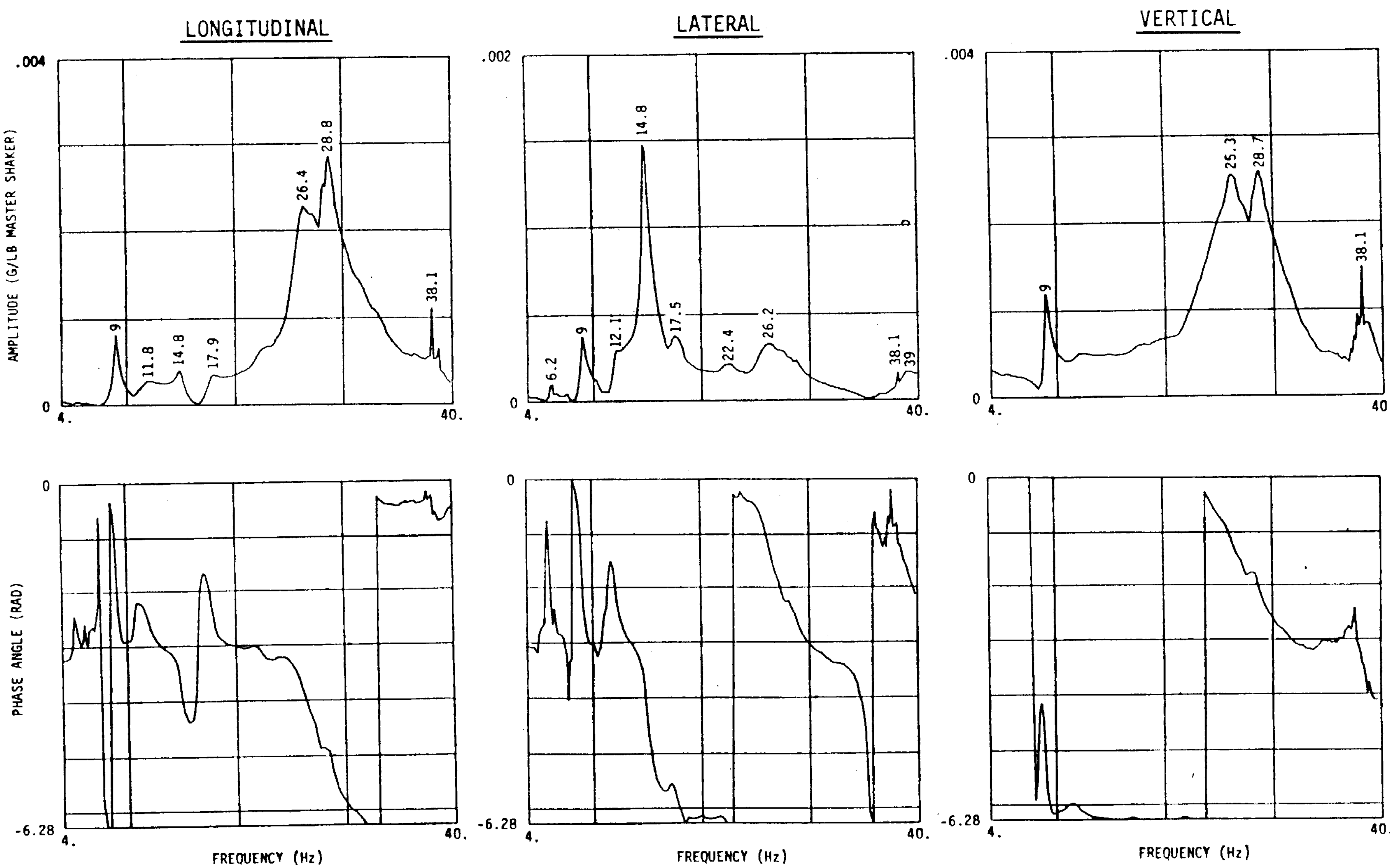

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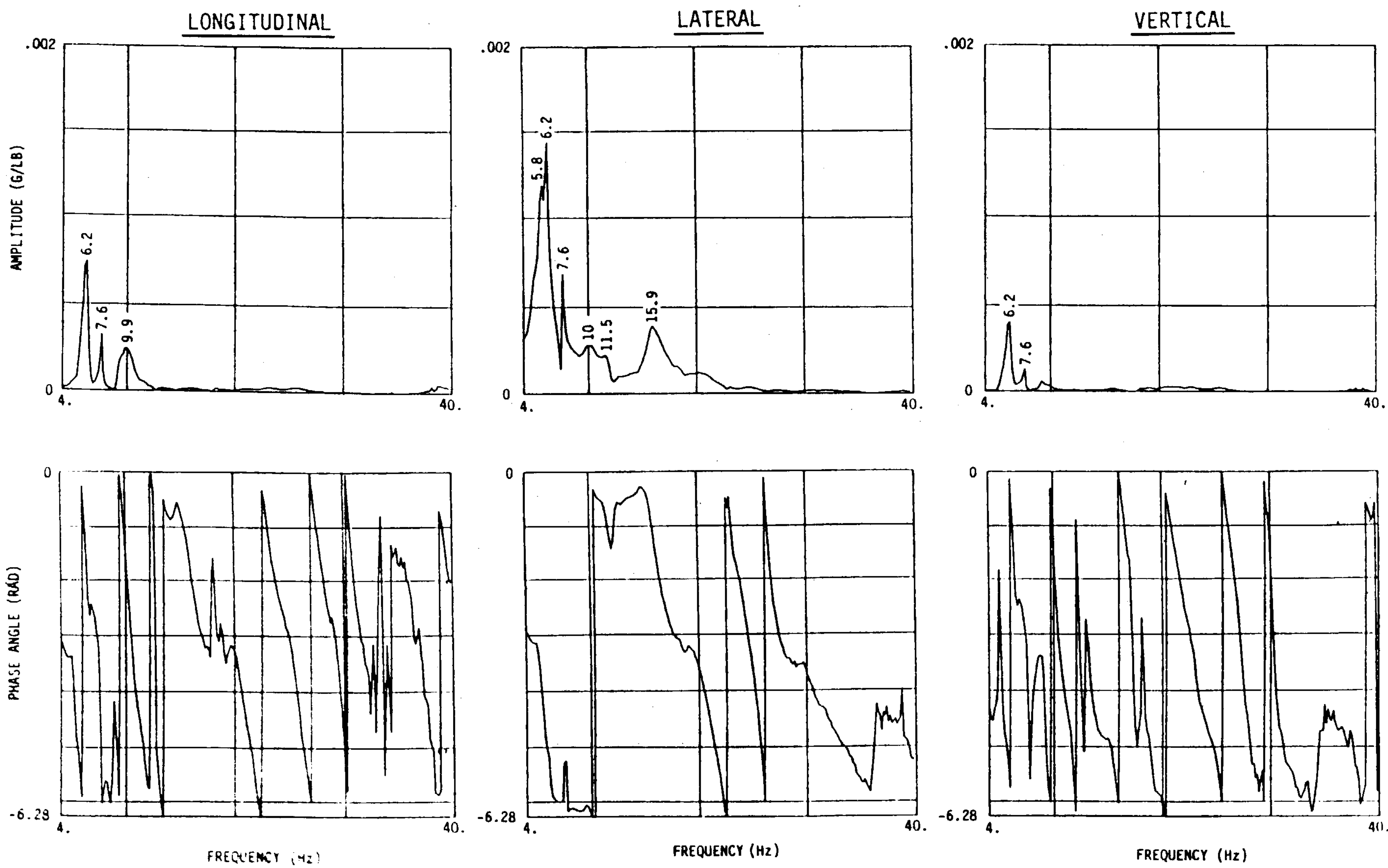
RESPONSE: FORWARD HUB (LOC. 2)



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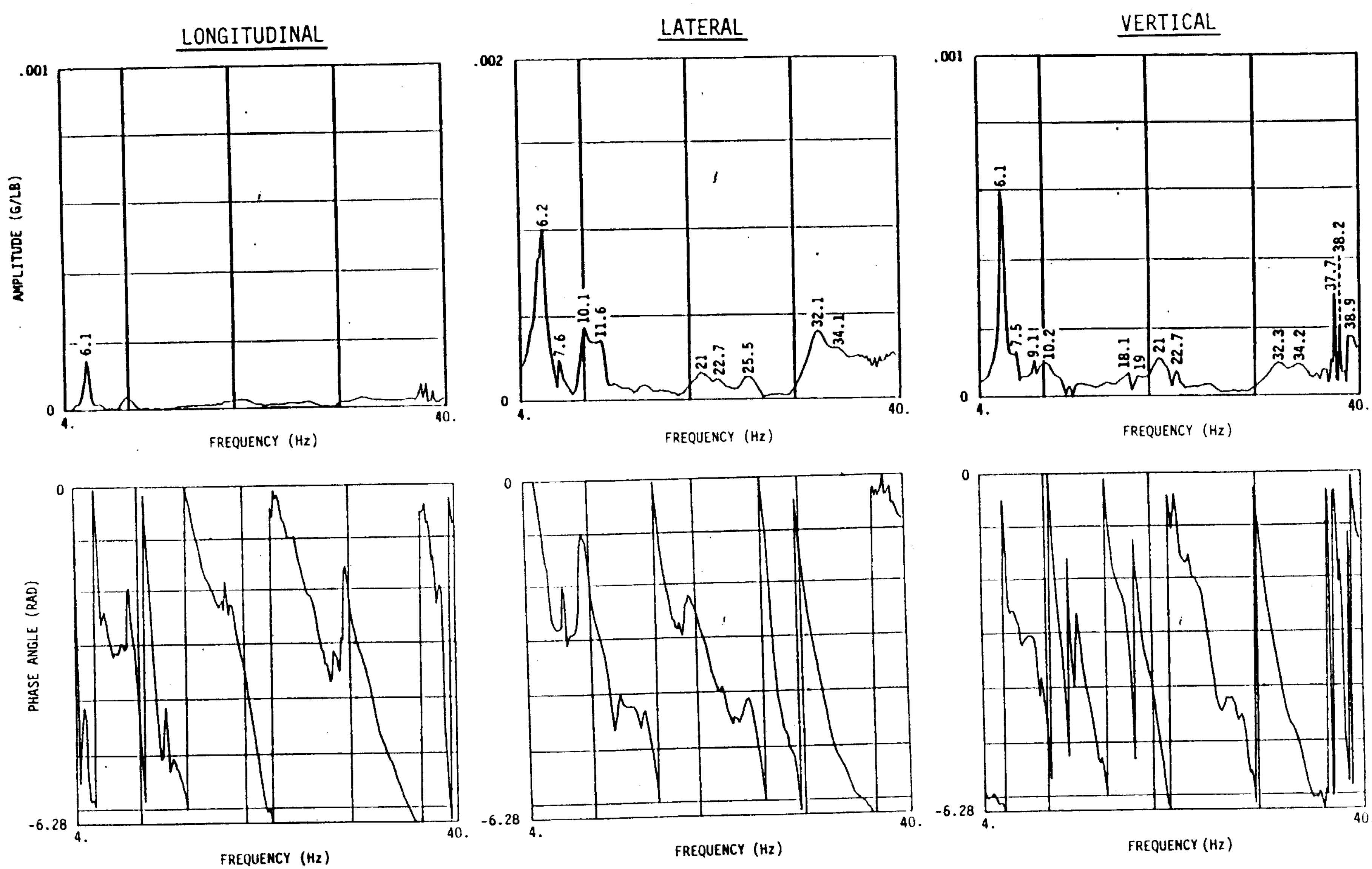

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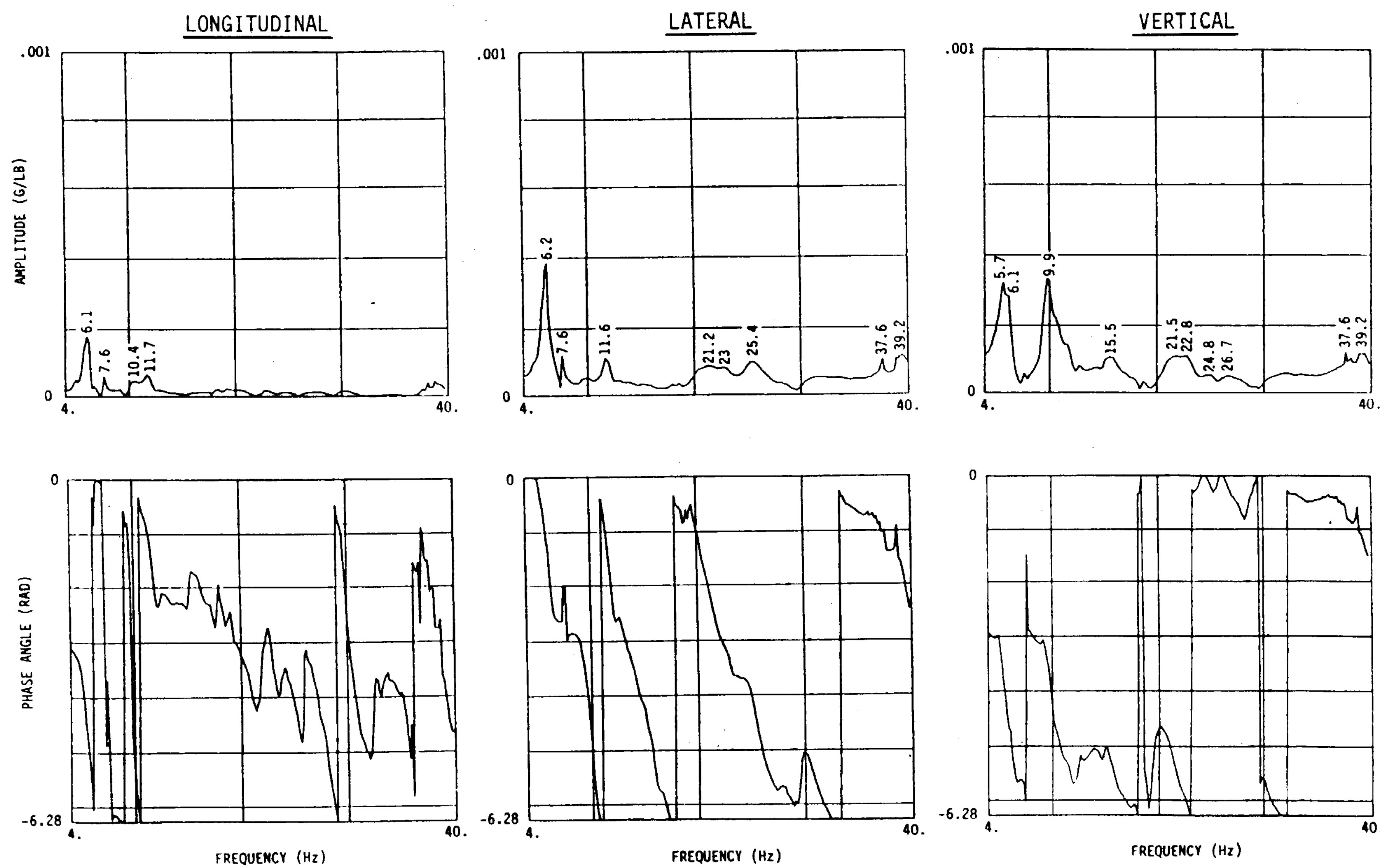

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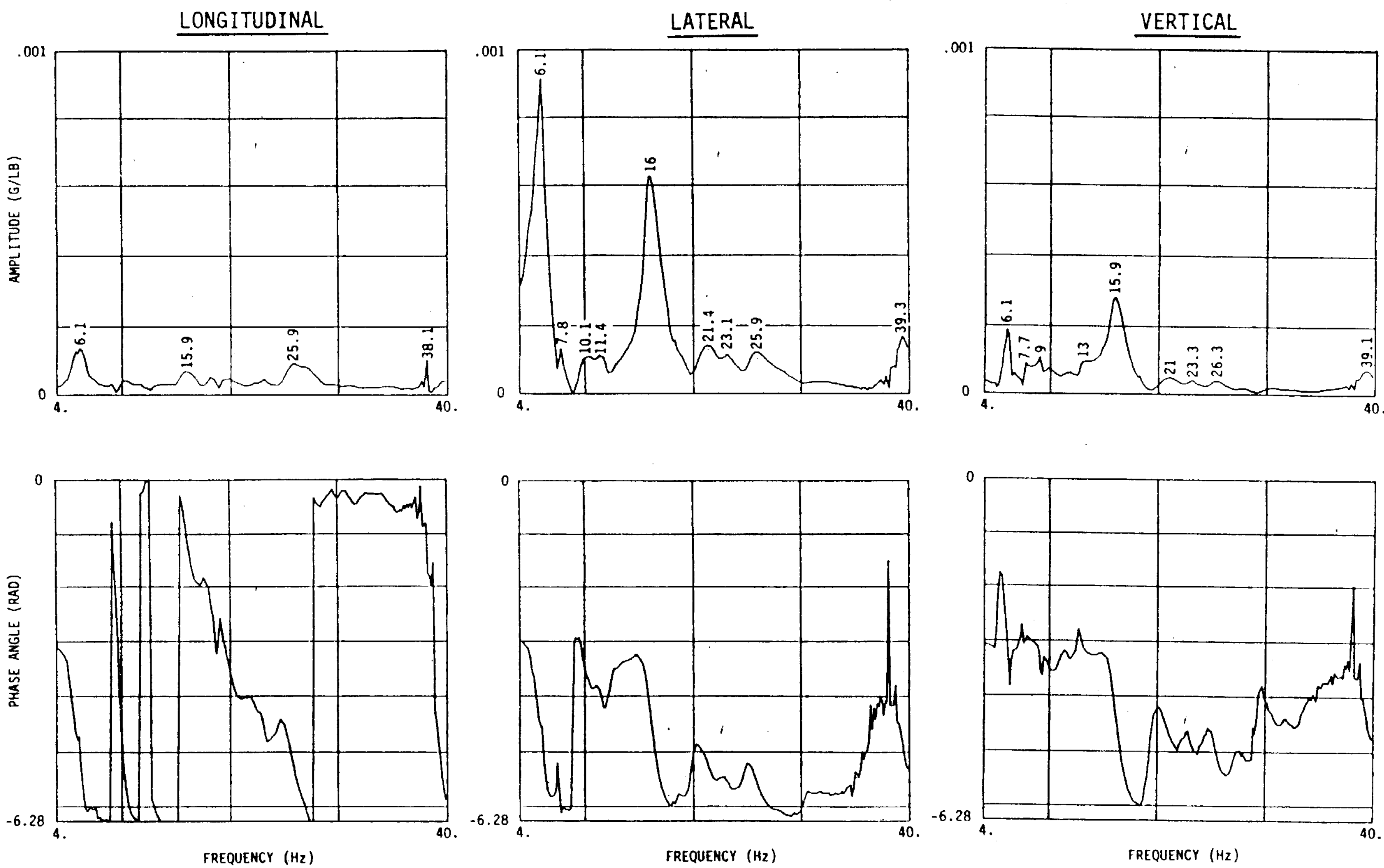

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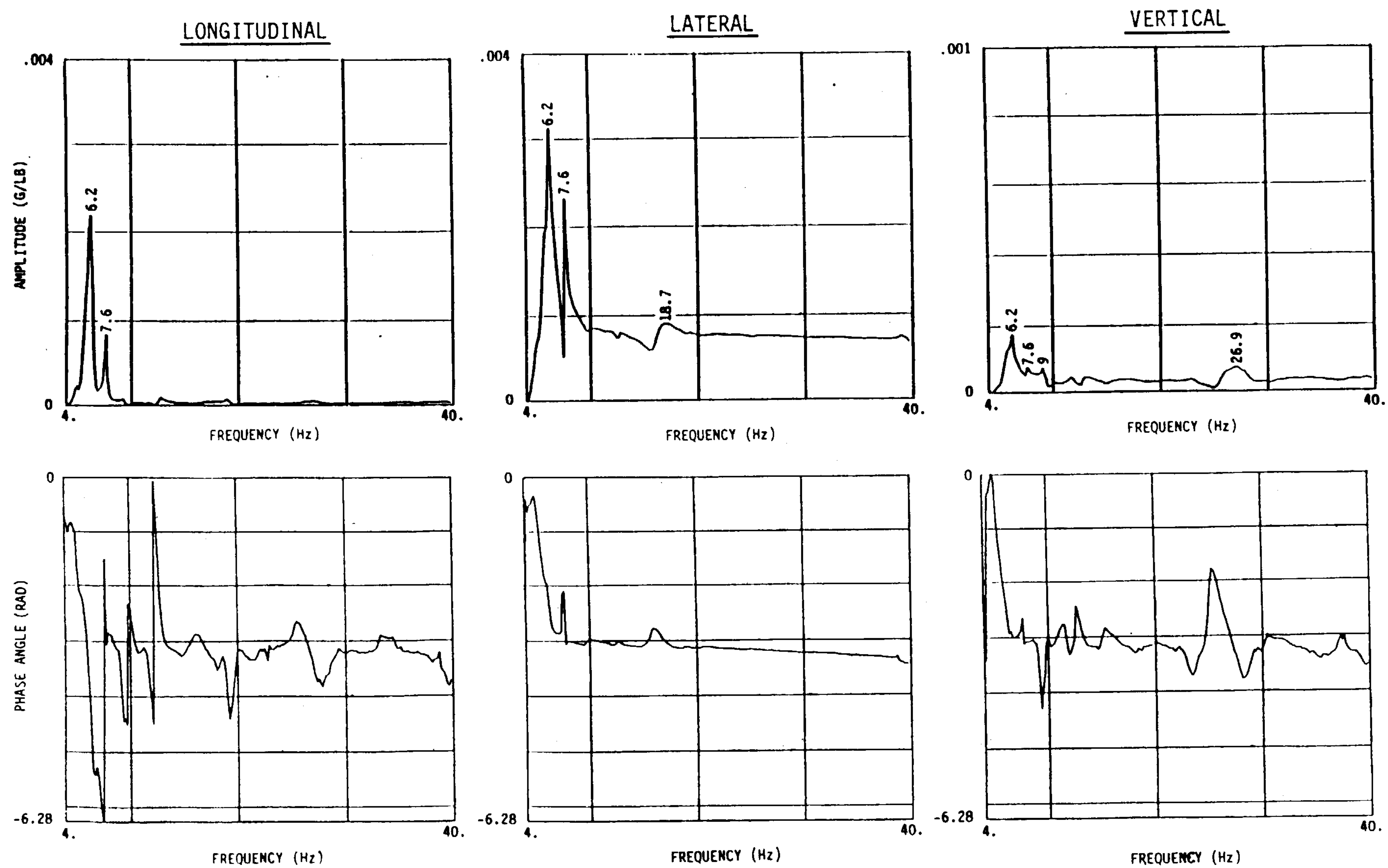

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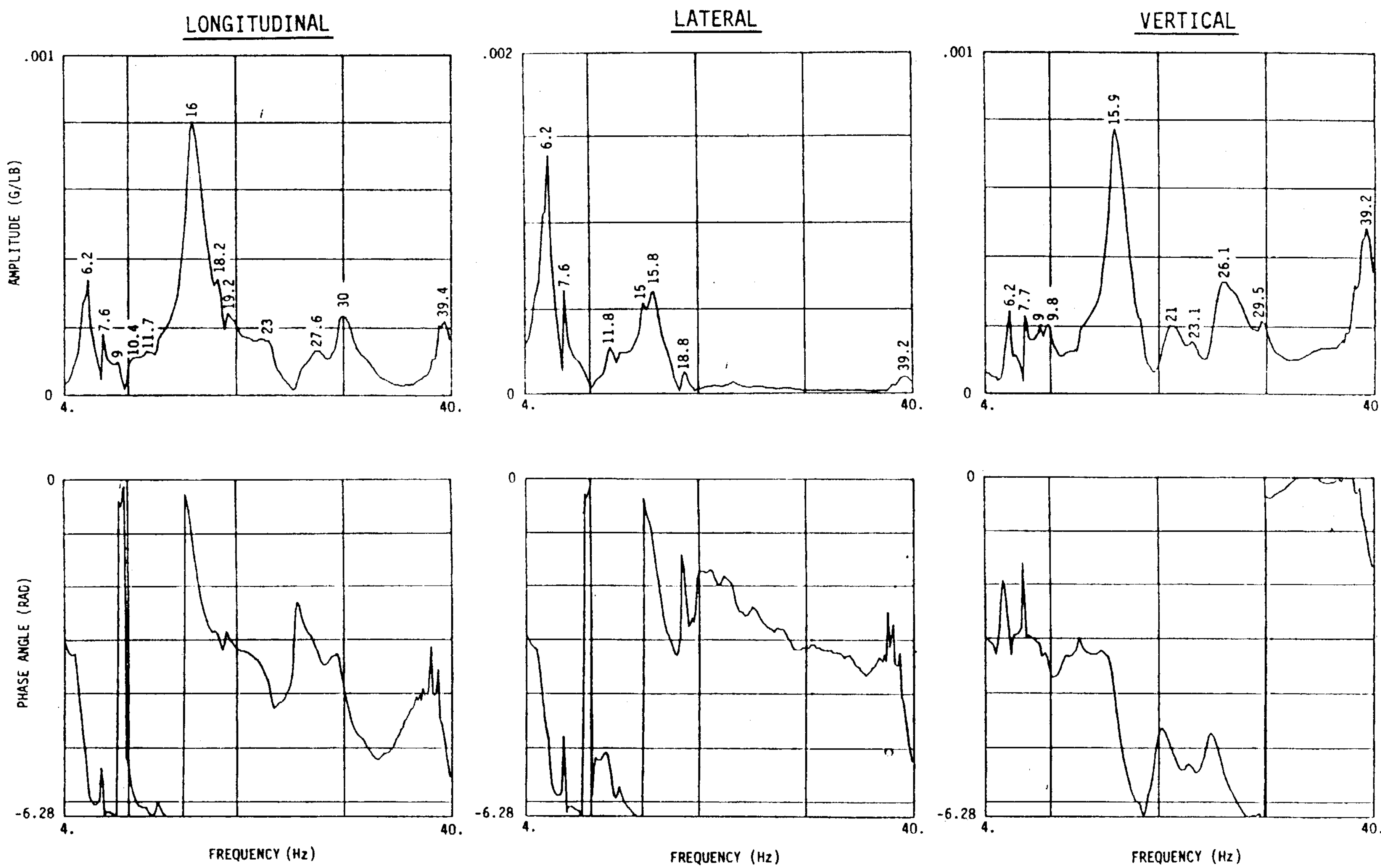

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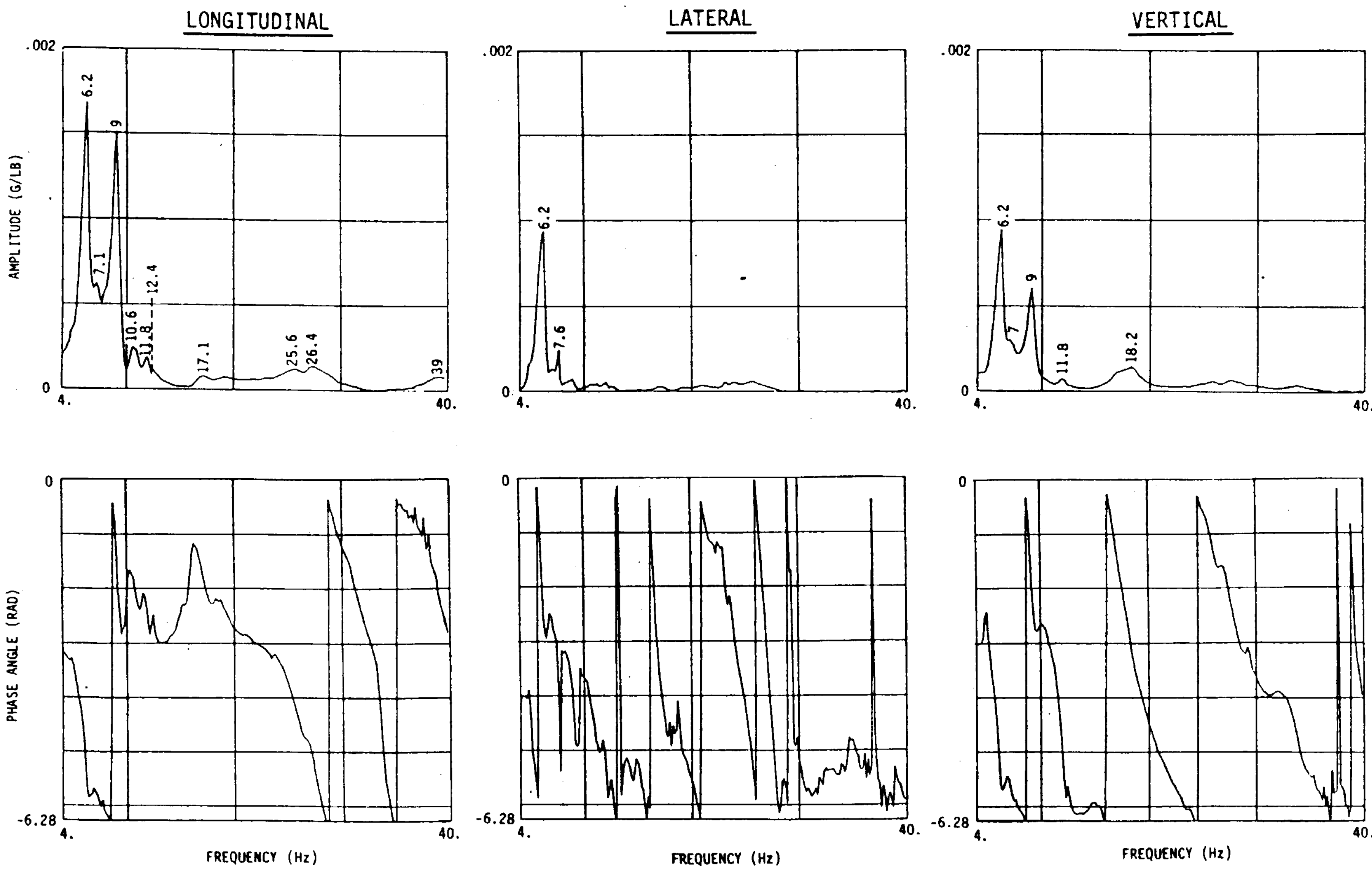

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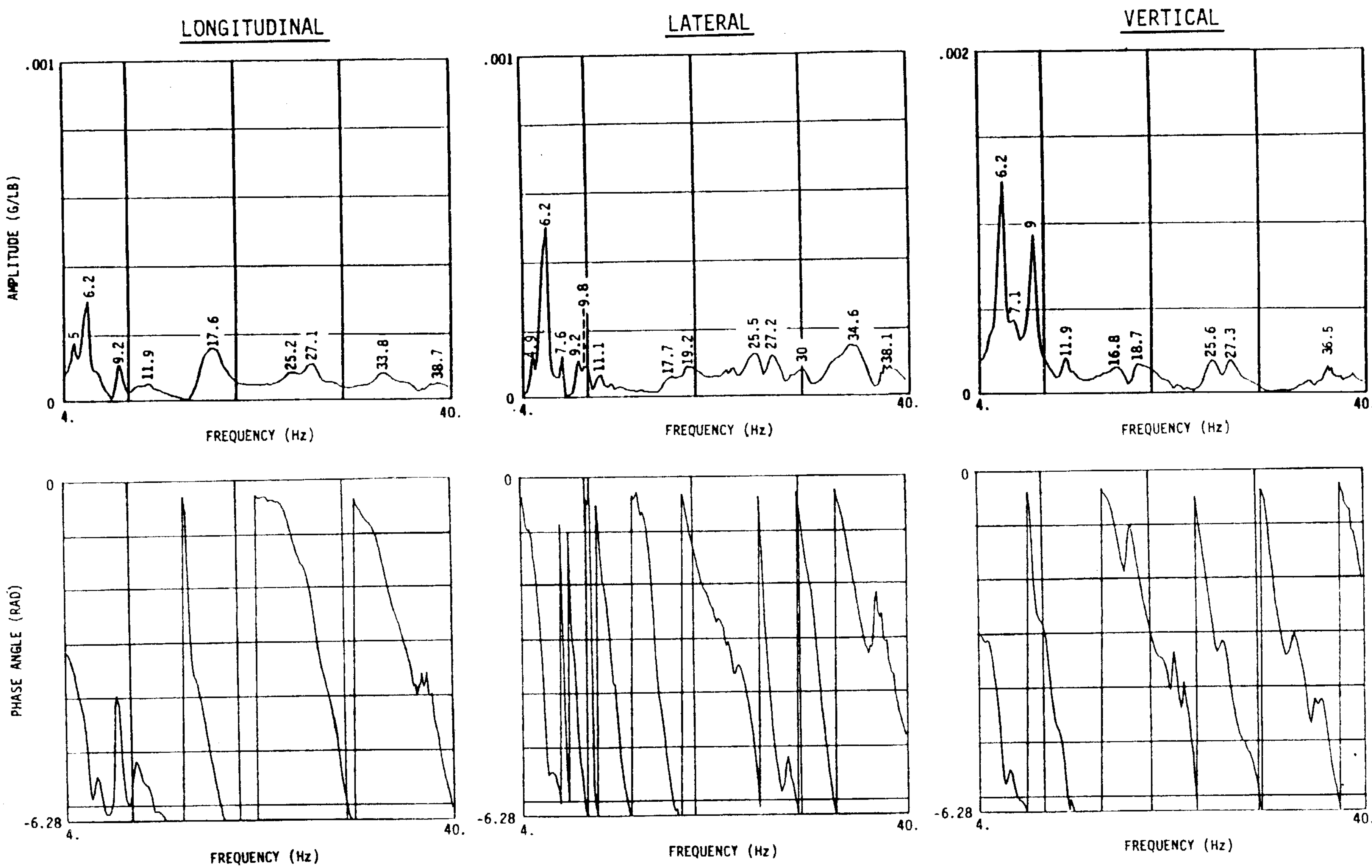

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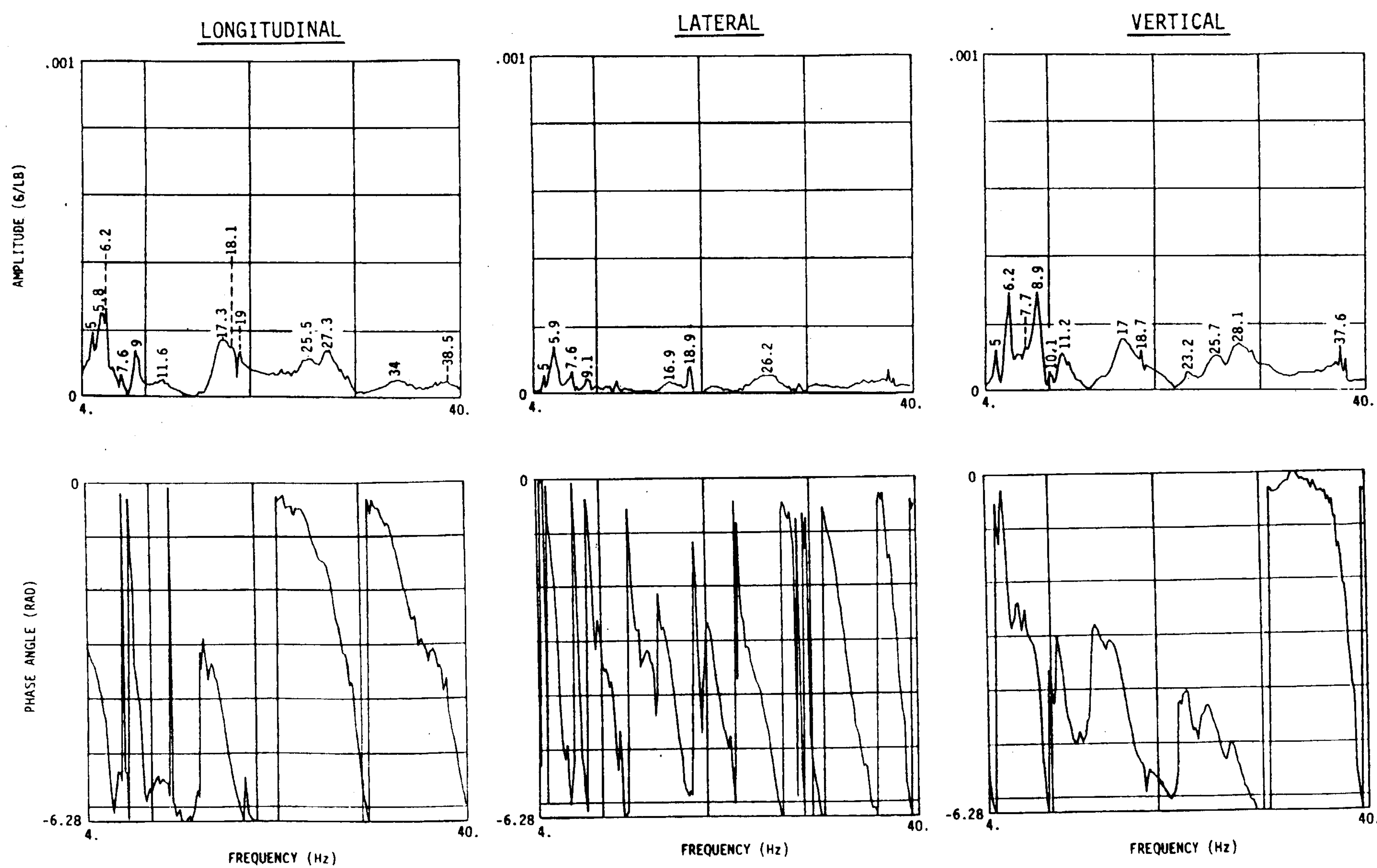

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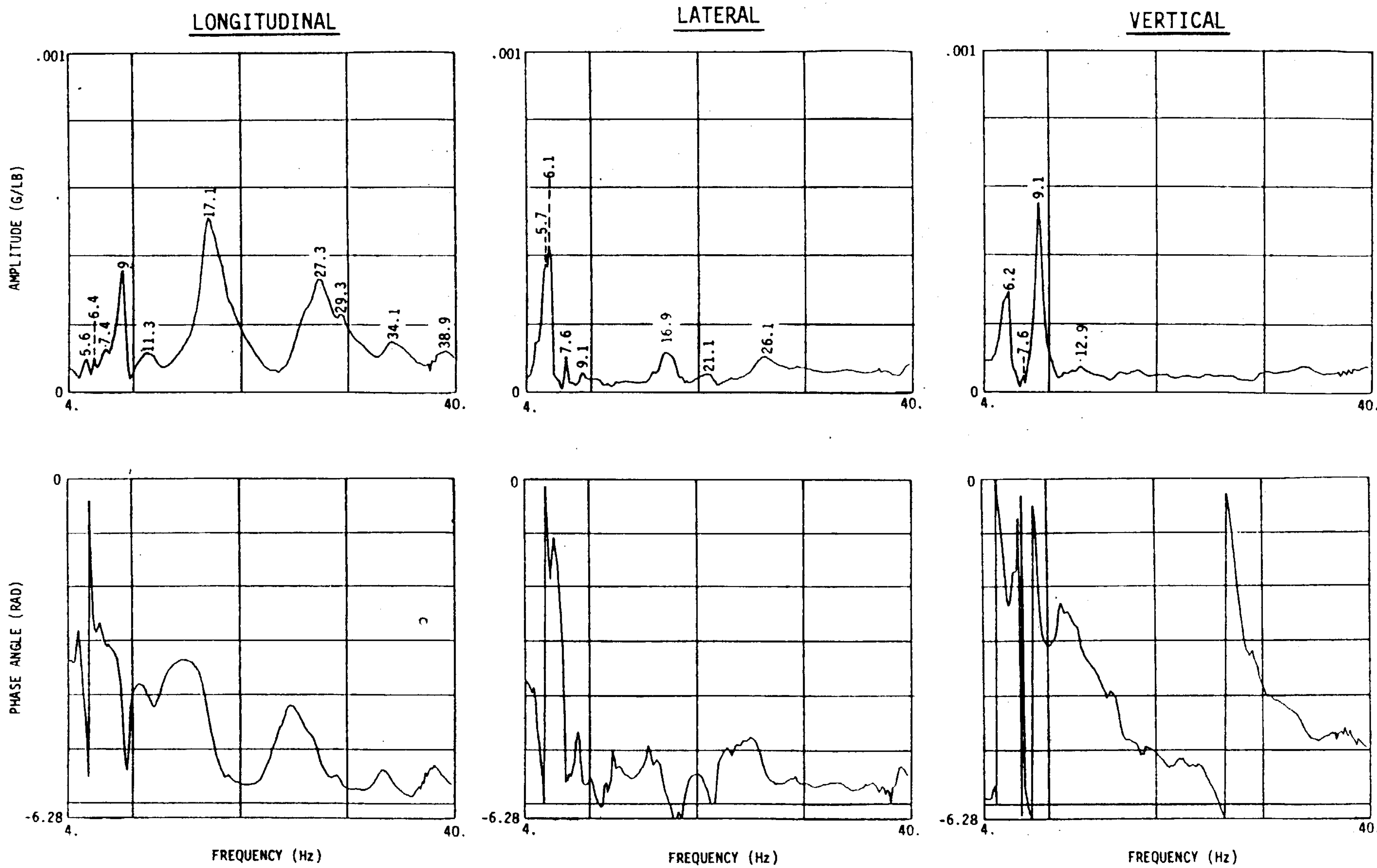

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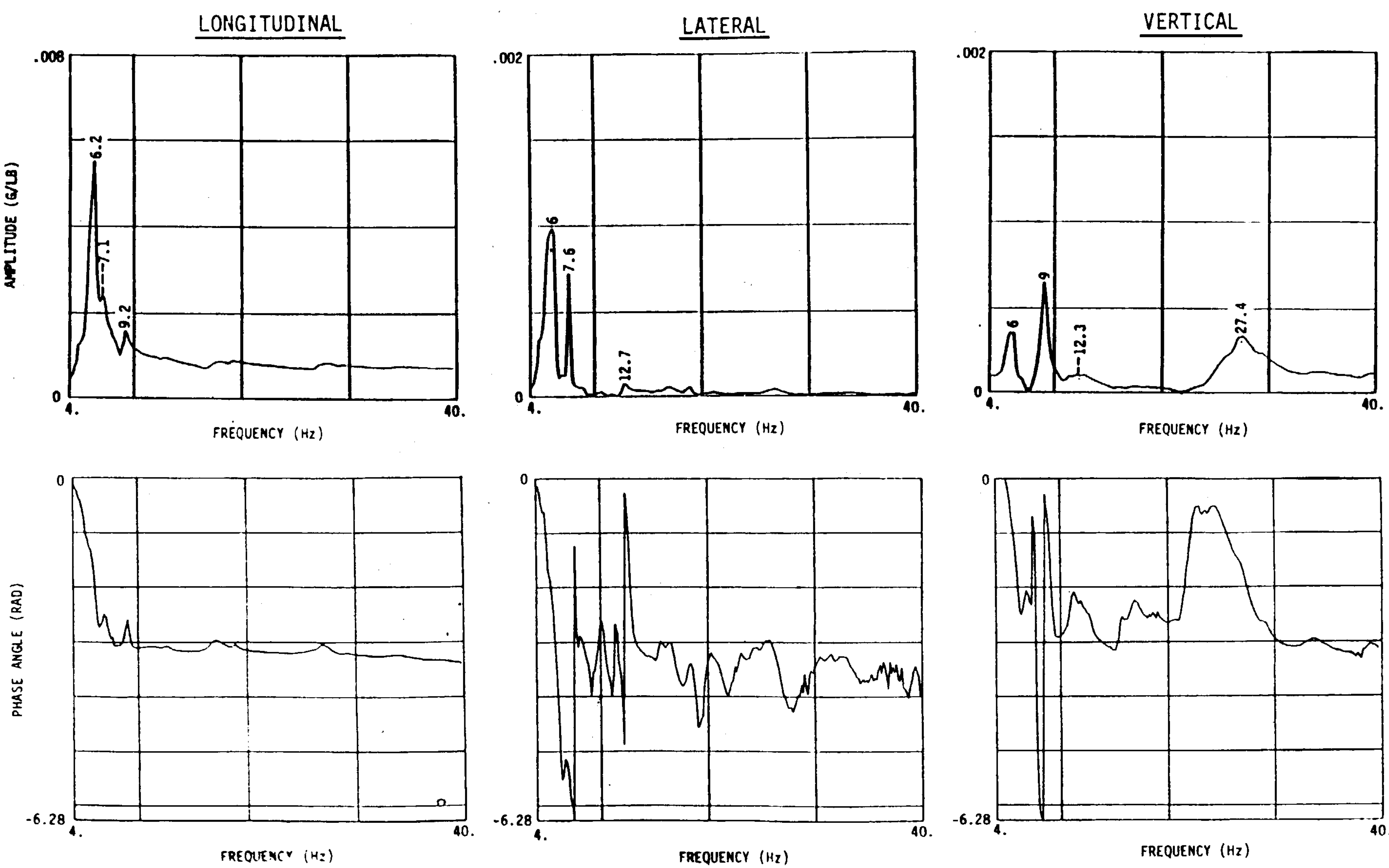

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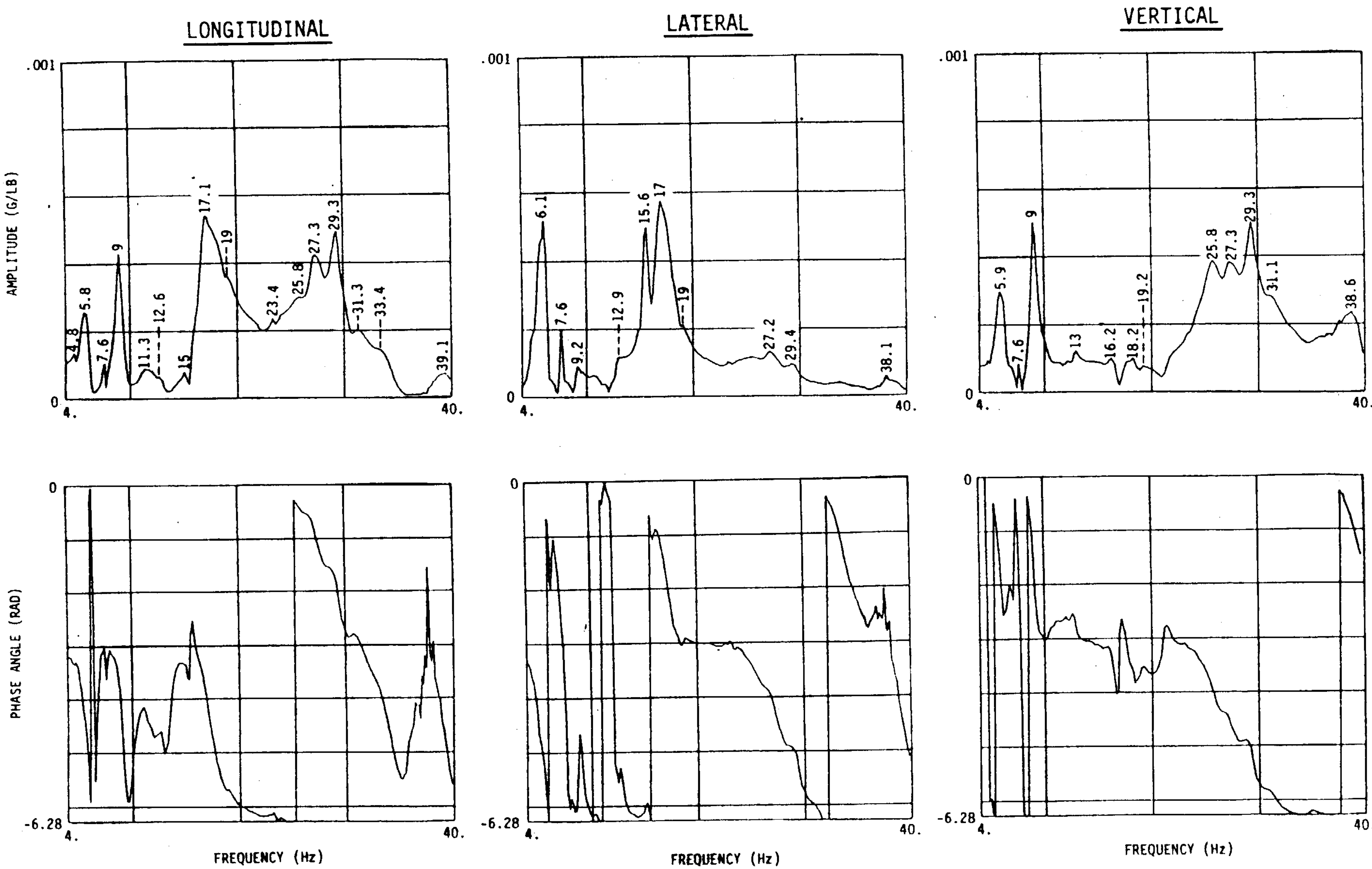

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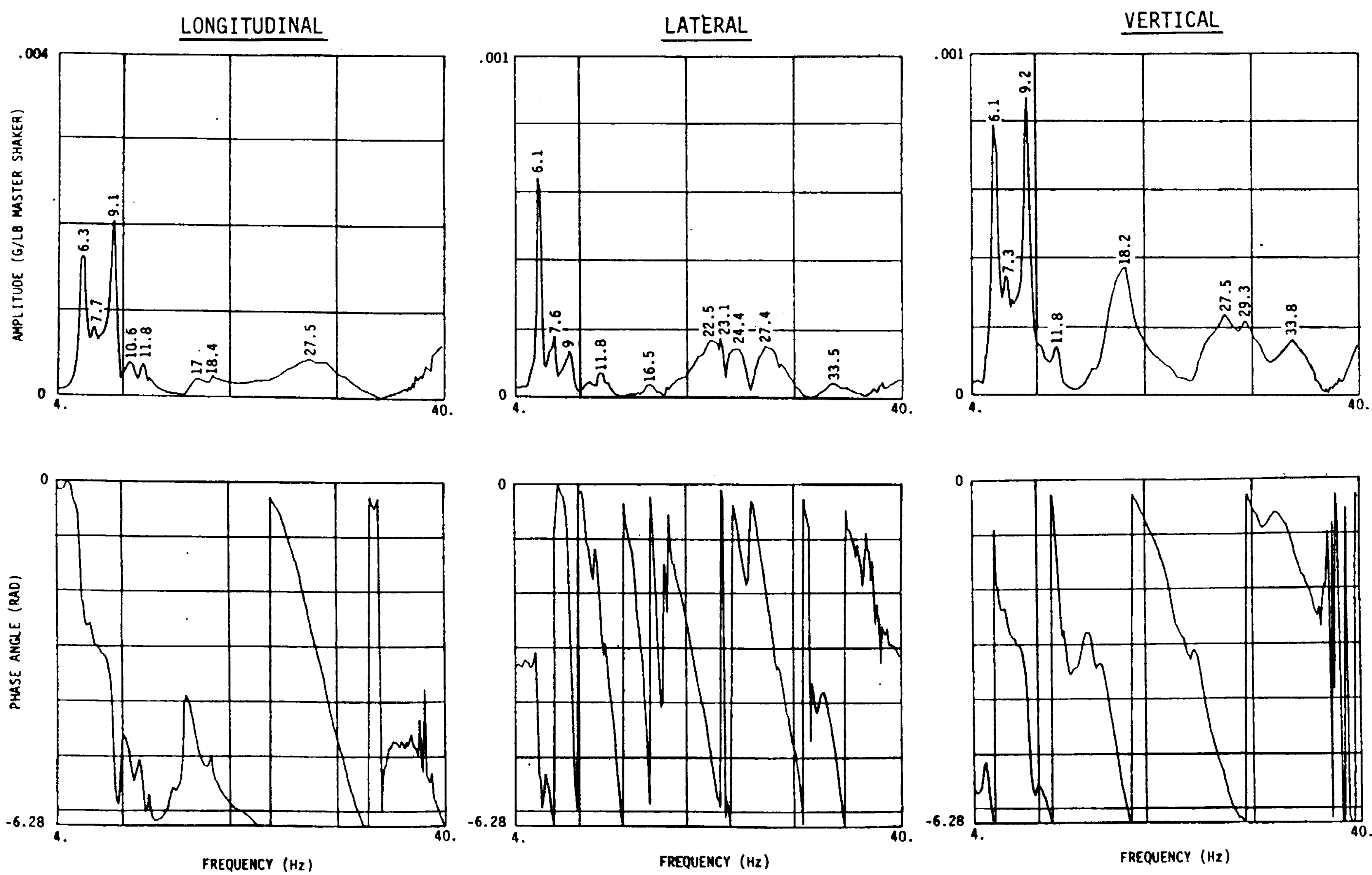

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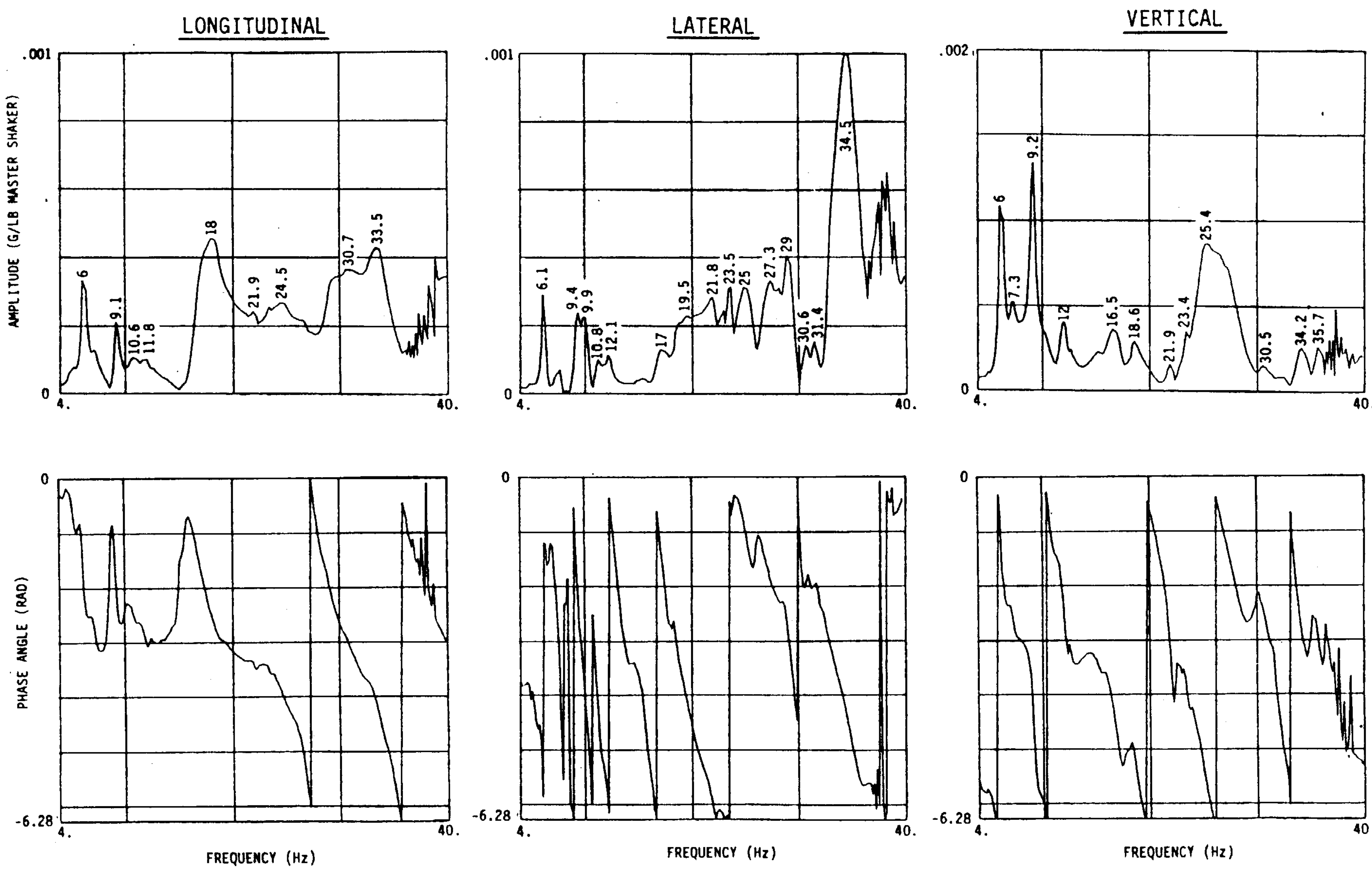

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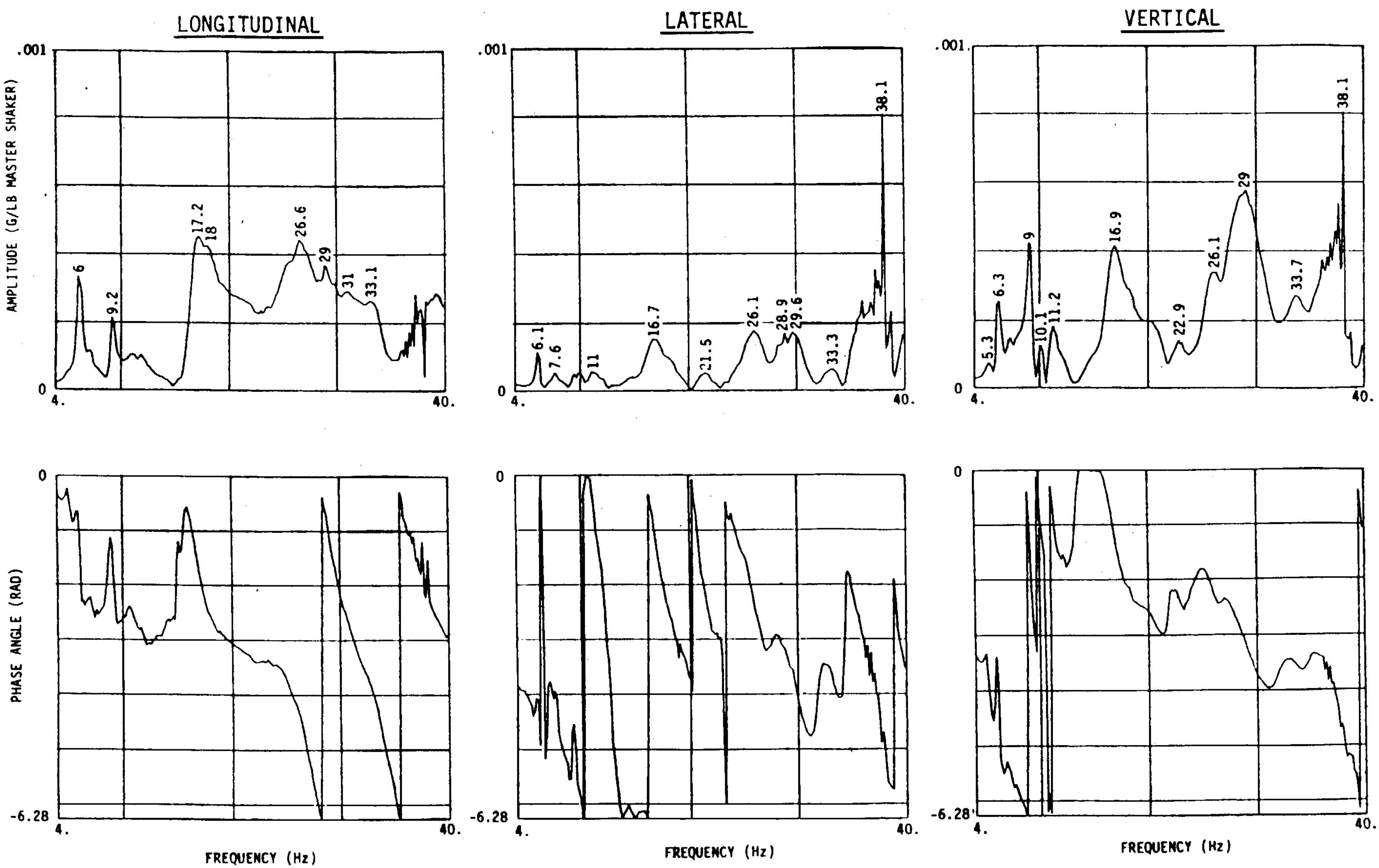

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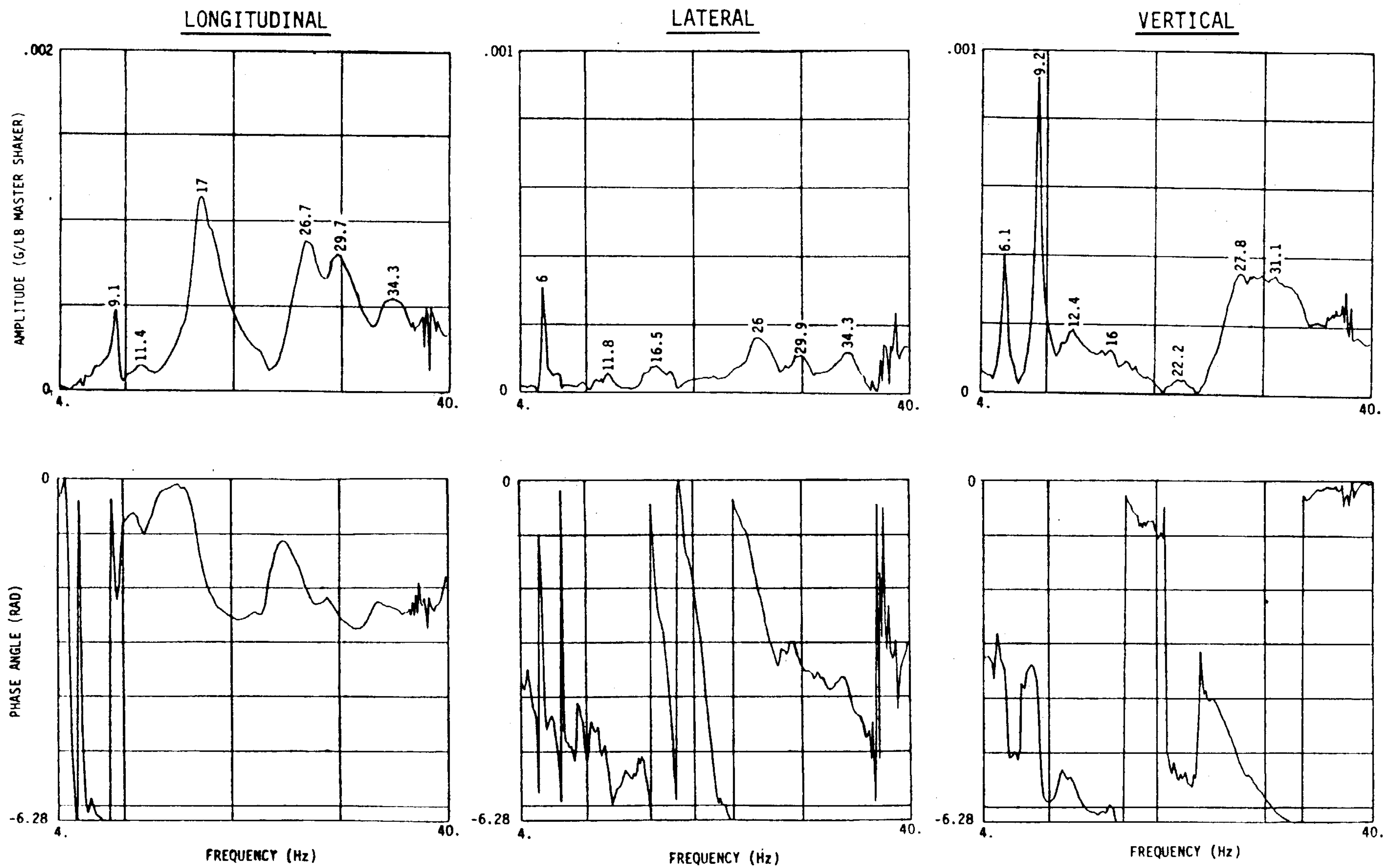

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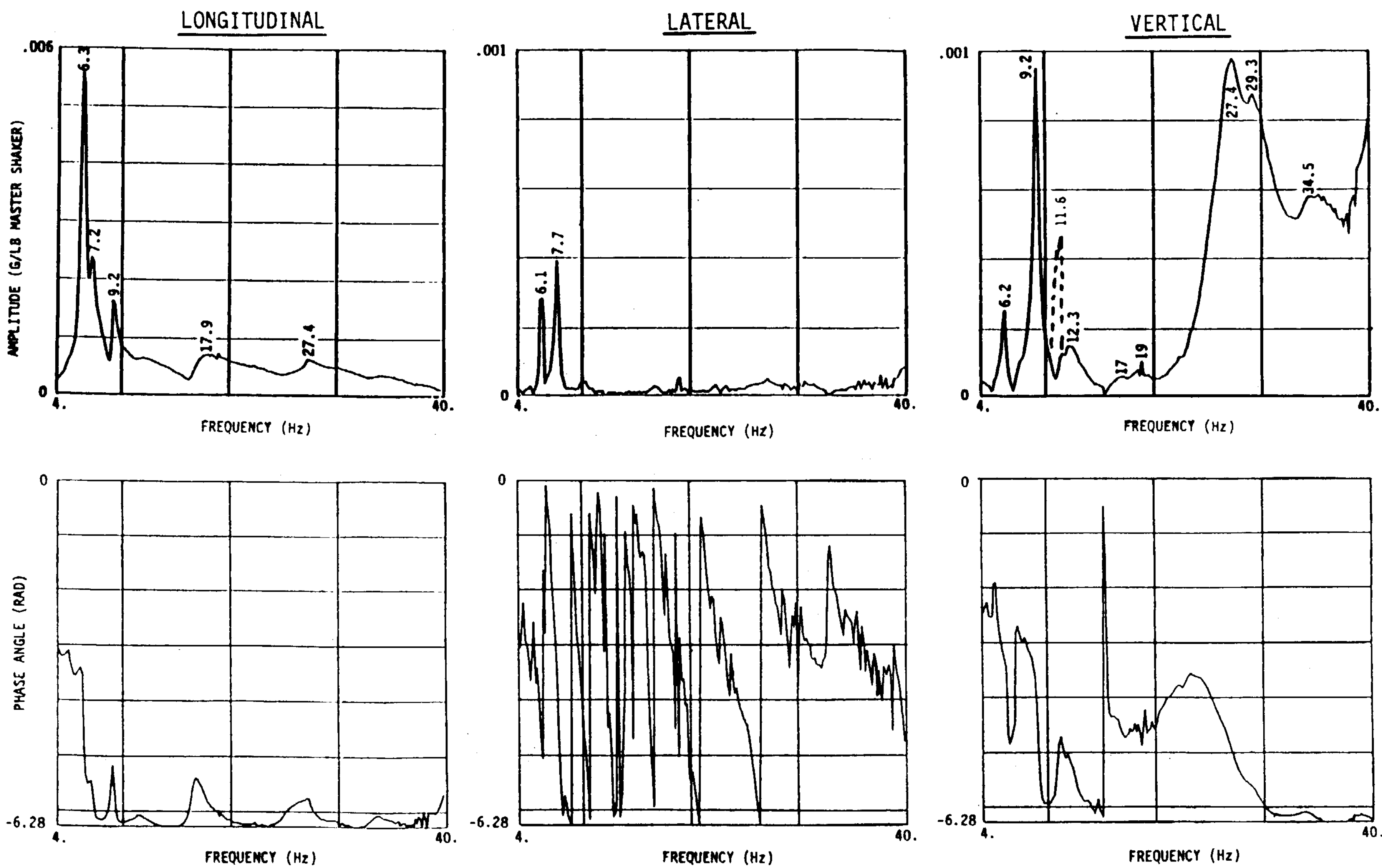

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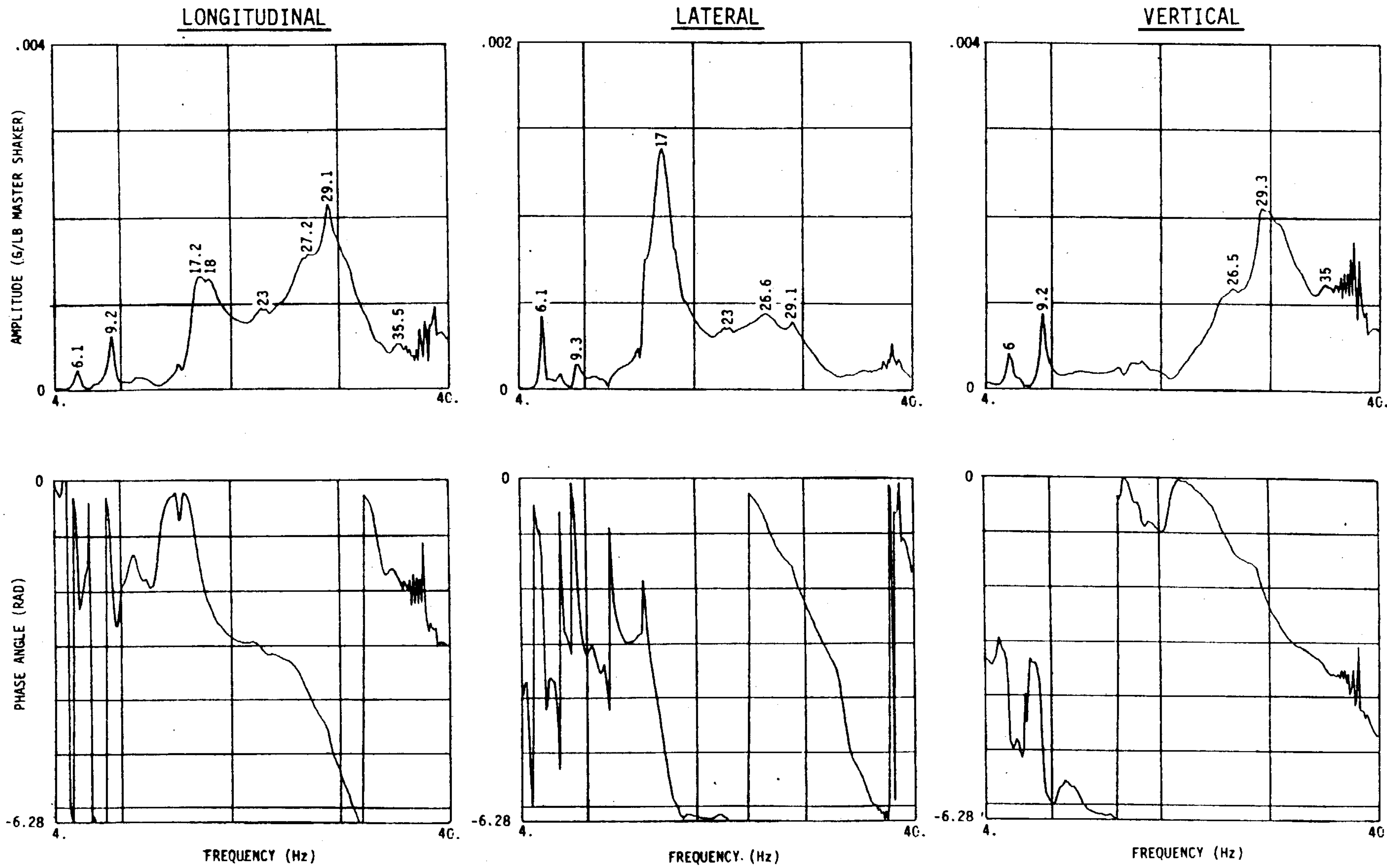

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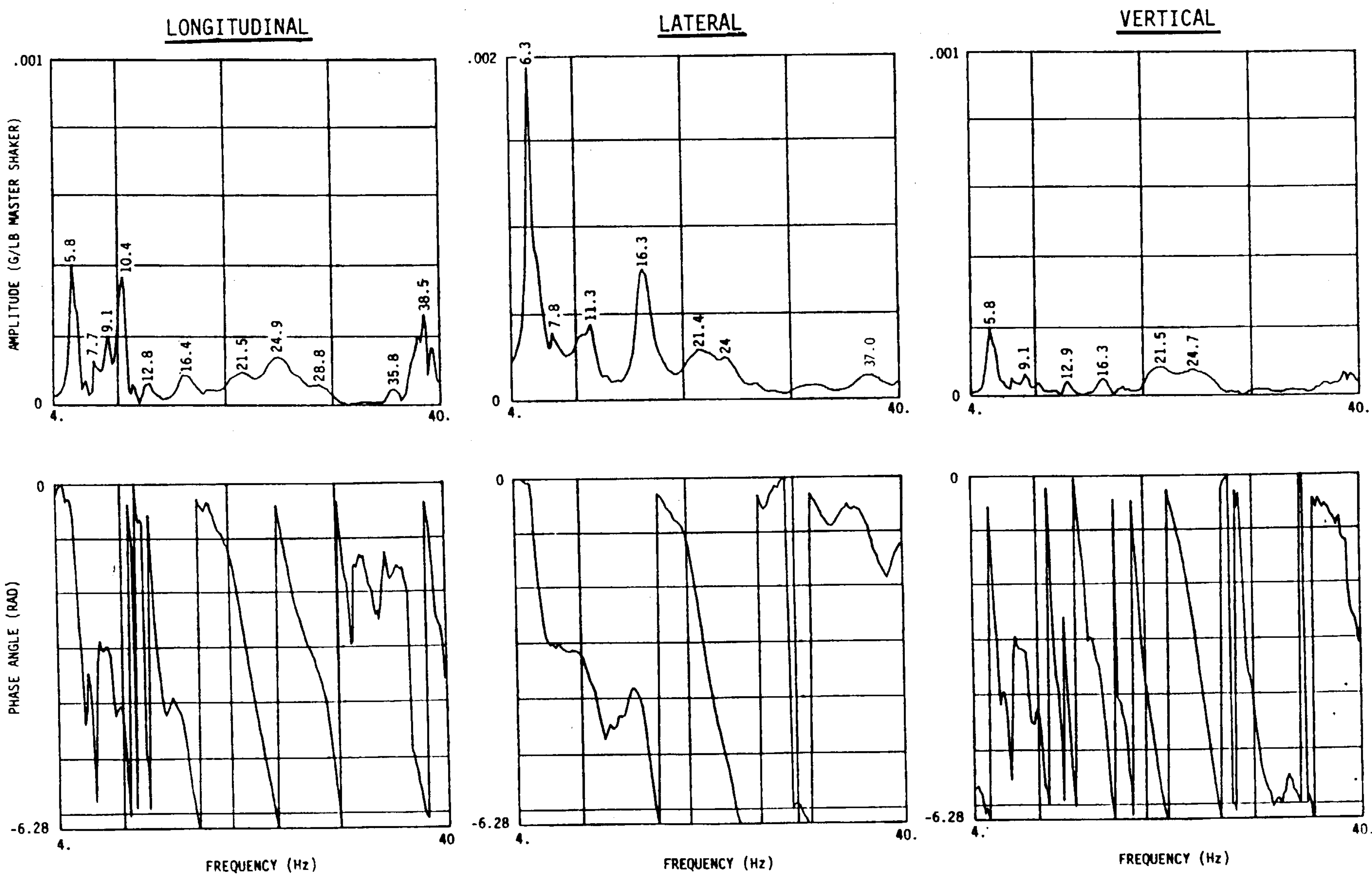

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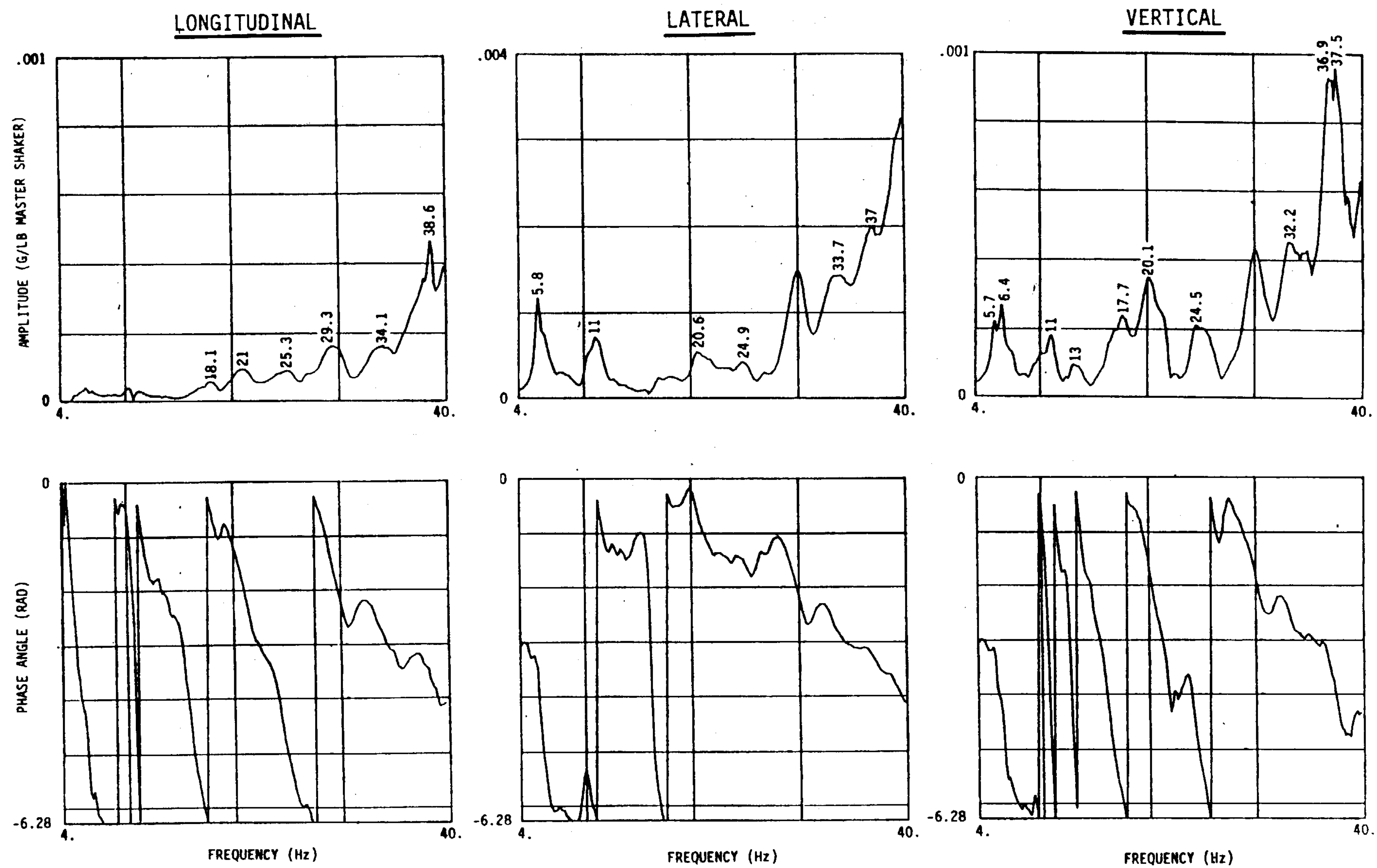

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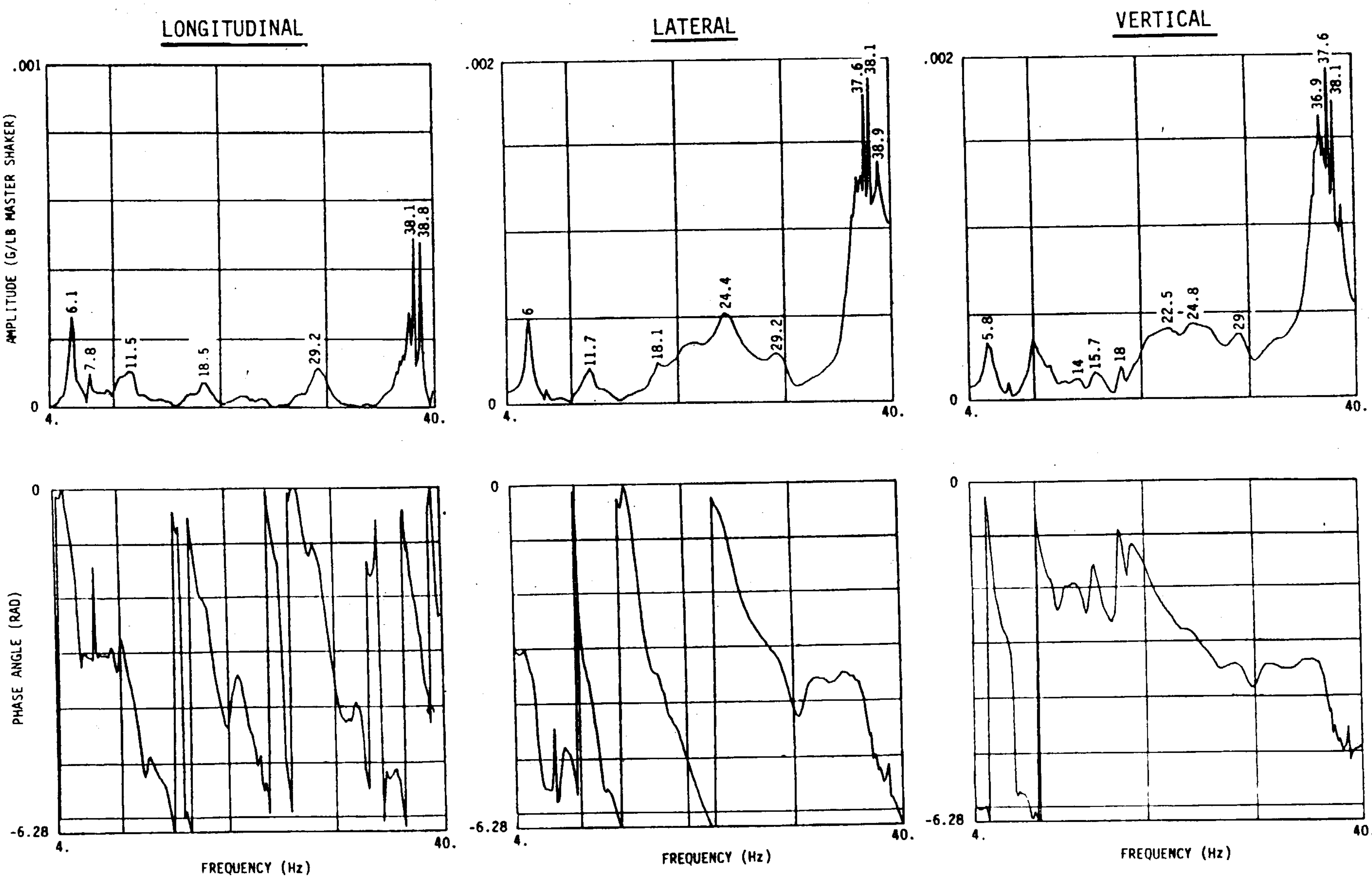

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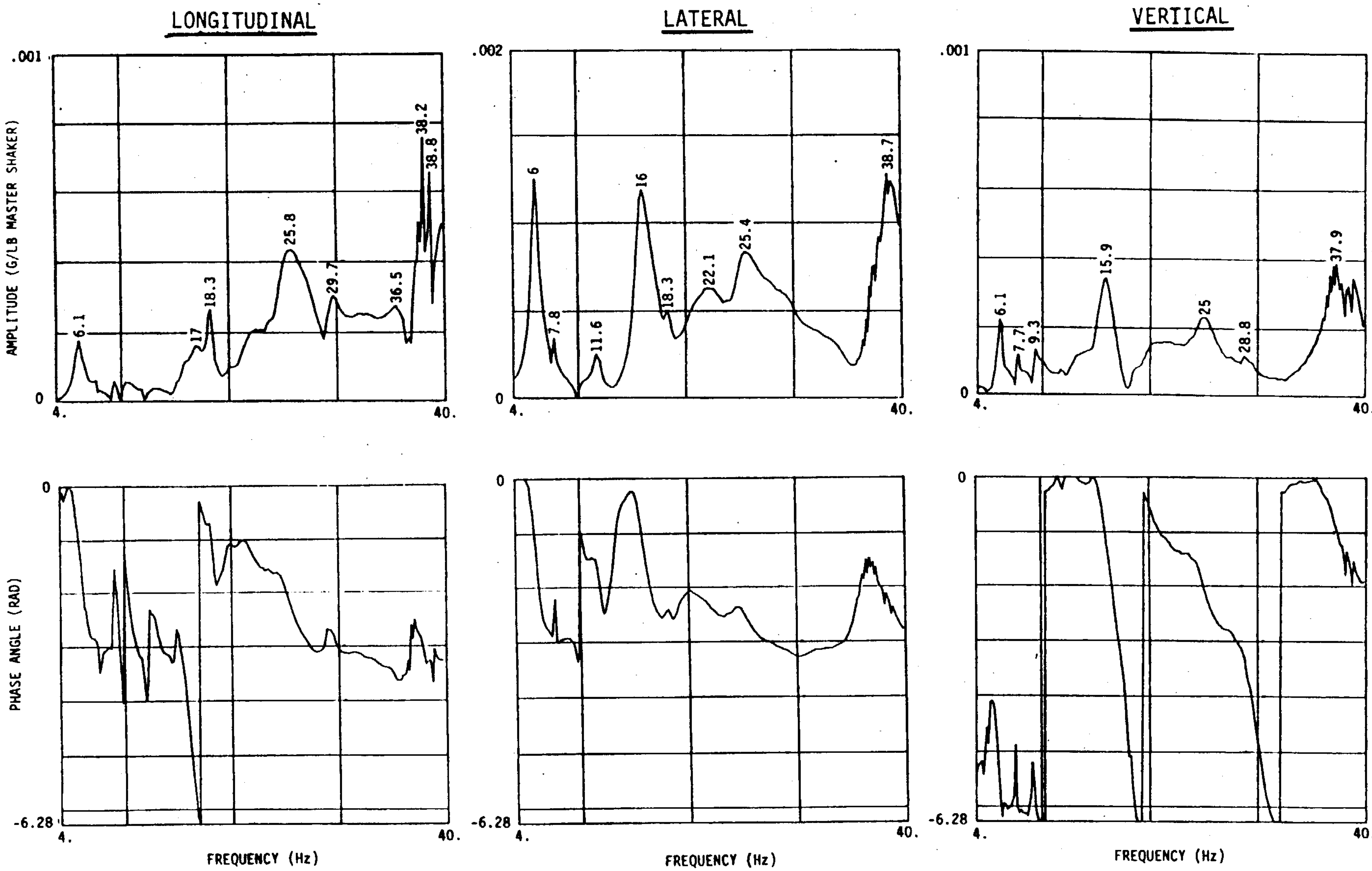

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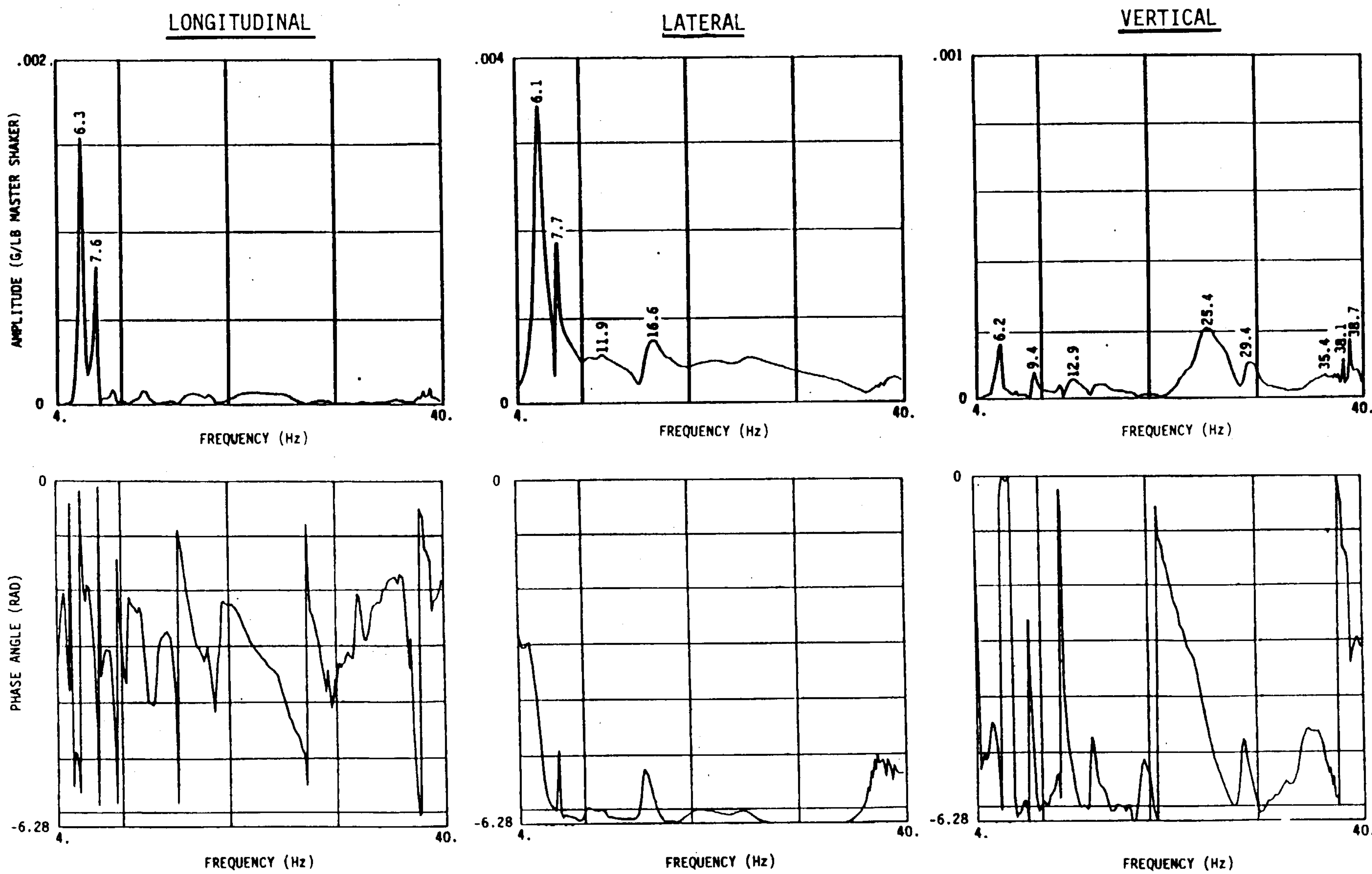

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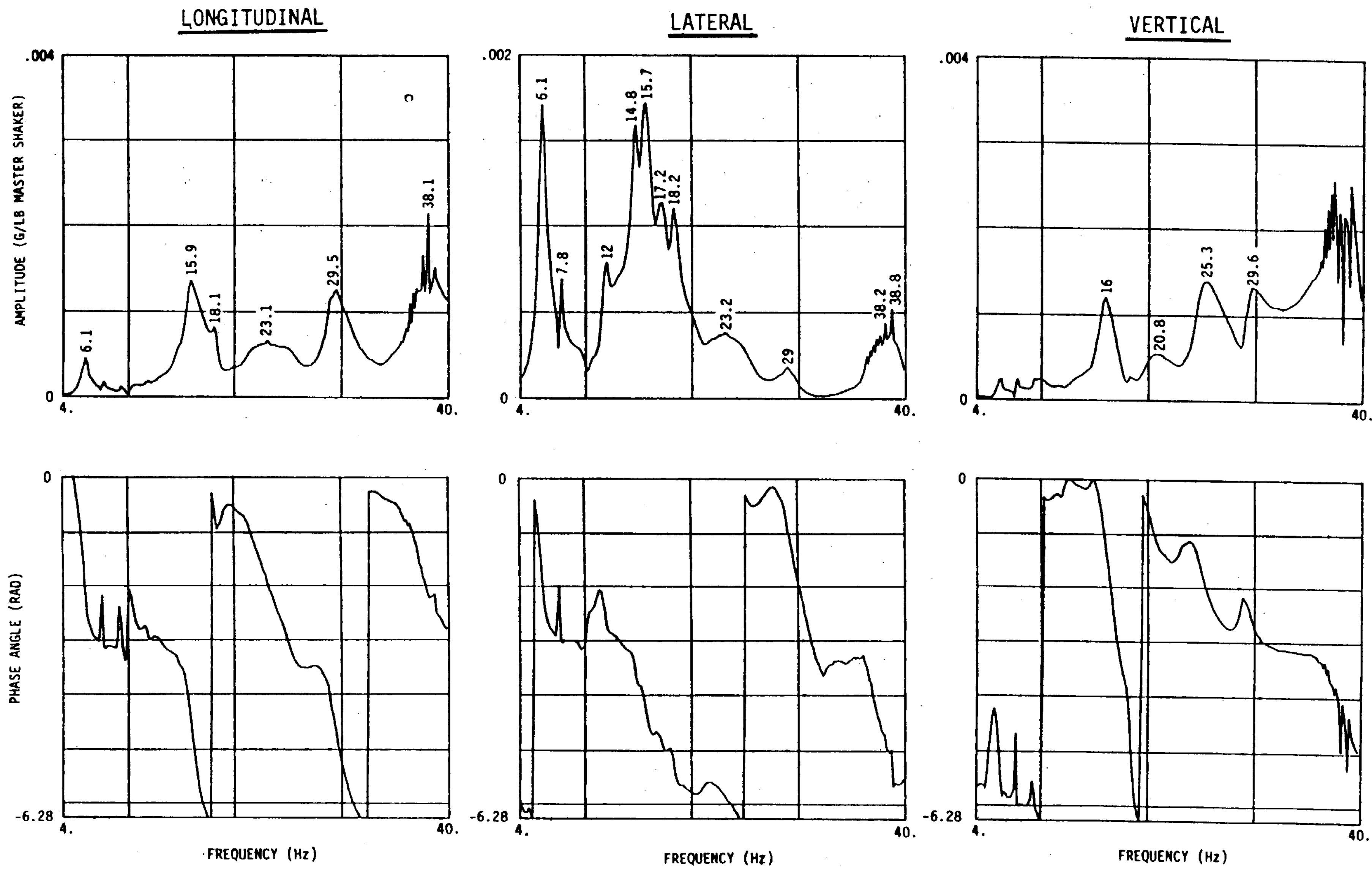

APPENDIX B

SCHEDULE AND RESOURCES

SCHEDULE AND RESOURCES

COMPARISON OF PLANNED AND ACTUAL SCHEDULES

The projected and actual schedules, in terms of elapsed time for the major program activities, are shown in this tabulation. Because of a major change in the aircraft schedule, the planned 12-month program was spread over a period of approximately 28 months.

SCHEDULE AND RESOURCES
COMPARISON OF PLANNED AND ACTUAL SCHEDULE

	ELAPSED TIME-WEEKS PLANNED	ACTUAL
• PLANNING		
PLAN MEASUREMENTS PROGRAM AND PREPARE NASA/INDUSTRY PRESENTATION	10	9
• EXECUTION		
PRETEST PREPARATIONS	12	1
CONDUCT TEST	3	4
POST TEST ANALYSIS AND TEARDOWN; PREPARATION OF TEST RESULTS; PREPARE NASA/INDUSTRY PRESENTATION; FINAL REPORT	16	18

1 THESE ACTIVITIES SPREAD OVER A 13 MONTH PERIOD DUE TO DELAY IN AIRCRAFT AVAILABILITY

SCHEDULE AND RESOURCES

COMPARISON OF ESTIMATED AND ACTUAL MAN-HOURS

This chart summarizes the estimated and actual man-hour expenditures to accomplish the major elements of the program. The total actual expenditure of 5123 man-hours exceeded the estimated hours of 4645 by approximately 10%.

SCHEDULE AND RESOURCES
COMPARISON OF ESTIMATED AND ACTUAL MAN-HOURS

		ENGINEERING MAN-HOURS			MANUFACTURING MAN-HOURS	
		ESTIMATED	ACTUAL		ESTIMATED	ACTUAL
• PLANNING						
PLAN MEASUREMENTS PROGRAM		220	324			
PREPARE AND DELIVER PRESENTATION		200				
• EXECUTION						
PRETEST PREPARATIONS		396	520		1469	1415
CONDUCT TEST		590	786	740	990	1203
POST TEST ANALYSIS AND TEARDOWN	200			250		
PREPARATION OF TEST RESULTS	200	780	875			
PREPARE AND DELIVER PRESENTATION	240					
FINAL REPORT	140					
		2186	2505		2459	2618

• COMBINED ENGINEERING & MANUFACTURING TOTALS

ESTIMATED = 2186 + 2459 = 4645

ACTUAL = 2505 + 2618 = 5123

NASA National Aeronautics and Space Administration

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15. Supplementary Notes

Langley Technical Monitor: Dr. Raymond G. Kvaternik
Final Report

16. Abstract

Boeing Helicopters, together with other U. S. Helicopter Manufacturers, is engaged in a finite element applications program designed to emplace in the United States a superior capability to utilize finite element analysis models in support of helicopter airframe structural design. This program has been given the acronym DAMVIBS (Design Analysis Methods for VIBrationS) and is sponsored by the NASA Langley Research Center.

This report reviews the test plan and presents results for a shake test of the Boeing Model 360 helicopter. Results of this test will serve as the basis for validation of a finite element vibration model of the helicopter.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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