SIFT PILOT-IN-THE-LOOP HANDLING QUALITIES TEST AND ANALYSIS TECHNIQUES

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INTRODUCTION

System Identification From Tracking (SIFT) is a new flight test and analysis technique for evaluating pilot-in-the-loop handling qualities. Normal stability and control flight test data are obtained during pilot-in-the-loop, mission-oriented, precision tracking maneuvers. These data are analyzed in the frequency domain to obtain frequency response transfer functions and modal parameters of the airplane aerodynamics, the flight control system, and the overall system (aerodynamics plus control system). These quantitative results are correlated with qualitative pilot comments and ratings obtained from the test maneuver. This correlation of quantitative and qualitative results provides insight into the pilot-in-the-loop handling qualities characteristics of the airplane.

Numerous applications of the SIFT techniques at AFFTC over the past two and a half years include a longitudinal short period pilot-induced-oscillation (PIO) investigation, an evaluation which uncovered the existence of a previously unsuspected lateral-directional coupling into the pitch axis, and a fixed-base simulator investigation.

The purpose of this paper is to briefly and informally outline the test and analysis techniques which make up SIFT. Formal preliminary documentation of the SIFT techniques and of AFFTC experience with these techniques is available in Reference 1. Development of these techniques is continuing at AFFTC, using flight test data and fixed-base simulator studies.

DISCUSSION

A schematic outline of the SIFT techniques is presented in Figure 1. For the purpose of discussion, this outline may be roughly divided into "test techniques" and "analysis techniques". Both quantitative and qualitative data are obtained during the test maneuver. Quantitative data are in the form of time histories of normal stability and control parameters recorded during the maneuver. The qualitative data are in the form of pilot ratings and comments. The quantitative data are analyzed in the frequency domain and the results are correlated with the qualitative pilot comment data to obtain insights into the pilot-in-the-loop handling qualities characteristics of the airplane.

Test Techniques

Test data are obtained during pilot-in-the-loop, mission-oriented, precision tracking maneuvers. Three test maneuvers have been successfully used at AFFTC. One of these is a specially developed "tail chase" precision air-to-air tracking maneuver called a Handling Qualities During Tracking (HQDT) maneuver. The other two are precision formation flying and aerial refueling. The latter two maneuvers are essentially standard maneuvers, flown just as they are flown "in the field".

The HQDT test maneuver is a nominally constant angle of attack, constant Mach number, constant altitude, carefully controlled precision air-to-air tracking maneuver. Special piloting techniques are used to assure good frequency content in the pilot's stick and rudder pedal inputs. These special piloting techniques include agressive and persistent attempts to correct even very small tracking errors. Good frequency content and controlled test conditions are important to a good data analysis. The HQDT test maneuver has been formally documented in Reference 2.

Extensive experience at AFFTC has demonstrated the HQDT test maneuver to be an excellent maneuver for eliciting useful pilot comments as well as good quantitative test data.

Analysis Techniques

The quantitative test data (time histories of stability and control parameters acquired during the test maneuver) are analyzed in the frequency domain to obtain open-loop frequency response transfer functions. These transfer functions may be the airframe aerodynamics, or the flight control system, or the overall airplane (aerodynamics plus control system), or some other component or system (e.g., a filter or a servoactuator). One of the advantages of the frequency response curves identified by SIFT analysis techniques is that they are a measure of the actual system as implemented. They are not based on a presumed model of the system.

After the frequency response curves have been identified, they may be curve fitted using a modal analysis program. The modal analysis program identifies the system gain, transport time delay, and first and second order characteristics. This identification is based on a system model provided by the program user.

The frequency response curves and modal parameters are correlated with pilot ratings and comments to provide insights into the handling qualities characteristics of the airplane being tested. This correlation of quantitative and qualitative data obtained from the same test maneuver has provided some interesting results at AFFTC. In one case, a previously unsuspected cross-coupling of lateral-directional dynamics into the pitch axis was discovered using SIFT techniques. This cross-coupling was evident to the pilot in the form of a two to three mil pitch bobble at twice the dutch roll frequency. A complete classical stability and control test program, conducted prior to the SIFT testing, had not uncovered this cross-coupling problem. In another case, the Smith PIO criteria were used with

SIFT techniques to confirm pilot reports of longitudinal short period PIO. In yet another case, the influence of an air-refueling boom on the dynamics of a refueling aircraft was observed. This was done by comparing the frequency response curves of the refueling airplane before hook-up with the frequency response curves after hook-up.

Example Test Results

A fixed base five degree of freedom engineering simulator was used at AFFTC to obtain test data, using SIFT test techniques. Two simulated HQDT test maneuvers were "flown" to obtain the data discussed here. A target was presented on a cathode ray tube (CRT) display for the tracking pilot. The target was programmed to fly a constant load factor, constant Mach number, level turn (3g, .080 Mach, 15000 ft). Seventy-one seconds of data were obtained during the first HQDT test maneuver, and sixty-three seconds of data were obtained during the second maneuver. The pilot flew these two maneuvers with his feet on the floor, i.e., without making any rudder pedal inputs. The pilot's Cooper-Harper rating for the configuration flown was a 3 for the pitch axis, a 3 for the lateral-directional axes, and a 3 overall.

The data obtained during these two maneuvers were analyzed in the frequency domain to obtain frequency response curves of the flight control system, the airplane aerodynamics, and the overall system (aerodynamics plus control system). The frequency response curves of the flight control system transfer function of stabilator deflection to pitch stick force (δ_e/F_s), along with power spectral density and coherence function plots, are presented in Figure 2. The power spectral density plot of pitch stick force shows the good frequency content elicited by the agressive, persistent, precision piloting technique used in SIFT testing.

The aerodynamic frequency response curves of the pitch rate to stabilator deflection transfer function ($q/-\delta_e$), along with power spectral density and coherence function plots, are presented in Figure 3. The overall system frequency response curves of the pitch rate to pitch stick force transfer function (q/F_s), along with power spectral density and coherence function plots, are presented in Figure 4.

It is evident from Figures 2 and 3 that a better identification was achieved for the flight control system than for the aerodynamics. This is largely because a very simple pitch axis control system was implemented for this test, consisting only of a stick force gradient and a servoactuator. Because the control system required relatively few components to simulate, there were fewer sources of noise and error compared to the more complex aerodynamics portion of the simulation.

Modal analysis of the identified frequency response transfer functions shown in Figures 2, 3, and 4 yielded the results presented in Figures 5, 6, and 7. The modal parameters are shown in the familiar factored transfer function form. Plots of the modal analysis curve fit overlaid on the identified frequency response transfer function curves are also presented. These overlaid plots provide an indication of how well the modal analysis matched the identified frequency response curves. For example, the short period frequency and damping ratio identified from the aerodynamic frequency response curves are $\omega_{n_{sp}} = 5.69$ radians/second and $\zeta_{sp} = 0.81$. These parameters, with the identified numerator time constant ($1/T_{\theta_2} = 2.04$/second) and gain ($K_q = 1.82 \frac{\text{degrees/second}}{\text{degree}}$), provide a pretty good match of the aerodynamics.

<u>Equivalent System Identification Using SIFT Techniques (Testing to the New MILSPEC)</u>

One of the proposed changes to the current flying qualities MILSPEC is the implementation of a second order equivalent system criteria for the pitch axis. An equivalent system criteria would be easy to test to using SIFT techniques. However, there are some questions concerning standardization of analysis procedures which need to be resolved. Two of these questions are: (1) how will the user initially estimate the equivalent system parameters, and; (2) what will be the frequency range of the curve fit.

Three examples illustrate the problems which may arise from these questions. The following equivalent system model was used in each case:

$$\frac{q}{F_s} = K_E e^{-as} \frac{\left(\frac{S}{1/T_E} + 1\right)}{\frac{S^2}{\omega_E{}^2} + \frac{2\zeta_E}{\omega_E} S + 1}$$

Table 1 shows the results of three equivalent system fits of the q/F_s transfer function presented in Figure 4. Two fits were constrained to the region zero to ten radians/second. The third fit was over the region zero to fifteen radians/second. Table 1 presents the initial user estimates of the equivalent system modal parameters, the final modal parameter estimates produced by the modal analysis program, and the cost function corresponding to each fit. The cost function provides a measure of how well the frequency response curves in Figure 4 were matched. Smaller cost functions indicate a better match. The respective matches are presented in Figures 8, 9, and 10.

It is apparent from Table 1 that it is possible to obtain different equivalent system matches of the same frequency response curves. The equivalent system parameters identified by modal analysis depend on the user's initial estimate of these parameters and on the frequency range being analyzed. This problem of non-uniqueness of fit has been widely recognized and emphasizes the need to develop uniform procedures for obtaining equivalent system parameters.

CONCLUSIONS

AFFTC experience with SIFT pilot-in-the-loop handling qualities testing has been uniformly encouraging. SIFT has been successfully used to identify and evaluate some unusual handling qualities problems as well as to identify traditional handling qualities parameters such as short period frequency and damping ratio. SIFT techniques are readily adaptable to the equivalent second order system criteria proposed for the revised flying qualities MILSPEC. A standardized procedure should be developed for identifying the equivalent system parameters.

REFERENCES

1. Twisdale, Thomas R. and Ashurst, Tice A., Jr., System Identification From Tracking (SIFT), a New Technique For Handling Qualities Test and Evaluation (Initial Report), AFFTC-TR-77-27, Air Force Flight Test Center, Edwards AFB, California, November 1977.

2. Twisdale, Thomas R. and Franklin, David L., Captain, USAF, Tracking Test Techniques for Handling Qualities Evaluation, AFFTC-TD-75-1, Air Force Flight Test Center, Edwards AFB, California, May 1975.

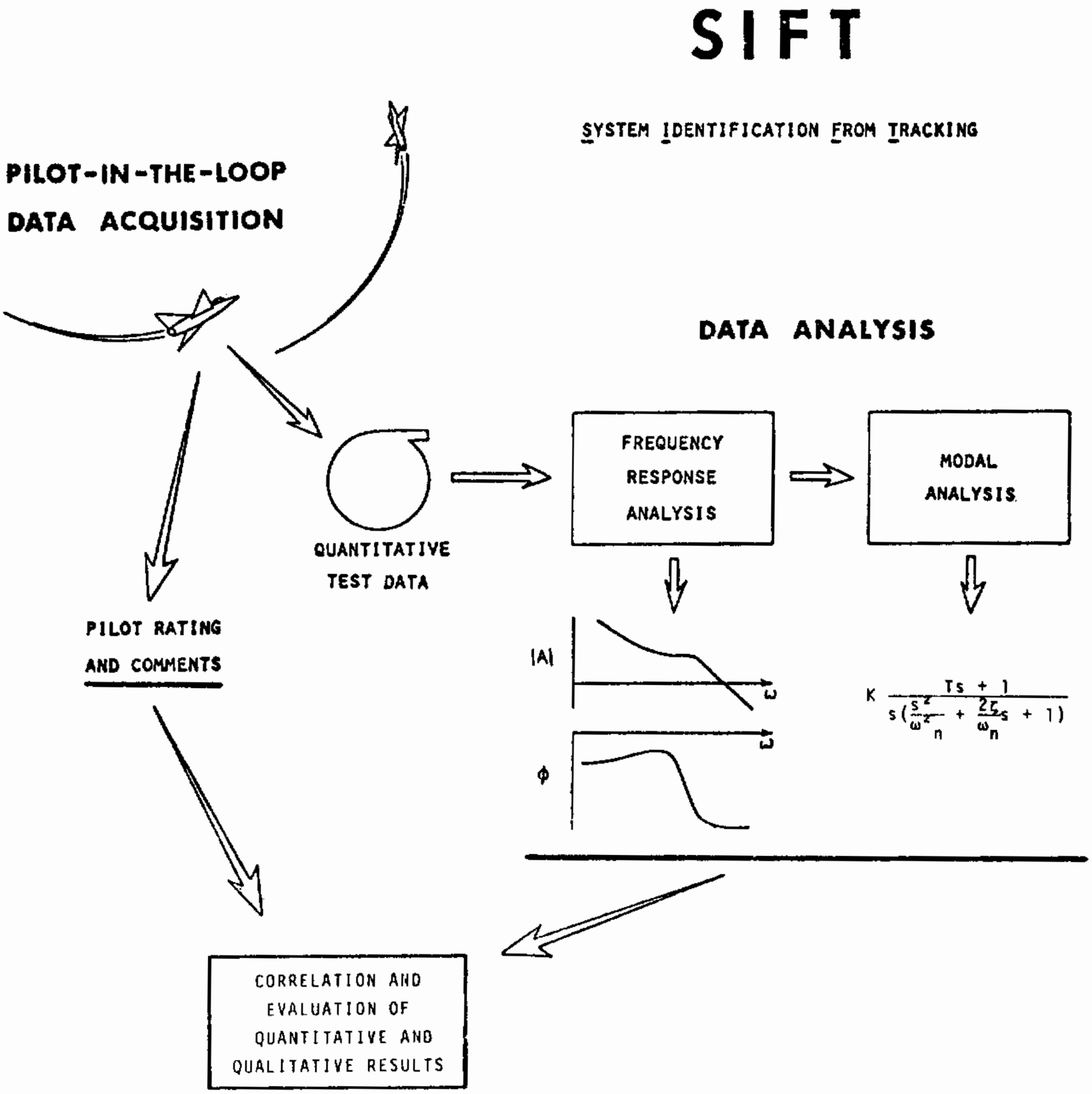
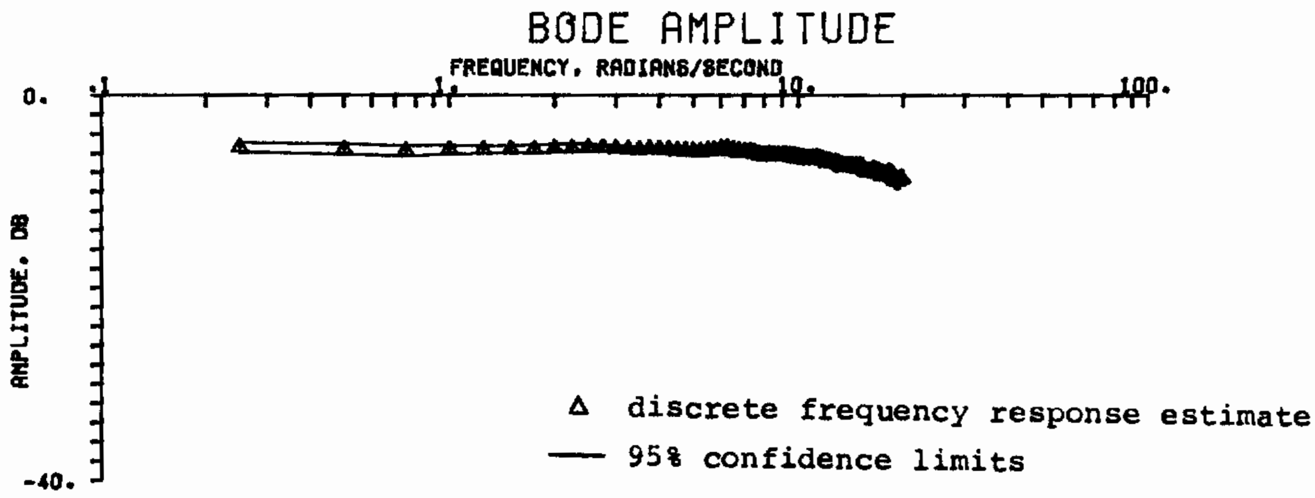


FIGURE 1 SCHEMATIC OUTLINE OF SIFT PILOT-IN-THE-LOOP HANDLING QUALITIES TEST TECHNIQUES



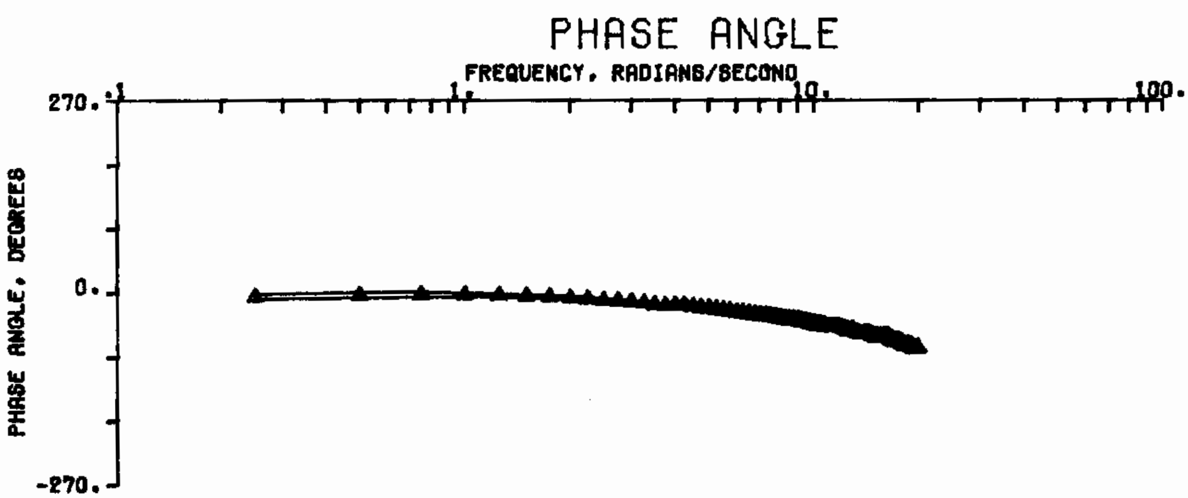


FIGURE 2 FLIGHT CONTROL SYSTEM IDENTIFICATION: FREQUENCY RESPONSE CURVES OF STABILATOR DEFLECTION TO PITCH STICK FORCE TRANSFER FUNCTION $\left(\frac{-\delta_e}{F_s}, \frac{\text{degrees}}{\text{pound}}\right)$

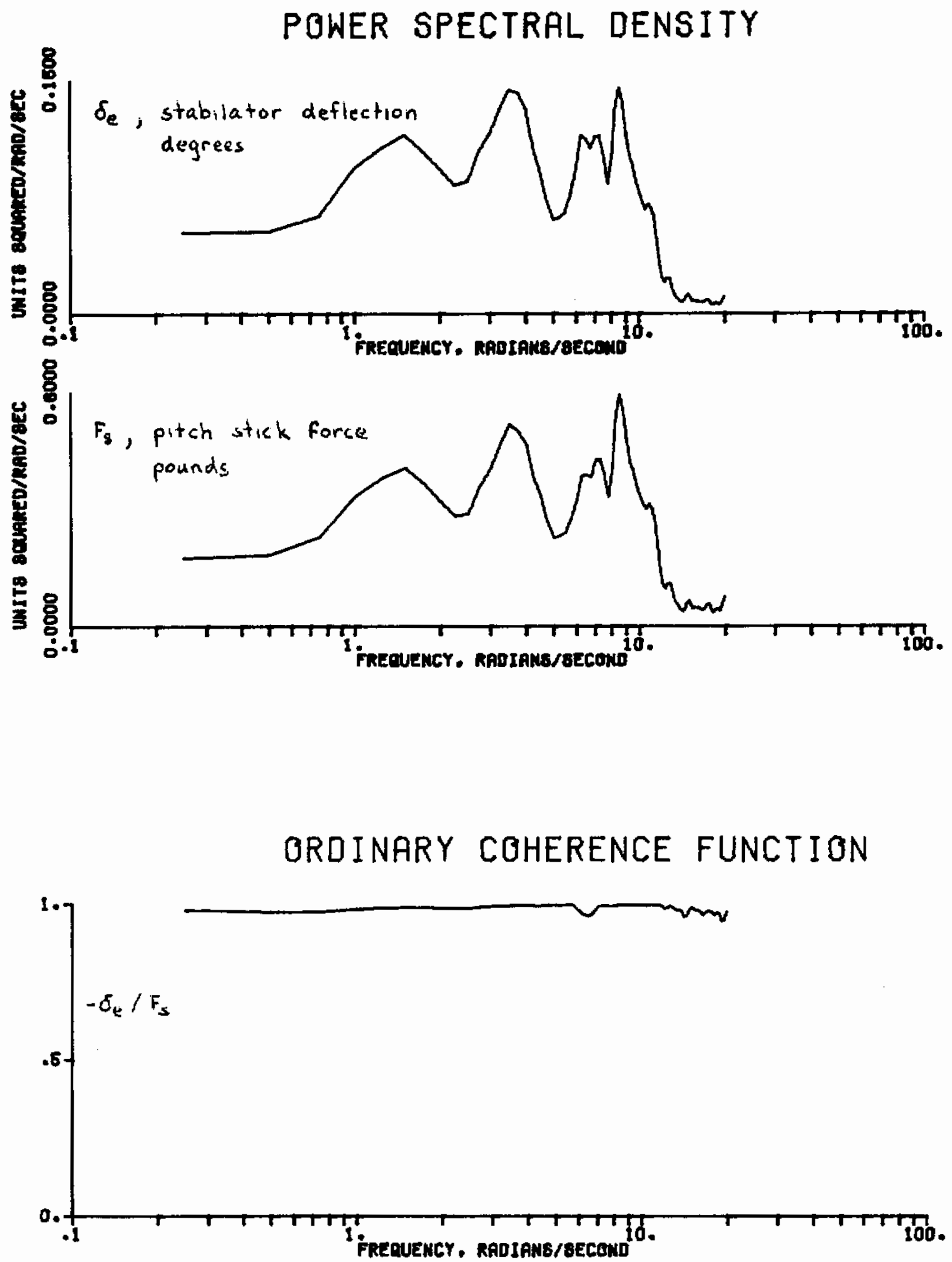
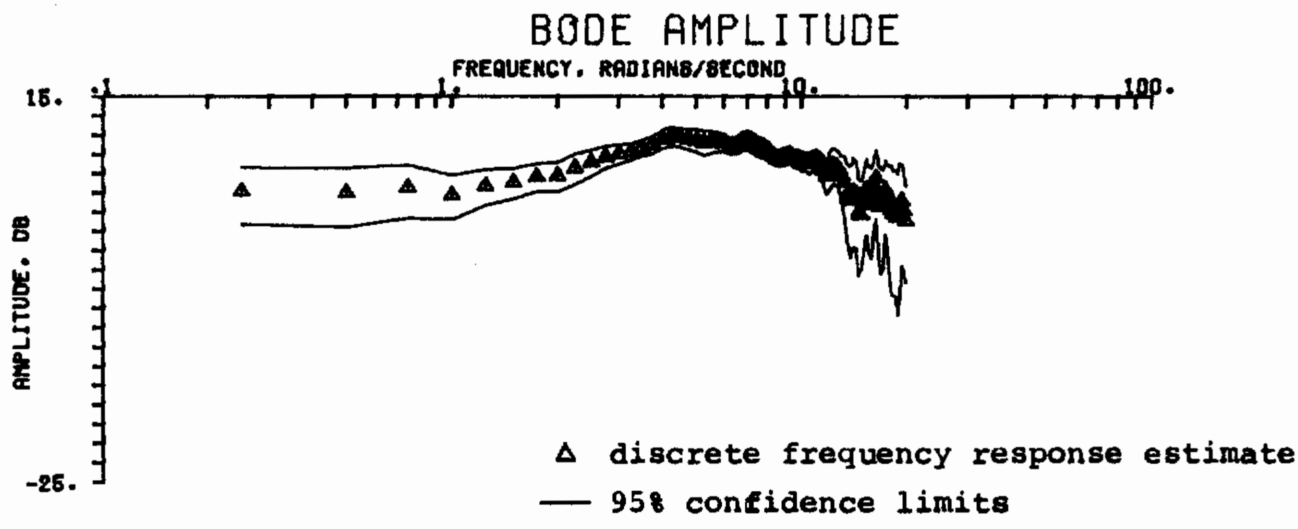


FIGURE 2 (CONCLUDED) FLIGHT CONTROL SYSTEM IDENTIFICATION: POWER SPECTRAL DENSITY AND COHERENCE FUNCTION PLOTS



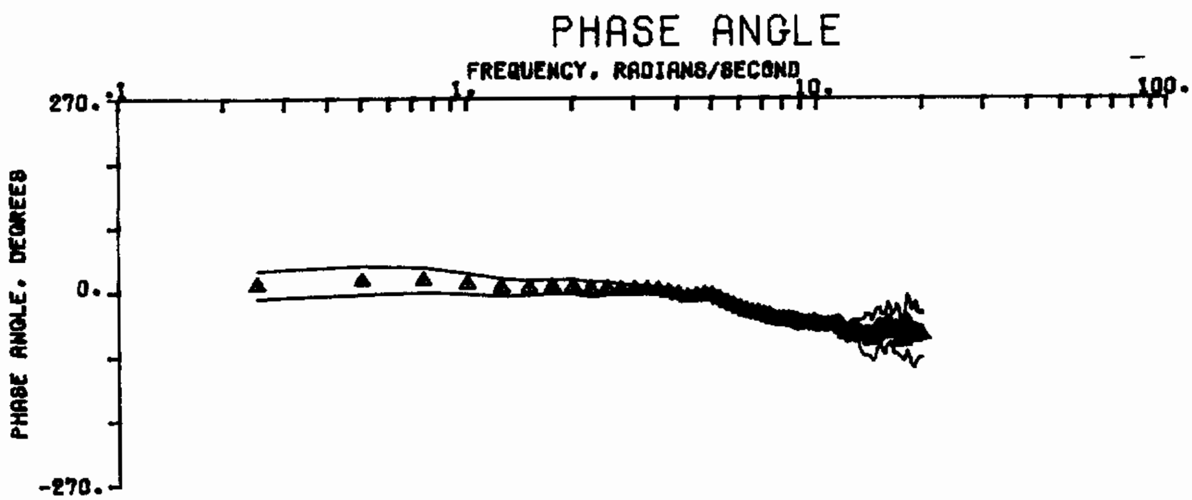
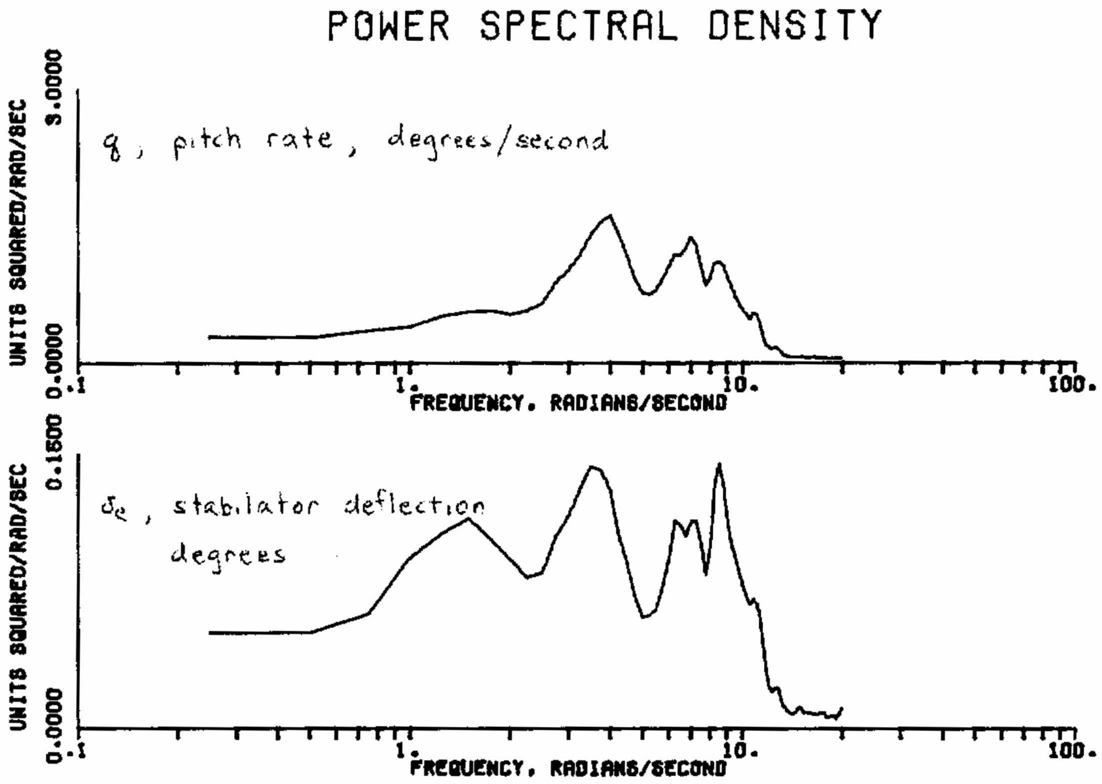


FIGURE 3 AIRFRAME AERODYNAMICS IDENTIFICATION: FREQUENCY RESPONSE CURVES OF PITCH RATE TO STABILATOR DEFLECTION TRANSFER FUNCTION $\left(\frac{q}{-\delta_e}, \frac{\text{degrees/second}}{\text{degree}}\right)$



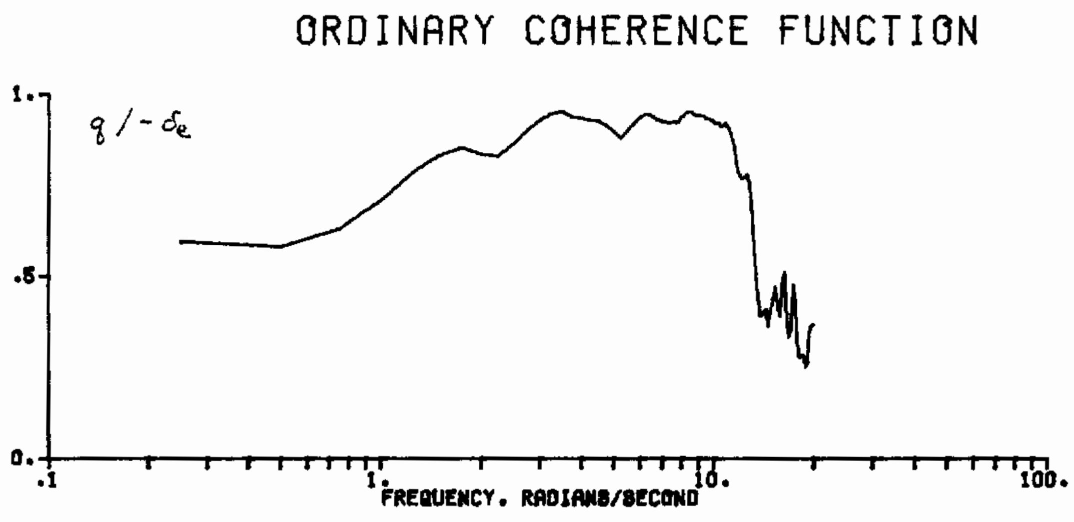


FIGURE 3 (CONCLUDED) AIRFRAME AERODYNAMICS IDENTIFICATION: POWER SPECTRAL DENSITY AND COHERENCE FUNCTION PLOTS

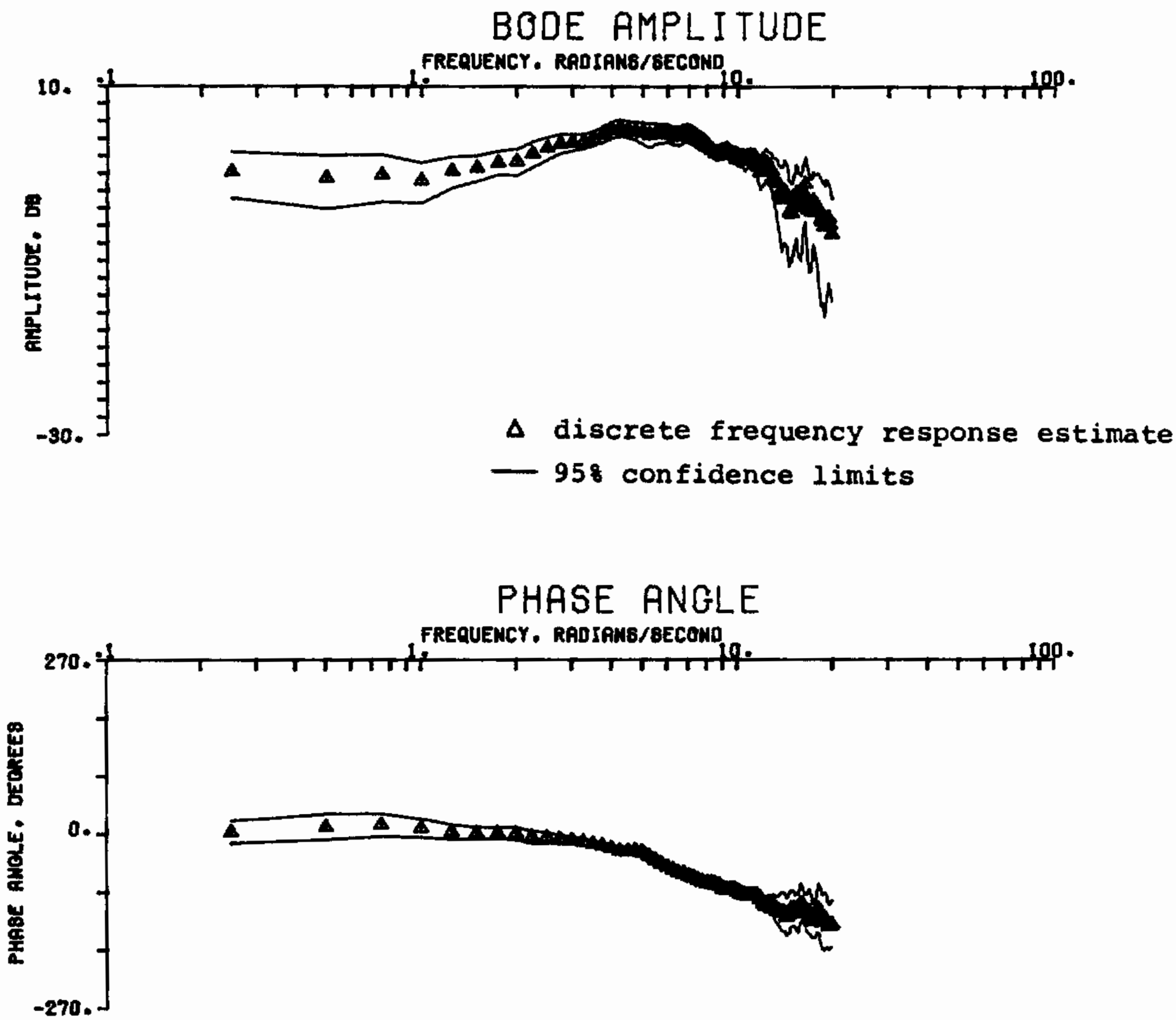
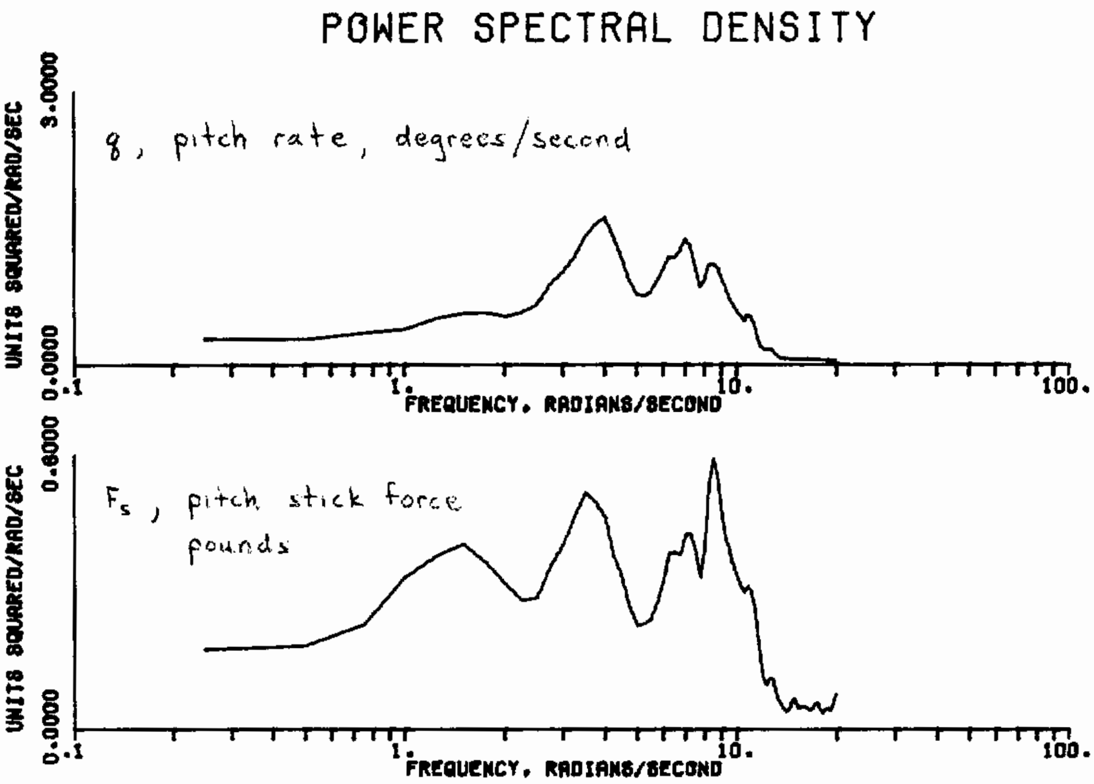


FIGURE 4 OVERALL SYSTEM IDENTIFICATION (AERODYNAMICS PLUS CONTROL SYSTEM): FREQUENCY RESPONSE CURVES OF PITCH RATE TO PITCH STICK FORCE TRANSFER FUNCTION

$$\left(\frac{q}{F_s},\ \frac{\text{degrees/second}}{\text{pound}}\right)$$



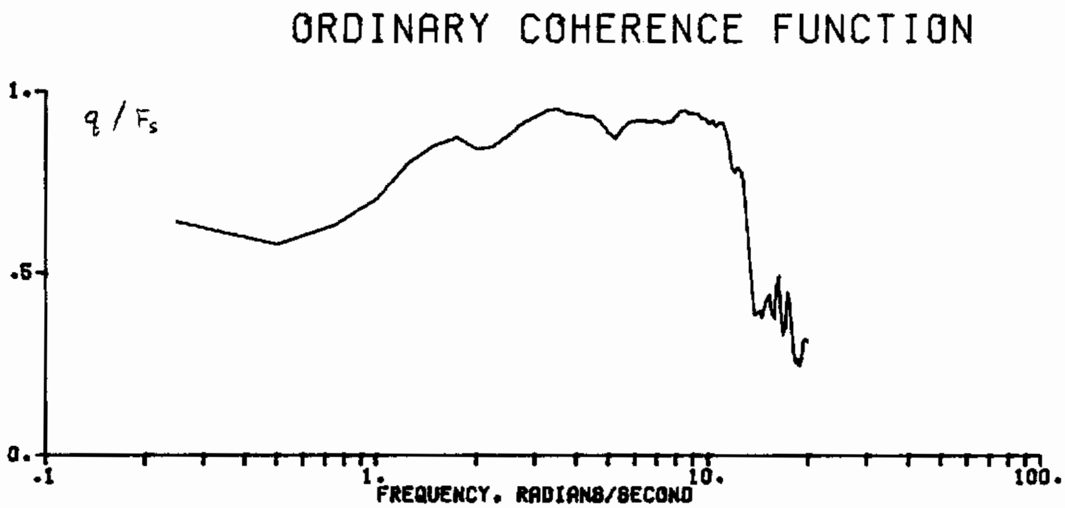


FIGURE 4 (CONCLUDED) OVERALL SYSTEM IDENTIFICATION (AERODYNAMICS PLUS CONTROL SYSTEM): POWER SPECTRAL DENSITY AND COHERENCE FUNCTION PLOTS

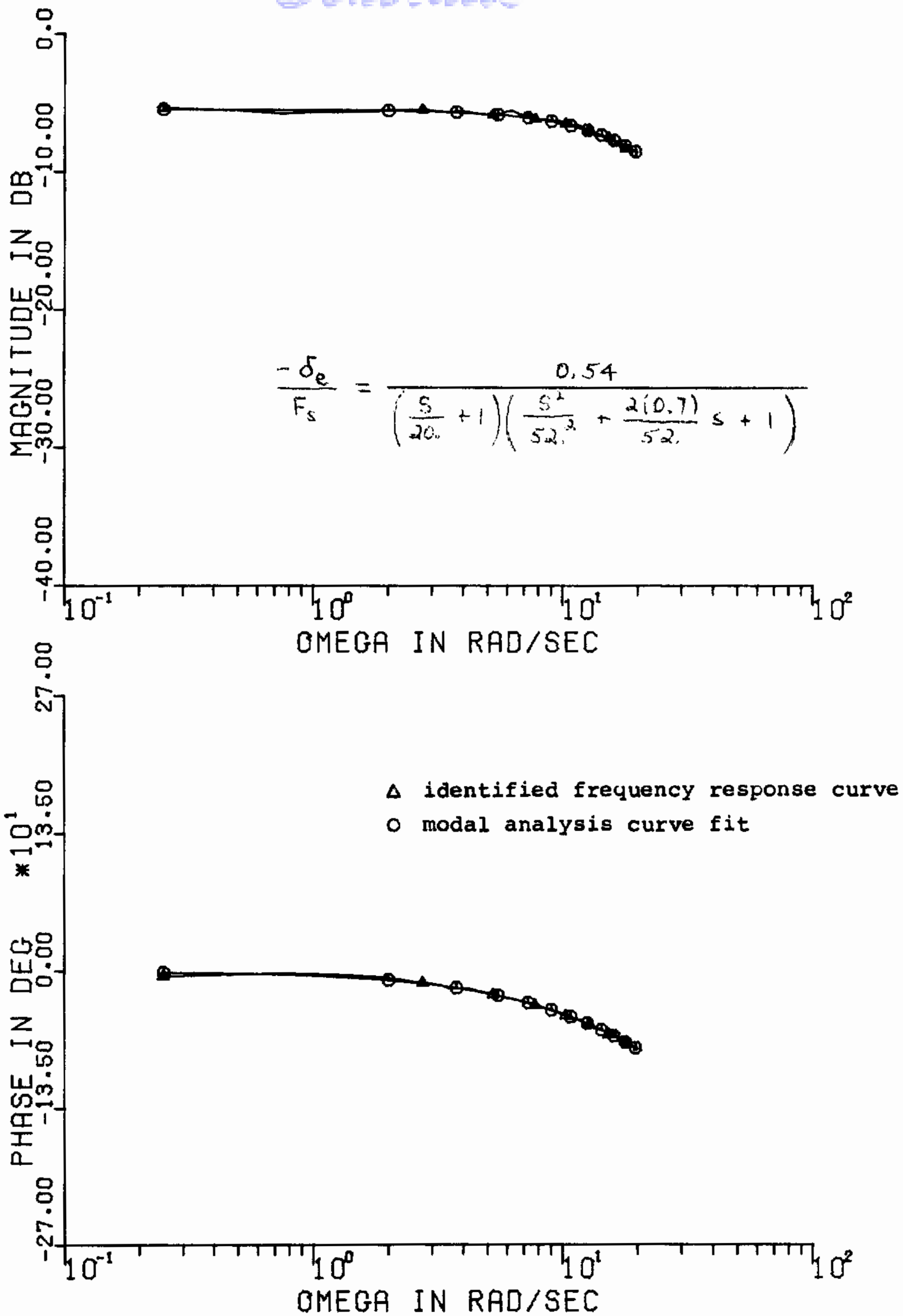


FIGURE 5 RESULTS OF MODAL ANALYSIS OF FLIGHT CONTROL SYSTEM FREQUENCY RESPONSE CURVES

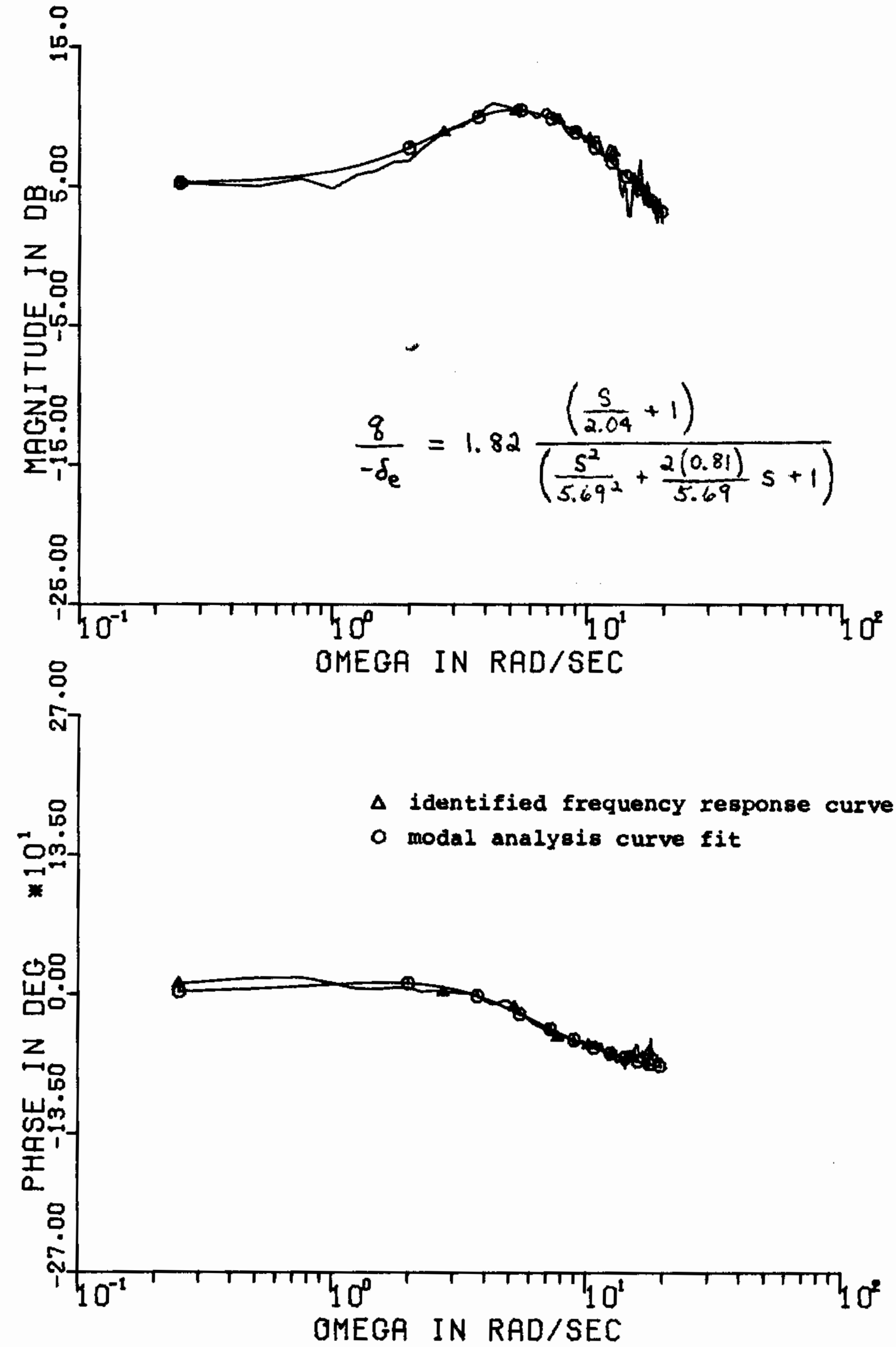


FIGURE 6 RESULTS OF MODAL ANALYSIS OF AIRFRAME AERODYNAMICS FREQUENCY RESPONSE CURVES

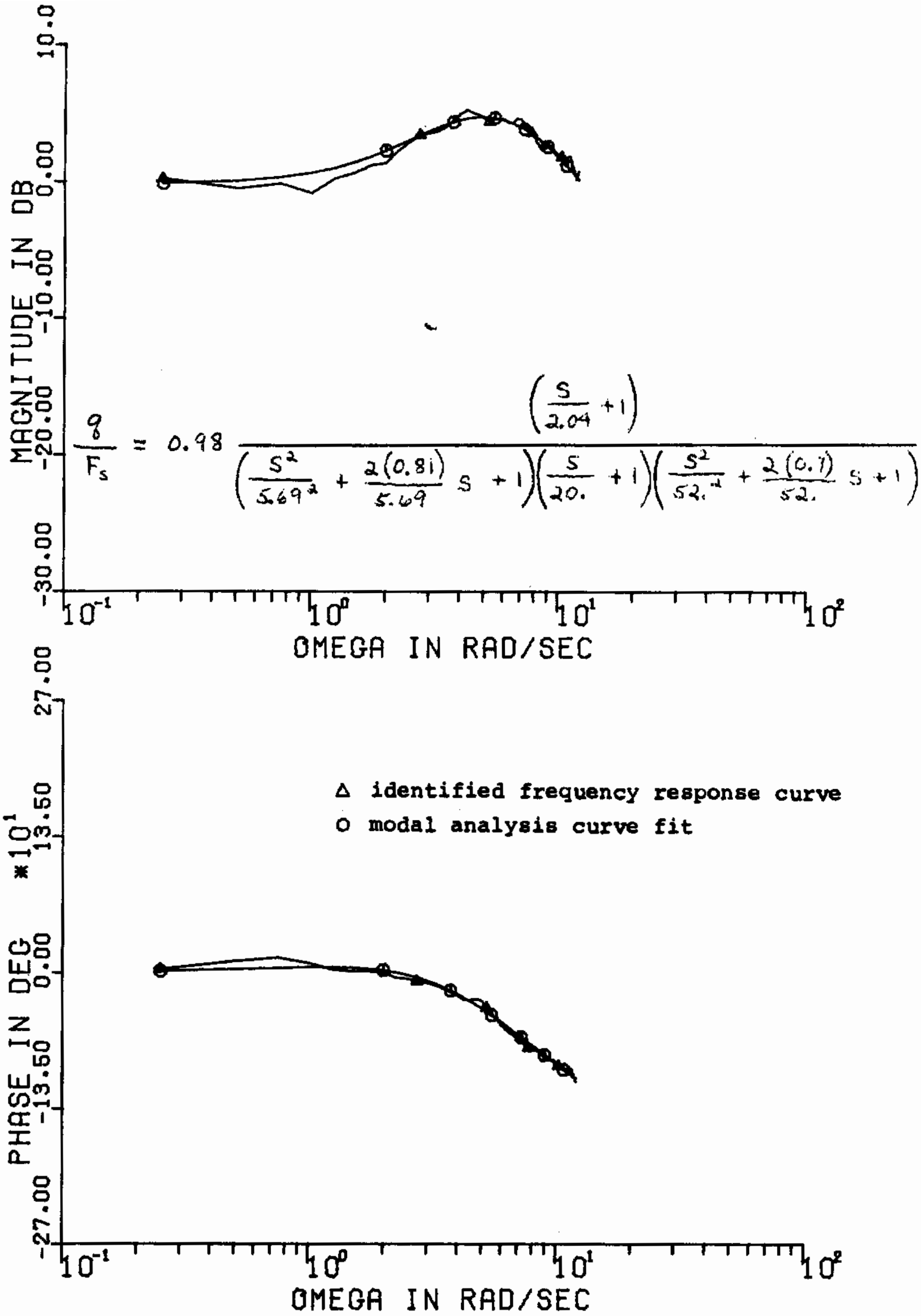


FIGURE 7 RESULTS OF MODAL ANALYSIS OF OVERALL SYSTEM FREQUENCY RESPONSE CURVES

EQUIVALENT SYSTEM MODAL PARAMETER	CASE 1 (FIGURE 8) (0 to 10 radians/sec)		CASE 2 (FIGURE 9) (0 to 10 radians/sec)		CASE 3 (FIGURE 10) (0 to 15 radians/sec)	
	INITIAL USER ESTIMATE	FINAL VALUE	INITIAL USER ESTIMATE	FINAL VALUE	INITIAL USER ESTIMATE	FINAL VALUE
K_E, $\frac{\text{degrees/second}}{\text{pound}}$	0.971	1.217	0.971	0.969	0.971	1.361
a, seconds	-0.05	-0.000077	0.10	0.066	-0.05	-0.000069
$\frac{1}{T_E}$, $\frac{1}{\text{seconds}}$	1.00	9.44	5.00	2.37	1.00	3.32
ω_E, radians/second	6.00	6.52	8.00	5.58	6.00	8.41
ζ_E, non-dimensional	0.70	0.42	0.90	0.71	0.70	0.46
		COST FUNCTION = 0.720		COST FUNCTION = 0.233		COST FUNCTION = 1.728

TABLE 1 RESULTS OF MODAL ANALYSIS OF FREQUENCY RESPONSE CURVES IN FIGURE 4, SHOWING THE INFLUENCE OF THE USER'S INITIAL ESTIMATE AND THE FREQUENCY RANGE OF THE FIT

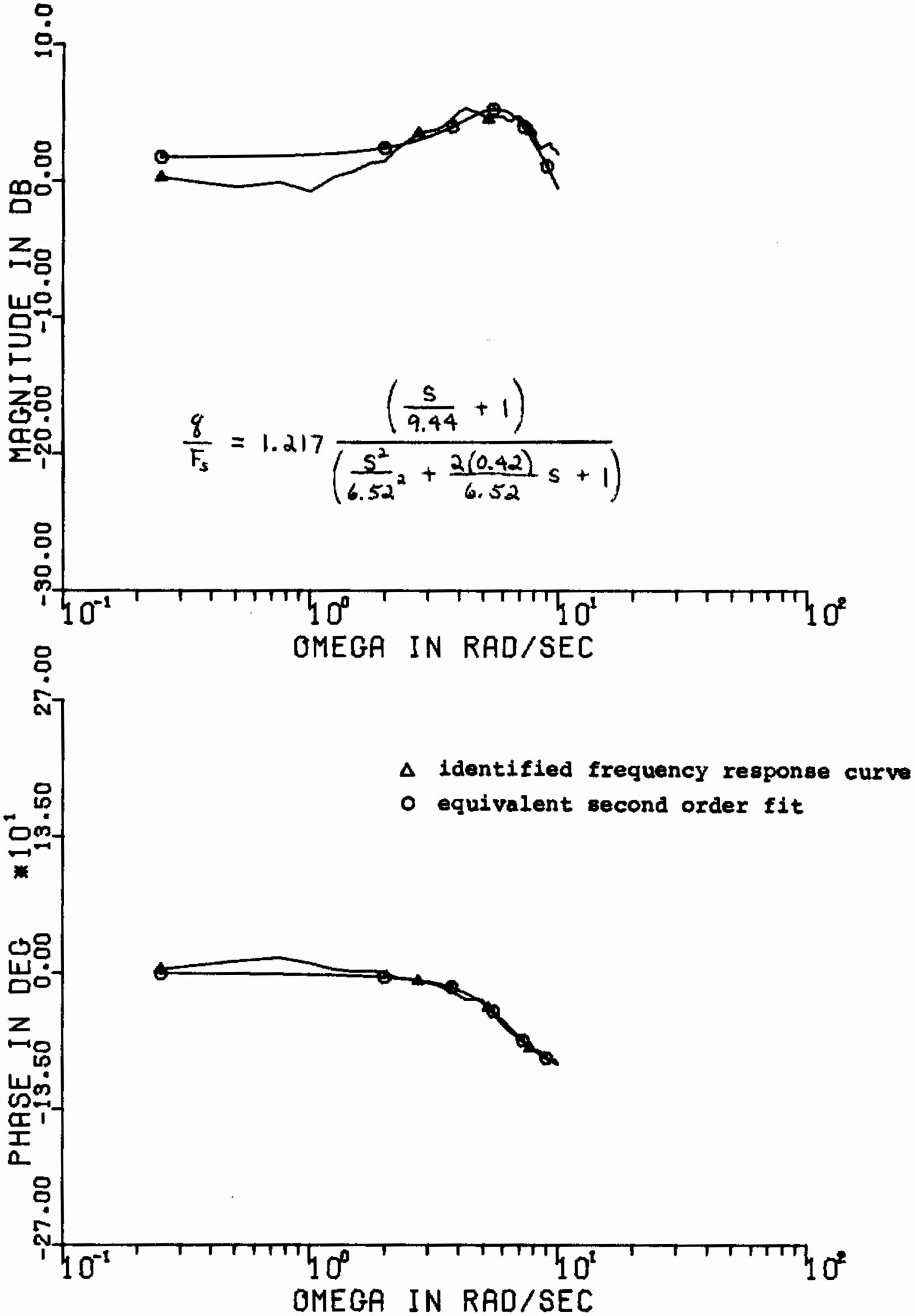


FIGURE 8 SECOND ORDER EQUIVALENT SYSTEM IDENTIFICATION, CASE 1 (SEE TABLE 1)

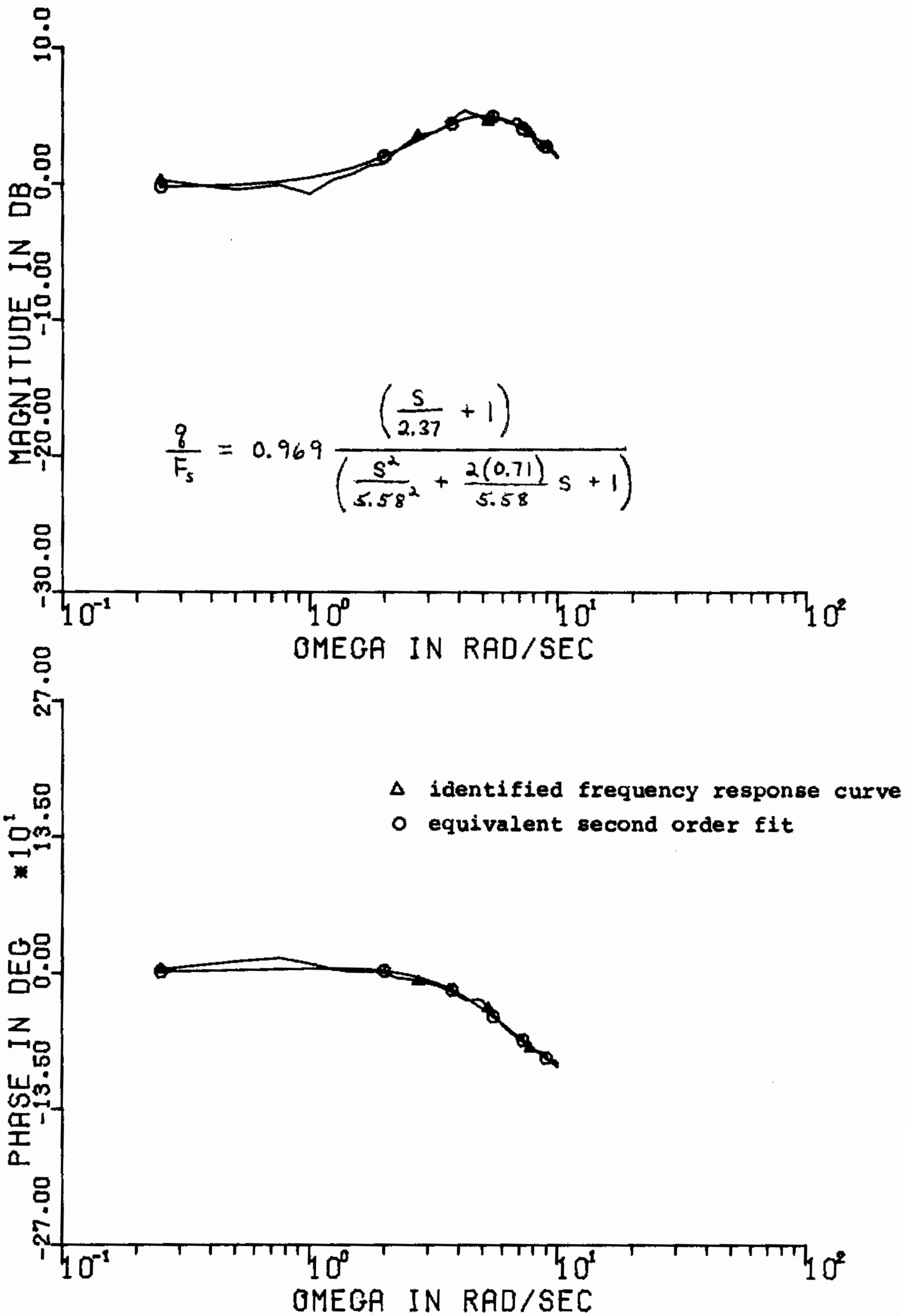


FIGURE 9 SECOND ORDER EQUIVALENT SYSTEM IDENTIFICATION, CASE 2 (SEE TABLE 1)

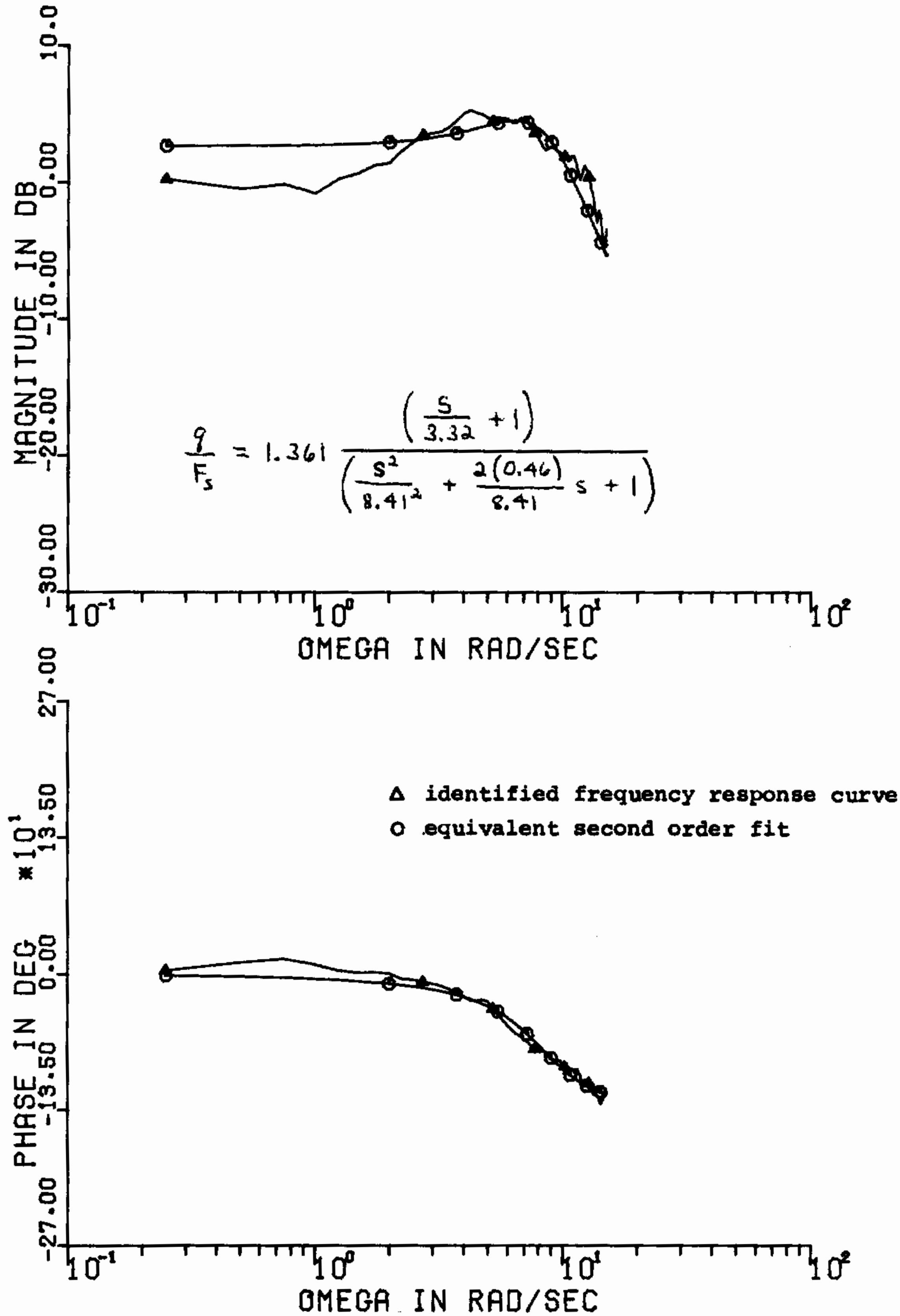


FIGURE 10 SECOND ORDER EQUIVALENT SYSTEM IDENTIFICATION, CASE 3 (SEE TABLE 1)

Ralph Smith, SRL: I'd like to merely comment that it is unfortunate that the equivalent systems work seems to detract from what I believe is the valuable part of your work. Namely, the frequency response measures of airplane response. This is what we need, I believe. I further believe that it's all we need.