N90-10116

STRUCTURAL STABILITY AUGMENTATION SYSTEM DESIGN USING BODEDIRECT: A QUICK AND ACCURATE APPROACH

By

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ABSTRACT

Both aft and forward sections of long slender aircraft suffer from lateral accelerations in turbulence. Some of these accelerations can be attributed to flexible body bending of the airplane in the 1-6 Hz region. Given an accurate flexible body model of the aircraft, a control law can be employed using lateral acceleration feedback loop augmented with the basic dutch roll yaw damper system to actively damp out these modes.

In this paper a methodology will be presented for a modal suppression control law design using flight test data instead of mathematical models to obtain the required gain and phase information about the flexible airplane. This approach will be referred to as BODEDIRECT. The purpose of the BODEDIRECT program is to provide a method of analyzing the modal phase relationships measured directly from the airplane. These measurements can be achieved with a frequency sweep at the control surface input while measuring the outputs of interest. The measured "Bode-models" can be used directly for analysis in the frequency domain, and for control law design. Besides providing a more accurate representation for the system inputs and outputs of interest, this method is quick and relatively inexpensive.

To date, the BODEDIRECT program has been tested and verified for computational integrity. Its capabilities include calculation of series, parallel and loop closure connections between Bode-model representations. System PSD, together with gain and phase margins of stability may be calculated for successive loop closures of multi-input/multi-output systems. Current plans include extensive flight testing to obtain a Bode model representation of a commercial aircraft for design of a structural stability augmentation system.

In addition to the BODEDIRECT approach, an indirect approach using flight test data to derive a mathematical mode for analysis using a Transfer Function Matching Routine will be presented along with the strengths and weaknesses of each approach.

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BOEING COMMERCIAL AIRPLANES

THE RIDE QUALITY PROBLEM

1 Rigid Body Airplane

a) Roll
b) Pitch
c) * Yaw
d) * Lateral Motion
e) Vertical Motion
f) Longitudinal Motion

2 Structural Airplane (Long Slender Bodies)

a) * Body Bending Modes
b) Tortional Modes
c) Wing and Empennage Modes

THE MODES WHICH MUST BE ACTIVELY CONTROLLED INCLUDE

<u>BASIC YAW DAMPER :</u>

The Dutch Roll Mode

Spiral Mode for turn coordination

<u>MODAL SUPPRESSION SYSTEM :</u>

1st and 2nd Body Bending Modes

All other modes must be passively controlled or have sufficient gain and phase margins.

Note : This discussion is limited to the sysnthesis of a modal suppression system using the BODEDIRECT program. It is assumed that a good basic yaw damper already exists.

TRADITIONAL METHOD

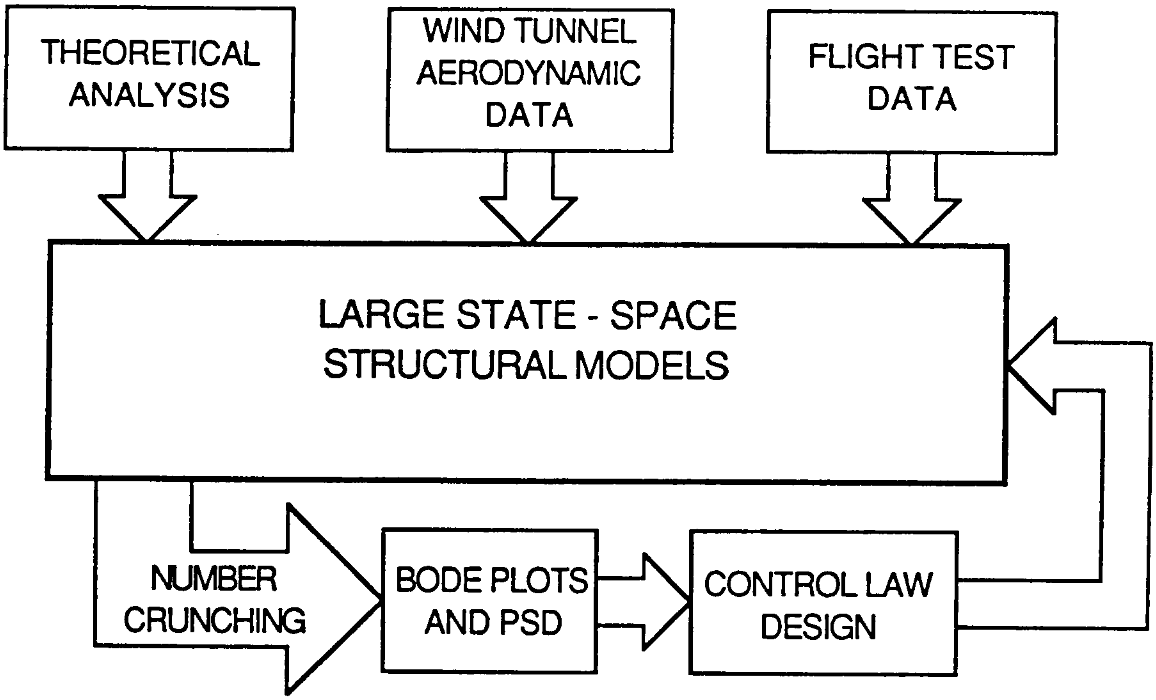

FIGURE 1A

BODEDIRECT

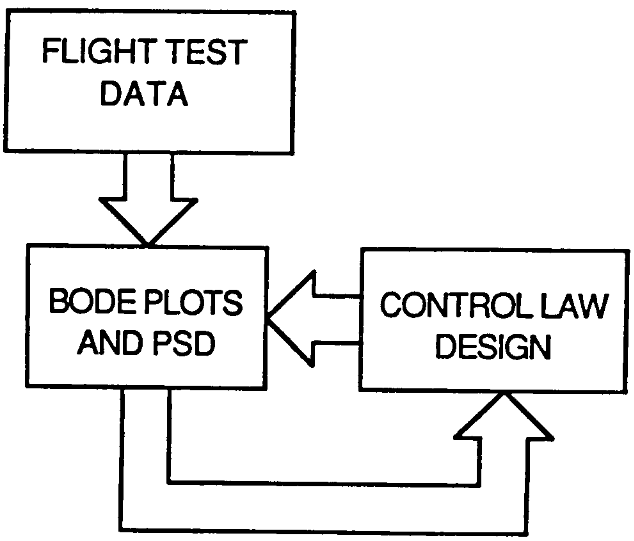

FIGURE 1B

Mathematical Models	BODEDIRECT
Advantages : 1) No prototype is necessary 2) Analysis in both time and frequency domain 3) Observability/controllability directly available 4) Eigenvalues & damping ratios directly available	**Disadvantages :** 1) A prototype must exist 2) Analysis in frequency domain only 3) Observability/controllability not directly available 4) Eigenvalues/damping ratios not directly available
Disadvantages : 1) Require large computing budgets (main frame computer) 2) Lack required precision	**Advantages :** 1) Quick and inexpensive (work station environment) 2) Accurate

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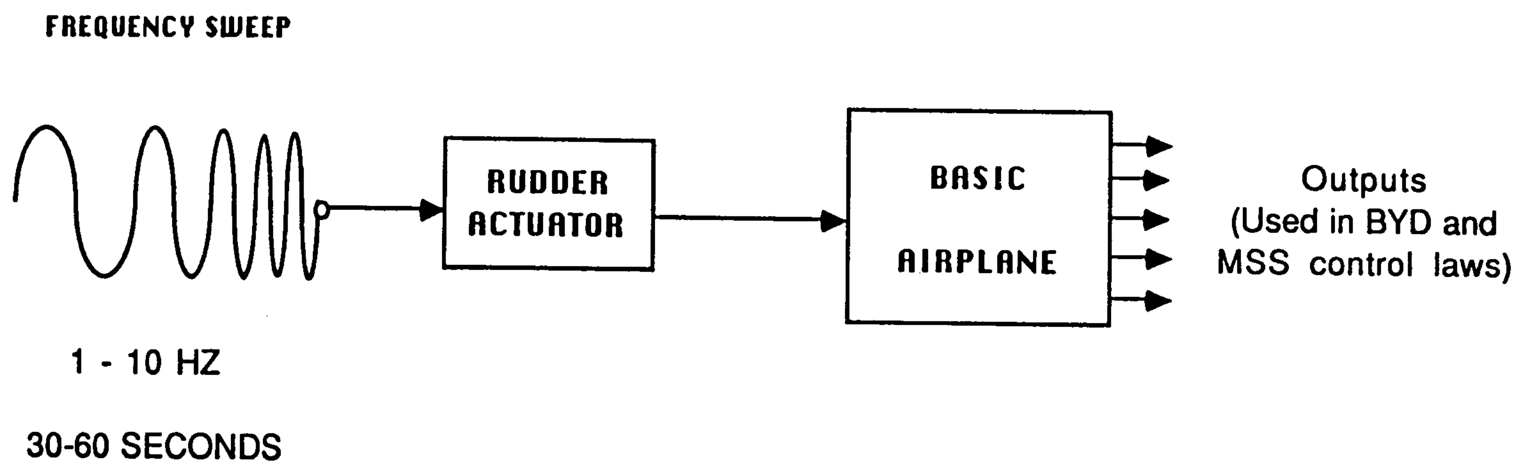
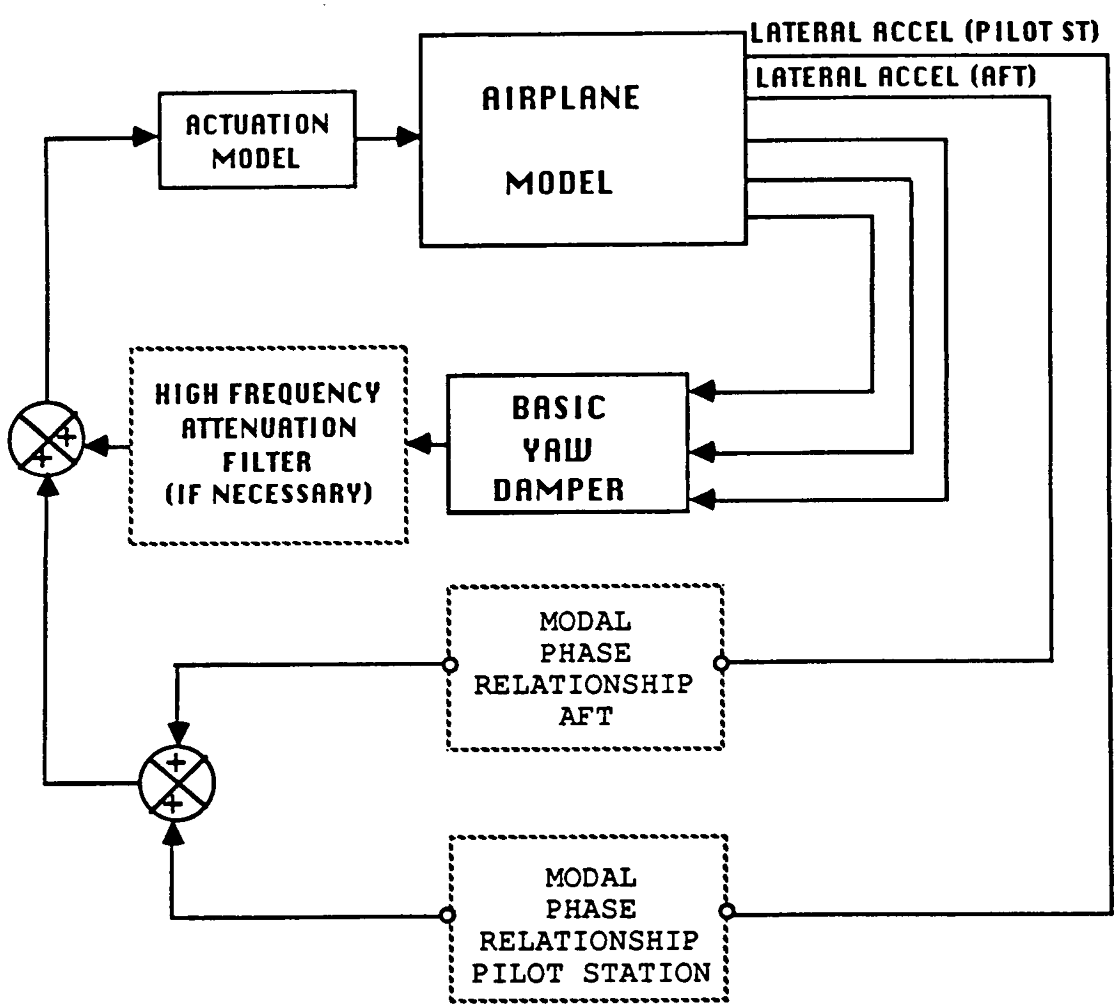
BODE - MODEL GENERATION



Bode-models are measured for all inputs and outputs of interest for the free-airplane

MODAL SUPPRESSION SYSTEM

CONTROL LAW DESIGN



For control law design, we determine the modal phase relationship in the feedback loop such that a compensator can be synthesized to bring the feedback signal into phase with the desired mode(s).

DATA PRE-PROCESSING

Each bode-model requires magnitude and phase at each frequency point.

With the current program version,

Up to 500 frequency points may be stored for the frequency range. The frequency vector may be loaded from a file or generated.

Example:

***LOAD FREQUENCY POINTS**
201

Number of frequency points (from file)

***GENERATE FREQUENCY POINTS**
LOG
0.1,10.0,201

Starting point   Ending point   Number of frequency points

Frequency points may be loaded or generated in log or linear scale.

Similarly bode-models may either be loaded from a file in terms of magnitude and phase or generated from a transfer function.

Example:

***LOAD 'modelname'**

***GENERATE 'modelname'**

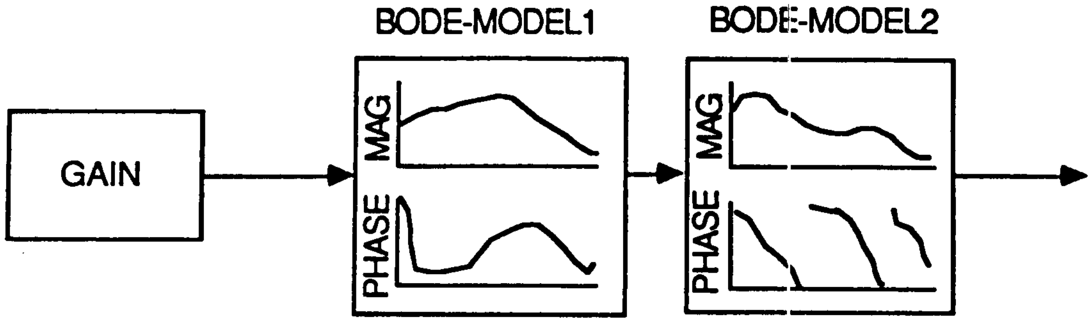
transfer function coefficients

In addition, a bode-model may be extrapolated from a previous bode-model or a set of lab test data using the command:

***CREATE BODE-MODEL 'modelname'**

data points to extrapolate

This allows quick bode-model generation from a few test data points.



*CONNECT IN SERIES :

MAG = GAIN * MAG1 * MAG2

PHASE = PHASE1 + PHASE2

IF(GAIN .LT. 0) PHASE = PHASE + 180°

*CONNECT IN PARALELL

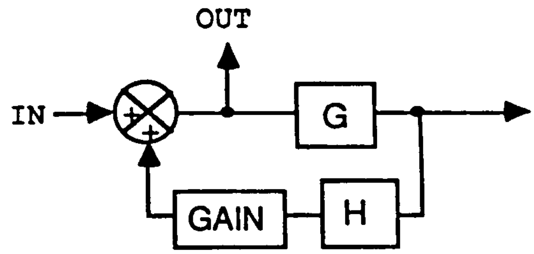
$$MAG = \sqrt{XCOM^2 + YCOM^2}$$

$$PHASE = TAN^{-1}(YCOM/XCOM)$$

where

$$XCOM = GAIN1 * MAG1 * COS (PHASE1) + GAIN2 * MAG2 * COS (PHASE2)$$

$$YCOM = GAIN1 * MAG1 * SIN (PHASE1) + GAIN2 * MAG2 * SIN (PHASE2)$$



***RESOLVE FEEDBACK JUNCTION**

$$MAG_{FBAC} = 1/\sqrt{XCOM^2 + YCOM^2}$$

$$PHASE_{FBAC} = -TAN^{-1}(YCOM/XCOM)$$

where

$$XCOM = 1.0 - MAG\ (G*H) * COS\ (PHAS\ (G*H)) * GAIN$$

$$YCOM = -MAG\ (G*H) * SIN\ (PHAS\ (G*H)) * GAIN$$

***RESOLVE CLOSED-LOOP SYSTEM**

CLOSED-LOOP = FBAC * G (SERIES CONNECTION)

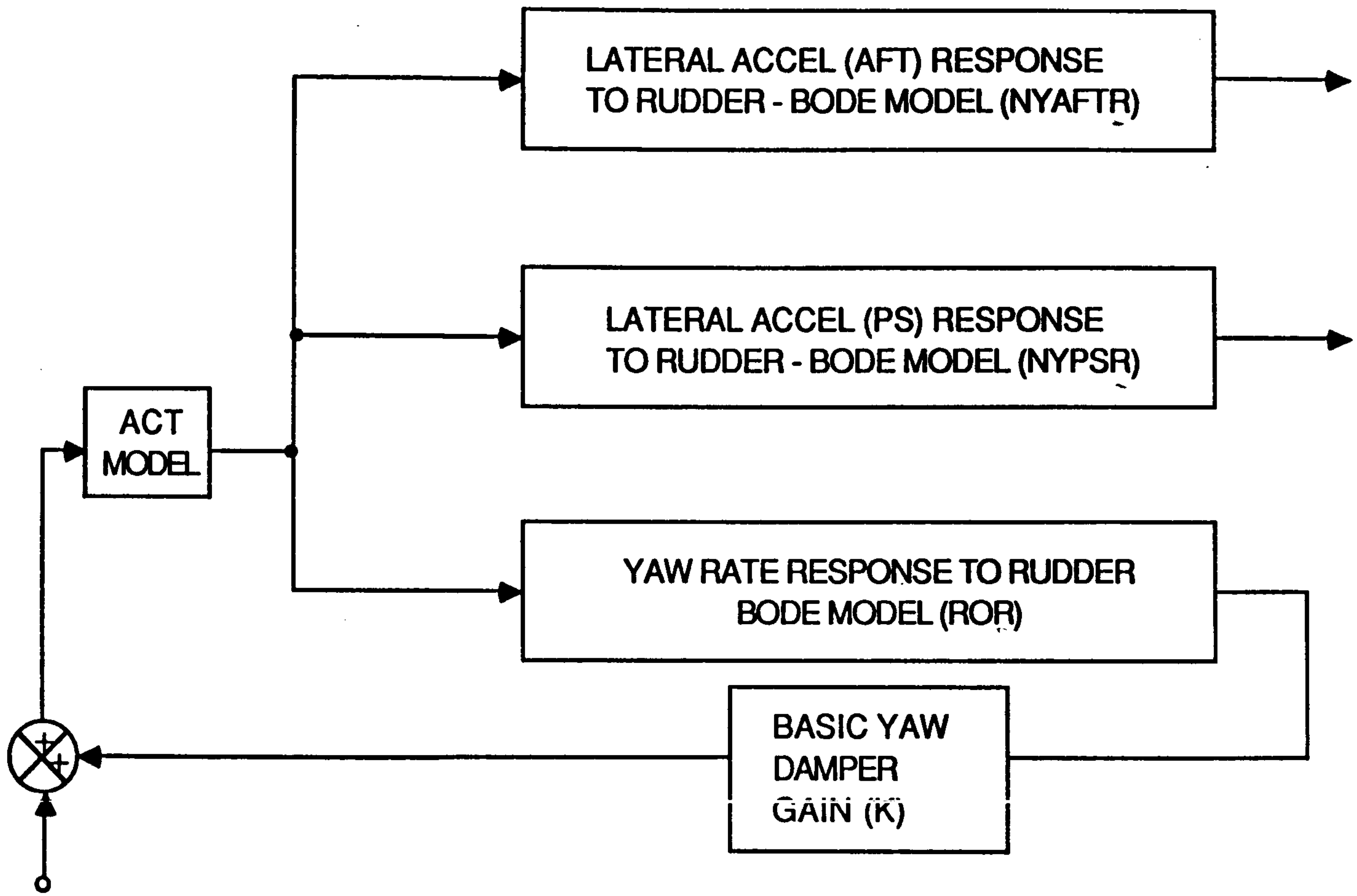
***COMPUTE BODE-LOCUS**

(This routine computes a locus of bode-plots for a range of specified closed-loop gains. The user provides G,H, and the range of gain values.)

***COMPUTE GAIN AND PHASE MARGINS**

(The gain and phase margins are determined from the broken loop system bode plot. For good stability the gain should be -6 db or less at the $\pm 180^{o}$ crossings. Additionally, the phase should be $\pm 45^{o}$ away from $\pm 180^{o}$ at the 0 db crossing. For clarity, all phase values are scaled between 0 and -360 in all bode-model plots. Uncertainty values for gain(db) and phase(deg) may be declared by the user. The program will warn of near 0 db or 180 deg crossings based on these uncertainties.)

EXAMPLE USING SIMPLE (YAW RATE ONLY) BASIC YAW DAMPER



$$MPR_{AFT} = \frac{G}{1 + GH} * NYAFTR$$

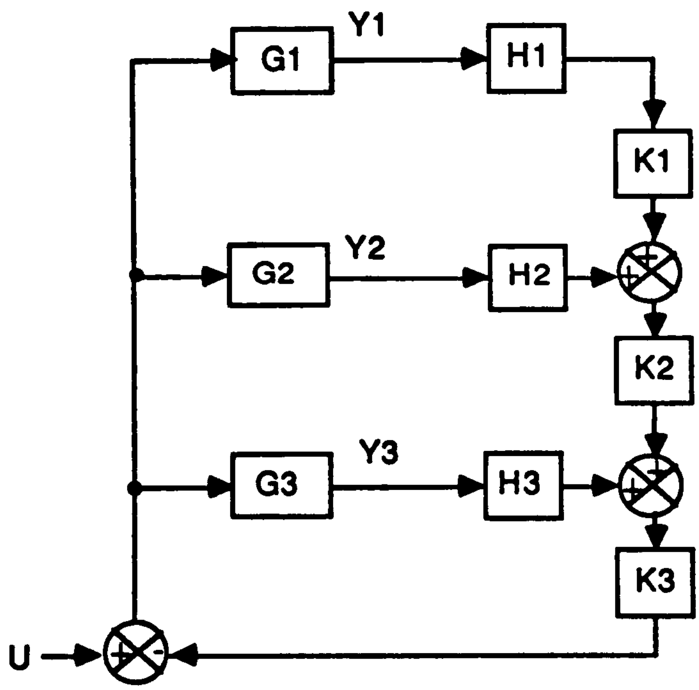
$$MPR_{PS} = \frac{G}{1 + GH} * NYPSR$$

where G = act model

and $H = ROR * K$

*RESOLVE OPEN-LOOP SYSTEM

THIS ROUTINE WILL RESOLVE THE OPEN LOOP BODE-MODELS (G1, G2, G3...) FOR A MULTILOOP SYSTEM IF THE CLOSED-LOOP AND FEEDBACK BODE-MODELS ARE KNOWN. A GAUSS-JORDON SOLUTION IS REPEATED FOR EACH FREQUENCY POINT TO SOLVE THE SET OF SIMULTANEOUS EQUATIONS.



THIS ROUTINE MAY BE USEFUL WHEN THE FLIGHT TEST DATA IS OBTAINED WITH THE BASIC YAW DAMPER ON AND THE EFFECTS OF THE YAW DAMPER ON STRUCTURAL MODES ARE THE DESIRED INFORMATION.

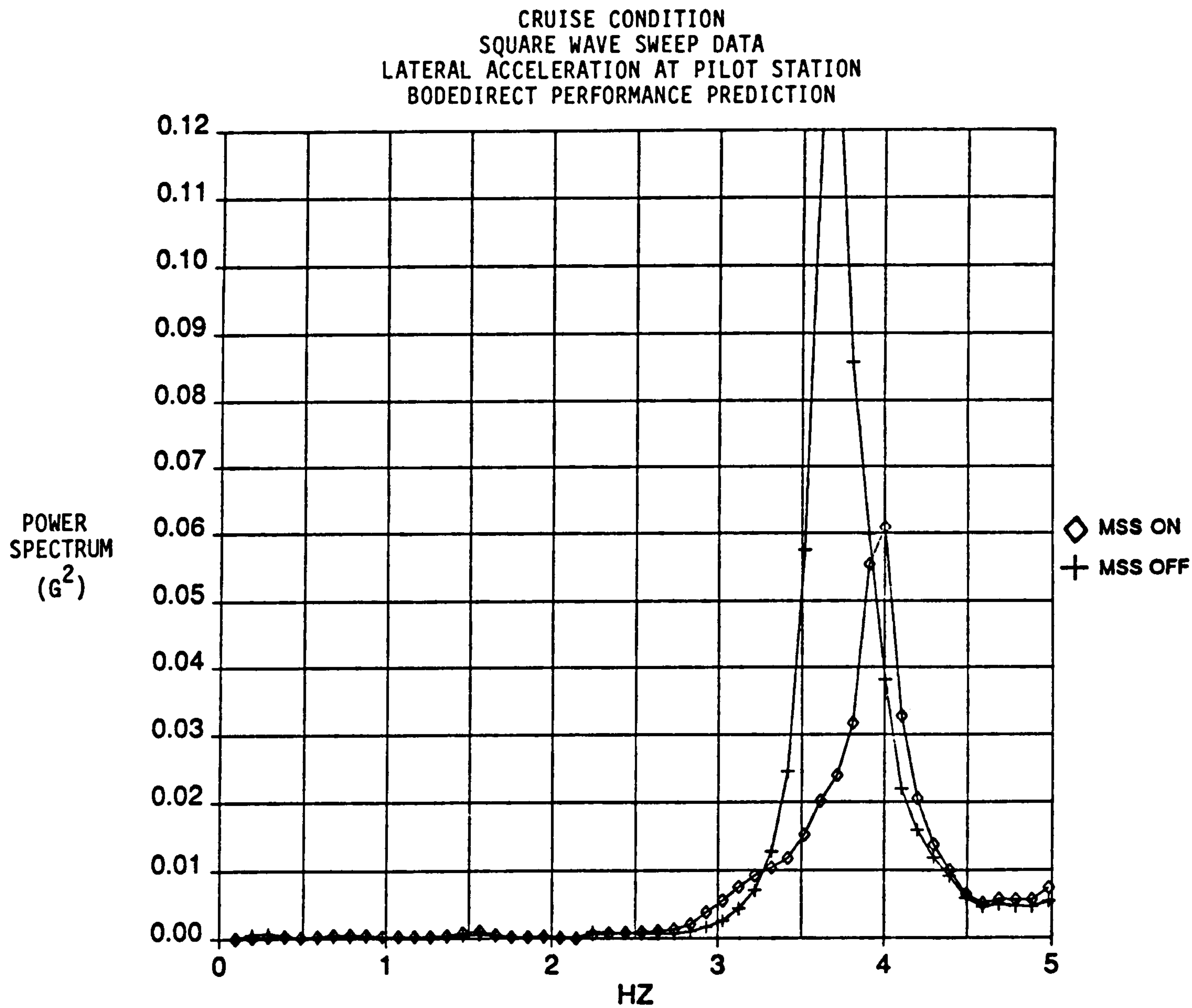
BODEDIRECT INCLUDES NONLINEAR CAPABILITIES

which incorporates a describing function (DF) analysis for the following :

a) hysteresis
b) rate or position limits
c) deadzones
d) variable gain

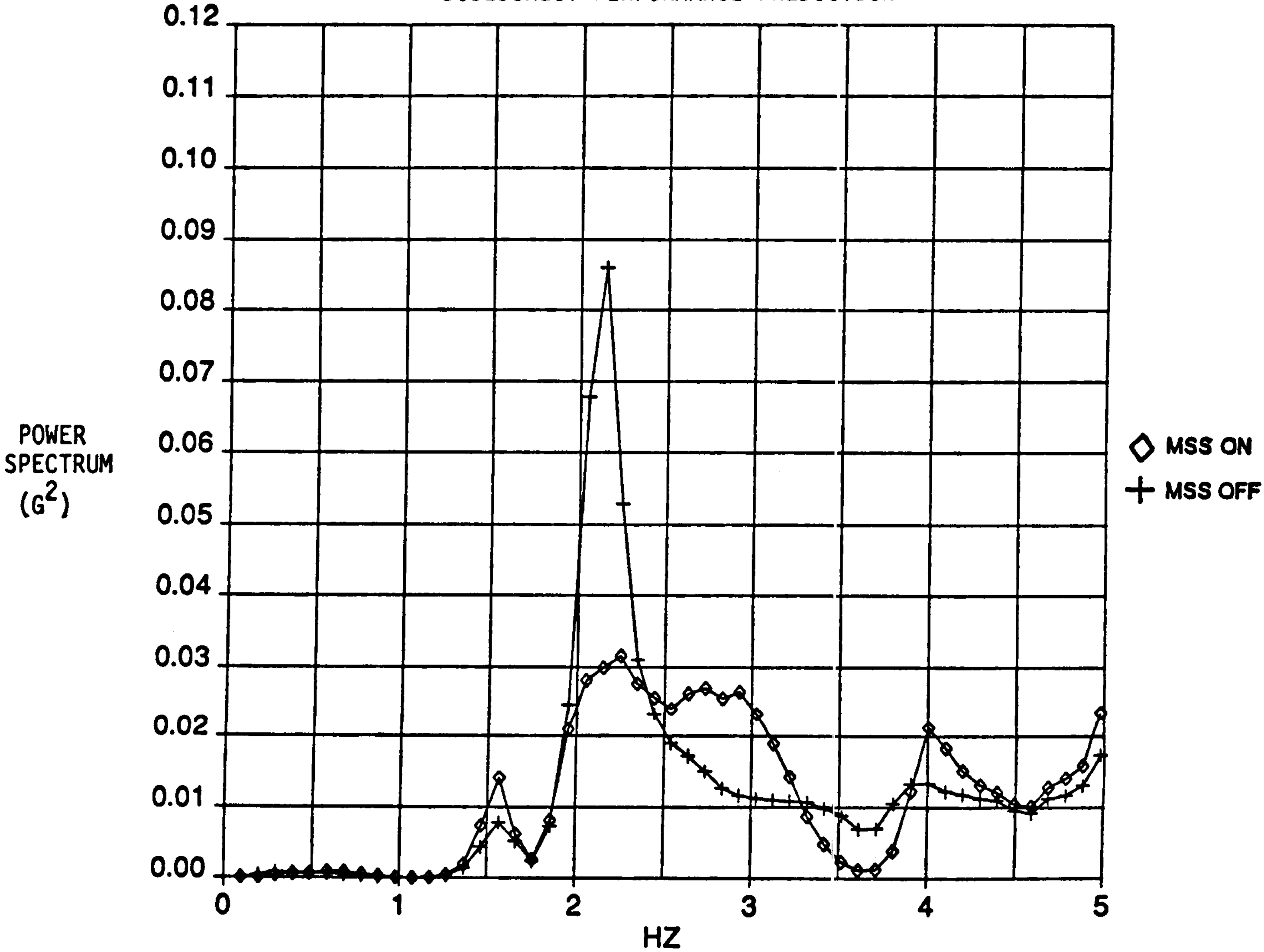
common nonlinearities in control actuation (rudder) systems

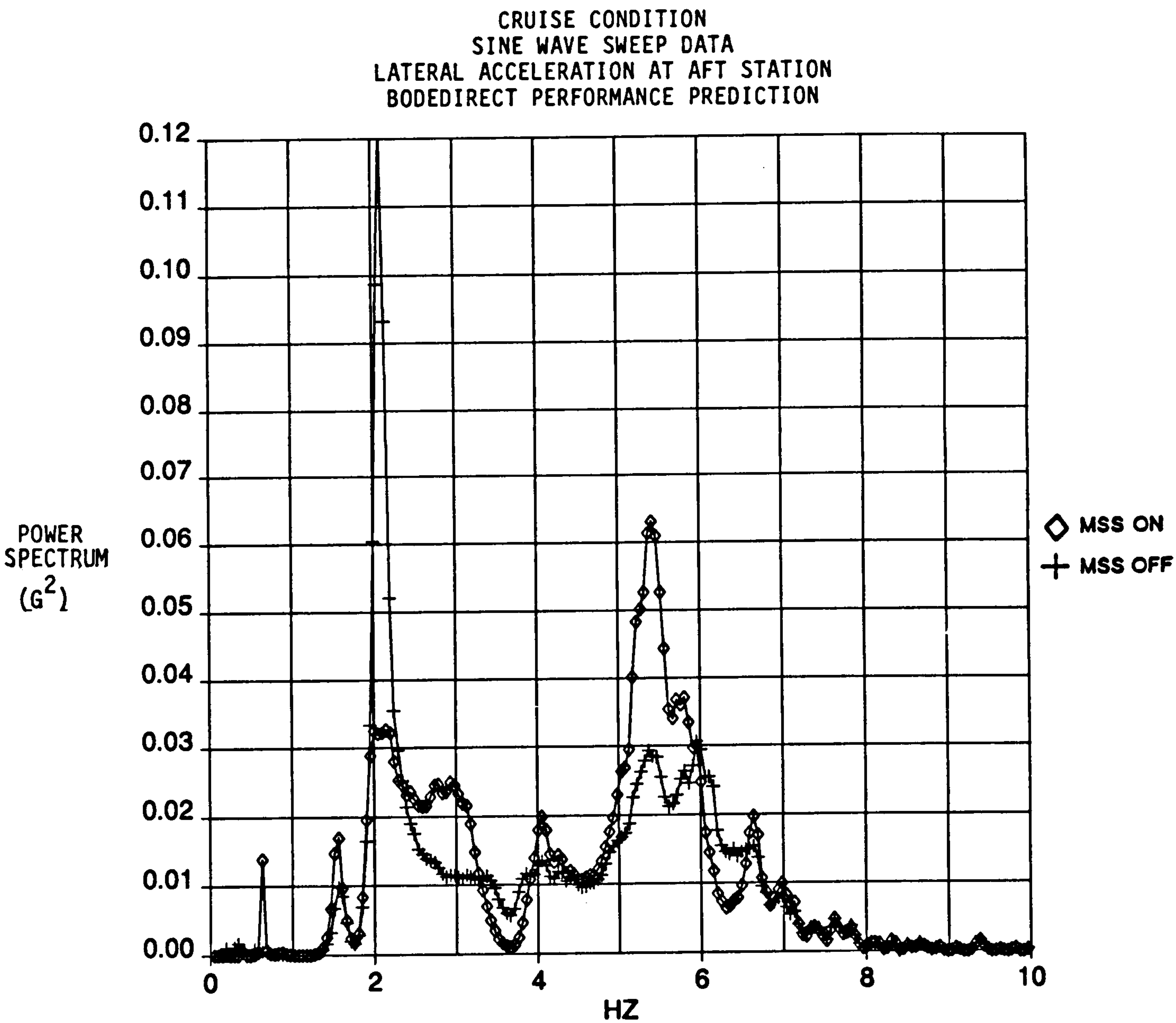
Using this analysis, different bode-models may be generated as a function of input amplitude. Using polar plots for the describing function a prediction can be made if limit cycling will occur and at what frequency and amplitude. Notice that BODEDIRECT may use actual lab test data for the rudder system if desired over the theoretical model.

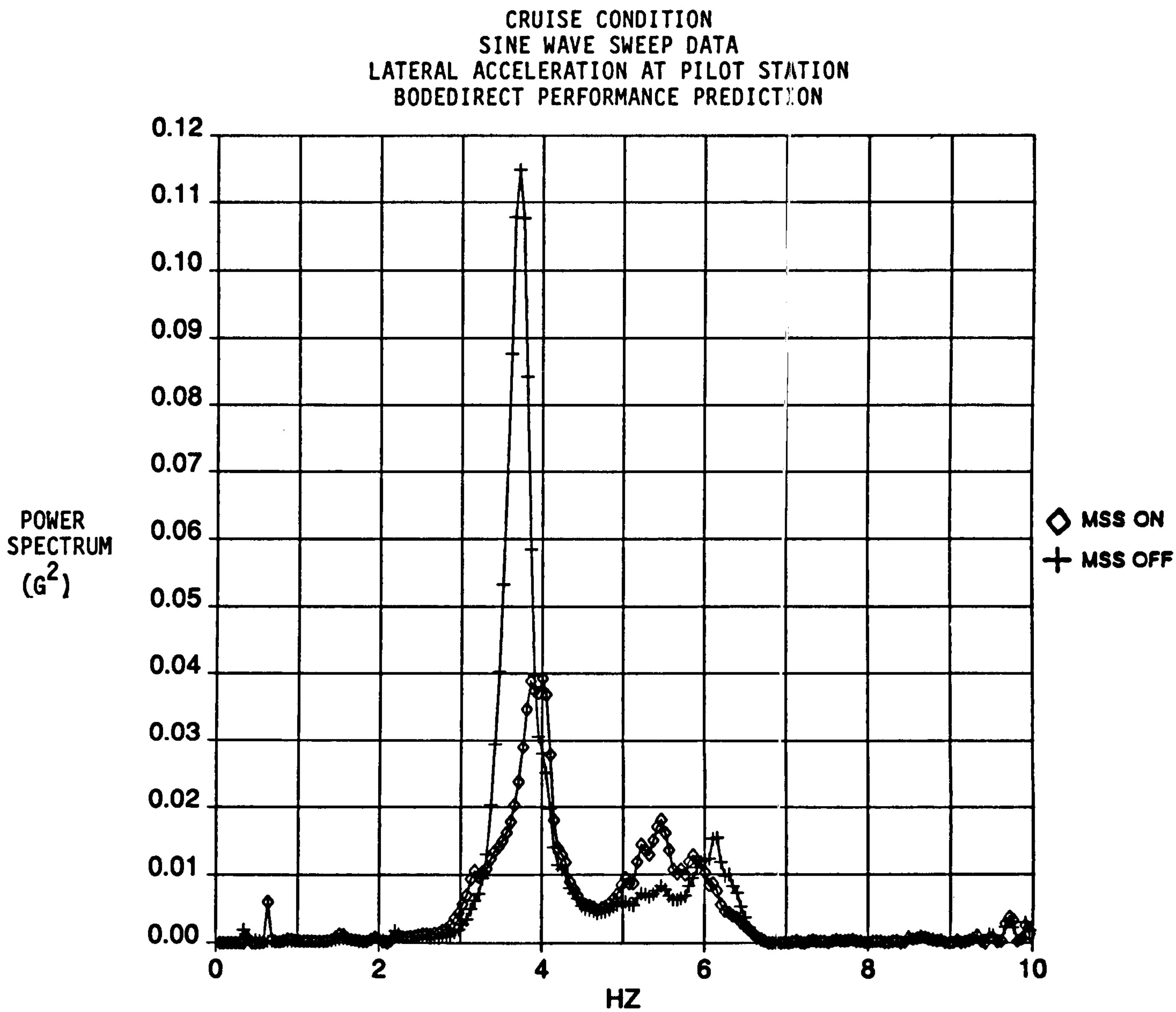


CRUISE CONDITION
SQUARE WAVE SWEEP DATA
LATERAL ACCELERATION AT PILOT STATION
BODEDIRECT PERFORMANCE PREDICTION
POWER SPECTRUM (G^2)
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
HZ
MSS ON
MSS OFF

CRUISE CONDITION
SQUARE WAVE SWEEP DATA
LATERAL ACCELERATION AT AFT STATION
BODEDIRECT PERFORMANCE PREDICTION




CRUISE CONDITION
SINE WAVE SWEEP DATA
LATERAL ACCELERATION AT AFT STATION
BODEDIRECT PERFORMANCE PREDICTION
POWER SPECTRUM (G^2)
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
2
4
6
8
10
HZ
MSS ON
MSS OFF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BODEDIRECT PERFORMANCE PREDICTION
POWER SPECTRUM (G^2)
0.12
0.11
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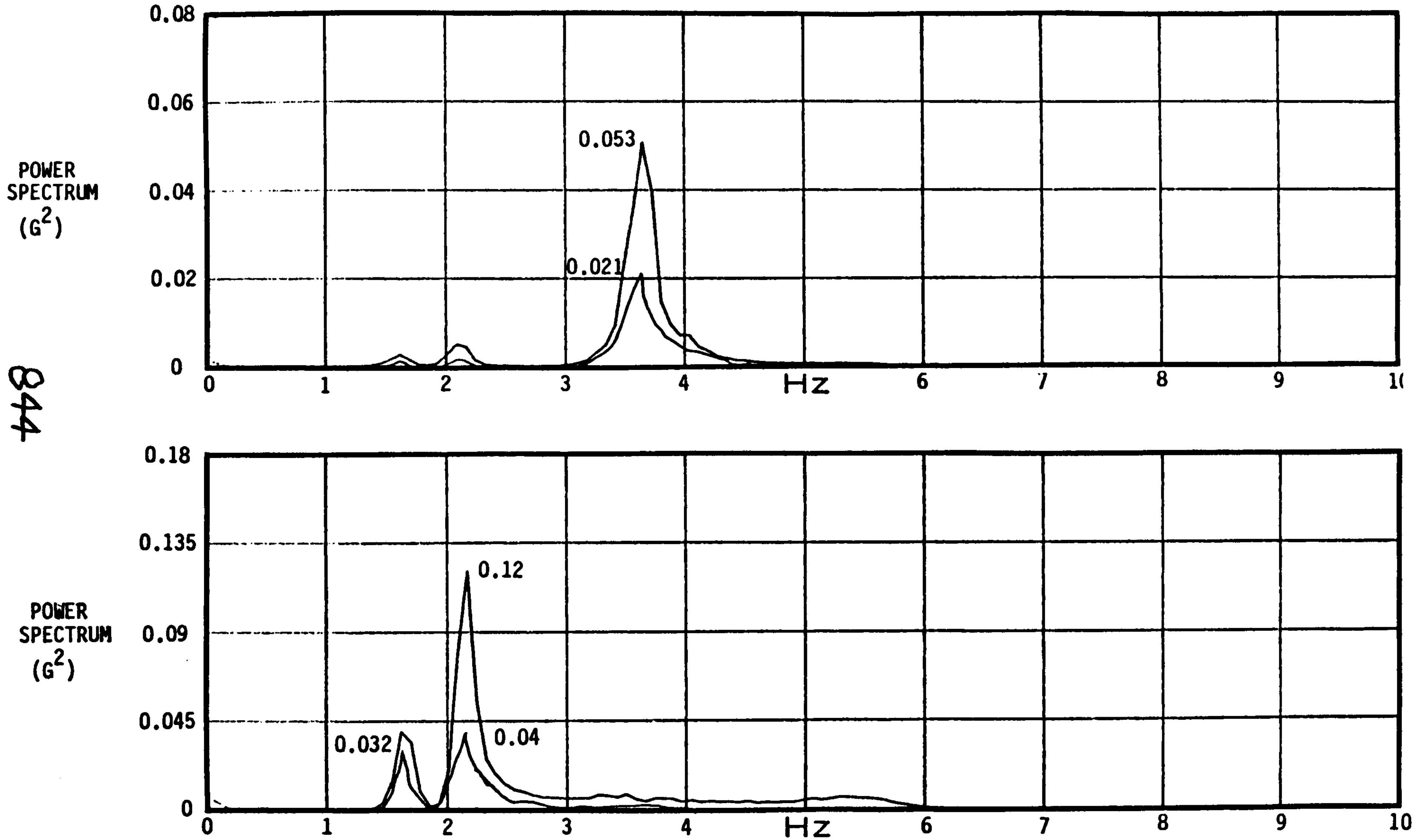
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
2
4
6
8
10
HZ
MSS ON
MSS OFF

FLIGHT TEST RESULTS - CRUISE CONDITION



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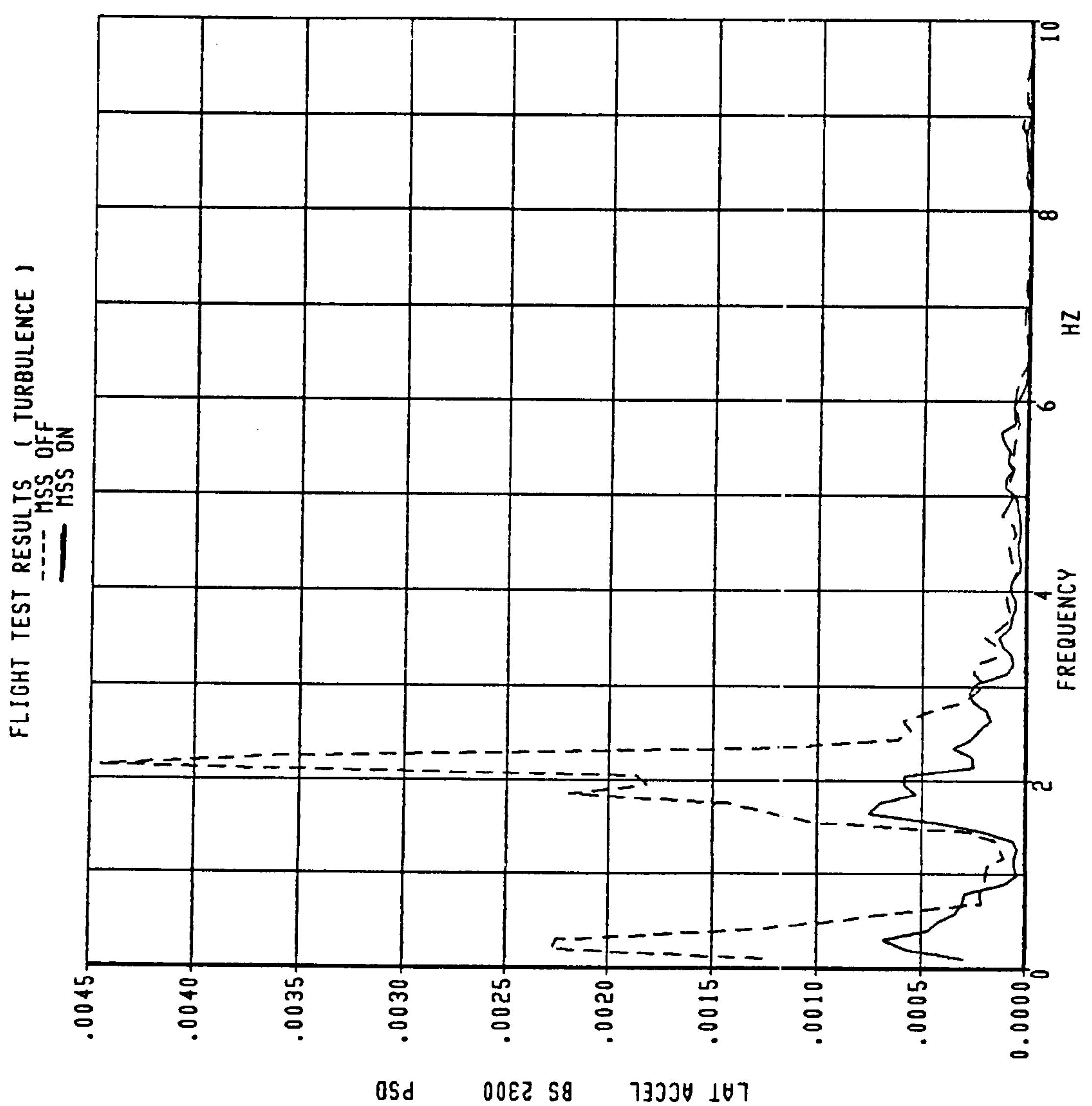
8000 ft
.5M



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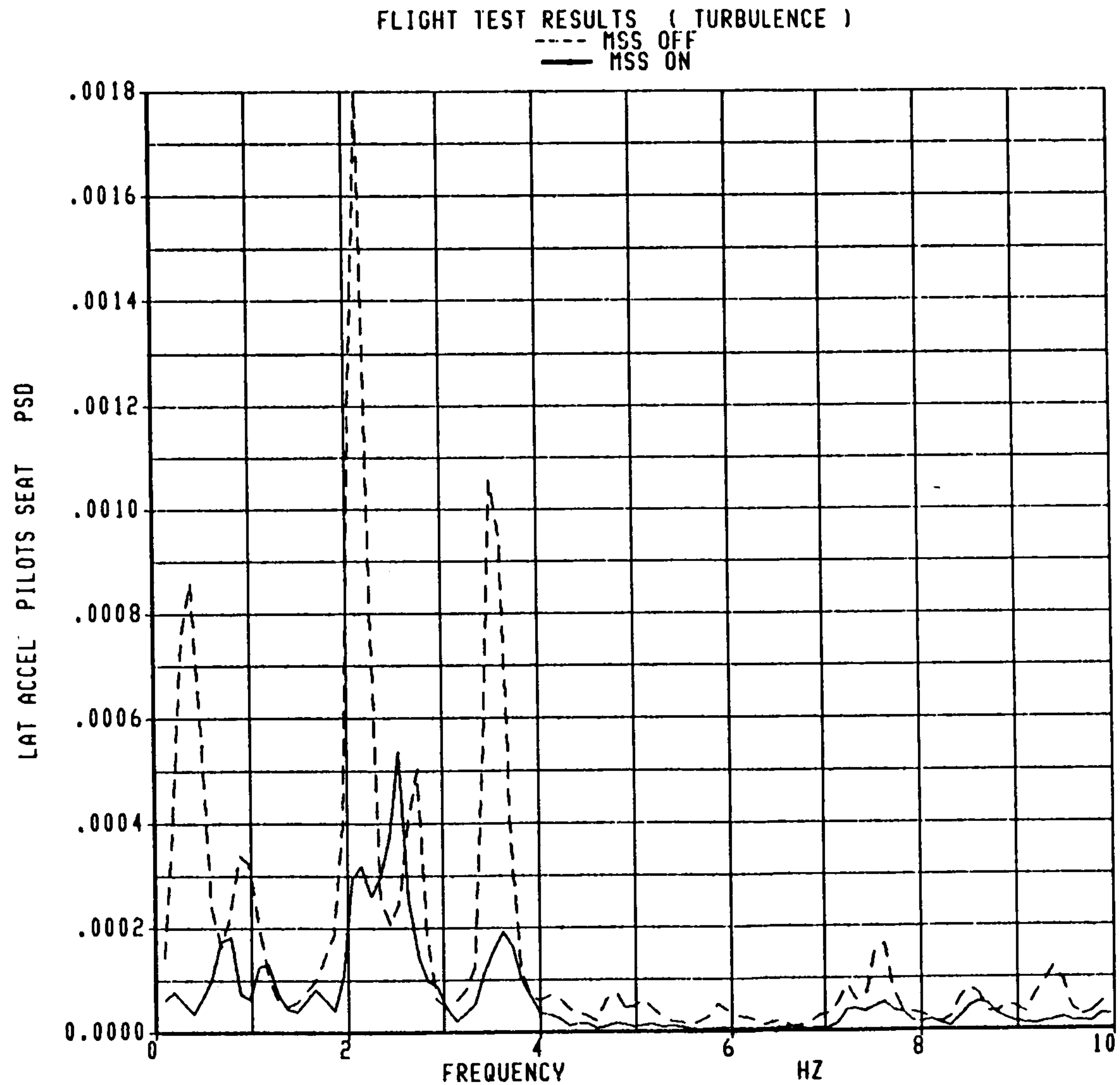

8000 ft

.5M

846

Mathematical Models	BODEDIRECT
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1) Require large computing budgets (main frame computer)	1) Quick and inexpensive (work station environment)
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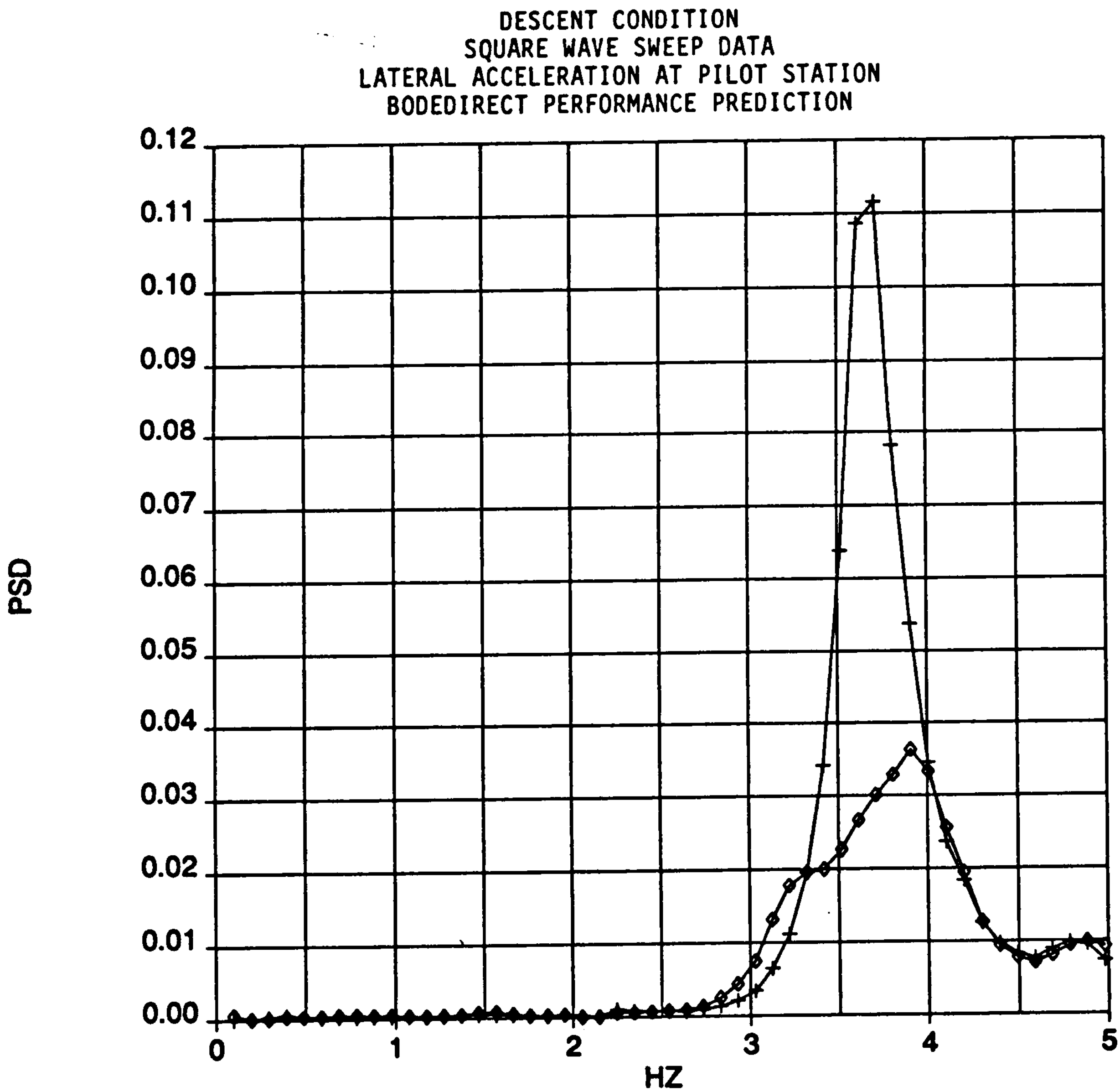
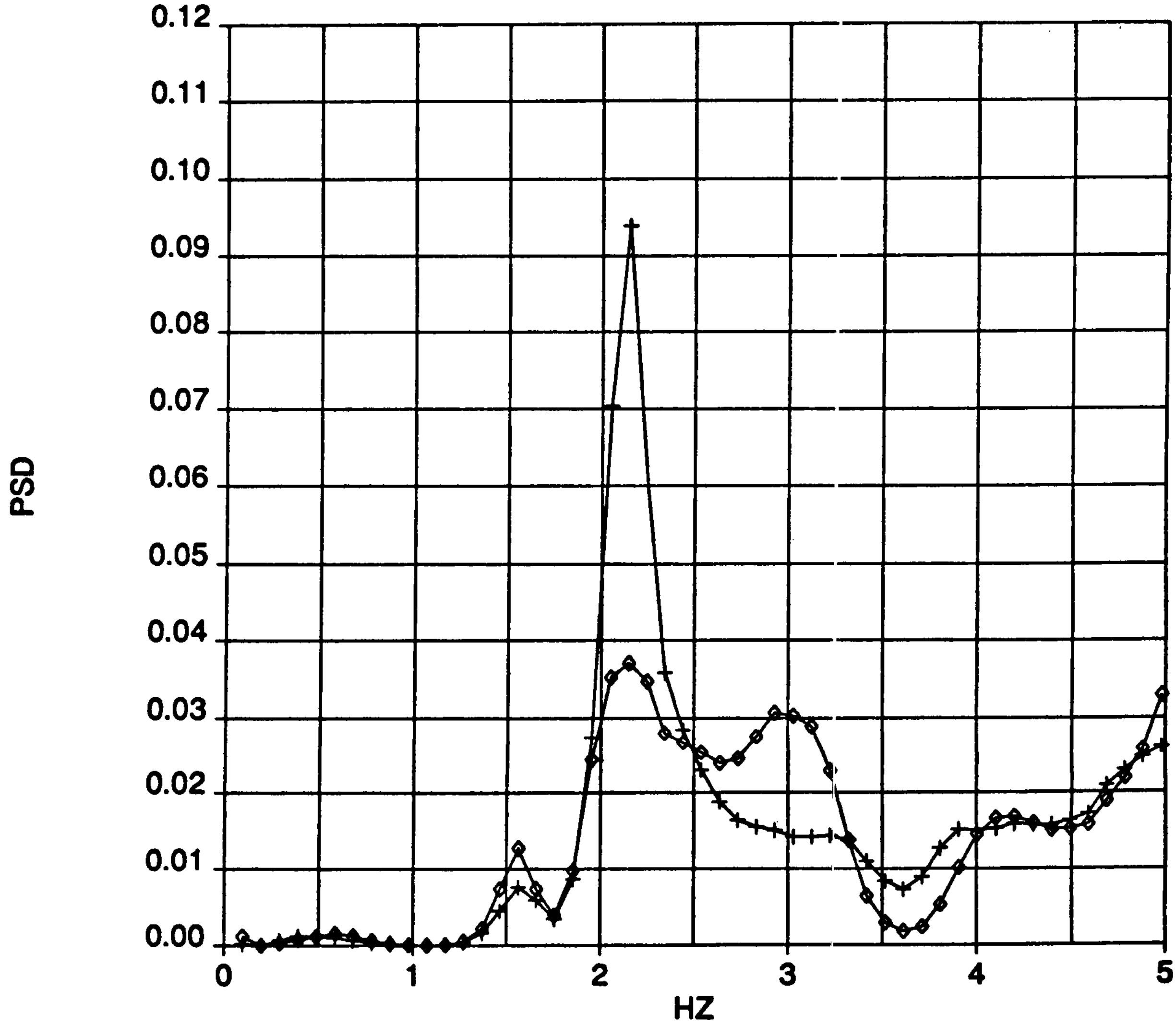
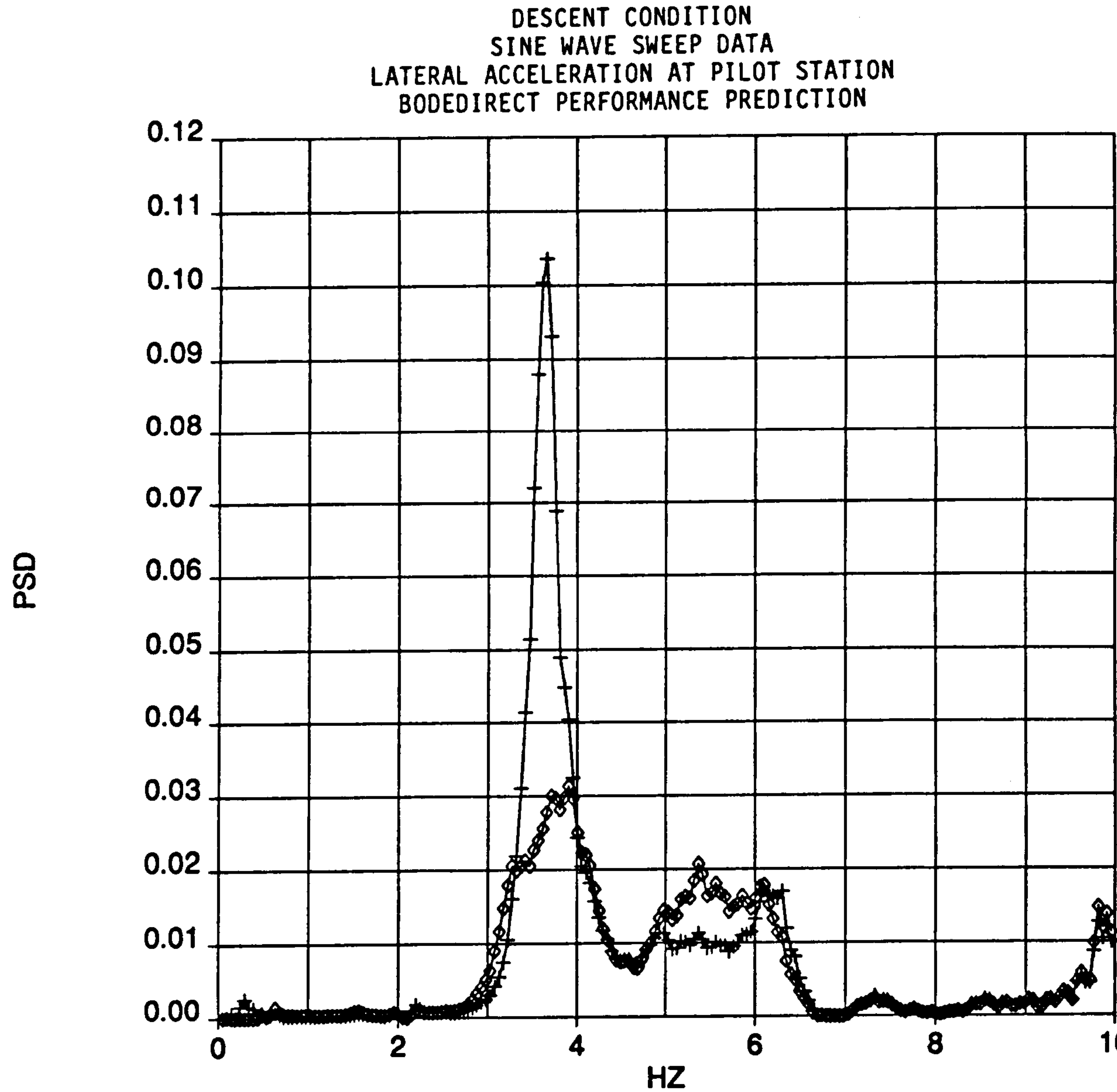

DESCENT CONDITION
SQUARE WAVE SWEEP DATA
LATERAL ACCELERATION AT PILOT STATION
BODEDIRECT PERFORMANCE PREDICTION
PSD
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
HZ

DESCENT CONDITION
SQUARE WAVE SWEEP DATA
LATERAL ACCELERATION AT AFT STATION
BODEDIRECT PERFORMANCE PREDICTION




DESCENT CONDITION
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PSD
0.12
0.11
0.10
0.09
0.08
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0.03
0.02
0.01
0.00
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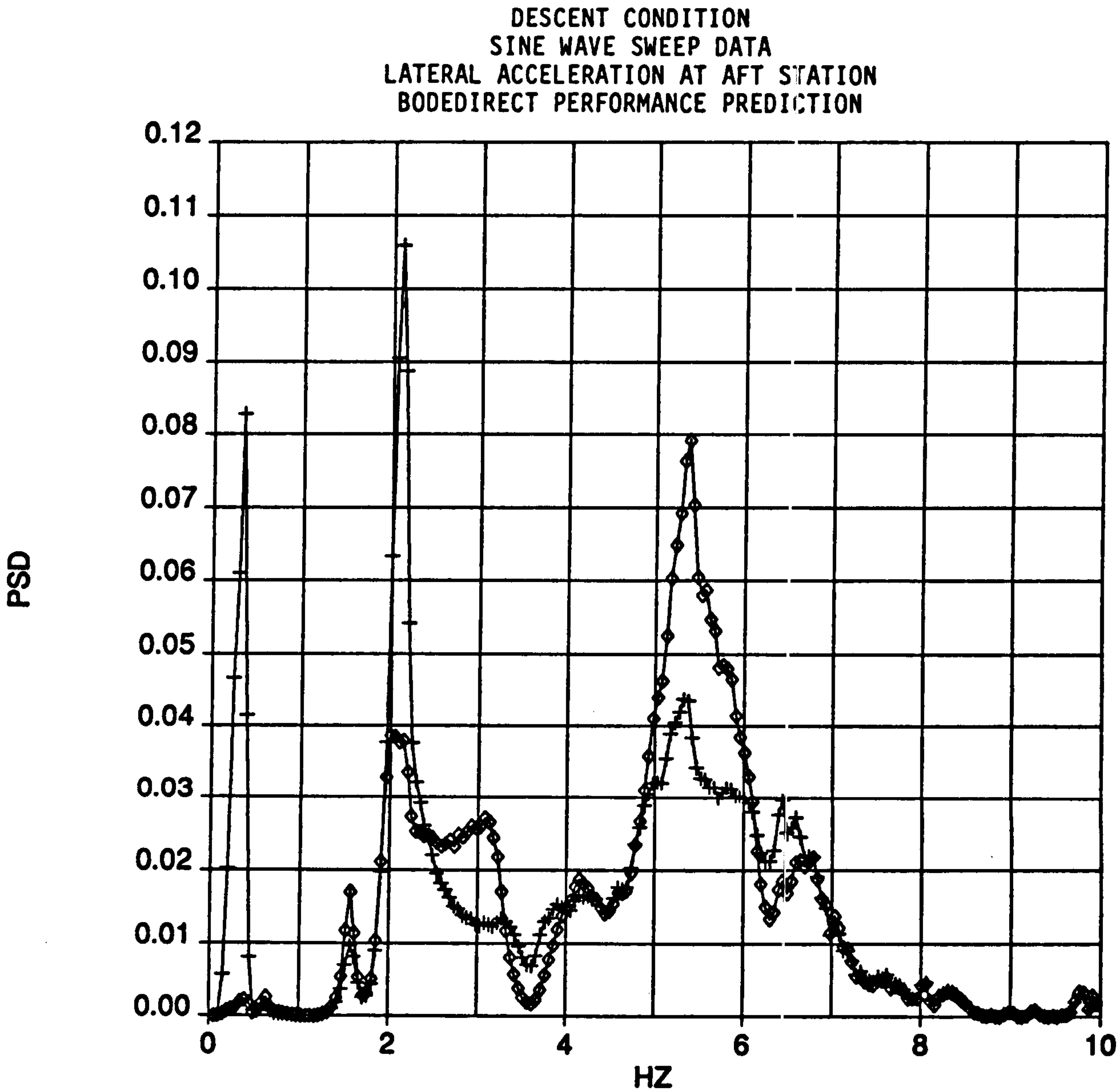
2
4
6
8
10
HZ



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