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critical task for aircraft with significant control system lags. For these aircraft, a sharp degradation in flying qualities takes place during this critical phase of the landing task; for example, severe pilot induced oscillations occurred during the landing task but were not in evidence during the approach task. The results provide a data base for the development of suitable flying qualities requirements which are applicable to aircraft with significant control system dynamics; the results show that the present landing approach requirements in MIL-F-8785B(ASG) are not adequate; in particular, they are not applicable to aircraft with complex flight control systems.

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FOREWORD

This report was prepared for the United States Air Force by Calspan Corporation, Buffalo New York, in partial fulfillment of Contract Number F33615-73-C-3051 and describes the results of the flight program performed under that contract.

The flying qualities experiment reported herein was performed by the Flight Research Branch of Calspan under sponsorship of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, as part of Project 8120, Task 16. Mr. G. Thomas Black was the Air Force Project Engineer and Mr. Jack Barry was the Program Manager for AFFDL. The research was conducted between June 1977 and March 1978, with this report submitted in March, 1978.

This report represents the combined efforts of many members of the Flight Research Branch. Rogers E. Smith was the Project Engineer for this investigation and also served as safety pilot. The evaluation pilots, who performed their important role in the experiment in a very professional manner despite the trials of a concentrated flight schedule, were Michael L. Parrag (Pilot A) and Robert P. Harper, Jr. (Pilot B). Ronald W. Huber was responsible for the modifications, calibration and maintenance of the NT-33 variable stability system. Dr. Philip Reynolds was the Program Manager for the overall NT-33 contract. The outstanding contributions of the following individuals are also gratefully acknowledged:

Messrs. Alva Schwartz and Raymond Miller- Aircraft Maintenance
Messrs. Thomas Franclemont and David Begier - Electronic Maintenance
Mr. Robert Ductor - Electronic Circuit Design
Messrs. James Lyons and Clarence Mesiah - Digital Data Analysis
Ms. Florence E. Scribner - Report Illustrating

Particular recognition is due Dr. K. S. Govindaraj who performed the bulk of the digital identification for the program and contributed the description of the procedure presented in Appendix IV.

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Finally, the assistance of Miriam Ford in the preparation of this report under somewhat difficult circumstances deserves very special credit.

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SYMBOLS AND ABBREVIATIONS

Symbol

dB	Decibel units for Bode amplitude, where amplitude in dB = $20 \log_{10}$ (amplitude)
DES	Pitch control stick displacement, positive aft (inches)
F_{AS}	Roll control stick force, positive right (lb)
F_{ES}	Pitch control stick force, positive aft (lb)
F_{RP}	Rudder pedal control force, positive right (lb)
F_{ES/n_z}	Steady-state stick force per unit normal acceleration, at constant speed (lb/g)
g	Acceleration of gravity (ft/sec ²)
HP	Pressure altitude (ft)
I_x	Moment of inertia about body x-axis (slug-ft ²)
I_y	Moment of inertia about body y-axis (slug-ft ²)
I_z	Moment of inertia about body z-axis (slug-ft ²)
I_{xz}	Product of inertia in body axes (slug-ft ²)
K_θ	Steady-state gain of constant speed θ/δ_{ES} transfer function (rad/lb)
$L_{\delta_{AS}}$	Rolling acceleration commanded by roll control stick about x-body axis (rad/sec ² per inch)
$L'_{\delta_{AS}}$	Rolling acceleration commanded by roll control stick about x-principal axis (rad/sec ² per inch) $= (1 - I_{xz}^2/I_x I_z)^{-1} (L_{\delta_{AS}} + \frac{I_{xz}}{I_x} N_{\delta_{AS}})$

SYMBOLS AND ABBREVIATIONS (CONT.)

Symbol

m	Aircraft mass (slugs)
$M_{(\)}$	$\frac{1}{I_y} \frac{\partial M}{\partial (\)}$ body axis dimensional pitching moment derivative (rad/sec ² per ())
$N_{\delta_{RP}}$	Yawing acceleration commanded by rudder pedals about z-body axis (rad/sec ² per inch)
$N_{\delta_{RP}}$	Yawing acceleration commanded by rudder pedals about z principal axis (rad/sec ² per inch) $= (1 - I_{xz}^2 / I_x I_z)^{-1} (N_{\delta_{RP}} + \frac{I_{xz}}{I_y} L_{\delta_{RP}})$
N_x	Longitudinal body axis acceleration, positive forward (ft/sec ²)
$n_z(NZ)$	Normal acceleration at c.g., positive for pull up; negative up for identification records (g's or ft/sec ²).
n_z/α	Steady-state normal acceleration per angle of attack (g's/rad)
NZP	Normal acceleration at pilot's station, positive for pull up (g's or ft/sec ²)
$q(Q)$	Body axis pitch rate (deg/sec or rad/sec)
s	Laplace operator (1/sec)
t	Time, seconds
T_d	Time to double amplitude, seconds
THR	Throttle position (inches)

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SYMBOLS AND ABBREVIATIONS (CONT.)

Symbol

TRK	Tracking needle displacement (inches)
U	Velocity along x body axis (ft/sec)
u	Perturbation velocity from trim along x body axis (ft/sec)
V_{ind} (VIAS)	Trimmed indicated airspeed (knots)
V_T	Trimmed true airspeed (knots)
w	Perturbation velocity from trim along z body axis (ft/sec)
$X_{(\)}$	$= \frac{1}{m} \frac{\partial X}{\partial (\)}$ body axis dimensional X-force derivative (ft/sec ² per ())
$Z_{(\)}$	$= \frac{1}{m} \frac{\partial Z}{\partial (\)}$ body axis dimensional Z-force derivative (ft/sec ² per ())
α	Angle of attack (deg or rad)
β	Angle of sideslip (deg or rad)
δ_{RS}	Roll stick deflection at grip, positive right (inches)
δ_{ES}	Pitch stick deflection at grip, positive aft (inches)
δ_e	Aircraft elevator deflection, positive trailing edge down (rad)
δ_{RP}	Rudder pedal deflection, positive right (inches)
ζ_a	Elevator actuator damping ratio
ζ_d	Dutch-roll damping ratio
ζ_{ph}	Phugoid damping ratio

SYMBOLS AND ABBREVIATIONS (CONT.)

Symbol

ζ_{sp}	Short period damping ratio
$\zeta_{3(4)}$	Damping ratio of second (and fourth) order prefilters
ζ_{ϕ}	Damping ratio of numerator of Φ/δ_{AS} transfer function
Θ (THET)	Pitch attitude (deg or rad)
τ	Transport time delay, $e^{-\tau s}$ (sec)
τ_1	Time constant of control system lead element (sec)
τ_2	Time constant of control system lag element (sec)
τ_R	Roll mode time constant (sec)
τ_S	Spiral mode time constant (sec)
$\tau_{\Theta,2}$	Airframe lead time constants in $\Theta/\delta_{\epsilon S}$ transfer function (sec)
$ \Phi/\beta _d$	Absolute value of controls fixed roll-to-sideslip ratio at ω_d
ω	Bode frequency (rad/sec)
ω_a	Undamped natural frequency of actuator (rad/sec)
ω_d	Dutch-roll undamped natural frequency (rad/sec)
ω_n	Undamped natural frequency (rad/sec)
ω_{ph}	Phugoid undamped natural frequency (rad/sec)
ω_{sp}	Short period undamped natural frequency (rad/sec)
$\omega_{3(4)}$	Undamped natural frequency of control system prefilters. (rad/sec)
ω_{ϕ}	Undamped natural frequency of numerator of Φ/δ_{AS} transfer function (rad/sec)

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SYMBOLS AND ABBREVIATIONS (CONT.)

Symbol

$\dot{(\)}$ Rate of change of () with time (()/sec)

$(\)_0$ Initial or trim value of ()

Abbreviations

c.g.	Center of gravity
EP	Evaluation Pilot
ILS	Instrument Landing System
KIAS	Knots, Indicated Airspeed
ms	Millisecs
PIO	Pilot Induced Oscillation
PR	Pilot Rating
SP	Safety Pilot

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Section 1

INTRODUCTION AND PURPOSE

In recent years, the demand for increased fighter capability, in combination with the demonstrated reliability of modern electronic systems, has led to more complex flight control systems. For example, the latest fighter aircraft designs include sophisticated digital flight control concepts and revolutionary fly-by-wire flight control systems. The additional complexity of these highly augmented aircraft designs is not a problem in itself; however, significant additional control system dynamics are typically introduced which can potentially alter the flying qualities of the aircraft dramatically. Flying qualities requirements, or control system design criteria, must account for the effects of these additional control system dynamics to be of any value. Unfortunately, response criteria based on classical aircraft characteristics, such as those presented in MIL-F-8785B (Reference 1) are not adequate to evaluate the flying qualities of modern highly augmented fighter aircraft.

A necessary first step in the development of suitable flying qualities evaluation criteria for aircraft with significant control system dynamics was the collection of applicable flying qualities data. In response to this need, a series of research programs was conducted using the USAF/Calspan NT-33A variable stability aircraft (References 2, 3, 4 and 5). These programs concentrated on the longitudinal flying qualities of highly augmented fighter aircraft for maneuvering and tracking tasks (Flight Phase Category A).

-
- Ref. 1. Anon, "Military Specification, Flying Qualities of Piloted Airplanes: MIL-F-8785B(ASG)," August 1969.
2. Parrag, M. L. E., "Pilot Evaluations In a Ground Simulator of the Effects of Elevator Control System Dynamics in Fighter Aircraft," AFFDL-TR-67-19, July 1967.
3. Di Franco, D. A., "In-Flight Investigation of the Effects of Higher-Order System Dynamics on Longitudinal Handling Qualities," AFFDL-TR-68-90, July 1968
4. Neal, T. P. and Smith, R. E., "An In-Flight Investigation to Develop Control System Design Criteria for Fighter Airplanes (Vol. I & II)," AFFDL-TR-70-74, December 1970.
5. Boothe, E. M., Chen, R. T. N., and Chalk, C. R., "A Two-Phase Investigation of Longitudinal Flying Qualities for Fighters," AFFDL-TR-74-9, April 1974.

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In particular, pitch maneuver response criteria which consider the total aircraft dynamic system were developed by Neal and Smith (Reference 4) for fighter aircraft performing tracking tasks. The closed-loop pitch attitude tracking criterion of Reference 4 has, in fact, been used with good success as a flying qualities evaluation tool for today's complex fighter aircraft.

In the absence of suitable flying qualities data for the landing approach task (Flight Phase Category C), the concepts developed in Reference 4 were modified somewhat and extrapolated to cover this flight phase (References 6 and 7). Unfortunately, this attempt to provide a suitable flying qualities criterion for this important flight phase which is applicable to fighter aircraft with significant control system dynamics failed its first real test.

Briefly the story of the test is as follows. Prior to their first flights, both the YF-16 and YF-17 prototypes were simulated in the NT-33A in-flight simulator (Reference 8); these aircraft are both highly augmented and exhibit higher order responses to pilot inputs due to the presence of significant control system dynamics. Of particular interest at this point is the experience in the NT-33A with the landing approach simulation of the YF-17.

-
- Ref. 6. Chalk, C. R. et al, "Revisions to MIL-F-8785B(ASG) Proposed by Cornell Aeronautical Laboratory Under Contract F33615-71-C-1254)," AFFDL-TR-72-41, April 1973.
7. Mayhew, D. R., "A Proposal and Justification for Revision Selected Portions of MIL-F-8785B," AFFDL Working Paper, February 1976.
8. Hall, G. W. and Harper, R. P., "In-Flight Simulation of the Light Weight Fighters," AIAA Paper 75-986, August 1975.

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- First, the original longitudinal flight control system as simulated in-flight, resulted in very poor flying qualities in the landing approach task, particularly in the final stages of the approach close to the runway.
- Second, this landing problem was not predicted by existing pitch maneuver response criteria, including the extrapolation of the closed-loop Neal/Smith criterion.
- Third, the very poor longitudinal flying qualities in the landing approach were not observed during ground simulation studies on a very sophisticated simulator; however, the deficiencies were dramatically exposed during the initial in-flight simulation sorties.

Control system modifications were then proposed, implemented, and evaluated in the NT-33A until satisfactory longitudinally flying qualities were observed.

The lessons presented by the YF-17 landing approach simulation experience, in combination with the previous research programs documenting the significant effects of control system dynamics on longitudinal flying qualities, clearly indicated the need for landing approach flying qualities data applicable to highly augmented aircraft. Further, the evidence showed that the tasks must include actual touchdowns. The research program described in this report was conceived in response to these observations.

The purpose of the research program described in this report may be summarized as follows:

- To gather pertinent background data on the longitudinal flying qualities of highly augmented fighter aircraft for the landing approach flight phase - including the flare and touchdown (Flight Phase Category C, Class IV.)

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- To show whether the flare and touchdown tasks are indeed more demanding than the approach task alone and therefore are the critical landing approach task.
- To lay the groundwork for the development of longitudinal response criteria for the landing approach tasks which are applicable to aircraft with complex control systems, as well as those whose dynamics can be described by classical parameters.
- To gather data on pilot induced oscillations (PIO's) in the landing task with which existing PIO criteria can be evaluated.

Details of the research program using the NT-33A in-flight simulator to study the effects of control system dynamics on landing approach longitudinal flying qualities are presented in this report. The report is organized as follows: a summary of the design of the experiment is presented in the next section, followed by sections on the conduct of the experiment, a discussion of the results, and finally the pertinent conclusions. Detailed background material and data are presented in a series of appendices. This report is Volume I of a two volume report on this research program; Volume II contains a more complete presentation of the performance data and additional analysis of the data.

Section 2 EXPERIMENT DESIGN

The purpose of this section is to describe the control system and aircraft characteristics for each of the configurations evaluated during the program. A discussion of the technique used to identify the longitudinal characteristics of the evaluation configurations and a more detailed summary of the characteristics is presented in Appendix IV. The reader is referred to Appendix V for a brief discussion of aircraft longitudinal transfer functions and equations of motion. A description of how the simulated configurations were mechanized in the variable stability NT-33 is presented in Appendix VI.

2.1 OBJECTIVES

The objective of the in-flight simulation program was to produce an approach and landing longitudinal flying qualities data base from which a suitable response criterion, applicable to highly augmented fighter aircraft, can eventually be developed. Accordingly, the primary evaluation characteristics were selected using the rationale that a broad range of representative aircraft and control system dynamics should be explored rather than specific control system augmentation schemes. In addition, a small portion of the flight program was devoted to the evaluation of configurations with special features; the details of these configurations are discussed in Subsection 2.5. The following subsection is directed at the primary evaluation configurations.

2.2 EXPERIMENT VARIABLES

The block diagram of Figure 1 represents how the pilot would view the total longitudinal pitch dynamic "package" which he flies.

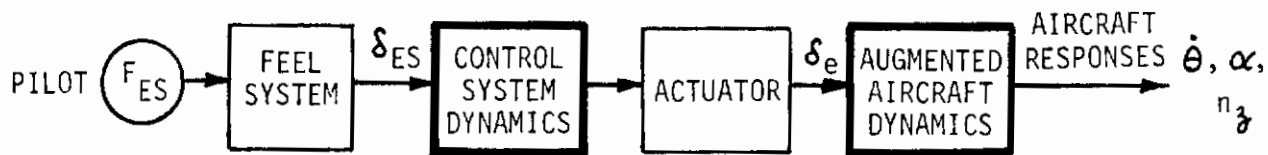


Figure 1: LONGITUDINAL RESPONSE BLOCK DIAGRAM

The primary variables in the experiment are the dynamic elements in the heavy blocks: the control system dynamics and the aircraft dynamics. One assumes that we are dealing with aircraft in which the desired augmented aircraft dynamics are achieved, but additional dynamics are introduced-in the form of prefilters, compensation networks, or digital computational delays - to produce a higher-order system. The term "higher-order system" is used to describe a system with additional significant dynamic modes in addition to the classical short period and phugoid longitudinal response modes. An alternate viewpoint would be that the aircraft dynamics, representing the bare airframe, are combined with prefilter dynamics to produce a higher-order system. The controlled experiment variables may be summarized as follows:

- Aircraft short period dynamics
- Control system dynamics
- Task
 - Full task, including flare and touchdown, or
 - Approach-only task with no touchdown

The details of the aircraft dynamics and control system dynamics selected to form the primary evaluation configurations are discussed in the following subsections. Other important characteristics which are not controlled variables in the experiment are discussed in the final subsections.

2.3 AIRCRAFT SHORT PERIOD DYNAMICS

In the absence of significant control system dynamics the constant speed transfer function relating pitch attitude to pilot stick displacement is:

$$\frac{\theta}{\delta_{ES}} = K_{\theta} \frac{(\tau_{\theta_2} s + 1)}{s \left(\frac{s^2}{\omega_{SP}^2} + \frac{2\zeta_{SP}}{\omega_{SP}} s + 1 \right)}$$

Five combinations of ω_{SP} and ζ_{SP} were selected to span fairly wide ranges, relative to the requirements of MIL-F-8785B (Category C). These configurations represent the experiment base configurations; each set of evaluation configurations consists of a base configuration in combination with a variety of control system dynamics. The five base configurations (1-1 through 5-1) are compared with the Category C MIL-F-8785B requirements in Figure 2 for the nominal (see Section 2.9) landing flight condition, which is:

- V_{ind} = 120 knots
- V_T = 205 ft/sec
- n_z/α = 4.5 g/rad
- τ_{θ_2} = 1.4 sec
- $1/\tau_{\theta_2} \approx 0.7$ rad/sec

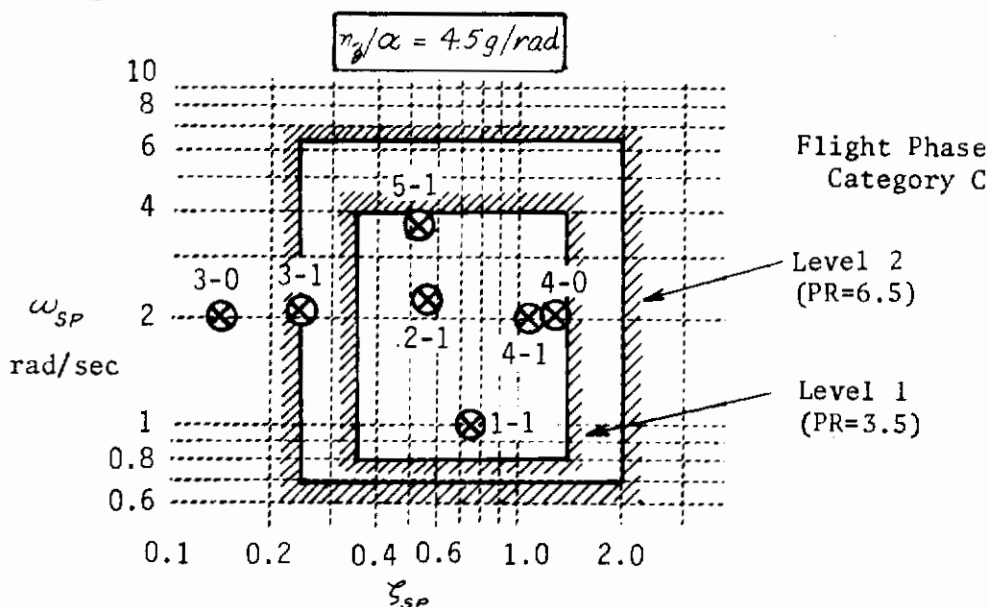


Figure 2: COMPARISON OF PRIMARY SHORT PERIOD CONFIGURATIONS WITH MIL-F-8785B

Since the speed was not constant during the complete landing task, the selection of a nominal flight condition requires some explanation; more details are presented in Subsection 2.9 and Appendix IV.

Configurations 3-0 and 4-0, shown in Figure 2, represent alternate base configurations which were never evaluated in combination with additional control system dynamics. The very lightly damped configuration (3-0) was specifically selected because it was predicted to be PIO-prone. Along with those configurations in which the addition of control system dynamics produce PIO's, this configuration was intended as an appropriate test of the PIO criterion of Reference 9. Configuration 4-0 was selected as a representative heavily damped configuration but was rejected as a base configuration in the initial phases of the evaluation flying because it was rated unsatisfactory by the pilot.

2.4 CONTROL SYSTEM DYNAMICS

Each base short period configuration was evaluated in combination with a variety of representative control system dynamics. The various forms of the control system dynamics selected which are representative of typical modern flight control system elements are summarized as follows:

- First order lag, $\frac{1}{\tau_2 s + 1}$, or
- First order lead/lag, $\frac{\tau_1 s + 1}{\tau_2 s + 1}$, or
- Second order lag prefilter $\frac{1}{\frac{s^2}{\omega_3^2} + \frac{2\zeta_3}{\omega_3} s + 1}$, or
- Fourth order lag prefilter $\frac{1}{\left(\frac{s^2}{\omega_3^2} + \frac{2\zeta_3}{\omega_3} s + 1\right)\left(\frac{s^2}{\omega_4^2} + \frac{2\zeta_4}{\omega_4} s + 1\right)}$

Ref. 9. Smith, R. H., "A Theory for Longitudinal Short-Period Pilot Induced Oscillations," AFFDL-TR-77-57, June 1977.

Contrails

The exact values selected for evaluation are summarized in Sub-section 2.6. Some general comments can however be made about the effects of the various control system dynamics on the overall response of the aircraft to pilot inputs. For reference, step response time histories for all the evaluation configurations are presented in Appendix III.

- Values of τ_1 and τ_2 were selected such that the poles and zeros of these control system elements are approximately the same magnitude as the short period frequency of the base configuration.
 - The addition of these elements can therefore significantly alter the shape of the response of the base configuration to pilot inputs. These elements introduce both phase and amplitude distortion.

- Values of ω_3 in the second order prefilter were selected over a wide range:
 - When ω_3 is approximately the same magnitude as the short period frequency, the shape of the response to pilot inputs can be significantly altered by the addition of this control system element.

 - When ω_3 is much greater than the short period frequency, the effect of the addition of this type of control system element is to leave the shape of the response to pilot inputs essentially unchanged but to introduce an initial delay. In this case, only phase distortion is introduced by this control system element.

 - $\zeta_3 = 0.7$ for all the prefilters evaluated.

 - Elements of this form are introduced to filter the pilot's inputs or as prefilter models in complex augmentation schemes such as in the original YF-17 design (Reference 8.)

- The fourth order prefilter selected was a Butterworth filter with $\zeta_3 = .93$, $\zeta_4 = .38$, and $\omega_3 = \omega_4 = 16$ rad/sec; designated 16(4th) in the report. This prefilter was selected partly for convenience since it was previously used in Reference 3; but more importantly, the effect of the filter is to introduce a transport time lag. Although effect of adding this element is to delay the response to pilot inputs in much the same fashion that the pilot's input can be delayed in a digital flight control system due to computational delays.

2.5 ADDITIONAL EVALUATION CONFIGURATIONS

Since the approach and landing results of the YF-17 simulation program conducted in the NT-33 (Reference 8) represent such a significant example of the effects of control system dynamics on longitudinal flying qualities, the previously simulated original and modified YF-17 configurations were selected for evaluation in this program. The original YF-17 landing case also represents an excellent data point for testing the PIO criterion suggested in Reference 9. In addition, inclusion of this case affords the opportunity to evaluate thoroughly a significant anomaly in the world of simulation: the extreme PIO problem was not observed during ground simulation studies but was clearly evident in the in-flight simulation. The configurations are identified as:

- 6-1: YF-17 original control system
- 6-2: YF-17 modified control system

In support of suggested revisions to MIL-F-8785B in the area of longitudinal static instability, three statically unstable configurations

were evaluated. Essentially these configurations are Configuration 2-1 with the center of gravity moved aft of the neutral point ($M_{\alpha} > 0$). These configurations are representative of failure states which could possibly occur in highly augmented aircraft like the F-16 which operate at negative static margins. If the angle of attack feedback should fail in this condition the pilot could be faced with landing a statically unstable aircraft. These configurations are identified as:

- 7-1, 7-2, 7-3

The detailed characteristics of these additional configurations are presented in the next subsection, the configuration summary, and in Appendix IV.

2.6 CONFIGURATION SUMMARY

A total of 49 configurations were evaluated: 44 basic control system/short period configurations and 5 additional configurations, as summarized in Figures 3 and 4. More details of the aircraft dynamic characteristics of each configuration are given in Appendix IV along with a summary of the variations from the normal dynamic characteristics with speed and weight changes. Representative time history response plots for each configuration are shown in Appendix III.

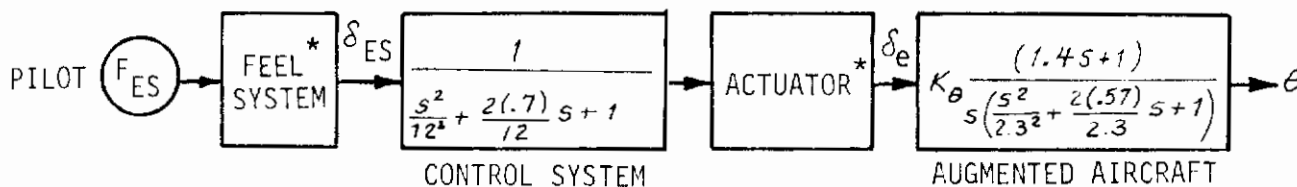
The existing Neal/Smith longitudinal flying qualities evaluation criterion (Reference 4) and the results of a study of the YF-16, YF-17 simulation program (Reference 10) were used to guide the initial configuration selection; the digital computer version of the criterion developed by Mayhew (Reference 11) was used in this process.

Ref. 10. Smith, R. E., "On the Evaluation of the YF-16 and YF-17 Aircraft Using Longitudinal Maneuver Response Criteria, Calspan FRM No. 510, November 1975.

11. Mayhew, D. R., "A Digital Computer Program for the Calculation of Parameters Necessary to Satisfy the Closed-Loop Criteria of T. P. Neal, Unpublished AFFDL/TM, August 1973.

Contrails

Before attempting to interpret the configuration summaries in Figures 3 and 4, a brief review is in order. A typical evaluation configuration consists of the dynamic elements of the feel system, control system, aircraft and actuator in series. For example, the constant speed transfer function of pitch attitude response to pilot stick force for Configuration 2-7 is:



* Feel system and actuator dynamics were fixed; details are in Subsection 2.7.

The value of K_{θ} is a function of the elevator gearing selected by the evaluation pilot as discussed in Subsection 2.8.

The CONTROL SYSTEM and AIRCRAFT DYNAMICS for the primary evaluation configurations are summarized in Figure 3; the important characteristics of the additional configurations are summarized in Figure 4. Remember that the total configuration dynamic model for each configuration includes the fixed dynamic contribution of the feel system and the actuator.

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CONTROL SYSTEM DYNAMICS				SHORT PERIOD DYNAMICS (Nominal)				
				$V_{ind} = 120 \text{ Kt}$ $\eta_2/\alpha = 4.5 \text{ g/rad}; \tau_{\theta_2} = 1.4 \text{ sec}$				
τ_1	τ_2	ω_3/ζ_3	ω_4/ζ_4	ω_{SP}/ζ_{SP}				
				1.0/.74	2.3/.57	2.2/.25	2.0/1.06	3.9/.54
0.4	0.1	-	-	1-A	2-A			
0.3	0.1	-	-	1-B				
0.2	0.1	-	-	1-C	2-C	3-C	4-C	
0	0	-	-	1-1	2-1	3-1(3-0)*	4-1(4-0)*	5-1
	0.1	-	-	1-2	2-2	3-2		
	0.25	-	-	1-3	2-3	3-3	4-5	5-3
	0.5	-	-	1-4	2-4		4-4	5-4
	1.0	-	-					5-5
	0	16/.7	-	1-6	2-6	3-6	4-6	5-6
		12/.7	-		2-7	3-7	4-7	5-7
		9/.7	-	1-8				
		6/.7	-		2-9			
		4/.7	-		2-10		4-10	
0	0	16/.93	16/.38	1-11	2-11		4-11	5-11

* ω_{SP}/ζ_{SP} for Configuration 3-0 is 2.1/.14; for Configuration 4-0, 2.1/1.23

- NOTES:
- First number indicates base aircraft configuration simulated; second number or letter identifies control system dynamics; letters for control system lead; numbers for lag.
 - Total configuration dynamic model includes feel system and actuator dynamics (see Subsection 2.7).
 - Complete aircraft dynamic characteristics are presented in Appendix IV.

Figure 3: Summary of Primary Evaluation Configurations

CONFIGURATION	CONTROL SYSTEM DYNAMICS	ω_{SP} / ζ_{SP}
6-1 (YF-17 Original)	$\frac{(.5s+1)(.43s+1)}{(.2s+1)(1.1s+1)\left(\frac{s^2}{4^2} + \frac{2(.7)}{4}s+1\right)}$	1.9 / .65
6-2 (YF-17 Modified)	$\frac{(.5s+1)(.43s+1)(.065+1)}{(.2s+1)(.1s+1)(1.1s+1)}$	1.9 / .65
	Time to Double Amplitude, T_d (Sec)	
7-1	≈ 6	
7-2	≈ 4	
7-3	≈ 2	

- NOTES:
- Total configuration dynamic model includes feel system and actuator dynamics (see Subsection 2.7).
 - Complete aircraft dynamic characteristics are presented in Appendix IV.

Figure 4: Summary of Additional Evaluation Configurations

2.7 PITCH FEEL SYSTEM AND ACTUATOR CHARACTERISTICS

The feel system characteristics were held fixed for all the configurations evaluated in the program; a representative spring gradient of 8 lb/in was chosen and essentially zero breakout or friction forces were present. The feel system transfer function is:

$$\frac{\delta_{ES}}{F_{ES}} = \frac{.125}{\left(\frac{s^2}{26^2} + \frac{2(.6)s}{26} + 1\right)} \quad (\text{in./lb})$$

The NT-33 pitch actuator characteristics were essentially constant for all configurations (see Appendix VI) with the following values:

$$\omega_a = 75 \text{ rad/sec}$$

$$\zeta_a = 0.7$$

2.8 PITCH CONTROL SENSITIVITY

The gearing ratio between the elevator and the stick position was selected by the pilot for each flight evaluation of a configuration, as discussed in more detail in Section 3. Ideally each dynamic configuration should have been evaluated with several values of gearing ratio, but this procedure was beyond the scope of this flight program.

2.9 APPROACH AND LANDING SPEED CONSIDERATIONS

A given configuration was evaluated during the program at different NT-33 fuel loads or weight since several configurations were evaluated during each flight. To minimize the effects of these weight variations on stall margin and dynamic characteristics, the approach speeds were selected as a function of the fuel load or weight of the NT-33. The complete speed schedule and associated variations in configuration dynamic characteristics as speed and weight varied are presented in Appendix IV. Since these variations are not considered to be significant to the results, the mid-flight weight is considered the nominal condition.

In addition, during an evaluation at any weight the speed varied during the landing approach task; the landing phase (50 feet down to touchdown) speed was about 15 knots less than the approach speed. Since the results show that the landing phase is the critical task, the dynamic characteristics applicable to the landing phase speed are the values quoted in the body of the report. Details of the effects of weight and speed variations are presented in Appendix IV.

In summary, the approach and landing speeds at the nominal weight are:

- Approach: 135 KIAS
($n_z/\alpha = 5.6 \text{ g/rad}$)
- Landing: 120 KIAS
(Less than 50 ft above touchdown)
 $n_z/\alpha = 4.5 \text{ g/rad}$
 $\tau_{\theta 2} = 1.4 \text{ sec}$

2.10 LONG TERM PITCH CHARACTERISTICS

For the majority of the Configurations (1 through 6) the phugoid, or long term, response characteristics are those of the NT-33 as modified somewhat by the longitudinal feedback gains used to achieve the short period dynamics. A complete summary of the identified phugoid characteristics is given in Appendix IV; for example, the values for Configuration 2 are:

$$\begin{aligned}\omega_{ph} &\approx .17 \text{ rad/sec} \\ \zeta_{ph} &\approx .15 \\ \tau_{\theta_1} &\approx 12 \text{ sec}\end{aligned}$$

For Configuration 7, where a specific degree of static instability was simulated, the long term response characteristics were somewhat different; the complete transfer functions are presented in Appendix IV.

From a flight path control viewpoint, all the evaluations were on the "front side" of the power required versus drag curve.

2.11 LATERAL-DIRECTIONAL CHARACTERISTICS

A "good" set of lateral-directional characteristics was selected for the evaluation program; these characteristics were mechanized with a constant set of NT-33 feedback gains. Variations in the characteristics did therefore occur due to changes in moments of inertia and approach speed as fuel was used. However, since the characteristics were consistently evaluated by the pilots as excellent and a positive factor in the evaluations, no attempt was made to hold the lateral directional characteristics constant.

Approximate lateral-directional characteristics, obtained from in-flight measurements representative of the nominal approach speed of 135 KIAS are shown below.

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$\omega_d \approx \omega_\phi \approx$	1.3	rad/sec
$\zeta_d \approx \zeta_\phi \approx$	0.2	
$ \phi/\beta _d \approx$	1.5	
$\tau_R \approx$	0.3	
$\tau_S \approx$	75	sec
$N'_{\delta_{RP}} \approx$	0.2	$\frac{\text{rad/sec}^2}{\text{in.}}$
$L'_{\delta_{AS}} \approx$	0.7	$\frac{\text{rad/sec}^2}{\text{in.}}$

The following lateral-directional feel characteristics were held constant for all the configurations evaluated.

$$\frac{\delta_{AS}}{F_{AS}} = \frac{.25}{\left(\frac{s^2}{26^2} + 2\frac{(.7)}{26}s + 1\right)} \quad (\text{in./lb})$$

$$\frac{\delta_{RP}}{F_{RP}} = \frac{.017}{\left(\frac{s^2}{26^2} + 2\frac{(.7)}{26}s + 1\right)} \quad (\text{in./lb})$$

Essentially zero breakout or friction forces were present in the lateral-directional feel characteristics.

Section 3

CONDUCT OF THE EXPERIMENT

The control system and aircraft dynamics discussed in Section 2 were mechanized in the USAF variable stability NT-33, operated by Calspan (see Figure 5). Details of this mechanization are contained in Appendix VI, and a complete functional description of the variable stability system can be found in Reference 12.

3.1 USAF/Calspan Variable Stability NT-33 Aircraft

In the NT-33 aircraft, the evaluation pilot occupies the front cockpit, which is shown in Figure 6 . The system operator in the rear cockpit, who also acts as safety pilot, can vary the stability and control characteristics about all three moment axes by changing the settings of the response feedback gain controls in the rear cockpit. In addition, through the use of switches and special cockpit gain controls, the safety pilot can select the appropriate control system combination desired for a particular evaluation configuration. It is important to note that the evaluation pilot cannot feel the control surface motions due to the actions of the variable stability system signals in the NT-33. During this experiment the evaluation pilot had no prior knowledge of the configuration characteristics.

The following subsections describe in detail the evaluation procedures, including the tasks performed, the pilot comment card and the pilot rating scales.

-
- Ref. 12. Hall, G. W. and Huber, R. W., "System Description and Performance Data for the USAF/Calspan Variable Stability T-33 Airplane". AFFDL-TR-70-71, July 1970.

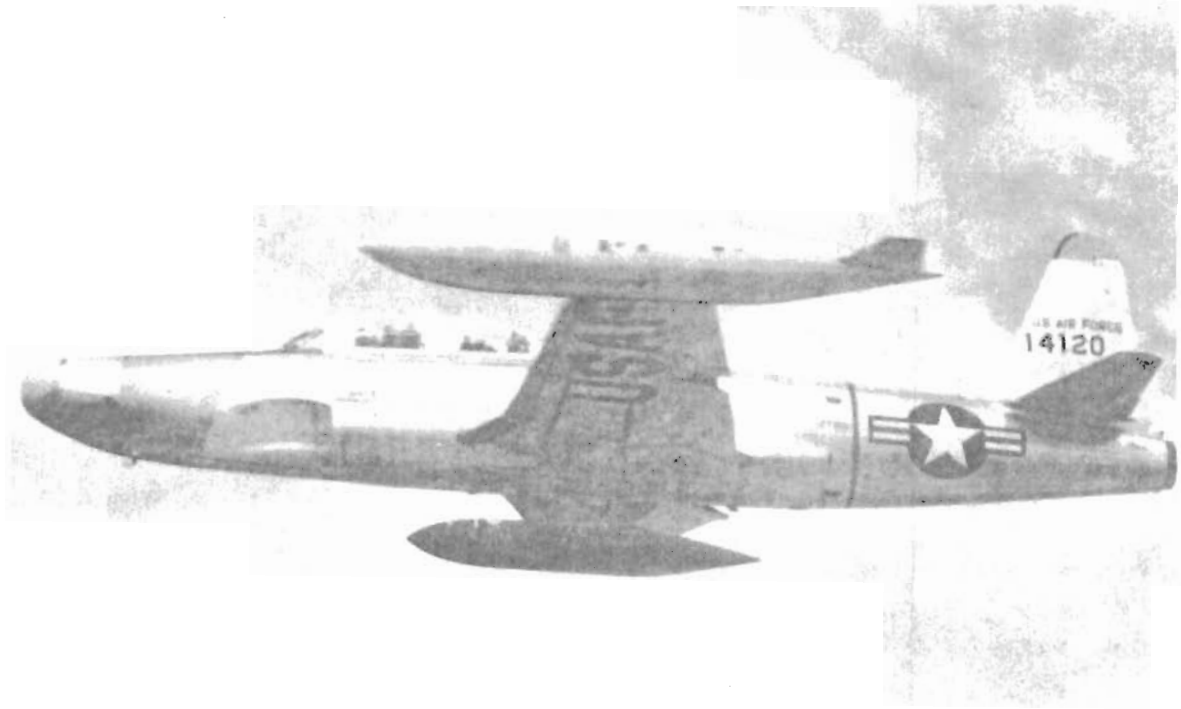


Figure 5 : USAF/Calspan Variable Stability NT-33 Aircraft

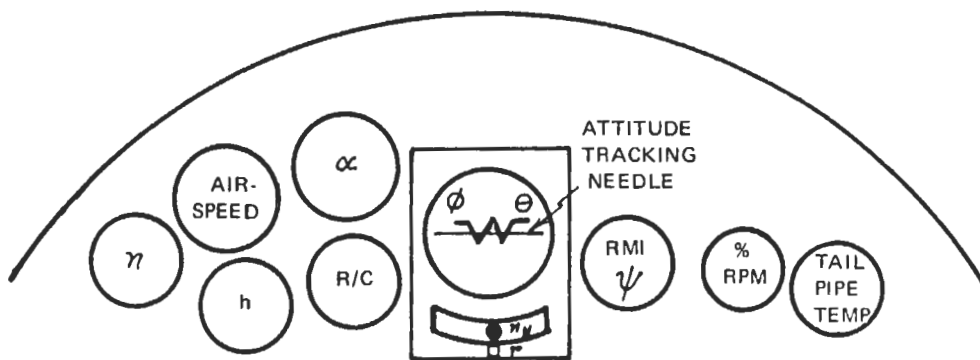
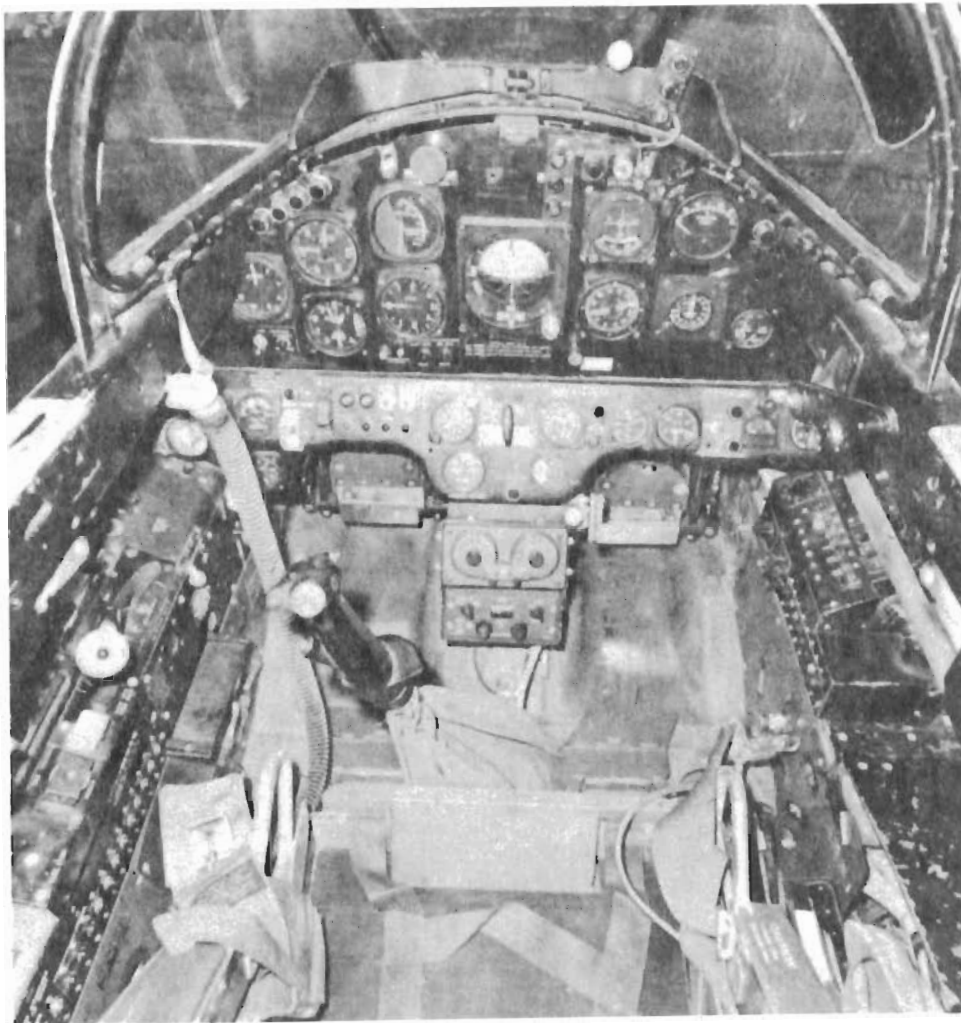


Figure 6: Evaluation Pilot Cockpit in NT-33 Aircraft

3.2 SIMULATION SITUATION

For this program, the simulated aircraft was defined as an all-weather, single seat, fighter aircraft (Class IV). The pilot was therefore required to extrapolate to this environment which would include additional duties such as navigation and communication.

Since inclusion of wind and turbulence as controlled variables was beyond the limited scale of this program, flights were, of necessity, conducted in a wide range of wind and turbulence; conditions encountered are considered normal for typical fighter operations. The pilots were asked to evaluate the aircraft in the conditions of the day, but to comment, if desired, on the projected effects of different wind and turbulence conditions.

3.3 EVALUATION PROCEDURES

The configurations were evaluated in a generally random order, either 3 or 4 evaluations per flight; the extra evaluation was performed by adding more fuel and limiting the initial evaluation configuration to a low-approach only task.

Each evaluation took approximately 25 minutes and was conducted in the following sequence:

- Evaluation pilot (EP) was given control of aircraft with gear down, flaps 30⁰ and speed brakes up at the approach speed appropriate for the fuel weight (see Appendix IV) and 2000 ft above ground.
- EP sampled the pitch sensitivity and made initial selection - he could request a change at any time during the remainder of the evaluation.

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- EP went under instrument hood, followed radar vectors to join ILS; performed ILS (2.5 deg glide path) at proper approach speed, "broke out" at 200 ft above runway. EP went visual, selected 45⁰ flap, speed brakes down and performed landing task (or low-approach only task if directed) making every effort to simulate a full-stop landing in the designated touchdown zone, i.e. power to idle, nose wheel on runway before go-around initiated.
- EP performed "take-off" after touchdown (touch and go landing), climbed to downwind for visual landing; visual landing included an intentional lateral sidestep maneuver; offset was about one runway width at 0.5 nm from touchdown point; visual procedure was repeated for second landing.
- SP then took control after climbout from second visual landing while EP assigned pilot ratings for both overall task, and approach task if possible, using appropriate pilot rating scales. EP then made comments using the comment card and reviewed ratings and noted any changes if final rating was different than initial rating. (See Subsection 3.6 for details).
- EP was given control again to perform discrete error tracking task.
- Finally, the necessary calibration records of the base configuration - control system dynamics removed - were taken.

Records were taken during the final phases of each approach using the on-board digital tape recorder. In addition, digital records were taken of the tracking task performance and the responses to the calibration inputs.

3.4 EVALUATION TASK SUMMARY

Since the exact definition of the task is important to any flying qualities investigation, the details of the tasks performed during each evaluation are summarized below. These tasks, in combination, provide the pilot with a solid basis for assessing the landing approach flying qualities of an evaluation configuration.

- ILS approach under simulated instrument conditions, down to 200 ft above runway, followed by a visual landing, plus
- Two visual close patterns and landings, with an intentional offset maneuver on close final in each case.

For those evaluations which intentionally did not include a touchdown, the same tasks were performed but a go-around was initiated at 50-100 ft above the runway.

Great care was taken to ensure that the evaluation pilots performed these tasks in a realistic fashion. For example, they were instructed to consider each approach and landing as a final "must land" situation; the 500 ft touchdown zone on the 9100 ft runway was clearly marked on the runway, beginning approximately 1500 ft from the threshold for flight safety reasons. The pilots were not allowed by the safety pilot to back out of the task and let the touchdown point drift down the runway in an unrealistic fashion. These instructions were not interpreted by the pilots to mean that the task was treated as an unrealistic "game" demanding unrealistic precision on the part of the pilots. Touchdown with normal sink rates could be made in the NT-33.

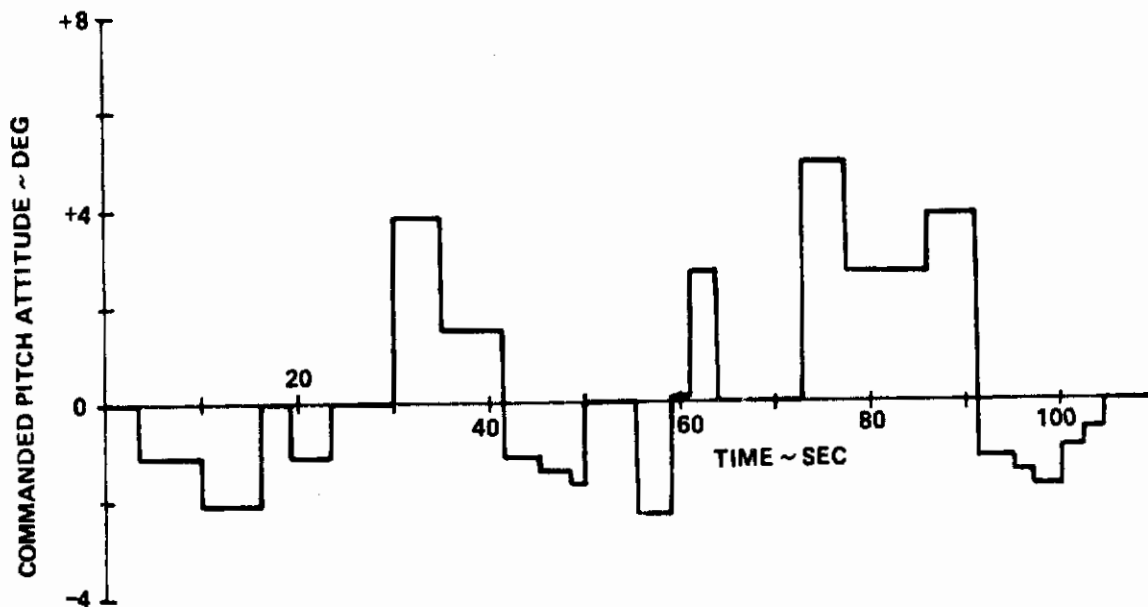
3.5 DISCRETE ERROR TRACKING TASK

The discrete-error pitch-attitude tracking task was included in each evaluation to give some insight into the pilot's ability to perform a

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closed-loop task. It was hoped that the records from this task might assist the analyst in understanding the pilot's ratings and comments if the performance of this controlled task was similar to the performance of the real landing task.

The task was mechanized by displaying the error between the actual pitch attitude and a programmed pitch attitude command signal on a horizontal needle on the attitude indicator. A complete cycle of the commanded pitch attitude is shown in Figure 7. In the 3 minutes allocated for this task during each evaluation, the pilots never learned the pattern of the commanded signal.



Note: 5 deg of attitude equals 1 inch of needle deflection.

Figure 7: Discrete-Error Pitch-Attitude Tracking Task

A command pitch attitude of + 5 degrees represented + 1 inch deflection of the horizontal needle. The evaluation pilot's task was to keep the error to a minimum; the degree of aggressiveness with which he approached this task is obviously a key factor in the resulting closed-loop performance. He was instructed to accomplish the task - zero the errors - with the same aggressiveness that he used in the landing task. Obviously, there was no way to ensure that the two tasks were performed in the same manner, but at least the tracking task was performed within some realistic guidelines.

After a brief period of familiarization, a 30 second record of the tracking task performance was taken for each configuration.

3.6 EXPERIMENT DATA

The data from the experiment take three forms: pilot ratings, pilot comments, and records of task performance, including the discrete error tracking tasks. Examples of the performance records are presented in Appendix II. The pilot ratings and comments are clearly tied together and should not be viewed as separate data. At the completion of the evaluation tasks, the pilot was asked to assign an overall pilot rating using the Cooper-Harper Rating Scale (Reference 13) as shown in Figure 8 . In addition, for the evaluations which included the complete landing task, the pilot was asked to give a separate rating for the approach task alone (down to approximately 50 feet above the runway). Only during the last half of the program did the pilots feel confident enough to give both ratings. The pilots were asked to assign the ratings before making detailed comments since their task performance was then fresh in their minds.

Ref. 13. Cooper, G. E. and Harper, R. P. Jr., "The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities," NASA TND-5153, April 1969.

The pilot was also required to assign a PIO rating in accordance with the scale shown in Figure 9 .

In addition to these ratings, the safety pilot assigned a pilot rating before the evaluation pilot gave his rating. This additional rating can be used to increase the credibility of the evaluation pilot's rating and potentially to understand any rating discrepancies which may arise.

After the initial ratings, the pilot was asked to make recorded comments on specific items listed on the Pilot Comment Card, which is reproduced below.

PILOT COMMENT CARD

1. Feel
 - forces, displacements?
 - pitch sensitivity? - trim?
2. Pitch attitude response to inputs required to perform task.
 - initial response
 - predictability of final response
 - special pilot inputs?
 - tendency towards PIO?
3. Airspeed Control?
4. Approach performance:
 - ILS
 - visual approaches (sidestep maneuver)
5. Flare and touchdown performance:
 - problems? - any special control techniques?
6. Differences between approach and landing tasks:
 - significant? - most difficult task?
7. Effects of turbulence/wind
8. Lateral-directional characteristics: a factor in evaluation?
9. Summary (brief):
 - major problems - good features
10. Cooper-Harper Pilot Rating (separate ratings for different tasks if possible) - PIO rating.

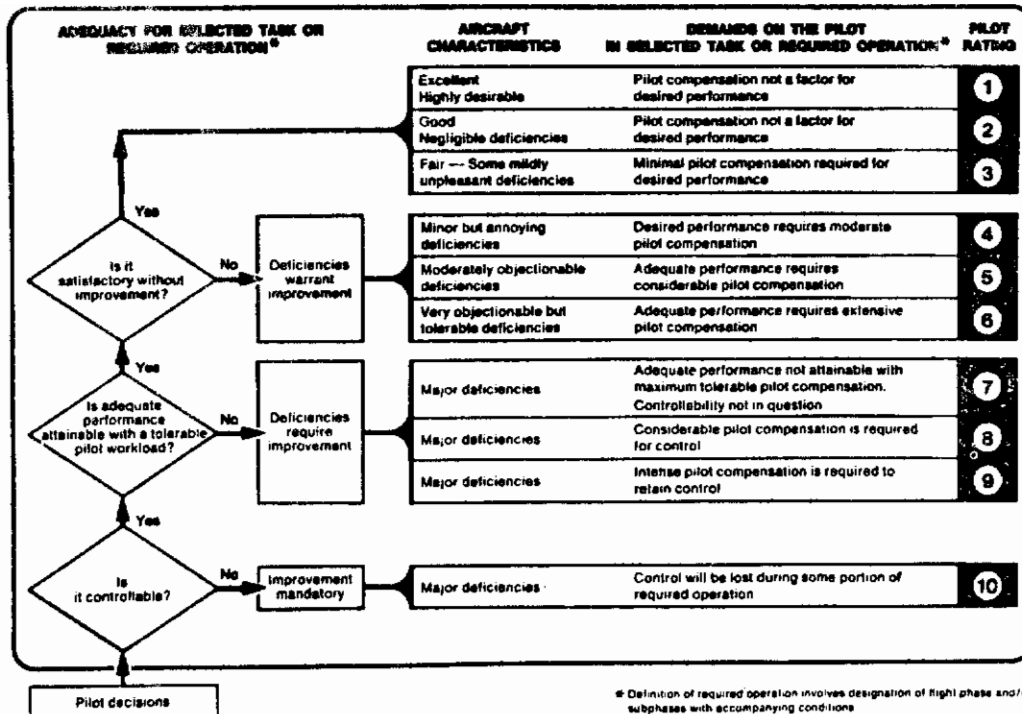


Figure 8 : Cooper-Harper Pilot Rating Scale

DESCRIPTION	NUMERICAL RATING
NO TENDENCY FOR PILOT TO INDUCE UNDESIRABLE MOTIONS	1
UNDESIRABLE MOTIONS TEND TO OCCUR WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL. THESE MOTIONS CAN BE PREVENTED OR ELIMINATED BY PILOT TECHNIQUE.	2
UNDESIRABLE MOTIONS EASILY INDUCED WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL. THESE MOTIONS CAN BE PREVENTED OR ELIMINATED BUT ONLY AT SACRIFICE TO TASK PERFORMANCE OR THROUGH CONSIDERABLE PILOT ATTENTION AND EFFORT.	3
OSCILLATIONS TEND TO DEVELOP WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL. PILOT MUST REDUCE GAIN OR ABANDON TASK TO RECOVER.	4
DIVERGENT OSCILLATIONS TEND TO DEVELOP WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL PILOT MUST OPEN LOOP BY RELEASING OR FREEZING THE STICK.	5
DISTURBANCE OR NORMAL PILOT CONTROL MAY CAUSE DIVERGENT OSCILLATION. PILOT MUST OPEN CONTROL LOOP BY RELEASING OR FREEZING THE STICK.	6

Figure 9 : Pilot Induced Oscillation Tendency Rating Scale

The final ratings assigned to the configuration after the detailed pilot comments are the final data for the configurations; any changes from the initial ratings were never significant.

3.7 EVALUATION SUMMARY

Two evaluation pilots participated in this flying qualities investigation; their backgrounds are as follows:

PILOT A - Calspan Research Pilot, limited experience as a flying qualities evaluation pilot but with extensive experience as a flying qualities instructor at the military Test Pilot Schools. His flight experience of 3000 hours includes experience in a variety of fighter aircraft.

PILOT B - Calspan Research Pilot with very extensive experience as a flying qualities evaluation pilot on a wide range of flying qualities research programs. His 5000 hours of flight experience include 1500 hours in fighter aircraft.

The two pilots performed a total of 83 flight evaluations of the 49 different configurations during the program requiring 24 flights of approximately 1½ hours each. The distribution of evaluations and flights between the pilots is as follows:

	<u>PILOT A</u>	<u>PILOT B</u>
Flights:	17	7
Evaluations with Landings:	51	21
Evaluation with Low-Approach Only:	8	3
	28	

Section 4 EXPERIMENT RESULTS

The results of the experiment described in the preceding sections are in the form of pilot ratings, comments and records of task performance. Since a complete analysis of the data and the development of appropriate design criteria or flying qualities requirements is clearly beyond the scope of this program, the discussion of the results in this section is centered on the pilot rating and comment data; a limited discussion of the applicability of the Neal/Smith closed-loop pitch attitude tracking criterion is, however, included.

A complete summary of the important experiment data is presented in Table 2 of Appendix I, which also contains the summarized pilot comments for each evaluation configuration. Additional background information for the discussion of the results is provided in Appendices II and III which contain representative task performance records and pitch rate step response time histories for the evaluation configurations. For reference, a summary of the pilot ratings for each configuration is presented in Table 1.

4.1 CORRELATION WITH MIL-8785B

The overall pilot ratings for the base configurations from each set of configurations - those with no significant additional control system dynamics - are compared in Figure 10 with the ω_{sp} , ζ_{sp} Category C boundaries from MIL-F-8785B (Reference 1). For these comparisons, the nominal 120 KIAS data are used.

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TABLE 1: PILOT RATING DATA SUMMARY

Config. No.	Aircraft ⁽¹⁾ ω_{50} / ζ_{50}	Control System ⁽²⁾			PILOT RATINGS			
					OVERALL ⁽⁴⁾		APPROACH ⁽³⁾	
		ζ_1	ζ_2	ω_3	PILOT A	PILOT B	PILOT A	PILOT B
1-A	1.0/.74	0.4	0.1	-	6(4TD)			
B		0.3	0.1	-	5			
C		0.2	0.1	-	4	4		
1-1		-	-	-	4	4		2
-2		-	0.1	-	5			
-3		-	0.25	-	9	10	6*	6*
-4		-	0.5	-	10			
-6		-	-	16	5		5*,2	
-8		-	-	9		8		5
-11		-	-	16(4th)		9		5
2-A		2.3/.57	0.4	0.1	-	4	6	2
-C	0.2		0.1	-	1½,4,3,1½		3	
2-1	-		-	-	2	2	3*	
-2	-		0.1	-	4½	4		
-3	-		0.25	-	6			
-4	-		0.5	-	9		5*	3*
-6	-		-	16	5		1½	
-7	-		-	12	7	6	4	3
-9	-		-	6		10		5
-10	-		-	4	10			
-11	-		-	16(4th)		8		4
3-C	2.2/.25	0.2	0.1	-	2	5(4TD)		5
3-0	2.1/.14	-	-	-	5,4			
3-1	2.2/.25	-	-	-	5(4TD)4	7(5TD)	5	7
-2		-	0.1	-	7		6*	
-3		-	0.25	-	10		7*	
-6		-	-	16	7	6	5	5
-7		-	-	12	8		5	

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TABLE 1: PILOT RATING DATA SUMMARY (CONT.)

Config. No.	Aircraft ⁽¹⁾ ω_{SP} / ξ_{SP}	Control System ⁽²⁾			PILOT RATING			
					OVERALL ⁽⁴⁾		APPROACH ⁽³⁾	
		τ_1	τ_2	ω_3	PILOT A	PILOT B	PILOT A	PILOT B
4-C	2.0 / 1.06	0.2	0.1	-	3	3	1½	2
4-0	2.1 / 1.23	-	-	-	6			
4-1	2.0 / 1.06	-	-	-	2			
-3		-	0.25	-	5,7	8	2	5
-4		-	0.5	-	7	6	5*,4	3
-6		-	-	16	4		1½	
-7		-	-	12	3		3	
-10		-	-	4	9		6	
-11		-	-	16(4th)	8		3	
5-1	3.9 / .54	-	-	-	7	5		4
-3		-	0.25	-	4½,8	6	4*,3	3*,2
-4		-	0.5	-	6		2	
-5		-	1.0	-	7		2	
-6		-	-	16		6		3
-7		-	-	12	6		2	
-11		-	-	16(4th)	7		3	
6-1	1.9 / .65	Unmodified YF-17			10			
-2		Modified YF-17			2			
	T_d (Sec)							
7-1	≈ 6	-	-	-	4			
-2	≈ 4	-	-	-	3			
-3	≈ 2	-	-	-	4	6(3TD)	2	6

NOTES: (1) Aircraft dynamics are for 120 KIAS nominal case:

$$V_T = 205 \text{ ft/sec}; \quad n_z/\alpha = 4.5 \text{ g/rad}; \quad \tau_{\theta_2} = 1.4 \text{ secs.}$$

- (2) Complete control system includes feel system and actuator dynamics (see Subsection 2.7); 16 rad/sec fourth order prefilter designated: 16(4th)
- (3) Asterisk (*) indicates evaluations for low-approach only task
- (4) TD stands for "touchdown"; pilot rating better for landing approach in these cases.

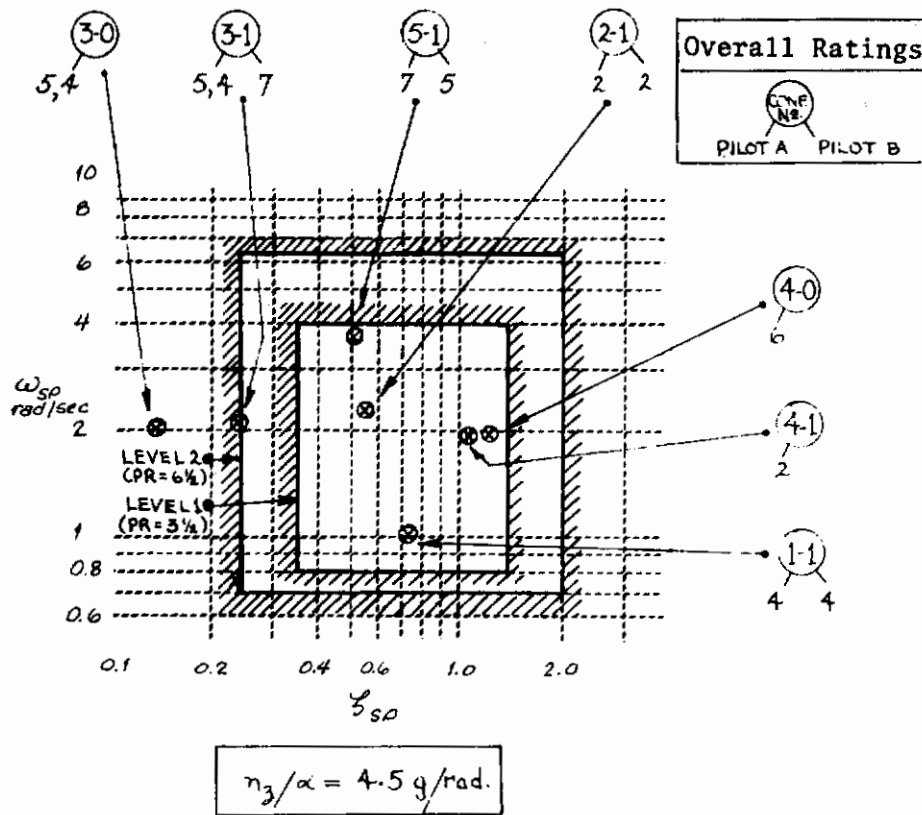


Figure 10 : Correlation of Base Configurations with MIL-F-8785 (Category C)

Although the quantity of data is hardly enough to allow definitive comments, the following comments can be made. The pilot ratings for Configurations 2-1 and 4-1 agree reasonably well with the -8785B Level 1 boundaries, while the ratings for Configuration 1-1 indicate that the lower frequency Level 1 boundary is too lenient. For Configuration 3-1, and the alternate base Configuration 3-0, the ratings are somewhat less severe than the -8785B boundaries would predict. Since all of these ratings were obtained in relatively smooth air and turbulence effects would certainly degrade these configurations, the correlation is considered reasonable. The results for Configuration 5-1 indicate that the Level 1 upper boundary on ω_{sp} is too lenient. Although the configuration is likely only of academic interest since aircraft are typically low frequency in the landing approach, the boundary in -8785B does appear to be suspect. Evaluation of this configuration in moderate turbulence would further emphasize the lack of correlation.

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The rating for the alternate base Configuration 4-0 should be viewed with some caution. Although the pilot substantiated his rating on a subsequent flight, the sharp change in rating between Configurations 4-1 and 4-0 is somewhat hard to understand.

These comparisons with -8785B Category C flying qualities boundaries serve two purposes: first, the reasonable correlation of several of the configurations (2-1, 3-1 and 4-1) with the existing boundaries lends credibility to the overall experiment; second, the lack of correlation with the high frequency Level 1 boundary and the questions raised about the high damping ratio boundary indicate the need for more landing approach data in these areas. The fact that the majority of the original background data for -8785B in the landing approach flight phase did not include actual landings should not be forgotten. Since the landing task is clearly a "higher pilot gain task" than the approach task, Category A boundaries may very well be more appropriate for the approach and landing task requirements.

The general credibility of the pilot rating data for the base configurations provides a solid base from which to view the remainder of the pilot rating data for these same configurations evaluated with significant additional control system dynamics.

MIL-F-8785B presently contains a requirement which is intended to place limits on control system dynamics by restricting the phase lag, at the short period frequency, between the stick force input and the control surface response. Although the Category A substantiation data (from Reference 3) used for the requirement were not really applicable to the landing approach task (Flight Phase Category C), the requirement applies to this flight phase. In light of the observations from this experiment, this previously unfounded extrapolation has some merit since the two tasks are not apparently that different. The original data suggested a limit of 30 deg of phase lag for Level 1 flying qualities; as shown in Reference 4, this requirement, in its present form, does not apply to aircraft with significant control system

dynamic elements whose characteristics frequencies are close to the aircraft's short period frequency. The results from this experiment corroborate this finding; for example, consider Configurations 1-2 and 2-11. In each case the phase lag of the control system at the short period frequency is on the order of 30 deg, yet the pilot ratings are Level 3.

As observed in the previous control system dynamics experiment in the NT-33 (Reference 4), the pilot evaluates the total response of the aircraft to his inputs and is not concerned with, or even aware of, the characteristics of the individual dynamic elements which combine to produce that response. The step response time histories for the evaluation configurations are presented in Appendix III and illustrate the effects of the various types of control system dynamics evaluated. The high frequency elements, such as the "-6" cases, effectively preserve the shape of the short period response but introduce a transport time delay; while the low frequency elements, such as the "-4" cases, significantly alter the shape of the response to pilot inputs.

Requirements are obviously needed for the landing flight phase which are based on the characteristics of the total response and are not dependent on identifying the response with certain modes of motion, such as the short period response.

4.2 THE CRITICAL TASK: FLARE AND TOUCHDOWN

One of the objectives of the experiment was to determine whether the final stage of the approach and landing task - the flare and touchdown - is the critical piloting task. Evidence from the simulation of the YF-17 prototype with the original control system (Reference 12) suggested that the major pitch flying qualities problems occurred close to touchdown.

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The pilot rating data for the majority of the configurations clearly indicate that the landing task, which means the last 50 ft to touchdown, is the critical task. For the approach task, that is down to 50 ft above the runway, the pilot ratings are typically better than for the overall task which includes the landing task; the difference is dramatic when significant additional control system dynamics are present. Aircraft with good longitudinal flying qualities, such as Configurations 2-C, 2-1, and 4-C, show little difference in the pilot ratings for approach alone versus the overall task with a landing. On the other hand, aircraft with significant additional lag dynamics in the control system, such as Configurations 2-4 and 4-10, show significant differences between the approach alone and overall pilot ratings. The more stringent flare and touchdown task exposes the "flying qualities cliffs" hidden in these aircraft.

For those approach pilot ratings marked with an asterisk, a go-around was initiated 50 to 100 ft above the runway. The other approach ratings represent the pilot's assessment of the approach portion of the overall task while performing the complete touchdown task. The approach-only ratings confirm the same differences between the approach task and the landing task observed previously, except that the approach pilot ratings for a configuration tend to be worse when only the approach was performed. In general, this difference is not significant except for the approach-only rating given to Configuration 1-6 (PR=5). The configuration received a PR=2 when evaluated in the total task later on the same flight; this variation in rating on the same flight tends to reduce the significance of this rating anomaly.

The critical nature of the last 50 ft of the task environment is dramatically illustrated in the task performance time histories for Configurations 1-3, 2-4, 2-9, 4-10, 5-3, and 6-2 in Appendix III, where a PIO suddenly develops at this point in the task.

Configurations 1-A, 3-0, 3-1, 3-C, 7-1, 7-2 and 7-3 represent exceptions to the observation that the landing task is the more critical task. For these configurations, which are essentially without significant control

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system dynamics, the pilots often commented that the flare and touchdown task was easier than the approach task. The pilot could fly the aircraft better in the flare than on the approach for reasons which further analysis will hopefully expose. All of these configurations, except 1-A, have a common feature: the basic aircraft has a major problem. Configuration 3 has a lightly damped short period response, while Configuration 7-1 through 3 are statically unstable. It could be that the initial response for these configurations is quick enough to allow the pilot to perform the exacting, fighter closed-loop, landing task more accurately than he can the approach task. During the less demanding approach task, the basic aircraft problems are more apparent and therefore annoy the pilot.

The evidence from this experiment indicates that the landing task is clearly different and generally more difficult than the approach task. In the landing task environment the pilot flies differently than on the approach - the experiment results, in general, show that he has a different standard of performance. The flying qualities of a configuration with a poor combination of dynamics can be degraded significantly by the demands of the landing task. Two factors which must be considered, before the credibility of these observations is established, are:

- Influence of ground effect: although no data was taken to document the NT-33 ground effect, the influence of ground effect in producing the severe flying qualities degradation noted for certain configurations is not considered to be a factor. As a test, Configuration 3-1 was identified at 15 ft above the runway using the digital identification technique outlined in Appendix IV; the short-term dynamics characteristics were essentially unchanged from previous calibration tests. The dynamic system which the pilot flew is therefore not believed to be significantly altered by the ground effect; changes in flying qualities were a result of significant changes in the pilot's standard of performance near the ground.

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- Flare requirement: since it is a requirement to flare the NF-33 prior to touchdown, a valid question might be - would the same flying qualities difficulties noted for the poor configuration occur if a no-flare "Navy" landing was employed? Obviously, a definitive answer is not possible; however, in the opinion of the safety pilot, the difference would not be significant. For those configurations with lurking PIO's near the ground, even when the pilot fortuitously made the flare without a problem, his next attempt to correct pitch attitude would cause a disastrous PIO. Since a no-flare landing is an essentially constant attitude task, flight observations from this program would indicate similar problems even trying to hold the attitude constant. Indeed, there is every reason to believe that PIO problems would occur earlier in a Navy approach because the mirror approach task is more exacting than the visual portions of the task in this experiment.

4.3 EFFECTS OF CONTROL SYSTEM DYNAMICS

Although the results in Table 4-1 almost speak for themselves, some comments on the effects of control system dynamics with reference to the task performance time histories shown in Appendix II are in order.

- Configuration 1:

The base configuration for this set (1-1) is a low frequency aircraft which requires some compensation on the part of the pilot (PR=4); tracking task records indicate only a slight overshoot. Addition of lead-lag elements to the control system (1-A, 1-B, 1-C), has little effect on the flying qualities since the lead effects are at frequencies somewhat higher than the short period. Even Configuration 1-A is rated the same as the base configuration in the landing task. This circumstance was the result of an implementation error and was not by design.

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The addition of a first order lag, Configuration 1-3, causes significant PIO problems (PR=10), as shown in the performance records (Figures II-2,3). These problems occur in the last 50 ft before touchdown; pitch oscillations at a frequency of 3.5 to 4.0 rad/sec and large pilot inputs of ± 12 lbs are evident. In contrast, for the low approach evaluation (PR=6), only a "mild" PIO is evident (Figure 14). Note that the tracking task performance is similar to the performance in the landing task.

The important general observation is that the additional control system dynamics have a significant effect on the longitudinal flying qualities in the landing task; for the approach task the effects are noticeable but not to the same degree.

- Configuration 2:

Configuration 2-1, the base configuration, and 2-A are both satisfactory aircraft; the task performance record for 2-1, Figure 15, confirms the pilot's rating (PR=2) and comments. The records show no large pilot inputs and relatively smooth control of pitch attitude. Tracking task performance is good, indicating a second-order like response with $\omega \approx 2.5$ rad/sec, $\zeta \approx 0.6$.

The degradation of pilot rating with the addition of lag dynamics is not as rapid as shown for Configuration 1, a reasonable trend since base Configuration 2-1 is rated better than 1-1. Task performance records for Configuration 2-4 are shown in Figures 16 and 17. An unmistakable PIO (PR=9) is evident during the last 10-15 seconds of the task (≈ 50 ft to touchdown) with stick inputs of ± 10 lbs at 5 rad/sec present. Again, a similar PIO is evident in the tracking task records. The low approach performance (Figure 18) is reasonable with no evidence of a similar PIO (PR=3). Note: Care should be taken to observe the scalings on the performance traces, particularly for the stick force.

The records for Configuration 2-7 (Figures 19, 20) indicate some tendency to oscillate in pitch attitude but the stick force oscillations are

only ± 5 lb near touchdown. Apparently, the smaller magnitude of the pitch oscillations and stick forces (compared to 2-4) were not as significant to the pilot since his rating was less severe (PR=6). Configuration 2-9, which has more lag, exhibits larger pitch oscillations and ± 12 lb stick force oscillations near touchdown (Figure 21); it is rated a disastrous 10.

- Configuration 3:

The interesting feature of the base configuration (3-1) and the alternate (3-0) is that significant PIO's did not occur in the landing task; in fact, the pilots typically commented that the aircraft were actually better in the landing than on the approach. This result was certainly a surprise since the light damping ratio of the short period was expected to produce strong PIO's. Figure 22, a typical task performance record for Configuration 3-1, does substantiate the pilot's comments. The bobbling tendency on approach is suppressed in the landing task, PR=5(4TD), although there is evidence of high frequency, moderate amplitude stick inputs near touchdown. The pilot apparently felt that the aircraft was predictable enough to be considered acceptable for the task. He recognized the light damping of the aircraft ("aircraft bounce") but did not get into closed loop instabilities.

The addition of first order lag elements causes a degradation in the pilot rating much the same as for Configuration 2 which has a quite different base pilot rating. Task performance records for Configuration 3-6, which has a second order prefilter are shown in Figures 23 and 24; the records in Figure 24 are of particular interest. In this case, the pilot appears willing to accept oscillations in pitch attitude near the ground which are approximately the same magnitude as those recorded for PIO-prone aircraft (PR=9) such as Configuration 2-4 (Figure 17). He is not as much "in the loop" in 3-6, as evidenced by the lack of stick force oscillations; apparently, since he knows that the response of this lightly-damped aircraft is bounded, or predictable in the sense of not divergent, his rating is better (PR=6). Clearly, full understanding of these results requires more detailed analysis. This difference in pilot "loop closures", seemingly as a function of the basic dynamics, will certainly challenge the development of suitable flying qualities response criteria.

- Configuration 4:

The results of adding control system dynamics to the base Configuration (4-1), which is an overdamped version of Configuration 2-1, are similar to those previously discussed for Configuration 2. There is some evidence, although hardly conclusive, that the increased damping is beneficial, i.e. a given lag element is not as degrading as in Configuration 2. Again, the task records for the configurations with significant control system lags show spectacular PIO problems suddenly developing in the flare and touchdown phase of the approach. Records for Configuration 4-10 (PR=9) are shown in Figures 26 and 27. Large stick force inputs of ± 12 lbs and associated pitch attitude oscillations at about 3.5 to 4.0 rad/sec are again evident. Again, the sharp change in rating between Configuration 4-1 and 4-0 is difficult to explain.

- Configuration 5:

The overall pilot ratings for this set of configurations with high ω_{sp} do not change significantly across the total range of control system dynamics evaluated. In addition, there is some evidence that these configurations were difficult for the pilots to evaluate consistently (Configuration 5-3, for example).

The addition of lag elements to the control system improved the approach ratings but problems with the flare and touchdown task remained throughout the range of configurations tested. The problems with initial abruptness and a tendency to PIO (Configuration 5-1) decrease as first order lag effects are increased, but overcontrolling problems still remain in Configuration 5-5 and the pilot rating is essentially unchanged. One evaluation of Configuration 5-3 (Figure 28) shows a strong PIO near touchdown with stick oscillations on the order of 6 rad/sec but of relatively low amplitude (note scale).

Introduction of second order prefilters creates a noticeable delay followed by a fast - mismatched - response which leads to PIO problems. The pilots specifically noted that the PIO was "high frequency" for these

configurations. Configuration 5-6 task performance records are shown in Figure 29; no real evidence of a PIO tendency is apparent but a major complaint was the abruptness of the initial response.

Note that these configurations were intentionally evaluated in only light turbulence conditions; the ratings would be somewhat worse in stronger turbulence since they are all very sensitive to turbulence.

- Configuration 6:

Configuration 6-1 essentially represents the unmodified YF-17 as simulated in the NT-33 and described in Reference 12. For this program, the damping ratio of the short period is somewhat less than in the previous simulation but the evaluation results indicate that the difference is not important.

This configuration was the worst of the bad aircraft (PR=10) flown - if such a distinction is permissible; the pilot suddenly found himself in a startling divergent PIO close to the ground. The performance records in Figures 30 and 31 clearly illustrate the pilot's problems. It should be emphasized that the pilot flew three approaches with each configuration and, for poor aircraft like 6-1, he could not learn to avoid the PIO "trap" in the landing task.

This configuration is a perfect example of the "flying qualities cliff" analogy: the cliff is apparently only exposed in the task environment near the runway. Since this problem was not evident in ground simulator studies during the YF-17 development, it would appear that the essential task environment can only be found, at present, in the real world.

Configuration 6-2, with the modified YF-17 control system dynamics - the 4 rad/sec, second order prefilter was replaced by a first order lag-lead network (lag breakpoint at 10 rad/sec) - is an excellent aircraft. The good task and tracking task performance shown in Figure 32 corroborate this statement.

4.4 EQUIVALENT TRANSPORT TIME DELAYS

Since the use of digital flight control systems is now a reality, it is important to understand the impact on flying qualities of the transport time delays associated with the necessary digital computations. Unfortunately, exact time delays, i.e. not lags but delays during which no response occurs, were not included in this experiment. However, an equivalent time delay can be estimated for the high frequency control system elements evaluated in the program. These elements, such as "-6" and "-11" for example, introduce phase lag but do not affect the amplitude of the response for frequencies near the relatively lower frequency short period. The effect of these higher frequency prefilterers is therefore similar to a pure time delay ($e^{-\tau s}$) for frequencies much lower than the prefilter natural frequency.

For a second order prefilter it can be shown, assuming small angles and equating the phase angle to that of a pure time delay, that

$$\frac{2\zeta (\omega/\omega_n)}{1 - (\omega/\omega_n)^2} \approx \omega \tau$$

and, if $\omega/\omega_n \ll 1$,

$$\tau \approx \frac{2\zeta}{\omega_n}$$

where ω_n is the prefilter natural frequency and ζ its damping ratio.

For example, consider a 6 rad/sec prefilter: at 3 rad/sec the difference in phase lag and amplitude between the filter and a pure time delay of 230 milliseconds is only about 3%.

For reference, the equivalent time delays, in milliseconds (ms), for the prefilterers simulated are:

ω_n	Control System Element	$\tau_{equiv} (ms)$
16	"-6"	90
12	"-7"	120
9	"-8"	160
6	"-9"	230
4	"-10"	250
16(4th)	"-11"	165
30	Feel System	45
75	Elevator Actuator	20

It should be emphasized that the effects of pure time delays will very likely be somewhat different than for the prefilters. However, the response to pilot inputs for the combination of these prefilters and the simulated aircraft dynamics is delayed approximately the calculated equivalent time delay. In fact, the equivalent time delay for Configuration 2-11 was estimated to be 250 ms in Reference 3.

Although an experiment which directly explores the effects of typical digital transport time delay effects is obviously necessary, the equivalent time delay estimates for the prefilters can be utilized to gain insight into the potential effects of digital time delays on longitudinal flying qualities.

4.5 CONFIGURATION 7: STATICALLY UNSTABLE CASES

These configurations were included in the evaluation matrix as a mini-experiment to gain some insight into the effects of static instabilities on landing flying qualities. The increased capabilities of modern fly-by-wire flight control system designs enable fighter aircraft to operate at more efficient aft c.g. conditions. However, this condition means that the unaugmented aircraft is statically unstable. An obvious question which then arises is: If part of the augmentation system should fail and the pilot is left with a statically unstable vehicle, can he land it safely?

The evaluation results for these configurations are rather startling in that the pilots could perform the landing task with relative ease (PR 3 to 4) even with rapid divergences as severe as 2 seconds to double amplitude. In the tight-control landing task the static instabilities were not a problem and, in fact, were not even noticed by the pilots. Only for the most unstable case, Configuration 7-3, was a problem evident and then only to Pilot B on the approach task (PR=6). It is reasonable that problems associated with the divergence should surface during the approach task in which the pilots control and attention is not as "tight". Task performance records for Configuration 7-3 (Pilot A) are shown in Figure 33.

4.6 TRACKING TASK RESULTS

In general, the performance on the pitch attitude tracking task is representative of the actual landing task performance. For Configuration 2-1, the pilot commented that there was a tendency to follow the tracking needle more aggressively than the landing task was flown; however, the particular tracking records look quite representative for the rating given (Figure 15). In contrast, the tracking task performance for Configuration 5-3 (Figure 28) is much better than the landing performance (PR=8). This configuration was apparently difficult to rate consistently, since the next evaluation by the same pilot resulted in a PR of $4\frac{1}{2}$. In this case, the tracking task results support the fact that this configuration is particularly sensitive to the pilot's performance standard or degree of aggressiveness.

In summary, the tracking task records will be very helpful for future analysis of the data from this experiment.

4.7 PITCH CONTROL SENSITIVITY

During the evaluations, the pilot was free to select the pitch control sensitivity, M_{SES} .

A complete listing of the values of pitch control sensitivity selected by the pilots for each evaluation is given in Table I-1 of Appendix I. The basis for the pilot's sensitivity selection is of interest. If he was attempting to hold $F_{ES} / \pi \zeta$ constant, for example, the pitch sensitivity must change as ω_{sp}^2 for the constant speed case. Clearly, such a variation is not evident in this experiment. A brief review of the data indicates that the sensitivity:

- Increases roughly in proportion to the change in ω_{sp}
- Increases in proportion to ζ_{sp} when ω_{sp} is constant
- Increases as the effective lag time constant increases.

It would appear, pending the necessary detailed analysis, that the pilot selects the pitch sensitivity as a function of the predominant system time constant, which is an equivalent value of $\zeta\omega$. In other words, he appears to want a constant pitch attitude response in a given time after his input.

4.8 EFFECTS OF WIND AND TURBULENCE

In general, no attempt was made in the conduct of the experiment to control the atmospheric conditions for the evaluations by judicious scheduling of flights. The exception to this rule was the evaluations of Configuration 5 which were intentionally limited to light turbulence. For the remainder of the evaluations none of the rating differences for specific configurations can be explained because of different wind and turbulence effects.

In summary, the effects of the realistic wind and turbulence conditions encountered during the evaluations cannot be isolated since consistent changes in the ratings are not evident. The effect of a crosswind was significant in one respect: the pilot is forced, in a realistic fashion, to stay "in the pitch loop". Since he must control bank angle precisely to land in a crosswind, he cannot avoid also flying the pitch task accurately.

4.9 PRELIMINARY CORRELATION WITH THE NEAL/SMITH CRITERION

Although a detailed analysis of the data from this program using the Neal/Smith closed-loop pitch attitude criterion developed in Reference 4 is beyond the scope of this report, some preliminary findings can be discussed.

The reader is referred to Reference 4 for details of the criterion; the important parameters which come out of the analysis are the closed-loop resonance and the pilot compensation at the bandwidth frequency. Recall that bandwidth can be viewed as the degree of aggressiveness with which the pilot makes changes in pitch attitude. Data for selected configurations from this preliminary analysis are presented below.

CLOSED-LOOP RESONANCE (dB)/PHASE ANGLE OF PILOT COMPENSATION (Deg)					
Config. No.	BANDWIDTH (rad/sec)				Average PR
	1.5	2.0	2.5	3.0	
2-1	3/-25	3/-6	5/20	6/42	2
2-C	-2/-25	3/-11	5/8	5/30	2½
4-1	-3/6	-3/27	-3/45	-1/59	2
6-2	-1/2	-1/27	0/48	3/61	2
2-9	3/-5	8/17	15/40	40/55	10
2-11	2/-17	7/11	11/40	19/52	8
4-2	-3/27	-2/50	3/65	8/74	6½
4-10	-2/37	4/57	12/71	32/77	9
5-1	-3/-43	0/-30	3/-18	12/-13	6
5-5	-3/-35	2/-23	9/-14	20/-8	7
6-1	0/27	6/53	16/67	30/80	10

Assuming that the application of a closed-loop pitch attitude criterion is valid - a point which must be demonstrated with more detailed analysis - the following points can be made:

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- No single bandwidth yields reasonable correlation with the flying qualities boundaries of Reference 4.
- Lower bandwidths (1.5 to 2.0) are required for the satisfactory aircraft ($PR < 3.5$) to correlate with the 3 db Level 1 boundary of Reference 4. The boundary may indeed be different for the landing task where it is reasonable that the pilot is more tolerant of attitude oscillations than in the air-to-air tracking situation.
- Higher bandwidths (2.5 to 3.0) are required to produce closed loop pitch tracking performance consistent with the pilot ratings and comments for the unacceptable aircraft ($PR > 6.5$).
- Although not listed, the results for Configuration 1 indicate that there must be a limit on pilot lead capability (time constant less than about 1.0 sec for acceptable ratings, $PR < 6.5$) to yield reasonable correlation.
- The sensitivity of the configuration to bandwidth appears to be a very important parameter. Note that all the satisfactory configurations show small changes in closed-loop resonance while each of the unacceptable aircraft show sharp changes in closed-loop resonance as bandwidth is increased.

Obviously, this brief discussion is incomplete but it does indicate that higher bandwidths than previously estimated (Reference 6) must be used for the landing task and that the sensitivity of the aircraft to a range of bandwidths may be an important correlation parameter. Development of a suitable longitudinal control system design criterion, or flying qualities requirement, for highly augmented aircraft in the landing task will require

Contrails

careful analysis of the data base produced in this experiment. The Neal/Smith criterion can potentially be used for this purpose but it is clear that correlation cannot be achieved without some modification to the correlating parameters.

Section 5 CONCLUSIONS

The experiment described in this report utilized the NT-33 variable stability aircraft which is capable of reproducing a wide range of aircraft and control system 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 and control system parameters realized in the experiment. Conclusions which may be drawn from this experiment on the effects of control system dynamics on longitudinal approach and landing flying qualities are:

- For aircraft with significant control system dynamics, the landing task, or flare and touchdown, is the critical piloting task.
- The critical area is the last 50 feet of the landing task; landing approach flying qualities evaluations must therefore include actual touchdowns, in a realistic environment, to be valid.
- Significant control system lags create PIO's in the landing task but not in the approach task; basic aircraft problems such as low short period damping or low static stability do not create PIO's in the landing task.
- For the landing approach task (Flight Phase Category C), the longitudinal flying qualities requirements of MIL-F-8785B(ASG) and suggested revisions are not applicable to aircraft with significant control system dynamics.

Contraails

- In general, the performance on the pitch attitude tracking task is representative of the actual landing task performance.
- Pilot could perform the landing task with relative ease (PR 3 to 4) even with rapid longitudinal divergencies as severe as 2 seconds time to double amplitude.
- From cursory analysis, it would appear that the pilot selects the pitch control sensitivity as a function of the dominant system time constant which is an equivalent value of $\zeta\omega$.

Section 6 RECOMMENDATIONS

The results of this experiment provide a suitable data base for the development of longitudinal flying qualities criteria for the landing approach task which are applicable to aircraft with significant control system dynamics. The following recommendations are therefore in order:

- A thorough analysis of the experiment data should be undertaken to develop a suitable flying qualities criteria for highly augmented aircraft.
- As an initial step in this development process, the available performance data from this experiment should be analyzed to measure the characteristics of the pilot when performing the longitudinal landing task.
- Further in-flight research experiments should be undertaken to study the effects of pure transport time delays, such as those associated with digital flight control systems, on flying qualities for both the landing approach and fighter tracking tasks.
- The effects of significant control system dynamics on lateral-directional flying qualities should be studied.
- Portions of this experiment should be repeated on a modern, sophisticated ground simulator to document the suspected differences between the in-flight and ground simulator for the evaluation of landing approach longitudinal flying qualities.

Section 7

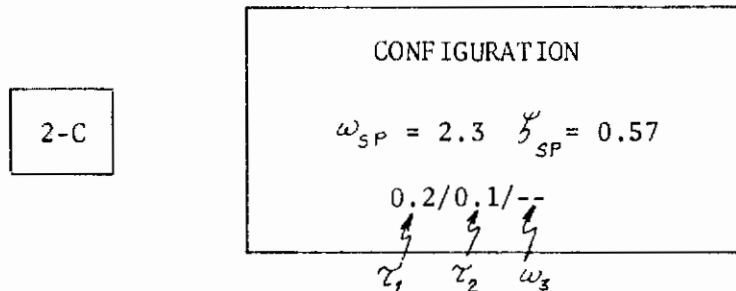
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APPENDIX I

PILOT COMMENTS AND DATA SUMMARY

Summaries of all the pilot comments and ratings are presented in this appendix for each configuration evaluated in this experiment. The block at the top of each set of pilot comments identifies the configuration by number/letter and identifies the important control system and aircraft characteristics for the configuration. Flight number and evaluation pilot are also given; for reference, the first evaluation flight in the program was Number 1883. For example, consider Configuration 2-C:



In the configuration identifier, the first number refers to the base aircraft dynamics; the second number or letter identifies the control system dynamics. Letters are used for configurations with lead dynamics (A indicating the largest lead time constant); the second number identifies the lag control system dynamics for each configuration. For example, Configuration 1-3 and 2-3 have the same first order control system lag but different base aircraft dynamics. τ_1 is the lead time constant, τ_2 the lag time constant and ω_3 is the natural frequency of the second or fourth order prefilter (see Section 2.4).

Note that a dash (--) indicates that that particular type of control system element is not present in the configuration. The fixed elements in each configuration control system are not included in the heading block; dynamics of these elements are:

- Feel System,
$$\frac{\delta_{ES}}{F_{ES}} = \frac{.125}{\left(\frac{s^2}{26^2} + \frac{2(.6)s}{26} + 1 \right)}$$

Contrails

- Elevator Actuator,
$$\frac{1}{\frac{s^2}{75^2} + \frac{2(.7)s}{75} + 1}$$

Since the control system dynamics for Configurations 6-1 and 6-2 are more complex, the details are not given in the heading block; the complete control system is described in Subsection 2.6. For Configuration 7, only the times to double amplitude are presented; the exact aircraft characteristics are given in Appendix IV.

Also included in the heading block are the pilot ratings:

- Overall
 - Cooper-Harper Pilot Rating of complete series of tasks, including touchdown.
 - In a few configurations the rating for the landing task was different than the overall rating; in those cases a touchdown (TD) rating is also given.
- Approach
 - Rating of approach task, down to 50 ft above the runway.
 - The intentional evaluations of approach task alone (no touchdown) do not have an overall rating.
- PIO
 - Rating using the Pilot Induced Oscillation Tendency Scale.

Note: The PIO rating given was approximately $\frac{1}{2}$ the pilot rating for all the configurations evaluated with the exception of Configuration 7. In effect, the scale provides redundant information already contained in the pilot rating and comments.

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- SP
 - Rating by the safety pilot immediately after evaluation tasks.
 - In effect, this rating represents an evaluation of the task performance; the effects of the stick forces and motions experienced by the evaluation pilot are not therefore incorporated in this rating.

For reference, the headwind (tailwind negative) and crosswind magnitudes in knots are shown along with a qualitative assessment by the safety pilot of the turbulence level. The selected pitch control sensitivity, $M_{\delta_{ES}}$ in rad/sec^2 per inch completes the information presented.

For convenience, the important experiment data are summarised in Table 2.

The pilot comment summaries were prepared from tape recorded comments made by the pilot during each evaluation with reference to the Pilot Comment Card discussed in Subsection 3.6. Comments on the lateral-directional characteristics are not included since the pilots consistently indicated that these characteristics were excellent and therefore not a factor in the evaluations.

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TABLE 2 : SUMMARY OF EXPERIMENT RESULTS

Config. No.	Pilot/Flt. No.	Aircraft Dyn. (1) $\omega_{SP} / \gamma_{SP}$	Control Syst. (2)			Pilot Ratings Overall/Appro.	Turb. (3) Level	M_{SES}
			τ_1	τ_2	ω_3			
1-A	A/1894	1.0/.74	0.4	0.1	-	6(4TD)/6	L	0.17
1-B	A/1886		0.3	0.1	-	5/-	L	0.17
1-C	A/1889		0.2	0.1	-	4/-	L	0.20
	B/1895		0.2	0.1	-	4/-	L'	0.30
1-1	A/1887		-	-	-	4/-	M*	0.30
	B/1907		-	-	-	4/2	L'	0.19
1-2	A/1883		-	0.1	-	5/-	L	0.26
1-3	A/1886		-	0.25	-	9/-	L	0.17
	B/1892		-	0.25	-	10/-	L	0.17
	A/1885		-	0.25	-	-/6	L	0.26
	B/1898		-	0.25	-	-/6	M*	0.14
1-4	A/1884		-	0.5	-	10/-	L	0.26
1-6	A/1899		-	-	16	5/2	M*	0.26
	A/1899		-	-	16	-/5	M*	0.26
1-8	B/1907		-	-	9	8/5	L'	0.14
1-11	B/1906		-	-	16(4th)	9/5	L	0.12
2-A	A/1904	2.3/.57	0.4	0.1	-	4/2	L	0.26
	B/1907		0.4	0.1	-	6/3	L'*	0.25
2-C	A/1885		0.2	0.1	-	4/-	L	0.34
	A/1887		-	-	-	1½/-	M*	0.43
	A/1890		-	-	-	1½/-	M	0.34
	A/1897		-	-	-	3/3	M*	0.26
2-1	A/1884		-	-	-	2/-	L	0.30
	B/1892		-	-	-	2/-	L	0.34
	A/1883		-	-	-	-/3	L	0.26
2-2	B/1902		-	0.1	-	4/2	L'	0.29
	A/1905		-	0.1	-	4½/2	L*	0.36
2-3	A/1891		-	0.25	-	6/-	L	0.43

Contrails

TABLE 2 : SUMMARY OF EXPERIMENT RESULTS (CONT.)

Config. No.	Pilot/ Flt. No.	Aircraft Dyn. (1) ω_{SP}/δ_{SP}	Control Syst. (2)			Pilot Ratings Overall/Appro.	Turb. (3) Level	M_{SES}
			τ_1	τ_2	ω_3			
2-4	A/1888	2.3/.57	-	0.5	-	9/-	L*	0.64
	A/1889		-	0.5	-	-/5	L	0.64
	B/1892		-	0.5	-	-/3	L'	0.38
2-6	A/1900		-	-	16	5/1½	M*	0.37
2-7	A/1897		-	-	12	7/4	M*	0.34
	B/1898		-	-	12	6/3	L*	0.34
2-9	B/1895		-	-	6	10/5	M'	0.26
2-10	A/1893		-	-	4	10/6	L	0.26
2-11	B/1906		-	-	16(4th)	8/4	L	0.34
3-C	A/1889	2.2/0.25	0.2	0.1	-	2/-	M	0.31
	B/1898		0.2	0.1	-	5(4TD)/5	M*	0.17
3-0	A/1884	2.1/0.14	-	-	-	4/-	L	0.26
	A/1887		-	-	-	5/-	L*	0.17
3-1	A/1883	2.2/0.25	-	-	-	4/-	L	0.26
	B/1892		-	-	-	7(5TD)/-	L'	0.24
	A/1893		-	-	-	5(4TD)/5	L	0.14
3-2	A/1885		-	0.1	-	7/-	L	0.26
	A/1887		-	0.1	-	-/6	M	0.26
3-3	A/1890		-	0.25	-	10/6	L	0.26
	A/1897		-	0.25	-	-/7	M	0.26
3-6	A/1900		-	-	16	7/5	M*	0.26
	B/1902		-	-	16	6/5	L'	0.21
3-7	A/1904		-	-	12	8/5	L'	0.34
4-C	A/1899	2.0/1.06	0.2	0.1	-	3/1½	M*	0.47
	B/1906		0.2	0.1	-	3/2	L'	0.38
4-0	A/1885	2.1/1.23	-	-	-	6/-	L	0.85
4-1	A/1889	2.0/1.06	-	-	-	2/-	M	0.51

Contrails

TABLE 2 : SUMMARY OF EXPERIMENT RESULTS (CONT.)

Config. No.	Pilot/Flt. No.	Aircraft Dyn. (1) ω_{SP}/ζ_{SP}	Control Syst. (2)			Pilot Ratings Overall/Appro.	Turb. (3) Level	$M_{S_{25}}$
			τ_1	τ_2	ω_3			
4-3	A/1891	2.0/1.06	-	0.25	-	5/-	L	0.60
	B/1895		-	0.25	-	8/5	L'	0.51
	A/1899		-	0.25	-	7/2	M*	0.60
4-4	A/1894		-	0.5	-	7/4	L*	0.60
	B/1902		-	0.5	-	6/3	L'	0.34
	A/1894		-	0.5	-	-/5	L*	0.51
4-6	A/1900		-	-	16	4/1½	M*	0.51
4-7	A/1903		-	-	12	3/3	L	0.34
4-10	A/1893		-	-	4	9/6	L	0.26
4-11	A/1905		-	-	16(4th)	8/3	L*	0.51
5-1	A/1890	3.9/0.54	-	-	-	7/-	L	0.94
	B/1901		-	-	-	5/4	L	0.60
5-3	A/1886		-	0.25	-	8/-	L*	1.0
	B/1901		-	0.25	-	6/2	L'*	0.73
	A/1904		-	0.25	-	4½/3	L'	1.0
5-4	A/1890		-	0.25	-	-/4	L	1.0
	B/1901		-	0.25	-	6/2	L'*	0.73
	A/1903		-	0.5	-	6/2	L	1.19
5-5	A/1904		-	1.0	-	7/2	L'	1.45
5-6	B/1901		-	-	16	6/3	L'*	0.77
5-7	A/1903		-	-	12	6/2	L	0.89
5-11	A/1905		-	-	16(4th)	7/3	L*	1.0
6-1	A/1888	1.9/0.65	Unmodified YF-17			10/-	L	0.30
6-2	A/1898		Modified YF-17			2/-	L	0.34

TABLE 2 : SUMMARY OF EXPERIMENT RESULTS (CONT.)

Config. No.	Pilot/Flt. No.	Aircraft Dyn. (1)	Control System ⁽²⁾			Pilot Ratings Overall/Appro.	Turb. (3) Level	M_{SES}
			ω_{SP} / ζ_{SP}	τ_1	τ_2			
7-1	A/1891	$T_{double} \approx 6$ sec	-	-	-	4/-	L	0.43
7-2	A/1894	4 sec	-	-	-	3/-	L	0.34
7-3	A/1897	2 sec	-	-	-	4/2	M*	0.26
7-3	B/1898	2 sec	-	-	-	6(3TD)6	M*	0.21

NOTES: (1) Aircraft dynamics are for 120 KIAS nominal case:

$$V_T = 205 \text{ ft/sec}$$

$$\eta_{\theta} / \alpha = 4.5 \text{ g/rad}$$

$$\tau_{\theta_2} = 1.4 \text{ secs}$$

- (2) Complete control system includes feel system and actuator dynamics (see Subsection 2.7)
- (3) Turbulence level is based on safety pilot assessment; prime (') indicates tailwind >5 kts; asterisk (*) indicates crosswind >5 kts.

Contrails

1-A	CONFIGURATION $\omega_{SP} = 1.0$ $\xi_{SP} = 0.74$ 0.4/ 0.1/ --	FLIGHT/PILOT 1894/A
PILOT RATING: OVERALL 6(4TD) APPROACH 6 PIO 1 SP 3 WIND/X-WIND: -05/0 TURBULENCE: Light $M_{\delta ES} = 0.17$		

FEEL:

- Forces: Comfortable for ILS, higher for landing but okay.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Airplane got underway well.
- Predictability: Seemed to initially get desired attitude but then drifted off. Okay visually but not good on instruments.
- Special Inputs: Had to pay attention to long term response drift on instruments.
- PIO Tendency: None.

AIRSPEED CONTROL:

Worked harder than desired on ILS; okay on visual approaches.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay but worked too hard.

Visual (Sidestep): Okay reduced workload.

- Landing tasks: High forces but predictability was good; comfortable no special control technique required.
- Differences: ILS was the most difficult.

WIND AND TURBULENCE:

No problem.

SUMMARY COMMENTS:

Major problem was final attitude response on instrument task.
 (SP: seemed like an extreme rating on the basis of the performance.)

Contrails

1-B	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ 0.3 / 0.1 / --	FLIGHT/PILOT 1886/A
PILOT RATING: OVERALL 5	APPROACH -- PIO 2	SP 4
WIND/X-WIND: 09/03	TURBULENCE: Light	$M_{\delta_{ES}} = 0.17$

FEEL:

- Forces: Forces a little light initially, made heavier for last approach.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Reasonable.
- Predictability: Lacking somewhat in flare.
- Special Inputs: Desire to tone down inputs to prevent tendency to bobble.
- PIO Tendency: Sight tendency to PIO.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 - ILS: Reasonable.
 - Visual (Sidestep): Visual fairly good, sidestep puts higher workload on longitudinal.
- Landing tasks: Hunting, a problem. Holding what I had rather than going aggressively for the touchdown point.
- Differences: Could fly smoothly on approach, couldn't at touchdown.

WIND AND TURBULENCE: Not significant in spite of higher winds.

SUMMARY COMMENTS: Tendency to PIO, not just a bobble.

Contrails

1-C	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ 0.2 / 0.1 / --	FLIGHT/PILOT 1889/A
PILOT RATING: OVERALL 4 WIND/X-WIND: 05/03	APPROACH -- PIO 1 TURBULENCE: Light	SP 2 $M_{\delta_{ES}} = 0.20$

FEEL:

- Forces: Comfortable but had a slight tendency to overcontrol so increased forces which helped (for last two approaches).
- Displacement:
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Felt comfortable.
- Predictability: Fair to good, some lack of precision but couldn't isolate it.
- Special Inputs: Had to tone down inputs on first approach.
- PIO Tendency: Never saw a tendency to PIO.

AIRSPEED CONTROL: No difficulty.

PERFORMANCE:

- Approach Tasks:
 ILS: Reasonable.

Visual (Sidestep): Went okay.

- Landing tasks: Only bobbed with initial high sensitivity, the others were not a problem.
- Differences: Only on first approach was the flare a problem.

WIND AND TURBULENCE: No comments.

SUMMARY COMMENTS: Could not get desired sensitivity without bobbling in flare.

Contrails

I- C	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ 0.2 / 0.1 / --	FLIGHT/PILOT 1895/B
PILOT RATING: OVERALL 4 WIND/X-WIND: -10/02	APPROACH -- PIO 1 TURBULENCE: Light	SP 3 $M_{\delta_{ES}} = 0.21$

FEEL:

- Forces: Felt heavy at low speed but good compromise.
- Displacement: No comments.
- Sensitivity: Good selection.

PITCH ATTITUDE RESPONSE:

- Initial: Slow.
- Predictability: Reasonable.
- Special Inputs: Had to provide lead.
- PIO Tendency: None.

AIRSPEED CONTROL:

Better, okay but not ideal.

PERFORMANCE:

- Approach Tasks:
 ILS: Moderately good.

Visual (Sidestep): Relatively easy.

- Landing tasks: Didn't have good tight control; slightly behind in flight path control. Had to anticipate.
- Differences: Not significant, touchdown task hardest.

WIND AND TURBULENCE:

Small crosswind, not difficult.

SUMMARY COMMENTS:

Slow, sluggish flight path and pitch response a problem but it was reasonably predictable.

Contrails

1-1	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / -- / --	FLIGHT/PILOT 1887/A
PILOT RATING: OVERALL 4 WIND/X-WIND: 15/11	APPROACH -- PIO 2 TURBULENCE: Moderate	SP 3 $M_{\delta ES} = 0.30$

FEEL:

- Forces: Moderate forces, comfortable.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response reasonable. Final response looked good at first but tended to drift.
- Predictability: No comments.
- Special Inputs: No special inputs.
- PIO Tendency: Slight tendency to PIO.

AIRSPEED CONTROL:

Airspeed problems due to drifting in long term pitch response.

PERFORMANCE:

- Approach Tasks:
 ILS: Went fairly well.

Visual (Sidestep): Sidestep and visuals okay. Slight tendency to low frequency PIO near ground.

- Landing tasks: Near touchdown there was a slight tendency to PIO. Backed off on inputs near the ground.
- Differences: Not a strong difference but different problems in each task.

WIND AND TURBULENCE:

Crosswind a slight attention diversion but not a major problem.

SUMMARY COMMENTS:

Problems not prominent but they were there as described.

Contrails

1-1	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / -- / --	FLIGHT/PILOT 1907/B
PILOT RATING: OVERALL 4 WIND/X-WIND: -8/0	APPROACH 2 PIO 1 TURBULENCE: Light	SP 4 $M_{\delta ES} = 0.19$

FEEL:

- Forces: Comfortable.

- Displacement: Little large in flare.

- Sensitivity: Good choice.

PITCH ATTITUDE RESPONSE:

- Initial: Slow.

- Predictability: Pretty good, had to compensate.

- Special Inputs: Had to overdrive it in tight control situations such as landing.

- PIO Tendency: None.

AIRSPEED CONTROL: Okay, not much airspeed feel.

PERFORMANCE:

- Approach Tasks:
 - ILS: Quite good; felt unloaded.

Visual (Sidestep): Comfortable.

- Landing tasks: Little slow for tight control of pitch attitude and flight path.

- Differences: Noticeable difference, landing more demanding.

WIND AND TURBULENCE: Smooth, no crosswind.

SUMMARY COMMENTS: No major problems.

Contrails

1-2	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / 0.1 / --	FLIGHT/PILOT 1883/A
PILOT RATING: OVERALL 5 WIND/X-WIND: 0/04	APPROACH -- PIO 2 TURBULENCE: Light	SP 6 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Heavy initially then light.
- Displacement: Okay.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response slow.
- Predictability: Final response not predictable; get 2 or 3 overshoots.
- Special Inputs: High control activity.
- PIO Tendency: Some tendency to PIO, especially when aggressive.

AIRSPEED CONTROL:

Not affected by bobbles.

PERFORMANCE:

- Approach Tasks:
 ILS: Fairly good.

Visual (Sidestep): No comments.

- Landing tasks: Initial flare okay, but in final stages got a bobble and had to concentrate to keep it under control.
- Differences: On ILS had to work harder than for visual approach but flare and touchdown required the most effort.

WIND AND TURBULENCE:

No significant effects. Weather is marginal and somewhat distracting.

SUMMARY COMMENTS:

Major problem was tendency to bobble in pitch because of initial delay in pitch.

Contrails

1-3	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / 0.25 / --	FLIGHT/PILOT 1886/A
PILOT RATING: OVERALL 9 WIND/X-WIND: 08/05	APPROACH -- PIO 4 TURBULENCE: Light	SP 8 $M_{\delta_{ES}} = 0.17$

FEEL:

- Forces: Heavy then reasonable in steady state.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Lags.
- Predictability: Nonexistent.
- Special Inputs: Had to stay out of loop.
- PIO Tendency: Definite PIO tendency.

AIRSPEED CONTROL:

Difficult, distracted by pitch.

PERFORMANCE:

- Approach Tasks:
 ILS: Reasonable, but hard work.

Visual (Sidestep): Everything okay until later stages of final approach.

- Landing tasks: Terrible performance. Try not to fly aircraft - can't avoid a PIO otherwise.
- Differences: Yes, close to the ground was most difficult.

WIND AND TURBULENCE:

Not a factor, although crosswind noticeable.

SUMMARY COMMENTS:

Unpredictable pitch response and tendency to PIO a major problem.

Contrails

1-3	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / 0.25 / --	FLIGHT/PILOT 1892/B
PILOT RATING: OVERALL 10	APPROACH - PIO 4	SP 8
WIND/X-WIND: -04/02	TURBULENCE: Light	$M_{DES} = 0.17$

FEEL:

- Forces: Felt spongy, forces very light in steady-state, moderate initially.
- Displacement: Large.
- Sensitivity: Low in that initial response was slow. Would like to repeat with heavier forces.

PITCH ATTITUDE RESPONSE:

- Initial: Absolutely terrible. Initial response was slow, big delay.
- Predictability: Very bad even in smooth air.
- Special Inputs: Had to try and guess when to put an input in, used pulses.
- PIO Tendency: Large tendency toward PIO's (even on take-off from touch and go).

AIRSPEED CONTROL:

No time to spend on airspeed and flight path control. Both poor as a result.

PERFORMANCE:

- Approach Tasks:
ILS: High workload, performance not too bad.

Visual (Sidestep): Always behind the airplane.

- Landing tasks: Got into a noticeable pitch PIO and could not control the touchdown point. Had to force yourself to pulse aircraft; impossible in turbulence.
- Differences: Significant; oscillatory PIO in flare and touchdown.

WIND AND TURBULENCE:

Smooth air.

SUMMARY COMMENTS:

Had to generate as much lead as possible, very difficult to do and without scaring the backseat pilot. Major problem was lag in pitch response which made it unpredictable and deteriorated speed and flight path control as well. (SP: very startling PIO on lift-off.)

Contrails

1-3	CONFIGURATION $\omega_{SP} = 1.0$ $\xi_{SP} = 0.74$ -- / 0.25 / --	FLIGHT/PILOT 1885/A
PILOT RATING: OVERALL --	APPROACH 6 PIO 2	SP 6
WIND/X-WIND: 0/04	TURBULENCE: Light	$M_{\delta ES} = 0.26$

FEEL:

- Forces: High initial forces, comfortable in steady state.
- Displacement: Normal.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response sluggish.
- Predictability: Final response not predictable; tendency to overshoot a couple of times.
- Special Inputs: Had to fly with small corrections otherwise easy to overcontrol.
- PIO Tendency: No comments.

AIRSPEED CONTROL:

Affected by control technique required by pitch.

PERFORMANCE:

- Approach Tasks:
 ILS: Fairly good, had to pay attention to pitch.

Visual (Sidestep): Easy to overcontrol on final approach.

- Landing tasks: Not performed.
- Differences: Not applicable.

WIND AND TURBULENCE:

Not a factor.

SUMMARY COMMENTS:

Tendency to overcontrol in pitch. Difficult to make large corrections fast.

Contrails

1-3	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / 0.25 / --	FLIGHT/PILOT 1898/B
PILOT RATING: OVERALL -- WIND/X-WIND: 13/15	APPROACH 6 PIO 3 TURBULENCE: Moderate	SP 5 $M_{\delta_{ES}} = 0.14$

FEEL:

- Forces: Light initially, then heavy; selected on heavy side.
- Displacement: Felt large, spongy.
- Sensitivity: Desirable level.

PITCH ATTITUDE RESPONSE:

- Initial: Very delayed.
- Predictability: Poor.
- Special Inputs: Keep your gain down and fly slowly like a big airplane.
- PIO Tendency: Definite tendency, tended to oscillate 2 or 3 cycles.

AIRSPEED CONTROL:

Bothersome, poor, objectionable.

PERFORMANCE:

- Approach Tasks:
 ILS: Not too bad, but heavily loaded.

Visual (Sidestep): Felt behind the airplane on sidesteps; approaches better than on ILS.

- Landing tasks: - Not done.
- Differences: Not applicable.

WIND AND TURBULENCE:

Moderate corsswind and turbulence.

SUMMARY COMMENTS:

Hard to fly. Very delayed initial response made for a high workload, particularly on the ILS.

Contrails

I-4	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / 0.5 / --	FLIGHT/PILOT 1884/A
PILOT RATING: OVERALL 10 WIND/X-WIND: 0/0	APPROACH -- PIO 4 TURBULENCE: None	SP 10 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Heavy initially but best compromise (need to tone down inputs).
- Displacement: No comments.
- Sensitivity: Difficult to comment about.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response lagged then took off.
- Predictability: Very unpredictable.
- Special Inputs: No comments.
- PIO Tendency: Strong tendency to PIO.

AIRSPEED CONTROL:

Clearly affected by diversion of attention; hesitant to make rapid corrections.

PERFORMANCE:

- Approach Tasks:
 ILS: Could get the job done.

Visual (Sidestep): No comments.

- Landing tasks: Things were okay until I got fairly close to the ground, then we went for a ride - unable to perform touchdown. On visual approach, aircraft was manageable until near the ground then unable to land.
- Differences: Significantly different, flare the problem area.

WIND AND TURBULENCE:

Not significant.

SUMMARY COMMENTS:

Major problem is initial lag which makes the aircraft totally unpredictable. No good features.

Contrails

1- 6	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / -- / 16	FLIGHT/PILOT 1899/A
PILOT RATING: OVERALL 5	APPROACH 2 PIO 2	SP 6
WIND/X-WIND: 17/06	TURBULENCE: Moderate	$M_{\delta ES} = 0.26$

FEEL:

- Forces: Comfortable until into the high workload task then a little heavy.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Not a noticeable delay.
- Predictability: Not a problem until the flare when there was a tendency to overcontrol.
- Special Inputs: Had to tone down inputs in the flare.
- PIO Tendency: None but a tendency to overcontrol.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Okay except for overcontrol near ground.

- Landing tasks: Working hard to avoid overcontrol; had to tone down inputs.
- Differences: Clearly a significant difference; worst close to the ground.

WIND AND TURBULENCE: Light to moderate turbulence.

SUMMARY COMMENTS: Didn't work hard until near the ground; then had a tendency to overcontrol.

Contrails

1-6	CONFIGURATION $\omega_{SP} = 1.0$ $\xi_{SP} = 0.74$ --/ -- /16	FLIGHT/PILOT 1899/A
PILOT RATING: OVERALL -- WIND/X-WIND: 17/06	APPROACH 5 PIO 2 TURBULENCE: Moderate	SP 6 $M_{DES} = 0.26$

FEEL:

- Forces: Moderate

- Displacement: No comments.

- Sensitivity: Best compromise.

PITCH ATTITUDE RESPONSE:

- Initial: A slight delay.

- Predictability: Impaired by mismatch between initial and subsequent response.

- Special Inputs: Used ramp type inputs.

- PIO Tendency: None but a tendency to overcontrol.

AIRSPEED CONTROL:

Not a great deal of difficulty; attention diverted somewhat by pitch problems.

PERFORMANCE:

- Approach Tasks:
 ILS: Worked hardest, reasonable.

Visual (Sidestep): Reasonable.

- Landing tasks: Not done.

- Differences: No comments.

WIND AND TURBULENCE:

Some response to turbulence but not a problem; crosswind from right.

SUMMARY COMMENTS:

Major problem is hesitancy to use aggressive inputs due to poor predictability.

Contrails

1-8	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ -- / -- / 9	FLIGHT/PILOT 1907/B
PILOT RATING: OVERALL 8 APPROACH 5 PIO 3 SP 9 WIND/X-WIND: -08/0 TURBULENCE: Light $M_{DES} = 0.14$		

FEEL:

- Forces: Felt heavy.
- Displacement: Large.
- Sensitivity: Satisfied with selection.

PITCH ATTITUDE RESPONSE:

- Initial: Almost not there.
- Predictability: Poor.
- Special Inputs: Overdrive it, hard to stop.
- PIO Tendency: Not as oscillatory as expected; others this slow were less controllable. Strong tendency to PIO in landing task.

AIRSPEED CONTROL:

Peculiar, thought it would be worse, fair overall.

PERFORMANCE:

- Approach Tasks:
 ILS: Not a good approach.

Visual (Sidestep): Not difficult if you take your time.

- Landing tasks: Get into a PIO in trying to control touchdown point. Actually hit the stops once.
- Differences: Significant, landing the worst.

WIND AND TURBULENCE:

Little turbulence but not a problem.

SUMMARY COMMENTS:

Confusing airplane to fly; really slow. Major problem is sluggish pitch response which results in PIO on landing and overrotation and oscillation on take off.

Contrails

1-11	CONFIGURATION $\omega_{SP} = 1.0$ $\zeta_{SP} = 0.74$ - / -- / 16(4th)	FLIGHT/PILOT 1906/B
PILOT RATING: OVERALL 9	APPROACH 5	PIO 3½
WIND/X-WIND: -04/0	TURBULENCE: None	SP 8 $M_{\delta_{ES}} = 0.12$

FEEL:

- Forces: Comfortable in steady state but heavy in transient.

- Displacement: Large.

- Sensitivity: Felt heavy forces selected saved it from being a 10 pilot rating.

PITCH ATTITUDE RESPONSE:

- Initial: Quite delayed, slow.

- Predictability: Important to trim; poor predictability.

- Special Inputs: Used a dither type input; high frequency closure.

- PIO Tendency: Exceedingly strong in landing; latent on approach but not a PIO.

AIRSPEED CONTROL:

Fair.

PERFORMANCE:

- Approach Tasks:
 - ILS: Felt a little behind (Note: no glide slope), poor performance.

Visual (Sidestep): Easy to perform until near the ground.

- Landing tasks: Had a pitch PIO close to the ground; tried to get on top of it by using smaller, quicker inputs.

- Differences: Significant; landing the most difficult because of the PIO (convergent).

WIND AND TURBULENCE:

None.

SUMMARY COMMENTS:

A very PIO prone aircraft in landing task because of delayed pitch resonance.

Contrails

2-A	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ 0.4/ 0.1 /--	FLIGHT/PILOT 1904/A
PILOT RATING: OVERALL 4	APPROACH 2 PIO 2	SP 3
WIND/X-WIND: -02/02	TURBULENCE: None	$M_{\delta ES} = 0.26$

FEEL:

- Forces: Felt fine until the flare.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: No lag.
- Predictability: Had a fast, staircase type approach to final response.
- Special Inputs: No comments.
- PIO Tendency: No comments.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Poor pilot performance, not airplane.

Visual (Sidestep): Could get it done; tended to have ratchety performance.

- Landing tasks: Abruptness a problem here; not a smooth response.
- Differences: Flare and touchdown the most difficult.

WIND AND TURBULENCE: No comments.

SUMMARY COMMENTS: Hard to define but there must be some lack of predictability. There was a high frequency hunting for the ground.

Contrails

2-A	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ 0.4 / 0.1 / --	FLIGHT/PILOT 1907/B
PILOT RATING: OVERALL 6	APPROACH 3 PIO 2½	SP. 5
WIND/X-WIND: -11/10	TURBULENCE: Light	$M_{\delta ES} = 0.25$

FEEL:

- Forces: Steady were heavy; initial light.

- Displacement: Small initially then larger.

- Sensitivity: Best compromise was in between values evaluated.

PITCH ATTITUDE RESPONSE:

- Initial: Abrupt.

- Predictability: Get a high frequency bobble in flare; final response reasonably predictable.

- Special Inputs: Smooth inputs to avoid abruptness.

- PIO Tendency: Very high frequency PIO evident in flare. Doesn't really affect task much. Annoying.

AIRSPEED CONTROL: Good.

PERFORMANCE:

- Approach Tasks:
 ILS: Good in smooth air of today.

Visual (Sidestep): All right.

- Landing tasks: Got into pitch bobble tendency here.

- Differences: Better on approach because of bobble in flare but not a big difference.

WIND AND TURBULENCE: Smooth with a tailwind.

SUMMARY COMMENTS: Abrupt initial response and tendency to bobble were major problems. Suspect that ratings would be worse in turbulence.

Contrails

2-C	CONFIGURATION $\omega_{SP} = 2.3$ $\xi_{SP} = 0.57$ 0.2/ 0.1 /--	FLIGHT/PILOT 1885/A
PILOT RATING: OVERALL 4 WIND/X-WIND: 00/04	APPROACH -- PIO 2 TURBULENCE: None	SP 3 $M_{\delta ES} = 0.34$

FEEL:

- Forces: Comfortable.
- Displacement: No comments.
- Sensitivity: Sensitive aircraft.

PITCH ATTITUDE RESPONSE:

- Initial: Good initial response
- Predictability: Predictability fairly good, except for a tendency to bobble at high frequency.
- Special Inputs: Necessary to resist chasing bobbles.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Satisfactory.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Went well.

- Landing tasks: Clearly a tendency to bobble but performance not affected. Good touchdown control.
- Differences: Had to pay more attention in flare. Flare and touchdown, the most demanding.

WIND AND TURBULENCE: Some crosswind but not a big factor.

SUMMARY COMMENTS: A minor problem is having to think about bobbling tendency.

Contrails

2-C	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ 0.2 / 0.1 / --	FLIGHT/PILOT 1887/A
PILOT RATING: OVERALL 1½	APPROACH -- PIO 1	SP 2
WIND/X-WIND: 11/11	TURBULENCE: Light to moderate	$M_{\delta_{ES}} = 0.43$

FEEL:

- Forces: Pretty comfortable.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Got what I wanted when I wanted it.

- Predictability: No comments.

- Special Inputs: No special inputs.

- PIO Tendency: No PIO.

AIRSPEED CONTROL: Went well.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Visual, sidestep: good.

- Landing tasks: Satisfactory, no special control techniques.

- Differences: No significant difference, landing the most difficult.

WIND AND TURBULENCE: Turbulence evident; not a problem.

SUMMARY COMMENTS: Enjoyed flying it.

Contrails

2-C	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ 0.2 / 0.1 / --	FLIGHT/PILOT 1890/A
PILOT RATING: OVERALL 1½ WIND/X-WIND: 03/04	APPROACH -- PIO 1 TURBULENCE: Light to moderate	SP 2 $M_{\delta ES} = 0.34$

FEEL:

- Forces: Changed to lighter forces, worked well.
- Displacement: No comments.
- Sensitivity: Final sensitivity comfortable.

PITCH ATTITUDE RESPONSE:

- Initial: Good.
- Predictability: Predictable.
- Special Inputs: None.
- PIO Tendency: No PIO tendency.

AIRSPEED CONTROL: Normal.

PERFORMANCE:

- Approach Tasks:
 ILS: ILS and visual approaches went well.

Visual (Sidestep): Went well.

- Landing tasks: No problem.
- Differences: No significant differences.

WIND AND TURBULENCE: Noticed turbulence but not bothersome.

SUMMARY COMMENTS: Very comfortable aircraft.

Contrails

2- C	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ 0.2 / 0.1 / --	FLIGHT/PILOT 1897/A
PILOT RATING: OVERALL 3 WIND/X-WIND: 08/13	APPROACH 3 TURBULENCE: Moderate	PIO 1 SP 2 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Not noticeable, okay.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Good.

- Predictability: Good.

- Special Inputs: None.

- PIO Tendency: None.

AIRSPEED CONTROL: Difficult because of turbulence.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay.

Visual (Sidestep): Good control, except for occasional turbulence inputs.

- Landing tasks: Not a problem, felt comfortable.

- Differences: No difference.

WIND AND TURBULENCE: Strong effect; increased workload.

SUMMARY COMMENTS: No problems, a satisfactory aircraft.

Contrails

2-1	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / -- / --	FLIGHT/PILOT 1884/A
PILOT RATING: OVERALL 2 WIND/X-WIND: 0/0	APPROACH -- PIO 1 TURBULENCE: None	SP 1 $M_{\delta_{ES}} = 0.30$

FEEL:

- Forces: Forces a bit high but not a problem.
- Displacement: No comments.
- Sensitivity: Sensitivity good.

PITCH ATTITUDE RESPONSE:

- Initial: Good.
- Predictability: No comments.
- Special Inputs: No special inputs.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Easy.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Good.

- Landing tasks: Predictable, easy to make with no special inputs.
- Differences: None.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS:

Good aircraft; easy to control; only noticed an overshoot when following the tracking task aggressively (there is a tendency to follow task more aggressively than in the approach.)

Contrails

2-1	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ --/ -- /--	FLIGHT/PILOT 1892/B
PILOT RATING: OVERALL 2	APPROACH -- PIO 1	SP 2
WIND/X-WIND: -04/0	TURBULENCE: Light	$M_{\delta ES} = 0.34$

FEEL:

- Forces: Solid.
- Displacement: Okay.
- Sensitivity: At approach speeds was satisfactory.

PITCH ATTITUDE RESPONSE:

- Initial: Prompt.
- Predictability: Good.
- Special Inputs: No special inputs.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL:

Strong float tendency at end of approach, must anticipate power reduction.

PERFORMANCE:

- Approach Tasks:
 ILS: Easy, glide slope very good.

Visual (Sidestep): Okay, only a problem with airspeed control near touchdown.

- Landing tasks: No pitch control problems but some effort required to predict touchdown point - not emphasizing this characteristic.
- Differences: No differences, no surprises.

WIND AND TURBULENCE:

Smooth air.

SUMMARY COMMENTS:

No major problems. Minor problem was prediction of touchdown point due to tail wind. Discounted in evaluation.

Contrails

2-1	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ --/ -- /--	FLIGHT/PILOT 1883/A
PILOT RATING: OVERALL -- WIND/X-WIND: 0/04	APPROACH 3 PIO 1 TURBULENCE: None	SP 1 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Little heavy, not uncomfortable, okay.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response okay, some tendency to overshoot, not a problem.
- Predictability: Tendency to overshoot one time when changing pitch attitude aggressively. For most of the task it was not a problem.
- Special Inputs: No comments.
- PIO Tendency: No comments.

AIRSPEED CONTROL: Adequate.

PERFORMANCE:

- Approach Tasks:
 ILS: Satisfactory.

Visual (Sidestep): No comments.

- Landing tasks: Not done.
- Differences: No comments.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Annoying overshoot tendency in pitch but this problem did not affect task performance.

Contrails

2-2	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ --/ 0.1 /--	FLIGHT/PILOT 1902/B
PILOT RATING: OVERALL 4	APPROACH 2 PIO 2	SP 2
WIND/X-WIND: -07/01	TURBULENCE: None	$M_{\delta ES} = 0.29$

FEEL:

- Forces: Lightened forces for last two approaches; Okay.

- Displacement: Felt large.

- Sensitivity: A good choice.

PITCH ATTITUDE RESPONSE:

- Initial: Slow.

- Predictability: Little delay causes small bobble; fair to good predictability on approach. Some tendency to overshoot in flare and touchdown.
- Special Inputs: Needed to anticipate near the ground.

- PIO Tendency: Very mild tendency to overshoot 1 or 2 times.

AIRSPEED CONTROL: Fairly good.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Comfortable - tended to be fast due to tailwind.

- Landing tasks: Problem was a tendency to get too much response; couldn't control touchdown point accurately enough.

- Differences: Yes - the landing task was more critical but not very difficult.

WIND AND TURBULENCE: Very smooth day; tailwind which confused energy management on approach.

SUMMARY COMMENTS: Only problem was a small tendency to overcontrol in the landing task.

Contrails

2-2	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ --/ 0.1 /--	FLIGHT/PILOT 1905/A
PILOT RATING: OVERALL 4½ WIND/X-WIND: 01/07	APPROACH 2 PIO 1 TURBULENCE: Light	SP 2 $M_{\delta ES} = 0.36$

FEEL:

- Forces: Went from heavy to light.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Seemed sluggish.
- Predictability: Was able to predict final response but everything seemed to lag.
- Special Inputs: High initial forces for large attitude changes suggest overdriving or lead inputs.
- PIO Tendency: No comments.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay.

Visual (Sidestep): No visible change in performance.

- Landing tasks: Lag tendency didn't lead to overcontrol but general heaviness.
- Differences: Only a problem in flare.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: No further comments.

Contrails

2-3	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / 0.25 / --	FLIGHT/PILOT 1891/A
PILOT RATING: OVERALL 6 WIND/X-WIND: 07/00	APPROACH -- PIO 3 TURBULENCE: Light	SP 4 $M_{\delta_{ES}} = 0.43$

FEEL:

- Forces: Comfortable.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Had a little bit of a lag but not a problem.

- Predictability: Was a problem.

- Special Inputs: No comments.

- PIO Tendency: Marked tendency toward low frequency PIO. Not a solid feeling aircraft.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well, worked hard.

Visual (Sidestep): Approaches OK.

- Landing tasks: Difficult in flare; problems. Had to try to hold what you had prior to touchdown. Incipient PIO in flare.

- Differences: Touchdown required the most attention.

WIND AND TURBULENCE: No effects.

SUMMARY COMMENTS: Difficult to set an attitude. Tendency to PIO in flare and in lift-off.

Contrails

2-4	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / 0.5 / --	FLIGHT/PILOT 1888/A
PILOT RATING: OVERALL 9 WIND/X-WIND: 06/05	APPROACH -- PIO 3 TURBULENCE: Light	SP 8 $M_{\delta ES} = 0.64$

FEEL:

- Forces: Were a little high on approach but needed to help in flare and touchdown.
- Displacement: No comments
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Not very good.
- Special Inputs: Worked to smooth inputs.
- PIO Tendency: A tendency to PIO.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well, could relax aggressiveness to achieve performance.

Visual (Sidestep): Okay until close to the ground.

- Landing tasks: Clearly a problem, tendency to PIO. Could get out of loop sometimes and stop on attitude.
- Differences: Flare and touchdown clearly the most difficult.

WIND AND TURBULENCE: No effect.

SUMMARY COMMENTS: Inability to achieve an attitude quickly and predictably was major problem.

Contrails

2-4	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / 0.5 / --	FLIGHT/PILOT 1889/A
PILOT RATING: OVERALL -- WIND/X-WIND: 05/03	APPROACH 5 TURBULENCE: None	PIO 2 SP 3 $M_{\delta ES} = 0.64$

FEEL:

- Forces: Somewhat heavy, but didn't mind them.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Okay, no noticeable lag.
- Predictability: Not very good. Very difficult to figure aircraft out.
- Special Inputs: No comments.
- PIO Tendency: Tendency to overcontrol, no PIO.

AIRSPEED CONTROL:

Had to work at it.

PERFORMANCE:

- Approach Tasks:
 ILS: Was not outstanding.

Visual (Sidestep): Approaches showed a slight tendency to overcontrol.

- Landing tasks: Not done.
- Differences: No comments.

WIND AND TURBULENCE:

Not a factor.

SUMMARY COMMENTS:

Little confused about this one, lot of distractions during evaluations. Not a solid aircraft but not bad, uncertain of rating.

Contrails

2-4	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ --/ 0.5 /--	FLIGHT/PILOT 1892/B
PILOT RATING: OVERALL -- WIND/X-WIND: -05/00	APPROACH 3 TURBULENCE: Light	PIO 1 SP 4 $M_{\delta ES} = 0.38$

FEEL:

- Forces: Okay.

- Displacement: A little large.

- Sensitivity: Okay, detected a little lag.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response was slow.

- Predictability: Good.

- Special Inputs: No special pilot techniques (perhaps a little lead.)

- PIO Tendency: No PIO tendency.

AIRSPEED CONTROL: Fairly good.

PERFORMANCE:

- Approach Tasks:
 ILS: Was okay (bad pilot performance.)

Visual (Sidestep): Visual approaches fine.

- Landing tasks: Not done.

- Differences: Not applicable.

WIND AND TURBULENCE: Smooth air.

SUMMARY COMMENTS: Minor problem was small pitch lag and a little more motion than desired. Generally a pretty good airplane.

Contrails

2-6	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ --/ -- /16	FLIGHT/PILOT 1900/A
PILOT RATING: OVERALL 5 WIND/X-WIND: 16/06	APPROACH $1\frac{1}{2}$ PIO $2\frac{1}{2}$ TURBULENCE: Moderate	SP 4 $M_{\delta ES} = 0.37$

FEEL:

- Forces: Comfortable.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Difficult to describe; only a problem near the ground. Didn't see much of a delay at any time.

- Predictability: Reasonable but something not perfect for aggressive inputs.

- Special Inputs: Used several inputs to get desired response.

- PIO Tendency: On one of the landings did get into an oscillation but it was controllable.

AIRSPEED CONTROL: No problems.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Good, particularly side step.

- Landing tasks: Had to hunt to get desired response; got into a low amplitude, damped PIO once. Had to be careful near the ground.
- Differences: Definite difference; landing the most difficult.

WIND AND TURBULENCE: Strong cross wind from the right which keeps you locked in the loop.

SUMMARY COMMENTS: Unsure of source of difficulties but touchdown required a moderate workload.

Contrails

2-7	CONFIGURATION $\omega_{SP} = 2.3$ $\xi_{SP} = 0.57$ -- / -- / 12	FLIGHT/PILOT 1897/A
PILOT RATING: OVERALL 7	APPROACH 4 PIO 3	SP 6
WIND/X-WIND: 08/13	TURBULENCE: Moderate	$M_{\delta ES} = 0.34$

FEEL:

- Forces: Comfortable for combination of tasks.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Reasonable for non-aggressive inputs; lagged for aggressive inputs.
- Predictability: Reasonable for ILS, not so for the flare and touchdown.
- Special Inputs: On close final must really concentrate on pitch attitude.
- PIO Tendency: Tendency to overshoot on ILS, but tendency to PIO on close final.

AIRSPEED CONTROL:

Not really problem except for turbulence.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay.

Visual (Sidestep): Okay.

- Landing tasks: Clearly where problems exist; have to tone down inputs. On the go-around it wasn't as bad if I didn't look at the ground.
- Differences: Significantly more difficult close to the ground.

WIND AND TURBULENCE:

Significant effects of turbulence and crosswind. Flare and touchdown more demanding.

SUMMARY COMMENTS:

Close in tendency to get into a low frequency PIO was major problem; had to abandon task to get it on the ground.

Contrails

2-17	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / -- / 12	FLIGHT/PILOT 1898/B
PILOT RATING: OVERALL 6	APPROACH 3 PIO 3	SP 6
WIND/X-WIND: 10/11	TURBULENCE: Light	$M_{\delta ES} = 0.34$

FEEL:

- Forces: Pleasant.
- Displacement: Okay except in the PIO.
- Sensitivity: Good.

PITCH ATTITUDE RESPONSE:

- Initial: Solid feel; approach was prompt; landing delayed initial response.
- Predictability: On approach okay; poor on landing, would overshoot and oscillate.
- Special Inputs: On landing had to generate as much lead as possible.
- PIO Tendency: None on approach; definite tendency on landing but not divergent.

AIRSPEED CONTROL: Good.

PERFORMANCE:

- Approach Tasks:
 ILS: Best for this flight; in command.

Visual (Sidestep): No difficulty.

- Landing tasks: Problems, tendency to PIO near the ground (3 or 4 half cycles). Tried to generate lead.
- Differences: Approach was good but landing was PIO prone.

WIND AND TURBULENCE: Light turbulence and strong crosswind.

SUMMARY COMMENTS: Major problem was PIO tendency on touchdown. Very poor for single pilot work.

Contrails

2-9	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / -- / 6	FLIGHT/PILOT 1895/B
PILOT RATING: OVERALL 10 APPROACH 5 PIO 3 SP 8 WIND/X-WIND: -08/02 TURBULENCE: Light to moderate $M_{DES} = 0.26$		

FEEL:

- Forces: Very spongy, heavy for maneuvering.
- Displacement: Large for rapid maneuvering.
- Sensitivity: Okay as is.

PITCH ATTITUDE RESPONSE:

- Initial: Slow.
- Predictability: Difficult to predict; on approach where you could do things slowly it wasn't too bad.
- Special Inputs: Develop lead to prevent PIO from going divergent.
- PIO Tendency: Yes, in flare.

AIRSPPEED CONTROL: Reasonably good.

PERFORMANCE:

- Approach Tasks:
 ILS: Best performance of the day.
- Visual (Sidestep): Not done.
- Landing tasks: Easy to over-rotate and get into damped PIO. Had to put in an input and wait.
- Differences: Very significant; flare and touchdown very difficult.

WIND AND TURBULENCE: Very smooth, slight crosswind.

SUMMARY COMMENTS: Only one approach, got down to 20 feet, got into PIO due to delayed response.

Contrails

2-10	CONFIGURATION $\omega_{SP} = 2.3$ $\xi_{SP} = 0.57$ --/ -- / 4	FLIGHT/PILOT 1893/A
PILOT RATING: OVERALL 10 WIND/X-WIND: -01/03	APPROACH 6 PIO 4 TURBULENCE: None	SP 10 $M_{\delta ES} = 0.26$

FEEL:

- **Forces:** Heavy initially, steady forces comfortable.

- **Displacement:** Okay.

- **Sensitivity:** Unpredictable.

PITCH ATTITUDE RESPONSE:

- **Initial:** Clearly a lagging response.

- **Predictability:** Not bad for nonaggressive inputs, but poor for inputs required in landing.

- **Special Inputs:** Must dramatically tone down inputs near the ground.

- **PIO Tendency:** Tendency to PIO at all times but is unavoidable near the ground.

AIRSPEED CONTROL:

Attention to pitch deteriorates speed control.

PERFORMANCE:

- **Approach Tasks:**
 ILS: Not good, hesitant to chase it.

Visual (Sidestep): Approaches were okay until latter part of final approach.

- **Landing tasks:** Definite problems; touchdown points are not predictable. Tried to just hold an attitude but it's very difficult to do. Any small correction starts a PIO.

- **Differences:** Very difficult, can't tone down inputs near ground and therefore a PIO results.

WIND AND TURBULENCE:

Not a factor.

SUMMARY COMMENTS:

PIO starts around 15 feet. Inability to get a pitch attitude predictably and quickly close to the ground was a major problem. Occasional divergent PIO.

Contrails

2-11	CONFIGURATION $\omega_{SP} = 2.3$ $\zeta_{SP} = 0.57$ -- / -- / 16(4th)	FLIGHT/PILOT 1906/B
PILOT RATING: OVERALL 8	APPROACH 4 PIO 3	SP 8
WIND/X-WIND: 05/01	TURBULENCE: None	$M_{\delta ES} = 0.34$

FEEL:

- Forces: Slightly heavy in steady state.
- Displacement: Felt a little spongy during oscillations.
- Sensitivity: Picked good compromise.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Poor in landing task where a damped PIO occurred.
- Special Inputs: Had to try and stay on top of aircraft.
- PIO Tendency: PIO in flare; occurred when attention was first focused on ground (approximately 10 feet).

AIRSPEED CONTROL: Good.

PERFORMANCE:

- Approach Tasks:
 ILS: Very good.
- Visual (Sidestep): Good; small bobble with gear and flap changes.
- Landing tasks: Was a problem; on one landing had to abandon touchdown point because of PIO.
- Differences: Significant; landing task the most difficult because of PIO.

WIND AND TURBULENCE: Noticeable at times but not a factor.

SUMMARY COMMENTS: Major problem was the PIO in landing in which controllability was in question

Contrails

3-C	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ 0.2/ 0.1 /--	FLIGHT/PILOT 1889/A
PILOT RATING: OVERALL 2	APPROACH -- PIO 1	SP 4
WIND/X-WIND: 05/03	TURBULENCE: Light to moderate	$M_{DES} = 0.31$

FEEL:

- Forces: Fairly heavy at first, changed to lighter; **not a factor.**
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Satisfactory.
- Predictability: Could get what was desired in final response.
- Special Inputs: No special inputs.
- PIO Tendency: No tendency toward PIO.

AIRSPEED CONTROL: OK.

PERFORMANCE:

- Approach Tasks:
 ILS: OK.

Visual (Sidestep): OK.

- Landing tasks: No problem.
- Differences: No significant difference.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Satisfactory aircraft.
 (SP: could see bobble on approach and lift-off)

Contrails

3-1C	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ 0.2 / 0.1 / --	FLIGHT/PILOT 1898/B
PILOT RATING: OVERALL 5(4TD) APPROACH 5 PIO 1½		SP 4
WIND/X-WIND: 13/15 TURBULENCE: Moderate.		$M_{\delta ES} = 0.17$

FEEL:

- Forces: Initially light, heavy in steady state.
- Displacement: Loose.
- Sensitivity: Close to best compromise.

PITCH ATTITUDE RESPONSE:

- Initial: Not quick but gets there.
- Predictability: Response prompt and oscillatory; disturbed by turbulence; modestly predictable.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Lots of speed stability; control not good, fair.

PERFORMANCE:

- Approach Tasks:
 ILS: Erratic and at best fair.

Visual (Sidestep): Little tendency to lose airspeed on sidesteps; bobbled in turbulence.

- Landing tasks: Surprisingly good; good accuracy of touchdown.
- Differences: Landing was easier than the approach.

WIND AND TURBULENCE: Noticeable, disturbed pitch attitude and flight path. Needed increased sensitivity for rudder in the face of the strong cross wind.

SUMMARY COMMENTS: Sensitive for small inputs, heavy in the steady state. Major problems was a looseness in pitch and turbulence response.

Contrails

3-0	CONFIGURATION $\omega_{SP} = 2.1$ $\zeta_{SP} = 0.14$ -- / -- / --	FLIGHT/PILOT 1884/A
PILOT RATING: OVERALL	4	APPROACH -- PIO 1
WIND/X-WIND: 00/00	TURBULENCE: None	SP 5 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Comfortable.
- Displacement: No comments.
- Sensitivity: Pitch sensitivity seemed okay initially; but sensitive for aggressive inputs.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response okay.
- Predictability: Final response not perfect but fairly good, one or two overshoots.
- Special Inputs: No conscious control technique on approach but must tone down inputs in flare.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Reasonably good.

PERFORMANCE:

- Approach Tasks:
 - ILS: Reasonably good.

Visual (Sidestep): No comments.

- Landing tasks: Did not have significant problems; had to tone down inputs a bit. Smooth inputs; tended to bobble with aggressive inputs.
- Differences: More attention required in flare. Flare the most difficult task.

WIND AND TURBULENCE: Noticeable.

SUMMARY COMMENTS: Not a bad airplane. More effort to get desired pitch attitude than satisfactory. On the fence with rating; 3 initially.

Contrails

3-0	CONFIGURATION $\omega_{SP} = 2.1$ $\xi_{SP} = 0.14$ -- / -- / --	FLIGHT/PILOT 1887/A
PILOT RATING: OVERALL 5 WIND/X-WIND: 08/13	APPROACH -- PIO 2 TURBULENCE: Light	SP 5 $M_{DES} = 0.17$

FEEL:

- Forces: Little light at first; changed to heavier for flare, comfortable.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initially quick.
- Predictability: Final response predictable since bobbles were relatively quick; annoying, not bothersome.
- Special Inputs: Had to tone down inputs.
- PIO Tendency: No PIO, just an airplane bounce.

AIRSPEED CONTROL: Not affected, good enough.

PERFORMANCE:

- Approach Tasks:
 ILS: Reasonable.

Visual (Sidestep): Okay.

- Landing tasks: Bobbling only bothersome close to the ground, had to smooth inputs (higher forces helped to do that.)
- Differences: As explained above, touchdown the hardest part of overall task.

WIND AND TURBULENCE: Turbulence noticeable.

SUMMARY COMMENTS:

Bobbling attitude response a problem on landing, annoying otherwise. Observation: pilot was able to smooth out bobbles for landing; tended to ride out the oscillations on the approach.

Contrails

3-1	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / -- / --	FLIGHT/PILOT 1883/A
PILOT RATING: OVERALL 4 WIND/X-WIND: 01/04	APPROACH -- PIO 2 TURBULENCE: None	SP 4½ $M_{\delta ES} = 0.26$

FEEL:

- Forces: Okay.
- Displacement: Okay.
- Sensitivity: Fairly high, get more response than expected.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response fast.
- Predictability: Could never get final response in one try; predictability poor.
- Special Inputs: No comments.
- PIO Tendency: Tendency to oscillate on its own.

AIRSPEED CONTROL:

Went fairly well, except for turbulence effects.

PERFORMANCE:

- Approach Tasks:
 - ILS: Went well, any pitch difficulties did not affect performance.
 - Visual (Sidestep): No comments.
- Landing tasks: Tendency to set attitude and wait to avoid making inputs. Tended to bobble if changes required near the ground. Could settle down before touchdown.
- Differences: No significant difference. Flare was the most difficult.

WIND AND TURBULENCE:

Some turbulence noticed in airspeed; not a big factor.

SUMMARY COMMENTS:

For quick responses, tended to bobble.

Contrails

3-1	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / -- / --	FLIGHT/PILOT 1892/B
PILOT RATING: OVERALL 7(5TD) APPROACH -- PIO 3 SP 6		
WIND/X-WIND: -05/00 TURBULENCE: Light $M_{\delta ES} = 0.24$		

FEEL:

- Forces: Very light for initial inputs.
- Displacement: Okay.
- Sensitivity: On high side.

PITCH ATTITUDE RESPONSE:

- Initial: Okay.
- Predictability: Poor.
- Special Inputs: Special technique was to put inputs in carefully.
- PIO Tendency: More tendency to PIO on approach than near touchdown.

AIRSPEED CONTROL: Generally degraded by attention required in pitch response.

PERFORMANCE:

- Approach Tasks:
 ILS: Was uncomfortable, didn't have it under control.

Visual (Sidestep): Visual approaches were better but still not tightly connected to aircraft.

- Landing tasks: Problems, tendency to overshoot attitude but it was easier to predict near the ground. Had to be more careful to use smooth inputs on approach.
- Differences: Reversed normal situation, approach more difficult either visual or ILS.

WIND AND TURBULENCE: Not a factor, would be more difficult in turbulence.

SUMMARY COMMENTS: Major problem was oscillatory pitch response. Increased predictability of flight path and pitch attitude near the ground was an interesting feature.

Contrails

3-1	CONFIGURATION $\omega_{SP} = 2.2$ $\xi_{SP} = 0.25$ -- / -- / --	FLIGHT/PILOT 1893/A
PILOT RATING: OVERALL 5(4TD) APPROACH 5 PIO 2 SP 5 WIND/X-WIND: 01/04 TURBULENCE: None $M_{\delta ES} = 0.14$		

FEEL:

- Forces: Were comfortable on approaches but high in flare.
- Displacement: No comments.
- Sensitivity: Some trim problems, tended to drift (a system problem.)

PITCH ATTITUDE RESPONSE:

- Initial: Bobbled in turbulence and to pilot inputs, required a fair amount of attention.
- Predictability: Bobbled in steady-state, required a lot of corrective inputs.
- Special Inputs: No comments.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Long term attitude problem degraded airspeed control.

PERFORMANCE:

- Approach Tasks:
 ILS: Average.

Visual (Sidestep): Went well, with moderate workload.

- Landing tasks: Trim changes were a problem, heavy forces. No overcontrol or PIO. Seemed to have to hold inputs in for a long time.
- Differences: Worked harder on ILS; heavy forces in flare. ILS was most difficult.

WIND AND TURBULENCE: Aircraft responded to turbulence and was noticeable.

SUMMARY COMMENTS: Problems were a drift and bobble on ILS and heavy forces in flare.

Contrails

3-2	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / 0.1 / --	FLIGHT/PILOT 1885/A
PILOT RATING: OVERALL 7 WIND/X-WIND: 00/04	APPROACH -- PIO 3 TURBULENCE: None	SP 7 $M_{\delta ES} = 0.26$

FEEL:

- Forces: High initially, but steady-state comfortable.
- Displacement: No comments.
- Sensitivity: Selected sensitivity intentionally on the heavy side to reduce overcontrol tendency.

PITCH ATTITUDE RESPONSE:

- Initial: Initially lagged.
- Predictability: Moderately predictable for non-aggressive inputs but in flare there was a tendency to overcontrol and PIO.
- Special Inputs: No comments.
- PIO Tendency: In flare a tendency to PIO.

AIRSPEED CONTROL:

In the process of trying to smooth out inputs airspeed control was difficult.

PERFORMANCE:

- Approach Tasks:
 ILS: Went fairly well.

Visual (Sidestep): Tendency to overshoot on side step maneuvers.

- Landing tasks: Flare and touchdown performance deteriorated. Had to try to tone down inputs.
- Differences: Significant difference, ask for changes more precisely and quicker in flare; PIO results - most critical task.

WIND AND TURBULENCE:

Not a factor.

SUMMARY COMMENTS:

Could not acquire a desired attitude quickly and precisely. Poor predictability. No good features.

Contrails

3-2	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / 0.1 / --	FLIGHT/PILOT 1887/A
PILOT RATING: OVERALL --	APPROACH 6 PIO 3	SP 5
WIND/X-WIND: 11/10	TURBULENCE: Moderate	$M_{\delta ES} = 0.26$

FEEL:

- Forces: Forces fairly light, greater tendency to overcontrol with heavier forces.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response: some lag but not significant.
- Predictability: Final response predictability was poor.
- Special Inputs: No comments.
- PIO Tendency: No comments.

AIRSPEED CONTROL: Reasonably good.

PERFORMANCE:

- Approach Tasks:
 - ILS: Could correct large errors, some tendency to PIO on breakout.
 - Visual (Sidestep): PIO on side step maneuver. Tendency to PIO on go-around.
- Landing tasks: Not done.
- Differences: Not applicable, but worst in later stage of approach.

WIND AND TURBULENCE: Crosswind requires extra attention.

SUMMARY COMMENTS: Difficult to acquire an attitude quickly and predictably. Tendency to PIO.

Contrails

3-3	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / 0.25 / --	FLIGHT/PILOT 1890/A
PILOT RATING: OVERALL 10 WIND/X-WIND: 03/04	APPROACH -- PIO 4 TURBULENCE: Light	SP 9 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Heavy but intentionally selected because of PIO problem.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial lag apparant.

- Predictability: Not predictable.

- Special Inputs: High workload, even on the ILS.

- PIO Tendency: Tendency to PIO.

AIRSPEED CONTROL: Not good because of attention required in pitch.

PERFORMANCE:

- Approach Tasks:
 ILS: Not really bad but very hard work.

Visual (Sidestep): Sidestep was a distraction.

- Landing tasks: Problems really magnified in this area. Attempt to be less aggressive, very hard to do.

- Differences: Significant differences; the landing was clearly the worst.

WIND AND TURBULENCE: Aircraft responded to turbulence which compounded problem.

SUMMARY COMMENTS: Inability to control attitude quickly and precisely out getting into a strong PIO.

Contrails

3-3	CONFIGURATION $\omega_{SP} = 2.2$ $\xi_{SP} = 0.25$ -- / 0.25 / --	FLIGHT/PILOT 1897/A
PILOT RATING: OVERALL --	APPROACH 7 PIO 3½	SP 7
WIND/X-WIND: 11/10	TURBULENCE: Moderate	$M_{\delta_{ES}} = 0.26$

FEEL:

- Forces: Comfortable, perhaps a bit light.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Not matched with response after input.

- Predictability: Poor; aircraft bounces in turbulence plus a tendency to PIO.

- Special Inputs: Had to spend a lot of time on attitude.

- PIO Tendency: Yes, had to work hard.

AIRSPEED CONTROL: Not bad but worked hard.

PERFORMANCE:

- Approach Tasks:
 ILS: Reasonable but hard work.

Visual (Sidestep): In a constant oscillation which was largely pilot induced.

- Landing tasks: Not done.

- Differences: Definite difference between instrument and visual approaches. More PIO tendency on visual.

WIND AND TURBULENCE: Aircraft responded which compounded difficulties.

SUMMARY COMMENTS: Tendency to bobble and to PIO were major problems.

Contrails

3-6	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / -- / 16	FLIGHT/PILOT 1900/A
PILOT RATING: OVERALL 7 WIND/X-WIND: 15/09	APPROACH 5 PIO 3 TURBULENCE: Moderate	SP 6 $M_{\delta ES} = 0.26$

FEEL:

- Forces: Appropriate for the situation.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Didn't notice a lag but there was a mismatch between initial and final response.

- Predictability: Had a low frequency oscillatory response to turbulence or pilot inputs; was able to contain oscillatory tendency until near the ground.

- Special Inputs: Had to try to suppress the oscillations with complex inputs near the ground.

- PIO Tendency: Near the ground there was a tendency to PIO; controllable.

AIRSPEED CONTROL:

Difficult to get a final attitude and therefore airspeed control deteriorated.

PERFORMANCE:

- Approach Tasks:
 ILS: Not as good as desired; had to work hard.

Visual (Sidestep): Fairly good until the flare.

- Landing tasks: Clearly where the difficulties occurred; a combination of pilot closed-loop problems and an oscillatory airplane.

- Differences: Landing was more difficult because one couldn't let the airplane go near the ground.

WIND AND TURBULENCE:

Annoying turbulence response; crosswind increased workload.

SUMMARY COMMENTS:

Oscillatory airplane response and tendency to couple with it near the ground were major problems.

Contrails

3-6	CONFIGURATION $\omega_{SP} = 2.2$ $\xi_{SP} = 0.25$ -- / -- / 16	FLIGHT/PILOT 1902/B
PILOT RATING: OVERALL 6	APPROACH 5 PIO 3	SP 6
WIND/X-WIND: -08/00	TURBULENCE: None	$M_{\delta_{ES}} = 0.21$

FEEL:

- Forces: Comfortable.

- Displacement: OK, but had significant displacement at times.

- Sensitivity: Good compromise.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed and slow.

- Predictability: Oscillatory but could control it in smooth air.

- Special Inputs: Had to provide the damping which can be done in smooth air.

- PIO Tendency: Definitely there, but could damp out oscillations in smooth air.

AIRSPEED CONTROL:

Fairly good.

PERFORMANCE:

- Approach Tasks:
 ILS: Suprisingly good, wants to oscillate.

Visual (Sidestep): Went pretty well but intermittently bursting into a series of pitch oscillations.

- Landing tasks: Had a closed-loop oscillation which could be damped with extra pilot effort.

- Differences: Approach and landing problems were about equal.

WIND AND TURBULENCE:

Smooth day, tail wind.

SUMMARY COMMENTS:

Initial comment: was worse in the approach than in landing; would be worse in turbulence. Major problem was the tendency to oscillate but could damp it today in smooth air. (Would be a 7 in turbulence.)

Contrails

3-7	CONFIGURATION $\omega_{SP} = 2.2$ $\zeta_{SP} = 0.25$ -- / -- / 12	FLIGHT/PILOT 1904/A
PILOT RATING: OVERALL 8 WIND/X-WIND: -06/03	APPROACH 5 PIO 4 TURBULENCE: None	SP 6 $M_{\delta_{ES}} = 0.34$

FEEL:

- Forces: Felt spongy, didn't like the whole thing.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Lag evident.
- Predictability: Poor for all parts of task.
- Special Inputs: Try to anticipate but not really possible to do it.
- PIO Tendency: Yes.

AIRSPEED CONTROL: Not good because of attention required in pitch.

PERFORMANCE:

- Approach Tasks:
 ILS: Went okay but had to work hard.

Visual (Sidestep): Oscillating in side step.

- Landing tasks: Oscillations became more intense near the ground.
- Differences: Clearly more difficult near the ground.

WIND AND TURBULENCE: Some effect of turbulence, but not a factor.

SUMMARY COMMENTS: Poor predictability lead to overcontrolling and a strong PIO near the ground.

Contrails

4-C	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ 0.2/ 0.1 / --	FLIGHT/PILOT 1899/A
PILOT RATING: OVERALL 3 WIND/X-WIND: 16/09	APPROACH 1½ PIO 1½ TURBULENCE: Moderate	SP 4 $M_{\delta_{ES}} = 0.47$

FEEL:

- Forces: Changed to heavier forces for last two approaches, not ideal.
- Displacement: No comments.
- Sensitivity: A compromise.

PITCH ATTITUDE RESPONSE:

- Initial: Fast, abrupt.
- Predictability: Jumpy response in flare and touchdown, good predictability in general; some deterioration in flare.
- Special Inputs: Must tone down inputs to counteract abrupt initial response.
- PIO Tendency: None, bobble disappeared with heavier forces.

AIRSPEED CONTROL: Good.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Very good.

- Landing tasks: Only problem was in final part of task because of abrupt response.
- Differences: Some, not really significant; landing most difficult.

WIND AND TURBULENCE: Aircraft jerky in turbulence; crosswind evident.

SUMMARY COMMENTS: Abrupt pitch response was a minor problem in landing.

Contrails

4- C	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ 0.2/ 0.1 / --	FLIGHT/PILOT 1906/B
PILOT RATING: OVERALL 3 WIND/X-WIND: -05/00	APPROACH 2 PIO 2 TURBULENCE: None	SP 2 $M_{\delta_{ES}} = 0.38$

FEEL:

- Forces: Perhaps a little heavy in steady state; light initially.
- Displacement: Small.
- Sensitivity: Best compromise but too abrupt initially.

PITCH ATTITUDE RESPONSE:

- Initial: Abrupt then slowed down.
- Predictability: Felt peculiar at first - abrupt then slowed down; predictability not a problem.
- Special Inputs: Little smoothing necessary.
- PIO Tendency: Not a PIO that affected the task; had a little bobble in flare.

AIRSPEED CONTROL: Good.

PERFORMANCE:

- Approach Tasks:
 ILS: Comfortable, good (Note; no glideslope).

Visual (Sidestep): Large aggressive side step because of good characteristics.

- Landing tasks: Little uncomfortable because of initial response
- Differences: Some, because of bobbling in landing task.

WIND AND TURBULENCE: Very smooth, slight tailwind.

SUMMARY COMMENTS: Only problem was high frequency pitch bobble; no major problems. Note: is the easiest aircraft yet seen in the tracking task (PR = 1).

Contrails

4-0	CONFIGURATION $\omega_{SP} = 2.1$ $\zeta_{SP} = 1.23$ --/ -- /--	FLIGHT/PILOT 1885/A
PILOT RATING: OVERALL 6 WIND/X-WIND: 00/04	APPROACH -- PIO 3 TURBULENCE: None	SP 4 $M_{\delta ES} = 0.85$

FEEL:

- Forces: Okay for overall task.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Tended to bobble with aggressive inputs. Must fly smoothly but close to ground unable to avoid bobbles.
- Predictability: Poor in flare but reasonable on ILS.
- Special Inputs: No comments.
- PIO Tendency: No comments.

AIRSPEED CONTROL: Had to pay attention but performance reasonable.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.
- Visual (Sidestep): Visual approaches okay. Sidestep maneuvers moderate workload.
- Landing tasks: Problem area. Hunting for ground but worked hard. Had to check aggressiveness.
- Differences: Flare and touchdown most critical.

WIND AND TURBULENCE: No comments.

SUMMARY COMMENTS: Very objectionable aircraft. NOTE: evaluation repeated on flight 1889 and some observations and deficiencies were noted - an unsatisfactory aircraft.

Contrails

4-1	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ -- / -- / --	FLIGHT/PILOT 1889/A
PILOT RATING: OVERALL 2 APPROACH -- PIO 1 SP 3 WIND/X-WIND: 05/04 TURBULENCE: Light to moderate $M_{\delta_{ES}} = 0.51$		

FEEL:

- Forces: Acceptable.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Good response, steady.
- Predictability: No comments.
- Special Inputs: No special inputs.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Adequate.

PERFORMANCE:

- Approach Tasks:
 - ILS: Good.
 - Visual (Sidestep): Good.
- Landing tasks: No problems.
- Differences: No differences.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Good aircraft, liked it.

Contrails

4-3	CONFIGURATION $\omega_{SP} = 2.0$ $\xi_{SP} = 1.06$ --/ 0.25 /--	FLIGHT/PILOT 1891/A
PILOT RATING: OVERALL 5 WIND/X-WIND: 07/00	APPROACH -- PIO 2 TURBULENCE: Light	SP 5 $M_{\delta_{ES}} = 0.60$

FEEL:

- Forces: Forces high initially but comfortable in steady state; best compromise.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Lagged a little initially.
- Predictability: Predictability affected by lag.
- Special Inputs: Important to keep errors small; overshoot on sidestep maneuver.
- PIO Tendency: Slight tendency to PIO in flare and go around; not solid.

AIRSPPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Was Okay.

Visual (Sidestep): No problem until close to ground.

- Landing tasks: Overcontrol problems seemed to occur very close to the ground.
- Differences: Touchdown was most difficult task (and take-off).

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Moderately hard to achieve desired performance.

Contrails

4-3	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ -- / 0.25 / --	FLIGHT/PILOT 1895/B
PILOT RATING: OVERALL 8	APPROACH 5 PIO 3	SP 3
WIND/X-WIND: -08/00	TURBULENCE: Light	$M_{\delta ES} = 0.51$

FEEL:

- Forces: Seemed appropriate.

- Displacement: On the large side.

- Sensitivity: Adequate statically but because of delay in response not adequate dynamically (spongy).

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.

- Predictability: Poor in tight tracking situations.

- Special Inputs: Tended to overdrive it and try to stop it.

- PIO Tendency: Yes, definite tendency towards PIO which lead to poor precision of control.

AIRSPEED CONTROL:

Bothersome, concentrated too much on pitch.

PERFORMANCE:

- Approach Tasks:
 ILS: Poor quality, behind the aircraft.

Visual (Sidestep): Better but airspeed control still a problem.

- Landing tasks: Had the problem that flight path couldn't be controlled properly; tried to back out of loop but one couldn't do it in turbulence or crosswind.
- Differences: Significant, better in approach.

WIND AND TURBULENCE:

Nil.

SUMMARY COMMENTS:

Would like to evaluate in turbulence and crosswinds. Major problems was pitch response, delayed, tended to oscillate.

Contrails

4-3	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ -- / 0.25 / --	FLIGHT/PILOT 1899/A
PILOT RATING: OVERALL 7 APPROACH 2 PIO 3 SP 7 WIND/X-WIND: 15/09 TURBULENCE: Moderate $M_{\delta_{ES}} = 0.60$		

FEEL:

- Forces: Comfortable in all the nonaggressive tasks; little heavy in flare.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Seemed okay.
- Predictability: All right until near the ground, then a problem.
- Special Inputs: Only in flare.
- PIO Tendency: Only near the ground and occurs with any corrections; not divergent, low amplitude.

AIRSPPEED CONTROL:

Not a problem, some turbulence response.

PERFORMANCE:

- Approach Tasks:
 ILS: Pretty good.

Visual (Sidestep): Good until near the ground.

- Landing tasks: With everything set, could get down okay, but with any corrections a PIO results.
- Differences: With crosswinds one is unable to get out of the loop and avoid PIO. Clearly close to the ground is the most difficult task.

WIND AND TURBULENCE:

Turbulence was noticeable, crosswind was a significant workload.

SUMMARY COMMENTS:

Tendency to PIO near the ground is a major problem.

Contrails

4-4	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ --/ 0.5 /--	FLIGHT/PILOT 1894/A
PILOT RATING: OVERALL 7 WIND/X-WIND: 00/05	APPROACH 4 PIO 3 TURBULENCE: Light	SP 7½ $M_{\delta ES} = 0.60$

FEEL:

- Forces: High but didn't want them lighter.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Initial lag then moved somewhat slowly.
- Predictability: Mismatch between initial and final response lead to overcontrolling.
- Special Inputs: Had to tone down inputs. Fly less aggressively for landing.
- PIO Tendency: Tendency to overcontrol on ILS but on landing and go-around there was a tendency to PIO.

AIRSPEED CONTROL:

Not too much of a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Once on I did pretty well.

Visual (Sidestep): Went well until the final part of flare and on go-around.

- Landing tasks: Trouble in setting a predictable attitude near the ground.
- Differences: A significant difference; flare and landing the problem. Can't reduce aggressiveness.

WIND AND TURBULENCE:

Noticed, did complicate ILS task somewhat.

SUMMARY COMMENTS:

Major factor was inability to get a quick, precise attitude for landing task, PIO resulted.

Contrails

4-4	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ --/ 0.5 / --	FLIGHT/PILOT 1902/B
PILOT RATING: OVERALL 6 WIND/X-WIND: -08/00	APPROACH 3 PIO 3 TURBULENCE: None	SP 5 $M_{\delta ES} = 0.34$

FEEL:

- Forces: Reasonable in steady state; transient forces heavy.
- Displacement: Large, heavy in transient inputs.
- Sensitivity: A good choice.

PITCH ATTITUDE RESPONSE:

- Initial: Very, very delayed.
- Predictability: Didn't seem to have as much problem as anticipated; did PIO but predictability was good enough that it was clearly bounded.
- Special Inputs: Had to overdrive it and remove input.
- PIO Tendency: Could anticipate final response even though some tendency to PIO was evident. Closed-loop oscillation was controllable. Couldn't hurry response much.

AIRSPEED CONTROL:

Fairly good.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): No problems.

- Landing tasks: Easy to overshoot, especially on takeoff. Was a problem very inert and couldn't achieve touchdown points as desired.
- Differences: Landing was the most difficult.

WIND AND TURBULENCE:

None, smooth day, tailwind; turbulence wouldn't be a problem anyway.

SUMMARY COMMENTS:

Almost inert at slow speeds. Bothersome in landing - like flying a large transport. Couldn't precisely control pitch attitude near the ground.

Contrails

4-4	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ -- / 0.5 / --	FLIGHT/PILOT 1894/A
PILOT RATING: OVERALL -- APPROACH 5 PIO 2 SP 3 WIND/X-WIND: 00/05 TURBULENCE: Light $M_{DES} = 0.51$		

FEEL:

- Forces: Fairly high but wouldn't want lighter.
- Displacement: No comments.
- Sensitivity: No comments

PITCH ATTITUDE RESPONSE:

- Initial: Lagged.
- Predictability: Wasn't very good but not too bad either.
- Special Inputs: Necessary to try to anticipate, reduce aggressiveness.
- PIO Tendency: Tendency to overcontrol.

AIRSPEED CONTROL:

More attention required because of lags in pitch but never bad.

PERFORMANCE:

- Approach Tasks:
 ILS: Able to do it.

Visual (Sidestep): Approaches went fairly well.

- Landing tasks: Not performed.
- Differences: Not applicable.

WIND AND TURBULENCE:

Not a factor.

SUMMARY COMMENTS:

No comments.

Contrails

4-6	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ -7 -- / 16	FLIGHT/PILOT 1900/A
PILOT RATING: OVERALL 4 APPROACH 1½ PIO 2 SP 3 WIND/X-WIND: 15/09 TURBULENCE: Moderate $M_{\delta_{ES}} = 0.51$		

FEEL:

- Forces: Comfortable.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: No comments.
- Predictability: Seemed reasonable enough but flare and touchdown was puzzling; higher workload and reduced predictability.
- Special Inputs: Hunting for touchdown point because of problems in the pitch response.
- PIO Tendency: No tendency to PIO just not precise near the ground.

AIRSPEED CONTROL: No problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Good until near touchdown.

- Landing tasks: Surprising problems near touchdown; had to work harder.
- Differences: Clearly landing was the most difficult.

WIND AND TURBULENCE: Changing crosswind on approach required special attention.

SUMMARY COMMENTS: No major problems but hunting in the flare and waveoff was bothersome.

Contrails

4-7	CONFIGURATION $\omega_{SP} = 2.0$ $\xi_{SP} = 1.06$ --/ -- / 12	FLIGHT/PILOT 1903/A
PILOT RATING: OVERALL 3	APPROACH 3	PIO 1
WIND/X-WIND: -01/05	TURBULENCE: None	SP 3 $M_{DES} = 0.34$

FEEL:

- Forces: Comfortable.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: No delay; initial impression was that it was going to be trouble but didn't materialize.
- Predictability: Felt worse on the ILS than on visual approaches.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Okay.

- Landing tasks: Did have a minor hunting tendency in the landing, not a big problem.
- Differences: No real differences.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Some worry about a final pitch attitude on ILS but a minor problem. Some hunting in pitch attitude; again a minor problem.

Contrails

4-10	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ -- / -- / 4	FLIGHT/PILOT 1893/A
PILOT RATING: OVERALL 9	APPROACH 6 PIO 4	SP 9
WIND/X-WIND: -01/04	TURBULENCE: None	$M_{\delta ES} = 0.26$

FEEL:

- Forces: Quite high maneuvering, comfortable on ILS.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Felt like it was glued in concrete.

- Predictability: Reasonable on approach but not near the ground.

- Special Inputs: No comments.

- PIO Tendency: Could control level of PIO until very close to the ground.

AIRSPEED CONTROL: Reasonable.

PERFORMANCE:

- Approach Tasks:
 - ILS: Couldn't chase it otherwise overcontrolling resulted, had to work hard.

Visual (Sidestep): Could do sidestep and visual approach reasonably well.

- Landing tasks: Got into PIO near the ground, not divergent but large amplitude. Attempt to limit aggressiveness but cannot do that near the ground.
- Differences: Had to work hard at all times but very difficult to control near the ground.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Tendency to overcontrol on ILS but at 10 feet a full PIO developed which was the major problem.

Contrails

4-11	CONFIGURATION $\omega_{SP} = 2.0$ $\zeta_{SP} = 1.06$ --/ -- / 16(4th)	FLIGHT/PILOT 1905/A
PILOT RATING: OVERALL 8 WIND/X-WIND: 01/07	APPROACH 3 TURBULENCE: Light	PIO 4 SP 7 $M_{\delta ES} = 0.51$

FEEL:

- Forces: Okay in ILS but very spongy in landing PIO.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Clearly some lag, spongy.
- Predictability: Some mild predictability problems on ILS; real problem close to the ground.
- Special Inputs: Try your best to tone down input.
- PIO Tendency: Strong tendency near the ground where aggressiveness cannot be avoided.

AIRSPEED CONTROL: Some difficulty because of poor control of attitude.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay, but working at it.

Visual (Sidestep): Okay until near the ground.

- Landing tasks: Strong PIO near the ground was a problem.
- Differences: Flare and touchdown the most difficult task.

WIND AND TURBULENCE: No problem.

SUMMARY COMMENTS: A big problem in the touchdown phase.

Contrails

5-1	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / -- / --	FLIGHT/PILOT 1890/A
PILOT RATING: OVERALL 7 APPROACH -- PIO 3 SP 4½ WIND/X-WIND: 03/04 TURBULENCE: Light $M_{\delta ES} = 0.94$		

FEEL:

- Forces: Comfortable on ILS but appeared overly sensitive; changed to suit needs of flare.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Tendency to bobble.
- Predictability: Not predictable enough, hard to define. Must tone down inputs with jumpy airplane.
- Special Inputs: No comments.
- PIO Tendency: Tendency to PIO in flare, low frequency hard to understand.

AIRSPEED CONTROL: Fairly reasonable.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Approaches okay.

- Landing tasks: Clearly different - demanded aggressiveness which resulted in PIO.
- Differences: Landing the worst.

WIND AND TURBULENCE: Turbulence noticeable, a factor.

SUMMARY COMMENTS: Overly sensitive airplane, got into a low frequency PIO on landing. Hard to evaluate.

Contrails

5-1	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / -- / --	FLIGHT/PILOT 1901/B
PILOT RATING: OVERALL	5	APPROACH 4 PIO 3 SP 4
WIND/X-WIND: 05/06	TURBULENCE: Light	$M_{\delta ES} = 0.60$

FEEL:

- Forces: Little heavy.
- Displacement: Perhaps a little large.
- Sensitivity: Good, on the heavy side in turns, sensitive on landing.

PITCH ATTITUDE RESPONSE:

- Initial: Quick, abrupt and objectionable.
- Predictability: Pretty good on approach but on landing predictability deteriorated. Tended to oscillate in flare.
- Special Inputs: Had to smooth inputs near the ground.
- PIO Tendency: Of the order of 4 half-cycle oscillations near the ground when a change in attitude required.

AIRSPEED CONTROL:

Good feel for airspeed changes, stiff in terms of airspeed, not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Pretty good but not as good as desired.

Visual (Sidestep): Comfortable; some evidence of very small amplitude pitch oscillations.

- Landing tasks: Tendency to oscillate; oscillations were bounded.
- Differences: Yes, PIO problems only evident in flare and touchdown.

WIND AND TURBULENCE:

Strong pitch response to turbulence was bothersome.

SUMMARY COMMENTS:

Tendency to PIO in flare and touchdown was the major problem. Secondary problems were high initial pitch response and abrupt response to turbulence. Note: could do the tracking task without any PIO tendency.

Contrails

5- 3	CONFIGURATION $\omega_{SP} = 3.9$ $\xi_{SP} = 0.54$ -- / 0.25 / --	FLIGHT/PILOT 1886/A
PILOT RATING: OVERALL 8	APPROACH -- PIO 3	SP 7
WIND/X-WIND: 07/06	TURBULENCE: Light	$M_{DES} = 1.0$

FEEL:

- Forces: Felt okay, good compromise.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Felt okay on ILS, but not so at other times.

- Predictability: Required double input to get desired attitude.
Not required.

- Special Inputs: No special inputs on ILS (hard work), but at other times
was confusing.

- PIO Tendency: Tendency to PIO in flare.

AIRSPEED CONTROL:

Airspeed bounced around, some difficulty.

PERFORMANCE:

- Approach Tasks:
 - ILS: Okay.

Visual (Sidestep): Only a problem on touchdown.

- Landing tasks: A problem, working really hard to remain safe.

- Differences: Significant increase in workload near touchdown.

WIND AND TURBULENCE:

Really felt turbulence.

SUMMARY COMMENTS:

Previously discussed.

Contrails

5-3	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / 0.25 / --	FLIGHT/PILOT 1901/B
PILOT RATING: OVERALL 6	APPROACH 2 PIO 3	SP 7
WIND/X-WIND: -08/08	TURBULENCE: Light	$M_{\delta_{ES}} = 0.73$

FEEL:

- Forces: Comfortable.

- Displacement: Okay.

- Sensitivity: Good.

PITCH ATTITUDE RESPONSE:

- Initial: Smooth, reasonably prompt on approach; in landing and take-off initial response mismatched with final response.

- Predictability: Good on approach; unpredictable in flare and touchdown.

- Special Inputs: None mentioned.

- PIO Tendency: Only near the ground.

AIRSPEED CONTROL:

Stiff but couldn't guess that by the control response to pilot inputs; good.

PERFORMANCE:

- Approach Tasks:
 ILS: Great except for some problem with turbulence response.

Visual (Sidestep): Only problem was in take-off after landing.

- Landing tasks: Tended to land long with tailwind problem; when flown accurately, tended to get a mild PIO on landing and lift-off.

- Differences: Landing the most difficult task; very sensitive to the tightness with which you do the task.

WIND AND TURBULENCE:

Strong pitch response to turbulence.

SUMMARY COMMENTS:

Couldn't see any initial abruptness until turbulence was encountered. Tendency to PIO on landing and lift-off was major problem.

Contrails

5-3	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / 0.25 / --	FLIGHT/PILOT 1904/A
PILOT RATING: OVERALL 4½ WIND/X-WIND: -06/02	APPROACH 3 PIO 2½ TURBULENCE: None	SP 5 $M_{\delta ES} = 1.0$

FEEL:

- Forces: Not noticeable.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: No special problem.

- Predictability: Couldn't really define the problem.

- Special Inputs: No comments.

- PIO Tendency: Did oscillate near the ground, but hard to define.

AIRSPEED CONTROL:

Had some difficulties on the ILS, not great.

PERFORMANCE:

- Approach Tasks:
 ILS: Fair.

- Visual (Sidestep): Okay.

- Landing tasks: Some difficulties, got into a slight oscillation.

- Differences: Most difficult near the ground; not really strong differences.

WIND AND TURBULENCE:

Noticed the turbulence but not a major problem.

SUMMARY COMMENTS:

Confused about the airplane; had to work too hard on landing.

Contrails

5-3	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / 0.25 / --	FLIGHT/PILOT 1890/A
PILOT RATING: OVERALL --	APPROACH 4 PIO 1	SP 4½
WIND/X-WIND: 04/03	TURBULENCE: Light	$M_{\delta_{ES}} = 1.0$

FEEL:

- **Forces:** Comfortable forces.

- **Displacement:** No comments.

- **Sensitivity:** Sensitivity okay.

PITCH ATTITUDE RESPONSE:

- **Initial:** Responded in desired fashion.

- **Predictability:** Predictable enough.

- **Special Inputs:** Very responsive to turbulence, annoying, increased workload.

- **PIO Tendency:** No special inputs or PIO tendency.

AIRSPEED CONTROL: Pretty good.

PERFORMANCE:

- **Approach Tasks:**
 ILS: Went well.

Visual (Sidestep): Appears okay.

- **Landing tasks:** Not done.

- **Differences:** Not applicable.

WIND AND TURBULENCE: Turbulence noticeable and is a factor.

SUMMARY COMMENTS: Annoying aircraft to fly, hard to evaluate. Tendency in pitch to wander off a problem, tended to come back.

Contrails

5-3	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / 0.25 / --	FLIGHT/PILOT 1901/B
PILOT RATING: OVERALL --	APPROACH 3 PIO 1	SP 4
WIND/X-WIND: -05/06	TURBULENCE: None	$M_{\delta_{ES}} = 0.85$

FEEL:

- Forces: Good.
- Displacement: About right.
- Sensitivity: Appropriate.

PITCH ATTITUDE RESPONSE:

- Initial: Quite prompt.
- Predictability: Good.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Easy, tended to fly slow.

PERFORMANCE:

- Approach Tasks:
 ILS: Quite good in smooth air.

Visual (Sidestep): Equally good, easy; could fly more aggressively than normal.

- Landing tasks: Not done.
- Differences: Not applicable.

WIND AND TURBULENCE: Smooth generally but did see a pitch bucking which was undesirable on occasion.

SUMMARY COMMENTS: Suspect that it would be unsatisfactory in moderate turbulence; only problem was turbulence response.

Contrails

5-4	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / 0.5 / --	FLIGHT/PILOT 1903/A
PILOT RATING: OVERALL 6 WIND/X-WIND: -05/02	APPROACH 2 PIO 2½ TURBULENCE: None	SP 5 $M_{\delta ES} = 1.19$

FEEL:

- Forces: Comfortable on ILS; little high on visuals.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Some initial lag.

- Predictability: Some problem which was very apparent in the flare; not a factor on the approach.

- Special Inputs: None on ILS. Had to reduce aggressiveness in landing task.

- PIO Tendency: A mild tendency in landing task.

AIRSPEED CONTROL: No difficulties.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Okay.

- Landing tasks: Not good, had a tendency towards a low frequency PIO. Had to work hard to achieve desired touchdown point.

- Differences: A significant difference; clearly the landing task was the most difficult.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Had difficulties in the landing task with a tendency to PIO.

Contrails

5-5	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / 1.0 / --	FLIGHT/PILOT 1904/A					
PILOT RATING: OVERALL	7	APPROACH	2	PIO	3	SP	4
WIND/X-WIND:	-06/02	TURBULENCE:	None			$M_{\delta ES}$	= 1.45

FEEL:

- Forces: Comfortable.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: A mismatch with final response.

- Predictability: No problem for non-aggressive inputs. Near the ground it was a problem.

- Special Inputs: Try to reduce aggressiveness.

- PIO Tendency: Near the ground it was there in the form of a large over-control tendency.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Good until near the ground.

- Landing tasks: Obviously a problem; tendency to PIO.

- Differences: Flare and touchdown the most difficult.

WIND AND TURBULENCE: Turbulence noticed but not bothersome.

SUMMARY COMMENTS: In aggressive situations, such as near the ground, there is a mismatch between initial and final response which leads to a strong tendency to overcontrol.

Contrails

5-6	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / -- / 16	FLIGHT/PILOT 1901/B
PILOT RATING: OVERALL 6 APPROACH 3 PIO 3 SP 6 WIND/X-WIND: -08/09 TURBULENCE: Light $M_{\delta ES} = 0.77$		

FEEL:

- **Forces:** Light then heavy in steady-state.
- **Displacement:** Okay.
- **Sensitivity:** Selected a compromise.

PITCH ATTITUDE RESPONSE:

- **Initial:** Sensitive, quick; sensed a lag when flying close to the ground.
- **Predictability:** Adequate.
- **Special Inputs:** None.
- **PIO Tendency:** Same tendency to oscillate in flare and touchdown.

AIRSPEED CONTROL:

Good; tended to be fast due to tailwind.

PERFORMANCE:

- **Approach Tasks:**
 ILS: Good.

Visual (Sidestep): Good, except for pitch response to turbulence.

- **Landing tasks:** Problems: bothered by tailwind and tended to oscillate near the ground - just didn't like the configuration.
- **Differences:** Didn't like it for either one in turbulence; landing was more demanding.

WIND AND TURBULENCE:

Turbulence response was objectionable.

SUMMARY COMMENTS:

Pitch oscillation was bounded but uncomfortable and tended to downgrade aircraft accordingly. Abrupt initial response and strong turbulence response were objectionable. Should likely be a 5; confused about rating. In smooth air approach would be a 3.

Contrails

5-7	CONFIGURATION $\omega_{SP} = 3.9$ $\zeta_{SP} = 0.54$ -- / -- / 12	FLIGHT/PILOT 1903/A
PILOT RATING: OVERALL 6	APPROACH 2 PIO 3	SP 7
WIND/X-WIND: -02/05	TURBULENCE: None	$M_{\delta_{ES}} = 0.89$

FEEL:

- Forces: Comfortable.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Something confusing there but not identifiable.

- Predictability: Only a problem with aggressive inputs used in landing task then a high frequency PIO resulted.

- Special Inputs: No comments.

- PIO Tendency: No direct comments.

AIRSPEED CONTROL: Not a problem.

PERFORMANCE:

- Approach Tasks:
 - ILS: Went well

Visual (Sidestep): Went well

- Landing tasks: Was the problem area; got into a relatively high frequency PIO.

- Differences: Significant differences; landing task the most difficult.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Major problem was high frequency oscillation in landing task.

Contrails

5-11	CONFIGURATION $\omega_{SP} = 3.9$ $\xi_{SP} = 0.54$ -/ -- /16(4th)	FLIGHT/PILOT 1905/A
PILOT RATING: OVERALL 7	APPROACH 3 PIO 3½	SP 9
WIND/X-WIND: 01/07	TURBULENCE: Light	$M_{DES} = 1.0$

FEEL:

- Forces: Comfortable, except during speed changes.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed, than a fast response.
- Predictability: Okay for approaches but poor for aggressive parts of task.
- Special Inputs: Try to get mean of PIO under control.
- PIO Tendency: High frequency PIO occurred in flare and touchdown.

AIRSPEED CONTROL:

Bothersome, tend to wander with turbulence.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay.

Visual (Sidestep): Okay.

- Landing tasks: Get into high frequency PIO near the ground; said control-ability was in question then decided that it was not.
- Differences: Yes, clearly more difficult in landing.

WIND AND TURBULENCE:

Noticeable on approach but not a factor in landing task.

SUMMARY COMMENTS:

Responds to turbulence and, in tight situations, there is a tendency towards a high frequency PIO. PIO is major problem.

Contrails

6-1	<p>CONFIGURATION</p> <p>$\omega_{SP} = 1.9$ $\zeta_{SP} = 0.65$</p> <p>(Unmodified YF-17 Control system)</p>	<p>FLIGHT/PILOT</p> <p>1888/A</p>
<p>PILOT RATING: OVERALL 10 APPROACH -- PIO 4 SP 9</p> <p>WIND/X-WIND: 06/05 TURBULENCE: Light $M_{\delta_{ES}} = 0.30$</p>		

FEEL:

- Forces: Heavy initially, comfortable during ILS.

- Displacement: No comments.

- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Lags.

- Predictability: Very poor predictability.

- Special Inputs: Had to use slow smooth inputs on ILS.

- PIO Tendency: Definite PIO.

AIRSPEED CONTROL: A lot of attention required.

PERFORMANCE:

- Approach Tasks:
 - ILS: Went fairly well except near the end lateral directional performance deteriorated.

 - Visual (Sidestep): Visual approaches deteriorated rapidly near the ground.

- Landing tasks: No compensation possible to resist PIO near the ground. Worked intensely to prevent PIO (managed one landing).

- Differences: Significant differences, performance worst close to the ground.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Tendency to lag and then take off - very unpredictable in pitch. Not controllable.

Contrails

6-2	CONFIGURATION $\omega_{SP} = 1.9$ $\zeta_{SP} = 0.65$ (Modified YF-17 Control System)	FLIGHT/PILOT 1888/A
PILOT RATING: OVERALL 2 WIND/X-WIND: 06/05	APPROACH -- PIO 1 TURBULENCE: Light	SP 1 $M_{\delta ES} = 0.34$

FEEL:

- Forces: Comfortable.
- Displacement: No comments.
- Sensitivity: A little high but not a problem.

PITCH ATTITUDE RESPONSE:

- Initial: Good, prompt.
- Predictability: Predictable.
- Special Inputs: No special inputs.
- PIO Tendency: No PIO tendencies.

AIRSPEED CONTROL: Good.

PERFORMANCE:

- Approach Tasks:
 ILS: Okay.

Visual (Sidestep): Visual approaches good.

- Landing tasks: No problems.
- Differences: None.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: Comfortable to fly.

Contrails

7-1	CONFIGURATION $\tau_{\text{double}} \approx 6 \text{ sec}$	FLIGHT/PILOT 1891/A
PILOT RATING: OVERALL 4	APPROACH -- PIO 1	SP 3
WIND/X-WIND: 07/01	TURBULENCE: Light	$M_{\delta_{ES}} = 0.43$

FEEL:

- Forces: Kind of heavy but didn't want any lighter forces.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Funny pitch attitude response: felt spongy, drift in steady state. Couldn't define problem, something mismatched.
- Predictability: Not predictable in the long term.
- Special Inputs: No comments.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Went pretty well.

PERFORMANCE:

- Approach Tasks:
 - ILS: Went well, had to pay attention to attitude because of long term difficulties.

Visual (Sidestep): Went fairly well.

- Landing tasks: Worked harder than desired and didn't understand why. Performance was satisfactory.
- Differences: Not much difference, worked equally hard on both. Flare seemed slightly more difficult but not a big difference.

WIND AND TURBULENCE: No comment.

SUMMARY COMMENTS: Problem was getting a good steady-state response quickly and reliably.

Contrails

7-2	CONFIGURATION $\tau_{\text{double}} \approx 4 \text{ sec}$	FLIGHT/PILOT 1894/A
PILOT RATING: OVERALL 3 WIND/X-WIND: 00/05	APPROACH -- PIO 1 TURBULENCE: Light	SP 3 $M_{\delta_{ES}} = 0.34$

FEEL:

- Forces: Bit high, aircraft felt spongy.
- Displacement: No comments.
- Sensitivity: Would have preferred more sensitivity.

PITCH ATTITUDE RESPONSE:

- Initial: Okay.
- Predictability: Fairly predictable but some sponginess in attitude response.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Pretty good.

PERFORMANCE:

- Approach Tasks:
 ILS: Went well.

Visual (Sidestep): Went well.

- Landing tasks: Maybe the sponginess was more bothersome in flare but no obvious difficulties.
- Differences: Not really much; landing was a little more difficult.

WIND AND TURBULENCE: No comments.

SUMMARY COMMENTS: Spongy feeling was there but didn't really affect performance.

Contrails

7-3	CONFIGURATION $T_{\text{double}} \approx 2 \text{ sec}$	FLIGHT/PILOT 1897/A
PILOT RATING: OVERALL 4 WIND/X-WIND: 08/13	APPROACH 2 PIO 1 TURBULENCE: Moderate	SP 5 $M_{\delta_{ES}} = 0.26$

FEEL:

- Forces: Comfortable except a little high for touchdown.
- Displacement: No comments.
- Sensitivity: No comments.

PITCH ATTITUDE RESPONSE:

- Initial: Seemed okay.
- Predictability: For aggressive inputs wasn't as good as desired.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL:

Turbulence was a factor; couldn't identify an airplane related problem.

PERFORMANCE:

- Approach Tasks:
 ILS: Good.

Visual (Sidestep): Okay.

- Landing tasks: Had to work too hard to make pitch corrections. Not as crisp as desired.
- Differences: Flare and touchdown was more difficult but not a great difference.

WIND AND TURBULENCE:

Moderate crosswind and turbulence increased workload.

SUMMARY COMMENTS:

Airplane was somewhat confusing; couldn't get precise control in landing task.

Contrails

7-3	CONFIGURATION $T_{\text{double}} \approx 2 \text{ sec}$	FLIGHT/PILOT 1898/B
PILOT RATING: OVERALL 6(3TD) APPROACH 6 PIO 1 SP 5 WIND/X-WIND: 10/11 TURBULENCE: Moderate $M_{\delta_{ES}} = 0.21$		

FEEL:

- Forces: Somewhat light at first, selected heavier.
- Displacement: Okay.
- Sensitivity: Ended up with a good level.

PITCH ATTITUDE RESPONSE:

- Initial: Little slow.
- Predictability: On approach: poor, wanted to keep going, not solid.
In landing: with higher gain could control attitude surprisingly well.
- Special Inputs: Could use high gain effectively, almost with a dither type input.
- PIO Tendency: Not seen on approach.

AIRSPPEED CONTROL:

Average on ILS; Okay.

PERFORMANCE:

- Approach Tasks:
 - ILS: Very poor, not an instrument airplane.

Visual (Sidestep): Better.

- Landing tasks: No great problem. Used tight attitude control.
- Differences: Significant difference; worst on ILS approach.

WIND AND TURBULENCE:

Not much turbulence but significant crosswinds.

SUMMARY COMMENTS:

Very confusing to evaluate since landing was much better than approaches. ILS approach was very demanding, high workload.

APPENDIX II

TASK PERFORMANCE RECORDS

The purpose of this appendix is to present task performance records for a representative sample of evaluation configurations. On each evaluation, performance records were taken for the last 60 secs of each landing approach task. The data were recorded on a 28 channel digital tape recorder and a back-up oscillograph recorder; unfortunately, undetected problems within the tape recorder resulted in the loss of the data from 9 of the 24 flights. However, the remaining data provide a reasonably complete coverage for the range of configurations evaluated during the program.

Since a complete presentation and analysis of the performance data gathered during this experiment is beyond the scope of this volume, the data from selected configurations are presented as background for the discussion of the results in Section 4. More detailed performance records and additional analysis of the data are given in Volume II.

The variables selected for presentation of approach, landing, and tracking task time histories are:

- HP - Pressure altitude ~ ft
(runway elevation was 590 ft mean sea level but, of course, pressure altitude at touchdown varied).
- NZP - Normal acceleration at front cockpit (6 ft ahead of c.g.), positive for pull up ~ g's. (In several cases NZ, normal acceleration at the c.g. is presented instead.)
- THET - Pitch attitude, positive nose up ~ deg.
- FES - Cockpit pitch stick force, positive aft ~ lb.
- VIAS - Indicated airspeed ~ knots.
- THR - Throttle position ~ in.
- TRK - Tracking needle, pitch attitude error = commanded pitch attitude minus pitch attitude ~ in.
(1 inch = 5 deg pitch attitude).

The approach and landing performance data presented are for approximately the last 30 seconds prior to touchdown (T.D.). Also presented are 15 second records for the pitch-attitude error tracking task discussed in Subsection 3.5 along with the associated record of pilot stick force input for the tracking task. For example, consider Figure 11 which presents the ILS and tracking task records for Configuration 1-1. The sharp vertical lines on the tracking needle record are the commanded pitch attitude changes; the pilot then attempts to return the needle to the zero position by changing the aircraft's pitch attitude. In this case he can do so with little or no overshoot.

Unfortunately the scales for key parameters, like stick force, are not always the same. Care should therefore be exercised when comparing configuration performance records.

Note that the IIP, VIAS and THIR records were filtered with a 3rd order, 0.5 cycles per second digital filter (zero phase lag) for clarity. The combination of a very poor selection of scale factor and a problem with the static pressure transducer necessitated this step.

The following records are presented in this appendix.

<u>CONFIGURATION</u>	<u>TASK</u>	<u>FIGURE</u>
1-1	ILS and Tracking	11
1-3	ILS and Tracking	12
1-3	Visual and Tracking	13
1-3	ILS (Low Approach)	14
2-1	ILS and Tracking	15
2-4	ILS and Tracking	16
2-4	Visual and Tracking	17
2-4	ILS (Low Approach)	18
2-7	ILS and Tracking	19
2-7	Visual	20
2-9	ILS	21

Contrails

<u>CONFIGURATION</u>	<u>TASK</u>	<u>FIGURE</u>
3-1	ILS and Tracking	22
3-6	Visual	23
3-6	ILS	24
4-3	ILS and Tracking	25
4-10	ILS and Tracking	26
4-10	Visual	27
5-3	ILS and Tracking	28
5-6	Visual	29
6-1	Visual	30
6-1	ILS and Tracking	31
6-2	Visual and Tracking	32
7-3	ILS	33

Note: Pilot ratings shown on titles are for the overall task and the approach alone: OVERALL/APPROACH.

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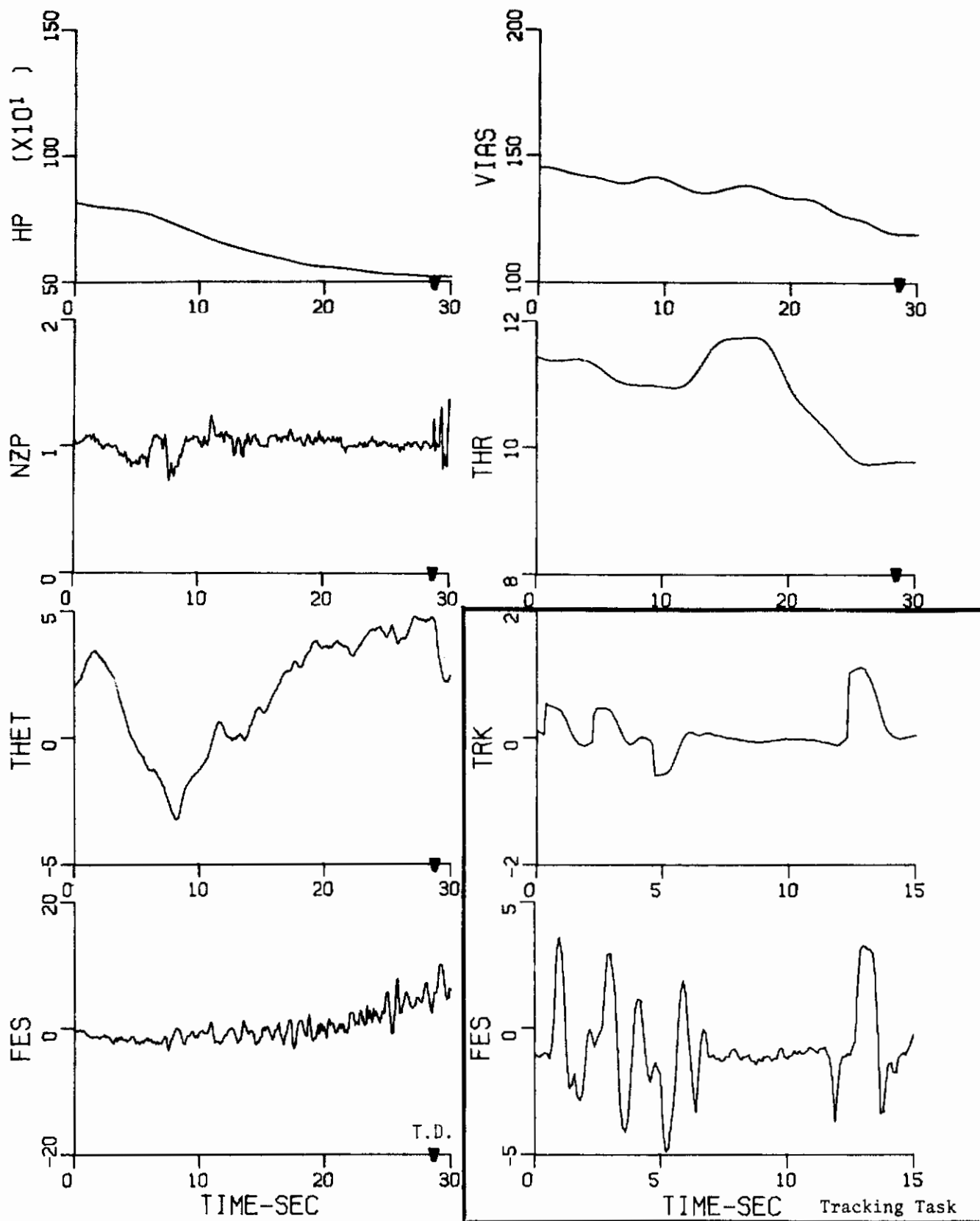


Figure 11: CONFIG. 1-1, PILOT A/1887, ILS AND TRACKING TASKS, PR: 4/--

Contrails

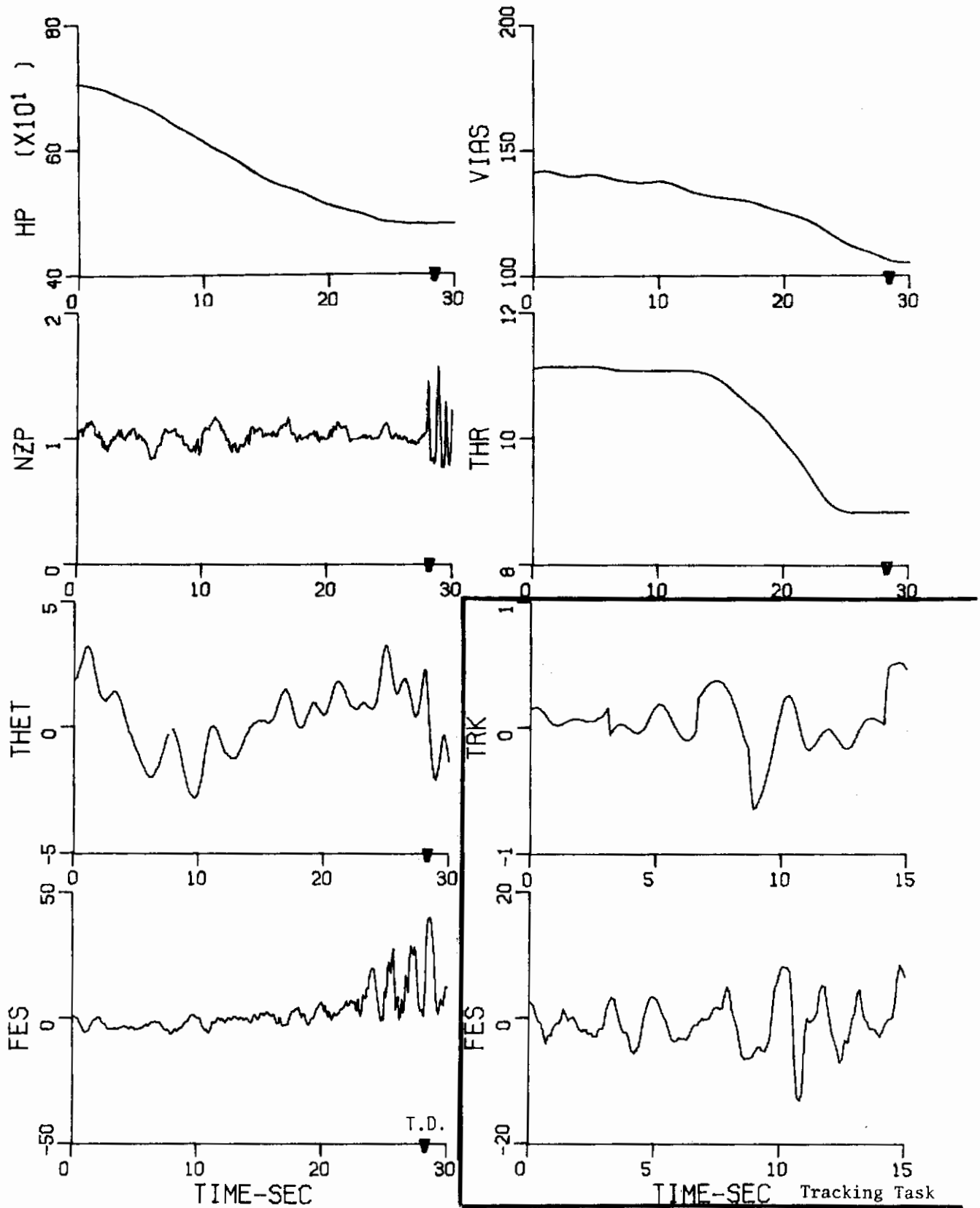


Figure 12: CONFIG. 1-3, PILOT B/1892, ILS AND TRACKING TASKS, PR: 10/--

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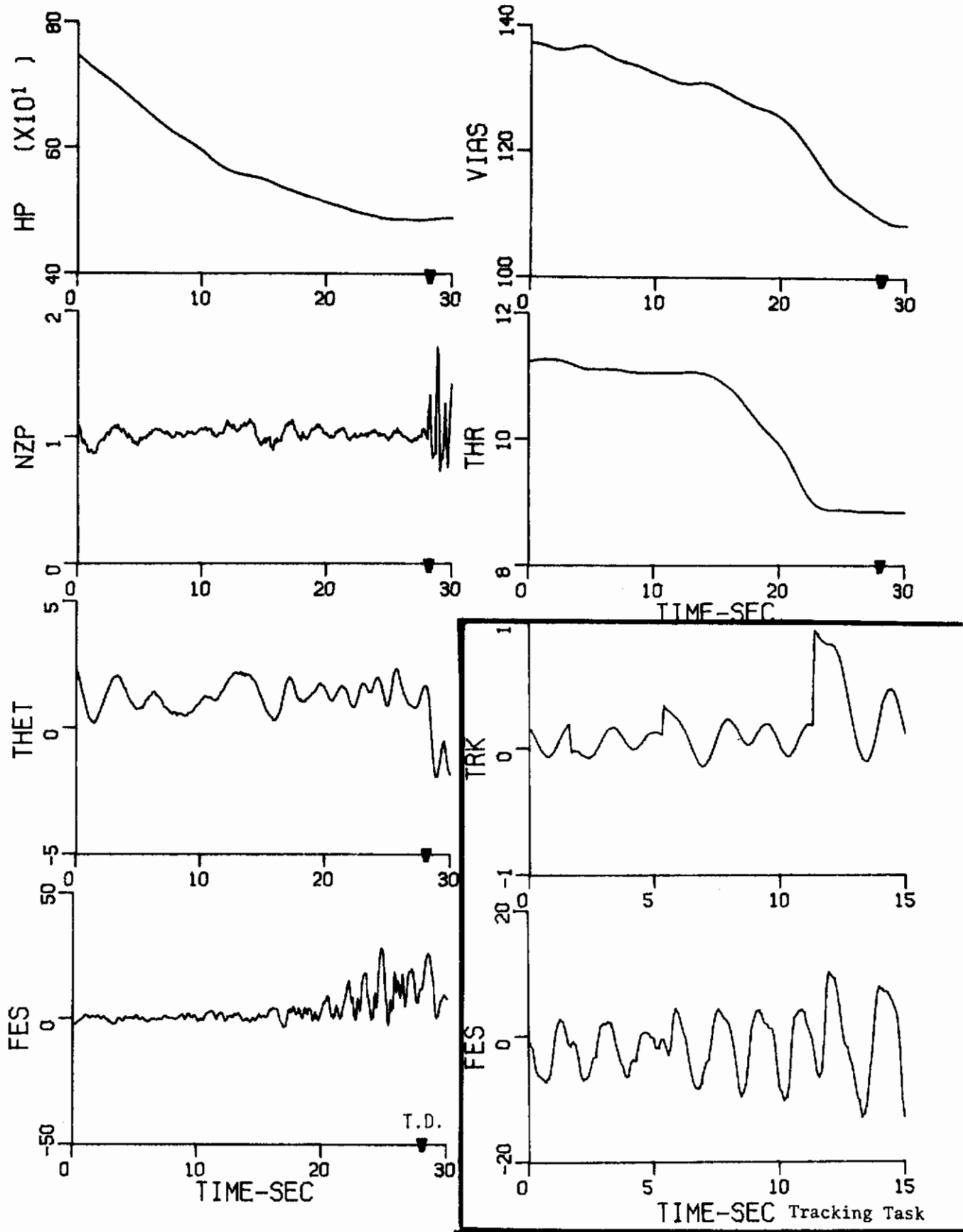


Figure 13: CONFIG. 1-3, PILOT B/1892, VISUAL TASK AND TRACKING TASKS, PR:10/--

Contrails

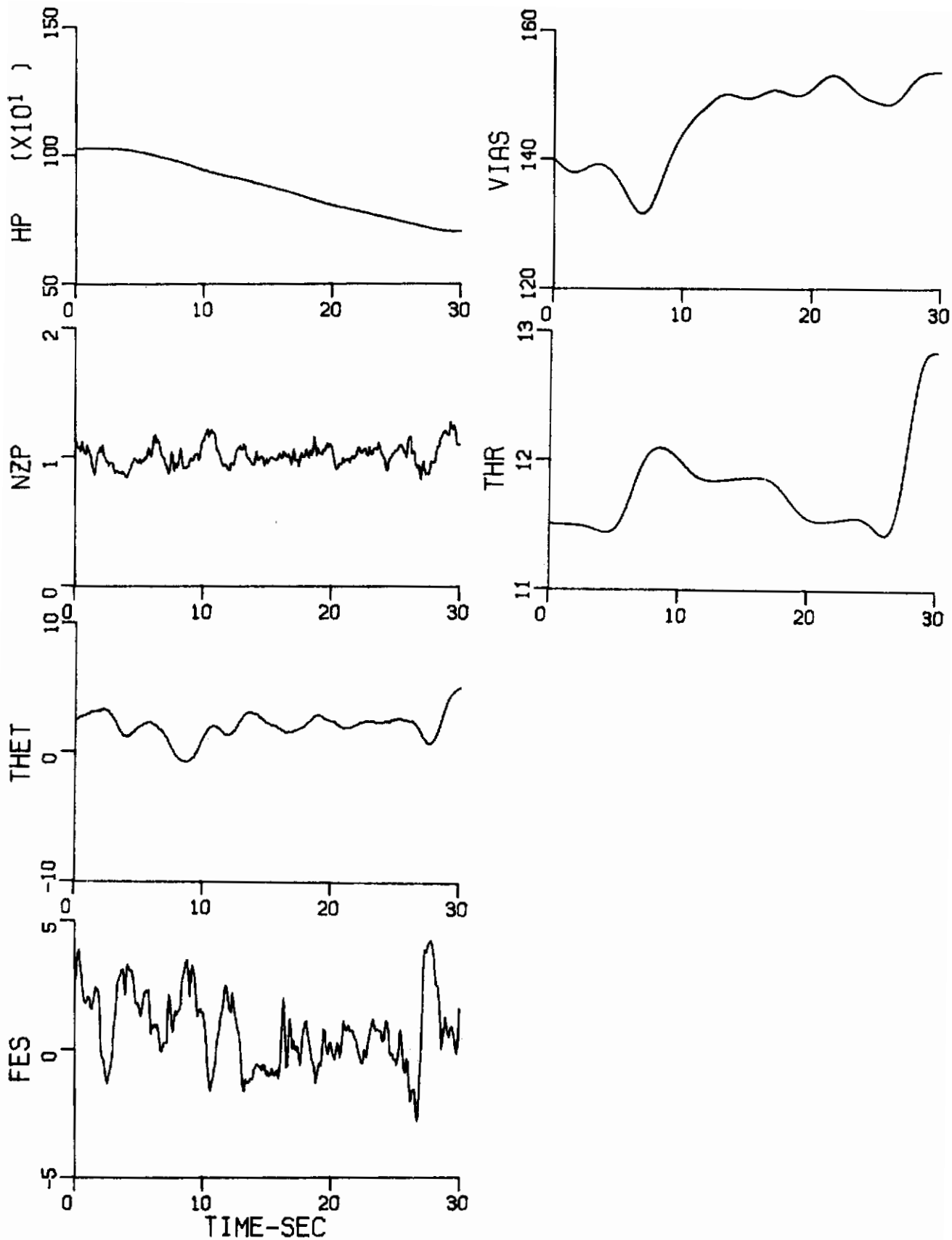


Figure 14: CONFIG. 1-3, PILOT B/1898, ILS (Low Approach) PR: --/6

Contrails

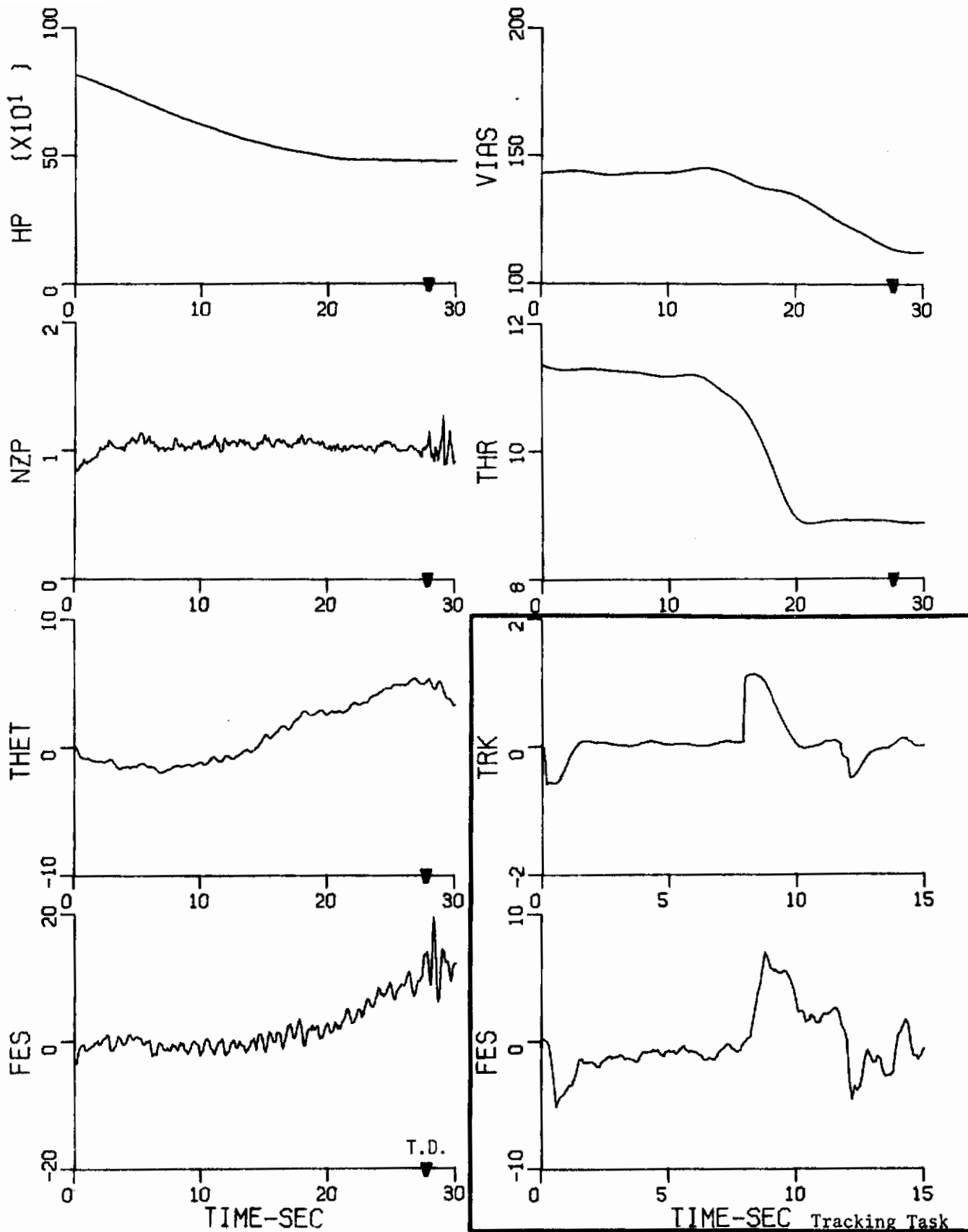


Figure 15: CONFIG. 2-1, PILOT B/1892, ILS AND TRACKING TASKS, PR: 2/--

Contrails

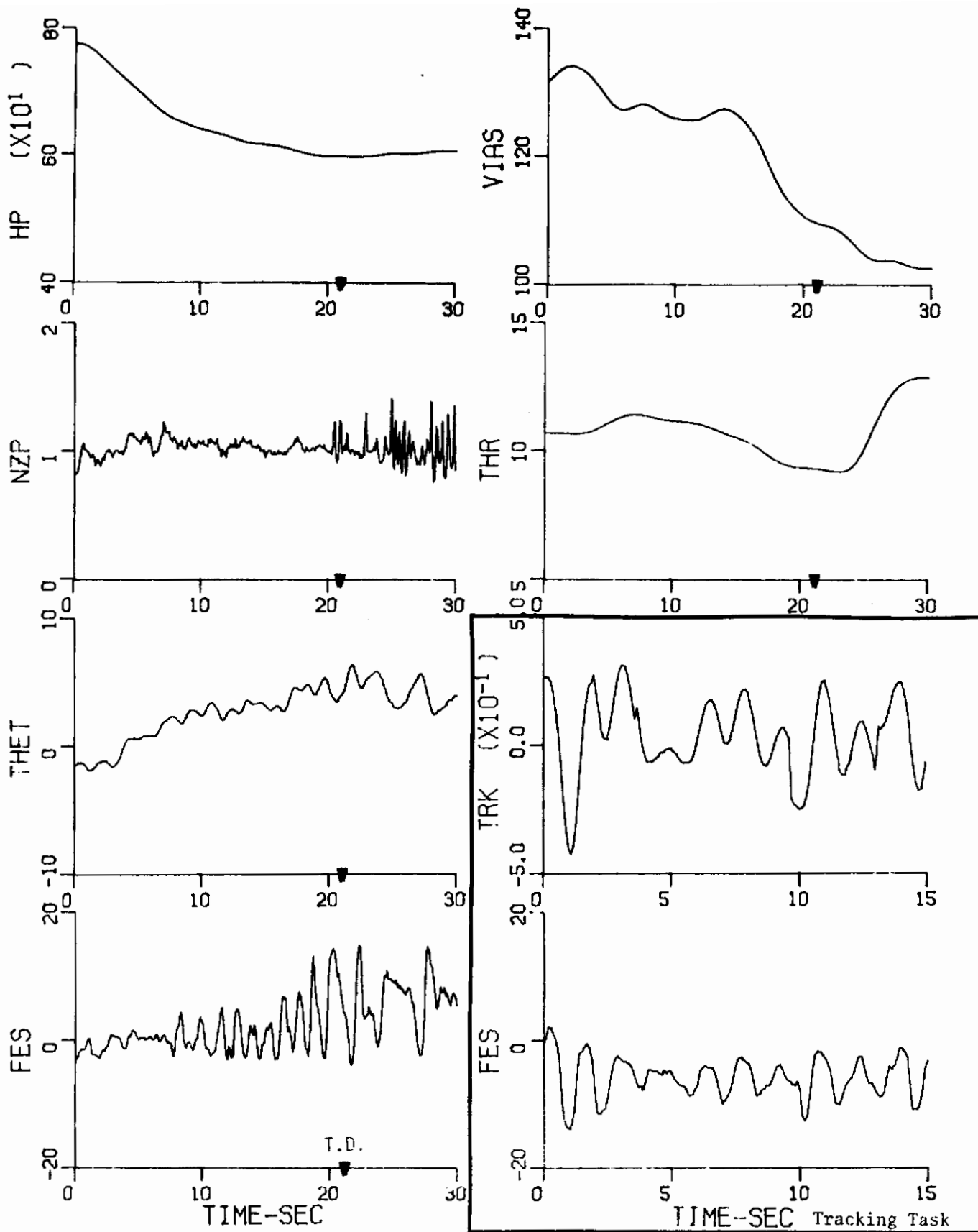


Figure 16: CONFIG. 2-4, PILOT A/1888, ILS AND TRACKING TASKS, PR: 9/--

Contrails

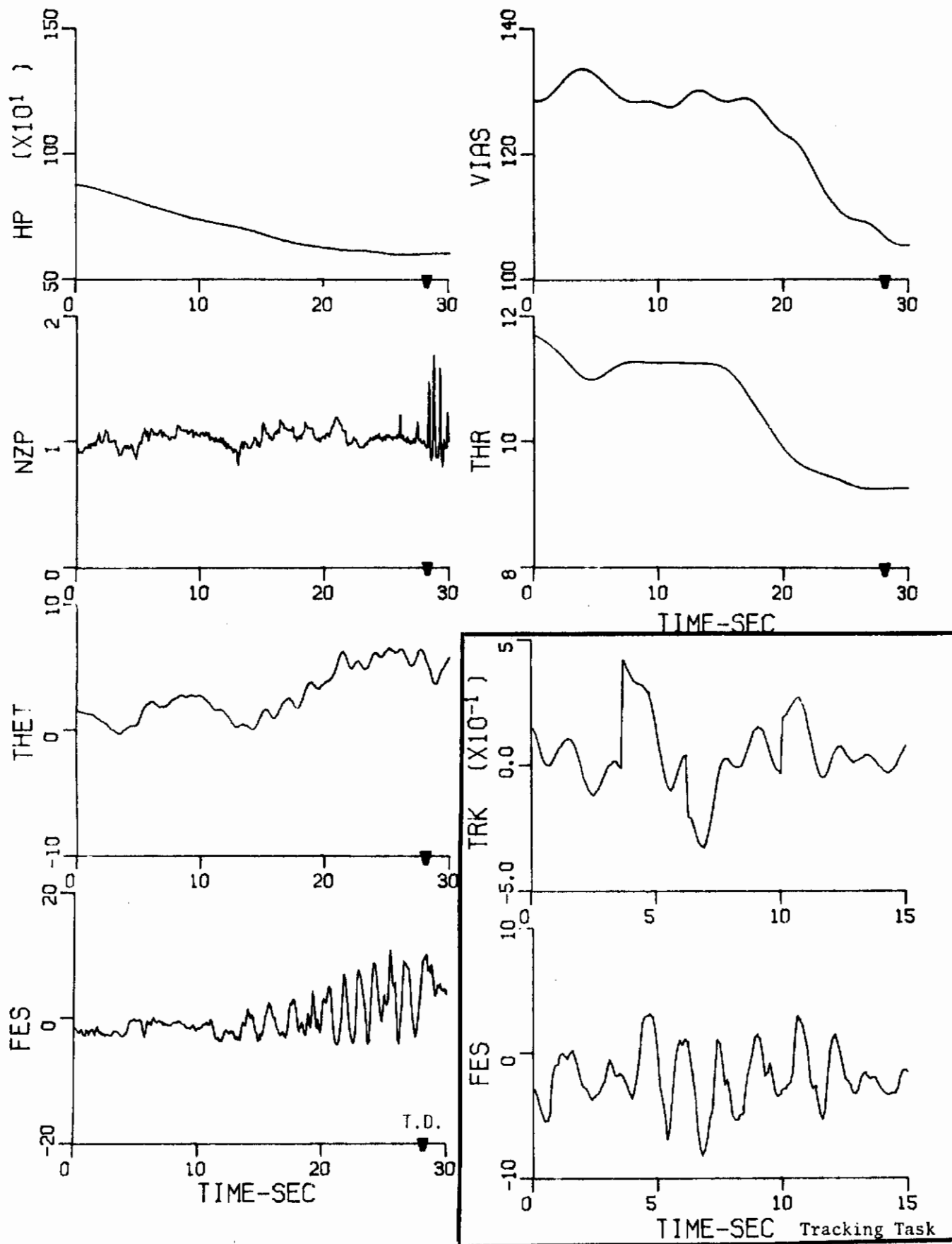


Figure 17: CONFIG. 2-4, PILOT A/1888, VISUAL TASK AND TRACKING TASKS, PR:9/--

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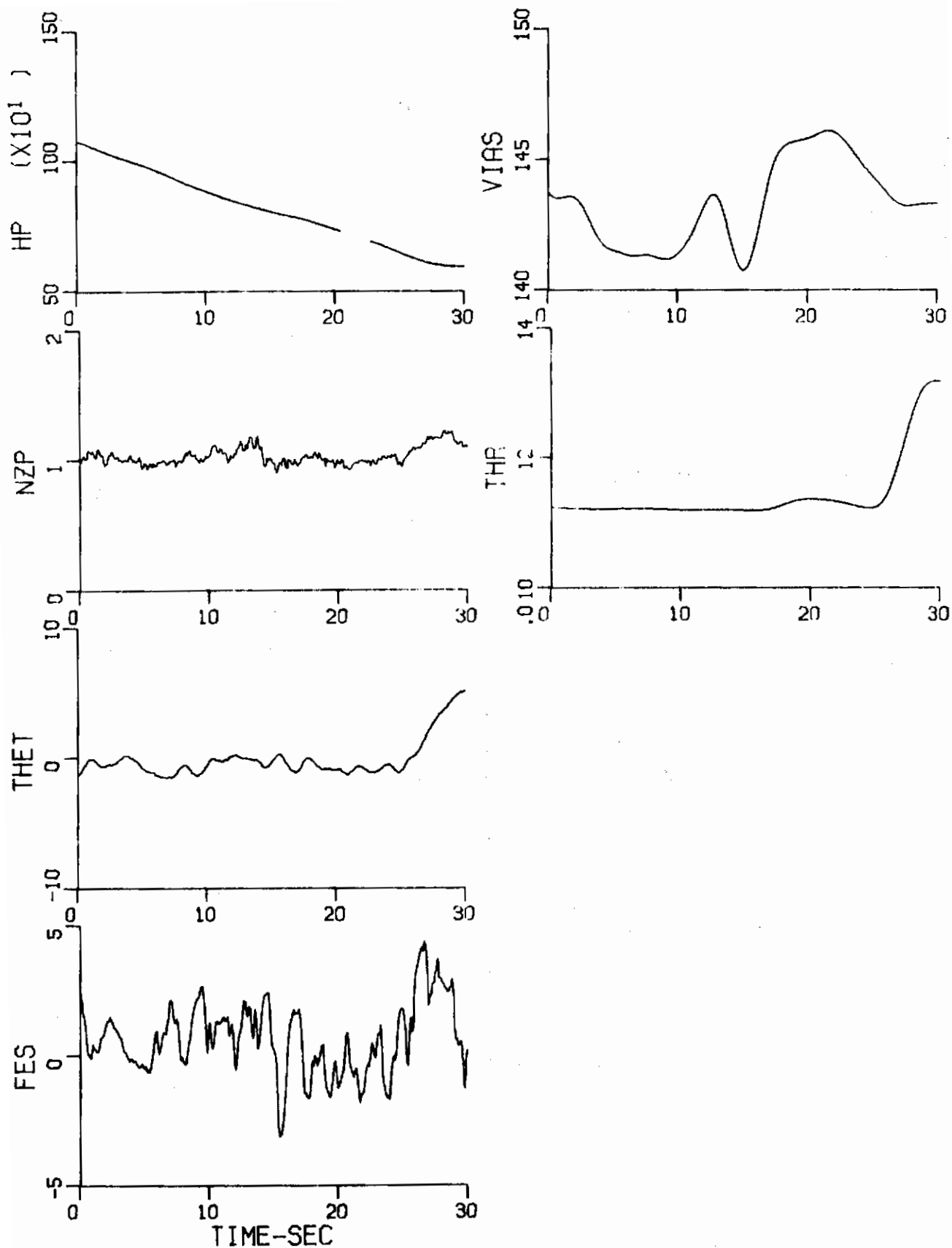


Figure 18: CONFIG. 2-4, PILOT B/1892, ILS (Low Approach) PR: --/3

Contrails

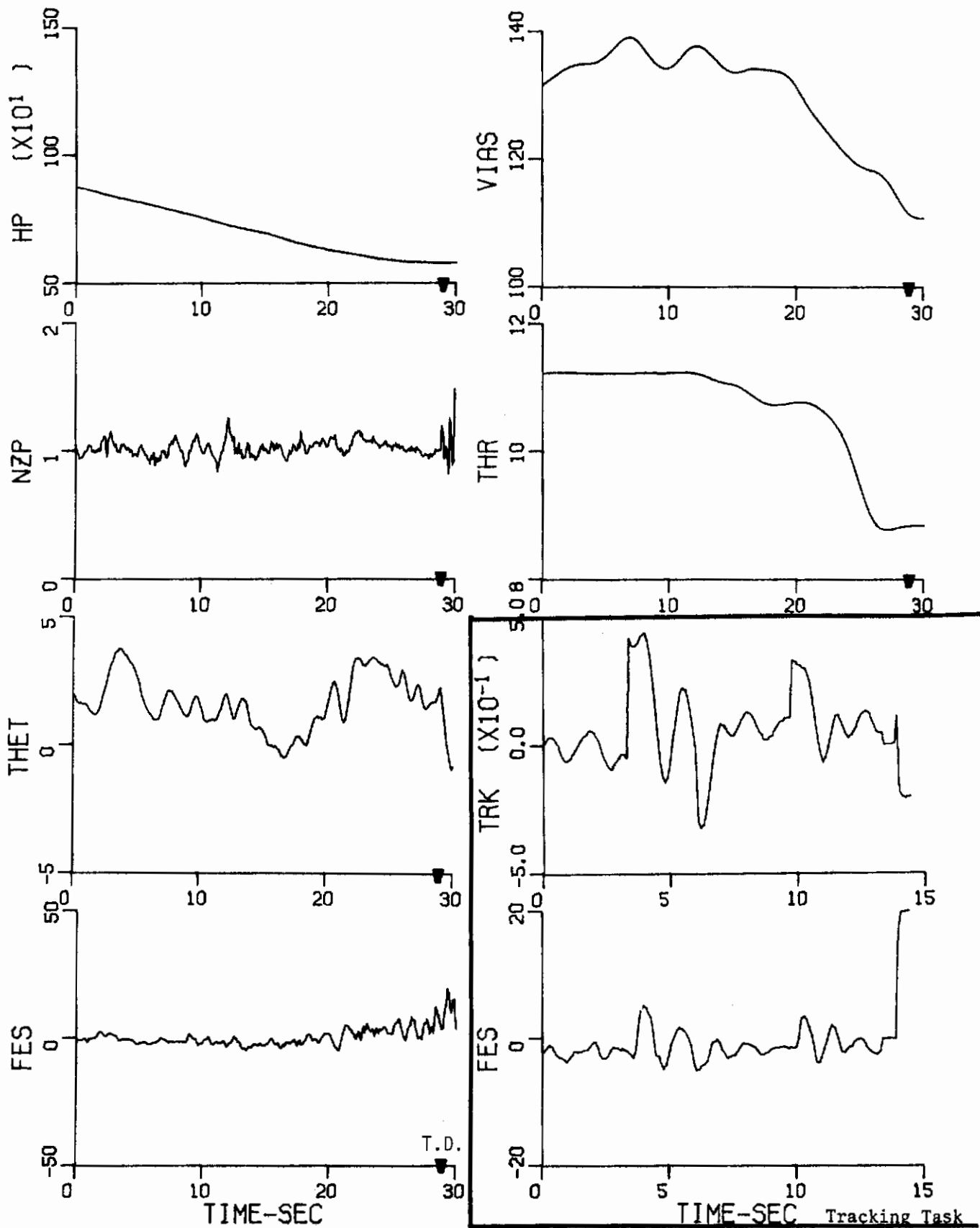


Figure 19: CONFIG. 2-7, PILOT B/1898, ILS AND TRACKING TASKS, PR: 6/3

Contrails

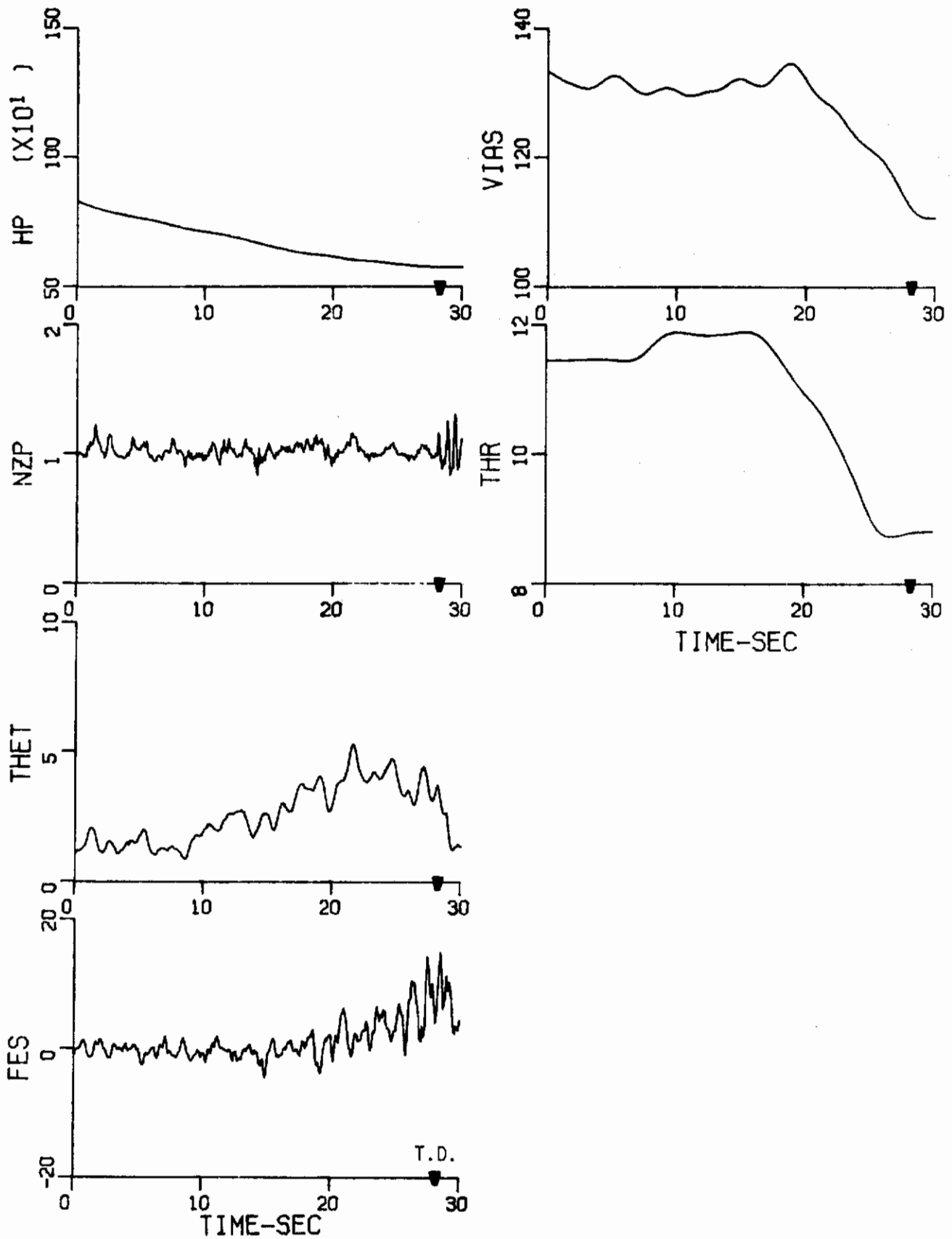


Figure 20: CONFIG. 2-7, PILOT B/1898, VISUAL TASK, PR: 6/3

Contrails

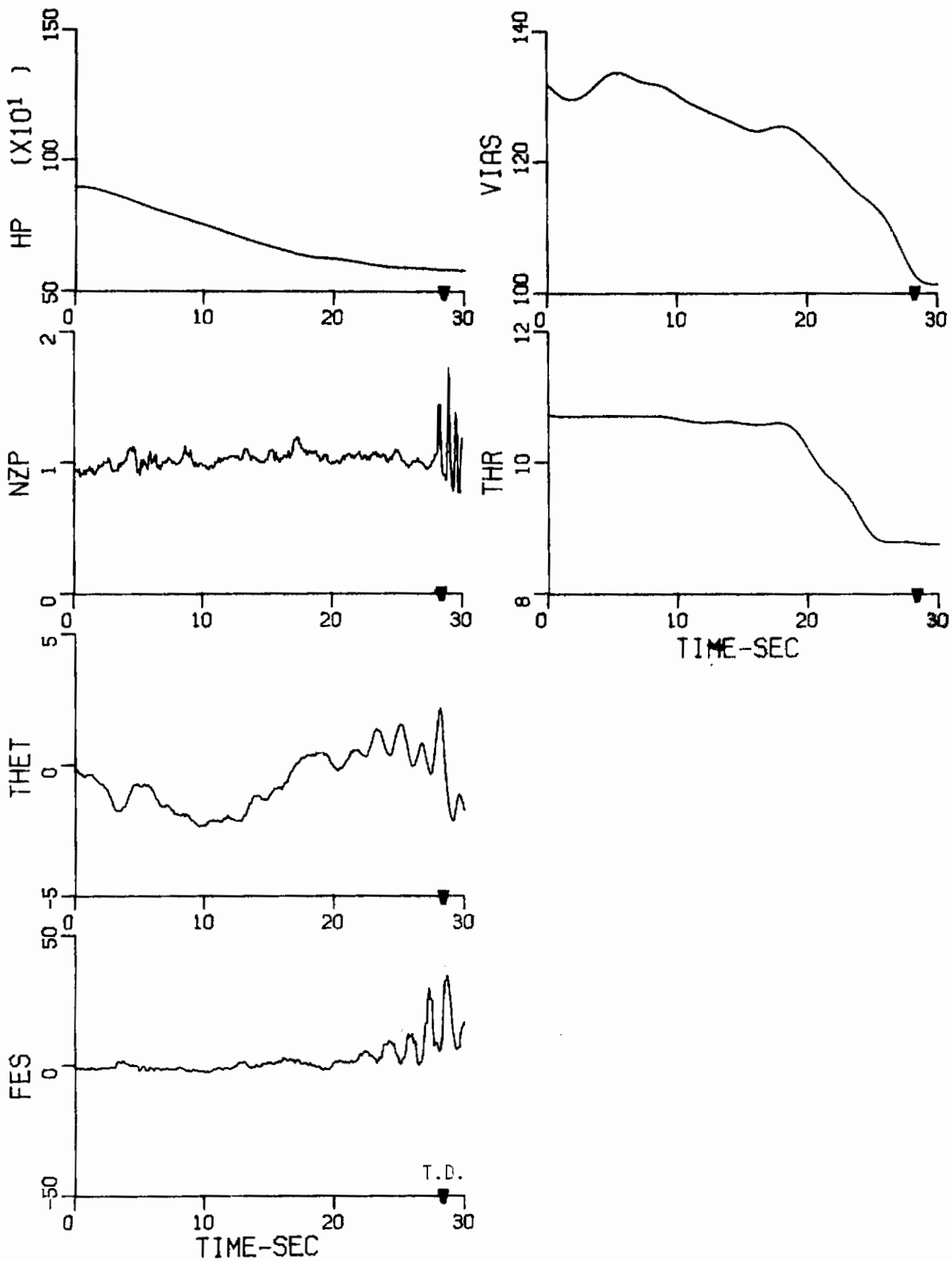


Figure 21: CONFIG. 2-9, PILOT B/1895, ILS TASK PR: 10/5

Contrails

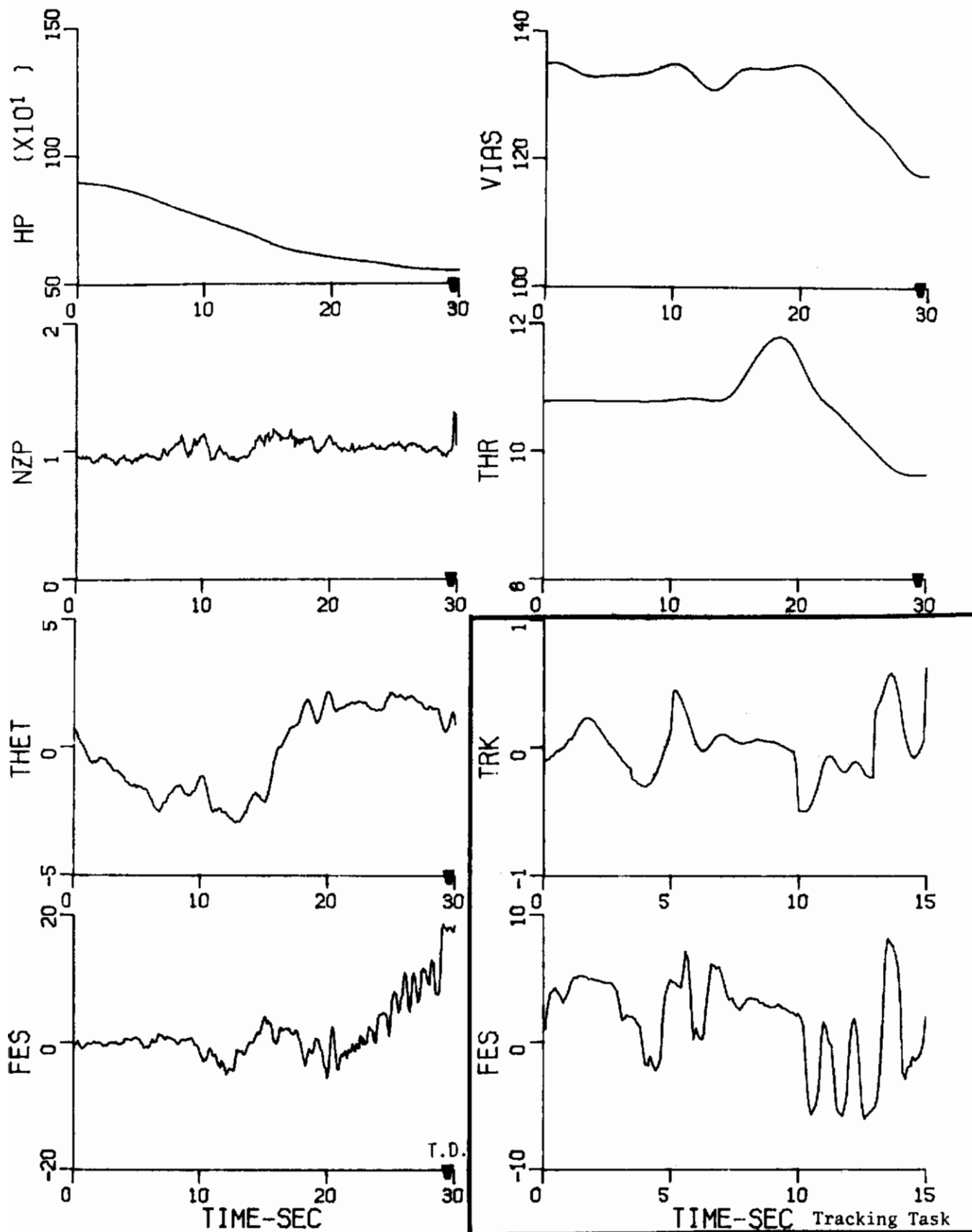


Figure 22: CONFIG. 3-1, PILOT A/1893, ILS AND TRACKING TASKS, PR: 5(4TD)/5

Contrails

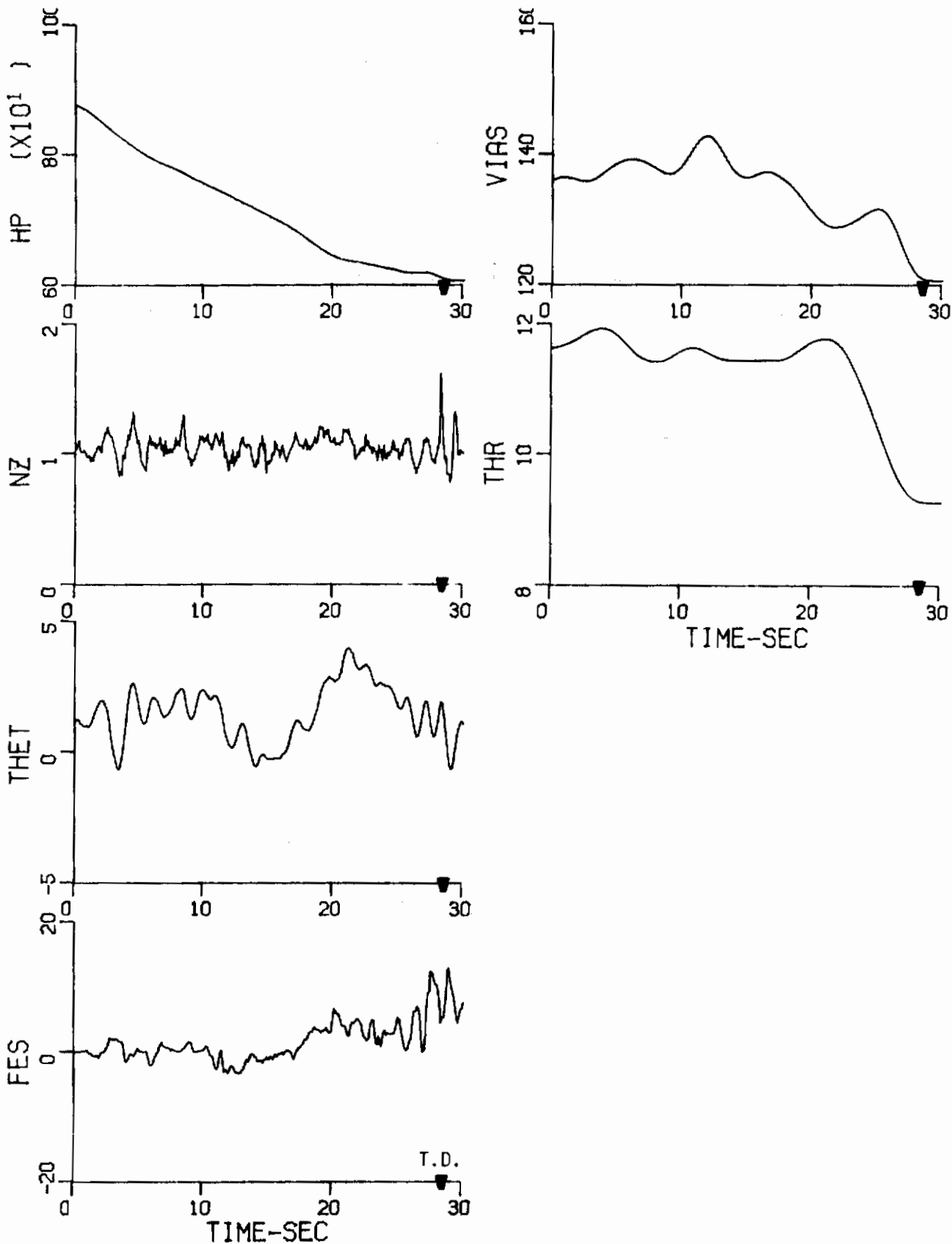


Figure 23: CONFIG. 3-6, PILOT A/1900, VISUAL TASK, PR: 7/5

Contrails

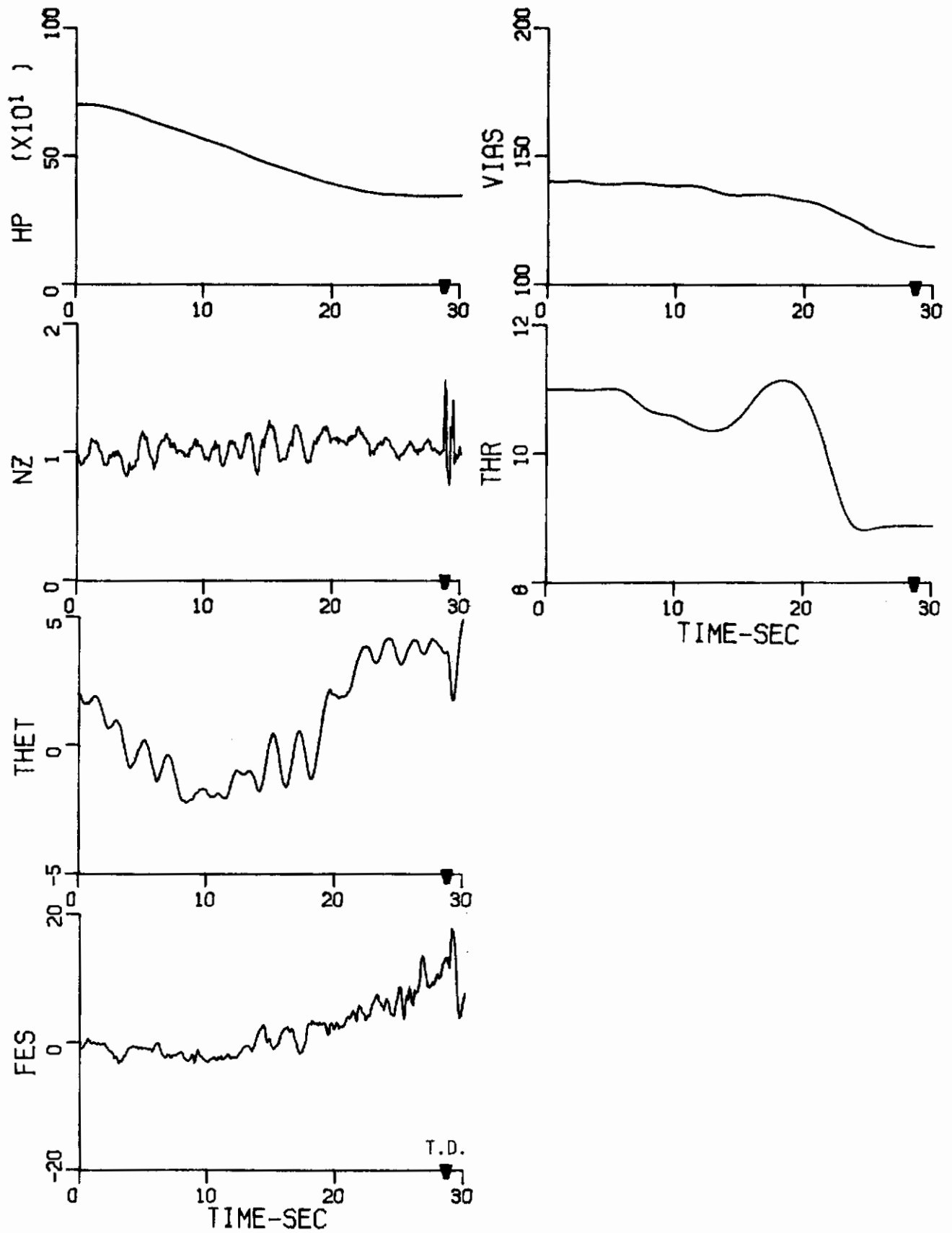


Figure 24: CONFIG. 3-6, PILOT B/1902, ILS TASK, PR: 6/5

Contrails

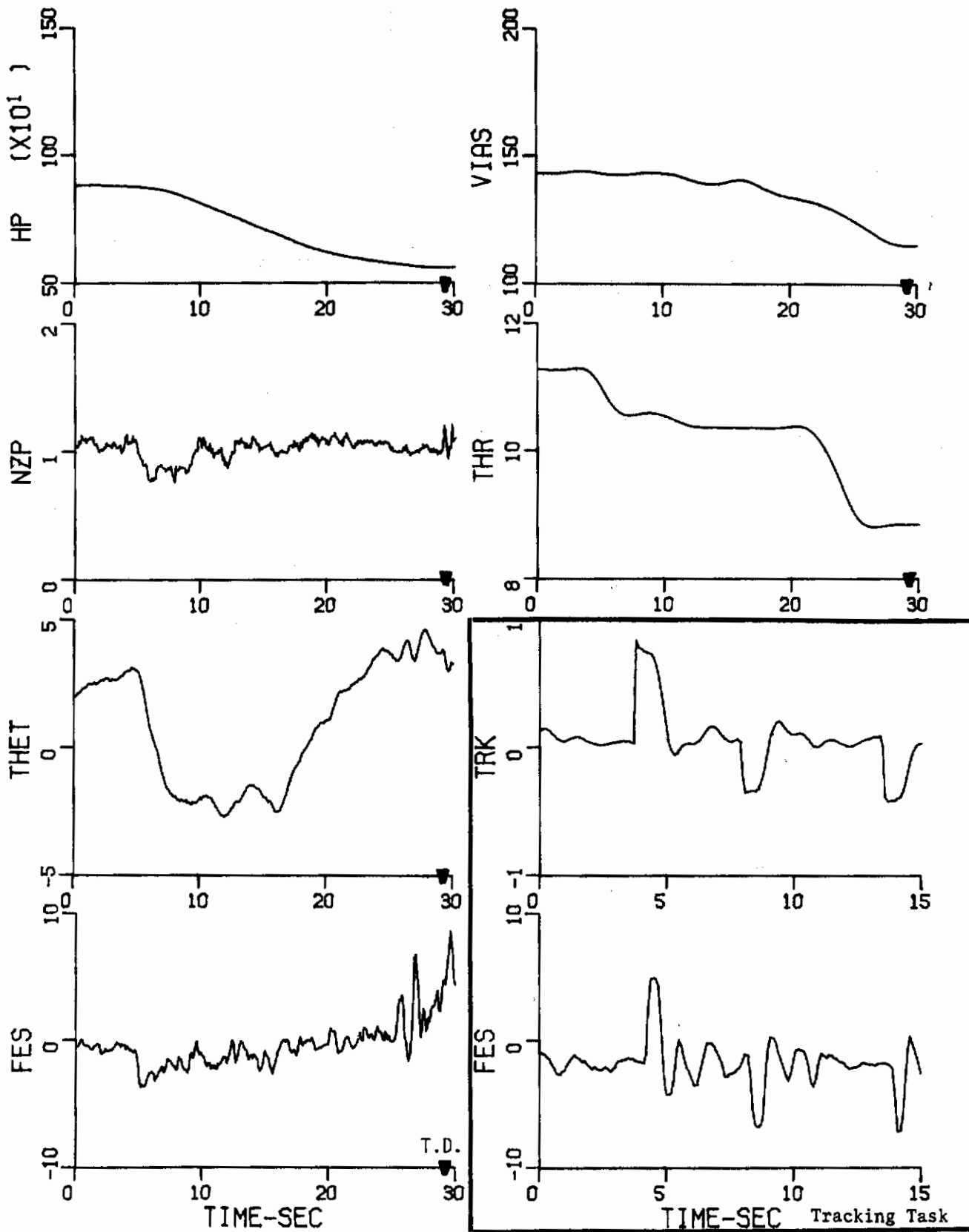


Figure 25: CONFIG. 4-3, PILOT A/1891, ILS AND TRACKING TASKS, PR: 5/--

Contrails

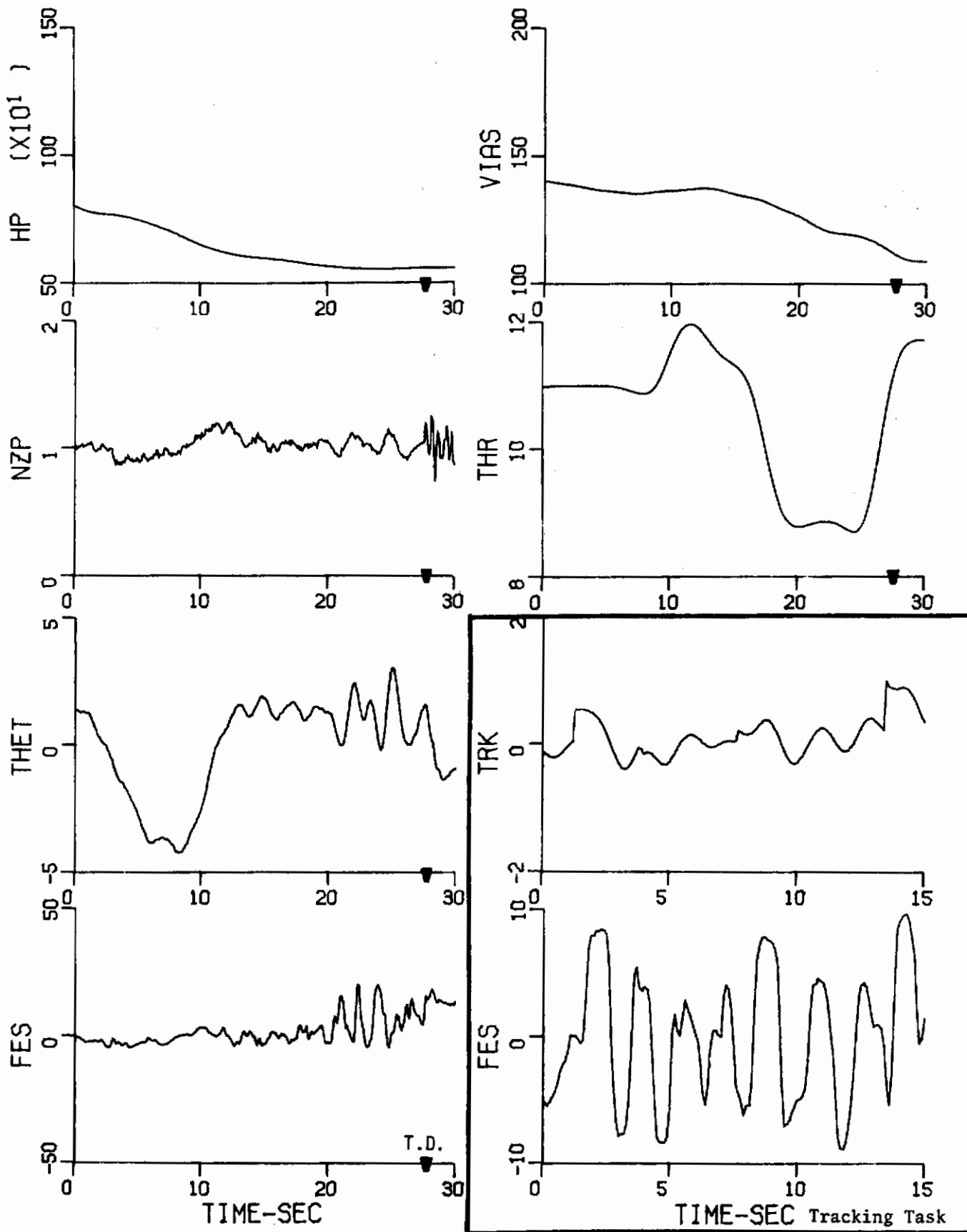


Figure 26: CONFIG. 4-10, PILOT A/1893, ILS AND TRACKING TASKS, PR: 9/6

Contrails

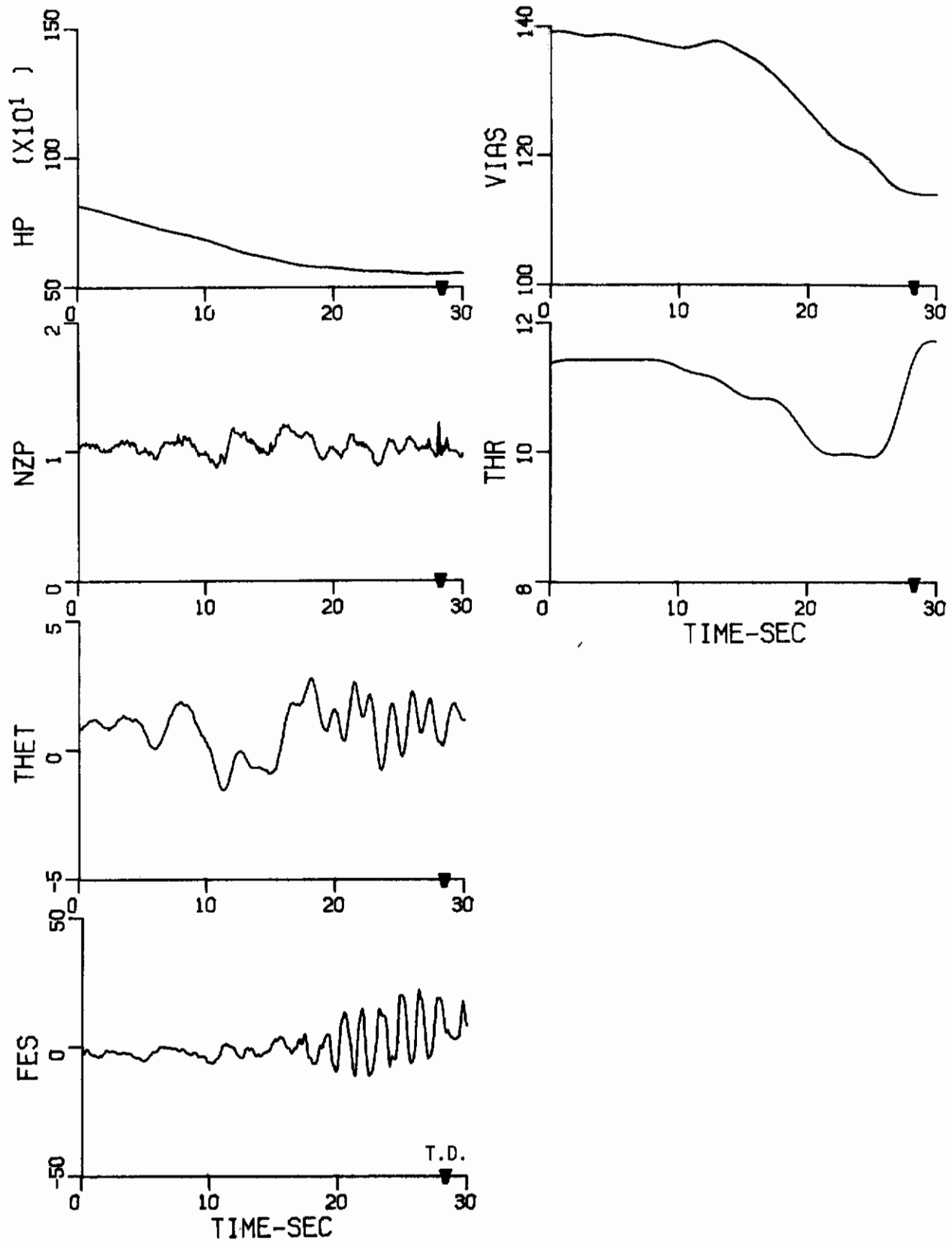


Figure 27: CONFIG.4-10, PILOT A/1893, VISUAL TASK, PR: 9/6

Contrails

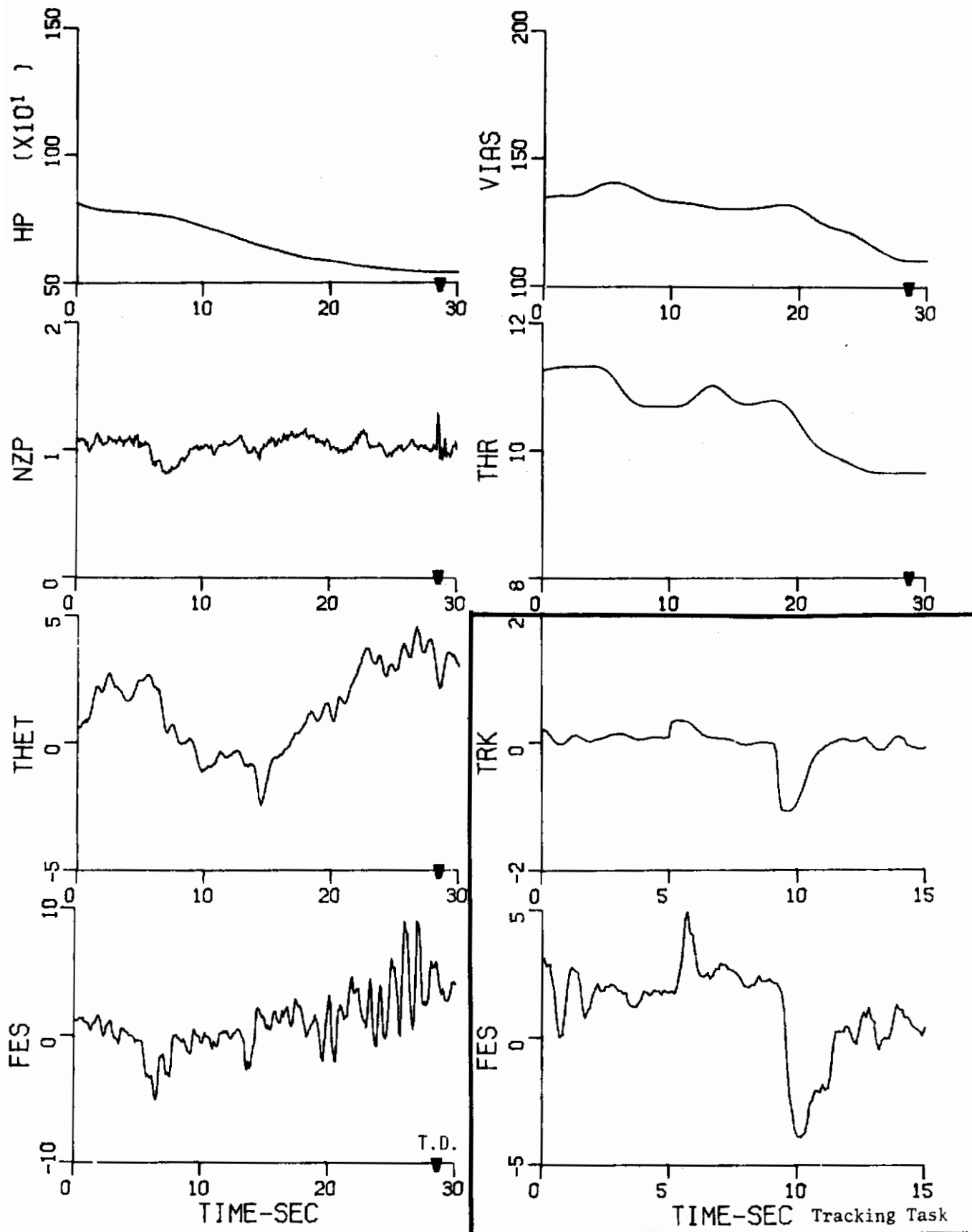


Figure 28: CONFIG. 5-3, PILOT A/1886, ILS AND TRACKING TASKS, PR: 8/--

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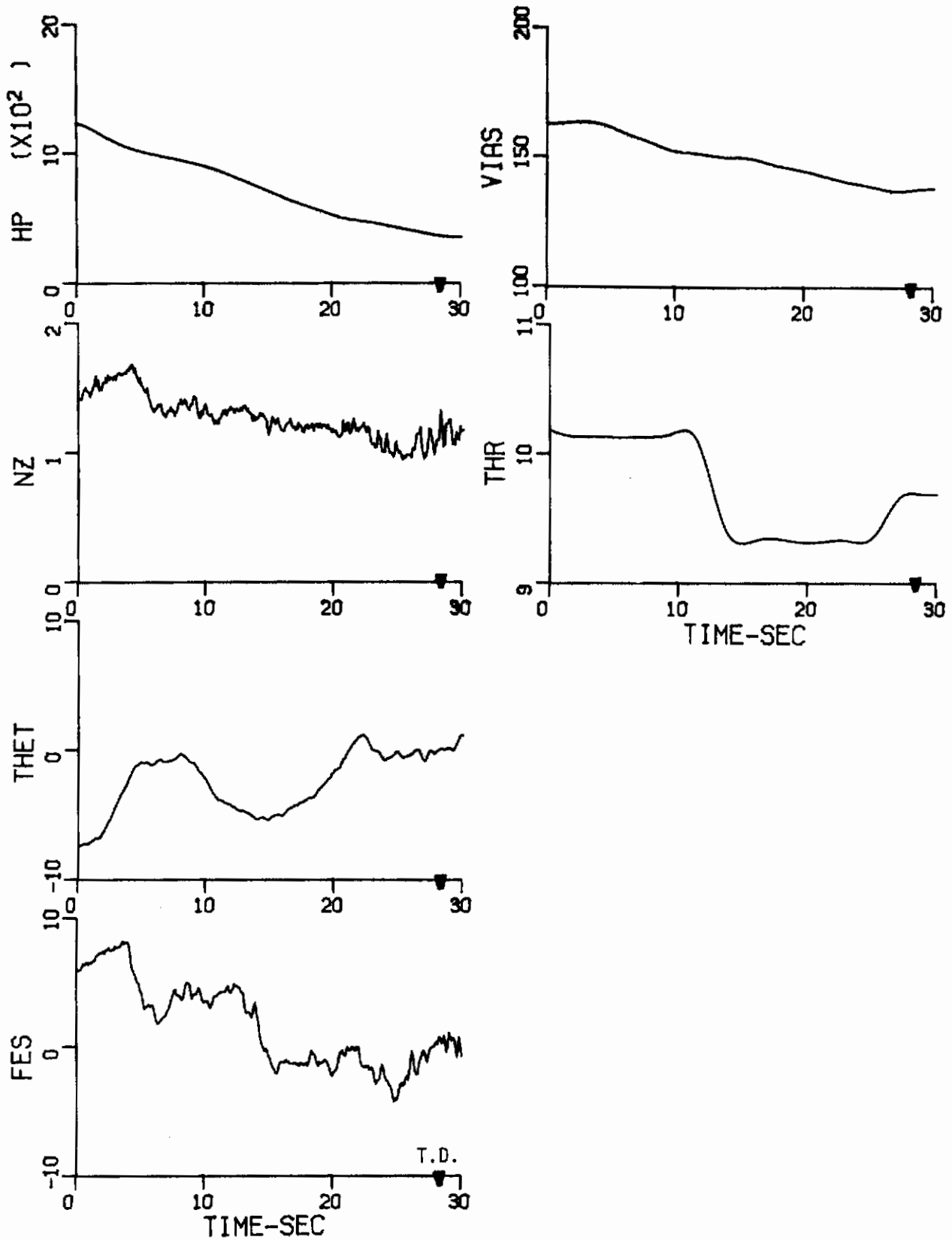


Figure 29: CONFIG. 5-6, PILOT B/1901, VISUAL TASK, PR: 6/3

Contrails

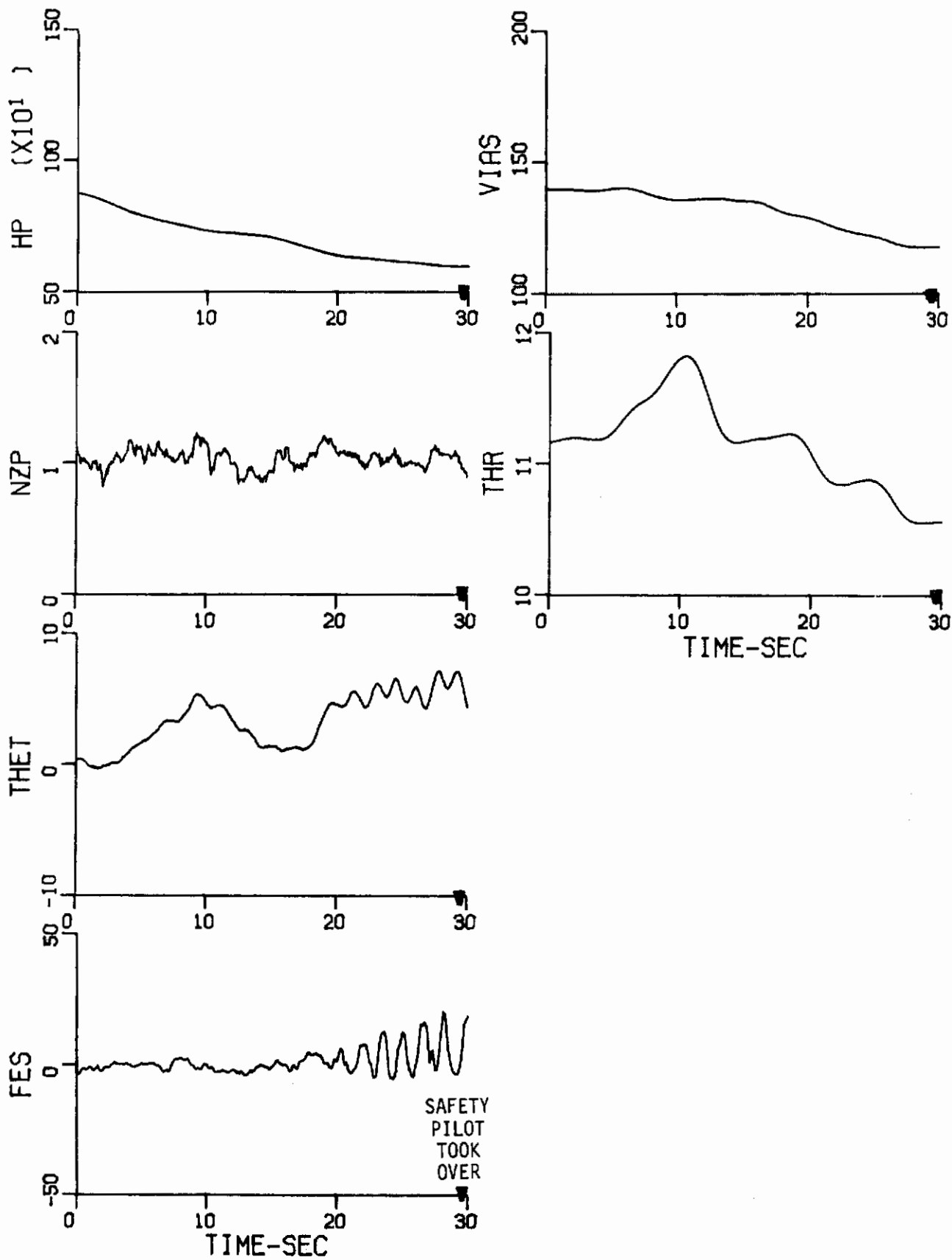


Figure 30: CONFIG. 6-1, PILOT A/1888, VISUAL TASK, PR: 10/--

Contrails

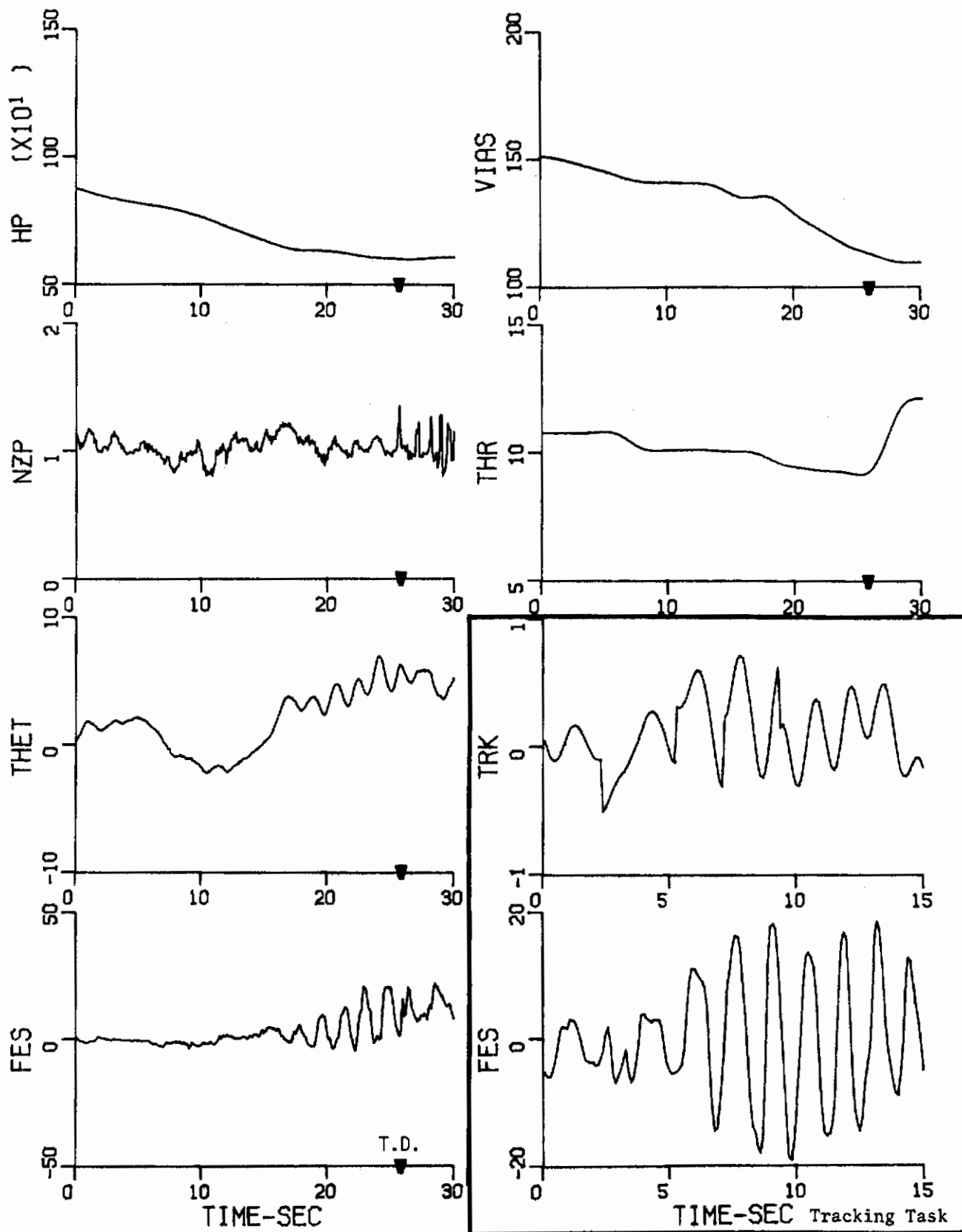


Figure 31: CONFIG. 6-1, PILOT A/1888, ILS AND TRACKING TASKS, PR: 10/--

Contrails

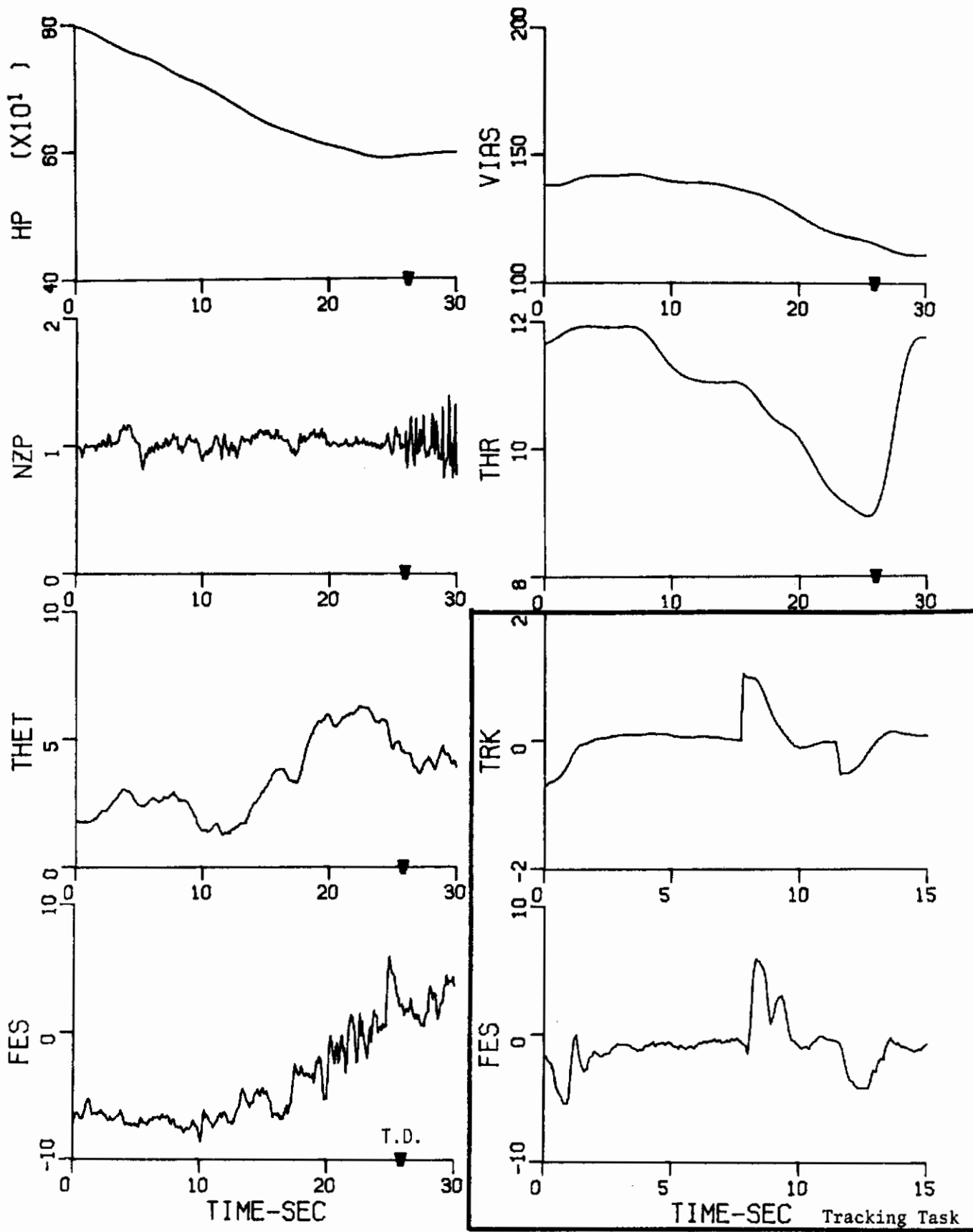


Figure 32: CONFIG. 6-2, PILOT A/1888, VISUAL AND TRACKING TASKS, PR: 2/--

Contrails

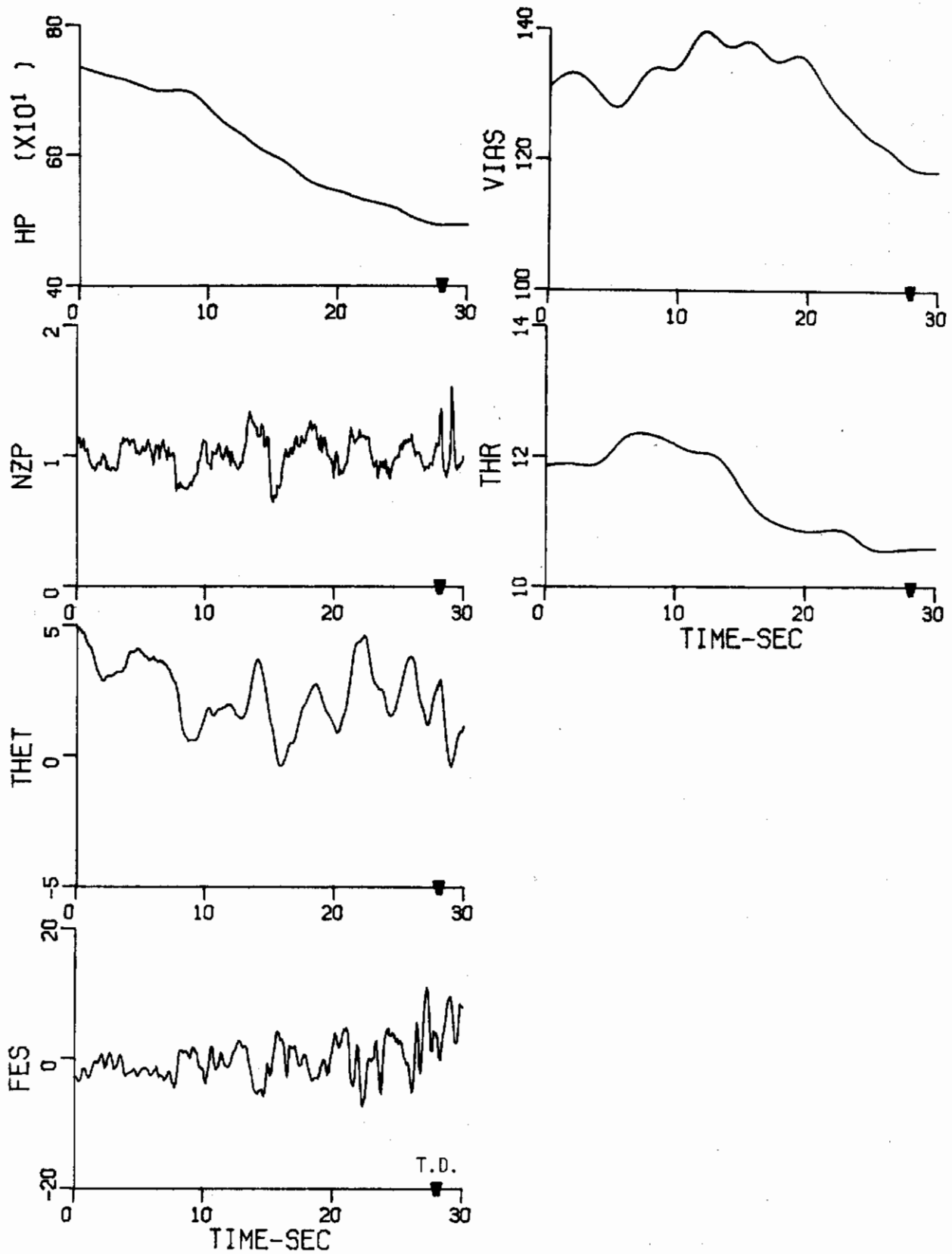


Figure 33: CONFIG. 7-3, PILOT A/1897, ILS TASK, PR: 4/2

APPENDIX III

CONFIGURATION TIME HISTORIES

The purpose of this appendix is to provide a picture of the effects of the control system dynamics on the response of the aircraft to pilot inputs. Time histories of the normalized constant speed pitch rate response (Q) to a step stick force input are presented for all the configurations evaluated in this experiment. For comparison, the response of the base aircraft, that is, the configurations without additional control system dynamics (Configurations 1-1, 2-1, 3-1, 4-1 and 5-1), are included as a dashed line on each time history. Note that the feel system and actuator dynamics are included in all cases.

For all the time histories, the unity gain form of the transfer functions was used and $(K_{\theta} \cdot F_{ES})_{SS}$ was held constant at 0.75. Therefore, all the time histories have the same steady-state value to facilitate comparisons. A time scale of either 3 or 6 seconds was chosen depending on the response shape of the configuration.

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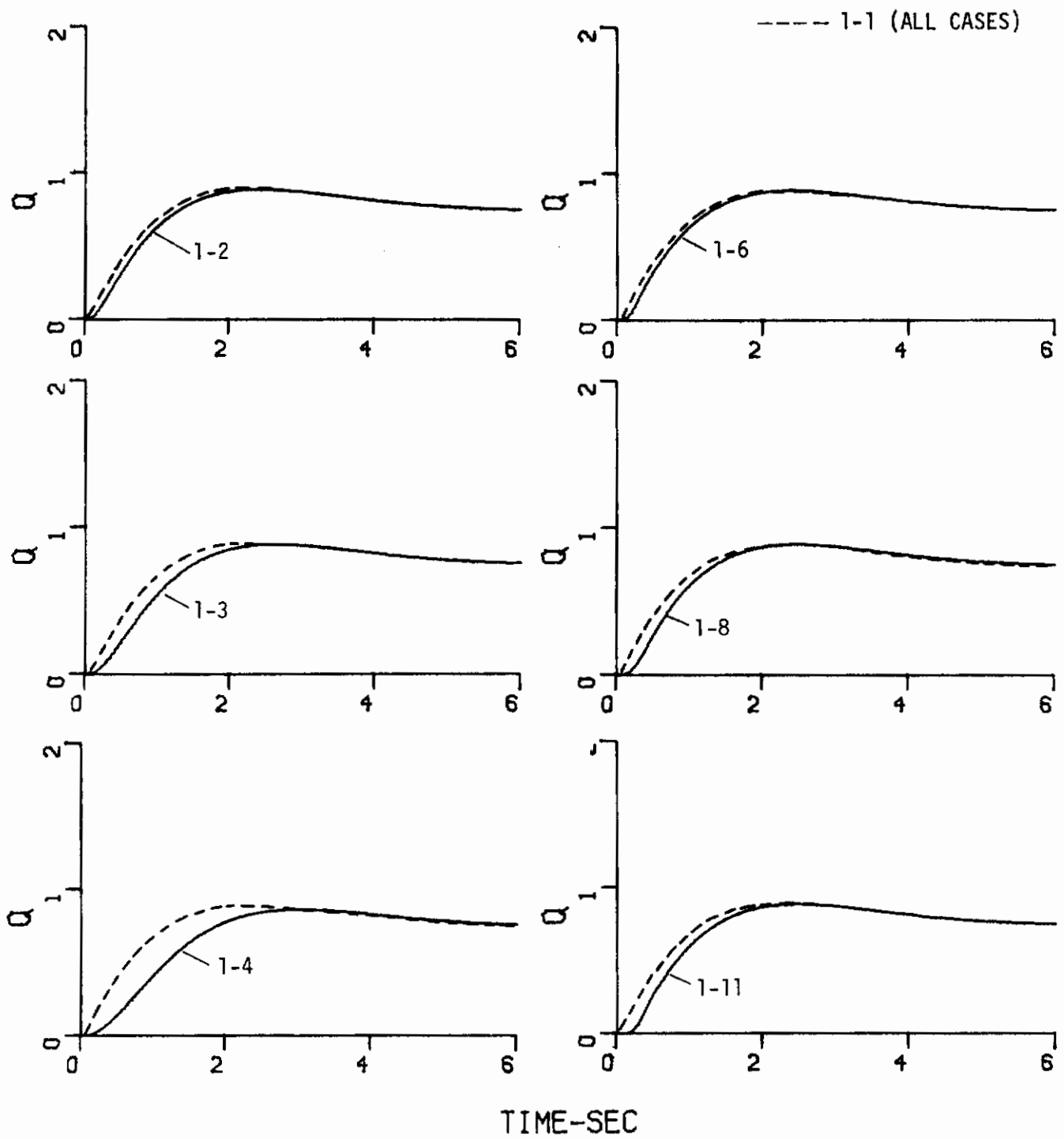


Figure 34 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 1

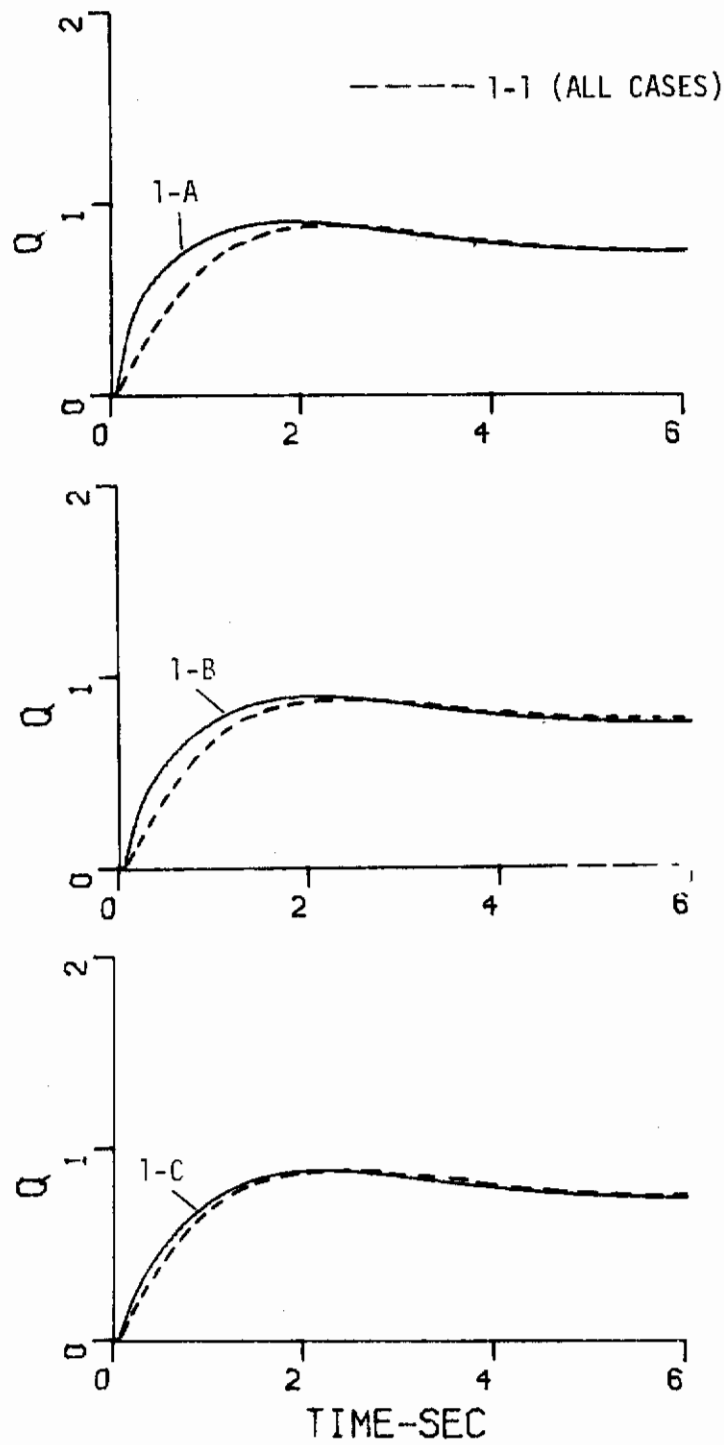


Figure 34 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 1 (Cont'd)

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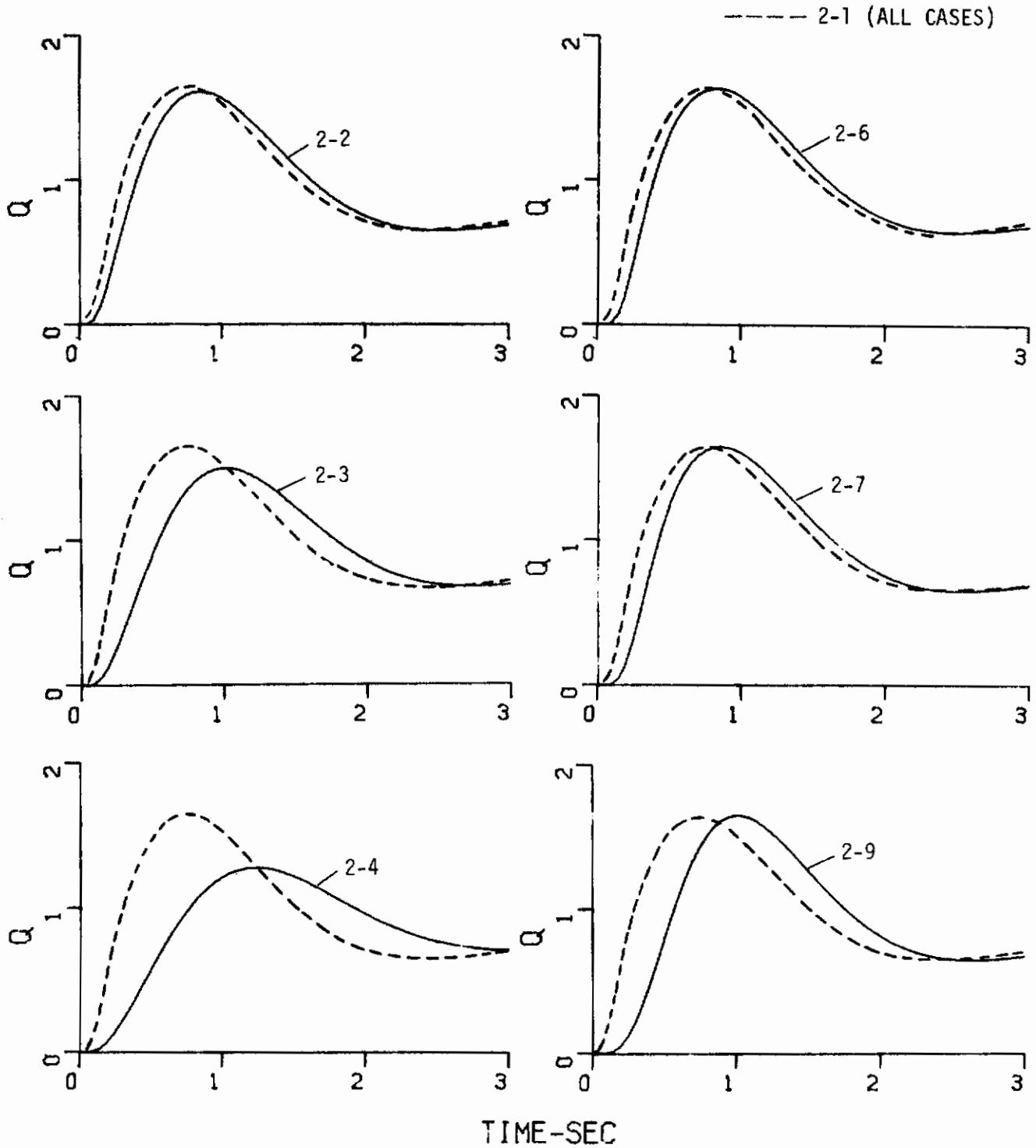


Figure 35 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 2

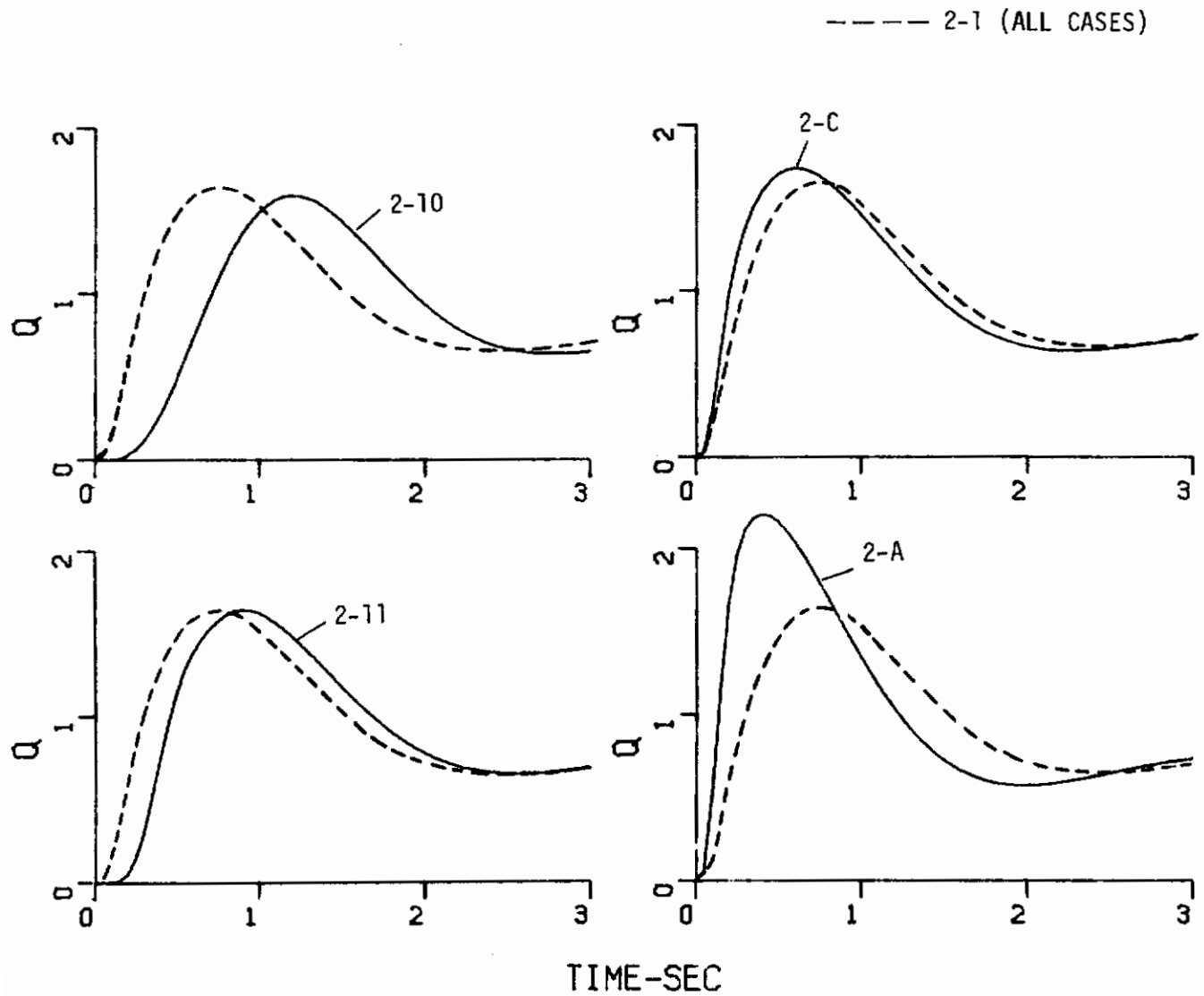


Figure 35 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 2 (Cont'd)

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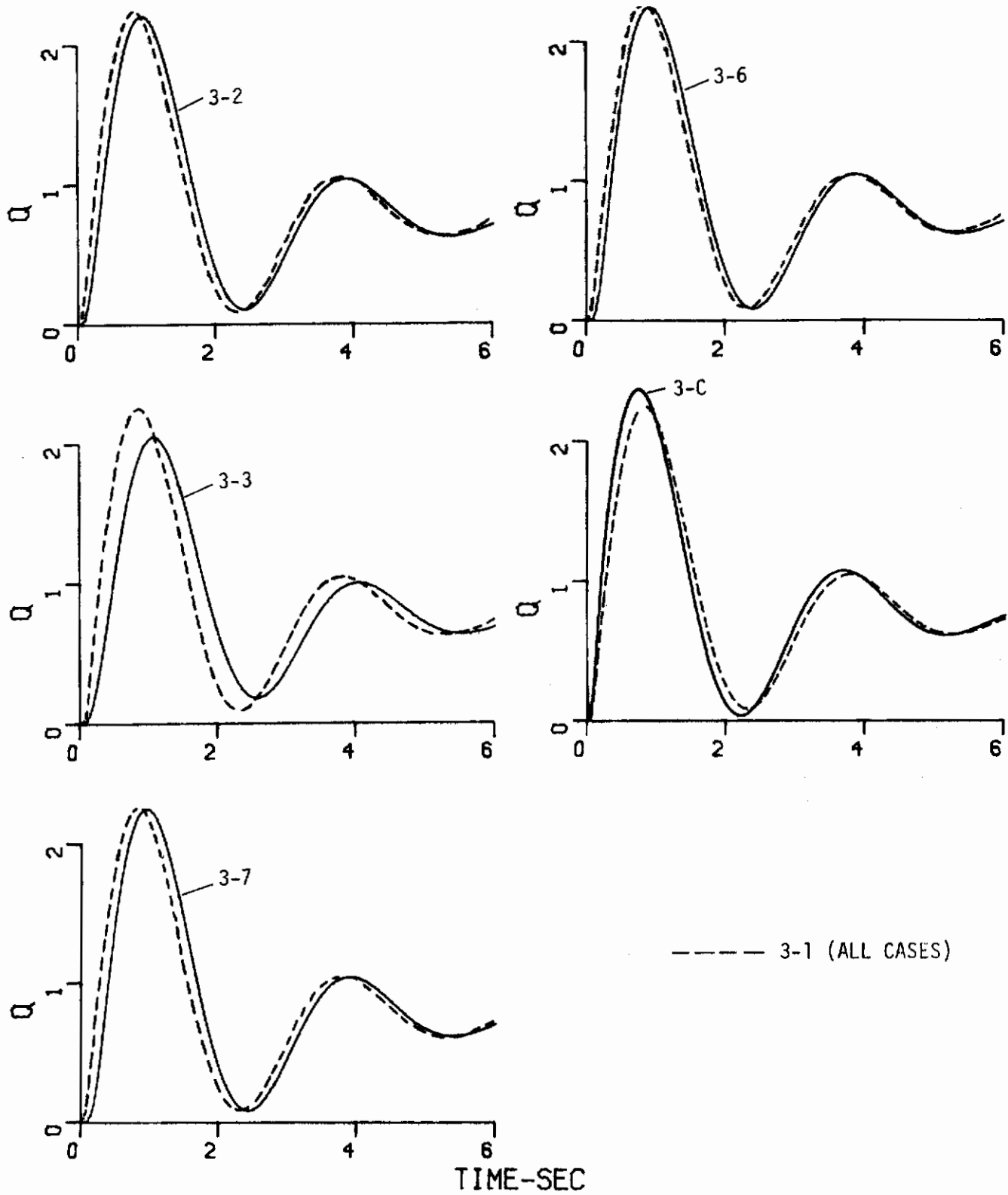


Figure 36 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 3

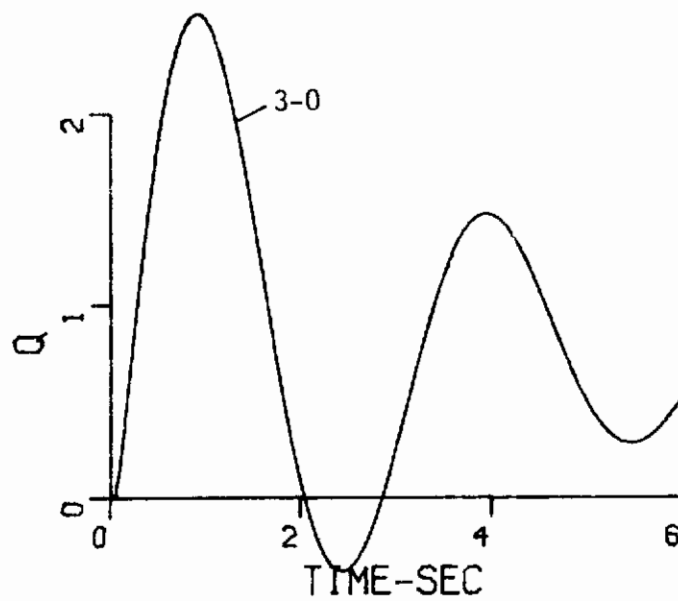


Figure 36 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 3 (Cont'd)

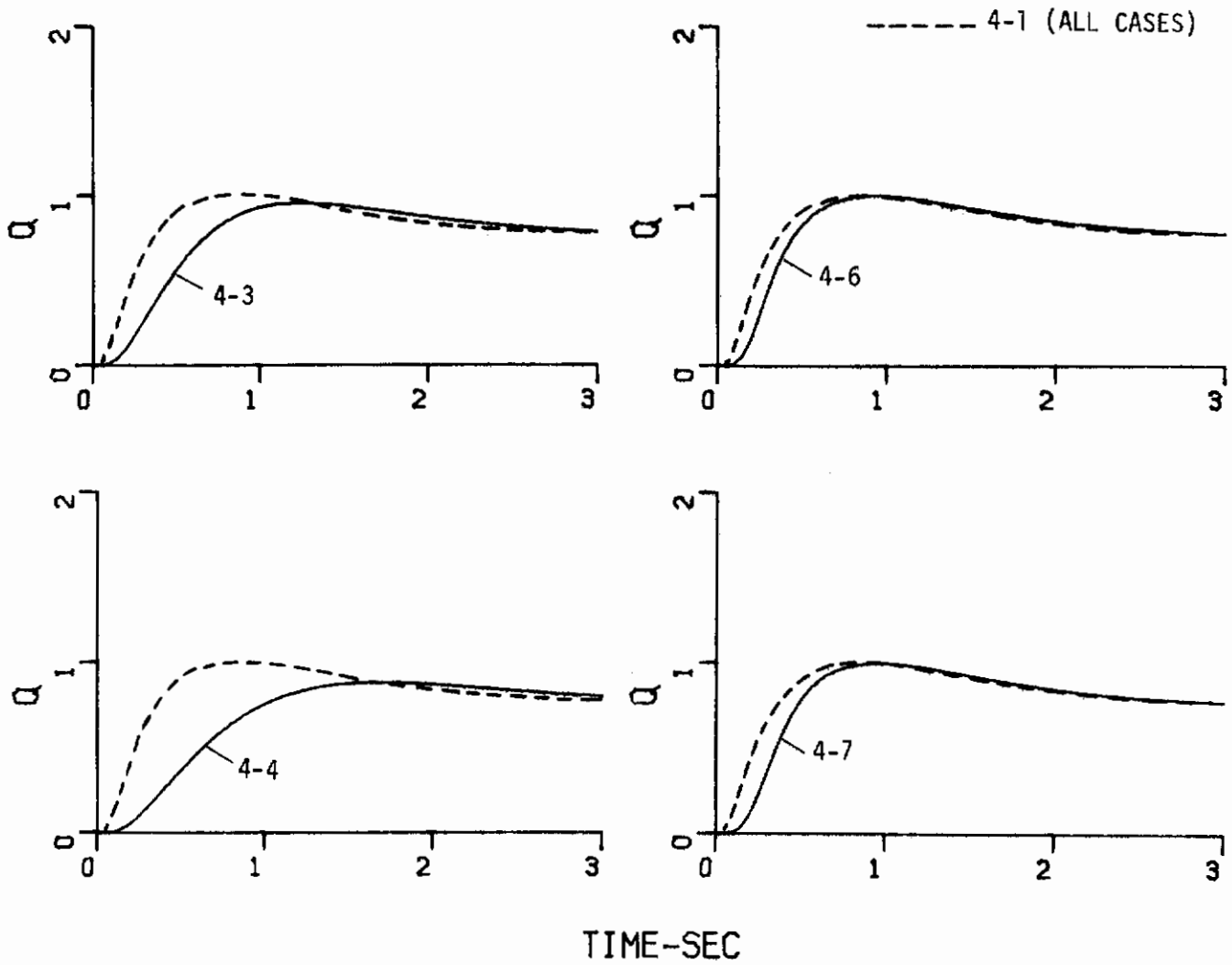


Figure 37: PITCH RATE STEP RESPONSES FOR CONFIGURATION 4

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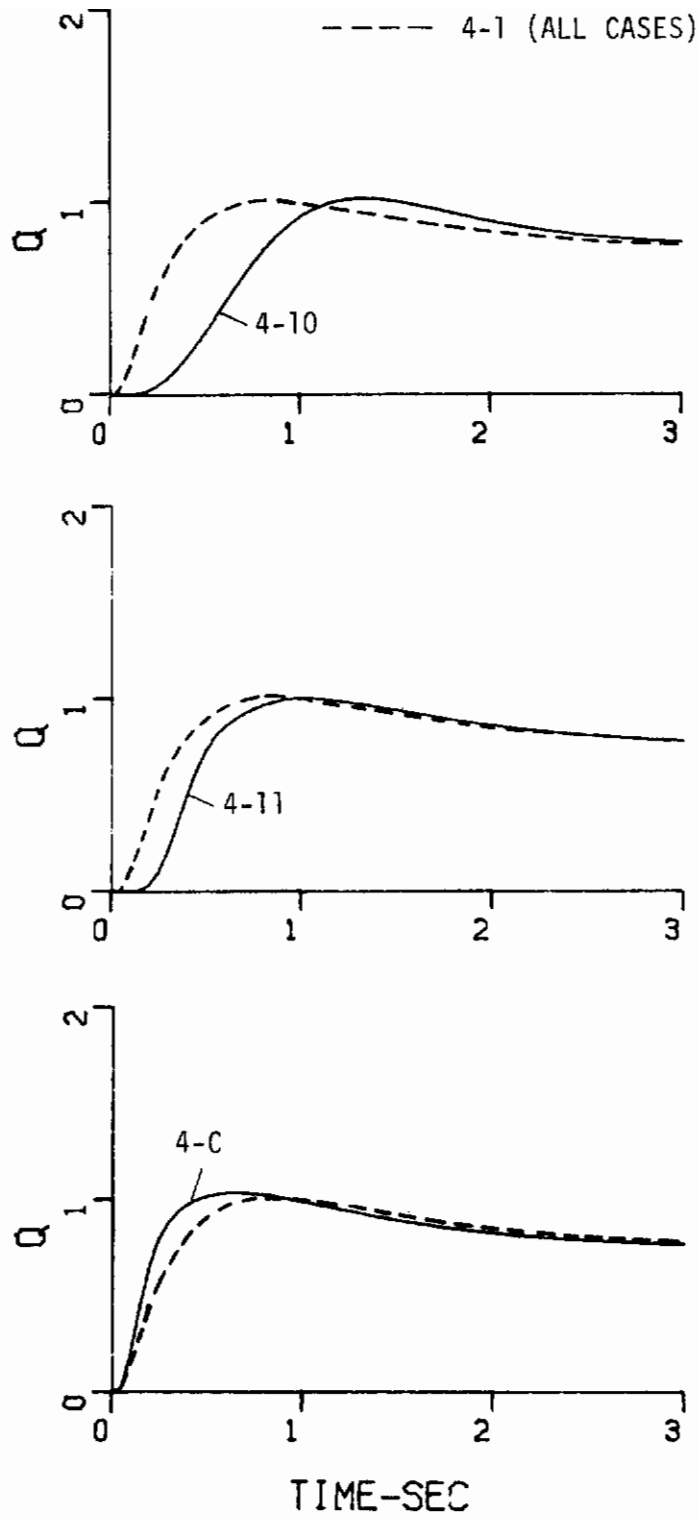


Figure 37; PITCH RATE STEP RESPONSES FOR CONFIGURATION 4 (Cont'd)

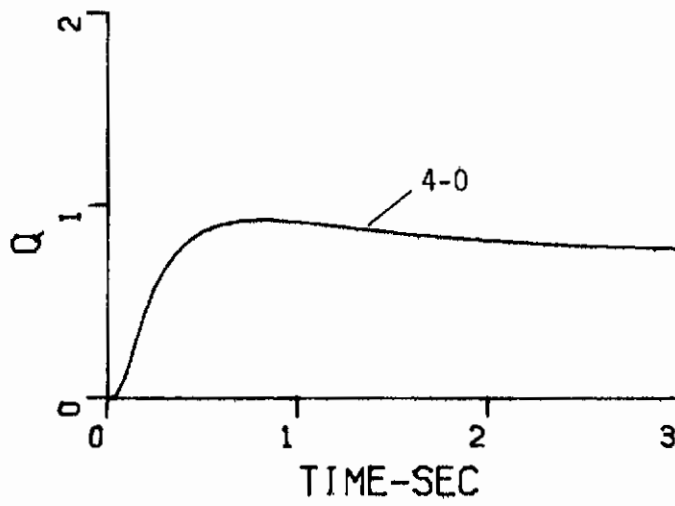


Figure 37 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 4 (Cont'd)

Contrails

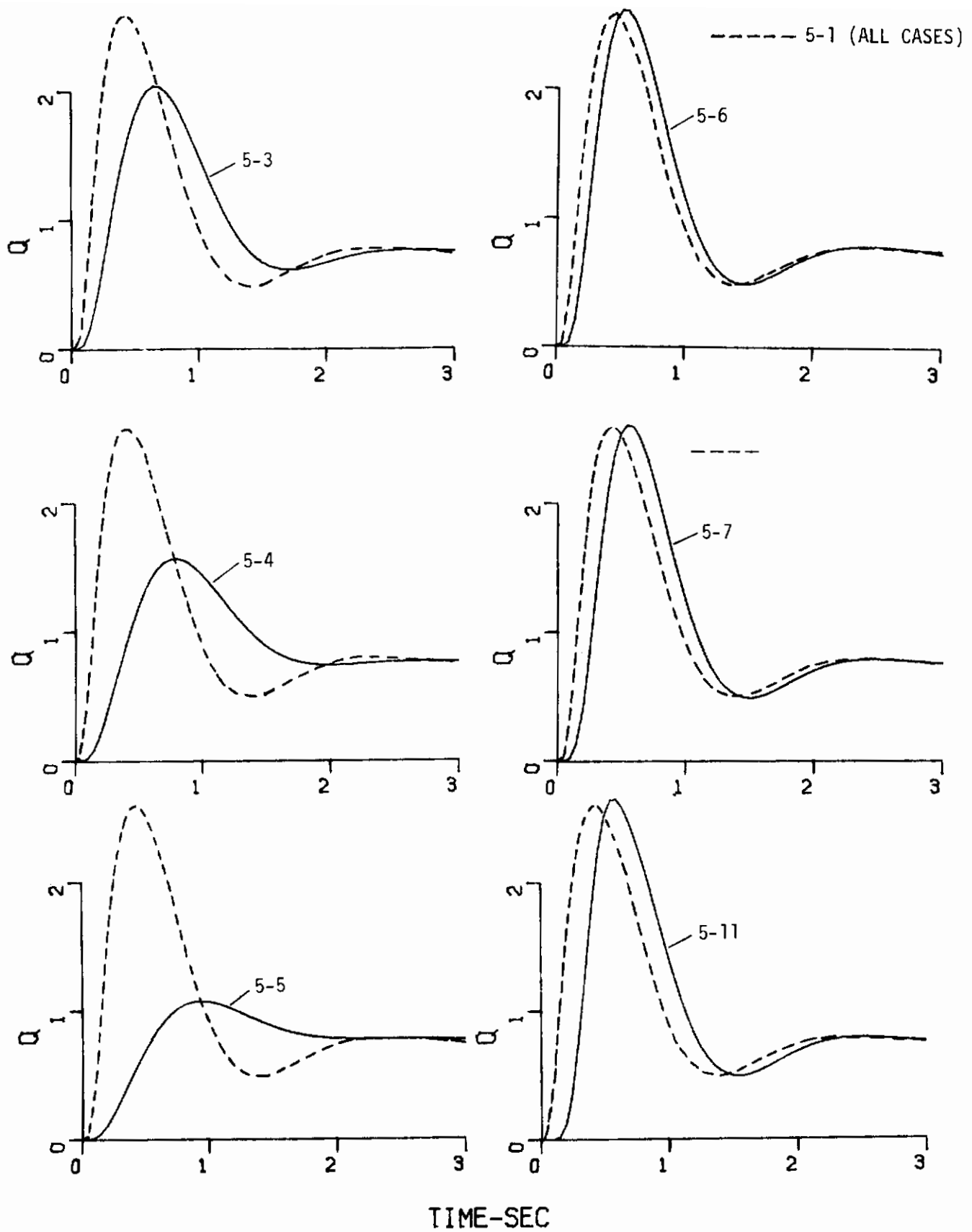


Figure 38 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 5

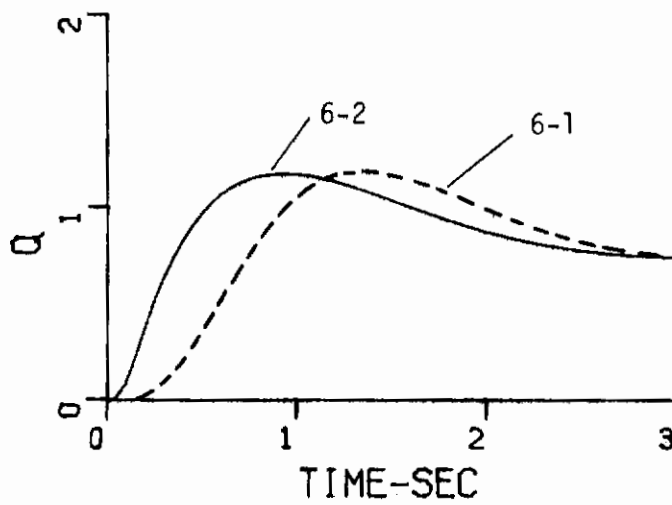


Figure 39 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 6

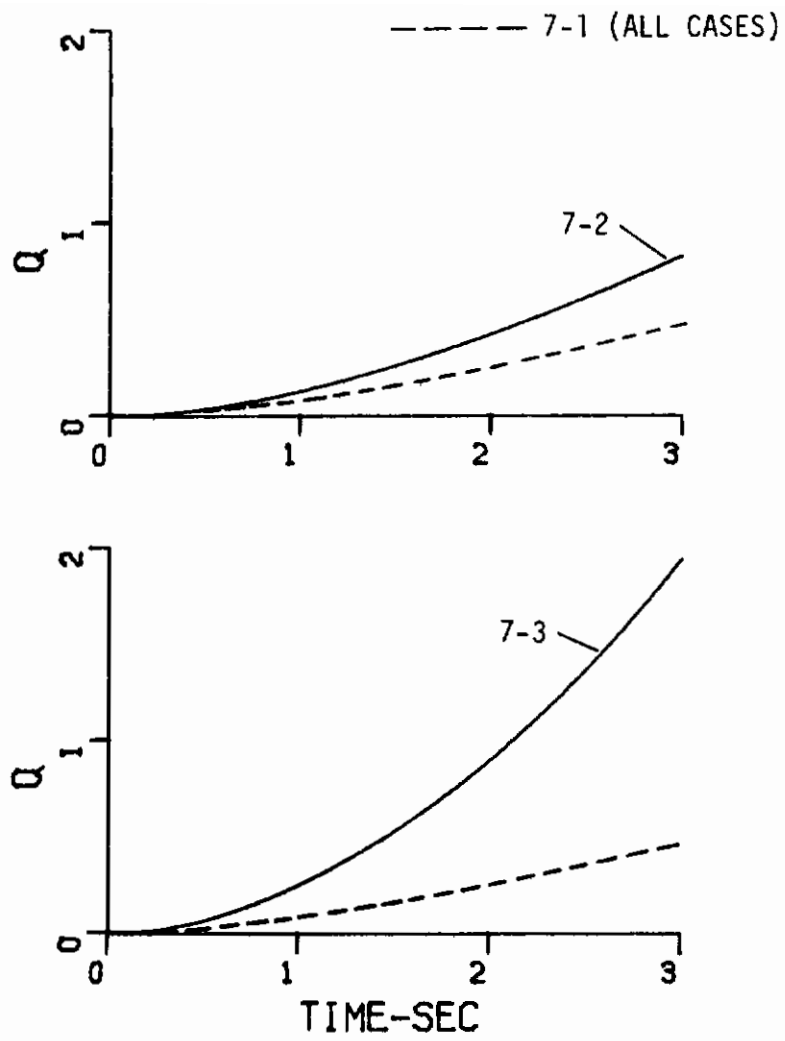


Figure 40 : PITCH RATE STEP RESPONSES FOR CONFIGURATION 7

APPENDIX IV

PARAMETER IDENTIFICATION TECHNIQUE AND CONFIGURATION CHARACTERISTICS

One purpose of this appendix is to present a brief outline of the parameter identification procedure used to identify the characteristics of the base aircraft dynamics for each set of evaluation configurations. In addition, an outline of the calibration procedures is presented along with a summary of the detailed dynamic characteristics of the identified configurations. Finally, the approach speed schedule employed in the program is presented, along with a review of the effects of these approach speed variations on the aircraft dynamics.

- DIGITAL PARAMETER IDENTIFICATION PROCEDURE
by Dr. K. S. Govindaraj

During the past ten years, techniques to identify the stability and control derivatives of a rigid body aircraft have been developed and steadily refined. The iterated Kalman filter and the maximum likelihood techniques have been extensively used for time-domain identification of the stability and control derivatives. (For example, References IV-1, 2). The transfer functions may be determined once the stability and control derivatives are identified. Since the transfer function coefficients determined are more closely related to flying qualities parameters, it is desirable to identify the transfer function coefficients directly.

-
- Ref. IV-1. 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", Calspan Report No. BM-2820-F-1, August 1971.
- IV-2. Eulrich, B. J., Mesiah, C. and Lyons, J.R., "F-106A Models for Use With the BML and LS Parameter Identification Computer Programs: Description and User's Guide", Calspan TIFS Memo No. 823 July 1977.

The equations of motion may be transformed, by a linear transformation into the transfer function form. This special form for identification is called the phase variable form (Reference IV-3). The numerator and the denominator coefficients of the transfer functions of the states representing the equations of motion are the parameters of the phase variable form. The stability derivatives may be determined once the phase variable parameters are identified. A brief description of the phase variable form for identification is given in this subsection.

The equations of motion that are used for identification may be described by a set of first order differential equations of the form

$$\begin{aligned}\dot{x}(t) &= Fx(t) + Gu(t) \\ z(t) &= Hx(t)\end{aligned}\tag{1}$$

where x is an $n \times 1$ state vector, u is a scalar input, and z is a $p \times 1$ measurement vector.

With the transformation

$$x = Ty\tag{2}$$

the transformed equations are given by

$$\begin{aligned}\dot{y} &= F_0 y + G_0 u \\ z &= H_0 y\end{aligned}\tag{3}$$

Ref. IV-3. Govindaraj, K.S. and Rynaski, E.G., "Parameter Identification Using Canonical Transformations", Calspan Flight Research Memorandum No. 524, November 1977.

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where

$$\begin{aligned}F_0 &= T^{-1}FT \\G_0 &= T^{-1}G \\H_0 &= HT\end{aligned}\tag{4}$$

$$F_0 = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -a_0 & -a_1 & \dots & \dots & -a_{n-1} \end{bmatrix} \quad G_0 = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ \vdots \\ 1 \end{bmatrix}$$

$$T = \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{n1} & t_{n2} & \dots & t_{nn} \end{bmatrix}\tag{5}$$

The elements of the last row of the F_0 matrix are obtained from the coefficients of the characteristic polynomial F

$$|SI - F| = s^n + a_{n-1}s^{n-1} + a_{n-2}s^{n-2} + \dots + a_1s + a_0\tag{6}$$

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The rows of the transformation matrix are obtained from the coefficients of the numerator polynomials of the transfer functions of the states of Equation (1). For instance, the numerators of the transfer functions x_1/u and x_2/u are

$$\begin{aligned}N\left(\frac{x_1}{u}\right) &= t_{1n} S^{n-1} + t_{1n-1} S^{n-2} + \dots + t_{12} S + t_{11} \\N\left(\frac{x_2}{u}\right) &= t_{2n} S^{n-1} + t_{2n-1} S^{n-2} + \dots + t_{22} S + t_{21}\end{aligned}\tag{7}$$

The stability and control derivatives are obtained from the phase variable form by transforming back into the equations of motion form (1):

$$\begin{aligned}F &= TF_0 T^{-1} \\G &= TG_0\end{aligned}\tag{8}$$

The advantages of the phase variable form for identification are significant. The transformation is canonical, which means that we obtain the minimum number of parameters required to define the dynamic characteristics of the airplane completely. This tends to eliminate the problem of linear dependency among parameters and enhances identifiability of parameters. Both stability and control derivatives and flying qualities parameters are obtained, so the data are in the correct form for aerodynamicists, flying qualities engineers and flight control system designers.

An additional technique has been developed by Calspan for the identification of unstable aircraft characteristics; this technique was used successfully in this program to identify the characteristics of Configurations 7-1 and 7-3, both of which were statically unstable aircraft. Simply stated, the method involves a translation of all the characteristic roots such that the unstable root is translated into the left half-plane, i.e. to a stable location. The identification procedure is then employed; the characteristics are identified and then the roots are translated back. Thus the unstable characteristic root can be successfully identified, which would not be the case using standard digital identification procedures.

The flight calibration records and the match produced using the identified digital characteristics are presented for all the basic aircraft dynamic configurations in Figures 41 through 50 . Note that the calibration data were obtained by having the pilot simply fly the aircraft in a manner which provides sufficient variation in the response parameters and a range of input frequencies. The initial pitch doublet was included for reference and is not a requirement of the calibration procedure. Typically, 30 second records were analyzed; only 24 seconds are shown in the figures.

For the figures, the following units apply:

THET	-	pitch attitude ~ deg
Q	-	pitch rate ~ deg/sec
W	-	body axis vertical velocity (c.g.) ~ ft/sec
DES	-	longitudinal stick position ~ inches (aft positive)
U	-	longitudinal true velocity ~ ft/sec
NX	-	longitudinal acceleration ~ ft/sec ² (forward positive)
NZ	-	normal acceleration ~ ft/sec ² (positive down)

In comparing the quality of the match between the flight and identified data for different configurations, care must be taken with the scaling of the plots; through the magic of digital plotting routines the scaling is not always the same.

Configuration 7, the configuration with an increasingly unstable characteristic root, was by far the most difficult to identify consistently. In fact, Configuration 7-2 could not be satisfactorily identified because the available flight record was of poor quality. Since it was not possible to repeat the flight records, the characteristics for this configuration were estimated using the results from Configurations 7-1 and 7-3.

The identified characteristics for each aircraft dynamic configuration are summarized in Figure 51 through 61 which are discussed further in the next subsection of this appendix.

- CONFIGURATION AIRCRAFT DYNAMIC CHARACTERISTICS

The detailed dynamics characteristics for each base aircraft configuration (1-1, 2-1, 3-0, 3-1, 4-0, 4-1, and 5-1) plus Configurations 6, 7-1, 7-2, and 7-3 are presented in Figures 51 through 61 for the nominal 120 KIAS landing task speed. These summaries present all the longitudinal dimensional stability derivatives relative to body axes, the solution to the characteristic equation (typically into short-period and phugoid modes), and the transfer functions of u , w and θ with respect to S_{ES} . The dynamics of the high frequency elevator actuator are not included in these summaries. Some of the stability derivatives require special definitions because of the nature of the identification procedure; see Appendix V for details.

For the summaries, velocities are in ft/sec, angular rates are in rad/sec, trim pitch attitude (THET) is in degrees, and S_{ES} (D1) is in inches. Format is outlined on Figure 51. The definitions of the derivatives are given in the list of symbols.

- CALIBRATION PROCEDURES

The electronic filters which represented the simulated control system dynamics for each configuration were calibrated on the ground by standard frequency response and step response measurements.

The augmented aircraft dynamics for Configurations 1-1, 2-1, 3-0, 3-1, 4-0, 4-1, 5-1, 6, 7-1, 7-2 and 7-3 were identified from special calibration records taken in flight at the nominal weight conditions (135 KIAS approach speed, flaps 45 deg) using the digital parameter identification technique described in the first subsection. These identified characteristics were then

extrapolated to the appropriate landing task speed, which for the nominal case is 120 KIAS. As shown in the final subsection in this appendix, the changes in the dominant dynamic characteristics, such as the short period dynamics, with changes in approach speed and weight, are not large. Further, after each flight evaluation, short-period calibration records were taken (where appropriate) to ensure that the correct base configuration had been evaluated.

● APPROACH AND LANDING SPEED SCHEDULE

The approach speed was varied with changes in fuel remaining or aircraft weight to maintain approximately the same stall margin at all times. The following schedule was used:

<u>Fuel Remaining (Gals)</u>	<u>Weight (lbs)</u>	<u>Indicated Approach Speed, Kts</u>
150 (\pm 50)	11,700	125
250 "	12,350	130
350 "	13,000	135*
450 "	13,650	140
550 "	14,300	140

*Nominal Case, $I_y \approx 22,800 \text{ slug-ft}^2$

The speed appropriate to the last 50 ft prior to touchdown, or the landing task, was approximately 15 knots below the appropriate approach speed.

Accordingly, for the body of the report, the dynamic characteristics appropriate for the nominal landing speed of 120 KIAS are used. Since a configuration could be evaluated at different weights and therefore approach speeds, the dynamic characteristics did vary somewhat. These variations are discussed in the next subsection.

- EFFECT ON LONGITUDINAL CHARACTERISTICS OF SPEED VARIATIONS

As discussed in the previous subsection, a given configuration could be evaluated at different aircraft weights and approach speeds, depending on when the configuration was evaluated during a flight. The longitudinal characteristics quoted in the report are for the nominal aircraft weight at the landing task speed of 120 KIAS. When flown at other weights, the landing task speed could vary from 110 to 125 KIAS. Fortunately, because the speed and weight both varied when a configuration was flown at off-nominal weights, the longitudinal dynamic characteristics did not vary more than $\pm 5\%$ with the range of off-nominal speed and aircraft weights encountered during the program. Essentially the tasks were flown at constant angles of attack.

For a given configuration, the approach speed was approximately 15 Kts faster than the landing task speed, i.e. between 125 and 140 KIAS. When a heavy weight, approach-only, evaluation was performed the speed was 145 KIAS. For the approach task, the dominant characteristics, such as short period frequency and pitch control sensitivity are about 20% higher than the landing task values. The value of τ_{θ_1} is about 10% less and the short period damping ratio is unchanged. The phugoid characteristics can be viewed as essentially unchanged, considering that the overall accuracy with which these characteristics were identified is somewhat less than that for the short-term characteristics.

Contrails

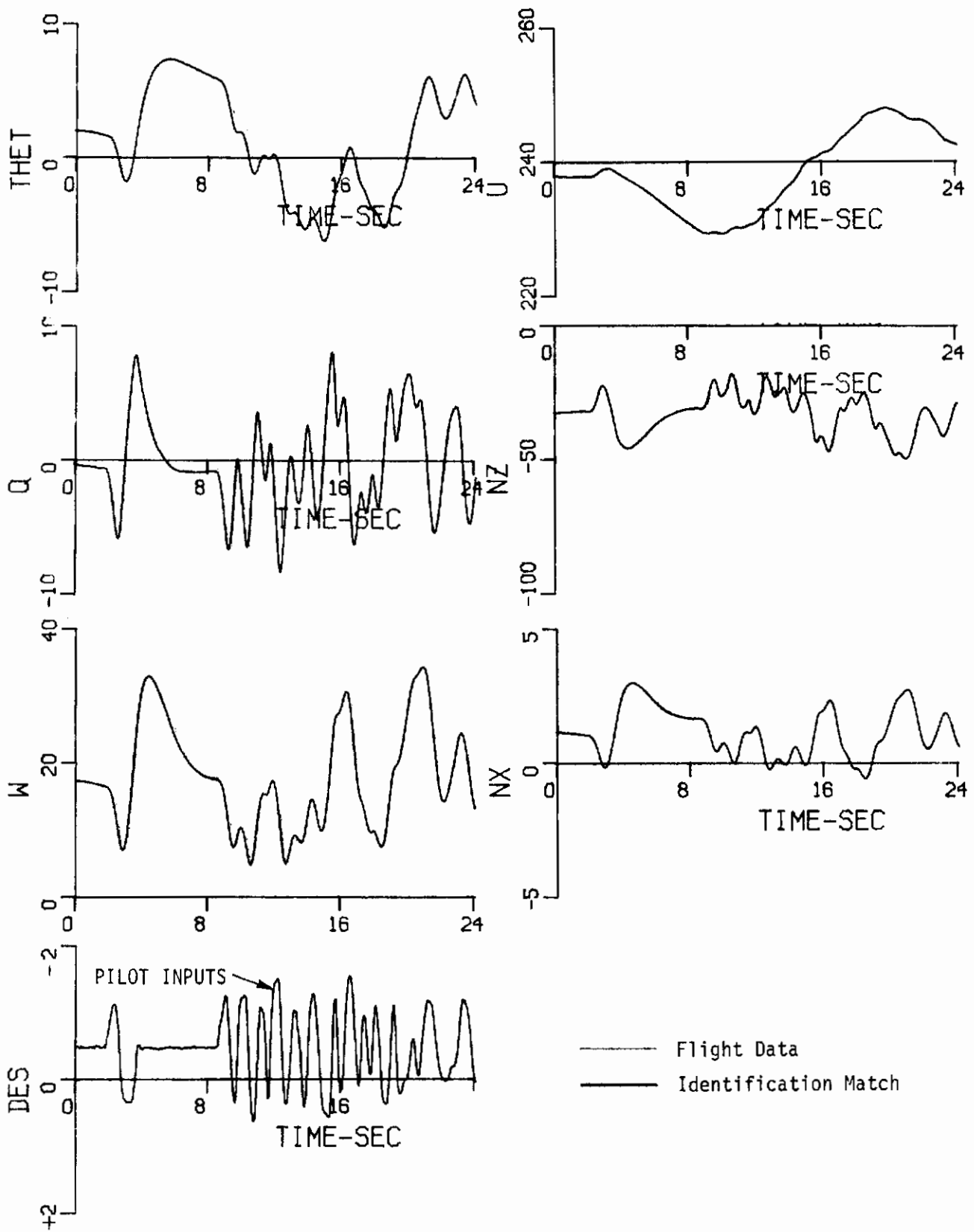


Figure 41 : CONFIGURATION 1-1 IDENTIFICATION RECORDS

Contrails

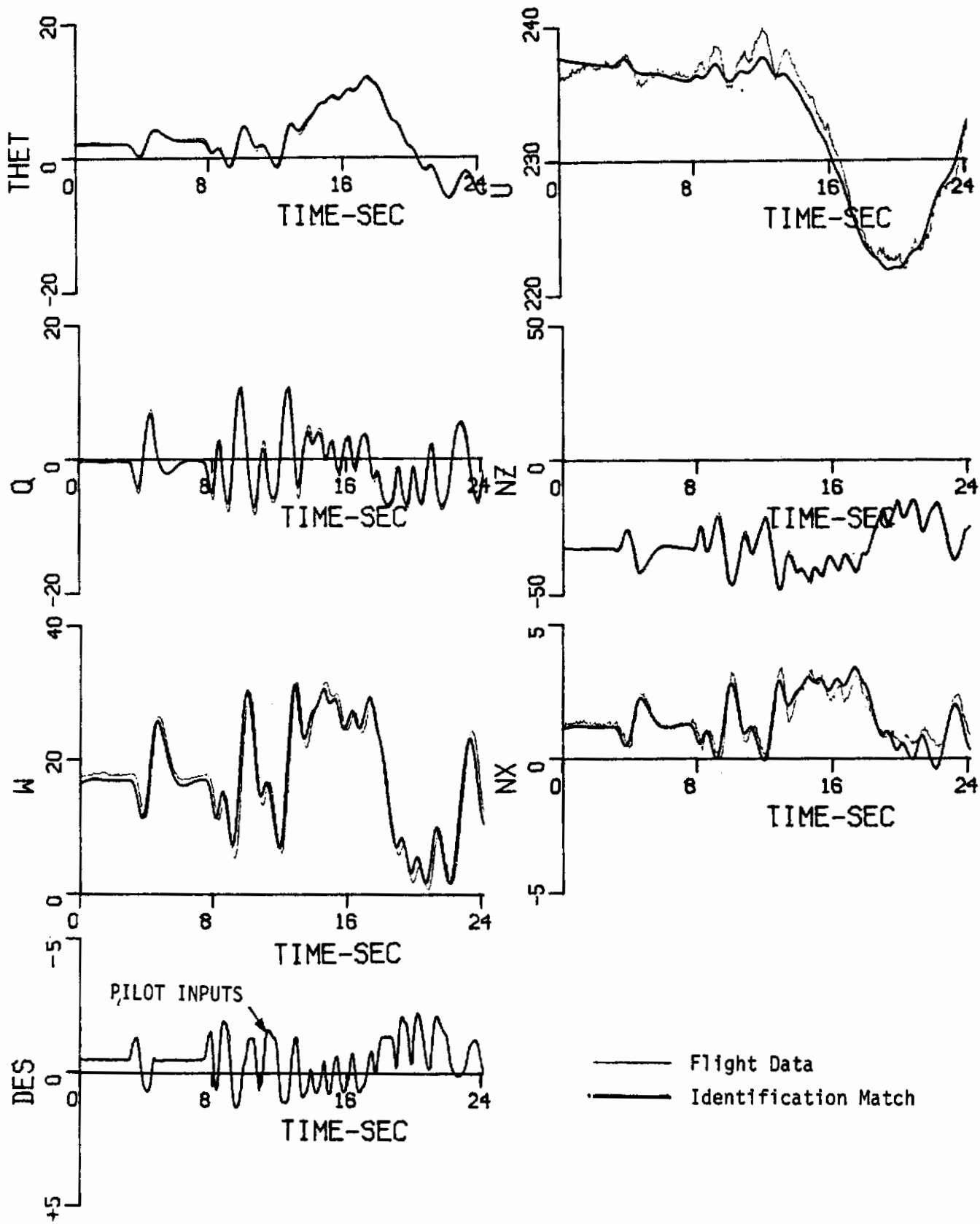


Figure 42 : CONFIGURATION 2-1 IDENTIFICATION RECORDS

Contrails

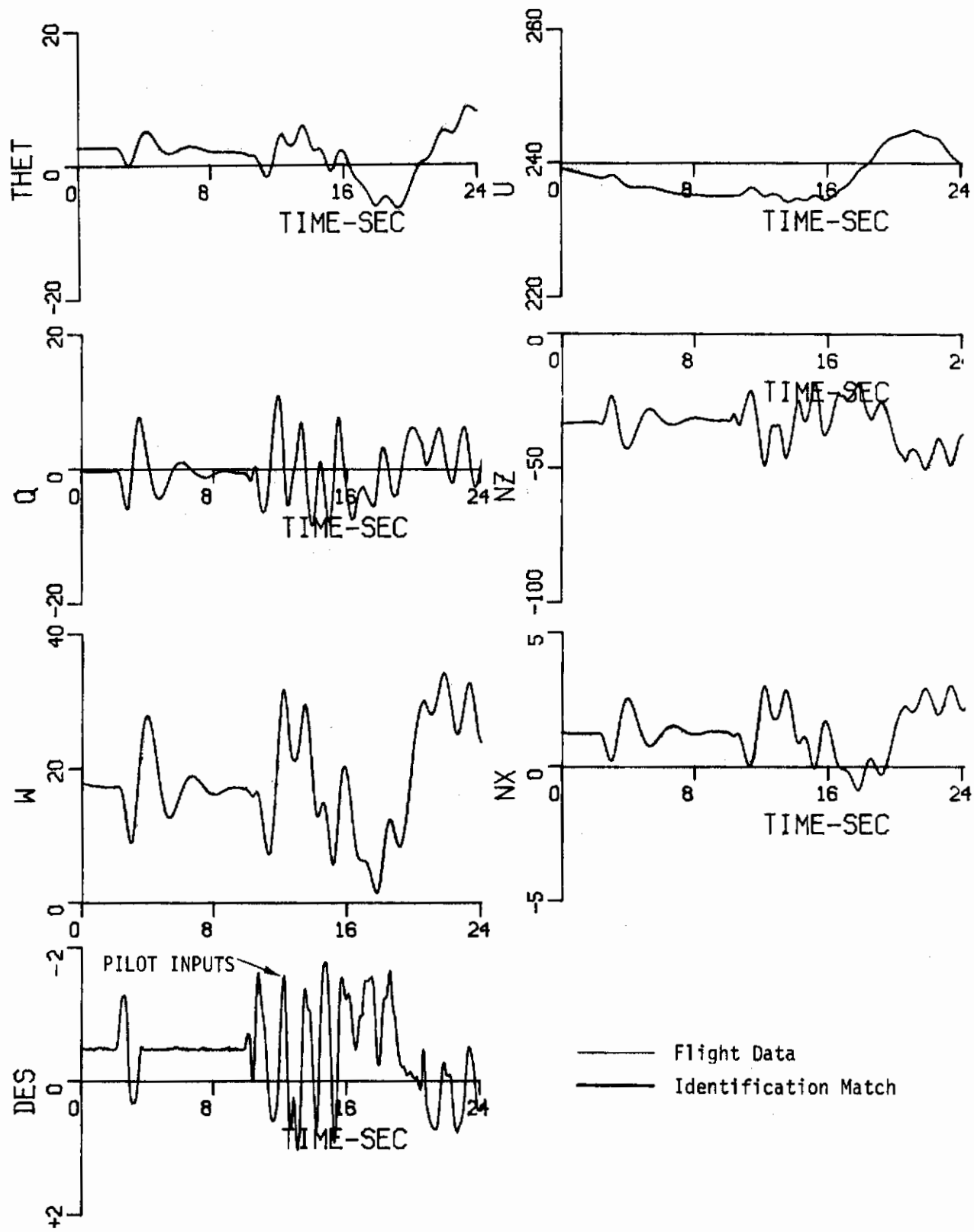


Figure 43 : CONFIGURATION 3-1 IDENTIFICATION RECORDS

Contrails

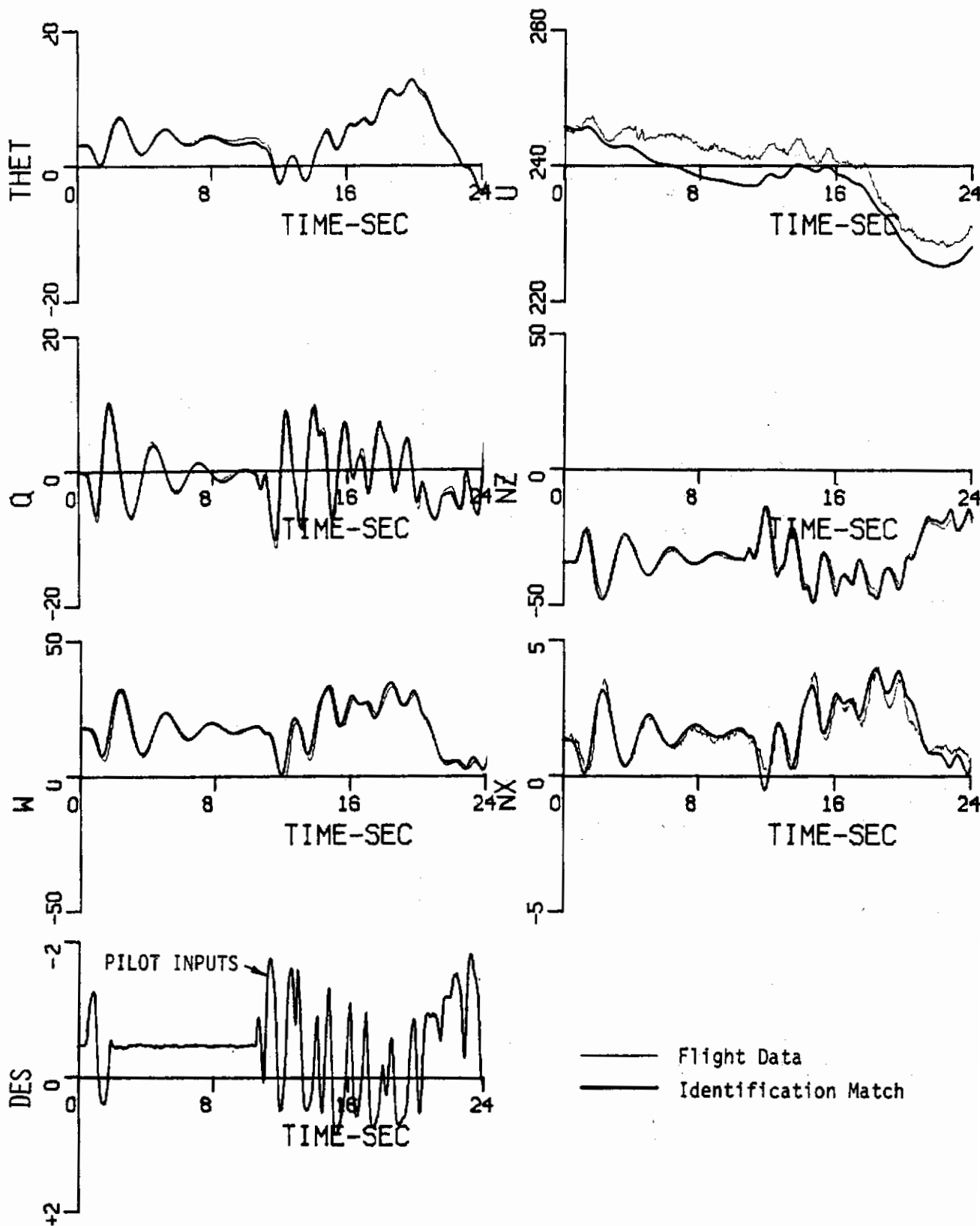


Figure 44 : CONFIGURATION 3-0 IDENTIFICATION RECORDS

Contrails

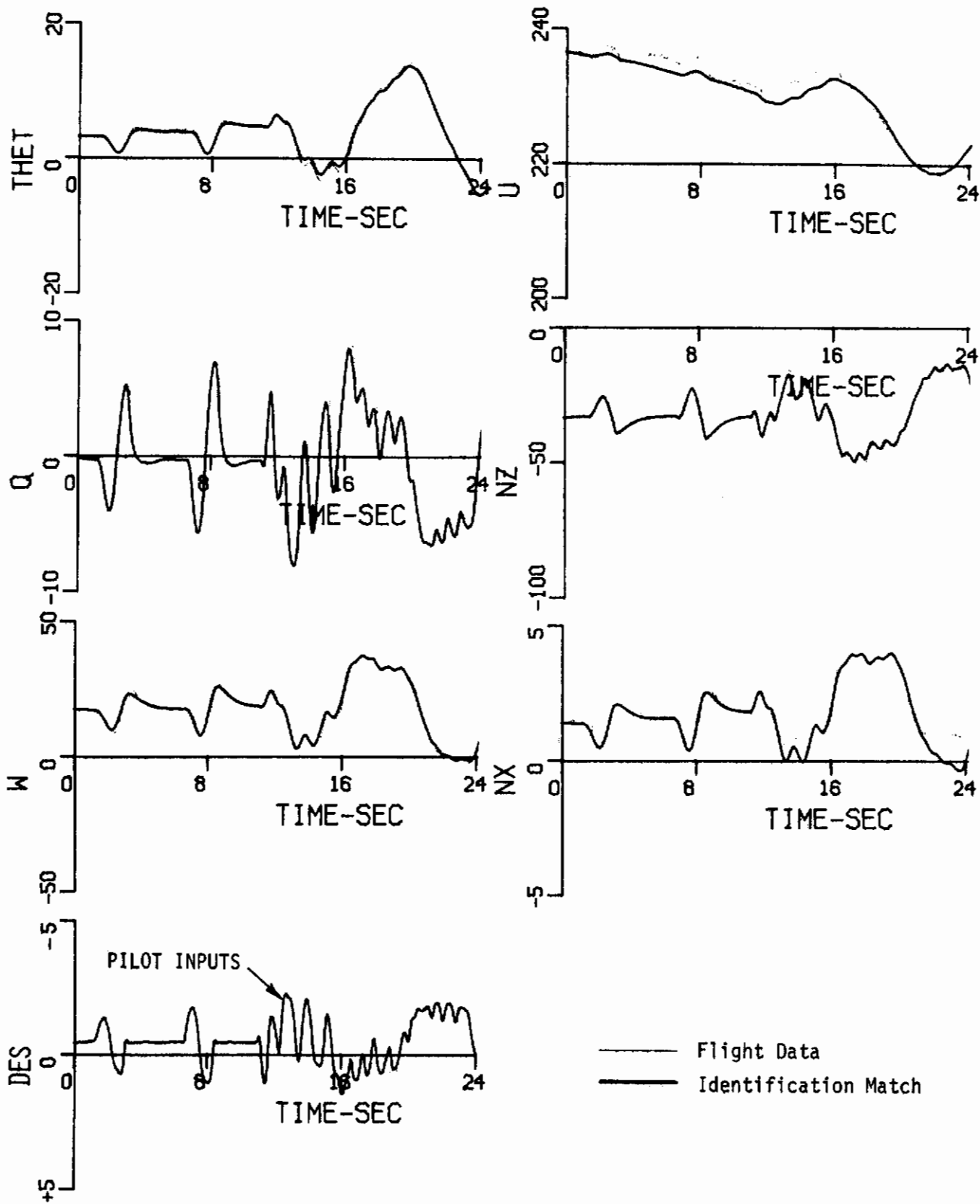


Figure 45 : CONFIGURATION 4-1 IDENTIFICATION RECORDS

Contrails

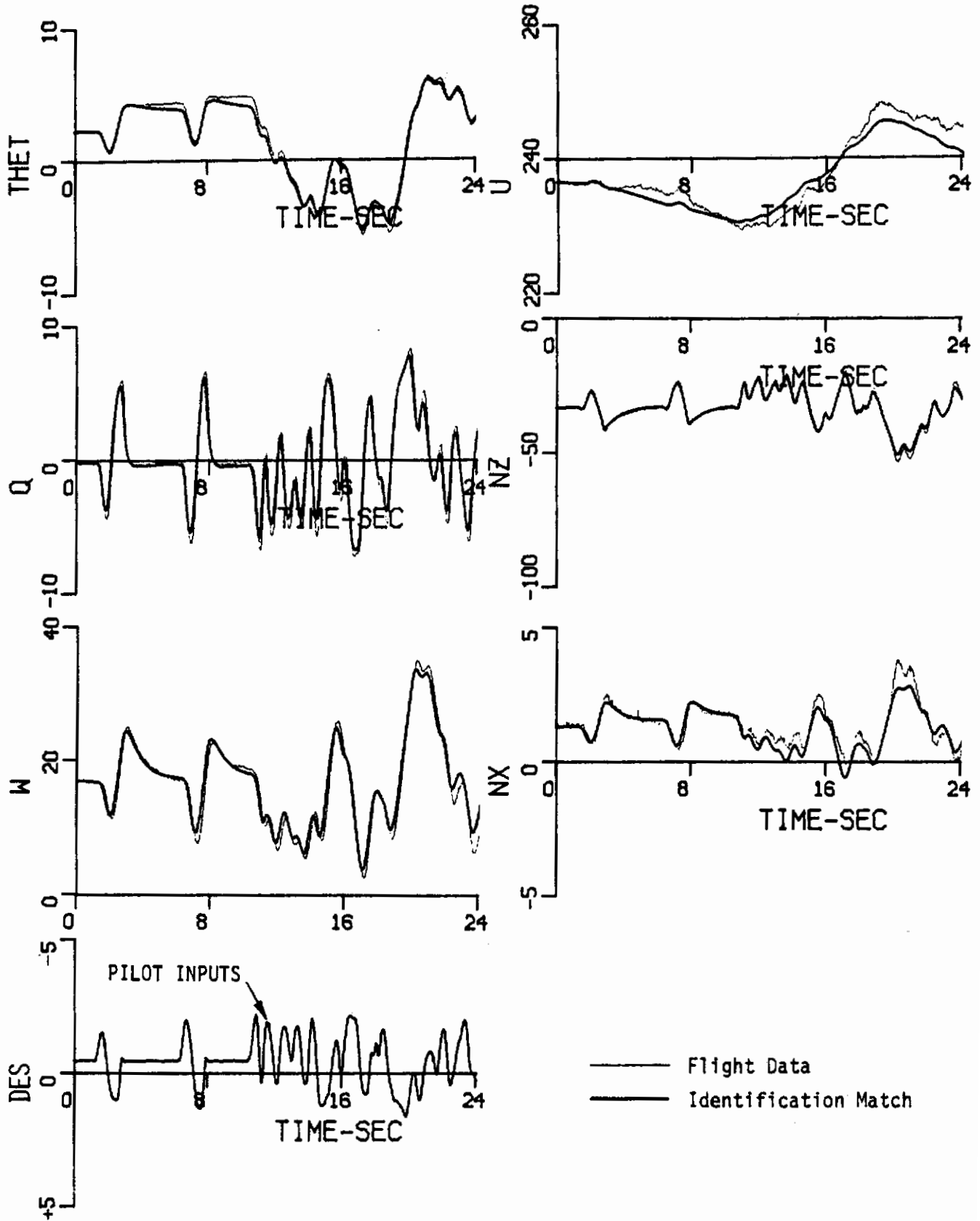


Figure 46 : CONFIGURATION 4-0 IDENTIFICATION RECORDS

Contrails

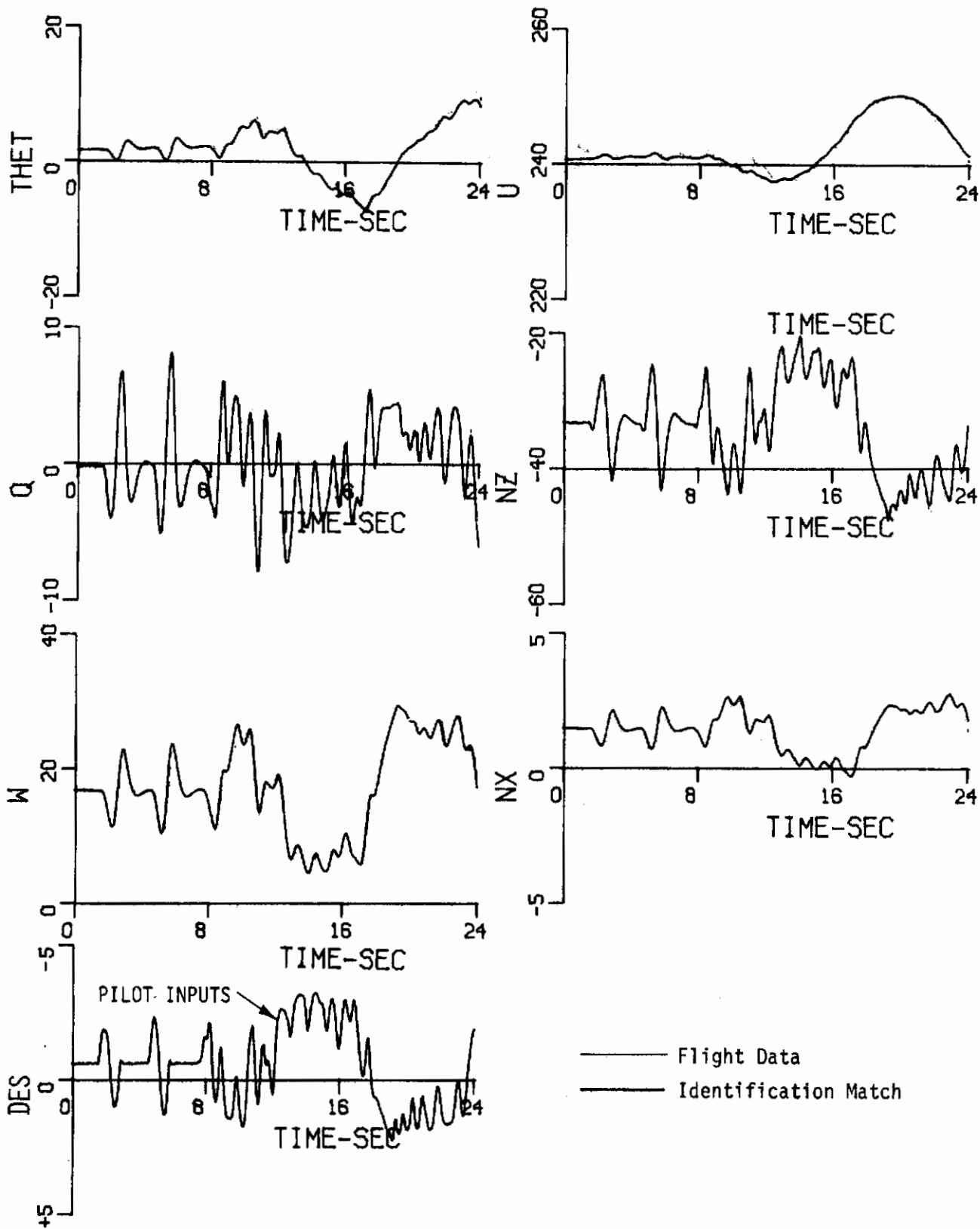


Figure 47 : CONFIGURATION 5-1 IDENTIFICATION RECORDS

Contrails

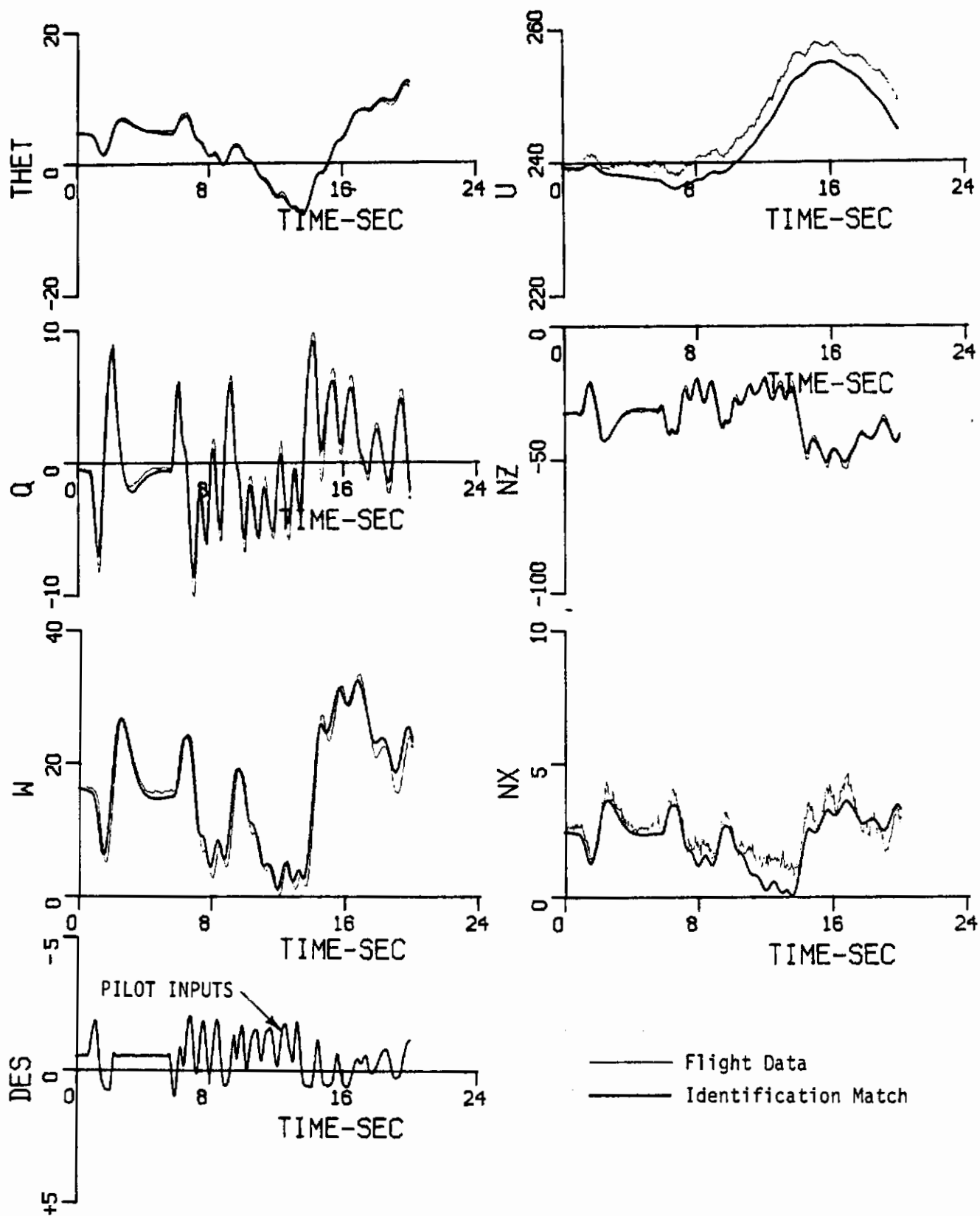


Figure 48 : CONFIGURATION 6 IDENTIFICATION RECORDS

Contrails

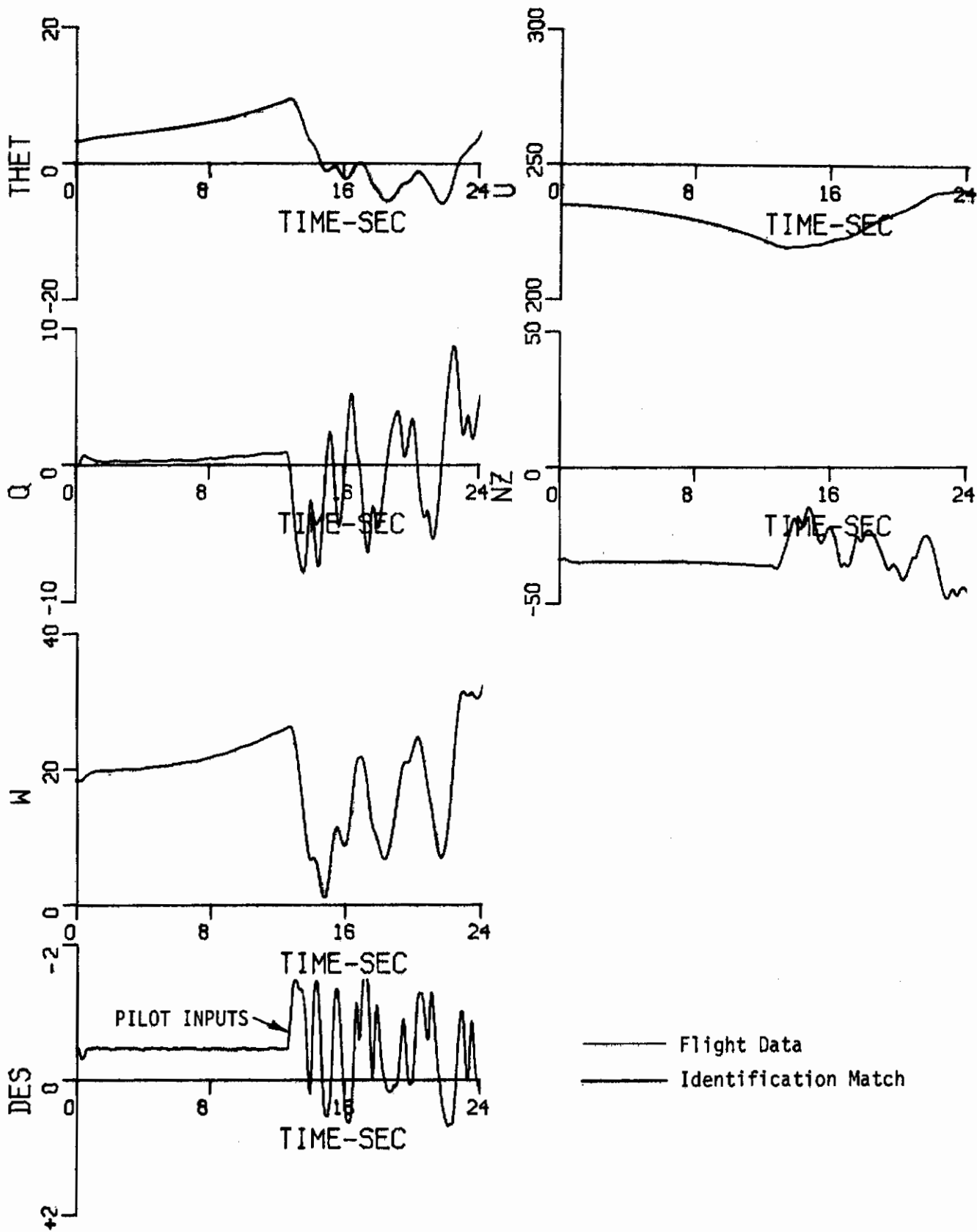


Figure 49 : CONFIGURATION 7-1 IDENTIFICATION RECORDS

Contrails

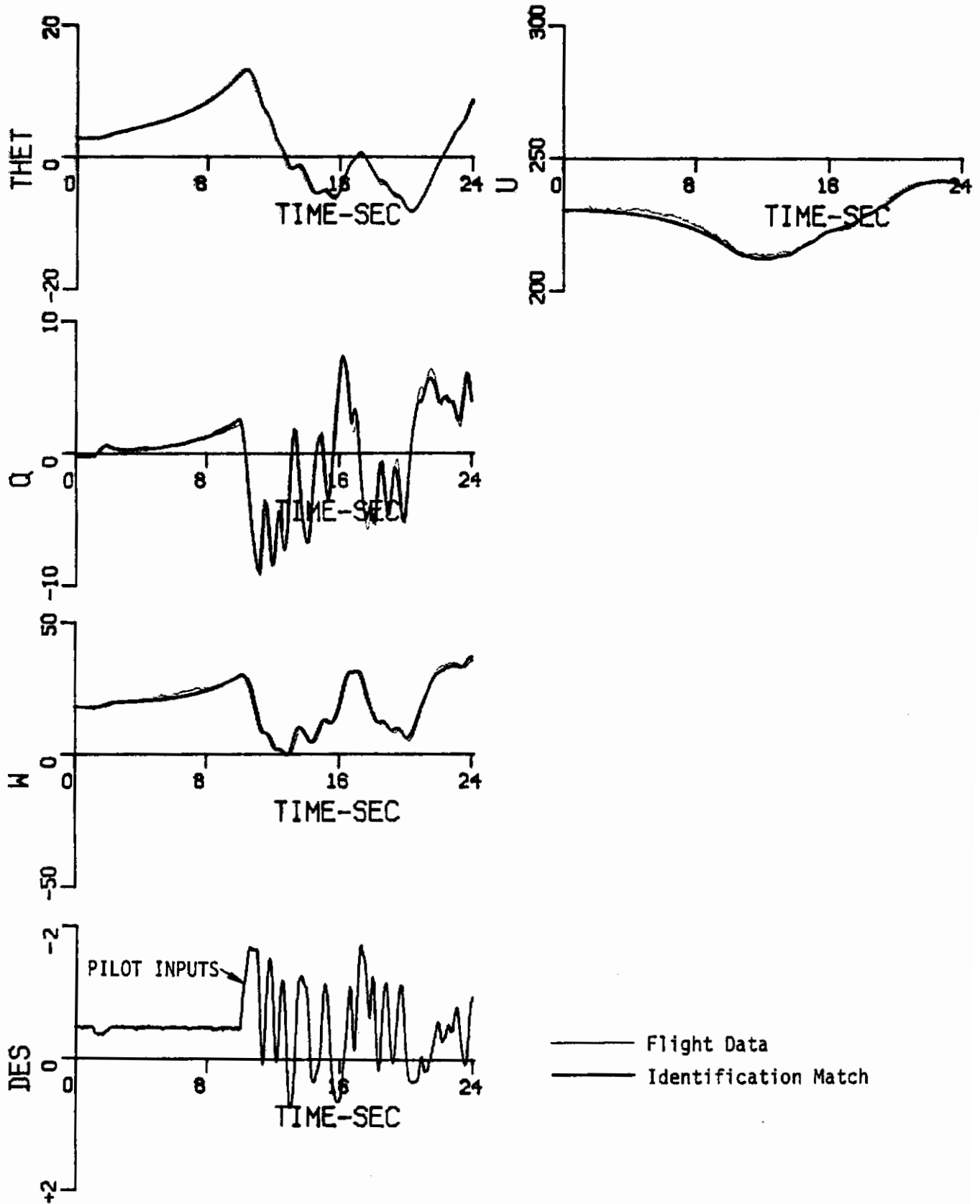


Figure 50: CONFIGURATION 7-3 IDENTIFICATION RECORDS

***** LONGITUDINAL INPUTS ***** Body Axis Dimensional Stability Derivatives

XU= -4.1000E-02 XW= 1.1000E-01 XQ= 0.0 WD= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.5000E-01 ZW= -7.5000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -2.3213E-03 MQ= -7.6000E-01 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION (IN DESCENDING POWERS OF S)

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W -DEG	THET/U	THET-DEG
1.0000E+00	1.5510E+00	1.1353E+00	7.2429E-02	1.8372E-02				
-7.5358E-01	6.9559E-01	7.3481E-01	1.0255E+00		2.4914E+01	1.4635E+02	8.1056E-02	-8.0415E+01
-2.1917E-02	1.3034E-01	1.6582E-01	1.3217E-01		1.8179E-01	1.7685E+02	4.2599E-03	6.7285E+01

Mode Ratios (Eigenvectors)

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W -DEG	THET/U	THET-DEG
U /D1 =	3.2000E-03	-8.2953E+00	-9.3644E+00	-8.1143E+00				
2.5934E 03				-3.8559E-04				
-5.6438E-01	-8.1193E-01	5.7077E-01	9.8882E-01					
W /D1 =	1.1000E+00	6.9933E+01	4.1199E+00	2.6660E+00				
-6.3518E+01				1.5744E-02				
-2.9183E-02	-1.9315E-01	1.4939E-01	1.9534E-01					
THETA/D1 =	3.3684E-01	2.6389E-01	1.9518E-02					
-8.2680E-02				1.2093E+01				
-7.0078E-01				1.4271E+00				

u/δEs

Numerator Polynomials
and Factors

w/δEs

δEs

Figure 51 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 1-1, V_{Ind}=120 KTS

*****LONGITUDINAL INPUTS*****

XU= -4.000E-02 XW= 1.1000E-01 XQ= 0.0 WD= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZW= -8.0000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -1.8745E-02 MQ= -1.8300E+00 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

1.0000E+00	2.6710E+00	5.4431E+00	3.4444E-01	1.5437E-01						
REAL	IMAGINARY	ZETA	OMEGA	TAU	W	/U	W	-DEG	THET/U	THET-DEG
-1.3101E+00	1.8830E+00	5.7011E-01	2.2980E+00		1.1825E+01		-1.6038E+02		4.9257E-02	2.5492E-01
-2.5359E-02	1.6908E-01	1.4832E-01	1.7097E-01		8.8904E-02		1.7766E+02		5.3775E-03	7.3775E+01

*****THE TRANSFER FUNCTIONS*****

U	/D1	=	3.2000E-03	-8.29175E+00	-9.19077E+00	-8.07526E+00
						-3.8576E-04
			-8.1632E-01	5.6166E-01	9.8665E-01	
W	/D1	=	1.10300E+00	7.11108E+01	4.25147E+00	2.77408E+00
						1.5483E-02
			-1.9537E-01	1.4939E-01	1.9760E-01	
THET/D1		=	3.36847E-01	2.62669E-01	1.98526E-02	
						1.1792E+01
						1.4389E+00

Figure 52 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 2-1, $V_{ind} = 120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.1000E-02 XW= 1.1000E-01 XQ= 0.0 WO= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZV= -8.1000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -2.2881E-02 MQ= 2.1000E-01 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W -DEG	THET/U	THET-DEG
1.0000E+00	6.4100E-01	4.5737E+00	2.7031E-01	1.8844E-01				
-2.9319E-01	2.1009E+00	1.3822E-01	2.1213E+00		9.4851E+00	-1.4631E+02	4.7359E-02	1.2281E+01
-2.7307E-02	2.0281E-01	1.3344E-01	2.0464E-01		1.7963E-02	-4.5474E+01	6.4341E-03	7.7376E+01

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.29825E+00	-9.41059E+00	-8.03740E+00
2.5943E+03				-3.8545E-04
-5.6696E-01	-8.0417E-01	5.7621E-01	9.8394E-01	
W /D1 =	1.1000E+00	6.38668E+01	4.16116E+00	2.77408E+00
-6.2546E+01				1.5988E-02
-2.9918E-02	-1.9856E-01	1.4900E-01	2.0080E-01	
THET/D1 =	3.36847E-01	2.61487E-01	1.98076E-02	
-8.5073E-02				1.1755E+01
-6.9121E-01				1.4467E+00

Figure 53 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 3-0, $V_{ind.} = 120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.1000E-02 XW= 1.1000E-01 XQ= 0.0 WD= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZW= -8.1000E-01 ZO= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -2.2392E-02 MQ= -2.9000E-01 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W	-DEG	THET/U	THET-DEG
1.0000E+00	1.1410E+00	4.8991E+00	2.9516E-01	1.8441E-01					
-5.4412E-01	2.1230E+00	2.4827E-01	2.1916E+00		1.0180E+01		-1.4929E+02	4.8647E-02	9.5073E+00
-2.6376E-02	1.9416E-01	1.3461E-01	1.9594E-01		1.7650E-02		-1.4945E+02	6.1607E-03	7.6443E+01

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.29665E+00	-9.36255E+00	-8.05463E+00
2.5938E+03				-3.8553E-04
-5.6418E-01	-8.0753E-01	5.7272E-01	9.8509E-01	
W /D1 =	1.1000E+00	6.94168E+01	4.18330E+00	2.77408E+00
-6.3046E+01				1.5861E-02
-2.9843E-02	-1.9776E-01	1.4921E-01	2.0000E-01	
THET/D1 =	3.36847E-01	2.62025E-01	1.98292E-02	
-8.4955E-02				1.1771E+01
-6.9292E-01				1.4432E+00

Figure 54 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 3-1, $V_{ind.} = 120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.1000E-02 XW= 1.1000E-01 XQ= 0.0 WO= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZW= -7.5000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -5.3267E-03 MQ= -4.4510E+00 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W	-DEG	THET/U	THET-DEG
1.0000E+00	5.2420E+00	4.6721E+00	3.3012E-01	4.3858E-02					
-1.0486E+00				9.5367E-01	9.9511E+00	-1.8000E+02		1.4857E-02	0.0
-4.1293E+00				2.4217E-01	1.0341E+01	-1.8000E+02		4.1467E-02	0.0
-3.2063E-02	9.5411E-02	3.1854E-01	1.0065E-01		2.6467E-01	1.7307E+02		3.1689E-03	5.3259E+01

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.28353E+00	-8.82438E+00	-8.00836E+00
2.5897E+03				-3.8615E-04
-5.3261E-01	-8.2626E-01	5.4180E-01	9.8305E-01	
W /D1 =	1.1000E+00	7.39939E+01	4.36750E+00	2.77408E+00
-5.7209E+01				1.4879E-02
-2.9259E-02	-1.9149E-01	1.5105E-01	1.9371E-01	
THET/D1 =	3.36847E-01	2.60586E-01	1.97560E-02	
-8.5196E-02				1.1738E+01
-6.8841E-01				1.4526E+00

Figure 55 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 4-0, $V_{ind}=120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.1000E-02 XW= 1.1000E-01 XQ= 0.0 WO= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZW= -7.6000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -6.5322E-03 MQ= -3.4900E+00 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E-00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

1.0000E+00 4.2910E+00 4.2149E+00 2.9067E-01 5.4619E-02

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	-DEG	THET/U	THET-DEG
-1.3912E+00				7.1883E-01	1.1625E+01	-1.8000E+02	2.6405E-02	0.0
-2.8411E+00				3.5198E-01	1.1194E+01	-1.8000E+02	4.0271E-02	0.0
-2.9373E-02	1.1533E-01	2.4987E-01	1.1756E-01		2.2741E-01	1.7295E+02	3.7054E-03	6.6594E+01

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.28657E+00	-8.99030E+00	-8.07035E+00
2.5906E+03				-3.8601E-04
-5.4242E-01	-8.2418E-01	5.4976E-01	9.8666E-01	
W /D1 =	1.1000E+00	7.29368E+01	4.32495E+00	2.77408E+00
-6.6247E+01				1.5095E-02
-2.9388E-02	-1.9238E-01	1.5062E-01	1.9511E-01	
THET/D1 =	3.3684/E-01	2.62519E-01	1.98364E-02	
-8.4786E-02				1.1794E+01
-6.9455E-01				1.4398E+00

Figure 56 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 4-1, $V_{ind.}=120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.1000E-02 XV= 1.1000E-01 XQ= 0.0 XD1= 3.2000E-03
 ZU= -2.5000E-01 ZW= -9.2000E-01 ZQ= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -5.9341E-02 MQ= -3.2500E+00 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0
 WO= 2.5000E+01 XT= 0.0
 UO= 2.0500E+02 ZT= 0.0
 MD1= 3.3685E-01 THET= 4.5000E+00
 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W	/U	W	-DEG	THET/U	THET-DEG
1.0000E+00	4.2110E+00	1.5354E+01	9.5023E-01	4.6870E-01						
-2.0785E+00	3.2829E+00	5.3493E-01	3.8855E+00		9.9658E+00			-1.6558E+02	4.3655E-02	1.7226E+00
-2.7014E-02	1.7788E-01	1.5015E-01	1.7992E-01		5.5156E-02			1.7729E+02	5.6358E-03	7.5498E+01

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.2868E+00	-8.8815E+00	-7.9397E+00
2.5907E+03				-3.8600E-04
-5.3585E-01	-8.1890E-01	5.4755E-01	9.7863E-01	
W /D1 =	1.0000E+00	7.2672E+01	4.3143E+00	2.7740E+00
-6.6007E+01				1.5150E-02
-2.9420E-02	-1.9324E-01	1.5052E-01	1.9546E-01	
THET/D1 =	3.36847E-01	2.58435E-01	1.97128E-02	
-8.5894E-02				1.1642E+01
-6.8132E-01				1.4677E+00

Figure 57 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 5-1, $V_{ind}=120$ KTS

***** LONGITUDINAL INPUTS *****
 XU= -4.1000E-02 XW= 1.1000E-01 XQ= 0.0 WO= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZW= -7.7000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= -1.1939E-02 MQ= -1.7500E+00 MT= 0.0 MD1= 3.3685E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W	-DEG	THET/U	THET-DEG
1.0000E+00	2.5610E+00	3.9063E+00	2.5187E-01	9.7495E-02					
-1.2556E+00	1.4761E+00	6.4794E-01	1.9379E+00	1.3298E+01	-1.6243E+02	5.2185E-02	-4.3006E+00		
-2.4853E-02	1.5919E-01	1.5425E-01	1.6112E-01	1.1980E-01	1.7645E+02	5.0806E-03	7.2307E+01		

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.2921E+00	-9.14264E+00	-7.99475E+00
2.5924E+03				-3.8574E-04
-5.5124E-01	-8.1232E-01	5.6151E-01	9.8170E-01	
W /D1 =	1.1000E+00	7.10228E+01	4.24793E+00	2.77408E+00
-6.4507E+01				1.5502E-02
-2.9630E-02	-1.9549E-01	1.4985E-01	1.9772E-01	
THET/D1 =	3.36847E-01	2.60160E-01	1.97440E-02	
-8.5316E-02				1.1721E+01
-6.8702E-01				1.4556E+00

Figure 58 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 6-1, $V_{ind.}=120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.0000E-02 XW= 1.1000E-01 XO= 0.0 WO= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.5000E-01 ZW= -7.3000E-01 ZO= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= 2.6700E-03 MO= -1.6000E+00 MT= 0.0 MD1= 3.3700E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W	/U	-DEG	THET/U	THET-DEG
1.0000E+00	2.3700E+00	7.4245E-01	5.9970E-02	-2.1995E-02					
-2.0198E+00				4.9510E-01	1.1784E+01		-1.3000E+02	3.7108E-02	0.0
-2.3483E-01	1.8932E-01	7.7769E-01	3.0196E-01	-8.3726E+00	1.0317E+00		1.1043E+02	6.6186E-03	1.4146E+02
1.1944E-01					4.6106E-01		-1.8000E+02	5.9943E-03	0.0

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.29654E+00	-9.23728E+00	-8.07798E+00
2.5938E+03				-3.8554E-04
-5.5664E-01	-8.1443E-01	5.6424E-01	9.8653E-01	
W /D1 =	1.1000E+00	7.08881E+01	4.17234E+00	2.77619E+00
-6.4385E+01				1.5531E-02
-2.9151E-02	-1.9583E-01	1.4724E-01	1.9799E-01	
THET/D1 =	3.3700E-01	2.62427E-01	1.95938E-02	
-8.3650E-02				1.1955E+01
-6.9507E-01				1.4387E+00

Figure 59 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 7-1, $V_{ind.}=120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.0000E-02 XW= 1.1000E-01 XQ= 0.0 WO= 2.5000E+01 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZV= -7.3000E-01 ZQ= 0.0 UO= 2.0500E+02 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= 4.0900E-03 MQ= -1.6000E+00 MT= 0.0 MD1= 3.3700E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

1.0000E+00 2.3700E+00 4.5135E-01 4.2681E-02 -3.3693E-02

REAL	IMAGINARY	ZETA	OMEGA	TAU	W	/U	-DEG	THET/U	THET-DEG
-2.1748E+00				4.5982E-01	1.1668E+01		-1.8000E+02	3.8179E-02	0.0
-1.8370E-01	2.3717E-01	5.1233E-01	2.9999E-01	-5.8089E+00	8.1040E-01		8.1550E+01	7.6940E-03	1.2428E+02
1.7215E-01					5.6172E-01		-1.8000E+02	7.5307E-03	0.0

*****THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.29654E+00	-9.27726E+00	-8.12806E+00
2.5938E+03				-3.8554E-04
-5.5905E-01	-8.1554E-01	5.6494E-01	9.8958E-01	
W /D1 =	1.1000E+00	7.08881E+01	4.17234E+00	2.77619E+00
-6.4385E+01				1.5531E-02
-2.9151E-02	-1.9583E-01	1.4724E-01	1.9799E-01	
THET/D1 =	3.3700E-01	2.63989E-01	1.96551E-02	
-8.3316E-02				1.2003E+01
-7.0003E-01				1.4285E+00

Figure 60 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 7-2, $V_{ind}=120$ KTS

***** LONGITUDINAL INPUTS *****

XU= -4.0000E-02 XW= 1.1000E-01 XQ= 0.0 XT= 0.0 XD1= 3.2000E-03
 ZU= -2.6000E-01 ZW= -7.3000E-01 ZQ= 0.0 ZT= 0.0 ZD1= 1.1000E+00
 MU= 0.0 MW= 7.5300E-03 MQ= -1.5000E+00 MT= 0.0 MD1= 3.3700E-01 THET= 4.5000E+00
 XD2= 0.0 XD3= 0.0 ZD2= 0.0 ZD3= 0.0 MD2= 0.0 MD3= 0.0

OUTPUT FORMAT : THE CHARACTERISTIC EQUATION IN DESCENDING POWERS OF S

REAL	IMAGINARY	ZETA	OMEGA	TAU	W /U	W -DEG	THET/U	THET-DEG
1.0000E+00	2.3700E+00	-2.6000E-01	4.3032E-04	-6.2279E-02				
3.2089E-01				-3.1163E+00	9.4533E-01	-1.8000E+02	1.1554E-02	0.0
-2.4790E+00				4.0338E-01	1.1411E+01	-1.8000E+02	3.9588E-02	0.0
-1.0593E-01	2.5898E-01	3.7858E-01	2.7980E-01		4.5827E-01	4.4184E+01	8.1656E-03	1.0210E+02

***** THE TRANSFER FUNCTIONS*****

REAL	IMAGINARY	ZETA	OMEGA	TAU
U /D1 =	3.2000E-03	-8.29654E+00	-9.37496E+00	-8.25046E+00
2.5938E+03				-3.8553E-04
-5.6494E-01	-8.2150E-01	5.6654E-01	9.9700E-01	
W /D1 =	1.1000E+00	7.08981E+01	4.17234E+00	2.77619E+00
-6.4385E+01				1.5531E-02
-2.9151E-02	-1.9583E-01	1.4724E-01	1.9799E-01	
THE T/D1 =	3.3700E-01	2.67806E-01	1.98049E-02	1.2118E+01
-8.2522E-02				1.4042E+00
-7.1215E-01				

Figure 61 : LONGITUDINAL CHARACTERISTICS, CONFIGURATION 7-3, $V_{cmd} = 120$ KTS

APPENDIX V LONGITUDINAL TRANSFER FUNCTIONS

In this appendix, the longitudinal transfer functions are developed in support of the discussions in the text. The equations of motion applicable to the identification procedure and the detailed summaries of configuration characteristics discussed in Appendix IV are:

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & X_w & -g \cos \theta_0 & -\omega_0 \\ Z_u & Z_w & -g \sin \theta_0 & u_0 \\ M_u & M_w & 0 & M_q \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} X_{S_{ES}} \\ Z_{S_{ES}} \\ M_{S_{ES}} \\ 0 \end{bmatrix} \begin{bmatrix} S_{ES} \end{bmatrix}$$

These equations imply that the reference axes are body axes and that the wings are always level. For small angles, $u_0 \approx V_T$, the trim true airspeed, and $\alpha_0 \approx \frac{\omega_0}{V_T}$. The variables u , $w(\alpha)$, θ and S_{ES} are incremental values from the reference trim condition.

Note that the equations do not contain the derivatives $Z_{\dot{w}}$ and $M_{\dot{w}}$. These derivatives cannot be derived separately from the identified transfer function coefficients - recall that the parameter identification procedure identifies the transfer function characteristics directly.

$M_{\dot{w}}$ is effectively included in the identified derivatives in the above matrix. ($Z_{\dot{w}}$ assumed zero). For example, the identified M_q is really the basic $M_q + u_0 M_{\dot{w}}$, and M_w is the basic $M_w + M_{\dot{w}} Z_w$. This definition of the derivatives does not affect the accuracy of the identified transfer functions.

The transfer functions for longitudinal stick inputs which follow, written in "lumped" derivative form, are representative of the transfer functions presented in Appendix IV for each configuration (except Configuration 7 which all have an unstable root). The specific derivatives which comprise each lumped parameter can be derived from the equations.

Contrails

$$\frac{u}{S_{ES}} = \frac{K_u (s + 1/\tau_u) (s^2 + 2\zeta_u \omega_u s + \omega_u^2)}{\underbrace{(s^2 + 2\zeta_{sp} \omega_{sp} s + \omega_{sp}^2)}_{D_1} \underbrace{(s^2 + 2\zeta_{ph} \omega_{ph} s + \omega_{ph}^2)}_{D_2}}$$

$$\frac{w}{S_{ES}} = \frac{K_w (s + 1/\tau_w) (s^2 + 2\zeta_w \omega_w s + \omega_w^2)}{D_1 D_2}$$

$$\frac{\theta}{S_{ES}} = \frac{K'_\theta (s + 1/\tau_{\theta_1}) (s + 1/\tau_{\theta_2})}{D_1 D_2}$$

where

$$K_u = X_{S_{ES}}$$

$$K_w = Z_{S_{ES}}$$

$$K'_\theta = M_{S_{ES}}$$

If the assumptions of constant speed and $\theta_0 \approx 0$ are made, and small terms are neglected, then the following transfer functions result:

Contrails

$$\frac{\theta}{S_{ES}} = \frac{M_{S_{ES}}}{\omega_{SP}^2 \tau_{\theta_2}} \frac{(\tau_{\theta_2} s + 1)}{s \left(\frac{s^2}{\omega_{SP}^2} + \frac{2\zeta_{SP} s}{\omega_{SP}} + 1 \right)}$$

$$\frac{\alpha}{S_{ES}} = \frac{1}{V_T} \frac{\omega}{S_{ES}} = \frac{M_{S_{ES}}}{\omega_{SP}^2} \frac{1}{\left(\frac{s^2}{\omega_{SP}^2} + \frac{2\zeta_{SP} s}{\omega_{SP}} + 1 \right)}$$

$$\frac{\eta_q}{S_{ES}} = \frac{M_{S_{ES}}}{\omega_{SP}^2} \left(\frac{V_T}{g \tau_{\theta_2}} \right) \frac{1}{\left(\frac{s^2}{\omega_{SP}^2} + \frac{2\zeta_{SP} s}{\omega_{SP}} + 1 \right)}$$

The following relationship can be derived from these transfer functions.

$$\frac{\eta_q}{\alpha} = \frac{V_T}{g} \frac{1}{\tau_{\theta_2}} \quad \sim g/\text{rad}$$

$$\frac{F_{ES}}{\eta} = \frac{\omega_{SP}^2}{M_{F_{ES}} (\eta/\alpha)} \quad ; \quad M_{F_{ES}} = \left(\frac{S_{ES}}{F_{ES}} \right) M_{S_{ES}}$$

and
$$K_{\theta} = \frac{M_{S_{ES}}}{\omega_{SP}^2 \tau_{\theta_2}}$$

APPENDIX VI SIMULATION MECHANIZATION

This in-flight experiment was performed in the three-axis variable stability NT-33 aircraft, modified and operated by Calspan for the USAF. The desired control system dynamics were simulated by altering the NT-33 "fly-by-wire" control system with suitable electronic circuits. Aircraft dynamic characteristics for each simulation configuration were achieved by using the variable stability response feedback system in the NT-33. As previously discussed in Section 2, the feel system characteristics were held fixed throughout the experiment; the feel system dynamics were mechanized using an electrohydraulic servo with position and rate feedbacks to control the frequency and damping. Although available, no friction or breakout forces were included in the simulation.

The desired short period dynamics were achieved by feeding back α and q signals to the NT-33 elevator actuator with the appropriate feedback gains; these gains were determined during special calibration flights. Unstable α feedback gains were used to produce Configuration 7. It is important to remember that because response feedbacks are used to the elevator, the numerators of the longitudinal transfer functions remain those of the NT-33 airframe. Specifically, z_{θ_2} is therefore the same for all configurations. Figure 62 shows a simplified block diagram of the mechanization of the aircraft dynamics. Figure 4 in Section 2 shows the complete longitudinal block diagram for the evaluation configurations.

Dynamics of the sensors and filters used in the NT-33 are defined in Reference 12. For this program a first order filter, $\tau = .03$ secs, was installed in the α feedback to the elevator to reduce the high frequency control surface activity in the turbulence when high α feedback gains were used to achieve Configuration 5 short period dynamics. For the α gains used in this program, the effect of this filter is not considered to be significant; reference the excellent identification matches presented in Appendix IV.

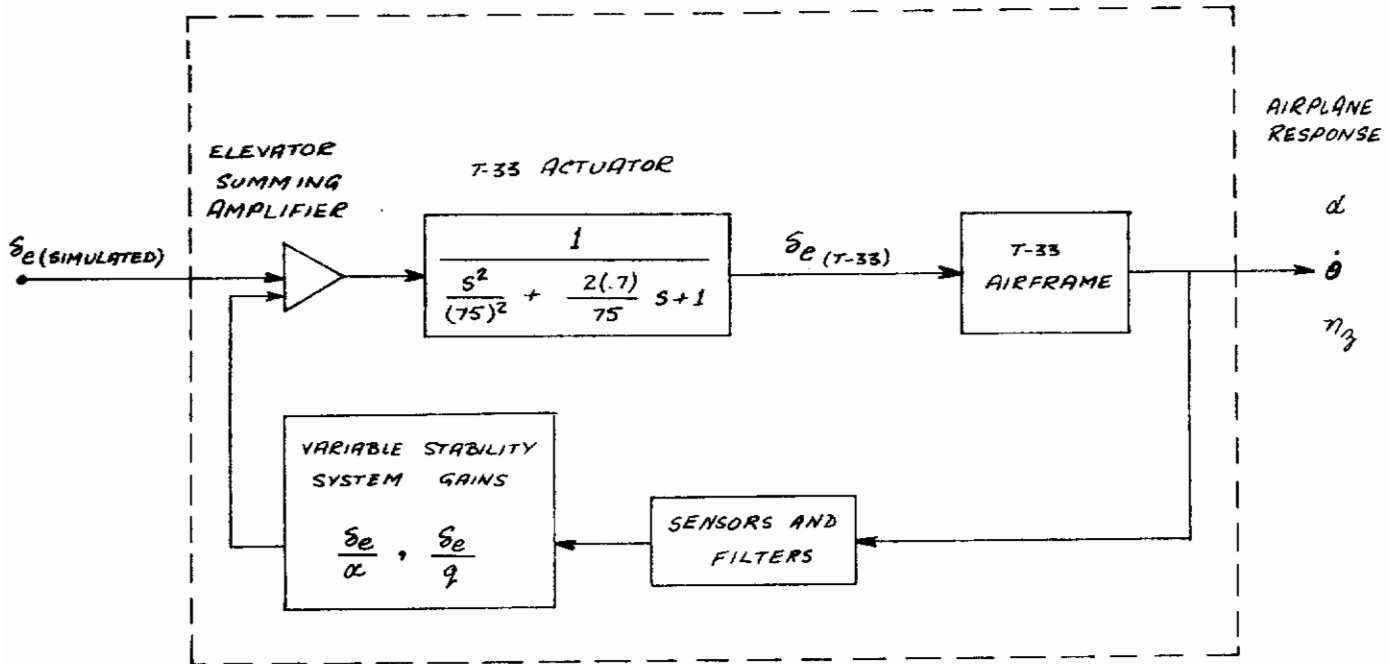


Figure 62: SIMULATION MECHANIZATION

With the response feedback loops closed, the NT-33 actuator roots will migrate somewhat; but since the roots are at high frequency, the movement is not of consequence and the characteristics can be viewed as fixed.

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

Contrails