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FOREWORD

This report was prepared for the National Aeronautics and Space Administration by Calspan Corporation, Buffalo, New York, in partial fulfillment of USAF Contract No. F33615-79-C-3618. This report describes an in-flight investigation of the effects of pilot-induced oscillation filters on the longitudinal flying qualities of fighter aircraft during the landing task.

The in-flight program reported herein was performed by the Flight Research Department of Calspan under sponsorship of the NASA/Dryden Flight Research Center, Edwards, California, working through a Calspan contract with the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratory, Wright-Patterson Air Force Base, Ohio. This work was part of Project 6645-F, NT-33, Task 9 and utilized the USAF/FDL NT-33 aircraft, modified and operated by Calspan. Mr. Jack Barry is the program manager for FDL; his assistance deserves special acknowledgement.

Completion of this program was dependent upon the contributions of many individuals from NASA/DFRC and Calspan. Mr. Donald Berry of NASA/DFRC was, to a large extent, primarily responsible for creating this program; his leadership and technical inputs were appreciated. The technical assistance of Messrs. Bruce Powers and James Stewart, NASA/DFRC is also gratefully acknowledged. Finally, this program could not have been performed without the diligent work put forth by the NASA Program Manager, Ms. Mary Shafer; her work warrants special recognition and thanks.

The work of the NASA/DFRC evaluation pilots, Mr. Thomas McMurtry and Mr. Michael Swann, deserves special acknowledgement particularly in light of the concentrated flight schedule and demanding flight tasks; their efforts were vital to successful program completion.

This report represents the combined efforts of many individuals of the Flight Research Department. The project engineer was Mr. Randall E. Bailey, assisted by the NT-33 Program Manager, Mr. Rogers E. Smith, who also served as safety pilot. The efforts of Messrs. Ronald Huber and Bernie Eulrich were instrumental in the successful integration of the NT-33 digital flight control capability; the work of Mr. Clarence Mesiah also deserves recognition for developing the necessary digital control software. The contributions of the following individuals are also gratefully acknowledged:

Messrs. Mark Bergum and John Babala — Electronic Design and Maintenance.

Messrs. Al Schwartz, Mike Sears, and Bill Palmer — Aircraft Maintenance.

Mr. Michael Parrag — Calibration Flying.

Mr. Charles Berthe — Safety Pilot (in relief of Rogers Smith).

Finally, the excellent work of Ms. Chris Turpin and Ms. Janet Cornell in preparation of this report deserves very special recognition.

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SYMBOLS AND ABBREVIATIONS

Symbol	
a	Position PIOS filter amplitude-frequency path prefilter break frequency (rad)
a_2	Rate PIOS filter exponential weighting, $e^{-a_2 T}$ (sec^{-1})
b	Position PIOS filter amplitude path prefilter break frequency (rad)
c	Position PIOS filter differential prefilter break frequency (rad)
CW	Slope of PIOS filter gain attenuation schedule
d	Position PIOS filter differential prefilter break frequency (rad)
F_{as}	Roll control stick force, positive right (lbs)
F_{es}	Pitch control stick force, positive aft (lbs)
F_{rp}	Rudder pedal control force, positive right (lbs)
g	Acceleration of gravity (ft/sec^2)
n_z/α	Steady state normal acceleration per angle of attack (g's/rad)
$M_{\delta'_{es}}$	$\frac{1}{I_y}\frac{\partial M}{\partial \delta'_{es}}$ body axis dimensional pitching moment per unit δ'_{es} (rad/sec^2 per inch)
q	Body axis pitch rate (deg/sec)
p	Body axis roll rate (deg/sec)
s	Laplace operator (1/sec)
V	Airspeed (knots)
W	Frequency of pilot inputs estimated by PIOS filters, $= x/y$
$WMIN$	Breakpoint of PIOS filter gain attenuation schedule
x	Position PIOS filter estimated pilot input amplitude x frequency
XK	PIOS filter gain attenuation factor
$XKMIN$	Minimum gain attenuation factor
y	Position PIOS filter estimated pilot input amplitude
α	Angle of attack (deg)
β	Angle of sideslip (deg)
δ	Pitch stick command past deadband (inches)
δ_{as}	Roll stick deflection at grip, positive right (inches)
δ_e	Elevator deflection (deg)

Symbol

δ_{es}	Pitch stick deflection at grip, positive aft (inches)
δ'_{es}	Commanded pitch stick input modified by control system dynamics (inches)
δ_{es_c}	Commanded pitch stick input (inches)
δ_{rp}	Rudder pedal deflection, positive right (inches)
$\zeta_{a,e,r}$	Aileron, elevator, rudder actuator damping ratio
ζ_{dr}	Dutch roll damping ratio
ζ_{ph}	Phugoid damping ratio
ζ_{sp}	Short period damping ratio
ζ_{ϕ}	Damping ratio of numerator ϕ/F_{as} transfer function
θ	Pitch attitude (deg)
λ_D	Control system lag prefilter break frequency (rad)
τ_D	Added control system (transport) time delay, $e^{-\tau_D s}$ (sec)
τ_r	Roll mode time constant (sec)
τ_s	Spiral mode time constant (sec)
$\tau_{\theta_{1,2}}$	Airframe lead time constants in θ/δ'_{es} transfer function (sec)
ϕ	Roll attitude (deg)
$\lvert\phi/\beta\rvert_{dr}$	Absolute value of controls-fixed roll-to-sideslip ratio at ω_{dr}
$\omega_{a,e,r}$	Undamped natural frequency of aileron, elevator, rudder actuator (rad/sec)
ω_{dr}	Dutch-roll undamped natural frequency (rad/sec)
ω_{ph}	Phugoid undamped natural frequency (rad/sec)
ω_{sp}	Short period undamped natural frequency (rad/sec)
ω_{ϕ}	Undamped natural frequency of numerator of ϕ/F_{as} transfer function (rad/sec)
$(\dot{\ })$	Rate of change of ( ) with time (( )/sec)

Abbreviations

DFBW	Digital Fly-by-Wire
DFRC	Dryden Flight Research Center
EP	Evaluation Pilot

SYMBOLS AND ABBREVIATIONS (CONT'D)

Abbreviations

FDL	Flight Dynamics Laboratory
ft	feet
KIAS	Knots, Indicated Airspeed
LAHOS	Landing Approach Higher Order System
LATHOS	Lateral Higher Order System
lbs	pounds
msec	millisecond
NASA	National Aeronautics and Space Administration
PIO	Pilot-Induced Oscillation
PIOR	Pilot-Induced Oscillation Classification Rating
PIOS	Pilot-Induced Oscillation Suppression
PR	Pilot Rating
rad	radian
SP	Safety Pilot
SPR	Safety Pilot Rating
USAF	United States Air Force

Section 1
INTRODUCTION

State-of-the-art aircraft designs, from fighters to supersonic cruise transports, are relying predominantly on digital flight control. The control system is used in these applications to augment the aerodynamics of the vehicle for maximum performance as well as compensate for stability and control deficiencies. Unfortunately, the most recent examples of aircraft employing this technology have exhibited poor flying qualities and pilot-induced oscillation tendencies during prototype flight test.

The flying qualities problems experienced by highly augmented aircraft have been the subject of numerous experiments and research (for example, References 1-4). This work has been fundamental in generating data on augmented aircraft flying qualities for subsequent development of appropriate design criteria. Further, these studies (most notably, References 2 and 4) and recent experiences in prototype flight testing have shown that the flying qualities of augmented aircraft are highly dependent upon the task and its associated piloting control requirements. The flying qualities deficiencies of augmented aircraft have been characterized as a "cliff" because the aircraft exhibits dramatic changes in flying qualities as pilot compensation increases for tasks which require precise control of aircraft attitude and position. A classical illustration of this behavior is the approach and landing task. In this case, benign flying qualities on approach have been witnessed to deteriorate in the flare near touchdown into full blown, pilot-induced oscillations (PIO).

The modern flight control system, clearly, must be designed with close regard to the available research and data to attain the potential afforded digital flight control. However, real world applications of this technology may be constrained by cost and design tradeoffs. These constraints may limit the design potential by imposing, for example, low actuator rate limits or insufficient control authority. Indirect solutions may be desirable or necessary to compensate for less than ideal flying qualities.

Adaptive filtering of pilot control inputs represents a potential indirect solution to improve flying qualities. The adaptive filter or Pilot-Induced Oscillation Suppression (PIOS) filter is a digital algorithm which adjusts the pilot's available command to the appropriate control surface as a function of the frequency and amplitude of his input. The filter can potentially suppress pilot-induced oscillations (PIO's) and prevent actuator rate limiting. Actuator rate limiting can, in itself, be a major cause of PIO's and in combination with other flight control system deficiencies, such as excessive time delay, can lead to serious PIO problems. When the filter operates in its ideal sense as a PIO suppressor, complete control of the aircraft is retained until the pilot control inputs approach those which are "known" to induce oscillations. When this condition occurs, the filter reduces the pilot's command gain to the control surfaces, thus minimizing the resultant aircraft motion. The filter, in essence, opens the pilot/vehicle control loop to suppress the PIO.

This report describes an in-flight investigation of adaptive filtering for the suppression of pilot-induced oscillations using the variable stability USAF/FDL NT-33A aircraft, modified and operated by Calspan. The investigation was designed to test different PIOS filters and determine their effects on fighter aircraft flying qualities in the visual approach and landing task (Flight Phase Category C). This program was limited to the evaluation of longitudinal flying qualities, however, the same technique of PIOS filtering can be applied to the lateral control axes. The evaluation task included aircraft flare and actual touchdowns.

This evaluation task was chosen primarily because precise, closed-loop piloting control of the aircraft is required for adequate task performance. As a result, the task is suitable for the evaluation of augmented aircraft flying qualities and pilot-induced oscillations. The task provides an excellent setting for proper evaluation of PIOS filtering.

The objectives of this flight program were to:

- Examine adaptive filtering (PIOS filters) of pilot inputs for the suppression of pilot-induced oscillations.

- Discern the effects of PIOS filters on the longitudinal flying qualities of fighter aircraft during the visual approach and landing task.

This report is essentially a data report in that no detailed analysis of the results have been made. Nevertheless, pertinent observations are included to add insight into the program where appropriate. The report is organized as follows: Section 2 contains the experiment design, objectives, and the experiment configuration characteristics; the conduct of the experiment, including descriptions of the evaluation procedures and tasks, is given in Section 3; Section 4 includes the experiment results and observations; finally, concluding remarks and recommendations based on this work are listed in Sections 5 and 6. Detailed background material and data are included in a series of appendices.

Section 2
EXPERIMENT DESIGN

This in-flight investigation was designed to satisfy the program objectives as completely as possible and to generate a coherent data base for subsequent analysis. Again, the program objectives were to:

- Examine adaptive filtering (PIOS filters) of pilot control inputs for the suppression of pilot-induced oscillations.

- Discern the effects of PIOS filters on the longitudinal flying qualities of fighter aircraft during the approach and landing task.

The experiment was performed using the variable stability NT-33, in-flight simulator. Details of the simulation mechanization,including calibration and implementation of the configuration characteristics, are given in Appendix III. A more thorough documentation of the NT-33A and its operation is provided in Reference 5.

This experiment was an investigation of longitudinal landing flying qualities; hence, the roll and yaw control systems were tailored to produce unobtrusive, Level 1 flying qualities. Evidence that this goal was achieved is found by the absence of adverse pilot commentary regarding the simulated aircraft's lateral-directional characteristics. These characteristics are documented in Appendix IV.

The following sections outline the configuration characteristics and experiment variables. The sections are organized to present, cumulatively, a complete dynamic description of the simulated longitudinal control system for each experiment configuration.

2.1 EXPERIMENT VARIABLES

Two primary experiment variables were clearly dictated for satisfaction of the experiment objectives: fighter aircraft longitudinal dynamics and PIOS filter designs. Four aircraft configurations, possessing different fighter flying qualities, were selected as the control group for the examination of PIOS filtering. Because this program was indirectly prompted by the flying qualities deficiencies experienced by highly augmented aircraft, the aircraft configurations were chosen to emulate both proper and improper augmented aircraft control system designs. In this manner, the examination of adaptive filtering (PIOS filters) was performed using aircraft configurations with various levels of flying qualities and PIO tendencies which potentially arise from digital flight control system designs.

The pitch control system of the experiment configurations is shown in Figure 2-1. The basic aerodynamic characteristics of the NT-33 aircraft were augmented by appropriate feedbacks to produce satisfactory, Level 1 pitch dynamics (Appendix III). This configuration represented the baseline augmented aircraft. Three additional aircraft configurations (completing the experiment control group) were developed by adding either digital time delay or lag prefiltering. These parameters replicate the degrading effects of increased computational time delay and cascaded filters on the longitudinal flying qualities of an otherwise Level 1, augmented airplane. Thus, four augmented aircraft configurations were used to establish the experiment control group of fighter longitudinal flying qualities for the evaluation of PIOS filtering.

2.2 AIRCRAFT CONFIGURATIONS

2.2.1 Baseline Dynamics

The pitch dynamics for the baseline augmented aircraft were identical to LAHOS Configuration 2-1 from the Landing Approach Higher Order Systems (LAHOS) program (Reference 2). This configuration was selected because its characteristics yielded excellent approach and landing flying qualities. The

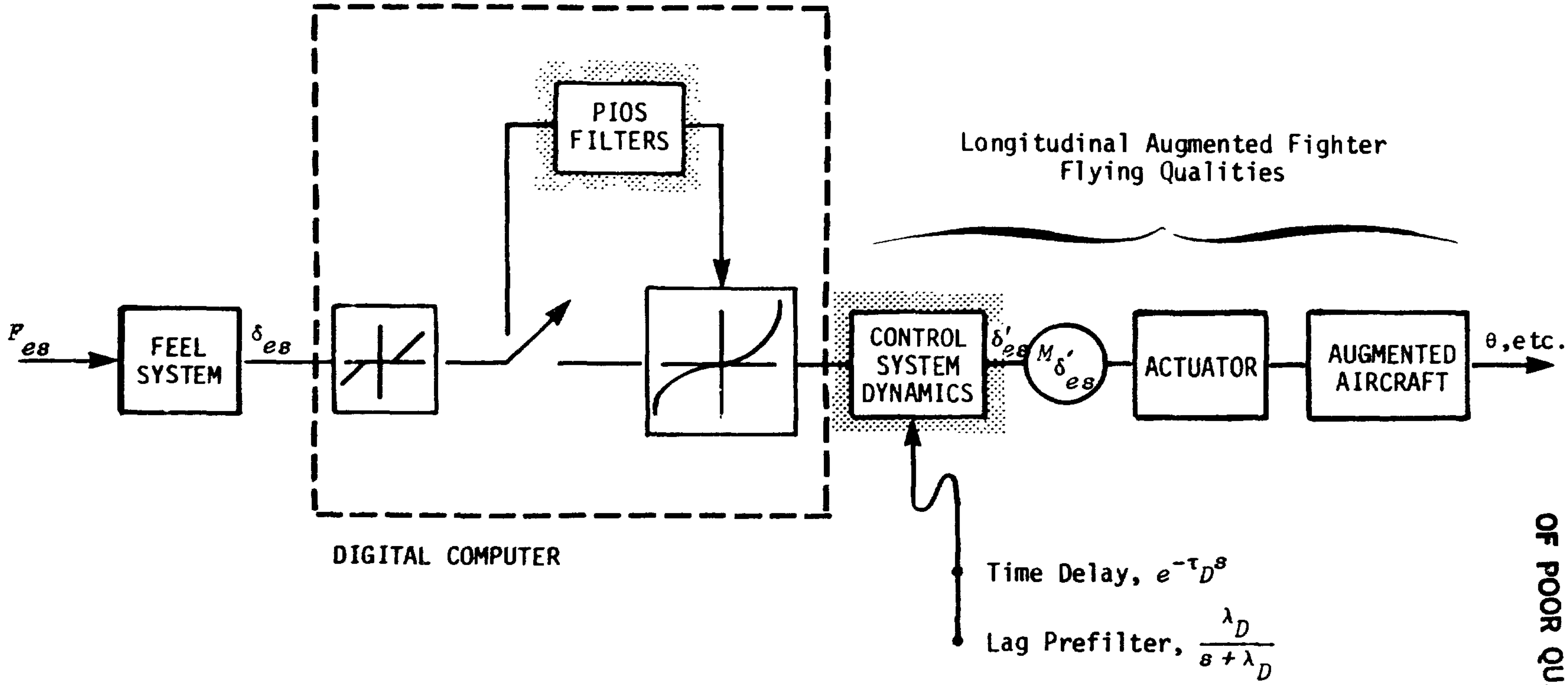

Figure 2-1: EXPERIMENT LONGITUDINAL CONTROL SYSTEM

configuration's constant speed pitch transfer function for the landing flare was:

$$\frac{\dot{\theta}}{\delta'_{es}} = \frac{M_{\delta'_{es}}(s+1/\tau_{\theta_2})}{s^2+2(0.6)(2.3)s+2.3^2}$$

where $\tau_{\theta_2} = 1.4$ sec

$n_z/\alpha = 4.5$ g/rad

and $V \approx 120$ KIAS

2.2.2 Other Aircraft Configuration Characteristics

With the augmented aircraft's short period pitch dynamics established, the remaining aircraft configurations were created by adding incremental values of time delay or a first-order lag prefilter to the pitch control system. The augmented aircraft without additional time delay or lag filtering was the "baseline" aircraft configuration (Configuration T0).

The amount of time delay or lag filtering required to degrade the baseline configuration and develop a PIO-prone aircraft was predicted using previous research data (Reference 2, for example). The first evaluation flight was used to finalize the configuration matrix. The objective was to create two configurations which had definite PIO tendencies but were not ridiculous to the extent that control was impossible or safety severely compromised. It was also desirable that the one configuration have flying qualities which were in between the baseline and two PIO-prone aircraft. These three configurations, created by adding control system dynamics to the baseline configuration, are described below.

A 2 radian per second, first order lag prefilter was added to form one configuration (Configuration F1). This configuration is nearly identical to LAHOS Configuration 2-4 which was evaluated in LAHOS as having very significant PIO tendencies (Reference 2). The lag prefilter produced a low frequency PIO due to a sluggish initial pitch response.

Another PIO-prone aircraft was developed by adding 120 milliseconds of pure time delay to the baseline augmented aircraft. This configuration (Configuration T2) was very representative of a digitally-controlled aircraft whose flying qualities are compromised by time delay. The characteristic PIO frequency of this configuration should provide good contrast with Configuration F1 and therefore test the ability of the adaptive filters for the suppression of different types of PIO.

The last configuration (Configuration T1) was chosen to possess only mild PIO tendencies, if any. This configuration was established by adding 70 milliseconds of transport delay to the baseline augmented aircraft control system.

The four configurations and their identifiers are summarized in Figure 2-2. Additional control system dynamics and characteristics are common to all the configurations as shown in Figure 2-1. These are documented in Section 2.4 since they are necessary to derive the complete dynamic description of the configurations. It is important to note that when transport time delay is introduced into the experiment flight control system, two analog filters are also included (Figure 2-2). The baseline configuration (Configuration T0), therefore, differs from Configuration T1 and T2 by the added digital time delay (70 and 120 msec, respectively) and the two filters. These filters are a necessary part of the NT-33's time delay network and could not be excluded. The filters are detailed fully in Section 2.4. Any analysis of the data and results from this program must include the filters as well as the added digital delay for correct interpretation.

2.3 PIOS FILTER CONFIGURATIONS

The pilot-induced oscillation suppression (PIOS) filter configurations were selected, in part, based on the results of work investigating PIOS filters which preceded this program (References 6 and 7). The number of experiment parameters was reduced to a manageable size by using the results of References 6 and 7 together with unpublished data from NASA/DFRC tests of PIOS filters during simulated aerial refueling tests.

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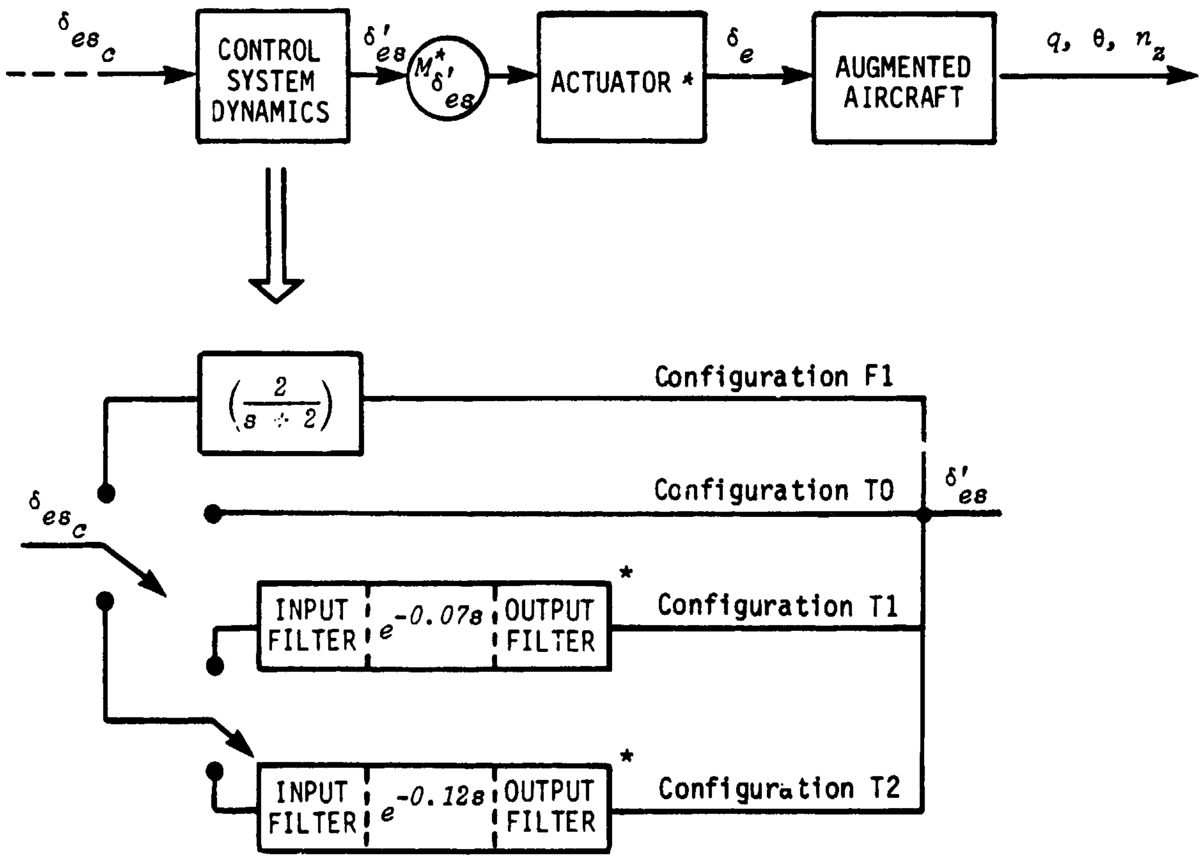


* See Section 2.4

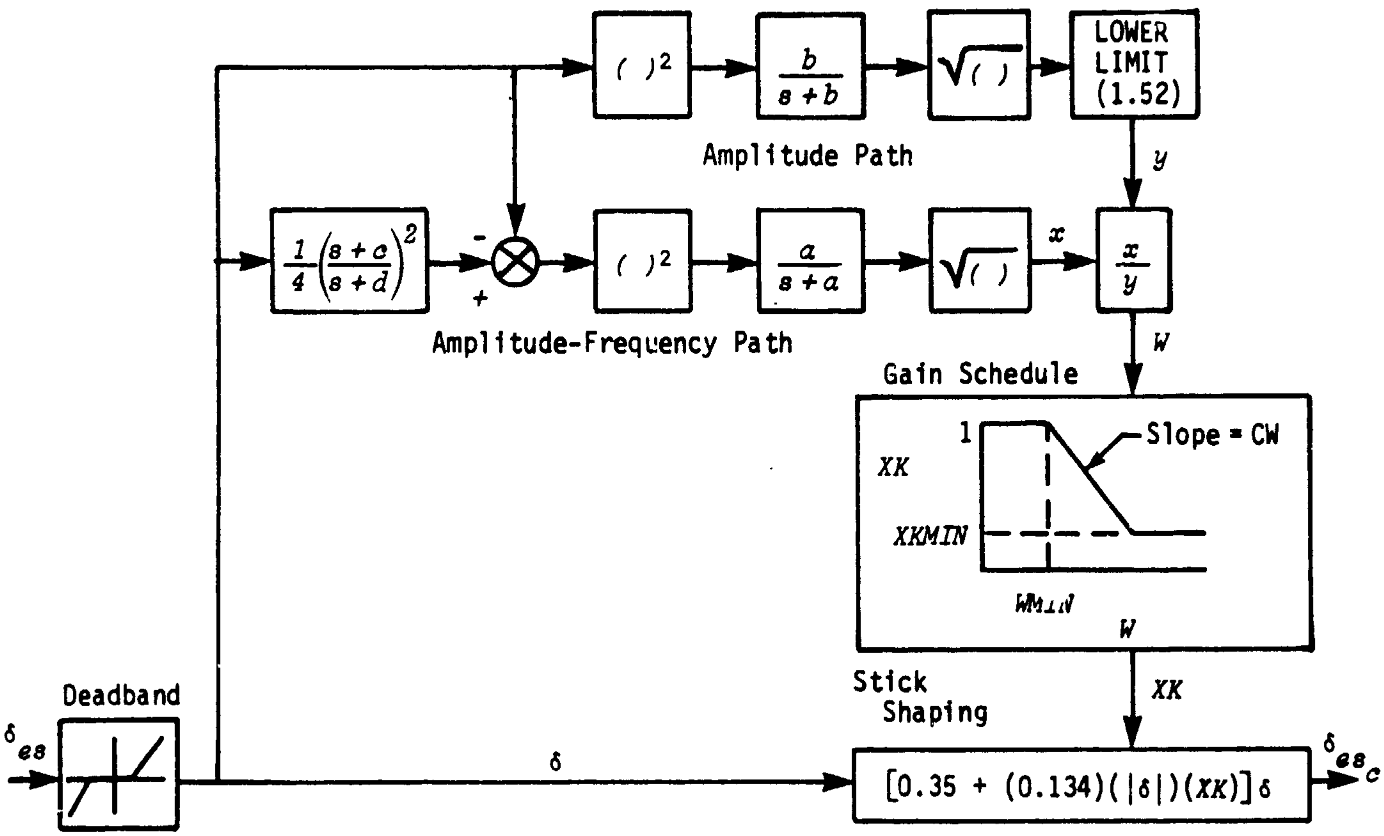
Figure 2-2: AUGMENTED AIRCRAFT CONFIGURATION

Two types of adaptive filters were tested in this program. Primary emphasis was placed on examining adaptive filters which act as a function of stick position (δ_{es}) (Figure 2-3). A brief look was also taken at adaptive filtering of pilot control inputs based on a weighted stick rate function (Figure 2-4).

Each of the two filtering algorithms calculate a forcing function, *W*. This forcing function is the measure of pilot control activity from which the amount of pilot control input attenuation is determined according to the gain attenuation schedule. The parameter, *W*, represents an estimated frequency of the pitch stick position movement for the position PIOS filter and an exponentially-weighted, time-rate of change of stick position for the rate PIOS filter.

This experiment was designed to investigate primarily the effects of PIOS filters on longitudinal flying qualities in terms of the degree to which the PIOS filters attenuate pilot control commands. To achieve this objective, the algorithms to compute the forcing functions for each of the filters were nearly identical to those investigated previously and held constant for this program. The gain attenuation schedule, therefore, was the primary filter variable. For each PIOS filter-type (position or rate PIOS filter), different gain attenuation schedules were examined. The schedules determine the level of input suppression through the factor *XK* and the nonlinear shaping gradient. For example, the calculation of *W* for all of the position PIOS filters with a given input was identical, but the level of input suppression (*XK*) for each configuration varied according to its gain attenuation schedule (Figure 2-5). Although the algorithms to calculate the forcing function, *W*, were not varied in this program, future work should investigate this area in an experimental fashion. The results of Reference 7 suggest that the calculation of *W* has a significant influence on the operation of the PIOS filters and, hence, flying qualities. The limited scope of this program, however, precluded examination of different algorithms to calculate the suppression filter forcing functions.

The gain attenuation schedule for each suppressor was uniquely described by a slope (*SW*) and breakpoint (*WMIN*) with the minimum value of



CONSTANT	NOMINAL VALUE
a	0.65
b	1.0
c	6.0
d	3.0
XKMIN	0.1
Deadband	0.1

Figure 2-3: STICK POSITION PIOS FILTER

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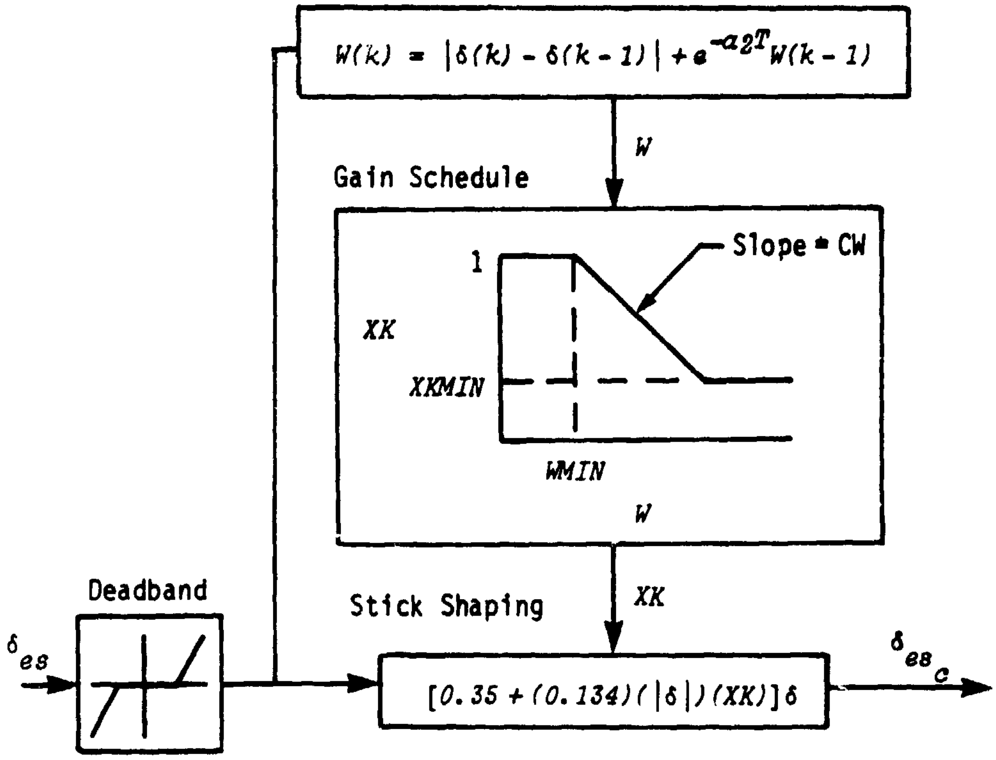
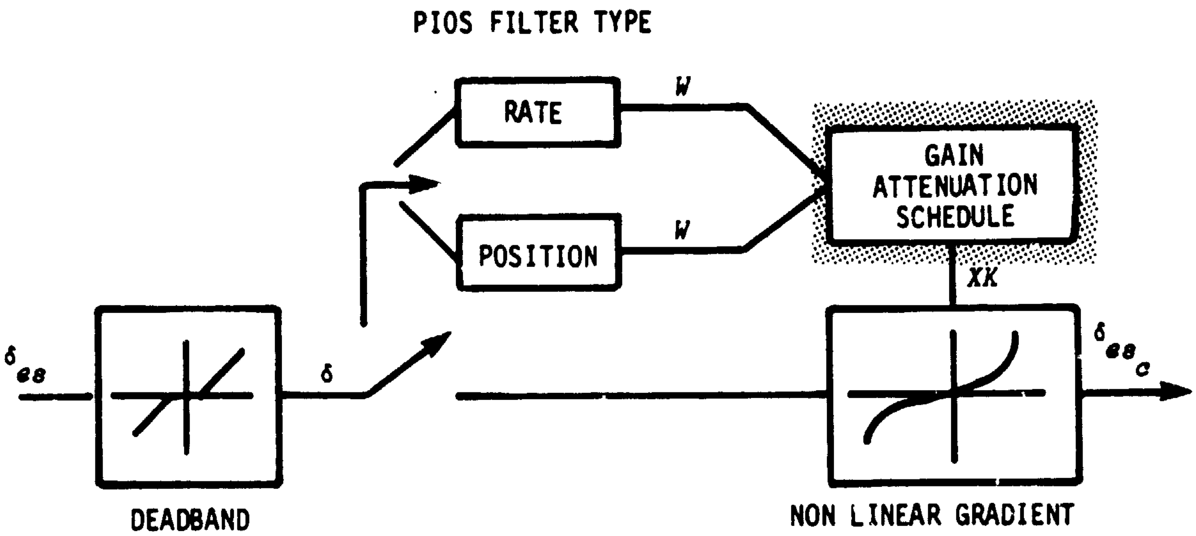


CONSTANT	NOMINAL VALUE
a_2	0.3
XKMIN	0.1
Deadband	0.1

Figure 2-4: STICK RATE PIOS FILTER



DEADBAND = 0.1 inch

NON LINEAR GRADIENT: $\delta_{es_c} = [0.35 + (0.134)(XK)|\delta|]\delta$

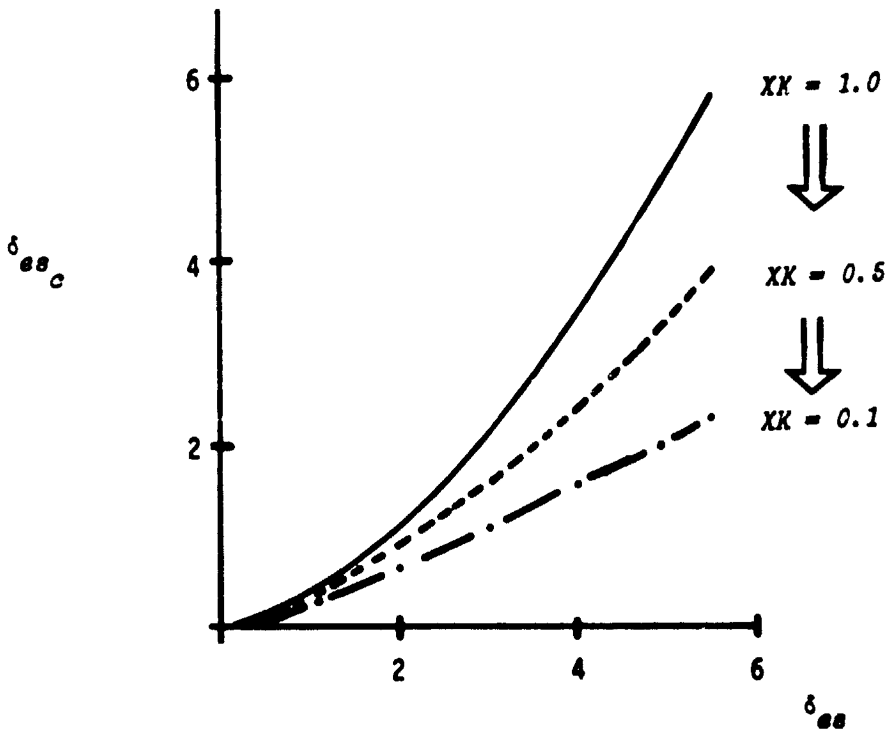


Figure 2-5: EXPERIMENT MECHANIZATION

is equal to 0.1 (*XKMIN*). Seven position PIOS filter configurations were created by different combinations of attenuation slopes and breakpoints. Four rate PIOS filter configurations were formed in the same manner. These configurations and their identifiers are given in Table I.

The PIOS filters were implemented as digital algorithms in the NT-33's digital flight control computer with stick position as the only input (Appendix III). Stick position was, in all cases, passed through a deadband of 0.1 inches. For evaluations of the aircraft configurations without filtering, the nonlinear gradient was mechanized with *XK* equal to 1.0; hence, the effect of PIOS filtering was isolated.

2.4 ADDITIONAL CONFIGURATION CHARACTERISTICS

The experiment variables (aircraft and PIOS filter configurations) have been described in the previous sections. This section completes the documentation of the nominal pitch dynamics and control system elements common to each configuration. Description of these elements completes the longitudinal transfer function description of the evaluated configurations.

2.4.1 Approach Pitch Dynamics

The augmented aircraft's pitch dynamics have been given for the landing flare in Section 2.2. Extrapolation of the landing flare dynamics are required to extract the approach pitch dynamics. Since the augmented aircraft was flown on a given flight at different fuel loads and thus, gross weight, the approach airspeed was scheduled with fuel remaining so angle of attack was held constant for each approach. This process effectively keeps the important dynamic characteristics constant throughout the flight. For the approach task, the constant speed pitch dynamics were approximately:

$$\frac{\dot{\theta}}{\delta'_{es}} = \frac{M_{\delta'_{es}}(s+1/\tau_{\theta_2})}{s^2+2(0.6)(2.6)s+2.6^2}$$

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TABLE I

PIOS FILTER CONFIGURATIONS

- GAIN ATTENUATION SCHEDULE:

$$XK = \begin{cases} 1.0 & \text{for } W < WMIN \\ 1+(W-WMIN)CW & \text{for } WMIN \le W \le (0.9/CW) + WMIN \\ 0.1 & \text{for } W > (0.9/CW) + WMIN \end{cases}$$

- POSITION PIOS FILTER CONFIGURATIONS:

Slope (*CW*)	BREAKPOINT (WMIN) 0.0	0.05	0.20
-10.0	A-1		
- 5.0	A-2	B-2	
- 3.3			C-3
- 2.0		B-4	
- 1.67			C-5
- 1.0	A-6		

- RATE PIOS FILTER CONFIGURATIONS:

Slope (*CW*)	BREAKPOINT (WMIN) 2.0	5.0	10.0
-0.25		E-7	
-0.075	D-8	E-8	F-8

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where $$\tau_{\theta_2} = 1.25\ sec$$

$$n_z/\alpha = 5.5\ g/rad$$

and $$V = 135\ KIAS$$

2.4.2 Long Term Pitch Characteristics

The augmented aircraft configuration's phugoid, or long term, pitch response characteristics are those of the NT-33A, modified slightly by the longitudinal feedbacks used to achieve the desired short period dynamics. For this experiment, the following values pertain:

$$\omega_{ph} = 0.17\ rad/sec$$
$$\zeta_{ph} = 0.15$$
$$\tau_{\theta_1} = 12\ sec$$

All approaches were flown on the front side of the power-required versus velocity curve.

2.4.3 Pitch Command Gain

The pitch command gain, $M_{\delta'_{es}}$, was selected according to pilot commentary at the beginning of evaluation flying to provide satisfactory stick forces throughout the approach, landing and subsequent takeoff. After evaluation flying began, the pitch command gain was fixed for all evaluations, including PIOS filter evaluations. There was, however, one evaluation which was flown with 1/2 the nominal value of $M_{\delta'_{es}}$ (see Section 4.2). For the landing flare, the nominal value of pitch command gain was:

$$M_{\delta'_{es}} = 0.47\ rad/sec^2\text{-}inch$$

In the approach flight phase, $M_{\delta'_{es}}$ increased by approximately 20%.

2.4.4 Feel System Characteristics

A center stick controller was implemented for aircraft pitch and roll control. The pitch center stick dimensions and travel are shown in Figure 2-6. The feel system characteristics for this controller were held fixed throughout the program and were chosen to be satisfactory and unobtrusive. Essentially, zero breakout or friction forces were present. The pitch feel system characteristics were:

$$\frac{\delta_{es}}{F_{ES}} = \frac{0.125}{\left(\frac{s}{26}\right)^2 + \frac{2(0.6)s}{26} + 1} \ (inches/lbs)$$

These feel system characteristics are identical to those flown in the LAHOS program (Reference 2).

2.4.5 Digital Computer

As noted earlier, the digital flight control capabilities of the NT-33 aircraft were utilized in this program for implementation of the PIOS filters. The computer was also used for evaluations without PIOS filtering to mechanize the nonlinear gradient and deadband, and include the inherent digital time delay of the computer in each configuration. The computer update rate was a constant 50 cycles per second resulting in a nominal 20 milliseconds of time delay. In addition, an 11 Hertz, second order filter with a damping ratio of 0.7 was placed on the output of the computer for signal smoothing.

2.4.6 Time Delay Filters

Time delay was added to the baseline configuration (Configuration T0) to create configurations T1 and T2. 70 msec and 120 msec of pure (transport) time delay were introduced in the experiment flight control system to simulate configurations T1 and T2. However, two analog filters are also included with the addition of this digital delay. The filters are a necessary part of the

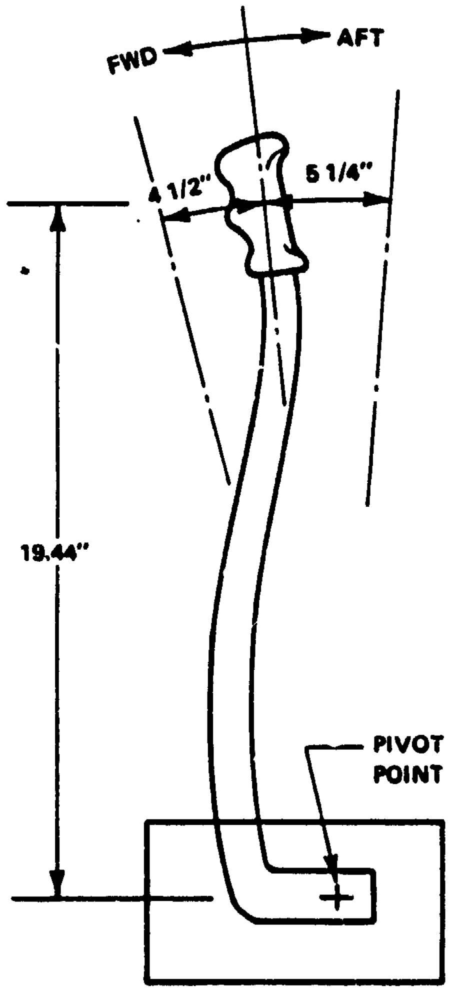


Figure 2-6: PITCH CENTERSTICK DIMENSIONS AND TRAVEL

time delay network in the NT-33's variable stability system. This network is described fully in Appendix III. For correct interpretation of the data and results, these filters must be included in any description of the experiment flight control system when appropriate. The filters are third-order Butterworth filters with dynamics as follows:

INPUT FILTER: $$\frac{1}{\left(\frac{s}{314}+1\right)\left[\frac{s^2}{314^2}+\frac{2(0.5)}{314}s+1\right]}$$

OUTPUT FILTER: $$\frac{1}{\left(\frac{s}{50}+1\right)\left[\frac{s^2}{50^2}+\frac{2(0.5)}{50}s+1\right]}$$

2.4.7 Actuator Dynamics

The NT-33A pitch actuator dynamics were constant for all configurations. Its dynamics are described by a second-order transfer function with:

$$\omega_e = 75 \text{ rad/sec}$$
$$\zeta_e = 0.7$$

In addition, signals to the actuator are passed through a first-order lag prefilter which has a break frequency of 200 radians per second.

2.5 CONFIGURATION IDENTIFIERS

The longitudinal augmented aircraft and PIOS filter configuration characteristics have been described in this section. Evaluation configurations were created by combinations of augmented aircraft and PIOS filter configurations. Four augmented aircraft configurations were created by adding different control system elements to the baseline pitch configuration. These established the experiment control group of aircraft flying qualities. Seven position and four rate PIOS filter configurations were the primary experiment variables.

For the remainder of this report, the configuration identifiers are used to describe an evaluation configuration and, therefore, the experiment variables it represents. The variables in the longitudinal control system are the control system dynamics, PIOS filter-type, and gain attenuation schedule. The configuration ingredients are summarized in Figure 2-2 and Table I. For example, Configuration T2(A-6) is

T2: Augmented aircraft configuration with 120 msec transport time delay added to the baseline configuration, and

A-6: Position PIOS filter with gain attenuation schedule determined by a slope (*CW*) of -1.0 and breakpoint (*WMIN*) of 0.0.

The complete longitudinal transfer functions are obtained by combining the block diagram of the individual control system elements as they have been presented in this section. The lateral-directional aircraft characteristics are summarized in Appendix IV.

Section 3
CONDUCT OF THE EXPERIMENT

3.1 USAF/FDL/CALSPAN VARIABLE STABILITY NT-33 AIRCRAFT

The simulated longitudinal and lateral configurations were mechanized using the USAF/FDL variable stability NT-33 aircraft operated by Calspan (Figure 3-1). A complete description of the aircraft's operation is contained in Reference 5. Details of the simulation mechanization,including the calibration procedures used in this progran,are given in Appendix III. In the variable stability aircraft, the evaluation pilot occupies the front cockpit, while the system operator, who occupies the rear cockpit, acts as safety pilot. The stability and control characteristics about all three axes can be varied in flight by changing the settings of the fly-by-wire system gain controls in the rear cockpit. The baseline augmented aircraft configuration was set up by the safety pilot using the appropriate calibrated system gains. If required, control system time delay and first order lag filtering were selectable using special switches in the rear cockpit. The PIOS filter configurations were engaged by the safety pilot through the Mode Control Unit of the digital computer from the rear cockpit (Appendix III). During a given flight, a maximum of sixteen PIOS configurations were accessible.

It is important to note that the evaluation pilot cannot feel the NT-33 control surface motions caused by the demands of the fly-by-wire control system in reproducing the desired configuration response characteristics.

3.2 SIMULATION SITUATION

Since inclusion of wind and turbulence as controlled parameters was beyond the scope of this experiment, the flights were flown in a variety of weather environments under visual flight conditions. All flights were operated in conditions which could be considered typical of normal fighter operations. Evaluation flying was performed at Dryden Flight Research Center, California.

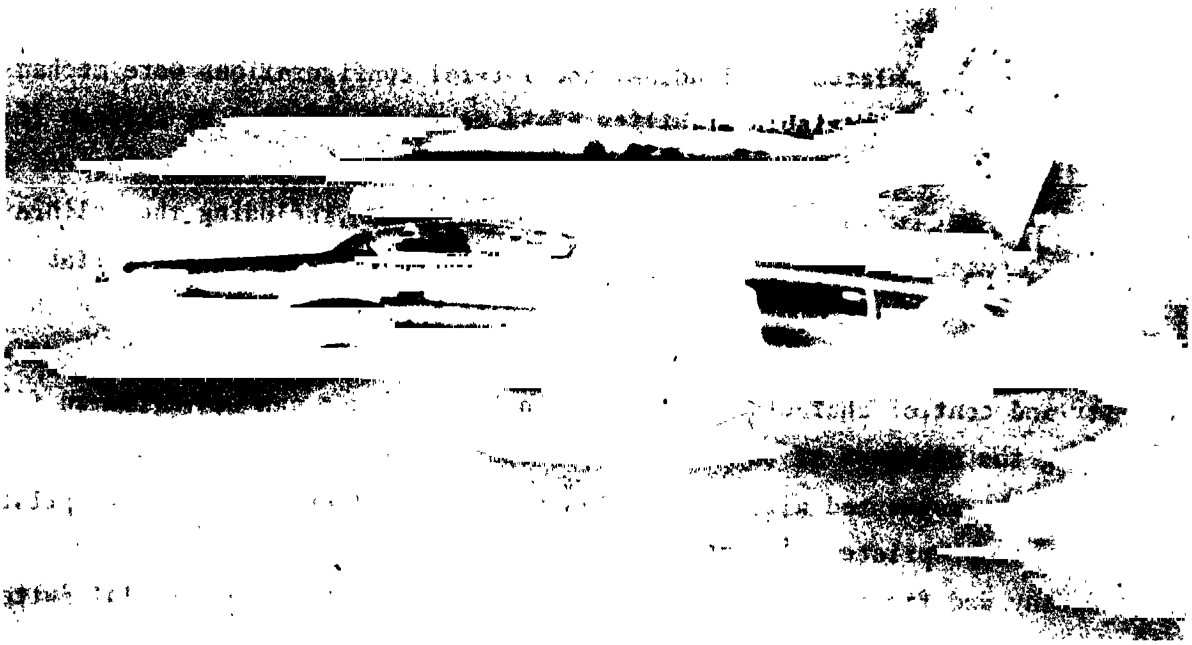


Figure 3-1 USAF/CALSPAN VARIABLE STABILITY NT-33 AIRCRAFT

For this program, the wind and turbulence were both generally light; however, on two flights (Flights 2693 and 2694), the turbulence and wind were significant factors. These conditions were ideal for comparison of configuration evaluations in turbulent as opposed to benign environments. The pilots were asked on each flight to evaluate the aircraft in the conditions of the day and comment, if desired, on the effect that wind and turbulence had on the evaluation or task.

3.3 EVALUATION PROCEDURE

The configurations were evaluated in a generally random order. The evaluation pilots had no knowledge of the configurations nor did they know if the configurations contained a PIOS filter. Yet, an important consideration in the conduct of this program was the "calibration" of the evaluation pilots.

Because the majority of the configurations had significant PIO tendencies and many possessed marginal controllability, biasing of the pilot ratings and evaluations was a real concern; that is, the evaluations may have become a comparison of poor flying qualities. To avoid this situation, a conscious effort was made during evaluation flying to have each pilot evaluate at least one "good" flying qualities configuration per flight. In addition, one touch-and-go was flown at the start of the evaluation flight with the baseline augmented aircraft (Configuration T0). These procedures recalibrated the pilot's sense of good aircraft flying qualities and ensured that the evaluations were more an absolute, rather than relative, measure of flying qualities. Biasing of the evaluations was, therefore, eliminated.

Each evaluation took an average of 20 minutes to complete. After the initial touch-and-go with the baseline aircraft, the evaluations were conducted in the following manner:

- The safety pilot implemented the evaluation configuration and engaged the variable stability system.

- Evaluation pilot was given control of the aircraft on downwind with gear down, flaps 30^{o}, and speed brakes closed at the approach airspeed appropriate for the fuel remaining.

- Pitch calibration records consisting of a pitch step and stick raps were taken for subsequent analysis.

- Evaluation pilot performed the evaluation following the task outline (Section 3.4).

- After completing the task, the safety pilot took control of the aircraft while the evaluation pilot assigned a Cooper-Harper pilot rating (PR) and pilot-induced oscillation classification/ rating (PIOR) using the appropriate scales (Figures 3-2 and 3-3).

- Evaluation pilot made recorded comments in reference to the comment card (Figure 3-4) and finally reviewed the pilot rating and made changes, if needed.

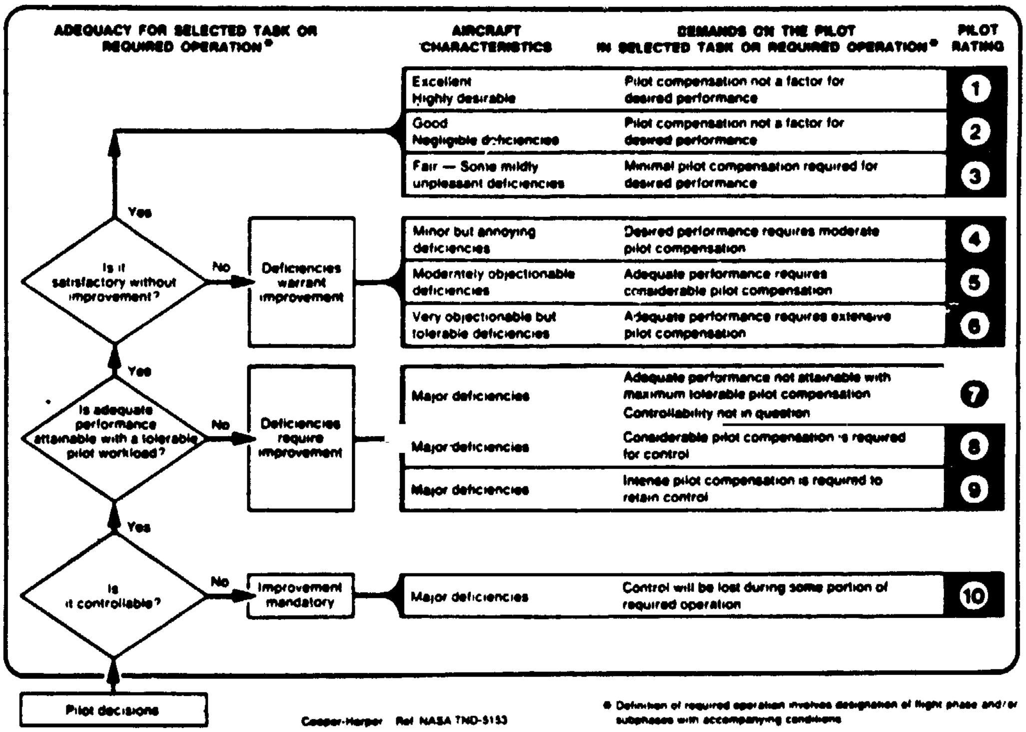
3.4 EVALUATION TASK

The evaluation task has been shown in numerous flying qualities experiments (for example, references 2 and 4) to be crucial to the proper evaluation of aircraft flying qualities. For this reason, the details of the task performed during each evaluation are summarized below.

- Two visual approaches to landing and takeoff (touch and-go's) were made for each evaluation. At discretion of evaluation pilot, a third touch-and-go would be performed.

- First approach was flown with a small lateral offset (∿75 ft) aligned to the edge of the painted runway outline (Figure 3-5). Sidestep maneuver to landing was initiated upon crossing start of paved runway at EDW Runway 22 (approximately 0.5 NM from runway threshold).

HANDLING QUALITIES RATING SCALE



DEFINITIONS FROM TN-D-5153

COMPENSATION

The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics

HANDLING QUALITIES

Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role.

MISSION

The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase

PERFORMANCE

The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task)

ROLE

The function or purpose that defines the primary use of an aircraft.

TASK

The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment

WORKLOAD

The integrated physical and mental effort required to perform a specified piloting task

Figure 3-2: COOPER-HARPER PILOT RATING SCALE

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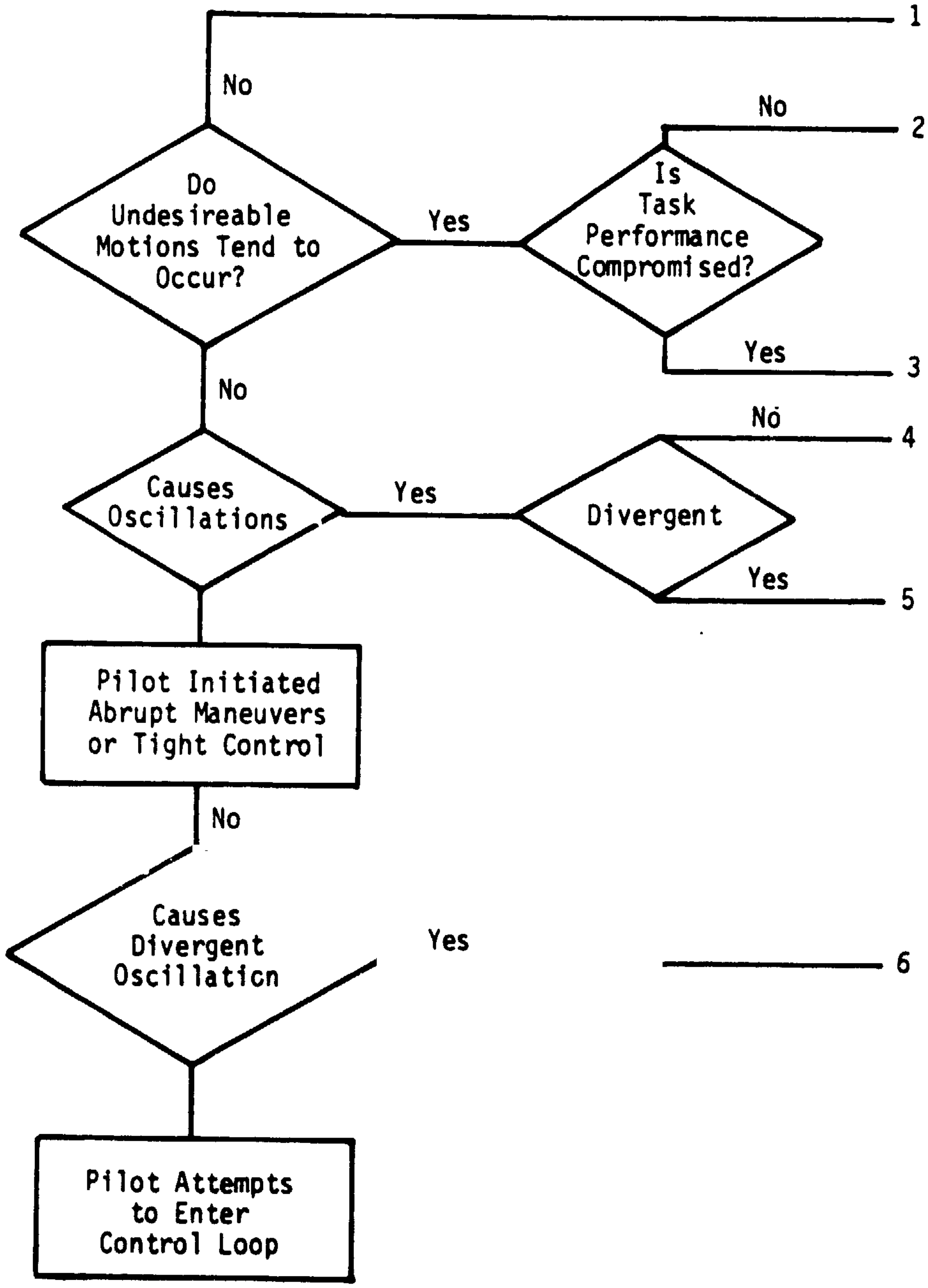

Figure 3-3: PIO CLASSIFICATION/RATING SCALE

- **Feel System Characteristics:**
  - **Forces/Displacements?**
  - **Pitch Sensitivity?**

- **Pitch Attitude Control:**
  - **Initial Response?**
  - **Final Response?**
  - **Predictability?**

- **Pilot-in-the-Loop Aircraft Behavior:**
  - **Any PIO tendency, undesirable motions?**
  - **Relative susceptibility to PIO, overshoot?**
  - **Any special piloting techniques/compensation required?**
  - **Any differences:**
    - **small vs. large inputs?**
    - **open vs. closed-loop control?**

- **Task Performance:**
  - **Airspeed control?**
  - **Touchdown point accuracy? (within limits?)**
  - **Sink rate at touchdown?**
  - **Runway alignment?**
  - **Level of aggressiveness used to control touchdown point?**
  - **Task differences: Approach/Landing/Takeoff?**

- **Additional Factors:**
  - **Any influence on evaluation due to:**
    - **wind/turbulence**
    - **lateral-directional characteristics**

- **Summary:**
  - **Any change in rating?**

Figure 3-4: PILOT COMMENT CARD

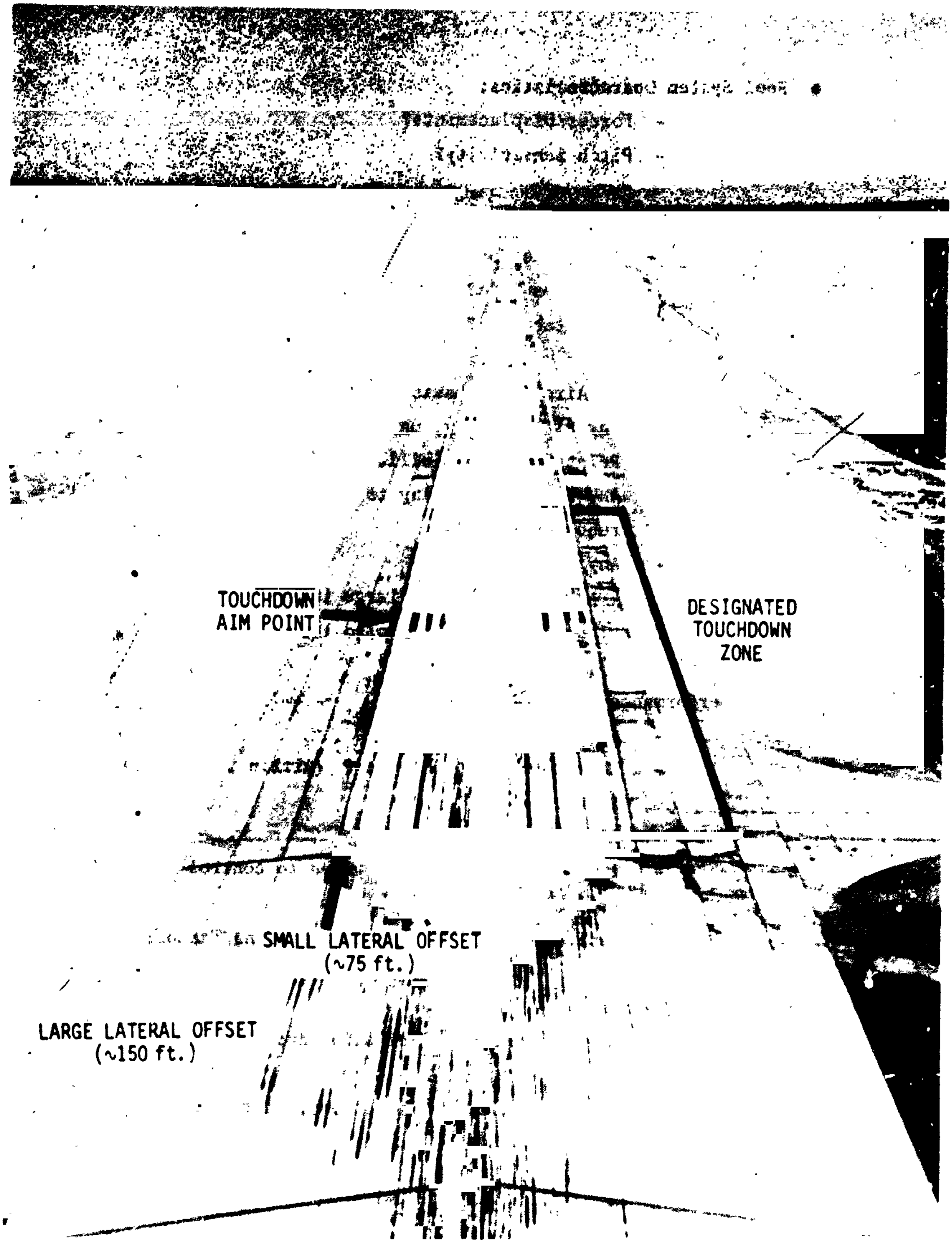

Figure 3-5. EVALUATION TASK: RUNWAY 22 AT EDWARDS AFB

- Second approach was flown with a large lateral offset aligned to the edge of the runway pavement (~150 ft). Offset correction was initiated at same point for landing lineup.

- Touchdown zone was 1,000 ft long starting at the runway threshold and aligned ±10 ft laterally of runway centerline. Touchdown aimpoint was 500 ft past the runway threshold for a ±500 ft spacing within the desired touchdown zone.

- Approach airspeed was maintained at ±5 kts of appropriate airspeed with touchdown at approximately 120 KIAS. At a nominal gross weight, NT-33 approach speed was 135 KIAS.

The importance of the task was continually stressed throughout the program. The pilots were instructed to treat each landing as a "must land" situation. In many cases, the nature of the configurations made touchdowns with any margin of safety difficult. However, each pilot approached the program knowing the importance of the task and stuck to it as closely as possible. Each pilot was given the opportunity to comment on the task and describe his ability to perform it. Knowing there was strict adherence to the task gives the analyst considerable insight into a configuration's flying qualities through the pilot comments.

3.5 EXPERIMENT DATA

The data from this program takes three forms: pilot ratings, pilot comments, and task performance records. Pilot ratings and comment data are summarized briefly in Section 4. Each evaluation and corresponding pilot comments are summarized in Appendix I. Task performance records of selected configurations and landings are included in Appendix II. These records show the approach to landing following the lateral sidestep maneuver. Detailed analysis of the data was beyond the scope of this data report.

3.6 EVALUATION PILOTS

Three evaluation pilots produced the flying qualities data in this program. Pilots A and B evaluated the majority of the configurations. A brief overview of each pilot's previous experience pertaining to this flying qualities investigation is presented to aid the analyst in the review of their respective pilot comments.

Pilot A: Thomas C. McMurtry, NASA/DFRC Test Pilot
No previous evaluation pilot experience with PIOS filters; however, he did fly some evaluations on the effects of control system time delays on landing flying qualities using the NASA/DFRC F-8 DFBW aircraft. (Reference 4).

Pilot B: Michael R. Swann, NASA/DFRC Test Pilot
Primary evaluation pilot during F-8 DFBW investigation of PIOS filtering during simulated aerial refueling task. He did not, however, participate as an evaluation pilot in the F-8 landing time delay study.

Pilot C: Rogers E. Smith, Calspan Engineering Test Pilot
No extensive PIOS filter evaluation flying experience. Pilot C was the safety pilot for both the LAHOS program and all NT-33/PIOS flights with Pilots A and B prior to his own evaluation flight.

Section 4
EXPERIMENT RESULTS

This section documents the results of this in-flight investigation and briefly discusses pertinent observations. Detailed analyses of the results were not undertaken.

4.1 FLIGHT PROGRAM SUMMARY

The data was gathered for this flight program during eight evaluation flights performed at Dryden Flight Research Center, California in June 1981. Forty evaluations of 27 configurations were made by the three project pilots. Twenty-one out of the total 27 configurations possessed PIOS filters.

The breakdown of evaluations and configurations flown by each pilot is tabulated below:

	Flights	Evaluations	Configurations
Pilot A:	4	20	18
B:	3	15	14
C:	1	5	5

Ten overlapping evaluations were flown; that is, two pilots evaluated the same configuration. These evaluations were for substantiation of the data base since they provide insight on each pilot's particular method of evaluation and the degree to which their evaluations concur.

4.2 EXPERIMENT DATA

The pilot rating data from this program is presented in Table II. This table summarizes the evaluated configurations and experiment parameters, the flight number, evaluation pilot, and pilot rating data. The complete configuration characteristics can be derived from the data of Section 2.

TABLE II

EXPERIMENT RESULTS SUMMARY

CONFIGURATION IDENTIFIER	FLIGHT NO.	PILOT	FCS DYNAMICS τ_D	FCS DYNAMICS λ_D	PIOS FILTER TYPE	PIOS FILTER CW	PIOS FILTER WMIN	PR/SPR	PIOR
T0	2686	A	---	---	---	---	---	2/2	1
	2691	B						2/2	1
	2697	C						3/2	1
T0(A-1)	2697	C			PSTN	-10.0	0.0	3/2	1
T0(A-2)	2693	A			PSTN	- 5.0	0.0	3/3	1
T0(A-6)	2692	A			PSTN	- 1.0	0.0	2/2	1
T0(C-3)	2694	B			PSTN	- 3.3	0.2	2/2	1
T0(E-7)	2696	A			RATE	- 0.25	5.0	4/3	1
T1	2693	A	0.07	---	---	---	---	6/6	3
	2694	B						5/6	3
T1(A-2)	2693	A			PSTN	- 5.0	0.0	5/4	--
T1(A-6)	2695	B			PSTN	- 1.0	0.0	5/3	3
T2	2686	A	0.12	---	---	---	---	9/8	5
	2691	B						9/8	5
T2'	2696	A			---	---	---	9/9	5
T2(A-1)	2695	B			PSTN	-10.0	0.0	4/6	2
	2696	A						5/7	2
T2(A-2)	2692	A			PSTN	- 5.0	0.0	6/8	3
	2692	A						7/7	3
	2695	B						5/5	3
	2695	B						9/8	4
T2(A-6)	2691	B			PSTN	- 1.0	0.0	7/7	4
	2692	A						8/9	4
T2(B-2)	2692	A			PSTN	- 5.0	0.05	7/7	4
T2(B-4)	2691	B			PSTN	- 2.0	0.05	8/9	4
T2(C-3)	2694	B			PSTN	- 3.3	0.20	8/8	5
T2(C-5)	2693	A			PSTN	- 1.67	0.20	7/8	4
T2(D-8)	2694	B			RATE	- 0.075	2.0	10/10	3

TABLE II (CONT'D)

EXPERIMENT RESULTS SUMMARY

CONFIGURATION IDENTIFIER	FLIGHT NO.	PILOT	FCS DYNAMICS τ_D	FCS DYNAMICS λ_D	PIOS FILTER TYPE	PIOS FILTER CW	PIOS FILTER WMIN	PR/SPR	PIOR
T2(E-7)	2696	A			RATE	- 0.25	5.0	8/9	5
T2(E-8)	2693	A			RATE	- 0.075	5.0	8/5	4
T2(F-8)	2694	B			RATE	- 0.075	10.0	10/10	6
T3	2686	A	0.16	---	---	---	---	10/9	5
F1	2686	A	---	2.0	---	---	---	7/8	4
	2695	B						8/7	5
	2697	C						7/6	4
F1(A-1)	2697	C			PSTN	-10.0	0.0	8/6	3
F1(A-2)	2696	A			PSTN	- 5.0	0.0	6/8	1
	2696	A						8/7	4
	2697	C						8/8	3
F1(A-6)	2695	B			PSTN	- 1 0	0.0	10/10	5

T2' — Configuration T2 with $M_{\delta'_{ES}}$ = 1/2 nominal $M_{\delta'_{ES}}$.

NOTES: • FCS Dynamics: $e^{-\tau_D s}$, where $[\tau_D]$ = [seconds]

$\frac{\lambda_D}{s+\lambda_D}$, where $[\lambda_D]$ = [radian/sec] (See Section 2.2)

$e^{-\tau_D s}$ is the amount of transport (pure) time delay introduced; see Section 2.4 for complete description of the time delay network.

• PIOS Filter: See Section 2.3

The pilot ratings (PR) and PIO ratings (PIOR) are based on the Cooper-Harper pilot rating and PIO classification/rating scales, respectively (Section 3.3). The safety pilot rating (SPR) is also included in the table to assist the analyst in evaluating the data. This rating was given independently by the safety pilot and is really a measure of the observed task performance.

The pilot comments from each evaluation are given in Appendix I. Task performance records from selected landings are presented in Appendix II. These task records are time histories of the approach and landing task starting at runway realignment and ending just prior to main gear liftoff on takeoff.

The pilot rating data is presented in a slightly different format to facilitate comprehension of the experiment results. In Figure 4-1, the effects of the position PIOS filters on the flying qualities of configurations T0 and T2 are shown. The symbols represent the mean pilot rating where multiple evaluations of a configuration were performed. The pilot rating extremes are indicated by the vertical lines. Lines are drawn, based on the data, approximating the change in pilot rating for increasing gain attenuation (*CW*) with a position PIOS filter for each of the three values of gain attenuation breakpoint (*WMIN*).

The effects of the position PIOS filters on the secondary configurations (Configurations T1 and F1) are illustrated in Figure 4-2. The same symbology is used in this figure when multiple evaluations were performed.

Finally, the effects of the rate PIOS filters are depicted in Figure 4-3. Rate PIOS filters were evaluated only with Configurations T0 and T2.

Two augmented aircraft configurations were evaluated but not flown with PIOS filters. These were designated Configurations T2' and T3. Configuration T3 was the baseline augmented aircraft with 160 milliseconds of transport time delay added to the control system. This configuration was flown on the first

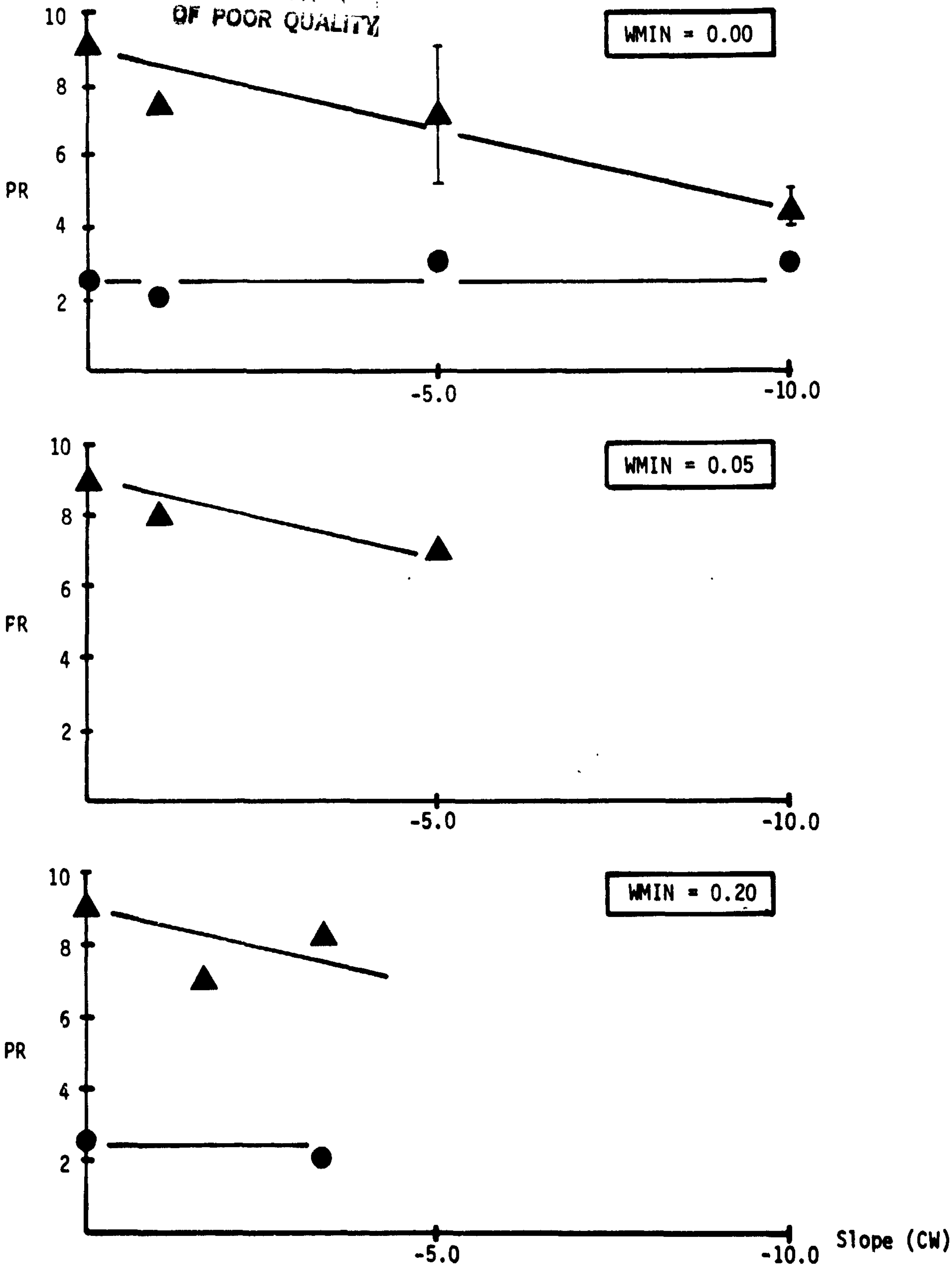

Figure 4-1: EFFECT OF POSITION PIOS FILTERS ON LANDING FLYING QUALITIES [CONFIGURATIONS TO (●) AND T2 (▲)]

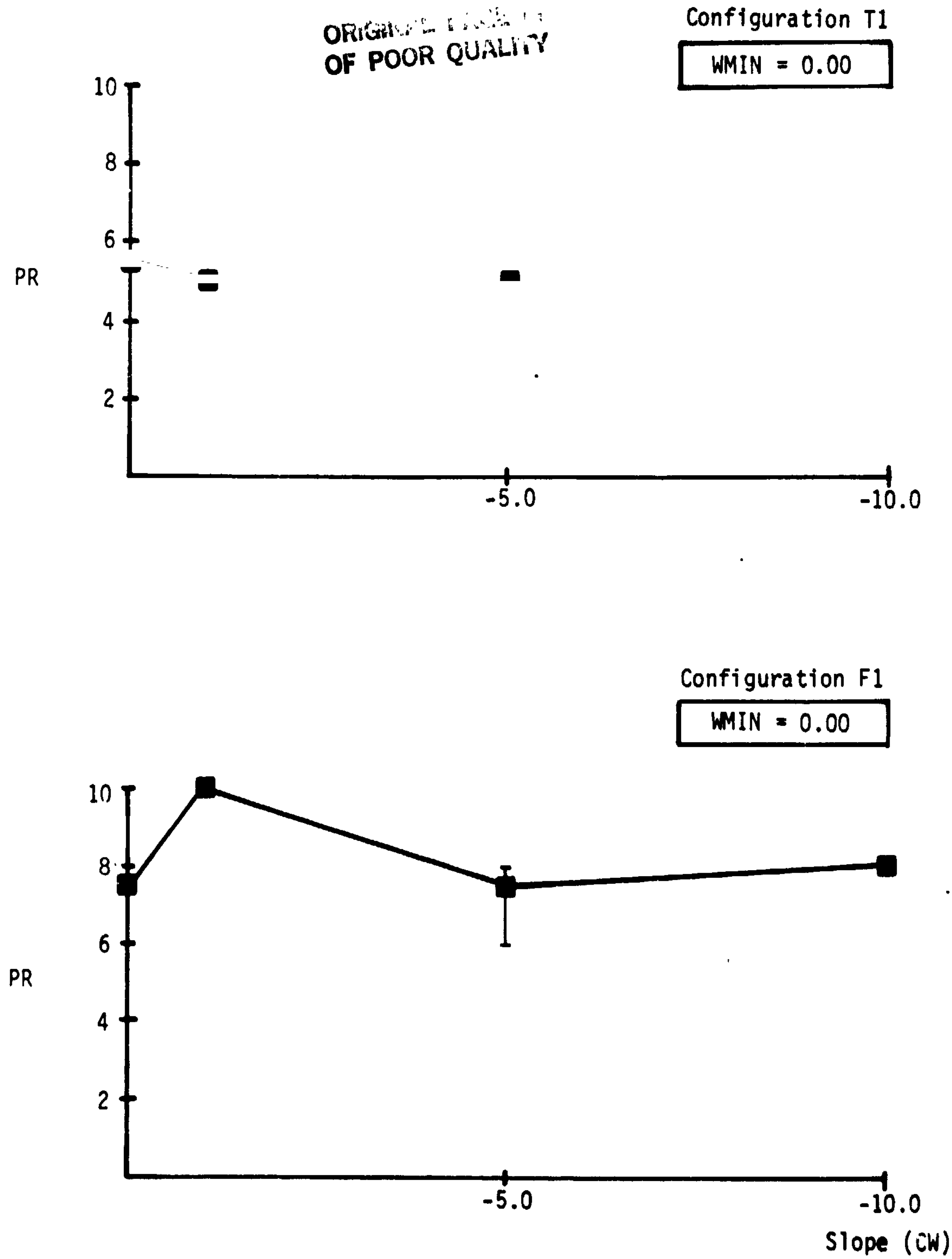

Figure 4-2: EFFECT OF POSITION PIOS FILTER ON LANDING FLYING QUALITIES [CONFIGURATIONS T1 AND F1]

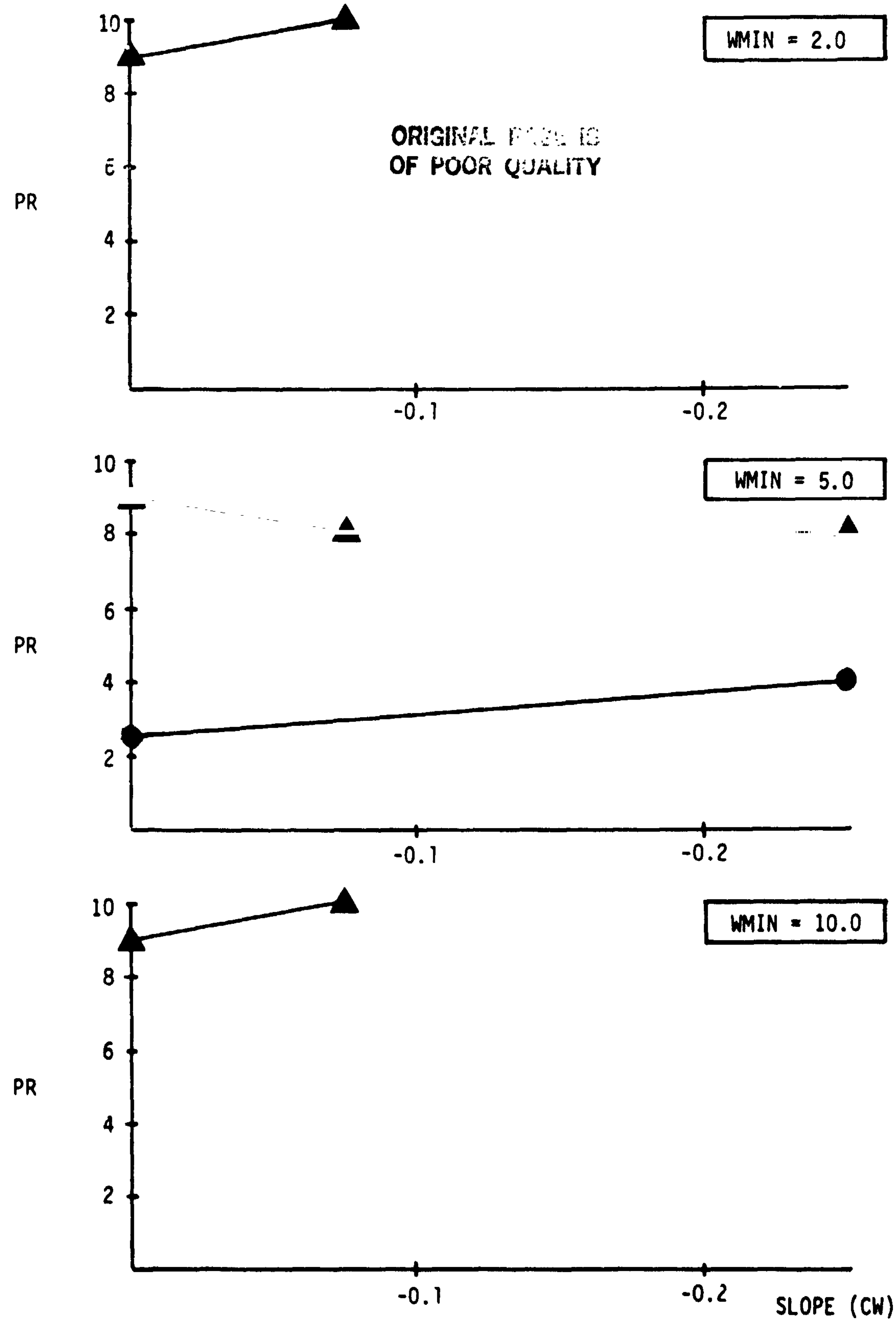

Figure 4-3: EFFECT OF RATE PIOS FILTER ON LANDING FLYING QUALITIES CONFIGURATIONS TO (●) AND T2 (▲)

flight to establish its flying qualities for possible investigation of PIOS filtering. It was not, however, used.

Configuration T2' was evaluated on Flight 2696 (see Table II). Configuration T2' is identical to Configuration T2 except its pitch command gain, $M_{\delta_{es}}$, is one-half the nominal value. This evaluation was an approximation of flying Configuration T2 with a "saturated" PIOS filter ($XK = 0.1$).

A comparison of the nonlinear gradient for Configuration T2' and the nonlinear gradient which results when a PIOS filter becomes saturated is shown in Figure 4-4. Configuration T2' was flown with the intent to test if a PIO-prone aircraft's flying qualities could be improved by merely decreasing the pilot's control authority rather than adaptively reducing pitch commands with PIOS filters. Whether the evaluation of Configuration T2' achieves its intended purpose depends on the validity of approximating the saturated nonlinear gradient. Nevertheless, decreasing the command gain of Configuration T2 by one half did not improve its flying qualities. Configuration T2' was rated identical to Configuration T2 (PR=9).

4.3 INTER/INTRA-PILOT RATING COMPARISON

Each of the evaluation pilots in this flight program adhered carefully to the evaluation task and provided invaluable pilot commentary despite numerous evaluations of marginally controllable aircraft configurations. Proof that the pilots stuck to the task and precisely followed the pilot rating decision tree is evident by the comparison of inter-pilot ratings (evaluations of the same configuration by two different pilots). This correlation is presented in Figure 4-5. The inter-pilot rating difference was very small as judged by all ratings being within ±1 pilot rating.

Although only a few repeat evaluations were performed (a pilot evaluating the same configuration), the same consistency in performing the task and in assigning pilot ratings was evident in repeat evaluations. There

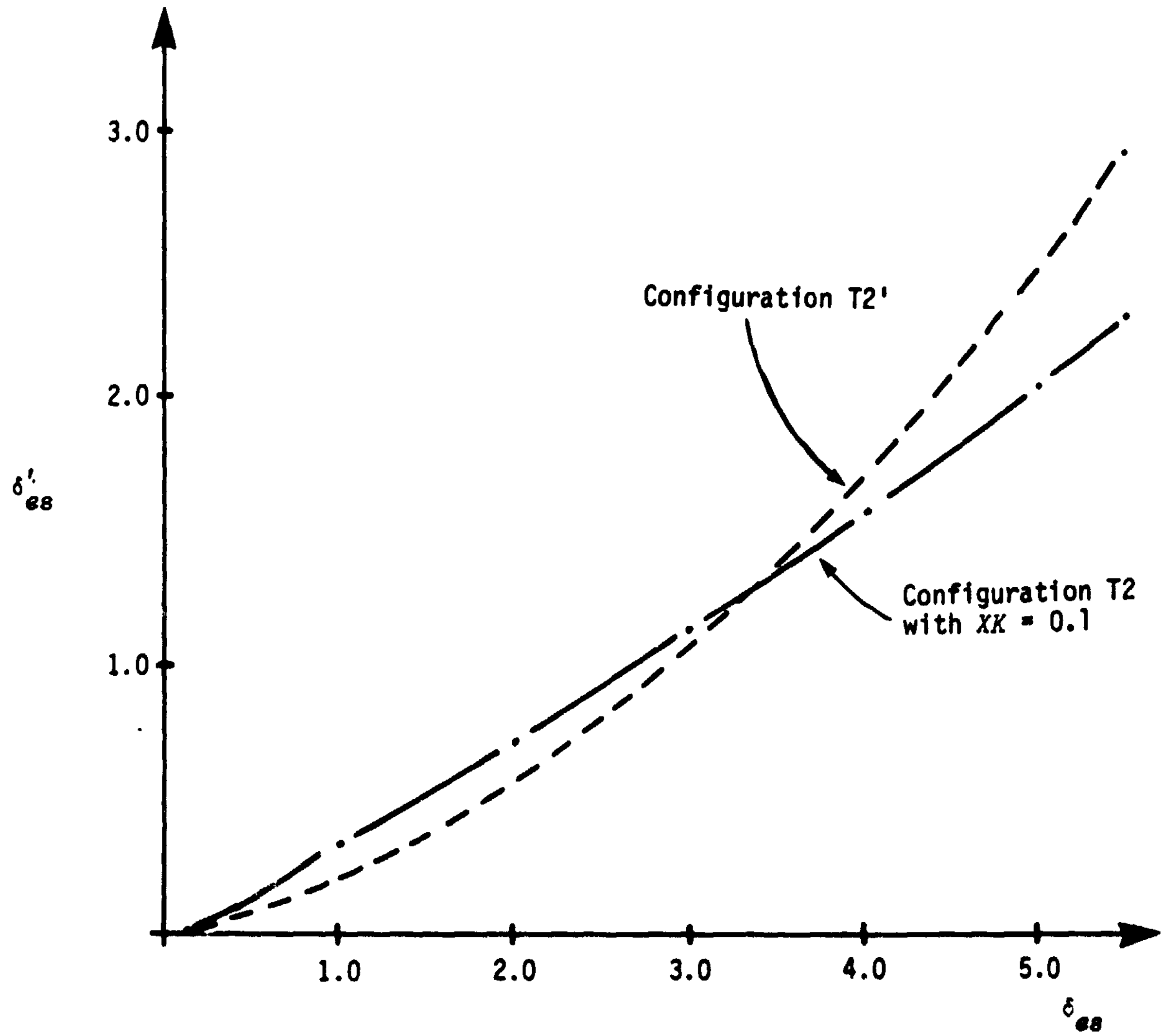

Figure 4-4: NON LINEAR PITCH COMMAND SHAPING GRADIENT FOR CONFIGURATION T2' AND CONFIGURATION T2 WITH SATURATED PIOS FILTER (XK = 0.1)

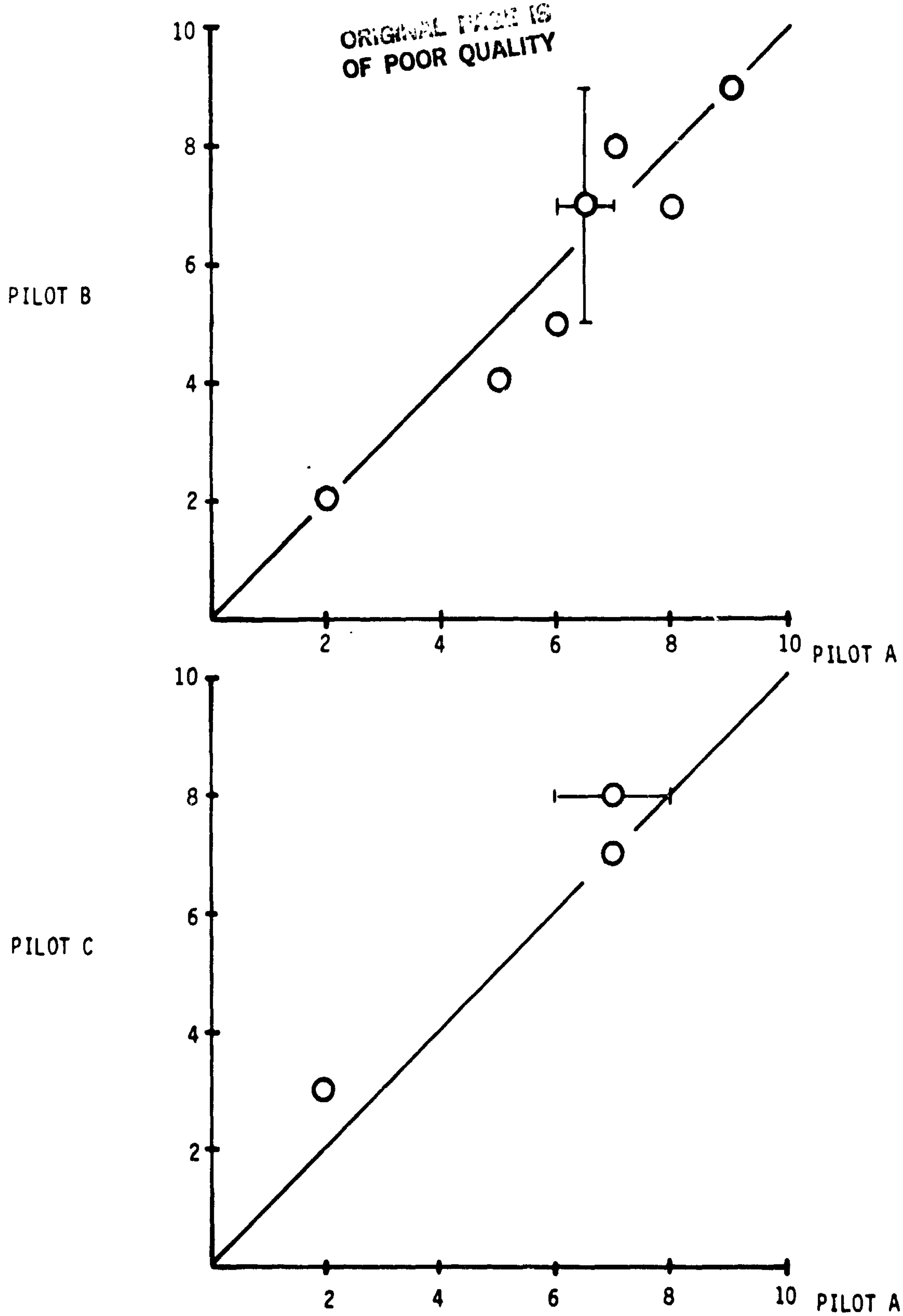

Figure 4-5: INTER-PILOT RATING COMPARISON

was, however, one exception which is more indicative of the erratic nature of the configurations with PIOS filters instead of inconsistency on the part of the pilots.

On Flight 2695, Pilot B, unknowingly, evaluated Configuration T2(A-2) twice. On the first evaluation, few flying qualities deficiencies were noted and a pilot rating of 5 was given. On the second evaluation, Pilot B elected to fly three approaches, attempting to sort out the flying qualities of the configuration. Although only one pilot rating was given for the entire evaluation (PR=9), an indication of the different performance that was achieved is given by the safety pilot ratings of 10, 6 and 8 for each of the three landings. Apparently, the position PIOS filter created very different appearing flying qualities depending upon the piloting technique. Detailed analyses have not been performed, but evaluations of several PIOS filters show similar erratic performance tendencies. More extensive analysis of the data should be performed to investigate this characteristic.

4.4 COMPARISON OF EXPERIMENT RESULTS WITH OTHER DATA

The pilot evaluations of the augmented aircraft configurations from this experiment are compared to other flying qualities data to provide a foundation for further discussions of the PIOS configurations.

- Configuration T0: PR = 2, 2, 3
  This configuration is essentially LAHOS Configuration 2-1 with a nonlinear gradient, slightly higher command gain, and digital time delay (approximately 20 milliseconds). From the LAHOS program (Reference 2), Configuration 2-1 was given, on two evaluations, a pilot rating of 2. The changes in this program to create Configuration T0 apparently had little effect on the flying qualities of LAHOS Configuration 2-1.

- Configuration F1: PR = 7, 8, 7
  This configuration was LAHOS 2-4 modified with a nonlinear gradient, slightly lower command gain, and digital time delay.

LAHOS Configuration 2-4 was evaluated once in the approach and landing task, and received a pilot rating of 9.

- Configurations T0, T1, T2 and T3:
  Prior to the start of evaluation flying, previous landing flying qualities data generated with the variable stability NT-33 aircraft were used in selecting the additional time delay required with Configuration T0 to create the desired additional configurations. These data have been extensively analyzed by the McDonnell Aircraft Company (MCAIR) using the Equivalent Systems approach. These studies were referenced accordingly. A pilot rating functional has been formulated from the data showing the degradation of landing longitudinal flying qualities with equivalent time delay (References 8 and 9). The comparison of this pilot rating functional and the evaluations of configurations T0, T1, T2, and T3 is given in Figure 4-6. The results of this program correlate very strongly with the Equivalent Systems, pilot rating functional.

4.5 EFFECTS OF PIOS FILTERING

The preceding section has shown that the flying qualities of the aircraft configurations were well established and substantiated by previous flying qualities data. This strong foundation for the experiment group facilitates the analysis of PIOS filtering. Although no detailed analyses have been undertaken, several observations concerning evaluations with the PIOS filters are made to complete the documentation of the experiment results.

Figures 4-1, 4-2, and 4-3 have been drawn illustrating the effects of PIOS filtering on landing flying qualities from this program. Figure 4-1, in particular, indicates that a position PIOS filter can be designed such that unacceptable aircraft flying qualities, characterized by Configuration T2, can be improved by adding PIOS filters to the pitch control system. However, this conclusion and any others drawn solely from the pilot rating data are

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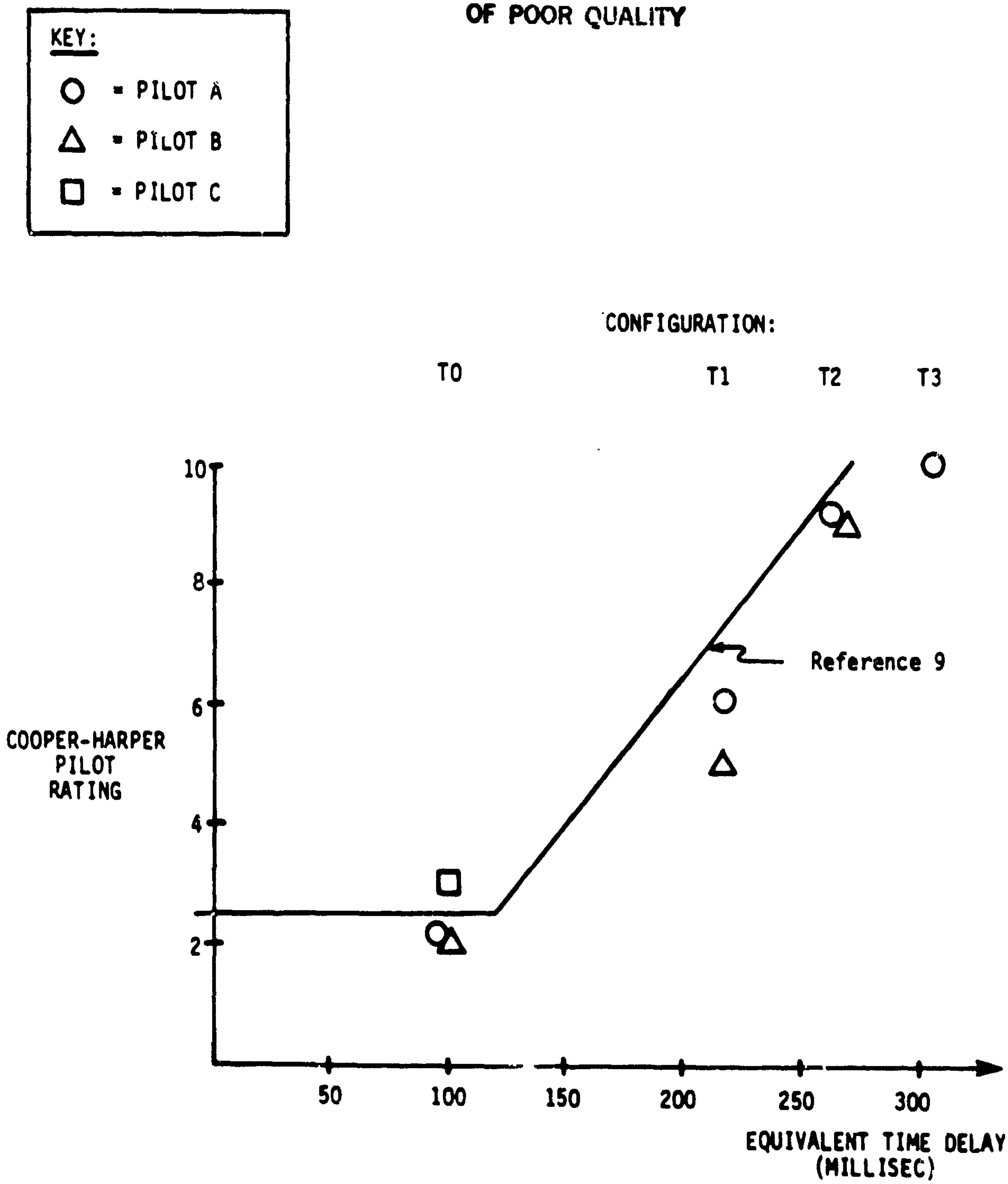

Figure 4-6: DEGRADATION OF LANDING LONGITUDINAL FLYING QUALITIES WITH INCREASING EQUIVALENT TIME DELAY

improper. Full regard must be given to the associated pilot commentary in interpreting the pilot rating data.

Configuration T2, in the absence of PIOS filtering, was evaluated as having unacceptable longitudinal landing flying qualities. Evaluations of Configuration T2 with position PIOS filtering showed improved pilot ratings with increased input suppression (Figure 4-1). For example, adding a position PIOS filter with a gain schedule breakpoint equal to 0.00, yielded improving flying qualities as a function of increasing gain schedule slope (CW) (the amount of input suppression). Configuration T2(A-6) [slope = -1.0] was rated a mean PR=7.5; Configuration T2(A-2) [slope = -5.0] was evaluated a mean PR=7; finally, Configuration T2(A-1) [slope = -10.0] was rated a mean PR=4.5. Closer examination of these evaluations through review of the pilot comments shows some interesting characteristics of the filters. Conclusions cannot be drawn without more detailed analyses, but general observations are made which are warranted for documentation of the experiment results and subsequent analysis.

As noted, increasing pilot input suppression (from a position PIOS filter with a gain schedule breakpoint equal to 0.0) improved the flying qualities of aircraft Configuration T2 as gauged by the mean pilot ratings. Increasing the gain schedule slope changes how the filter interacts with the pilot and the amount of "adaptive" pilot input suppression. The three values of gain attenuation slope (CW) evaluated with the PIOS filter described above and aircraft Configuration T2 illustrate this point.

In the evaluation of Configuration T2(A-6), the PIOS filter was not very active in terms of changing gain attenuation (XK). The value of XK was relatively constant, thus little adaptive gain changing occurred (see Appendix II for landing time histories). The pilot ratings for this configuration were nearly the same as those given for the baseline aircraft without PIOS filtering (Configuration T2). The pilot comments indicated that the filter had little effect other than to decrease the aircraft's control authority and initial pitch response.

Increasing the gain attenuation slope further (as characterized by Configuration T2(A-2)) created a PIOS filter which was very interactive with the pilot in the landing flare because of continual changes in input suppression (XK). The filter was very "adaptive" in nature. Consequently, erratic pilot/airplane system performance was seen. This erratic performance was described in Section 4.3 and illustrated by the time histories included in Appendix II.

Finally, the position PIOS filter with a gain schedule slope of -10.0 (Configuration T2(A-1)) produced the best landing flying qualities with aircraft Configuration T2 (mean PR=4.5). Interestingly, the PIOS filter was saturated (XK=0.1) for almost the entire landing flare. Little adaptive gain changing or interaction with the pilot was, therefore, exhibited. The pilot was essentially flying Configuration T2 with a reduced (constant), nonlinear command-gradient.

Based on the results from evaluations of Configuration T2(A-1), an approximation of flying a saturated PIOS filter (XK=0.1) was attempted (Section 4.2). This attempt (Configuration T2') was made to investigate if improved landing flying qualities could be achieved without the adaptive algorithm by just reducing the available command gain. Detailed analyses have not been performed but the data from the evaluations of Configurations T2(A-1) and T2' should be examined to explore the effects of PIOS filtering.

The same PIOS filter, which greatly improved the landing flying qualities of Configuration T2, was flown with another PIO-prone aircraft, Configuration F1. The flying qualities of this configuration (Configuration F1(A-1)) did not improve. In fact, none of the filters added to Configuration F1 showed much improvement in the configuration's flying qualities. Although analyses have not been completed, it is likely that the sluggish initial pitch response of Configuration F1 compounded by the reduced control authority from the position PIOS filters outweighed any potential benefit of the adaptive filters. When these same filters were flown with a good flying aircraft configuration (Configuration TC) or an acceptable, but not totally satisfactory airplane (Configuration T1), little change in landing flying qualities occurred.

The comments from Pilot B's evaluations were particularly interesting since he participated extensively as an evaluation pilot investigating PIOS filtering prior to this program. His experience stems from the PIOS filter investigations at NASA/DFRC using the F-8 DFBW in a simulated aerial refueling task. In several cases, Pilot B made comments which related his past experiences to this program. These comments were extremely interesting for comparison of the respective evaluation tasks as well as providing an experienced voice reflecting a pilot's viewpoint of PIOS filtering. These comments are included in the pilot comment summaries when made with regard to a particular configuration. It should be remembered that Pilot B did not, at any time, know the configuration characteristics being simulated nor if a PIOS filter was implemented.

It should also be noted that in only one instance did Pilot B make mention of a configuration which acted like a PIOS filter he was accustomed to flying from the F-8 program. This configuration was Configuration T2(A-1) which, as stated above, the time histories from this evaluation showed that the PIOS filter was saturated (XK=0.1) for most of the flare to touchdown.

As a general comment, Pilot B questioned the difference between a trimmed versus untrimmed task with a PIOS filter operational. His remarks were not related to any specific configuration but the comment does reflect an important consideration in comparing the landing approach task and other evaluation tasks during PIOS filter investigations. Pilot B hypothesized that the PIOS filter operates in a more noticeable fashion to the pilot in the landing task rather than the aerial refueling task. In the aerial refueling task, the mean stick force or displacement is equal to zero because the aircraft is trimmed at the proper airspeed for the task; whereas, the landing task dictates increasing aft stick forces to bleed off airspeed in the flare with the aircraft trimmed for the approach. Since the pilot is operating about a steady state, non-zero, stick position in the landing task, any change that the PIOS filters make in changing the nonlinear command gradient (XK) should be quite evident to the pilot. On the other hand, command gain changes by the PIOS filters during the aerial refueling task should not be as noticeable because the pilot inputs are centered about zero stick displacement. As illustrated in Figure 2-5, changes in the nonlinear command gradient due to variations in XK are greater about a non-zero stick displacement than they are about the zero steady-state stick position. Hence, the difference between a trimmed and untrimmed evaluation task may be an important aspect in analyzing the experiment results and, in particular, the pilot commentary. This hypothesis was made by Pilot B as a general comment and was not related to any single configuration. The issue is relevant, nonetheless, and should be considered for further investigation.

Only five evaluations of rate PIOS filters were performed. The results are generally inconclusive. Although the underlying concept behind the rate PIOS filters is the same as the position PIOS filters (that is, the pilot command to the appropriate control surface is reduced as the "PIO-condition" is approached), the different filter mechanization created very different pilot/aircraft response characteristics. As a general remark, the rate PIOS filters that were flown did not improve landing flying qualities and, in two cases, very serious control problems were evident (PR=10); however, on one of these evaluations rated as uncontrollable (Configuration T2(F-8)), the suppression filter was never active (XK=1.0). This case would be identical to flying the baseline aircraft Configuration T2. Clearly, more definitive examination of the data is required to clarify these results.

4.6 EVALUATION TASK

The results of this experiment — the pilot ratings and comments — illustrate that the definitive task for the evaluation of landing flying qualities was the flare and touchdown. Even though the takeoff portion of the overall task was, at times, as difficult as the flare, flying qualities deficiencies, if they were present, were exposed during the last 50 ft of the approach to touchdown. Repeatedly the comment was made that the approach task was no problem. These observations again substantiate that the flare and touchdown tasks are required for the evaluation of landing flying qualities.

The variety of wind and turbulence conditions for this program should be carefully weighed in the analysis of the data. It was noted several times by the evaluation pilots that they were, to some degree, forewarned of potential PIO-prone configurations on approach by delayed pitch attitude responses to their inputs. Any influence that this may have had on their evaluations can be extracted by comparing evaluations from Flights 2693 and 2694. On these flights, the light to moderate turbulence effectively masked the aircraft's pitch response on approach. Consequently, the evaluation pilots could not discern on approach if lags or delays were present and an element of surprise was added to the landing task. Yet, in all cases, each pilot approached the task with the same, consistent level of aggressiveness and performance standard. As always, the pilot ratings alone cannot be used in any analysis of the experiment results. The pilot comments must be referenced with the pilot rating data to examine the effects of PIOS filters on landing flying qualities.

Section 5
CONCLUDING REMARKS

An in-flight investigation of Pilot-Induced Oscillation Suppression (PIOS) filters was performed using the AFFDL variable stability NT-33 aircraft operated by Calspan. Forty evaluations of 27 configurations were flown in eight flights. The data generated in this experiment are in the form of pilot ratings, pilot comments, and task performance records (time histories). Although detailed analyses have not been performed, the data indicate that:

- Actual landings and subsequent takeoffs (touch-and-go's) are required for the proper evaluation of landing flying qualities.

- PIOS filters can be designed such that the flying qualities of an aircraft configuration which exhibits pilot-induced oscillation tendencies can be improved by adding PIOS filters to the pitch control system.

- The ability of PIOS filters to improve flying qualities, however, is dependent not only on the filter design but also on the characteristics of the aircraft configuration. For example, the data suggest that a PIOS filter which improves the flying qualities of a configuration compromised by control system time delay, will slightly degrade the flying qualities of a configuration that is characterized by excessive control system filtering.

- The PIOS filters tested in this experiment did not degrade good longitudinal aircraft flying qualities to the extent that desired performance was not attainable.

- Very erratic pilot/airplane system performance is evident when the PIOS filter is very "active" about the same operating point (for example, stick displacement) that the pilot is also controlling the aircraft.

- The data generated in this program are suitable for more extensive analyses to explore the effects of PIOS filter.

Section 6
RECOMMENDATIONS

The results of this program provide an excellent foundation for analyses to explore the effects of PIOS filtering on the longitudinal landing flying qualities of fighters. The following recommendations for future work are drawn based on this work.

- A follow-on program should be undertaken to investigate:

  1) The effects of different internal PIOS filter implementations (for example, different position PIOS filter time constants) on fighter aircraft landing flying qualities.
  2) The interaction between various short period dynamic characteristics and PIOS filtering.
  3) The flying qualities of a PIO-prone configuration with a saturated PIOS filter.
  4) The influence of actuator rate limiting in conjunction with PIOS filters on landing flying qualities.

- Detailed analyses should be performed to interpret the configuration flying qualities of this investigation. This effort should include the development of closed-loop pilot/aircraft models for flying qualities analysis.

- Portions of this experiment should be repeated on a modern, sophisticated ground simulator to document suspected differences between the in-flight and ground simulators for the evaluation of approach and landing longitudinal flying qualities.

- Portions of this experiment should be repeated using the DFBW/F-8 in the simulated aerial refueling or longitudinal target tracking tasks to examine the effects of task in the evaluation of PIOS filtering and aircraft flying qualities.

- Future in-flight investigations of PIOS filters should examine the influences of a trimmed versus untrimmed evaluation task on the flying qualities of aircraft using PIOS filtering. The PIOS filters should also be tested in applications for the suppression of lateral pilot-induced oscillations.

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Appendix I

PILOT COMMENT SUMMARY

Summaries of the pilot comments from each evaluation are presented on the following pages of this appendix. These comment summaries are based on the recorded comments made by each pilot in reference to the comment card (Figure 3-4). Comments on the lateral-directional characteristics are not included because the pilots consistently indicated that these characteristics were excellent and, therefore, not a factor in the evaluations.

The headings on each pilot comment summary list pertinent information concerning the evaluation configuration characteristics and task environment.

The configuration identifier (Section 2.5) is given for each evaluation with the assigned pilot rating (PR), safety pilot rating (SPR), and PIO classification rating (PIOR). If any change in these ratings were made, this decision is reflected in the summary remarks.

For reference, the experiment variables consisting of the configuration control system dynamic elements and PIOS filter are given. A dashed line (—) is placed under the appropriate heading if any of these elements were not included in the configuration. The PIOS filter characteristics are defined by the slope (*CW*) and breakpoint (*WMIN*) of the gain attenuation schedule (Section 2.3). The type of PIOS filter is identifiable by the configuration identifier. The control system dynamic elements are the control system time delay ($e^{-\tau_D s}$, where τ_D is in units of seconds) or first order, lag prefilter ($\lambda_D/(s+\lambda_D)$ with λ_D in units of radians per second). These elements were added to the baseline augmented aircraft configuration to create the experiment control group of longitudinal augmented aircraft configurations (Section 2.2).

The flight number and order of the evaluation are also listed. For example, 2692-2 signifies that the evaluation was flown on Flight 2692 and it was the second configuration evaluated on that flight. The evaluation pilot is also specified.

Finally, the headwind and crosswind magnitudes (in knots) at the time of the evaluation are given including a qualitative assessment of the turbulence level described by the safety pilot.

Even though the pilot rating data suggests little difference between the evaluations by the three pilots, the manner in which each pilot approached the evaluation was slightly different. These differences may be instructive to the analyst when reviewing the pilot comments, since they give insight into the effects of PIOS filtering. For this reason, several observations on each of the pilot's flying/evaluation techniques are noted:

- Pilot A (the "primary" evaluation pilot) followed the pilot comment card very closely. His piloting technique could be considered exploratory in nature because, on most evaluations, he tried different ways to fly the configuration, yet still perform the task. In any case, the techniques he used were explai... fully, and he extrapolated this effort or required compensation very astutely into the pilot rating/evaluation process. Consequently, his evaluations were realistic in terms of the performance that can be consistently obtained with a configuration while various techniques to control the aircraft were explored.

- Pilot B, at times, gave narratives in an attempt to explain what he saw rather than following the comment card to the letter. His experiences in previous PIOS filters studies were sometimes related to what he saw in this program. Pilot B's piloting techniques could be classified as "smoother" than Pilot A's and Pilot B was usually willing to stay in a PIO in an attempt to control it. These techniques were likely the result of his past experiences with marginally controllable aircraft. Pilot B nevertheless, evaluated configurations on their merit alone and not on his specialized piloting techniques.

- Pilot C flew only one evaluation flight but acted as the safety pilot for the evaluation flights with Pilots A and B. The results of his flight are instructive to the analyst as a fresh look at the configurations. Pilot C was very familiar with the task and peculiarities of landing the NT-33 aircraft, so learning curve effects were not a factor. (Pilots A and B flew familiarity/practice evaluation flights prior to the start of evaluation flying to minimize learning curve effects).

Overall, each of the pilots was extremely consistent in evaluations and very skilled in their trade. Their strict adherenco to the task and frank pilot comments made the successful completion of this program possible and the data invaluable.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2686-2	τ_D	λ_D	SLOPE	BREAK PT.	TO		
	–	–	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	00/05		None		2	2	1

- INITIAL REMARKS: Good flying airplane.

- FEEL SYSTEM CHARACTERISTICS: Forces/displacements/sensitivity: good, satisfactory.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Good, no compensation required.
  - Final Response? - Even with high pilot gain, no problems with controlling final response.
  - Predictability? - Good.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Tried to be extra aggressive on "go" using sharp inputs, yet no PIO tendency.
  - Piloting Techniques?
  - Small vs. Large Inputs? - No differences noted.
  - Open vs. Closed-Loop Control? - No PIO tendency at all.

- TASK PERFORMANCE:
  - Airspeed Control - Good.
  - Touchdown Point Accuracy - Good, well within limits.
  - Sink Rate at Touchdown - Satisfactory.
  - Runway Alignment - Good.
  - Aggressiveness - Normal level of aggressiveness used although not concerned if large inputs required near ground.
  - Task Differences - No differences in terms of performance.

- ADDITIONAL FACTORS: - None.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
	τ_D	λ_D	SLOPE	BREAK PT.			
2691-2	–	–	–	–	TO		
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	07/04		None		2	2	1

- INITIAL REMARKS: Good configuration.

- FEEL SYSTEM CHARACTERISTICS: All OK.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Very nice.
  - Final Response? - Like the base airplane.
  - Predictability? - Very good.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No PIO tendency.
  - Piloting Techniques? - None required.
  - Small vs. Large Inputs? - No differences
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - OK; still a little unsure of T-33's throttle response.
  - Touchdown Point Accuracy - Good, within limits.
  - Sink Rate at Touchdown - Good.
  - Runway Alignment - Good.
  - Aggressiveness - Fairly aggressive.
  - Task Differences - No apparent differences.

- ADDITIONAL FACTORS: - None.

- SUMMARY:

<table>
<tr><td>FLIGHT NO-EVAL</td><td colspan="2">FCS DYNAMICS</td><td colspan="2">PIOS CONFIGURATION</td><td colspan="3">CONFIGURATION</td></tr>
<tr><td rowspan="2">2697-2</td><td>τ_D</td><td>λ_D</td><td>SLOPE</td><td>BREAK PT.</td><td colspan="3" rowspan="2">TO</td></tr>
<tr><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>EVAL. PILOT</td><td colspan="2">WIND/X-WIND</td><td colspan="2">TURBULENCE</td><td>PR</td><td>SPR</td><td>PIOR</td></tr>
<tr><td>C</td><td colspan="2">04/10</td><td colspan="2">Light</td><td>3</td><td>2</td><td>1</td></tr>
</table>

- INITIAL REMARKS: Pitch response seemed a little lagged.

- FEEL SYSTEM CHARACTERISTICS: Used larger than desired displacements (minor deficiency), low sensitivity.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Satisfactory.
  - Final Response?
  - Predictability? - Yes.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - None.
  - Piloting Techniques? - No special techniques required.
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control? - Can be aggressive with airplane and feel connected one-to-one with it.

- TASK PERFORMANCE:
  - Airspeed Control - Good.
  - Touchdown Point Accuracy - No problems with airplane.
  - Sink Rate at Touchdown - Good.
  - Runway Alignment
  - Aggressiveness - Could use whatever level I choose.
  - Task Differences - No differences noted.

- ADDITIONAL FACTORS: - Slight crosswind becoming a factor.

- SUMMARY: Debated between PR=2 and PR=3.

<table>
<tr><th>FLIGHT NO-EVAL</th><th colspan="2">FCS DYNAMICS</th><th colspan="2">PIOS CONFIGURATION</th><th colspan="3">CONFIGURATION</th></tr>
<tr><td rowspan="2">2697-5</td><td>τ_D</td><td>λ_D</td><td>SLOPE</td><td>BREAK PT.</td><td colspan="3" rowspan="2">TO (A-1)</td></tr>
<tr><td>–</td><td>–</td><td>-10.0</td><td>0.0</td></tr>
<tr><th>EVAL. PILOT</th><th colspan="2">WIND/X-WIND</th><th colspan="2">TURBULENCE</th><th>PR</th><th>SPR</th><th>PIOR</th></tr>
<tr><td>C</td><td colspan="2">05/15</td><td colspan="2">Light</td><td>3</td><td>2</td><td>1</td></tr>
</table>

- INITIAL REMARKS: Don't like the force levels in flare. Felt like bottom fell out right at the end.

- FEEL SYSTEM CHARACTERISTICS: Forces heavy, displacements large, and would like more pitch sensitivity.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Reasonable.
  - Final Response? - Reasonable and predictable.
  - Predictability? - Yes.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - None.
  - Piloting Techniques? - Flew airplane naturally and I got the job done.
  - Small vs. Large Inputs? - No comment.
  - Open vs. Closed-Loop Control? - No difference.

- TASK PERFORMANCE:
  - Airspeed Control - Satisfactory.
  - Touchdown Point Accuracy - Within limits.
  - Sink Rate at Touchdown - Good.
  - Runway Alignment - No problem.
  - Aggressiveness - Normal level of aggressiveness.
  - Task Differences - No differences except high forces in flare.

- ADDITIONAL FACTORS: - Slight crosswind added to task/workload. Had no problems with it.

- SUMMARY: Only problem with this configuration was the large aft stick and loss of pitch sensitivity near end of flare.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2693-4	τ_D	λ_D	SLOPE	BREAK PT.	TO (A-2)		
	–	–	-5.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	08/10		Light to moderate		3	3	1

- INITIAL REMARKS: Airplane didn't flare as smoothly as would have liked but overall a nice flying airplane.

- FEEL SYSTEM CHARACTERISTICS: Forces/displacements: OK. Sensitivity - not quite adequate in the flare but not poor by any means.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Good.
  - Final Response? - A little heavier than desired.
  - Predictability? - OK but could control other configurations more precisely.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No, even when intentional high gain type inputs used.
  - Piloting Techniques? - Not aware of any.
  - Small vs. Large Inputs? - Not as much pitch rate in proportion for large inputs.
  - Open vs. Closed-Loop Control? - No differences.

- TASK PERFORMANCE:
  - Airspeed Control - Acceptable.
  - Touchdown Point Accuracy - Floated a bit on the second landing.
  - Sink Rate at Touchdown - Could have been a little better.
  - Runway Alignment - OK.
  - Aggressiveness - Felt comfortable with airplane when aggressive near ground.
  - Task Differences - Little differences.

- ADDITIONAL FACTORS: - Crosswind, but not an influence on rating.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
	τ_D	λ_D	SLOPE	BREAK PT.			
2692-3	–	–	-1.0	0.0	TO (A-6)		
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	05/02		Light		2	2	1

- INITIAL REMARKS: Good airplane.

- FEEL SYSTEM CHARACTERISTICS: Satisfactory. No problem with displacements.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - As desired.
  - Final Response? - Good.
  - Predictability? - Excellent.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - None.
  - Piloting Techniques? - None.
  - Small vs. Large Inputs? - No differences.
  - Open vs. Closed-Loop Control? - Well behaved aircraft with pilot in or out of control loop.

- TASK PERFORMANCE:
  - Airspeed Control - Good.
  - Touchdown Point Accuracy - Good.
  - Sink Rate at Touchdown - Good.
  - Runway Alignment - Satisfactory, offset was easily performed.
  - Aggressiveness - Didn't hesitate to be aggressive.
  - Task Differences - No differences noted.

- ADDITIONAL FACTORS: - None.

- SUMMARY: Felt very comfortable with airplane.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2694-3	τ_D	λ_D	SLOPE	BREAK PT.	TO (C-3)		
	–	–	-3.3	0.2			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	17/06		Moderate		2	2	1

- INITIAL REMARKS: Very slight pitch bobble noticed.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response?
  - Final Response?
  - Predictability? - Very predictable.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No, maybe slight susceptibility for undesirable motions.
  - Piloting Techniques? - None.
  - Small vs. Large Inputs? - Would have felt confident using either large or small inputs.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - Good.
  - Touchdown Point Accuracy - Fine.
  - Sink Rate at Touchdown - Good.
  - Runway Alignment - Good.
  - Aggressiveness
  - Task Differences

- ADDITIONAL FACTORS: - Weather added to task; slight wind shear on final.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2696-3	τ_D	λ_D	SLOPE	BREAK PT.	TO (E-7)		
	–	–	-0.25	5.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	02/01		None		4	3	1

- INITIAL REMARKS:

- FEEL SYSTEM CHARACTERISTICS: Forces/displacements satisfactory. Pitch sensitivity acceptable, although may be a little insensitive.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - OK but a little slow.
  - Final Response? - No overcontrol tendencies.
  - Predictability? - Good.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No, maybe a little pitch nodding though.
  - Piloting Techniques? - Not aware of any.
  - Small vs. Large Inputs? - No difference.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - OK.
  - Touchdown Point Accuracy - Within limits, but floated a bit on each landing.
  - Sink Rate at Touchdown - Satisfactory.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - A little less aggressive than might have been with best airplane.
  - Task Differences - None noted.

- ADDITIONAL FACTORS: - None.

- SUMMARY: No change in ratings.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2693-1	τ_D	λ_D	SLOPE	BREAK PT.	T1		
	0.07	–	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	06/08		Light to moderate		6	6	3

- INITIAL REMARKS:

- FEEL SYSTEM CHARACTERISTICS: Forces satisfactory. Noticed tendency to pump stick. Sensitivity sluggish.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Not quick; lagged/delayed.
  - Final Response? - Unsure of final response, overcontrolled.
  - Predictability? - Cannot be extremely precise.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Slight.
  - Piloting Techniques? - Tried to avoid very tight aggressive control.
  - Small vs. Large Inputs? - No differences detected.
  - Open vs. Closed-Loop Control? - PIO tendency seen only during closed loop.

- TASK PERFORMANCE:
  - Airspeed Control - Not very good.
  - Touchdown Point Accuracy - Poor because of problems controlling pitch attitude.
  - Sink Rate at Touchdown - Higher than desirable.
  - Runway Alignment - Crosswind made alignment more difficult.
  - Aggressiveness - Did not want to get that aggressive.
  - Task Differences - Landing and takeoff more difficult.

- ADDITIONAL FACTORS: - Crosswind/turbulence adds to task workload. Realistic conditions.

- SUMMARY:

FLIGHT NO-EVAL	PCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2694-1	τ_D	λ_D	SLOPE	BREAK PT.	T1		
	0.07	–	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	17/06		Light to moderate		5	6	3

- INITIAL REMARKS: Turbulence, wind and crosswind make task different and more difficult than before.

- FEEL SYSTEM CHARACTERISTICS: No comments.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Delayed.
  - Final Response? - Cannot accurately judge amount of response associated with input.
  - Predictability? - Lacking.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Undesirable motions.
  - Piloting Techniques? - Not aware of any.
  - Small vs. Large Inputs? - No difference.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - Complicated by wind shear but no problems due to aircraft.
  - Touchdown Point Accuracy - No problems due to configuration.
  - Sink Rate at Touchdown - Firm but acceptable.
  - Runway Alignment - Good.
  - Aggressiveness - Fairly high.
  - Task Differences

- ADDITIONAL FACTORS: - Slight wind shear on final.

- SUMMARY: Evaluation as well as task complicated by weather since one cannot tell if airplane is acting in response to pilot inputs or weather.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2693-5	τ_D	λ_D	SLOPE	BREAK PT.	T1 (A-2)		
	0.07	–	-5.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	08/10		Light to moderate		5	5	

- INITIAL REMARKS:

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response?
  - Final Response?
  - Predictability?

Pilot comments lost -
voice recorder malfunction

- PILOT-IN-THE-LOOP:
  - PIO Tendency?
  - Piloting Techniques?
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control
  - Touchdown Point Accuracy
  - Sink Rate at Touchdown
  - Runway Alignment
  - Aggressiveness
  - Task Differences

- ADDITIONAL FACTORS:

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2695-1	τ_D	λ_D	SLOPE	BREAK PT.	T1 (A-6)		
	0.07	–	-1.0	0.00			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	09/05		None		5	5	3

- INITIAL REMARKS: Not too bad of an airplane except for the pitch response in flare.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Just slightly sluggish.
  - Final Response? - More response than expected based on initial response.
  - Predictability? - It is predictable - not frightened by it.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No oscillations, but undesirable motions because of mismatch between initial and final response
  - Piloting Techniques? - Had to use small inputs.
  - Small vs. Large Inputs? - Airplane's bad characteristics appeared when making large inputs to put airplane on the ground.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - No comment.
  - Touchdown Point Accuracy - First landing a little long. Second OK.
  - Sink Rate at Touchdown - Acceptable.
  - Runway Alignment
  - Aggressiveness - Fair amount of aggressiveness
  - Task Differences - Landing task rather than approach or take off is where bad characteristics showed up.

- ADDITIONAL FACTORS:

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION
2686-3	τ_D	λ_D	SLOPE	BREAK PT.	T2
	0.12	-	-	-	

EVAL. PILOT	WIND/X-WIND	TURBULENCE	FR	SPR	PIOR
A	00/05	Light	9	8	5

- INITIAL REMARKS: Significant control problems on first landing - 2nd approach/landing performance was better out not great.

- FEEL SYSTEM CHARACTERISTICS: Displacements seemed large. Pitch sensitivity poor, lagged.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Not there, delayed.
  - Final Response? - Confusing response with pilot in loop.
  - Predictability? - None at all.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, low frequency PIO near ground.
  - Piloting Techniques? - Tried to use small inputs or back off from task.
  - Small vs. Large Inputs? - No differences noted.
  - Open vs. Closed-Loop Control? PIO with closed loop, high gain control

- TASK PERFORMANCE:
  - Airspeed Control - Adequate.
  - Touchdown Point Accuracy - Well past on first landing, within limits on second.
  - Sink Rate at Touchdown - Not really all that controllable.
  - Runway Alignment - OK.
  - Aggressiveness - Tried as hard as possible.
  - Task Differences - Second takeoff caused PIO. Approach can be flown satisfactorily.

- ADDITIONAL FACTORS: - SP: get crosswind disturbance from left at threshold.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION
	τ_D	λ_D	SLOPE	BREAK PT.	
2691-3	0.12	–	–	–	T2

EVAL. PILOT	WIND/X-WIND	TURBULENCE	PR	SPR	PIOR
B	07/04	None	9	8	5

- INITIAL REMARKS: Waved off first approach because of unpredictable pitch attitude response.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Kind of sluggish.
  - Final Response? - Overshoots.
  - Predictability? - None.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes.
  - Piloting Techniques? - Used small input, open loop type control.
  - Small vs. Large Inputs? - Would not want to make large inputs near ground.
  - Open vs. Closed-Loop Control? - Tried to avoid closed loop control.

- TASK PERFORMANCE:
  - Airspeed Control - Poor.
  - Touchdown Point Accuracy - Poor.
  - Sink Rate at Touchdown - Too high.
  - Runway Alignment - Good.
  - Aggressiveness - Could not be aggressive.
  - Task Differences

- ADDITIONAL FACTORS: - None.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2696-6	τ_D	λ_D	SLOPE	BREAK PT.	T2'		
	0.12*	–	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	04/01		None		9	9	5

- INITIAL REMARKS:

- FEEL SYSTEM CHARACTERISTICS: Displacements quite noticeable, large. Forces didn't seem that high. Sensitivity delayed.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Was there; lagged, delayed.
  - Final Response?
  - Predictability? - Not there.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, certainly.
  - Piloting Techniques? - Tried to do everything just to put airplane safely on ground.
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - A little fast.
  - Touchdown Point Accuracy - Had enough problems just maintaining control.
  - Sink Rate at Touchdown - Not too bad.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - Got pretty aggressive although I didn't want to.
  - Task Differences - Yes, landing and go-around was where PIO's occurred.

- ADDITIONAL FACTORS: - Airplane seemed sluggish to trim.

- SUMMARY: Possibly a PR=10 airplane.
  *Nominal configuration T2 except command gain reduced by 1/2.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2695-6	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-1)		
	0.12	—	-10.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	08/03		None		4	6	2

- INITIAL REMARKS: Reasonable application of PIOS filter - had similar impressions as to what goes on in F-8.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Moderate, did not see any monster delays, but still not like base airplane.
  - Final Response? - No real overshoots.
  - Predictability? - Good. All that was required to control aircraft was to fly it aggressively.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Some unpredictable motions not strictly related to control inputs.
  - Piloting Techniques? - Tried not to abandon control loop.
  - Small vs. Large Inputs? - Some unpredictable things for small inputs.
  - Open vs. Closed-Loop Control? - Always tried to stay in the loop.

- TASK PERFORMANCE:
  - Airspeed Control - No problem.
  - Touchdown Point Accuracy - Good.
  - Sink Rate at Touchdown - Fine.
  - Runway Alignment - Good.
  - Aggressiveness - Flew aggressively to maintain closed loop control.
  - Task Differences

- ADDITIONAL FACTORS:

- SUMMARY: Could put aircraft where I wanted to if aggressive.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2696-5	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-1)		
	0.12	–	-10.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	04/01		None		5	7	2

- INITIAL REMARKS: When near ground using small, quick inputs, couldn't get effective results.
- FEEL SYSTEM CHARACTERISTICS: Forces not too high but displacements large. Airplane felt sensitive at first but had rather average to low sensitivity overall.
- PITCH ATTITUDE CONTROL:
  - Initial Response? - Sluggish in flare.
  - Final Response? - Would have liked more responsive airplane.
  - Predictability? - Had problems controlling pitch especially on first landing.
- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Saw pitch nodding on takeoffs.
  - Piloting Techniques? - Had to anticipate pitch response.
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control?
- TASK PERFORMANCE:
  - Airspeed Control
  - Touchdown Point Accuracy - Floated on second approach. Navy landing on first.
  - Sink Rate at Touchdown - Too high on first.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - Moderate, especially after seeing sluggish pitch response on first approach.
  - Task Differences - Landing and takeoff more difficult.
- ADDITIONAL FACTORS: - None.
- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2692-2	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-2)		
	0.12	–	-6.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	04/01		Light		6	8	3

- INITIAL REMARKS: Near ground, working airplane pretty hard.

- FEEL SYSTEM CHARACTERISTICS: Forces OK. Stick displacements large but not as bad as previous configuration. Pitch not as sensitive as would like.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Small lag, not too bad until near ground.
  - Final Response? - Couldn't sort it out from the initial response.
  - Predictability? - Good on initial part of flare; below adequate near ground.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, slight tendency near ground.
  - Piloting Techniques? - Accepted higher sink rates than normal.
  - Small vs. Large Inputs? - Delay more noticeable with large inputs.
  - Open vs. Closed-Loop Control? - Problems occurred during closed loop control.

- TASK PERFORMANCE:
  - Airspeed Control - Adequate.
  - Touchdown Point Accuracy - Within the desired area.
  - Sink Rate at Touchdown - A little high.
  - Runway Alignment - Good.
  - Aggressiveness - More than normal.
  - Task Differences - Approach easy, PIO tendency during touch and go.

- ADDITIONAL FACTORS:

- SUMMARY: Had to force airplane down. Very high pilot workload to land within touchdown area (desired performance).

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2692-5	τ_D	λ_D	SLOPE	PEAK PT.	T2 (A-2)		
	0.12	–	-5.0	0.00			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	05/03		Light		7	7	3

- INITIAL REMARKS: Airplane has major deficiences.

- FEEL SYSTEM CHARACTERISTICS: Displacements large in flare. Sensitivity poor; forces OK.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Not satisfactory, especially near ground.
  - Final Response? - Always had to lead aircraft.
  - Predictability? - Poor, overcontrolled pitch.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, when trying to touch down within desired area.
  - Piloting Techniques? - Get in loop enough to land aircraft at bottom of PIO cycle.
  - Small vs. Large Inputs? - Both cases exhibit initial lag, delay.
  - Open vs. Closed-Loop Control? - No comments.

- TASK PERFORMANCE:
  - Airspeed Control - Airspeed intentionally a little slow to achieve desired landing performance despite pitch control.
  - Touchdown Point Accuracy - Within limits but had problems.
  - Sink Rate at Touchdown - Too high.
  - Runway Alignment
  - Aggressiveness
  - Task Differences

Remainder of pilot comments lost because of voice recorder malfunction.

- ADDITIONAL FACTORS:

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2695-3	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-2)		
	0.12	–	-5.0	0.00			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	08/03		None		5	5	3

- INITIAL REMARKS: Debated briefly between desired and adequate performance to arrive at pilot rating.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response?
  - Final Response? - Some undesirable motions.
  - Predictability? - Minor, suitable bits of unpredictability.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Not really; undesirable motions which compromised task performance slightly.
  - Piloting Techniques? - Not aware of any.
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - Problems on second approach.
  - Touchdown Point Accuracy -
  - Sink Rate at Touchdown - Surprised that we touched down as hard as we did.
  - Runway Alignment
  - Aggressiveness - Reasonable aggressive at all times.
  - Task Differences

- ADDITIONAL FACTORS:

- SUMMARY: Not much improvement required to make airplane Level 1.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2695-5	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-2)		
	0.12	–	-5.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	08/03		None		9	8*	4

- INITIAL REMARKS: On first and third approach, control authority in question; no problems due to phasing of aircraft response to control inputs. On second approach, felt out of phase with airplane, but resultant aircraft motions seemed OK. Confusing.
- FEEL SYSTEM CHARACTERISTICS:
- PITCH ATTITUDE CONTROL:
  - Initial Response? - Control gearing too low.
  - Final Response? - Control system (suppressor?) seems to change response in flare while holding aft stick.
  - Predictability? - Lack of controllability.
- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, but apparently not divergent oscillations.
  - Piloting Techniques? - Results will be the same whatever the level of pilot compensation.
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control?
- TASK PERFORMANCE:
  - Airspeed Control
  - Touchdown Point Accuracy - First approach wave off. Second approach OK. Third approach OK until flare.
  - Sink Rate at Touchdown
  - Runway Alignment
  - Aggressiveness
  - Task Differences
- ADDITIONAL FACTORS: - On short final, configuration or whatever gave impression that turbulence was outside.
- SUMMARY: * SPR=10: 1st approach
  SPR= 6: 2nd approach
  SPR= 8: 3rd approach

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2691-1	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-6)		
	0.12	—	-1.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	07/04		None		7	7	4

- INITIAL REMARKS: Controllability of aircraft was not adequate for the task.

- FEEL SYSTEM CHARACTERISTICS: All adequate.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Typical of transport delay.
  - Final Response? - Predictable but delayed in time.
  - Predictability? - Reasonable.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes.
  - Piloting Techniques? - Watch response to first input before attempting another.
  - Small vs. Large Inputs? - No large inputs used.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - OK.
  - Touchdown Point Accuracy - Not good, ragged performance.
  - Sink Rate at Touchdown - Too high.
  - Runway Alignment - Good.
  - Aggressiveness - More aggressive on second landing to land within desired area.
  - Task Differences - Landing most difficult.

- ADDITIONAL FACTORS: - None.

- SUMMARY: Pilot workload was not extremely high, particularly when compared to the simulated aerial refueling task.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2692-1	τ_D	λ_D	SLOPE	BREAK PT.	T2 (A-6)		
	0.12	-	-1.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	04/01		Light		8	9	4

- INITIAL REMARKS:

- FEEL SYSTEM CHARACTERISTICS: Forces OK; displacements objectionably large especially near ground.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Don't get anything initially. Overcontrolled pitch as a result.
  - Final Response? - Can't figure out how much response for a given input.
  - Predictability? - Poor.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, for high gain task near ground.
  - Piloting Techniques? - Get it near ground, tweek airplane nose down, and then rotate enough to get satisfactory sink rate.
  - Small vs. Large Inputs? - With small inputs, PIO tendency not as bad.
  - Open vs. Closed-Loop Control? - Even "trim" response on approach lagged, poor.

- TASK PERFORMANCE:
  - Airspeed Control - Airplane seems speed unstable.
  - Touchdown Point Accuracy - Spiked airplane on within desired area.
  - Sink Rate at Touchdown - Not great but best possible.
  - Runway Alignment - OK.
  - Aggressiveness - Got very aggressive near ground.
  - Task Differences - Satisfactory performance on approach, but PIO on landing and takeoff.

- ADDITIONAL FACTORS: - None.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2692-4	τ_D	λ_D	SLOPE	BREAK PT.	T2 (B-2)		
	0.12	–	-5.0	0.05			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	05/03		Light		7	7.5	4

- INITIAL REMARKS: Debated between PR=6 and PR=7. Airplane has major deficiencies.

- FEEL SYSTEM CHARACTERISTICS: Forces high but acceptable in flare. Displacements large. Sensitivity inadequate.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Saw some initial response but not adequate.
  - Final Response? - Not predictable.
  - Predictability? - Poor; overcontrolled pitch attitude in attempt to get adequate initial response.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, initiated during flare.
  - Piloting Techniques? - Spiked airplane on ground, accepted higher sink rates.
  - Small vs. Large Inputs? - Saw control problems with large inputs.
  - Open vs. Closed-Loop Control? - No comments.

- TASK PERFORMANCE:
  - Airspeed Control - Good.
  - Touchdown Point Accuracy - Less than satisfactory but within desired area.
  - Sink Rate at Touchdown - Satisfactory, but on high side.
  - Runway Alignment - Good.
  - Aggressiveness - Not as aggressive as would be with nice flying airplane.
  - Task Differences - Landing and go-around task were more difficult.

- ADDITIONAL FACTORS: - None.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2691-4	τ_D	λ_D	SLOPE	BREAK PT.	T2 (B-4)		
	0.12	–	-2.0	0.05			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	07/04		None		8	9	4

- INITIAL REMARKS: Could tell the configuration was oscillatory on final; therefore, suspicious during landing.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Somewhat lagged.
  - Final Response? - Seemed lagged also, definitely oscillatory.
  - Predictability? - Oscillations had some degree of predictability about them.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes.
  - Piloting Techniques? - Used pitch oscillations to control aircraft rather than using smooth pilot control inputs.
  - Small vs. Large Inputs? - Large inputs could be used.
  - Open vs. Closed-Loop Control? - More closed loop control used during this evaluation than others in this flight.

- TASK PERFORMANCE:
  - Airspeed Control - Good.
  - Touchdown Point Accuracy - OK.
  - Sink Rate at Touchdown - Firm, not hard.
  - Runway Alignment - No problem.
  - Aggressiveness - Moderately.
  - Task Differences - Any pitch attitude change resulted in oscillatory response.

- ADDITIONAL FACTORS: - None.

- SUMMARY: Pilot compensation was key to controlling this aircraft.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2694-2	τ_D	λ_D	SLOPE	BREAK PT.	T2 (C-3)		
	0.12	-	-3.3	0.20			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	17/06		Light to moderate		8	8	5

- INITIAL REMARKS:

- FEEL SYSTEM CHARACTERISTICS: No comments.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Delayed.
  - Final Response? - "Over-response" although magnitude of over-response not as large as seen with some previous configurations
  - Predictability? - Not predictable.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes.
  - Piloting Techniques? - Gently herded aircraft by intentionally abandoning tight control at onset of PIO.
  - Small vs. Large Inputs? - Would not want to use large inputs.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - No comment.
  - Touchdown Point Accuracy - Touched down inadvertently at bottom of PIO once.
  - Sink Rate at Touchdown - OK, firm.
  - Runway Alignment
  - Aggressiveness - Fairly high using special piloting technique - not in a continuous closed loop fashion.
  - Task Differences

- ADDITIONAL FACTORS: - Slight wind shear on final, weather added to task.

- SUMMARY: SP: erratic, small amplitude PIO's noted.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION
2693-2	τ_D	λ_D	SLOPE	BREAK PT.	T2 (C-5)
	0.12	—	-1.67	0.20	

EVAL. PILOT	WIND/X-WIND	TURBULENCE	PR	SPR	PIOR
A	07/09	Light to moderate	7	8	4

- INITIAL REMARKS: Noted pitch "nodding" about center of gravity in flare and takeoff.

- FEEL SYSTEM CHARACTERISTICS: Forces not a problem. Displacements high especially in flare. Sensitivity average, not really sluggish but not quick.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Slow, a little bit of delay.
  - Final Response? - Unsure of inputs required to control final pitch response.
  - Predictability? - Average, not really good.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, aggressiveness near runway excited PIO.
  - Piloting Techniques? - Tried to anticipate aircraft responses.
  - Small vs. Large Inputs? - None detected.
  - Open vs. Closed-Loop Control? - Yes, airplane seemed reasonable open loop.

- TASK PERFORMANCE:
  - Airspeed Control - Satisfactory.
  - Touchdown Point Accuracy - OK, but could be improved.
  - Sink Rate at Touchdown - Acceptable but would like lower rates.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - Tried to be aggressive.
  - Task Differences - Approach no problem, control problems in both flare and on the "go".

- ADDITIONAL FACTORS: - Slight crosswind a little problem. Turbulence not a problem.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
	τ_D	λ_F	SLOPE	BREAK PT.			
2694-5	0.12	—	-0.075	2.0	T2 (D-8)		
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	17/06		Moderate		10	10	3

- INITIAL REMARKS: Sneaky configuration; had to go around on second landing.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Some airplane responses seemed unrelated to pilot control inputs.
  - Final Response?
  - Predictability? - Very little, surprising airplane responses.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No PIO tendency; undesirable motions.
  - Piloting Techniques?
  - Small vs. Large Inputs? - Equally unpredictable.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - Not the problem.
  - Touchdown Point Accuracy - Within limits on only landing.
  - Sink Rate at Touchdown - High sink rate on first landing.
  - Runway Alignment
  - Aggressiveness
  - Task Differences

- ADDITIONAL FACTORS: - Gusty wind; slight wind shear.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2696-2	τ_D	λ_D	SLOPE	BREAK PT.	T2 (E-7)		
	0.12	–	-0.25	5.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	02/01		None		8	9	5

- INITIAL REMARKS: Initial delay in pitch response lead to PIO.

- FEEL SYSTEM CHARACTERISTICS: Forces not too high but displacements large. Quite sensitive except for initial delay.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Delayed.
  - Final Response? - Overcontrolled, out of phase with airplane.
  - Predictability? - Poor.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes.
  - Piloting Techniques? - Not aware of any except for extensive compensation required to keep control.
  - Small vs. Large Inputs? - Delay independent of input size.
  - Open vs. Closed-Loop Control? - Looked like pitch rate command system open loop. PIO with closed loop control.

- TASK PERFORMANCE:
  - Airspeed Control - Satisfactory.
  - Touchdown Point Accuracy - Within the limits.
  - Sink Rate at Touchdown - Not satisfactory.
  - Runway Alignment - Good.
  - Aggressiveness - As aggressive as I would want to be.
  - Task Differences - Landing most difficult.

- ADDITIONAL FACTORS:

- SUMMARY: Got better pitch rates for small inputs when aggressive.

C-2

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2693-3	τ_D	λ_D	SLOPE	BREAK PT.	T2 (E-8)		
	0.12	–	-0.075	5.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	07/09		Light to moderate		8	5	4

- INITIAL REMARKS: Configuration had a funny pitch attitude response.

- FEEL SYSTEM CHARACTERISTICS: Forces OK. Displacements a little large. Pumped stick.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Quick response initially but final response seemed to die out.
  - Final Response? - Nonlinear?
  - Predictability? - Not predictable because of mismatch between initial/final response.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, especially near ground with aggressive inputs.
  - Piloting Techniques? - Backed off on second approach to avoid PIO.
  - Small vs. Large Inputs? - For small inputs, initial response better, more predictable.
  - Open vs. Closed-Loop Control? - Closed loop control was the problem.

- TASK PERFORMANCE:
  - Airspeed Control - Not too good.
  - Touchdown Point Accuracy - Within the touchdown zone limits.
  - Sink Rate at Touchdown - OK.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - Was very aggressive on first landing and got into a PIO which may have grown in amplitude.
  - Task Differences

- ADDITIONAL FACTORS:

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2694-4	τ_D	λ_D	SLOPE	BREAK PT.	T2 (F-8)		
	0.12	–	-0.075	10.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	17/06		Moderate		10	10	6

- INITIAL REMARKS: Whatever is done in the control system make the smaller transport delays less predictable. Couldn't fly the aircraft by trying to control the pitch oscillations.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Unpredictable nose up and nose down response to inputs.
  - Final Response?
  - Predictability? - None, even oscillations are unpredictable.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, large amplitude, low frequency PIO's
  - Piloting Techniques? - Go-around.
  - Small vs. Large Inputs? - PIO not related to input size.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control
  - Touchdown Point Accuracy
  - Sink Rate at Touchdown
  - Runway Alignment
  - Aggressiveness
  - Task Differences

- ADDITIONAL FACTORS: - Gusty wind conditions, slight wind shear.

- SUMMARY: Bad features of configuration not noticeable until flare. Without the gusty wind conditions which require a lot of pitch inputs, may not have found out about airplane deficiencies until pretty late.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2686-1	τ_D	λ_D	SLOPE	BREAK PT.	T3		
	0.16	–	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	Calm		None		10*	9	5*

- INITIAL REMARKS: 1st approach: Waved off; a lot of lag in system.
  2nd approach: Hard landing; airplane sank out from underneath.

- FEEL SYSTEM CHARACTERISTICS: Forces/displacements: satisfactory.
  Pitch sensitivity sluggish.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Satisfactory on approach; noticeable delay in flare.
  - Final Response? - Poor, overcontrolled pitch attitude.
  - Predictability? - Poor.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, out of phase with airplane on first approach.
  - Piloting Techniques? - No special techniques used.
  - Small vs. Large Inputs? - For small inputs, airplane seemed controllable.
  - Open vs. Closed-Loop Control? - No tendency for airplane to wander off open loop.

- TASK PERFORMANCE:
  - Airspeed Control - Poor on 2nd approach.
  - Touchdown Point Accuracy - Within limits on 2nd approach.
  - Sink Rate at Touchdown - Too high.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - As aggressive as I would want.
  - Task Differences - Landing not predictable; low frequency PIO on takeoff.

- ADDITIONAL FACTORS: - None.

- SUMMARY: * EP gave pilot ratings for each approach because of different task performance:
  1st approach: PR=10, PIOR=5
  2nd approach: PR=6, PIOR=3

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2686-4	τ_D	λ_D	SLOPE	BREAK PT.	F1		
	–	2.0	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	00/05		Light		7	8	4

- INITIAL REMARKS: Adequate performance but deficiences require improvement.

- FEEL SYSTEM CHARACTERISTICS: Displacements large especially near ground. Pitch sensitivity poor.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - A lot of lag; not necessarily time delay, just real sluggish.
  - Final Response? - Could stop pitch attitude once it got there.
  - Predictability? - Poor, never knew how much input to get pitch attitude.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Low frequency PIO.
  - Piloting Techniques? - None used.
  - Small vs. Large Inputs? - Took big inputs for control.
  - Open vs. Closed-Loop Control? - No differences noted.

- TASK PERFORMANCE:
  - Airspeed Control - Satisfactory.
  - Touchdown Point Accuracy - Surprised at accuracy, better than expected.
  - Sink Rate at Touchdown - Satisfactory.
  - Runway Alignment - Good.
  - Aggressiveness - Would not like to be any more aggressive.
  - Task Differences - PIO during takeoff and landing phases.

- ADDITIONAL FACTORS: - SP: get burst of crosswind from left at threshold.

- SUMMARY: Debated between PR=6 and PR=7.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2695-2	τ_D	λ_D	SLOPE	BREAK PT.	F1		
	–	2.0	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	08/03		None		8	7	5

- INITIAL REMARKS: Appeard to be a large transport delay airplane with PIO suppressor which made it a low frequency, sluggish responding configuration.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Very sluggish.
  - Final Response? - Low frequency, low amplitude PIO.
  - Predictability? - Not predictable due to variation of flying qualities.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, when you are "moderately" in the loop.
  - Piloting Techniques? - Being more aggressive on second approach, made airplane more controllable and airplane did what I expected.
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control? - Aggressive, closed loop control yields improved flying qualities.

- TASK PERFORMANCE:
  - Airspeed Control
  - Touchdown Point Accuracy - Abandoned first attempt, accurate when aggressive on second landing.
  - Sink Rate at Touchdown - OK.
  - Runway Alignment - Good.
  - Aggressiveness - High Cooper-Harper pilot rating due primarily to variation of flying qualities with level of aggressiveness.
  - Task Differences - Landing task by far more difficult.

- ADDITIONAL FACTORS:

- SUMMARY: Changed rating from PR=7 after pilot comments. No change in PIOR.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2697-4	τ_D	λ_D	SLOPE	BREAK PT.	F1		
	–	2.0	–	–			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
C	04/15		Light		7	6	4

- INITIAL REMARKS: Very different airplane. Somewhat predictable in that you can get the job done.

- FEEL SYSTEM CHARACTERISTICS: Not as many complaints as past. Forces/ displacements no problem. Adequately sensitive.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Delayed.
  - Final Response? - After initial delay, response came on a little abruptly.
  - Predictability? - Degraded for tight tasks.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - PIO during last 20 ft of landing task.
  - Piloting Techniques? - Controlled gain to keep oscillations under control and achieve some landing success.
  - Small vs. Large Inputs? - Small, rapid inputs were the order of the day.
  - Open vs. Closed-Loop Control? - Didn't feel you could close the loop tightly.

- TASK PERFORMANCE:
  - Airspeed Control - Satisfactory.
  - Touchdown Point Accuracy - Within limits.
  - Sink Rate at Touchdown - Reasonable, surprisingly so at times.
  - Runway Alignment
  - Aggressiveness - Had to control aggressiveness to get landing performance.
  - Task Differences

- ADDITIONAL FACTORS: - Slight crosswind adding to workload.

- SUMMARY: Changed pilot rating from PR=6 after pilot comments. No change in PIOR.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION
	τ_D	λ_D	SLOPE	BREAK PT.	
2697-3	–	2.0	-10.0	0.0	F1 (A-1)

EVAL. PILOT	WIND/X-WIND	TURBULENCE	PR	SPR	PIOR
C	04/12	Light	8	6	3

- INITIAL REMARKS: Ridiculous airplane. Ran out of control authority near ground.

- FEEL SYSTEM CHARACTERISTICS: Really big displacements near ground. Pitch sensitivity too low in flare.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Very sluggish, poor.
  - Final Response? - Cannot compensate for airplane in a predictable fashion.
  - Predictability? - None.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No real oscillations. Airplane did what it wanted rather than what I wanted.
  - Piloting Techniques? - Worked hard to get nose to move.
  - Small vs. Large Inputs? - Had to use large inputs.
  - Open vs. Closed-Loop Control? - Didn't close the loop that tightly.

- TASK PERFORMANCE:
  - Airspeed Control - Landing performance was not bad considering the airplane deficiencies.
  - Touchdown Point Accuracy - Within limits.
  - Sink Rate at Touchdown - Got lucky with sink rate.
  - Runway Alignment
  - Aggressiveness - Reasonably aggressive; not that apprehensive about making big inputs.
  - Task Differences - Landing by far most difficult.

- ADDITIONAL FACTORS: - Slight crosswind adding a bit to workload.

- SUMMARY: Not as afraid of this airplane as I was of the previous PR=8 airplane (Config. F1 (A-2)).

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2696-1	τ_D	λ_D	SLOPE	BREAK PT.	F1 (A-2)		
	—	2.0	-5.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	03/02		None		6	8	1

- INITIAL REMARKS: Flew airplane smoothly on first approach because I thought sluggish pitch response would lead to PIO. Flew second approach aggressively to get satisfactory pitch rates.

- FEEL SYSTEM CHARACTERISTICS: Forces high, displacement OK. Sensitively low, sluggish.

- PITCH ATTITUDE CONTROL:

  - Initial Response? - It was there, pitch response just very slow.
  - Final Response? - Looked like a pitch rate command system.
  - Predictability? - Pitch rate was predictable but troubles in flare to get enough response for smooth touchdown.

- PILOT-IN-THE-LOOP:

  - PIO Tendency? - No. Saw some pitch nodding on take off but didn't feel it was a PIO.
  - Piloting Techniques?
  - Small vs. Large Inputs?
  - Open vs. Closed-Loop Control? - Forces got heavy once in control loop.

- TASK PERFORMANCE:

  - Airspeed Control - Satisfactory.
  - Touchdown Point Accuracy - OK on first landing. Floated past on second.
  - Sink Rate at Touchdown - Satisfactory.
  - Runway Alignment - Good.
  - Aggressiveness - Tried to be extra aggressive on second approach.
  - Task Differences - Takeoff appeared to be most difficult.

- ADDITIONAL FACTORS:

- SUMMARY: SP comment: Saw PIO on second landing and take off.

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2696-4	τ_D	λ_D	SLOPE	BREAK PT.	F1 (A-2)		
	—	2.0	-5.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
A	04/00		None		8	7	4

- INITIAL REMARKS: Dangerous airplane.

- FEEL SYSTEM CHARACTERISTICS: Forces high. Lots of displacement. Sensitivity very low, poor.

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Some response, no delays, but very sluggish.
  - Final Response?
  - Predictability? - Some predictability but airplane too sluggish.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Yes, if abrupt maneuvers or tight control attempted.
  - Piloting Techniques? - Keep gain down. Set up airplane before flare.
  - Small vs. Large Inputs? - No differences.
  - Open vs. Closed-Loop Control?

- TASK PERFORMANCE:
  - Airspeed Control - Too fast because of pitch response.
  - Touchdown Point Accuracy - Easy to overshoot although managed to land within limits.
  - Sink Rate at Touchdown - OK.
  - Runway Alignment - Satisfactory.
  - Aggressiveness - Low, did not want to be aggressive. Tried to get things under control.
  - Task Differences

- ADDITIONAL FACTORS: - Had troubles trimming the airplane on approach.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2697-1	τ_D	λ_D	SLOPE	BREAK PT.	F1 (A-2)		
	—	2.0	-5.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
C	05/08		Light		8	8	3

- INITIAL REMARKS: Made three approaches. Great apprehension about airplane.

- FEEL SYSTEM CHARACTERISTICS: Seemed to be a deadband. Displacements large and sensitivity low.

- PITCH ATTITUDE CONTROL.
  - Initial Response? - Very sluggish.
  - Final Response? - Not predictable due to initial response.
  - Predictability? - Could get to 20' and then sluggish initial response degrades all predictability.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - No PIO in terms of regular oscillations, rather undesirable motions.
  - Piloting Techniques? - Backed away from task, did not want to fight it.
  - Small vs. Large Inputs? - Feared large inputs.
  - Open vs. Closed-Loop Control? - Opened loop often. Did not want to use closed loop-type control near ground.

- TASK PERFORMANCE:
  - Airspeed Control - Poor.
  - Touchdown Point Accuracy - Not within limits. Consistently overshot.
  - Sink Rate at Touchdown - Not good control.
  - Runway Alignment - Reasonable.
  - Aggressiveness - Afraid to be aggressive down low.
  - Task Differences - Landing most difficult. Take off ragged. Approach no problem.

- ADDITIONAL FACTORS: - Got into lateral PIO on first approach while using enormous pitch inputs. No problem after that.

- SUMMARY:

FLIGHT NO-EVAL	FCS DYNAMICS		PIOS CONFIGURATION		CONFIGURATION		
2695-4	τ_D	λ_D	SLOPE	BREAK PT.	F1 (A-6)		
	–	2.0	-1.0	0.0			
EVAL. PILOT	WIND/X-WIND		TURBULENCE		PR	SPR	PIOR
B	08/03		None		10	10	5

- INITIAL REMARKS: Waved off both landings; inadvertently touched down in middle of PIO on second approach.

- FEEL SYSTEM CHARACTERISTICS:

- PITCH ATTITUDE CONTROL:
  - Initial Response? - Sluggish.
  - Final Response? - Overshoots, very low frequency PIO.
  - Predictability? - None.

- PILOT-IN-THE-LOOP:
  - PIO Tendency? - Constant amplitude oscillations on verge of being divergent.
  - Piloting Techniques? - Tried to use small inputs without success.
  - Small vs. Large Inputs? - Small inputs gradually got large.
  - Open vs. Closed-Loop Control? - Frequency of oscillation so low that not confident to abandon control loop and come back to it.

- TASK PERFORMANCE:
  - Airspeed Control - OK.
  - Touchdown Point Accuracy - Not achievable.
  - Sink Rate at Touchdown
  - Runway Alignment
  - Aggressiveness
  - Task Differences

- ADDITIONAL FACTORS:

- SUMMARY:

Appendix II
TASK PERFORMANCE RECORDS

The following time histories provide records of task performance for several of the evaluations. Five parameters are plotted in each time history: aircraft pitch attitude (θ), aircraft pitch rate (q), stick position (δ_{es}), the output of the PIOS filter (δ_{es_c}), and the PIOS filter, gain attenuation factor (XK). The aircraft pitch attitude and pitch rate were recorded at positions near the aircraft's center of gravity. To extrapolate these values to the aircraft's precise center of gravity or pilot location requires information on the NT-33's dimensional characteristics. This information is contained in Reference 4.

The plots are scaled such that 10 millemeters on the time axis is equal to 2 seconds. Approximately 30 seconds of record, starting at the pilot's initiation of runway alignment, are shown for each approach. A triangular symbol (▲) is placed at the lower edge of the pitch rate time history to signify main gear touchdown. If no symbol is presented, touchdown was not made because the pilot initiated go-around.

The title for each time history identifies the configuration, flight number, evaluation pilot, and approach number. The same procedure was used on all evaluations; consequently, the first approach included a small lateral sidestep maneuver before touchdown and the second approach, or third if flown, involved a large lateral offset correction prior to landing. The time history parameters are defined in the units: θ(degrees), q(degrees/second), and δ_{es}, δ_{es_c} (inches).

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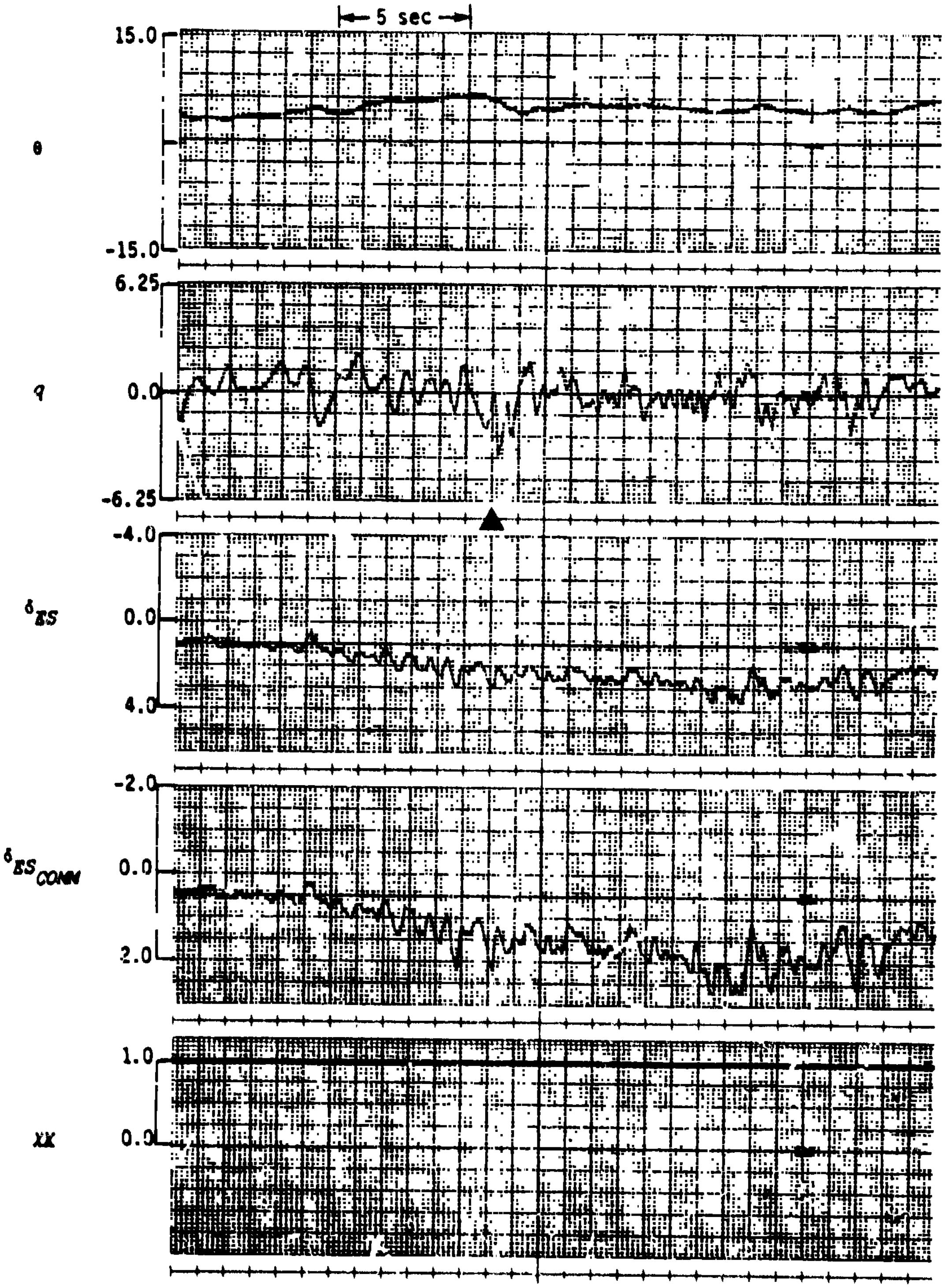

Figure II-1: CONFIGURATION TO PILOT A/2686 2nd LANDING OF 2

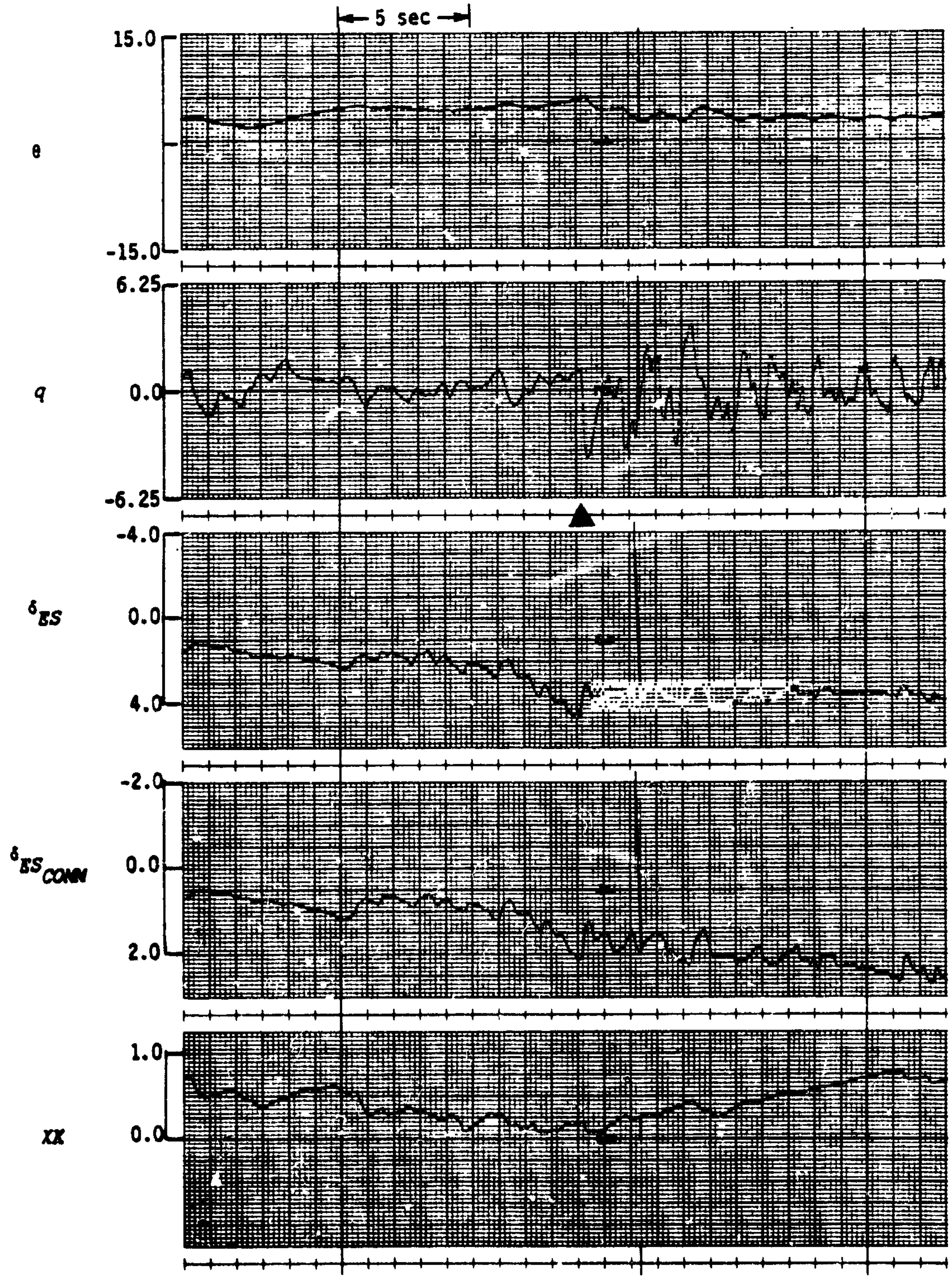

Figure II-2: CONFIGURATION TO (A-1) PILOT C/2697 1st LANDING OF 2

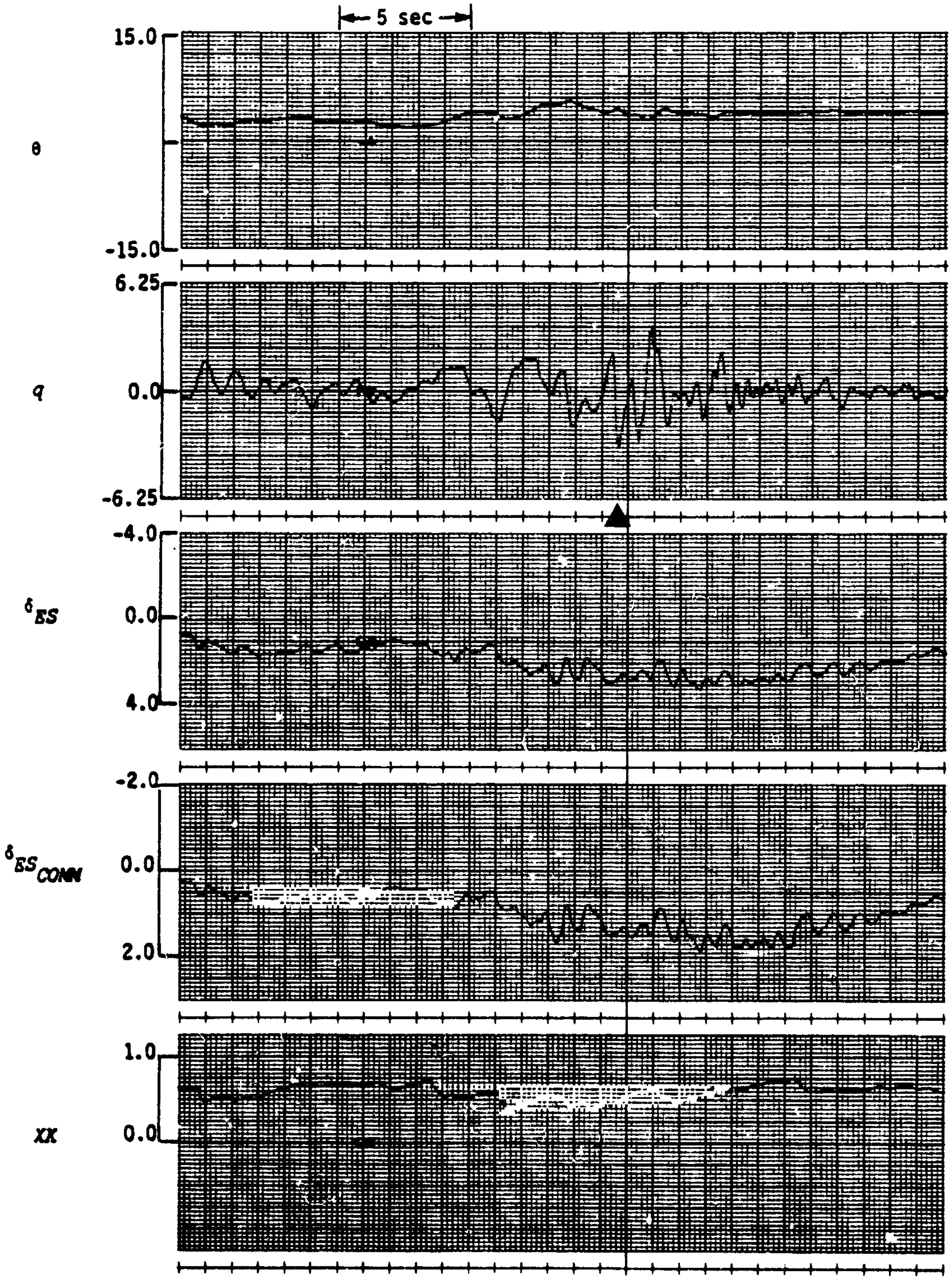

Figure II-3: CONFIGURATION TO (A-2) PILOT A/2693 2nd LANDING OF 2

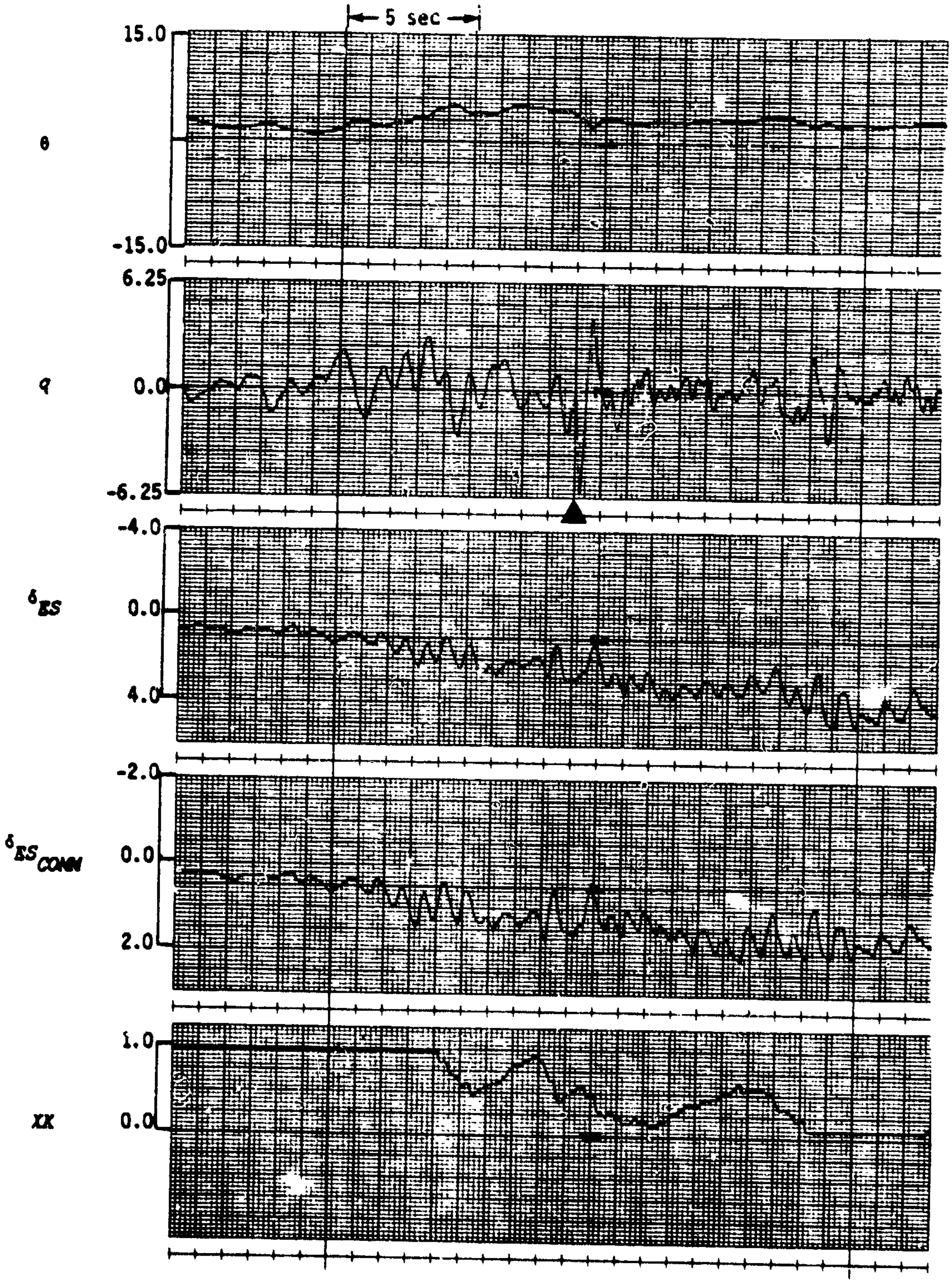

Figure II-4: CONFIGURATION TO (E-7) PILOT A/2696 1st LANDING OF 2

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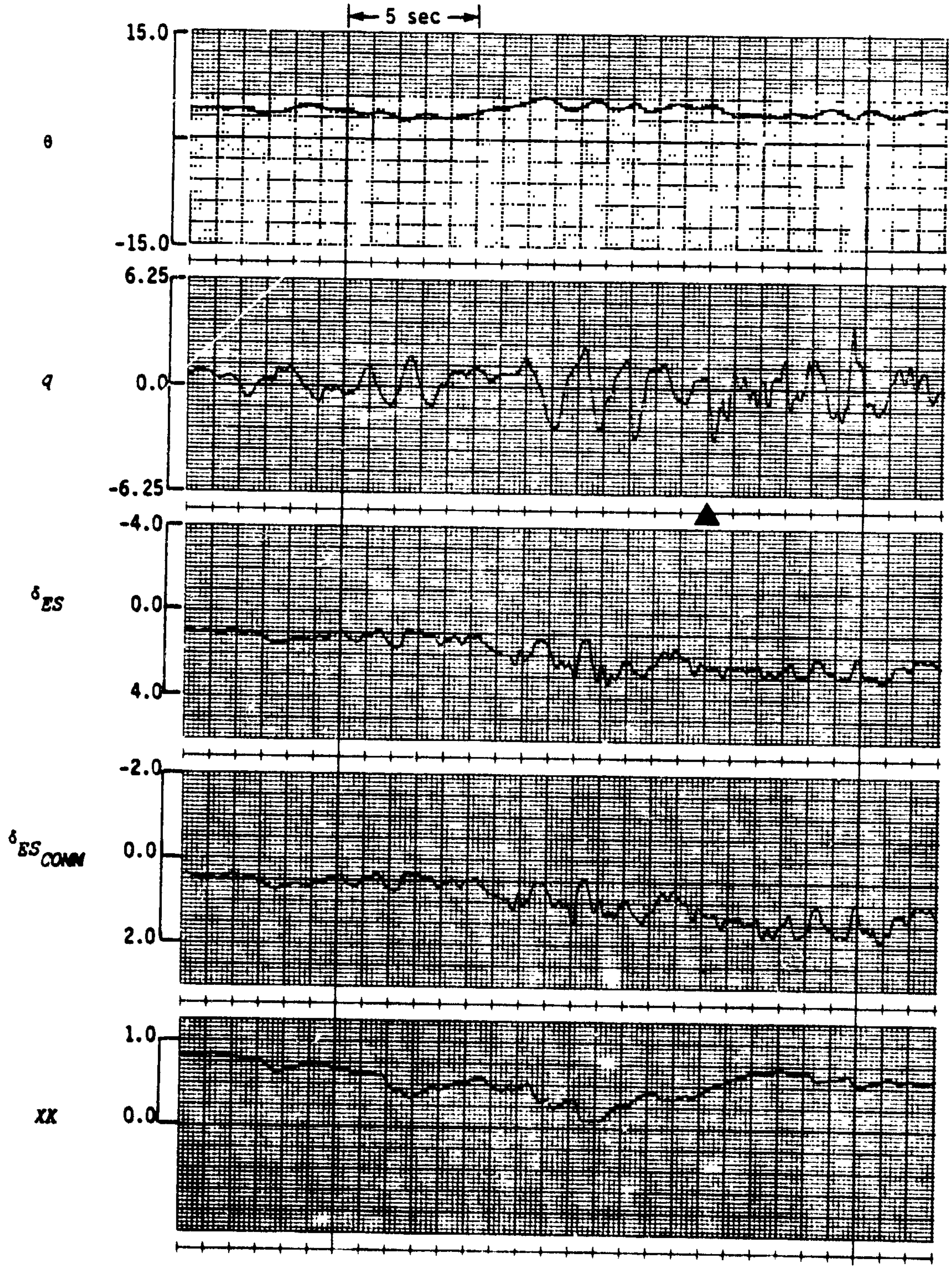

Figure II-5: CONFIGURATION T1 (A-2) PILOTA/2693 2nd LANDING OF 2

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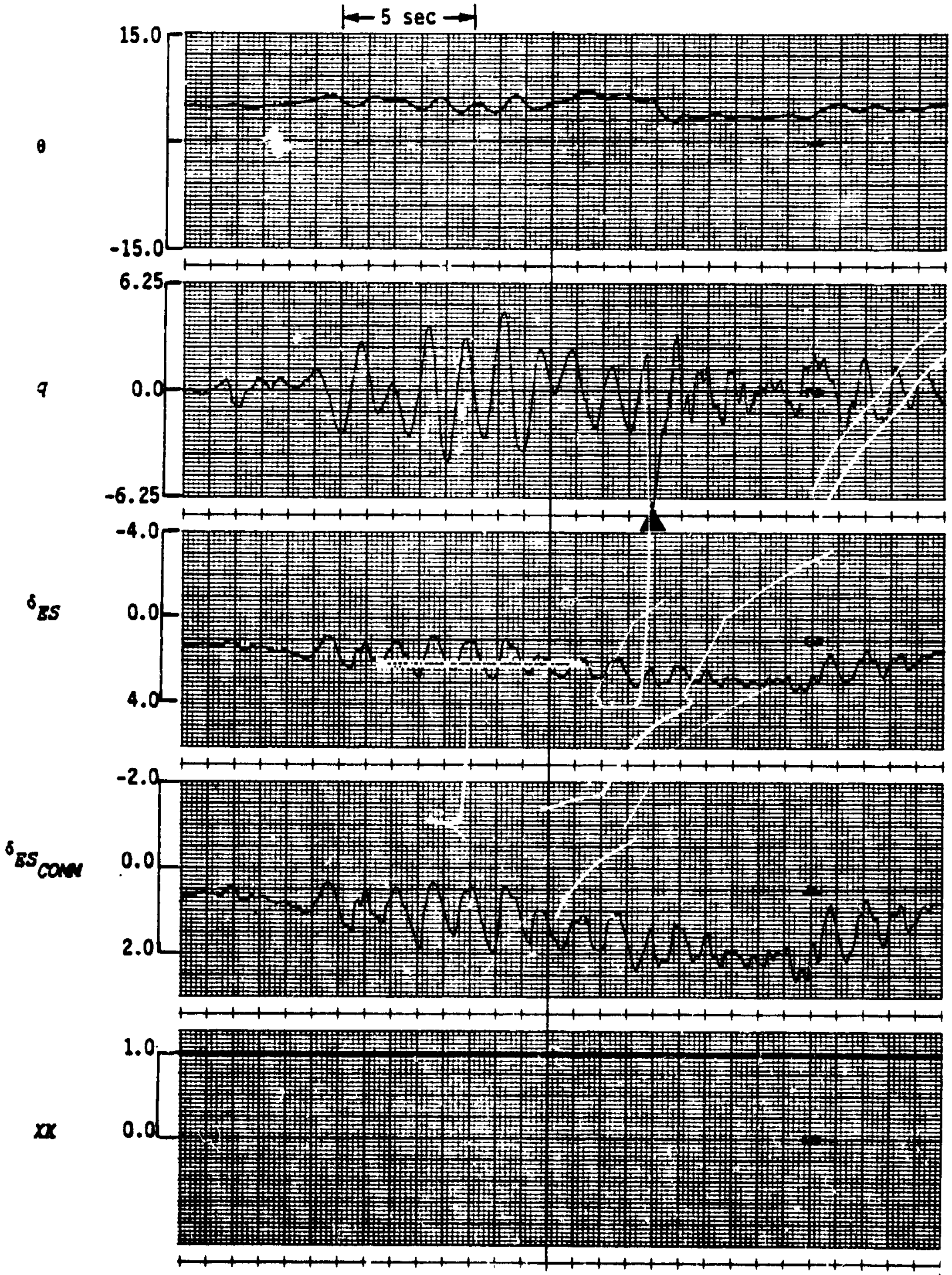

Figure II-6: CONFIGURATION T2 PILOT A/2686 1st LANDING OF 2

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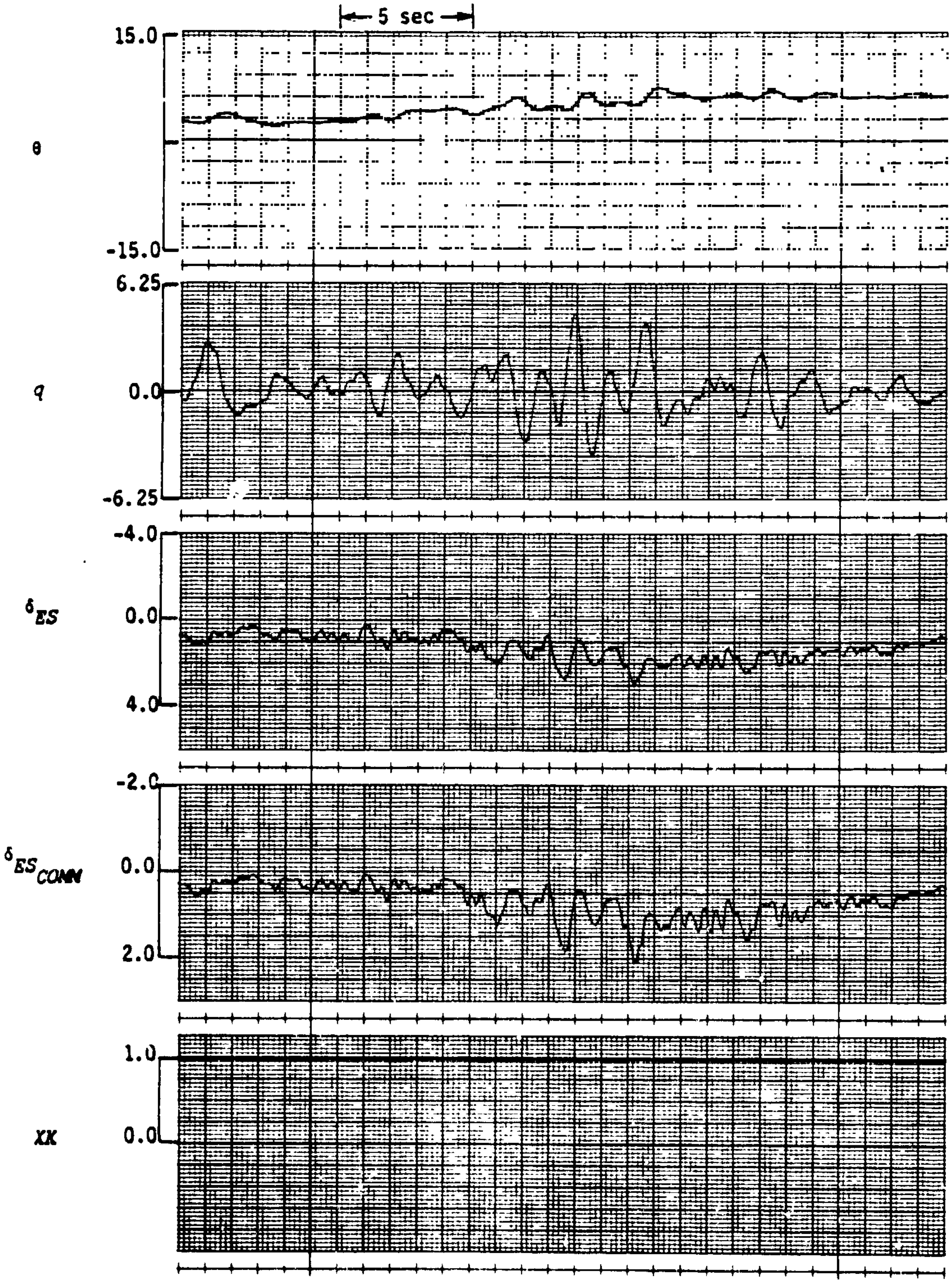

Figure II-7: CONFIGURATION T2 PILOT B/2691 1st LANDING OF 2

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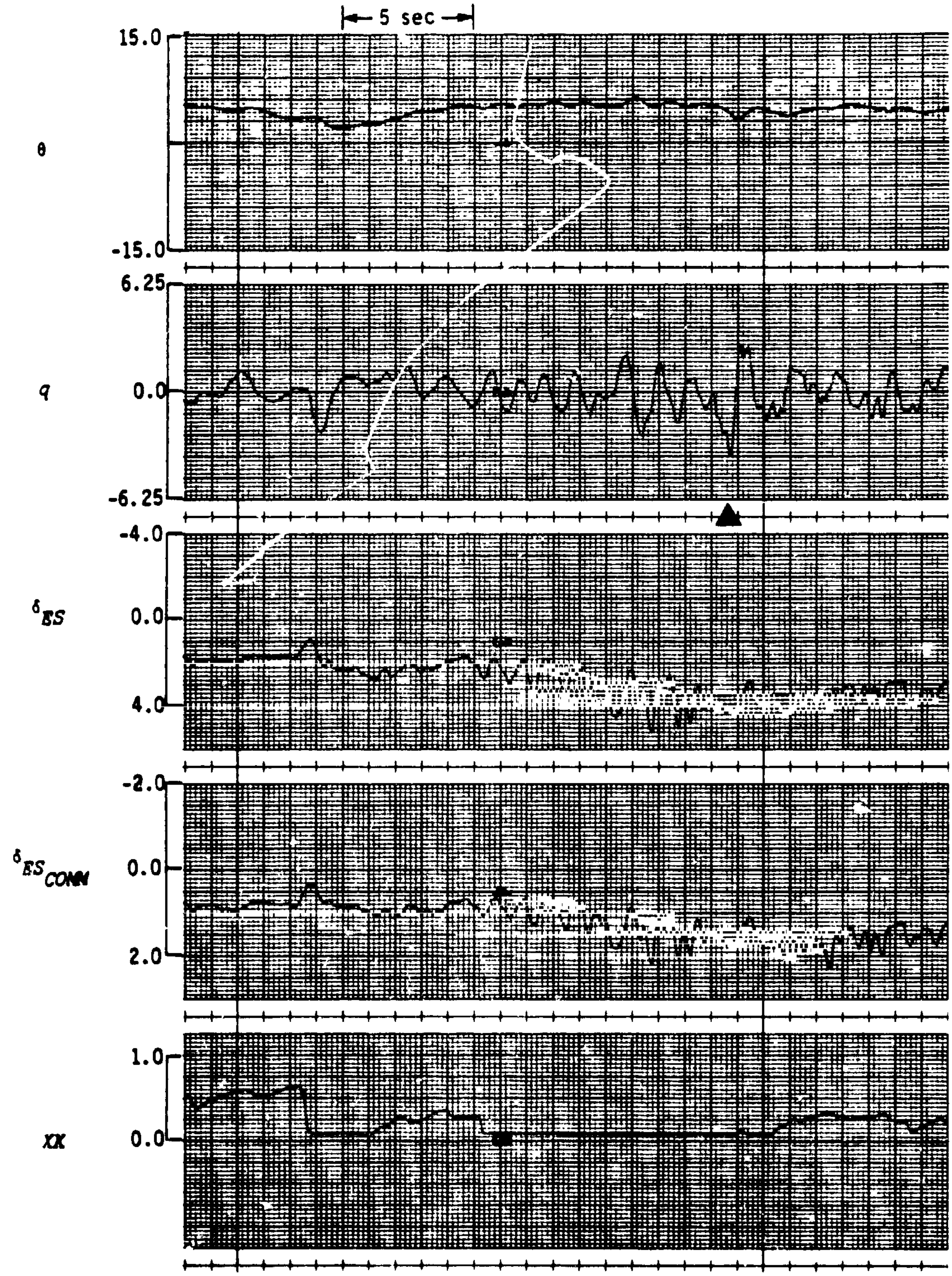

Figure II-8: CONFIGURATION T2 (A-1) PILOT B/2695 2nd LANDING OF 2

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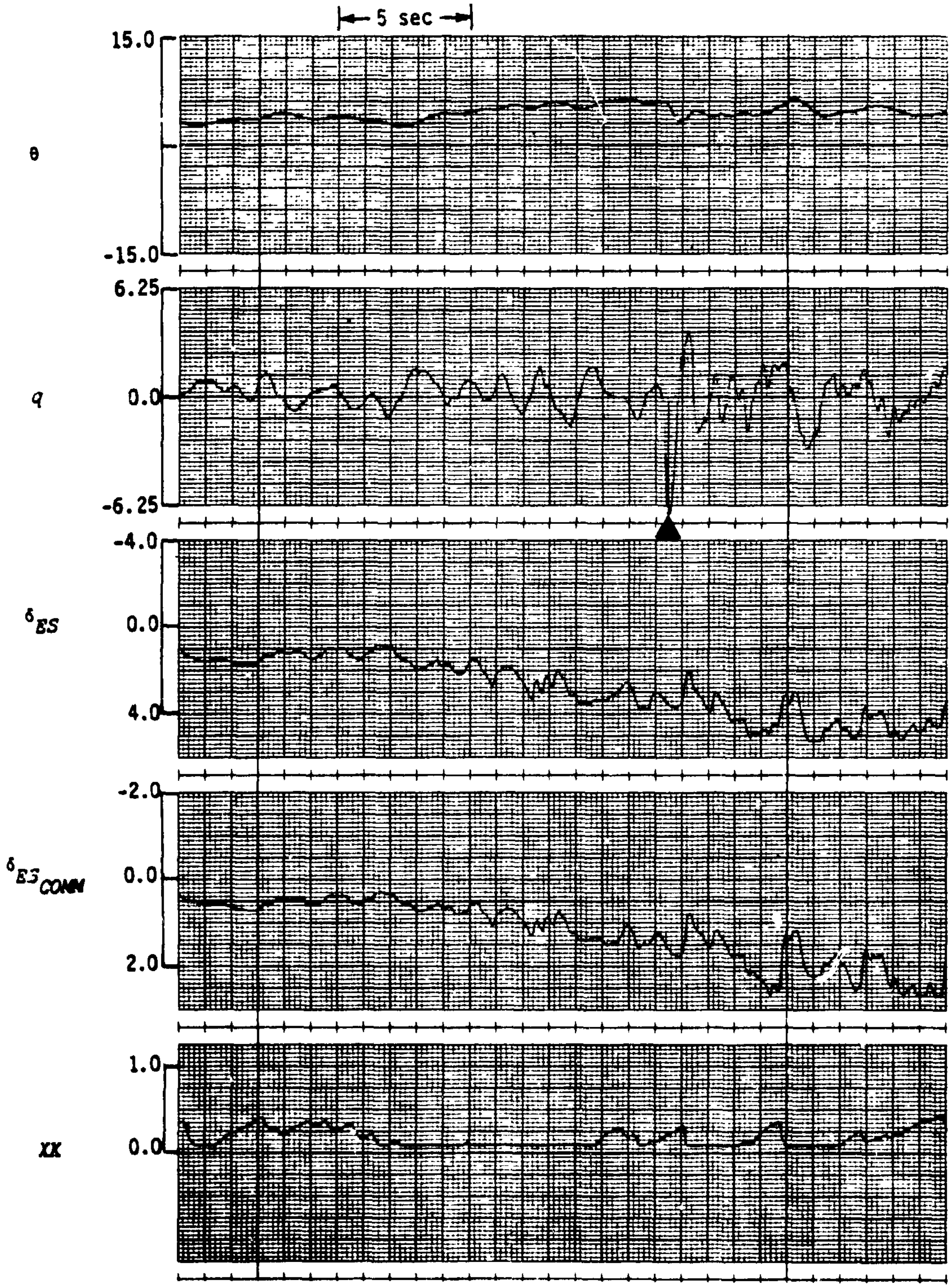

Figure II-9: CONFIGURATION T2 (A-1) PILOT A/2696 2nd LANDING OF 2

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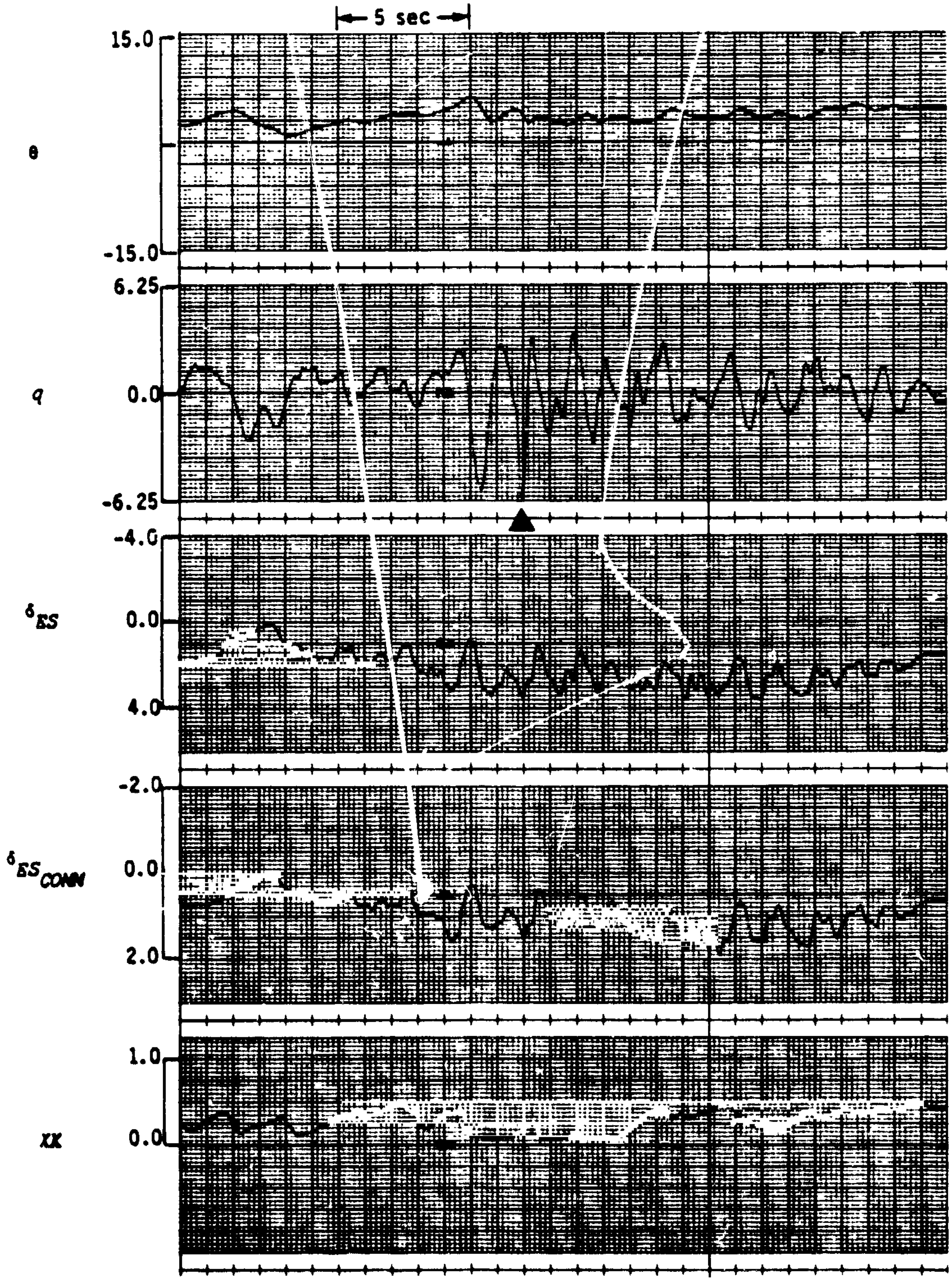

Figure II-10: CONFIGURATION T2 (A-2) PILOT A/2692-2 1st LANDING OF 2

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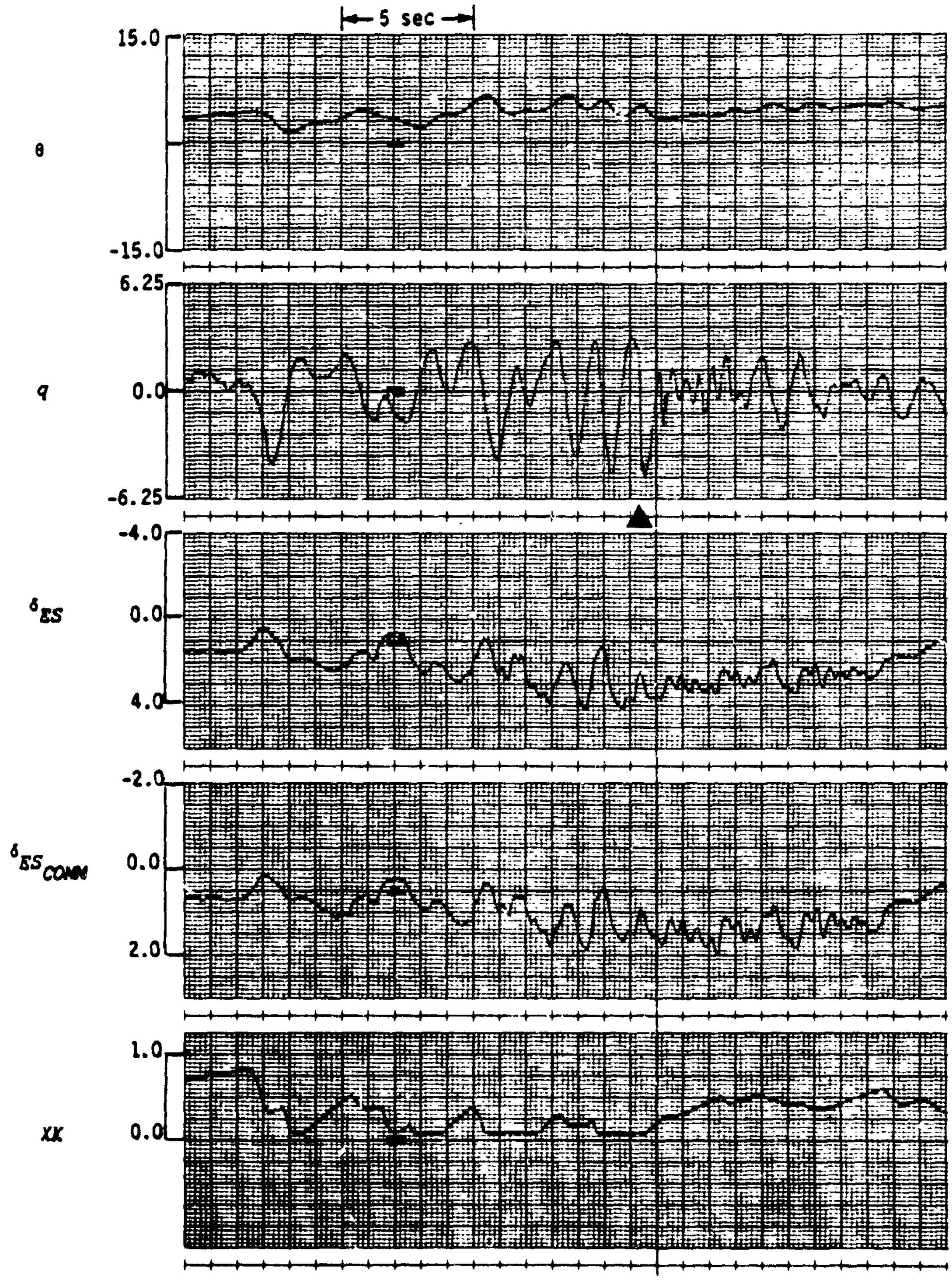

Figure II-11: CONFIGURATION T2 (A-2) PILOT A/2692-5 2nd LANDING OF 2

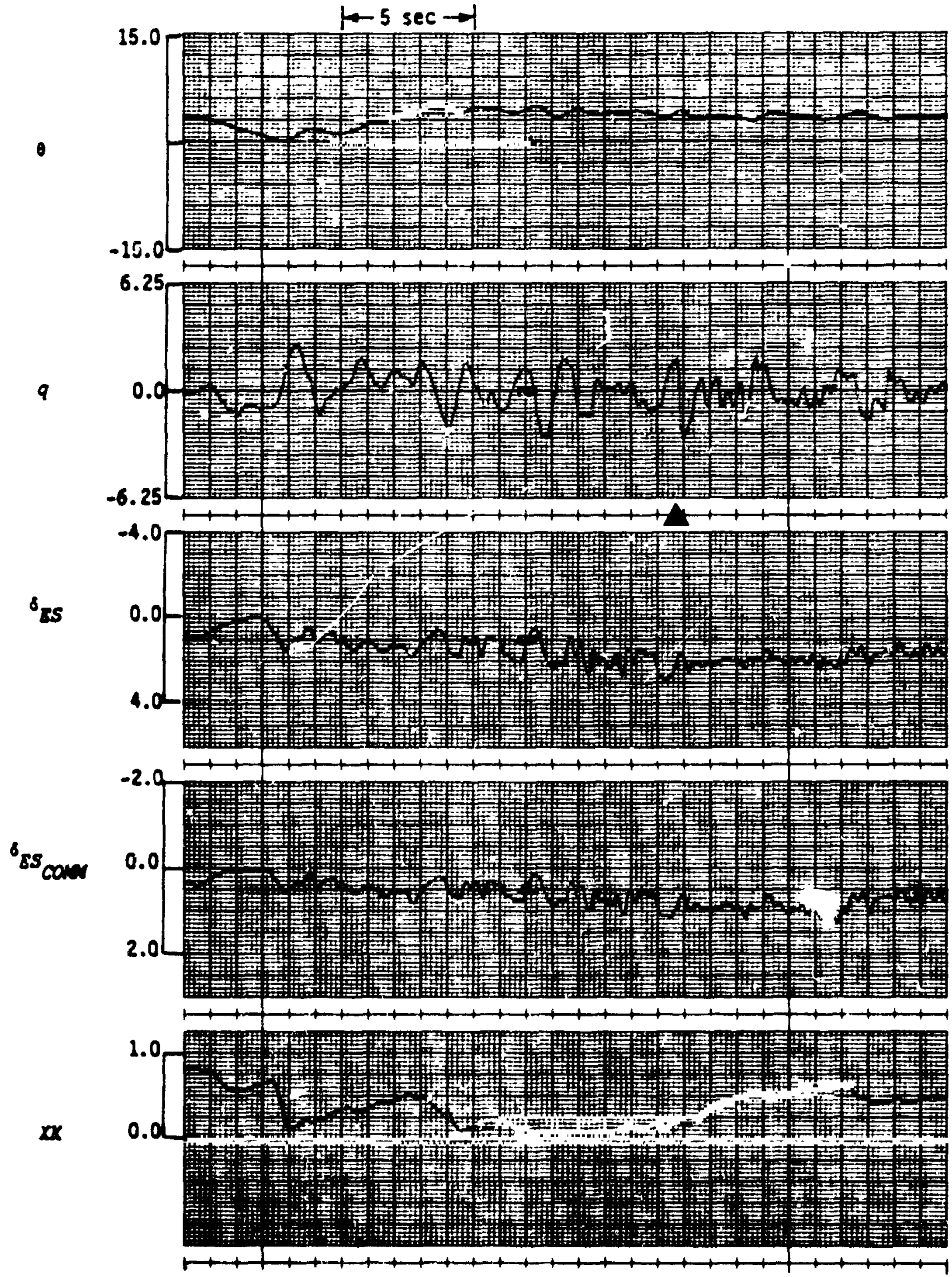

Figure II-12: CONFIGURATION T2 (A-2) PILOT B/2695-3 1st LANDING OF 2

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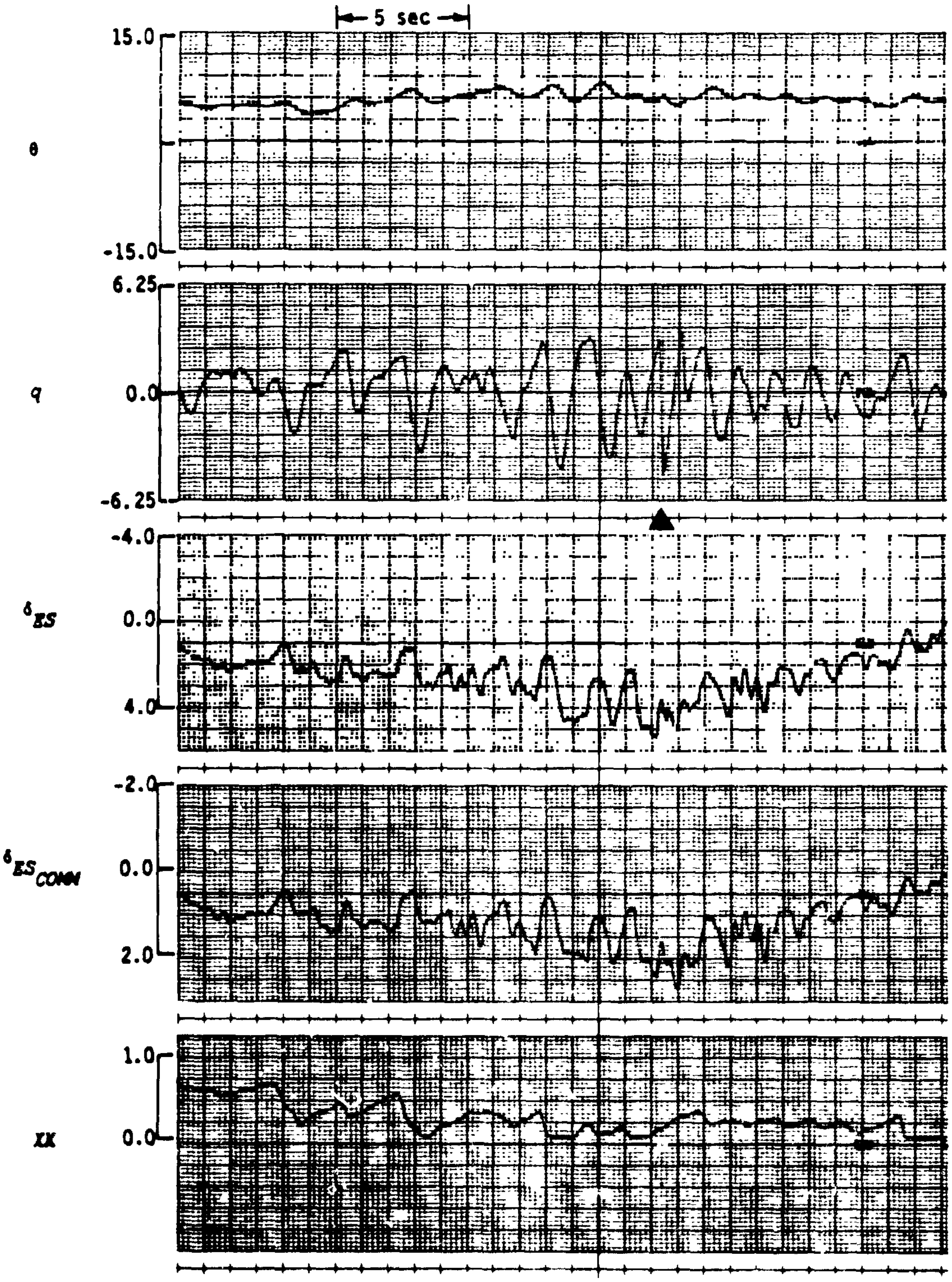

Figure II-13: CONFIGURATION T2 (A-2) PILOT B/2695-5 3rd LANDING OF 3

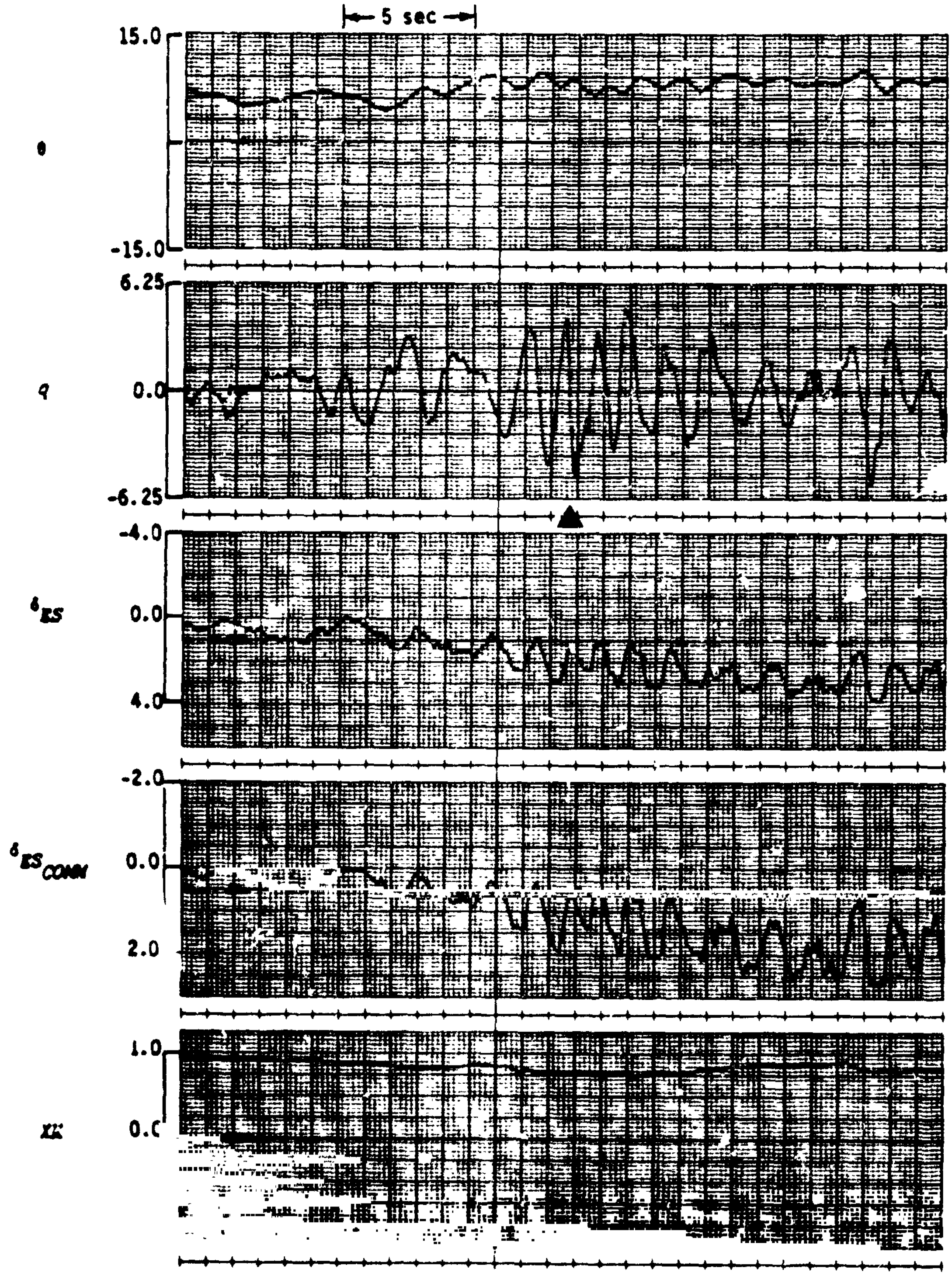

Figure II-14: CONFIGURATION T2 (A-6) PILOT A/2692 2nd LANDING OF 2

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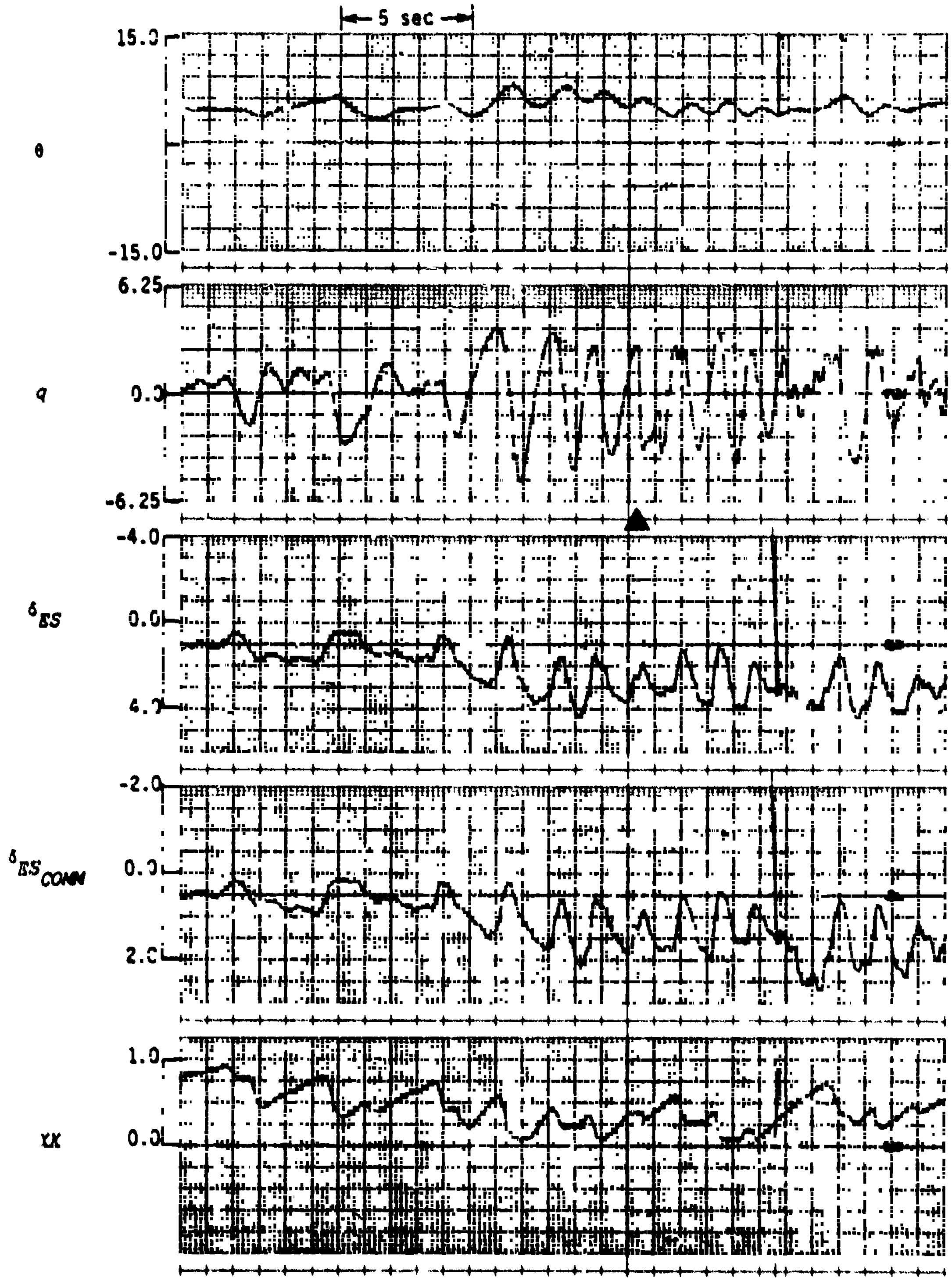

Figure II-15: CONFIGURATION 12 (B-2) PILOT A/2692 2nd LANDING OF 2

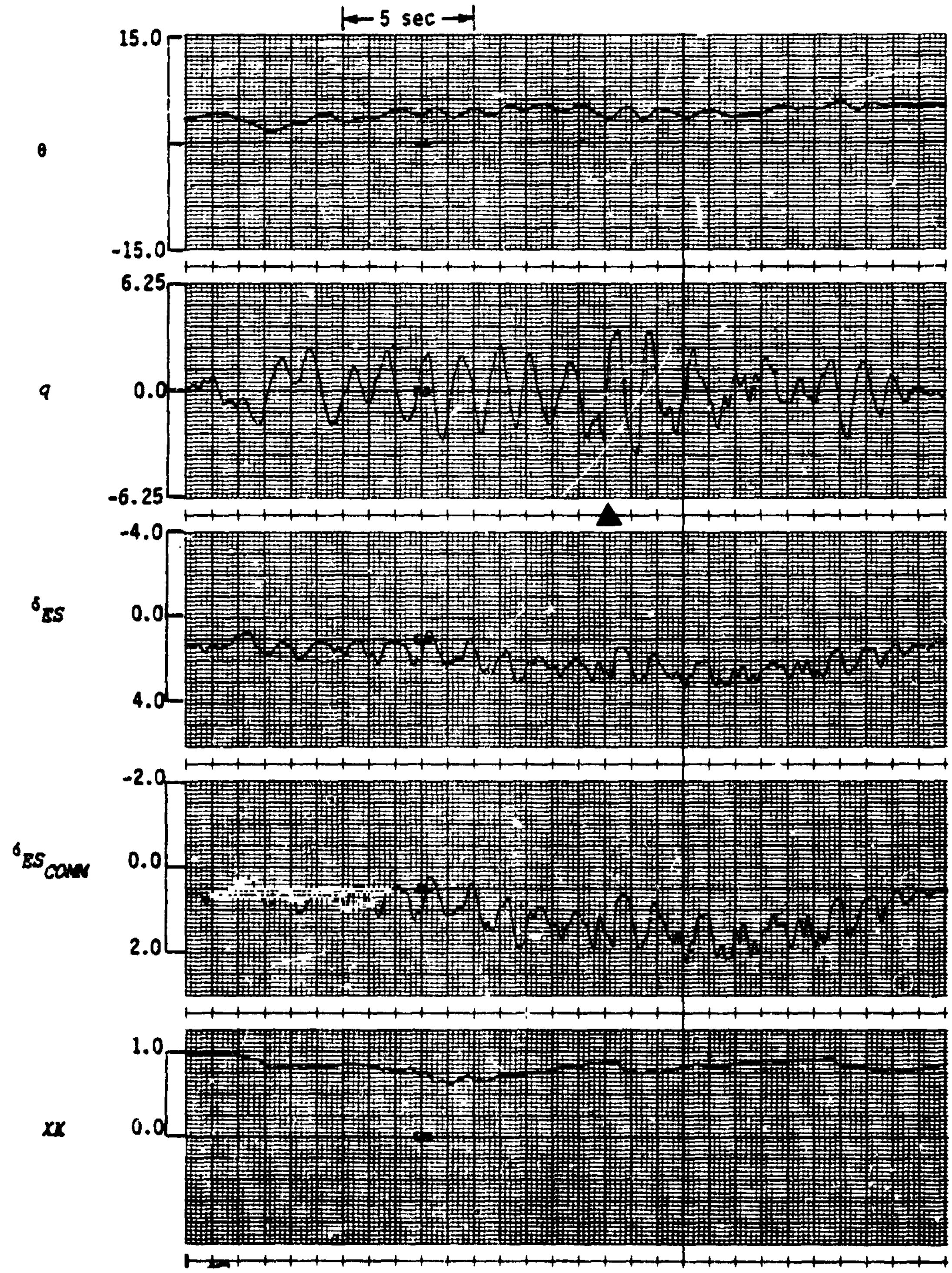

Figure II-16: CONFIGURATION T2 (B-4) PILOT B/2691 1st LANDING OF 2

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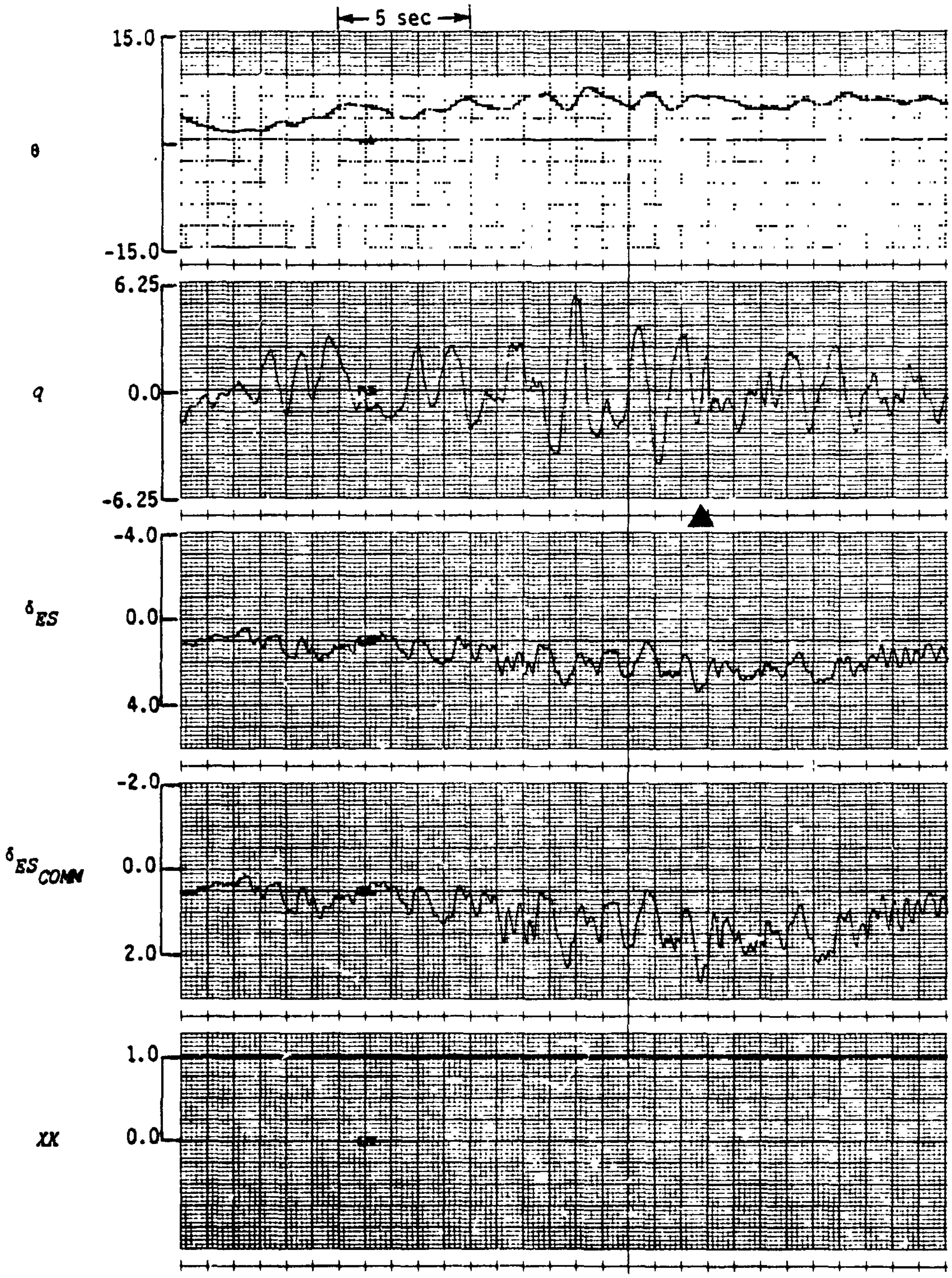

Figure II-17: CONFIGURATION T2 (C-3) PILOT B/2694 1st LANDING OF 2

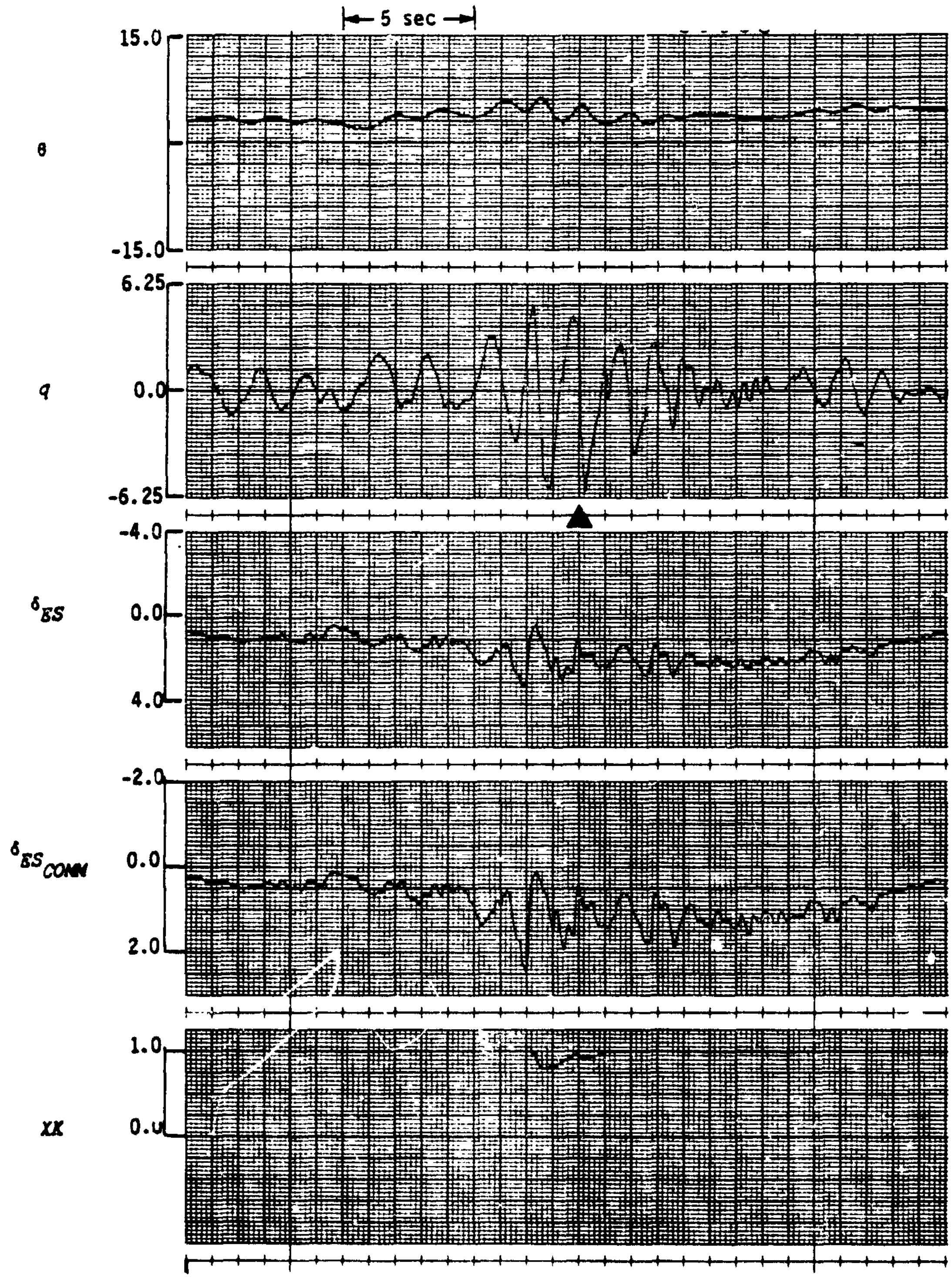

Figure II-18: CONFIGURATION T2 (C-5) PILOT A/2693 1st LANDING OF 2

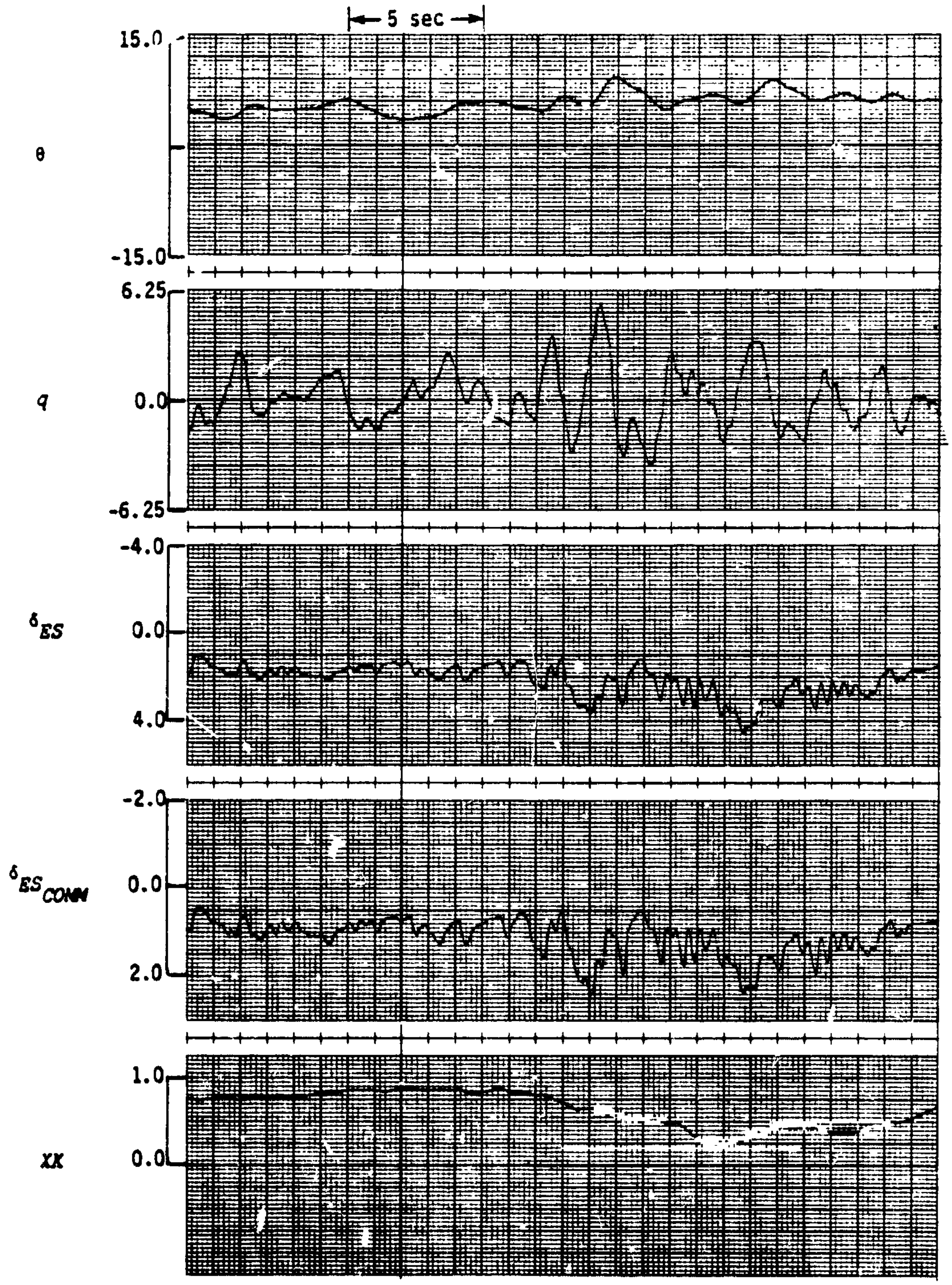

Figure II-19: CONFIGURATION T2 (D-8) PILOT B/2694 2nd LANDING OF 2

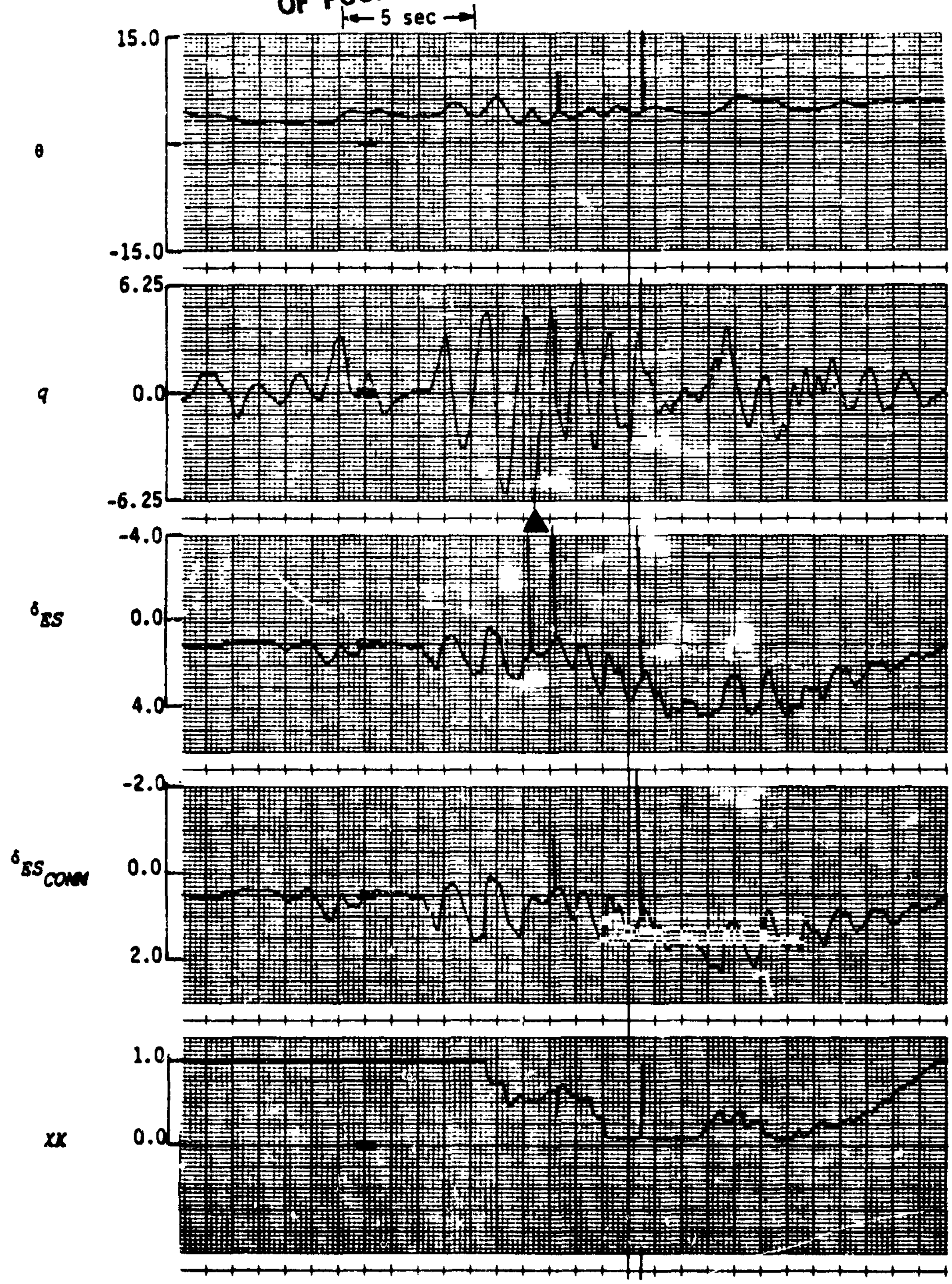

Figure II-20: CONFIGURATION T2 (E-7) PILOT A/2696 2nd LANDING OF 2

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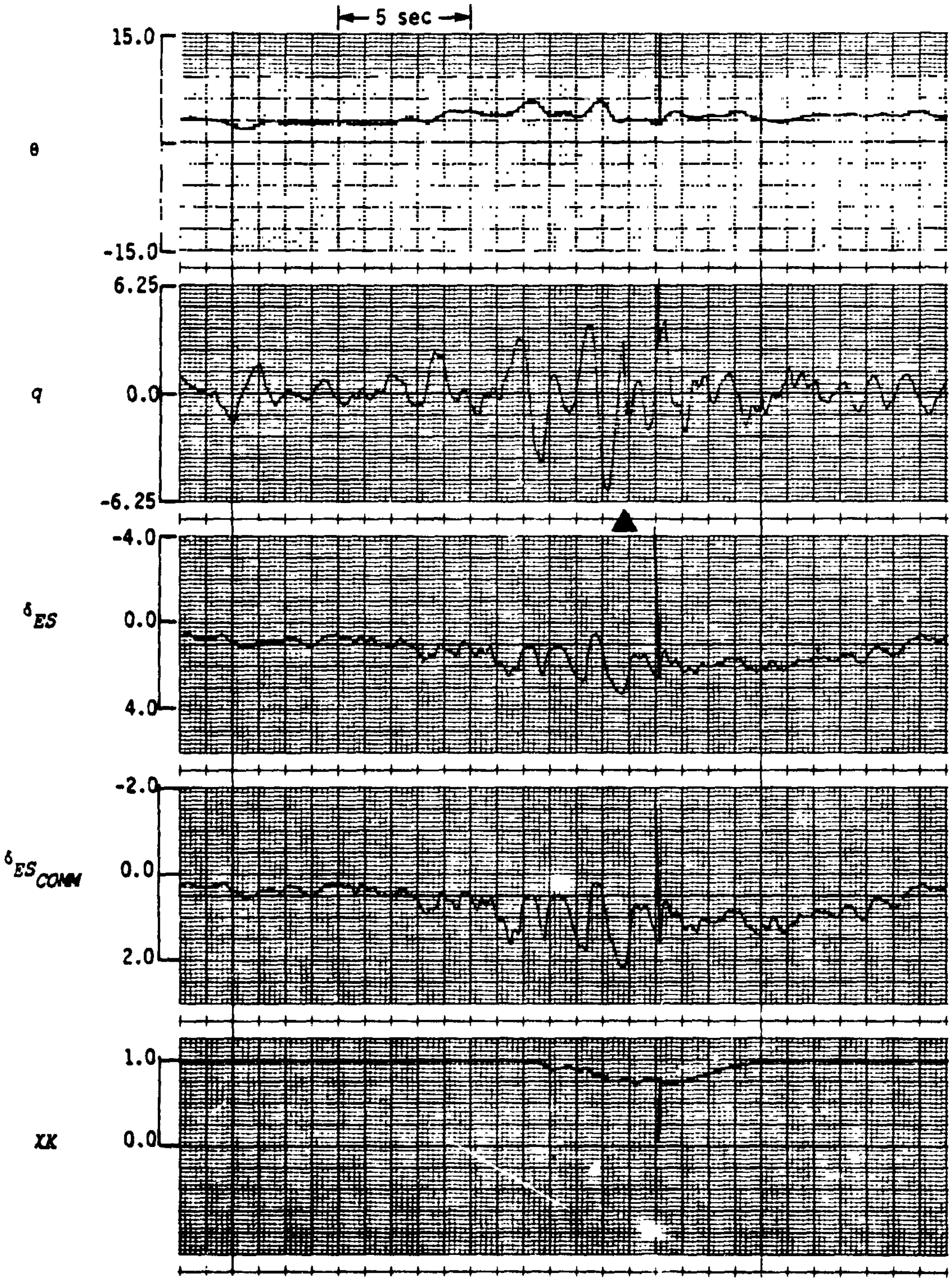

Figure II-21: CONFIGURATION T2 (E-8) PILOT A/2693 1st LANDING OF 2

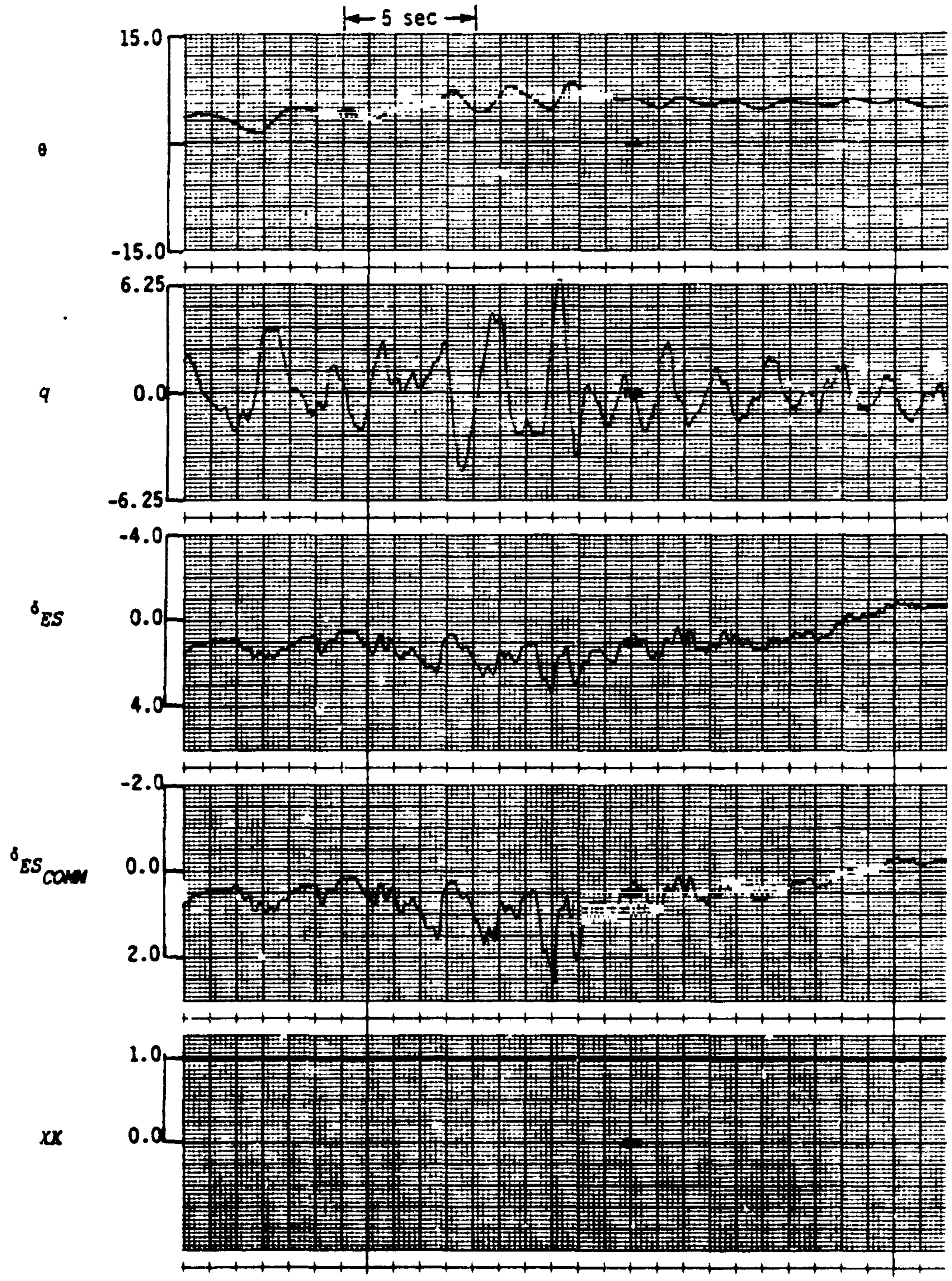

Figure II-22: CONFIGURATION T2 (F-8) PILOT B/2694 1st LANDING OF 2

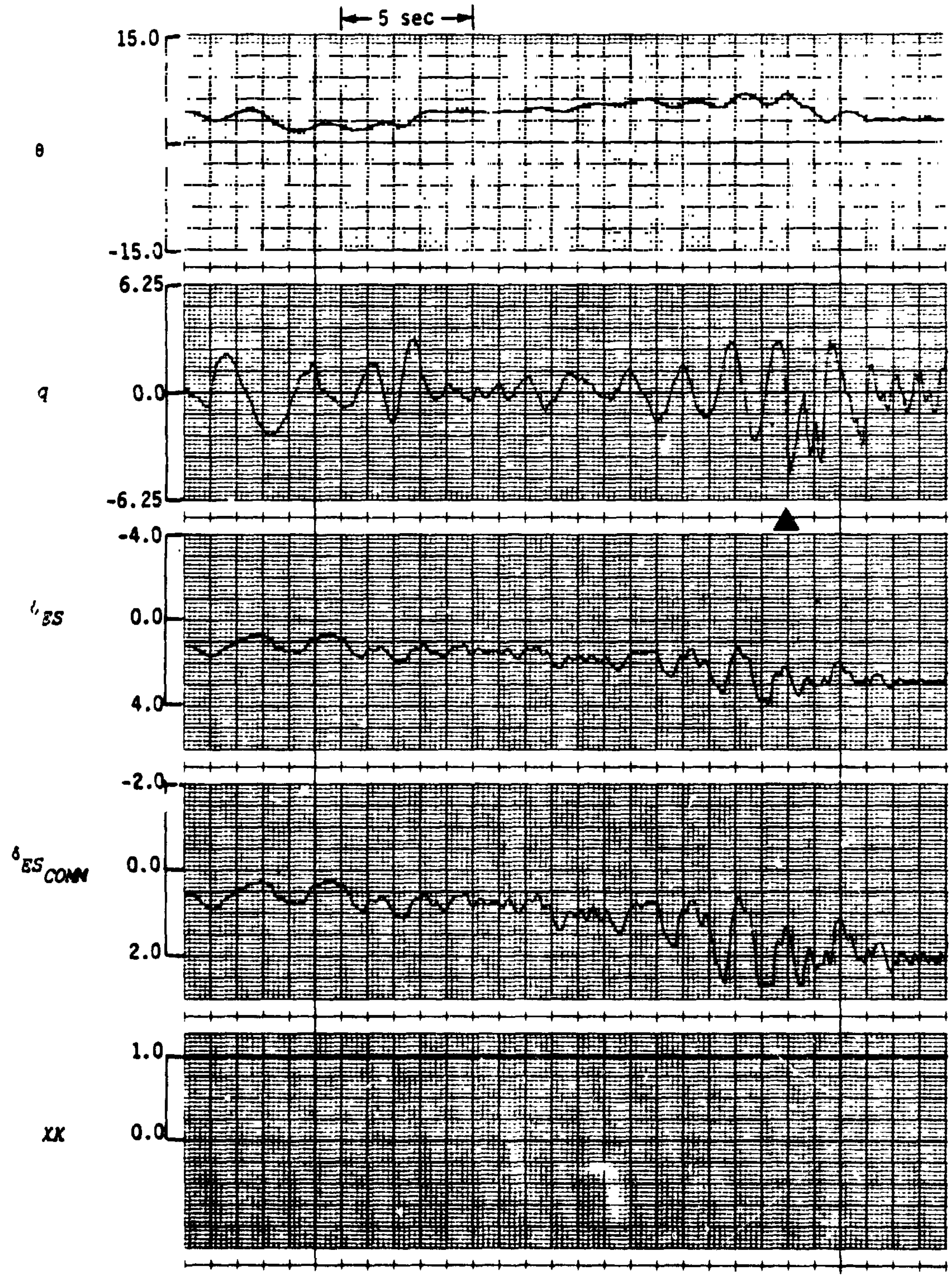

Figure II-23: CONFIGURATION F1 PILOT C/2697 2nd LANDING OF 2

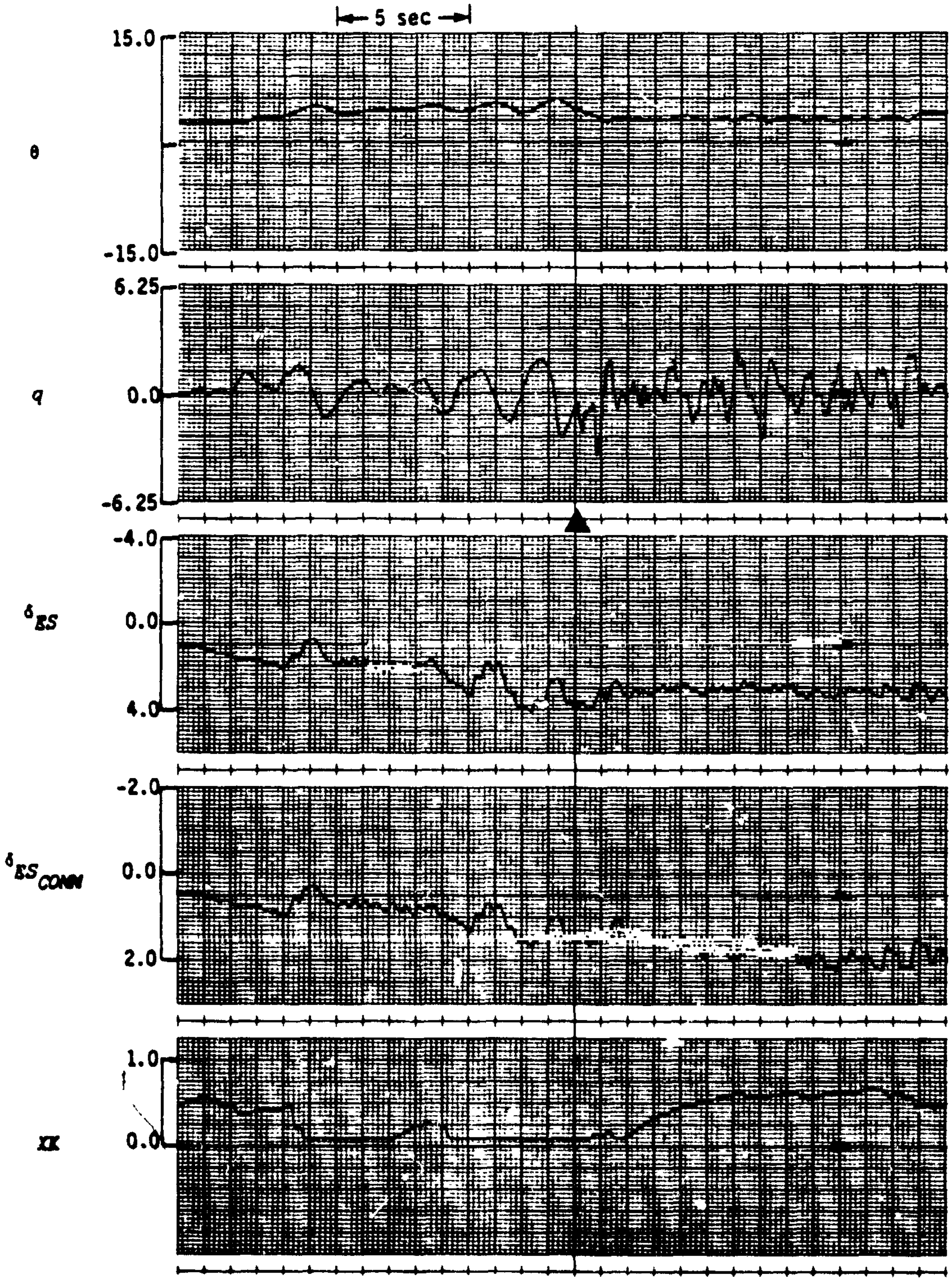

Figure II-24: CONFIGURATION F1 (A-1) PILOT C/2697 1st LANDING OF 2

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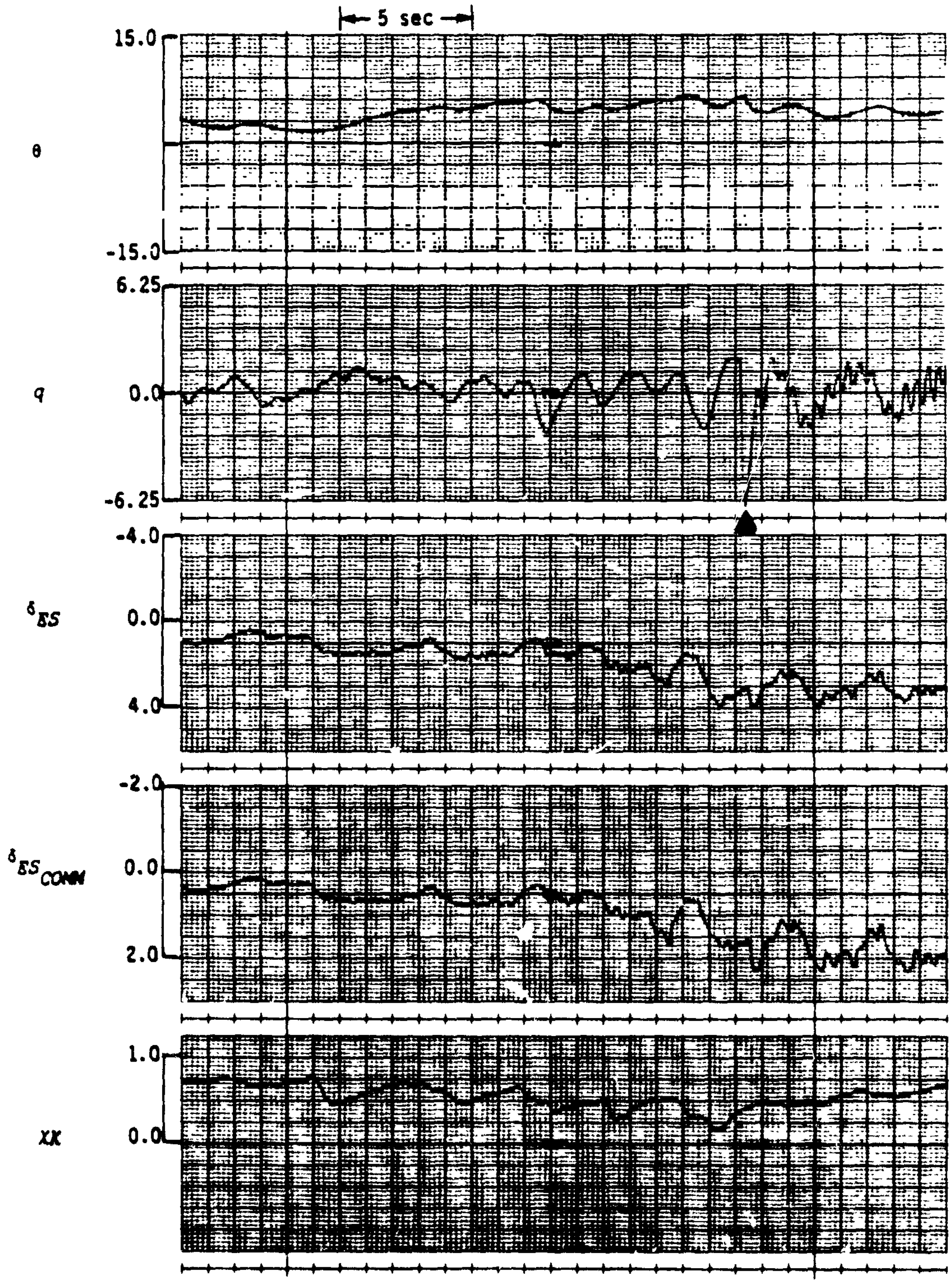

Figure II-25: CONFIGURATION F1 (A-2) PILOT C/2697 2nd LANDING OF 2

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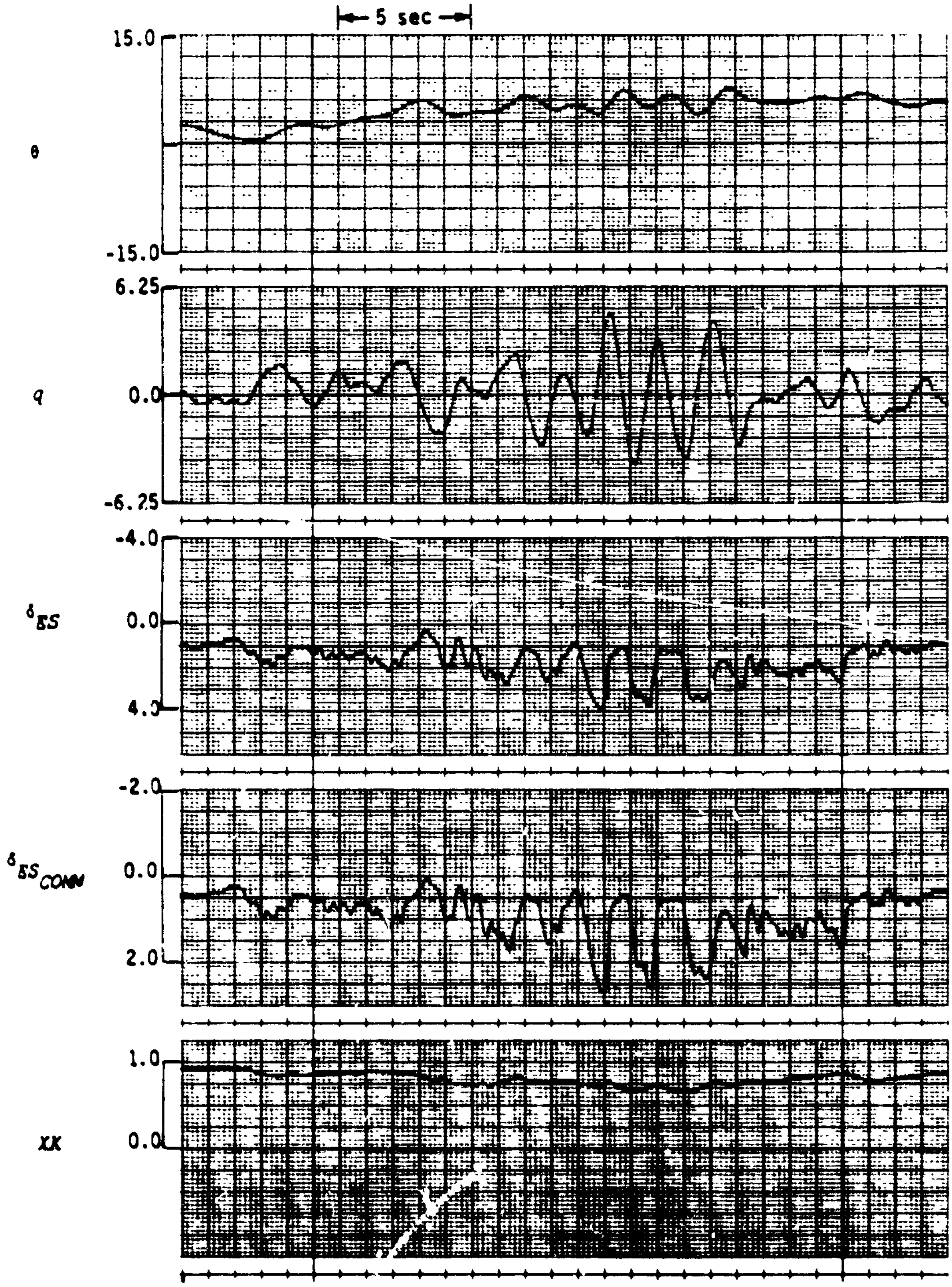


Figure II-26: CONFIGURATION F1 (A-6) PILOT B/2695 1st LANDING OF 2

Appendix III
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. This appendix describes the simulation mechanization in some detail; whereas, the reader is referred to Reference 5 for complete documentation of the simulation mechanization and operation of the NT-33A aircraft.

The aircraft dynamic characteristics for the simulated aircraft configuration were achieved by using the variable stability, response feedback system in the NT-33A. The configuration dynamics were implemented by feeding back the appropriate signals to the NT-33 control surface actuators with the proper feedback gains (Figure III-1). Closure of the feedback loops will cause the actuator roots to migrate somewhat, but because these roots are at very high frequency, this movement is not of consequence and the actuator roots are assumed constant. The effects of the filters and sensors in the feedback paths on the simulation are also considered minimal.

The longitudinal augmented aircraft dynamics were achieved by feeding back angle of attack and pitch rate. The proper feedback gains were determined during the calibration flying through data reduction using standard flight test techniques (Reference 10) and a digital onboard recorder. Since the gross weight of the NT-33 changes as fuel is depleted, the approach airspeed was scheduled as a function of fuel remaining. This procedure maintains a fixed approach angle of attack and the configuration dynamics remain approximately constant for the flight. The given values of augmented aircraft dynamics for a nominal approach speed of 135 KIAS are very representative, although some variation of the dynamics still occurs due to slight changes in pitch inertia.

On the other hand, the large contribution that tip tank fuel makes in the roll and yaw inertia requires that the lateral gains be scheduled to obtain constant configuration dynamics. Standard in-flight data reduction techniques were again used to determine the proper feedback gains. By scheduling these as a function of fuel remaining, approximately constant

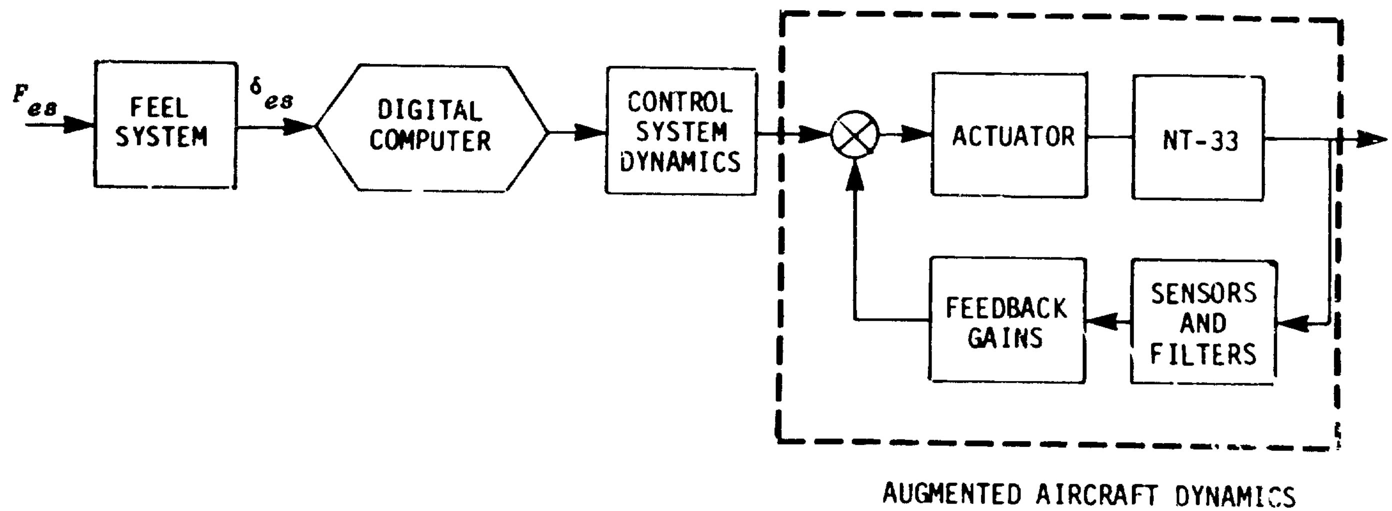


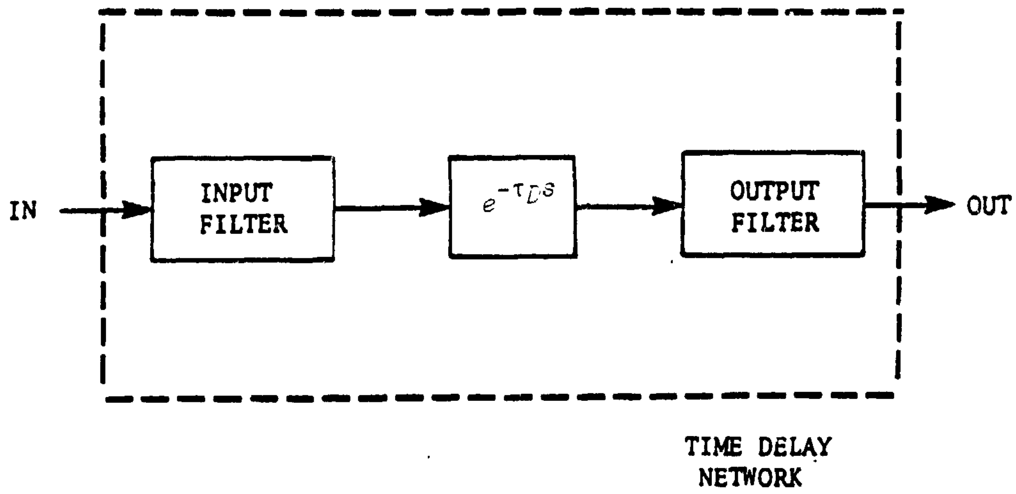
Figure III-1: SIMULATION MECHANIZATION (PITCH AXIS) lateral-directional configuration characteristics were maintained (Appendix IV).

A position command control system was used in the three control axis with the feel system characteristics of each held fixed. The feel system dynamics were mechanized using an electrohydraulic servo with position and rate feedbacks to control the frequency and damping as well as the desired spring force gradient. Although available, no friction or breakout forces were included in the simulation. A digitally implemented deadband was, however, added to the pitch control system.

The desired control system dynamics were simulated by altering the NT-33A "fly-by-wire" control system with suitable electronic circuits. The two radian per second, first-order prefilter for Configuration F1 was implemented by the proper analog circuits. Its introduction to the pitch control system was selectable by a switch in the rear, safety pilot cockpit. No additional control system dynamics were added to either the roll or yaw channels for this program.

A digital time delay was added to the pitch control system to implement configurations T1, T2, and T3. Although values of transport time delay ($e^{-\tau s}$) have been specified according to each configuration identifier, a precise definition of the time delay network is presented to allow correct interpretation of its effects and avoid confusion over semantics (e.g. "equivalent" vs. "pure" time delay).

The time delay circuit of the NT-33A is, by itself, a pure time delay which merely "holds" the input signal a finite period of time before it is output. This circuit is a digital system producing a pure time delay which does not affect the amplitude content of the signal in any way. However, this time delay circuit is surrounded by two low-pass analog filters in the fly-by-wire NT-33A control system for the suppression of noise and signal smoothing. The two analog filters are third-order Butterworth filters with break frequencies of 50 cycles per second and 50 radians per second for the input and output filters, respectively (Figure III-2).



INPUT FILTER: $$\frac{1}{\left(\frac{s}{314}+1\right)\left[\frac{s^2}{314^2}+\frac{2(0.5)}{314}\,s+1\right]}$$

OUTPUT FILTER: $$\frac{1}{\left(\frac{s}{50}+1\right)\left[\frac{s^2}{50^2}+\frac{2(0.5)}{50}\,s+1\right]}$$

Figure III-2. NT-33A TIME DELAY NETWORK

The effect of the analog filters on longitudinal flying qualities can be approximated as a time delay by using an equivalent systems method such as described in References 8 and 9, since the dynamics of the filters are of relatively high frequency. By this technique, the filters are shown to contribute a constant value of 45 msec equivalent time delay.

The table below summarizes the pure delay ($e^{-\tau_D s}$) and equivalent time delay due to the time delay circuit for a given configuration identifier; remembering, of course, that associated with the pure time delay are two analog filters which together produce the "total" time delay.

Configuration Identifier	Pure Digital Delay (msec)	Equivalent Delay (msec)
T1	70	115
T2	120	165
T3	160	205

Pure time delay with appropriate "warnings" that the analog filters are also included with this delay has been used throughout this report so that changes from one configuration to another are described exactly. It is important to note that the values of time delay described are the amount of delay added to the flight control system. Additional analysis is required to determine the "total" equivalent time delay of the experiment flight control system.

A digital computer was placed in the pitch control system for implementation of the PIOS filters and mechanization of the nominal nonlinear gradient for evaluations without PIOS filtering. The digital computer is part of the overall NT-33/Display Evaluation Flight Test (DEFT) system (Reference 11) and is now integrated into the NT-33 VSS for digital flight control applications. For this program, the digital computer was not used to close any feedback loops.

The digital computational capability is centered around a ROLM 1602A general purpose digital computer. It consists of a 5 MHz microprogrammed central processing unit with 32K of memory (expandable to 64K), direct memory access, expanded instruction set, real time clock, power monitor with automatic restart, and floating point firmware, as well as all the necessary input/output, control, and storage devices. The computer was interfaced through the Mode Control Unit in the safety pilot cockpit. The pilot selected an "experiment" which corresponded to a PIOS filter configuration depending upon the program tape that was loaded into the computer memory. The experiment number was recorded on the digital flight recorder for confirmation of the simulated PIOS configuration. In addition, the input to the PIOS filter (δ_{es}), PIOS filter output (δ_{es_c}), and gain attenuation factor (XK) were also recorded.

Modified z-transformations were used to digitize the position PIOS filter. No transformations were required to implement the rate PIOS filter. Note that the computer update rate for this program was an essentially constant 50 cps. The effects of different update rates should be referenced when comparing the results of this experiment to others.

Aside from checking the transformation and computer equations, the mechanization of each PIOS filter was verified by comparing time responses of the filters. The time history comparisons included step and sine wave responses at numerous frequencies and amplitudes. A wide range of inputs were examined because of the nonlinear nature of the filters. Data on the PIOS filter mechanization in the NT-33 was produced by feeding the appropriate electrical signals as inputs to the onboard computer. This data was then compared with generated data for the same input. Static measures were also checked where possible. The comparison of the NT-33 mechanization and the known filter responses were, for all practical purposes, exact.

Appendix IV

LATERAL-DIRECTIONAL CHARACTERISTICS

Since this program was an investigation of longitudinal fighter flying qualities, the lateral-directional characteristics of the NT-33A were tailored to produce unobtrusive, Level 1 flying qualities. Fortunately, a wealth of data on lateral flying qualities using the NT-33 aircraft was available from a recently completely investigation of higher order system effects (Reference 3). From this program, it was a relatively straightforward process to choose good lateral flying qualities. The calibration and identification of the lateral configuration dynamics is thoroughly documented in Reference 3 and not repeated here for that reason. This appendix briefly summarizes the lateral-directional characteristics simulated. (The lateral configuration dynamics are identical to configuration L2-1 from Reference 3 except the lateral command gain was increased by 50%).

The modal characteristics of the simulated lateral-directional configuration are tabulated in Table IV-1. A position command yaw and roll control system were mechanized with linear command gradients.

For this experiment, a standard center stick and rudder pedal arrangement was used for aircraft roll and yaw control. The physical dimensions of these controllers are illustrated in Figure IV-1. A simulated linear spring force gradient was mechanized in the center stick and rudder pedal feel systems and held constant throughout the program. The values were chosen to approximate closely the spring force gradients of other high performance fighter aircraft, but more importantly, the stick force per deflection gradients were tailored to levels which were not objectionable to the evaluation pilots. Although available, essentially no friction or breakout forces were included in either controller.

The lateral center stick feel system characteristics were held fixed for all configurations. The lateral feel system dynamics were selected to be sufficiently fast and not a factor in the experiment.

TABLE IV-1

SIMULATED LATERAL-DIRECTIONAL
MODAL CHARACTERISTICS

$\tau_R = 0.45\ sec$	$\zeta_{dr} = \zeta_\phi = 0.30$
$\tau_s = 100\ sec$	$\omega_{dr} \approx \omega_\phi = 1.5\ rad/sec$
$\lvert P/F_{as} \rvert = 7.5\ deg/sec/lbs$	$\lvert \phi/\beta \rvert_{dr} = 1.0$

AILERON STICK DIMENSIONS AND TRAVEL:

RUDDER PEDAL DIMENSIONS AND TRAVEL:

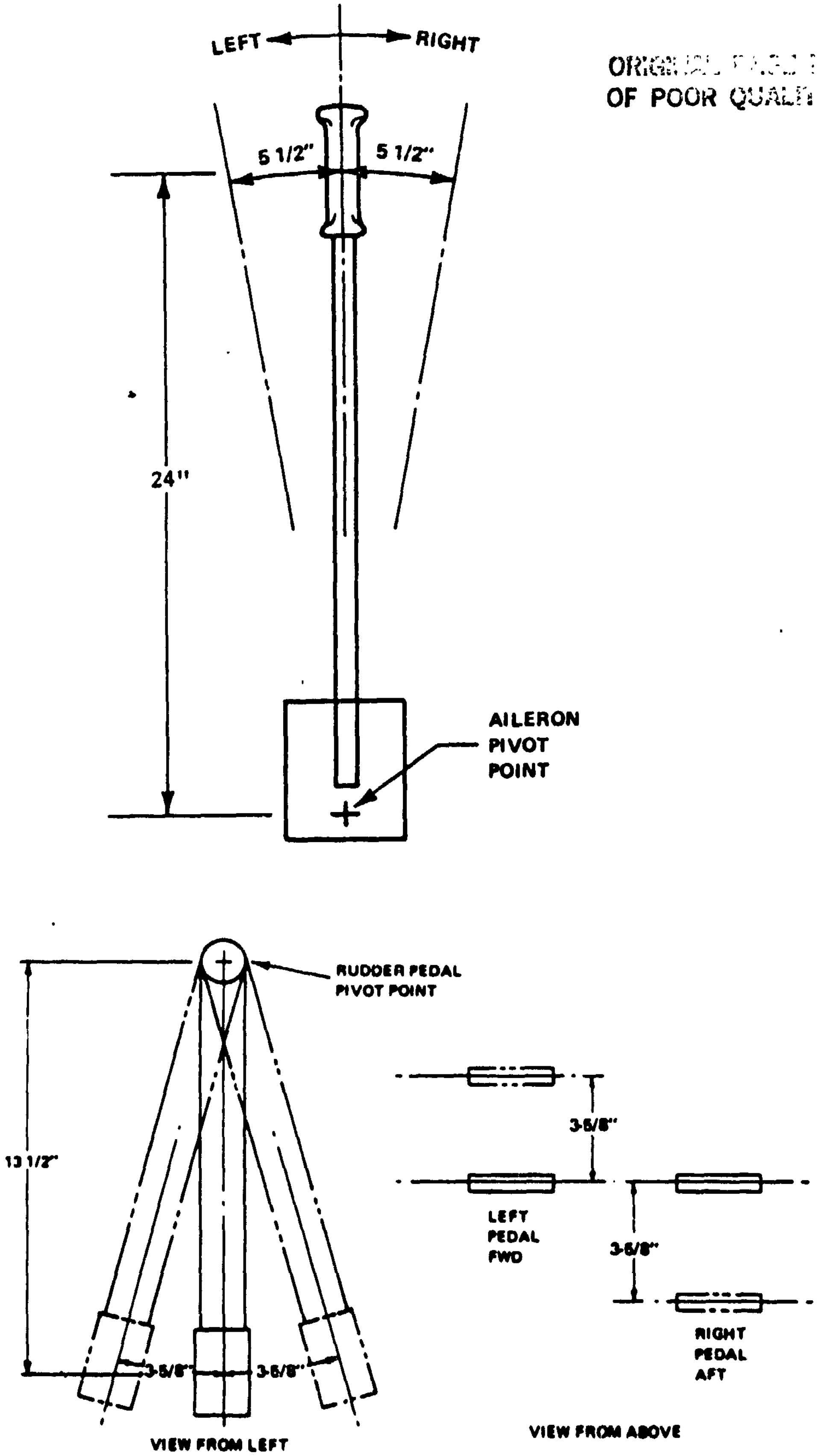


Figure IV-1. AILERON STICK AND RUDDER PEDAL GEOMETRIES

The lateral feel system characteristics were approximately:

$$\frac{\delta_{AS}}{F_{AS}} = \frac{0.29}{\left(\frac{s}{25}\right)^2 + \frac{2(0.7)}{25}\ s+1} \quad (in/lb)$$

with the aileron actuator transfer function described by a second order system possessing the characteristics:

$$\omega_a = 60 \text{ rad/sec}$$
$$\zeta_a = 0.7$$

For this flight phase category C task, the rudder pedal feel system was mechanized as:

$$\frac{\delta_{RP}}{F_{RP}} = \frac{0.0125}{\left(\frac{s}{30}\right)^2 + \frac{2(0.6)}{30}\ s+1} \quad (in/lb)$$

The rudder actuator is described as a second order system possessing the characteristics:

$$\omega_r = 60 \text{ rad/sec}$$
$$\zeta_r = 0.7$$

Signals to both the aileron and rudder actuators are passed through a first-order lag prefilter with a break frequency of 200 radians per sec.