AD-754 840

FLIGHT INVESTIGATION OF VARIOUS LONGITUDINAL SHORT-TERM DYNAMICS FOR STOL LANDING APPROACH USING THE X-22A VARIABLE STABILITY AIRCRAFT

R. E. Smith, et al

Calspan Corporation

Prepared for:

Naval Air Systems Command

January 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

REPORT TB-3011-F-2

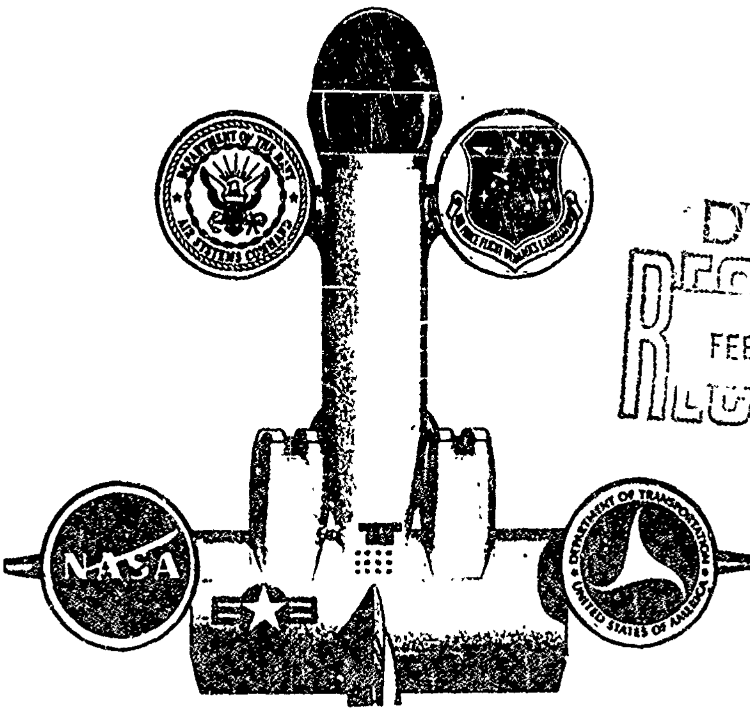
FLIGHT INVESTIGATION OF VARIOUS LONGITUDINAL SHORT-TERM DYNAMICS FOR STOL LANDING APPROACH USING THE X-22A VARIABLE STABILITY AIRCRAFT

FINAL REPORT
(AUGUST 1971 TO MARCH 1972)

JANUARY 1973

By:

R.E. Smith
J.V. Lebacqz
J.M. Schuler



Prepared Under Contract N00019-71-C-0044

for:

NAVAL AIR SYSTEMS COMMAND
DEPARTMENT OF THE NAVY

By

CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK

217

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Calspan Corporation Box 235 Buffalo, New York 14221	2a REPORT SECURITY CLASSIFICATION 2b GROUP

3 REPORT TITLE

Flight Investigation of Various Longitudinal Short-Term Dynamics for STOL Landing Approach Using the X-22A Variable Stability Aircraft

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report (August 1971 to March 1972).

5 AUTHOR(S) (Last name, first name, initial)

Smith, R.E.; Lebacqz, J.V.; Schuler, J.M.

6 REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO OF REFS
January 1973.	~~200~~ 217	25

8a CONTRACT OR GRANT NO. N00019-71-C-0044	9a. ORIGINATOR'S REPORT NUMBER(S) TB-3011-F-2
b. PROJECT NO. c d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 AVAILABILITY/LIMITATION NOTICES

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES Details of illustrations in this document may be better studied on microfiche	12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command Department of the Navy

13. ABSTRACT

The first in-flight flying qualities experiment using the variable stability X-22A aircraft investigated longitudinal flying qualities requirements for STOL aircraft in terminal area operations. Emphasis was placed on defining minimum requirements for the short-term response in VFR and IFR landing approaches at representative steep STOL approach conditions of 65 and 80 knots. Evaluation flights were conducted in negligible and moderate turbulence for a wide range of short-term frequencies and dampings. Identification of the dynamics of the evaluation configurations was performed, to a large extent, by a new, advanced digital identification technique developed for the X-22A aircraft. The results were compared with the short-term response requirements of MIL-F-83300, MIL-F-8785B, the new proposed revisions to MIL-F-8785B, AGARD 408 and AGARD 577. The specified Level 1 and 2 boundaries of MIL-F-83300, and the normal flight and single failure limits of AGARD 408, were found to be approximately valid in moderate turbulence, for both VFR and IFR flight conditions, at short-term undamped natural frequencies above 1.2 rad/sec. The primary difference in pilot ratings between negligible and moderate turbulence was found to be a degradation in moderate turbulence of pilot ratings for the highest short-term undamped natural frequency investigated (2.6 rad/sec). Pilot rating gradients with damping were more apparent than with frequency for the range investigated.

14

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
X-22A Variable Stability Aircraft						
STOL						
Flying Qualities						
Longitudinal Short-Term Criteria						
In-Flight Simulation						

UNCLASSIFIED

Security Classification

AFLC-WPAFB-JUL 66 3M

FLIGHT INVESTIGATION OF VARIOUS LONGITUDINAL SHORT-TERM DYNAMICS FOR STOL LANDING APPROACH USING THE X-22A VARIABLE STABILITY AIRCRAFT

CAL REPORT NO. TB-3011-F-2

FINAL REPORT

JANUARY 1973

R.E. Smith
J.V. Lebacqz
J.M. Schuler

CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK

On November 17, 1972 Cornell Aeronautical Laboratory (CAL) changed its name to Calspan Corporation and converted to for-profit operations. Calspan is dedicated to carrying on CAL's long-standing tradition of advanced research and development from an independent viewpoint. All of CAL's diverse scientific and engineering programs for government and industry are being continued in the aerosciences, electronics and avionics, computer sciences, transportation and vehicle research, and the environmental sciences. Calspan is composed of the same staff, management, and facilities as CAL, which operated since 1946 under federal income tax exemption.

Prepared Under Contract N00019-71-C-0044
for
NAVAL AIR SYSTEMS COMMAND
DEPARTMENT OF THE NAVY

1c

FOREWORD

This report was prepared for the United States Naval Air Systems Command, the United States Air Force Flight Dynamics Laboratory, the National Aeronautics and Space Administration Langley Research Center, and the Federal Aviation Agency under Contract Number N00019-71-C-0044 by the Cornell Aeronautical Laboratory, Inc. (CAL), Buffalo, New York.

The flying qualities experiment reported herein was performed by the Flight Research Department, CAL. Mr. J.L. Beilman was the Program Manager, and Mr. J.M. Schuler the Principal Investigator. Mr. J.V. Lebacqz was the research engineer, and Mr. R.E. Smith served as both safety pilot and research engineer. Technical monitoring was performed by the X-22A Flight Research Steering Group, chaired by Mr. R. Siewert of the Naval Air Systems Command. The authors are grateful to Mr. Siewert and the members of the Steering Group for their interest and support throughout the program, and wish to acknowledge their appreciation to Mr. J.L. Shea, Mr. W.J. Klotzback, Mr. T.L. Neighbor, USAF; Mr. R.J. Tapscott, Mr. J. Garren, and Mr. R. Wasicko, NASA; Mr. F. Pierce, NAVAIR; Mr. J. Teplitz, FAA; and Mr. C. Mazza, NADC.

This program was the first to use the variable stability X-22A V/STOL aircraft as a research tool. In view of the complexity of this machine, as well as that of the associated data telemetry and processing equipment, the successful completion of the flight program is the result of the efforts of a large number of individuals at CAL. In particular, the authors wish to acknowledge the outstanding contributions of the following persons:

Mr. J.L. Beilman -- X-22A Program Manager

Messrs. N.L. Infanti and G.W. Hall -- safety and evaluation pilots

Mr. R.D. Till -- Lead Electronics Engineer

Mr. G. Ewers -- Aircraft Crew Chief

Messrs. F. Erny and W. Wilcox -- Aircraft Maintenance Supervision

Messrs. J. Wilson and J. Shattuck -- Electronics Maintenance

Messrs. T. Gavin, B.J. Eulrich, W. Shed, C. Mesiah, P. Shelton, J. Lyons -- Digital Data Acquisition System

Messrs. H. Chmura, D. Dobmeier, W. Howell, E. Melbourne -- Aircraft Maintenance

In addition, special thanks are due to Messrs. C. Mesiah, J. Lyons, and C. Poppenberg for their efforts in the extensive amount of digital data processing that went into the analysis of the data. The bulk of the secretarial work during the program was done by Mrs. J. Cornell; in the preparation of this report, we are grateful to Mrs. J.A. Martino, who was the technical editor, and to Messrs. C.R. Chalk, G.W. Hall, and D.L. Key for their reviews and assistance.

ABSTRACT

The first in-flight flying qualities experiment using the variable stability X-22A aircraft investigated longitudinal flying qualities requirements for STOL aircraft in terminal area operations. Emphasis was placed on defining minimum requirements for the short-term response in VFR and IFR landing approaches at representative steep STOL approach conditions of 65 and 80 knots. Evaluation flights were conducted in negligible and moderate turbulence for a wide range of short-term frequencies and dampings. Identification of the dynamics of the evaluation configurations was performed, to a large extent, by a new, advanced digital identification technique developed for the X-22A aircraft. The results were compared with the short-term response requirements of MIL-F-83300, MIL-F-8785B, the new proposed revisions to MIL-F-8785B, AGARD 408 and AGARD 577. The specified Level 1 and 2 VFR boundaries of MIL-F-83300, and the normal flight and single failure limits of AGARD 408, were found to be approximately valid in moderate turbulence, for both VFR and IFR flight conditions, at short-term undamped natural frequencies above 1.2 rad/sec. The primary difference in pilot ratings between negligible and moderate turbulence was found to be a degradation in moderate turbulence of pilot ratings for the highest short-term undamped natural frequency investigated (2.6 rad/sec). Pilot rating gradients with damping were more apparent than with frequency for the range investigated.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT.)

LIST OF ILLUSTRATIONS (CONT.)

LIST OF TABLES

LIST OF SYMBOLS

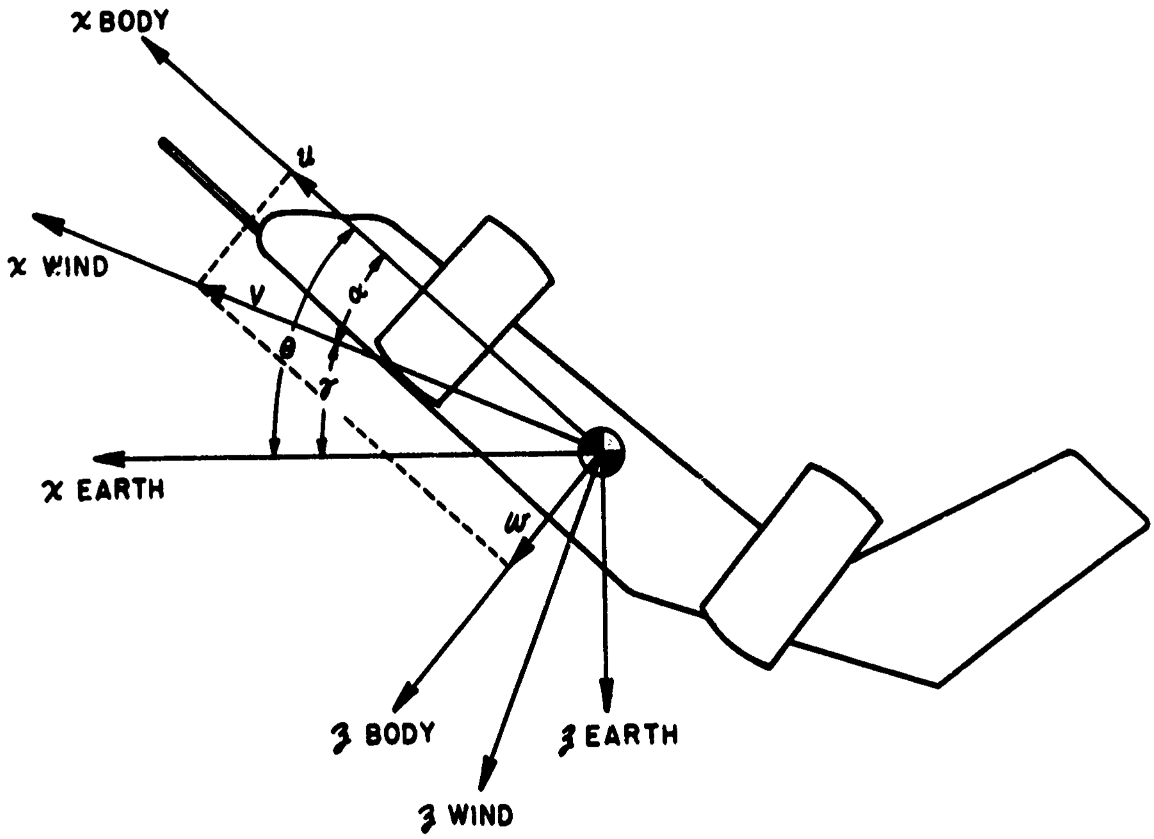
$B_{( )}$	Average propeller pitch angle in ( ) duct, degrees
F_{ES}	Pitch control stick force, lb
$\frac{F_{ES}}{n_z}$	Pitch control stick force per g, lb/g
g	Acceleration due to gravity (32.2 ft/sec^2)
$\dot{h}$	Rate of climb (or descent), feet/sec or feet/min
I	Pitching moment of inertia, slug ft^2
K_u	Gain of u/δ_{ES} transfer function
K_α	Gain of α/δ_{ES} transfer function
K_θ	Gain of θ/δ_{ES} transfer function
$L'_{\delta_{AS}}$	Roll acceleration control displacement sensitivity, $\frac{\text{rad/sec}^2}{\text{inch}}$
$L'_{F_{AS}}$	Roll acceleration control force sensitivity, $\frac{\text{rad/sec}^2}{\text{lb}}$
M	Total aerodynamic pitching moment, ft-lb
M_c	Pitch control power, rad/sec^2
$M_{( )}$	$= \frac{1}{I}\frac{\partial M}{\partial ( )}$, dimensional pitch moment derivative, $\frac{\text{rad/sec}^2}{( )}$
$N'_{\delta_{RP}}$	Yaw acceleration control displacement sensitivity, $\frac{\text{rad/sec}^2}{\text{inch}}$
$N'_{F_{RP}}$	Yaw acceleration control force sensitivity, $\frac{\text{rad/sec}^2}{\text{lb}}$
n_x	Acceleration along body x-axis, ft/sec^2 or g's
n_z	Acceleration along body z-axis, ft/sec^2 or g's
$\frac{n_z}{\alpha}$	Steady-state normal acceleration per angle of attack, g's/rad
$P( )$	Probability density of ( )
p	Roll rate, rad/sec
q	Pitch rate, rad/sec
r	Yaw rate, rad/sec
s	Laplace transform variable, rad/sec
U_o	Trim velocity in body x-axis, ft/sec
u	Velocity (also perturbation from trim) along body x-axis, ft/sec
V_a	Velocity of aircraft with respect to air, ft/sec
V_g	Velocity of aircraft with respect to ground, ft/sec
V_T	True velocity (with respect to air), ft/sec or kt

LIST OF SYMBOLS (Cont.)

V_w	Velocity of wind with respect to ground, ft/sec
w	Velocity (also perturbation from trim) along body z-axis, ft/sec
w_0	Trim velocity along body x-axis, ft/sec
X	Total aerodynamic force along body x-axis, lb
$X_{(\ )}$	$= \frac{1}{m}\frac{\partial X}{\partial(\ )}$ dimensional X-force derivative, ft/sec^2/( )
Δy	Lateral offset displacement, ft
Z	Total aerodynamic force along body z-axis divided by mass, ft/sec^2
$Z_{(\ )}$	$= \frac{1}{m}\frac{\partial Z}{\partial(\ )}$ dimensional Z-force derivative, ft/sec^2/( )
α	Angle of attack at the aircraft center of gravity, degrees
α_V	Angle of attack measured by the nose-boom vane, degrees
β_V	Angle of sideslip measured by the nose-boom vane, degrees
γ	Flight path angle with respect to the ground, positive in climb, degrees
Δ_{ES}	Displacement of safety pilot's pitch control stick, positive aft, inches
Δ'_{ES}	Summation of VSS electrical pitch commands, inches
δ_c, δ_{cs}	Collective control stick position, degrees
δ_{AS}	Rolling moment control stick position, positive right, inches
δ_{ES}	Pitching moment control stick position, positive aft, inches
δ_{RP}	Yawing moment control pedal position, positive right, inches
ε_{GS}	Glide slope error, positive up, degrees
ζ_d	Damping ratio of Dutch roll mode characteristic roots
ζ_{FS}	Damping ratio of feel system
ζ_p	Damping ratio of phugoid mode characteristic roots
ζ_{ST}, ζ_{SP}	Damping ratio of short-term (or short-period) characteristic roots
ζ_α	Damping ratio of α/δ_{ES} transfer function numerator
ζ_ϕ	Damping ratio of ϕ/δ_{AS} transfer function numerator
θ_0	Trim pitch attitude, radians or degrees
θ	Pitch attitude (also perturbation from trim), radians or degrees
λ	X-22A duct angle, measured from horizontal, degrees
$\lambda_{1,2}$	Real roots of second order system, 1/sec
$\mu_{(\ )}$	Mean, ( )
$\sigma_{(\ )}$	Standard deviation, ( )
τ_R	Roll mode time constant, seconds

LIST OF SYMBOLS (Cont.)

τ_s	Spiral mode time constant, seconds
$1/\tau_{u_{1,2}}$	Zeroes of u/δ_{ES} transfer function, rad/sec
$1/\tau_{\theta_{1,2}}$	Zeroes of θ/δ_{ES} transfer function, rad/sec
ϕ	Roll angle, degrees or radians
$\lvert\phi/\beta\rvert_d$	Magnitude of roll-to-sideslip ratio in Dutch roll component
ω_d	Undamped natural frequency of the Dutch roll mode, rad/sec
ω_{FS}	Undamped natural frequency of the feel system, rad/sec
ω_o	Cutoff frequency of Butterworth filter, rad/sec
ω_p	Undamped natural frequency of the phugoid mode, rad/sec
$\omega_{ST,SP}$	Undamped natural frequency of the short-term (or short period) mode, rad/sec
ω_α	Undamped natural frequency of the α/δ_{ES} transfer function numerator, rad/sec
ω_θ	Bandwidth frequency, rad/sec
ω_ϕ	Undamped natural frequency of the ϕ/δ_{ES} transfer function numerator, rad/sec
$(\Delta A/\Delta \measuredangle)_\theta$	Slope of amplitude-phase open-loop θ/δ_{ES} curve, dB/degree
$\Delta \measuredangle_\theta$	Phase angle of open-loop θ/δ_{ES} transfer function, degrees
$(\dot{\ })$	Time rate of change of ( ), ( )/sec
$(\ )_o$	Initial or trim value of ( )
$\Phi_{(\ )}$	Power spectral density of ( )



BODY AXIS SYSTEM

ABBREVIATIONS

AGL	Above Ground Level
CTOL	Conventional Take-Off and Landing
IFR	Instrument Flight Rules
ILS	Instrument Landing System
LORAS	Low Range Airspeed System
PIO	Pilot-Induced Oscillation
PR	Pilot Rating (Cooper-Harper)
VAA	Visual Approach Aid
VFR	Visual Flight Rules
VSS	Variable Stability System
deg	degrees (angle)
fpm	feet per minute
kt	knots (airspeed)
rms	root-mean-square
Hz	Frequency (hertz)

SECTION I

INTRODUCTION

A prerequisite for the design of future STOL aircraft is a proper definition of the flying qualities such aircraft should exhibit in critical flight phases such as landing approach. Very few flying qualities data for this flight regime exist; in general, approach velocities on the order of 60-80 knots and steep glide paths must be considered, and few aircraft currently operating provide the capability to investigate this regime. Studies that have been made have been concerned with specific aircraft; in these studies the dynamic characteristics of the aircraft were fixed and hence no quantitative indication of the interaction of aircraft dynamics with flying qualities at these flight conditions can be made. Particularly noticeable is the paucity of flying qualities data for longitudinal short term (short period) dynamic characteristics in STOL landing approach, as can be seen by referring to the background document for the new Military Specification -- Flying Qualities of Piloted V/STOL Aircraft (References 1 and 2).

This report describes the results of the first flying qualities experiment to be performed using the variable stability X-22A aircraft. In view of the unique character of the X-22A and the lack of flying qualities data for STOL aircraft, the program had two main objectives:

1. To generate meaningful and valid longitudinal flying qualities data for STOL aircraft during terminal area operations, and

2. To demonstrate the capability of the X-22A variable stability aircraft as a research tool.

To achieve these objectives, an experiment was designed to obtain flying qualities data pertinent to the development of minimum requirements for the longitudinal short-term response of STOL aircraft during terminal area operations -- Flight Phase Category C of MIL-F-83300 and MIL-F-8785B, and their associated Background Information and User Guides (References 1 through 4). Specifically, attention was focused upon VFR and IFR approaches at a representative STOL approach velocity (65 knots) at the steepest practical glide slope angle ($\gamma = -9^o$) with various combinations of short-term response frequency and damping, in both smooth and moderately turbulent ambient conditions. The effect of glide slope angle was briefly investigated by repeating selected configurations at 65 knots, $\gamma = -6^o$. Ancillary data were also obtained at an additional representative flight condition (80 knots and $\gamma = -7^o$).

Two evaluation pilots participated in the program and made a total of 50 evaluations of 29 different combinations of short-term frequency and damping for the two flight conditions. Each pilot recorded his comments during the evaluations and then assigned two pilot ratings using the Cooper-Harper Scale (Reference 5): one rating for the aircraft considering the VFR approach task alone, and an overall rating for the aircraft in the context of terminal area operations, based upon both a VFR and an IFR approach task. In each case, a turbulence effect rating was assigned based upon the degree of deterioration in task performance due to ambient turbulence. Aircraft flight variables were recorded continuously during all flights and processed digitally to obtain identification of evaluation configuration dynamic characteristics and statistical measures of control usage and task performance.

This report is organized as follows. Section II discusses the design of the experiment; Section III outlines the conduct of the experiment, including a brief description of the equipment used. The results of the experiment in the form of pilot ratings and comments are presented in Section IV. Correlations of the pilot rating data with existing flying qualities criteria are presented in Section V, while Section VI presents the results of the statistical analyses to measure task performance and pilot workload (control usage). Finally, the conclusions and recommendations are given in Sections VII and VIII, respectively.

SECTION II

DESIGN OF THE EXPERIMENT

The purpose of the flying qualities experiment was to generate data that may be used to substantiate or develop minimum requirements for the longitudinal short-term (or short-period) response in terminal area operations (Flight Phase Category C). To best accomplish this objective, the landing approach subphase was chosen as the area in which to concentrate quantitatively, with the actual landing subphase to receive qualitative attention through extrapolation. The approach subphase encompasses the following elements: visual approach "tracking," localizer capture, glide slope capture, ILS tracking, and wave off. As discussed in the next section, the evaluation task was designed to exercise all of these elements, thereby studying in depth the approach subphase.

As has been previously noted, very few flying qualities data pertinent to STOL aircraft in the landing approach flight phase exist -- a fact which placed this experiment clearly in the exploratory category. For example, NASA has studied steep approaches under VFR and IFR conditions using the Breguet 941 (References 6 and 7), and the Royal Aircraft Establishment has also investigated steep VFR approaches, at speeds above the nominal STOL range, using conventional transport aircraft (Reference 8). However, in these studies no indication of the interaction of aircraft dynamics with flying qualities can be obtained. More specifically, the only substantiating data for the longitudinal short-term response criterion in MIL-F-83300 (Section 3.3.2) were obtained in a NASA study using a variable stability helicopter (Reference 9). In this study, angle of attack stability, pitch damping and control effectiveness were varied; the evaluation task was not, however, particularly representative of landing approach.

This section will describe the design of the experiment, including the rationale behind the priorities assigned to the many potential factors which must be considered, and summarize the characteristics of the evaluation configurations.

2.1 Background and Purpose

There are clearly many factors to consider that are important to STOL longitudinal flying qualities in the landing approach subphase. A partial list of variables includes:

1. Aircraft Characteristics

   - short-term dynamics (short-period), ω_{ST}, ζ_{ST}
   - thrust inclination, $Z_{\delta_C}/X_{\delta_C}$
   - n_z/α
   - power "backsidedness," $d\gamma/dV$
   - thrust offset, M_{δ_C}
   - control system dynamics

2. Task Characteristics

- approach velocity, V_{T_∞}
- glide path angle or rate of descent ($\gamma, \dot{h}$)
- wind and turbulence
- approach condition, VFR or IFR.

Since most of these factors are to some degree interrelated, a very large matrix of configurations would be required to properly isolate the effects of each factor on the aircraft's flying qualities. An experiment of this scale was not possible in the flight hours available.

To ensure that the data generated from the experiment would provide valid and useful information, it was necessary to decide which of these variables were most important for this initial investigation. Probably the most important aircraft characteristics in landing approach for satisfactory longitudinal flying qualities are those that affect the ability to control pitch attitude precisely; this ability is closely related to the aircraft short-term response characteristics such as natural frequency, damping ratio or total damping, the "high frequency" numerator root $1/T_{\theta_2}$ or normal acceleration per angle of attack, the control effectiveness for longitudinal control, $M_{\delta_{ES}}$, and longitudinal control system dynamics. Also of obvious importance are those characteristics that relate to control of velocity and flight path angle. For STOL aircraft, such characteristics include conventional parameters such as the "low frequency" numerator root in the altitude to elevator transfer function, which is related to "backsidedness" on the power-required curve, and normal acceleration per angle of attack; in addition, however, it is likely that STOL aircraft will have some direct lift capability, either through a separate control or through inclination of the thrust vector, and the characteristics of this capability in conjunction with undesirable side effects (e.g., moment due to thrust) may also be important.

Considering now the task characteristics listed, it is clear that mean wind velocity and the concomitant turbulence level may be important in the STOL landing approach task. At representative STOL approach velocities (60-80 knots), a 15 knot headwind gust produces a relatively large percentage change in approach velocity and rate of descent compared to conventional aircraft approaches, necessitating proportionally higher control efforts. In addition, recent research has demonstrated the importance of rms turbulence level to pilot rating in the landing approach. The influence of approach condition -- that is, whether the approach is flown IFR or VFR -- may also be important. The short term response criteria of MIL-F-83300 are more stringent under IFR than VFR conditions; it is important to ascertain whether or not this differentiation makes any sense from a flying qualities point of view. The effect of glide slope angle, or perhaps more correctly rate of descent, also requires consideration. Past experience indicates that a maximum of approaximately 1000 fpm rate of descent will be tolerated by pilots in an IFR approach (Reference 10); this limit is clearly a function of breakout altitude and slant range to touchdown (and hence approach velocity). If the limit is assumed valid, it is important to ascertain whether pilot comments and ratings are affected by the steepness of the descent up to this limit, and hence a more moderate rate of descent should be investigated in addition to the maximum. Finally, the approach velocity itself may have an effect on the landing approach task, although, in general, the influence of this variable would be most important to the actual landing.

Of the aircraft and task characteristics discussed above, the test program was designed to focus expressly on the effects on the aircraft's flying qualities of:

1. longitudinal short-term frequency, ω_{ST}, and total damping, $2\omega_{ST}\zeta_{ST}$
2. approach conditions, VFR or IFR
3. turbulence.

The flight condition chosen for the major portion of this investigation was a representative steep STOL approach at 65 knots at a glide path angle (relative to the ground) of $\gamma = -9°$. This glide path angle yields a rate of descent of approximately 1030 fpm in zero wind conditions which corresponds with the upper limit on rate of descent for STOL IFR approaches of 1000 fpm suggested in NASA STOL research work. The effect of glide path angle was briefly investigated by repeating selected dynamic configurations (ω_{ST}, ζ_{ST}) at a more shallow glide path angle ($\gamma = -6°$). The thrust inclination, moment due to thrust, n_γ/α, and power "frontsidedness" ($d\gamma/dV$) were maintained constant at the nominal X-22A values for this duct angle-speed combination ($\lambda = 50°$, 65 knots). The duct angle of 50° was chosen to give the maximum descent rate capability at 65 knots (see Appendix VI).

The purpose of this major portion of the experiment, then, was to quantitatively define minimum requirements on short-term frequency and damping for VFR and IFR conditions, and to ascertain, to some extent, the effects of turbulence and glide path angle on these requirements.

A more cursory investigation of several of the remaining characteristics was performed by flying approaches for a smaller number of short-term dynamic configurations at an approach velocity of 80 knots. This approach velocity results in a different X-22A duct angle ($\lambda = 30°$) than at 65 knots ($\lambda = 50°$), hence thrust inclination, moment due to thrust, and n_γ/α are different. The glide path angle for these approaches was $\gamma = -7°$ which corresponds to essentially the same zero-wind rate of descent as for the 65 knots, $\gamma = -9°$ flight condition; i.e., 1030 fpm.

The purpose in performing the ancillary approaches at the 80 kt condition was to examine quantitatively what, if any, effect approach velocity has on the selected task. In addition, the lower bounds on short-term frequency in MIL-F-83300 are functions of n_γ/α, and hence are more stringent at the 80 knot flight condition; therefore, low-frequency dynamic configurations should obtain worse ratings at 80 knots than at 65 knots. The 80-knot approaches were necessary to test this hypothesis.

2.2 Flight Conditions

The following table summarizes the aircraft characteristics which were constant for each flight condition:

V_T kt/fps	λ deg	$-\gamma$ deg	$\dot{h}$ (zero wind) fpm	n_z/α g/rad	$d\gamma/dV$ deg/kt	$\left(\frac{\Delta z}{\Delta x}\right)_{\delta_c}$	M_{δ_c} $\frac{\text{rad/sec}^2}{\text{deg}}$
65/110	50	9	1030	1.7	-0.22	-1.65	0.094
65/110	50	6	690	1.7	-0.22	-1.65	0.094
80/135	30	7	1030	2.9	-0.14	-1.05*	0.033*

* Estimated data.

2.3 Evaluation Configurations

The specific combinations of ω_{s_T} and $2\zeta_{s_T}\omega_{s_T}$ selected for evaluation at the two flight conditions are summarized in Figure 2-1. The number next to each point is the configuration identification number which will be used throughout the report to facilitate correlation of the data. The configurations were selected to span the present MIL-F-83300 Level 1 and Level 2 boundaries at frequencies above ω_{s_T} = 1.0 rad/sec. As can be seen from the figure, the primary emphasis in the experiment was concerned with defining the minimum damping (or damping ratio) boundaries. The number of configurations with $\omega_{s_T} < 1.0$ rad/sec is insufficient to properly define the low frequency boundaries as given in MIL-F-83300, but do represent realistic values of the lowest frequencies that might sensibly be found in an aircraft in the X-22A weight and size class. Simulation of lower frequencies is difficult to mechanize; in addition, the identification of the dynamic characteristics of such a simulation becomes tenuous. For example, the dynamic characteristics of configurations 19 and 20, which had the lowest frequencies investigated, could not be identified. Appendix VI explains how the simulated configurations were mechanized in the variable stability X-22A aircraft, and contains a more detailed discussion of the problems associated with simulating low frequency configurations. A summary of all the pertinent data associated with each configuration is contained in Appendix II, while Appendix III outlines the methods employed during the program to identify the dynamic characteristics of each configuration.

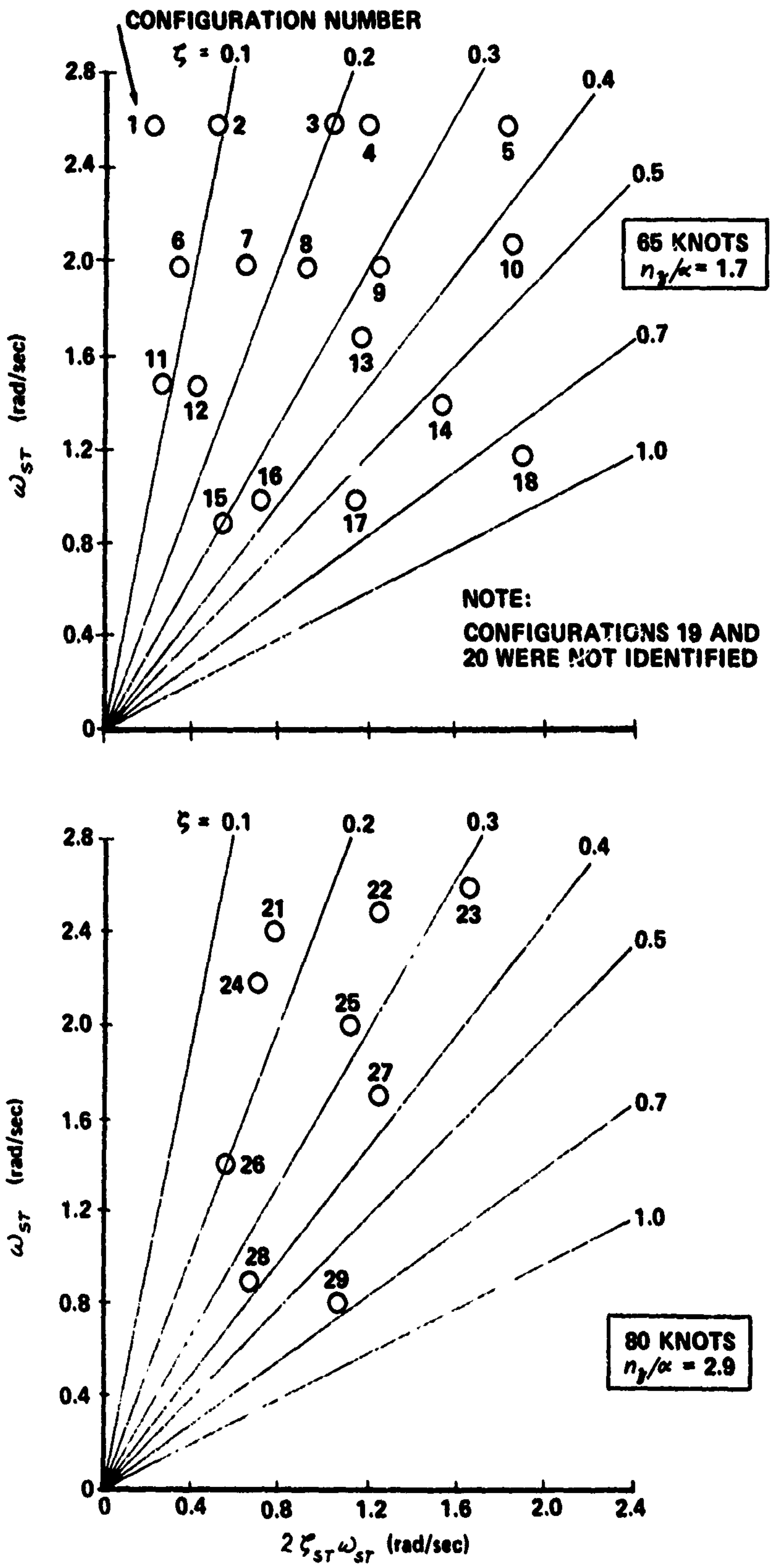


Figure 2-1 SUMMARY OF SHORT TERM DYNAMICS FOR EVALUATION CONFIGURATIONS

2.4 Feel System Characteristics

The longitudinal feel system dynamics and force gradient were held fixed for all 29 configurations evaluated in the program. The dynamics are second order, and had the following values:

Longitudinal Feel System
$\omega_{FS} = 14$ rad/sec
$\zeta_{FS} = 0.6$
$F_{ES}/\delta_{ES} = 7.5$ lb/in.

No breakout force or hysteresis was introduced into the longitudinal control system for this program. These longitudinal feel system dynamics were considered to be "fast" for the landing approach task with the range of short-term dynamics simulated and therefore were not considered to be a factor in the flying qualities evaluations. Longitudinal stick travel was ±5.6 in.

2.5 Longitudinal Gearing

The gearing ratio between the X-22A longitudinal control and the evaluation pilot's stick, which determines the pitch control sensitivity, $M_{\delta_{ES}}$, was selected by the pilot at the beginning of each evaluation. The purpose of this process was to avoid having pilot opinion degrade because the stick forces were too high or too low. Ideally, each dynamic configuration should have been evaluated with several values of the longitudinal gearing ratio, but this would have required a much larger flight program.

2.6 Phugoid Characteristics

No attempt was made to maintain the long-term or phugoid roots at one specific frequency and damping. The phugoid characteristics were measured for each short-term configuration evaluated and found to be essentially constant for the medium and high ω_{ST} cases and sufficiently slow so as not to be a factor in the pilot ratings. For the low ω_{ST} cases, where the distinction between "short-term" and "long-term" may become nebulous, there was some variation in phugoid characteristics. The significance of these effects will be discussed in Section IV. A summary of the phugoid characteristics is given in Appendix II.

2.7 Thrust Control

The evaluation pilot controlled the thrust directly with a collective-type control and the available normal, or direct lift, force with collective is, of course, a function of the duct angle, λ . No time lag of any significance was present in the thrust control system.

2.8 Lateral-Directional Characteristics

Lateral-directional characteristics were selected by the evaluation pilots during the practice evaluation flights and remained constant for each flight condition throughout the evaluations. Although the characteristics were not specifically optimized, the pilot comments indicate that they did not influence to any great extent the pilot ratings obtained in the evaluation.

The lateral-directional characteristics, obtained from in-flight measurements, are summarized in the following table.

	65 kt/50° λ	80 kt/30° λ
ω_d	1.6 rad/sec	1.5 rad/sec
ζ_d	0.10	0.07
ω_ϕ	1.5 rad/sec	1.2 rad/sec
ζ_ϕ	0.27	0.32
τ_R	0.6 sec	0.6 sec
τ_S	5.0 sec (stable)	5.0 sec (stable)
$\lvert\phi/\beta\rvert_d$	1.2	1.8

The lateral and directional control sensitivities were selected by the evaluation pilots and fixed for the experiment at the following values:

$$L'_{\delta_{AS}} = 0.54 \text{ rad/sec}^2/\text{in.}$$

$$N'_{\delta_{RP}} = 0.37 \text{ rad/sec}^2/\text{in.}$$

The force gradients were:

$$F_{AS}/\delta_{AS} = 3.3 \text{ lb/in.}$$

$$F_{RP}/\delta_{RP} = 58 \text{ lb/in.}$$

Therefore, $L'_{F_{AS}} = 0.16 \text{ rad/sec}^2/\text{lb}$

$$N'_{F_{RP}} = 0.0064 \text{ rad/sec}^2/\text{lb}$$

No lateral breakout force or hysteresis was included, but 7 pounds of breakout force on the rudder pedals was necessary due to an operational difficulty with the feel system. The lateral and directional feel system dynamics were sufficiently fast so as not to be a factor in the evaluations. Control travel was ±3.2 in. for the rudder pedals and ±5.2 in. for the lateral stick.

2.9 Turbulence and Wind Considerations

As has been discussed, turbulence level and mean wind speed and direction are important task variables in STOL terminal area operations. The present capabilities of the X-22A VSS are not sufficiently developed to simulate these variables in a controlled manner, however, and they were therefore introduced into the experiment by selective use of existing ambient conditions.

Mean wind direction was controlled by aligning the approach guidance aids, discussed in Section 3.2, so that the approaches were always made into the wind. The X-22A, like many V/STOL aircraft, has a high value of side-force-due-to-sideslip, which makes lateral tracking in crosswinds difficult, and this procedure eliminated these problems from the evaluation tasks. The variation in turbulence level was introduced by performing the evaluation flights either in light winds with negligible turbulence present or in moderate winds with a concomitantly higher turbulence level. This procedure allows a qualitative distinction to be made concerning the effects of turbulence level on the evaluations. A discussion of the simulation of turbulence response characteristics in a variable stability aircraft is given in Appendix IV, while a documentation of the wind/turbulence environment for the evaluation configurations is given in Appendix II.

SECTION III

CONDUCT OF THE EXPERIMENT

3.1 Variable Stability X-22A Aircraft

The desired dynamic characteristics of the evaluation configurations, both longitudinal and lateral-directional, discussed in Section II were mechanized on the variable stability X-22A aircraft operated by CAL (Figure 3-1). Briefly, the X-22A is a four-ducted-propeller V/STOL aircraft with the capability of full transition between hover and forward flight. The four ducts are interconnected and can be rotated to change the duct angle (λ) and therefore the direction of the thrust vector to achieve the desired operating flight condition defined by a particular V- λ combination. The thrust magnitude is determined by a collective pitch lever, very similar to a helicopter. Normal aircraft-type pitch, roll and yaw controls in the cockpit provide the desired control moments by differentially positioning the appropriate controls in each duct (propeller pitch and/or elevon deflection). A mechanical mixer directs and proportions the pilot's commands to the appropriate propellers and elevons as a function of the duct angle.

In this aircraft, the evaluation pilot occupies the left hand seat in the cockpit, which is shown in Figure 3-2. The system operator, who also serves as the safety pilot, occupies the right hand seat. The evaluation pilot's inputs, in the form of electrical signals, operate the appropriate right hand flight controls through electrohydraulic servos when the VSS is operating. In addition to these signals proportional to the evaluation pilot's inputs, signals proportional to appropriate aircraft motion variables, for example, α_v, q, and u , are fed back to move the right hand controls in the required manner and thus modify the aircraft's response characteristics as desired. The response-feedback and input gain controls are located beside the safety pilot and were used to set up the simulation configurations in flight. Note that the evaluation pilot cannot feel the X-22A control motions due to the variable stability system. Also, in this experiment, he had no prior knowledge of the evaluation configuration characteristics.

Control feel to the evaluation pilot's stick and rudder pedals was provided by electrically controlled hydraulic feel servos which provide opposing forces proportional to the stick or rudder deflections: in effect, a simple linear spring feel system. An adjustable friction level was provided for the collective stick.

The evaluation pilot's instrument panel is shown in Figure 3-2. Instrumentation for IFR flight was comprised of the normal X-22A flight instruments plus an attitude indicator with integrated ILS cross-pointers, thereby providing a "baseline" or minimum IFR instrument package for the experiment (e.g., no flight director, etc.). Full scale deflection of the ILS cross pointers represented localizer errors of ± 2.5 degrees and glide path errors of ± 0.9 degrees for the instrument landing system used for the predominant part of the experiment.

Figure 3-1 X-22A VARIABLE STABILITY AIRCRAFT

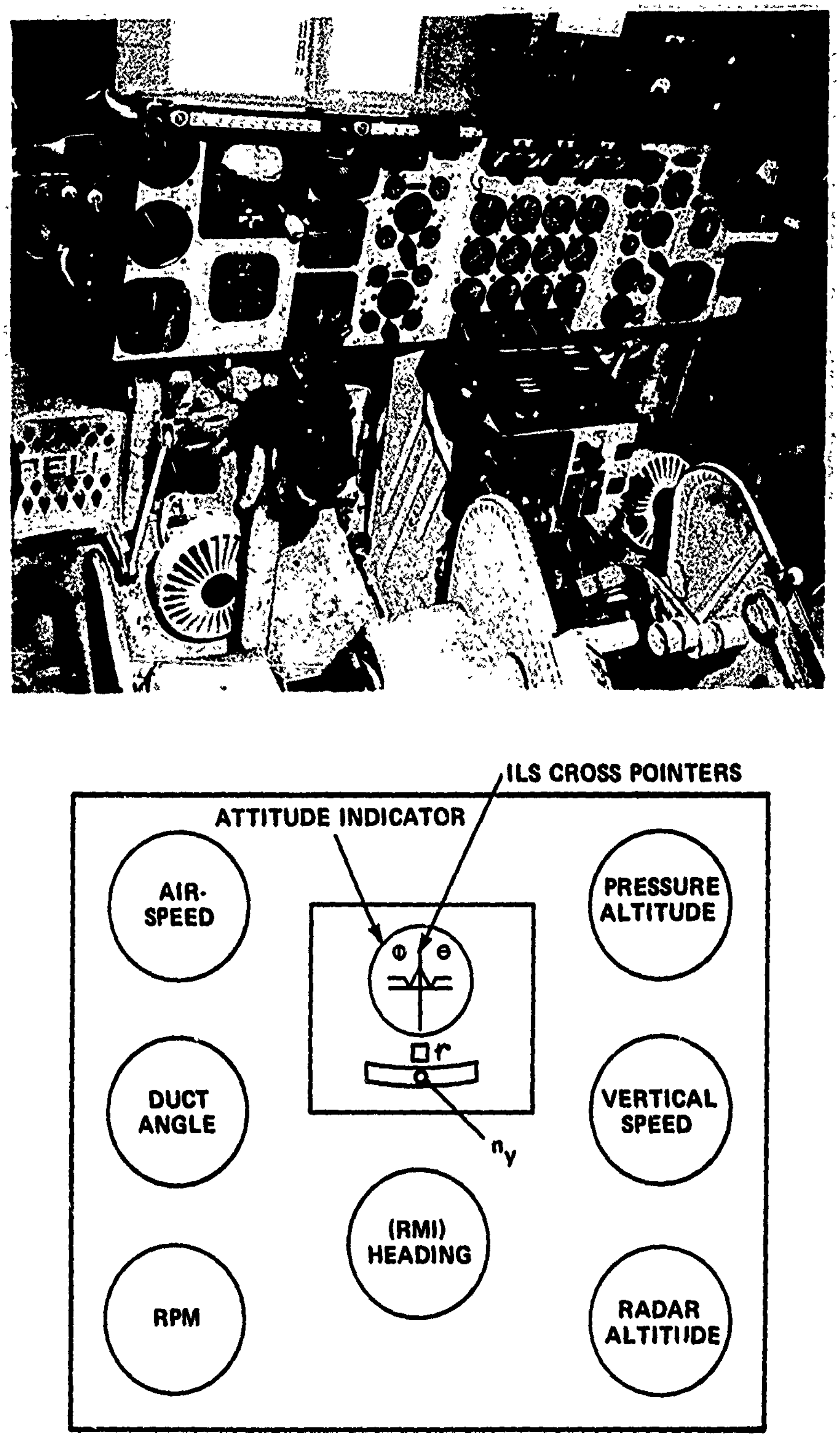


Figure 3-2 EVALUATION PILOT'S COCKPIT IN X-22A

More details of the X-22A aircraft and the mechanization of the VSS for the experiment are contained in Appendix VI. The next subsection describes the other equipment essential to the conduct of the experiment.

3.2 Other Equipment

Two approach guidance systems were employed during the program. For the IFR approaches, a TALAR low-angle microwave instrument landing system (ILS) with a variable glide path capability was used. Sensitivities of this unit were ±2.5 deg on the localizer and ±0.9 deg on the glide path. Attempts were made to use a "high-angle" TALAR unit, which had the decreased sensitivity considered necessary with high glide path angles and co-located localizer and glide path sources: ±4 degrees on localizer, up to ±2 degrees on glide path. Operational difficulties precluded extensive use of this unit in the program, however. Somewhat surprisingly, the glide slope sensitivity on the low-angle unit used did not present piloting difficulties even at the steepest glide path tested (γ = -9 degrees). The localizer, on the other hand, was objected to as being too sensitive both at localizer acquisition and during the last part of the instrument approach.

For the VFR approaches, a ring and bar, similar to that discussed in Reference 8, was constructed (see Appendix VI). Figure 3-3 shows this visual approach aid (VAA), as well as the TALAR unit, in position for an evaluation flight. The purpose of the VAA was to constrain, to some extent, the VFR approaches to the angle used for the IFR approaches. The glide slope sensitivity of the VAA was generally less than that of the TALAR (approximately ±2.5 deg) but this advantage was somewhat counteracted by the fact that the pilots received only minimal glide slope information from the VAA until the last 1000 feet of the approach.

Both experimental and flight safety data were telemetered to and monitored by the Digital Data Acquisition and Monitoring System developed expressly for the X-22A by CAL and housed in a mobile van. Since the complexity of the X-22A makes it impossible for the pilot to monitor all the important flight safety parameters, it is essential to have ground monitoring of the flight safety variables. The flight safety parameters were monitored on chart recorders and by a mini-digital computer in the van. In addition, a continuous recording of all telemetered data was obtained on the "bit-stream" recorder for later analysis and processing. An oscillograph in the X-22A provided a backup source for the pertinent experimental data. During the program, good telemetry coverage was achieved at ranges between the van and the X-22A of up to twenty miles.

The details of the Digital Data Acquisition System are covered more fully in Appendix V.

3.3 Simulation Situation

To obtain valid flying qualities data in the form of pilot ratings and comments, careful attention must be given to defining, for the evaluation pilot, the mission (or use) which the aircraft/pilot combination will perform

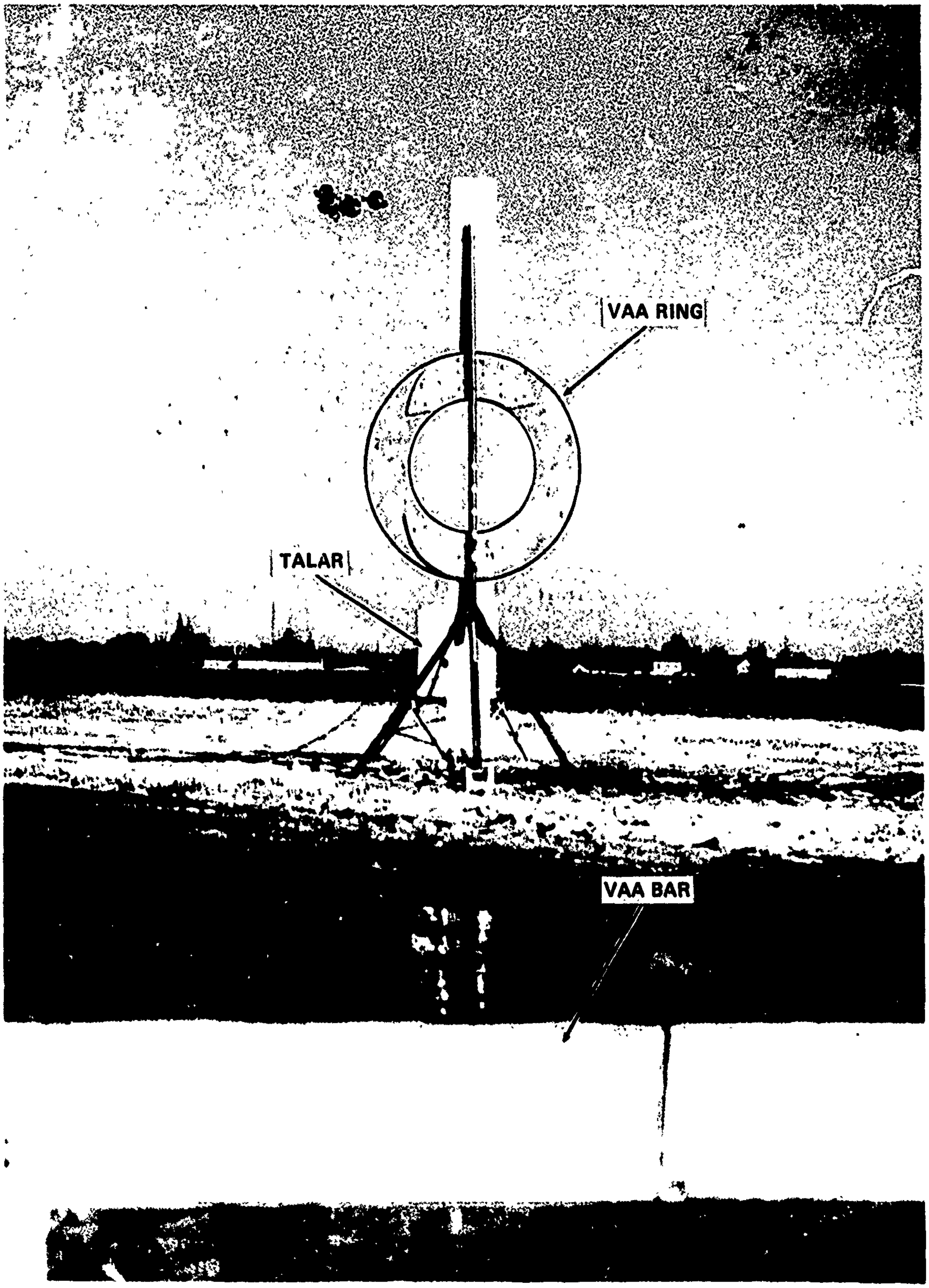


Figure 3-3 INSTRUMENT GUIDANCE SYSTEM (TALAR) AND VISUAL APPROACH AID (VAA) IN POSITION

and the conditions in which it will be performed. For the current experiment, the simulated aircraft was defined as an all-weather STOL transport performing terminal area operations; the aircraft was considered a two-pilot operation to the extent that no allowance was made for typical additional duties, e.g., flap setting, communications. Additional factors such as passenger comfort were not considered by the pilot in making his evaluations.

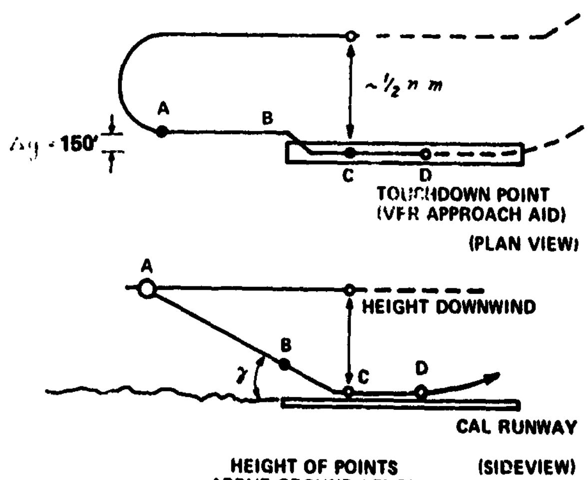
3.4 Evaluation Tasks

Although the mission involves many tasks, an evaluation of the vehicle flying qualities can be accomplished by having the evaluation pilot perform a series of maneuvers representative of those tasks anticipated in the mission. With the general conditions defined as above, the specific tasks to be accomplished were defined as a VFR approach followed by an IFR approach. These tasks are summarized in Figures 3-4 and 3-5. According to Reference 3, the approach subphase, which is a part of the overall terminal area operation, encompasses: visual approach "tracking," localizer capture, glide slope capture, ILS tracking, and wave-off. The evaluation tasks were designed to exercise all of these elements, thereby studying in depth the approach subphase. The actual landing subphase received attention only through pilot extrapolation, since operational constraints prevented the evaluation pilot from actually touching down.

3.5 Evaluation Procedures

The evaluation procedure was as follows. The safety pilot engaged the VSS at approximately 1200 feet AGL and gave the aircraft to the evaluation pilot under VFR conditions. The evaluation pilot trimmed the aircraft carefully and took the necessary calibration records, usually two longitudinal doublet responses for each evaluation. The evaluation pilot sampled the aircraft briefly, selected his longitudinal control sensitivity and then initiated the VFR approach essentially into the wind using the visual approach aid as a guide. At 400 feet AGL he was instructed by the safety pilot to perform a 150-foot lateral offset, or sidestep maneuver, to line up with a pseudo-runway centerline consisting of a 150 foot strip of high visibility weighted plastic. At 200 feet AGL he arrested the rate of descent, leveled off, and then performed a wave-off maneuver. While flying back to the initial point for the instrument approach, he tape-recorded comments with reference to a short comment card and assigned a VFR-only pilot rating for the configuration and a turbulence rating. The Cooper-Harper pilot rating scale shown in Figure 3-6 was used; the turbulence effect rating scale is shown in Figure 3-7.

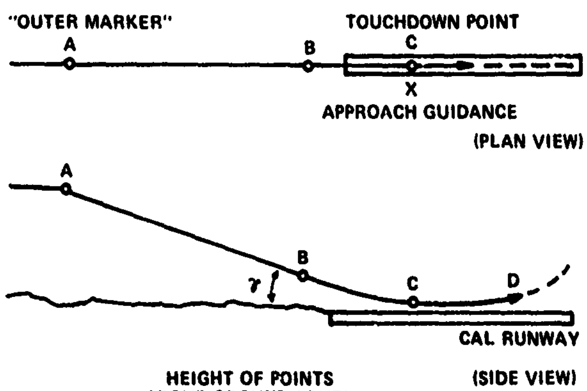
The complete Pilot Comment Card is reproduced below. After the visual approach, the evaluation pilot commented on only the VFR designated items.



HEIGHT OF POINTS
ABOVE GROUND LEVEL

POINT	HEIGHT (FT)
A	1200
B	400
C	200
D	200

Figure 3-4 VFR APPROACH TASK



HEIGHT OF POINTS
ABOVE GROUND LEVEL

POINT	HEIGHT (FT)
A	1700
B	200
C	100 (APPROXIMATELY)
D	100 (APPROXIMATELY)

Figure 3-5 IFR APPROACH TASK

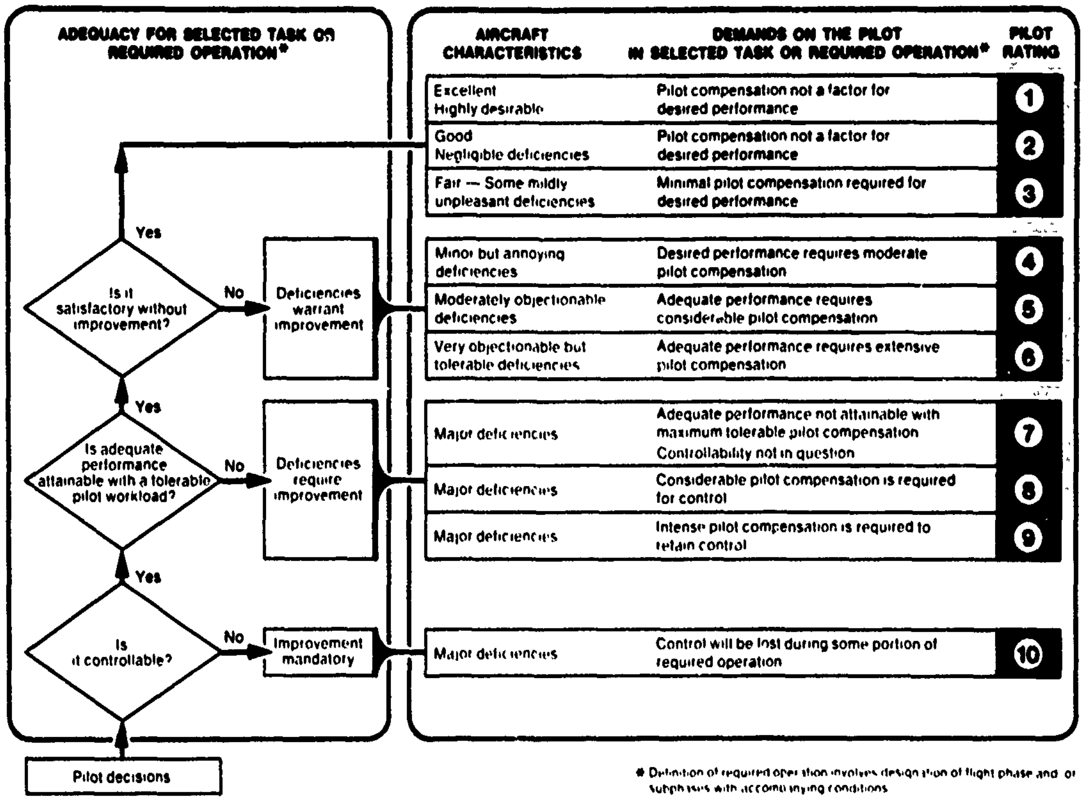


Figure 3-6 COOPER HARPER PILOT RATING SCALE

INCREASE OF PILOT EFFORT WITH TURBULENCE	DETERIORATION OF TASK PERFORMANCE WITH TURBULENCE	RATING
NO SIGNIFICANT INCREASE	NO SIGNIFICANT DETERIORATION	A
MORE EFFORT REQUIRED	NO SIGNIFICANT DETERIORATION	B
	MINOR	C
	MODERATE	D
	MODERATE	E
BEST EFFORTS REQUIRED	MAJOR (BUT EVALUATION TASKS CAN STILL BE ACCOMPLISHED)	F
	LARGE (SOME TASKS CANNOT BE PERFORMED)	G
UNABLE TO PERFORM TASKS		H

Figure 3-7 TURBULENCE EFFECT RATING SCALE

PILOT COMMENT CARD

[VFR]* 1. Ability to trim.

2. Feel characteristics.

   a. Forces.

   b. Displacements.

[VFR] 3. Response to inputs required to perform task.

   a. Pitch attitude control.

      - initial response, predictability of final response.
      - describe pilot inputs required to achieve desired response.

   b. Collective control.

[VFR] 4. Velocity control.

   a. Control technique?

   b. Satisfactory?

[VFR] 5. Approach performance.

   a. ILS - ability to intercept and track glide path and localizer?
      - glide path control technique?
      - primary instruments?
      - display complaints?
      - performance satisfactory?

[VFR] b. Sidestep maneuver.
      - any special problems?

6. Ability to arrest rate of descent.

   - technique?
   - any special problems?
   - could you land from IFR approach?

7. Differences between IFR and VFR

   - any problems peculiar to type of approach?
   - any second thoughts on VFR rating?

[VFR] 8. Effects of turbulence/wind.

9. Lateral-directional characteristics.

   - were they a factor in the evaluation?

Summary Comments

[VFR] 1. Good features.

[VFR] 2. Objectionable features.

[VFR] 3. Pilot rating.

4. Turbulence.

- effects, longitudinal, lateral-directional, both
- turbulence rating.

*Note: Comments for VFR approach only.

Upon completion of the VFR comments and rating, the evaluation pilot went "under the hood" at approximately 1700 feet AGL and followed simulated radar vectors to localizer intercept. He then performed an IFR approach with breakout at 200 feet AGL, after which he first arrested the rate of descent at approximately 100 feet AGL and then performed a wave-off maneuver. After the wave-off, the safety pilot took control of the aircraft again and set up the next evaluation configuration while the evaluation pilot made comments with reference to the complete pilot comment card. After finishing his detailed comments, the evaluation pilot assigned an <u>overall</u> pilot rating for the aircraft in the context of STOL terminal area operations, including both the VFR and IFR approaches, and a turbulence rating.

Several salient points in the evaluation procedure as described bear consideration.

1. Note that a VFR-only, as well as overall, rating was assigned to the aircraft. In general, a useful pilot rating should include the pilot's weighting of the performance achieved in all tasks representative of the flight phase or subphase under consideration -- hence, the overall rating assigned during this program. However, it was anticipated that the minimal sophistication of the instrument display might downgrade the IFR portion of the evaluation to an unrealistic extent in terms of future instrument displays. Therefore, brief comments and a rating on the VFR-only approach, which might be considered the target for operation under IFR conditions with more sophisticated displays, were also obtained to ascertain whether or not this effect was present in the overall rating.

2. It is important to recognize that the pilot rating data include only quantification for the glide slope performance, ability to arrest the rate of descent and the wave-off maneuver. Extrapolation to actual landing performance was not included in the rating as this is not a valid procedure at the altitudes AGL used in this program

(precisely, it is not valid unless the aircraft is actually landed); the evaluation pilot was asked to comment specifically upon whether he thought he could land the aircraft from the IFR approach, but was asked not to include this decision in his rating.

3. The turbulence rating was not per se a quantitative indication of the turbulence level encountered. The overall pilot rating properly includes the pilot's weighting of the aircraft/pilot system in a turbulence environment and the purpose of the turbulence effect rating is primarily to provide a qualitative indication to the analyst of how much the turbulence affected the flying qualities.

3.6 Evaluation Summary

Two evaluation pilots participated in this flying qualities investigation; their backgrounds are summarized below.

Pilot A - CAL Research Pilot with extensive experience as an evaluation pilot in flying qualities investigations. His flight experience of 3000 hours includes over 500 hours in helicopters and he is a qualified X-22A pilot.

Pilot B - CAL Chief Pilot with extensive experience as both a test pilot and as an evaluation pilot in flying qualities work. He has approximately 5500 hours total flying time of which 500 hours are in helicopters and is qualified in the X-22A aircraft.

A total of 42.4 hours was flown in this first research program with the X-22A aircraft, of which 23.1 hours were devoted to evaluation flights; the remaining hours were devoted to pilot checkout and calibration of the simulated evaluation configurations. The two pilots performed a total of 50 evaluations of 29 different combinations of short-term frequency and damping (ω_{ST}, ζ_{ST}) at the two flight conditions investigated. The distribution of configurations and evaluation flights is summarized in the following tables.

1. Configuration Summary

Flight Condition ($V/\lambda/\gamma$)	Dynamic Configurations
65/50/-9,-6	20
80/30/-7	9

2. <u>Evaluations</u>

Flight Condition $(V/\lambda/\gamma)$	Pilot A	Pilot B	Turb/No Turb.
65/50/-9	31(2)	3	18/16(2)
65/50/-6	4	0	4/0
80/30/-7	0	9(1)	3/6(1)
Totals	35(2)	12(1)	25/22(3)

The total evaluations by both pilots (including repeats) were 47 complete evaluations plus 3 where only VFR evaluations were performed which are shown in the table in parentheses. Also shown in the table is the distribution of evaluations with respect to the ambient turbulence present during the evaluations.

SECTION IV

EXPERIMENT RESULTS AND DISCUSSION

The direct results of the experiment described in the preceding sections are in the form of pilot ratings and pilot comments. A complete summary of the pilot ratings (PR), both VFR-only and overall, the turbulence effect ratings and the associated data for each configuration is presented in Appendix II. The summarized pilot comments for each configuration are contained in Appendix I, which also shows representative time history plots for a longitudinal stick pulse input.

This section will present the correlations between the pilot rating data and the short-term dynamics, and discuss the associated pilot comment data.

4.1 V_T = 65 Knots, γ = -9 Deg, Negligible Turbulence

The 16 combinations of ω_{ST}, $2\zeta_{ST}\omega_{ST}$ evaluated in negligible turbulence are plotted in Figure 4-1. The top graph gives the VFR-only pilot ratings and the lower graph gives the overall ratings. Numbers are pilot ratings, while the letters are turbulence effect ratings (refer to Figures 3-6, 3-7). The approximate iso-opinion 3.5 (Level 1) and 6.5 (Level 2) boundaries are also shown. Determination of these iso-opinion boundaries is far from an exact process and in this case not only the gradients of pilot rating, but also the pilot comments, were used to estimate the boundaries. The variations in PR among the four data points at $0.8 < \omega_{ST} < 1.6$ rad/sec and $2\zeta_{ST}\omega_{ST}$ approximately 1.0 and 2.0 in negligible turbulence were not considered to be significant, on the basis of the pilot comments. The iso-opinion boundaries in moderate turbulence (as Figure 4.2) were therefore used as a guide for these points.

All of the evaluations in Figure 4-1 are from the primary evaluation pilot (Pilot A).

4.2 V_T = 65 Knots, γ = -9 Deg, Moderate Turbulence

The 13 combinations of ω_{ST}, $2\zeta_{ST}\omega_{ST}$ evaluated in moderate turbulence are plotted in Figure 4-2 in the same fashion as in Figure 4-1. Note that 11 of 13 combinations of dynamics are the same as those evaluated in negligible turbulence. The three ratings marked with crosses (+) are those of the second evaluation pilot (Pilot B). Separation of the data according to the turbulence level was largely done on the basis of the pilot comments, supported by the turbulence effect ratings. The results for moderate turbulence were generally obtained in ambient winds of 10 to 20 knots while for those obtained in negligible turbulence the surface winds were less than 10 knots, usually about 5 knots. In Appendix I, these configurations flown in moderate turbulence have an "M" after the wind strength report under the heading "WIND".

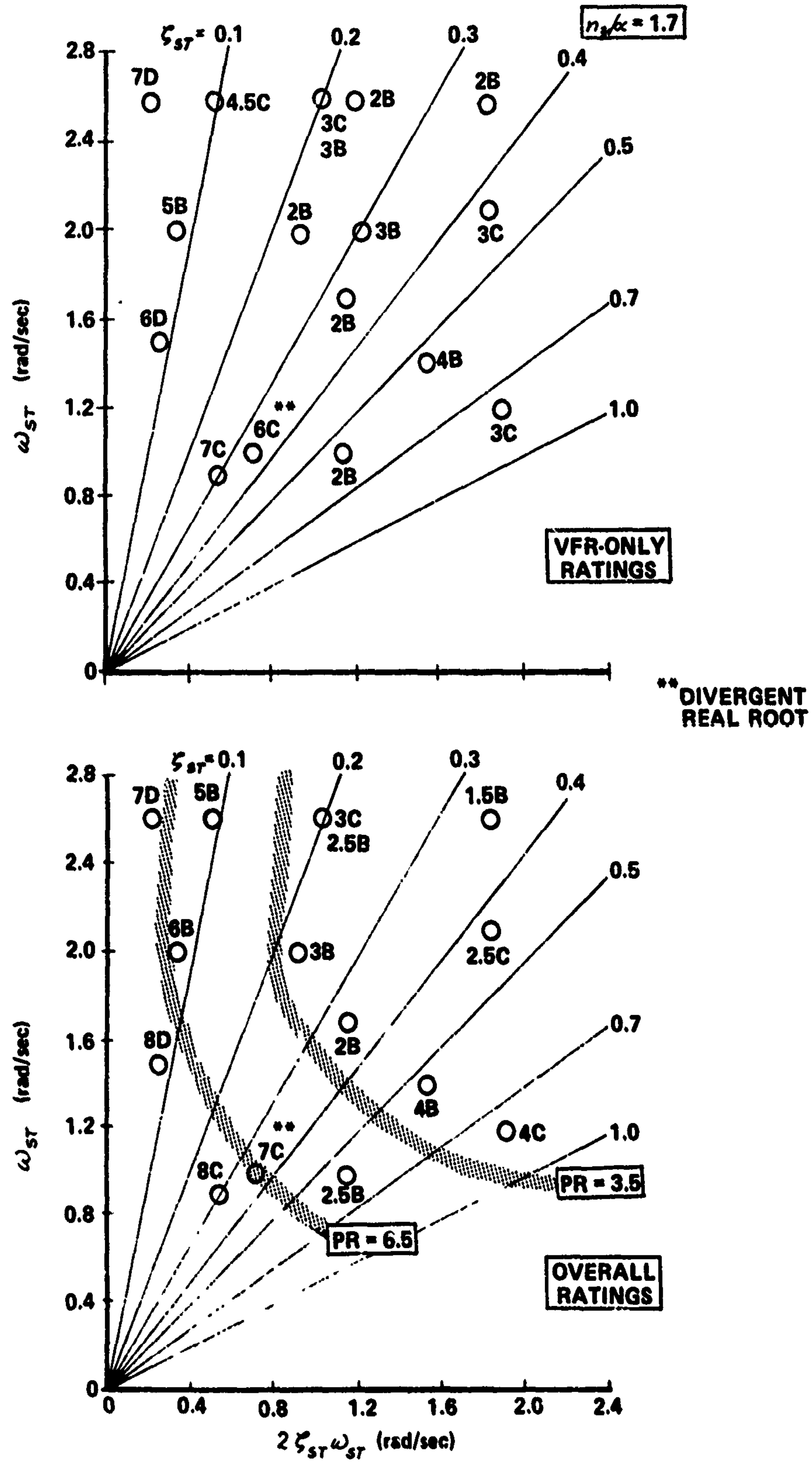


Figure 4-1 CORRELATION OF PILOT RATING WITH SHORT-TERM DYNAMICS (V_T = 65 KT, γ = -9 DEG, NEGLIGIBLE TURBULENCE, PILOT A)

4.3 V_T = 65 Knots, γ = -6 Deg, Moderate Turbulence

The four points evaluated by Pilot A to briefly investigate the effect of glide slope angle are presented in Figure 4-2 as ratings with asterisks. Note that all four points are repeats of configurations flown at $\gamma = -9°$ in moderate turbulence.

4.4 V_T = 80 Knots, γ = -7 Deg

The eight combinations of ω_{ST}, $2\zeta_{ST}\,\omega_{ST}$ evaluated by Pilot B at 80 knots are presented in Figure 4-3. As a result of the small number of evaluations at this flight condition, evaluations in both levels of turbulence are presented: the solid points (●) represent evaluations in moderate turbulence, and the open points (o) those in negligible turbulence. No iso-opinion curves are presented, due to the limited number of data points. Note that one additional configuration was evaluated for VFR only, which, considering the close correlation between the VFR and overall pilot ratings, effectively adds an additional data point.

4.5 Effect of ω_{ST} and $2\zeta_{ST}\,\omega_{ST}$

The data pertinent to this discussion are presented in Figures 4-1 and 4-2. For the purposes of this discussion, the results in moderate turbulence (Figure 4-2) will be examined to ascertain effects of the dynamics; specific effects of turbulence level will be discussed in a following subsection.

At the lower frequencies investigated ($0.8 < \omega_{ST} < 1.5$ rad/sec), the gradient of pilot rating with frequency is small in moderate turbulence. This somewhat surprising result does not mean that the pilot did not notice the difference in frequencies pilot commentary for the lowest frequency points includes remarks on initial hesitation of the pitch response and the necessity to "overdrive" the aircraft, whereas the higher frequencies ($2.0 < \omega_{ST} <$ 2.6 rad/sec) were generally described as providing a one-to-one relationship between the longitudinal control and the aircraft. Compare, for example, the pilot comments for Configurations 5 and 18, both of which have good damping. In general, however, it appears that the disadvantage of slow pitch response to a longitudinal control input is offset by the decrease in pitch response to turbulence as a result of the reduction in angle-of-attack stability for the frequencies investigated.

The data do not define a low-frequency boundary, although the iso-opinion lines do indicate such a trend for the 3.5 boundary. It is apparent that, at the lower frequencies, the primary influence on pilot rating is short-term damping ($2\zeta_{ST}\,\omega_{ST}$). As has been noted, at low frequency the pilot must overdrive the control input to achieve the desired initial response; his selection of control effectiveness, $M_{\delta_{ES}}$, in fact, becomes difficult due to the trade off between the large initial inputs required and the small steady-state changes in control. In addition, however, he must also remove or even

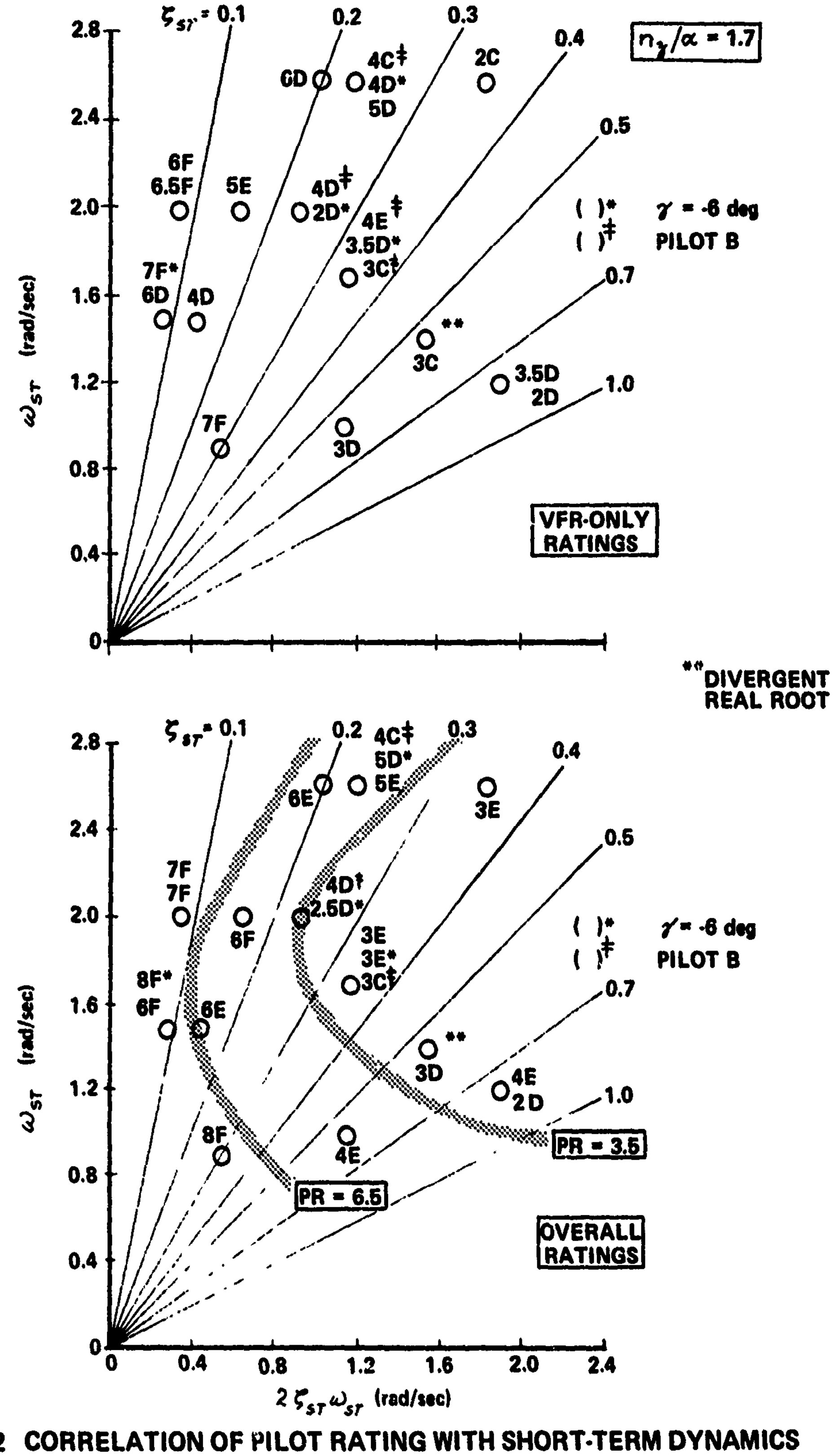


Figure 4-2 CORRELATION OF PILOT RATING WITH SHORT-TERM DYNAMICS (V_T = 65 KT, γ = -9 AND -6 DEG, MODERATE TURBULENCE, PILOT A EXCEPT AS NOTED)

reverse his control input at precisely the correct time to achieve the desired final response. This two-part control input is difficult and becomes increasingly objectionable as the damping decreases, which makes the final response even less predictable. This hypothesis is based on pilot comments; for example, compare the pilot comments for configurations 15 and 18. The aircraft is described as having a tendency to "take off" and require an excessive two-part type of input for the low-frequency, low-damped case (Config. 15), whereas the well-damped low-frequency case, while still considered slow responding, is described as having predictable final responses (Config. 18).

At the higher frequencies ($2.0 < \omega_{ST} < 2.6$ rad/sec), the gradient of pilot rating with frequency remains relatively small in moderate turbulence, and the ratings become increasingly dependent on damping ratio. At these frequencies, low damping ratio appears as "bobbles" or overshoots in the response to a control input by the pilot and tends to degrade his approach performance. In addition, the inputs from atmospheric turbulence continually oscillate the aircraft leading to an increased pilot workload. Since the aircraft response is "one-to-one with the stick" at these frequencies, the pilot does not need to overdrive his input (reference Config. 5). He is concerned primarily with damping out residual high-frequency oscillations caused by either his input or the turbulence; when the frequency is high, his inability to compensate for the "bobbles" caused by external inputs translates into a requirement for increased open-loop aircraft damping $(2\zeta_{ST}\omega_{ST})$ with increasing frequency.

4.6 Effect of Task Condition: VFR and IFR

The data pertinent to the effect of VFR/IFR flight on pilot rating are shown in Figures 4-1 through 4-3. It is clear that the overall pilot rating, which includes the pilot's weighting of his performance in an IFR approach, varies little from the VFR-only rating -- usually within one pilot rating. Pilot commentary indicates that, if there is degradation of IFR over VFR, it is due to lack of damping cues IFR, but in general this degradation is no more than one pilot rating. It should be noted that the VFR approach in this experiment is also somewhat of a precision task, corresponding to some extent to a heads-up display approach. It appears, therefore, that the minimal IFR display did not compromise the experiment.

4.7 Effect of Turbulence

The effect of turbulence on pilot rating is best seen by comparing individual points of Figures 4-1 and 4-2. In Reference 11, the important effect was rms magnitude; in the X-22A experiment, the effect of this characteristic on pilot rating was investigated by performing the evaluation approaches in either "smooth" ambient conditions or "moderate" turbulence. The data are presented, therefore, in two groups to obtain an indication of the extent to which the results depend on turbulence level.

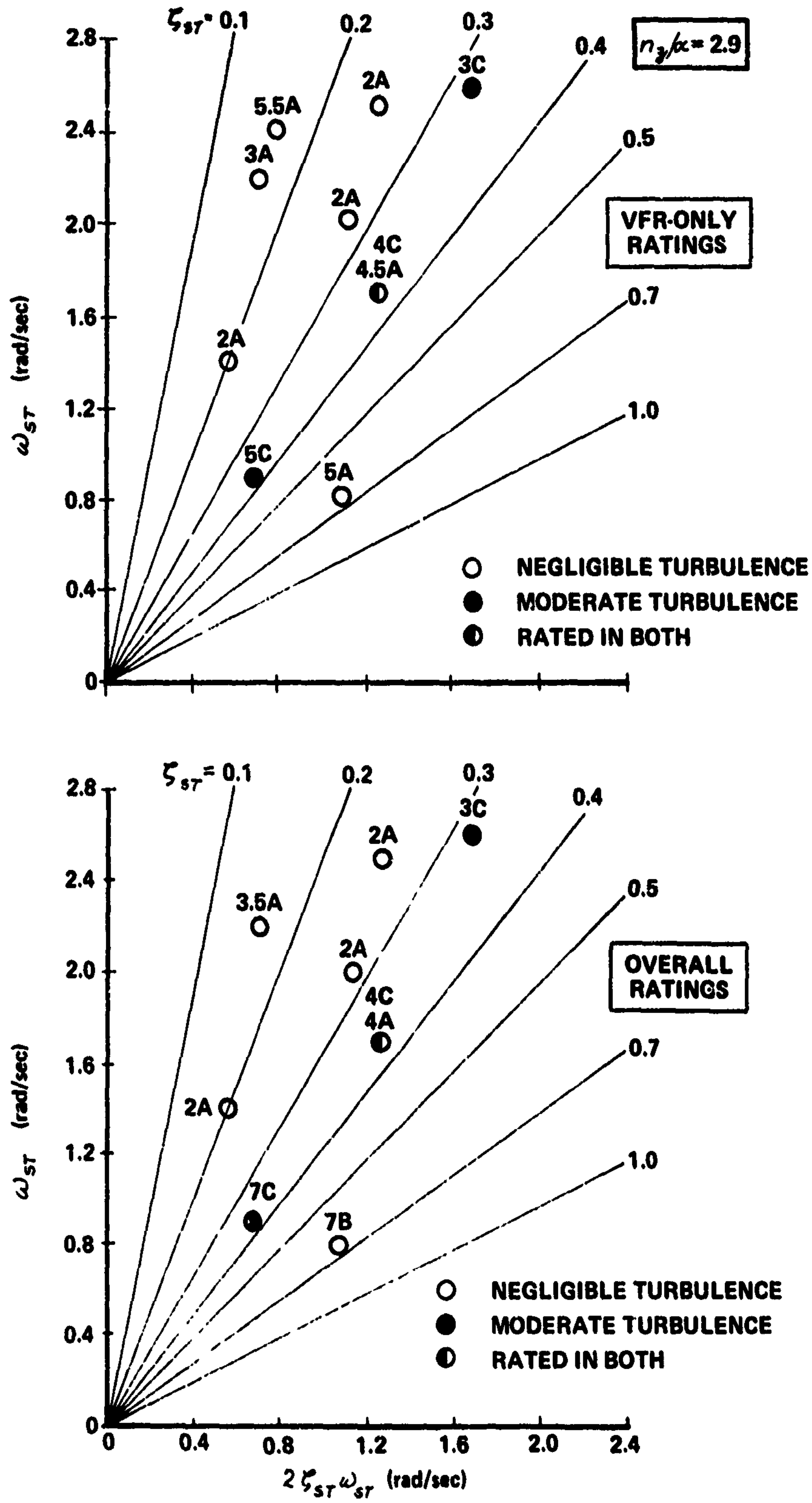


Figure 4-3 CORRELATION OF PILOT RATING WITH SHORT-TERM DYNAMICS (V_T = 80 KT, γ = -7 DEG, MODERATE AND NEGLIGIBLE TURBULENCE, PILOT B)

Referring to Figure 4-1, it is apparent that, in negligible turbulence, pilot rating is primarily a function of total damping for the frequency range tested. In moderate turbulence, Figure 4-2, there is an increasing dependence on damping ratio at the higher frequencies that is not as apparent in negligible turbulence. The pilots note the tendency toward "bobble" for the low-damping ratio configurations in negligible turbulence, but for damping ratios as low as approximately $\zeta_{sT} = 0.2$, the bobble apparently can be easily compensated for by the pilot. For example, compare the pilot comments for Configuration 3 in and out of turbulence. The significant point, of course, is that the absence of external inputs from turbulence allows the pilot to perform this compensation easily; in turbulence, the low-damping ratio configurations are continually excited in pitch thereby increasing the pilot's workload considerably.

Comparing the figures, it is apparent that an effect of turbulence was to degrade pilot ratings of the configurations tested at high frequencies ($\omega_{sT} > 1.6$ rad/sec), particularly at the lowest dampings tested. For the medium and low frequencies, no significant effect of turbulence level is evident. Any changes in pilot ratings in this area are small and do not correlate with the changes in turbulence level. The degradation in pilot ratings with increased turbulence level demonstrated at the high frequencies is different from that reported in Reference 11 but this difference is attributable to the fact that the lowest ζ_{sT} investigated in Reference 11 was $\zeta_{sT} \simeq 0.5$. As has been noted, it is at damping ratios below 0.3 that the continual oscillation due to turbulence inputs becomes annoying to the pilot.

The result in this experiment that the flying qualities of the low-frequency configurations are not affected by turbulence is somewhat at odds with those of References 11 and 12, both of which state that turbulence effects downgrade pilot ratings of low frequency configurations for ILS approaches. The reason for this discrepancy may be the difference in n_z/α between the X-22A experiment and that of the aircraft in the references. The low n_z/α (approximately 1.7) of the X-22A at 65 knots reduces the heave response due to turbulence although the accompanying low value of $1/\tau_{\theta_2}$ also makes glide slope corrections as a result of pitch attitude changes somewhat slow. In Reference 12 particularly, the low frequency points were downrated because turbulence heaved the aircraft off the glide slope and the pitch response required to correct was slow responding. The X-22A, however, has a much smaller heave-to-turbulence response, and the low-frequency (low M_α) configurations proved beneficial in reducing pitch response to turbulence.

4.8 Effect of Glide Slope Angle and Rate of Descent

The effect of glide slope relative to the ground was investigated independently by repeating selected configurations with approach velocity of 65 knots at $\gamma = -6°$. The data are shown in Figure 4-2 as the points having asterisks. No significant differences in pilot ratings are apparent. In general, pilot comments indicated that the task at $\gamma = -6°$ was easier, primarily because of the increased "down" capability (ability to correct for being above the glide slope) of the X-22A. The steep ($\gamma = -9°$) approaches generally gave the pilot a "down" capability of about 500 fpm before the onset of duct buffet which was an operational constraint. It is clear from the ratings, however, that the increased capability at $\gamma = -6°$ did not significantly improve pilot rating. A further note of interest is that, for the $\gamma = -9°$ evaluations, the rate of descent was lower (by 200-300 fpm) for the configurations evaluated in turbulence than for those evaluated in negligible turbulence. This difference is a result of the higher headwinds experienced for the turbulent conditions, i.e., 0-10 knots for negligible turbulence and 12-20 knots for moderate-to-severe turbulence. If the reduction in rate of descent had been important to the pilot, it might have counteracted to some degree the effects of turbulence. No such counteraction is evident, however, in either pilot ratings or comments.

4.9 Effect of Approach Velocity, n_z/α, and Thrust Inclination

The data pertinent to this discussion are presented in Figure 4-3 and will be compared with those in Figures 4-1 and 4-2. These data were obtained by flying a different configuration of the X-22A, i.e., the duct angle was 30° instead of 50°. At this lower duct angle, the trim velocity was higher (80 knots) and the normal force per angle of attack approximately twice that at 65 knots, i.e., 2.9 versus 1.7; the thrust inclination is obviously lower, also resulting in less direct lift control due to thrust.

At the middle and higher frequencies ($1.5 < \omega_{ST} < 2.5$ rad/sec), the limited number of frequency-damping points at this flight condition show good correlation of pilot ratings with those at 65 knots both in negligible and moderate turbulence. The increased velocity and the lower thrust inclination do not appear to significantly affect pilot ratings for these configurations.

The one data point at 80 knots with low short-term frequency and good damping (Configuration 29) indicates a degradation in pilot rating when compared with the same dynamic configuration flown at 65 knots (Configuration 17). For the 65-knot approaches, pilot comments indicated that, while on the glide slope, pitch attitude (through longitudinal stick) was used to control flight path and thrust (through collective) to control speed; at breakout, however, the technique used to arrest the rate of descent and level off was to use collective, which provided a good deal of direct normal force control at this flight condition, and to use longitudinal stick mainly to control a level pitch attitude. At the 80-knot case with less direct control of normal force, however, pitch attitude was used in addition to collective to arrest the rate of descent, and the slow response for the low-frequency configurations was therefore downrated. The evidence of this data point, although hardly conclusive, indicates that the minimum frequency may indeed be a function of one of the parameters that was varied, for example, n_z/α, but this experiment did not determine whether the dependence is on n_z/α, direct lift control, or approach velocity.

4.10 Longitudinal Control Sensitivity

As part of the evaluation procedure in this experiment, the evaluation pilot was required to select the longitudinal control sensitivity, $M_{\delta_{ES}}$, prior to evaluating each configuration. This procedure was used because the available evaluation flight hours precluded the inclusion of $M_{\delta_{ES}}$ as a controlled variable in the experiment and it was desired to eliminate, as much as possible, adverse effects of this parameter. Stick force sensitivity, $M_{F_{ES}}$, is related to $M_{\delta_{ES}}$ by the spring gradient of the control system, which was 7.5 lb/in. throughout the evaluations. The selected values of $M_{\delta_{ES}}$ and $M_{F_{ES}}$ for each configuration are summarized in Appendix II. Figures 4-4, 4-5, and 4-6 show the selected values of $M_{F_{ES}}$ for each dynamic configuration evaluated at each flight condition in negligible and moderate turbulence. Configurations with PR $\leq$ 4.0 on the figures have $M_{F_{ES}}$ enclosed in a block. In general, the evaluation pilots made no significant comments about the gearing selection and, for the range of dynamics investigated, apparently had no difficulties in achieving the sometimes conflicting requirements for precision control and gross maneuvering, such as the wave-off.

For STOL aircraft, $M_{F_{ES}}$ is felt to be the basis on which to compare control sensitivity, rather than $M_{\delta_{ES}}$. In support of this statement consider the following example. A recent STOL landing approach investigation using a ground simulator, Reference 13, noted that $M_{\delta_{ES}}$ should be ideally about $0.1 \frac{\text{rad/sec}^2}{\text{inch}}$ and values higher than 0.2 could lead to PIO problems. In the present experiment, however, the nominal value of $M_{\delta_{ES}}$ selected was .41 with values as high as $0.54 \frac{\text{rad/sec}^2}{\text{inch}}$ selected for some cases with no piloting problems noted (see, for example, configuration 5). This apparent contradiction is a result of the different force gradients used in the two experiments: 1.8 lb/in. in the ground simulator program compared with 7.5 lb/in. in the present experiment. When this difference is taken into account, the value of $M_{F_{ES}}$ for the optimum pilot ratings of Reference 13 is $0.055 \frac{\text{rad/sec}^2}{\text{lb}}$, which is a representative average value for the data presented on Figures 4-4 to 4-6. It would appear, therefore, that the response per pound of force is the important characteristic to the pilot, provided that the force gradient is such that the stick displacements are not objectionable.

The values of $M_{F_{ES}}$ presented in Figures 4-4 to 4-6 neglect any effects of the feel system dynamics, which are assumed to be sufficiently fast to make this approximation valid. Overall, the results indicate that the pilot selected an approximately constant value of $M_{F_{ES}}$ during the experiment. (For example, the variability in $M_{F_{ES}}$ for a given configuration, e.g., configuration 13, is of the same order as the variations in $M_{F_{ES}}$ across the whole experiment.) The variability that is evident may be due in part to the fact that, during the evaluations, the pilot did not spend a large amount of time optimizing the sensitivity, since his main purpose was to select a longitudinal gain value that would not cause undue bias in the evaluation. The data do indicate some

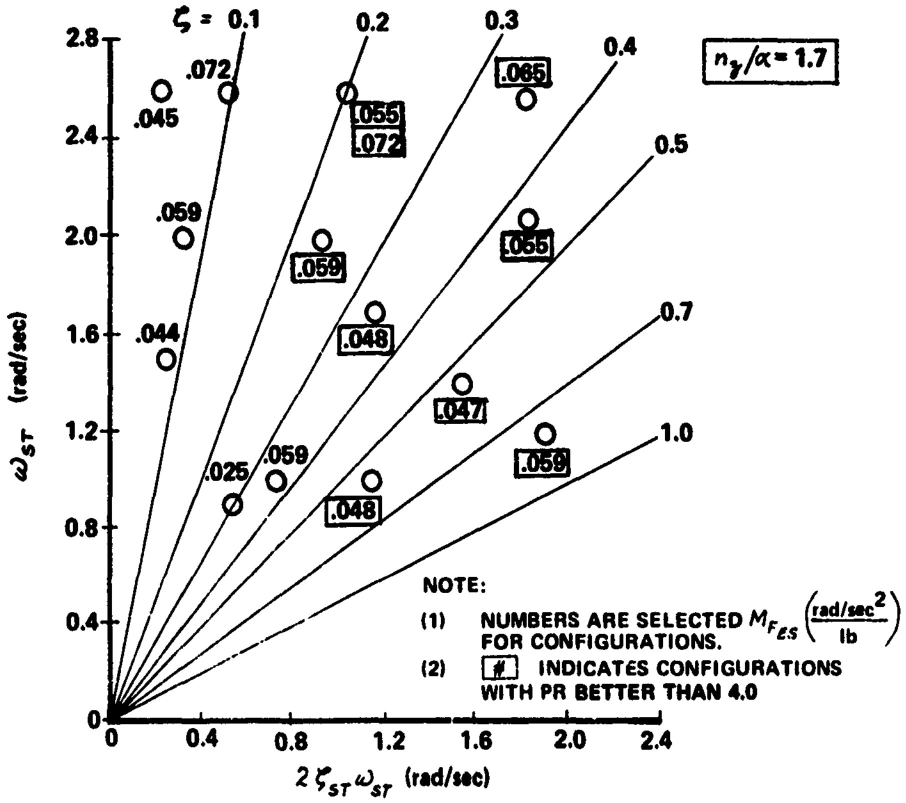


Figure 4-4 CORRELATION OF $M_{F_{ES}}$ WITH SHORT-TERM DYNAMICS (V$_T$ = 65 KT, γ = -9 DEG, NEGLIGIBLE TURBULENCE)

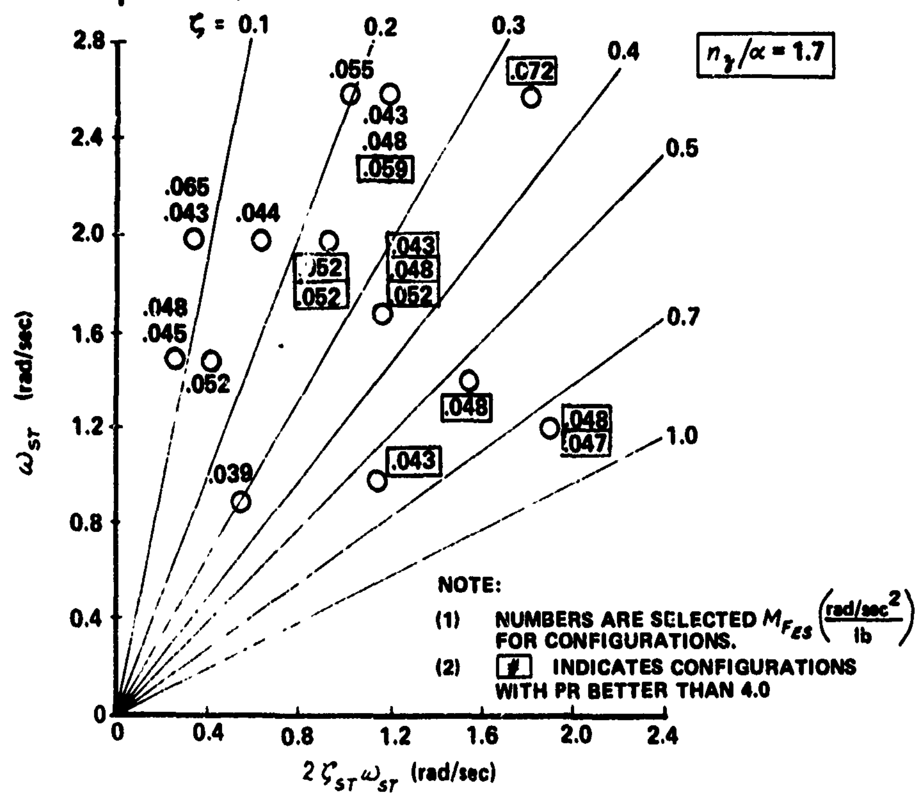


Figure 4-5 CORRELATION OF $M_{F_{ES}}$ WITH SHORT-TERM DYNAMICS (V$_T$ = 65 KT, γ = -9 AND -6 DEG, MODERATE TURBULENCE)

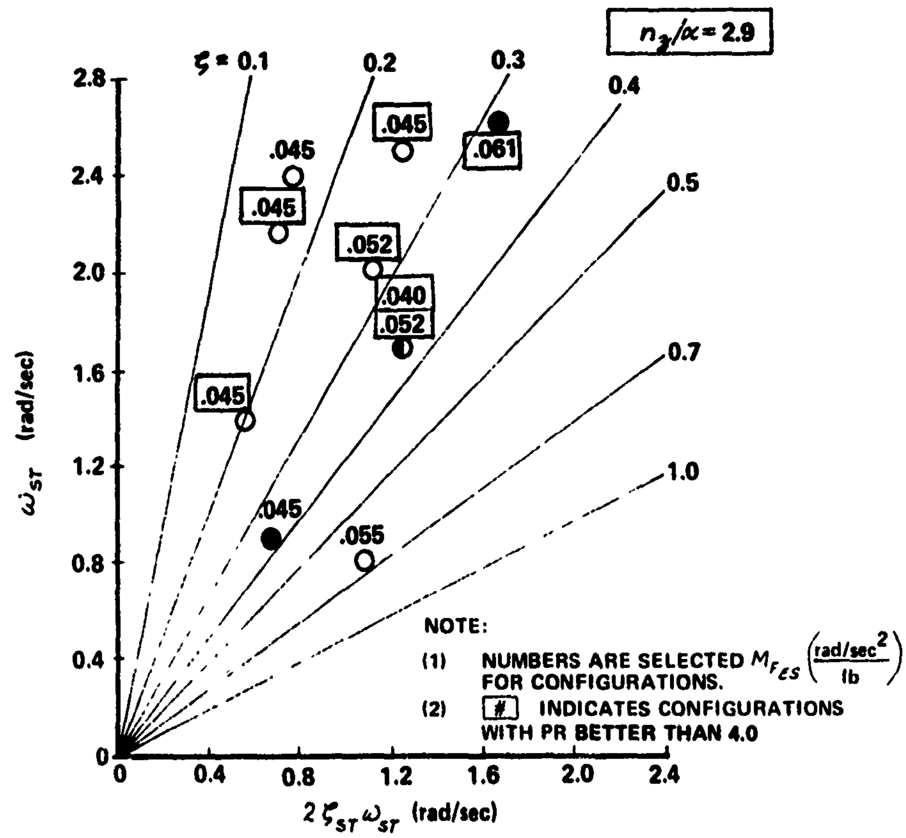


Figure 4-6 CORRELATION OF $M_{F_{ES}}$ WITH SHORT-TERM DYNAMICS (V_T = 80 KT γ = -7 DEG, MODERATE AND NEGLIGIBLE TURBULENCE)

trend towards higher sensitivities as the short-term frequency increases, but in the face of the variability in selected values this trend is not felt to be significant. Other experiments, Reference 14 for example, have suggested that the pilot selects his longitudinal gain to hold α/F_{ES} constant, which is approximately the gain in the θ/F_{ES} transfer function at the short period frequency, i.e., $M_{F_{ES}}/\omega_{ST}^2$. The results from this experiment do not support such a criterion.

Assuming constant speed (see Appendix II),

$$\frac{F_{ES}}{n_z} = \frac{\omega_{ST}^2}{(n_z/\alpha)M_{F_{ES}}}$$

If $M_{F_{ES}}$ is held constant, then F_{ES}/n_z will vary as a function of ω_{ST}^2 for constant (n_z/α) at a given flight condition.

As indicated in the data summary table in Appendix II, the value of F_{ES}/n_z calculated from the above expression using the selected values of $M_{F_{ES}}$ varies from as low as 4 lb/g to as high as 92 lb/g. Configuration 5 for example, out of turbulence, received a pilot rating of 1.5 with F_{ES}/n_z = 61 lb/g. These results indicate that the longitudinal control gain was not selected on the basis of F_{ES}/n_z considerations. Therefore, at the low values of n_z/α flown in these evaluations, F_{ES}/n_z does not seem to be a meaningful parameter to the pilot.

4.11 Effects of Phugoid Characteristics

Although no attempt was made to hold the phugoid characteristics fixed during the experiment, for the majority of the evaluation configurations at each flight condition this result was in fact achieved. In addition, for these cases, sufficient separation existed between the short-period, or short-term, roots and the phugoid roots, even at the lowest ω_{ST} tested, that the short-term response occurred at essentially constant speed in the classic airplane sense. For these cases, the average phugoid characteristics were $\omega_p \approx 0.20$ rad/sec and $\zeta_p \approx 0.35$. Variations about these mean values were on the order of 20%.

For configurations 14, 16 and 29, the long-term response was composed of two real roots. Configurations 16 had an unstable real root yielding a time to double amplitude of 9 seconds. Configuration 14, on the other hand, had an unstable real root, caused by unstable M_u that was not augmented, with a time to double of 5 seconds which, according to the pilot comments, did degrade the flying qualities even in the "tight" landing approach task where the long-term response characteristics are somewhat secondary in importance. The PR in moderate turbulence of 3 would therefore be somewhat better with a statically stable aircraft and thus be more consistent with the other data. The real roots for configuration 29 were both stable and are not considered a factor in the evaluations. The phugoid characteristics are summarized in Appendix II.

4.12 Operational Considerations

The landing approaches for this experiment were performed at the Greater Buffalo International Airport in Buffalo, New York. The X-22A, like many V/STOL aircraft, has a high side-force-due-to-sideslip, and, to eliminate from the evaluation task the problem of maintaining heading in a crosswind, all of the evaluation approaches were performed as nearly as possible into the wind. This procedure necessitated setting up the TALAR and VAA at a spot between the two active runways and aligning them approximately into the wind. As a result, the experimental approaches frequently crossed the active runway at the Buffalo airport; an ancillary result of the program worth noting is that the X-22A approaches did not interfere with normal aircraft traffic as a result of the steep approach angles, thereby demonstrating, to some extent, the feasibility of integrating STOL and CTOL traffic.

4.13 Pilot Control Techniques

The control techniques used by the evaluation pilots throughout the program are documented in the pilot comments in Appendix I and may be summarized as follows. For most of the 65 kt approaches, longitudinal stick inputs were used to control pitch attitude and correct for glide path errors, while the collective stick was used to control the airspeed. However, in one or two configurations with very light damping (e.g. configuration 6), the collective was also used to control rate of descent, as longitudinal stick inputs provoked oscillatory tendencies. At the end of the 65 kt approaches, the collective was used to arrest the rate of descent, and the longitudinal stick was used to change the attitude from the nose-down value of the approach to level for the wave-off maneuver. For the 80 kt approaches, it would be expected that a combination of collective and longitudinal stick would be used to arrest the rate of descent, since n_z/α is higher and normal force due to collective input is lower at this flight condition; insufficient data exist, however, to confirm this hypothesis.

SECTION V

CORRELATION OF RESULTS WITH FLYING QUALITIES CRITERIA

5.1 Introduction

This section compares the flying qualities results of this experiment, discussed in Section IV, with current flying qualities criteria. The emphasis is on the correlation of the short period (or short term) dynamic characteristics with the Level 1 and Level 2 boundaries of these criteria. Only the results obtained in moderate turbulence at the 65 kt approach speed are compared; these results are more applicable as substantiation data than those for negligible turbulence because they represent environmental conditions that are more demanding on the pilot. As was discussed in Section IV, the results obtained at the 80 kt approach speed generally confirmed those obtained at 65 kt, with the exception of configuration 29 (the better damped point at the lowest frequency). The possible significance of this point will be discussed where applicable, but the remaining 80-kt data are not presented.

5.2 Correlation With MIL-F-83300

The data at 65 kts in moderate turbulence are plotted on the short-term plane of MIL-F-83300 (Reference 1) in Figure 5-1. The pilot ratings shown are the overall ratings; as discussed in Section IV, the difference between the VFR-only and the overall ratings generally was no larger than one. Note that the MIL-F-83300 criteria are different for VFR and IFR flight conditions, and that the low frequency Level 1 and Level 2 boundaries are determined by the value of n_γ/α of the X-22A aircraft at 65 kt.

It is clear that the pilot ratings for the configurations with short-term frequency above ω_{s_T} = 1.2 rad/sec (configurations 3-8, 11-14), tend to substantiate the VFR Level 1 and Level 2 boundaries. It has been noted that the VFR-only ratings and the overall ratings, which include the pilot's weighting of the IFR approach obtained in this experiment, do not show marked differences; hence, the distinction between VFR and IFR conditions in the MIL-F-83300 criteria are not substantiated by these data, and the present IFR Level 2 boundary is too stringent above ω_{s_T} = 1.2 rad/sec. If, however, the VFR boundaries are used for both IFR and VFR conditions, the data indicate that they are approximately valid above ω_{s_T} = 1.2 rad/sec, if perhaps a bit stringent.

The data do not extend to sufficiently low frequencies to either substantiate or redefine the low frequency Level 1 and Level 2 boundaries, but they do indicate that the Level 1 boundary may be too lenient. Note that the ratings for configurations 17 and 18 are borderline Level 1 but that the frequencies for these points are well above the boundary. There is also an indication that those boundaries do change with flight condition: configuration 29, evaluated at 80 kt, had a short-term frequency of 0.8 rad/sec, which is above the Level 1 line for the appropriate n_γ/α of 2.9, but it was rated at 7.

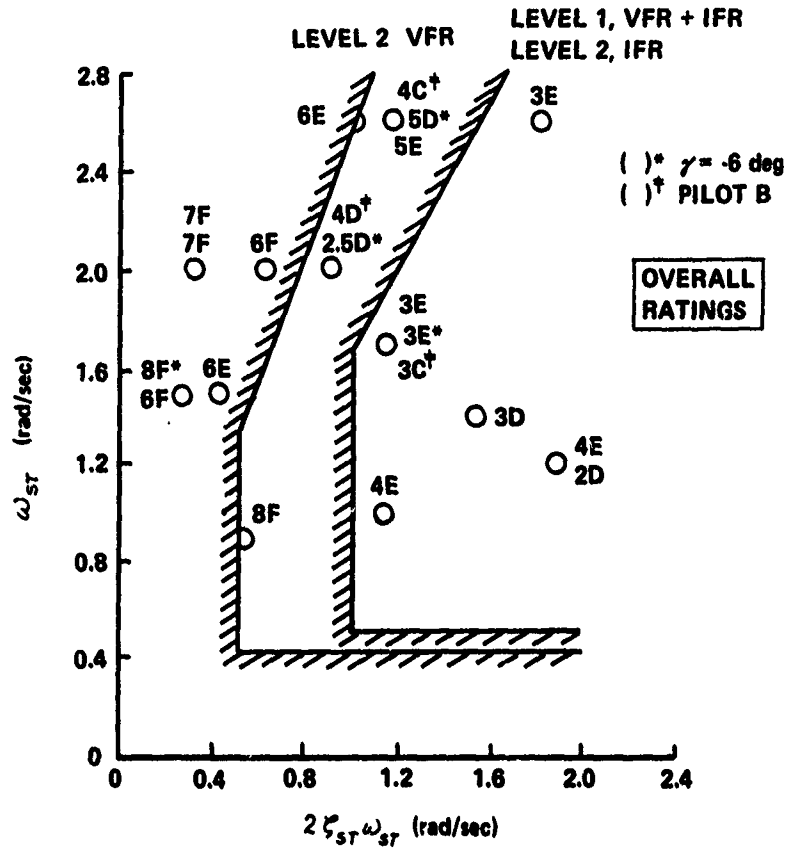


Figure 5-1 CORRELATION OF PILOT RATING DATA WITH MIL-F-83300 LEVEL 1 AND LEVEL 2 BOUNDARIES

As was previously discussed in Section 4.10, F_{es}/n_z does not seem to be a very significant parameter to the pilot in the landing approach task. This fact is apparently recognized in MIL-F-83300 where no upper limits are placed on F_{es}/n_z ; the only restriction is a minimum value of 3 lb/g. The data from this experiment substantiate this type of "open-ended" criterion.

5.3 Correlation With MIL-F-8785B(ASG)

Although there is a tendency to consider MIL-F-83300 as the applicable specification for STOL aircraft, there is no reason to exclude MIL-F-8785B from consideration, as the transition point between the two is difficult to define. Accordingly, the pilot rating data for 65 kt in moderate turbulence are compared in Figure 5-2 with the ω_{sp}, ζ_{sp} boundaries from MIL-F-8785B, Sections 3.2.2.1.1 and 3.2.2.1.2.

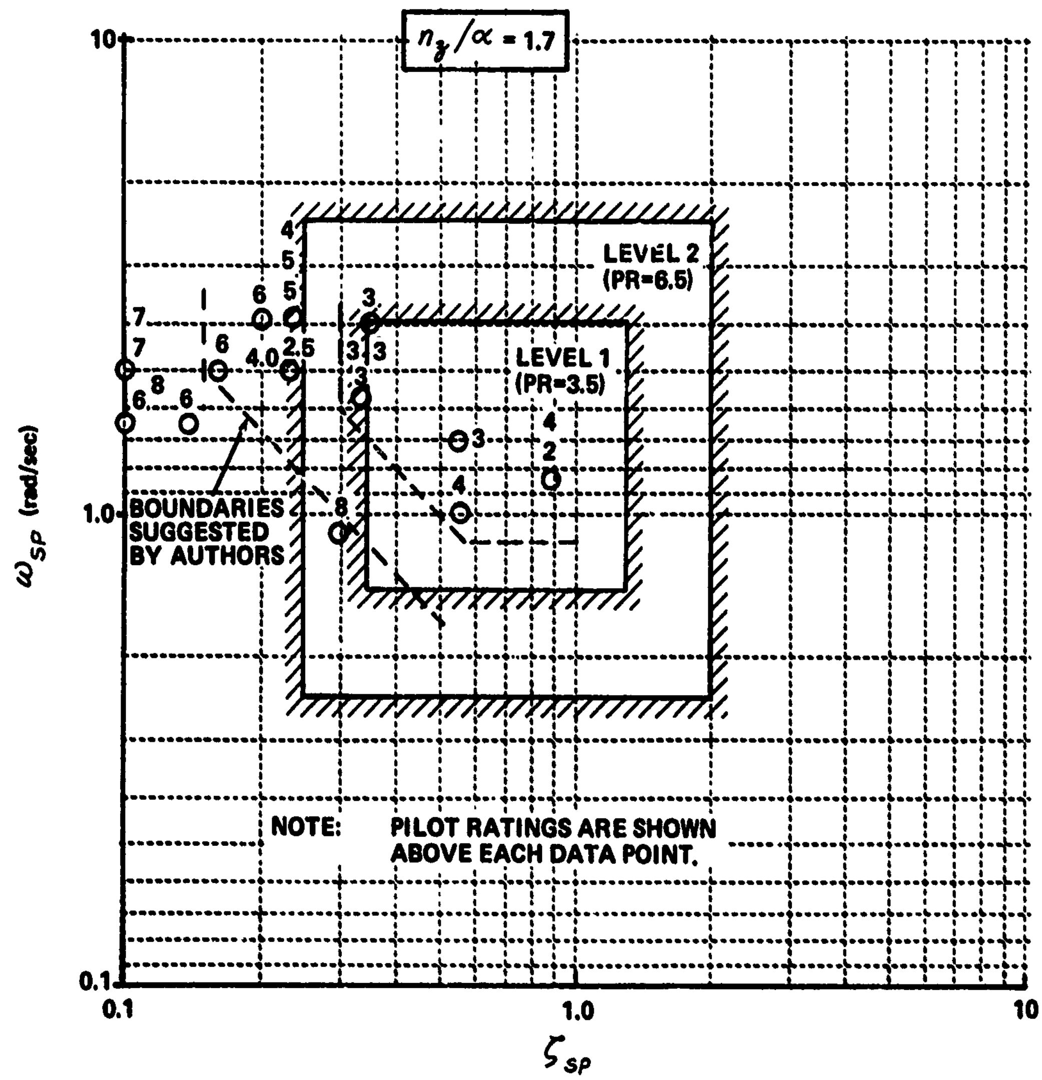


Figure 5-2 CORRELATION OF PILOT RATING DATA WITH MIL-F-8785B(ASG) FOR CLASS III-L AIRCRAFT, CATEGORY C (V_T = 65 KT, γ = -9 AND -6 DEG, MODERATE TURBULENCE)

The Level 1 block for Class II aircraft, Flight Phase Category C from 8785B, was obtained by extrapolating the ω_{sp} versus n_z/α requirements to an n_z/α of 1.7, since the Level 1 boundary on n_z/α in the specification is 2.0. Clearly, this limit on n_z/α is not correct because Level 1 configurations were obtained in this experiment at a lower n_z/α. Correlation of the data with the specification boundaries is generally not very good. The Level 1 and 2 minimum ζ_{sp} boundaries in the specification appear to be too stringent for these data. Minimum values of ζ_{sp} of approximately 0.3 and 0.15, for the Level 1 and Level 2 boundaries respectively, would provide a more reasonable correlation. However, it should be noted that the minimum boundaries in 8785B were somewhat arbitrarily increased to include the effects of turbulence. The data also suggest a correlation with a constant total damping line ($2\zeta_{sp}\omega_{sp}$) below $\omega_{sp} \approx 1.5$ rad/sec, which would cut off the lower left corner of the square boundaries as shown by the dashed lines in Figure 5-2. This trend would, in effect, revise the 8785B boundaries to the same form used in 83300. Again, as in the correlation with 83300, the low frequency Level 1 boundary in 8785B appears to be too lenient and the data suggests a boundary at approximately 1.0 rad/sec. These boundaries, which provide better correlation, are shown as dashed lines.

As discussed in Section 4.10, F_{ES}/n_z, the stick force per g does not seem to be a very significant parameter to the pilot in the landing approach task. The maximum limits on F_{ES}/n_z given in 8785B for center stick controllers (Section 3.2.2.2.1) are 28 lb/g for Level 1 and 42.5 lb/g for Level 2, but these values are overly restrictive insofar as the results of this experiment are concerned (see Appendix II for a summary of values for each configuration). Configurations were rated Level 1 in this experiment with values of F_{ES}/n_z as high as 60 lb/g. The 8785B requirements on F_{ES}/n_z are therefore not reasonable for STOL type aircraft in the landing approach task. In fact, the applicability of such a requirement for this flight phase is questionable for STOL aircraft; a more reasonable approach might be to put limits on $M_{F_{ES}}$, the stick force sensitivity.

5.4 Correlation With Recommended Revision to MIL-F-8785B(ASG)

A study to recommend revisions to MIL-F-8785B was recently completed by CAL for the Air Force (Reference 15). One of the major contributions of this study is a new "short-period" response criterion which replaces the criteria on short-period frequency and acceleration sensitivity, and short-period damping in 8785B, which were discussed in Section 5.3. The proposed new requirements are somewhat more general in that they are based upon considerations of the overall maneuvering response of the airframe/control-system combination; they appear to be applicable to aircraft having flight control systems with significant dynamics as well as to those that exhibit only the classical short-period and phugoid dynamic characteristics. As this criterion is new and less directly applied than those involving short-period frequency and damping, a brief review is included here prior to the discussion of the correlation of the data from this experiment with the proposed criterion.

The new requirement is an extension of the maneuver response criteria developed in Reference 16. Those criteria were originally developed using a closed-loop analysis of the pilot-aircraft combination; it was observed in their development, however, that parameters in the closed-loop formulation were strongly related to the open-loop slope and phase of the uncompensated aircraft attitude-to-elevator amplitude-phase curve near the frequency which was being used as the closed-loop bandwidth. This basic open-loop requirement was then modified by the study in Reference 15, and appropriate bandwidth frequencies were chosen for the Flight Phase Categories. The resulting criteria are shown plotted on the plane of open-loop slope and phase of the amplitude-phase curve, in Figure 5-3, with several of the data points in moderate turbulence at 65 kt plotted upon them. The bandwidth used was 1.2 rad/sec, which is the recommended value for Flight Phase Category C.

In general, the correlation is reasonably good, although there are too few points to either substantiate or redefine the boundaries. Although the criterion was derived in Reference 15 using constant speed assumptions, it should be noted that, as applied to the data from this experiment, it includes the short-period, phugoid and control system characteristics; hence, it is a more preferable means of specifying desirable dynamics than considering only one part of the response. This fact, in conjunction with the fact that the open-loop criterion is based on closed-loop considerations, makes this method very attractive, and further data and study to formulate such criteria for V/STOL vehicles are desirable.

5.5 Correlation With AGARD 408 and AGARD 577

The initial AGARD work relating to V/STOL handling qualities criteria resulted in the publication of AGARD 408 (Reference 17) in 1962; the most recent efforts to improve these criteria are summarized in AGARD 577 (Reference 18), published in 1970. The criteria in AGARD 408 are given in terms of a "concave downward" requirement on normal acceleration and a relationship between damped frequency and damping ratio; AGARD 577 has backed off somewhat on the quantitative nature of the criteria by stating that all characteristic roots should be stable and that the damping ratio of the second-order pair of roots which predominantly determine the "short-term" response be at least 0.3. These criteria are shown on the $\omega_{sr} \sim 2\zeta_{sr}\omega_{sr}$ plane in Figure 5-4, and compared to the 65 kt moderate turbulence results of this experiment. The correlation of the data with the AGARD 408 boundaries is best above ω_{sr} = 1.2 rad/sec, if the boundaries are interpreted as PR = 3.5 and PR = 6.5 criteria. The $\zeta_{sr} \geq 0.3$ criterion suggested by AGARD 577 is also a reasonable fit to the data for frequencies above ω_{sr} = 1.2 rad/sec. It is clear for the lower frequencies, however, that the AGARD 577 criterion is too lenient; note that configuration 15, which received a pilot rating of 8, has a damping ratio of 0.3 and hence would meet this criterion. The lower frequency boundary of AGARD 408, which

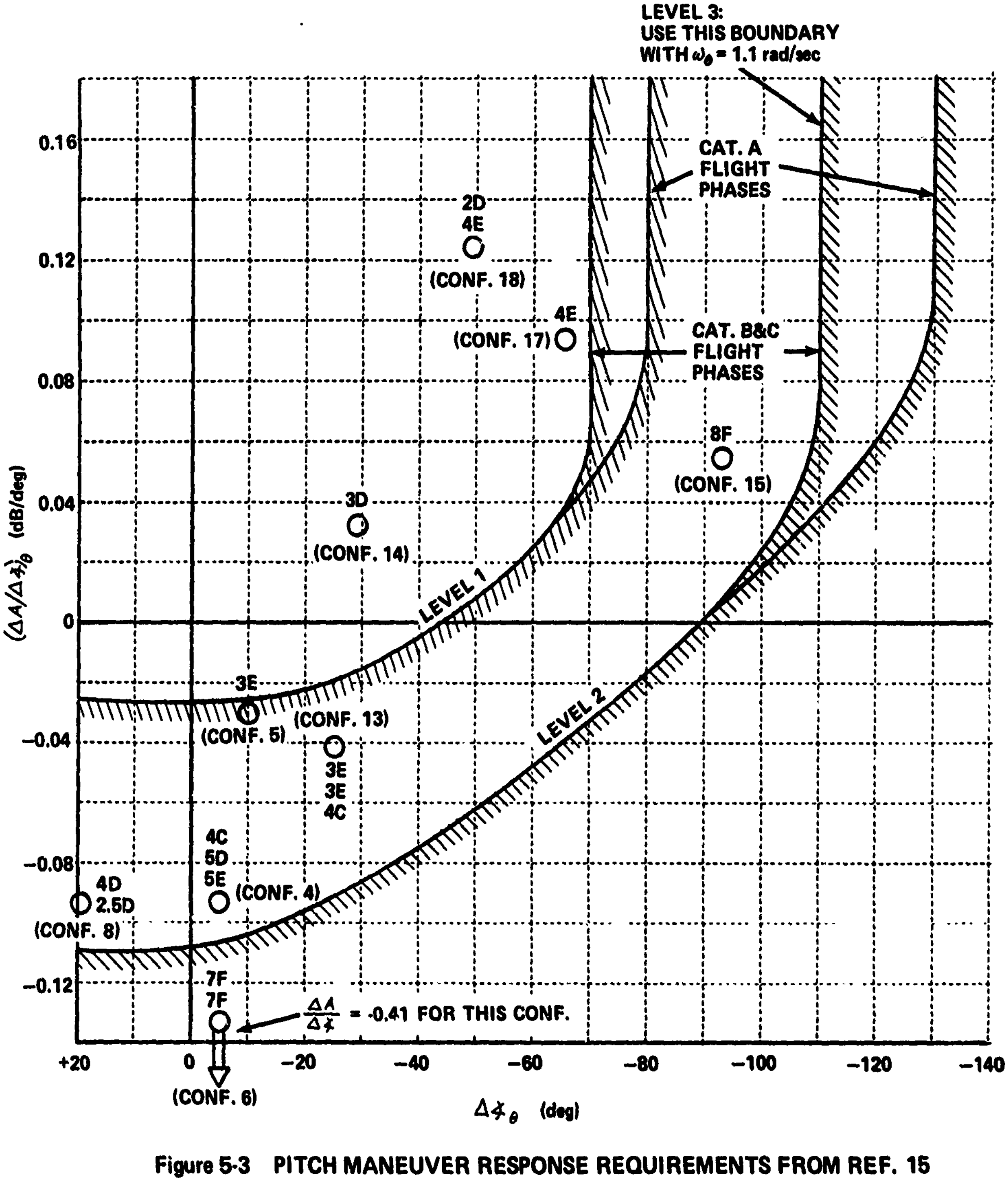


Figure 5-3 PITCH MANEUVER RESPONSE REQUIREMENTS FROM REF. 15

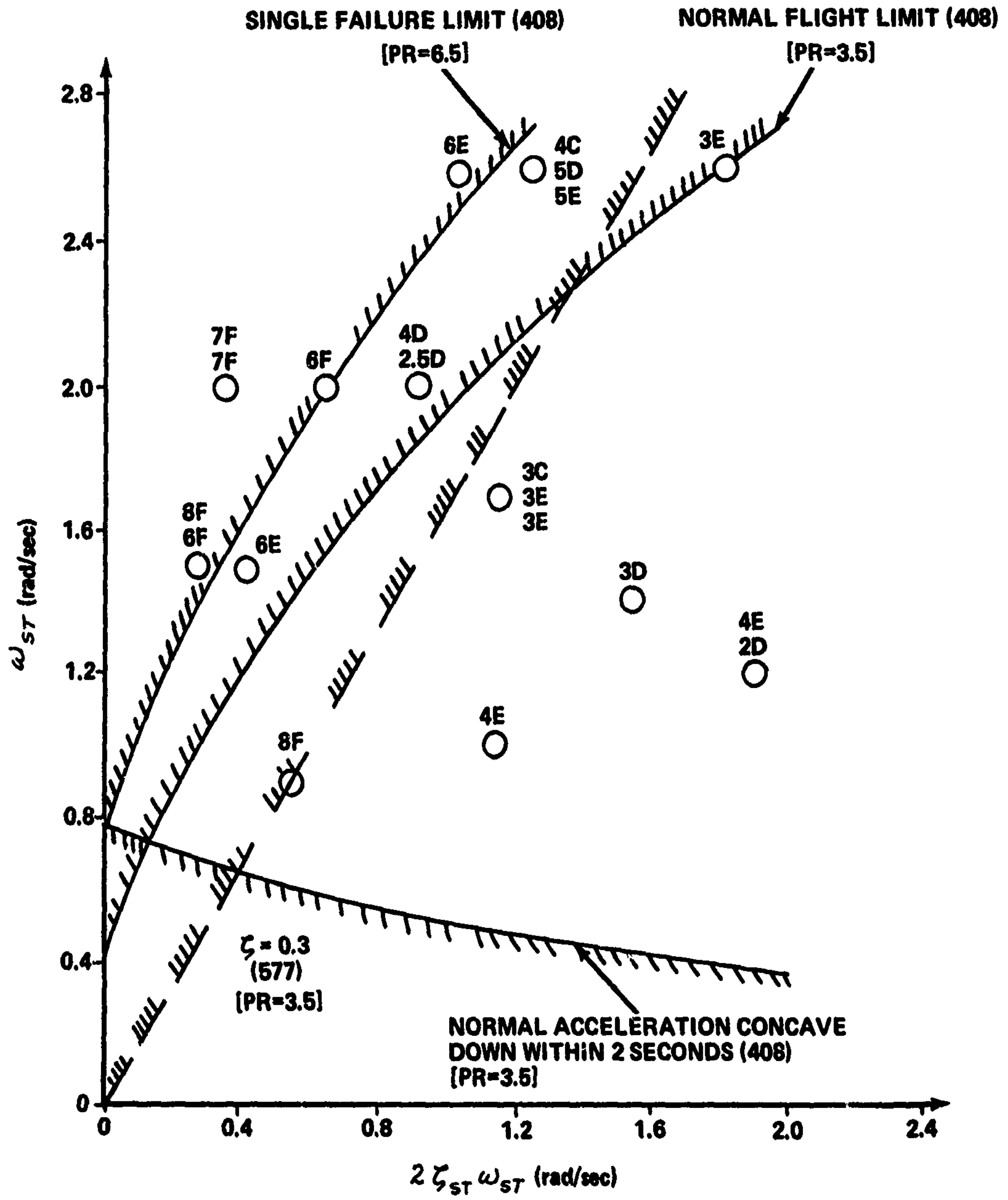


Figure 5-4 RESPONSE CRITERIA OF AGARD 408 (REF. 17) AND AGARD 577 (REF. 18)

in this case is determined by the "concave downward" requirement, appears too lenient also, although the data tend to corroborate the trend of allowing lower frequencies as the total damping increases.

A final point of interest concerns the force gradients. AGARD 577 specifies that the longitudinal control force gradient be between 2 and 5 lb/inch for STOL aircraft. In this experiment, the control force gradient was fixed at 7.5 lb/inch, including those configurations that were rated Level 1. The maximum stick-force-per-g is specified in AGARD 577 to be 20 to 40 lb/g; as was discussed in Section 5.3 in the correlation with MIL-F-8785B, some configurations in this experiment were rated Level 1 with a stick-force-per-g on the order of 60 lb/g. Again, this parameter appears to have very little meaning for the landing approach task for STOL aircraft.

SECTION VI

SUMMARY OF STATISTICAL ANALYSIS

A selected set of data from the evaluation landing approaches was analyzed to obtain probability densities and power spectral densities of variables related to approach performance and pilot workload. These analyses were performed (1) to provide a representative sample of typical statistical data for this experiment, (2) to attempt to quantify the levels of turbulence present during the experiment, and (3) to investigate any possible correlations between these data and the pilot rating data discussed in Sections IV and V of this report. A detailed discussion of the analyses and interpretations of the resulting data is contained in Appendix VII; the purpose of this section is to summarize briefly the results and relevant conclusions.

Essentially three characteristics from the statistical analyses were investigated: standard deviation of the probability densities, form of the probability densities (e.g., Gaussianity, skewness), and form of the power spectral densities. The standard deviations of longitudinal and collective and pitching acceleration were compared to pilot rating and turbulence level. No trends of control usage, glide slope tracking, or normal acceleration with pilot rating were found. The data from one flight did demonstrate that approach velocity performance actually degraded with improving flying qualities, but insufficient data were analyzed to make any explanation of this trend. It was found, however, that the standard deviation of pitching acceleration correlated strongly with pilot rating: the standard deviation increased as pilot rating degraded. On the basis of these attempted correlations, it is clear that efforts to define a performance index in terms of standard deviations of most workload and performance parameters will not provide an accurate indication of pilot rating, but that, perhaps, use of pitching acceleration statistics may prove a useful starting point.

The standard deviations were also examined to attempt to provide a more quantitative indication of the levels of turbulence that were present in the experiment. It was found that an excellent correlation between the wind velocity (Table II-1) and the standard deviation of velocity (σ_u) could be obtained, yielding the relationship (Figure 6-1):

$$\sigma_u \cong 0.3\, V_w$$

Since the airspeed standard deviation may be considered a good approximation to the turbulence level (σ_{u_g}) for landing approach, this correlation, in conjunction with the mean wind velocities recorded for each evaluation, allows interpretation of the statistical data in terms of turbulence level.

On this basis, two salient conclusions may be drawn from Figure 6-1. First, it is clear that longitudinal stick control usage increases with increasing turbulence level (wind speed), and, further, that the control power required, as evidenced by σ_{M_c}, also increases with increased turbulence level.

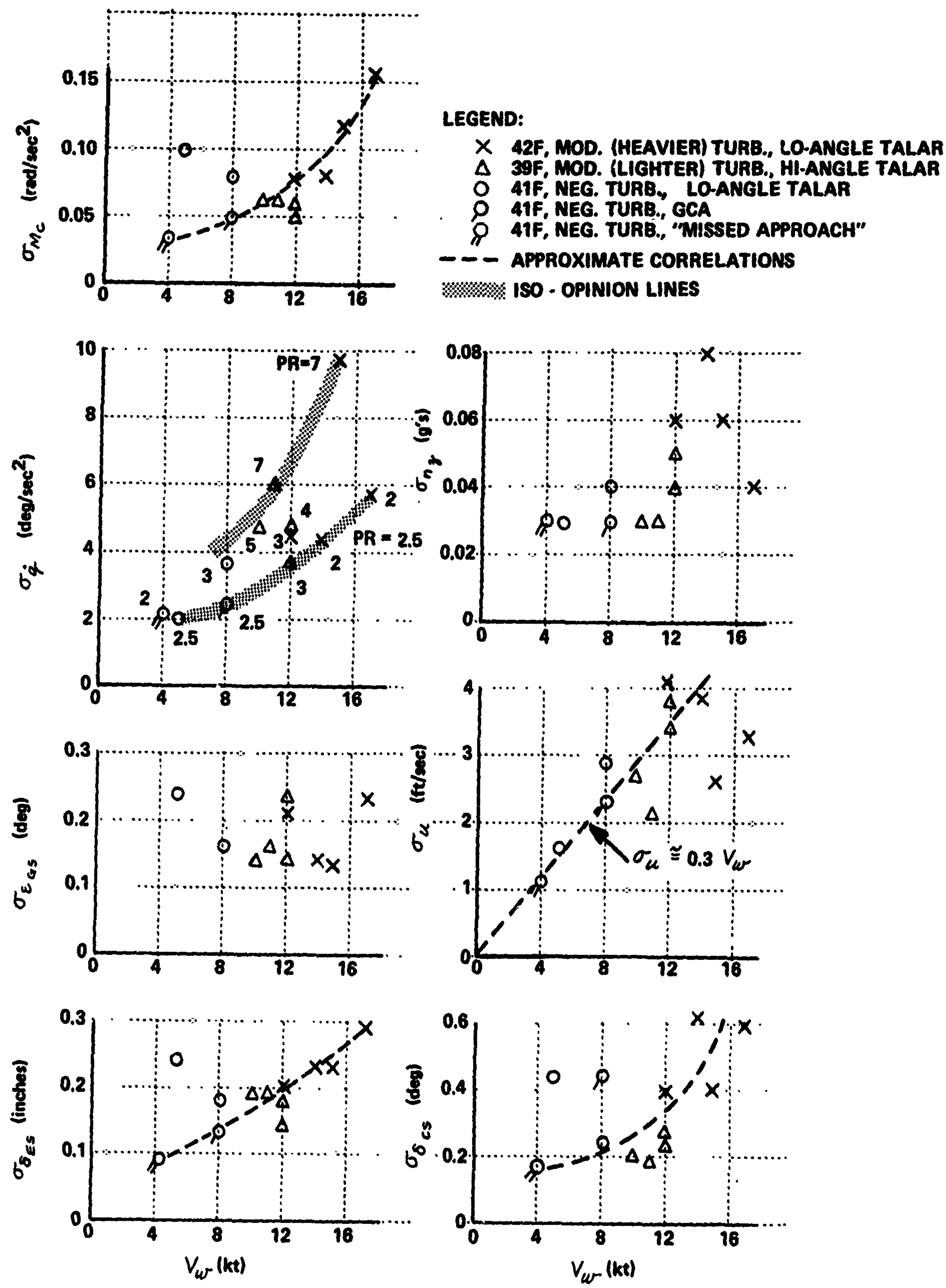


Figure 6-1 STATISTICS DURING INSTRUMENT APPROACHES CORRELATED WITH WIND SPEED (TURBULENCE LEVEL)

Second, the standard deviation of pitching acceleration ($\sigma_{\dot{q}}$) also increases with turbulence level; since $\sigma_{\dot{q}}$ also correlates well with pilot rating, it may be possible to obtain an indication of the degradation in pilot rating caused by turbulence level by examining these statistics.

The investigation of the shape of the probability densities demonstrated the following characteristics. The longitudinal stick and pitching moment distributions were relatively Gaussian, having little skew and a single peak. An interesting characteristic was found for the glide slope tracking distribution. Although a central peak was observed, the distributions also had peaks at the extremes. This characteristic implies a sinusoidal glide path deviation, and, in fact, such an oscillation was evident in the time histories. It is possible that the high sensitivity ($\pm .9^\circ$) of the TALAR unit used for the predominant part of the experiment induced this oscillation, although the pilot comments did not indicate any difficulties caused by this sensitivity.

Power spectral densities of longitudinal stick motion and pitching moment acceleration were also computed. These spectra were investigated to ascertain whether their form could provide an insight into the pilot ratings obtained. No definitive rule should be defined on the basis of the limited amount of data presented. It was found that, although peaks in the spectra around 3.0 rad/sec were prevalent in many of the $\dot{q}$ and δ_{ES} spectra, correlation of these peaks with pilot rating is somewhat tenuous. General conclusions are drawn in Appendix VII.

In general, the results of the statistical analyses performed on the data from this experiment should be viewed as preliminary. The correlation of the $\dot{q}$ statistics with pilot rating and turbulence level, however, appears to be a fruitful area for further research, and further studies of the $\dot{q}$ and δ_{ES} spectral densities should be pursued. A complete discussion of the trends that have been presented in this section, and the presentation of the relevant data, is contained in Appendix VII of this report for reference.

SECTION VII

CONCLUSIONS

The experiment described in this report was performed using the X-22A variable stability V/STOL aircraft which is capable of reproducing a wide range of aircraft characteristics. Therefore, the results are largely independent of the actual aircraft employed and are restricted only by the task, range of dynamics, flight conditions and aircraft parameters realized in the experiment.

General conclusions which may be drawn from the successful completion of the flight program are:

1. Steep, non-decelerating STOL approaches can be performed under IFR conditions with minimal sophistication of instrument displays for the velocities and rates of descent investigated (approximately 1000 fpm) given satisfactory flying qualities as defined by the data gathered in this experiment for the tasks considered.

2. The X-22A variable stability V/STOL aircraft is a valid and useful research tool for flying qualities research.

Specific results pertinent to the effects of the aircraft and task variables investigated in this experiment lead to the following conclusions:

1. The VFR-only and overall pilot ratings generally agreed within one pilot rating. Any distinction between VFR and IFR short-term response criteria, such as those used in MIL-F-83300, was not substantiated for the conditions investigated in this experiment. The VFR and IFR short-term criteria should be the same.

2. In moderate turbulence, pilot rating gradients depend primarily upon damping ratio at the higher frequencies ($1.6 < \omega_{ST} < 2.6$ rad/sec) investigated and upon total damping at the lower frequencies ($0.8 < \omega_{ST} < 1.6$ rad/sec). In negligible turbulence, the dependence remains primarily on total damping at the higher frequencies also.

3. The Level 1 and Level 2 VFR short-term response boundaries of MIL-F-83300 are approximately valid for both VFR and IFR operation in moderate turbulence at short-term frequencies above $\omega_{ST} \cong 1.0$ rad/sec, but the low frequency boundaries are too lenient.

4. The normal flight and single failure short-term response limits of AGARD 408, if interpreted as PR = 3.5 and PR = 6.5 boundaries, are approximately valid for both VFR and IFR operation in moderate turbulence at short-term frequencies above $\omega_{ST} \cong 1.0$ rad/sec. The $\zeta_{ST} \geq 0.3$ criterion of AGARD 577 is approximately valid for the same conditions for short-term frequencies above $\omega_{ST} \cong 1.5$ rad/sec, but should include a low frequency boundary. The "concave downward in 2 seconds" criterion of AGARD 408 appears to be too lenient.

5. The Level 1 and Level 2 short-period response boundaries of MIL-F-8785B were not substantiated by the results of this experiment. The lower limit on n_z/α is too high to be applicable to STOL aircraft, and the dependence of pilot rating gradients on total damping at low frequencies is not accounted for. The revisions to these criteria proposed in Reference 15, while not substantiated either, appear to provide a more reasonable approach.

6. Degradation of pilot rating with increased turbulence level was greatest at the highest short-term natural frequency investigated ($\omega_{ST} \approx 2.6$ rad/sec). No degradation of pilot rating with increased turbulence level was demonstrated for the lower short-term frequencies tested.

7. No significant effect of glide slope angle and rate of descent on pilot rating was found for the range of these variables that was investigated.

8. The pitching moment control sensitivity parameter $M_{F_{ES}}$ rather than $M_{\delta_{ES}}$ should be used to compare longitudinal control gains. For this experiment, the pilots selected longitudinal control gains which resulted in essentially a constant value of $M_{F_{ES}}$, with an optimal value of approximately .055 $\frac{\text{rad/sec}^2}{\text{lb}}$.

9. For the cases analyzed statistically, control usage was dependent only on turbulence level; pitch acceleration standard deviations correlated with pilot rating and turbulence level for the IFR approaches.

SECTION VIII
RECOMMENDATIONS

On the basis of the results obtained in this experiment, the following recommendations are pertinent to future investigations of STOL longitudinal flying qualities in the landing approach:

1. A more quantitative indication of the effects of turbulence characteristics is desirable, including pertinent statistical measurements, such as control usage. Specifically, experimenters should make an effort to measure and document the primary turbulence characteristics such as mean intensity.

2. Further work is necessary to define low frequency limits for the short-term response, and to ascertain the functional dependence of these limits on aircraft characteristics such as n_z/α, approach velocity, and thrust inclination.

3. Criteria similar to those proposed in Reference 15 for conventional aircraft, which are based on closed-loop pilot/vehicle considerations and consider all of the aircraft and flight control system dynamic characteristics, should be developed for STOL aircraft.

This page left blank intentionally

APPENDIX I

PILOT COMMENTS AND TIME HISTORIES FOR EACH CONFIGURATION

Summaries of all the pilot comments and sample time histories are presented in this appendix for each configuration simulated in this experiment.

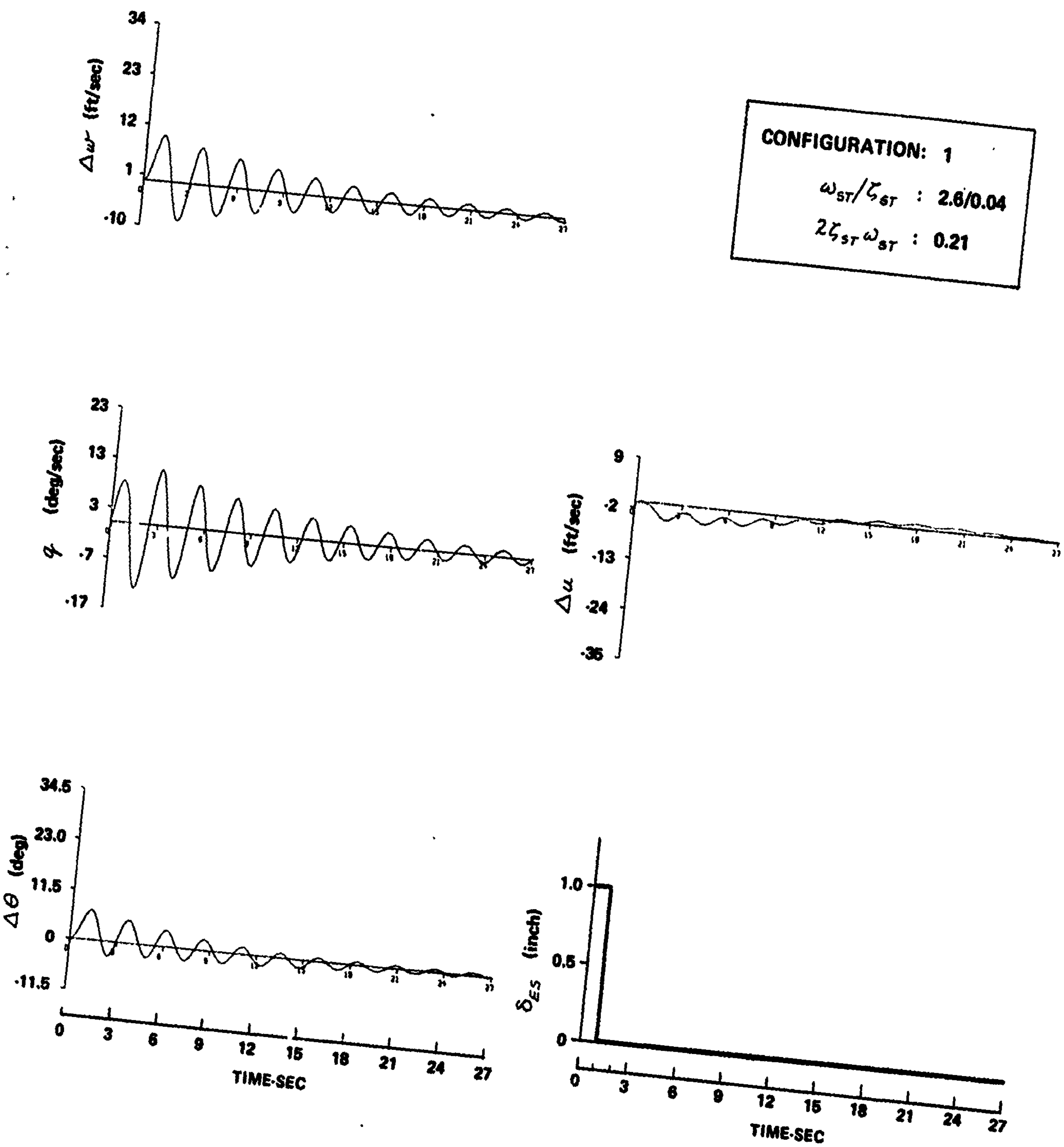
The pilot comment summaries were prepared from transcriptions of the recorded comments made by the pilot during each evaluation in support of his VFR and overall pilot ratings. Referring to the Pilot Comment Card discussed in Section 3.5, the comments under specific headings of "Response to inputs required to perform task - collective control," and "Lateral-directional characteristics" are not included in the summaries. Collective control response was not specifically commented on by the pilots and the lateral-directional characteristics were not considered a factor in the evaluations. Some of the headings in the summaries are changed from those in the comment card for the sake of clarity.

Two of the configurations, numbers 19 and 20, could not be properly identified and were therefore not included in the data plots in the report. The pilot comments are, however, included in the appendix for completeness, along with the estimated dynamic characteristics.

The pertinent characteristics for each configuration are summarized at the top of the page, and time history plots of the α, $\dot{\theta}$, θ and u response to a longitudinal pulse input are presented at the end of the pilot comments for each configuration. A complete summary of the data for each configuration can be found in Appendix II.

ω_{ST}/ζ_{ST}:	2.6/0.04	PILOT RATINGS:		CONFIGURATION:	1
$2\zeta_{ST}\omega_{ST}$:	0.21	VFR:	7D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.34	OVERALL:	7D	PILOT:	A
FLIGHT NO:	40F-24			WIND:	

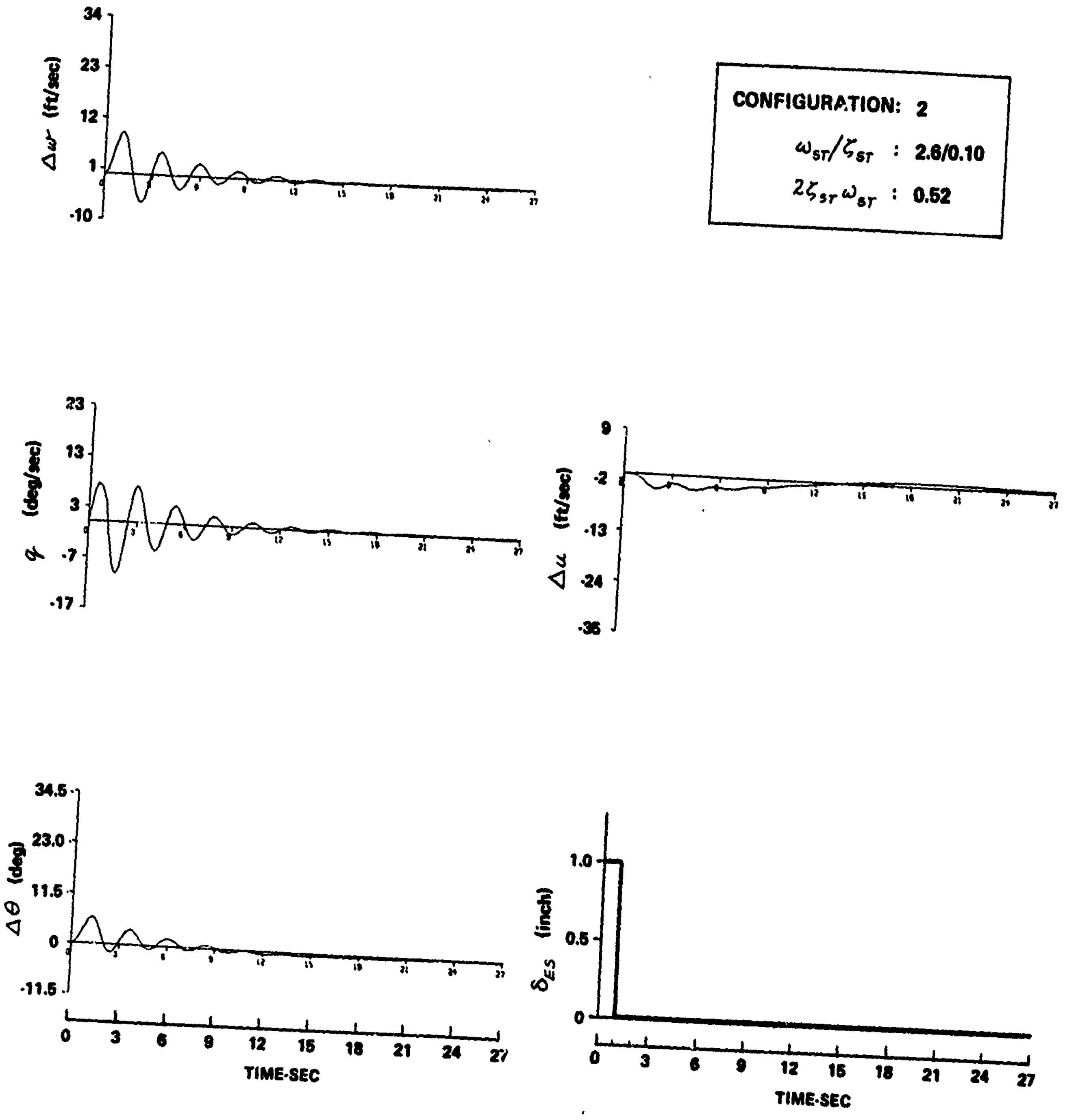
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Not very good because airplane is very oscillatory.	Can't trim very well.
FEEL CHARACTERISTICS:		Very difficult to get proper compromise, forces and displacements okay.
PITCH ATTITUDE CONTROL:	Really quite poor, initial response is a little slow and then takes off and get a noticeable residual oscillation going. Very difficult to dampen oscillations.	Slow initially and then takes off. Tended to ride out oscillations on approach more than VFR but workload much too high.
VELOCITY CONTROL:	Okay since oscillations are high enough frequency that airspeed is not affected.	Surprisingly good.
APPROACH:		
PERFORMANCE:	Must devote attention to dampen the airplane rather than glide path control. Performance poor.	Really wasn't too bad, but could not do satisfactory job consistently.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUE:		Tend to use collective for glide path control so as not to get pitch oscillation going.
SIDESTEP MANEUVER:	Lateral okay but pitch oscillations really got out of hand.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		Can stop sink rate but pitch oscillations get stirred up.
LANDING?:		No because of large pitch oscillations.
DIFFERENCES IFR/VFR:		Yes, IFR turned out a little easier because tended to ride out oscillations.
EFFECTS OF TURBULENCE:	No turbulence.	Very little turbulence present.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	Speed control okay.
OBJECTIONABLE FEATURES:	Unpredictability of pitch response, ridiculous pitch oscillations.	Large and quite bothersome pitch oscillations with stick inputs.



CONFIGURATION: 1
ω_{ST}/ζ_{ST} : 2.6/0.04
$2\zeta_{ST}\omega_{ST}$: 0.21
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST}/ζ_{ST}:	2.6/0.10	PILOT RATINGS:		CONFIGURATION:	2
$2\zeta_{ST}\omega_{ST}$:	0.52	VFR:	4.5C	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.54	OVERALL:	5B	PILOT:	A
FLIGHT NO:	43F-27			WIND:	06

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Good.
FEEL CHARACTERISTICS:		No problem.
PITCH ATTITUDE CONTROL:	Initial response relatively fast, but with tendency to oscillate a few times, final response is not predictable. Using pulse-type inputs.	Initial response reasonably snappy. Final response not too predictable because airplane oscillates.
VELOCITY CONTROL:	Good.	Collective used for velocity and rate of sink.
APPROACH:		
PERFORMANCE:	Pretty good, tendency to bobble around quite a bit.	Not too bad in the face of pitch oscillations -- didn't really take the time to try to dampen them.
INTERCEPT AND TRACKING:		Went pretty well.
CONTROL TECHNIQUE:		Primarily using collective for glide path and trying not to disturb the airplane in pitch.
SIDESTEP MANEUVER:	Can be done okay but tend to bobble airplane in pitch.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		No, quite comfortable, no oscillations.
LANDING?:		No comments.
DIFFERENCES IFR/VFR:		Yes, tended to oscillate more IFR.
EFFECTS OF TURBULENCE:	None.	Practically no turbulence.
SUMMARY COMMENTS:		
GOOD FEATURES:	Initial pitch response.	Good collective control, can leave stick alone and fly glide path with collective.
OBJECTIONABLE FEATURES:	Cannot stop the airplane precisely.	Pitch oscillations, inability to predict final response.


CONFIGURATION: 2
ω_{ST}/ζ_{ST} : 2.6/0.10
$2\zeta_{ST}\omega_{ST}$: 0.52
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0
3
6
9
12
15
18
21
24
27
TIME-SEC

ω_{sr}/ζ_{sr}:	2.6/0.20	PILOT RATINGS:		CONFIGURATION:	3
$2\zeta_{sr}\omega_{sr}$:	1.04	VFR:	6D	V_T/γ :	65/-9
$M_{\delta_{ES}}$	0.41	OVERALL:	6E	PILOT:	A
FLIGHT NO:	38F-22			WIND:	11 (M)

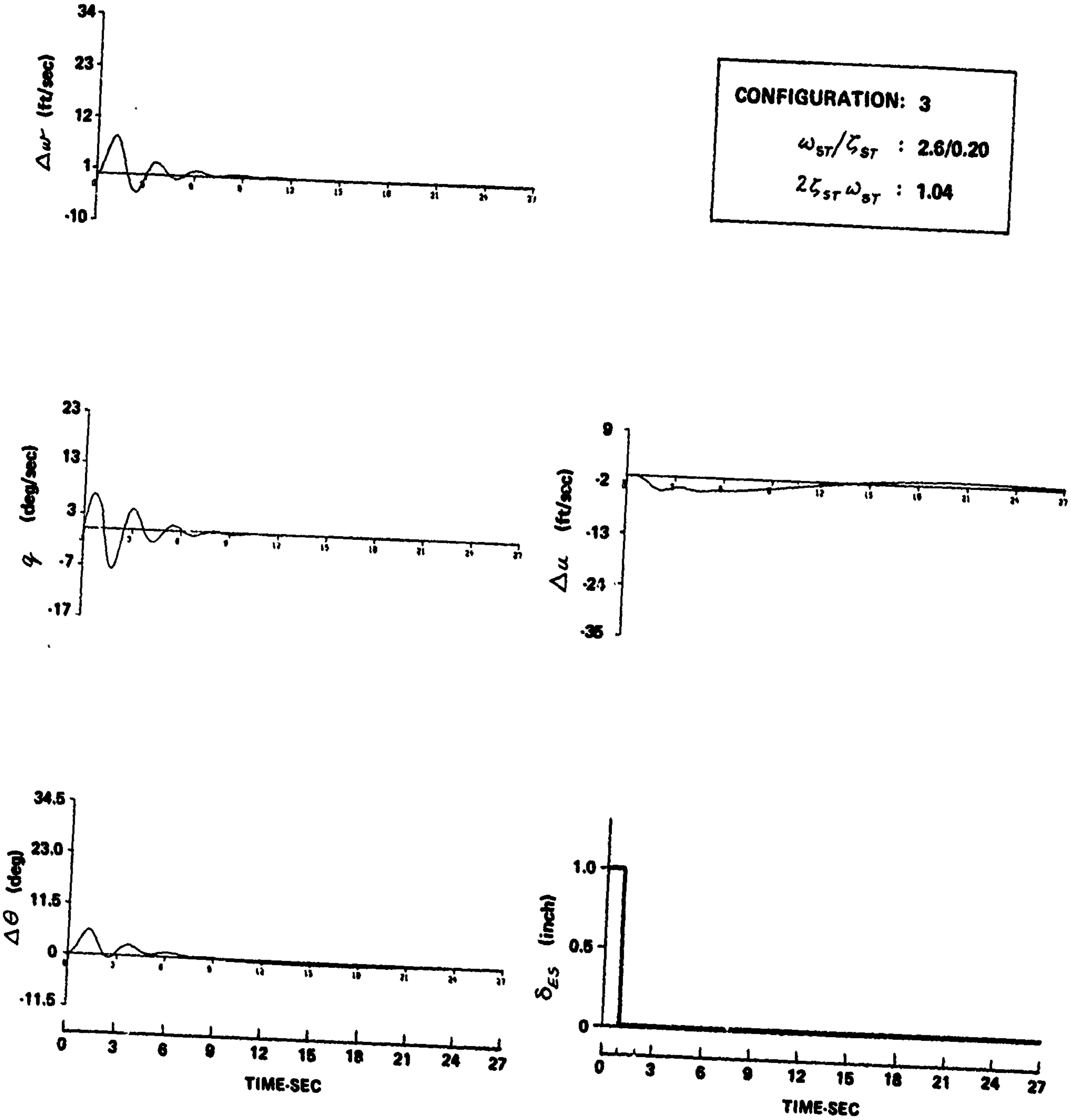
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Not too bad. Aircraft seems relatively sloppy longitudinally. Seems to have a little bit of a mind of its own.	Not too bad.
FEEL CHARACTERISTICS:		Forces nice and light. Displacements small. Not a problem.
PITCH ATTITUDE CONTROL:	After input, get aircraft disturbed and get 3 or 4 nose oscillations. Does settle down, though, finally, so final response is really relatively predictable. Used mostly small inputs.	Any pitch input causes aircraft to oscillate quite noticeably in pitch. Final response does come out somewhere near desired. Have been putting in input and then working a little bit to dampen it out. It does damp by itself -- it's not something I have to do.
VELOCITY CONTROL:	Satisfactory.	Okay. Oscillations fast enough so that don't get real significant velocity changes.
APPROACH:		
PERFORMANCE:	Pretty good. Oscillations are fast enough so they don't affect actual glide slope performance too much.	Okay
INTERCEPT AND TRACKING:		Good rate of sink control, heading control getting better.
CONTROL TECHNIQUE:		No comment.
SIDESTEP MANEUVER:	More critical due to crosswind. Lateral-directional still pretty rocky.	
LEVEL OFF:		
TECHNIQUE:		Used mostly a collective input.
PROBLEMS:		No problem. Did get nose excited, aircraft oscillates quite a bit, could still do the job.
LANDING?:		No because of rapid pitch attitude oscillations.
DIFFERENCES IFR/VFR:		No real differences. Oscillates more IFR than VFR due to lack of external cues.
EFFECTS OF TURBULENCE:	Quite an effect. Rocks up and down a bit.	Large effect, noticeably in pitch.
SUMMARY COMMENTS:		
GOOD FEATURES:	No comments.	Can do the job.
OBJECTIONABLE FEATURES:	Lightly damped oscillation with every input.	Noticeable lightly damped pitch oscillation.

$\omega_{sT}/\zeta_{\theta T}$:	2.6/0.20	PILOT RATINGS:		CONFIGURATION:	3
$2\zeta_{sT}\omega_{sT}$:	1.04	VFR:	3B	V_T/γ :	65/-9
$M_{\delta_{BS}}$:	0.41	OVERALL:	2.5B	PILOT:	A
FLIGHT NO:	41F-25			WIND:	05

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Quite good.
FEEL CHARACTERISTICS:		Good, forces and displacements small.
PITCH ATTITUDE CONTROL:	Quite good, initial and final response satisfactory. Must put in an input and hold it in and then nose wants to settle back down further than normal.	Good.
VELOCITY CONTROL:	Good, used collective.	Satisfactory, used collective.
APPROACH:		
PERFORMANCE:	Okay.	No comments.
INTERCEPT AND TRACKING:		Localizer too sensitive but otherwise okay.
CONTROL TECHNIQUE:		Glide path a combination of stick and collective - collective for speed, stick for approach path.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Collective to arrest rate of descent, stick for desired altitude and speed.
PROBLEMS:		None.
LANDING?:		Yes
DIFFERENCES IFR/VFR:		No.
EFFECTS OF TURBULENCE:	No problem.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch response.	Pitch control.
OBJECTIONABLE FEATURES:	Slow trim and large stick inputs for new altitude.	None.

ω_{ST}/ζ_{ST}:	2.6/0.20	PILOT RATINGS:		CONFIGURATION:	3
$2\zeta_{ST}\omega_{ST}$:	1.04	VFR:	3C	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.54	OVERALL:	3C	PILOT:	A
FLIGHT NO:	43F-27			WL.):	11

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Pretty good.	Good.
FEEL CHARACTERISTICS:		Good.
PITCH ATTITUDE CONTROL:	Pretty good initially, although a little tendency to bobble the airplane. Predictability only fair. Tend to use step-type input and damping motion after that.	Initial response satisfactory, final response not quite as predictable as desired -- oscillates a couple of times. Step-type inputs used.
VELOCITY CONTROL:	Collective used, good speed control.	Combination of collective and stick with the collective being primary velocity control -- good speed control.
APPROACH:		
PERFORMANCE:	No comments.	Pretty good.
INTERCEPT AND TRACKING:		Good.
CONTROL TECHNIQUES:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Collective to stop rate of descent.
PROBLEMS:		None.
LANDING?:		No comment.
DIFFERENCES IFR/VFR:		No significant differences, easier IFR.
EFFECTS OF TURBULENCE:	Very little, only minor deterioration.	Very little effect.
SUMMARY COMMENTS:		
GOOD FEATURES:	Good pitch control.	Initial pitch response.
OBJECTIONABLE FEATURES:	Bobble in final response.	Final response tends to bobble a little but not a problem.


CONFIGURATION: 3
ω_{ST}/ζ_{ST} : 2.6/0.20
$2\zeta_{ST}\omega_{ST}$: 1.04
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

ω_{sp}/ζ_{sp}:	2.6/0.24	PILOT RATINGS:		CONFIGURATION:	4
$2\zeta_{sp}\omega_{sp}$:	1.25	VFR:	5D	V_T/γ:	65/-9
$M_{\delta_{ES}}$:	0.32	OVERALL:	5E	PILOT:	A
FLIGHT NO:	39F-23			WIND:	10 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Fair, trim control is not good.	Somewhat poor.
FEEL CHARACTERISTICS:		Acceptable.
PITCH ATTITUDE CONTROL:	Snappy in pitch, fairly lightly damped. Final response relatively predictable.	Tends to bobble with each input, predictable but must work at controlling oscillations -- tend to couple with the oscillations.
VELOCITY CONTROL:	Collective.	Satisfactory, better than VFR, used collective.
APPROACH:		
PERFORMANCE:	Pretty good, only problem is with pitch oscillation with every input.	No comment.
INTERCEPT AND TRACKING:		Pretty good.
CONTROL TECHNIQUE:		Glide path -- used collective more than normal since got oscillation with stick.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Collective.
PROBLEMS:		None.
LANDING?:		Yes but worried about oscillations in pitch.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	Stirs up pitch oscillation.	Really bobbles this thing around.
SUMMARY COMMENTS:		
GOOD FEATURES:	No comments.	Can put the airplane where desired and fly a good approach.
OBJECTIONABLE FEATURES:	Oscillatory nature of response.	Bobbly pitch response.

ω_{sT}/ζ_{sT}:	2.6/0.24	PILOT RATINGS:		CONFIGURATION:	4
$2\zeta_{sT}\omega_{sT}$:	1.25	VFR:	2B	V_T/γ :	65/-9
$M_{\delta_{es}}$:	0.49	OVERALL		PILOT:	A
FLIGHT NO:	43F-27			WIND:	05

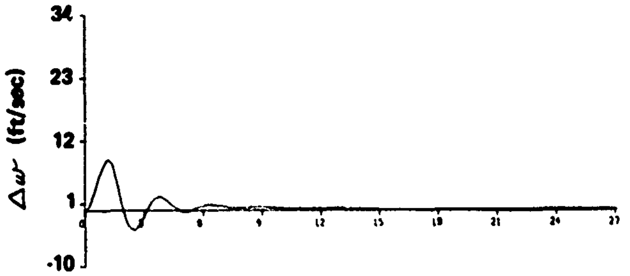
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM	Quite good.	NOT DONE
PITCH ATTITUDE CONTROL:	Forces were light and displacements small. Attitude control very straight forward. Initial response good, final response predictable. Step-type inputs.	
VELOCITY CONTROL:	Good, used collective.	
APPROACH:		
PERFORMANCE:	Very good, rates of descent up to 1200 fpm.	
SIDESTEP MANEUVER:	No problem.	
EFFECTS OF TURBULENCE:	Not a factor.	
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch control, good airplane.	
OBJECTIONABLE FEATURES:	NONE	

ω_{sT} / ζ_{sT} :	2.6/0.24	PILOT RATINGS:		CONFIGURATION:	4
$2\zeta_{sT}\omega_{sT}$:	1.25	VFR:	4D	V_T/γ :	65/-6
$M_{\delta_{ES}}$:	0.36	OVERALL:	5D	PILOT:	A
FLIGHT NO:	51F-31			WIND:	20 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM.	Very nice.	Nice.
FEEL CHARACTERISTICS:		Okay, perhaps a little heavy, used a lot of trim to change pitch attitude. Steady forces heavy.
PITCH ATTITUDE CONTROL:	Fast initial response and nice predictable final response. Flying will step-type inputs. Real sharp response to pilot inputs and gusts.	Snappy initial response, final response predictable.
VELOCITY CONTROL:	Pretty good with collective.	Okay, collective used.
APPROACH:		
PERFORMANCE:	Good, tendency to bobble the airplane a little bit. Little shallower than normal-satisfactory.	Not especially good but acceptable.
INTERCEPT AND TRACKING:		Easy, less frantic than higher glide paths.
CONTROL TECHNIQUES:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None, slight tendency to over control and bobble in pitch.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Object more to holding forces waiting for the trim IFR.
EFFECTS OF TURBULENCE:	Really hits the airplane strongly every now and then. Both longitudinally and lateral-directional.	Really jangles the airplane around in pitch and roll.
SUMMARY COMMENTS:		
GOOD FEATURES:	Good pitch control.	Lot easier to maneuver around glide path with shallower glide path. Good glide path and speed control.
OBJECTIONABLE FEATURES:	Little too abrupt, certainly to turbulence.	Had to work a little too hard and too responsive to turbulence.

ω_{sr}/ζ_{sr} :	2.6/0.24	PILOT RATINGS:		CONFIGURATION:	4
$2\zeta_{sr}\omega_{sr}$:	1.25	VFR:	4C	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.44	OVERALL:	4C	PILOT:	B
FLIGHT NO:	54F-33			WIND:	14 (M)

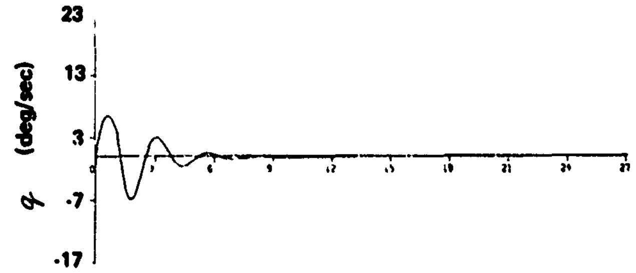
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	No particular problem.	No problem.
FEEL CHARACTERISTICS:		Forces moderate, displacements to large.
PITCH ATTITUDE CONTROL:	Reference seems as low side, requiring large inputs. Little sluggish.	Observation response bit sluggish, had a tendency to force the airplane.
VELOCITY CONTROL:	No problems.	Little trouble here, fair, satisfactory.
APPROACH:		
PERFORMANCE:	No comments.	Low frequency oscillation on glide path. Localizer too sensitive. Pretty good.
INTERCEPT: AND TRACKING		Okay.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	Good, no problems.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None
LANDING:		Yes
DIFFERENCES IFR/VFR:		Problem with low frequency glide path oscillations evident IFR.
EFFECTS OF TURBULENCE:	Not desirable, too responsive to turbulence.	No comments.
SUMMARY COMMENTS:		
GOOD FEATURES:	Airspeed control, easy to establish desired rate of descent. Ability to stop rate of descent and level off.	Fairly well damped, final response predictable.
OBJECTIONABLE FEATURES:	Little on the sluggish side.	Sluggish initial response.

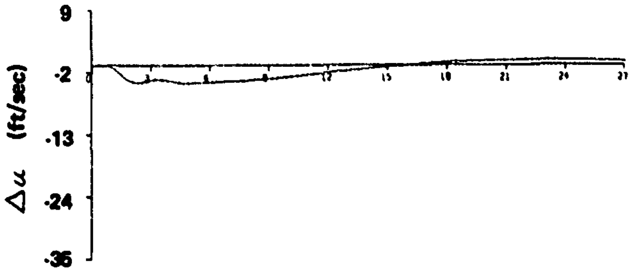


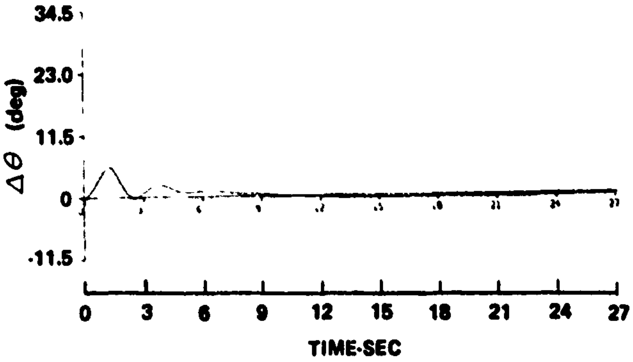
CONFIGURATION: 4

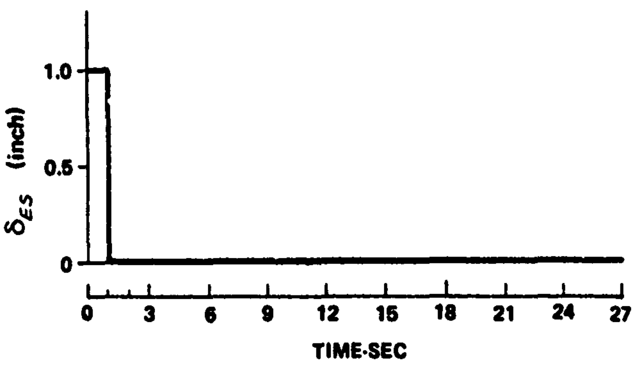
ω_{ST}/ζ_{ST} : 2.6/0.24

$2\zeta_{ST}\,\omega_{ST}$: 1.25







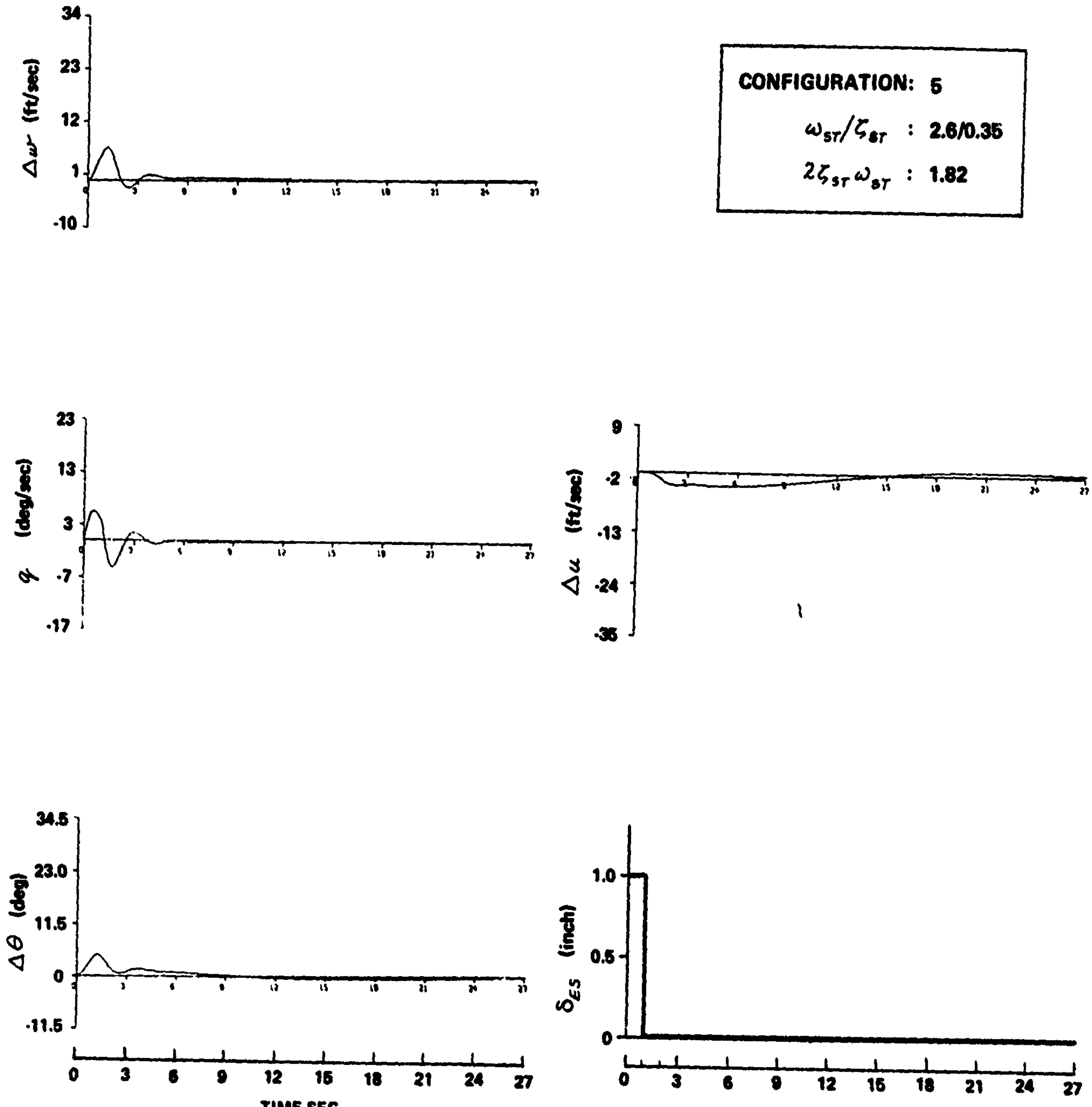


ω_{SP}/ζ_{SP}:	2.6/0.35	PILOT RATINGS:		CONFIGURATION:	5
$2\zeta_{SP}\omega_{SP}$:	1.82	VFR:	2B	V_T/γ:	65/-9
$M_{\delta_{ES}}$:	0.49	OVERALL:	1.5B	PILOT:	A
FLIGHT NO:	40F-24			WIND:	14

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Real nice.	Really fine.
FEEL CHARACTERISTICS:		Forces were nice and light, displacements small.
PITCH ATTITUDE CONTROL:	Very good, nicely coupled, initial response a little snappy but it's almost the way it should be. Predictable. Used stick for pitch attitude control.	Very good pitch attitude control, predictable final response.
VELOCITY CONTROL:	Excellent, used collective.	Very good, used a combination of collective and stick to correct errors.
APPROACH:		
PERFORMANCE:	Very good.	Quite good.
INTERCEPT AND TRACKING:		Good.
CONTROL TECHNIQUE:		Normal techniques, nothing special.
SIDESTEP MANEUVER:	Went very well.	
LEVEL OFF:		
TECHNIQUE:		With combination of real good attitude control and responsive collective control could stop the airplane as desired.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	Very little turbulence present and didn't seem to have much effect.	Not much of a factor.
SUMMARY COMMENTS:		
GOOD FEATURES:	Good pitch attitude control, no oscillations, good one-to-one correlation with the airplane.	Excellent longitudinal control.
OBJECTIONABLE FEATURES:	None.	None.

$\omega_{s\tau} / \zeta_{s\tau}$:	2.6/0.35	PILOT RATINGS:		CONFIGURATION:	5
$2\zeta_{s\tau}\omega_{s\tau}$:	1.82	VFR:	2C	V_T/γ :	65/-9
$M_{\delta_{es}}$:	0.54	OVERALL:	3E	PILOT:	A
FLIGHT NO:	42F-26			WIND:	15 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	No comments.	Good.
FEEL CHARACTERISTICS:		Good, forces and displacements small.
PITCH ATTITUDE CONTROL:	Airplane very nicely connected to the stick, initial response good, final response predictable using step type inputs to control attitude.	Attitude control through step-type inputs, good control over attitude.
VELOCITY CONTROL:	Good.	Speed varied 5-8 kts, but feel that turbulence is the cause, collective used.
APPROACH:		
PERFORMANCE:	Satisfactory.	Not outstanding but satisfactory.
INTERCEPT AND TRACKING:		Okay (localizer too sensitive.)
CONTROL TECHNIQUE:		Glide path: stick, speed and rate of descent: collective.
SIDESTEP MANEUVER:	No problem, must use collective to compensate for loss of lift.	
LEVEL OFF:		
TECHNIQUE:		Collective to arrest rate of descent.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Quite a bit more trouble IFR, primarily because of the turbulence.
EFFECTS OF TURBULENCE:	More effort required.	Quite an effect.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch control, well damped.	Pitch control good even in turbulence.
OBJECTIONABLE FEATURES:	None.	Turbulence response.



CONFIGURATION: 5
ω_{ST}/ζ_{ST} : 2.6/0.35
$2\zeta_{ST}\omega_{ST}$: 1.82
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

ω_{sr}/ζ_{sr}:	2.0/0.09	PILOT RATINGS:		CONFIGURATION:	6
$2\zeta_{sr}\omega_{sr}$:	0.36	VFR:	6.5F	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.32	OVERALL:	7F	PILOT:	A
FLIGHT NO.	39F-23			WIND:	11 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Not good.	Fair.
FEEL CHARACTERISTICS:		No objections.
PITCH ATTITUDE CONTROL:	Pitch input sets off oscillation, significantly increases difficulty of task. Moderately fast initial response. Final response major problem due to oscillations. Had to dampen response with additional pitch inputs.	Slow initial response, final response oscillatory.
VELOCITY CONTROL:	Not as good as desired, primarily because didn't have time to put emphasis on it.	No problems, tended to be fast on approach.
APPROACH:		
PERFORMANCE:	Okay.	Good.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUE:		Longitudinal control for glide path, collective for velocity.
SIDESTEP MANEUVER:	No problems, except pitch oscillation when levelling off.	
LEVEL OFF:		
TECHNIQUE:		Collective, then longitudinal control to dampen oscillations.
PROBLEMS:		
LANDING:		No.
DIFFERENCES IFR/VFR:		More difficult IFR because of large pitch attitude changes on approach.
EFFECTS OF TURBULENCE:	Sets off lightly damped oscillation.	
SUMMARY COMMENTS:		
GOOD FEATURES:	None	Glide path and localizer CONTROL were amazingly good.
OBJECTIONABLE FEATURES:	Slow initial response, and oscillatory final response.	Large pitch oscillations which are difficult to control.

ω_{sT}/ζ_{sT} :	2.0/0.09	PILOT RATINGS:		CONFIGURATION:	6
$2\zeta_{sT}\omega_{sT}$:	0.36	VFR:	6F	V_T/γ :	65/-9
$M_{\delta_{es}}$:	0.49	OVERALL:	7F	PILOT:	A
FLIGHT NO:	42F-26			WIND:	15 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Reasonable, not good but okay.	Only fair, difficult to tell in the face of oscillations.
FEEL CHARACTERISTICS:		Can feel the forces a lot when pumping the stick trying to damp out the fairly significant oscillations in pitch. In smooth air it's heavy but in turbulence when airplane oscillates it's too light.
PITCH ATTITUDE CONTROL:	Initial response comes along real fast but airplane oscillates quite a bit and is therefore not too predictable. Pulsing the controls quite a bit trying to act like a damper.	Initial response slow or fast depending on presence of gusts. Final response quite unpredictable, because of oscillatory nature of response.
VELOCITY CONTROL:	Collective used.	Collective used, still acceptable even with all the oscillations in pitch attitude.
APPROACH:		
PERFORMANCE:	Pretty good even though the airplane oscillated all the way down the approach.	Not really satisfactory.
INTERCEPT AND TRACKING:		Okay but not very comfortable.
CONTROL TECHNIQUE:		Glide path, tended to forget the oscillations and let the airplane go and control glide path and localizer as best I could -- tended to use collective for glide path control.
SIDESTEP MANEUVER:	Accomplished but had fairly significant pitch attitude oscillations.	
LEVEL OFF:		
TECHNIQUE:		
PROBLEMS:		No problems arresting rate of descent but controlling pitch attitude was ridiculous.
LANDING?:		No.
DIFFERENCES IFR/VFR:		No comments.
EFFECTS OF TURBULENCE:	Turbulence really gets to this one, aircraft oscillates quite a bit.	Really batters this airplane.
SUMMARY COMMENTS:		
GOOD FEATURES:	Initial response in pitch okay.	None.
OBJECTIONABLE FEATURES:	Pitch oscillation is major objection and inability to predict final response.	Quite large and significant pitch oscillations in turbulence.

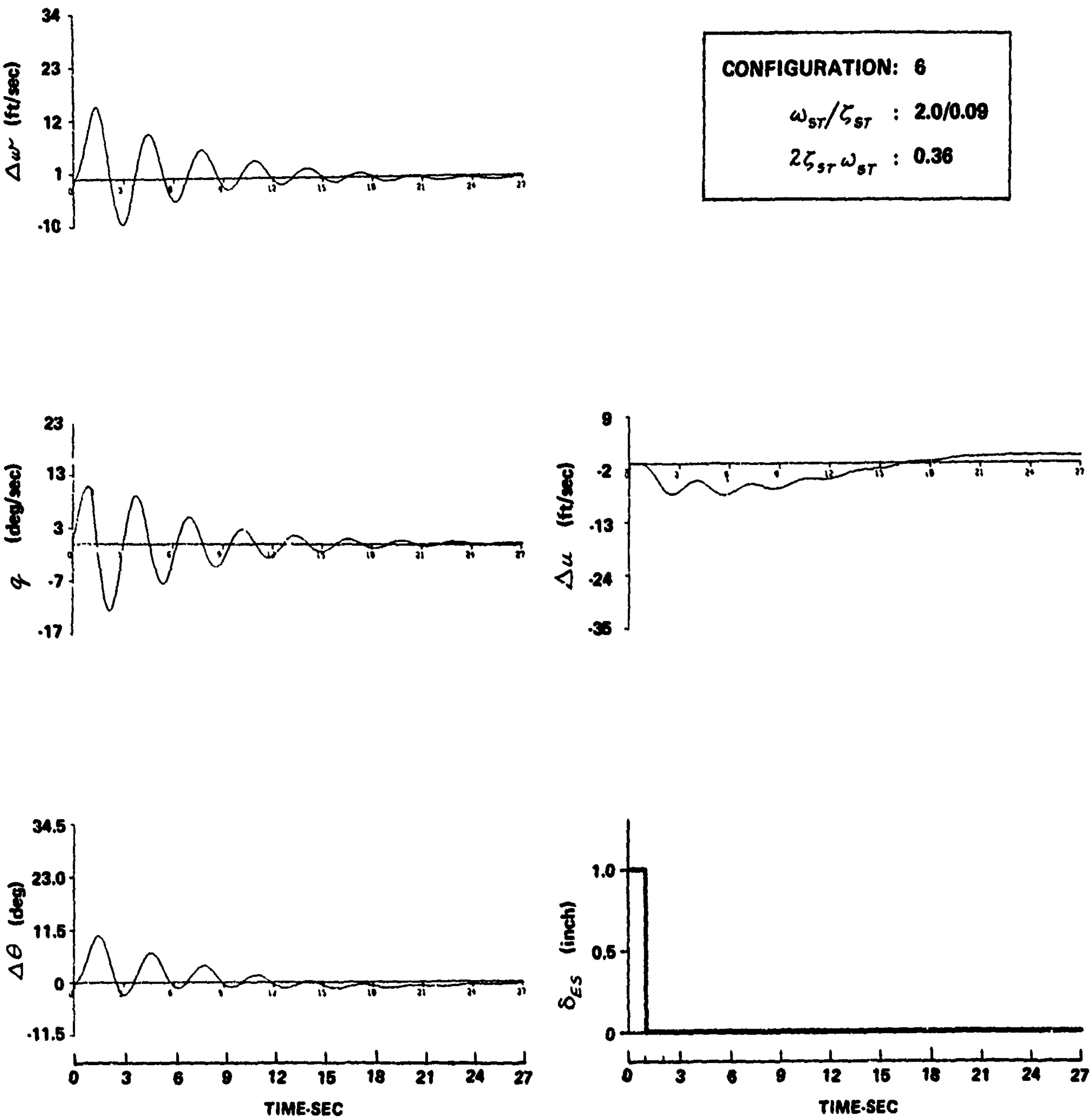
ω_{s_T}/ζ_{s_T} :	2.0/0.09	PILOT RATINGS:		CONFIGURATION:	6
$2\zeta_{s_T}\omega_{s_T}$:	0.36	VFR:	5B	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.44	OVERALL:	6B	PILOT:	A
FLIGHT NO.:	48F-29			WIND:	06

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Reasonably good.	Surprisingly good in the face of pitch oscillations.
FEEL CHARACTERISTICS:		No problem.
PITCH ATTITUDE CONTROL:	Not too bad. Initial response, really takes off. Final response lightly damped but stops close to desired attitude.	Really wants to take off and set up a fairly large oscillation with any input. Oscillations are uncomfortable but eventually settles down and can predict where it's going to be.
VELOCITY CONTROL:	Reasonably good in spite of real steep descent (2000 fpm)	A problem but felt it was due to poor intercept.
APPROACH:		
PERFORMANCE:	High all the way, no real feel for ability to make small corrections.	Not really good, not satisfactory, not acceptable.
INTERCEPT AND TRACKING:		
CONTROL TECHNIQUE:		Tend to use collective to control rate of descent and not stick because of tendency to oscillate which deteriorated the performance.
SIDESTEP MANEUVER:	No real problem.	
LEVEL OFF:		
TECHNIQUE:		Used collective.
PROBLEMS:		None.
LANDING?:		No, pitch control not good enough to land.
DIFFERENCES IFR/VFR:		Primarily pilot's proficiency, more tendency to bobble IFR. Changing VFR rating to a 5 from a 4.
EFFECTS OF TURBULENCE:	Very little turbulence present.	None present.
SUMMARY COMMENTS:		
GOOD FEATURES:	None given.	Could get the approach done.
OBJECTIONABLE FEATURES:	Airplane takes off in pitch but feel that job can be done.	Large pitch attitude changes and the fact that the airplane oscillates almost continuously.

CONFIGURATION: 6

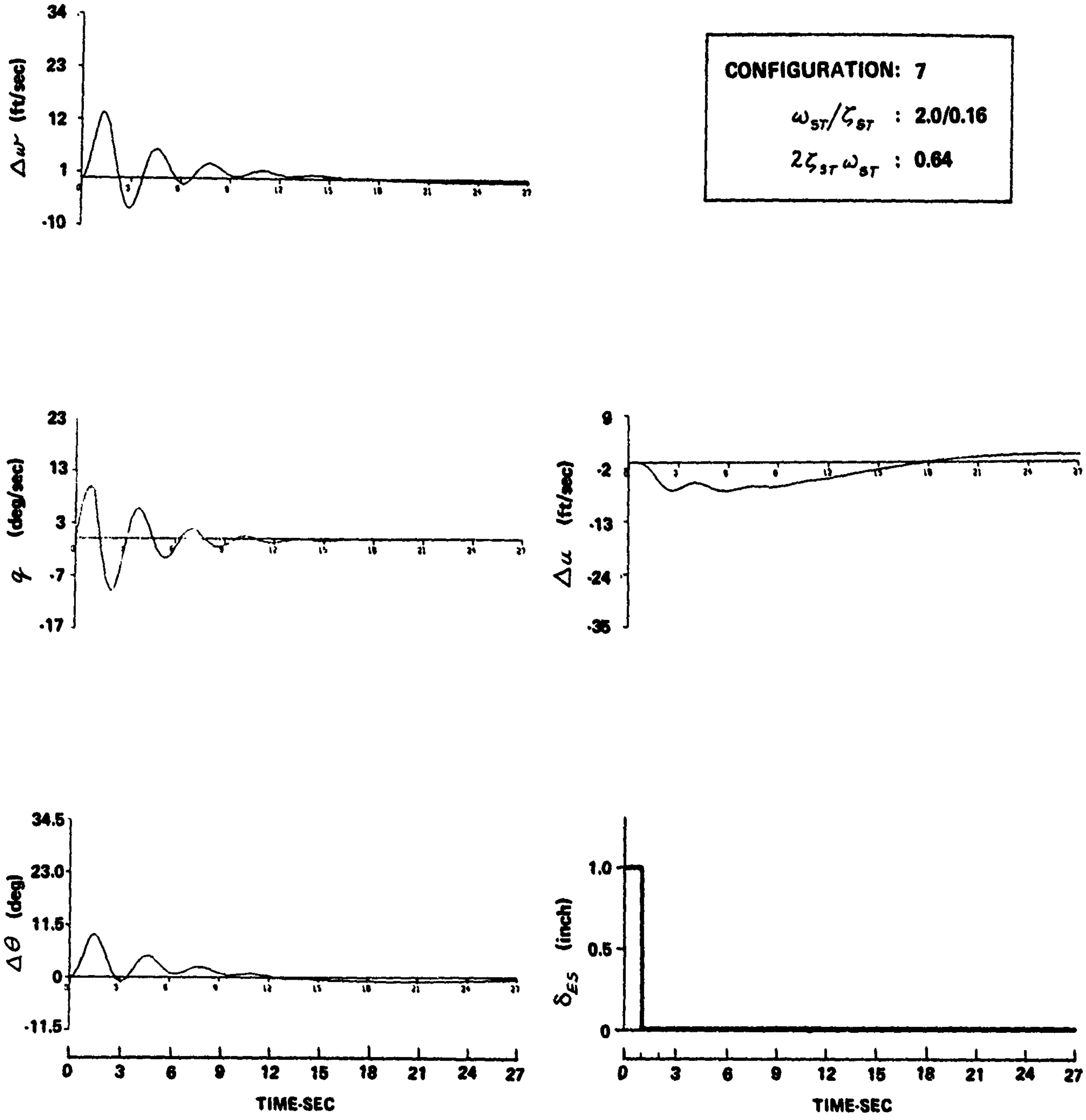
ω_{ST}/ζ_{ST} : 2.0/0.09

$2\zeta_{ST}\omega_{ST}$: 0.36



ω_{ST} / ζ_{ST} :	2.0/0.16	PILOT RATINGS:		CONFIGURATION:	7
$2\zeta_{ST}\omega_{ST}$:	0.64	VFR:	5E	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.33	OVERALL:	6F	PILOT:	A
FLIGHT NO:	50F-30			WIND:	14 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Okay.	Only fair.
FEEL CHARACTERISTICS:		Noticeable but not objectionable.
PITCH ATTITUDE:	Initial response a little slow, then takes off a bit and sets up fairly noticeable pitch oscillation - not predictable.	Initial response unpredictable, depends on turbulence inputs strongly. Final response a problem. Much stick pumping required.
VELOCITY CONTROL:	Good, used collective, which was one of the better parts of the airplane.	
APPROACH:		
PERFORMANCE:	Didn't really have very fine control of the airplane because the pitch changes were quite dramatic - didn't like it.	Acceptable but not satisfactory.
INTERCEPT AND TRACKING:		
CONTROL TECHNIQUE:		Stick for attitude control, collective for speed but considerable problems with pitch attitude control - wouldn't stay on new attitude.
SIDESTEP MANEUVER:	Accomplished reasonably well in spite of pitch oscillations.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		No real problem, although airplane does pitch noticeably with a collective input and set off oscillation.
LANDING:		No.
DIFFERENCES IFR/VFR:		More difficult IFR because of poor predictability, revise VFR rating from a 6 to a 5.
EFFECT OF TURBULENCE:	Really a mess with this configuration.	Really a problem.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	None.
OBJECTIONABLE FEATURES:	Airplane has a mind of its own and oscillates with quite large pitch attitude changes.	Unpredictability of the initial and final response of pitch attitude.


CONFIGURATION: 7
ω_{ST}/ζ_{ST} : 2.0/0.16
$2\zeta_{ST}\omega_{ST}$: 0.64
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sr}/ζ_{sr} :	2.0/0.23	PILOT RATINGS:		CONFIGURATION:	8
$2\zeta_{sr}\omega_{sr}$:	0.92	VFR:	2B	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.44	OVERALL:	3B	PILOT:	A
FLIGHT NO:	41F-25			WIND:	08

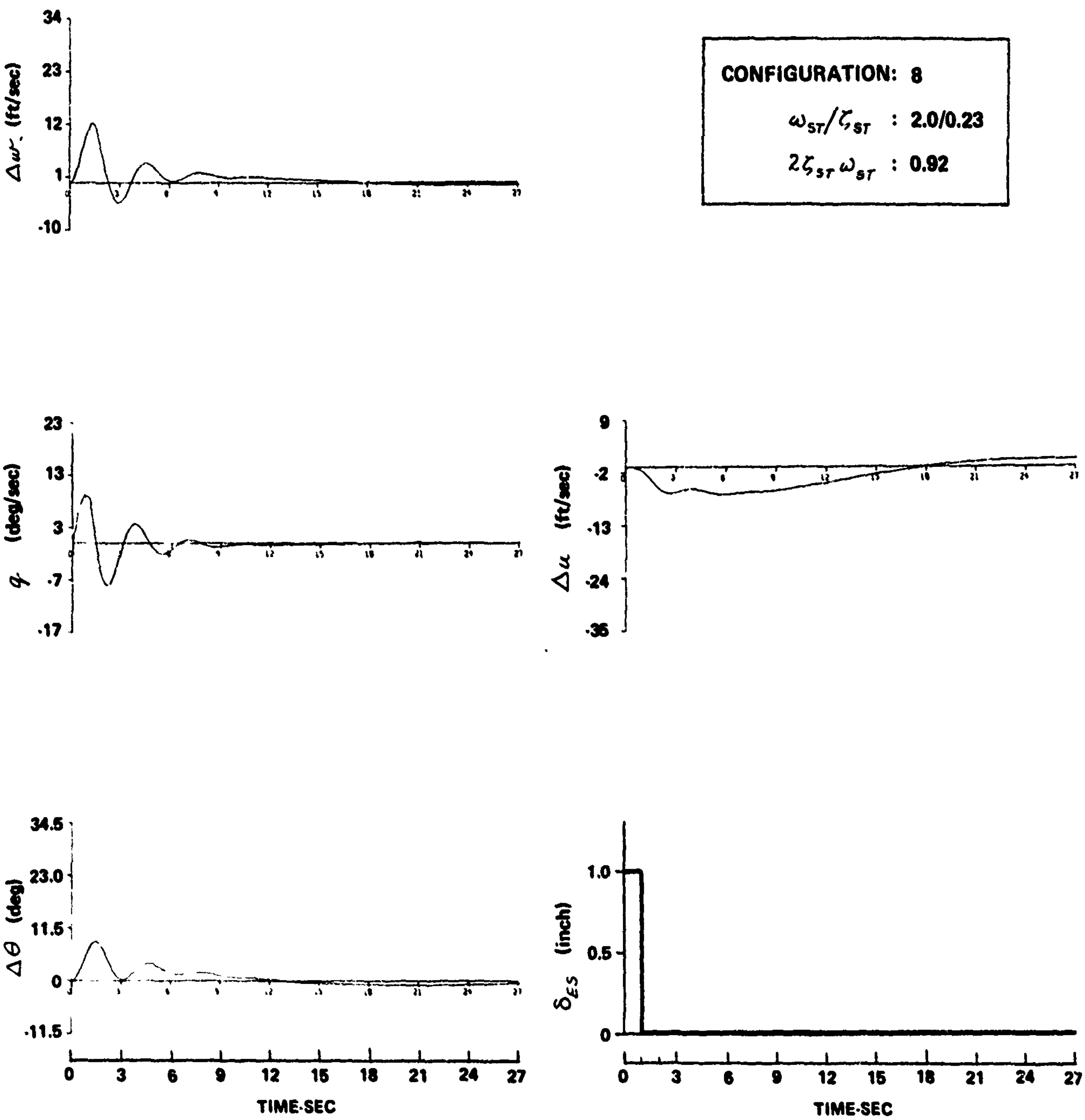
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Reasonably good.	Pretty good.
FEEL CHARACTERISTICS:		Forces light, displacements small.
PITCH ATTITUDE CONTROL:	Good initial response, final response a little lightly damped but wasn't a problem on approach.	Good initial response with small problem in predicting final response because of slight tendency to bobble.
VELOCITY CONTROL:	Good.	Pretty good.
APPROACH:		
PERFORMANCE:	Difficult to see approach aid, otherwise no problems noted.	Glide path control not very difficult.
INTERCEPT AND TRACKING:		Localizer too sensitive.
CONTROL TECHNIQUE:		Stick for pitch attitude, collective for speed.
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		Collective to arrest rate of descent.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Not as good IFR because predictability of attitude response reduced.
EFFECTS OF TURBULENCE:	No problems.	No significant deterioration.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pleasant quick response with reasonable predictability.	Velocity control, initial response in pitch attitude good.
OBJECTIONABLE FEATURES:	Slight tendency to bobble in pitch but not badly.	Tendency to bobble in pitch when trying to achieve desired attitude.

ω_{sT}/ζ_{sT} :	2.0/0.23	PILOT RATINGS:		CONFIGURATION:	8
$2\zeta_{sT}\omega_{sT}$:	0.92	VFR:	2D	V_T/γ :	65/-6
$M_{\delta_{ES}}$:	0.39	OVERALL:	2.5D	PILOT:	A
FLIGHT NO:	51F-31			WIND:	17 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Pretty good.	No problem.
FEEL CHARACTERISTICS:		Good.
PITCH ATTITUDE CONTROL:	Pretty good, predictable, no problems.	Initial response okay, final okay.
VELOCITY CONTROL:	Good, used collective.	Satisfactory, used collective.
APPROACH:		
PERFORMANCE:	Very good.	Good glide path control, no problems.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		No comments.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	No problem, controllable.	Really bounced aircraft around.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch attitude control.	Good pitch control, easy.
OBJECTIONABLE FEATURES:	Turbulence response, although easily controlled.	None, except for turbulence.

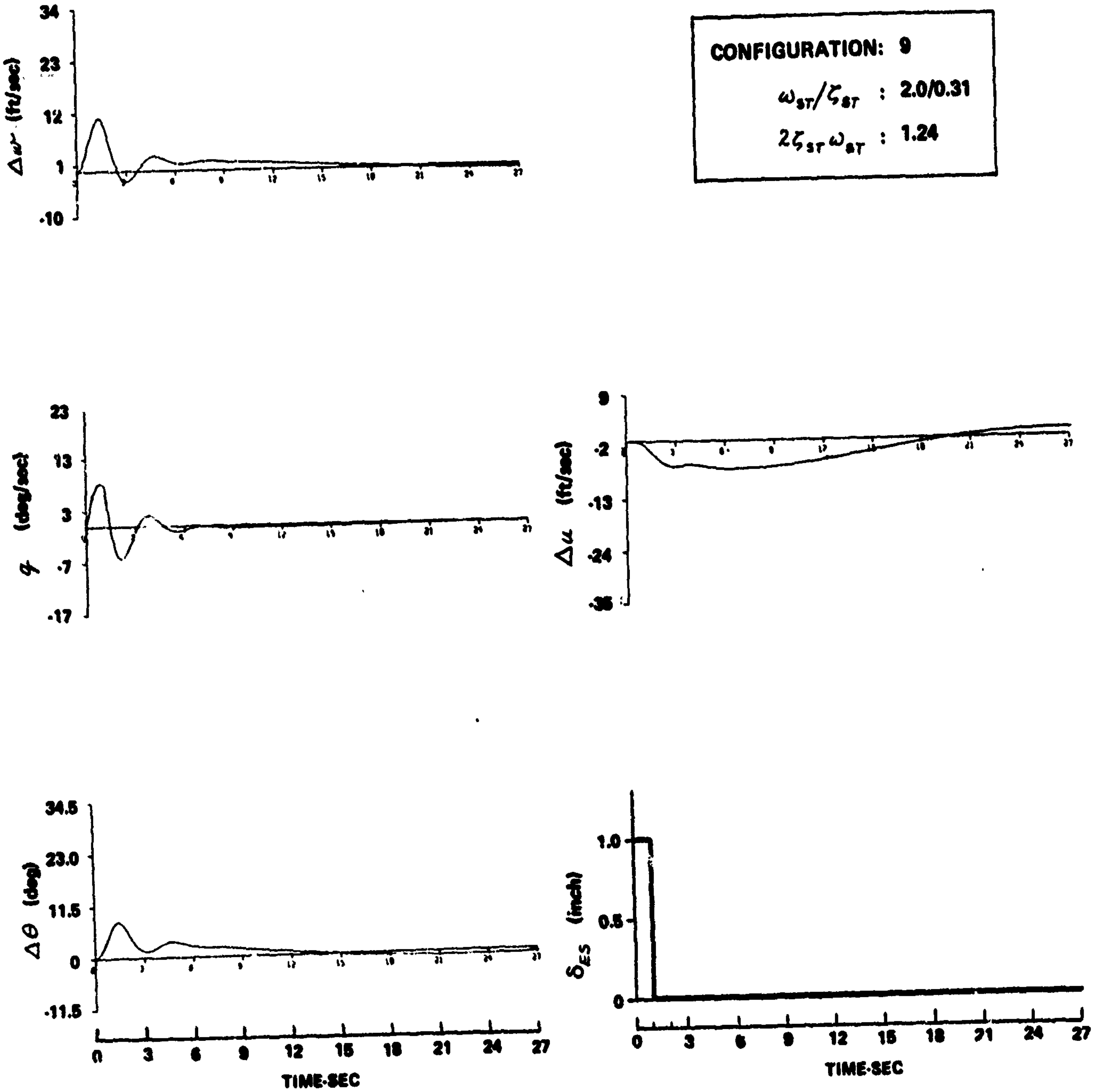
ω_{ST} / ζ_{ST} :	2.0/0.23	PILOT RATINGS:		CONFIGURATION:	8
$2\zeta_{ST}\omega_{ST}$:	0.92	VFR:	4D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.39	OVERALL:	4D	PILOT:	B
FLIGHT NO:	54F-33			WIND:	15 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	No problem at all.	No problem.
FEEL CHARACTERISTICS:		Displacements too high, forces light.
PITCH ATTITUDE CONTROL:	Pitch control seems a little delayed. Initial response a little slow, final response not too bad. Have to overdrive input a bit.	No trouble in getting the desired attitude but have trouble tracking when making corrections in both axes.
VELOCITY CONTROL:	Not too bad, used collective, satisfactory.	
APPROACH:		
PERFORMANCE:	Okay.	Not good, difficulties with localizer lead to glide path problems, unsatisfactory.
INTERCEPT AND TRACKING:		Glide path okay but localizer poor.
CONTROL TECHNIQUE:		
SIDESTEP MANEUVER:	Crosswind a bit of a problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		No but because of poor approach performance.
DIFFERENCES IFR/VFR:		No.
EFFECTS OF TURBULENCE:	Most noticeable in lateral directional.	No comments.
SUMMARY COMMENTS:		
GOOD FEATURES:	Ability to trim steady-state, pitch control.	Trimmability and ability to establish rates of descent. Airspeed control.
OBJECTIONABLE FEATURES:	Somewhat sluggish, didn't like force/displacement combination.	Little bit sluggish, localizer sensitivities.


CONFIGURATION: 8
ω_{ST}/ζ_{ST} : 2.0/0.23
$2\zeta_{ST}\omega_{ST}$: 0.92
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sr} / ζ_{sr} :	2.0/0.31	PILOT RATINGS:		CONFIGURATION:	9
$2\zeta_{sr}\omega_{sr}$:	1.24	VFR:	3B	V_T/γ :	65/-9
$M_{\delta_{es}}$:	0.49	OVERALL:		PILOT:	A
FLIGHT NO:	401-24			WIND:	13

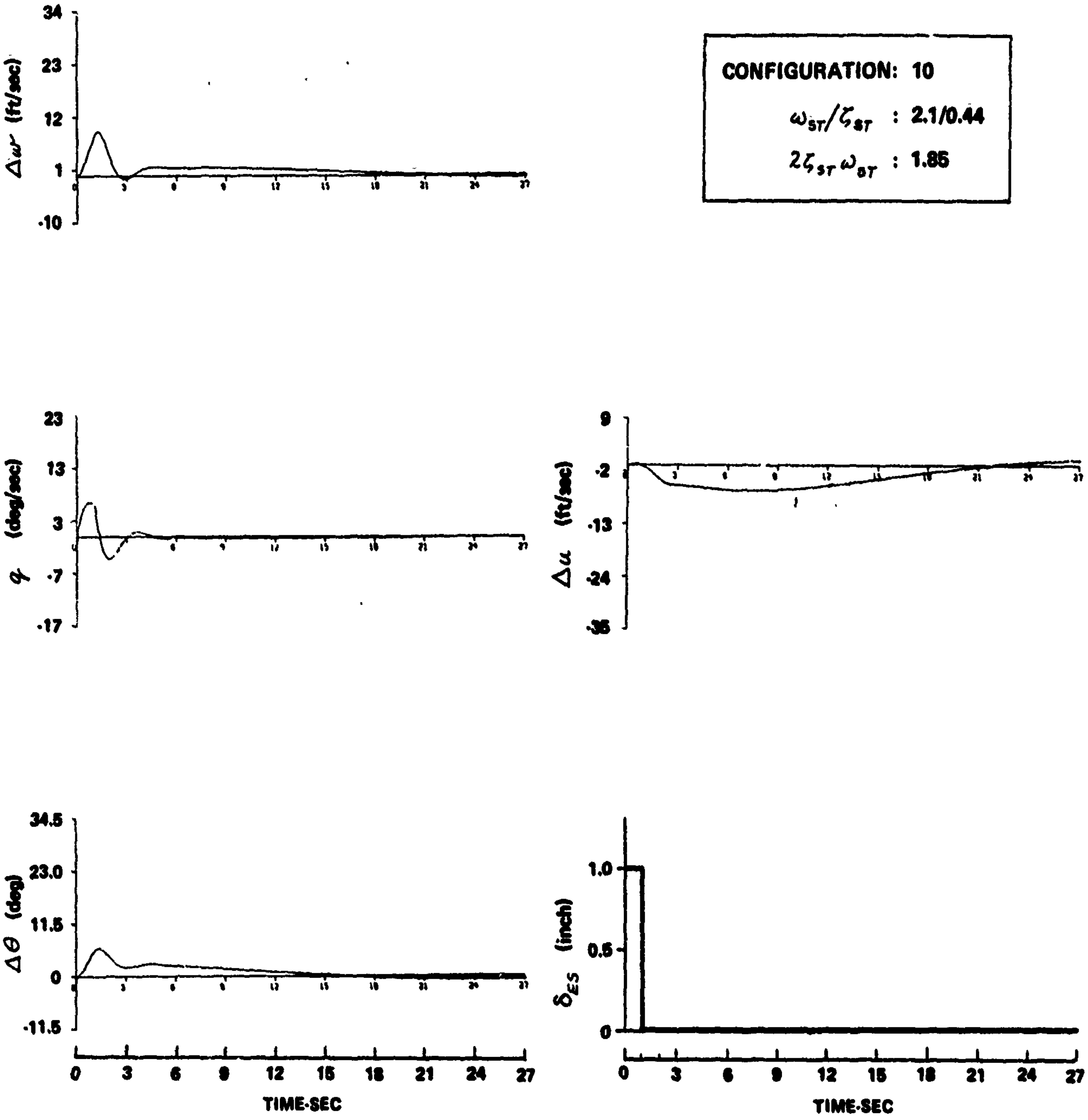
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Not too bad.	Not done
FEEL CHARACTERISTICS:		
PITCH ATTITUDE CONTROL:	Satisfactory initial and final response. Stick for pitch attitude control.	
VELOCITY CONTROL:	Pretty good, used collective.	
APPROACH:		
PERFORMANCE:	Not good but control of airplane was good.	
INTERCEPT AND TRACKING:		
CONTROL TECHNIQUE:		
SIDESTEP MANEUVER:	No special problems.	
LEVEL OFF:		
TECHNIQUE:		
PROBLEMS:		
LANDING?:		
DIFFERENCES IFR/VFR:		
EFFECTS OF TURBULENCE:	No significant deterioration in performance.	
SUMMARY COMMENTS.		
GOOD FEATURES:	Good pitch attitude control.	
OBJECTIONABLE FEATURES:	Could be a little faster responding with a more one-to-one correlation but not a major objection.	



CONFIGURATION: 9
ω_{ST}/ζ_{ST} : 2.0/0.31
$2\zeta_{ST}\,\omega_{ST}$: 1.24
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST} / ζ_{ST} :	2.1/0.44	PILOT RATINGS:		CONFIGURATION:	10
$2\zeta_{ST}\omega_{ST}$:	1.85	VFR:	3C	V_T / γ :	65/-9
$M_{\delta_{ES}}$:	0.41	OVERALL:	2.5C	PILOT:	A
FLIGHT NO:	36F-21			WIND:	10

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM	Very good.	Pretty good.
FEEL CHARACTERISTICS		More noticeable (than VFR) because I'm having to work the aircraft, notice turbulence.
PITCH ATTITUDE CONTROL:	Aircraft very well connected stick in one-to-one fashion. Pretty good, predictable. Used nose for glide path control.	Very good. Initial response -- aircraft moves as soon as I put in input. Final response seems well damped: it stops where I want it. Worked attitude control more than collective
VELOCITY CONTROL	Good. Started out fast but could correct it nicely.	Good in general, a little fast and high starting out. Satisfactory.
APPROACH:		
PERFORMANCE:	Pretty good. Making corrections on glide path no problem. Used combination of collective and stick to put aircraft where desired. Quite satisfactory performance.	No comments.
INTERCEPT AND TRACKING:		Pretty good, even though we started too close in. Problem is lateral-directional -- getting localizer settled down. Glide slope control pretty good.
CONTROL TECHNIQUE:		Combination of collective and stick to get control of aircraft
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None. Ability to stop good. No oscillations.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		No real differences. Stronger concentration on heading control IFR. Keep trying to do things about turbulence-caused motion that don't seem to be necessary.
EFFECTS OF TURBULENCE:	Did affect aircraft. Disturbances in pitch easily corrected.	Airplane bobbles around itself. Increases workload, but with these characteristics it wasn't difficult to handle.
SUMMARY COMMENTS:		
GOOD FEATURES:	One-to-one correlation between the nose and stick. Velocity control.	Pitch control and velocity control were quite good.
OBJECTIONABLE FEATURES:	No real bad ones. Response to turbulence more than I would like.	No real bad ones. Minor one is that aircraft bobs around like a cork.


CONFIGURATION: 10
ω_{ST}/ζ_{ST} : 2.1/0.44
$2\zeta_{ST}\omega_{ST}$: 1.85
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

ω_{sT}/ζ_{sT} :	1.5/0.09	PILOT RATINGS:		CONFIGURATION:	11
$2\zeta_{sT}\omega_{sT}$:	0.27	VFR:	6D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.34	OVERALL:	6F	PILOT:	A
FLIGHT NO:	38F-22			WIND:	20 (M)

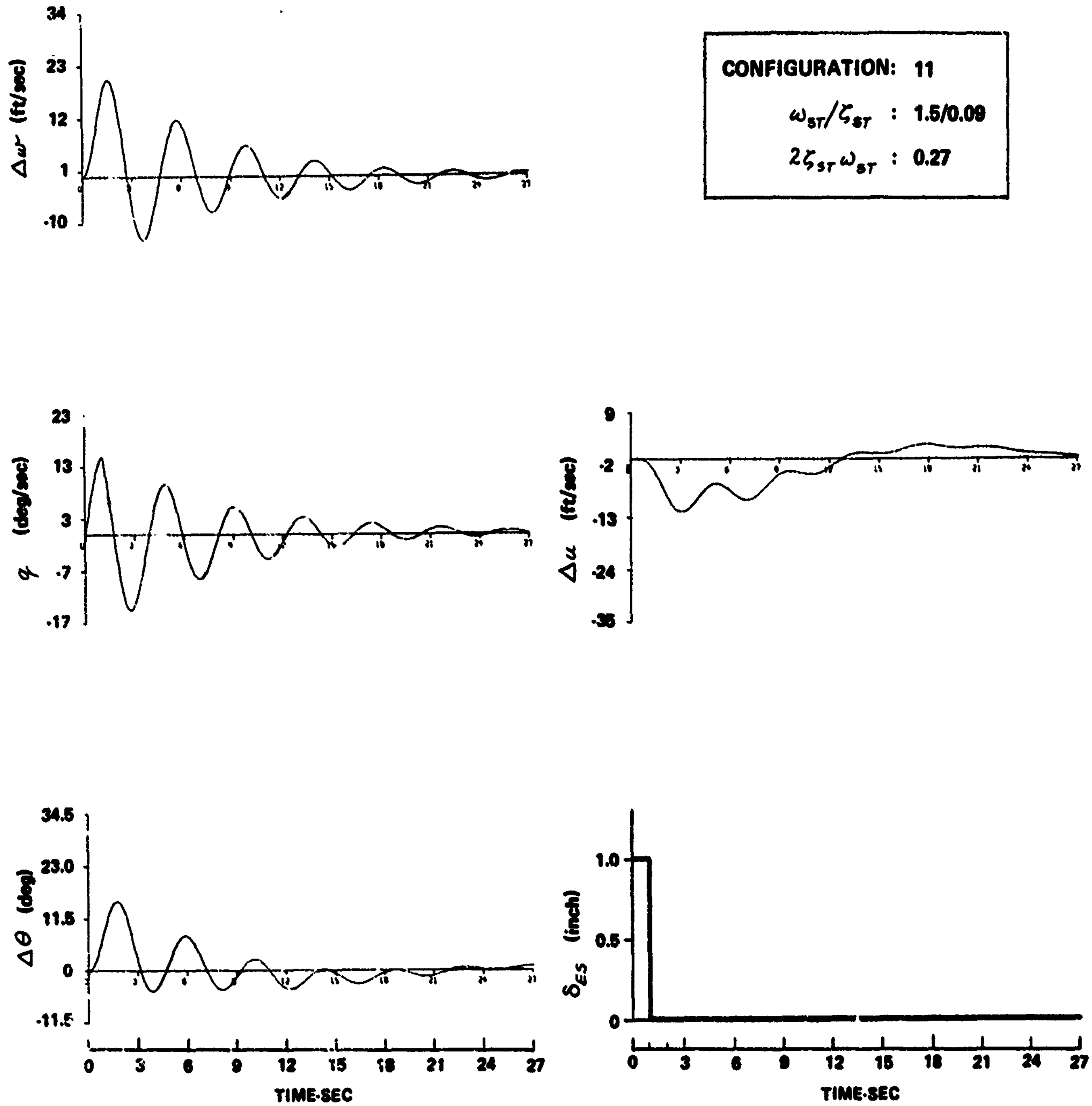
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Fair -- somewhat slow responding, but stays at trim.	Somewhat worse under IFR than VFR.
FEEL CHARACTERISTICS:		Forces light, displacements small.
PITCH ATTITUDE CONTROL:	Not as good as wanted. Nose comes along slowly, followed by 1 or 3 cycle oscillation. Initial response slow. Final response predictable but too slow. Have to overdrive input and then take it out.	Biggest problem. Large attitude changes as a result of slow initial response and inability to stop nose. Put in input, wait for response, then two or three attempts to get nose were desired.
VELOCITY CONTROL:	Not as good as wanted: acceptable but not satisfactory.	Not satisfactory.
APPROACH:		
PERFORMANCE:	Pretty good.	Pretty good.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No special problems, can stop rate of descent.	
LEVEL OFF:		
TECHNIQUE:		Collective control to stop, stick to correct nose.
PROBLEMS:		Significant pitch due to collective.
LANDING?:		Marginal.
DIFFERENCES IFR/VFR:		Attitude more difficult IFR
EFFECTS OF TURBULENCE:	Bobbles around a lot.	Bobbles, oscillates. Difficult to separate out pilot inputs from turbulence inputs.
SUMMARY COMMENTS:		
GOOD FEATURES:	Could fly aircraft, go where desired.	Could do job, could control rate of descent, had good ILS approach.
OBJECTIONABLE FEATURES:	Slow pitch response. additional 2 or 3 inputs to stop nose.	Slow response, somewhat of a PIO tendency, aircraft has mind of its own.

ω_{ST} / ζ_{ST} :	1.5/0.09	PILOT RATINGS:		CONFIGURATION:	11
$2\zeta_{ST}\omega_{ST}$:	0.27	VFR:	6D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.33	OVERALL:	8D	PILOT:	A
FLIGHT NO.	48F-29			WIND:	12

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Reasonably good in spite of light damping.	
FEEL CHARACTERISTICS:		
PITCH ATTITUDE CONTROL:	Comes along initially and then has a fairly large overshoot - quite difficult to predict-very difficult to control oscillations following an input.	Interesting record close to the ground-oscillation felt almost divergent. Initial response okay but final response difficult to predict and large oscillations present. Considerable pumping of the stick to try and dampen oscillations.
VELOCITY CONTROL:	Got away because much attention was required to keep the attitude oscillations from getting too large but still acceptable.	Not satisfactory, got quite high, because of attention required for pitch control.
APPROACH:		
PERFORMANCE:	Not too bad but uncomfortable - could get the job done.	Not even acceptable.
INTERCEPT AND TRACKING:		Good start.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	Lateral okay but trying to level aircraft out often sidestep got into a PIO.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		Could stop rate of sink okay, but the aircraft wants to oscillate badly in pitch - very, very uncomfortable.
LANDING?:		No.
DIFFERENCES IFR/VFR:		More difficult IFR because of poor ability to dampen out oscillations.
EFFECTS OF TURBULENCE:	Very little present but what is there causes problems.	Very little but enough to give a moderate deterioration.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	None.
OBJECTIONABLE FEATURES:	Have to fight the pitch oscillations constantly.	Real large pitch oscillations, too much attention required to control.

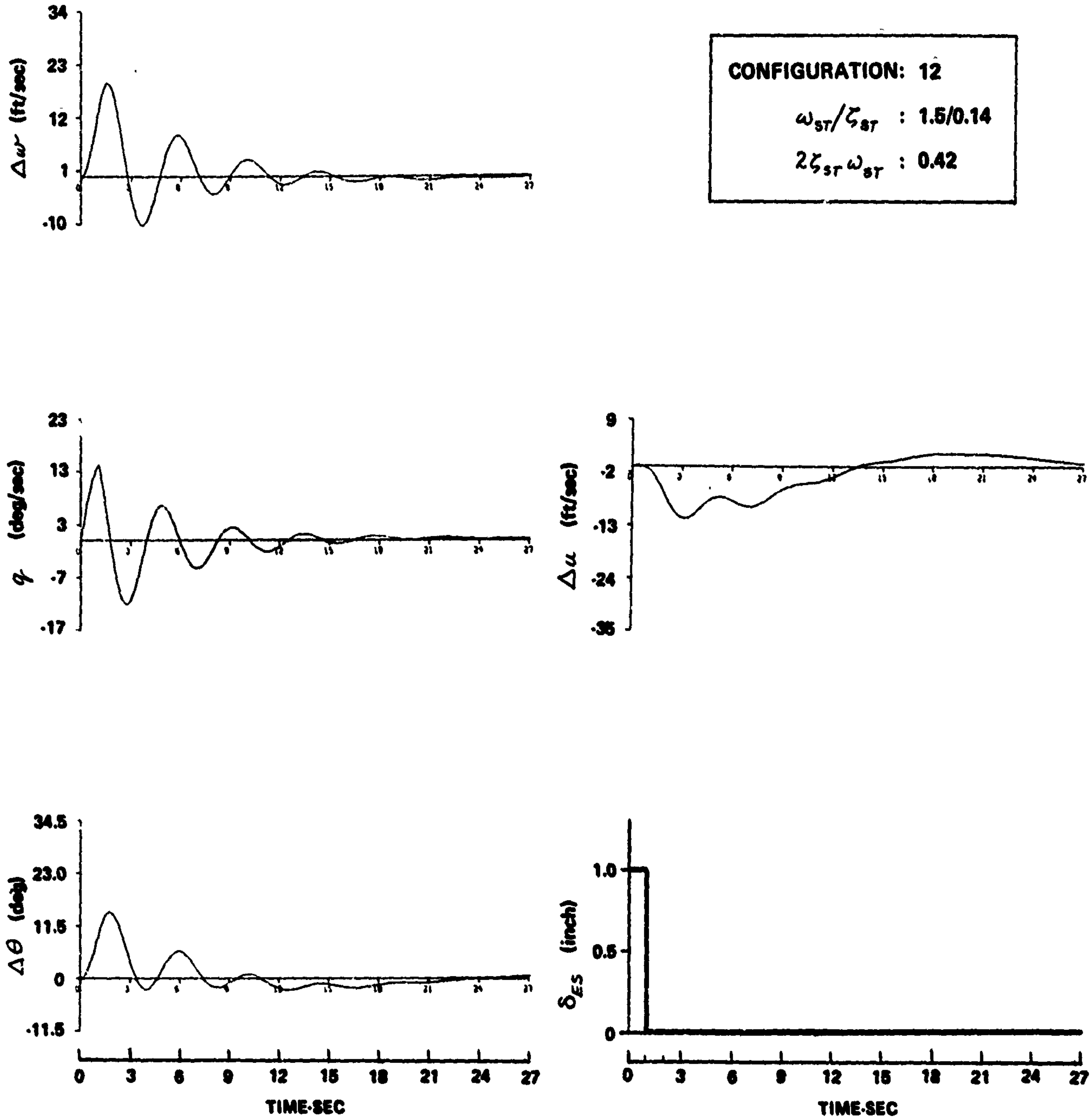
ω_{sr}/ζ_{sr}:	1.[illegible] .0[illegible]	PILOT RATING:		CONFIGURATION:	11
$2\zeta_{sr}\omega_{sr}$:	[illegible] 7		7F	V_T/γ :	65/-6
$M_{\delta_{es}}$:	0.[illegible]	OVERALL	8F	PILOT:	A
FLIGHT NO:	51F-31			WIND:	20 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Ability to trim is practically negligible.	Very poor.
FEEL CHARACTERISTICS:		Noticeable because must fight the airplane continuously.
PITCH ATTITUDE CONTROL:	Put in an input, then immediately go to damping it out with the stick and the airplane is one continuous oscillation which is very objectionable. Final response very unpredictable. Ridiculous pilot inputs required.	Practically zero because of oscillations. Initial and final response both oscillatory.
VELOCITY CONTROL:		Poor, no time to devote to it. Fast most of the time.
APPROACH:		
PERFORMANCE:	Not good because of oscillatory characteristics.	Not satisfactory, very bad close in.
INTERCEPT AND TRACKING:		Easy with lower glide path.
CONTROL TECHNIQUES:		Ride out oscillations.
SIDESTEP MANEUVER:	Lateral okay, strong crosswind, but longitudinal control a problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		No.
DIFFERENCES IFR/VFR:		Pitch oscillations a real problem IFR.
EFFECTS OF TURBULENCE:	Really influences the flying qualities of this machine.	Really gets to this airplane and makes it bobble and oscillate even more than it already is.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	None.
OBJECTIONABLE FEATURES:	Continuous pitch oscillations are a bit on the ridiculous side. Turbulence response.	Continuous pitch oscillations in and out of turbulence. Really don't like it.


CONFIGURATION: 11
ω_{ST}/ζ_{ST} : 1.5/0.09
$2\zeta_{ST}\omega_{ST}$: 0.27
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

ω_{ST} / ζ_{ST} :	1.5/0.14	PILOT RATINGS:		CONFIGURATION:	12
$2\zeta_{ST}\omega_{ST}$:	0.42	VFR:	4D	V_T/γ :	65/-9
$M_{\delta_{BS}}$:	0.39	OVERALL:	6E	PILOT:	A
FLIGHT NO:	50F-30			WIND:	15 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Reasonable, fair.	Still only fair.
FEEL CHARACTERISTICS:		Noticeable because of large continuous forces required but acceptable.
PITCH ATTITUDE CONTROL:	Initial response a little slow, then picks up and get 3 or 4 oscillations, so final response not predictable. Oscillatory.	Initial response sometimes unpredictable final response not as predictable as desired.
VELOCITY CONTROL:	Okay, got away a little bit.	Got to be a problem, got away a couple of times and felt uncomfortable.
APPROACH:		
PERFORMANCE:	Tracking was good until near the end.	Not very good, glide path control degraded close in-unsatisfactory.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUES:		No comments.
SIDESTEP MANEUVER:	Smart pitch up with collective started oscillations in pitch.	
LEVEL OFF:		
TECHNIQUE:		
PROBLEMS:		Can be done but get an uncomfortable pitch up with collective input.
LANDING?:		
DIFFERENCES IFR/VFR:		Much more difficult IFR.
EFFECTS OF TURBULENCE:	Large effect, bobbles in pitch.	Really a problem.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	None.
OBJECTIONABLE FEATURES:	Slow pitch response and the oscillations.	Did not have fine control of pitch attitude - almost got away a couple of times. Rating probably lenient.


CONFIGURATION: 12
ω_{ST}/ζ_{ST} : 1.5/0.14
$2\zeta_{ST}\omega_{ST}$: 0.42
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sr}/ζ_{sr}:	1.7/0.34	PILOT RATINGS:		CONFIGURATION:	13
$2\zeta_{sr}\omega_{sr}$:	1.16	VFR:	2B	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.36	OVERALL:	2B	PILOT:	A
FLIGHT NO:	41F-25			WIND:	05

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Good.
FEEL CHARACTERISTICS:		Good, forces and displacements are small.
PITCH ATTITUDE CONTROL:	Initial and final response satisfactory, like the pitch control.	Good initial response, quite predictable.
VELOCITY CONTROL:	Collective used, good control.	Quite good, used collective.
APPROACH:		
PERFORMANCE:	Quite good.	Good.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		Collective to arrest rate of descent, stick for desired attitude and speed.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		None.
EFFECT OF TURBULENCE:	None.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch control.	Pitch attitude control very good.
OBJECTIONABLE FEATURES:	None.	None.

ω_{sr} / ζ_{sr} :	1.7/0.034	PILOT RATINGS:		CONFIGURATION:	13
$2\zeta_{sr}\omega_{sr}$:	1.16	VFR:	4E	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.39	OVERALL:	3E	PILOT:	A
FLIGHT NO:	42F-26			WIND:	12 (M)

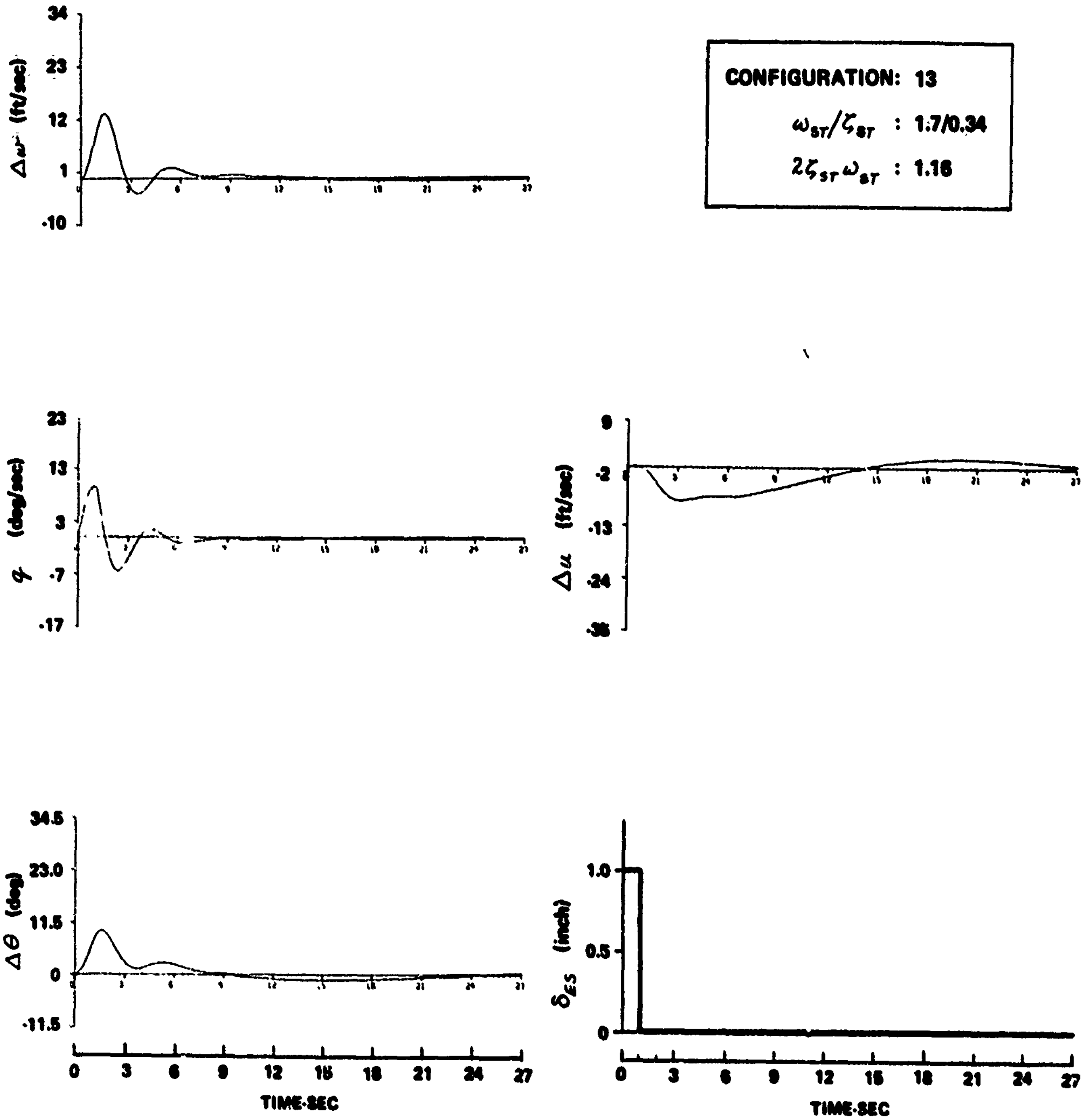
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	No problem.	No problem.
FEEL CHARACTERISTICS:		Good.
PITCH ATTITUDE CONTROL:	Seems to be delayed a tiny bit, confusing, comes along faster once started. Final response predictable. Must use small pulse to stop the nose where desired but not difficult to do.	Attitude control pretty good, slight hesitation; final response relatively predictable. Must put the input in, start it out, then back off to stop it.
VELOCITY CONTROL:	Collective control used.	Collective used, can't keep it any closer than within 3-5 kts.
APPROACH:		
PERFORMANCE:	Good.	Good attitude and rate of descent control. Satisfactory.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUE:		
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Collective for rate of descent, stick to maintain desired attitude and speed.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Better time of it IFR, perhaps due to less turbulence response.
EFFECTS OF TURBULENCE:	Really a problem.	Real problem, airplane bobbling around like a cork.
SUMMARY COMMENTS:		
GOOD FEATURES:	None given.	Ability to control glide path.
OBJECTIONABLE FEATURES:	Can't stop the nose exactly where desired, slight hesitation in pitch response.	Slight hesitation in pitch response, must make an effort to stop the nose once it starts.

ω_{ST}/ζ_{ST}:	1.7/0.034	PILOT RATINGS:		CONFIGURATION:	13
$2\zeta_{ST}\omega_{ST}$:	1.16	VFR:	3.5D	V_T/γ :	65/-6
$M_{\delta_{ES}}$:	0.36	OVERALL:	3E	PILOT:	A
FLIGHT NO:	51F-31			WIND:	10 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Okay.	Good.
FEEL CHARACTERISTICS:		No problem.
PITCH ATTITUDE CONTROL:	Really pretty good. Initial response pretty good, predictability of final response could be better. Using step-type inputs.	Initial response and final response okay. Fly the airplane kind of in steps.
VELOCITY CONTROL:		A problem because of turbulence.
APPROACH:		
PERFORMANCE:	Not too bad.	Good most of the way down, satisfactory, turbulence a problem, particularly laterally.
INTERCEPT AND TRACKING:		
CONTROL TECHNIQUE:		Attitude for glide path will stick and collective for velocity.
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Smoother IFR.
EFFECTS OF TURBULENCE:	Whole airplane really bobbles around in turbulence.	Really beating us today.
SUMMARY COMMENTS:		
GOOD FEATURES:	Reasonable control of pitch attitude.	Can do a pretty good job with pitch attitude control.
OBJECTIONABLE FEATURES:	Like a little finer control in pitch.	Center mostly around turbulence. A minor objection: airplane is a little slower stopping in final steady state than desired.

ω_{sr}/ζ_{sr} :	1.7/0.34	PILOT RATINGS:		CONFIGURATION:	13
$2\zeta_{sr}\omega_{sr}$:	1.16	VFR:	3C	V_T/γ :	65/-9
$M_{\delta_{es}}$:	0.32	OVERALL:	3C	PILOT:	B
FLIGHT NO:	54F-33			WIND:	17 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Okay.
FEEL CHARACTERISTICS:		Displacements a little large.
PITCH ATTITUDE CONTROL:	Quite good.	Okay, initial response a little slow.
VELOCITY CONTROL:	Generally 70, but able to hold airspeed.	Good.
APPROACH:		
PERFORMANCE:	No problem at all.	Localizer too sensitive close in. 900 fpm rate of descent. Performance was so so-good until close in.
INTERCEPT AND TRACKING:		Intercept okay, tracking good until close in.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING:		No comments.
DIFFERENCES IFR/VFR:		No.
EFFECTS OF TURBULENCE:	More noticeable lateral-directional then longitudinal.	Mostly lateral, rocking +5 deg in bank angle - affects tracking a little.
SUMMARY COMMENTS:		
GOOD FEATURES:	Ability to fly attitude precisely.	Ability to track, response to inputs was fair.
OBJECTIONABLE FEATURES:	Turbulence effect on airplane.	Initial response a little on the slow side.

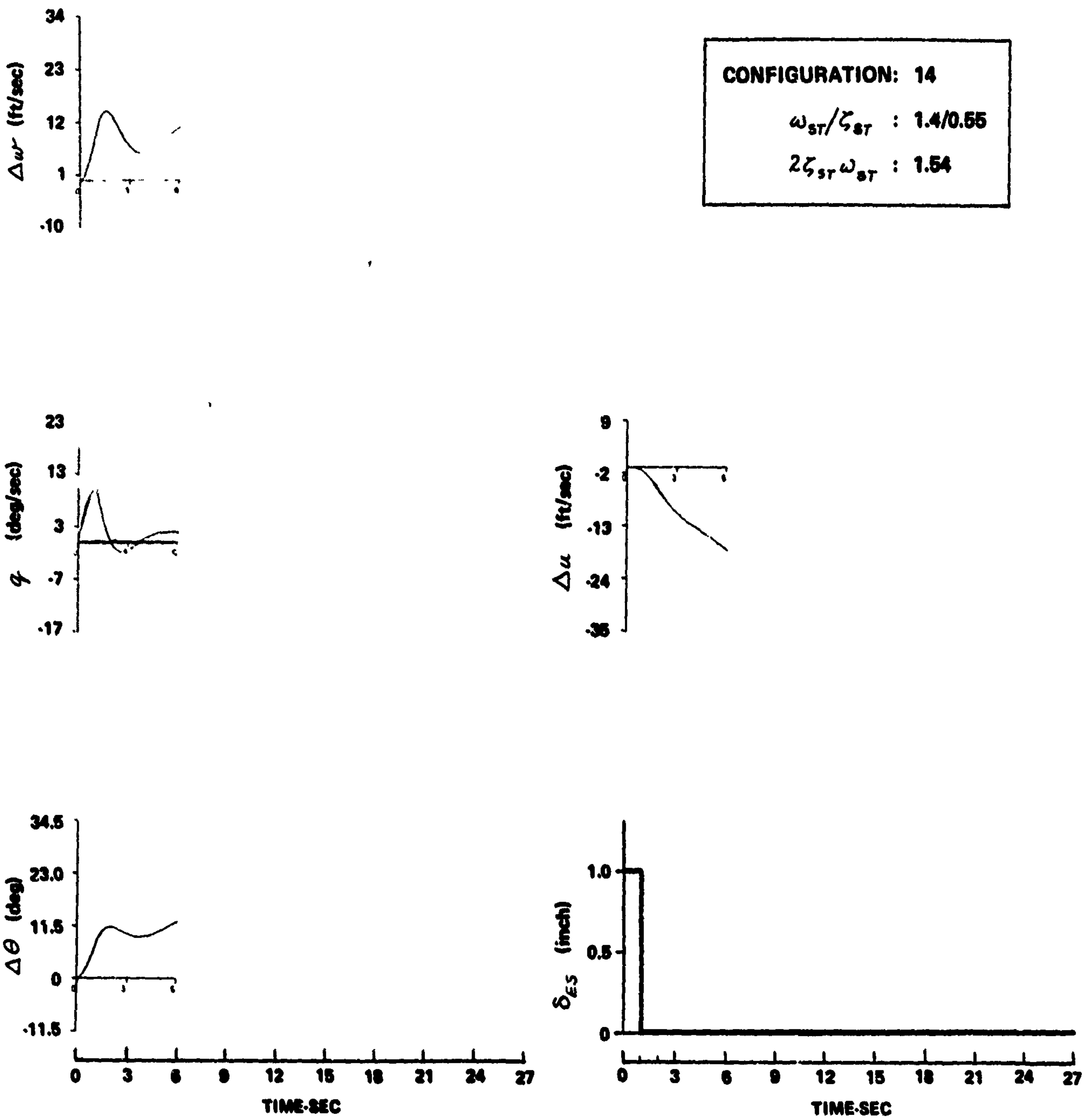

CONFIGURATION: 13
ω_{ST}/ζ_{ST} : 1.7/0.34
$2\zeta_{ST}\omega_{ST}$: 1.16
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sp}/ζ_{sp} :	1.4/0.55	PILOT RATINGS:		CONFIGURATION:	14
$2\zeta_{sp}\omega_{sp}$:	1.54	VFR:	3C	V_T/γ :	65/-9
$M_{\delta_{ES}}$	0.36	OVERALL:	3D	PILOT:	A
FLIGHT NO:	39F-23			WIND:	12 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM	Fair to good.	Fair to good. aircraft doesn't always stay at trim as it should.
FEEL CHARACTERISTICS:		Good. Forces light, displacements no problem.
PITCH ATTITUDE CONTROL:	Attitude control required nice small inputs. Initial response slow but positive. Relatively predictable final response.	Initial and final responses predictable.
VELOCITY CONTROL:	Good, satisfactory.	Not as good as desired: speed had tendency to pick-up or bleed off, slow response to collective change, used attitude and collective.
APPROACH:		
PERFORMANCE:	Good.	Good.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		Pitch attitude control glide path, collective to control speed.
SIDESTEP MANEUVER:	No comments	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None: no pitch up.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		A little more difficult velocity control IFR than VFR.
EFFECTS OF TURBULENCE:	Very little ambient turbulence, but aircraft very susceptible to it.	Very little turbulence, but it does bobble aircraft.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch control good, aircraft seems stable.	Good pitch attitude control, good glide path and localizer control.
OBJECTIONABLE FEATURES:	Somewhat slow in pitch response.	Difficulty in keeping speed precisely constant.

ω_{ST}/ζ_{ST}:	1.4/0.55	PILOT RATINGS:		CONFIGURATION:	14
$2\zeta_{ST}\omega_{ST}$:	1.54	VFR:	4B	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.35	OVERALL:	4B	PILOT:	A
FLIGHT NO.	43F-27			WIND:	08

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Relatively poor, drifts off.	Fair, not as bad as anticipated.
FEEL CHARACTERISTICS:		No problem, good.
PITCH ATTITUDE CONTROL:	Initial response okay, but tends to take-off without attention. Pulse-type inputs used.	Initial response good. Use small pulse-type inputs to control attitude -- seems natural.
VELOCITY CONTROL:	No problem, primarily collective.	On approach was good, moderate attention required. Combination of collective and stick used.
APPROACH:		
PERFORMANCE:	Good, good short-term control of the airplane.	Good.
INTERCEPT AND TRACKING:		Good.
CONTROL TECHNIQUE:		Collective for rate of sink and then attitude to keep rate of sink and airspeed together.
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		Collective to stop rate of descent, and stick to get desired attitude.
PROBLEMS:		Large nose-up pitch up with collective requires large stick input.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	None present, not a factor.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Initial response.	Glide path control.
OBJECTIONABLE FEATURES:	Cannot fly hands off because airplane has a mind of its own.	Speed control required attention.



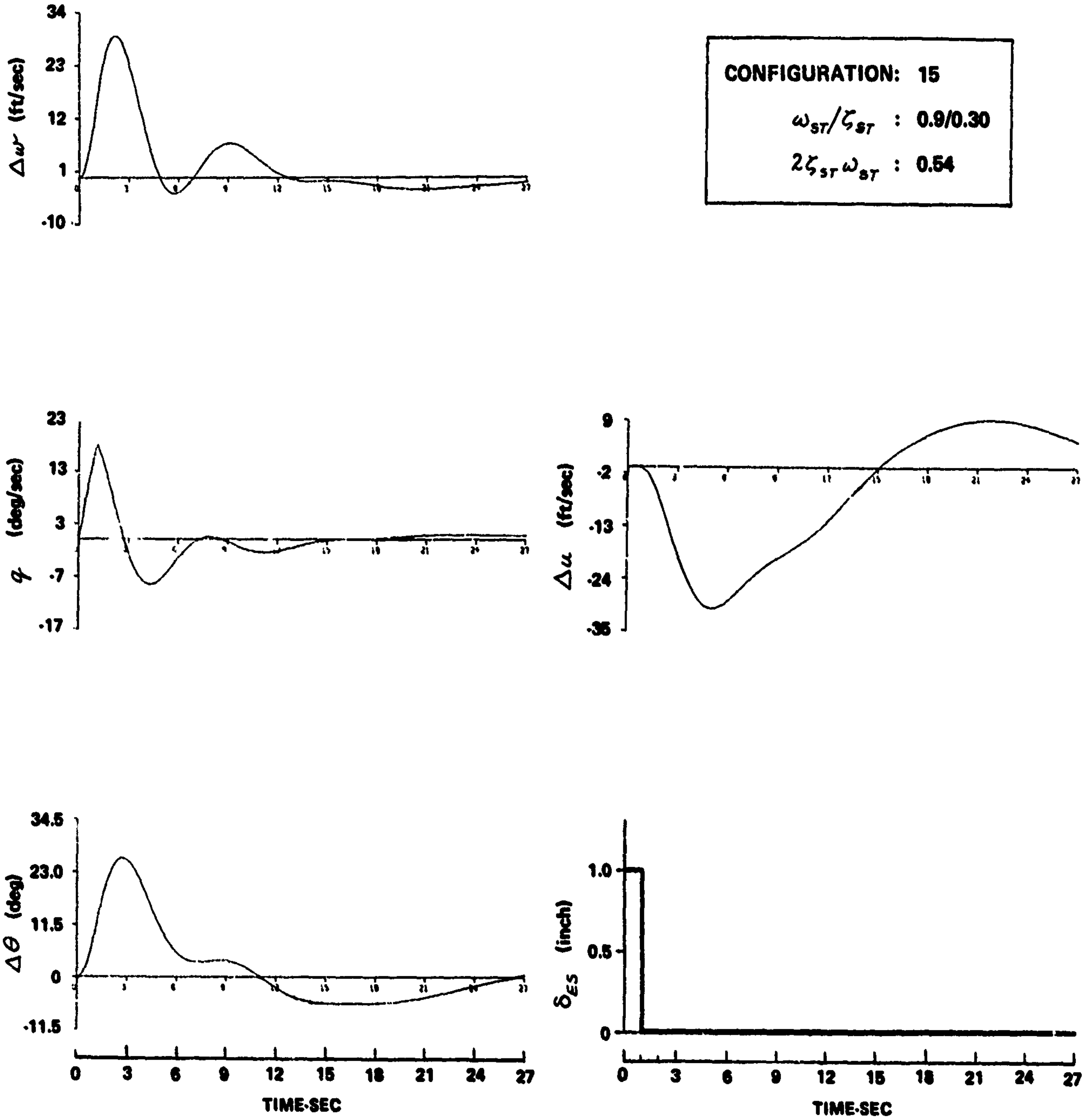
CONFIGURATION: 14
ω_{ST}/ζ_{ST} : 1.4/0.55
$2\zeta_{ST}\omega_{ST}$: 1.54
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{SP}/ζ_{SP} :	0.9/0.30	PILOT RATINGS:		CONFIGURATION:	15
$2\zeta_{SP}\omega_{SP}$:	0.54	VFR:	7F	V_T/γ :	65/-9
$M_{\delta_{es}}$:	0.29	OVERALL:	8F	PILOT:	A
FLIGHT NO:	38F-22			WIND:	12 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Poor: does not hold trim. Seems to want to diverge.	Poor.
FEEL CHARACTERISTICS:		No problem. Light forces, displacements noticeable but small.
PITCH ATTITUDE CONTROL:	Biggest problem. Slow to respond -- initial response comes on too late. Final response unpredictable -- Aircraft wants to take off, needs conscious effort to stop it. Put in input, wait for response then take out input as aircraft starts responding.	Really a problem IFR due to not enough information. Initial response slow, final response unpredictable, working hard to keep aircraft under control.
VELOCITY CONTROL:	A problem, primarily because am so far behind in pitch. Unsatisfactory. Used collective.	Tried with collective, not a good job. Very poor control -- unsatisfactory.
APPROACH:		
PERFORMANCE:	Okay.	No comments.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		Glide path with stick, velocity with collective.
SIDESTEP MANEUVER:	No comments.	
LEVEL OFF:		
TECHNIQUE:		Used collective.
PROBLEMS:		Could be done. Nose pitched up, used stick to stop.
LANDING?:		No.
DIFFERENCES IFR/VFR:		Pitch attitude control more a problem IFR than VFR.
EFFECTS OF TURBULENCE:	Bobble around like a cork -- oscillates so much that must continually work controls. Wants to diverge away from initial attitude.	Kicks aircraft around, sets off low frequency oscillations.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	Could at least control it.
OBJECTIONABLE FEATURES:	Slow response, aircraft wants to take off, it is a two-input problem to start and stop it, large velocity variations.	Slow pitch response, pilot couples with it to get PIO.

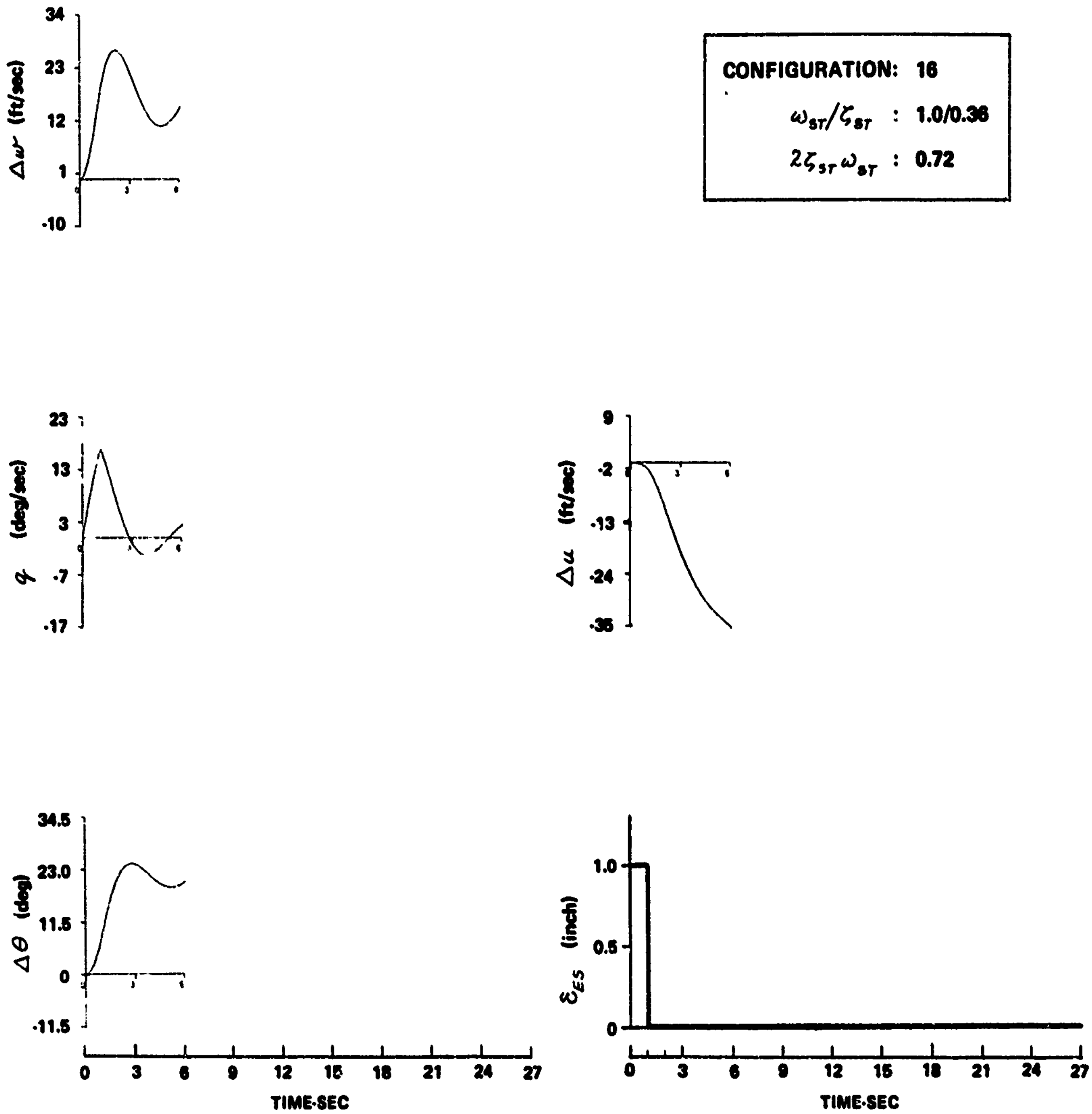
$\omega_{\theta r}/\zeta_{\theta r}$:	0.9/0.30	PILOT RATINGS:		CONFIGURATION:	15
$2\zeta_{\theta r}\omega_{\theta r}$:	0.54	VFR:	7C	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.19	OVERALL:	8C	PILOT:	A
FLIGHT NO.:	43F-27			WIND:	08

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Okay, but with some reservations.	Very poor.
FEEL CHARACTERISTICS:		No problem, initial forces and displacements noticeable.
PITCH ATTITUDE CONTROL:	Primarily step-type inputs and then a kind of pull and hold. Initial response slow and final response not too predictable. Two part control.	Initial pitch response very slow and final response is really unpredictable. Can almost get into a PIO if tight control is attempted. Must pulse the thing along.
VELOCITY CONTROL:	Primarily collective, notice pitching moment, which upsets pitch control; however, speed control satisfactory.	Okay as long as not tight in the loop with pitch control but when pitch gets away so does speed. - Not satisfactory.
APPROACH:		
PERFORMANCE:	Oscillated around on approach, didn't like it. An uncomfortable airplane because it moves around so slowly.	Poor; very uncomfortable.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	Felt uncomfortable because of slow pitch response.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		Yes, pitching moment due to collective is difficult to control.
LANDING?:		No.
DIFFERENCES IFR/VFR:		More difficult IFR because you can't keep up with the pitch oscillations.
EFFECTS OF TURBULENCE:	No turbulence, not a factor.	None present.
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	None.
OBJECTIONABLE FEATURES:	Longitudinal response slow initially then takes off.	Very slow response and inability to control the pitch attitude with sufficient precision.


CONFIGURATION: 15
ω_{ST}/ζ_{ST} : 0.9/0.30
$2\zeta_{ST}\omega_{ST}$: 0.54
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST}/ζ_{ST}:	1.0/0.36	PILOT RATINGS:		CONFIGURATION:	16
$2\zeta_{ST}\omega_{ST}$:	0.72	VFR:	6C	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.44	OVERALL:	7C	PILOT:	A
FLIGHT NO.:	48F-29			WIND:	08

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Not very good, wants to wander around in pitch quite a bit.	Not very good.
FELL CHARACTERISTICS:		No problem.
PITCH ATTITUDE CONTROL:	Kind of a delay and then takes off. Must pulse the controls. Final response not predictable.	Starts off pretty good but really wants to take off and very difficult to predict. Try to pulse my way through it and didn't do a very good job.
VELOCITY CONTROL:	Satisfactory, used collective.	Pretty good, got fast, satisfactory but more work than is desirable.
APPROACH:		
PERFORMANCE:	Okay, tended to rely more a collective than longitudinal stick.	Really quite poor, unacceptable.
INTERCEPT AND TRACKING:		Poor.
CONTROL TECHNIQUE:		Longitudinal stick for attitude and glidepath and collective for speed control.
SIDESTEP MANEUVER:	No problems if you climb but trying to level off introduces slow pitch oscillation.	
LEVEL OFF:		
TECHNIQUE:		Used collective, waved-off high because of poor longitudinal control.
PROBLEMS:		None.
LANDING?:		No.
DIFFERENCES IFR/VFR:		Much more difficult IFR.
EFFECTS OF TURBULENCE:		No turbulence present (which is probably a good thing)
SUMMARY COMMENTS:		
GOOD FEATURES:	None given.	None.
OBJECTIONABLE FEATURES:	Unpreditable final response and tendency to oscillate in pitch.	Real slow pitch response and the airplane takes off following an input. Sensitivity probably a little high.

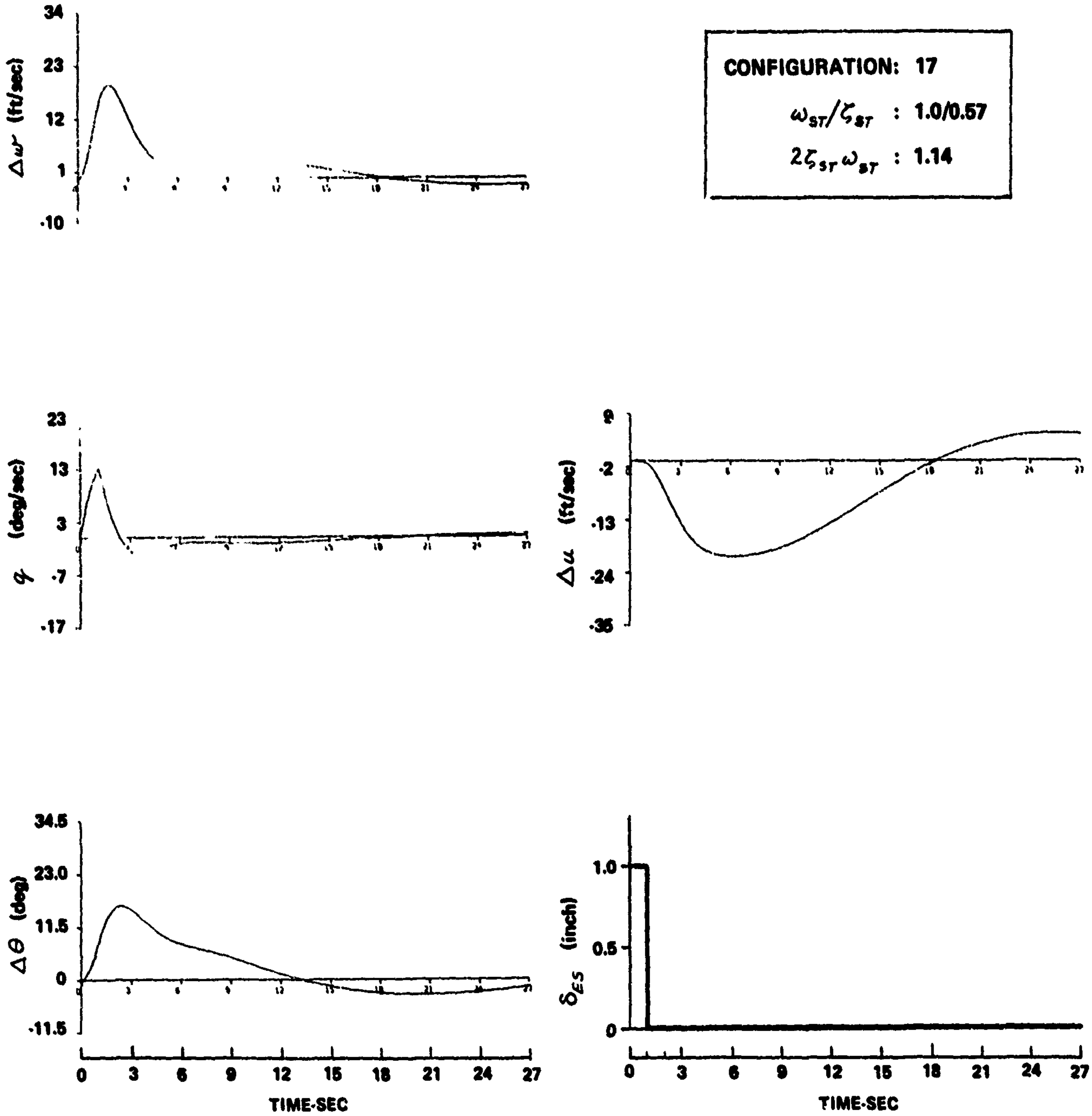

CONFIGURATION: 16
ω_{ST}/ζ_{ST} : 1.0/0.36
$2\zeta_{ST}\omega_{ST}$: 0.72
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST}/ζ_{ST} :	1.0/0.57	PILOT RATINGS:		CONFIGURATION:	17
$2\zeta_{ST}\omega_{ST}$:	1.14	VFR:	3D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.32	OVERALL:	4E	PILOT:	A
FLIGHT NO:	39F-23			WIND:	12 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Not great but no trouble.	No comments.
FEEL CHARACTERISTICS:		Kind of like these; forces light, displacements small.
PITCH ATTITUDE CONTROL:	Small initial delay but comes along pretty good, tends to overshoot but can stop it okay - relatively predictable.	Seemed okay but had trouble with final response which likely explains problems with speed control.
VELOCITY CONTROL:	Satisfactory, used collective.	Terrible - very confusing, used collective a fair amount.
APPROACH:		
PERFORMANCE:	No comments.	ILS okay but speed control poor.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUE:		Longitudinal stick for attitude, collective for speed.
SIDESTEP MANEUVER:	No problems.	
LEVEL OFF:		
TECHNIQUE:		Collective.
PROBLEMS:		None.
LANDING:		Yes.
DIFFERENCES IFR/VFR:		Yes, there was problems IFR with velocity control.
EFFECTS OF TURBULENCE:	Knocks nose around in an insidious way leading to airspeed control problems	Speed and pitch changes a problem.
SUMMARY COMMENTS:		
GOOD FEATURES:	Well damped, pretty good control of pitch attitude.	Good glide path control.
OBJECTIONABLE FEATURES:	Slow initial response and little bit of a tendency to overshoot - very slight objections.	Speed control was poor and don't really understand why.

ω_{ST}/ζ_{ST}:	1.0/0.57	PILOT RATINGS:		CONFIGURATION:	17
$2\zeta_{ST}\omega_{ST}$:	1.14	VFR:	2B	V_T/γ:	65/-9
$M_{\delta_{ES}}$:	0.36	OVERALL:	2.5B	PILOT:	A
FLIGHT NO:	41F-25			WIND:	08

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Pretty good.
FEEL CHARACTERISTICS:		Forces light, displacements small.
PITCH ATTITUDE CONTROL:	Initial response okay, comes along a little slower than desired, not quite one-to-one with airplane but it's okay.	Not as snappy as desired, predictable.
VELOCITY CONTROL:	Good, used collective.	Little slow, used collective, satisfactory.
APPROACH:		
PERFORMANCE:	Pretty good.	Satisfactory.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		Stick for attitude and glide path, collective for speed.
SIDESTEP MANEUVER:	No problem, noticed aircraft descend with large bank angles.	
LEVEL OFF:		
TECHNIQUE:		Collective to arrest rate of descent, stick to hold desired altitude.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES VFR/IFR:		None.
EFFECTS OF TURBULENCE:	None.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Like the response of the airplane, well damped.	Initial response satisfactory, could be faster.
OBJECTIONABLE FEATURES:	None.	Nothing major.


CONFIGURATION: 17
ω_{ST}/ζ_{ST} : 1.0/0.57
$2\zeta_{ST}\omega_{ST}$: 1.14
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST}/ζ_{ST}:	1.2/0.79	PILOT RATINGS:		CONFIGURATION:	18
$2\zeta_{ST}\omega_{ST}$:	1.90	VFR:	3C	V_T/γ:	65/-9
$M_{\delta_{ES}}$:	0.44	OVERALL:	4C	PILOT:	A
FLIGHT NO:	40F-24			WIND:	14

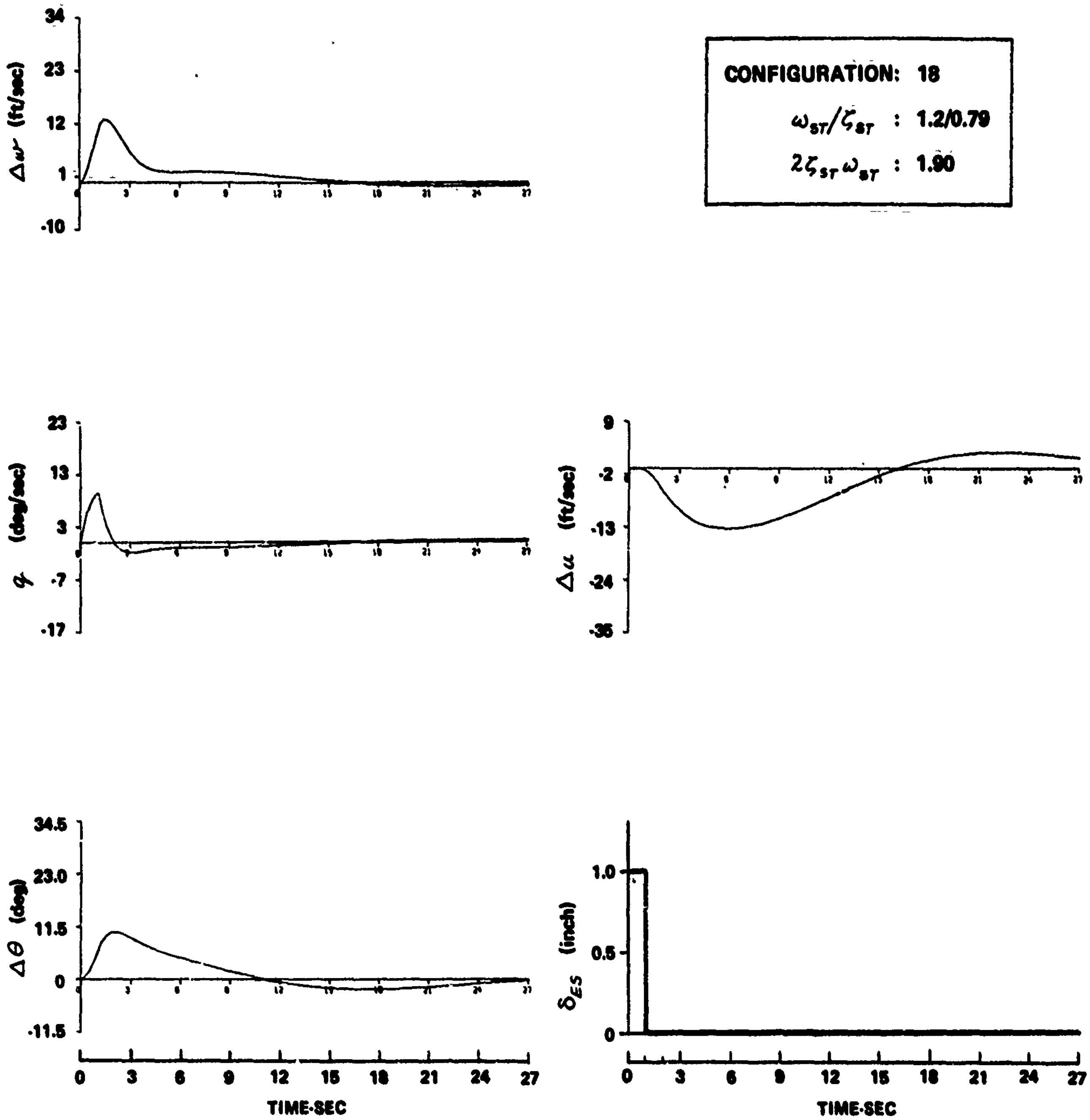
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good but with some reservations.	Somewhat difficult, any inattention such as putting on IFR "hood" is a problem.
FEEL CHARACTERISTICS:		Forces okay with small displacement.
PITCH ATTITUDE CONTROL:	Little slow but okay, has a tendency to overshoot but not badly. Must put in an input to start the airplane then a couple of inputs to stop it. Stick for attitude control.	Initial response slower than desired, final response is predictable with constant attention. Tend to pulse the nose with stick during approach. Stick for attitude control.
VELOCITY CONTROL:	Satisfactory, used collective.	Satisfactory, used collective.
APPROACH:		
PERFORMANCE:	Good, had adequate "down" control on the glide path.	Satisfactory.
INTERCEPT AND TRACKING:		Okay.
CONTROL TECHNIQUE:		Used stick for glide path control and collective for velocity control, control activity high on approach.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Collective to arrest rate of descent and stick to hold desired attitude.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Yes, considerably harder to fly under the IFR situation due to insidious small changes in attitude around trim point.
EFFECTS OF TURBULENCE:	No effect.	No comments.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pretty good control of pitch attitude and speed.	Reasonable attitude control, good speed control.
OBJECTIONABLE FEATURES:	Like to have it a little more one-to-one and little faster responding.	These slow changes from the trim conditions require extra attention to pitch attitude control which causes lateral-directional performance to deteriorate.

ω_{ST}/ζ_{ST}:	1.2/0.79	PILOT RATINGS:		CONFIGURATION:	18
$2\zeta_{ST}\omega_{ST}$:	1.90	VFR:	2D	V_T/γ :	65/-9
$M_{\delta_{E\theta}}$:	0.35	OVERALL:	2D	PILOT:	A
FLIGHT NO:	42F-26			WIND:	12 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Pretty good.	Pretty good.
FEEL CHARACTERISTICS:		Good.
PITCH ATTITUDE CONTROL:	Initial response slow but smooth, final response predictable. Kind of a step-type input and take it out to stop response.	Not real fast but comfortable, predictable, use step-type controls to get what I want and then relaxing.
VELOCITY CONTROL:	Satisfactory, collective used.	Collective used.
APPROACH:		
PERFORMANCE:	Pretty good.	Quite good.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		Collective for speed control combination of stick and collective to get attitude and rate of descent.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Collective to stop rate of descent, stick to keep the attitude and speed as desired.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	Big problem.	Big problem.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pitch attitude good, little slower than desired but okay.	Pitch attitude control.
OBJECTIONABLE FEATURES:	Turbulence response.	Turbulence response.

ω_{sT} / ζ_{sT}:	1.2/0.79	PILOT RATINGS:		CONFIGURATION:	18
$2\zeta_{sT}\omega_{sT}$:	1.90	VFR:	3.5D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.36	OVERALL:	4E	PILOT:	A
FLIGHT NO:	50F-30			WIND:	12 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Reasonably good.	Okay.
FEEL CHARACTERISTICS:		No problem.
PITCH ATTITUDE CONTROL:	Relatively slow but seems well damped and well behaved, predictable. Using long pulse-type input.	Initial response not quite as responsive as desired. Flying with halfway between a step and pulse type input.
VELOCITY CONTROL:	Collective control used, no problems.	Pretty good, does get away a bit when attention devoted to pitch attitude control.
APPROACH:		
PERFORMANCE:	Good.	Good.
INTERCEPT AND TRACKING:		Pretty good.
CONTROL TECHNIQUE:		Stick for attitude control cou[illegible]ed with collective for speed control.
SIDESTEP MANEUVER:	No real problem except right at the end of maneuver speed got away a bit.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		Nothing significant.
EFFECT OF TURBULENCE:	Hit a little patch of turbulence which bothered the aircraft.	A big problem for this configuration.
SUMMARY COMMENTS:		
GOOD FEATURES:	Good glide path control.	Nice approach, smooth.
OBJECTIONABLE FEATURES.	Like to see the airplane a little faster.	Slowness of the pitch attitude response and sensitivity to turbulence.


CONFIGURATION: 18
ω_{ST}/ζ_{ST} : 1.2/0.79
$2\zeta_{ST}\omega_{ST}$: 1.90
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST}/ζ_{ST}:	.9/.66*	PILOT RATINGS:		CONFIGURATION:	19
$2\zeta_{ST}\omega_{ST}$:	1.19*	VFR:	7D	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.36	OVERALL:	8D	PILOT:	A
FLIGHT NO:	48F-29			WIND:	12

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Very poor.	Poor, work IFR, can't seem to feel out insidious attitude changes.
FEEL CHARACTERISTICS:		Okay.
PITCH ATTITUDE CONTROL:	Quite a delay in pitch response and it seems to have a mind of its own. Cannot predict what is going to happen.	Initial response a little slow and predictability of the final response is very poor. Using pulse inputs.
VELOCITY CONTROL:	Satisfactory, used collective.	A problem but just due to overall difficulty in controlling aircraft, but acceptable.
APPROACH:		
PERFORMANCE:	Unsatisfactory, perhaps unacceptable.	Quite unsatisfactory, just along for the ride.
INTERCEPT AND TRACKING:		Poor.
CONTROL TECHNIQUE:		Tried to use collective for glide path control and little stick, therefore speed control got out of hand.
SIDESTEP MANEUVER:	Very difficult with poor longitudinal control.	
LEVEL OFF.		
TECHNIQUE:		
PROBLEMS:		Can do it but don't have much control over pitch attitude.
LANDING?:		No.
DIFFERENCES IFR/VFR:		Worse IFR.
EFFECTS OF TURBULENCE:		Little turbulence present really gives me fits.
SUMMARY COMMENTS:		
GOOD FEATURES:	None given.	None.
OBJECTIONABLE FEATURES:	Pitch attitude control very unpredictable.	Very little or no feeling where the attitude of the airplane is going to end up.

*Not identified, estimated from gains used, not used in data analysis.

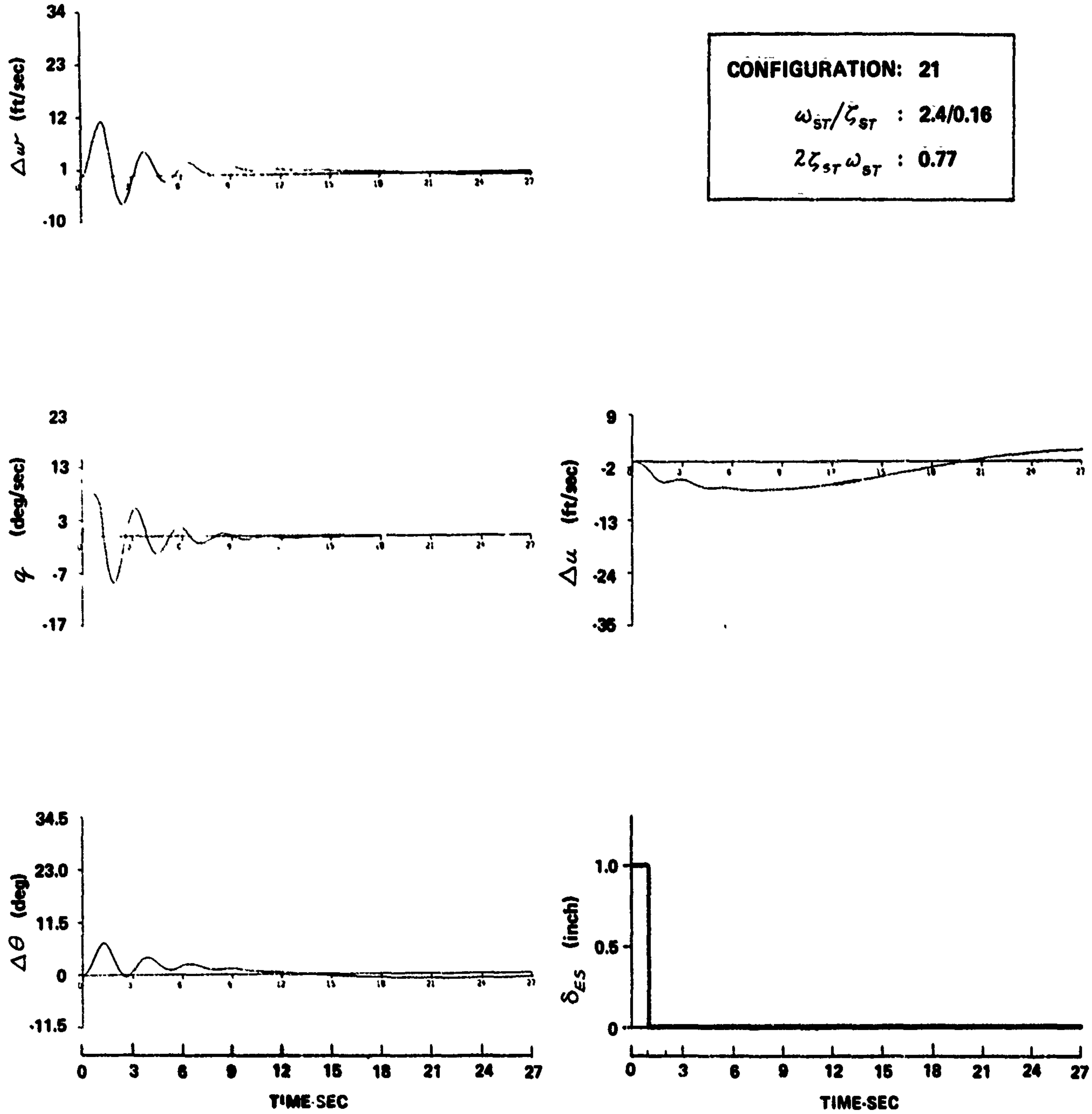
ω_{sr}/ζ_{sr} :	.8/.35*	PILOT RATINGS:		CONFIGURATION:	20
$2\zeta_{sr}\omega_{sr}$:	.56*	VFR:	6E	V_T/γ :	65/-9
$M_{\delta_{ES}}$:	0.36	OVERALL:	6F	PILOT:	A
FLIGHT NO:	50F-30			WIND:	12 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Ridiculous airplane, very difficult to trim.	Still poor.
FEEL CHARACTERISTICS:		Acceptable but not good, with large inputs required.
VELOCITY CONTROL:	Not satisfactory, no time to devote to it, used collective.	Acceptable but deteriorated, because of attention required for attitude control.
APPROACH:		
PERFORMANCE:	Not very comfortable, some really large pitch attitude changes.	Pretty good considering work required.
INTERCEPT AND TRACKING:		Reasonably good.
CONTROL TECHNIQUE:		Very large inputs required for glide path control, didn't like that.
SIDESTEP MANEUVER:	Okay.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		Only with pitch control.
LANDING?:		No.
DIFFERENCES IFR/VFR:		Get large, inadvertent attitude changes IFR.
EFFECTS OF TURBULENCE:	Very uncomfortable in turbulence.	
SUMMARY COMMENTS:		
GOOD FEATURES:	None.	None.
OBJECTIONABLE FEATURES:	Very little pitch control, airplane has a mind of its own.	Very slow pitch attitude control and inability to control properly.

*Not identified, estimated from gains used, not used in data analysis.

ω_{sp}/ζ_{sp}:	2.4/0.16	PILOT RATINGS:		CONFIGURATION:	21
$2\zeta_{sp}\omega_{sp}$:	0.77	VFR:	5.5A	V_T/γ :	80/-7
$M_{\delta_{ES}}$:	0.34	OVERALL:		PILOT:	B
FLIGHT NO:	59F-38			WIND:	10

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	No comments.	Not done
PITCH ATTITUDE CONTROL:	Response is fine, damping too low - would like a lower gearing.	
VELOCITY CONTROL:	No comments.	
APPROACH:		
PERFORMANCE:	Okay.	
INTERCEPT AND TRACKING:		
CONTROL TECHNIQUE:		
SIDESTEP MANEUVER:	No comments.	
LEVEL OFF:		
TECHNIQUE:		
PROBLEMS:		
LANDING:		
DIFFERENCES IFR/VFR:		
EFFECTS OF TURBULENCE:	Not a factor.	
SUMMARY COMMENTS:		
GOOD FEATURES:	None given.	
OBJECTIONABLE FEATURES:	Constant oscillations	



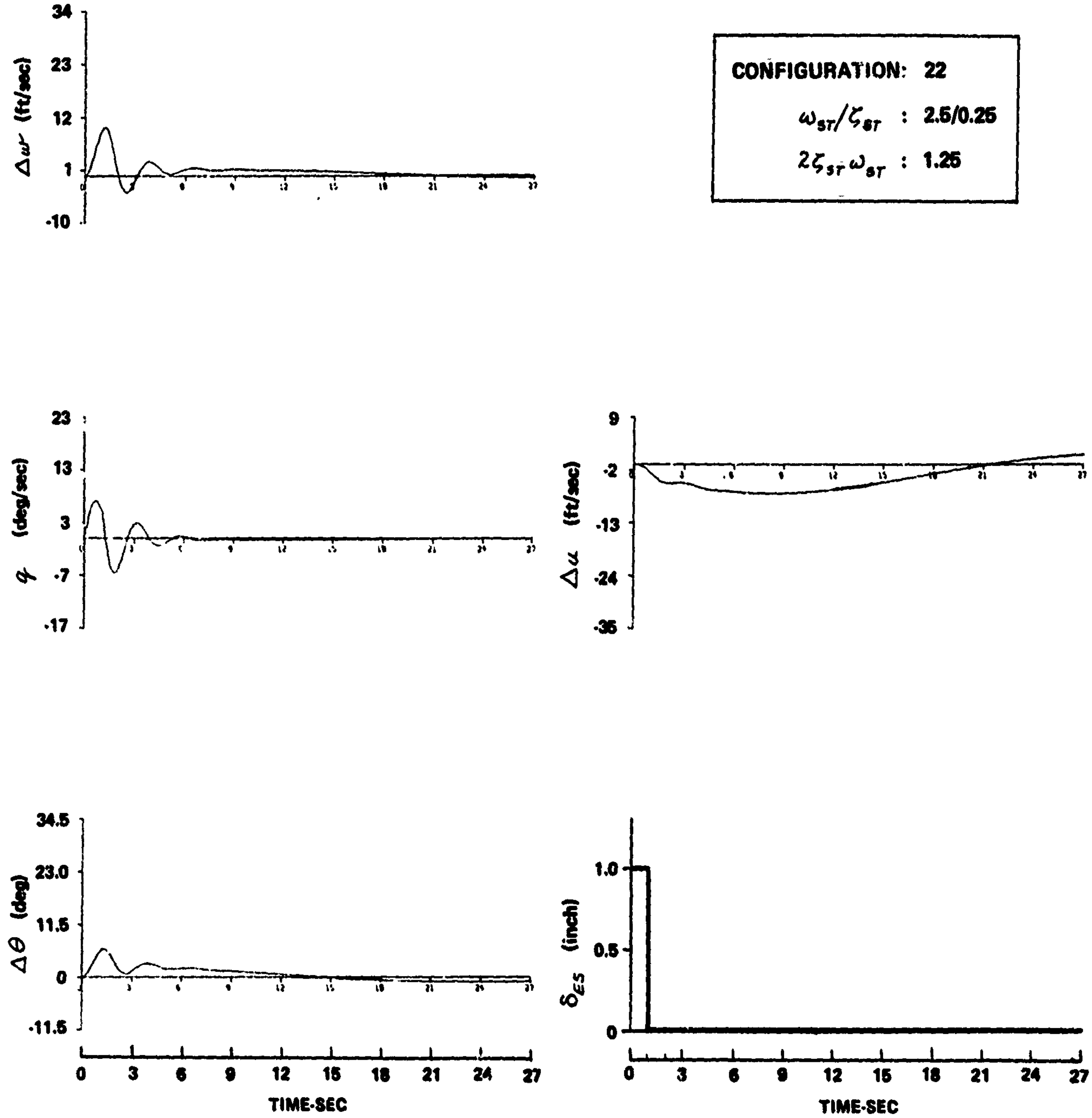
CONFIGURATION: 21

ω_{ST}/ζ_{ST} : 2.4/0.16

$2\zeta_{ST}\omega_{ST}$: 0.77

ω_{sr}/ζ_{sr} :	2.5/0.25	PILOT RATINGS:		CONFIGURATION:	22
$2\zeta_{sr}\omega_{sr}$:	1.25	VFR:	2A	V_T/γ :	80/-7
$M_{\delta_{ES}}$:	0.34	OVERALL:	2A	PILOT:	B
FLIGHT NO.:	57F-36			WIND:	08

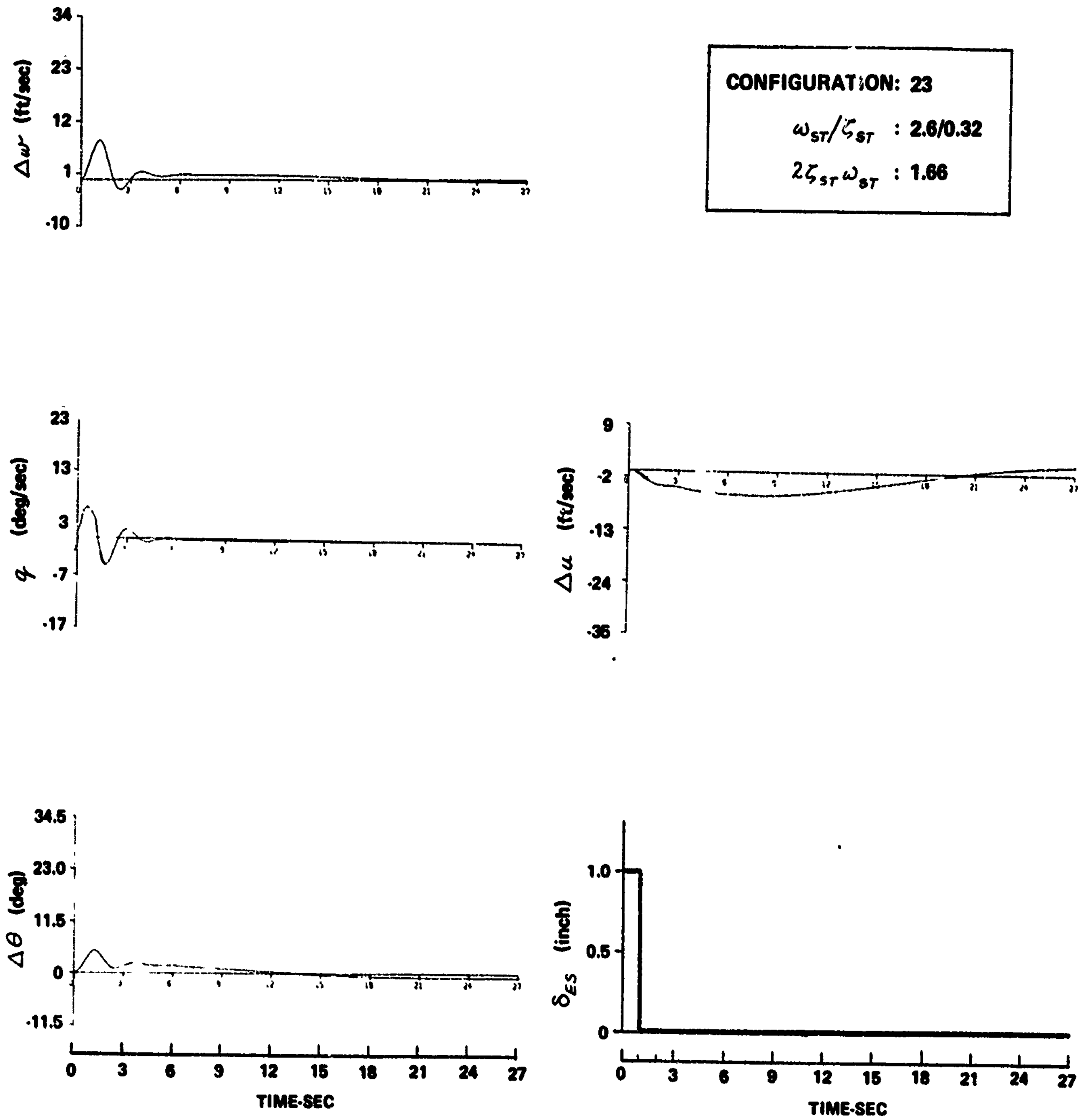
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Good.
FEEL CHARACTERISTICS:		Displacements too high.
PITCH ATTITUDE CONTROL:	Pretty good.	Reasonably good, oscillated a bit.
VELOCITY CONTROL:	No comments.	No comments.
APPROACH:		
PERFORMANCE:	Okay.	Okay, except for last couple of hundred feet but felt it was a piloting problem. Satisfactory.
INTERCEPT AND TRACKING:		Okay, tried to track too tightly and messed up performance as a result.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		No.
EFFECTS OF TURBULENCE:	None.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Feels solid.	Good solid airplane.
OBJECTIONABLE FEATURES:	Slight tendency to bobble when trying to be very accurate in pitch.	Some difficulty in the very tight precision control.



CONFIGURATION: 22
ω_{ST}/ζ_{ST} : 2.5/0.25
$2\zeta_{ST}\omega_{ST}$: 1.25
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{ST}/ζ_{ST} :	2.6/0.32	PILOT RATINGS:		CONFIGURATION:	23
$2\zeta_{ST}\omega_{ST}$:	1.66	VFR:	3C	V_T/γ :	80/-7
$M_{\delta_{ES}}$:	0.46	OVERALL:	3C	PILOT	B
FLIGHT NO:	56F-35			WIND:	22 (M)

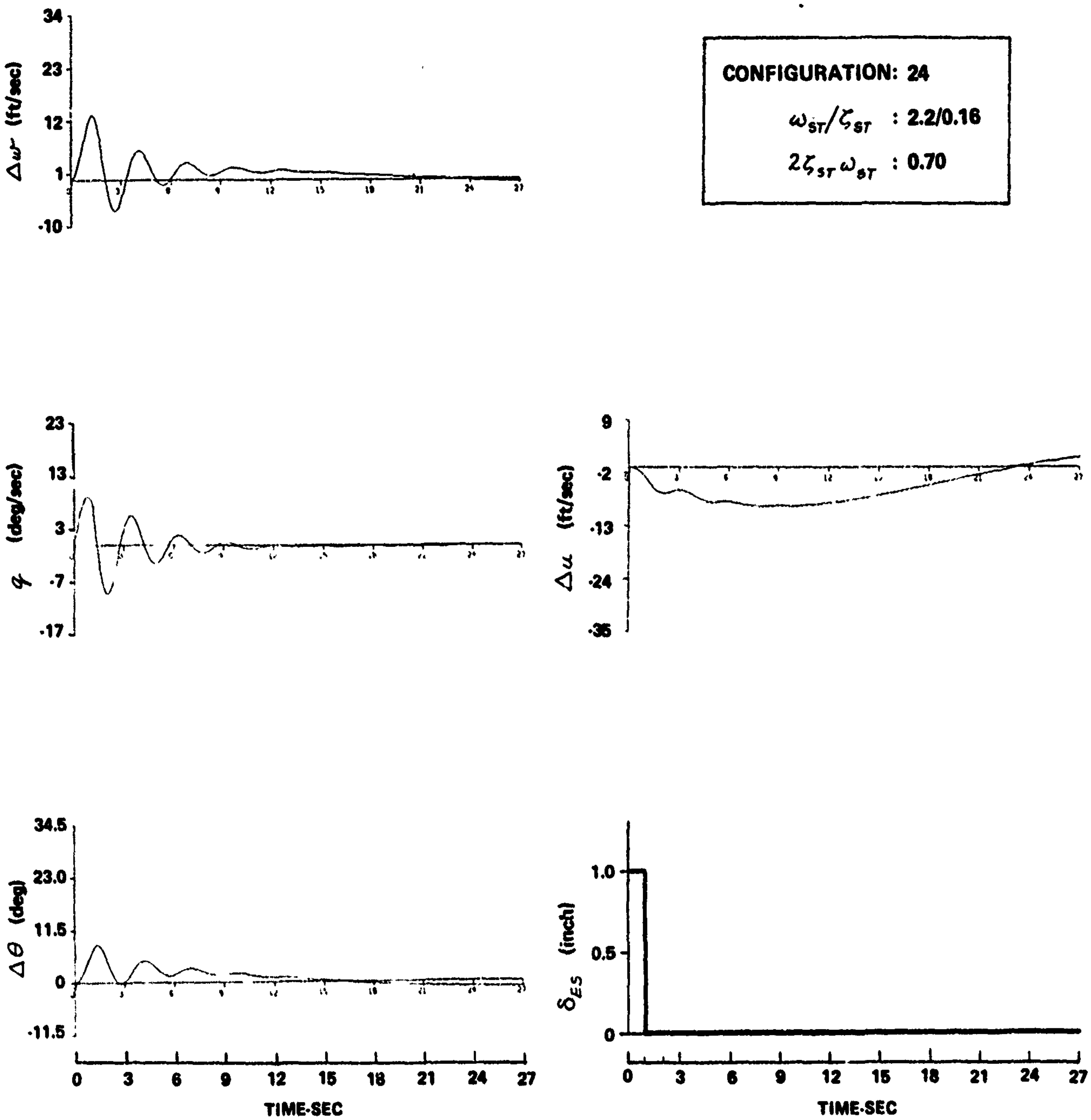
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Quite good.	No real problem.
FEEL CHARACTERISTICS:		Pretty good.
PITCH ATTITUDE CONTROL:	Pretty good, sensitivity could be a bit high.	Tendency to over control, bobble fairly good. Godd initial response.
VELOCITY CONTROL	Little bit of a problem, high (85).	Good.
APPROACH:		
PERFORMANCE:	Adequate.	Would like a collective position indicator.
INTERCEPT AND TRACKING		Poorly set-up. Tracking good.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Comments lost.
PROBLEMS:		Comments lost.
LANDING:		Comments lost.
DIFFERENCES IFR/VFR:		Tendency to bubble mor IFR.
EFFECTS OF TURBULENCE:	Moderate turbulence.	Little bit of a problem with this airplane.
LATERAL-DIRECTIONAL CHARACTERISTICS:		Not a factor.
SUMMARY COMMENTS:		
GOOD FEATURES:	Solid feeling airplane.	Good precision for tracking.
OBJECTIONABLE FEATURES:	Would like better damping, perhaps a sensitivity problem.	Tendency to bobble.



CONFIGURATION: 23
ω_{ST}/ζ_{ST} : 2.6/0.32
$2\zeta_{ST}\omega_{ST}$: 1.66
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sT}/ζ_{sT}:	2.2/0.16	PILOT RATINGS:		CONFIGURATION:	24
$2\zeta_{sT}\omega_{sT}$:	0.70	VFR:	3A	V_T/γ:	80/-7
$M_{\delta_{ES}}$:	0.34	OVERALL:	3.5A	PILOT:	B
FLIGHT NO.:	57F-36			WIND:	10

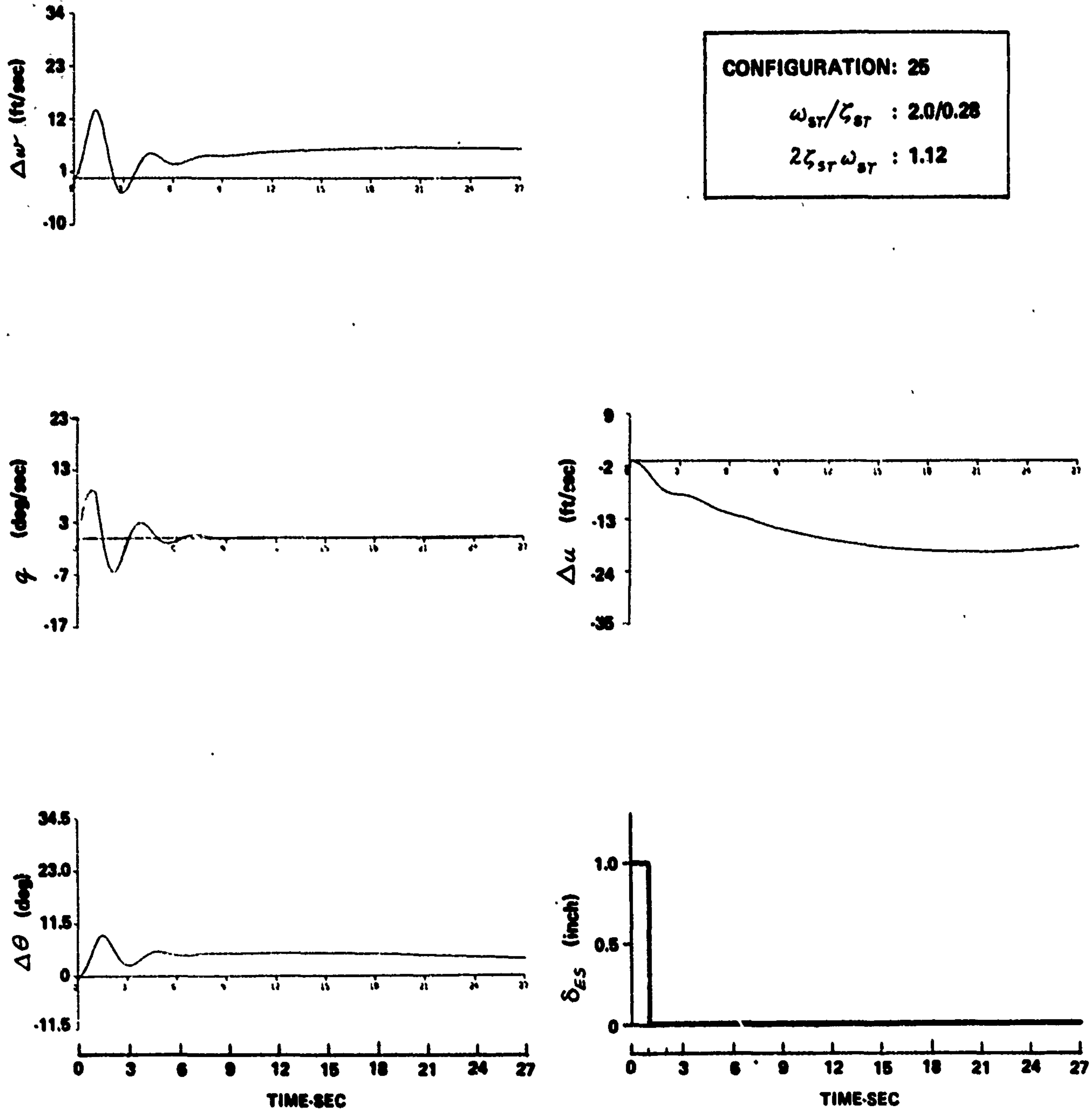
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	No problem.
FEEL CHARACTERISTICS:		Don't like the displacements but forces are okay.
PITCH ATTITUDE CONTROL:	Little sluggish, no direct connection between stick and airplane nose. Tendency to PIO a little bit.	Tendency to overcontrol, little sluggish response.
VELOCITY CONTROL:	No real problem.	Bit of a problem with no collective (power) reference indicator.
APPROACH:		
PERFORMANCE:	Okay, did get a PIO at one stage trying to correct to the glide path.	Nothing great - had some TALAR difficulties.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comment.
PROBLEMS:		None, but waved-off early.
LANDING?:		Probably could do it.
DIFFERENCES IFR/VFR:		Overcontrol tendency in pitch were noticeable in IFR.
EFFECTS OF TURBULENCE:	No effect at all.	No comments.
SUMMARY COMMENTS:		
GOOD FEATURES:	Trim capability.	No comments.
OBJECTIONABLE FEATURES:	Little sluggish.	No comments.



CONFIGURATION: 24
ω_{ST}/ζ_{ST} : 2.2/0.16
$2\zeta_{ST}\omega_{ST}$: 0.70
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

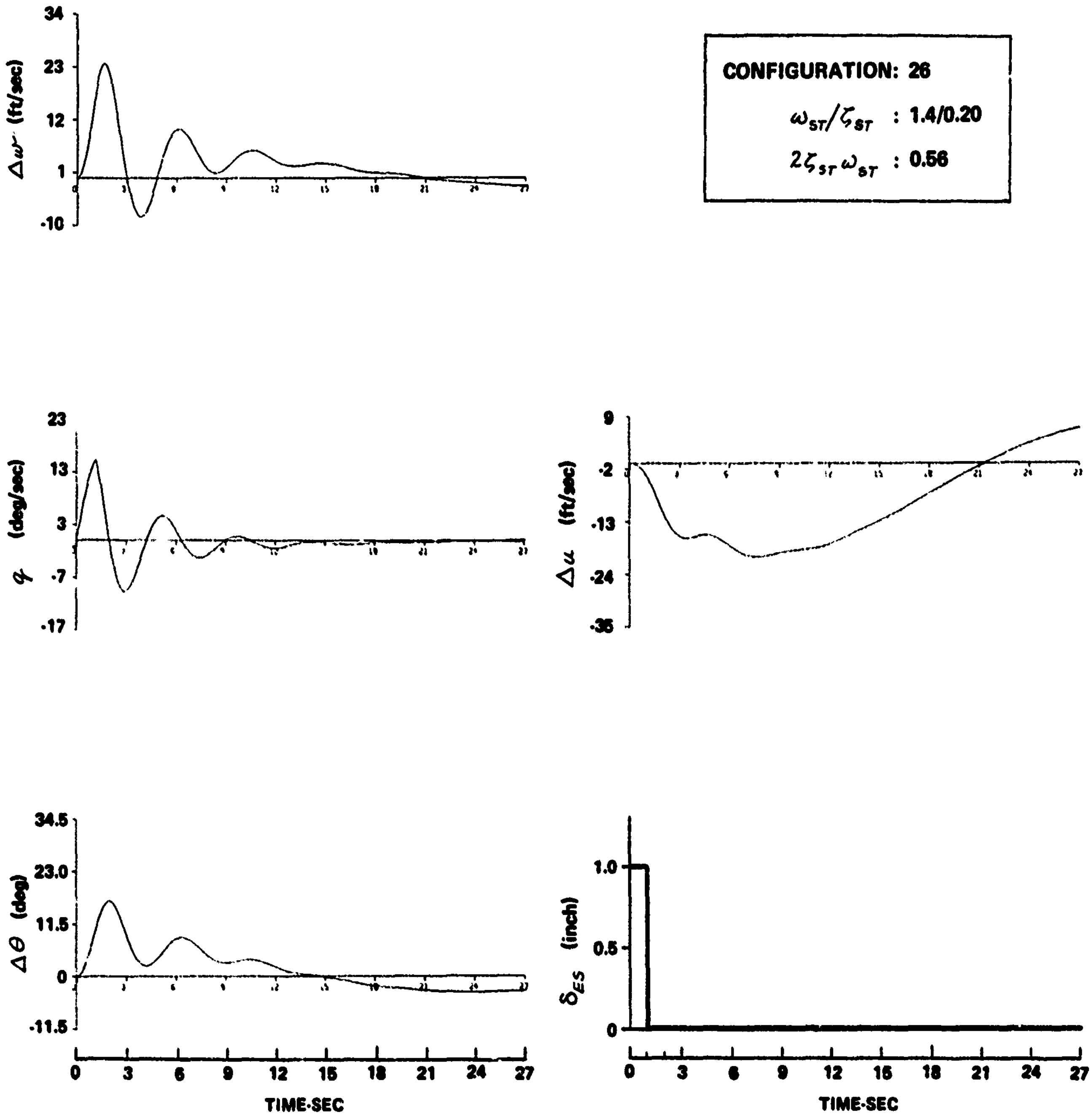
ω_{ST}/ζ_{ST} :	2.0/0.28	PILOT RATINGS:		CONFIGURATION:	25
$2\zeta_{ST}\omega_{ST}$:	1.12	VFR:	2A	V_T/γ :	80/-7
$M_{\delta_{ES}}$:	0.39	OVERALL:	2A	PILOT:	B
FLIGHT NO.:	S7F-36			WIND:	08

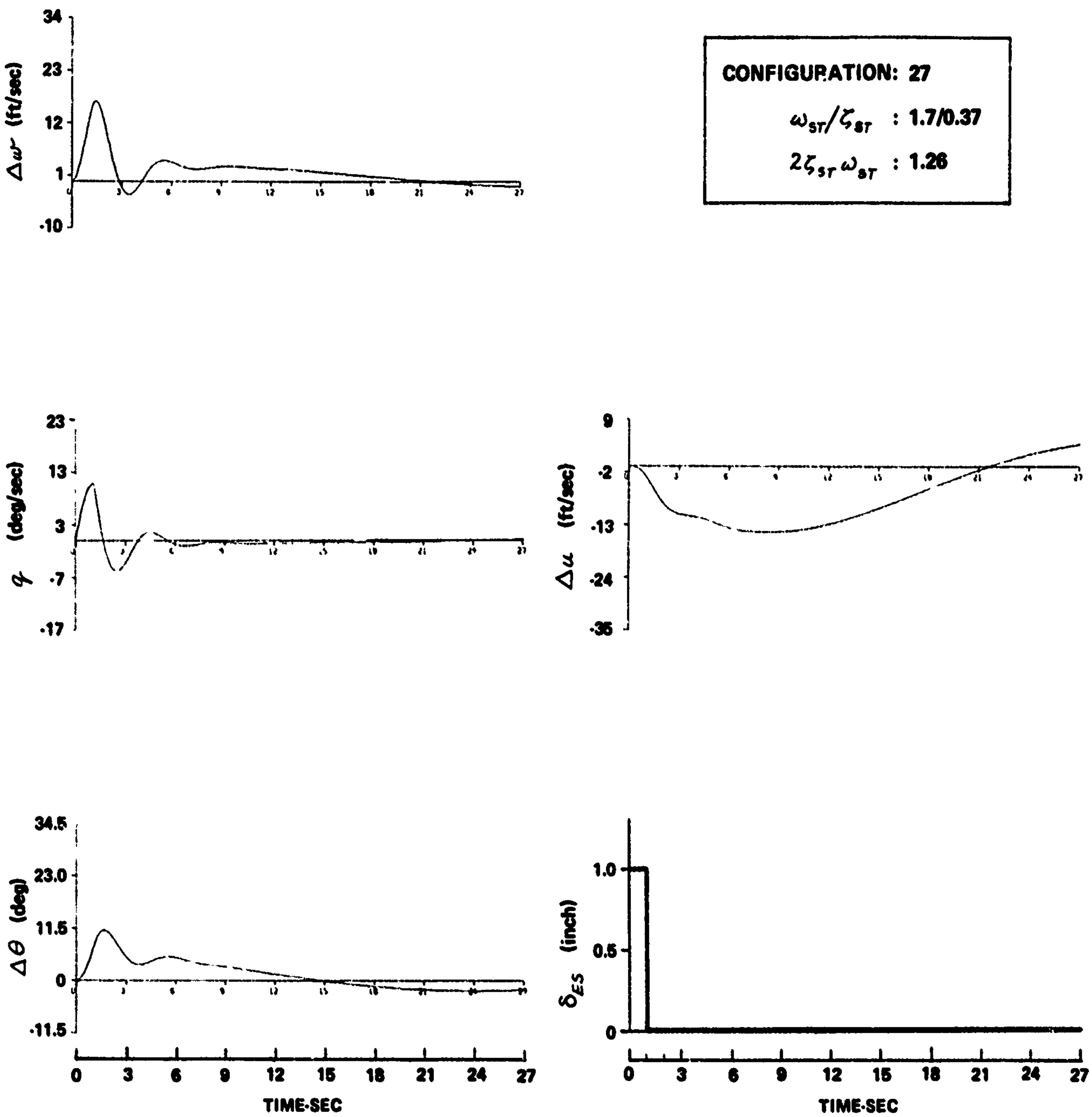
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Good.	Good.
FEEL CHARACTERISTICS:		Good.
PITCH ATTITUDE CONTROL:	Pretty good, tendency to get one oscillation in the final response.	Good, slight tendency to oscillate.
VELOCITY CONTROL:	Good.	Good.
APPROACH:		
PERFORMANCE:	No problem.	Excellent, good airplane all around.
INTERCEPT AND TRACKING:		No comments.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	Good.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	Not a factor.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Good airplane.	Good all around airplane.
OBJECTIONABLE FEATURES:	Do not have real tight, precise pitch attitude control.	None.


CONFIGURATION: 25
ω_{ST}/ζ_{ST} : 2.0/0.28
$2\zeta_{ST}\omega_{ST}$: 1.12
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sp}/ζ_{sp}:	1.4/0.20	PILOT RATINGS:		CONFIGURATION:	26
$2\zeta_{sp}\omega_{sp}$:	0.56	VFR:	2A	V_T/γ:	80/-7
$M_{\delta_{ES}}$:	0.34	OVERALL:	2A	PILOT:	B
FLIGHT NO.:	57F-36			WIND:	10

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Excellent.	No problem.
FEEL CHARACTERISTICS:		Displacements too large, forces okay.
PITCH ATTITUDE CONTROL:	Pretty reasonable, however final response a little oscillatory, doesn't feel real solid.	Pretty good, slight tendency to bobble the airplane if you force it to respond too rapidly. Feels fairly good.
VELOCITY CONTROL:	Excellent.	No problem.
APPROACH:		
PERFORMANCE:	Excellent.	Satisfactory.
INTERCEPT AND TRACKING:		Okay, biggest problem is the localizer because of sensitivity.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No Problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		More effort required IFR, but not significantly.
EFFECTS OF TURBULENCE:	Not a factor.	No effect.
SUMMARY COMMENTS:		
GOOD FEATURES:	Pretty good airplane.	Good feeling airplane.
OBJECTIONABLE FEATURES:	Bit on the sluggish side, minor problem with precision of control.	Minor-gearing and stick force combination, and precision of pitch control.


CONFIGURATION: 26
ω_{ST}/ζ_{ST} : 1.4/0.20
$2\zeta_{ST}\omega_{ST}$: 0.56
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC
0 3 6 9 12 15 18 21 24 27
TIME-SEC


CONFIGURATION: 27
ω_{ST}/ζ_{ST} : 1.7/0.37
$2\zeta_{ST}\omega_{ST}$: 1.26
Δw (ft/sec)
34
23
12
1
-10
q (deg/sec)
23
13
3
-7
-17
Δu (ft/sec)
9
-2
-13
-24
-35
$\Delta\theta$ (deg)
34.5
23.0
11.5
0
-11.5
δ_{ES} (inch)
1.0
0.5
0
0 3 6 9 12 15 18 21 24 27
TIME-SEC

ω_{sT}/ζ_{sT}:	1.7/0.37	PILOT RATINGS:		CONFIGURATION:	27
$2\zeta_{sT}\omega_{sT}$:	1.26	VFR:	4.5A	V_T/γ:	80/-7
$M_{\delta_{ES}}$:	0.30	OVERALL:	4A	PILOT:	B
FLIGHT NO.:	S9F-38			WIND:	10

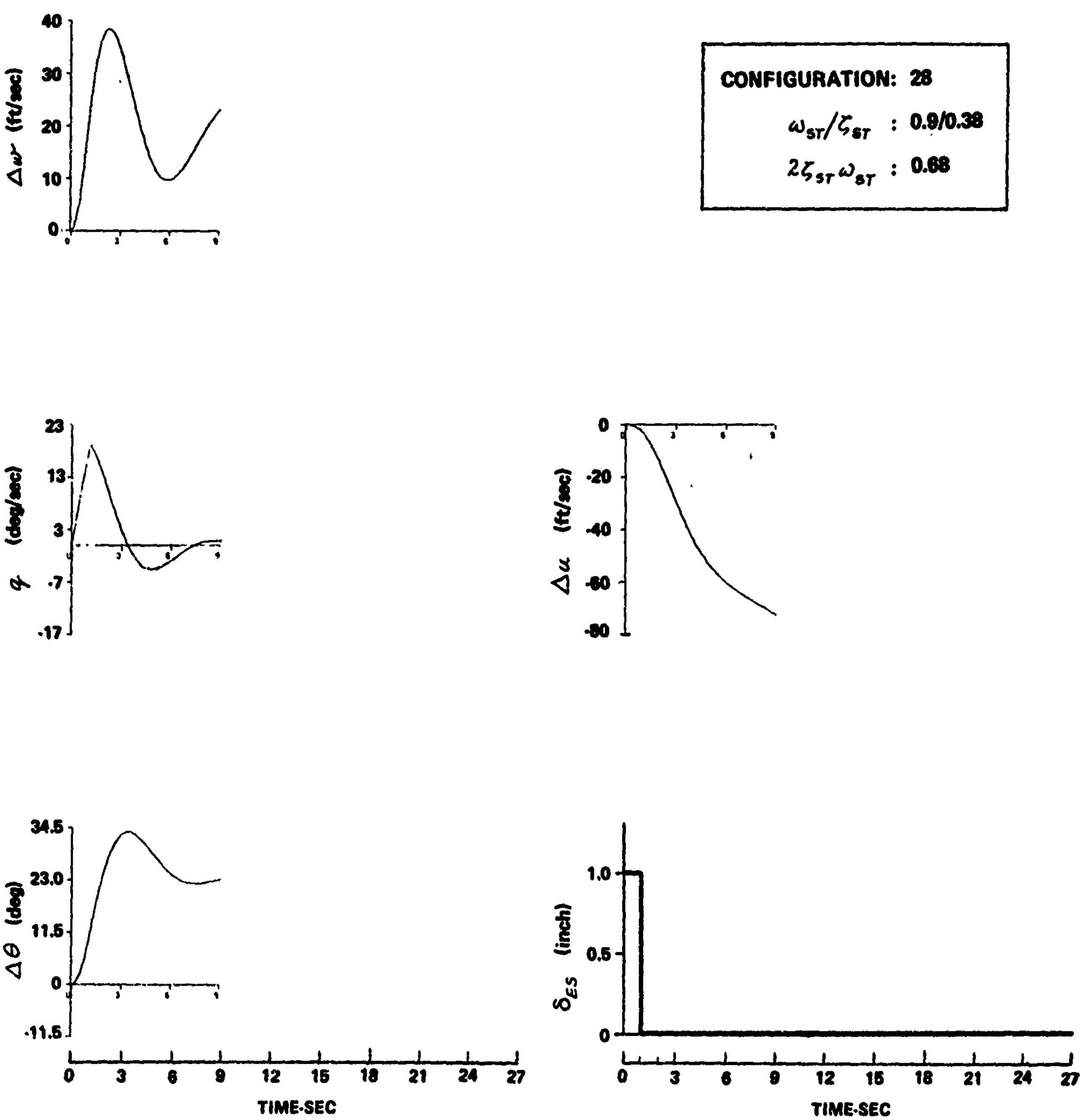
	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Little bit of a problem, but not much.	Trouble but suspect trim rate too high.
FEEL CHARACTERISTICS:		Forces are reasonable for the displacements.
PITCH ATTITUDE CONTROL:	Little bit loose, sluggish response.	Sluggish response.
VELOCITY CONTROL:	Trouble with it, fast 85 kts, but holding 85 was not a problem.	No problem.
APPROACH:		
PERFORMANCE:	Okay, approach aid no good.	Worked hard on approach.
INTERCEPT AND TRACKING:		Can do it but localizer too sensitive.
CONTROL TECHNIQUE:		Did use collective a fair amount.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		None.
LANDING?:		Yes.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	Only light patches.	None.
SUMMARY COMMENTS:		
GOOD FEATURES:	Damping is fair.	Can track fairly well.
OBJECTIONABLE FEATURES:	Feels loose, initial response slow, stick feels soft.	No specific comments, not happy with airplane.

ω_{ST}/ζ_{ST} :	1.7/0.37	PILOT RATINGS:		CONFIGURATION:	27
$2\zeta_{ST}\omega_{ST}$:	1.26	VFR:	4C	V_T/γ :	80/-7
$M_{\delta_{ES}}$:	0.39	OVERALL:	4C	PILOT:	B
FLIGHT NO.:	56F-35			WIND:	17 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Fair.	Fair.
FEEL CHARACTERISTICS:		Forces and displacements not match like they should be.
PITCH ATTITUDE CONTROL:	Moderate response in pitch, little sluggish, well damped.	Sluggish, tendency to overdrive the airplane, not very strong.
VELOCITY CONTROL:	Pretty good.	Little bit poor, because of poor set-up; overall fair.
APPROACH:		
PERFORMANCE:	Fair, but largely due to poor set-up for approach.	Fair, trouble lining up on localizer.
INTERCEPT AND TRACKING:		Rushed, no comments on tracking.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		No, but the stop on collective.
LANDING?:		No comments.
DIFFERENCES IFR/VFR:		None.
EFFECTS OF TURBULENCE:	Somewhat of a factor.	Shaken up more IFR.
SUMMARY COMMENTS:		
GOOD FEATURES:	Well damped, fair trimmability.	Good damping.
OBJECTIONABLE FEATURES:	Little sluggish, only minor objections.	Sluggish to some extent.

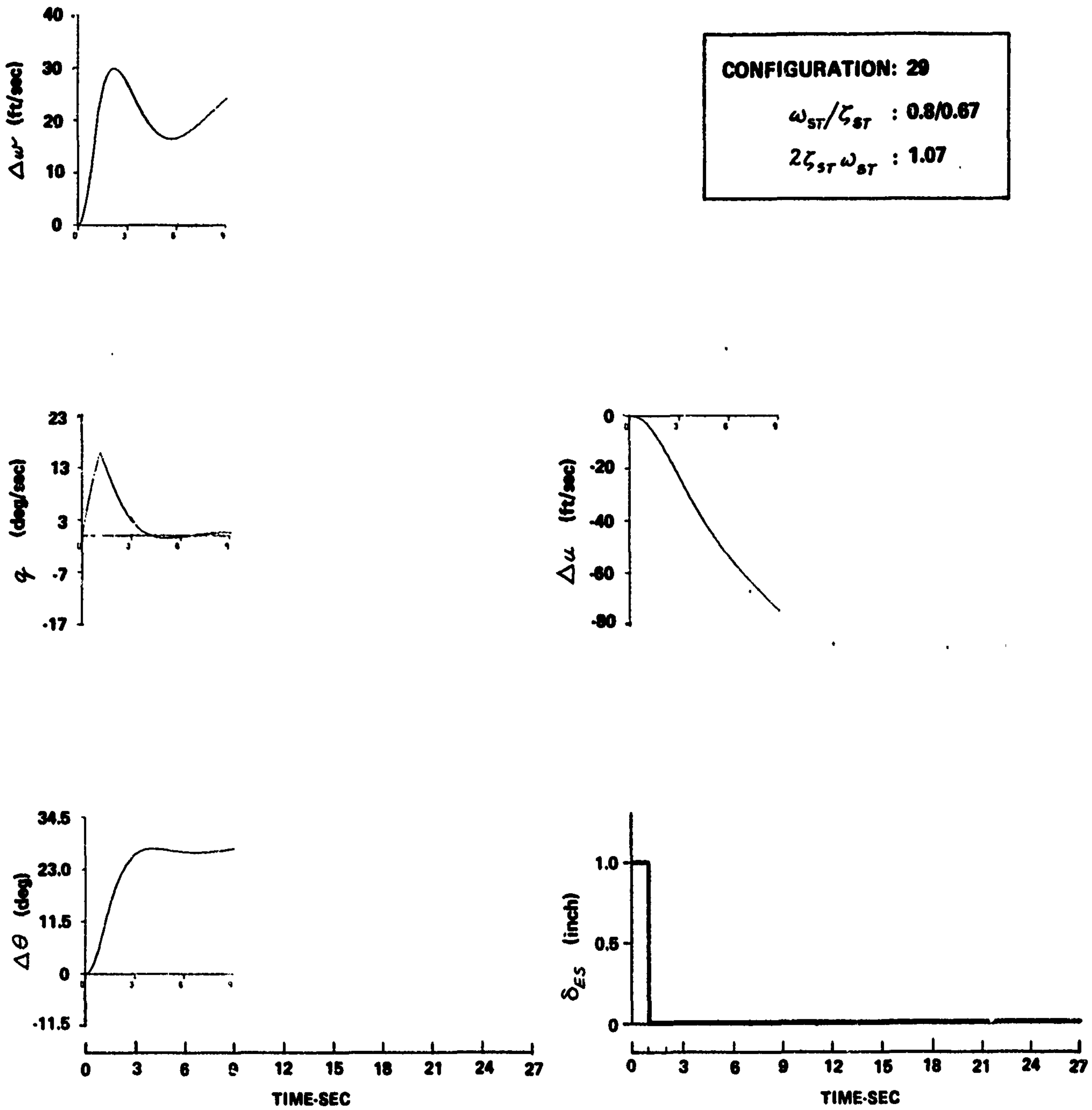
ω_{sp}/ζ_{sp}:	0.9/0.38	PILOT RATINGS:		CONFIGURATION:	28
$2\zeta_{sp}\omega_{sp}$:	0.68	VFR:	5C	V_T/γ:	80/-7
$M_{\delta_{ES}}$:	0.34	OVERALL:	7C	PILOT:	B
FLIGHT NO.:	56F-35			WIND:	20 (M)

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Some fiddling around required.	Degraded IFR.
FEEL CHARACTERISTICS:		Don't like them, displacements too large, forces okay.
PITCH ATTITUDE CONTROL:	Sluggish, large stick displacements required.	Very poor, better VFR, didn't like it, low frequency PIO on glide path. Typical low frequency compromise between initial and final response.
VELOCITY CONTROL:	No real problem.	Reasonable.
APPROACH:		
PERFORMANCE:	Little spotty, only fair.	Fair for middle portion, unacceptable near the end.
INTERCEPT AND TRACKING:		Difficult
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		No comments.
PROBLEMS:		Could stop quick but trying to establish wave-off attitude was very difficult.
LANDING?:		No, not sure, only in smooth air.
DIFFERENCES IFR/VFR:		A lot worse IFR, would change VFR to perhaps a 5.
EFFECTS OF TURBULENCE:	Fair amount of pitch disturbance with gusts - not really acceptable.	Large problems IFR.
SUMMARY COMMENTS:		
GOOD FEATURES:	Could track fairly well.	None.
OBJECTIONABLE FEATURES:	Sluggish response.	Can't control the pitch too well. Pilot should not be subjected to this type of airplane.


CONFIGURATION: 28
ω_{ST}/ζ_{ST} : 0.9/0.38
$2\zeta_{ST}\omega_{ST}$: 0.68
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

ω_{SP}/ζ_{SP}:	0.8/0.67	PILOT RATINGS:		CONFIGURATION:	29
$2\zeta_{SP}\omega_{SP}$:	1.07	VFR:	5A	V_T/γ:	80/-7
$M_{\delta_{ES}}$:	0.41	OVERALL:	7B	PILOT:	B
FLIGHT NO.:	57F-36			WIND:	10

	VFR COMMENTS	IFR COMMENTS
ABILITY TO TRIM:	Little bit of trouble with it.	Not very good at all.
FEEL CHARACTERISTICS:		Stick feels sloppy, displacements seem large, forces no problem.
PITCH ATTITUDE CONTROL:	Sluggish responding airplane, must overdrive airplane.	Sluggish and wants to take off, very difficult to fly the approach. Large control motions required.
VELOCITY CONTROL:	Trouble with this airplane; strong tendency to approach at 85 rather than 80.	Difficult to get time to concentrate on velocity with pitch attitude problems.
APPROACH:		
PERFORMANCE:	No comments.	Poor.
INTERCEPT AND TRACKING:		Intercept okay but tracking poor.
CONTROL TECHNIQUE:		No comments.
SIDESTEP MANEUVER:	No problem.	
LEVEL OFF:		
TECHNIQUE:		Nothing special, use collective.
PROBLEMS:		None
LANDING?:		No comments.
DIFFERENCES IFR/VFR:		Yes, IFR more problems.
EFFECTS OF TURBULENCE:	Only a little present.	Little bit of turbulence, harder to handle in turbulence.
SUMMARY COMMENTS:		
GOOD FEATURES:	None given.	None.
OBJECTIONABLE FEATURES:	Not easy to trim, pitch attitude control not precise.	Poor precision of pitch control, poor glide path control.



CONFIGURATION: 29
ω_{ST}/ζ_{ST} : 0.8/0.67
$2\zeta_{ST}\omega_{ST}$: 1.07
Δw (ft/sec)
q (deg/sec)
Δu (ft/sec)
$\Delta\theta$ (deg)
δ_{ES} (inch)
TIME-SEC
TIME-SEC

APPENDIX II

LONGITUDINAL TRANSFER FUNCTIONS AND DATA SUMMARY

In this appendix, the longitudinal transfer functions are developed in support of the discussions in the text and the data summary. The following equations of motion are used to represent the airplane for this purpose.

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{\theta} \\ \dot{q} \end{bmatrix} = \begin{bmatrix} X_u & 0 & -g & -w_o \\ Z_u & Z_w & -g\theta_o & u_o \\ 0 & 0 & 0 & 1 \\ M_u & M_w & 0 & M_q \end{bmatrix} \begin{bmatrix} u \\ w \\ \theta \\ q \end{bmatrix} + \begin{bmatrix} 0 & X_{\delta_c} \\ 0 & Z_{\delta_c} \\ 0 & 0 \\ M_{\delta_{ES}} & M_{\delta_c} \end{bmatrix} \begin{bmatrix} \delta_{ES} \\ \delta_c \end{bmatrix}$$

These equations imply that the reference axes are body axes and that the wings are always level. Small angles are assumed, therefore:

$$u_o \simeq V_T \quad \text{, the true airspeed}$$

$$\alpha_o \simeq \frac{w_o}{V_T}$$

In addition, X_w, $M_{\dot{w}}$, $X_{\delta_{ES}}$, and $Z_{\delta_{ES}} \simeq 0$. The variables u, $w(\alpha)$, θ and $\delta_{ES,C}$ are incremental values from the reference condition.

The transfer functions for longitudinal stick inputs which follow are written in "lumped" derivative form. The specific derivatives which comprise each lumped parameter in the transfer function can easily be derived from the equations.

$$\frac{u}{\delta_{ES}} = \frac{K_u\left(s + \frac{1}{T_{u_1}}\right)\left(s + \frac{1}{T_{u_2}}\right)}{\underbrace{\left(s^2 + 2\zeta_p\omega_p\, s + \omega_p^2\right)}_{D_1}\underbrace{\left(s^2 + 2\zeta_{ST}\,\omega_{ST}\, s + \omega_{ST}^2\right)}_{D_2}}$$

$$\frac{\alpha}{\delta_{ES}} = \frac{K_\alpha\left(s^2 + 2\zeta_\alpha\,\omega_\alpha s + \omega_\alpha^2\right)}{D_1 D_2}$$

$$\frac{\theta}{\delta_{ES}} = \frac{K_\theta\left(s + \frac{1}{T_{\theta_1}}\right)\left(s + \frac{1}{T_{\theta_2}}\right)}{D_1 D_2}$$

where

$$K_u = -\alpha_o V_T M_{\delta_{ES}}$$

$$K_\alpha = M_{\delta_{ES}}$$

$$K_\theta = M_{\delta_{ES}}$$

Constant Speed Expressions:

If the assumptions of constant speed and $\theta_o = 0$ are now made, it can be shown that:

$$\omega_{ST}^2 = -M_\alpha + M_q \frac{Z_\alpha}{V_T}$$

$$2\zeta_{ST}\omega_{ST} = -\frac{Z_\alpha}{V_T} - M_q$$

$$\frac{1}{T_{\theta_2}} = -\frac{Z_\alpha}{V_T} = -Z_w \qquad (Z_{\delta_{ES}} \simeq 0)$$

Further, the expressions for n_z/α and F_{ES}/n_z, which by definition are measured at constant speed, are:

$$\frac{n_z}{\alpha} = \frac{-Z_\alpha}{g}$$

and

$$\frac{F_{ES}}{n_z} = \frac{\omega_{ST}^2}{M_{\delta_{ES}} \left(\frac{\delta_{ES}}{F_{ES}}\right)_{SS} \frac{n_z}{\alpha}}$$

$$\frac{F_{ES}}{n_z} = \frac{\omega_{ST}^2}{M_{F_{ES}} (n_z/\alpha)}$$

Data Summary

The following tables represent a complete summary of the characteristics for all the configurations evaluated in the program. The characteristics documented therein were primarily obtained by identification of level flight calibration records as discussed in Appendix III. It is worth noting here that, although the characteristics are determined for level flight, they do not change

Table II-1
DATA SUMMARY FOR EVALUATION CONFIGURATIONS

CONFIGURATION NUMBER	FLIGHT NO.	V_T/γ kt/deg	PILOT	WIND kt	ω_{ST} rad/sec	ζ_{ST} —	$2\zeta_{ST}\omega_{ST}$ rad/sec	$M_{\delta_{ES}}$ $\frac{rad/sec^2}{in.}$	$M_{F_{ES}}$ $\frac{rad/sec^2}{lb}$	$\frac{F_{ES}}{n_y}$ lb/g	PILOT RATING AND TURBULENCE RATING: VFR	PILOT RATING AND TURBULENCE RATING: OVERALL
1	40F-24	65/-9	A	10	2.6	0.04	0.21	0.34	0.045	86	7D	7D
2	43F-27	65/-9	A	6	2.6	0.10	0.52	0.54	0.072	56	4.5C	5B
3 (M) *	38F-22	65/-9	A	11	2.6	0.20	1.04	0.41	0.055	70	6D	6E
3	41F-25	65/-9	A	5	2.6	0.20	1.04	0.41	0.055	70	3B	2.5B
3	43F-27	65/-9	A	11	2.6	0.20	1.04	0.54	0.072	54	3C	3C
4 (M)	39F-23	65/-9	A	10	2.6	0.24	1.25	0.32	0.043	92	5D	5E
4	43F-27	65/-9	A	5	2.6	0.24	1.25	0.49	0.065	61	2B	–
4 (M)	51F-31	65/-6	A	20	2.6	0.24	1.25	0.36	0.048	82	4D	5D
4 (M)	54F-33	65/-9	B	14	2.6	0.24	1.25	0.44	0.059	67	4C	4C
5	40F-24	65/-9	A	14	2.6	0.35	1.82	0.49	0.065	61	2B	1.5B
5 (M)	42F-26	65/-9	A	15	2.6	0.35	1.82	0.54	0.072	55	2C	3E
6 (M)	39F-23	65/-9	A	11	2.0	0.09	0.36	0.32	0.043	54	6.5F	7F
6 (M)	42F-26	65/-9	A	15	2.0	0.09	0.36	0.49	0.065	35	6F	7F
6	48F-29	65/-9	A	6	2.0	0.09	0.36	0.44	0.059	39	5B	6B
7 (M)	50F-30	65/-9	A	14	2.0	0.16	0.64	0.33	0.044	52	5E	6F
8	41F-25	65/-9	A	8	2.0	0.23	0.92	0.44	0.059	38	2B	3B
8 (M)	51F-31	65/-6	A	17	2.0	0.23	0.92	0.39	0.052	43	2D	2.5D
8 (M)	54F-33	65/-9	B	15	2.0	0.23	0.92	0.39	0.052	43	4D	4D
9	40F-24	65/-9	A	13	2.0	0.31	1.24	0.49	0.065	34	3B	–
10	36F-21	65/-9	A	10	2.1	0.44	1.85	0.41	0.055	47	3C	2.5C
11 (M)	38F-22	65/-9	A	20	1.5	0.09	0.27	0.34	0.045	30	6D	6F
11	48F-29	65/-9	A	12	1.5	0.09	0.27	0.33	0.044	31	6D	8D
11 (M)	51F-31	65/-6	A	20	1.5	0.09	0.27	0.36	0.048	28	7F	8F
12 (M)	50F-30	65/-9	A	15	1.5	0.14	0.42	0.39	0.052	25	4D	6E
13	41F-25	65/-9	A	5	1.7	0.34	1.16	0.36	0.048	34	2B	2B
13 (M)	42F-26	65/-9	A	12	1.7	0.34	1.16	0.39	0.052	32	4E	3E
13 (M)	51F-31	65/-6	A	10	1.7	0.34	1.16	0.36	0.048	34	3.5D	3E
13 (M)	54F-33	65/-9	B	17	1.7	0.34	1.16	0.32	0.043	38	3C	3C
14 (M)	39F-23	65/-9	A	12	1.4	0.55	1.54	0.36	0.048	26	3C	3D
14	43F-27	65/-9	A	8	1.4	0.55	1.54	0.35	0.047	25	4B	4B
15 (M)	38F-22	65/-9	A	12	0.9	0.30	0.54	0.29	0.039	13	7F	8F
15	43F-27	65/-9	A	8	0.9	0.30	0.54	0.19	0.025	19	7C	8C
16	48F-29	65/-9	A	8	1.0	0.36	0.72	0.44	0.059	10	6C	7C
17 (M)	39F-23	65/-9	A	12	1.0	0.57	1.14	0.32	0.043	15	3D	4E
17	41F-25	65/-9	A	8	1.0	0.57	1.14	0.36	0.048	13	2B	2.5B
18	40F-24	65/-9	A	14	1.2	0.79	1.90	0.44	0.059	14	3C	4C
18 (M)	42F-26	65/-9	A	12	1.2	0.79	1.90	0.35	0.047	18	2D	2D
18 (M)	50F-30	65/-9	A	12	1.2	0.79	1.90	0.36	0.048	18	3.5D	4E
**19	48F-29	65/-9	A	12	–	–	–	0.36	0.048	–	7D	8D
**20 (M)	50F-30	65/-9	A	12	–	–	–	0.36	0.048	–	6E	6F
21	59F-38	80/-7	B	10	2.4	0.16	0.77	0.34	0.045	45	5.5A	–
22	57F-36	80/-7	B	8	2.5	0.25	1.25	0.34	0.045	46	2A	2A
23 (M)	56F-35	80/-7	B	22	2.6	0.32	1.66	0.46	0.061	39	3C	3C
24	57F-36	80/-7	B	10	2.2	0.16	0.70	0.34	0.045	38	3A	3.5A
25	57F-36	80/-7	B	8	2.0	0.28	1.12	0.39	0.052	26	2A	2A
26	57F-36	80/-7	B	10	1.4	0.20	0.56	0.34	0.045	15	2A	2A
27 (M)	56F-35	80/-7	B	17	1.7	0.37	1.26	0.39	0.052	18	4C	4C
27	59F-38	80/-7	B	10	0.37	1.26	0.30	0.040	24	24	4.5A	4A
28 (M)	56F-35	80/-7	B	20	0.9	0.38	0.68	0.34	0.045	6	5C	7C
29	57F-36	80/-7	B	10	0.8	0.67	1.07	0.41	0.055	4	5A	7B

*(M) - Moderate Turbulence **Short-Term Dynamics Could Not be Identified

markedly in descent. The primary effect is seen in the numerator zero $1/\tau_{u_2}$ of the u/δ_{ES} transfer function, which changes sign as u_0 changes sign; in general, however, this effect is not significant. The phugoid frequency and damping were generally affected by no more than 10% for the changes from $\gamma = 0°$ to $\gamma = -9°$ investigated in this experiment.

Table II-2

PHUGOID CHARACTERISTICS

CONFIGURATION	ω_p / ζ_p	λ_1 / λ_2
14	–	-0.20/ 0.13
16	–	-0.14/ 0.08
29	–	-0.06/-0.01
ALL OTHERS	0.20/0.35	–

WHERE λ_1 AND λ_2 ARE REAL ROOTS, rad/sec.

The numerator characteristics, or zeros, of the δ_{ES} transfer functions do not change as the denominator roots are varied with the X-22A variable stability system using only feedback terms to the X-22A longitudinal control. Table II-3 summarizes the numerator zeros for the u/δ_{ES}, α/δ_{ES} and θ/δ_{ES} transfer functions for each flight condition.

Table II-3

NUMERATOR ZEROS

FLIGHT COND.	n_z/α	$1/\tau_{u_1}$	$1/\tau_{u_2}$ *	ω_α	ζ_α	$1/\tau_{\theta_1}$	$1/\tau_{\theta_2}$
65	1.7	0.50	-5.0	0.27	0.38	0.22	0.50
80	2.9	0.68	+4.6	0.24	0.30	0.13	0.68

* AVERAGE VALUE

To complete the data summary, the thrust control derivatives are presented in Table II-4.

Table II-4

THRUST CONTROL CHARACTERISTICS

FLIGHT COND.	X_{δ_C}	Z_{δ_C}	M_{δ_C}
65	1.32	-2.20	0.094
80	1.51*	-1.59*	0.033*

* ESTIMATED

The estimated stability derivatives, from which these modal characteristics were calculated, were determined by the identification techniques discussed in Appendix III, and are presented in Table II-5.

Table II-5

ESTIMATED STABILITY DERIVATIVES OF THE EVALUATION CONFIGURATIONS

A – 65 Kt

X_u = −0.22 sec^{-1}	Z_u = −0.25 sec^{-1}
X_w = 0.0 sec^{-1}	Z_w = −0.50 sec^{-1}
$X_{\delta_{ES}}$ = 0.0 ft/sec^2/inch	$Z_{\delta_{ES}}$ = 0.0 ft/sec^2/inch

CONFIG.	M_u, rad/ft-sec	M_w, rad/ft-sec	M_q, 1/sec
1	-0.009	-0.0611	+0.362
2	-0.009	-0.060	+0.013
3	-0.009	-0.057	-0.437
4	-0.009	-0.0478	-0.629
5	-0.009	-0.054	-1.23
6	-0.009	-0.0345	+0.242
7	-0.009	-0.0329	+0.047
8	-0.009	-0.0327	-0.30
9	-0.009	-0.0304	-0.61
10	-0.009	-0.0304	-1.26
11	-0.0037	-0.0222	+0.294
12	-0.0037	-0.0209	+0.146
13	-0.0024	-0.0216	-0.572
14	-0.009	-0.0116	-0.899
15	-0.0017	-0.00775	+0.05
16	-0.0048	-0.00816	-0.057
17	-0.00112	-0.00654	-0.579
18	+0.0006	-0.00655	-1.33

B – 80 Kt

X_u = −0.13 sec^{-1}	Z_u = −0.24 sec^{-1}
X_w = 0.0 sec^{-1}	Z_w = −0.68 sec^{-1}
$X_{\delta_{ES}}$ = 0.0 ft/sec^2/inch	$Z_{\delta_{ES}}$ = 0.0 ft/sec^2/inch

CONFIG.	M_u, rad/ft-sec	M_w, rad/ft-sec	M_q, 1/sec
21	-0.009	-0.0437	-0.051
22	-0.009	-0.042	-0.50
23	-0.009	-0.0468	-0.99
24	-0.009	-0.0370	+0.035
25	-0.009	-0.0271	-0.330
26	-0.0037	-0.016	+0.18
27	-0.0037	-0.0178	-0.38
28	-0.0017	-0.00575	+0.124
29	-0.0010	-0.00290	-0.335

APPENDIX III

IDENTIFICATION OF EVALUATION CONFIGURATIONS

Other than the performance of the evaluation flights, the most extensive effort on this experiment involved the development of a digital data acquisition and processing system and the subsequent identification of the evaluation configuration dynamic characteristics from flight data. The data acquisition and processing system is described in Appendix V; this appendix will discuss the identification of the evaluation configurations and present representative results. It should be clear that the knowledge of the descriptors of the dynamic characteristics of the simulated aircraft that were evaluated is of prime importance in a flight research program using a variable stability aircraft. As this experiment was the first to use the X-22A as a flying qualities research tool, the problem of the identification of these descriptors from flight records received a major amount of attention. Two different methods of identification were employed and will be discussed.

Analog Matching Identification

The discussion of this "classical" method of identification of dynamic characteristics from flight data will be brief, as the techniques are well known (Reference 20). During the early part of the program, analog matching methods were used as the primary identification technique for two reasons:

1. The digital data processing capability was not completed until late in the program.

2. Analog matching of linear systems is a rapid post-flight technique for estimating the dynamic characteristics achieved. This rapidity is particularly desirable when a large number of candidate configurations must be analyzed to choose suitable evaluation configurations.

Three different implementations of the analog matching technique were used, and are briefly described in the following paragraphs.

The simplest and most rapid method of analog matching the response of a second-order linear system is free-response matching of the frequency and damping. For aircraft which have relatively well separated short period and phugoid characteristic roots, the dynamic response to a longitudinal doublet input is essentially constant speed over several periods of the short period response; hence, for this time, the dynamics of the aircraft may be approximated as a second order system, and free-response analog matching may be accomplished. This technique is particularly amenable to obtaining rapid estimates of the short period (short term) dynamic characteristics (ω_{sT}, ζ_{sT}) of a large number of candidate configurations, and was used in this experiment to select the configurations whose dynamics were approximately those desired.

The second method of analog matching used in this experiment involved programming the three-degree-of-freedom linear longitudinal equations of motion on an analog computer. To exactly reproduce the input used to obtain the flight records, the test input unit from the aircraft was used to generate the analog computer input. The computer-generated responses in φ, θ and α were then compared with the flight records and the stability derivatives on the analog computer adjusted to produce the desired match. This method, while a good deal more time consuming than the free-response method, has the advantage that all responses of the total fourth order system are matched, thereby yielding a consistent set of stability derivatives. Flight records of almost all of the configurations actually evaluated were identified with this technique as a back-up to the digital identification to be discussed shortly.

The third type of analog matching employed during this experiment was not used primarily for identification per se, but rather for general studies of X-22A flight dynamics. In this case, the programmed equations of motion included nonlinear kinematic and gravitational terms, and the actual pilot inputs, which are recorded as discussed in Appendix V, were played back to serve as the computer input. With this technique, then, no specific calibration input is required, and the matched time histories can be of quite long duration. This technique was used to demonstrate the validity of linearizing the gravitational and kinematic effects for the flight conditions investigated in this experiment.

Advanced Kalman Filter Digital Identification

This experiment was the first flying qualities research program to employ the advanced Kalman filter digital identification technique developed by CAL (Reference 21). This technique offers increased accuracy and efficiency of the identification process, and its successful use on a semiproduction type basis during this program marks a significant increase in this capability. In this section, the technique itself is briefly reviewed, the data processing required to transform the recorded X-22A flight data into the proper form for identification is outlined, and representative examples of the identification results are presented.

The Kalman filter technique used in this program is the most recent of the many identification techniques that the advent of the digital computer has made possible. The digital computer has introduced the capability of handling large amounts of data in equations that need to be solved numerically. This capability led first to so-called "equation error" techniques, such as the well known equations-of-motion method, and then to more advanced "response-error" techniques, usually called by the name of the computer technique used, such as "quasilinearization" or "Newton-Raphson."

The merits or debits of all these techniques are a function of the quality of their parameter estimates in the presence of various types of uncertainty, or noise. For the aircraft problem, as well as most others, there are two types of noise that are of importance:

(1) Measurement noise. The parameters of the mathematical model are estimated in all cases by making use of measurements of the state of the system (e.g., velocity, attitude, etc.) over a time span. Since no measurement is perfect, these state measurements will have uncertainties, or noise, which will affect the parameter estimates.

(2) Process noise. Process noise may, in general, consist of unknown random inputs to the system (e.g., gusts, fuel change) and any errors in the mathematical model (e.g., neglecting a stability derivative in the model).

Essentially, equation-error techniques give biased estimates in the presence of measurement noise, and pure response-error techniques give biased estimates in the presence of process noise. Although response-error techniques such as quasilinearization can be shown to exhibit certain advantages over equation-error techniques, experience has shown that they still remain extremely vulnerable to problems such as nonuniqueness.

Without going into the mathematical details, the identification technique developed by CAL circumvents many of these difficulties by employing a very powerful three-stage refining process:

(1) Initial estimates of the parameters, and their variances, in the assumed equations are obtained by a method that is essentially an equation-error technique. Since the variances obtained by this method are somewhat underestimated, an improved variance estimate, employing the parameters estimated above, is obtained by a Cramer-Rao lower bound computation.

(2) An extended Kalman filter, utilizing a "local iteration" or "multi-correction" algorithm, is used to refine the initial estimates of the parameters. Although the extended Kalman filter gives biased estimates when applied to a nonlinear problem, which is inherent to parameter identification, it can be shown that the multi-correction scheme reduces biases due to nonlinearities by improving the reference trajectory between data points.

(3) A fixed-point smoothing algorithm, which actually works in conjunction with the multi-corrector at each data point, is used to further refine the parameter estimates and separate out the effects of process noise. This step is extremely important as a first attempt at determining the mathematical modeling error, as well as improving the parameter estimates. Also, a more accurate variance computation of the parameter estimate is obtained.

A simplified block diagram of this process is shown in Figure III-1.

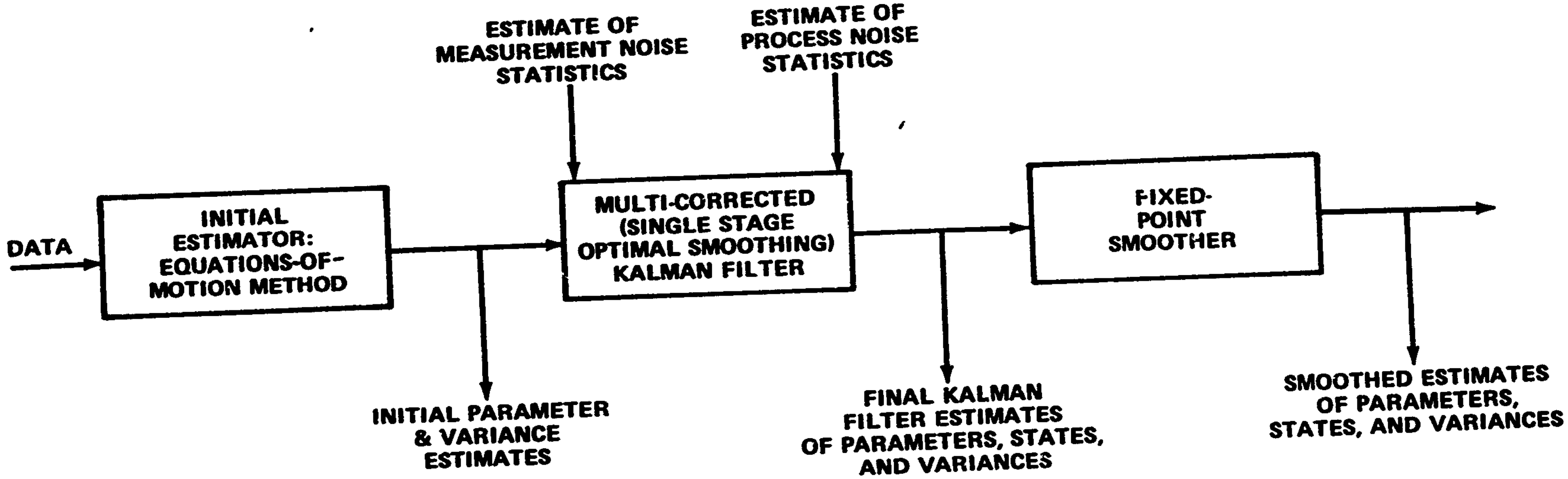


Figure VII-1 SCHEMATIC DIAGRAM OF KALMAN FILTER DIGITAL IDENTIFICATION PROCESS

For this experiment, it was desired to obtain the best identification of the parameters in a set of equations with linear aerodynamics, which analog matching studies had shown to be a suitable approximation. The equations used were

$$\dot{u} + wq + g\sin\theta = X_0 + X_u(u - u_0) + X_w(w - w_0) + X_{\delta_{ES}}(\delta_{ES} - \delta_{ES_0}) + X_{\delta_C}(\delta_C - \delta_{C_0})$$

$$\dot{w} - uq - g\cos\theta = Z_0 + Z_u(u - u_0) + Z_w(w - w_0) + Z_{\delta_{ES}}(\delta_{ES} - \delta_{ES_0}) + Z_{\delta_C}(\delta_C - \delta_{C_0})$$

$$\dot{q} = M_0 + M_u(u - u_0) + M_w(w - w_0) + M_q(q - q_0) + M_{\delta_{ES}}(\delta_{ES} - \delta_{ES_0}) + M_{\delta_C}(\delta_C - \delta_{C_0})$$

The calibration records were always taken in smooth air, and hence process noise was assumed absent; the fixed point smoothing algorithm, therefore, was not used for most of the identification runs.

To perform digital identification using the equations given above, a fairly involved data processing procedure is required to transform the recorded flight data into a suitable format. A description of the general process is given in Appendix V; details pertinent to this specific problem are reviewed in the following paragraphs.

First, the flight data are digitally filtered by a third-order Butterworth filter with the one-way transfer function:

$$G(s) = \frac{1}{1 + 2\left(\frac{s}{\omega_0}\right) + 2\left(\frac{s}{\omega_0}\right)^2 + \left(\frac{s}{\omega_0}\right)^3}, \quad \omega_0 = 12\pi \text{ rad/sec}$$

The digital filtering was required to reduce the sampling rate used in the Kalman filter program to 1/0.08 samples/sec without introducing aliasing errors, and, further, to increase the accuracy of the equation-error estimate. The filtering is performed by passing the data through the above filter in a forward fashion, reversing it in time, and passing it through the filter again. By performing the filtering in this manner, no phase shift is introduced into the data, but high frequencies are doubly attenuated.

Second, the necessary transformations are performed to convert the measured variables to those used in the equations of motion. Specifically, the body X-velocity (u) and Z-velocity (w) are calculated as follows from the measurements:

$$u = u_m + q_m \ell_{z_t}$$

$$w = u \tan\alpha_{v_m} + q_m \ell_x = u_m \tan\alpha_{v_m} + q_m(\ell_{z_t} \tan\alpha_{v_m} + \ell_x)$$

where ℓ_{z_t} = 15.5 ft (height of vertical tail to u-LORAS)

ℓ_x = 23.0 ft (length from α-vane on boom to center of gravity)

$(\ )_m$ = measured value.

The data processing and digital identification procedure may therefore be summarized as follows. The flight data of interest that are recorded on-line by the "bit-stream" recorder are edited and placed into IBM 370/65 compatible format by the mini-computer and re-recorded onto digital tape (see Appendix V for a description of these units). In this form, the data are transformed to the appropriate variables and digitally filtered as described above, edited to be compatible with the Kalman filter identification computer programs, and again re-recorded into a final data tape.

This final data tape is then used to obtain initial parameter estimates using an equation error method. The outputs of this initial estimation procedure are essentially these initial parameter values and an indication of the accuracy of the estimates (the variances). Inputs required for the Kalman filter program are:

(1) Reference conditions

(2) Measurement noise statistics (rms)

(3) Process noise statistics (rms)

(4) Initial parameter estimates

(5) Variances of the initial estimates

The parameter estimates obtained from the equation-error initial estimator are used as the initial guesses for the Kalman filter, but since the variances of the equation-error estimator calculated are generally optimistic (too small), they are multiplied by ten (10) to be used as Kalman filter inputs. The reference conditions are obtained from the final data tape; since the calibration records are taken about trimmed flight, the first data point of the record generally is an accurate enough reference value. As was previously mentioned, since the calibration records are obtained in turbulence-free air and since the best fit to the assumed linear equations is desired, process noise is assumed absent. The measurement noise statistics were obtained from analyses of the flight records, and those used for the identification runs were:

σ_u = 1.0 ft/sec

σ_w = 0.25 ft/sec

σ_θ = 0.15 deg

σ_q = 0.1 deg/sec

At this point it should be noted that there is an option in the Kalman filter identification technique which allows the inclusion of acceleration measurements if desired. In general, as was shown in Reference 20, the use of the acceleration measurements tends to provide better estimates of the parameters; in particular, it is obvious that the control derivatives should be more accurately identified. In this experiment, however, the n_x measurement was extremely inaccurate due to an accelerometer malfunction, and the quality of the n_z measurement was compromised by a bias introduced by accelerometer stiction.* The results that are presented in this appendix were therefore obtained without using the acceleration measurements.

The outputs of the Kalman filter program are the values of the stability and control derivatives in the assumed equations of motion and the variances of these parameter estimates, which give an indication of their accuracy. The transfer functions, which are given in Appendix II, are then obtained from the following equations with the identified stability and control derivatives substituted:

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{\theta} \\ \dot{q} \end{bmatrix} = \begin{bmatrix} X_u & X_w & -g & -w_0 \\ Z_u & Z_w & -g & u_0 \\ 0 & 0 & 0 & 1 \\ M_u & M_w & 0 & M_q \end{bmatrix} \begin{bmatrix} u \\ w \\ \theta \\ q \end{bmatrix} + \begin{bmatrix} X_{\delta_{ES}} & X_{\delta_c} \\ Z_{\delta_{ES}} & Z_{\delta_c} \\ 0 & 0 \\ M_{\delta_{ES}} & M_{\delta_c} \end{bmatrix} \begin{bmatrix} \delta_{ES} \\ \delta_c \end{bmatrix}$$

Most of the configurations evaluated at 65 kt (configurations 1-18) were identified with the Kalman filter process as described, and representative examples are shown in Figures III-2-III-9. In each case, the crosses are the recorded flight data, and the solid lines are the response of the equations with the identified derivatives. As can be seen from the figures, the matching of the state variables is very good; this fact in conjunction with the fact that the Kalman filter and analog matching results are in good agreement supports the validity of the answers.

*This bias was identified by modifying the input-output data to the Kalman filter in a separate identification, and was approximately 1 ft/sec^2.

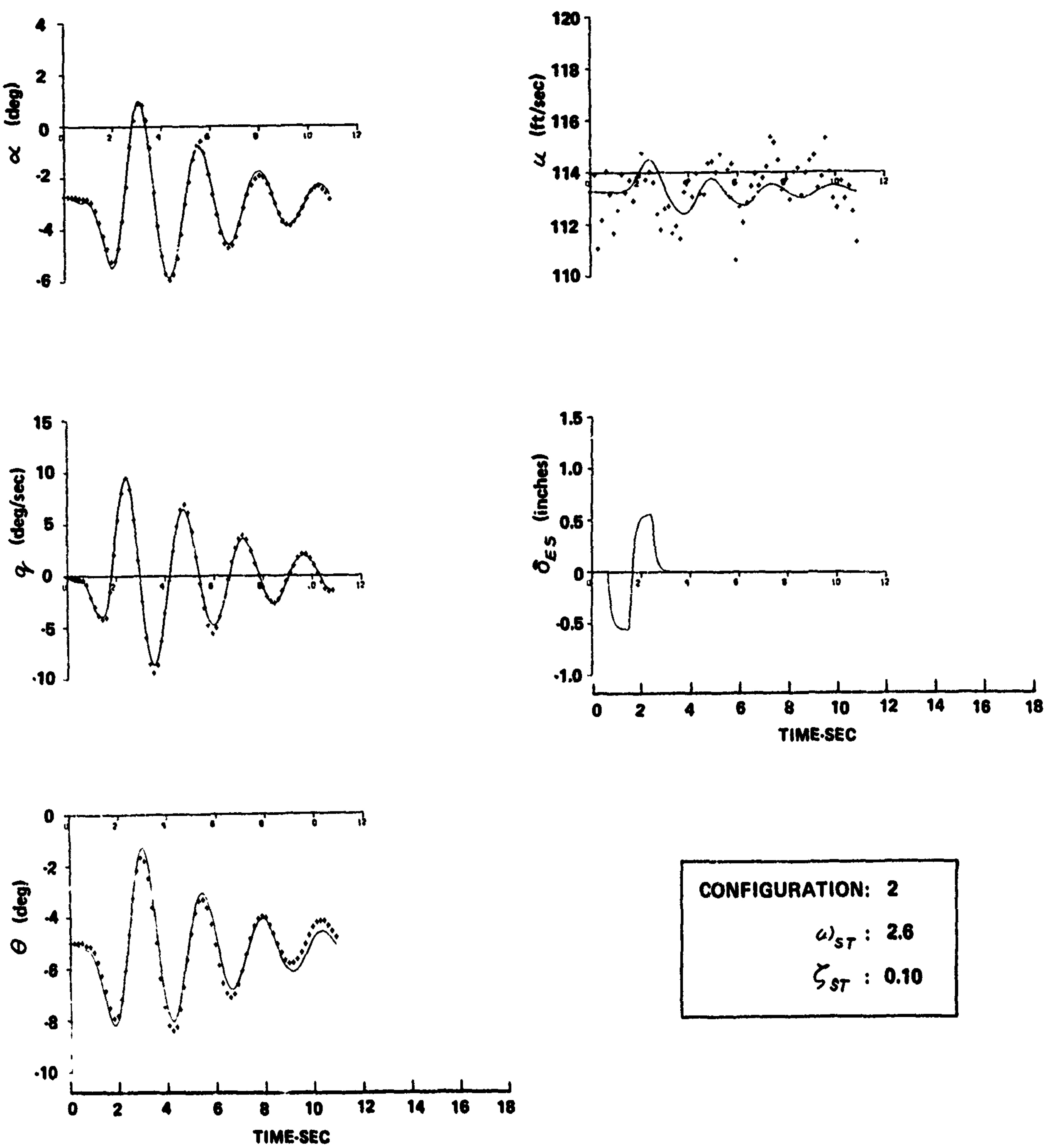


Figure III-3 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 2

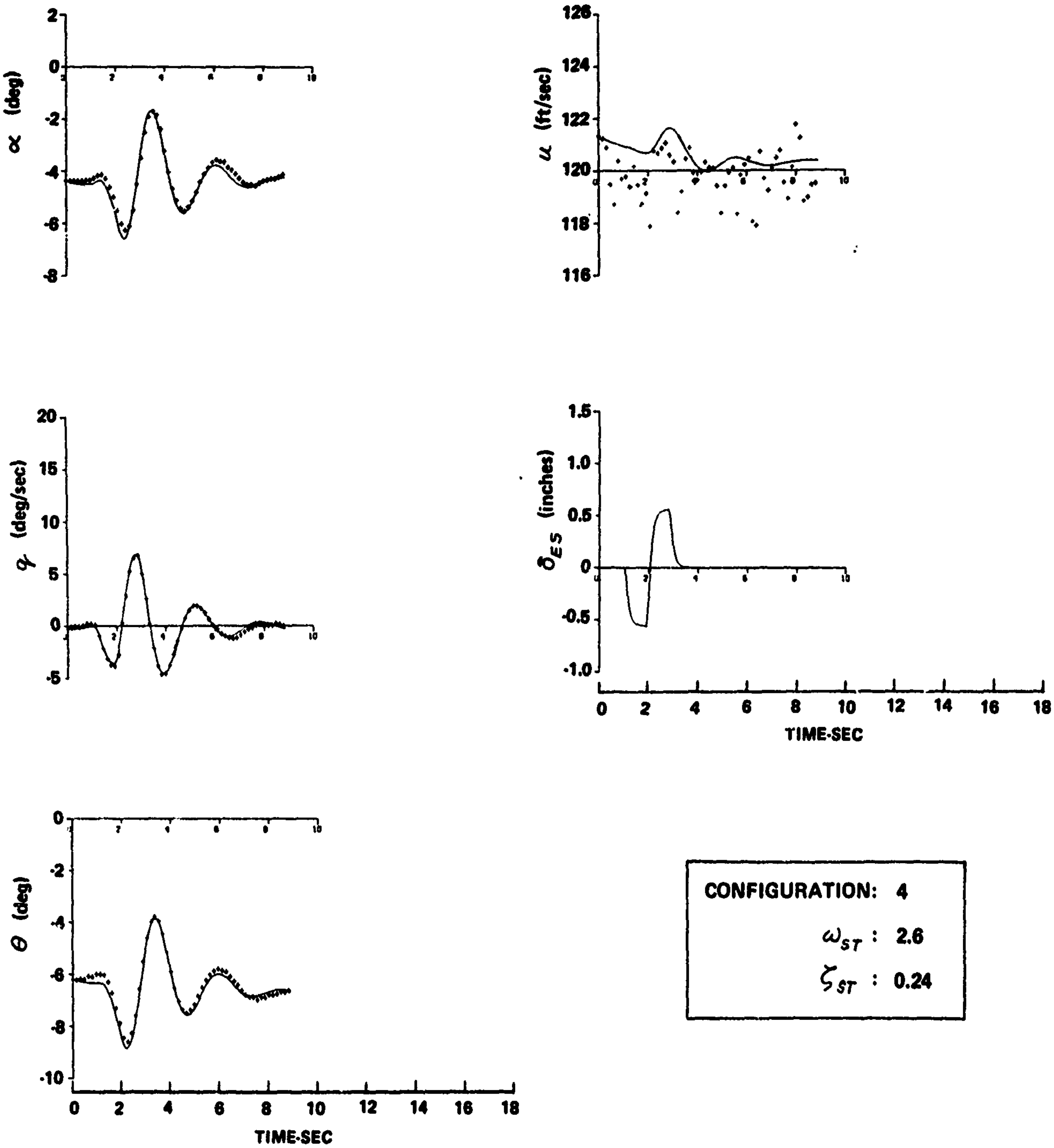


Figure III-4 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 4

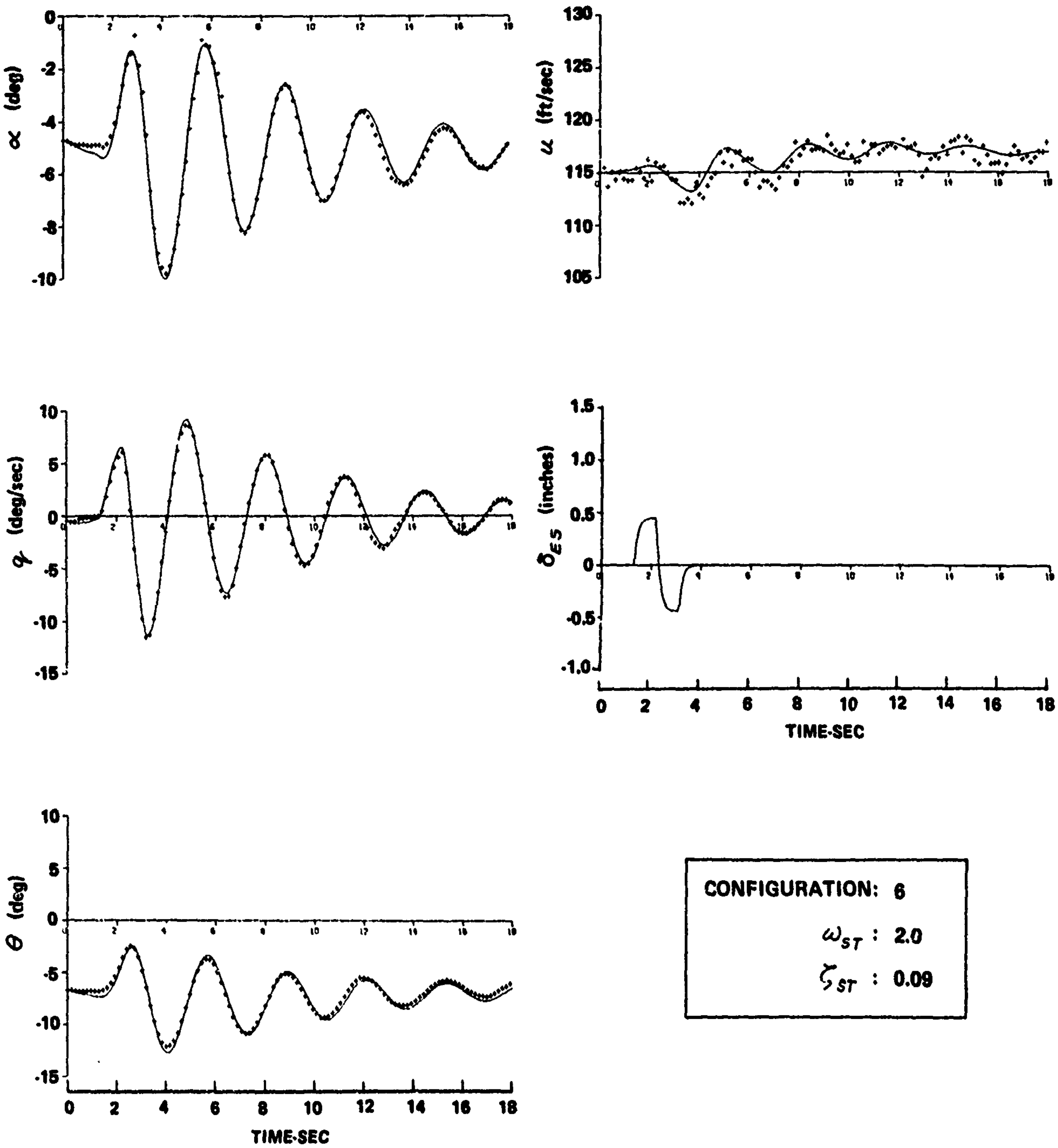


Figure III-5 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 6

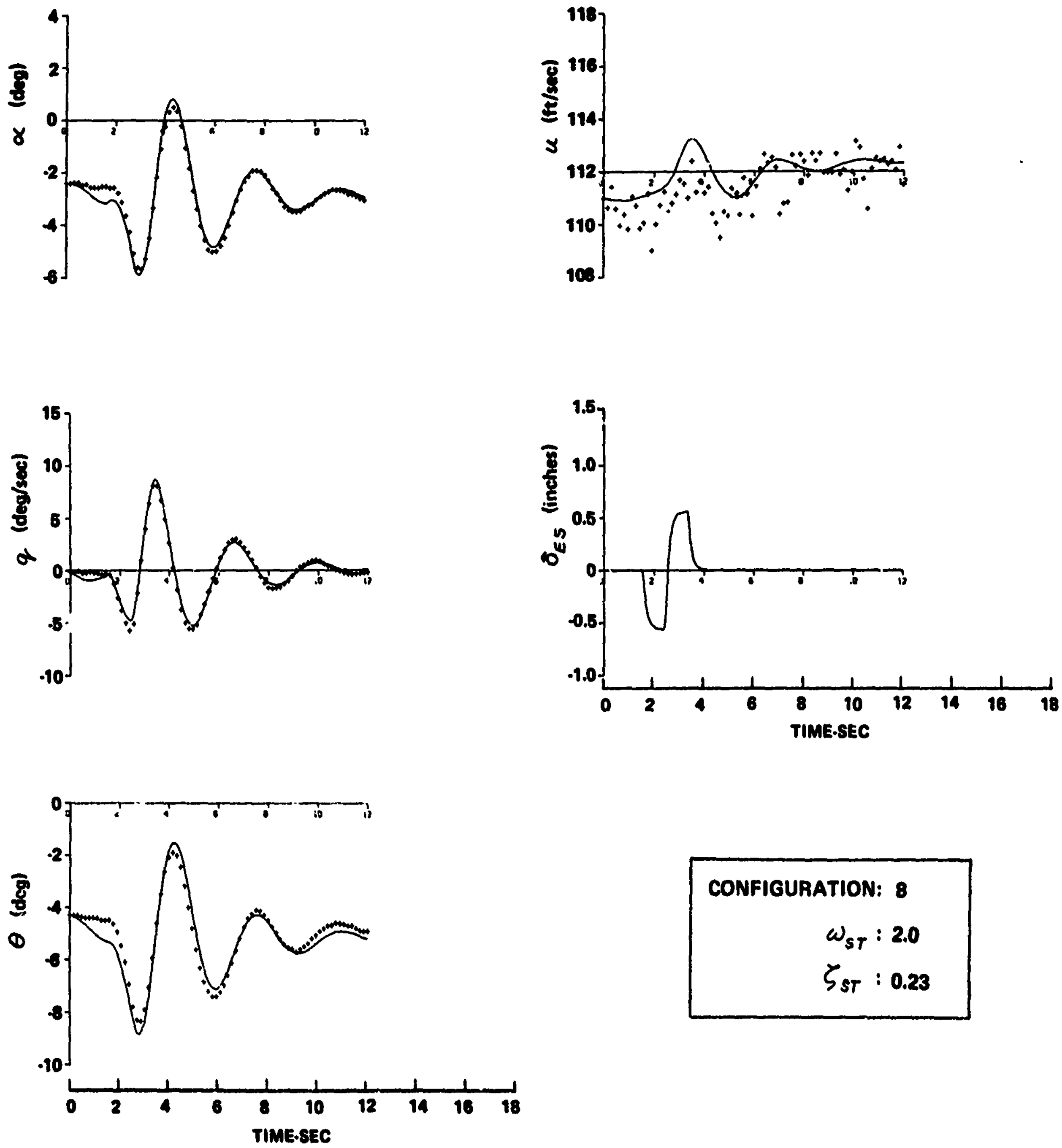


Figure III-6 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 8

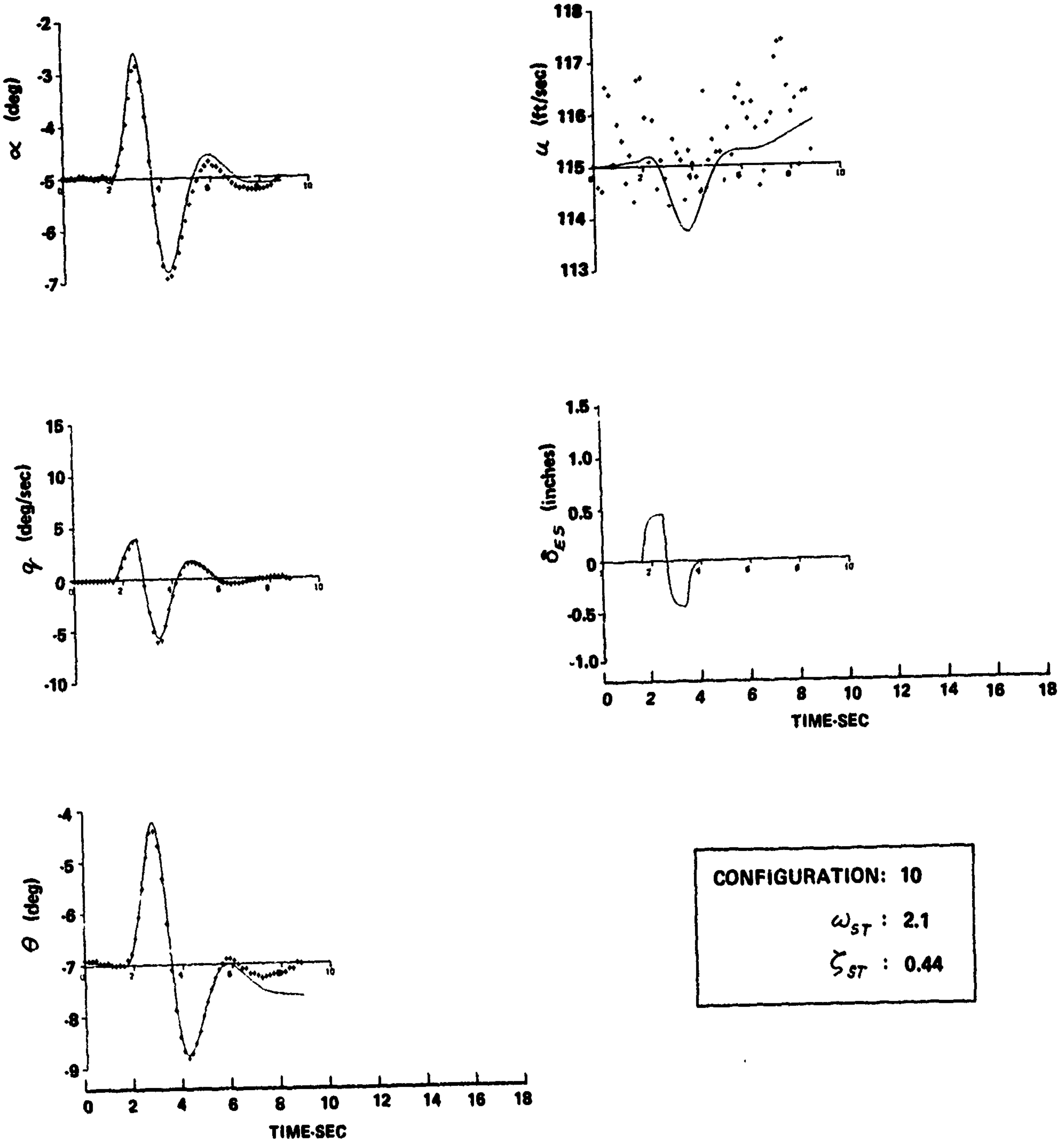


Figure III-7 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 10

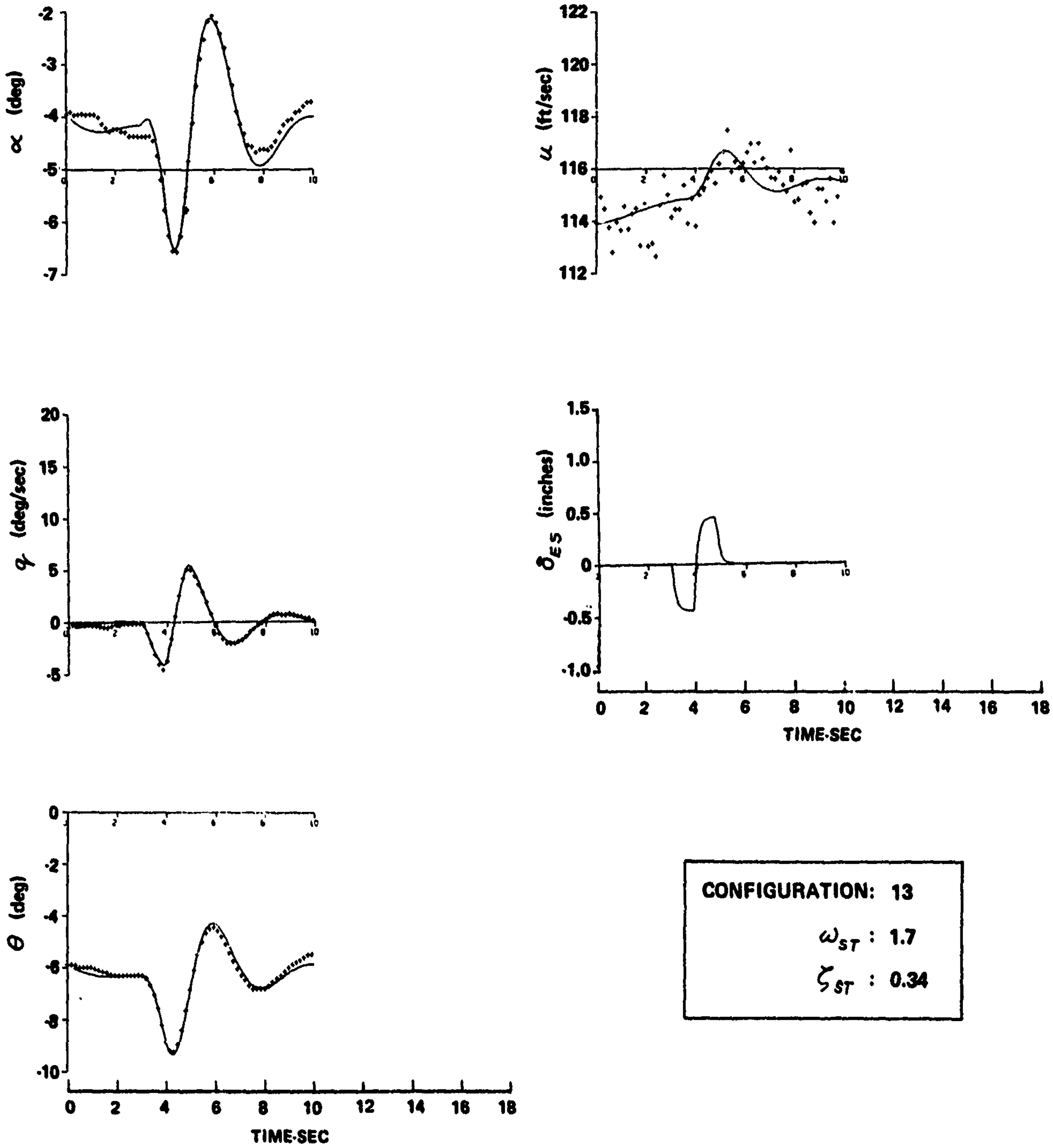


Figure III-8 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 13

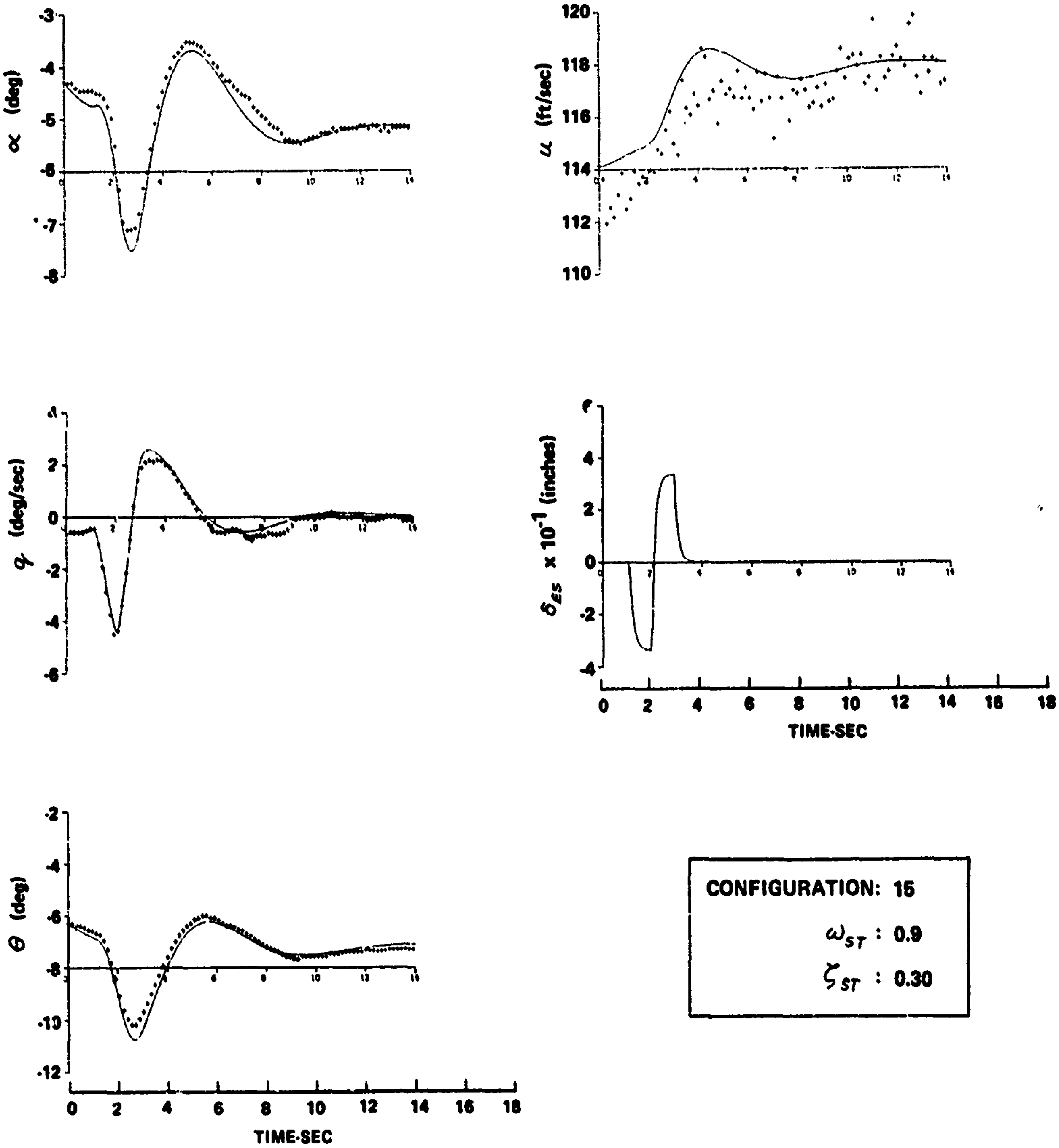


Figure III-9 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 15

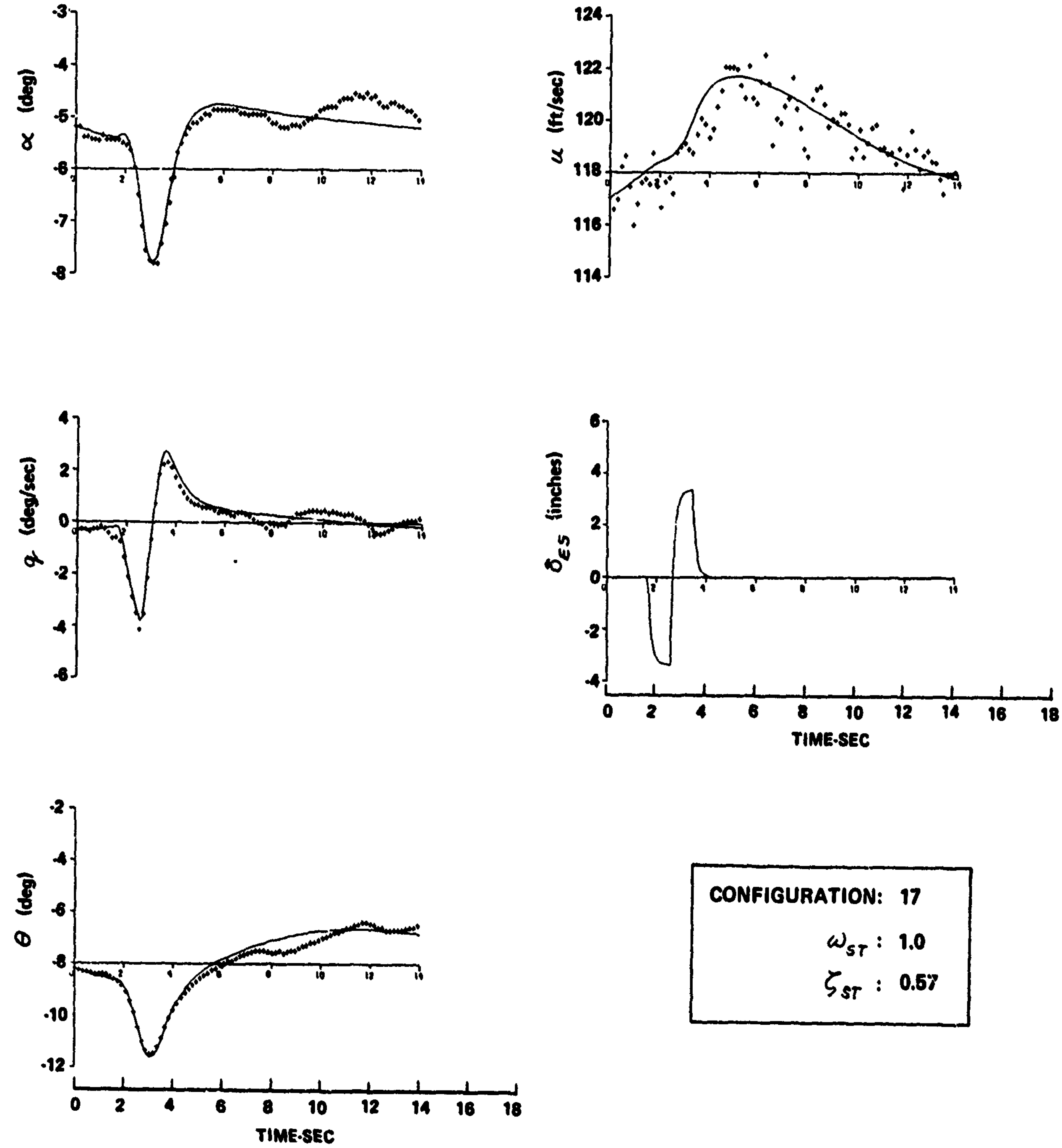


Figure III-10 KALMAN FILTER DIGITAL IDENTIFICATION OF CONFIGURATION 17

The identification of the configurations evaluated at 80 kt was performed primarily by equations-of-motion analog matching, and no Kalman filter results are reported here. The primary reason is that telemetry dropouts on the 80 kt calibration flight precluded generation of a digital tape with records of all nine configurations on it. It is worth noting that the excellent success in processing the 65 kt data digitally speaks well for the data acquisition system described in Appendix V.

As has been discussed, the Kalman filter output consists of the final derivative values and an estimate of their validity through the final variance calculation. Examples of the accuracy with which two of the more important derivatives (M_w, M_q) are identified for several of the configurations presented in Figures III-2-III-9 are presented below in terms of the standard deviation of the estimate:

CONFIG.	M_w	σ_{M_w}	M_q	σ_{M_q}
2	-0.060	0.00021	0.133	0.013
4	-0.048	0.00018	-0.636	0.18
10	-0.028	0.00035	-1.23	0.022
14	-0.012	0.00023	-0.894	0.026
16	-0.0082	0.00012	-0.259	0.011

Generally, the standard deviation of the M_w estimate is less than 2%, and that of M_q less than 10%.

To summarize this appendix briefly, then, both analog matching and digital identification techniques were used for this experiment. In general, the values of the derivatives identified by both methods were the same for the linear dynamics investigated. The digital identification technique, however, provides a better indication of identification accuracy and, of course, matches all state variables and accelerations simultaneously for more precise results. It is recommended that future X-22A experiments use the Kalman filter digital identification technique for the final identification of evaluation configurations if possible. Accurate results may also be obtained with analog matching techniques, and these techniques provide a useful, rapid means of estimating configuration dynamics for linear equations.

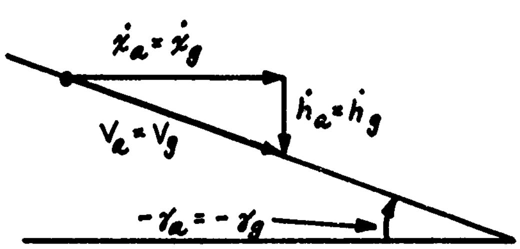
APPENDIX IV

DISCUSSION OF WINDS AND TURBULENCE

It is clear that mean wind velocity and turbulence level may have an important effect on the landing approach task. For this experiment, it was not possible to describe the turbulence level quantitatively because of the lack of appropriate measurements, although the mean wind was recorded for each evaluation. Nonetheless, it is important that a general understanding of the effects of these atmospheric variables be obtained to aid in the interpretation of the data. This appendix will therefore briefly review the general effect of a headwind on the tasks used for this experiment and present a general discussion, using a simple example, of factors that must be considered in simulating the response of various aircraft to turbulence.

As was discussed in Section III of this report, the landing approaches for this experiment were always flown nearly "into the wind." Further, to at least qualitatively obtain an indication of the effects of turbulence on the flying qualities, the flights were flown in either "negligible" or "moderate" turbulence; this distinction was generally a function of the mean wind, as the flights were performed during the winter in what were probably generally neutral or stable atmospheric conditions and hence the production of turbulence was primarily mechanical from wind shear. The evaluation flights therefore were performed in headwinds of varying magnitude, and it is important to review quickly what variables are changed.

As an example, consider the 65 kt, $\gamma = -9°$ approach condition. The pilot attempts to maintain velocity with respect to the air constant at 65 kt and glide slope with respect to the ground constant at -9°. With no headwind, this situation results in the following ground speed and rate of descent:

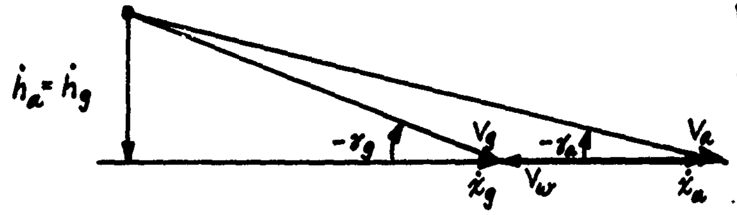


$\dot{x}_a = \dot{x}_g = (65) \cos 9° = 64.2$ kt

$\dot{h}_a = \dot{h}_g = (65) \sin 9° = 10.25$ kt = 1030 fpm

$\gamma_a = \gamma_g = -9°$

If we now introduce a 10 kt headwind, the ground velocity and rate of descent become:



V_a = 65 kt, V_w = 10 kt

γ_g = -9°

$$\dot{x}_g = (55.1)(\cos 9°) = 54.5 \text{ kt}$$
$$\dot{h}_a = \dot{h}_g = (55.1)(\sin 9°) = 8.6 \text{ kt} = 870 \text{ fpm}$$
$$\gamma_a \cong -7.5°$$

Note that maintaining airspeed and ground glide slope angle constant reduces the approach speed with respect to the ground, the rate of descent, and the flight path angle with respect to the air. Although γ_a is changed, the trim conditions and stability derivatives remain nearly constant, and hence the feedback gains did not need to be changed for a given configuration.

The mean wind recorded for each evaluation is given in Table II-1 in Appendix II. The values of the wind velocity were obtained from the airport tower and from the weather station in the mobile van. As can be seen from the table, the flights performed for "negligible" turbulence were generally flown in mean winds less than 10 kt, while the "moderate" turbulence cases generally correspond to winds in the range 10-20 kt. It is interesting to note that, clearly, the flights performed in "moderate" turbulence therefore generally resulted in a lower rate of descent than those in negligible turbulence.

In this experiment, attempts to investigate the effects of turbulence were made by performing the evaluations in conditions which the pilot called either "negligible" or "moderate." This procedure was followed because the current capabilities of the X-22A variable stability system do not include the capacity to simulate turbulence inputs to the aircraft. In general, even given such a capability, such simulations may be severely compromised by the model of turbulence used and the implementation of the simulation. Although the turbulence characteristics were not controlled in this experiment, the response of the X-22A aircraft to the ambient turbulence is generally correct for the aircraft being simulated because the aircraft employs response feedback of wind-sensed variables. The simple example that follows is intended to provide an understanding of the fundamental concepts and difficulties that are involved in simulating the aircraft responses to turbulence, either through "canned" turbulence or actual ambient conditions.

Consider the plunge mode of a hovering VTOL aircraft in an air mass initially at rest with respect to the earth (this assumption is not necessary: the air mass may be moving at a constant velocity initially and still be an "inertial" system, but we use the assumption for simplicity). Define the vertical velocity of the aircraft with respect to the earth as w_I, with respect to the air as w_V, and any vertical movement of the air with respect to the earth as w_G. With no movement (acceleration) of the air with respect to the earth, the equation of motion of the aircraft can then be written as:

$$\dot{w}_I = Z_w w_I + Z_\delta \delta \qquad \text{with respect to earth (inertial axes)} \qquad \text{(IV-1a)}$$

or

$$\dot{w}_V = Z_w w_V + Z_\delta \delta \qquad \text{with respect to air (inertial axes)} \qquad \text{(IV-1b)}$$

where

$w_I = w_V$

Z_w is vertical damping

Z_δ is control sensitivity

δ is control input.

Now allow the air mass to move with respect to the earth with acceleration $\dot{w}$ and velocity w_G. Recalling that the vertical damping effect depends on the velocity of the aircraft with respect to the air, the equation of motion now becomes:

$$\dot{w}_I = Z_w (w_I + w_G) + Z_\delta \delta \qquad \text{with respect to earth (inertial axes)} \qquad \text{(IV-2a)}$$

or

$$\dot{w}_V - \dot{w}_G = Z_w w_V + Z_\delta \delta \qquad \text{with respect to air} \qquad \text{(IV-2b)}$$

and

$$w_V = w_I + w_G$$

For simplicity, assume a step gust (w_G) input. Consider the following responses for an aircraft which can sense w_V (through an air vertical velocity sensor) and employs a response feedback variable stability system to simulate another aircraft with a different vertical damping:

1. Ground velocity response to gust.
2. Air velocity (w_V) response to gust.
3. Ground velocity response to simulated gust.

Let the airplane we are attempting to simulate have the same control sensitivity (Z_δ) but different vertical damping (Z'_w) so that:

$$\dot{w}_{IS} = Z'_w w_{IS} + Z_\delta \delta + Z'_w w_G \qquad \text{(IV-3)}$$

Then the response we might wish to simulate, w_{IS}/w_G , is given by:

$$\frac{w_{IS}}{w_G}(s) = \frac{Z'_w}{s - Z'_w} \tag{IV-4}$$

If the airplane we wish to simulate has an air velocity sensor and indicator, the response of the indicator will be given by:

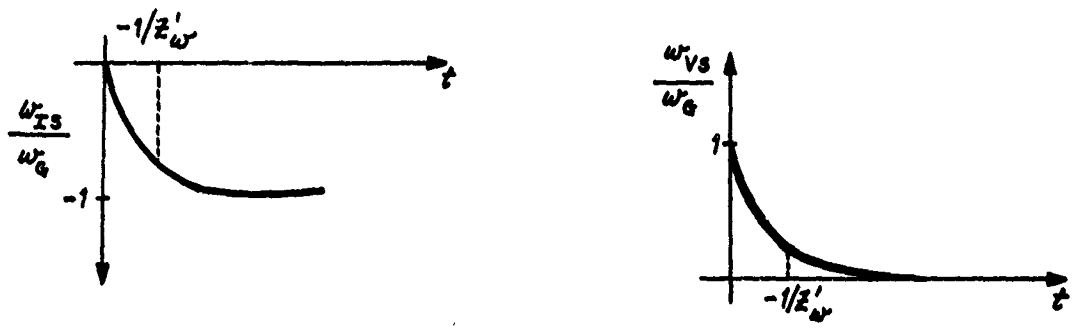
$$\dot{w}_{VS} - \dot{w}_G = Z'_w (w_{VS} - w_G) + Z_\delta \delta + Z'_w w_G$$

or

$$\dot{w}_{VS} = Z'_w w_{VS} + Z_\delta \delta + \dot{w}_G$$

$$\frac{w_{VS}}{w_G}(s) = \frac{s}{s - Z'_w} \tag{IV-5}$$

Before we consider how we are going to simulate this aircraft, consider briefly what equations (IV-4) and (IV-5) imply. The time responses to a step gust input may be sketched as:



Note that the ground velocity response is "transparent" to high frequency inputs (initial part of step) and that the aircraft then responds (one-to-one) in the steady state. The air velocity indicator, on the other hand, responds instantaneously (neglecting sensor dynamics) and then goes to zero as the aircraft moves more and more with the gust. For a simulation, it is necessary to match both of these responses if possible.

Let us now consider again the VSS aircraft, employing response feedback to the control to simulate different values of Z_w . Depending on how the velocity is sensed, we may have either:

$\delta = -K_V w_V$ -- uses air velocity sensor

or $\delta = K_I w_I$ -- integrates accelerometer to obtain ground velocity.

In most applications, <u>air velocity</u> is used. Then:

$$\dot{w}_I = Z_w w_I + Z_\delta (-K_V w_V) + Z_w w_G \tag{IV-6}$$

Equation (IV-6) describes the motion of the VSS aircraft in a <u>real gust</u> environment. Recalling that $w_V = w_I + w_G$:

$$\dot{w}_I = Z_w w_I - K_V Z_\delta w_I - K_V Z_\delta w_G + Z_w w_G$$

$$= Z'_w w_I + Z'_w w_G , \quad \text{where} \quad Z'_w - K_V Z_\delta$$

Then

$$\frac{w_I}{w_G}(s) = \frac{Z'_w}{s - Z'_w} \quad . \tag{IV-7}$$

Equation (IV-7) is identical to equation (IV-4): therefore, a response feedback airplane will have the same ground-velocity-to-gust transfer function in a real gust environment as the simulated airplane.

We may also calculate the air-velocity response:

$$\dot{w}_V - \dot{w}_G = Z_w (w_V - w_G) + Z_\delta (-K_V w_V) + Z_w w_G$$

or

$$\dot{w}_V = Z'_w w_V + \dot{w}_G$$

Hence:

$$\frac{w_V}{w_G} = \frac{s}{s - Z'_w} \quad . \tag{IV-8}$$

Equation (IV-8) is identical to equation (IV-5), and so the air-velocity response is also matched in a real gust environment.

Now let us turn our attention to the VSS aircraft flying in <u>calm air</u> (no real gust inputs), and simulating gust inputs (as well as Z'_w) <u>with the</u> control. The basic equation of motion is:

$$\left.\begin{array}{l}\dot{w}_I = Z_w w_I + Z_\delta \delta \\ \text{\underline{\underline{or}}} \\ \dot{w}_V = Z_w w_V + Z_\delta \delta\end{array}\right\} \quad \text{because } w_I \triangleq w_V \text{ with no gusts } (w_G = 0). \qquad \text{(IV-9)}$$

For the basic VSS aircraft to simulate its <u>own</u> response to a gust input:

$$Z_\delta \delta = Z_w w_{GS} \quad , \text{ where } w_{GS} \text{ is the simulation of } w_G$$

or

$$\delta = \frac{Z_w}{Z_\delta} w_{GS} \quad .$$

Then:

$$\left.\begin{array}{l}\dot{w}_I = Z_w w_I + Z_w w_{GS} \\ \\ \dot{w}_V = Z_w w_V + Z_w w_{GS}\end{array}\right\} \qquad \text{(IV-10)}$$

Hence:

$$\frac{w_I}{w_{GS}}(s) = \frac{Z_w}{s - Z_w} \qquad \text{(IV-11a)}$$

and

$$\frac{w_V}{w_{GS}}(s) = \frac{Z_w}{s - Z_w} \qquad \text{(IV-11b)}$$

Clearly, the VSS aircraft can simulate its ground-velocity-to-gust-input response (IV-11a is identical to IV-4 with $Z'_w = Z_w$), but it does not simulate air velocity response. (This means that the w_V indicator in the cockpit must have the w_{GS} signal electrically added to it to provide the pilot with the correct information display.)

Now we consider the VSS aircraft, in calm air, attempting to simulate the response of another airplane to gust inputs, using the "canned" gust and control feedback K_V :

$$\dot{w}_I = Z_w w_I + Z_\delta \delta$$

$$\delta = \underbrace{\frac{Z_w}{Z_\delta} w_{GS}}_{\text{Canned Gust}} - \underbrace{K_V w_V}_{\text{Feedback from Vane}}$$

so $$\dot{w}_I = Z_w w_I + Z_w w_{GS} - Z_\delta K_V w_V$$

but, recall that $w_I = w_V$ in calm air.

Hence,

$$\dot{w}_I = Z'_w w_I + Z_w w_{GS}$$

or

$$\dot{w}_V = Z'_w w_V + Z_w w_{GS}$$

$$\frac{w_I}{w_{GS}}(s) = \frac{Z_w}{\delta - Z'_w} = \frac{w_V}{w_{GS}}(s) \qquad \text{(IV-12)}$$

Note that w_I/w_{GS} is not the correct relationship (IV-4) -- the gust effectiveness is not properly modelled. Again, w_V/w_{GS} is also not matched. We can see that, to model the gust response properly, we cannot just feed back w_V if we are using "canned" gusts -- we must also change the gust effectiveness by scaling w_{GS}. Further, to display the correct signal to the pilot, the gust signal must be added to the air velocity indicator.

We could obtain the correct air-velocity (indicator) response, at the expense of ground velocity response, by reproducing the derivative of w_{GS} with the control. That is, let:

$$\delta = \frac{1}{Z_\delta} \dot{w}_{GS} - K_V w_V$$

Then $$\dot{w}_I = Z_w w_I + \dot{w}_{GS} - Z_\delta K_V w_V ,$$

or since $w_I = w_V$:

$$\frac{w_V}{w_{GS}}(s) = \frac{s}{s - Z'_w} \qquad \text{(IV-13)}$$

but, also

$$\frac{w_I}{w_{GS}}(s) = \frac{s}{s - Z'_w}$$, which is wrong.

With the simple example we have considered, the following statements are therefore relevant:

1. A response-feedback aircraft which uses air-sensed variables for its VSS will respond to real gusts as does the airplane it is simulating.

2. If canned turbulence is used, the gust effectiveness must be varied when the feedback gains are varied to produce the correct gust response.

3. If canned turbulence is used, the gust signal should be added to the air sensor signal to provide realistic information to the pilot.

The implications of these results on this experiment may therefore be summarized as follows. The short period frequencies and dampings mechanized for the evaluation configurations were obtained by angle of attack feedback (sensed with an α -vane) and pitch rate feedback (sensed with a rate gyro) to obtain the simulated aircraft M'_w , Z'_w , and M'_q . The aerodynamic response of the X-22A to a zero-gradient α (or w) gust is therefore exactly that of the simulated aircraft, since α is sensed with respect to the air mass. The response to a q -gust (e.g., w gust with a linear longitudinal gradient), however, is determined by the X-22A's basic M_q derivative, and not by the simulated M'_q because the q feedback is not sensed aerodynamically. Generally the response to the zero-gradient portion is the largest and hence, in this experiment, the flying qualities results in moderate turbulence represent the correct effects for the aircraft that were simulated.

APPENDIX V

DATA ACQUISITION AND PROCESSING SYSTEM

The X-22A aircraft and variable stability system are extremely complex systems, requiring monitoring during flight of many more variables than can be easily scanned by the pilot. A sophisticated system for data telemetry, acquisition, and processing was therefore designed for the X-22A system, and will be briefly described in this appendix. A more complete description is given in Reference 22.

All data pertinent to the flight of the X-22A aircraft are telemetered to a ground station via a pulse-code-modulated "L-band" telemetry link. Eighty (80) channels are provided, with the data sampled at a 200 Hz rate and encoded into 9-bit words. Of these 80 channels, five are required for time and synchronization, one is subcommutated to 64 additional channels, and one more is required to identify the subcommutated channel. There are, then, 137 channels available for data transmission, of which 73 are sampled 200 times per second and 64 at 200/64 times per second.

Patch panels in the X-22A aircraft permit selection of the 137 variables to be telemetered from approximately 200 that are available. For this experiment, approximately 80 flight safety variables, such as bearing hanger vibration levels and various oil temperatures and pressures, were telemetered and monitored as will be described; the remaining 57 variables, such as angle of attack, stick control positions, and VSS electrical commands, were of interest to the flying qualities experiment.

The data were telemetered to a ground station and experiment control center housed in a mobile van (Figure V-1). The van contains the following equipment:

(1) an omnidirectional antenna and a steerable, directional antenna

(2) a telemetry receiver

(3) a PCM decommutator and signal simulator

(4) a tape recorder for recording the complete data stream (the bit stream recorder)

(5) a 32-channel digital-to-analog converter (DAC)

(6) four 6-channel chart recorders

(7) a panel of nine meters for continuous display of a fixed set of flight safety variables

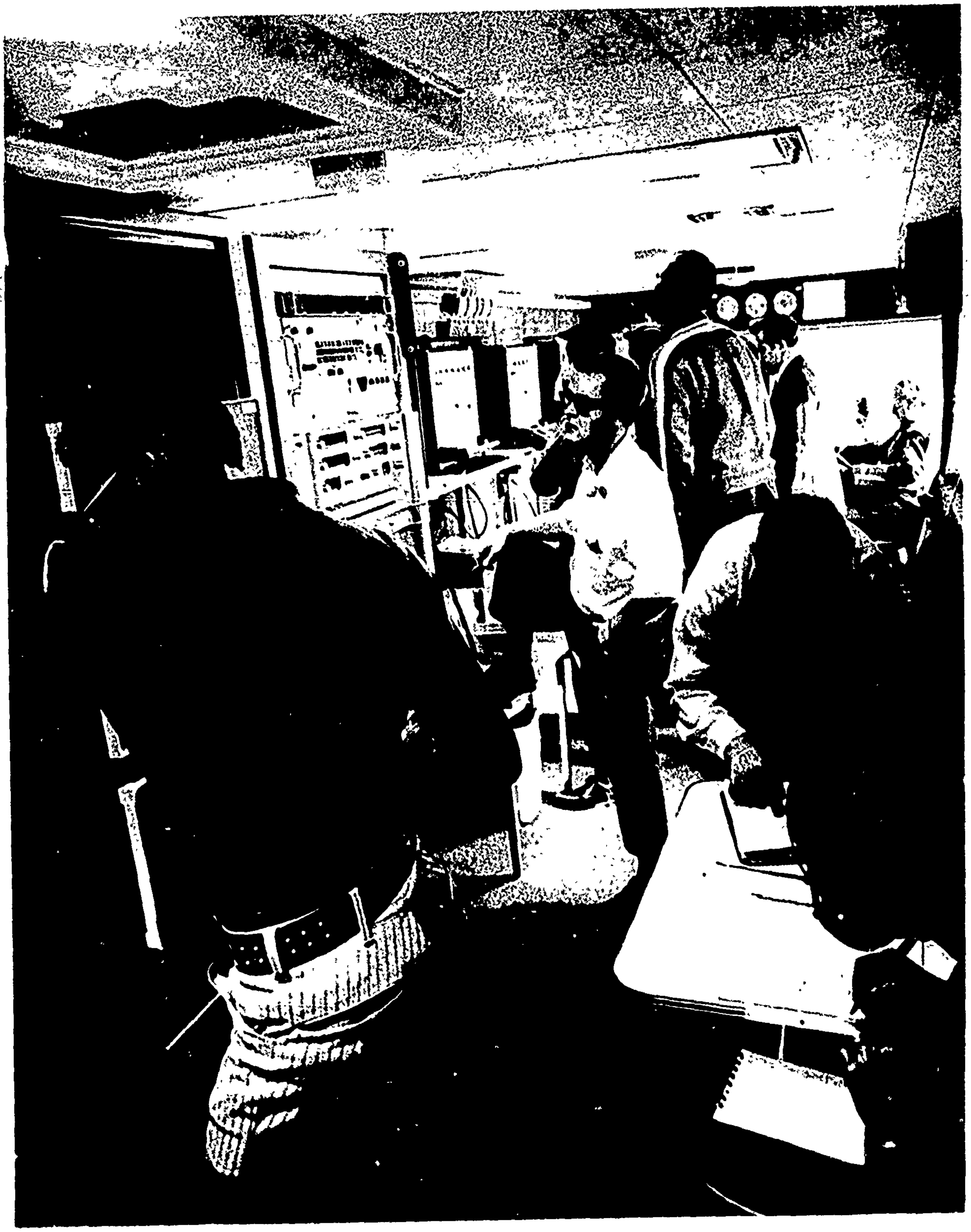


Figure V-1 MOBILE TELEMETRY VAN, INTERNAL VIEW

(8) a patch panel to select a desired set of 32 variables for the DAC's

(9) a paper printer

(10) a mini-computer with 16K storage capacity, 800 nanosecond effective cycle time, 36 channels of DAC's and 12 channels of analog-to-digital converters

(11) a teletypewriter

(12) a high-speed paper tape unit

(13) a 9-channel digital tape recorder

(14) a 360-channel VHF transceiver

(15) a voice-actuated magnetic tape recorder

(16) a weather station and

(17) two 5 kW 115-volt, 60 Hz generators

A simplified block diagram of the functions of this equipment during a flight is shown in Figure V-2. The primary purposes of the equipment include flight safety monitoring, experiment control, and data processing, each of which is briefly described below.

As has been discussed, the complexity of the X-22A aircraft requires constant monitoring of a large number of flight safety variables. This function is performed by the mini-computer in the mobile van. High and/or low limit values for the variables are stored in the computer; the telemetered data is processed through the computer on-line and compared continuously with these limits. In the event of a variable exceeding these preset limits, the teletypewriter unit immediately points out the variable in question and its value. It is also possible to monitor the variable visually on a chart recorder by addressing the appropriate channel with a "roving" DAC. The high speed paper tape unit acts as an independent backup by printing out on command the values of all of the telemetered variables.

The mobile van acts as the experiment control center during a flight. Pilot input and aircraft response variables are monitored on-line with the four chart recorders. An example of the variables typically monitored on the chart recorders is given in Table V-1. The flight test director is in continuous communication with the aircraft, and, on the advice of the engineers monitoring the flight variables, can, for example, request the repeat of a calibration record. In addition, although this capability was not used during this experiment, it is possible to program the desired equations of motion on the

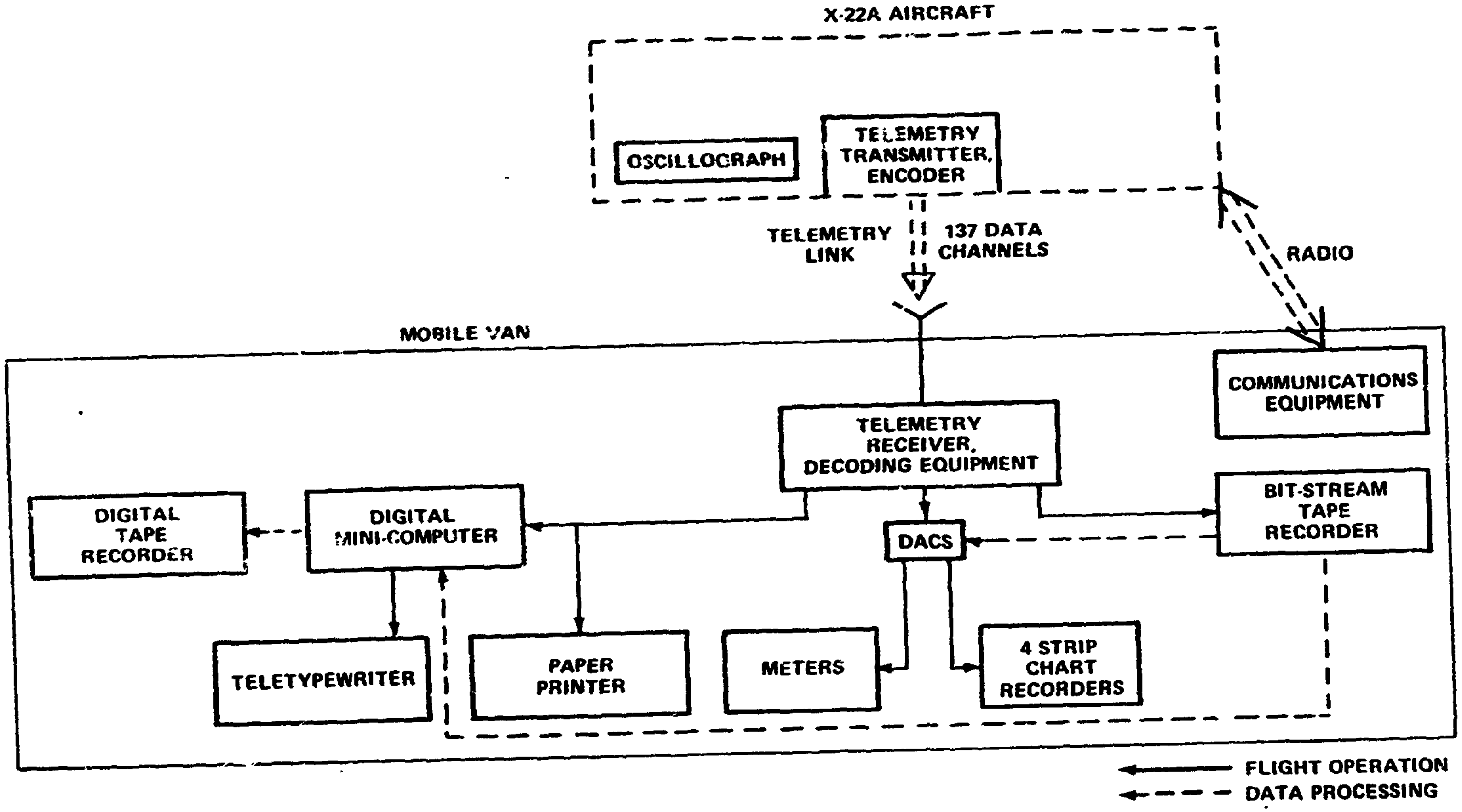


Figure V-2 SCHEMATIC DIAGRAM OF DIGITAL DATA ACQUISITION SYSTEM

Table V-1

SUMMARY OF VARIABLES MONITORED ON STRIP CHART RECORDERS

RECORDER	CHANNEL	VARIABLE	SCALE FACTOR
	1	ROVING	CHOSEN
	2	B_{LF}	10 deg/volt
1	3	B_{LA}	10 deg/volt
	4	B_{RA}	10 deg/volt
	5	B_{RF}	10 deg/volt
	6	Δ_{CS}	3.78 deg/volt
	1	δ_{LF}	10 deg/volt
	2	δ_{LA}	10 deg/volt
2	3	δ_{RA}	10 deg/volt
	4	δ_{RF}	10 deg/volt
	5	TEST INPUT UNIT	3.24 %/volt
	6	u	30.9 kt/volt
	1	δ_{CS}	5.3 deg/volt
	2	δ_{ES}	1 in./volt
3	3	α_V	5.11 deg/volt
	4	q	4 deg/sec/volt
	5	θ	5 deg/volt
	6	Δ'_{ES}	1.07 in./volt
	1	δ_{AS}	1 in./volt
	2	δ_{RP}	1 in./volt
4	3	β_V	5.02 deg/volt
	4	[illegible]	19.8 deg/sec/volt
	5	r	9.8 deg/sec/volt
	6	ϕ	11.5 deg/volt

mini-computer, drive these equations with the telemetered control inputs to the aircraft, and compare the desired responses with the actual aircraft responses. This capability allows iteration of the VSS gains on-line to achieve the desired configuration dynamics.

The equipment in the van also serves to process the flight data digitally "off-line" after a flight. All telemetered data during a flight are recorded continuously on the bit-stream recorder. For digital data analysis, the appropriate portions of the appropriate channels must be selected from the bit-stream recorder, and the format changed from the 9-bit word of the telemetered data to an 11-bit-plus-sign format compatible with the IBM 370/165 computer used for the analyses. This function is performed by the mini-computer: the data are taken off the bit-stream recorder, edited and formatted by the mini-computer, and recorded in blocked and gapped form by the digital recorder. This digital tape is then processed by the IBM 370/165 computer as discussed in Appendix III.

APPENDIX VI

DETAILS OF SIMULATION MECHANIZATION AND EQUIPMENT

This appendix will present more detailed information on the basic X-22A aircraft, the variable stability system (VSS), the technique used to achieve the simulated configurations using the VSS, and the design of the visual approach aid.

The Basic X-22A

As is evident from Figure VI-1, the X-22A has four ducted propellers and four engines. The four engines are connected to a common system of rotating shafts which distribute propulsive power to the four propellers. The ducts are interconnected so that all rotate through the same angle when it is desired to change the direction of the thrust vector. Thrust magnitude is determined by a collective pitch lever, very similar to a helicopter. Normal looking pitch, roll and yaw controls in the cockpit provide the desired control moments by differentially positioning the appropriate control elements (propeller pitch or elevon deflection) in each duct.

In hovering flight, the X-22A employs fore and aft differential blade pitch for pitching moments, left and right differential blade pitch for rolling moments, and left and right differential elevon deflection for yawing moments. In forward flight, fore and aft differential elevon deflection is used for pitching moments, left and right differential elevon deflection for rolling moments, and left and right differential blade pitch for yawing moments. A mechanical mixer directs and proportions the pilot's commands to the appropriate propellers and elevons as a function of the duct angle.

The rate of descent capability for the X-22A at various speed and duct angle combinations (Reference 23) is illustrated in Figure VI-2. For this experiment, a speed/duct angle combination of 65 kt/50 deg was chosen to maximize the X-22A rate of descent capability.

The X-22A VSS

There are four VSS controllers - thrust, pitch, roll and yaw - each employing electrohydraulic servos. When rigged for VSS flight the left hand flight controls are mechanically disconnected from the right hand flight controls and connected to a set of VSS pitch, roll and yaw artificial feel servos. The evaluation pilot occupies the left hand seat; the safety pilot and system manager occupies the right hand seat. The VSS thrust servo operates the boost servo for the collective pitch system. The VSS pitch, roll and yaw servos operate the right hand flight controls, moving the same linkages which are moved manually by the right hand pilot in normal non-VSS flight. (In fact, these same actuators serve a dual role by providing artificial feel for the primary flight control system when the VSS is not engaged.) Phasing of these control motions to the blades and elevons is accomplished by the mechanical mixer as for normal flight.

GENERAL SPECIFICATIONS

DIMENSIONS

Length	39.57 ft	
Height	20.69 ft	
Tread	8.0 ft	
Wing	Front	Aft
Area	139 sq ft	286 sq ft
Span	22.97 ft	39.24 ft
Aspect Ratio	3.86	5.38

ENGINE RATINGS

SHP	SLS	Thrust	rpm	Min.
1250	Mil.	154	19,500	30
1050	Nor.	132	19,500	Cont.

POWER PLANT

No. & Model	(4) YT58-GE-8D
Mfr.	General Electric Co.
Type	Free Power Turbine
Reduction	
Gear Ratio	0.133
Prop Mfr.	Hamilton Standard
Prop. Dia.	84 in.
No. of Blades	3
Tail Pipe	Fixed Area

WEIGHTS

Loading	lb
Empty	11,622
Gross	15,287
Max Takeoff	18,420
Max Landing	15,287

FUEL

No. Tanks	Gal	Location
1	465	Fuselage

Fuel Grade JP-4 or JP-5

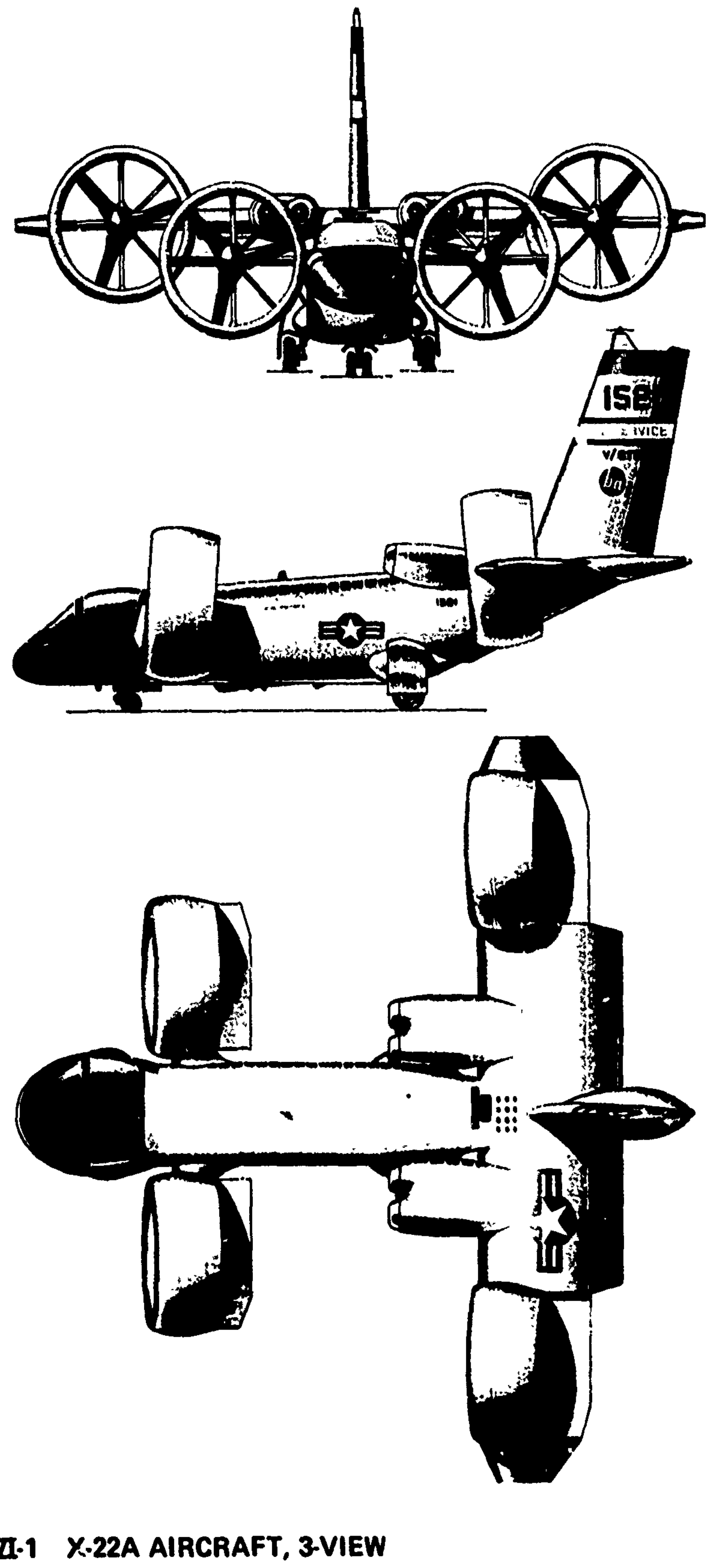


Figure VI-1 X-22A AIRCRAFT, 3-VIEW

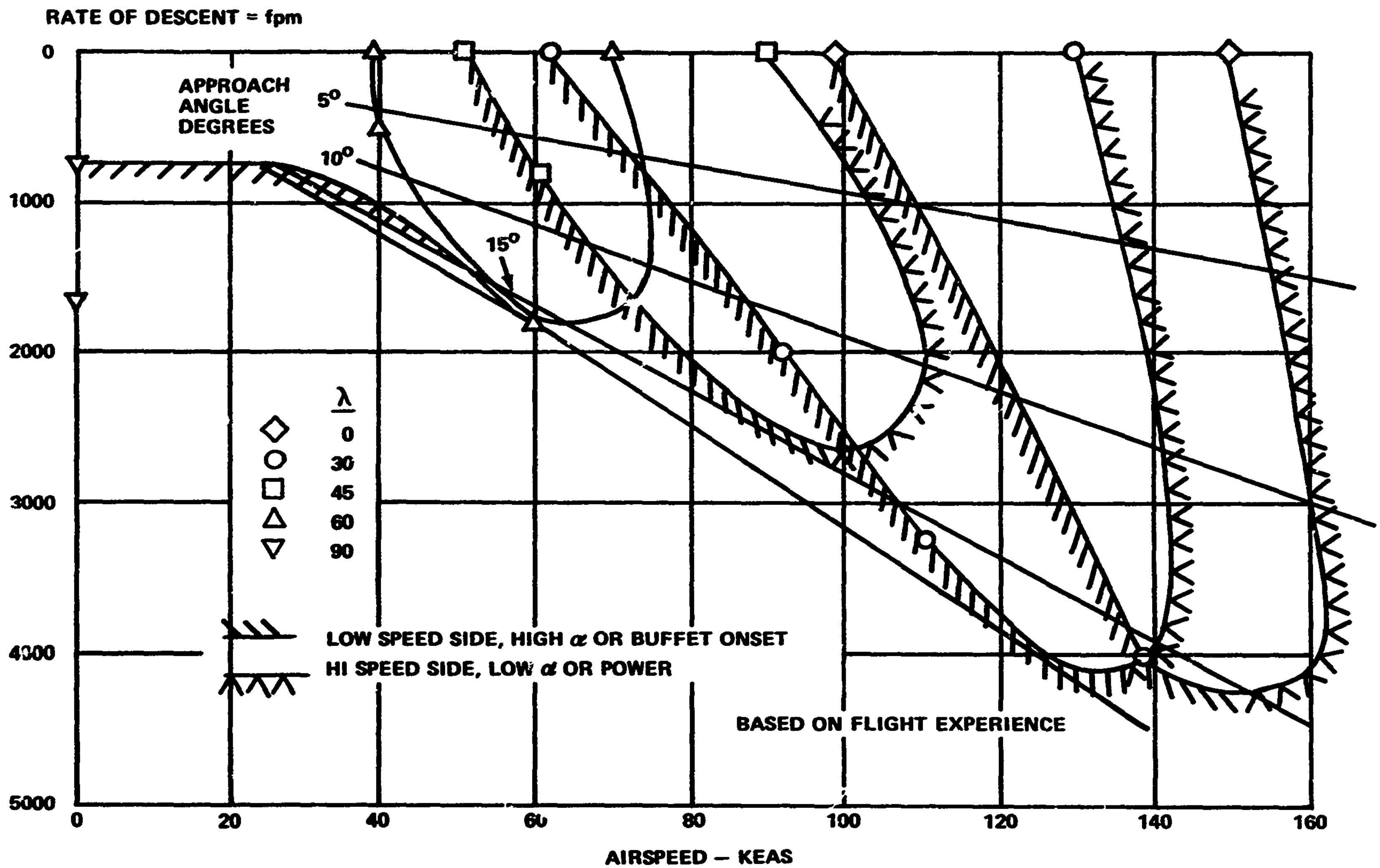


Figure VI-2 RATE OF DESCENT CHARACTERISTICS

All of the X-22A flight control positions, rigid body motions, relative wind variables and pilot control inputs are sensed by the VSS electronics. Desired combinations of these signals are used to move the basic airplane's flight controls to modify the airplane response to pilot inputs. When flying on the VSS, the evaluation pilot has complete control of the aircraft and cannot feel the X-22A control motions required to produce the desired simulated response characteristics. The response-feedback gain controls, located beside the safety pilot as shown in Figure VI-3, are set by the safety pilot in flight to values required to achieve the desired response characteristics. These gain settings were previously determined in the initial calibration phase of the experiment.

A simplified example of the X-22A variable stability system mechanization is shown in Figure VI-4. This example illustrates how the desired values of the derivatives $M_{\delta_{ES}}$ and M_{α} are achieved with this response feedback technique. Figure VI-5 shows the full schematic for the pitch channel of the VSS, including the artificial feel system.

Unique Features of the X-22A VSS

One unique feature of the X-22A VSS is that the response feedback gains are programmable with airspeed throughout the full range of airspeeds, from -30 knots rearward through zero to 150 knots forward airspeed. This is accomplished by a 48-channel function generator which receives its airspeed input from the LORAS (Linear Omnidirectional Airspeed System, Figure VI-6). LORAS was developed by CAL specifically for the X-22A.

Another unique feature of the X-22A is the Feedforward Flight Control System (FFCS) shown in Figures VI-4 and VI-5. This is a limited authority, precision control system which acts like a vernier on the basic X-22A flight control system during VSS operation. The FFCS makes it possible to achieve a precision on the order of 0.1 percent of full scale in positioning the actuators for the X-22A final aerodynamic controls - propeller pitch and elevon angle. Such control system precision is required for the satisfactory operation of the "closed-loop" VSS airplane.

The special Test Input Unit (TIU), which is a part of the X-22A VSS, greatly facilitates the in-flight calibration procedures. This unit generates electrical step, doublet, or pulse inputs, whose magnitude and time scale are selectable, which can be inserted with any of the four VSS channels. Thus calibration records can be taken with repeatable, easily controlled, inputs.

Mechanization of the VSS for the Experiment

The desired short-term dynamics (ω_{ST}, ζ_{ST}), were achieved by feeding back α and q signals to the X-22A longitudinal control (Δ_{ES}) with the appropriate feedback gains. It is important to remember that because response feedbacks to only the longitudinal stick are used, the numerators of the longitudinal

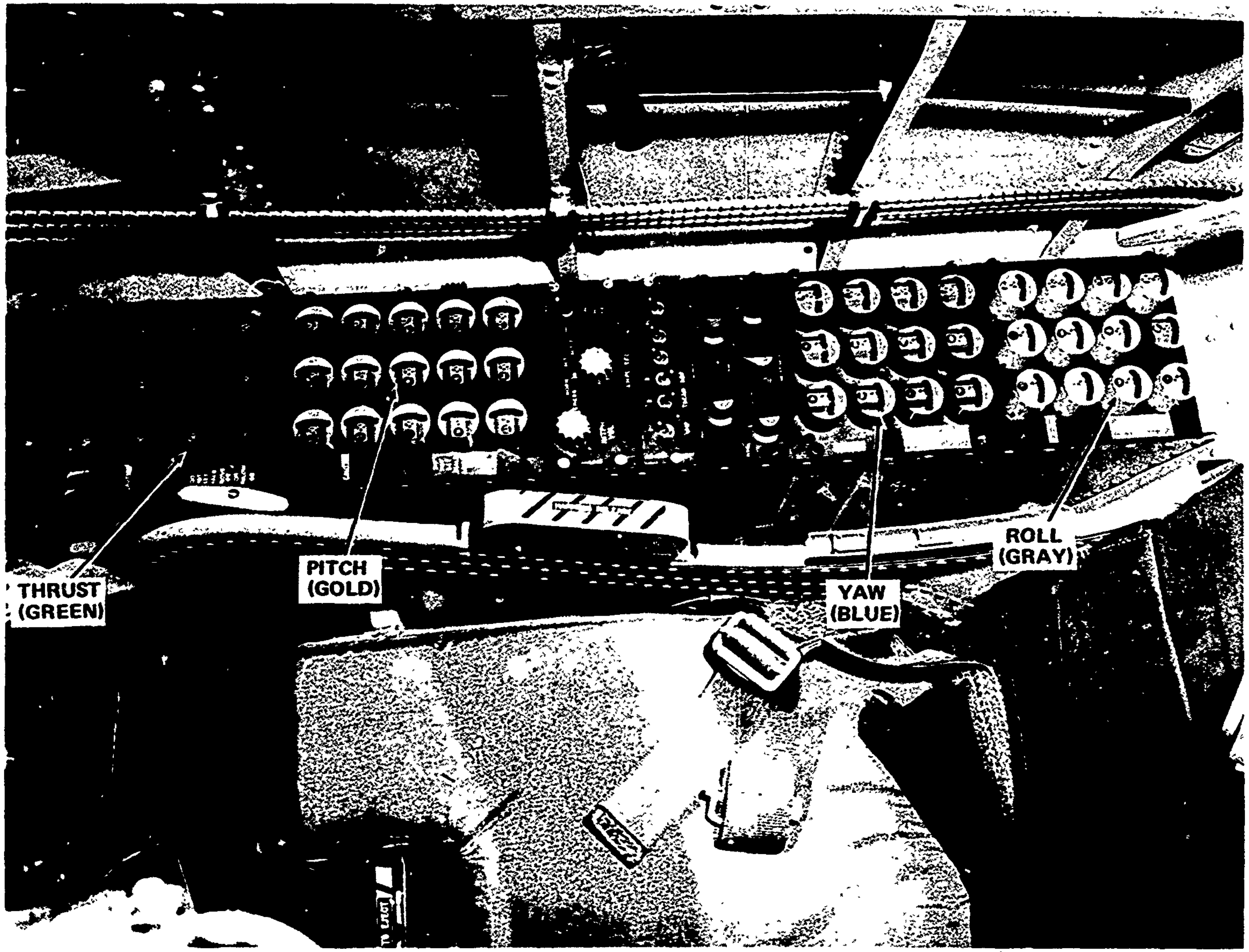
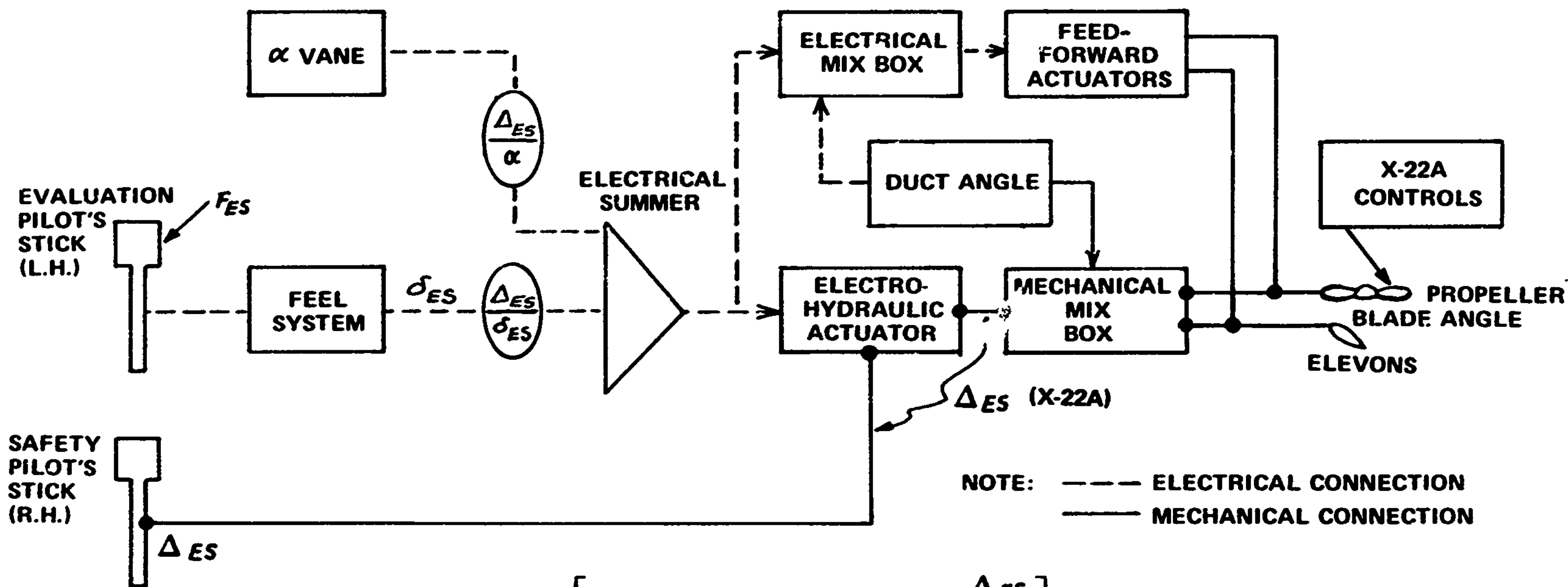


Figure VI-3 VSS GAIN CONTROLS IN X-22A COCKPIT



$$M_{\alpha\,(\text{SIMULATED})} = \left[M_{\alpha(X-22A)} \pm M_{\Delta ES(X-22A)} \frac{\Delta_{ES}}{\alpha} \right]$$

$$M_{\delta_{ES}\,(\text{SIMULATED})} = \left[M_{\Delta ES(X-22A)} \frac{\Delta_{ES}}{\delta_{ES}} \right]$$

Figure VI-4 SIMPLIFIED EXAMPLE OF THE X-22A VARIABLE STABILITY SYSTEM MECHANIZATION

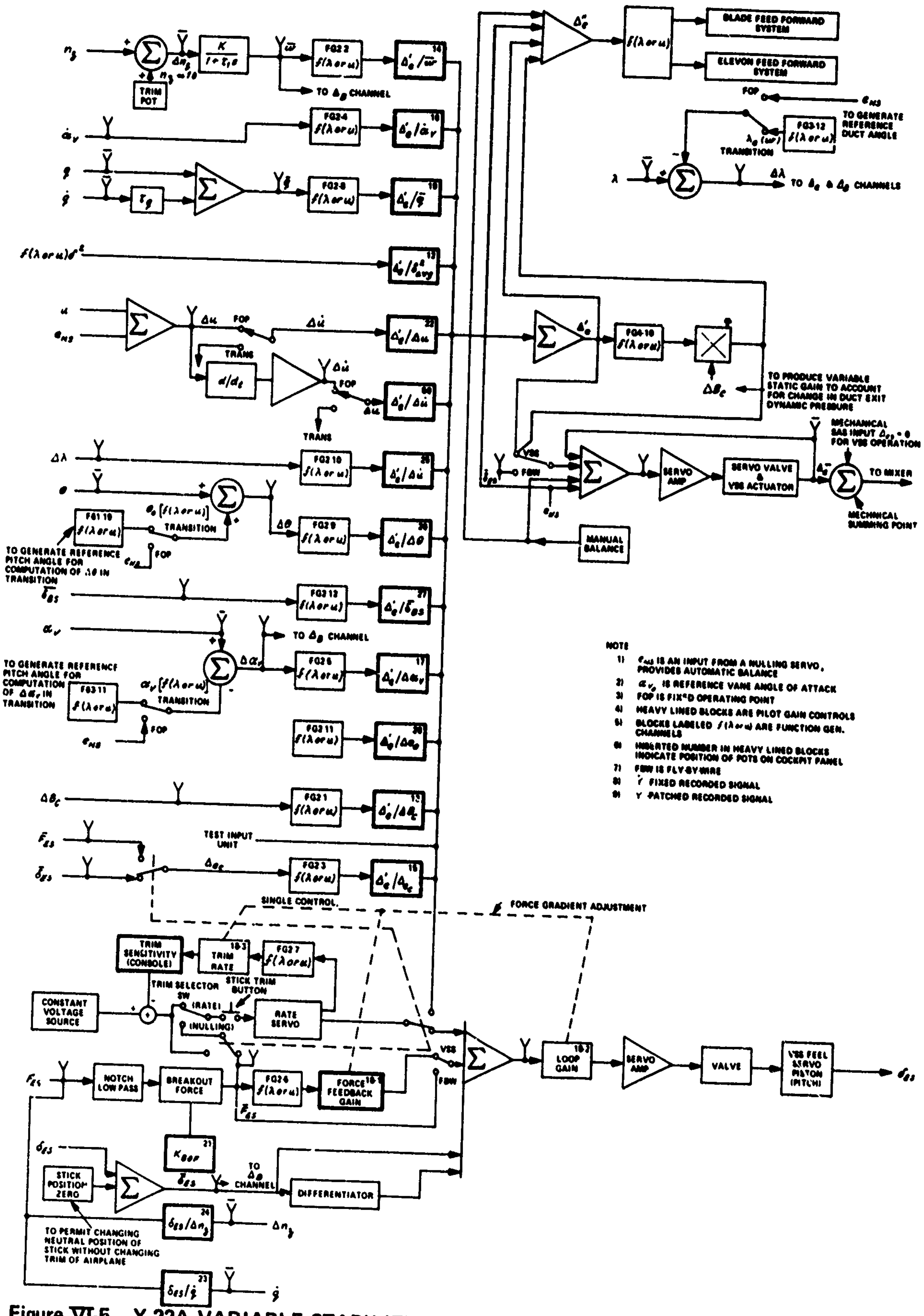


Figure VI-5 X-22A VARIABLE STABILITY AND CONTROL SYSTEM FUNCTIONAL BLOCK DIAGRAM – PITCH CONTROL

Figure VI-6 LORAS INSTALLED ON X-22A AIRCRAFT transfer function remain those of the X-22A airframe. For the low frequency configurations, where it was necessary to reduce the angle of attack stability, M_α, of the X-22A, an additional feedback gain proportional to u was used to maintain a stable long term response, which complicated the calibration procedure to some extent.

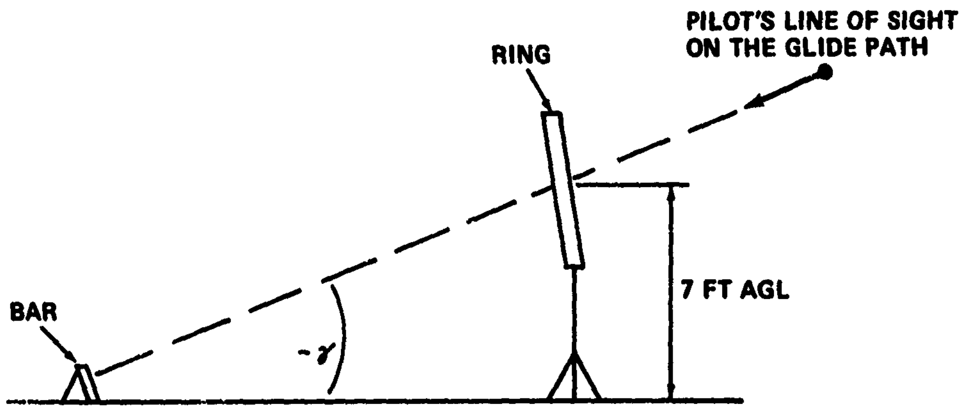
The lateral-directional characteristics simulated in this experiment were achieved using the appropriate response-feedback gains in a manner analogous to the longitudinal examples discussed above.

Determination of the feedback gains, Δ_{ES}/u, Δ_{ES}/q, Δ_{ES}/α_V required to achieve the desired short-term dynamics was done, largely by an iterative process, during the calibration phase of the flight program. During the evaluation phase, calibration records were taken of each configuration evaluated in order to identify the longitudinal dynamics, as discussed in some detail in Appendix III.

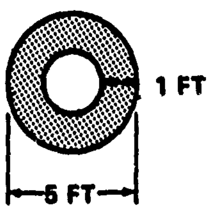
The Visual Approach Aid

The design details of the visual approach aid (VAA) are given in Figure VI-7. The visual aid was used in the experiment to ensure that the approach angles flown in the VFR approaches were similar to the glide path angles used in the IFR approaches.

For this experiment, the VAA served its intended purpose, that is, giving the pilots rough glide path information, but was not considered to be a satisfactory approach aid. The pilots had considerable difficulty in locating the VAA from distances beyond one mile despite the use of various color schemes designed to alleviate this problem. This type of approach aid is therefore not recommended for use in future programs.



RING –



PAINTED "DAY GLOW" RED

BAR – 6 BOARDS 8 FT x 1 FT PAINTED "DAY GLOW" YELLOW

OPERATION –
- ON GLIDE PATH WHEN BAR "SPLITS" CENTER OF RINGS
- GLIDE PATH DETERMINED BY DISTANCE OF BAR FROM RING
- FOR γ = -9.0 DEG, GLIDE PATH SENSITIVITY WAS ≈ ±2.5 DEG

Figure VI-7 DETAILS OF THE VISUAL APPROACH AID (REFERENCE 8)

APPENDIX VII

STATISTICAL AND SPECTRAL ANALYSIS OF DATA

The measured control inputs, performance, and acceleration of the aircraft have been analyzed for their statistical and spectral characteristics during the final approach phase for three evaluation flights, Flights 39F-23, 41F-25, and 42F-26. Each flight contained four evaluations, each with a visual and an instrument approach. Only the instrument approaches were analyzed from Flight 39F, but all approaches were analyzed from 41F and 42F.

The flight records were examined for each approach; that portion of the approach from the time the pilot had acquired and stabilized on the glide slope to the time he initiated the flare was selected for analysis. Stabilization was assumed when the angle of attack and elevator deflection reached a relatively constant level after the initial push-over for glide slope acquisition. Flare initiation was usually clearly indicated by a rapid aft elevator stick motion accompanied by an upward collective stick motion. Six variables were selected for statistical analysis: elevator stick deflection (δ_{ES}) and collective stick motion (δ_{CS}) to measure control usage, glide slope error ($\mathcal{E}_{GS}$) and airspeed error (Δu) to measure performance, and pitch acceleration ($\dot{q}$) and normal acceleration (Δn_z) to describe the aircraft motions. In addition, it was hoped that the statistics of Δu would provide a measure or index of the level of turbulence. For subsequent analysis on CAL's IBM 370 computer, digital tape records of the six variables (δ_{ES}, δ_{CS}, $\mathcal{E}_{GS}$, Δu, $\dot{q}$, and n_z) were prepared, from the complete flight data records preserved on the bit-stream recorder tapes. Mean values (μ), standard deviations (σ), and probability density functions were computed for the six variables for the selected portion of each landing approach. In addition, the value of $M_{\delta_{ES}}$ (extracted from flight test data) was used to convert $\sigma_{\delta_{ES}}$ to σ_{M_C} (normal control power units of rad/sec^2). As pointed out in Reference 24, power spectral densities can be useful in correlating pilot rating data and interpreting statistical control usage data. Accordingly, power spectra of δ_{ES} and $\dot{q}$ were computed for each landing approach. Also, power spectra of Δu were computed for selected cases with different turbulence levels to see if these would aid in determining a quantitative index to the turbulence level, but no such significance could be readily determined.

There were two purposes behind the digital computer analysis of the time history data for their statistical and spectral characteristics. One purpose was to develop the data processing techniques and programs for more general use in subsequent flying qualities experiments using the X-22A and its associated data acquisition system. The second purpose was to provide a selected amount of statistical and spectral data for the current research experiment.

Statistical Data

The conditions pertinent to each landing approach analyzed are presented in Table VII-1; the statistics in terms of mean (μ) and standard

Table VII-1

STATISTICAL AND SPECTRAL ANALYSIS – SUMMARY OF CHARACTERISTICS

CASE NO.	APPROACH AID	TURBULENCE LEVEL	FLIGHT NO.	CONFIG. NO.	ω_{ST}/ζ_{ST}	$M_{\delta_{ES}}$ $\frac{rad/sec}{in}$	P.R.	V_W kt
1	INSTR.	MOD	39F-23	14	1.4/0.55	0.36	3D	12
2	INSTR.	MOD	39F-23	6	2.0/0.09	0.32	7F	11
3	INSTR.	MOD	39F-23	4	2.6/0.24	0.32	5E	10
4	INSTR.	MOD	39F-23	17	1.0/0.57	0.32	4E	12
14	INSTR.	MOD	42F-26	5	2.6/0.35	0.54	3E	17
16	INSTR.	MOD	42F-26	13	1.7/0.34	0.39	3E	12
18	INSTR.	MOD	42F-26	18	1.2/0.79	0.35	2D	14
20	INSTR.	MOD	42F-26	6	2.0/0.09	0.49	7F	15
6	INSTR.	NEG	41F-25	8	2.0/0.23	0.44	3B	8
10	INSTR.	NEG	41F-25	3	2.6/0.20	0.41	2.5B	5
8	GCA*	NEG	41F-25	17	1.0/0.57	0.36	2.5B	8
12	"MISSED* APPROACH"	NEG	41F-25	13	1.7/0.34	0.36	2B	4
13	VISUAL	MOD	42F-26	5	2.6/0.35	0.54	2C	15
15	VISUAL	MOD	42F-26	13	1.7/0.34	0.39	4E	12
17	VISUAL	MOD	42F-26	18	1.2/0.79	0.35	2D	12
19	VISUAL	MOD	42F-26	6	2.0/0.09	0.49	6F	15
5	VISUAL	NEG	41F-25	8	2.0/0.23	0.44	2B	8
7	VISUAL	NEG	41F-25	17	1.0/0.57	0.36	2B	8
11	VISUAL	NEG	41F-25	13	1.7/0.34	0.36	2B	5

*NO GLIDE-SLOPE DATA WAS AVAILABLE FOR THIS CASE

NOTE: NO DATA COULD BE PROCESSED FOR CASE 9 DUE TO TELEMETRY "NOISE".

deviation (σ) are presented in Table VII-2. Each case analyzed has been given a case number to facilitate reference. The data are successively grouped in the tables according to turbulence level, type of approach aid, and succession in the particular flight. The configuration and flight number are also given to allow cross-referenc..ng with Table II-1. Two of the instrument approaches were unusual, Cases 8 and 12. The TALAR malfunctioned prior to the approach of Case 8 and using the visual approach aid for reference, the safety pilot substituted oral commands (simulated GCA) for the missing glide slope and localizer signals on the attitude instrument. The evaluation pilot never did acquire the glide slope in the approach for Case 12 and this has been labeled as a "missed approach."* The results for Cases 8 and 12 should be interpreted with these considerations in mind.

Several of the experimental procedures are pertinent to interpretation of the statistical and spectral density data. The position of the pilot's controls is defined by where these controls were located on engagement of the variable stability system, usually occurring near level flight trim at 65 knots indicated airspeed. The elevator stick is positioned by the variable stability feel system, and was engaged at the same location each time. The collective stick, on the other hand, is positioned for engagement by the evaluation pilot, and he was asked to select the same place each time. The edge of the pilot's seat gave a good appropriate reference for the collective stick. Thus, the mean value for δ_{cs} (Table VII-2) is relatively constant, but no real significance should be attached to the absolute value of δ_{cs}. The elevator stick position, on the other hand, is measured from its engagement point. Thus the mean value of δ_{es} represents the incremental change going from trimmed level flight to the glide slope, and is a function of aircraft static stability and the changes in angle of attack, power setting ($\Delta\delta_{cs}$), and airspeed (nominal $\Delta u = 0$). The mean value of Δu would be expected to reflect the average error from the nominal approach speed that the pilot was supposed to hold, 65 knots (110 fps) for all the analyzed cases. However, like the elevator stick deflections, the reference value of u for the incremental Δu is the value of u at variable stability system engagement. The reason that Δu was used instead of u for analysis is that the resolution for the incremental signal was four times that for the total signal. In the cockpit there were three airspeed indicators: LORAS u which was centered above the normal instrument panel (Figure 3-2), and the left and right hand pilot's normal pitot-static airspeed indicators. On instrument approaches, the evaluation pilot used his normal airspeed indicator since it was the only one that could be readily incorporated in his scan pattern. Thus, the mean values of Δu do not give an accurate measure of the amount the pilot was off from the nominal or desired approach speed. Finally,

---

*To complete his evaluation, the pilot asked for and was allowed to make a second instrument approach, but the corresponding flight data was not processed for computer analysis.

Table VII-2

STATISTICAL AND SPECTRAL ANALYSIS – STANDARD DEVIATIONS (σ) AND MEAN (μ)

CASE NO.	δ_{ES} ~ in σ/μ	δ_{CS} ~ deg σ/μ	ϵ_{GS} ~ deg σ/μ	Δu ~ ft/sec σ/μ	$\dot{q}$ ~ deg/sec^2 σ/μ	Δn_z ~ g σ/μ	σ_{M_C} ~ rad/sec^2
1	0.14/0.09	0.24/13.2	0.23/0.16	3.8/4.4	3.7/0.2	0.04/0.01	0.050
2	0.19/0.81	0.18/13.9	0.16/0.01	2.1/5.3	5.9/0.3	0.03/0.03	0.061
3	0.19/0.91	0.20/14.0	0.14/-0.36	2.7/5.4	4.7/0.2	0.03/0.02	0.061
4	0.18/0.55	0.27/13.3	0.14/-0.10	3.4/0.0	4.7/0.2	0.05/0.02	0.058
14	0.29/1.01	0.59/13.0	0.23/-0.05	3.3/6.5	5.7/0.2	0.04/0.00	0.156
16	0.20/0.80	0.39/13.3	0.21/0.15	4.1/0.0	4.6/0.3	0.06/0.02	0.078
18	0.23/0.80	0.61/13.1	0.14/-0.16	3.9/-1.7	4.3/0.2	0.08/0.01	0.080
20	0.23/0.98	0.40/13.3	0.13/0.00	2.6/7.2	9.7/0.1	0.06/0.03	0.118
6	0.18/0.53	0.24/12.9	0.16/0.11	2.9/17.1	3.7/0.2	0.04/0.03	0.079
10	0.24/1.15	0.44/13.0	0.24/0.30	1.6/7.1	2.0/0.3	0.03/0.02	0.098
8	0.13/0.40	0.44/13.3	–	2.3/11.2	2.4/0.2	0.03/0.02	0.047
12	0.09/0.61	0.17/13.8	–	1.1/8.1	2.2/0.2	0.03/0.04	0.033
13	0.20/1.03	0.36/13.0	–	2.7/6.3	5.5/0.2	0.03/0.01	0.070
15	0.12/0.66	0.27/13.7	–	2.6/-0.3	4.1/0.2	0.03/0.01	0.047
17	0.11/0.76	0.25/13.2	–	2.2/0.8	3.3/0.2	0.03/0.02	0.038
19	0.11/1.31	0.09/13.8	–	1.7/1.5	5.3/0.2	0.02/0.02	0.049
5	0.08/0.96	0.17/12.3	–	1.4/11.4	3.1/0.2	0.02/0.02	0.035
7	0.06/0.49	0.07/12.9	–	0.8/11.9	1.8/0.3	0.02/0.02	0.022
11	0.08/0.77	0.12/13.5	–	1.2/8.5	2.2/0.3	0.02/0.02	0.029

it was planned to use the high-angle TALAR throughout the experiment, but after Flight 39F the unit was no longer available and the rest of the program was conducted using the low-angle TALAR. The nominal sensitivities, listed in terms of glide-slope error for full-scale needle deflection on the attitude indicator, are

Hi-Angle TALAR $\pm 2.5^{\circ}$
Lo-Angle TALAR $\pm 0.9^{\circ}$

A positive needle deflection is down, indicating a "fly down" command or that the aircraft was above the desired glide path.

Standard Deviations as a Function of Pilot Rating

The standard deviations (σ), or the r.m.s. values from the mean, are plotted vs. pilot rating in Figure III-1 for the instrument approaches. The data from Flight 39F (triangles) have overall pilot ratings of 3, 4, 5, and 7, and hence can be used as good indicators of trends. Control usage ($\sigma_{\delta_{ES}}$, $\sigma_{\delta_{CS}}$, σ_{M_C}) indicates no correlation with pilot rating. In fact, the 39F data are nearly invariant with pilot rating, and the one point (PR=3, Case 1) not on a level with the other three (in $\sigma_{\delta_{ES}}$ and σ_{M_C}) had an unstable long-period mode (Appendix II) which may account for its slightly anomalous characteristics.

The $\sigma_{\epsilon_{GS}}$ data strongly suggest that glide-slope tracking is invariant with pilot ratings. The pilot compensates for deficiencies in the aircraft to keep performance relatively constant unless the compensation becomes so difficult that he cannot perform the task at all (approaching a PR=10). The pilot's ability to hold airspeed (σ_u) does show correlation with pilot rating; viewed by itself the 39F data clearly indicates decreasing performance (increasing σ_u) with improved flying qualities, and if the GCA and "missed approaches" cases are deleted, then all the points lie fairly close to a straight line drawn through the 39F (triangular) points with one exception (Case 10, PR=2.5). No specific explanation for such a trend is available, and since the variation of all the points is more than that of the 39F points, the observed trend of the 39F data may simply represent scatter which by chance lined up.

The values of σ_{n_z} show no consistent trends with pilot rating, but the 42F points are higher than the 39F points, though both flights were considered to have been flown in moderate turbulence. The $\sigma_{\ddot{\theta}}$ points do show significant trends: there is clearly an increase in $\sigma_{\ddot{\theta}}$ with pilot rating; furthermore, straight lines can be drawn through the data points for Flights 39F and 42F, each taken individually. Additionally, most of the points for Flight 41F, considered to have been flown in negligible turbulence, are substantially below the other points. Two observations can be drawn from the $\ddot{\theta}$ statistics. First pitch acceleration activity is closely related to the flying qualities of a STOL aircraft in the instrument landing approach task. This observation is not surprising since "bobbling" of the aircraft is a common pilot complaint when flying qualities are deficient. Secondly, turbulence might be the source of the difference in variation of $\sigma_{\ddot{\theta}}$ with PR for the three flights analyzed.

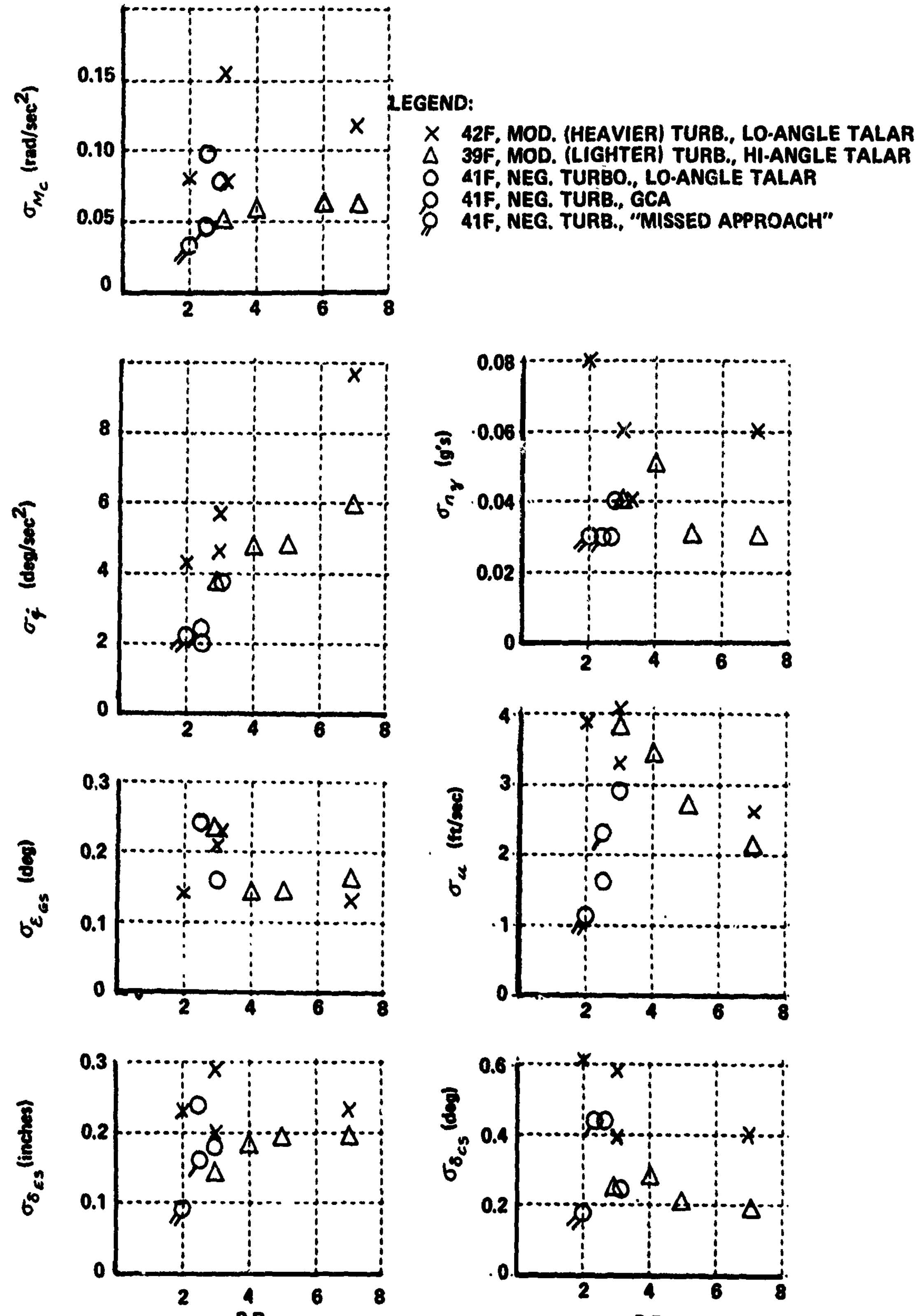


Figure VII-1 STATISTICS DURING INSTRUMENT APPROACHES CORRELATED WITH PILOT RATING

Figure VII-2 presents the standard deviations plotted vs. pilot rating for the visual approaches made using the "ring and bar" visual aid. The conclusions arrived at for the instrument approach data are supported by the visual approach data, though there is, of course, no measure of glide-slope performance. One noticeable difference is that the σ values are generally smaller in all cases.

Effect of Turbulence on Standard Deviations

Based on the conclusion, drawn from the variation of $\sigma_{\dot{z}}$ with PR, that variations in the turbulence level might be strongly affecting the statistical data, a search was made for some method to quantitize turbulence level more finely than simply "negligible" or "moderate". Several power spectra of Δu were examined with inconclusive results. Although turbulence itself was not measured in the experiment, the airport tower reported wind speed (V_W) and direction for each approach and this data was recorded. The low-level turbulence model from Reference 19 gives, for the vertical component of gust velocity:

$$\sigma_{\hat{w}} = \varepsilon R_T \bar{V} = .2 V_W$$

where the parameters reflect farmland terrain, a neutral lapse rate, and an altitude of 500 to 700 feet, and where $\hat{u}$, $\hat{v}$, and $\hat{w}$ denote the components of turbulence (along, vertical, and tranverse) with respect to the mean wind, $\bar{V}$.

The σ statistics are plotted vs. tower-reported wind speed (V_W) for the instrument approaches in Figure VII-3, and some strong correlations are indicated. To start, σ_u is roughly proportional to V_W, and a line through the origin and the bulk of the points gives

$$\sigma_u \cong .3 V_W$$

Assuming for simplicity that $\sigma_{\hat{u}} \approx \sigma_{\hat{w}}$, and noting that the X-22A approaches were all made very nearly into the wind, then $\sigma_{\hat{w}} \approx \sigma_{u_g}$. In a landing approach, if the airspeed changes are primarily those due to turbulence then $\sigma_{\hat{u}} \approx \sigma_u$, so the correspondence between the above two expressions for $\sigma_{\hat{w}}$ and σ_u is satisfying. Using a value of $\sigma_{u_g} = \sigma_{w_g} = .3 V_W$ (since wind at altitude was probably higher than near the ground), a rough approximation to the average turbulence on the three flights would be:

		$\sigma_{w_g} = \sigma_{u_g}$
Flt. 41F	Moderate (heavier) Turbulence	4 - 5 ft/sec
Flt. 39F	Moderate (lighter) Turbulence	3 ft/sec
Flt. 42F	Negligible Turbulence	1 - 2 ft/sec

Examining the $\sigma_{\dot{z}}$ data next, a strong trend toward increasing $\sigma_{\dot{z}}$ with V_W is indicated, as expected. Furthermore, if upper and lower boundaries for the data are plotted, and PR values attached to the points, then the upper boundary is a PR=7 iso-opinion line (except at the lower end where PR's are all between 2 and 3), the lower boundary is a PR≅2 iso-opinion line, and the

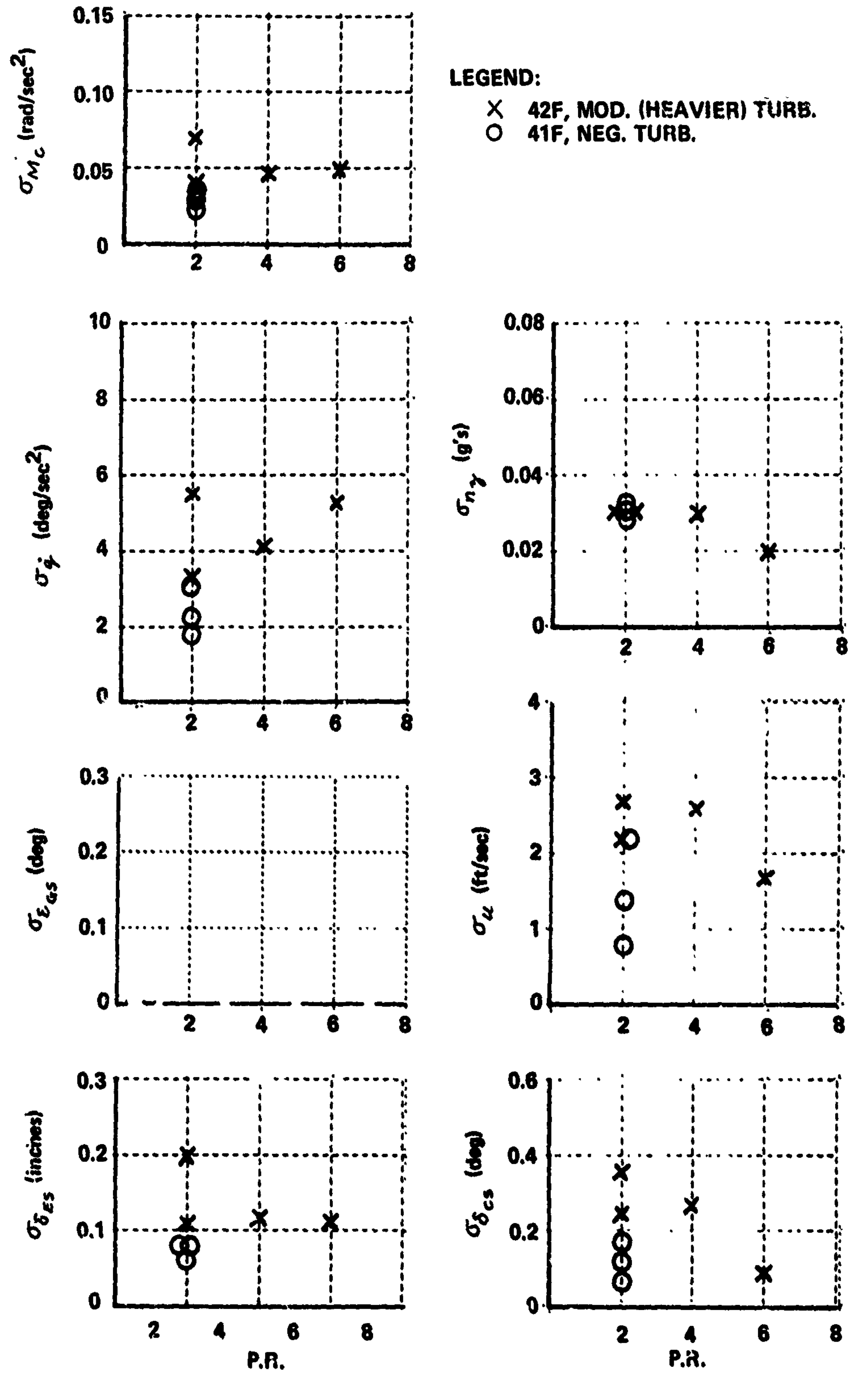


Figure VII-2 STATISTICS DURING VISUAL APPROACHES CORRELATED WITH PILOT RATING

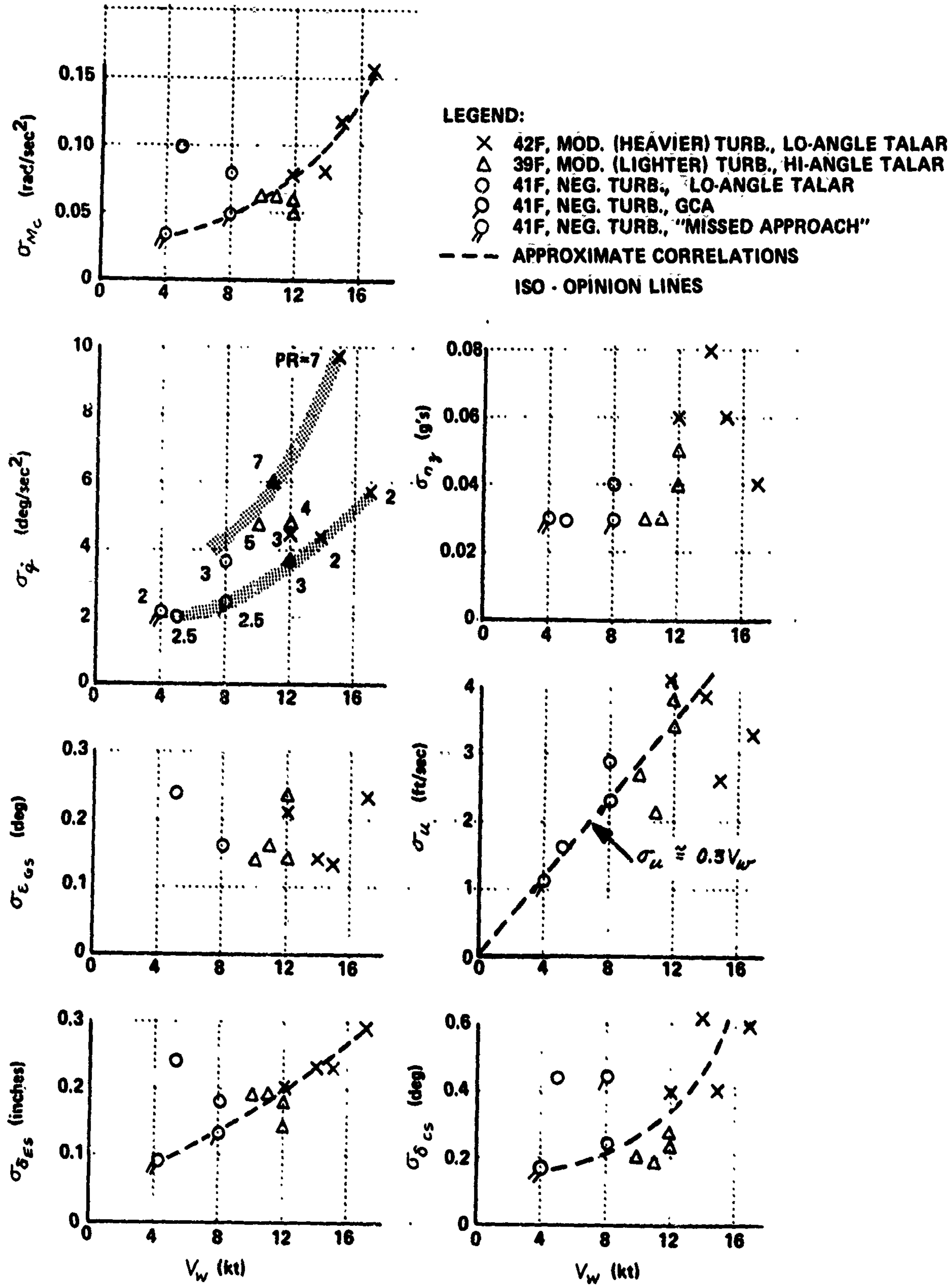


Figure VII-3 STATISTICS DURING INSTRUMENT APPROACHES CORRELATED WITH WIND SPEED (TURBULENCE LEVEL) points between have an appropriate gradient of PR. These characteristics suggest that $\sigma_{\dot{\theta}}$ and turbulence level are dominant factors on pilot rating for instrument landing approaches; but a word of caution is needed. There are only a few data points, and $\sigma_{\dot{\theta}}$ is not a quantity that can be calculated from aircraft characteristics. Rather, $\sigma_{\dot{\theta}}$ is a quantity, characteristic of the closed-loop pilot and airplane, that can be measured and perhaps used as an index to flying qualities along with measurements of turbulence level.

A very strong correlation with V_W for both $\sigma_{\delta_{ES}}$ and σ_{M_C} is indicated in Figure VII-3. Only one point, Case 10 which was noted earlier as anomalous in Figure VII-1, lies significantly off a curve drawn through the bulk of the $\sigma_{\delta_{ES}}$ points. The same can be said of the σ_{M_C} data, but there is more scatter in these data points (also noticeable in Figure 6-1). This strong one-dimensional correlation of control usage with wind speed, presumed with evidence to be equivalent to turbulence level, suggests that control power requirements for V/STOL aircraft can be formulated as a function of turbulence level, just as structural requirement(s) for aircraft are now formulated. If control power required is defined as that required for (1) trim, (2) maneuvers, and (3) disturbances, then the data presented in Figure VII-3 suggests that the turbulence contribution to control power required for disturbance should not be difficult to define, and this task should be pursued vigorously.

The collective control usage data indicate that there is a fairly strong trend to $\sigma_{\delta_{CS}}$ vs. V_W, provided Case 10 (again the anomaly) and the GCA aproach are deleted. However, the scatter is considerable. Collective pitch control deflections on the glide path were small (as viewed in the time history data), the pilot apparently using elevator stick as his primary control on the approach, thus explaining the presence of scatter. In addition, the poor resolution of the collective pitch recording channel may account for some of the scatter. In view of the above circumstances, it is felt that the one-dimensional description alluded to above might pertain if additional and more accurate data were obtained.

The normal acceleration data show generally increasing σ_{n_z} with V_W and hence turbulence level, but no definitive trends are indicated. The glide-slope performance shows no dependence on turbulence.

The σ statistics for the visual approaches are presented in Figure VII-4 and the conclusions arrived at for the instrument approaches are generally supported by the visual approach data. However, the strong dependence of σ_u on V_W, noted for the instrument approach case, is less pronounced for the visual case, particularly for the approaches in negligible turbulence. The variation of $\sigma_{\dot{\theta}}$ is relatively one-dimensional, exhibiting no variation with pilot rating, and a mean curve through the points corresponds to the lower (PR=2) boundary for the instrument approach data (Figure VII-3). The curve of $\sigma_{\delta_{ES}}$ vs. V_W for the visual approaches has lower values of $\sigma_{\delta_{ES}}$ at the higher V_W than does the IFR data set, indicating that the

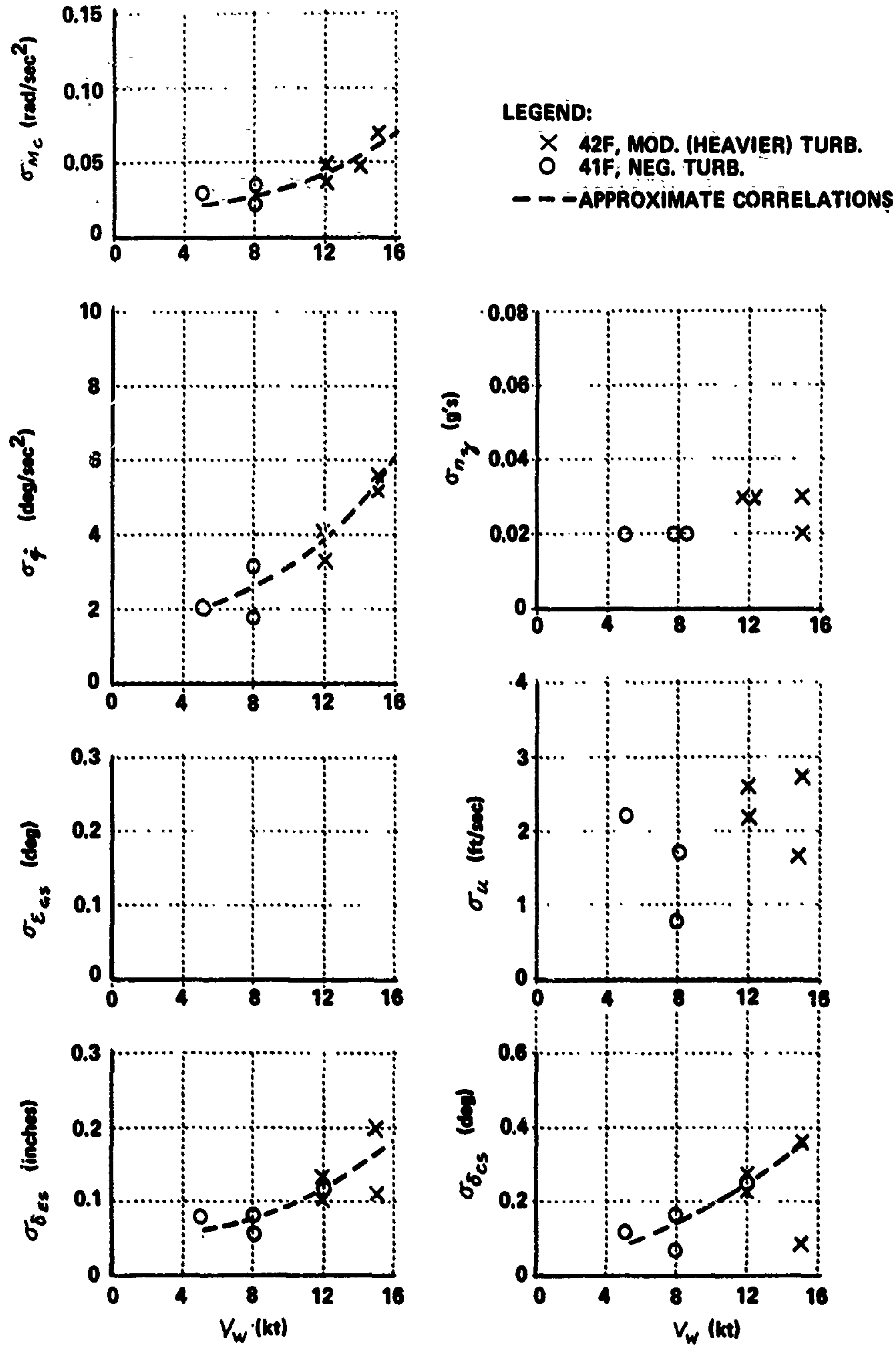


Figure VII-4 STATISTICS DURING VISUAL APPROACHES CORRELATED WITH WIND SPEED (TURBULENCE LEVEL) instrument approach is more critical with respect to control power required; the same comment applies to the σ_{M_c} and $\sigma_{\delta_{CS}}$ data, and for the latter again considerable scatter is evident. In general, one can say that all the data for the visual approaches exhibit lower σ values and less activity, probably indicating that the visual approaches were less demanding than the instrument ones.

Probability Densities

The probability density distributions corresponding to the σ statistics discussed previously are presented in Figures VII-5 through 10. The grouping of the data is similar to that used for the σ statistics, but the two special instrument approach cases (GCA and "missed approach") are segregated in Figure VII-10. The probability densities are plotted against the actual variable as measured, and have neither been centered with respect to the mean nor normalized with respect to the standard deviation.

Instrument Approach Data

The probability densities from the instrument approaches of Flight 39F are presented in Figure VII-5. The P (δ_{ES}) distributions are relatively Gaussian or normal, being fairly smooth and unskewed, and having only one central peak with moderate tails. The same comments apply to P ($\dot{q}$). Gratifyingly, P ($\dot{q}$) for Case 2 (Configuration 6) with its PR=7 has an obviously broader shape (larger σ) than the others.

The P (ε_{GS}) distributions do not look very Gaussian. They are somewhat ragged and skewed. However, they do have single peaks. The same comments apply to the P (Δu) distributions.

The P (δ_{CS}) distributions are even less Gaussian, two having multi-peaks, and reflect the considerable scatter evidenced in the σ statistics noted previously. The P (Δn_z) distributions are ragged, but are somewhat normal having single peaks, moderate tails, and are not badly skewed. These characteristics suggest that the σ_{n_z} data did not have a large amount of scatter, but rather, that σ_{n_z} has at most a secondary influence on flying qualities for STOL aircraft on final approach.

Turning to the data from Flight 42F (Figure VII-6), we find some marked differences as compared with the 39F distribution data. P (δ_{ES}) is somewhat similar to that seen previously, but the distribution for Case 14 (Configuration 5) is clearly non-Gaussian, and is indicative (two peaks at the extremes) of a large amplitude oscillation of the elevator stick.

The P ($\dot{q}$) distributions look relatively normal again, and the very broad distribution (Case 20, Configuration 6) again goes with the PR=7.

Performance on the glide slope, P (ε_{GS}), is markedly non-Gaussian. These distributions, though having a central peak, also have peaks at the

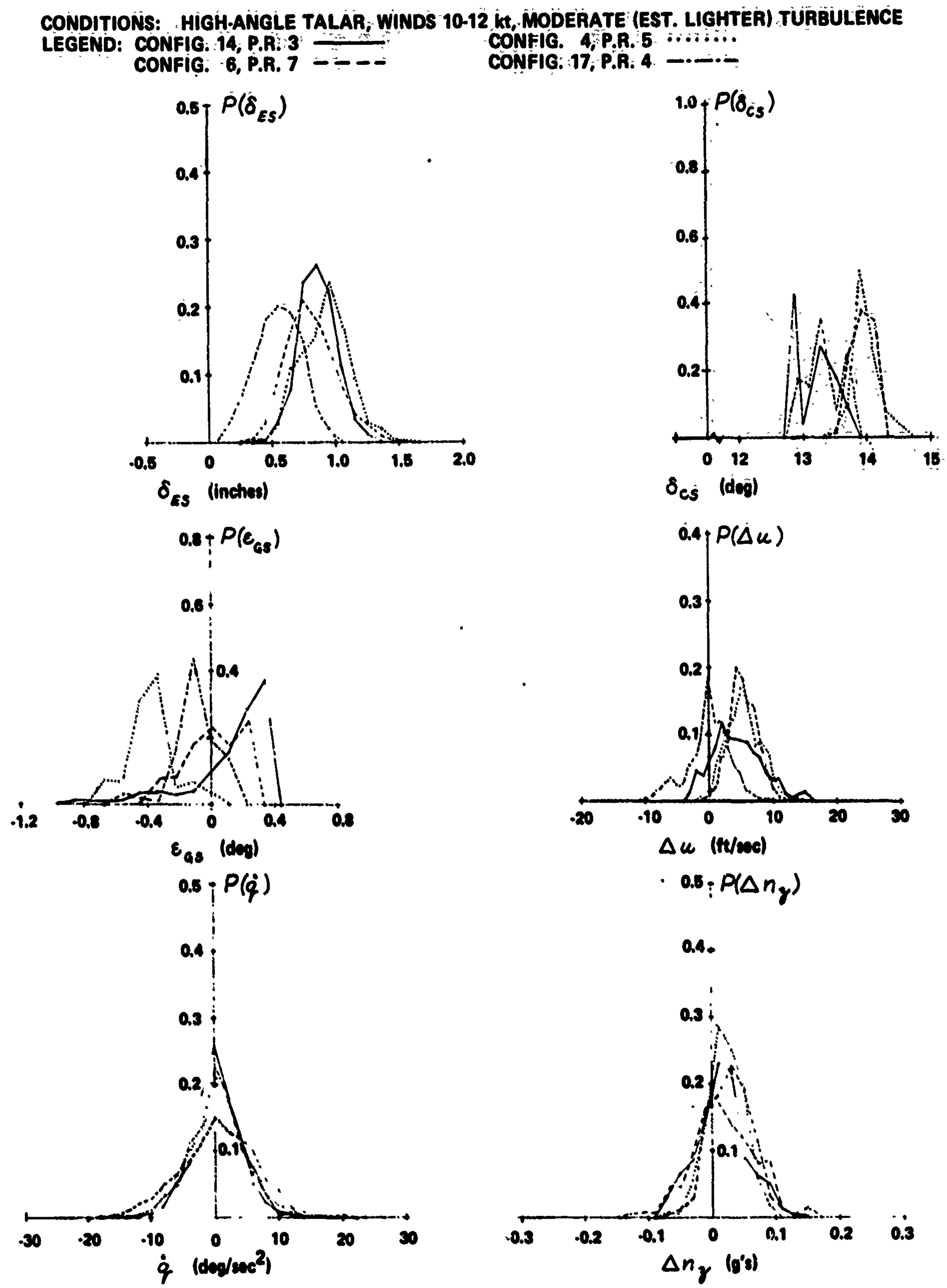


Figure VII-5 PROBABILITY DENSITIES FOR INSTRUMENT APPROACHES – FLIGHT 39F-23

CONDITIONS: LOW-ANGLE TALAR, WINDS 12-17 kt, MODERATE (EST. HEAVIER) TURBULENCE
LEGEND: CONFIG. 5, P.R. 3 ——— CONFIG. 18, P.R. 2 ·········
CONFIG. 13, P.R. 3 – – – – CONFIG. 6, P.R. 7 —·—·—

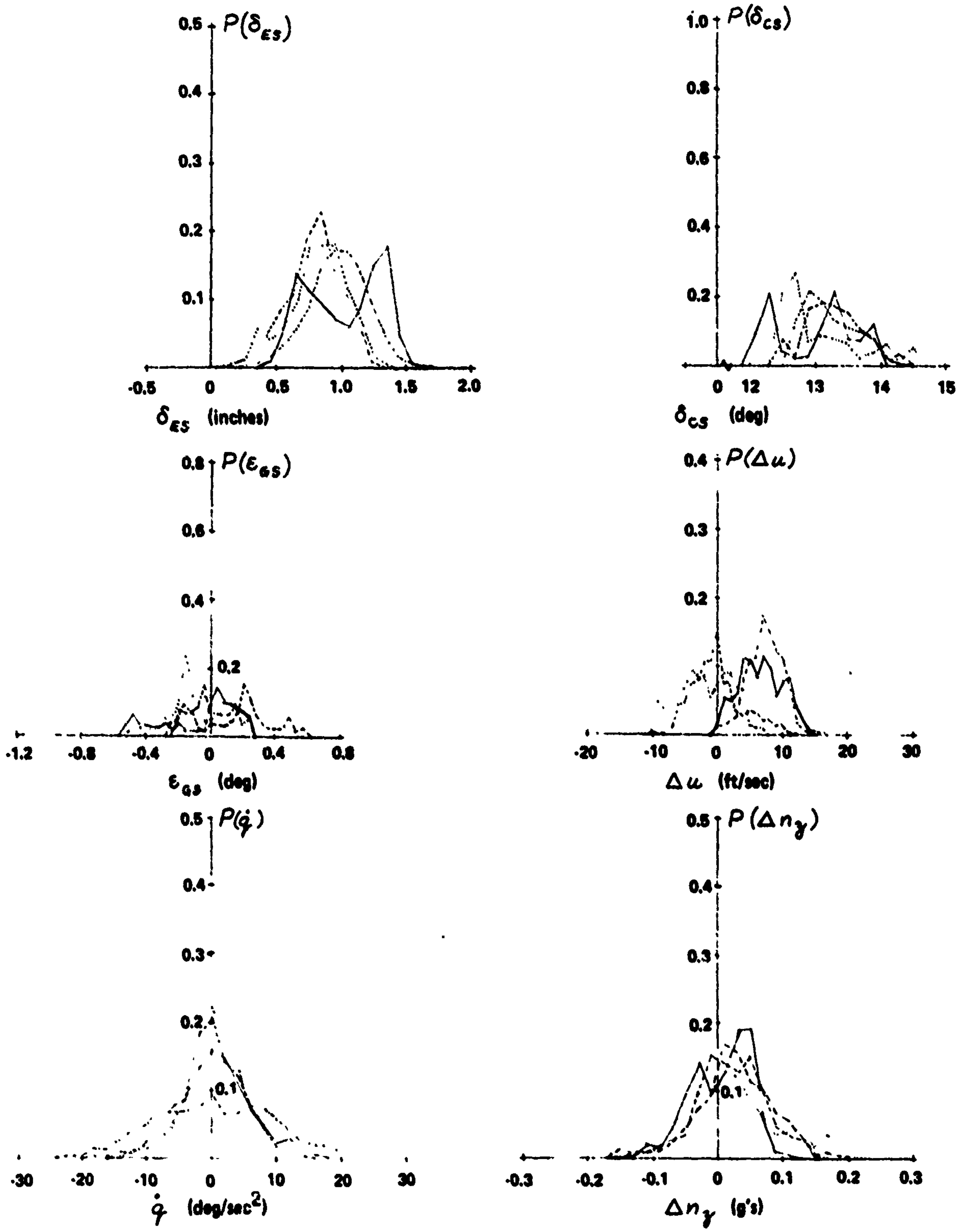


Figure VII-6 PROBABILITY DENSITIES FOR INSTRUMENT APPROACHES – FLIGHT 42F-26

extremes. This again indicates a large amplitude overall oscillation which was verified by the time histories of ε_{GS} (not presented). The oscillations were quite evident, and of varying frequency. Initially, the oscillations had a period of about 26 sec; but as the aircraft got closer to the runway, the frequency increased, and just before flare, the oscillations had a period of about 12 seconds. The P (ε_{GS}) data for 41F shown in Figure VII-7 show similar characteristics. The evidence strongly indicates that the narrow glide-slope beam of the low-angle TALAR was responsible. The high sensitivity apparently induced a large amplitude, low frequency oscillation in the pilot-airplane-guidance (TALAR) system. This tendency is reflected throughout the instrument approach data from Flights 41F and 42F, with two notable and confirming exceptions. In the two special instrument approaches, the GCA and "missed approach" ones (Cases 8 and 12), the pilot did not fly the glide-slope indicator (it was pegged in the missed approach). Figure VII-10 shows relatively normal distribution, thus confirming the conjecture that the high glide-slope sensitivity of the low-angle TALAR may have been responsible for inducing closed-loop pilot-airplane guidance system oscillations.

The P (δ_{cs}) distributions are generally ragged for all the instrument approaches, reflecting the scatter indicated in the $\sigma_{\delta_{cs}}$ statistics. This characteristic has been attributed in part to poor recording system resolution, but there may also have been a sensitivity problem (though not indicated by the pilot comment data) since the statistics do indicate oscillatory tendencies for all instrument approaches.

Visual Approaches

The probability distributions for the visual approaches are presented in Figures VII-8 and VII-9. All the data look relatively normal (Gaussian) except for P (δ_{cs}). The differences between the data for Flights 42F and 41F dramatically show the effects of turbulence. In the absence of significant turbulence, all the distributions are relatively narrow. The P ($\dot{q}$) distributions exhibit an interesting characteristic: the breadths of the distributions do not seem to correlate with pilot rating. This was, of course, also noted as characteristic of the $\sigma_{\dot{q}}$ data for the visual approaches.

Power Spectral Data

The power spectra for elevator stick deflections, $\Phi_{\delta_{ES}}$, and pitch accelerations, $\Phi_{\dot{q}}$, are presented in Figures VII-11 through VII-15. Spectra were computed for all landing approaches except Case 5, where computer difficulties were encountered. These data are presented primarily for reference and analysis. The following general characteristics can be readily observed.

The $\Phi_{\dot{q}}$ spectra provide some insight concerning the flying qualities data. As flying qualities deteriorate, $\Phi_{\dot{q}}$ exhibits a sharp peak, and this peak in the various $\Phi_{\dot{q}}$ spectra generally occurs at $f \cong .45$ Hz = 2.8 rad/sec. For example, Cases 2 and 20, both with PR=7, show a very marked sharp peak in $\Phi_{\dot{q}}$ (Figures 6-11 and 6-12). Both cases have the same short-term dynamics, but Case 20 has

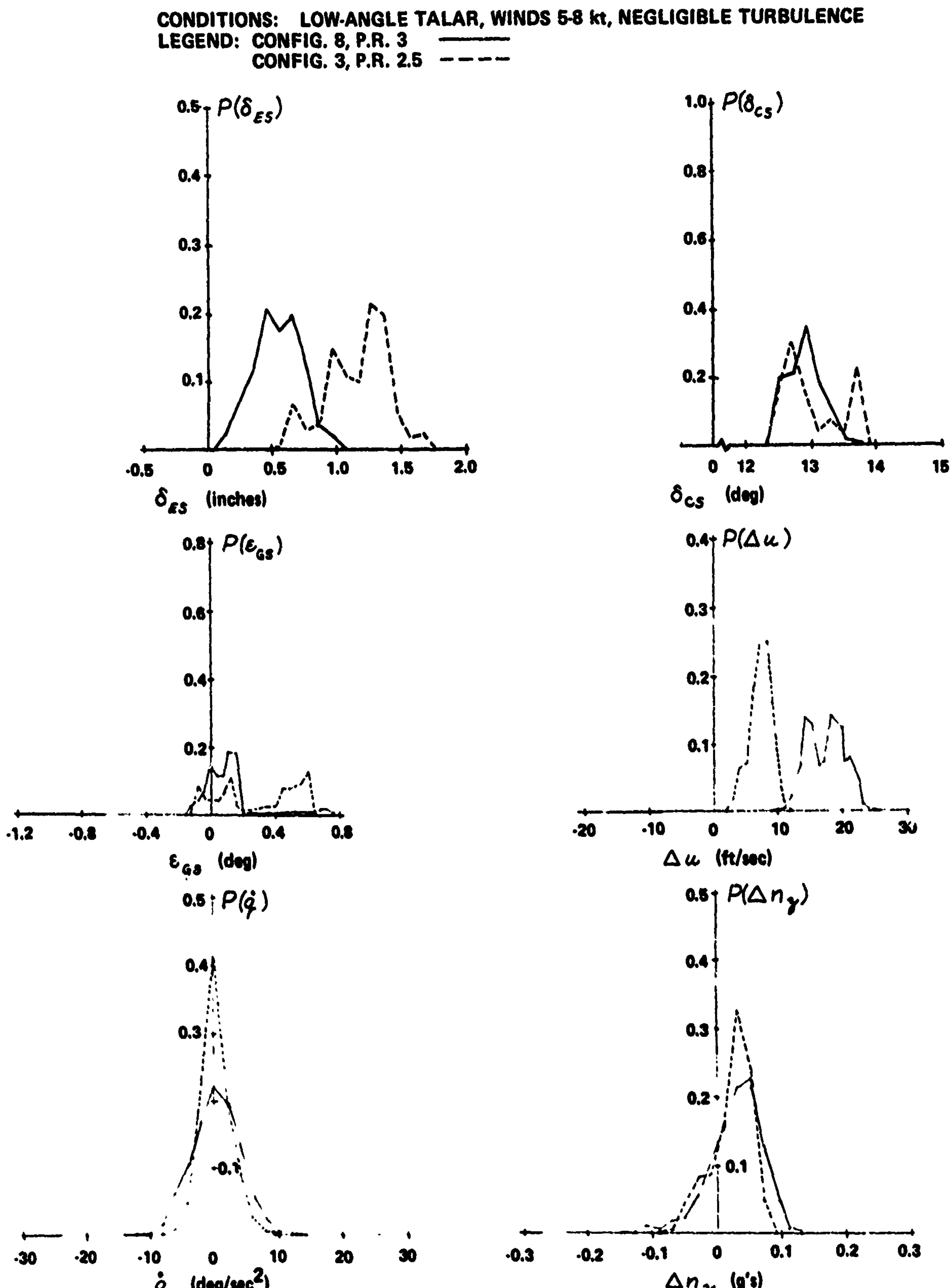


Figure VII-7 PROBABILITY DENSITIES FOR INSTRUMENT APPROACHES – FLIGHT 41F-25

CONDITIONS: LOW-ANGLE TALAR, WINDS 12-15 kt, MODERATE (EST. HEAVIER) TURBULENCE

LEGEND: CONFIG. 5, P.R. 2 ——— CONFIG. 18, P.R. 2 ········ CONFIG. 13, P.R. 4 - - - - CONFIG. 6, P.R. 6 —·—·—

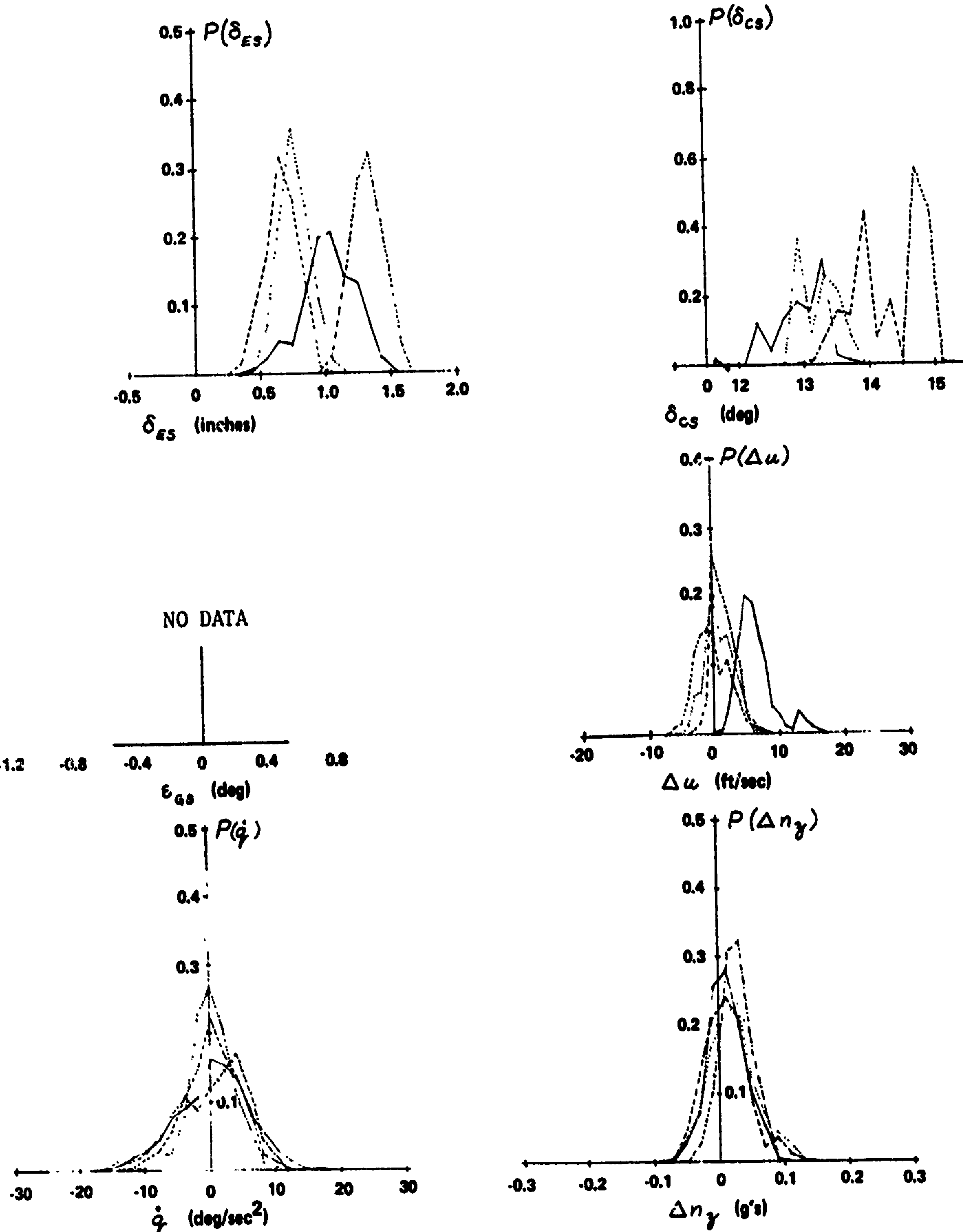


Figure VII-8 PROBABILITY DENSITIES FOR VISUAL APPROACHES – FLIGHT 42F-26

CONDITIONS: LOW-ANGLE TALAR, WINDS 5-8 kt, NEGLIGIBLE TURBULENCE
LEGEND: CONFIG. 17, P.R. 2 ——— CONFIG. 8, P.R. 2 ·········
CONFIG. 13, P.R. 2 – – – –

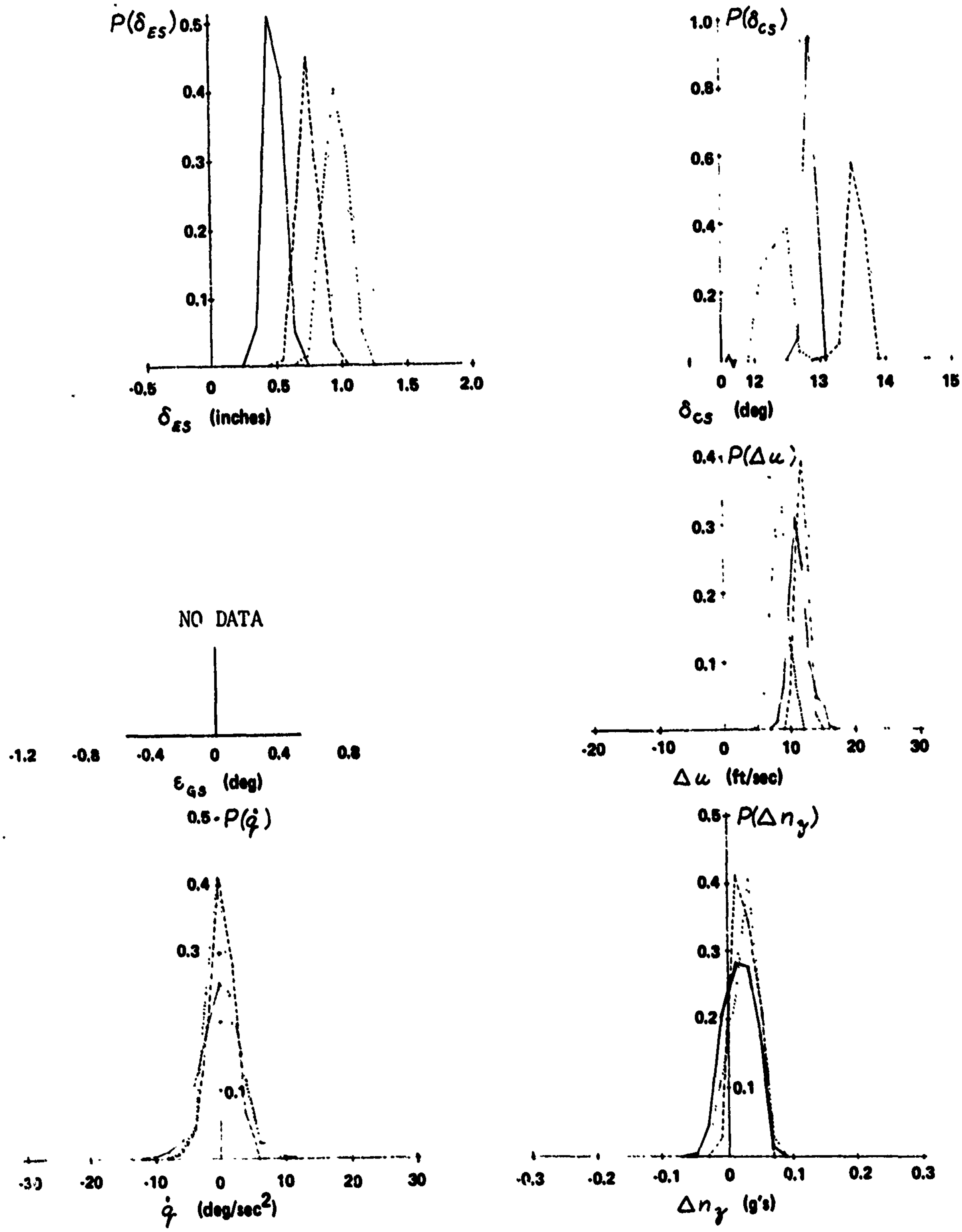


Figure VII-9 PROBABILITY DENSITIES FOR VISUAL APPROACHES – FLIGHT 41F-25

CONDITIONS: LOW-ANGLE TALAR, WINDS 4-8 kt, NEGLIGIBLE TURBULENCE
LEGEND: CONFIG. 17, P.R. 2.5, G.C.A. ———
CONFIG. 13, P.R. 2, MISSED APPROACH - - - -

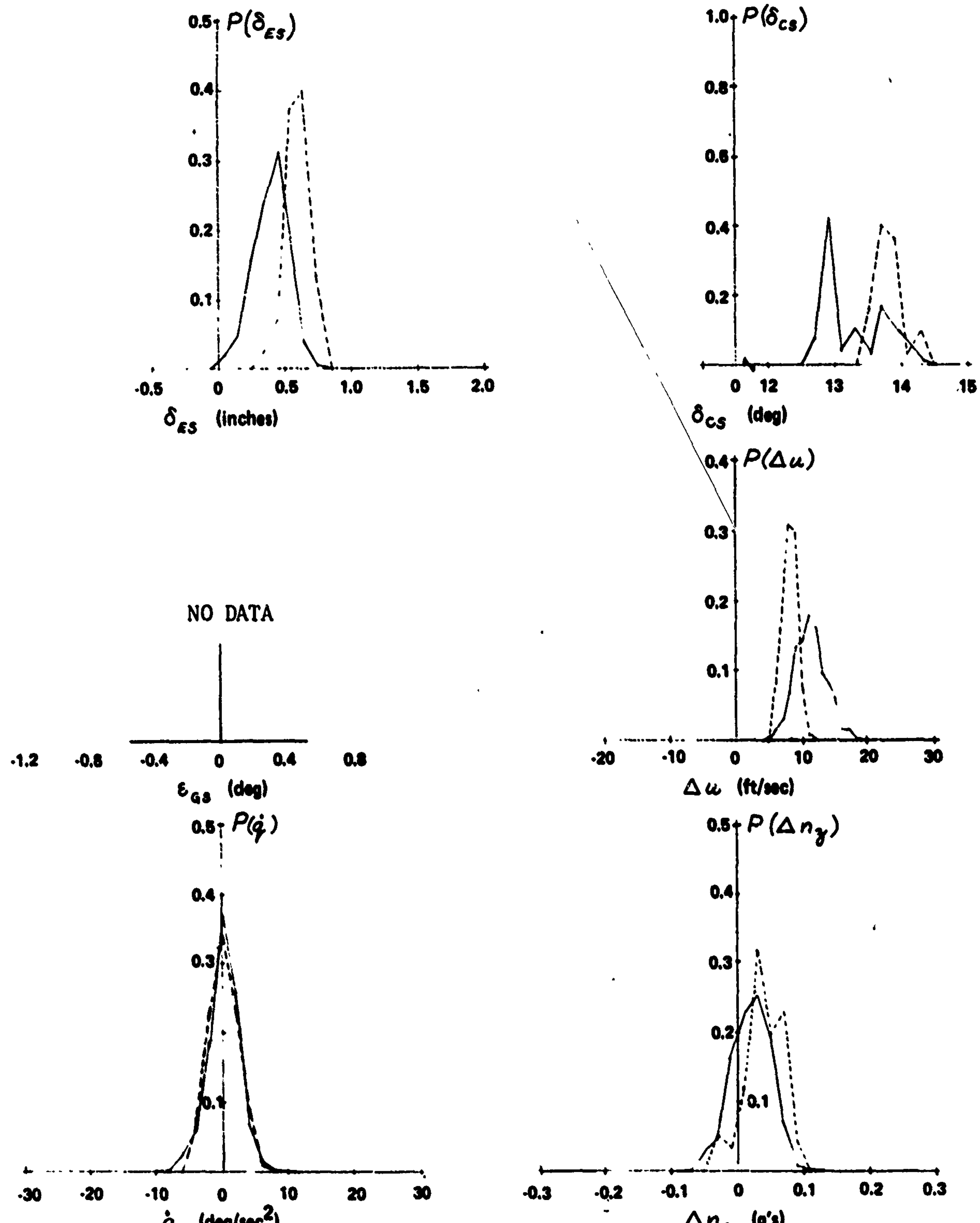


Figure VII-10 PROBABILITY DENSITIES FOR GCA AND MISSED APPROACH – FLIGHT 41F-25

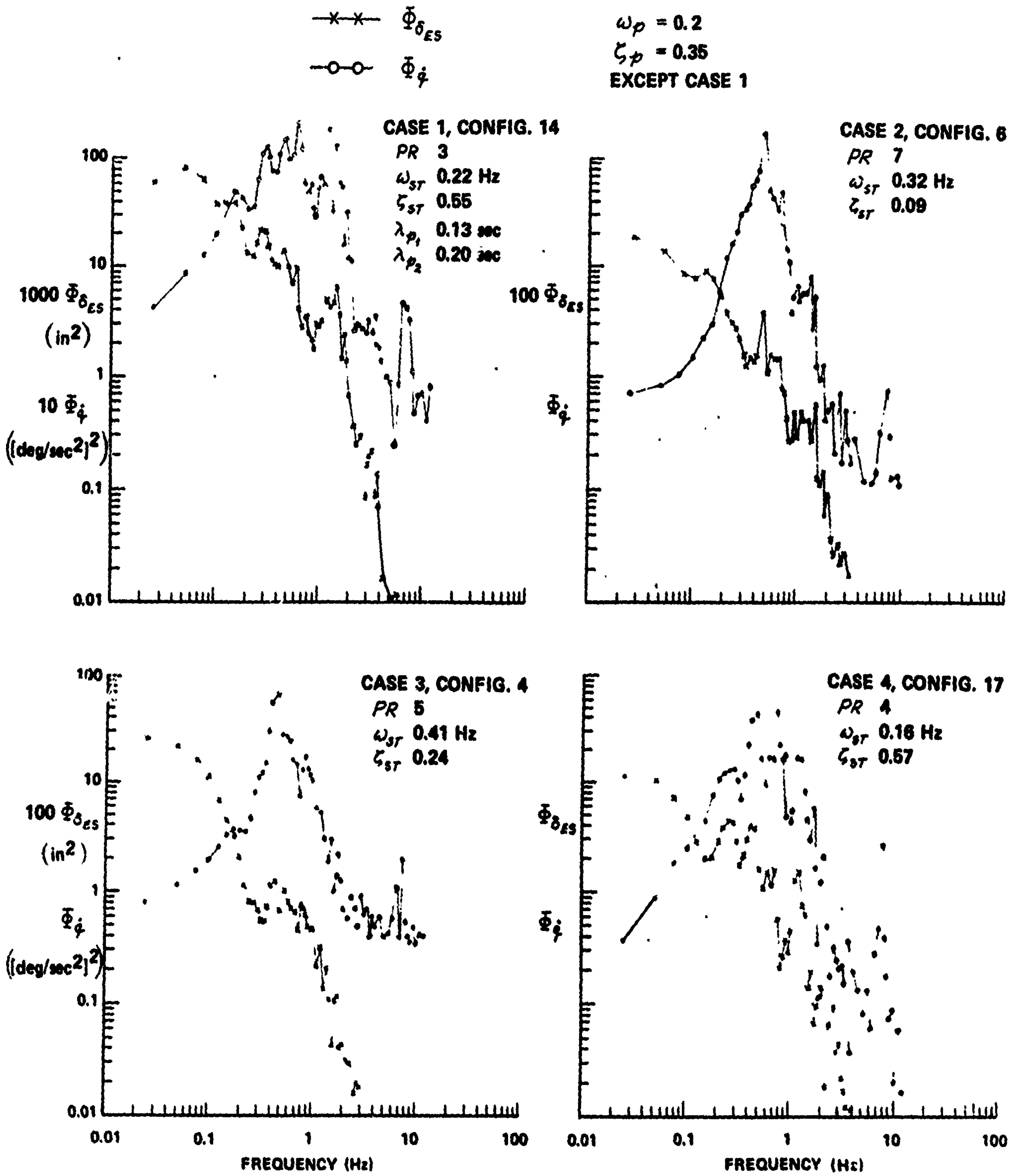


Figure VII-11 POWER SPECTRA DENSITIES FOR INSTRUMENT APPROACHES – FLIGHT 39F

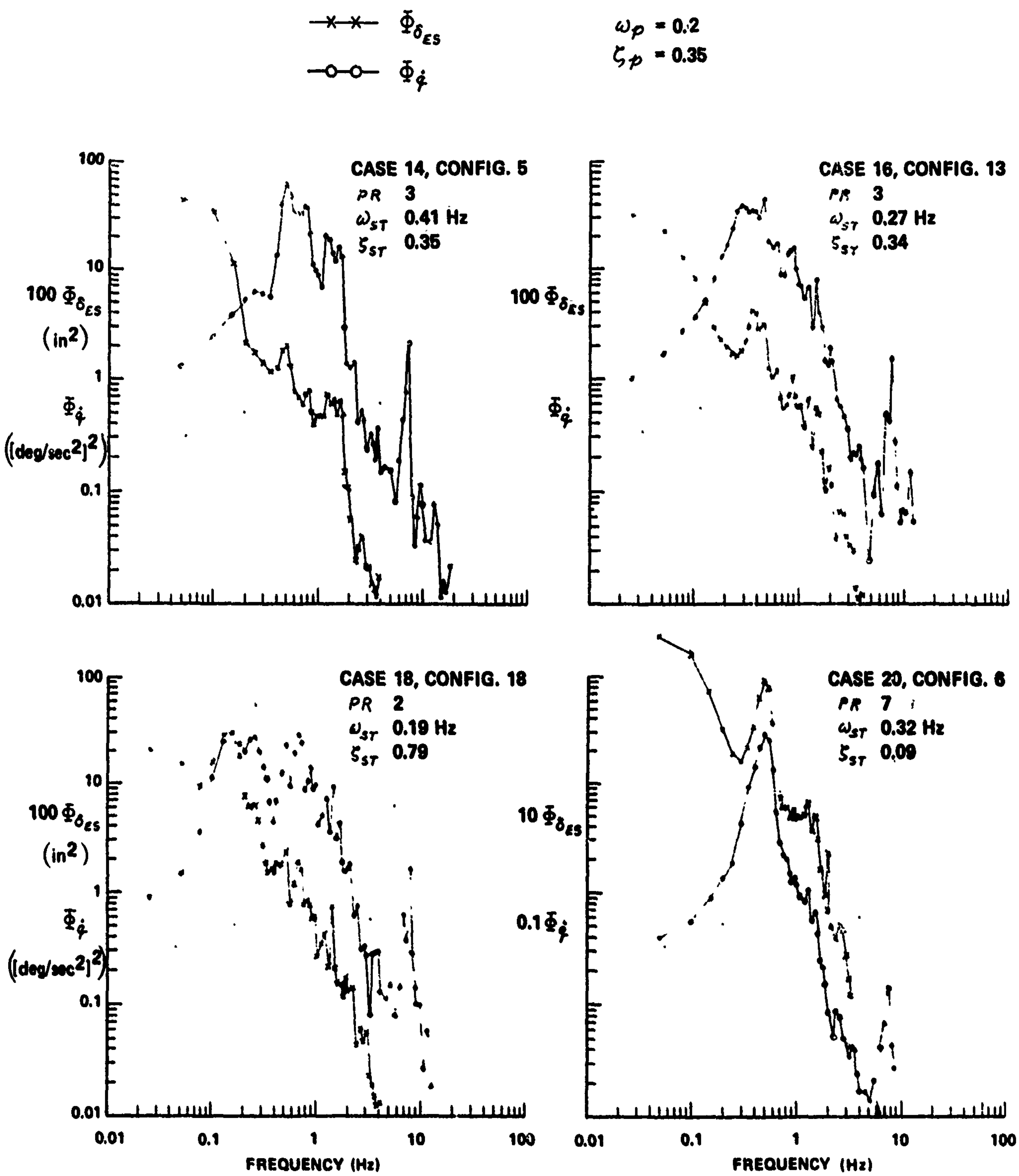


Figure VII-12 POWER SPECTRA DENSITIES FOR INSTRUMENT APPROACHES – FLIGHT 42F

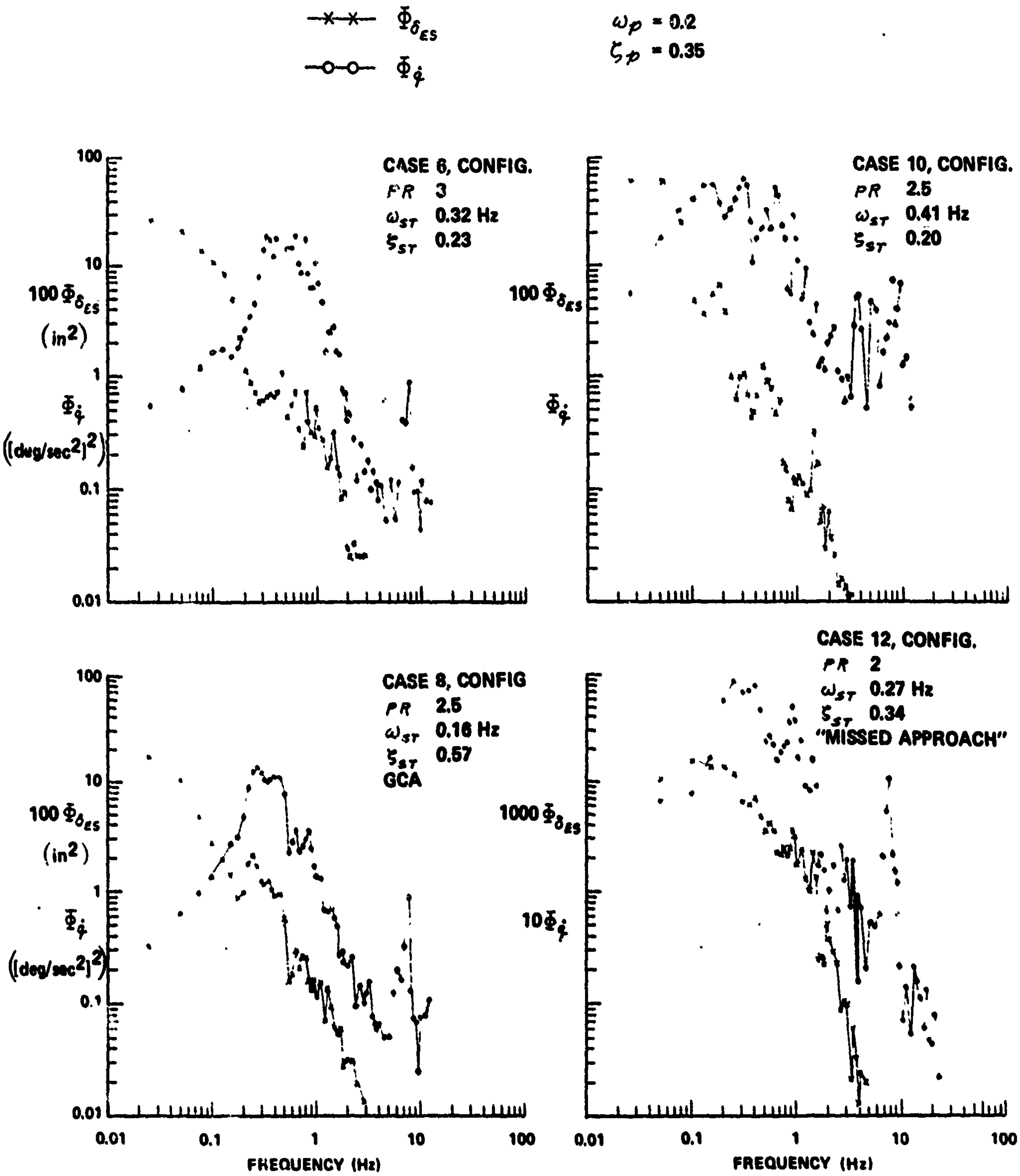


Figure VII-13 POWER SPECTRA DENSITIES FOR INSTRUMENT APPROACHES - FLIGHT 41F

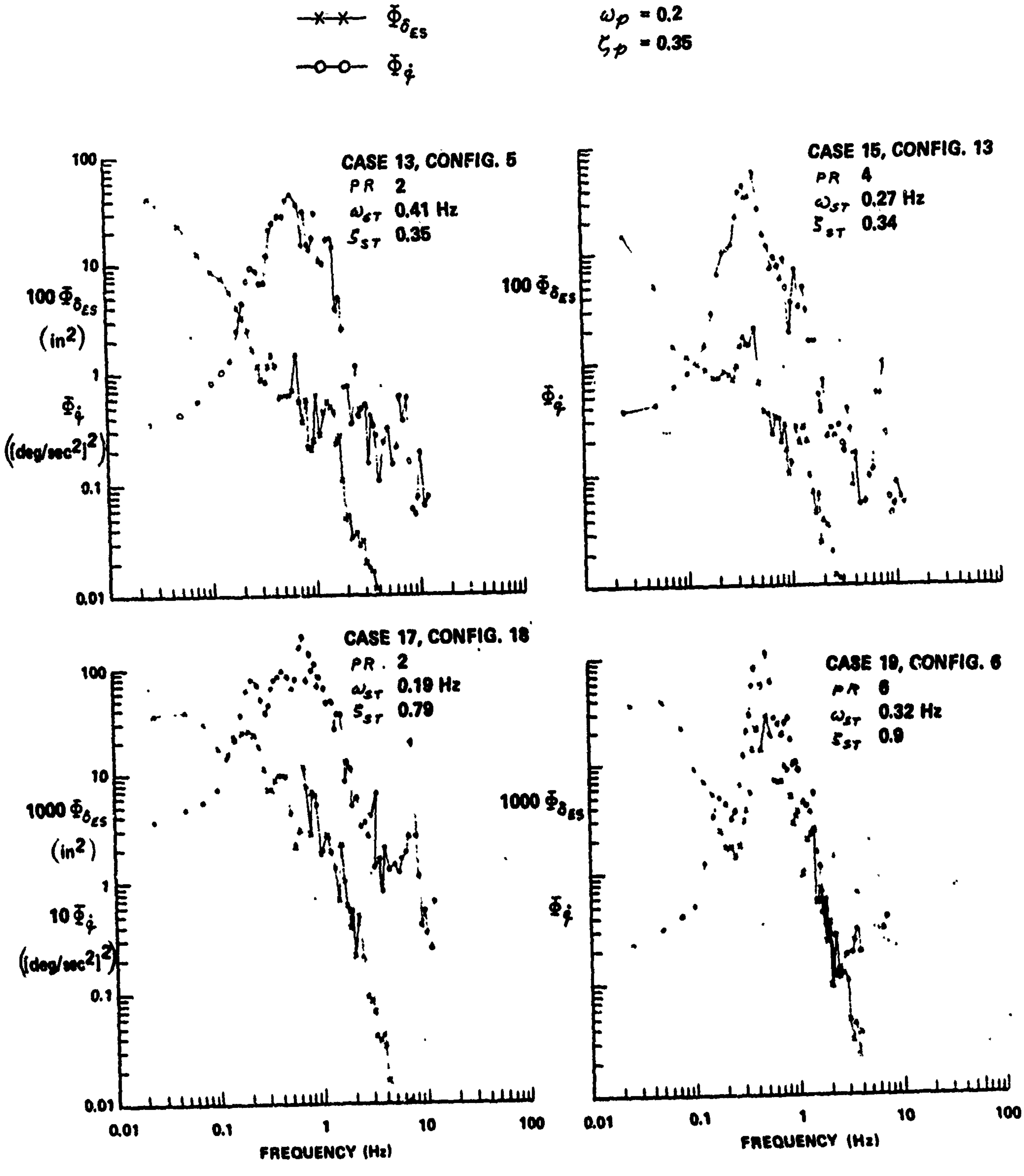


Figure VII-14 POWER SPECTRA DENSITIES FOR VISUAL APPROACHES – FLIGHT 42F

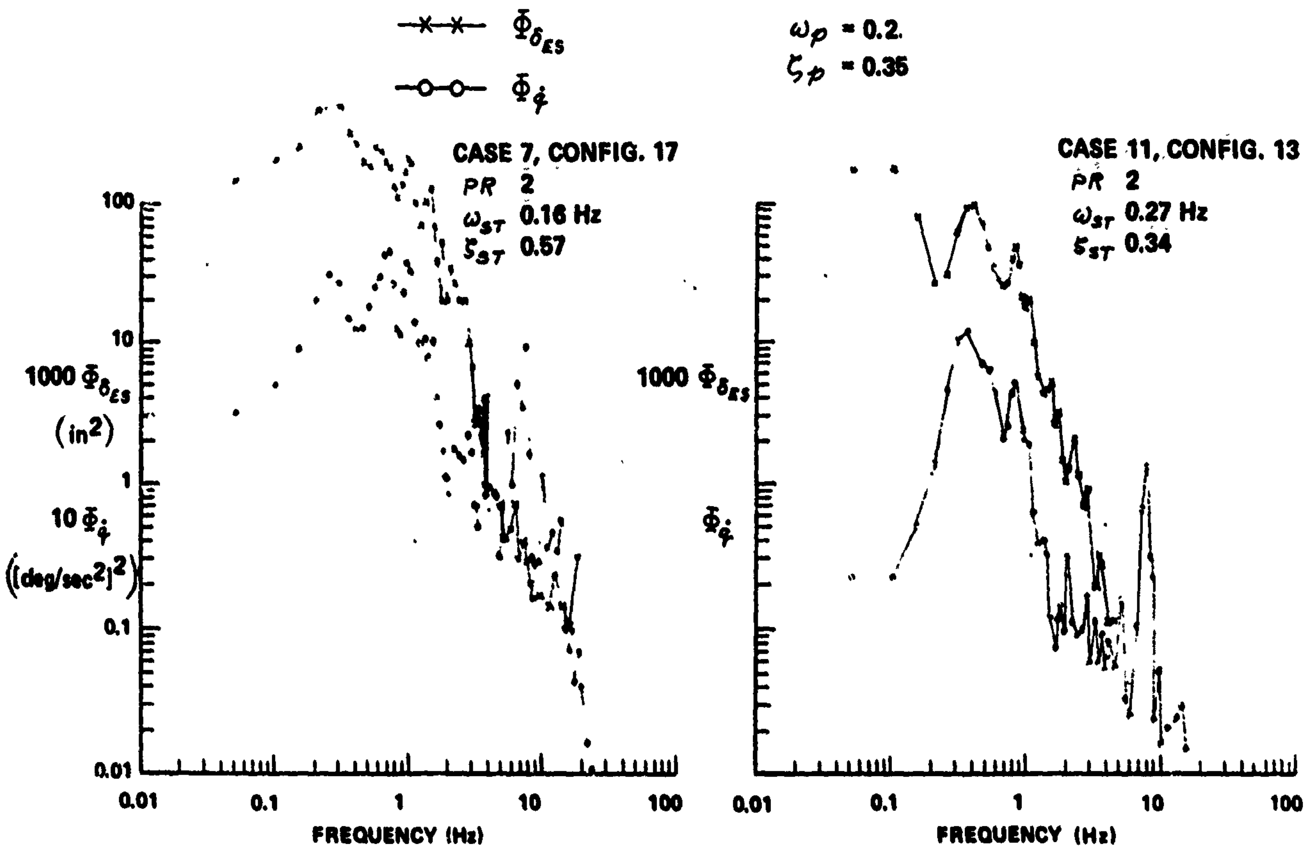


Figure VII-15 POWER SPECTRA DENSITIES FOR VISUAL APPROACHES – FLIGHT 41F a 50% higher elevator sensitivity ($M_{\delta_{ES}}$) or gain. If the two $\Phi_{\dot{q}}$ spectra are examined, their shape is almost identical, and they differ only in amplitude. However, if the corresponding $\Phi_{\delta_{ES}}$ spectra are examined, they are quite different. Case 20 with the higher gain ($M_{\delta_{ES}}$) has a marked peak in $\Phi_{\delta_{ES}}$ at f = .5 Hz, but no similar peak occurs for Case 2. This comparison, for cases having equal pilot ratings but $\Phi_{\delta_{ES}}$ differing by the existence of a sharp peak, indicates that the lack of peaks in control input spectra at the higher frequencies (.1 to 1 Hz range) do not necessarily indicate good flying qualities. An examination of all the $\Phi_{\delta_{ES}}$ spectra further supports a broader conclusion: the magnitude of spectral peaks in the higher frequency range does not seem to correlate with the pilot ratings, as was suggested by Reference 24. The form of the $\Phi_{\dot{q}}$ spectra, however, does show some correlation with pilot rating; for example, those $\Phi_{\dot{q}}$ spectra with high narrow peaks (cases 2, 19, 20) correspond to the worst flying qualities (7, 6, 7, respectively).

REFERENCES

1. Anon, "Military Specification--Flying Qualities of Piloted V/STOL Aircraft," MIL-F-83300, December 1970.

2. Chalk, C.R., Key, D.L. , Kroll, J., Jr., Wasserman, R., Radford, R.C., "Background Information and User Guide for MIL-F-83300--Military Specification--Flying Qualities of Piloted V/STOL Aircraft," AFFDL-TR-70-88, February 1971.

3. Anon, "Military Specification--Flying Qualities of Piloted Airplanes," MIL-F-8785B(ASG), August 1969.

4. Chalk, C.R., Neal, T.P., Harris, T.M., Pritchard, F.E., and Woodcock, R.J., "Background Information and User Guide for MIL-F-8785B(ASG)--Military Specification--Flying Qualities of Piloted Airplanes," AFFDL-TR-69-72, August 1969.

5. Cooper, G.E. and Harper, R.P., Jr., "The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities," NASA TN-D-4364, March 1968.

6. Quigley, H.C., Innis, R.C. and Holzhauser, C.A., "A Flight Investigation of the Performance, Handling Qualities, and Operational Characteristics of a Deflected Slipstream STOL Transport Airplane Having Four Interconnected Propellers," NASA TN-D-2231, March 1964.

7. Innis, R.C, Holzhauser, C.A. and Gallant, R.P., "Flight Tests under IFR with an STOL Transport Aircraft," NASA TN-D-4939, December 1968.

8. O'Leary, C.O. and Slatter, N.V., "Flight Tests to Investigate the Problems of Steep Approaches by STOL Aircraft," Royal Aircraft Establishment TR-69277, December 1969.

9. DiCarlo, D.J., Kelley, J.R. and Sommer, R.W., "Flight Investigation to Determine the Effect of Longitudinal Characteristics on Low-Speed Instrument Operations," NASA TN-D-4364, March 1968.

10. Innis, R.C., Holzhauser, C.A. and Quigley, H.C., "Airworthiness Considerations for STOL Aircraft," NASA TN-D-5594, January 1970.

11. Franklin, J.A., "Flight Investigation of the Influence of Turbulence on Longitudinal Flying Qualities", AIAA Paper No. 71-905, presented at the AIAA Guidance, Control, and Flight Mechanics Conference, August 1971.

12. Chalk, C.R., "Flight Evaluation of Various Short Period Dynamics at Four Drag Configurations for the Landing Approach," CAL Report No. TB-1630-F-3 (FDL-TDR-64-60), November 1963.

13. Berg, R.A. and Shirley, W.A., "A Flight Simulator Study of STOL Transport Longitudinal Control Characteristics," Final Report under Contract DOT FA70WA-2395 performed by Douglas Aircraft Company, December 1971.

14. Chalk, C.R., "Fixed-Base Simulator Investigation of the Effects of L_α and True Speed on Pilot Opinion of Longitudinal Flying Qualities," CAL Report No. TB-1630-F-1, (ASD-TDR-64-60), November 1963.

15. Chalk, C.R., Chen, R.T.N., Lebacqz, J.V., and Neal, T. P., "Revisions to MIL-F-8785B(ASG), Proposed by Cornell Aeronautical Laboratory under Contract F33615-71-C-1254," Draft of CAL Report No. BM-3054-F-1 (to be published as an AFFDL-TR), July 1972.

16. Neal, T.P. and Smith R.E.," An In-Flight Investigation to Develop Control System Criteria for Fighter Airplanes," AFFDL-TR-70-74, December 1970.

17. Anon, "Recommendations for V/STOL Handling Qualities," AGARD Report No. 408, October 1962.

18. Anon, "V/STOL Handling-Qualities Criteria," AGARD Report No. 577, December 1970.

19. Pritchard, F.E., Easterbrook, C.C. and McVehil, G.E., "Spectral and Exceedance Probability Models of Atmospheric Turbulence for Use in Aircraft Design and Operation," AFFDL TR-65-122, October 1965.

20. Hall,G.W., "A Method of Matching Flight Test Records with the Output of an Analog Computer," CAL FDM No. 400, September 1966.

21. Chen, R.T.N., Eulrich, B.J., and Lebacqz, J.V., "Development of Advanced Techniques for the Identification of V/STOL Aircraft Stability and Control Parameters," CAL Report No. BM-2820-F-1, August 1971.

22. Beilman, J.L., "An Integrated System of Airborne and Ground-Based Instrumentation for Flying Qualities Research with the X-22A Airplane," paper presented at the 28th Annual National Forum of the American Helicopter Society, May 1972.

23. Anon, "X-22A Tri-Service V/STOL Aircraft--Final Progress Report," Bell Aerospace Company, Report No. 2127-933073, December 1969.

24. Chalk, C. R. and Key, D.L., "Experiment Design and Data Acquisition for V/STOL Flying Qualities Simulations". SAE Paper No. 690695, National Aeronautical and Space Engineering and Manufacturing Meeting, Los Angeles, California, October 6-10, 1969.

25. Schuler, J. M., Kroll, J., Jr. and Key, D. L., "VTOL Flying Qualities and the Flight Research Use of VTOL Variable Stability Aircraft." Canadian Aeronautics and Space Journal, June 1966.