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AIRCRAFT MODAL SUPRESSION SYSTEM: EXISTING DESIGN APPROACH AND ITS SHORTCOMINGS

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ABSTRACT

The bending of flexible body aircraft may degrade the ride comfort of passengers. This is especially noticeable towards the aft end of the aircraft (due to the relatively large tail surfaces) which may easily be excited when flying through turbulence. In addition, some aircraft may experience a front body bending mode which can be annoying to the cabin crew and first class passengers. Normally, this dominant body bending mode falls between 1-5 Hz. This range is easily perceived by the human body. Also, in some situations, the rigid body control law may be out of phase with the mode and aggravate the vibration. Hence, an active modal suppression system is desirable for improving the ride quality of the airplane.

The size of the mathematical model, which has both the airplane rigid body and flexible characteristics, could easily exceed 100 states. This paper addresses the computational burden and fidelity of this large structural model. Later, the design methodology of the control law, which could be categorized into three steps:--(1) sensor selection, (2) modal phase determination and (3) modal suppression filter design--will be discussed. Each of these steps will be discussed in detail. Then we will present the theoretical results and compare them with flight test results. Here we will highlight the shortcomings of this design approach and briefly discuss what can be done in light of these deficiencies. Finally, we will include a brief description of the software tools.

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802

OBJECTIVES OF MODAL SUPPRESSION YAW DAMPER

- CONTROL DUTCH ROLL RESPONSE
- PROVIDE GOOD TURN COORDINATION
- IMPROVE LATERAL RIDE COMFORT BY SUPPRESSING FLEXIBLE BODY MODES

DESIGN PROCESS

- MODEL GENERATION
- BASIC YAW DAMPER DESIGN
- MODAL SUPPRESSION SYSTEM DESIGN
  - SELECTION OF SENSOR LOCATION, CONTROL SURFACE
  - ESTABLISHMENT OF MODAL PHASE RELATIONSHIP
  - MODAL SUPPRESSION FILTER DESIGN
- FLIGHT TEST
- ITERATE IF NEEDED

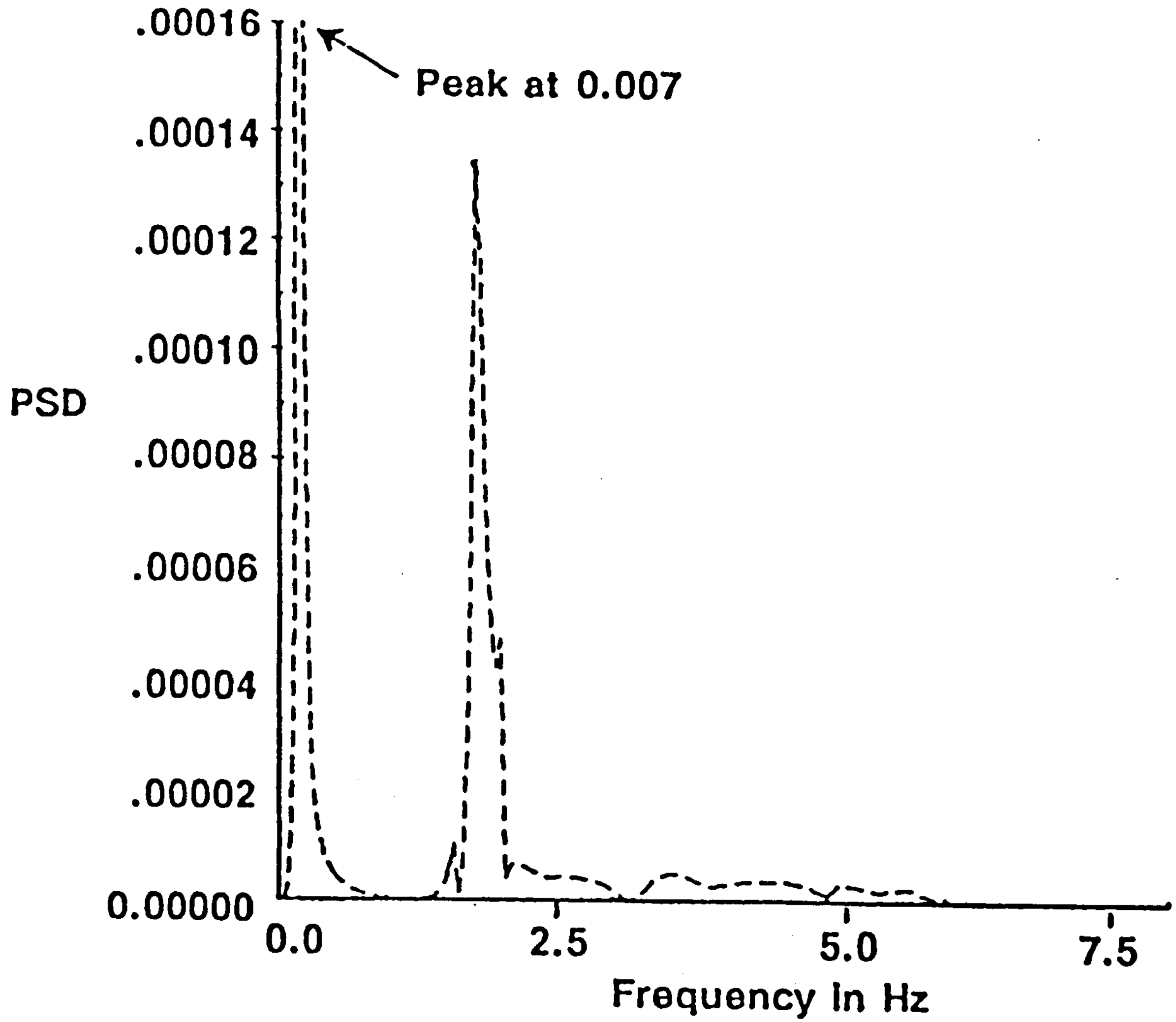
STRUCTURAL MODEL

- ORDER OF STRUCTURAL MODEL EXCEEDS 60 STATES
- WITH ANTI-ALIASING FILTER, TRANSPORT DELAY, SAMPLE AND HOLD, CONTROL LAW, RUDDER PCU, ORDER OF MODEL EXCEEDS 100 STATES
- MAIN FRAME COMPUTER REQUIRED FOR REASONABLE TURNAROUND TIME

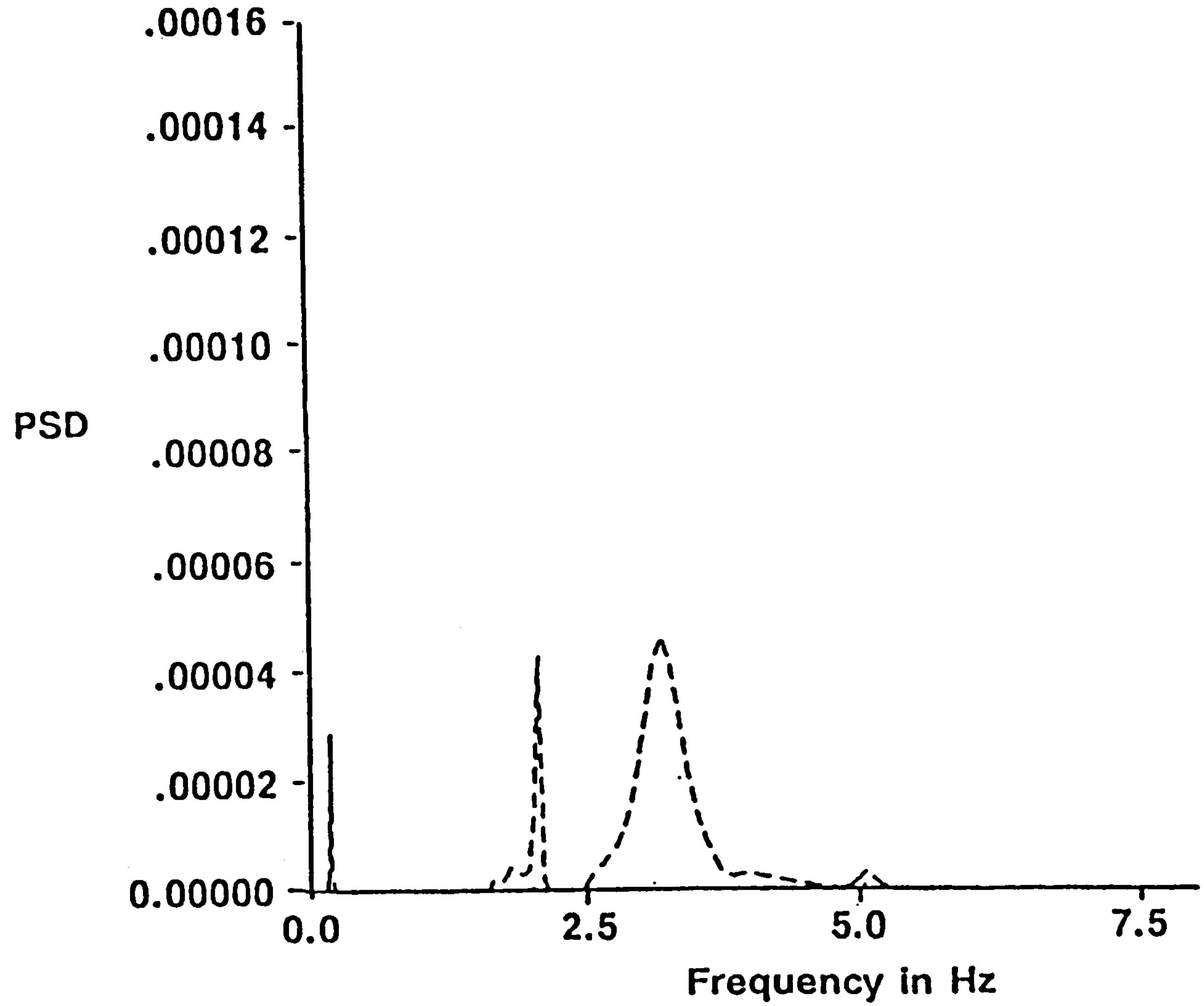
Design Requirements

The damping ratio for the closed loop airplane should be 0.4 or greater for the Dutch roll mode. Phase and gain margin requirements are:

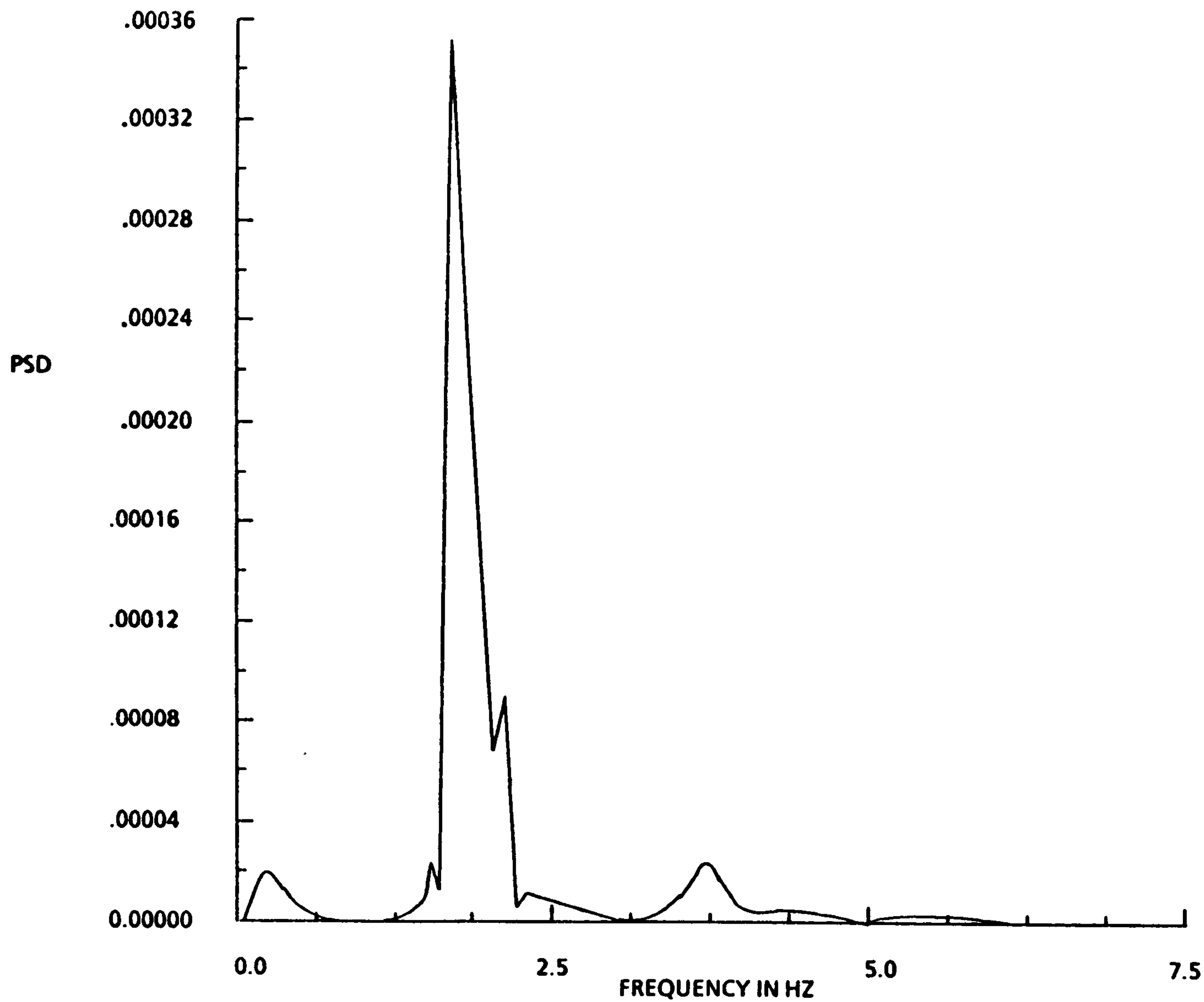
Mode frequency (fM) Hz	Gain Margin dB	Phase Margin degs
fM <= 0.06	> ±3	> ±20
.06 <= fM <= 1st aeroelastic mode	> ±4.5	> ±30
fM > 1st aeroelastic mode	> ±6	> ±45



PSD Level of the Lateral Acceleration at the Aft Galley

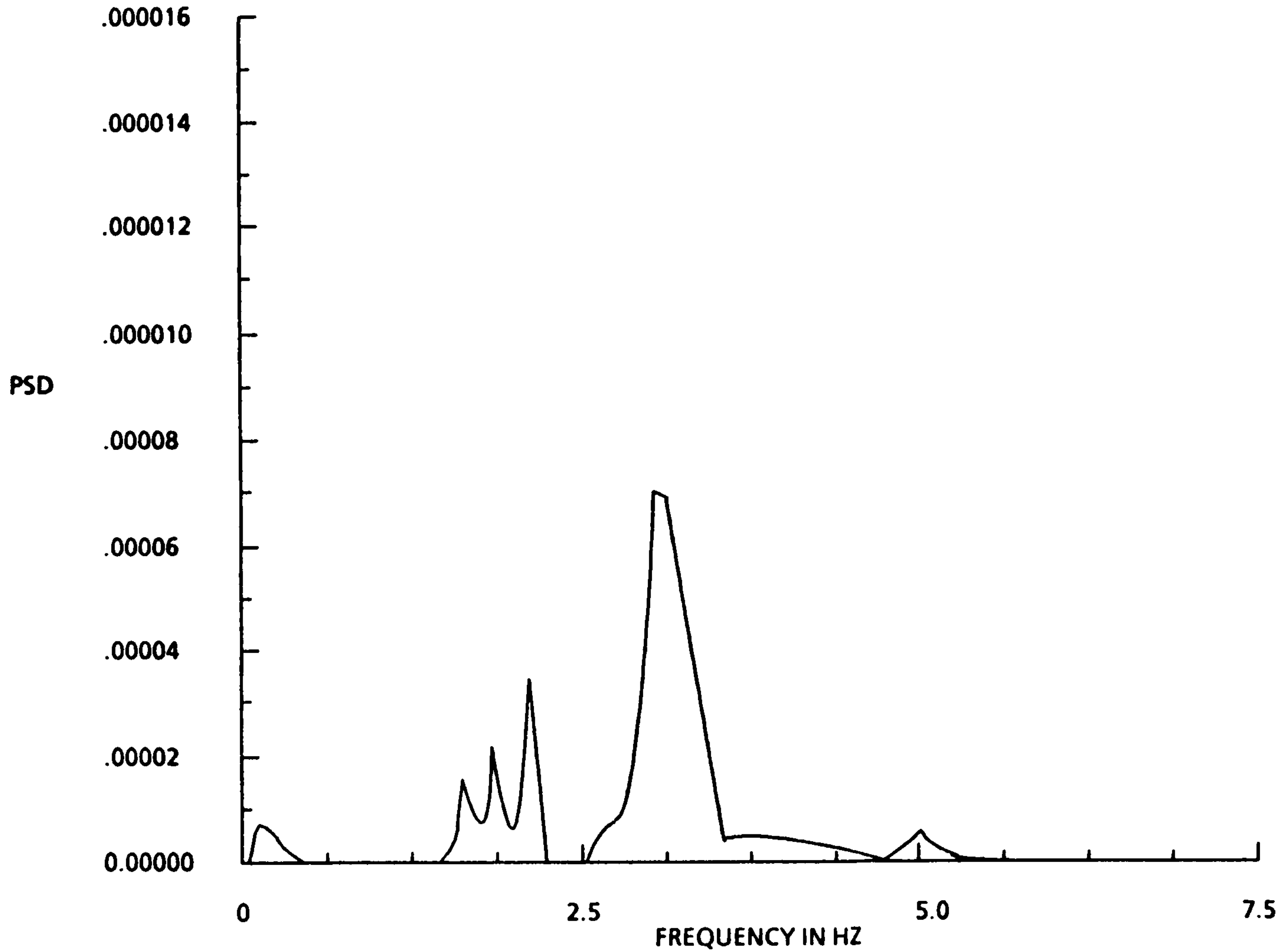


PSD Level of the Lateral Acceleration at the Pilot Station



YAW DAMPER CLOSED LOOP AIRPLANE
PSD OF THE LATERAL ACCELERATION AT THE AFT STATION

018



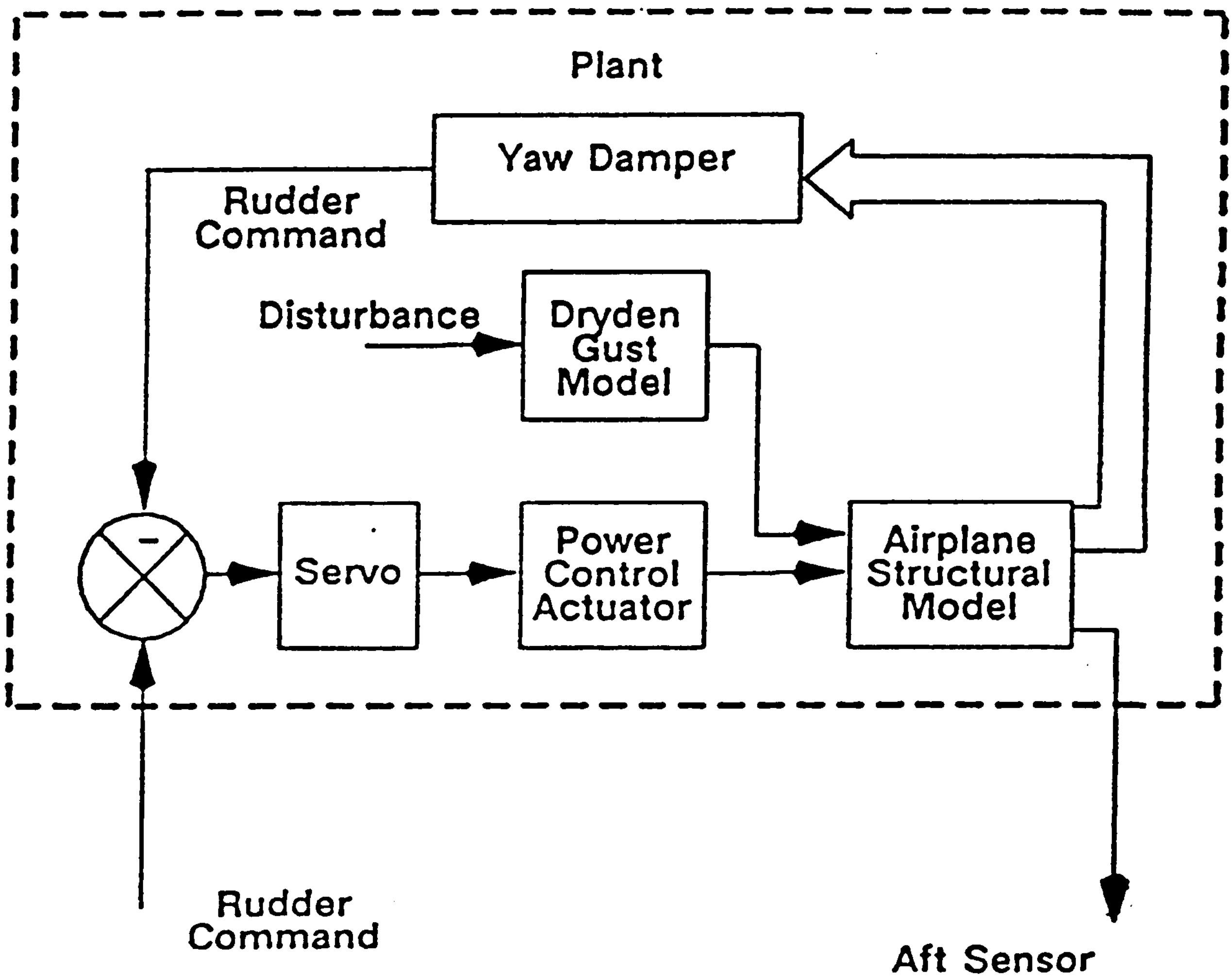
YAW DAMPER CLOSED LOOP AIRPLANE
PSD OF THE LATERAL ACCELERATION AT THE PILOT STATION

- WITH BASIC YAW DAMPER LOOP CLOSED, USE <u>MPAC</u> TO COMPUTE OBSERVABILITY AND CONTROLLABILITY

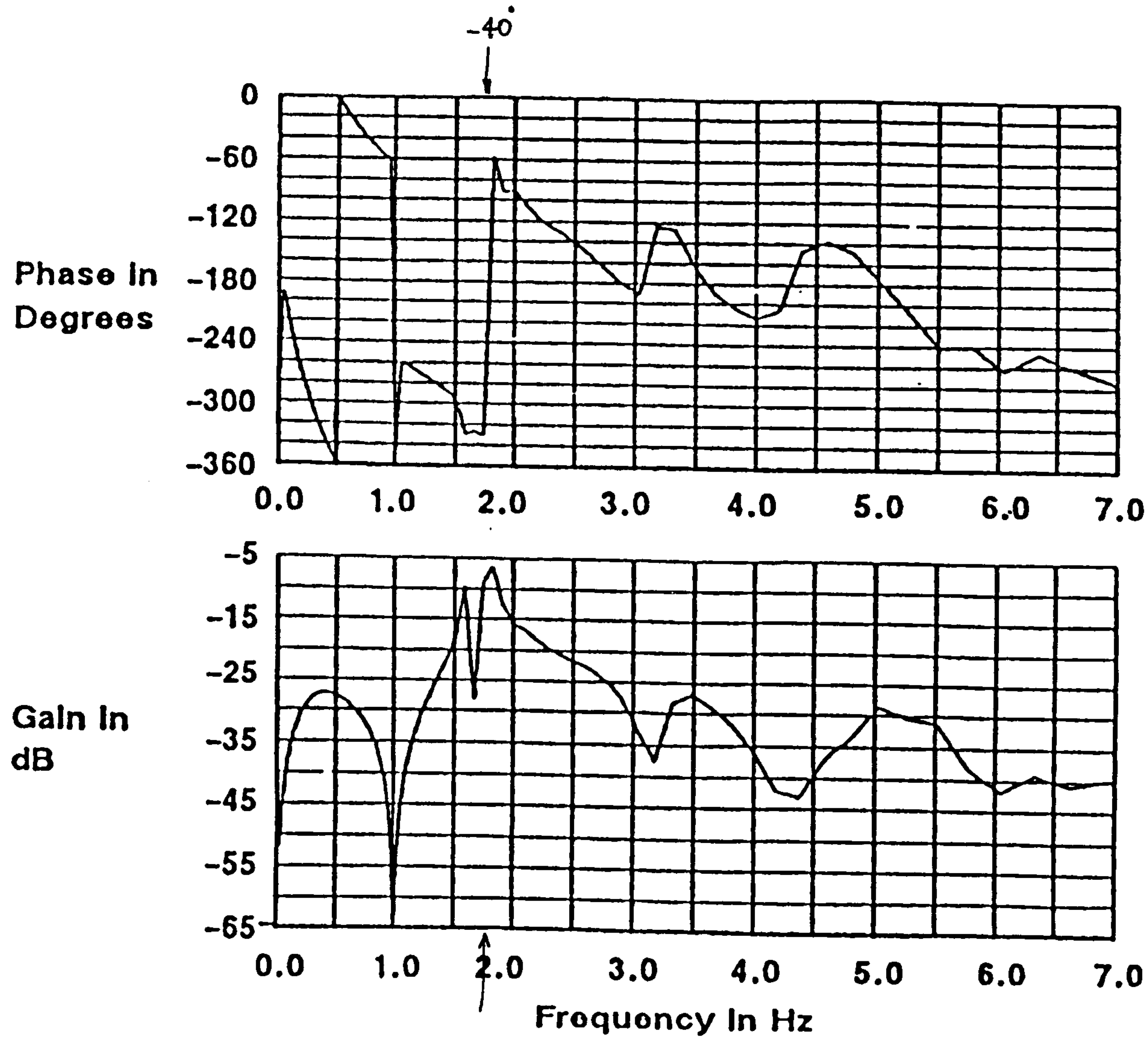
- PICK $\left\{ \begin{array}{l} \text{LATERAL ACCEL AT PILOT STATION} \\ \text{LATERAL ACCEL AT AFT GALLEY} \end{array} \right\}$ AS SENSORS

  PICK RUDDER AS CONTROL SURFACE

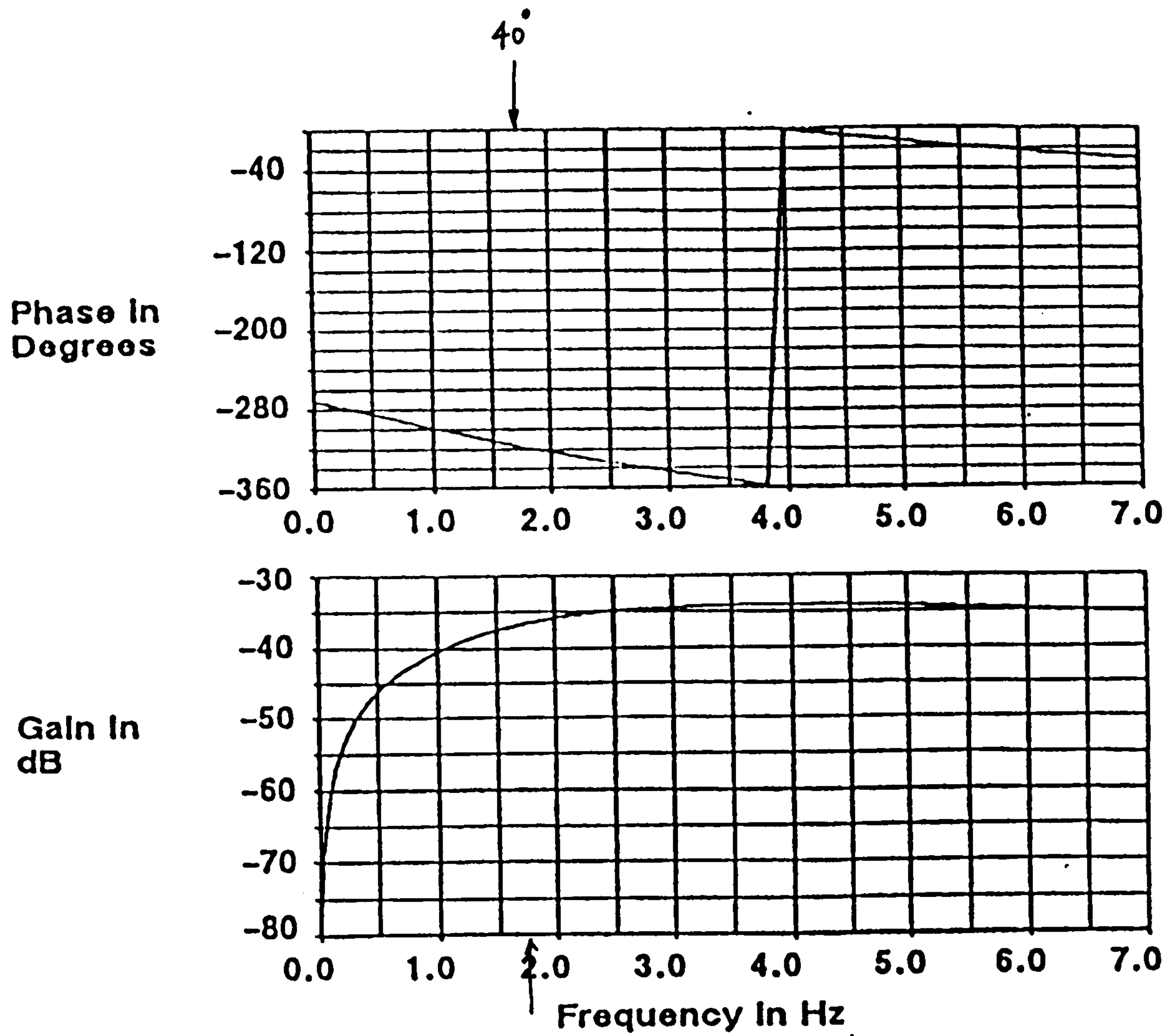
- DESIGN AFT FILTER FIRST BY DETERMINING ITS MODAL PHASE RELATIONSHIP



Plant Model for Aft Filter Design

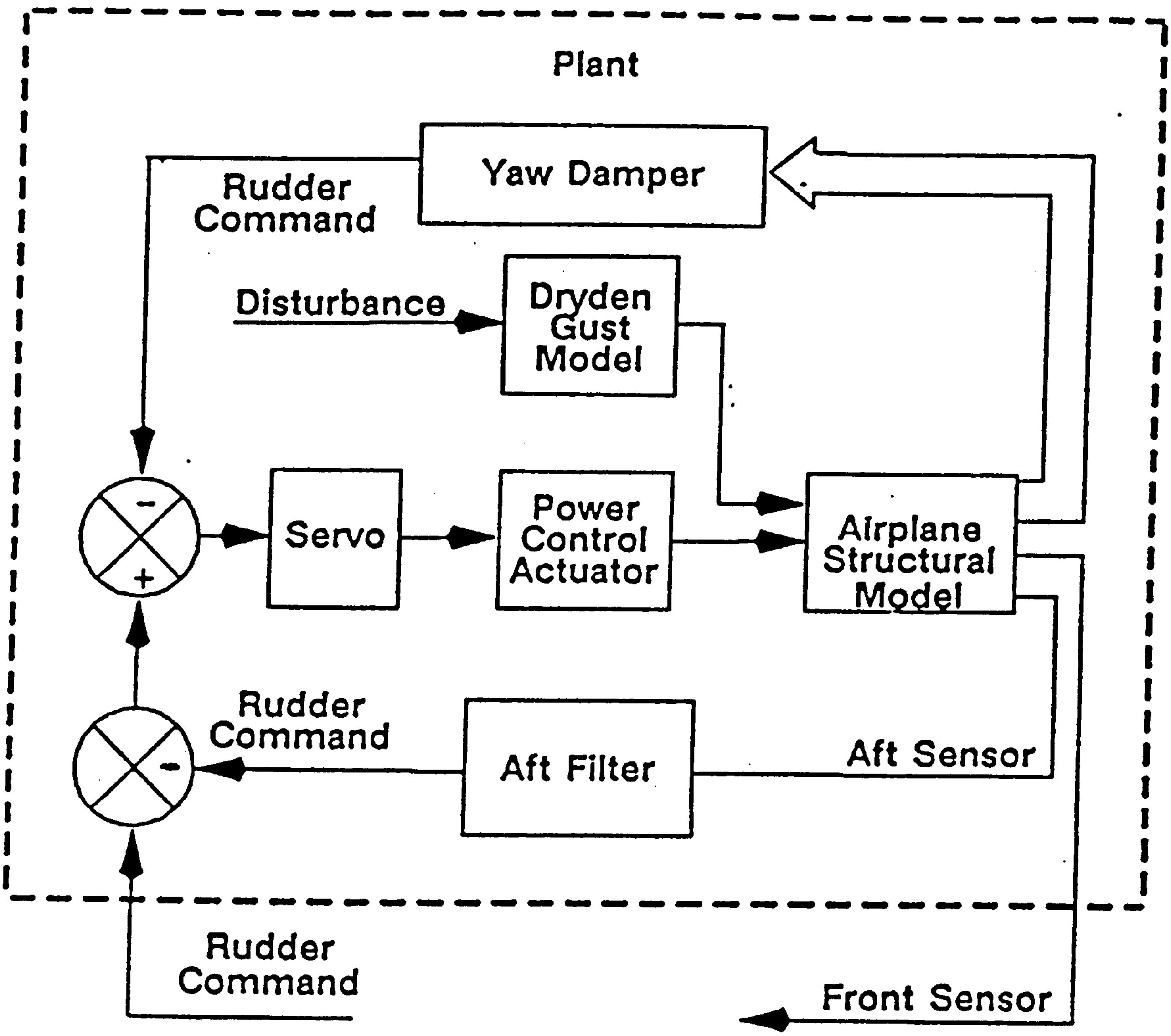


Bode Plot of the Transfer Function From Rudder Command to Aft Galley Sensor

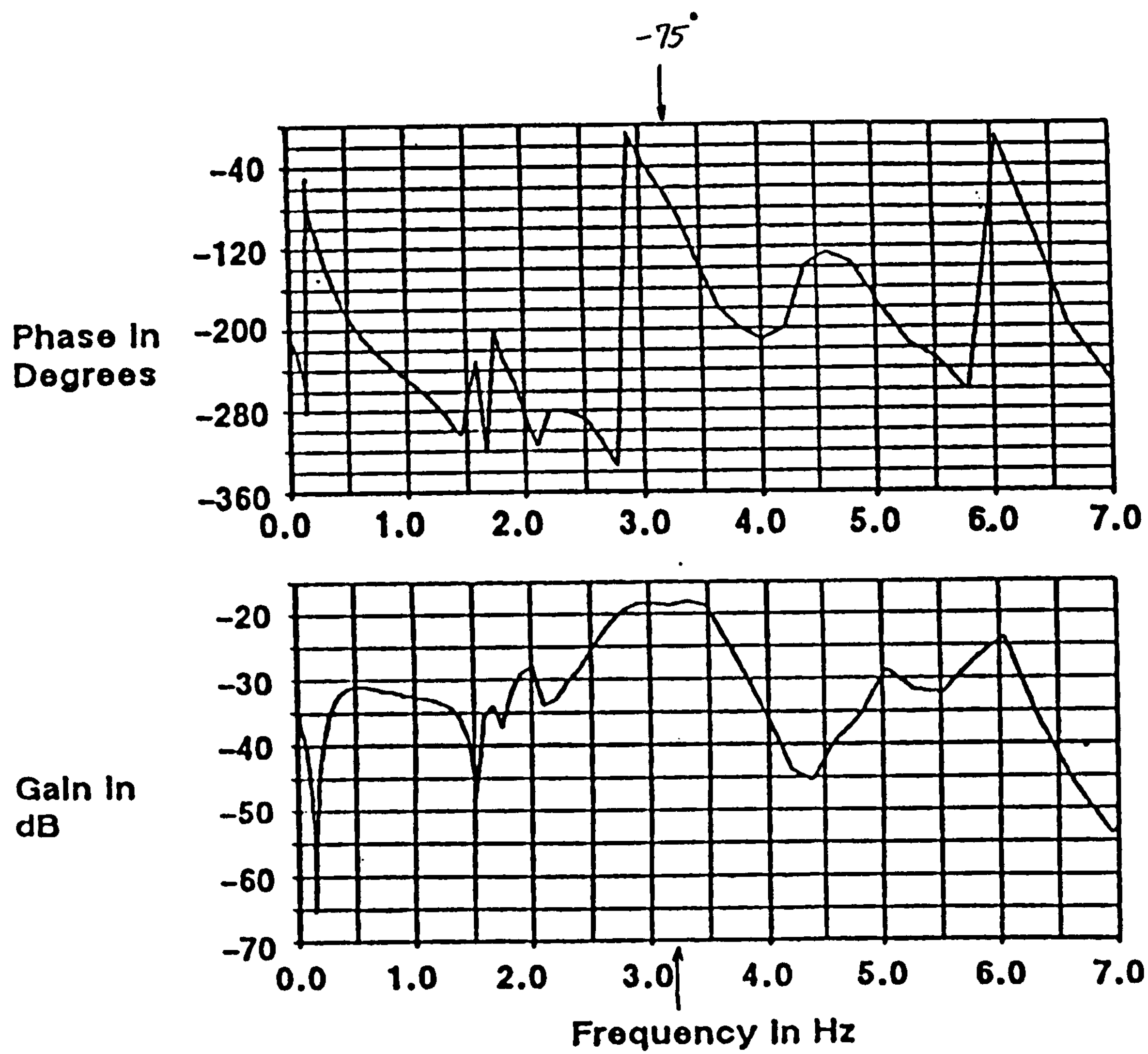


Bode Plot of the Aft Filter

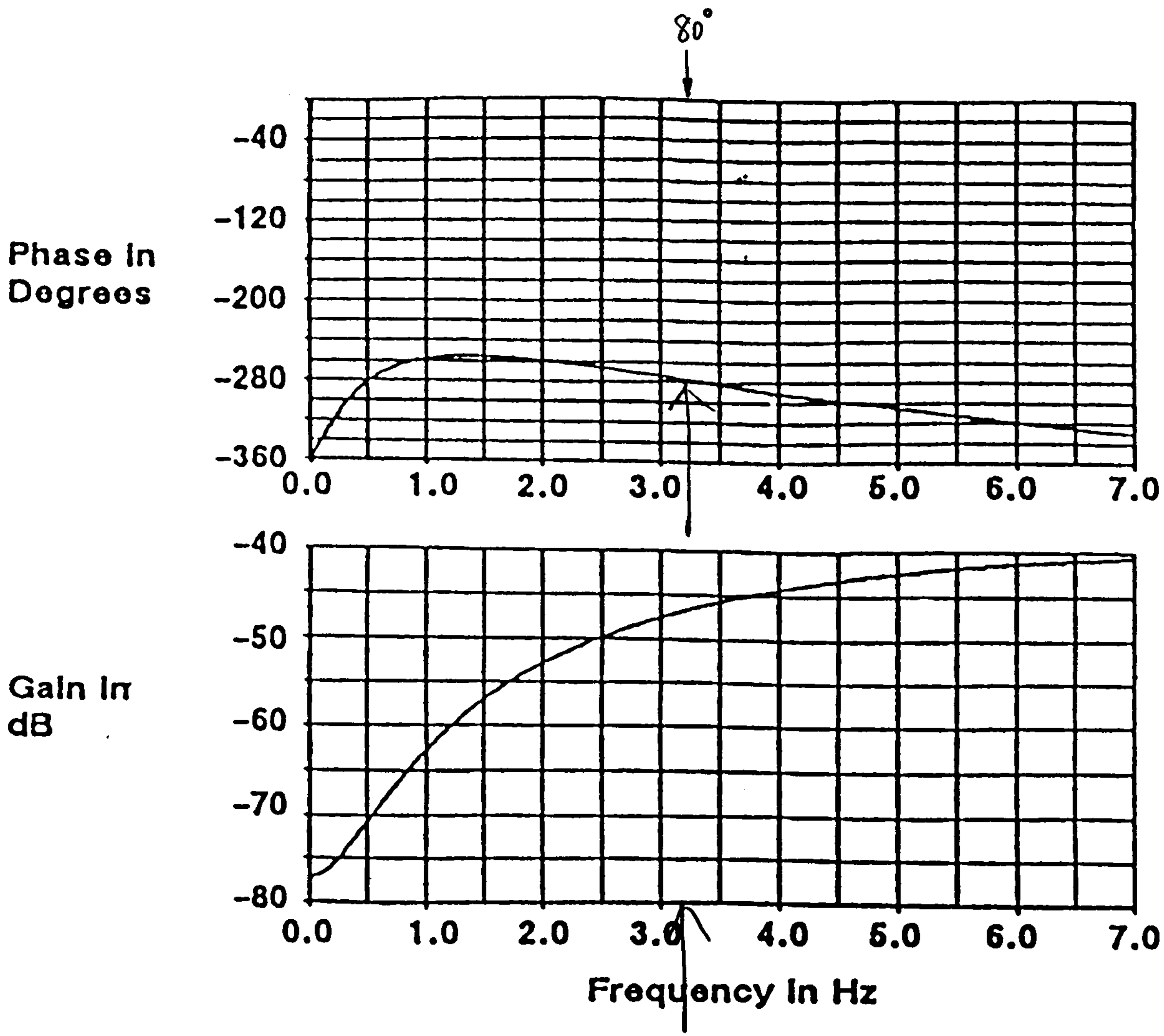
814



Plant Model for Pilot Station Filter Design

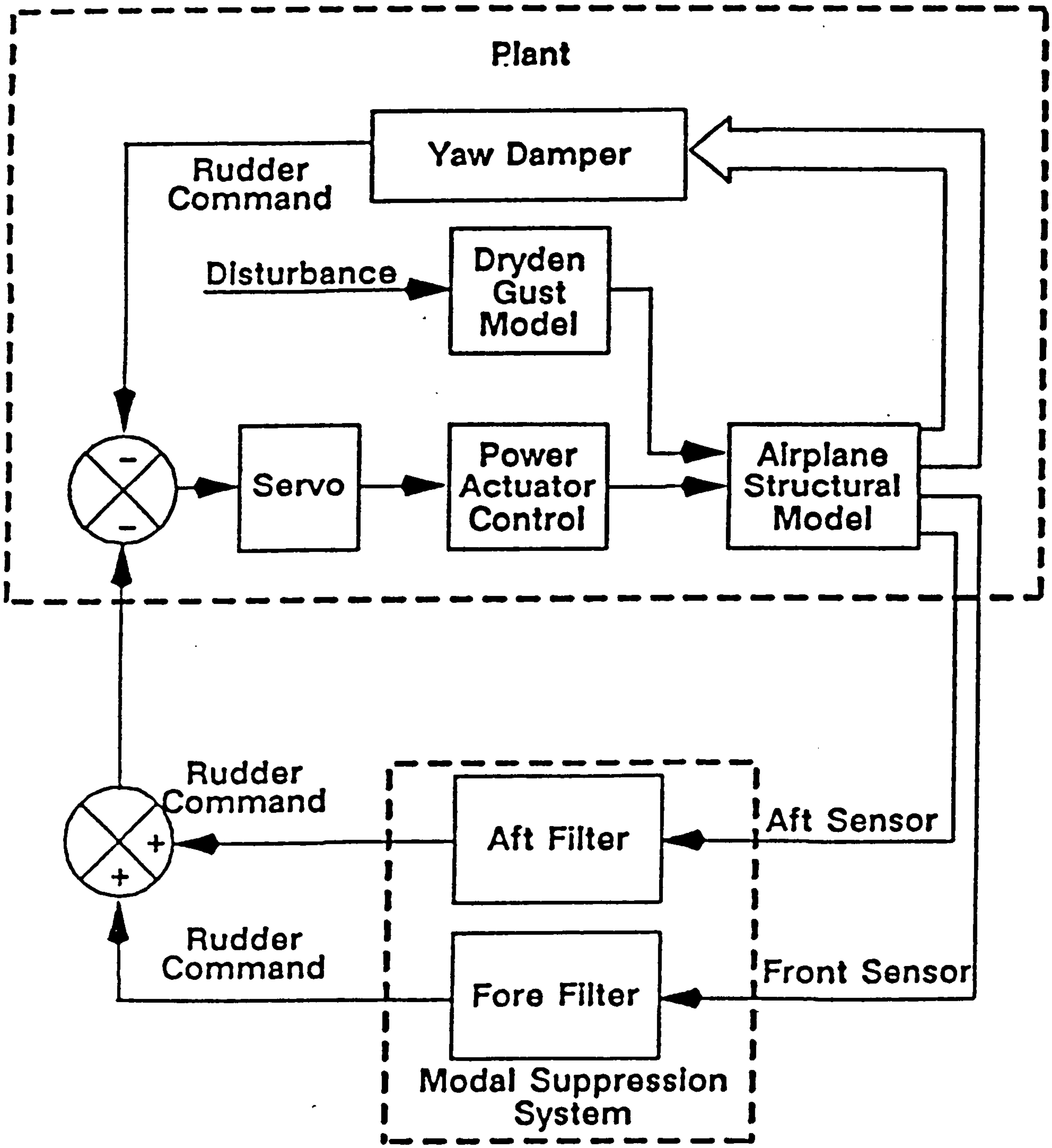


Bode Plot of the Transfer Function From Rudder Command to Pilot Station Sensor



Bode Plot of Pilot Station Filter

817



Closed-Loop System

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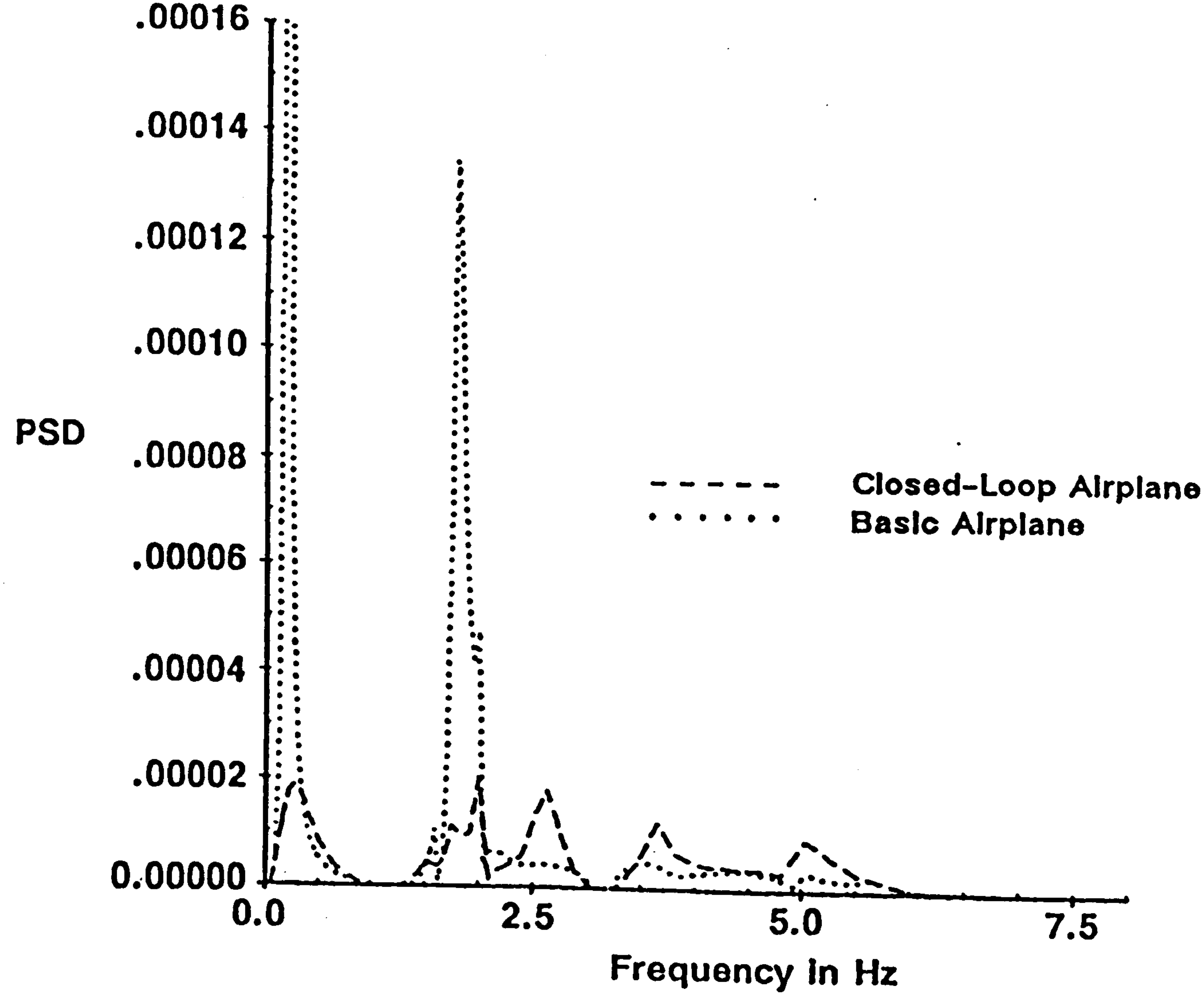
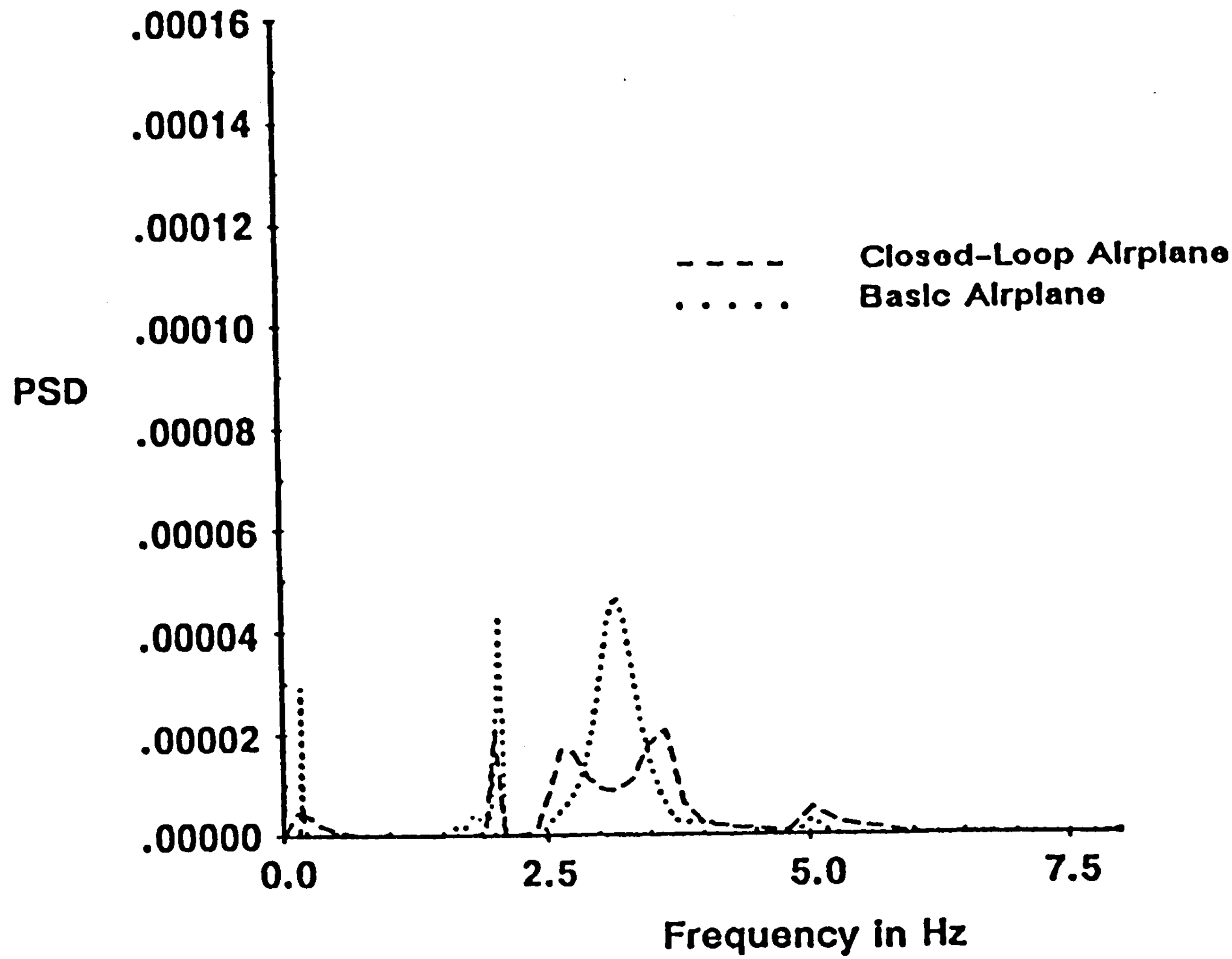


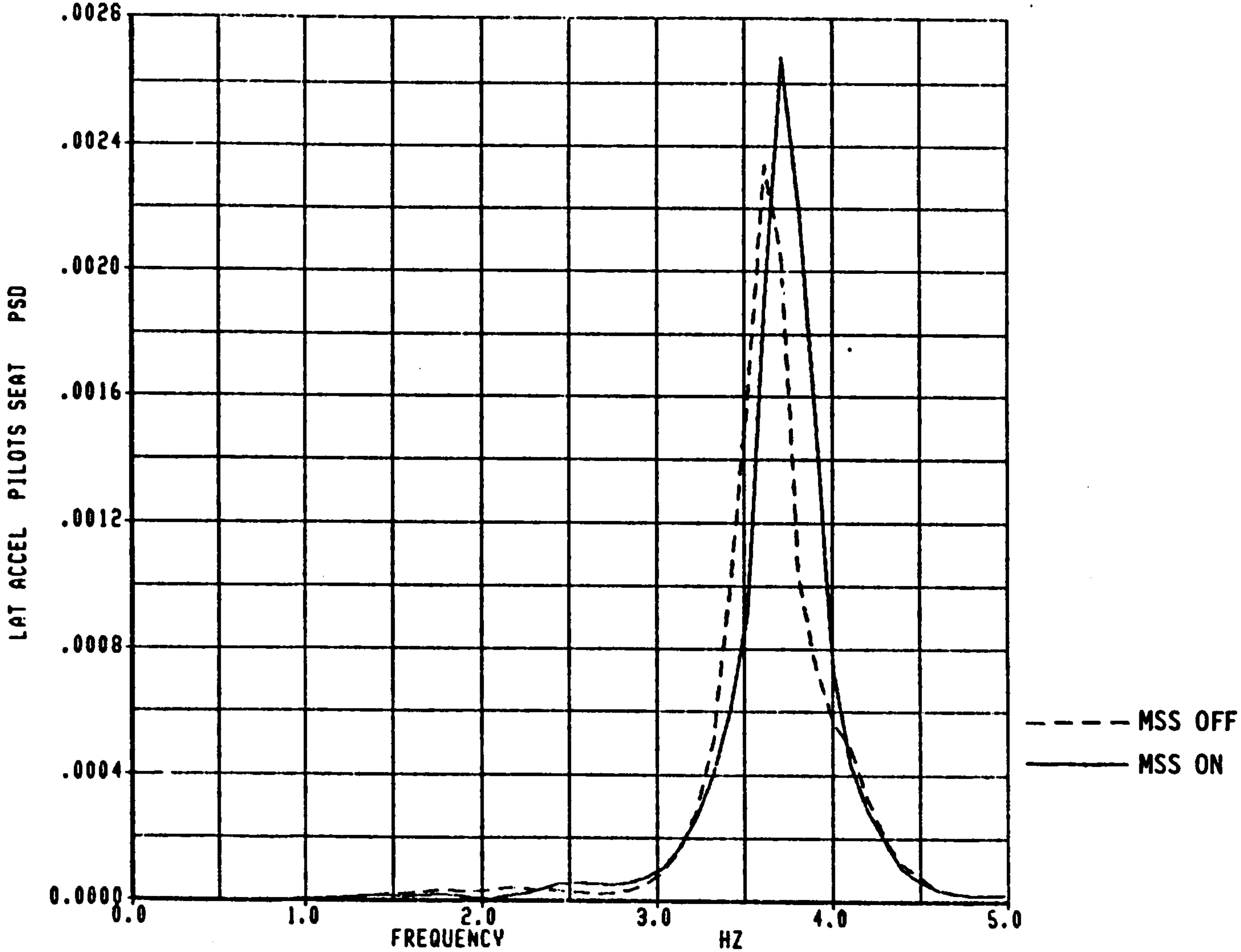
PSD of the Lateral Acceleration at the Aft Galley

820

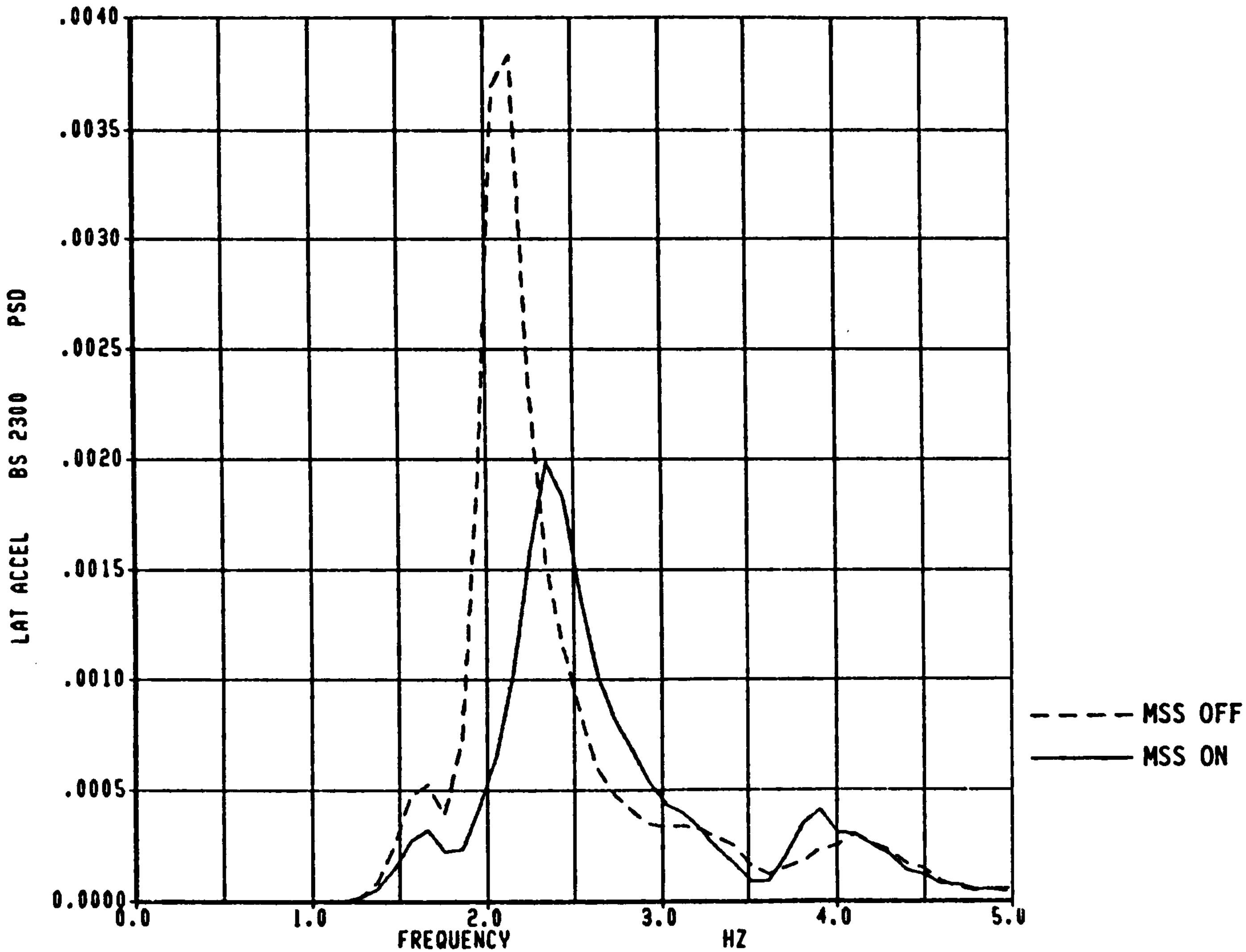


PSD of the Lateral Acceleration at Pilot Station

FLIGHT TEST RESULTS



FLIGHT TEST RESULTS



MODELLING DIFFICULTIES

- LACK OF ACCURACY IN STRUCTURAL MODEL
- RUDDER ACTUATION SYSTEM INCLUDES NON-LINEAR ELEMENTS:

  RATE SATURATION, POSITION LIMITER, HYSTERESIS, DEADZONE, VARIABLE GAIN
- USE OF TRANSFER FUNCTIONS RESULT IN LOSS OF ACCURACY IN FREQUENCY DOMAIN