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# Interaction of Feel System and Flight Control System Dynamics on Lateral Flying Qualities

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## FOREWORD

This report was prepared for the United States Air Force by the Calspan Corporation, Buffalo, New York, in partial fulfillment of USAF Contract No. F33615-83-C-3603. This report describes an experimental investigation of the effects of the feel system dynamics on fighter aircraft lateral flying qualities.

The work reported herein was performed principally by the Flight Research Department of Calspan under contract from the USAF Wright Aeronautical Laboratory (AFWAL), Wright Patterson Air Force Base. Mr. Randall E. Bailey was the project engineer, assisted by Mr. Michael Parrag, who provided technical advice and guidance while also participating as a safety pilot. This program was NT-33A Task 13 of the overall TIFS/NT-33 USAF contract. Mr. Steve Markman was the program manager for AFWAL.

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## ABSTRACT

An experimental investigation of the influence of lateral feel system characteristics on fighter aircraft roll flying qualities was conducted using the variable stability USAF NT-33. 42 evaluation flights were flown by three engineering test pilots. The investigation utilized the power approach, visual landing task and up-and-away tasks including formation, gun tracking, and computer-generated compensatory attitude tracking tasks displayed on the Head-Up Display. Experimental variations included the feel system frequency, force-deflection gradient, control system command type (force or position input command), aircraft roll mode time constant, control system prefilter frequency, and control system time delay. The primary data were task performance records and evaluation pilot comments and ratings using the Cooper-Harper scale. The data highlight the unique and powerful effect of the feel system of flying qualities. The data show that the feel system is not "equivalent" in flying qualities influence to analogous control system elements. A lower limit of allowable feel system frequency appears warranted to ensure good lateral flying qualities. Flying qualities criteria should most properly treat the feel system dynamic influence separately from the control system, since the input and output of this dynamic element is apparent to the pilot and thus, does not produce a "hidden" effect .

## LIST OF SYMBOLS

$c$	damping coefficient
$e^{-ts}$	Time delay, $\tau$ (sec), Laplace notation
$F_{as}$	Roll control stick force, positive right (lb)
$F_{as_{SS}}$	Side stick roll stick force, positive right (lb)
$F_{es}$	Pitch control stick force, positive aft (lb)
$F_{rp}$	Rudder pedal control force, positive right (lb)
$g$	Acceleration of gravity (ft/sec <sup>2</sup> )
$h$	Altitude (ft)
$I_x$	Moment of inertia about X axis (ft-lb sec <sup>2</sup> )
$I_y$	Moment of inertia about Y axis (ft-lb sec <sup>2</sup> )
$I_z$	Moment of inertia about Z axis (ft-lb sec <sup>2</sup> )
$I_{xz}$	Product of inertia (ft-lb sec <sup>2</sup> )
$K$	Gain constant
$L$	Rolling moment (ft-lb)
$l_{x_{ep}}$	Distance measured along aircraft body axis axial direction (x) from c.g. to pilot eye point, $f_i$
$l_{z_{ep}}$	Distance measured along aircraft body axis normal direction (z) from c.g. to pilot eye point (ep), ft.
$L( )$	$= \frac{1}{I_x} \frac{\partial L}{\partial ( )}$
$L'_i$	$= \left( 1 - \frac{I_{xz}^2}{I_x I_z} \right)^{-1} \left( L_i + \frac{I_{xz}}{I_x} N_i \right)$
$N$	Yawing moment (ft-lb)
$N( )$	$= \frac{1}{I_z} \frac{\partial N}{\partial ( )}$
$N'_i$	$= \left( 1 - \frac{I_{xz}^2}{I_x I_z} \right)^{-1} \left( N_i + \frac{I_{xz}}{I_z} L_i \right)$
$n_y$	Side acceleration (g's)

## LIST OF SYMBOLS (Cont.)

$N_{yp}, N_{yep}$	Side acceleration at pilot's reference eye point (g's)
$n_z$	Normal acceleration (g's)
$n_z/\alpha$	Normal acceleration-per-unit angle-of-attack (g's/rad)
$p$	Roll rate (deg/sec or rad/sec)
$p_{ss}$	Steady-state roll rate (deg/sec)
$\dot{p}_{max}$	Maximum roll acceleration (deg/sec <sup>2</sup> )
$\dot{p}_{max} / F_{as}$	Maximum roll acceleration per unit lateral stick force (deg/sec <sup>2</sup> /lb)
$r$	Yaw rate (deg/sec)
$s$	Laplace operator (sec <sup>-1</sup> )
$ss$	Steady-state or sidestick
$v_i$	Indicated airspeed (kts)
$v_t$	True velocity (ft/sec)
$\bar{x}$	Mean value
$Y$	Side force (lb)
$Y_{( )}$	$= \frac{1}{mv_t} \frac{\partial Y}{\partial ( )}$
$Y_c$	Control Element ("Plant") Transfer Function Element
$Y_p$	"Pilot Model" Transfer Function Element
$x, y, z$	Stability axes (i.e., a right hand orthogonal body axis system with origin at the c.g., the z axis in the plane of symmetry and the x-axis aligned with the relative wind at zero sideslip trimmed flight)
$\alpha$	Angle-of-attack (deg)
$\beta$	Angle-of-sideslip (deg)
$\delta_a$	Aileron (deg)
$\delta_{ac}$	Aileron Deflection Command, deg
$\delta_{as}$	Roll control (centerstick) stick deflection at grip (in)
$\delta_{as_{ss}}$	Roll Sidestick Deflection, deg
$\delta_{es}$	Pitch control (centerstick) stick deflection at grip (in)

## LIST OF SYMBOLS (Cont.)

$\delta_{rp}$	Rudder pedal deflection (in)
$\zeta_{DR}$	Dutch-roll damping ratio
$\zeta_{FS}$	Feel System Damping Ratio
$\zeta_{PF}$	Second Order Prefilter Damping Ratio
$\zeta_{ph}$	Phugoid damping ratio
$\zeta_{sp}$	Short period damping ratio
$\zeta_{\phi}$	Damping ratio of numerator $\phi/F_{AS}$ transfer function
$\theta$	Pitch attitude (deg)
$\sigma$	Standard deviation
$\tau$	Time constant, sec
$\tau_D$	Pure digital time delay, sec
$\tau_e$	Equivalent time delay (frequency domain measurement), sec
$\tau_{eff}$	Effective time delay (time domain measurement), sec
$\tau_{PF}$	Time constant of first-order prefilter, sec
$\tau_R$	Roll mode time constant (sec)
$\tau_{R_e}, \tau_{R_{eff}}$	Equivalent, effective roll mode time constant (sec)
$\phi$	Bank angle (deg)
$\phi_c$	Commanded bank angle (deg)
$\phi_e$	Bank angle error, $\phi_e = \phi_c - \phi$ (deg)
$ \phi/\beta _{DR}$	Absolute value of controls-fixed roll to sideslip ratio at $\omega_{DR}$
$\Psi$	Heading angle (deg)
$\omega$	Natural frequency, rad/sec
$\omega_{a,e,r}$	Undamped natural frequency of aileron, elevator, and rudder actuators
$\omega_{DR}$	Undamped natural frequency of Dutch-roll (rad/sec)
$\omega_{ph}$	Longitudinal phugoid undamped natural frequency (rad/sec)
$\omega_{sp}$	Longitudinal short period undamped natural frequency (rad/sec)



## LIST OF SYMBOLS (Cont.)

- $\omega_{FS}$  Natural frequency of second order feel system, rad/sec
- $\omega_{PF}$  Natural frequency of second-order prefilter dynamics, rad/sec
- $(\lambda)$  Short-hand notation for first-order dynamic element of the form:  $\frac{1}{\lambda}(s + \lambda)$
- $[\zeta, \omega]$  Short-hand notation for second-order dynamic element of the form:  
$$\left[ \frac{s^2}{\omega^2} + \frac{2\zeta}{\omega}s + 1 \right]$$
- $(\dot{\phantom{x}})$  Time rate-of-change of parameter i.e.,  $\frac{d(\phantom{x})}{dt}$

## LIST OF ABBREVIATIONS AND ACRONYMS

AFWAL	Air Force Wright Aeronautical Laboratories
AGL	Above Ground Level
AMP	Amplitude, dB
AR	Air Refueling task
BW	Bandwidth
c.g.	center of gravity
cmmd	Command
DEFT	Display Evaluation Flight Test
DFBW	Digital Fly-by-Wire
deg	degrees
ep	eyepoint (position reference)
EP	Evaluation Pilot
ESP	Equivalent System Program
FDL	Flight Dynamic Laboratory
ff	Formation Flying
FFT	Fast Fourier Transformation
fps	feet per second
freq	frequency, rad/sec
FR	Fuel Remaining
HUD	Head-Up Display
GT	Gun Tracking
HQDT	Handling Qualities During Tracking
HQR	Handling Qualities Rating
HOS	High Order System
Hz	Hertz, cycles per second
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
in	inches
KIAS	Knots, Indicated Airspeed

## LIST OF ABBREVIATIONS AND ACRONYMS

kts	knots
LATHOS	Lateral Higher Order System
lb, lbs	pounds
LOS	Low Order System
MAC	Mean aerodynamic chord, ft
mil	milliradian
MIL-SPEC	Military Specification
MOA	Military Operating Area
msec	millisecond
MSL	Mean Sea Level
NRMSE	Normalized Root Mean Squared Error, $\text{rms}\phi_e/\text{rms}\phi_c$
O	Overall
PA	Power Approach
PIO	Pilot-induced Oscillation
Pot	Potentiometer
PR	Pilot Rating
rad	radian
rms	root-mean-square
rps	radians per second
sec	seconds
SOS	sum-of-sines
SP	Safety Pilot
SPR	Safety Pilot Rating
TAS	True Airspeed
TD	Time Delay
Tgt	Target
TR	Formation and Gun Tracking Task
UA	Up-and-away

## **LIST OF ABBREVIATIONS AND ACRONYMS**

<b>USAF</b>	<b>United States Air Force</b>
<b>USAFTPS</b>	<b>United States Air Force Test Pilot School</b>
<b>VFR</b>	<b>Visual Flight Rules</b>
<b>VMC</b>	<b>Visual Meteorological Conditions</b>
<b>VSS</b>	<b>Variable Stability System</b>

## Section 1 INTRODUCTION

Modern, full authority digital flight control systems have provided significant performance and handling benefits. Witness, for example, the X-29 aircraft. A quadruple redundant digital flight control computer suite stabilizes an extremely unstable airframe (static margin of -35% MAC) using multiple pitch control effectors and with automatic control surface scheduling for optimal lift-to-drag ratios (Reference 1).

Unfortunately, these enabling technologies have also introduced potential flying qualities penalties by the introduction of control system lags or delays. Aircraft, such as the F-18A, Tornado, and Space Shuttle have encountered dramatic pilot-induced oscillations (PIOs) during flight test which were induced by excessive control system time delay (Reference 2).

To a large degree, these events occurred because of the absence of applicable and accurate design criteria and data for governing control system delay. In response to these deficiencies, data and criteria have gradually been generated. For instance, the military specification for flying qualities of piloted airplanes, MIL-F-8785C (Reference 3), specifies that the "response of the aircraft motion shall not exhibit a time delay longer than .10 sec for Level 1 flying qualities for a pilot initiated step force input." Although the simplicity of this requirement is attractive, numerous pitfalls arise. Research has shown, for example, that accepted delay measurement techniques and their attendant flying qualities implications are not equivalent (Reference 2). Also, the 100 msec requirement was based predominantly on fighter aircraft requirements; thus, 100 msec is too stringent for large aircraft flying less demanding piloting tasks (for instance, see Reference 5).

Recently, however, the design experiences of the X-29 and F-18 have also pointed out a lack of sufficiency in the specification of the maximum allowable control system time delay for fighter aircraft (Reference 7). The particular deficiencies involve two questions:

- Is the cockpit control force or position input the more appropriate and more accurate time delay input definition, and
- what role do the feel system characteristics play in the time delay specification?

As documented in Reference 7, the X-29A uses a position command roll flight control system which places the feel system in the forward command path. A frequency domain, equivalent system analysis using the stick force signal as the input definition as required by MIL-F-8785C predicted the X-29A to have excessive (Level 3) control system time delay. However, flight test results have shown the X-29A to approach Level 1 flying qualities in roll, in contrast to the MIL-F-8785 time delay predictions. No piloting performance degradation is apparent due to time delay.

One unique feature of the X-29A control system is its relatively "slow" feel system. In roll, the feel system can be characterized by the transfer function:

$$\frac{\delta_{as}}{F_{as}} = \frac{.5(13^2)}{s^2 + 2(.7)(13)s + 13^2}$$

This lateral feel system, which has a spring gradient of approximately 2 lb/in, contributes approximately 0.10 sec of equivalent time delay or approximately 45 percent of the overall time delay when the force signal is used as the time delay input definition. When this feel system is removed from the equivalent system analysis (the cockpit controller position signal is used as the input definition), the resulting equivalent delay values fall into the borderline Level 1-Level 2 flying qualities region which is consistent with the piloted flight evaluations. Past experimental evaluations of time delay on aircraft flying qualities have been performed exclusively with high frequency feel systems ( $\omega_{FS} \approx 25$  rad/sec). The dynamic response of the position output to pilot force inputs in these systems is sufficiently fast that the dynamic position response is not distorted nor obtrusive (i.e., it is "transparent") to the pilot control input (Reference 2).

Very similar flying qualities trends were experienced in the F-18 development. Early flight control laws used a force command architecture which has one advantage of eliminating the delay contribution of the feel system. However, the force command system was subsequently eliminated in part, because the time delay reduction was fictitious. The latest F-18 models have shown that referencing the time delay measurements to the stick position with a position command architecture provided good correlation between flight results and the MIL-F-8785C requirements. The feel system is, of course, a unique flight control system element in that both the input (pilot-applied force) and output (controller position) of the feel system transfer function, are perceived by the pilot.

An extensive flight research program has been conducted by the Calspan Flight

Research Department to investigate these issues. The objectives of this study were to:

- Investigate the influence of feel system dynamics on lateral flying qualities.
- Examine lateral flying qualities in the presence of control system time delay where the time delay may be either "hidden" or accessible to the pilot and correlate how these delays should be treated in a flying qualities specification. Hidden time delays are produced by those dynamic elements downstream of the feel system in the flight control system command path.

The USAF variable stability NT-33A aircraft was used as the flight test vehicle. Various control system architectures, control system filters, feel systems, and simulated aircraft dynamics were mechanized for piloted flight test evaluation. In this report, the experiment, its results, and detailed analyses are presented. The ultimate goal of this work is an enhanced understanding of the role of the feel system for aircraft flying qualities and improved design criteria for lateral flying qualities and time delay specification.

## Section 2 BACKGROUND

Background information, germane to this study, are presented. The information primarily summarizes other works which contributed to the shaping of this experiment and its subsequent analysis. Foremost in this presentation is a brief review of control system time delay definitions for flying qualities specification.

### 2.1 TIME DELAY DEFINITIONS

To a pilot, delay between his cockpit control input and the beginning of the aircraft response is of critical importance. Naturally, flying qualities requirements should be based on this perceived delay. Models of the pilot's perception of the aircraft's initial response using descriptions of the human vestibular, haptic, and visual sense organs are, however, complex, and only marginally valid. Time delay measures and corresponding flying qualities criteria have evolved instead from more easily measured aircraft response states which are approximations of the perceived delay.

By definition, a system which reproduces the exact form of an input after a specific interval of time is defined as exhibiting transport time delay or pure time delay. In Laplace notation, pure time delay is expressed as  $e^{-\tau s}$ . The initial response delay of today's aircraft to pilot commands is not, however, due solely to pure time delays. Additional delay in the aircraft's response occurs from sources which do not, by definition exhibit pure time delays. A pure time delay element, in the frequency domain, exhibits a unity gain amplitude response but phase lag ( $\phi$ ) is introduced proportionally to the frequency ( $\phi = 57.3 \tau \omega$ ). Any element that introduces phase lag without significant amplitude distortion may, therefore, be approximately described as a time delay element. These elements are characterized as "equivalent" time delay elements. The pilot is, of course, concerned with the overall delay of his input which is the sum of any pure time delay and the "equivalent" time delay from other sources.

Two methods are primarily employed in measuring time delay for flying qualities application. Both attempt to measure the total delay of a system thereby approximating the delay in aircraft response perceived by the pilot after a control input. The first method - equivalent time delay ( $\tau_e$ ) - is defined in the frequency domain (Reference 4). It is computed from minimizing the squared error difference in gain and phase between the high order frequency response and a low



order model where an "equivalent" time delay term is included in the low order model. This delay will be approximately equal to the phase lag of the unmodeled "higher order" dynamic elements in the frequency range of interest (Figure 1).

Effective time delay ( $\tau_{\text{eff}}$ ) is a time domain metric calculated by the maximum slope intercept method (Figure 2). The effective time delay measure does not explicitly require a "model" assumption.

Typically, the pitch rate or roll rate response are used for derivation of the equivalent or effective time delay measures. Time delay flying qualities data, design guidelines, and specifications must include a clear definition of the measurement techniques involved as the measurement techniques do not always yield the same answers. For instance, the effective time delay measured from the roll rate and roll attitude responses to a piloted step input will differ because of the different dynamic order of these two aircraft states. Also, the time domain (effective) and frequency domain (equivalent) time delay measures will differ if nonlinearities are present, or if the unmodeled higher-order dynamics in the equivalent systems method are not of high frequency with respect to the frequency range of the equivalent systems match.

### 2.1.1 MIL-F-8785C Time Delay

The maximum allowable delay limits are defined as:

Level 1: .10 sec  
Level 2: .20 sec  
Level 3: .25 sec

The time delay specification in MIL-F-8785C is, unfortunately, poorly defined and too restrictive. For instance:

- The requirement (Section 1) is stated in the time domain but an appropriate measurement technique, such as the effective time delay, is not specified. Rather, the requirement permits application of the equivalent system methodology but not with sufficient definition. Neither the equivalent system model order nor the frequency range of the match are specified. These two attributes are but two features that can significantly impact the equivalent time delay measurement.

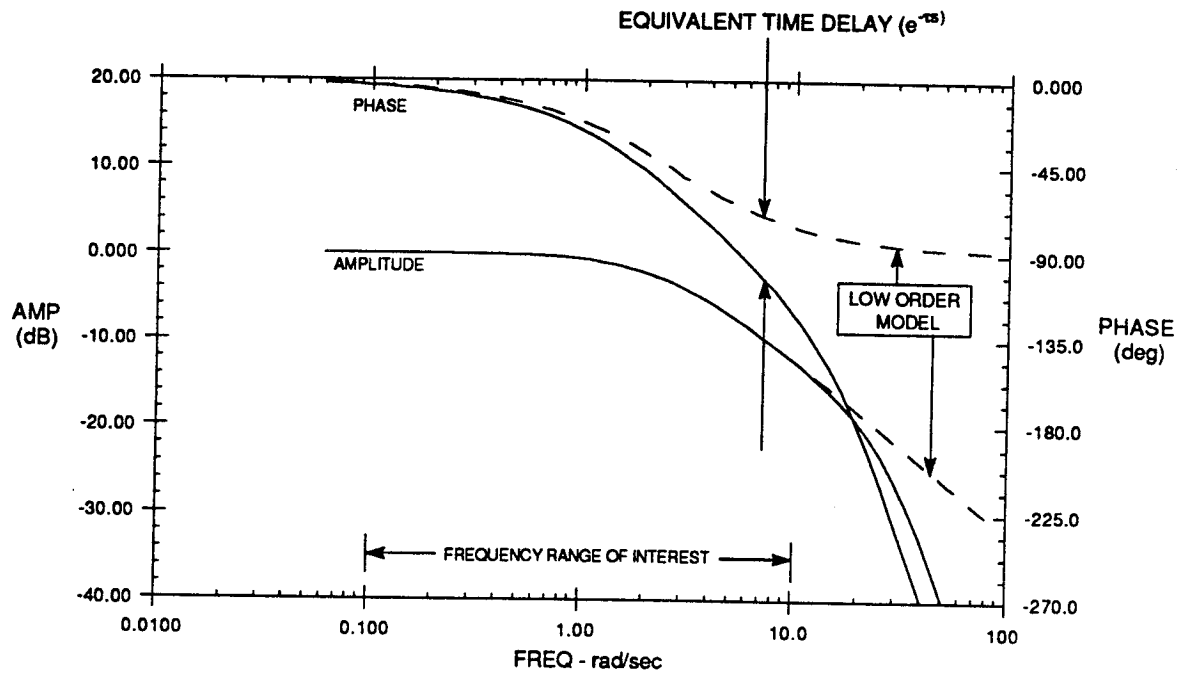


Figure 1 "EQUIVALENT" TIME DELAY DERIVED BY LOW ORDER MODEL PLUS TIME DELAY MATCH OF HIGH ORDER SYSTEM

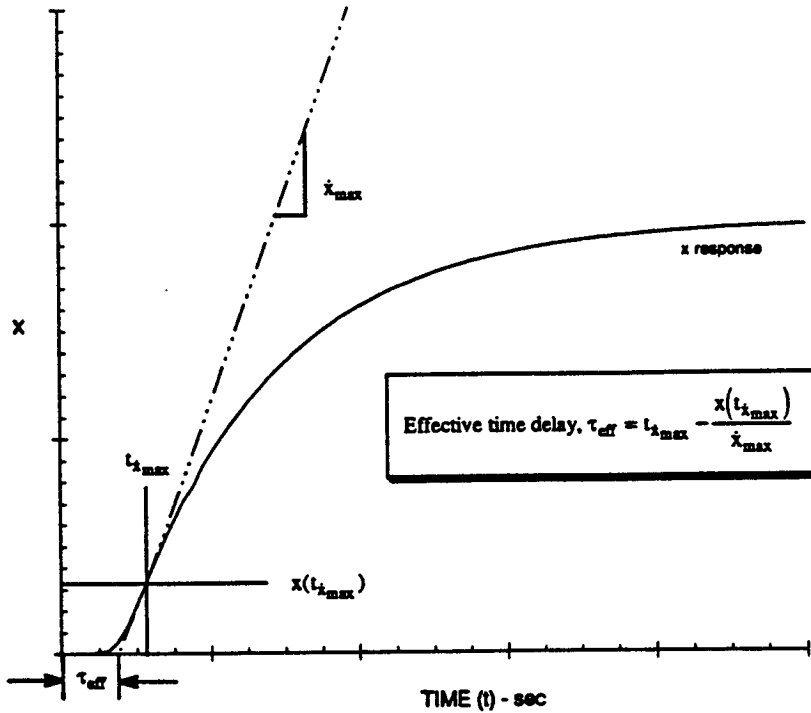


Figure 2 "EFFECTIVE" TIME DELAY CALCULATED BY MAXIMUM SLOPE INTERCEPT METHOD

- The allowable delays are identical for any measurement method irrespective of the inherent differences between the measurement techniques. For instance, the same system can yield different equivalent and effective time delay measurements dependent upon numerous factors (Reference 2).
- This delay requirement covers all aircraft and missions. Unfortunately, such blanket requirements may be overly-restrictive. Results of the NASA DFBW (Digital Fly-By-Wire) F-8 program (Reference 6) have shown that task performance demands are a critical factor in flying qualities, particularly when affected by the presence of time delay. Less demanding tasks show less flying qualities degradation with added control system time delay than do higher demanding tasks with the same delay. Further, large aircraft flying qualities have proven to be less susceptible to degradation with added time delay than small, highly maneuverable fighter aircraft (Reference 5 and 8).

Revisions to the current delay requirements are needed because they may not ensure a good design (because of the poorly defined delay measurements for compliance), yet they may also require an over-design, such as is the case of the large aircraft designed to the current requirement.

## **2.2 LATHOS EXPERIMENT**

Time delay effects have also been shown to be proportional to the aircraft control sensitivity. For more responsive and higher control sensitivities, more rapid flying qualities degradations are noted with added time delay. These effects were demonstrated vividly during the LATHOS (LATeral High Order System) experiment.

The LATHOS program (Reference 9) was an experimental investigation of lateral fighter aircraft flying qualities. The USAF variable stability NT-33 was the flight test vehicle. Three pilots evaluated over 200 configuration in Flight Phase Category A (up-and-away) and Category C (power approach) tasks. Using a force command control system architecture, experimental variations of roll mode time constant, roll command gain, time delay, and roll prefilter break-frequency were flown and evaluated.

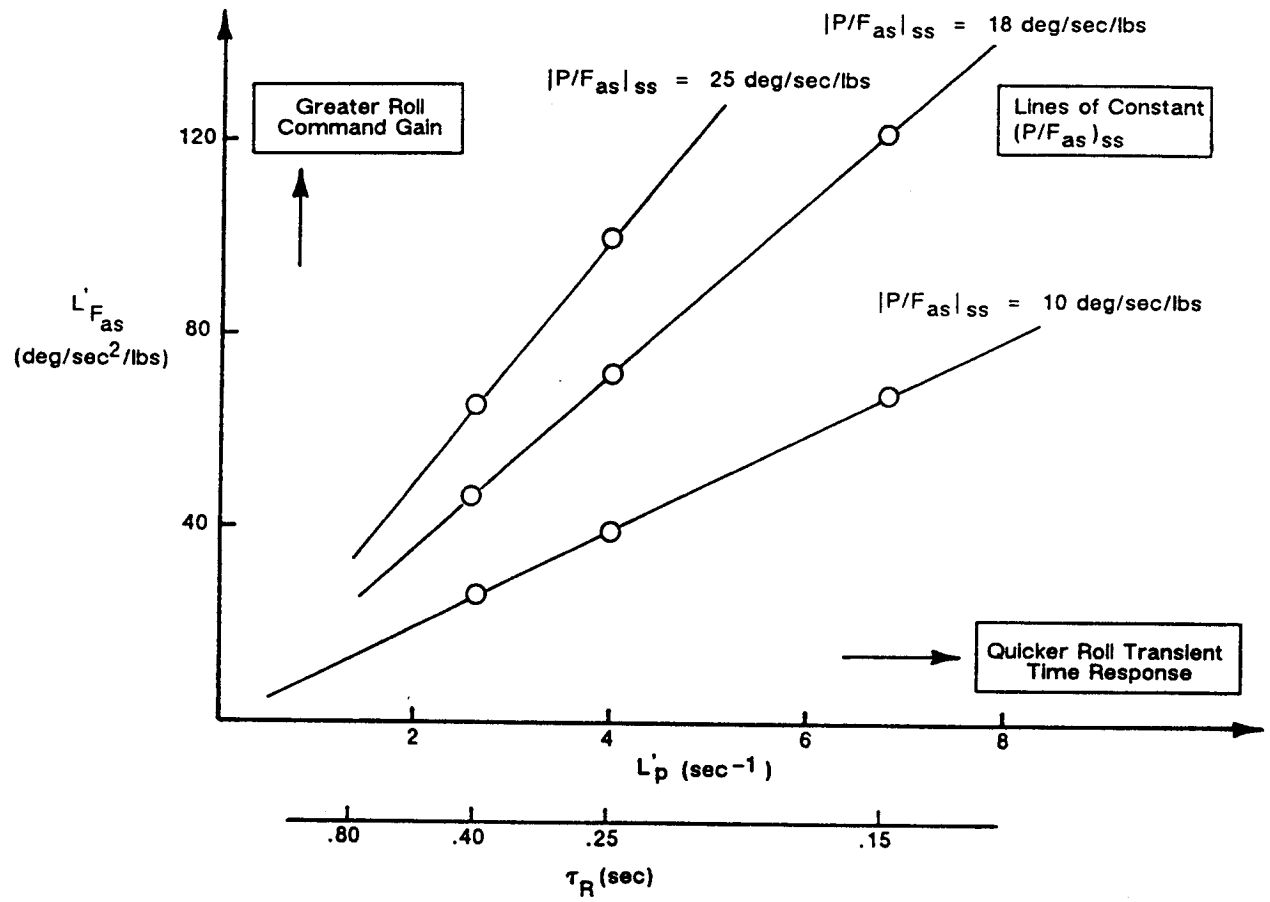


Figure 3 LATHOS EXPERIMENT AIRCRAFT MATRIX DESIGN

The primary experiment was developed from the tradeoff of roll damping (roll mode time constant) and roll command/control authority ( $L'F_{as}$ ), as shown in Figure 3, to achieve constant steady-state roll rate-per-unit lateral stick force (for a linear response to cockpit control command). This demonstrates the design tradeoff between roll performance ( $p_{ss}/F_{as}$ ) and roll damping. For instance, as the roll time constant is decreased (roll damping is increased) for a quicker roll transient response, the roll command gain has to be proportionally increased for adequate steady-state maneuver capability. As the program results demonstrated, this tradeoff cannot proceed indefinitely without flying qualities penalty. Eventually, the transient response for a given level of steady-state roll performance became objectionally quick and abrupt. Control problems, such as "roll ratchet" (discussed subsequently), develop in these situations.

As time delay was varied experimentally, the flying qualities effects were in proportion to the control sensitivity. This relationship was summarized using the effective time delay ( $\tau_{eff}$ ) and an effective roll mode time constant ( $\tau_{R_{eff}}$ ) as shown in Figure 4. These parameters are defined in Figure 5.

The rating trends shown in Figure 4 document a decreasing flying qualities tolerance to added time delay as the effective roll mode time constant decreased. The results for the two flight phase categories were similar; the data for the power approach task were, however, more sparse. A decreasing roll mode time constant, for a linear command gradient and a constant steady-state roll rate-per-stick force, translates into greater roll sensitivity, where the sensitivity is the rate of change of the roll response for a pilot input.

The rating results of Figure 4 are for the "optimal" roll control command gearing, that is, the criterion assumed that the effective roll mode time constant and effective time delay are necessary but perhaps not sufficient prerequisite for good roll flying qualities. The proper application of the criterion should include an "effective" roll command gain metric. In this manner, the primary ingredients for good roll flying qualities would be mapped: initial response delay ( $\tau_{eff}$ ), initial response slope or acceleration by some (as yet undefined) "effective" command gain criterion, and transient response time defined by  $\tau_{R_{eff}}$ . For a linear response, these three specifications would be sufficient to define both the initial and final roll response flying qualities. For a nonlinear situation, additional parameters would have to be defined and specified to completely define roll flying qualities of highly augmented aircraft.

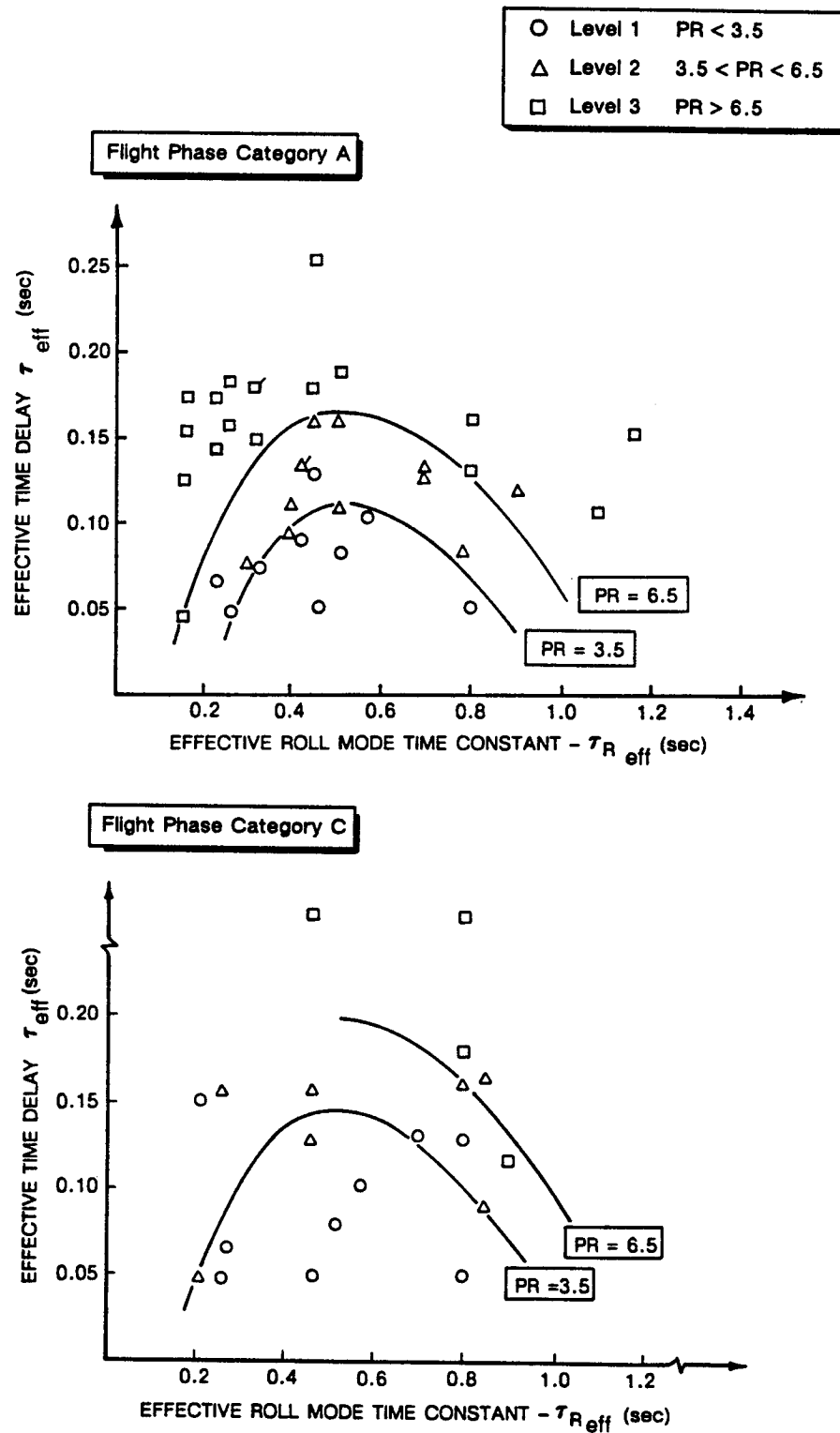


Figure 4 LATHOS RESULTS PLOTTED AGAINST EFFECTIVE PARAMETERS

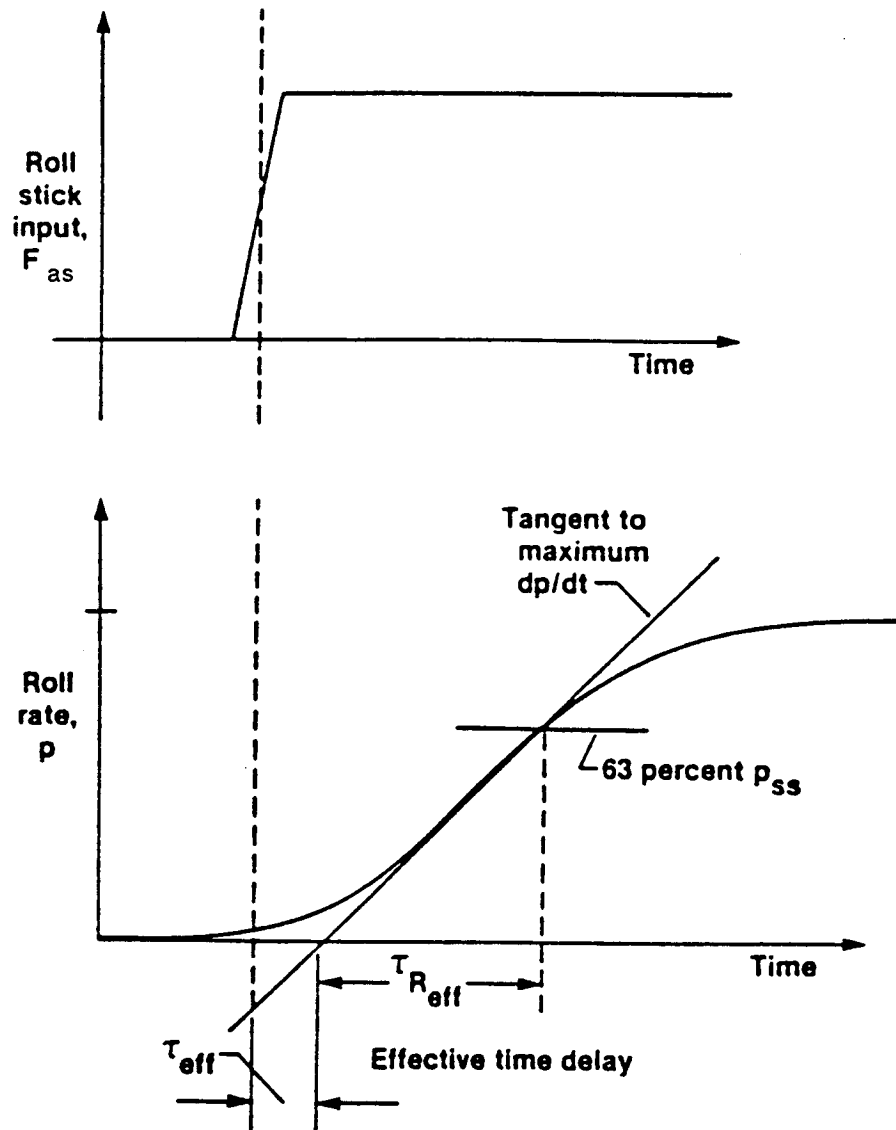


Figure 5 EFFECTIVE TIME DELAY AND ROLL MODE TIME CONSTANT

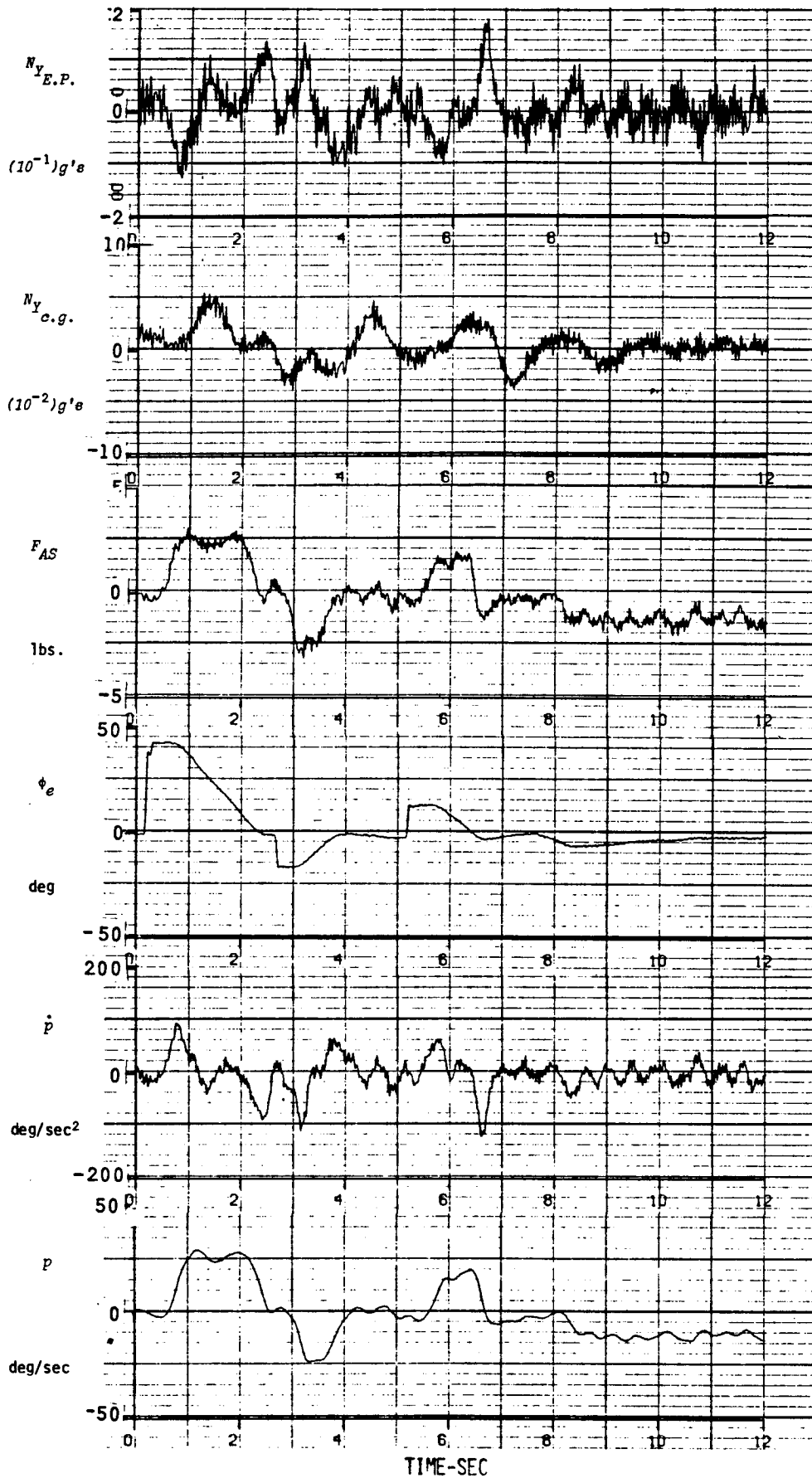
Several LATHOS experiment parameters were guided by the design experiences from the F-18A and F-16A. For instance, a force command architecture was used just as the F-16 and early F-18 versions had used. The cockpit controller was a centerstick, with a constant force deflection gradient of approximately 4 lbs/inch. This deflection gradient was similar to that proposed for the F-18. The feel system dynamics were designed by being sufficiently fast ( $\omega_{FS} \simeq 26$  rad/sec) and with good damping ( $\zeta = .7$ ). Because force commands were used, a first-order roll prefilter was used to smooth the pilot inputs. A 40 rad/sec break-frequency was selected as the nominal filter. More significant filters (lower break-frequencies) were investigated. The chosen steady-state roll rate commands of 10, 18, and 25 deg/sec/lb spanned MIL-F-8785B roll rate requirements.

### 2.3 ROLL RATCHET

The LATHOS experiment was of particular interest in the exploration of "roll ratchet." The term, "ratchet," was used by the evaluation pilots to describe a configuration which exhibited an exceptionally abrupt roll response which caused a high frequency ( $\omega \simeq 10-18$  rad/sec) pilot-induced oscillation (Figure 6).

The LATHOS experiment data showed that a flying qualities degradation existed in the tradeoff between roll damping and roll control authority for roll performance. For instance, as the roll damping was increased to shorten the roll response transient, the roll command gain was increased to maintain the steady-state roll rate. In doing so, the roll rate onset or abruptness became quite objectionable. The flying qualities degradation occurred as the roll time constant decreased below .20 sec. The pilot comments and ratings indicated that these vehicles had objectionably abrupt roll accelerations with adequate steady-state roll performance ( $|p_{SS}/F_{as}| > 10$  deg/sec/lbs, see Figure 7) the evaluation pilots rated as being Level 3 according to the Cooper-Harper pilot rating scale (Reference 10). Although good roll tracking performance could be attained, the roll response of these configurations was characterized as having "square corners." As such, there existed a tendency for the pilot to couple with the aircraft during tracking and produce a small amplitude, high frequency ( $\omega \simeq 10-18$  rad/sec) PIO described as roll ratcheting. The presence of added control system time delay confounded the problems and worsened the roll ratchet tendency. A simple closed-loop analysis was performed (Reference 9) and the observed ratcheting problem could be reproduced in a reasonable fashion if the following scenario was followed:





**Figure 6 HUD TRACKING TASK RECORD, CONFIGURATION 5-2 (EVALUATION NO. 12) "ROLL RATCHETING" TAKEN FROM REFERENCE 9**

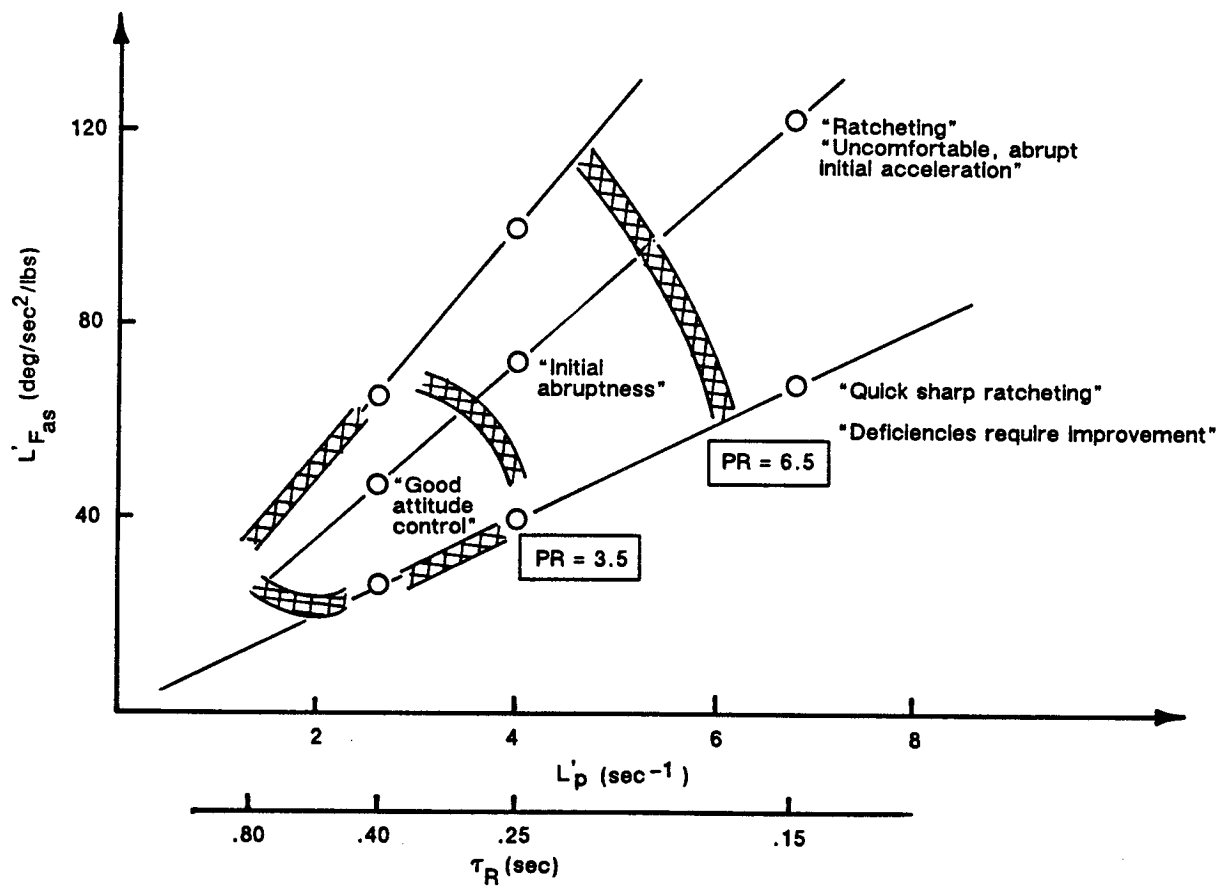


Figure 7 SUMMARY OF LATHOS PILOT RATING AND COMMENTS

- A simple pilot model consisting of a gain, a first-order lag compensator and 0.3 transport delay is adjusted to achieve a satisfactory closed-loop bank angle tracking bandwidth of approximately 2 rad/sec for a K/s-like aircraft (very short roll mode time constant).
- This compensation and bandwidth allow satisfactory bank angle control and avoid abrupt inputs which produce unwanted high accelerations.
- Suppose the pilot reverts to an abrupt input technique to demand the desired response more rapidly, creates high angular accelerations and then switches his closure to angular acceleration error instead of bank angle error. With sufficient pilot gain, a ratcheting-type oscillation of approximately 16 rad/sec results. The study concludes that roll angular acceleration and the lateral linear accelerations at the pilot station are important considerations in flying qualities. Roll sensitivity (command gain) is a necessary ingredient.

Because of these experiences, more data and analysis were generated investigating the roll ratchet phenomena (References 11 and 12). These investigations were conducted using a fixed-based, ground simulator despite the very real evidence that the roll angular and lateral linear accelerations are necessary ingredients in the roll ratchet. These ground simulator investigations were initiated under the premise that roll ratchet is caused by coupling between the control manipulator and human pilot's neuromuscular system dynamics without influence from the motions exerted onto the pilot in flight.

## **2.4 TIME DELAY SPECIFICATION CONCERNS**

During the development of the Tornado, F-18, Space Shuttle and other aircraft, severe flying qualities deficiencies were encountered. Pilot-induced oscillations were uncovered in critical flight phases, such as the final stages of the landing (Reference 6), attributed to excessive control system time delay. Considerable research was generated in consequence, leading to a better appreciation and understanding of the time delay problems. Data and flying qualities design criteria evolved accordingly (Reference 2).

In the F-18 aircraft development, control system time delay reductions were a major thrust in its control system evolution after encountering severe flying qualities deficiencies during

the initial flight test phases. One of the major changes for a time delay reduction was the restructuring of the force command system architecture into a position command system. This change permitted the removal of forward path structural filters and stick prefilters, thus, reducing the time delay total (Reference 13). According to the current military specification, this delay reduction would be offset somewhat by the addition of equivalent time delay due to the feel system now being in the forward path between cockpit control force and aircraft motion response. Present production versions of the F-18A are quoted as having about 120 msec of equivalent time delay of which one-half of that value is contributed by the feel system. A delay of 120 msec is between the Level 1/Level 2 boundary according to the military specification (Reference 3). Level 1 flying qualities in roll are being demonstrated with this vehicle with no apparent problems due to time delay.

The X-29A employs a position command architecture in roll with a relatively slow, 13 rad/sec feel system. Before first flight, MIL-F-8785C "predictions" using the force input definitions indicated Level 3 flying qualities due to excessive time delay, of which almost one-half of the total delay (110 msec) was due to the low frequency feel system. As previously mentioned, the X-29 flight test results have not demonstrated any flying qualities degradation in roll attributed to the presence of time delay. These design experiences, by the X-29 and F-18, pointed out a lack of sufficiency in the specification of the maximum allowable control system time delay. The particular deficiencies involve:

- whether the cockpit control force or the position input is the more appropriate input for time delay definition, and
- what role the feel system characteristics play in the time delay specification and lateral flying qualities in particular.

## **2.5 FEEL SYSTEM**

The feel system is a unique flight control system element. Several observations become relevant in the understanding of its characteristics.

- The input (pilot-applied force) and output (controller position) of this element are both perceptible to the pilot. In a position command system architecture (Figure 8), the feel system is an equivalent/effective time delay contributor if the force signal is

the time delay input definition despite the fact that the position output of the feel system is "known" to the pilot. The X-29 and F-18 experiences suggest that the position signal, rather than the force, should be used to define the time delay input since it is the pilot input to the control system.

- In a laboratory tracking experiment (reported in Reference 15), pilots performed compensatory tracking with the display output being either the actual control stick position or, using isometric (fixed stick) or isotonic (free-moving stick) controllers, an analog of the artificial feel system. In terms of tracking error (integral mean squared error), superior tracking performance was attained for the mechanical system (Config. A in Figure 9). Performance was comparable to tracking performance obtainable with isometric or isotonic stick and no analog dynamics as the feel system frequency became greater than 8 rad/sec. Poor tracking performance occurs when the system output is "hidden" from the pilot's perceptual realm. Therefore, when the pilot is given information regarding the system under his control during tracking, superior control performance is attained. As the frequency of the mechanical feel system became greater than 8 rad/sec, tracking performance was comparable to the case where no dynamics were in the system under control. This data would support the contention that the feel system dynamics in a position command system should not be treated as a time delay element because the pilot is fully cognizant of input and output through this system element. (Although laboratory experiments, such as this one, have repeatedly demonstrated better tracking performance for isometric sticks, better flying qualities (improved task performance and lower pilot workload) have been demonstrated in-flight for non-isometric controllers (Reference 21). There is an optimum stick movement, however, as excessive stick travel is also shown to degrade flying qualities just as the isotonic, free-moving stick exhibited degraded performance in comparison to the non-isotonic controllers).
- Laboratory experiments have also demonstrated tracking performance improvements when the feel system dynamics are "matched" to the plant dynamics (flight control system plus aircraft). In References 14 and 15, tracking errors were reduced by reflecting the plant output in the controller force and/or position or augmenting the controller dynamics to compensate ideally for the plant. The controller is effectively utilized to augment the information available to the pilot

regarding the plant dynamics and its output.

In this experiment, complete resolution of these design issues is certainly not possible given the large matrix of possible design options such as controller type (sidestick, centerstick, or "mini"-stick), control system gradient, and nonlinearities. The intent of this program is to begin addressing the influences of these design parameters in terms of flying qualities, closed-loop pilot/vehicle task performance, pilot workload, and/or pilot compensation.

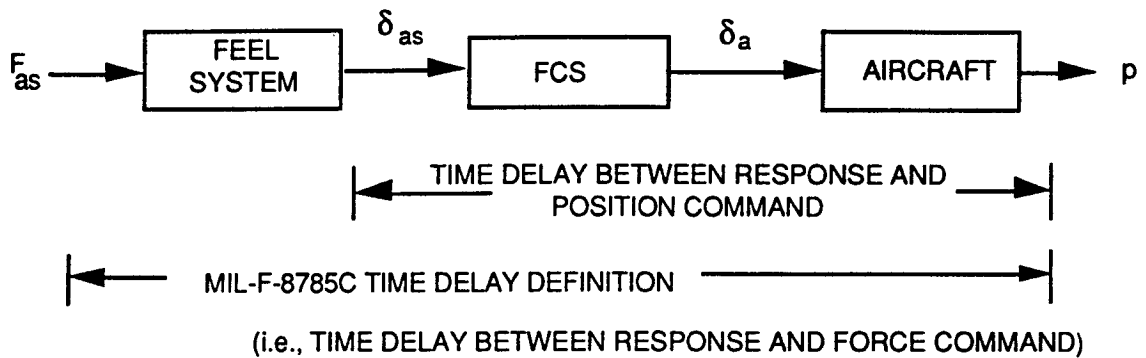
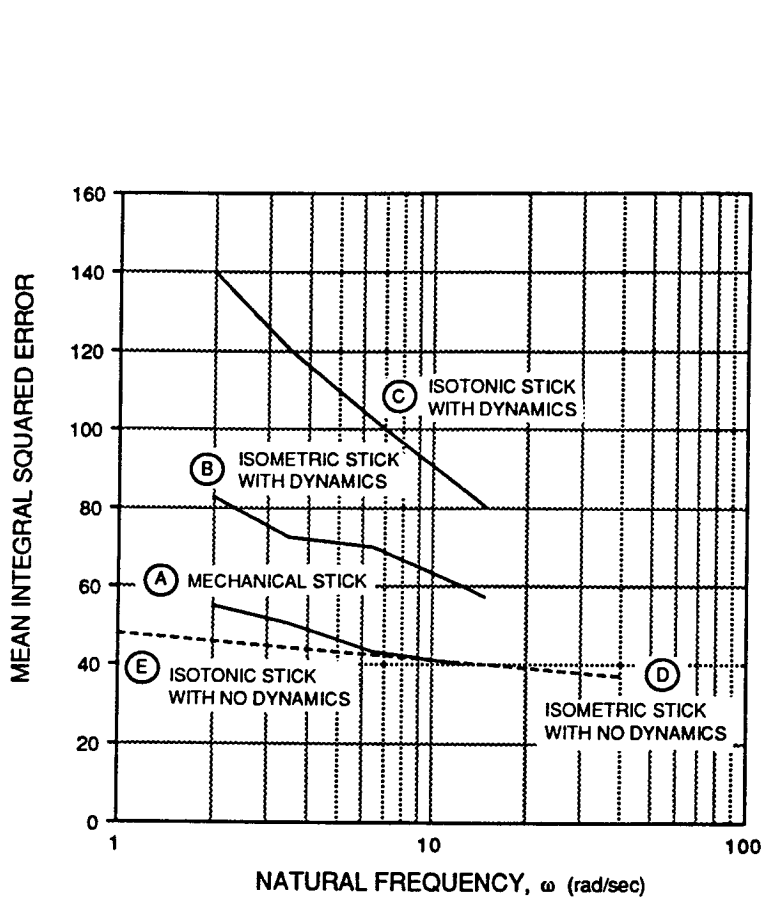
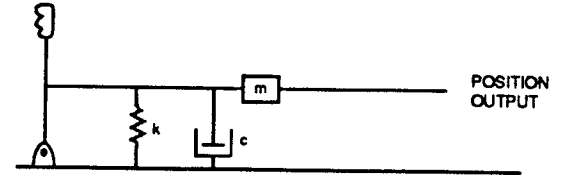


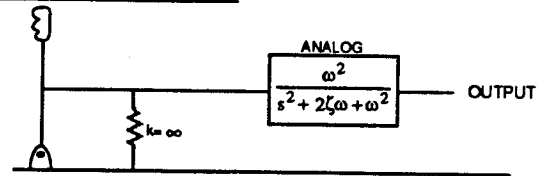
Figure 8 POSITION COMMAND CONTROL SYSTEM



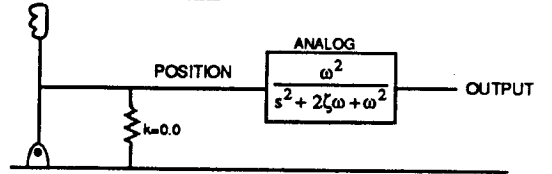
**CONFIG A: MECHANICAL SYSTEM**



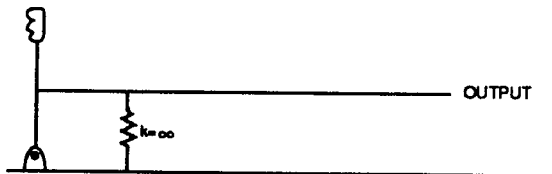
**CONFIG B: ISOMETRIC SYSTEM**



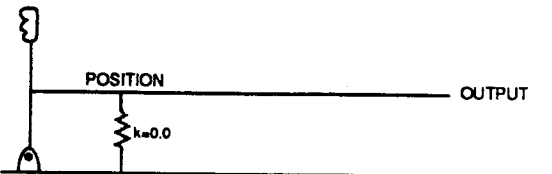
**CONFIG C: ISOTONIC SYSTEM**



**CONFIG D: ISOMETRIC SYSTEM WITH NO DYNAMICS**



**CONFIG E: ISOTONIC SYSTEM WITH NO DYNAMICS**



**Figure 9** MEAN INTEGRAL SQUARE ERROR AS FUNCTION OF FEEL SYSTEM PARAMETERS, DAMPING RATIO,  $\zeta = .8$ , RECREATED FROM REFERENCE 15

### Section 3 EXPERIMENT

An in-flight experiment was designed to achieve several objectives. These objectives were shaped by the background as it was briefly outlined in Section 2.

#### 3.1 EXPERIMENT OBJECTIVES

The objectives of this study are:

- Revisit and extend the LATHOS program results:

The revisitation would concentrate on "Roll Ratchet" situations and the extension would focus on areas where data are missing or sparse. This objective, in conjunction with the LATHOS experiment results, provides the foundation from which the remaining objectives would be satisfied.

- Investigate the effects of feel system dynamics on lateral flying qualities:

Feel system characteristics were chosen from current and predicted design trends. Both centerstick and sidestick controllers were used.

- Examine the effects of time delay on lateral flying qualities where the time delay may be either "hidden" or accessible to the pilot and correlate how these delays should be treated in a flying qualities specification. The accessibility of the time delay is governed by whether the delay is resident in the feel system or the flight control system.

To satisfy these objectives, a series of mini-experiments were performed. The mini-experiment format evolved to manage the program scope and results. As the results show, overlap between the different mini-experiments was inevitable.

The generic experimental control system structure, shown in Figure 10, was established for the mini-experiment design. The experiment variables included:

- 1.) Cockpit controller type (Sidestick or centerstick)



- 2.) Command signal type (Force or position)
- 3.) Feel System:
  - frequency,  $\omega_{FS}$
  - damping,  $\zeta_{FS}$
  - force-deflection gradient ( $\delta_{as}/F_{as}$ )
- 4.) Prefilter dynamics ( $(\tau_{PF}), [\zeta_{PF}, \omega_{PF}]$ , or None)
- 5.) Additional pure time delay ( $\tau_D$ )
- 6.) Augmented aircraft:
  - roll mode time constant,  $\tau_R$
  - command gain,  $(L'_{F_{as}})$  or  $|p/F_{as}|_{ss}$

Seven mini-experiments were established. Additional mini-experiments were identified but flight time did not permit their evaluation.

The mini-experiments, described in the following section, are enumerated below:

- 1.) LATHOS replication
- 2.) Extension of LATHOS
- 3.) Effect of feel system dynamics on LATHOS results/replication
- 4.) Effect of force/position gradient on LATHOS results/replication
- 5.) Effect of position commands on LATHOS results/replication
- 6.) "Hidden" time delays
- 7.) Influence of controller type on roll ratchet tendencies

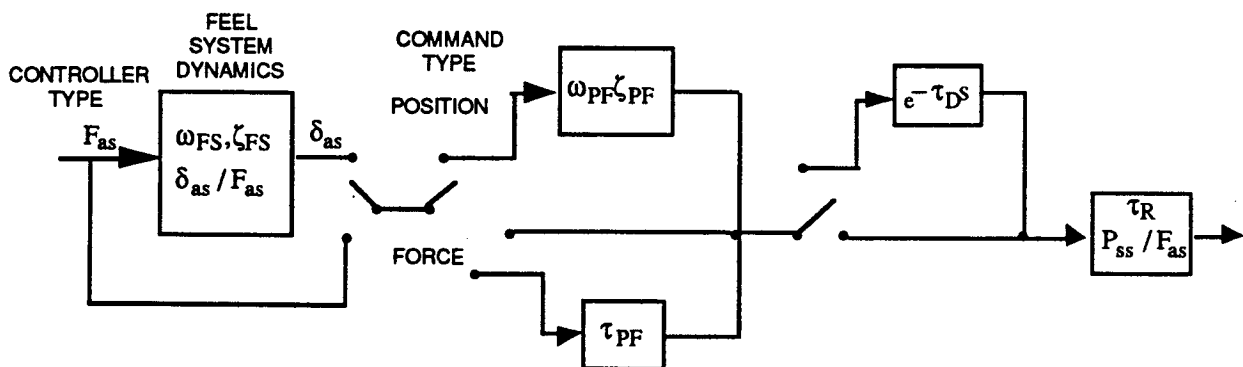


Figure 10 EXPERIMENTAL SET-UP

### 3.2 MINI-EXPERIMENT DESIGN

For each mini-experiment, common augmented aircraft configurations were available for each evaluation.

The form of the augmented aircraft roll dynamic response was the same for each mini-experiment. In equivalent system form, it was:

$$\text{Augmented Aircraft } \frac{p}{\delta_{ac}} = \frac{L'_{F_{as}} \tau_R}{(\tau_R s + 1)} e^{-.040s}$$

The equivalent time delay of 40 msec accounts for the delay due to high order, high frequency flight control system elements and the aileron actuator dynamics required for the simulation. Details of the equivalent systems form, the simulated aircraft and its mechanization are presented in Appendix B. The dutch roll dynamics were suppressed and the dutch roll damping was heavily augmented ( $\zeta_{dr} \approx .6$ ) so that only the first-order roll transfer function, shown here, is accurate. The roll mode time constant and roll command gain were experimentally varied.

The roll command gain, ( $L'_{F_{as}}$ ), and roll mode time constant,  $\tau_R$ , were varied, as they were in the LATHOS program, to span current fighter aircraft trends and flying qualities roll response requirements for performance. Two flight phases were evaluated in this program: Flight Phase Category A, up-and-away tasks; and Flight Phase Category C, power approach tasks. Evaluation task details are presented in the following section.

Three roll mode time constants were simulated in each flight phase. The roll mode time constants were:

Up-and-Away,  $\tau_R$ : .15, .25, .40 sec

(Nominal Flight Condition of 275 KIAS, 7,500 ft altitude)

Power Approach,  $\tau_R$ : .20, .30, .45 sec

(Nominal Approach Flight Condition of 130 KIAS, 1,200 ft altitude)

In MIL-F-8785C, only a maximum allowable roll mode time constant of 1.0 for Level 1, Class IV aircraft is specified. These  $\tau_R$  values clearly meet that requirement. The roll command gains was chosen for two levels of roll rate-per-unit lateral stick force ( $|p/F_{as}|_{ss}$ ) at each flight phase. The two command authorities were:

Up-and-Away,  $(p/F_{as})_{ss}$ : 10, 18 deg/sec/lb

Power Approach,  $(p/F_{as})_{ss}$ : 5, 10 deg/sec/lb

The combination of roll mode time constant and roll command gain,  $(L'_{F_{as}})$ , yields six up-and-away and five power approach augmented aircraft configurations for evaluation, as illustrated in Figure 11.

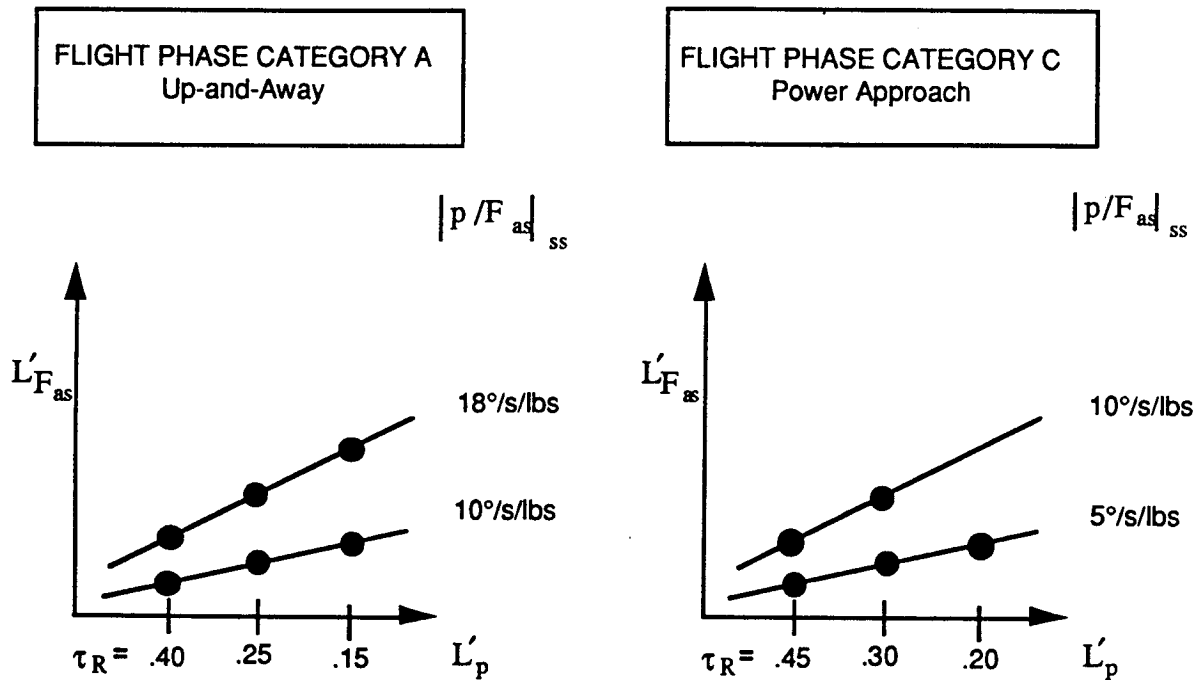


Figure 11 SIMULATED AUGMENTED AIRCRAFT ROLL MODE PARAMETERS

The 10 deg/sec/lbs roll command and the .2 roll mode time constant could not be simulated with the NT-33 aircraft in the power approach flight conditions. Therefore, this configuration was not available for evaluation.

A linear command gearing was used exclusively. A nonlinear gearing was not used because:

- Analysis is complicated for nonlinear gearings
- Design of a good nonlinear gearing is not straight forward due to the lack of suitable design criteria.

The program results can be applied in post-flight analysis to “project” nonlinear gearing design criteria. A centerstick controller was used predominantly. The controller had negligible friction and no breakout force was simulated. The nominal force deflection gradient was 4 lbs/inch. Centerstick dimensions are given in Appendix B.

With these simulated vehicles available, the mini-experiment objectives are achieved by appropriate control system manipulations.

### 3.2.1 Mini-Experiment #1: LATHOS Replication

The objectives of this mini-experiment were to:

- Re-establish the LATHOS results by replicating LATHOS configurations and establishing a foundation from which to proceed , and
- Analyze these data in more detail through pilot-in-the-loop data obtained from actual and computer-generated tracking tasks. These data should primarily examine the roll ratchet issue.

The force command, roll control system architecture from the LATHOS program (Reference 9) was simulated. In a simplified form, the pilot lateral stick force input commanded the simulated aircraft, as shown in Figure 12, through a first-order prefilter.

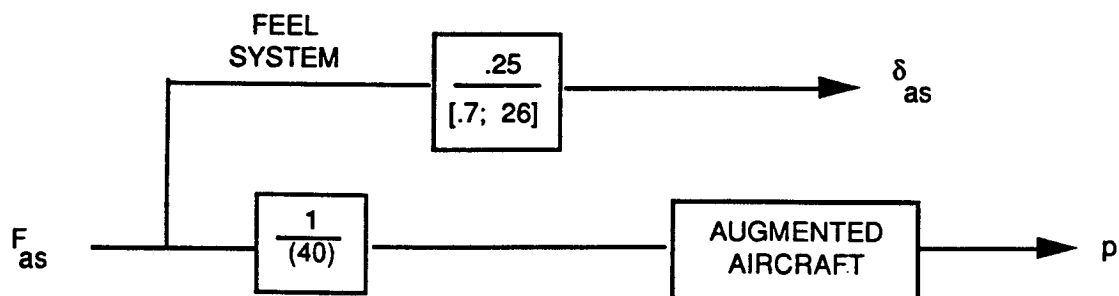


Figure 12 ROLL FCS ARCHITECTURE FOR MINI-EXPERIMENT

For this mini-experiment, the first-order roll prefilter and the feel system were held constant. The first-order prefilter had a break frequency of 40 rad/sec. The feel system dynamics were second-order with a natural frequency of 26 rad/sec and a damping ratio of .7.

With a fixed control system and feel system, this mini-experiment replicates the LATHOS program in many respects. In comparison to the time domain criteria derived from the LATHOS program (Figure 4), the configurations are shown in Figure 13.

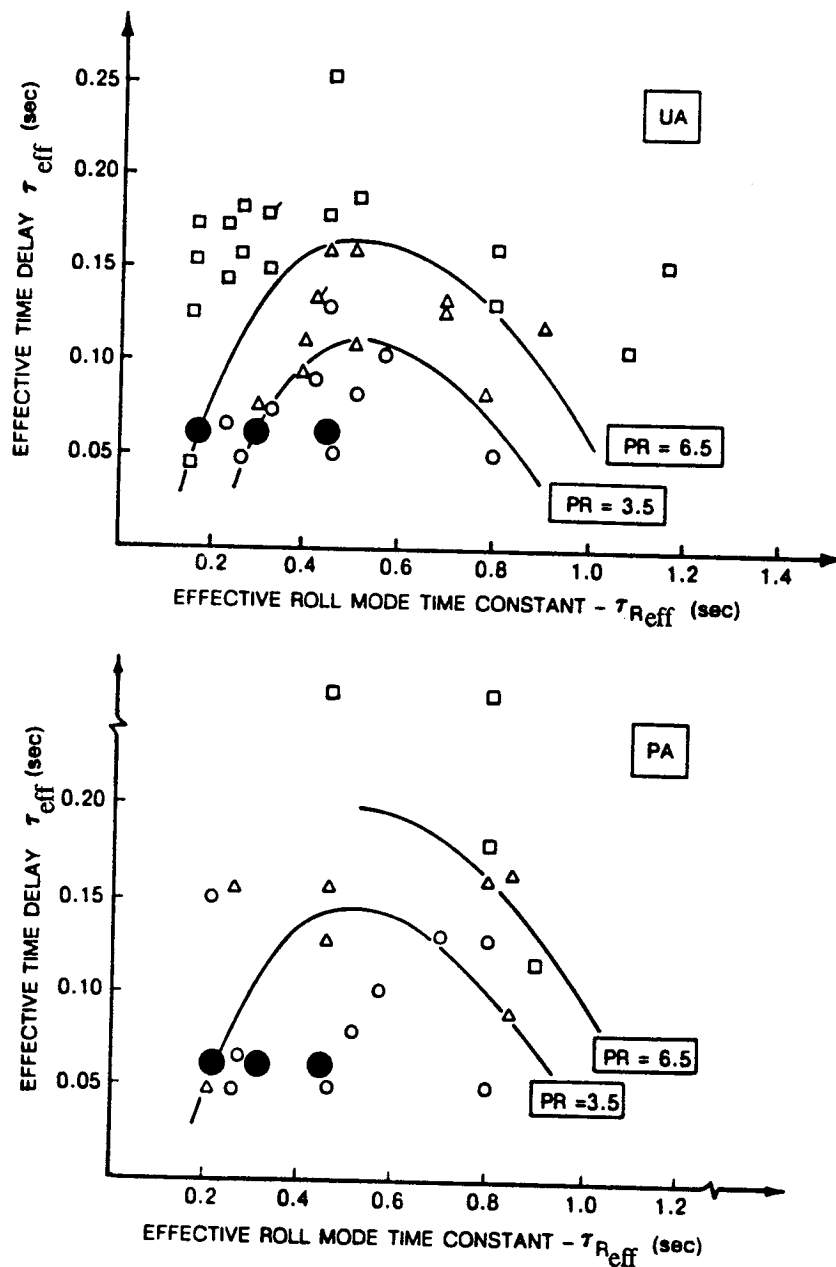


Figure 13 COMPARISON OF MINI-EXPERIMENT NO. 1 CONFIGURATIONS WITH TIME DOMAIN CRITERIA

Note that the time domain criteria is "independent" of the command gain. The time delay and roll response criterion assumes an "optimum" command gain under the premise that good roll dynamic response is a necessary but perhaps not sufficient prerequisite to good roll flying qualities. Also, the nominal time delay for this program is slightly higher by (15 msec) than the LATHOS program minimum due to a slightly different mechanization of the NT-33 time delay circuit (see Appendix B). The time delay added experimentally in this program is pure digital time delay.

### 3.2.2 Mini-Experiment #2: Extension of LATHOS

The objective of this mini-experiment was to:

- Extend LATHOS results, particularly in power approach, to better establish the time domain criteria of Figure 13.

The time domain effective delay and roll response criteria, shown in Figure 13, is not well-substantiated in the power approach flight phase at short values of roll mode time constant. The flight control system architecture of Figure 14 was employed. This architecture and the component values are identical to that of Mini-Experiment #1 with the addition of a pure time delay experiment element.

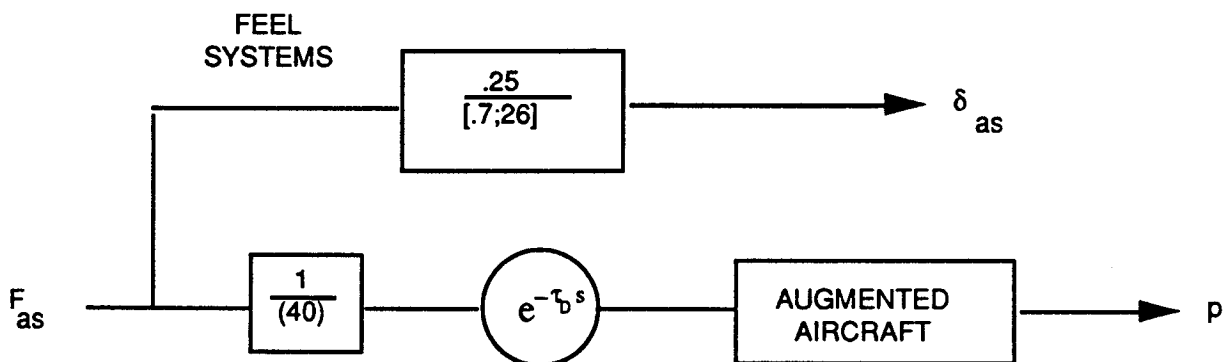


Figure 14 ROLL FCS ARCHITECTURE FOR MINI-EXPERIMENT

Four time delay values were available. These were:

$$e^{-\tau_D^s}: \tau_D = 25, 55, 110, 175 \text{ msec}$$

The configurations developed by these procedures provide data, as shown in Figure 15, to supplement the existing time domain criteria.

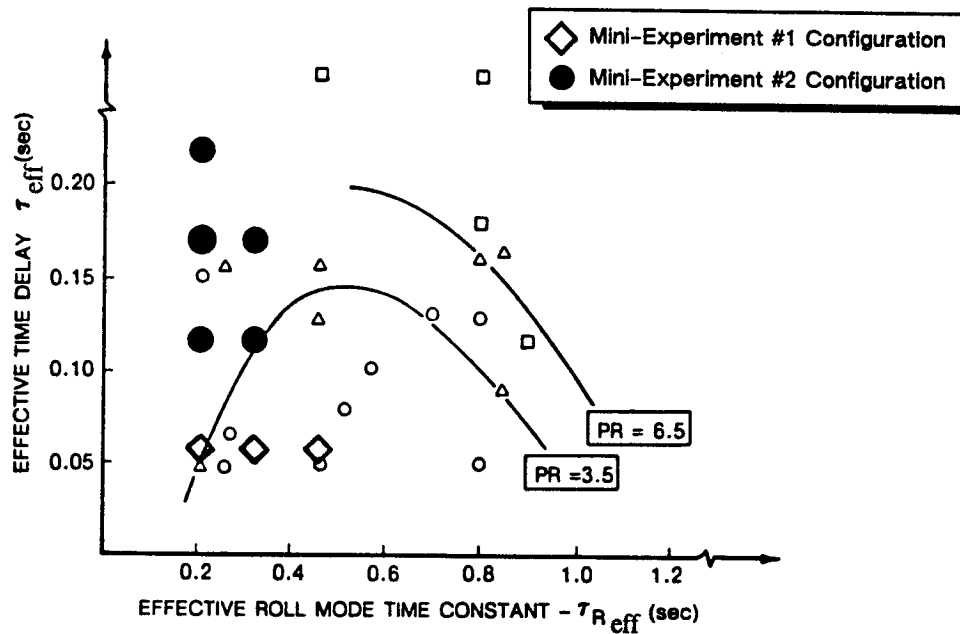


Figure 15 COMPARISON OF MINI-EXPERIMENT #2 CONFIGURATIONS TO TIME DOMAIN CRITERIA

Figure 15 COMPARISON OF MINI-EXPERIMENT #2 CONFIGURATIONS TO TIME DOMAIN CRITERIA

The objective of this Mini-Experiment was to:

- Investigate the influence of the feel system natural frequency on the LATHOS results.

Using the force command flight control system architecture of Mini-Experiment #1, the feel system natural frequency was varied (Figure 16). The feel system damping ratio was held constant at .7.

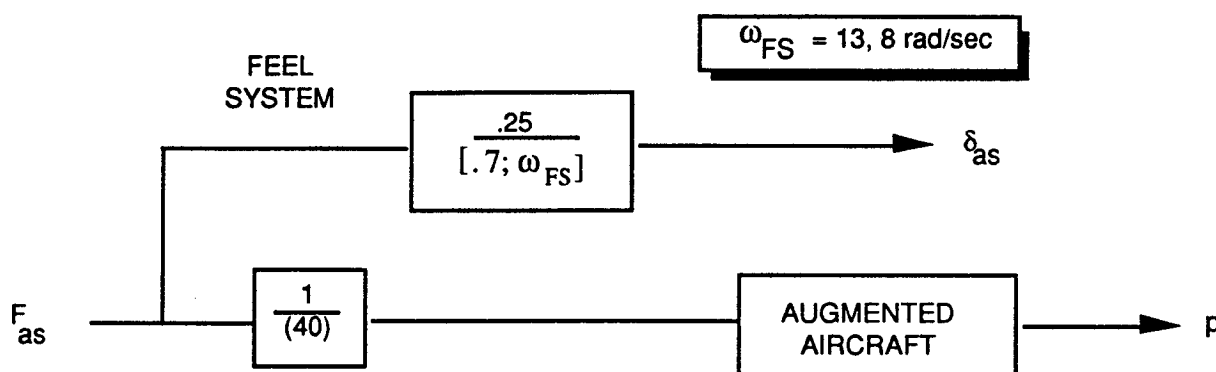


Figure 16 SCHEMATIC DIAGRAM OF MINI-EXPERIMENT #3 CONFIGURATION

Two feel system natural frequencies were simulated: 13 and 8 rad/sec. The 13 rad/sec was chosen from the X-29 experience; the 8 rad/sec provided a "data point" beyond the 13 rad/sec to establish trends. Feel system natural frequencies above 26 rad/sec were not considered for investigation since 26 rad/sec seemed to be near the state-of-the-art and it was known that feel system dynamics of that frequency were essentially "transparent" to the pilot.

With this mini-experiment, the roll control system forward path is unaltered from Mini-Experiment #1. The experimental variation occurs solely in the dynamics of an element in parallel to the roll command path. Currently available design criteria would not predict a change in flying qualities because the affected dynamic element is not in the forward path. The hypothesis has been made that increased filtering of the pilot's control system interface (i.e., the control stick) by decreasing the feel system frequency and "smoothing" his input may possibly



ameliorate abrupt objectionable roll response characteristics such as roll ratcheting. This hypothesis will be tested using this set-up.

### 3.2.4 Mini-Experiment #4: Effect of Force Deflection Gradient

The objective of this mini-experiment was to:

- Determine if a lighter force-deflection gradient (more motion-per-unit force) affects the LATHOS replication of Mini-Experiment #1.

The flight control system of Mini-Experiment #1 is retained with a feel system natural frequency of 26 rad/sec and damping ratio of .7. The feel system statics, however, are changed such that the force-deflection gradient is 2.75 lbs/inch versus the nominal 4.0 lbs/inch (Figure 17).

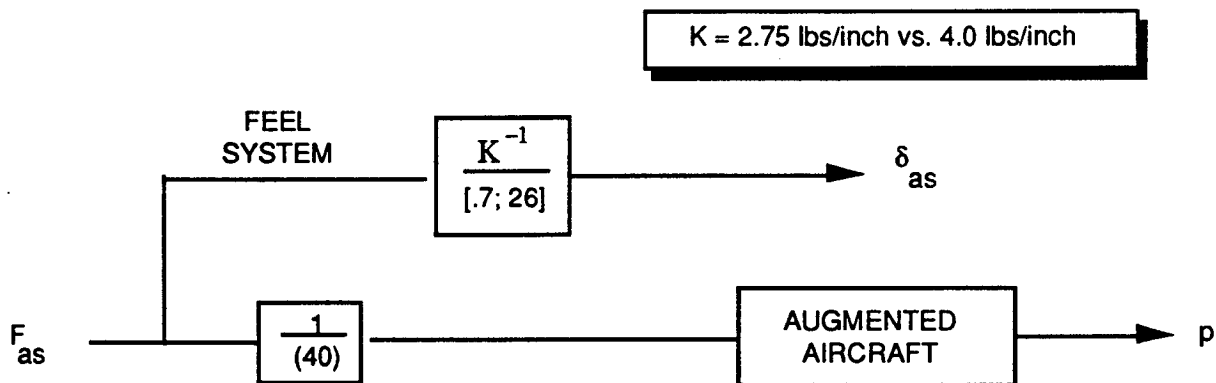


Figure 17 ROLL FCS ARCHITECTURE FOR MINI-EXPERIMENT

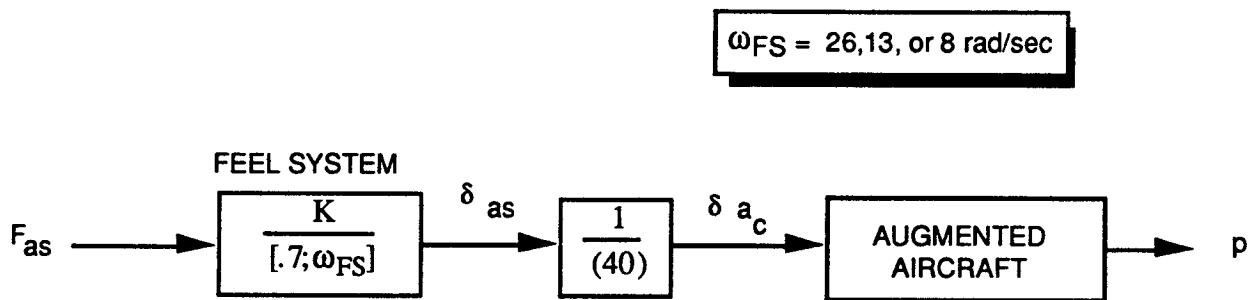
The lighter gradient was again selected based on some current applications (notably the AV-8B and X-29 aircraft). The X-29 was designed for approximately 4 lbs/inch deflection gradient in roll but in the actual vehicle, a 2.0 lbs/inch deflection gradient resulted. The 2.75 lbs/inch is the lowest gradient that could be simulated with good fidelity in the range of desired NT-33A feel system frequencies. Available flying qualities criteria would again suggest no change in the evaluation pilot ratings despite the change in the feel system response to pilot force inputs.

### 3.2.5 Mini-Experiment #5: Effect of Position Commands

The objectives of this mini-experiment are to:

- Determine if a position command system affects the results of Mini-Experiment #1 and #3, and
- Help resolve whether the force or position input should be used as the time delay specification parameter for position command control systems.

The roll flight control system elements used in Mini-Experiment #1 and #3 are retained; however, the lateral stick position signal rather than the force is employed as the command, thus, placing the feel system in the forward command path as shown in Figure 18.



**Figure 18 POSITION COMMAND ROLL FCS ARCHITECTURE FOR MINI-EXPERIMENT #5**

To illustrate the time delay specification differences depending upon whether the force or position signal is used to define the measurement input, equivalent time delays are calculated for these two situations. These values are tabulated in Table I. As this table shows, the equivalent delay measured from control position input to roll response is unaffected by the change in feel system frequency. Conversely, the decreased natural feel system frequency, introduces equivalent delay when the delay is measured from the pilot input of force to the roll response.

**Table I**  
**EQUIVALENT TIME DELAY APPROXIMATION**  
**FOR POSITION COMMAND SYSTEM**

<i>FEEL SYSTEM FREQUENCY</i>	<i>EQUIVALENT TIME DELAYS FOR ROLL FCS*</i>	
	<i>Measured from Force Input</i>	<i>Measured from Position Input</i>
26 rad/sec	120 msec	65 msec
13 rad/sec	175 msec	65 msec
8 rad/sec	240 msec	65 msec

\* Equivalent time delay is calculated by using  $(2\zeta/\omega)$  approximation

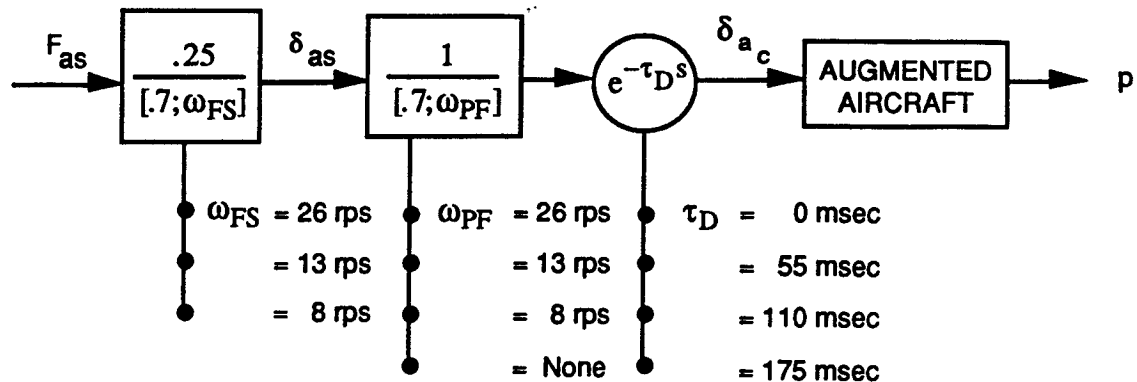
This comparison vividly demonstrates that if a force input is used for the time delay measurement, significantly different time delay values result depending on the feel system frequency. Conversely, if a position signal is used for the input definition, no time delay differences are noted. The delay values for the position input (65 msec) correspond to the Level 1 time delay requirement of MIL-F-878IC. For the force input measurement, the delays range from borderline Level 1/Level 2 to Level 3 in the case of the 8 rad/sec feel system. The evaluation results of this Mini-Experiment will establish which time delay measure is a more accurate indicator of the configuration flying qualities and hence, determine what measurement technique should be used for MIL-SPEC requirements.

### 3.2.6 Mini-Experiment #6: "Hidden" Time Delays

The objectives of this mini-experiment were to:

- Continue the determination of whether the force or position signal is more appropriate as the time delay specification requirement.
- Investigate the pilot's usage of available feel system cues in gauging the time delay attributes of the system under pilot control.

This mini-experiment is a pseudo-continuation of the fifth mini-experiment with variations of additional delays and flight control system dynamics. The flight control system architecture of Figure 19 was employed.



**Figure 19 EXPERIMENT SET-UP OF MINI-EXPERIMENT #6**

The feel system and prefilter dynamics were of second-order with a damping ratio of .7. The feel system, prefilter, and added time delay were matched for equal units of equivalent time delay. Three values of natural frequencies were available for implementation: 26, 13, or 8 rad/sec. The feel system force-deflection gradient was a constant 4.0 lbs/inch.

The pure time delay values were 55, 110, or 175 msec with this set-up. The three elements - feel system, prefilter, and added time delay - can be traded off since they were scaled to be equal units of equivalent delay. (The equivalent time delays were approximate values computed from the  $2\zeta/\omega$  approximation and the "equivalence" is not exact.) This experiment varies where the pilot encounters the time delay and what type of delay it is (i.e., equivalent or pure digital time delay). For instance, the "equivalent" time delays are identical between the pilot-applied force input and the roll response for the following three configurations (equal to 165 msec):

Feel System, $\omega_{FS}$	= 26 rps	Feel System, $\omega_{FS} = 13 \text{ rps}$	Feel System $\omega_{FS} = 26 \text{ rps}$
Prefilter, $\omega_{PF}$	= 13 rps	(or) Prefilter, $\omega_{PF} = 26 \text{ rps}$	(or) Prefilter $\omega_{PF} = 26 \text{ rps}$
Delay, $\tau$	= 0 msec	Delay, $\tau = 0 \text{ msec}$	Delay, $\tau = 55 \text{ msec}$

Despite the "equivalence" in delay between pilot-input force and the roll response, the distribution of the dynamics within the pilot's perceptual range and the type of response filtering effects that each provide are clearly different.

This experiment design also allows examination of whether a "matched manipulator" technique is beneficial (References 14 and 15). In laboratory tracking experiments, improved performance and workload reduction was demonstrated when feedback of the plant (aircraft) is

given to the pilot from the cockpit controller. This kinesthetic information can take many forms; its relevance to actual aircraft applications may be investigated using these data.

### 3.2.7 Mini-Experiment #7: Influence of Controller Type

The objective of this mini-experiment was to:

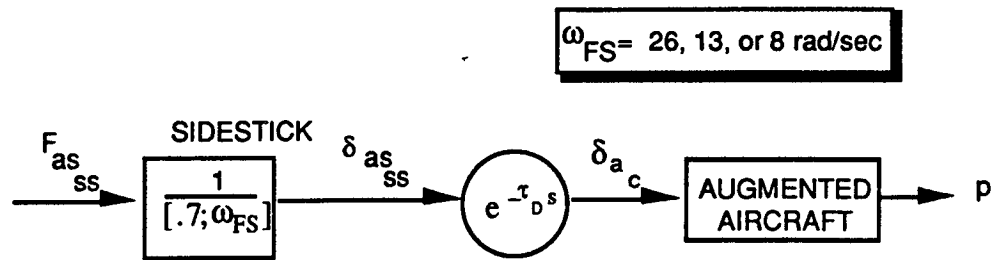
- Investigate the influence of controller type on lateral flying qualities.

Originally, this mini-experiment was to repeat selective centerstick mini-experiment evaluations using a sidestick controller. However, the mini-experiment became a USAF/Test Pilot School project USAFTPS student project (Reference 16) because this mini-experiment was beyond the scope of the program resources.

As a final curriculum project, a student team, composed of four test pilot candidates and a flight test engineer, design and conduct an in-flight research program under the guidance of the Test Pilot School instructors. This mini-experiment was performed by a Fall 1987 USAFTPS class student team. The results are briefly highlighted in this report due to its relevance. The complete USAFTPS report is listed in Reference 16 and should be referenced for details

The roll flight control system was mechanized analogously to Mini-Experiment #6. The position output of the sidestick was the control system command (Figure 20). The sidestick feel system natural frequency was varied between 26, 13, or 8 rad/sec. The feel system damping ratio was held at .7 and the force-deflection gradient was 1.9 lbs/deg, where the force is measured at the stick reference point. No friction or breakout forces were simulated. The sidestick characteristics are presented in Appendix B.

For the three feel system frequencies, configurations were created by adding pure delay ( $e^{-\tau_D^S}$ ) as required for three values of effective time delay ( $e^{-\tau_{eff}^S}$ ) where the effective time delay is measured using the maximum slope intercept method shown in Figure 5.



**Figure 20 FLIGHT CONTROL SYSTEM ARCHITECTURE USAFTPS**

### 3.3 TEST VEHICLE

The test vehicle was the USAF/Flight Dynamics Laboratory NT-33A variable stability aircraft (Figure 21).

The NT-33A aircraft was modified by Calspan and is now operated by Calspan under USAF contract as an in-flight simulator. The vehicle is an extensively modified Lockheed T-33 jet trainer. The evaluation pilot, who sits in the front cockpit, controls the aircraft through a standard center-stick or sidestick and rudder pedal arrangement. The front seat control system of the NT-33A has been replaced by a full authority fly-by-wire flight control system and a variable response artificial feel system. A fully programmable head-up display (HUD) is installed in the front cockpit.

The front seat, fly-by-wire control system and variable response feel system were programmed as required by the experiment objectives. The system operator in the rear cockpit, who also acts as safety pilot, controls the simulated HUD and aircraft configuration characteristics. During this experiment, the evaluation pilot had no prior knowledge of the configuration characteristics.

Safety features are an essential and integral part of the NT-33 research aircraft. Continuous safety monitors activate an automatic "safety trip" system to disconnect the evaluation pilot from the fly-by-wire control system before unsafe flight conditions occur. Aircraft control reverts to the safety pilot who occupies the NT-33A rear seat and has mechanical controls. The safety pilot provides an additional, redundant margin of safety by his ability to disengage the variable stability system and assume manual control of the airplane.

### 3.3.1 Actuator Dynamics

The NT-33A aircraft has independent control of 3 degrees-of-freedom for in-flight simulation. The simulation technique utilizes a response feedback methodology with the three moment controllers of the vehicle (elevator, aileron, and rudder) as the simulation effectors. Using response feedback, the NT-33A vehicle stability and control characteristics are augmented by the appropriate feedforward and feedback variable stability system (VSS) loops and gains to achieve the desired simulation dynamics. The evaluation pilot cannot feel the control surface motions of the NT-33 necessary to achieve the desired simulation.

The control surface deflections due to surface deflection commands are described by linear second-order transfer functions. For the aileron actuator, this transfer function is:

$$\left(\frac{\delta_a}{\delta_{ac}}\right) = \frac{60^2}{s^2 + 2(.7)(60)s + 60^2}$$

Since the control surface actuator is inside the response feedback simulation control loop, the actuator roots migrate somewhat from their nominal locations; however, the root migration is not considered of consequence and the nominal descriptions given here can be used without a significant loss in accuracy.

### 3.3.2 Equivalent Time Delay of Simulated Aircraft

An equivalent delay of 40 msec was included in the augmented aircraft transfer function description in Section 3.2. This equivalent delay arises from the phase lag of the high frequency actuator and flight control system filters. The 60 rad/sec actuator constitutes the primary component (25 msec) of the 40 msec equivalent time delay of the simulated augmented aircraft dynamics. The remaining 15 msec occurs from two third-order high frequency filters in the command path. The third-order filters are described by the transfer function:

$$\frac{(300)(300^2)}{(s+300)(s^2 + 2(.5)(300)s + 300^2)}$$

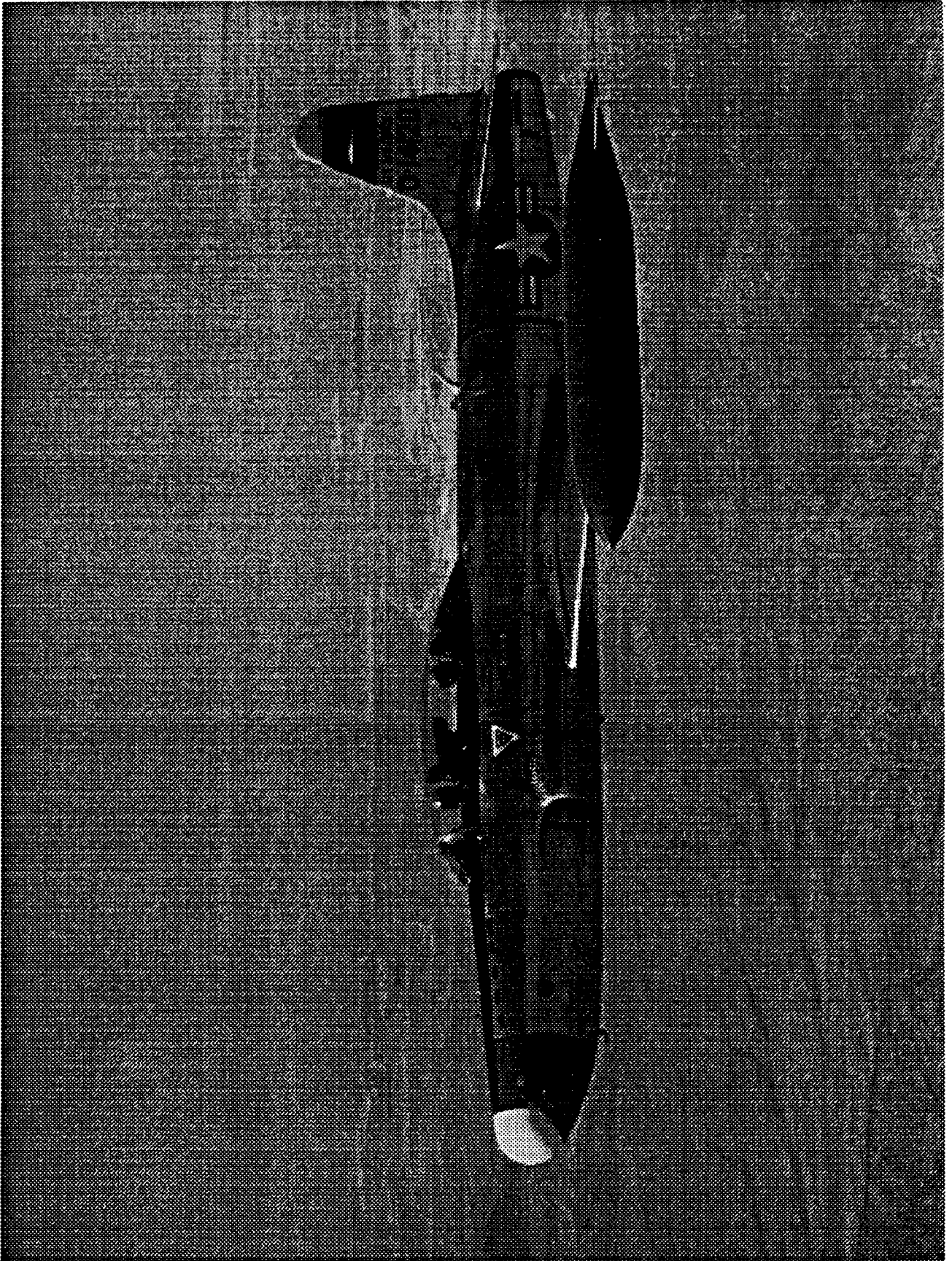


Figure 21 USAF/FDL NT-33A RESEARCH AIRCRAFT



When time delay was added to the simulated flight control system, the delay was a pure digital delay created from a register-shifting operation.

### 3.3.3 Feel System

Cockpit control feel is provided to the evaluation pilot by an electro-hydraulic feel system. The front seat centerstick controller was used predominantly. A variable feel sidestick controller was used by the USAFTPS team under Mini-Experiment #7.

The roll centerstick geometry is shown in Figure 22. The feel system static and dynamic characteristics were set-up according to the mini-experiment requirements. The feel system is described by the second-order transfer function:

$$\frac{\delta_{as}}{F_{as}} = \frac{K_{FS}\omega_{FS}^2}{s^2 + 2(.7)(\omega_{FS})s + \omega_{FS}^2}$$

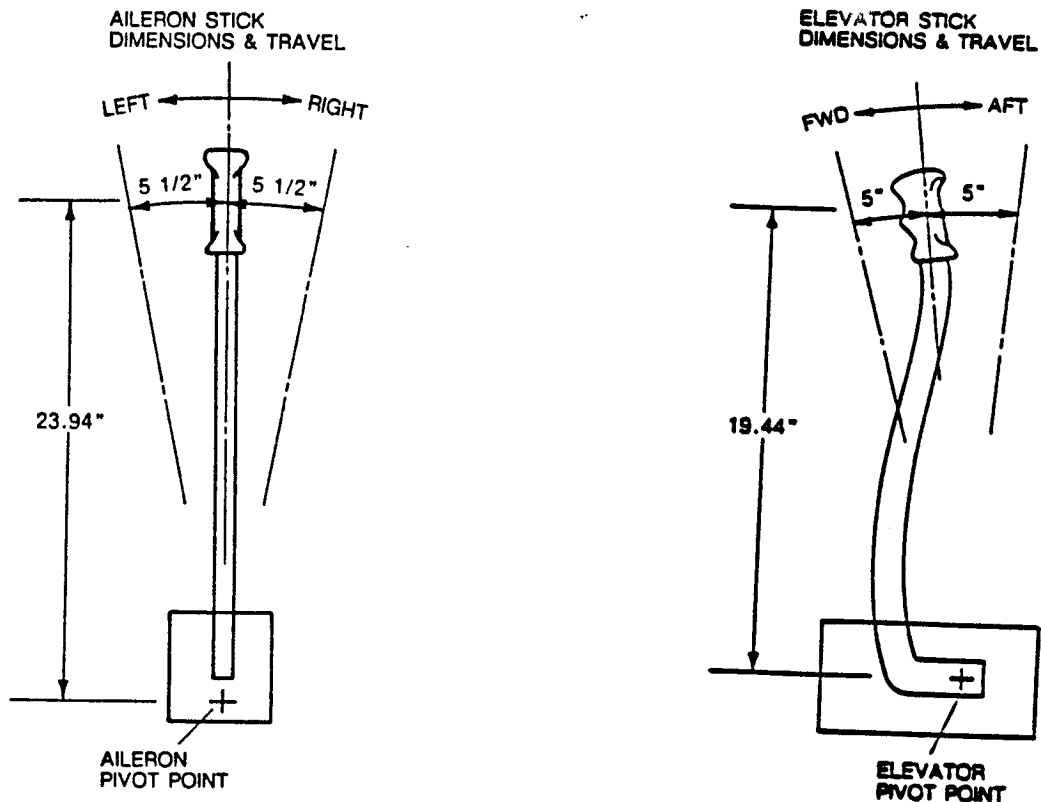
The natural frequency,  $\omega_{FS}$  and force-deflection gradient,  $K_{FS}$ , varied according to the mini-experiment. The damping ratio was held constant. Calibration data are shown in Appendix B.

Breakout, friction, and hysteresis of the centerstick were negligible. The pitch centerstick dynamics were fast ( $\omega \simeq 26$  r/s) and the damping ratio was .7. The pitch force-deflection gradient was approximately 8 lbs/inch. These were held constant.

### 3.3.4 Simulated Lateral-Directional Dynamics

The variable stability system feedforward and feedback gains were used to simulate the desired lateral-directional aircraft dynamics. The simulated roll rate transfer function from a commanded aileron deflection (neglecting the actuator dynamics) was:

$$\frac{p}{\delta_a} = \frac{L'_{Fas} \tau_R}{(\tau_R s + 1)}$$



**Figure 22 CENTERSTICK GEOMETRIES IN PITCH AND ROLL**

The dutch roll residue was eliminated from this transfer function by appropriate control system gain selection. The sideslip response due to a command aileron input was minimal. The dutch roll damping ratio ( $\zeta_{DR}$ ) was approximately .6 and the dutch roll frequency ( $\omega_{DR}$ ) was approximately 2.5 rad/sec in up-and-away and 2.0 rad/sec in power approach flight phase. The pilots were instructed to fly "feet-on-the-floor". If they felt that rudder pedal inputs were desired or required, they were permitted to do so and appropriately comment with regard to their rudder pedal usage.

Since high angles of attack were not used in these evaluation tasks, roll about the velocity vector was not a significant issue. A fixed pipper was used as the aiming index.

The lateral linear acceleration response experienced at the evaluation cockpit design eye point (*ep*) was primarily due to the roll angular accelerations for aileron inputs:

$$N_{y_{ep}} = N_{y_{cg}} - \dot{p} \ell_{z_{ep}} + \dot{r} \ell_{x_{ep}}$$

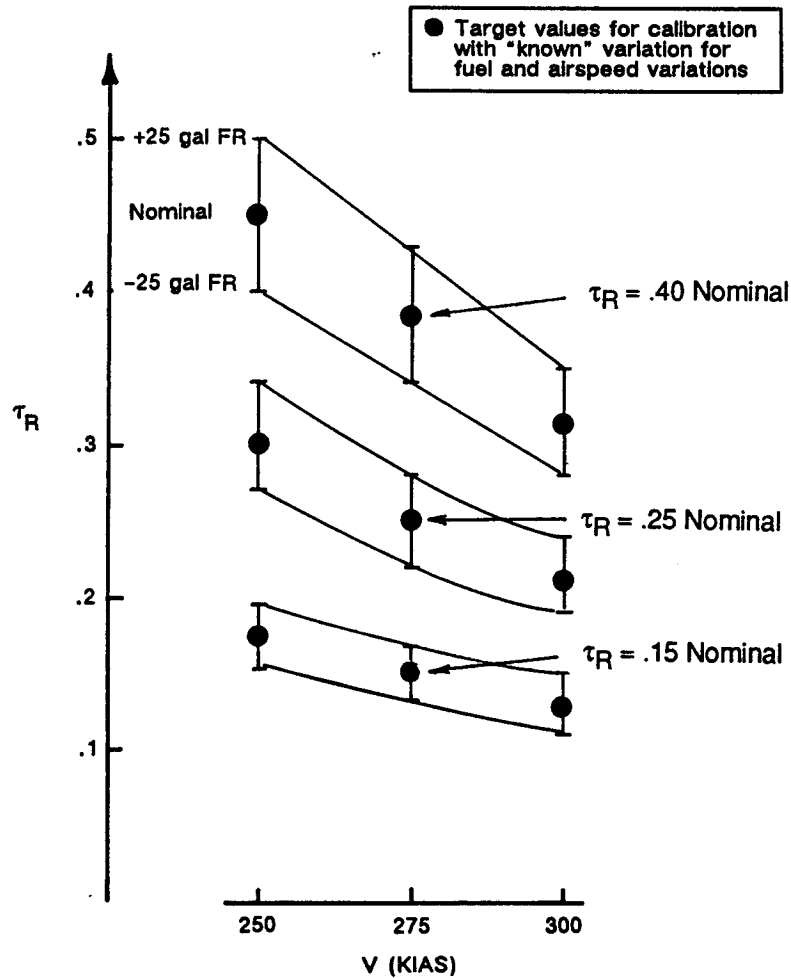
The side force term,  $N_{y_{cg}}$  is minimal for the NT-33A. The design "eye point" of the evaluation cockpit is approximately 2.7 ft above the center of gravity ( $\ell_{z_{ep}} = 2.7$ ) and the pilot sits 7.4 ft forward of this point ( $\ell_{x_{ep}} = 7.4$ ).

The lateral-directional variable stability system gains were scheduled as a function of the fuel remaining. This procedure kept the lateral-directional characteristics essentially constant as the mass and inertia properties of the NT-33 changed with tip tank fuel. The roll gains were scheduled at 50 gallon increments starting at 650 gallons total fuel remaining and continuing until 300 gallons. A typical evaluation flight started at 650 gallons. The tip tanks are empty at 350 gallons fuel remaining. Fuel expended below this value does not dramatically affect the NT-33 inertial characteristics and therefore, further gain scheduling was not required. The yaw gains were scheduled at 100 gallon increments.

A gain schedule with fuel remaining was not needed for the longitudinal control system gains because the pitch inertia characteristics of the NT-33 are relatively invariant with fuel.

Up-and-away evaluations began with the NT-33 trimmed at approximately 275 KIAS and 7,500 ft altitude. The altitude varied by air traffic control and weather/visibility restrictions. During the evaluations, the airspeed varied slightly. (Evaluation task details are highlighted in Section 3). Because of fuel and airspeed variations with the response feedback simulation, the simulated roll mode time constant could differ from the nominal values. The steady-state roll rate-per-unit cockpit control force is invariant with airspeed and fuel remaining. The roll mode time constant variation with airspeed and fuel remaining ( $\pm 25$  gallon increment about the scheduled fuel) is illustrated in Figure 23 for the up-and-away flight phase.

For power approach evaluations, the roll mode time constant variation takes an identical shape. The nominal roll mode time constants of .45, .30, and .20 differed by approximately 10% at the  $\pm 25$  gallon fuel remaining difference from the fuel remaining schedule, and the roll mode time constant increased by approximately 10% at touchdown due to the airspeed decrease to approximately 110-115 KIAS in the flare.



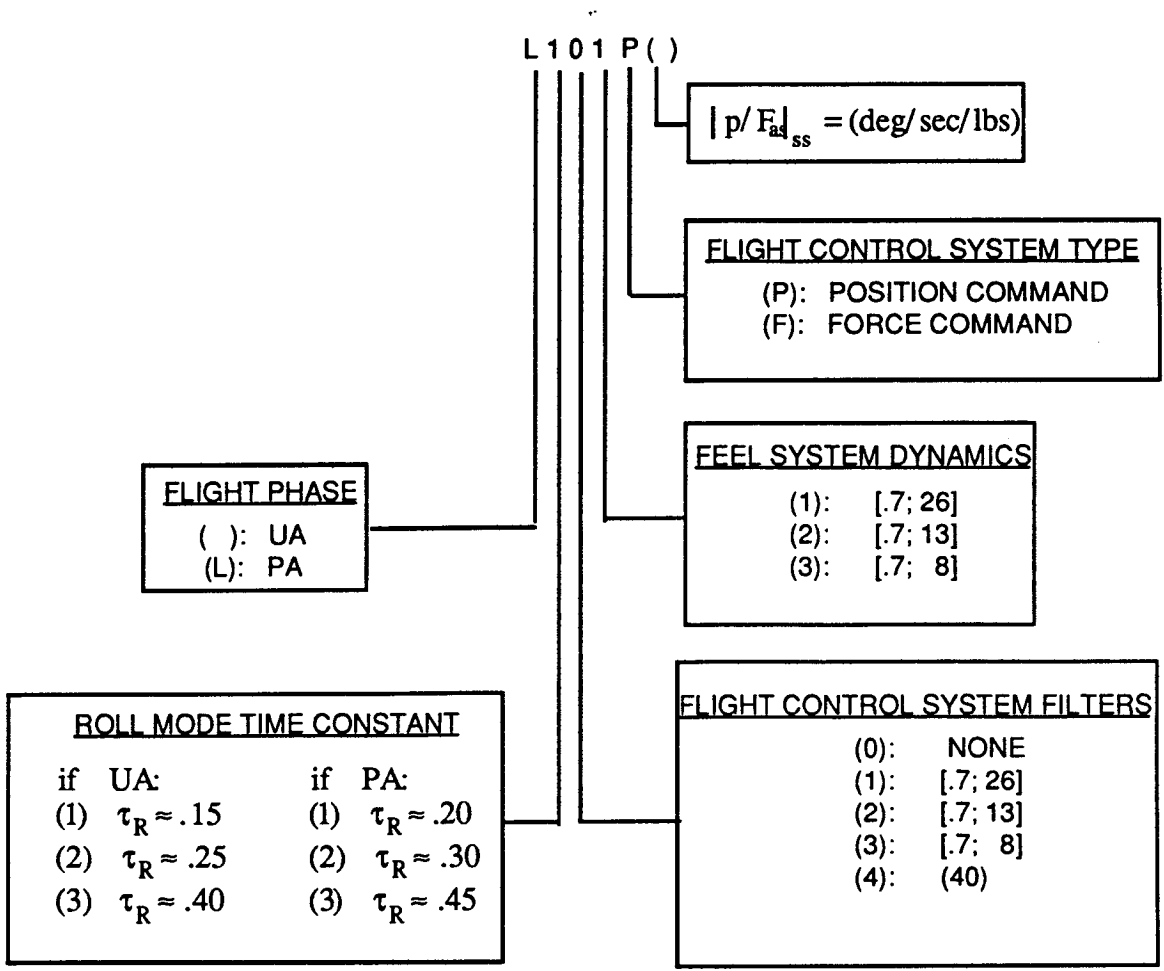
**Figure 23 VARIATION OF NOMINAL ROLL MODE TIME CONSTANT WITH FUEL REMAINING AND AIRSPEED**

### 3.3.5 Pitch Characteristics

The pitch flying qualities were tailored to be Level 1 and unobtrusive in the evaluation of lateral flying qualities.

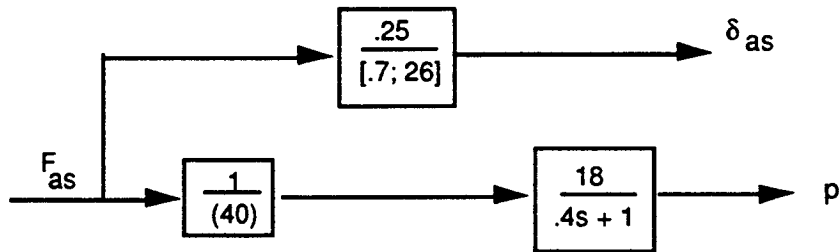
## 3.4 CONFIGURATION SUMMARY

A shorthand notation was used to identify configurations. This identification scheme is shown in Figure 24. The main ingredients of the experiment and also, of the configuration identifier are the flight phase, roll mode time constant, flight control system command, and



**EXAMPLE**

Configuration 341F (18)



**Figure 24 CONFIGURATION IDENTIFICATION SCHEME**

command gain described by  $|p/F_{as}|_{ss}$ . In a force command control system, a flight control system filter had to be present for smoothing of the force signal.

## **Section 4**

### **CONDUCT OF THE EXPERIMENT**

The conduct of the experiment is described in this section. Details of the evaluation tasks and procedures are included as well as the influences of the individual pilot differences on the experiment results.

#### **4.1 EXPERIMENT DATA**

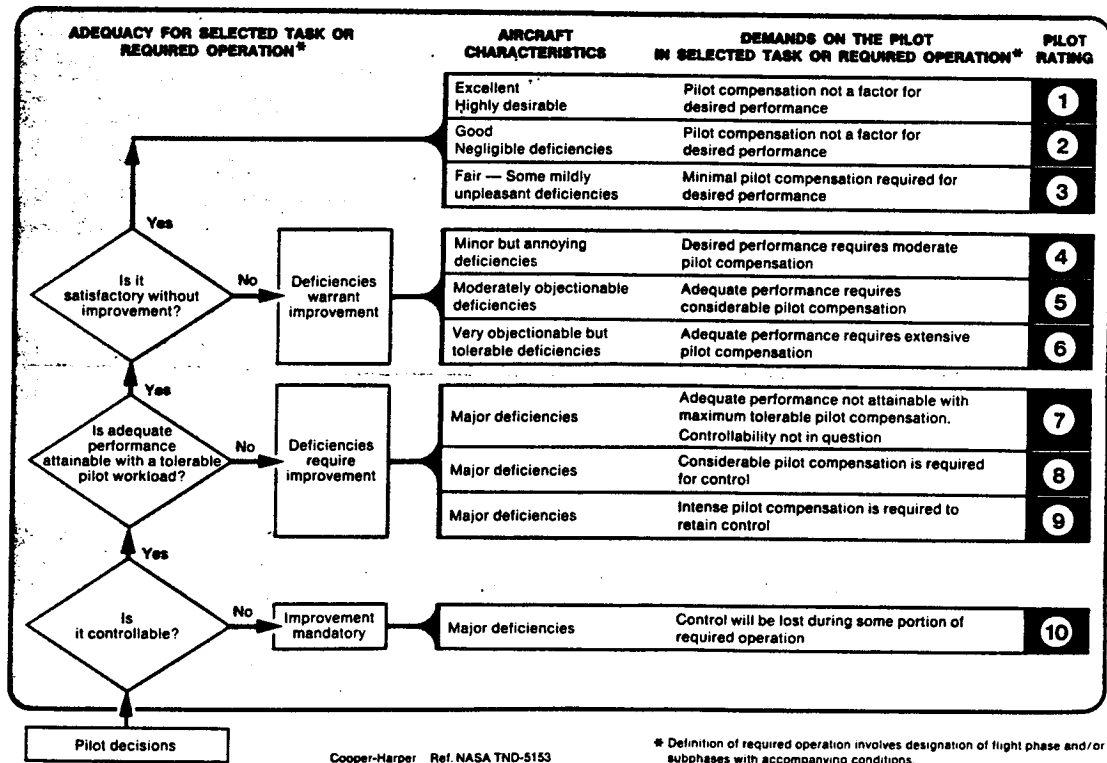
The experiment data consisted of pilot ratings, pilot comments, and task performance records. The task performance records include 28 parameters recorded on an on-board digital flight recorder and video taken by a camera mounted just aft of the HUD combining glass. The digital data was recorded at 100 hertz.

Pilot ratings were made with reference to the Cooper-Harper pilot rating scale (Reference 10). The key feature of the rating scale (Figure 25) is the decision tree logic to arrive at a numerical rating quantifying the subjective piloted evaluation/assessment.

Pilot ratings should never be viewed without full regard to the pilot comments. As such, pilot comments were given after an evaluation with reference to the comment card shown in Figure 26. The comments were designed to evoke specific responses from each of the pilots regarding the aircraft response under closed-loop control, the piloting techniques that they felt were required for task performance, and what differences they noted between the various tasks for that configuration. These comments are in addition to those remarks made informally during the course of the evaluation.

Central to the Cooper-Harper pilot rating scale are definitions of the aircraft mission, its task(s) or required operations, and desired/adequate performance levels. The simulation was of a fighter (Class IV) aircraft. Evaluation tasks were designed accordingly. The normal acceleration capability of the NT-33 aircraft (3 to 4 g's) is not commensurate with that of today's fighter aircraft; therefore, tasks may not have been as demanding on the pilot. However, the tasks emphasized roll control issues that are just as relevant at low as well as high "g" loading levels. The simulated normal acceleration levels are not, consequently, considered to be a deterring factor to the flying qualities data applicability and relevance.

## 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.

#### WORKLOAD

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

#### 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.

**Figure 25 COOPER-HARPER PILOT RATING SCALE**



### FEEL SYSTEM CHARACTERISTICS

- Forces/Displacements
- Roll Sensitivity?
- Pitch/Roll Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL

- Roll Attitude Response:
  - Initial Response?
  - Predictability of Response?
- PIO Tendency?
- Any Special Piloting Techniques/Compensation Required?

### TASK COMPARISON

- (UA) Differences in Handling Qualities Between the Different Tasks?
- (UA) Differences in Required Pilot Control Techniques for the Different Tasks?
- (PA) Differences Between Approach and Landing Tasks?

### ADDITIONAL FACTORS

- Any Factors Due to:
  - Wind/Turbulence?
  - Pitch Flying Qualities

### SUMMARY

- Summary
- Any Change in Rating?

**Figure 26 PILOT COMMENT CARD**

## 4.2 EVALUATION PROCEDURES

The configurations were presented for evaluation in a generally random order although some selectivity was asserted by the test conductor in an attempt to provide a range of configuration characteristics on a given flight. This procedure minimized the potential for pilot ratings based on relative rather than absolute "levels of flying qualities goodness." No ordering or selection was made with regard to the mini-experiments.

The evaluation pilots had no prior knowledge of the configuration characteristics. The pilots were aware of the program objectives and the interest in lateral flying qualities.

The evaluation procedures were consistent throughout the program. These were:

- 1) With the variable stability system configured according to the required configuration characteristics, the evaluation pilot is given command of the simulated vehicle.
- 2) After brief familiarization with the vehicle handling characteristics, a roll step input is initiated and recorded as a calibration measurement.
- 3) The evaluation tasks are flown according to the flight card. (The evaluation tasks are described in the next section.) After each up-and-away evaluation task, the pilot was asked to give an individual task pilot rating using the Cooper-Harper scale. Also, brief, informal pilot commentary regarding the task performance and observed handling qualities characteristics were recorded.
- 4) After completion of all assigned evaluation tasks, the evaluation pilot gives an overall pilot rating using the Cooper-Harper rating scale, which quantifies the flying qualities of that vehicle for the "overall" fighter aircraft mission. After this rating, comments following the comment card of Figure 26 were given. These comments describe the configuration as it applies to all of the evaluation tasks. After the comments, the pilot could revise his overall rating if he should so desire. Some interpretation/extrapolation may be required in this rating since flying qualities differences may have been apparent in the different evaluation tasks used. However, the overall rating provided the best summary of the configuration flying qualities.

5) These procedures are repeated until completion of the flight.

#### 4.3 EVALUATION PILOTS

Three engineering test pilots were evaluation subjects. Pilot A and Pilot B were NASA/Ames-Dryden test pilots. Pilot C was a Calspan engineering test pilot. An even-split of evaluations between the three pilots was attempted. Evaluation configurations were not selected according to the particular evaluation subject. Logistic constraints did, however, dictate that Pilots A and B flew more up-and-away evaluations than did Pilot C. All three pilots were familiar with the flying qualities evaluation process; their experience levels varied. Pilot A had considerably more flying qualities evaluation time than did either Pilot B or C.

#### 4.4 EVALUATION FLYING

Evaluation flying was conducted in essentially two phases. The first phase occurred in May 1987 at NASA/Ames-Dryden Flight Research Facility. The second phase occurred in June and July 1987 and concluded in October and November 1987. 42 evaluation flights were flown for a total of 56.5 hours. 5 flights totaling 6.8 hours were needed for aircraft calibration and evaluation task checkout.

A total of 203 evaluations were performed of 67 configurations. 84 of the evaluations were conducted in the up-and-away flight phase of 34 configurations and 19 evaluations in power approach flying were made of 33 configurations. The breakdown of evaluation flying by pilot is shown in Table II.

**Table II**  
**EVALUATION FLYING ACCORDING TO PILOT**

	<i>PILOT</i>		
	<i>A</i>	<i>B</i>	<i>C</i>
Evaluation Flights	15	14	13
Flight Hours	19.1	17.0	13.6
Total Evaluations	78	72	53
Up-And-Away Evals	35	37	12
Power Approach Evals	43	35	41

As indicated in Table II, the evaluation flights were fairly evenly distributed. Pilot C, however, flew less flight hours and fewer evaluations because he predominantly performed power approach evaluations which were shorter flights. This allocation of evaluations occurred because up-and-away evaluations were flown primarily at NASA Dryden and cost/schedule logistics dictated emphasis for the two NASA pilots, Pilots A and B.

The flights were conducted from the Calspan Flight Research facility in Buffalo, New York and from the NASA Ames-Dryden Flight Research facility at Edwards AFB, California.

The flight log and evaluation summary are contained in Appendix A. The flights were conducted in the following time periods:

- First Phase: Flts 4051 - 4057 at NASA, May 1987
  
- Second Phase: Flts 4065 - 4080 at Buffalo, June 1987  
Flts 4118 - 4128 at Buffalo, October 1987  
Flts 4153 - 4162 at NASA, Oct/Nov 1987

"First phase" and "second phase" differentiate a major change in the evaluation tasks. The time gap between evaluation flying periods was required by aircraft inspections and other aircraft program commitments. The time between June and October was used to analyze the program data obtained up to that point and direct the next phase of evaluations as appropriate.

#### **4.5 EVALUATION TASKS**

Both up-and-away and power approach flight phases were investigated. For up-and-away evaluations, the nominal flight condition was 275 KIAS at 7,500 ft altitude. For power approach evaluations, the approach speed varied according to fuel remaining to maintain an approximately constant angle of attack. The indicated airspeed schedule is presented in Table III.

**Table III**  
**NT-33A SPEED PROFILE - APPROACH AND LANDING TASK**

Fuel Remaining (Gallons)	$V_i$ (KIAS)
150 ± 50	125
250 ± 50	127
350 ± 50	130
450 ± 50	133

#### 4.5.1 Power Approach Evaluations

For power approach flight phase, the only evaluation task consisted of the visual landing task with a lateral offset.

In the offset landing task, the evaluation pilot flew a visual approach with the aircraft aligned approximately 300 feet left or right of the runway centerline. At 150 to 200 feet above the ground, the pilot corrects back to the centerline and attempts to touchdown within the desired parameters. Offsets to the left or right were used interchangeably. The offset landing task introduced a disturbance in the visual landing to increase the direct involvement of the pilot in the manual control task near the final stages of the landing.

In the Buffalo, NY area, the landing evaluations were flown primarily to Niagara Falls International Airport, however, the evaluation was occasionally continued to the Greater Buffalo International Airport for the final landing. At Edwards AFB, the landing evaluations were conducted at the main base Runway 4/22. The offset landing task is illustrated in Figure 27 with Niagara Falls Runway 28R used for the depiction.

The touchdown aimpoint was the instrument landing markers located approximately 1000 ft from the runway threshold. Each landing was treated as a "must land" situation. The desired and adequate landing performance standards are summarized on Table IV and illustrated in Figure 28.

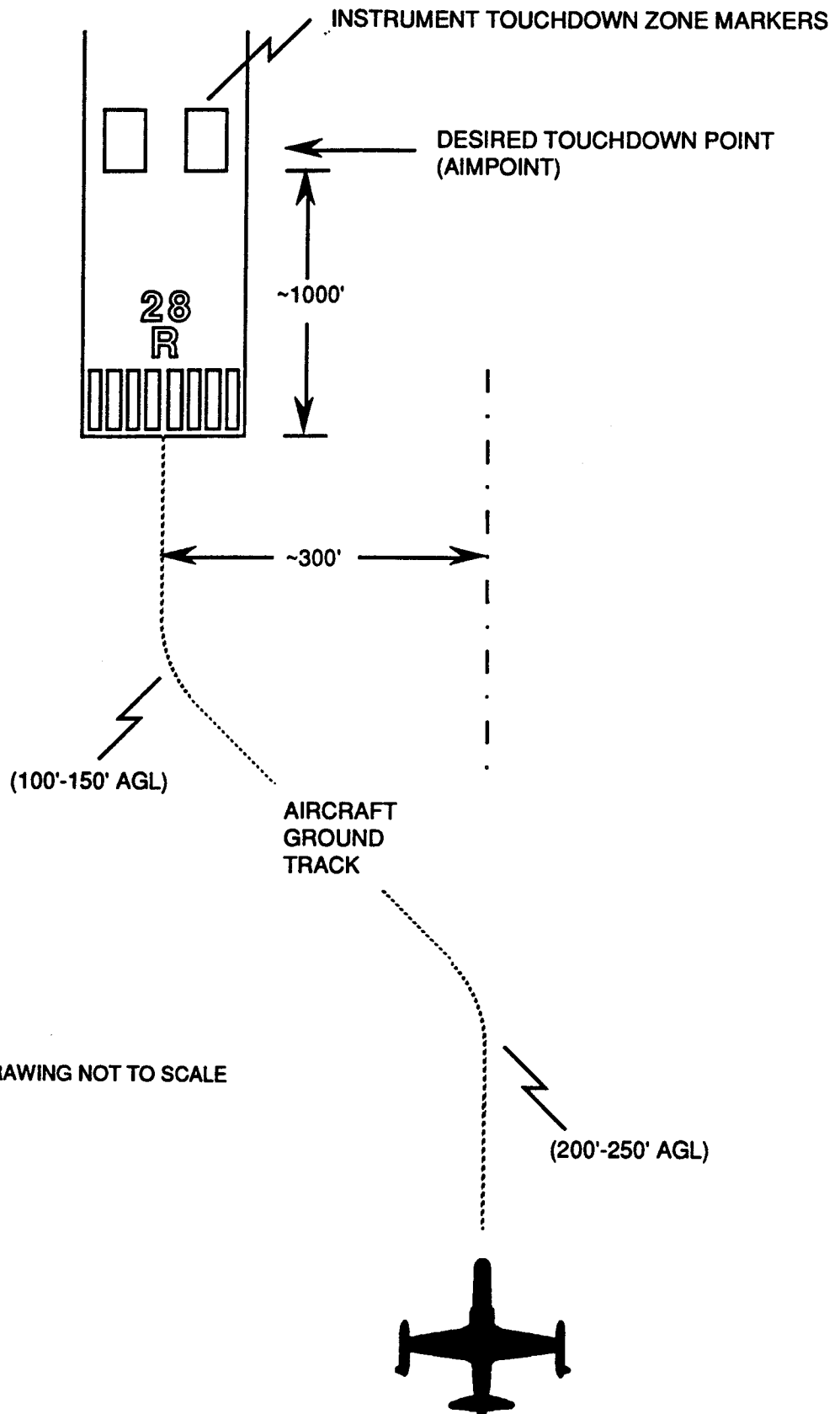
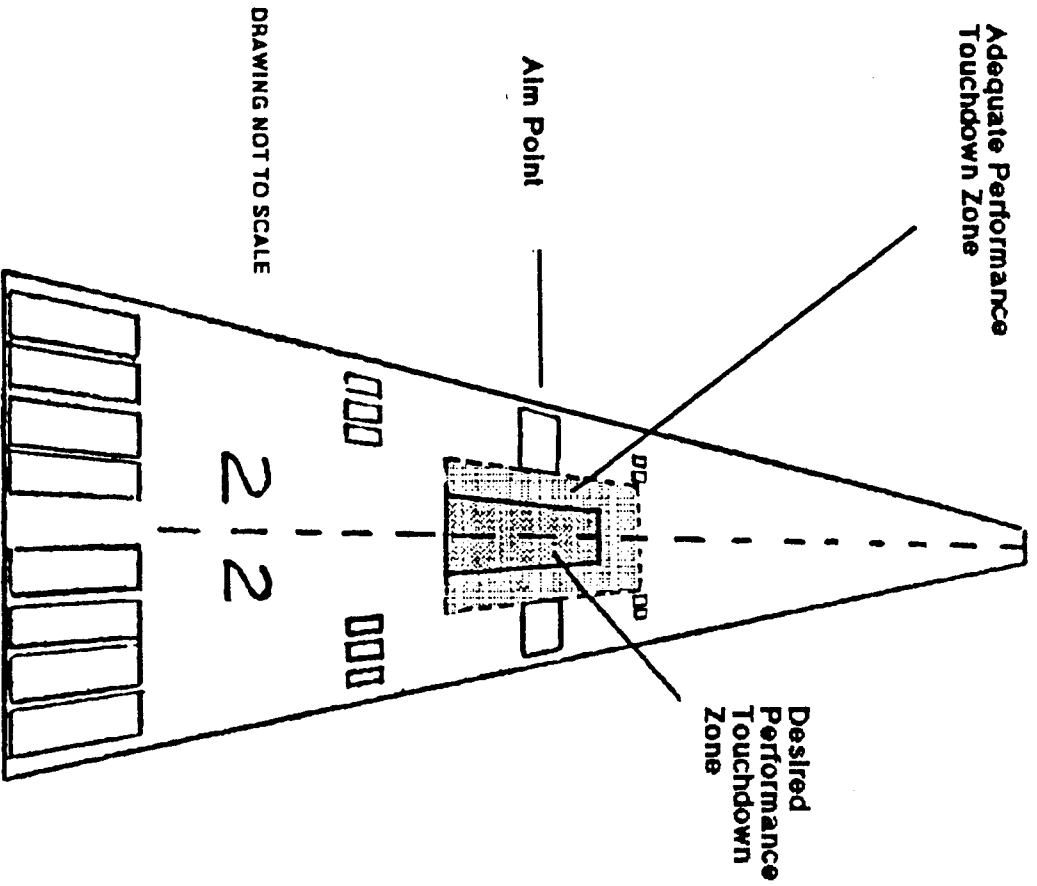


Figure 27 LATERAL OFFSET TASK



**Figure 28 DESIRED AND ADEQUATE LANDING TASK PERFORMANCE**

**Table IV**  
**APPROACH AND LANDING TASK PERFORMANCE STANDARDS**

<i>Desired Performance</i>	<i>Adequate Performance</i>
No PIO's Touchdown within 5 ft of centerline (main wheels on centerline) Touchdown within $\pm 250$ ft of aimpoint Approach airspeed maintained within $\pm 5$ kts.	Touchdown within 25 ft of centerline (tip tank on centerline) Touchdown within -250, +750 of aimpoint Approach airspeed maintained within -5 kts/+10 kts.

**4.5.2 Up-And-Away Evaluations**

An up-and-away evaluation consisted of HUD-generated tracking tasks and if a target aircraft was available, actual fighter-type maneuvers with the target airplane. Fighter maneuvers consisted of formation flying and gun tracking.

The evaluation tasks evolved over the course of the program. The original program plan called for up-and-away evaluations to consist solely of HUD-generated tracking tasks after an initial validation phase where the HUD tracking tasks were demonstrated to be equivalent in terms of handling qualities evaluation results. The first phase, however, did not demonstrate this equivalence and target/chase aircraft were predominantly used for up-and-away evaluations.

Target aircraft support was provided by NASA/Ames-Dryden and the 107th Fighter Interceptor Group of the New York Air National Guard stationed at Niagara Falls, New York.

Up-and-away evaluation tasks were as follows:

**First Phase (NT-33 Flights 4051 - 4057)**

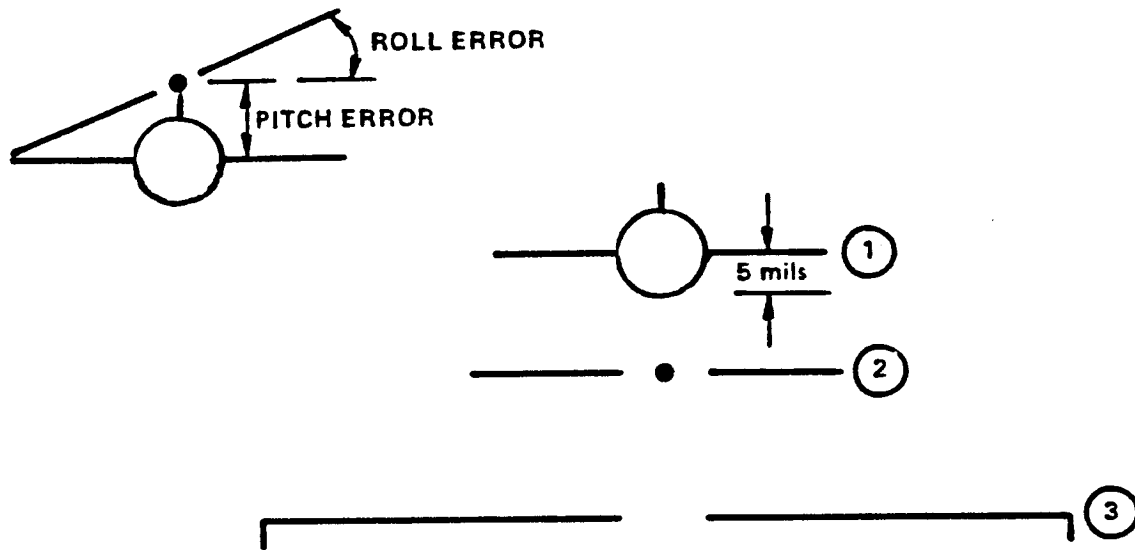
Evaluations consisted of: (1) formation flying, (2) gun tracking, (3) pitch-and-roll "discrete" HUD tracking, and (4) roll-only sum-of-sines using the "Time Delay Study" (Reference 17) tracking task.

The formation flight and gun tracking tasks used the chase/target aircraft.



The gun target tracking task consisted of predictable and unpredictable target maneuvering with the simulated aircraft (NT-33) assuming an "offensive" position. The gun tracking exercise included gross acquisition of an initial tracking solution and then fine tracking. An "extended wings" flight path marker, fixed in the waterline position, was used as the pipper. This aiming symbol is approximately 10 mils in diameter and the intersection of the "tail" and the "wings" (center of the marker circle) was the aimpoint. The HUD format is shown in Figure 29. The gun tracking task was executed as follows:

- Target aircraft takes flight lead and NT-33 falls into a 1,000 ft trail position.
- Target begins a 2g level turn. The evaluation pilot maintains wings level during the initial part of target turn. As the target passes the NT-33A canopy bow (approximately 30° angle-off) the evaluation pilot initiates a maneuver to acquire a fine tracking solution. The evaluation pilot, during fine tracking, attempts to move the pipper and track alternate wing tips of the target. NT-33 calls target reversal. Repeat in other direction.
- After predictable target maneuvering, target aircraft begins random maneuvering with unannounced reversals. New target maneuvering planes are held for five to ten seconds. The following target maneuver limits apply:
  - +3 to + $\frac{1}{2}$ g
  - 250 KIAS minimum
  - 300 KIAS maximum
  - ± 120° bank angle
  - ± 20° pitch angle
- Gun tracking task performance standards are given in Table V.



- ① "EXTENDED-WINGS" FLIGHT PATH MARKER (FIXED PIPPER REFERENCE)
- ② COMMAND BAR FOR TRACKING TASKS
- ③ HORIZON LINE

Figure 29 HUD FORMAT

In the random or unpredictable maneuvering, tracking planes were held to allow the evaluation pilot time to track. Although this constraint is not realistic of an air combat maneuver scenario, if the maneuver planes were not held, then tracking capability could not be accurately assessed and the assigned performance standards would be compromised.

The gun tracking task procedures were invariant during the course of evaluation.

**Table V**  
**GUN TARGET TRACKING PERFORMANCE STANDARDS**

<i>Desired Performance</i>	<i>Adequate Performance</i>
<u>Gross Acquisition:</u> No PIO's 1 overshoot maximum within 10 mils of aimpoint	<u>Gross Acquisition:</u> 2 overshoots maximum within 20 mils of aimpoint
<u>Fine Tracking:</u> No PIO's Pipper within 2 1/2 mils of aimpoint 50% of time not to exceed 10 mils	<u>Fine Tracking:</u> Pipper within 5 mils of aimpoint 50% of time not to exceed 10 mils

The formation flying task was flown as follows:

- Task starts with NT-33A at target's 5 o'clock or 7 o'clock position with 50 ft spacing. If flying qualities allow, evaluation pilot moves in to a close formation position at 5 or 7 o'clock but maintains nose-tail separation. Evaluation pilot directs target to begin maneuver. Target aircraft flies straight and level, then a 30° bank, 180° right turn, and finally, a 60° bank 180° left turn.
- Evaluation pilot maintains close formation position and continues to follow lead aircraft through s-turn maneuvers up to 90° bank angle keeping  $\frac{1}{2} > N_z < 2.5g$ .
- Task performance standards are shown in Table VI.

**Table VI**  
**FORMATION FLYING TASK PERFORMANCE STANDARDS**

<i>Desired Performance</i>	<i>Adequate Performance</i>
No PIO's Translational Position Within $\pm 2$ feet of desired Vertical Position Within $\pm 2$ feet of desired	Translational Position Within $\pm 4$ feet of desired Vertical Position Within $\pm 4$ feet of desired

After completion of the formation flying and gun tracking, two HUD-generated tracking tasks were flown. Unfortunately, the HUD tasks in this first phase were not specifically designated for this evaluation program. A programming error and time constraints did not permit evaluations to begin with the proper HUD tasks. The two HUD tasks in the first phase were:

- Pitch-and-Roll, Discrete Tracking:

This discrete maneuvering task has been flown on past programs and has been found to be effective in assessing handling qualities. The tracking task command profile is illustrated in Figure 30. The task emphasizes combined axis tracking with coordinated pulling and rolling maneuvers. Unfortunately for this evaluation of roll flying qualities, it is predominantly a pitch tracking exercise.

- Roll Sum-of-Sines:

A roll-only sum-of-sines tracking task was created for the study reported in Reference 17. This task was used as a interim replacement of a specific task design. The task had an effective bandwidth of .55 rad/sec formed by shaping the sine component amplitude in the form of a Butterworth filter of that frequency.

All HUD tasks employed the display format shown in Figure 29. Each task was a compensatory tracking display with a "fly-to" tracking sense. Each task lasted approximately 90 seconds. The desired and adequate performance standards are shown in Table VII.

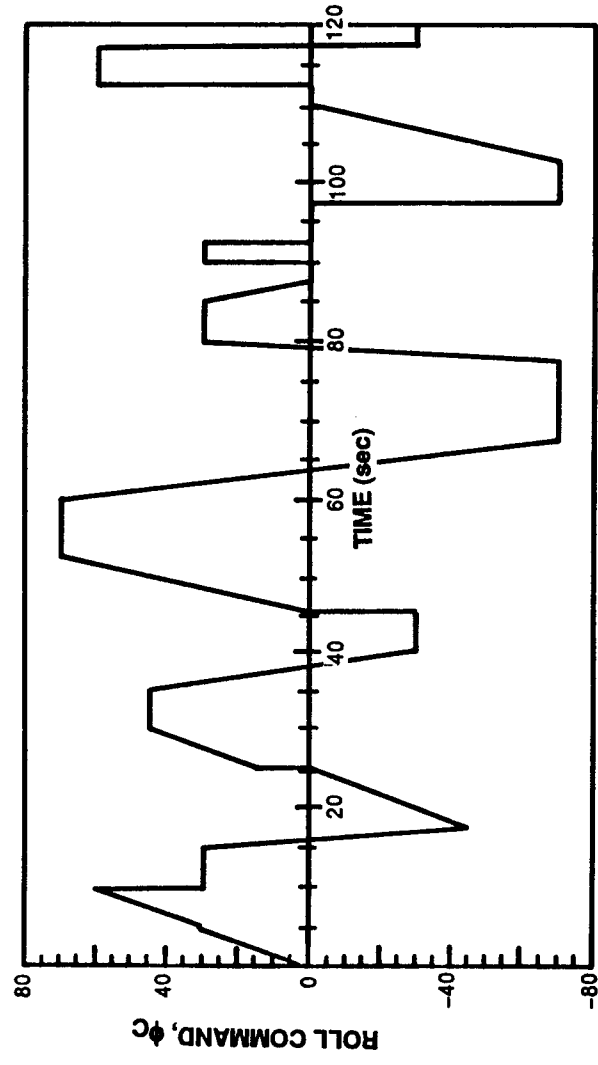
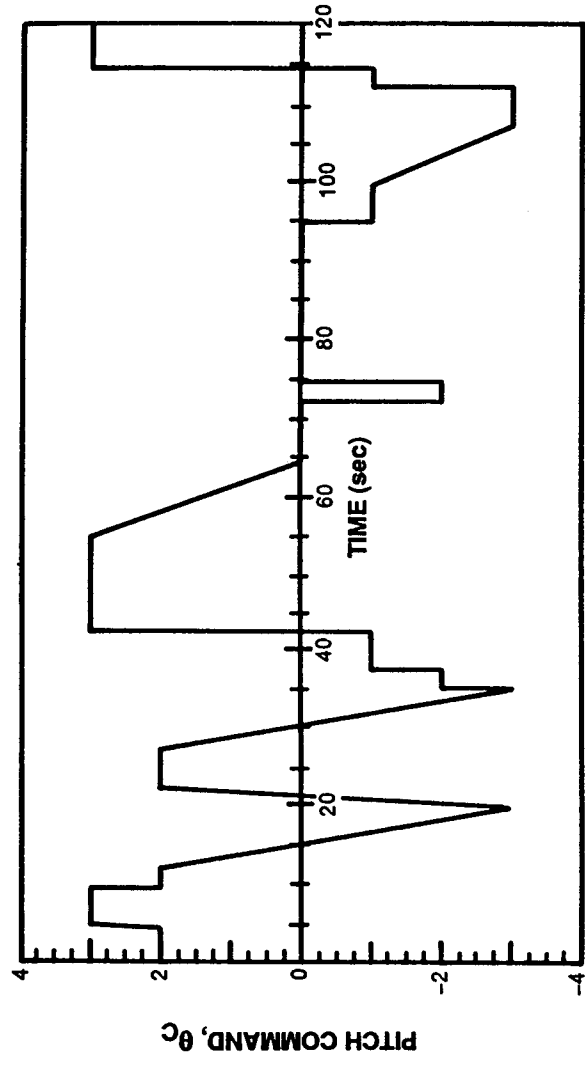
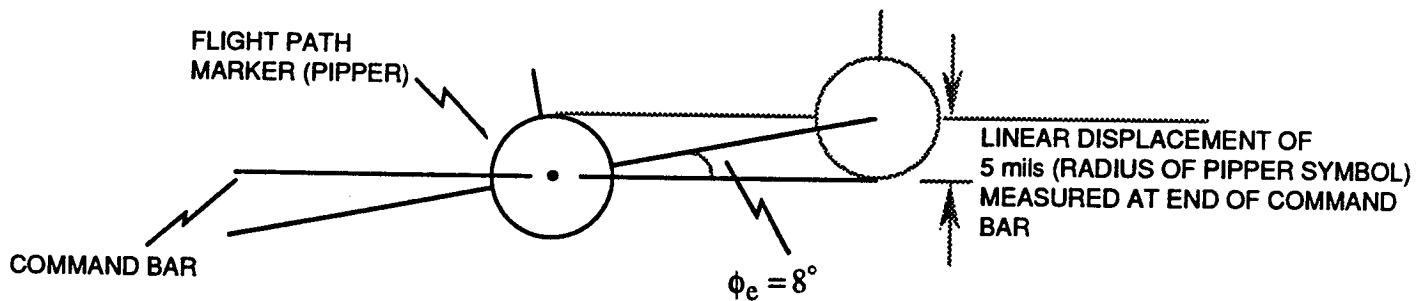


Figure 30 FIGHTER DISCRETE TRACKING TASK

**Table VII**  
**TASK PERFORMANCE STANDARDS**

<i>Desired Performance</i>	<i>Adequate Performance</i>
No PIO's Command attitude maintained within 5 mils in pitch and 5 mils in bank measured at the end of the command bar 50% of task (Except immediately following step commands)	Command attitude maintained within 10 mils in pitch and 10 mils in bank measured at the end of the command bar 50% of task (Except immediately following step commands)

For roll performance, the error was defined by the linear displacement between the command bar and pipper at the end of the pipper "wing." This criterion was really an angular displacement standard. However, the linear displacement measure was used because it was more easily visualized by the pilot. As shown in Figure 31, the linear displacement of 5 mils at the end of the pipper wing corresponded to approximately 8 degrees of roll error.



**Figure 31 DESIRED PERFORMANCE IN ROLL**

Second Phase (NT-33 Flights 4065 - 4162)

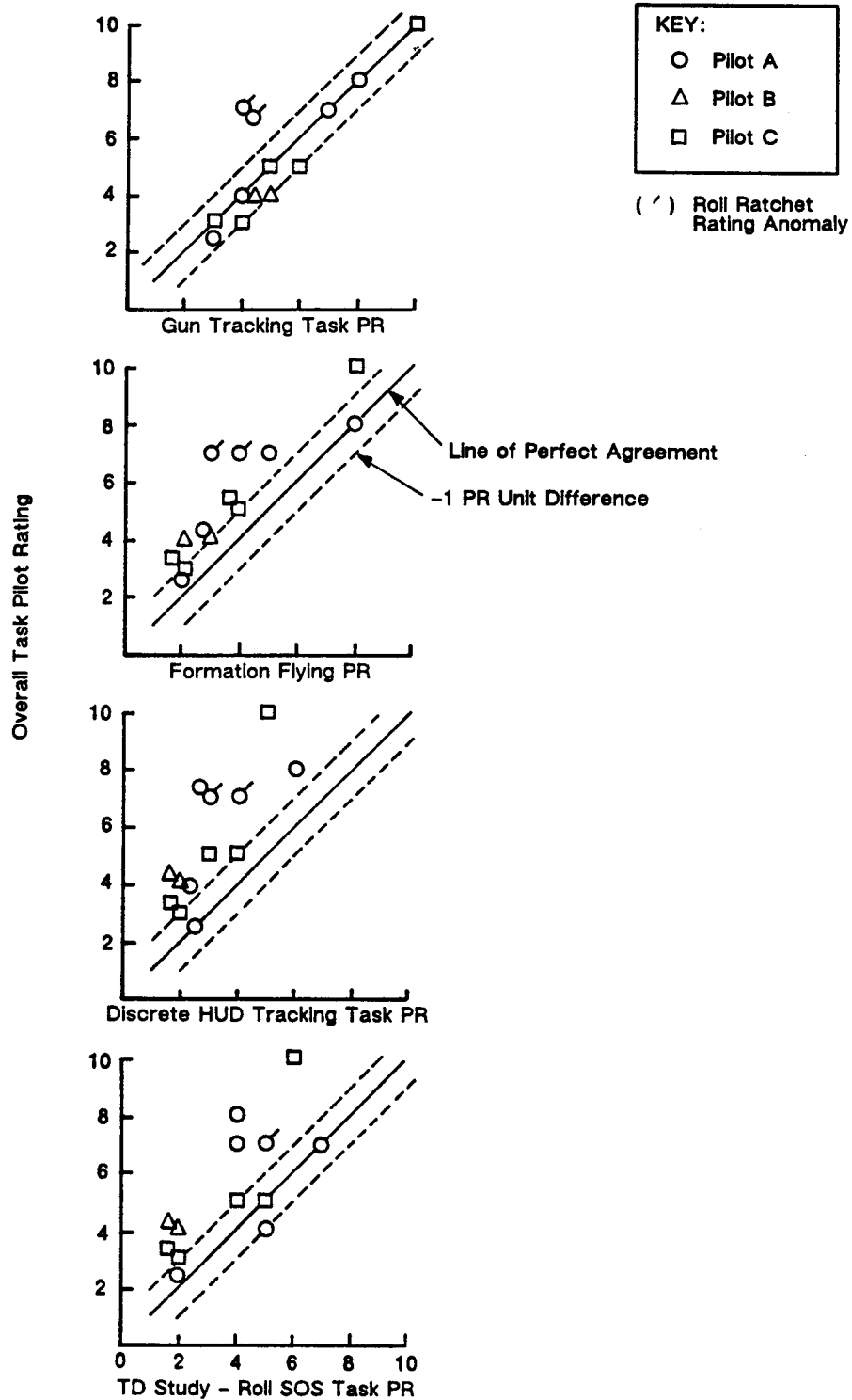
Pilot ratings and brief pilot comments were given after each task. Overall rating and formal pilot comments were given at the completion of all of the tasks. The overall rating summarized the configuration flying qualities for the fighter mission. Before the beginning of

the second phase, the first phase results were analyzed. Two decisions were made affecting the up-and-away evaluation tasks:

- Formation flying was eliminated.
- Gun tracking would be used for all up-and-away evaluations, if possible and with the proper HUD tasks.

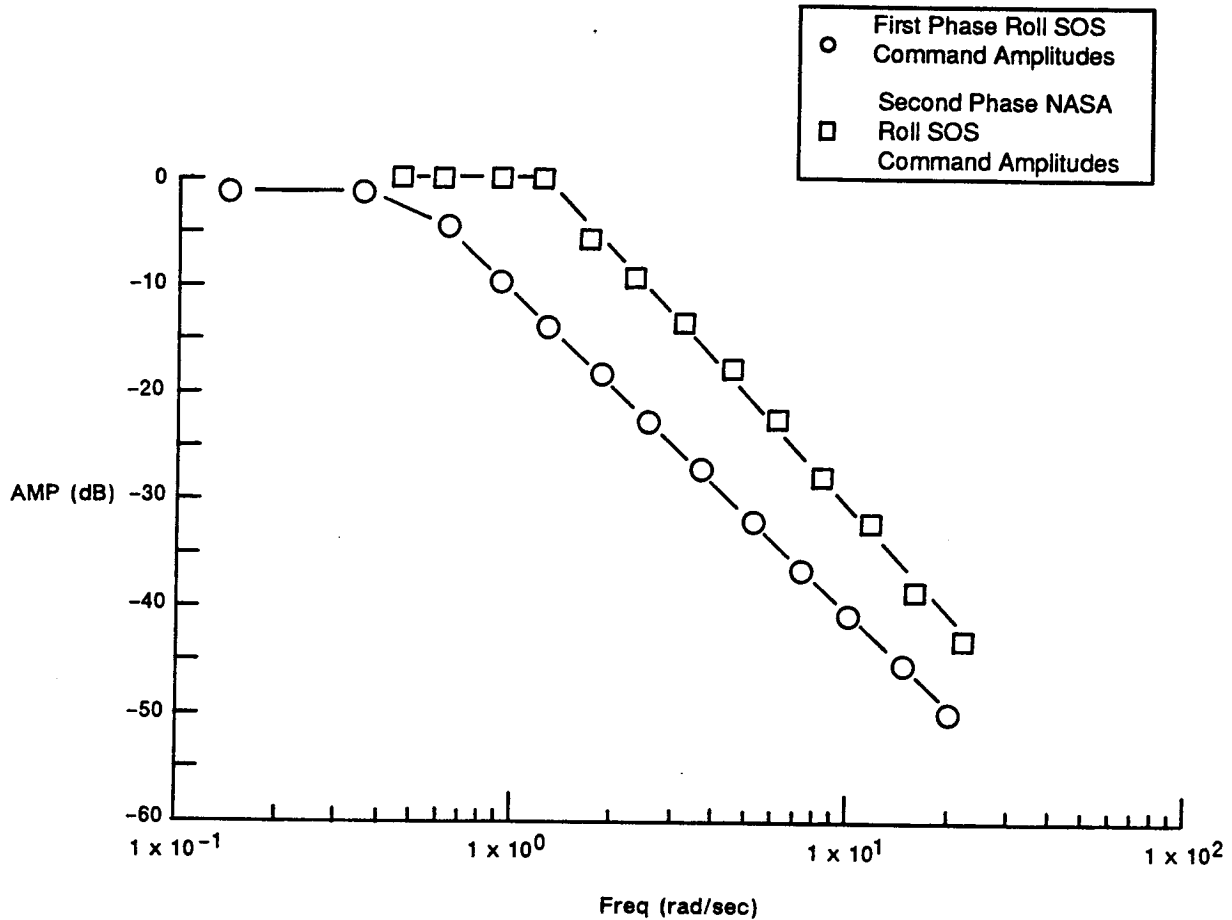
Formation flying was eliminated from the up-and-away evaluations because it was very time-consuming and yet, it did not prove to be as discriminating of flying qualities as the gun tracking task. The individual task pilot ratings from the first phase are plotted in Figure 32 against the overall pilot rating given to that configuration. The data of Figure 32 indicates:

- A very clear correspondence between the gun tracking task and the overall pilot rating. Only two evaluations were outside of the  $\pm 1$  pilot rating unit deviation from perfect correlation. For these two evaluations, a rating anomaly caused by "roll ratcheting" was evident which, as will be discussed, are valid ratings but are not indicative of the task performance or pilot workload. These two ratings are not, therefore, given much weighting in this correlation.
- The formation task was rated a consistent one-to-two rating units better than the overall task. The relative ease of the formation task was likely due to the aircraft separation requirements for safe flight test operations. To get a high piloting "gain" task required for proper flying qualities evaluation, the wing tip-to-wing tip clearance would have to be smaller. These distances would be unacceptably close in this testing environment. The formation flying was also time consuming, particularly when using dissimilar aircraft with very different thrust and drag characteristics.
- The HUD tasks were also less discriminating of the configuration's flying qualities. These tasks were not specifically designed for this program and consequently, it was believed that they were less discriminating of roll flying qualities. The roll SOS task was fairly demanding in that the pilot had to use high frequency inputs to accomplish the task satisfactorily although the task bandwidth was fairly low ( $\omega_{BW} = .55$  rad/sec).



**Figure 32 CORRELATION BETWEEN OVERALL TASK CONFIGURATION PILOT RATING AND UNDER DUAL TASK PILOT RATING FOR FIRST PHASE EVALUATIONS**





**Figure 33 COMPARISON OF ROLL SOS COMMAND TASK AMPLITUDE USED FOR FIRST PHASE AND SECOND PHASE EVALUATIONS**

Because of these results, up-and-away evaluations were not limited solely to HUD evaluations as had been the plan. Up-and-away evaluations for Phase 2 consisted of:

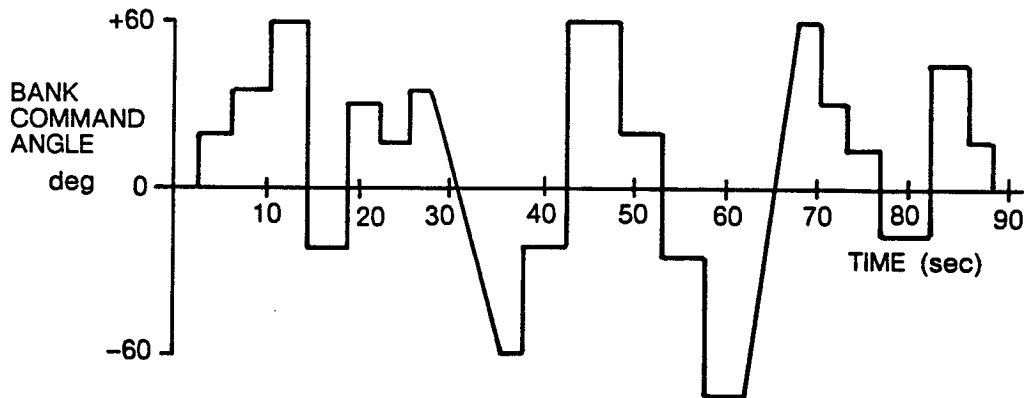
- Gun Target Tracking
- NASA/Roll Sum-of-Sines HUD TrackingTask
- LATHOS Roll Discrete Tracking Task

The gun tracking task was unchanged from the first phase evaluations.

The roll SOS task, designed for this program and used in the second phase, had a higher bandwidth and was shaped slightly different (Figure 33) than the first phase task. The bandwidth was on the order of 1.5 rad/sec.

The "LATHOS" HUD tracking task was a roll axis-only compensatory tracking task. The commands consisted of a series of step-and-ramps (Figure 34). The task was identical to the HUD tracking task created and validated for the LATHOS program. Only up-and-away evaluations used this task.

The desired and adequate performance standards shown in Table VII were used for the roll SOS and LATHOS tasks.



**Figure 34 LATHOS, ROLL-ONLY STEP-AND-RAMP TRACKING TASK COMMANDS**

The individual and overall task pilot rating data from the second phase evaluations are compared in Figure 35. These comparisons and the corresponding pilot comment data indicate a much better correlation between the individual tasks and the overall evaluation; however, these figures do not adequately reflect the task dependency of some configurations. There were numerous occurrences where good performance and negligible flying qualities deficiencies were noted in one task but with the same configuration in another task, the flying qualities and/or task performance were not satisfactory. These differences are addressed more completely in the next section since it is a critical design consideration. One item of note is shown in Figure 35 where only two HUD-roll sum-of-sines task evaluations in the second phase were outside of the  $\pm 1$  rating unit deviation from the line of perfect correlation to the overall task ratings. Very good

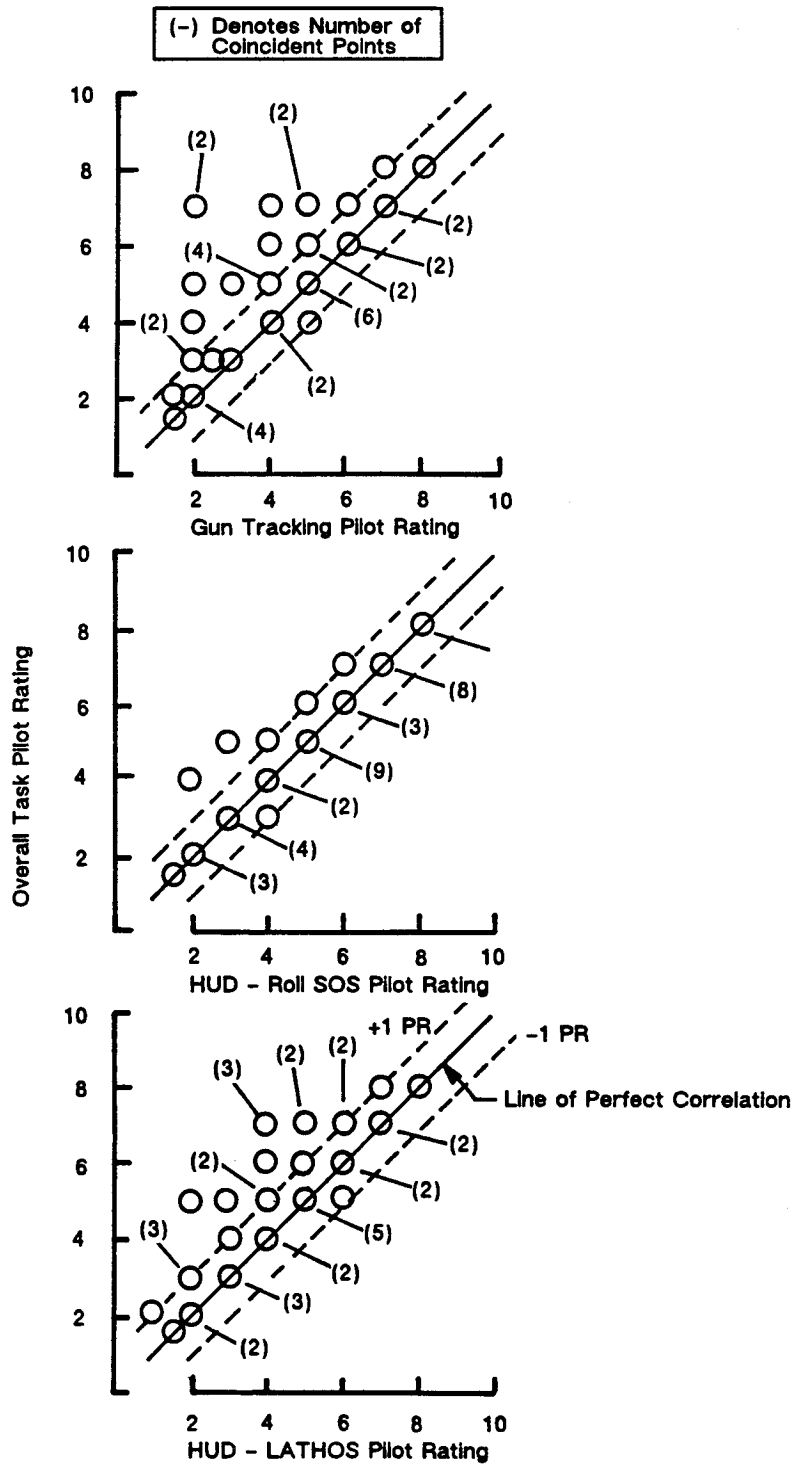
agreement between the roll SOS and the overall task pilot ratings was, consequently, demonstrated.

Up-and-away evaluations were sometimes performed without a target aircraft. These HUD-only evaluation tasks are denoted accordingly to differentiate them from the up-and-away evaluations with a target. These HUD-only evaluations validate or refute the utility of HUD task as a stand-alone evaluation tool.

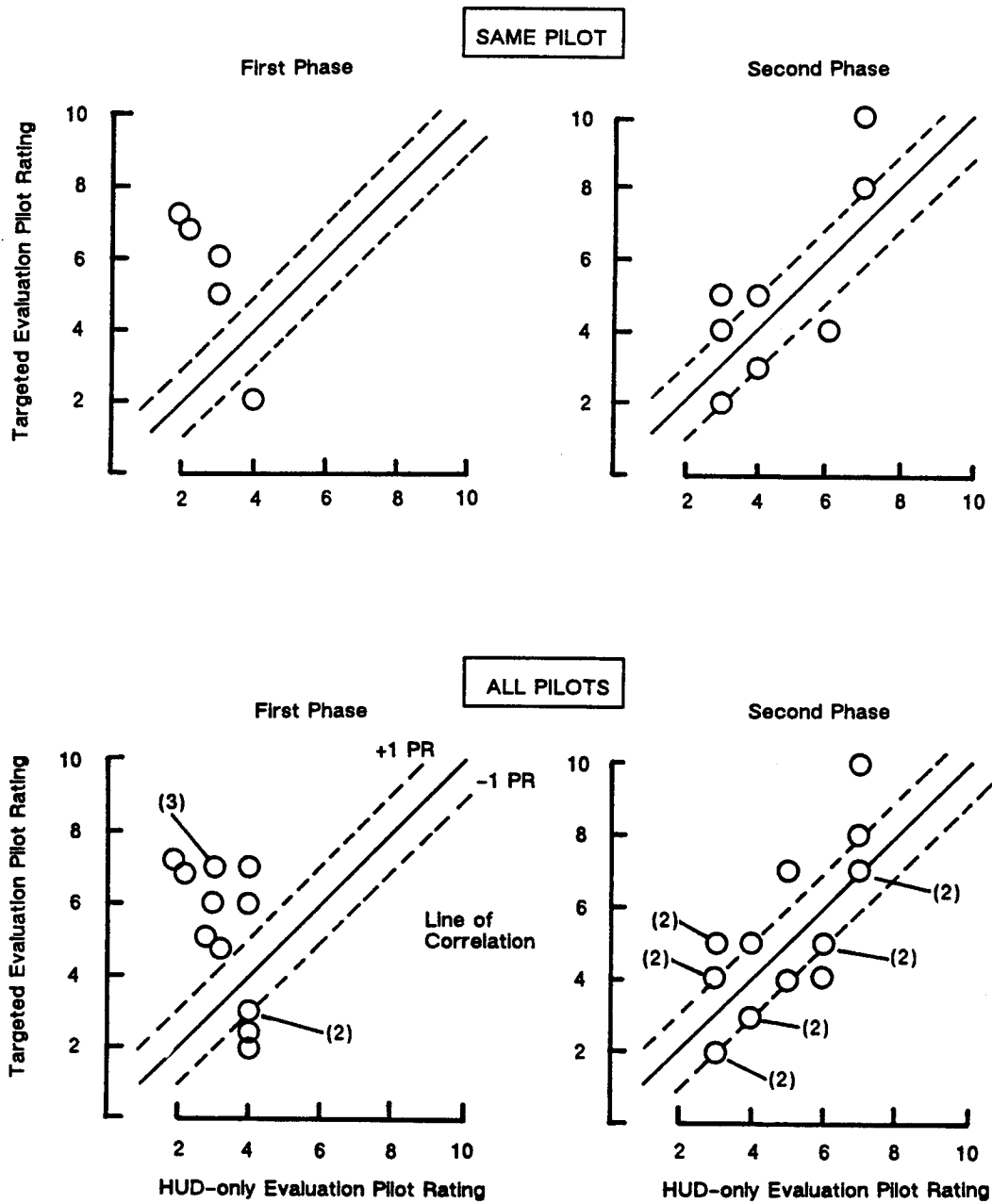
The HUD-only evaluation tasks are compared to evaluations involving a target aircraft in Figure 36. The data of this figure are delineated according to evaluations of the first phase (Flights 4051-4057) or second phase, thus reflecting the change in HUD tasks. Also, the data are shown for HUD-only and targeted evaluations which were performed of the same configuration by the same pilot and the same configuration by the same and different pilots. The latter comparison is less precise because inter-pilot rating differences are introduced.

The poor rating comparisons for the first phase in Figure 36, again, reflect the poor design of these tasks for a lateral flying qualities program. In no instance were the HUD-only evaluation data equivalent to the targeted evaluation data. Typically, the targeted evaluations spanned a significant range of flying qualities (both the good and bad) but the HUD-only evaluations showed only good (PR<4) flying qualities characteristics.

For the second phase evaluations, the HUD-only evaluations correspond well to the trends for targeted evaluations. There does, however, appear to be more rating scatter about the line of perfect correlation than what is generally present from handling qualities evaluations. The HUD-only evaluation data fall about the line of perfect agreement with the target evaluations with a deviation of approximately  $\pm 1.5$  rating units for evaluations by the same pilot and 1.25 rating units when all piloted evaluations are included. These results would suggest that the HUD-only evaluations can be used as stand-alone evaluation tasks (i.e., evaluation tasks without target/formation aircraft). However, these data also indicate that the pilot rating data will exhibit more rating scatter than generally expected and by comparison to the first phase results that the HUD tasks must be carefully designed to emphasize the maneuvering characteristics required of the aircraft during actual tasks. Further, the pilots in this comparison were properly "calibrated" to the demands of the real tasks; hence, the HUD tasks were not flown like a video game but were flown in a manner analogous to the actual task (i.e., similar pilot aggressiveness in performing HUD tasks, same roll rates in closing on errors, etc.).



**Figure 35 COMPARISON OF INDIVIDUAL TASK PILOT RATINGS FOR SECOND PHASE EVALUATIONS**



**Figure 36 COMPARISON OF HUD-ONLY AND TARGET EVALUATION PILOT RATING DATA**

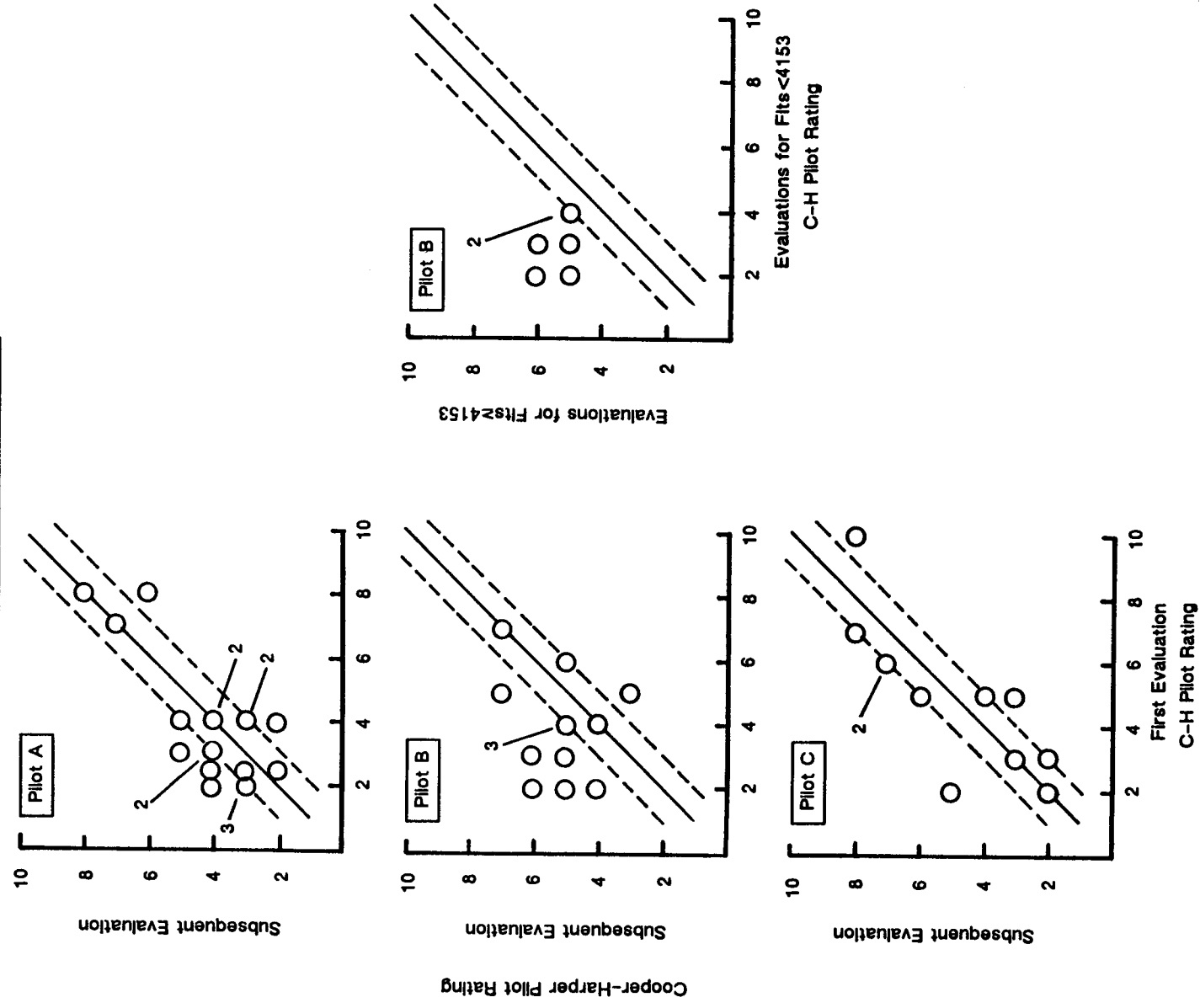
#### 4.6 INTRA-PILOT RATING COMPARISON

The intra-pilot ratings are compared in Figure 37. The data show the first and subsequent pilot ratings given by a pilot for the same configuration. The pilots did not have any knowledge of the configuration characteristics or that he may be evaluating a configuration for the second time. Repeat evaluations are, therefore, an effective means of checking the pilot rating process for consistency.

The data of Figure 37 indicate fairly good repeatability for Pilots A and C; these pilots were fairly consistent in their evaluation process. Lines of perfect correlation with  $\pm 1$  PR unit envelopes about that line have been drawn. The  $\pm 1$  rating unit deviation is generally expected in the Cooper-Harper rating scale. For Pilots A and C, less than 30% of their repeat evaluations were outside of this region. Pilot A was always inside a 2 rating deviation from perfect correlation. The same consistency occurred for Pilot C except on one occasion, a subsequent evaluation pilot rating deviated by 3 rating units from the first evaluation rating. The influence of the different evaluation tasks between the first and second phases were not factored out of these comparisons.

For Pilot B, some rating inconsistency was noted. A fairly distinct change occurred before the final evaluation period at NASA/Ames-Dryden (after Flights 4153). Before that period, Pilot B was more forgiving of some flying qualities characteristics which led to better ratings on his part in comparison to the other pilots. After Flight 4153, his evaluations showed in better agreement with the other pilots (as will be shown later). In Figure 37, his repeat evaluations are shown for all evaluations and also for evaluations before and after Flight 4153. When considering all of his evaluations, significant scatter in inter-pilot ratings is present. As shown in the comparison of pre- and post-Flight 4153 evaluations, the majority of the overall inter-pilot rating scatter for Pilot B was the result of this distinct rating change.

**KEY:**  
 Numbers indicate multiple data points  
 HUD - only evaluations excluded



**Figure 37 INTRA-PILOT RATING COMPARISON**

## Section 5 EXPERIMENT RESULTS

The experiment results are presented using the mini-experiment format and objectives which were established in the experiment design (see Section 3.2). In Section 6, the data are cumulatively analyzed with regard to criteria for fighter aircraft flying qualities and flight control system design.

### 5.1 LATHOS REPLICATION

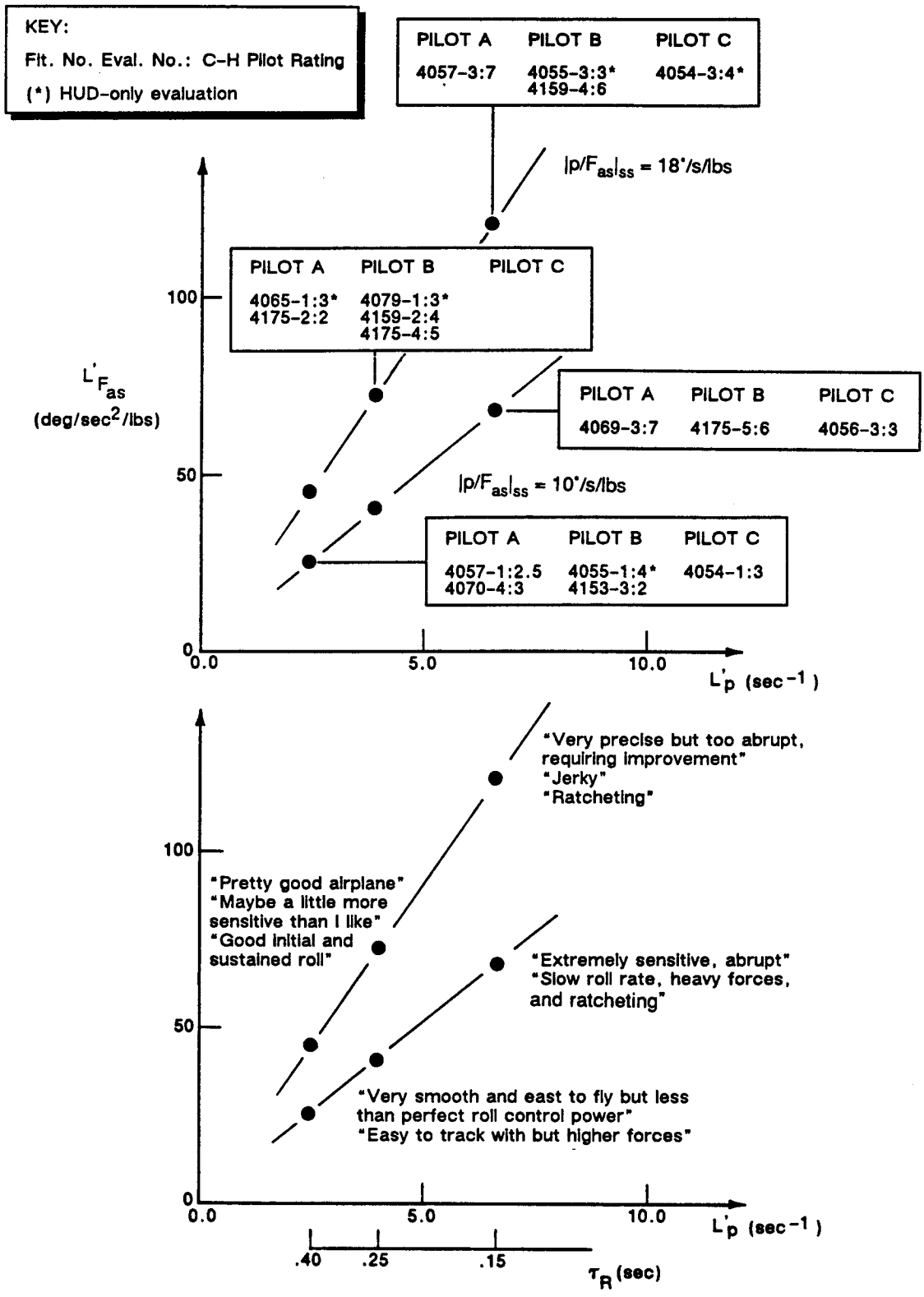
40 evaluations of 9 configurations were flown in Mini-Experiment #1 which mimicked the LATHOS (Reference 9) experiment design. In a force command system architecture, the roll mode time constant ( $\tau_R$ ) and steady-state roll rate-per-unit stick force ( $lp/F_{as}|_{ss}$ ) were varied with a linear command gradient.

#### 5.1.1 Up-and-Away Task Results

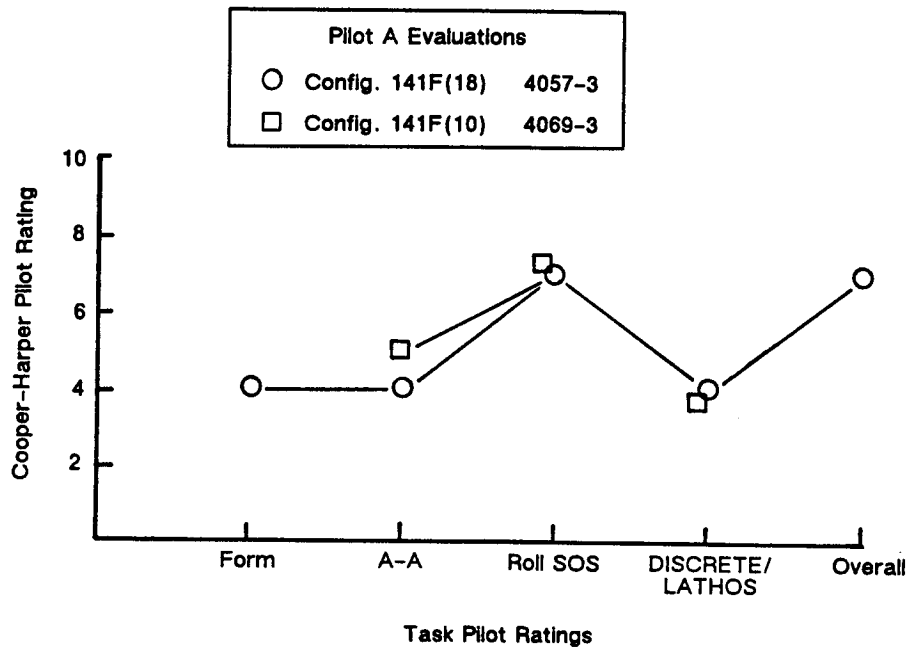
The pilot rating results and a pilot commentary synopsis are presented in Figure 38 for the up-and-away Flight Phase Category A tasks. HUD-only evaluations are duly noted. The rating data establish that, as the roll mode time constant decreases from .40 to .15 (Configurations 341F(-) to 141F(-)), the pilot ratings indicate degradation from Level 1 ( $PR \leq 3\frac{1}{2}$ ) to Level 3 ( $PR > 6\frac{1}{2}$ ). This trend occurs for both the 10 and 18 deg/lb command gains. The flying qualities degradation with increased roll damping was primarily caused by the excessive roll accelerations and abruptness. Roll ratchet was often encountered. Nevertheless, the pilot comments are almost contradictory since the pilots, in general, like the roll performance capability provided by the short roll mode time constant. However, the roll accelerations are too great and thus distracting or disruptive. These results are in agreement with the LATHOS data (Reference 9).

In three cases, Level 1 ratings are given for the short roll mode time constant configurations; however, these evaluations were flown without the benefit (demands) of the NASA HUD roll sum-of-sines task. The configuration flying qualities are very task dependent. For instance, the individual task ratings by Pilot A are plotted in Figure 39. For the formation, air-to-air, and step-and-ramp discrete HUD tasks, desired task performance was attained and the roll abruptness was not objectionable. Level 2 ratings ( $PR = 4$ ) were given, however, because the roll abruptness was a minor but annoying aircraft deficiency. As noted by Pilot A, these





**Figure 38 MINI-EXPERIMENT NO. 1 PILOT RATING DATA AND PILOT COMMENT SYNOPSIS**



**Figure 39 INDIVIDUAL TASK PILOT RATINGS - PILOT A**

configurations have "an abrupt initial response yet it stops exactly where you want it. Predictability is, therefore, good and performance is excellent."

However, flying qualities during the roll sum-of-sines task were not good. Overall, the two configurations were rated as 7 because, in summary, the roll abruptness was a deficiency which required rather than just warranted improvement. Under the Cooper-Harper scale, deficiencies which require improvement are Level 3. The sum-of-sines task is unique because of its broad frequency content and random appearance. These characteristics preclude specialized, adaptive-type pilot control input techniques such as smooth, lagged control inputs or an intermittent control. These techniques help to alleviate roll abruptness and may be successfully used in some tasks to produce desired roll performance. The random, high frequency roll SOS task demands do not allow intermittent or lagged pilot control inputs without sacrificing task performance; thus, the objectionable roll abruptness was apparent and the Level 3 pilot ratings were given accordingly.

These pilot rating data substantiate that the HUD-generated tracking tasks and the roll sum-of-sines task, in particular, were a significant influence in the overall flying qualities assessment. The remaining configurations from Mini-Experiment #1 were examined with regard to task influences. These data show that the individual task pilot ratings for the roll sum-of-sines task were, with one exception, equal to or worse than the overall task pilot rating. The discrete, step-and-ramp HUD task was equal to or worse than the overall task pilot rating for Pilot B but, for Pilot A, the discrete task pilot ratings are more closely aligned to the air-to-air gun tracking task ratings.

The cause and relevance of the significant HUD tracking influence is not exactly known but several factors to consider include:

- A lack of precise roll demands in the gun tracking task. For the HUD tasks, precise roll attitude commands and errors were displayed to the pilot and were used directly in the evaluation task. For the gun tracking task, a fixed reticle pipper was employed, with only an aimpoint on the target aircraft specified. Thus, the HUD tasks convey the roll angular errors more obviously and precisely to the pilot than the gun tracking task. The gun tracking situation is more operationally orientated, but the task is very dynamic and roll attitude control of the tracking vehicle is only one ingredient in a very dynamic task primarily involving maneuver plane orientation.

- The ability to adapt to configuration characteristics with a "known" target such as the chase aircraft in the gun tracking task. The great adaptability of pilots to control a wide range of vehicle characteristics is known. This is particularly evident when the task is predictable. In the gun tracking task, the target airplane, unlike that of the HUD tasks, conveys information which the pilot can use to anticipate the future position of the target. For instance, wing alignment and target pitch attitude immediately provide an estimate of the target's maneuver plane. This lead information allows the pilot to better control his own vehicle. None of this lead information is available in the HUD tasks. The target roll rate in the discrete task, step commands is "infinite". The target in the HUD sum-of-sines task is random and never quiescent. The lack of lead information in the HUD tasks, therefore, restricts the adaptability of the pilot in performing these tasks which confounds task comparison. The flying qualities data that these tasks highlight is, nonetheless, of great interest in the lateral flying qualities design problem.

The HUD tasks are "artificial" in comparison to the real fighter task of air-to-air gun tracking, yet these data demonstrate that the overall rating was influenced by the different tasks. The overall rating, based on the HUD and actual target tasks, is used in this report to describe a configuration flying qualities. This procedure is felt to be reasonable and not biased toward artificial task demands. For instance:

- Although possibly better flying qualities can be attained in the real task, the ratings, based on the real and "artificial" HUD tasks, are derived from very demanding pilot control requirements. Since future applications of this data cannot be predicted, any design criteria, developed from this data, should be sufficient for any flight control system design of a present or future fighter task.
- The demanding HUD tasks may compensate for the removal of some real piloting task demands required by experimental procedures. For instance, pilot control requirements in roll are lessened by the absence of a lead-computing optical gun sight. In addition, real-world stresses, such as those caused by real air-to-air combat were certainly not simulated.
- The rating differences between the different tasks are indicative of the configuration flying qualities characteristics and the ability of the pilot to adapt to certain configuration characteristics. Design requirements, based on tasks which preclude

pilot adaptation, prevent a design which requires special pilot compensation to be learned and trained. A training requirement to learn to compensate for undesirable aircraft characteristics should be avoided.

Selected time histories are presented to illustrate the results. A portion of the gun tracking task performed by Pilot A with Configuration 141F(10) is shown in Figure 40. Episodes of high frequency, pilot-induced-oscillations (roll ratchet) are highlighted. The oscillations are most apparent in the roll acceleration response and occur at a frequency of approximately 15 rad/sec. The oscillations are not detectable in either the roll rate or roll attitude responses. The pilot comments note that desired task performance can be attained but the time history traces of roll response was too abrupt and it was, therefore, not satisfactory without improvement. A pilot rating of 5 was given. The pipper error in the air-to-air task was not an instrumentable parameter so the control law structure that the pilot was acting upon cannot be verified analytically. This information is available, however, for the HUD tasks.

In Figure 41, a portion of the LATHOS task is shown for this same evaluation. Almost identical time history characteristics to the air-to-air task are shown; although, in this case, the roll ratchet oscillation is evident in the roll rate as well as roll acceleration responses. The oscillations tend to occur during gross acquisition of a step command as the stick input is relaxed. The pilot comments note that desired performance was attained and the roll abruptness was noticeable. A pilot rating of 4 was assigned to this task.

The LATHOS tracking task time history for Configuration 341F(18) is presented in Figure 42. This roll attitude tracking by Pilot A is almost identical to the tracking for Configuration 141F(10) (e.g., compare  $\phi_e$  time histories). In both cases, desired task performance was attained. The primary difference between the time histories for Configuration 141F(10) and 341F(18) is the absence, in the case of Configuration 341F(18), of roll ratchet oscillation in roll acceleration. The pilot comments for Configuration 341F(18) note the good roll attitude response and almost ideal roll sensitivity. A pilot rating of 1 was given for the LATHOS tracking portion of this evaluation.

Statistics were calculated from the HUD tracking tasks. These data are examined briefly to uncover tracking differences possibly due to experimental factors. The experiment was not designed nor was it intended to develop statistically significant data for tracking performance and/or pilot modeling based on the HUD tracking tasks. The cost of such an endeavor would be prohibitive and the results would likely be inconclusive since individual piloting differences, such as those shown in these data, were very significant. This experiment was designed for flying

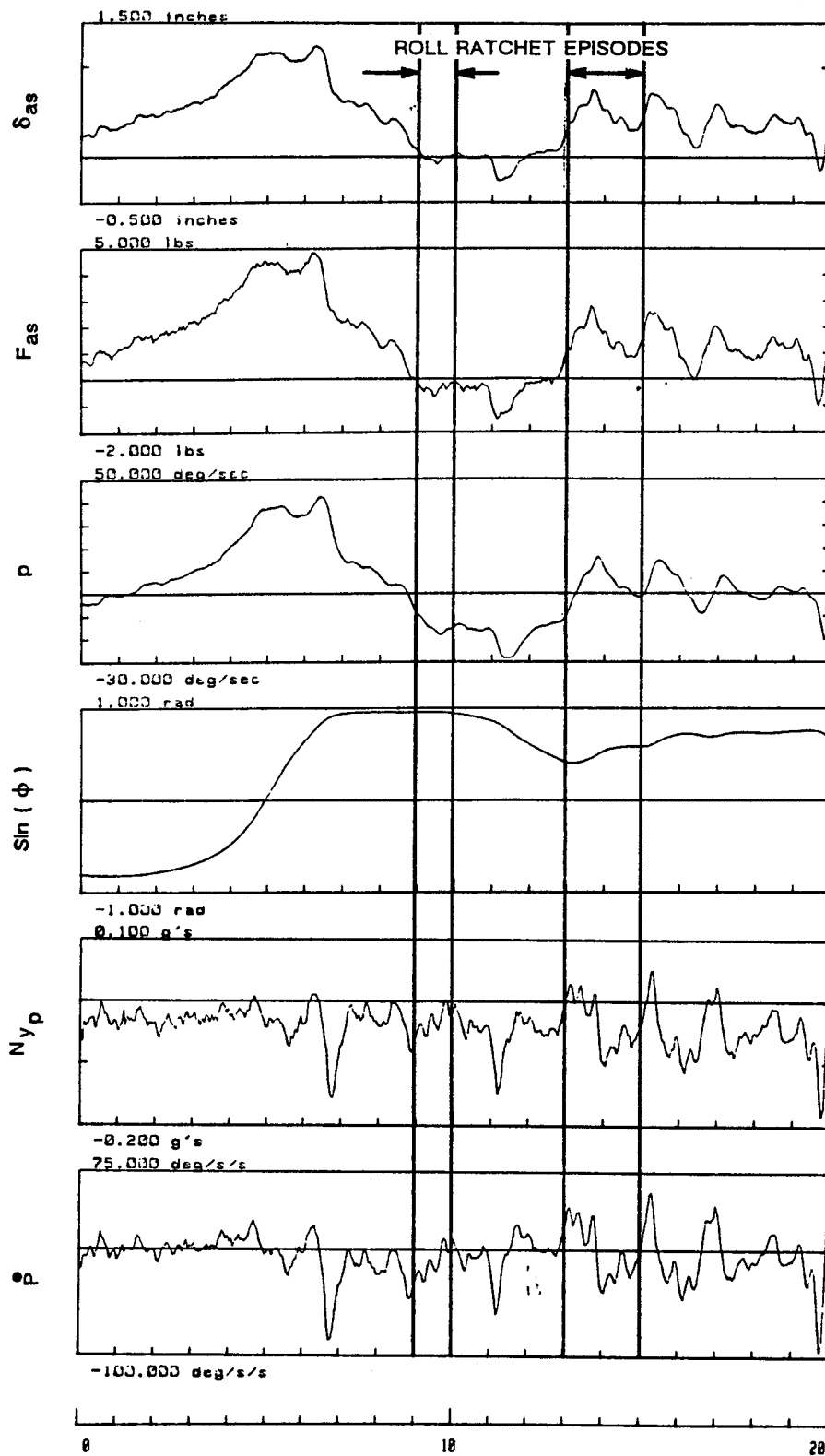


Figure 40 FLIGHT #4069, REC #10; CONFIG: 141F (10), GUN TRACKING BY PILOT A

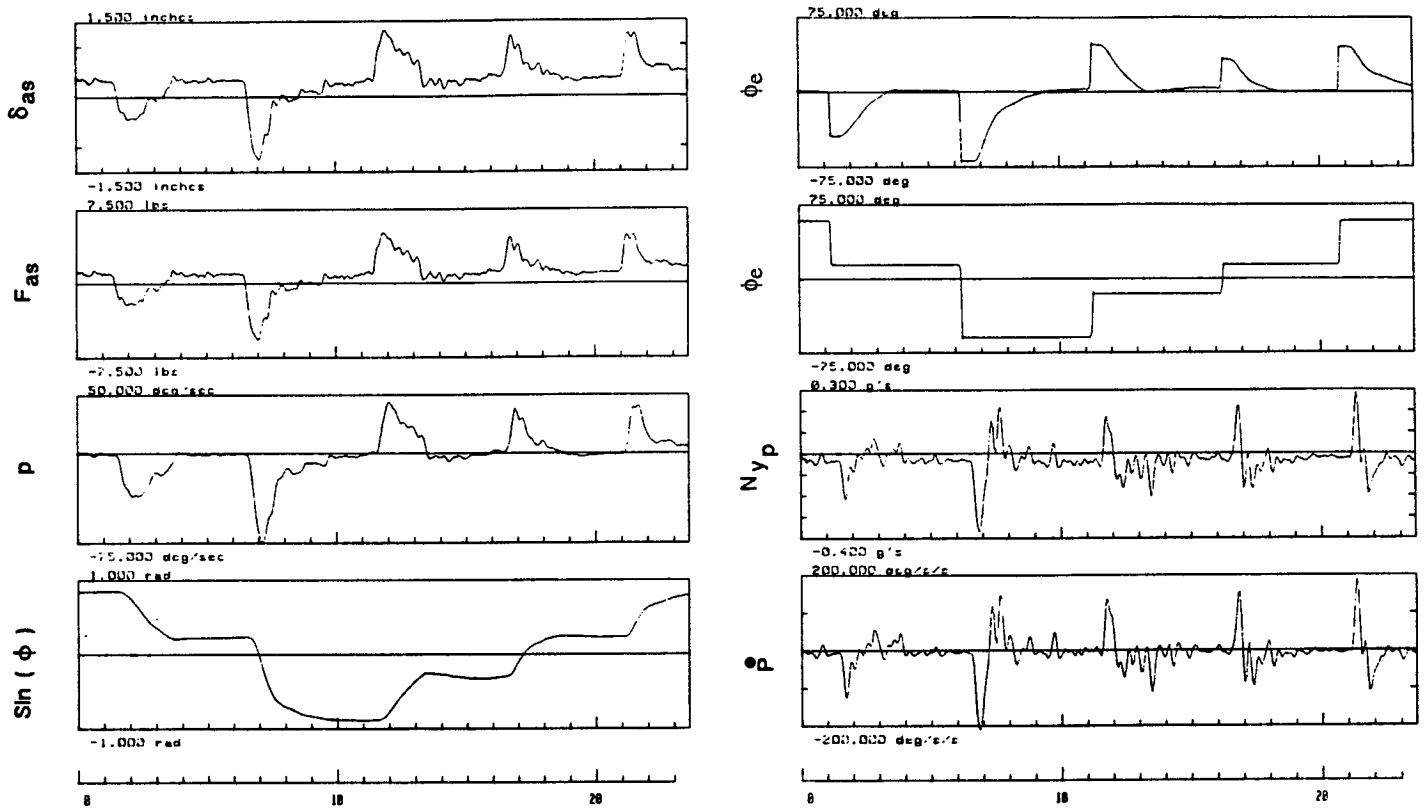


Figure 41 FLIGHT #4069, REC #12; CONFIG: 141F (10), LATHOS TRACKING

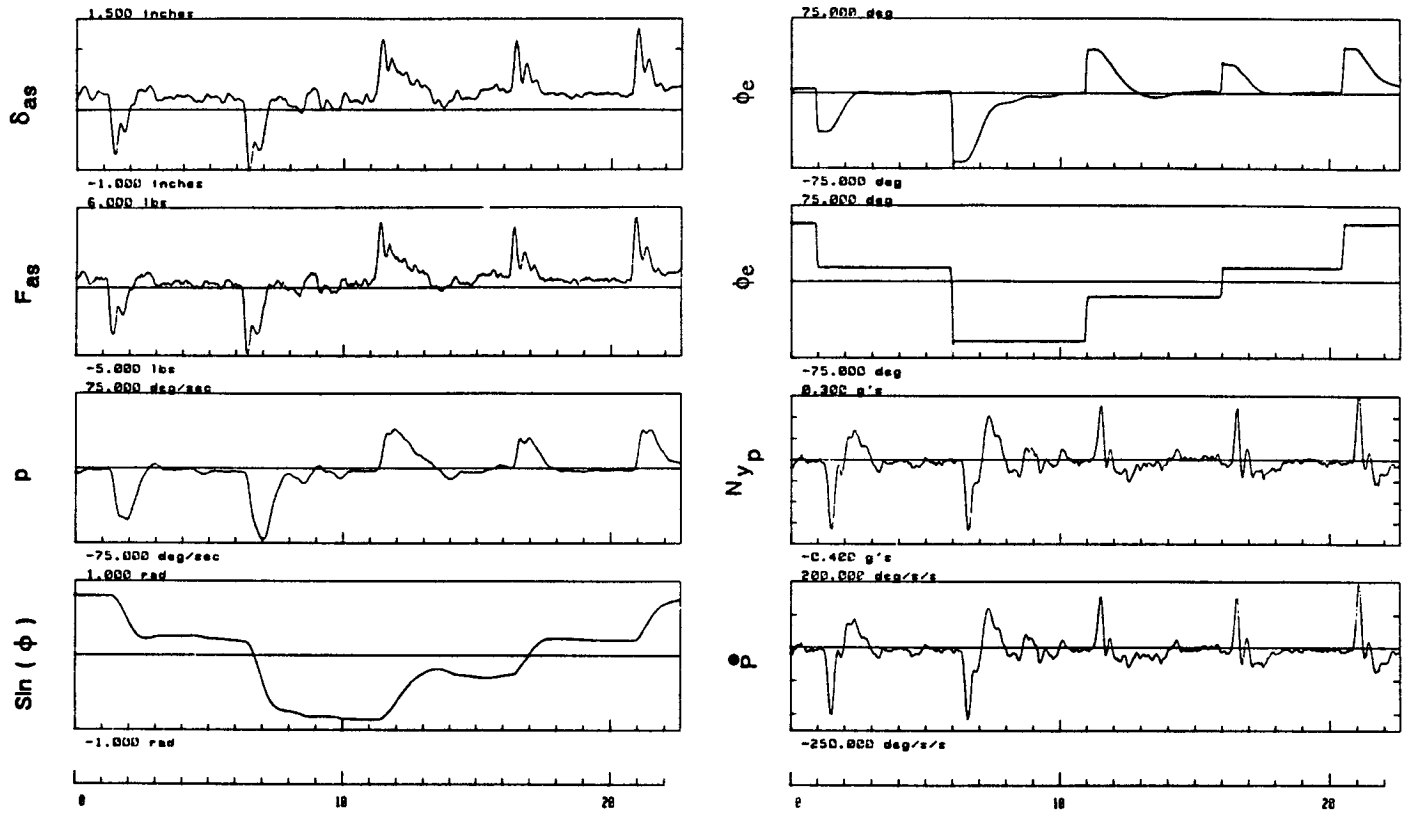


Figure 42 FLIGHT #4176, REC #12; CONFIG: 341F (18), LATHOS TRACKING



qualities research and the tracking data shown here, are used to illustrate and reiterate the subjective flying qualities data rather than provide statistically significant tracking data correlations.

Four performance measures were calculated from the roll sum-of-sines tracking tasks: (1) NRMSE, normalized rms error ( $\text{rms}\phi_e/\text{rms}\phi_c$ ); (2) crossover frequency: the estimated frequency at which the  $Y_p Y_c$  frequency response crosses 0 dB amplitude; (3) phase margin: the estimated difference in phase between the  $Y_p Y_c$  phase at crossover frequency and  $180^\circ$ ; and (4)  $\sim \dot{F}_{as}$ : the approximate rate of change of roll centerstick force (an approximate measure of control activity). The frequency response measures were computed using a describing function analysis of the roll sum-of-sines task. The crossover frequency and phase margin were estimated from the frequency response data using a least squares data fit. The nomenclature,  $Y_p Y_c$ , denotes the open-loop transfer function of the system sketched in Figure 43 and follows the crossover model development of Reference 19, for example.

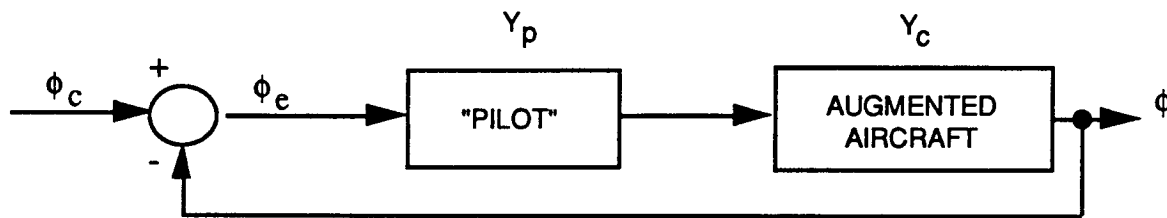


Figure 43 OPEN-LOOP DESCRIBING FUNCTION  $Y_p Y_c$

The HUD task tracking statistics show very slight differences due to configuration and pilot. There is a general trend of decreasing rms roll error as the roll mode time constant decreases and for increased roll command gain (e.g., Configuration 341F(10) to 141F(18)). As expected from the tracking error data, the crossover frequency increased slightly although not significantly (less than 10%) as the configuration roll mode time constant decreased. Phase margin and control activity differences were not significant. The statistical differences between configurations are not nearly as great as the pilot opinion (subjective rating) differences. These differences, once again, demonstrate that tracking statistics are not the complete picture of flying qualities, thus analysis of tracking data alone can be misleading in flying qualities analysis.

The describing function data are presented as examples. The effect of roll mode time constant variations are shown by the open-loop,  $Y_p Y_c$ , in Figure 44 and 45 for the roll SOS task for Pilot A and B, respectively. The change in roll mode time constant did not produce any significant changes in the frequency response data at low frequencies. The crossover frequency and phase margin are essentially unchanged although the crossover is slightly greater for the shorter roll mode time constants. At the highest frequencies (between 10 to 20 rad/sec), the short

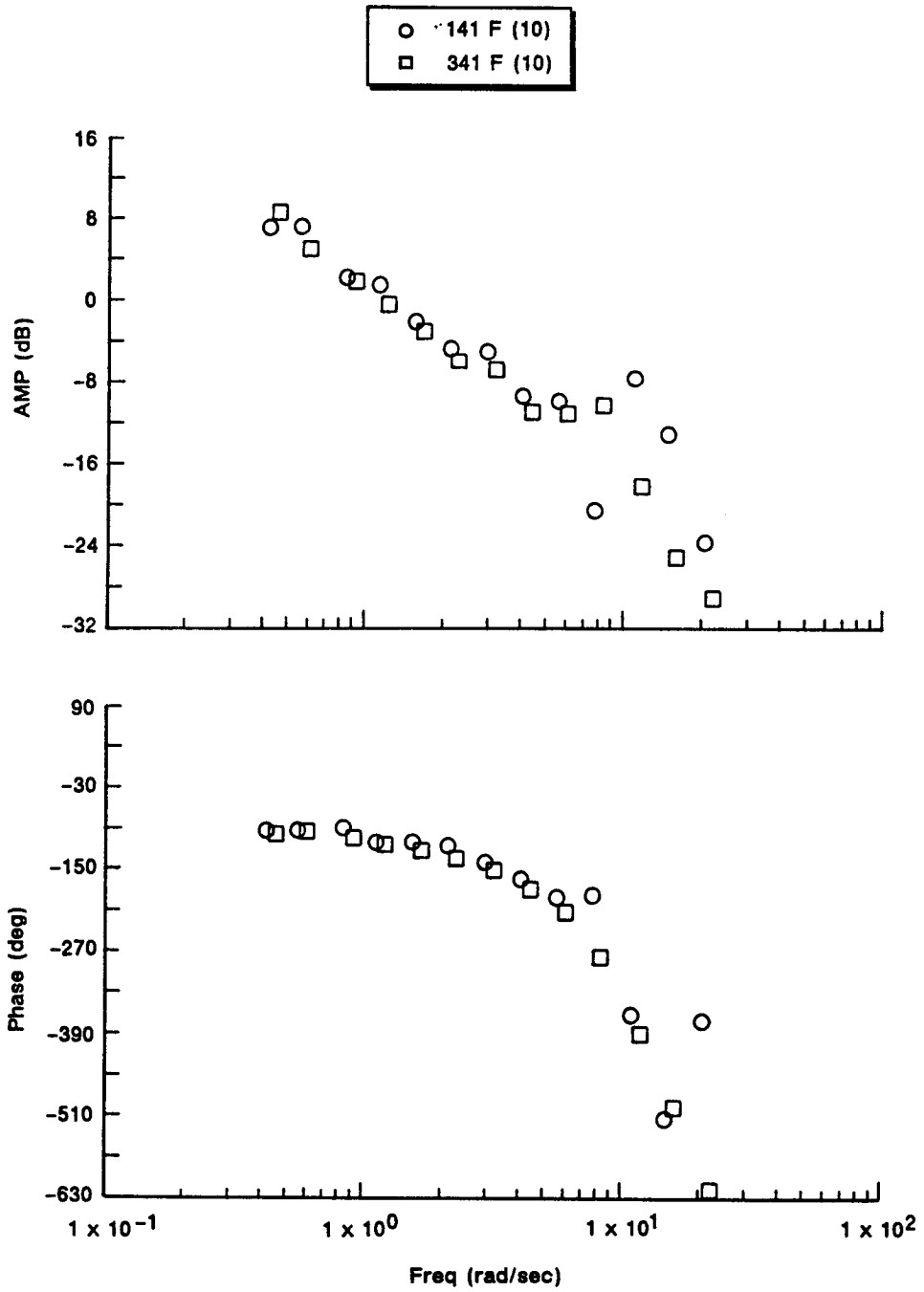


Figure 44 EFFECT OF ROLL MODE TIME CONSTANT, PILOT A

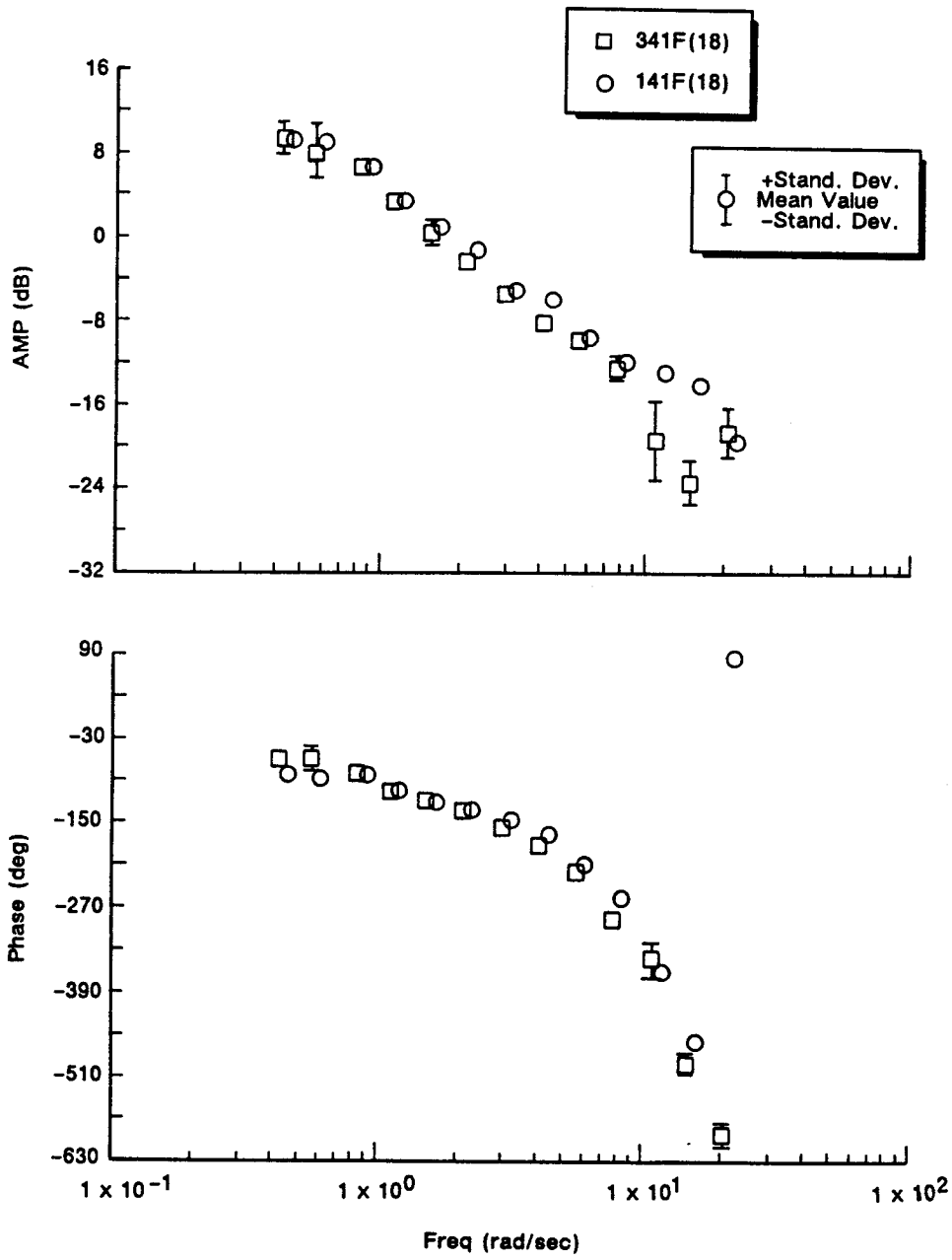


Figure 45 EFFECT OF ROLL MODE TIME CONSTANT, PILOT B

C-2

roll mode time constant configurations exhibit a slight "peaking" tendency in amplitude response in comparison to the longer roll mode time constants. It has been suggested that this peaking tendency marks the occurrence or potential for roll ratchet. (Reference 11). However, the rapid falling-off in phase and the very low amplification levels do not support that this peaking tendency is indicative of a pilot-induced oscillation. Also, the peaking tendency is quite different between pilots A and B.

The influence of the different tasks are shown in the open-loop  $Y_p Y_c$  frequency response data of Figure 46. For Pilot B tracking with Configuration 141F(18), the frequency response data in the roll SOS are compared to the LATHOS task. The crossover frequencies obtained in the LATHOS task are significantly lower ( $\sim 1$  rad/sec versus  $\sim 1.9$  rad/sec) than the roll SOS task. The peaking tendency in amplitude at the higher frequencies is also significantly greater for the roll SOS task. These different task features are consistent in all of the data for this mini-experiment.

From this comparison, two observations are made:

- The roll SOS task evoked higher levels of aggressiveness in the task (higher crossover frequencies which are approximately equivalent to the closed-loop system bandwidth) than the LATHOS task.
- The reduced peaking tendency in amplitude of the LATHOS task suggests a reduced roll ratchet potential based on the work of Reference 11 and 12.

The first bullet supports the subjective data that claim the roll SOS task was a primary determinant of the overall pilot rating. The roll SOS was flown by the pilots in a more aggressive and with less specialized control techniques than the LATHOS task. Consequently, this task provides a good flying qualities test for a configuration.

The second bullet refutes the contention of the frequency response methodology proposed in Reference 11 for "prediction" of roll ratchet. Roll ratchet, as shown in Figure 41, clearly occurs in the LATHOS task yet the peaking tendency derived from the describing function frequency data is minimal. From inspection of time histories, the roll ratchet oscillation is time-varying and therefore, frequency data obtained from linear, "steady-state" describing function analysis are not sufficient in adequately defining roll ratchet potential. Describing function data are examined further in Section 6 with regard to understanding the pilot control behavior.

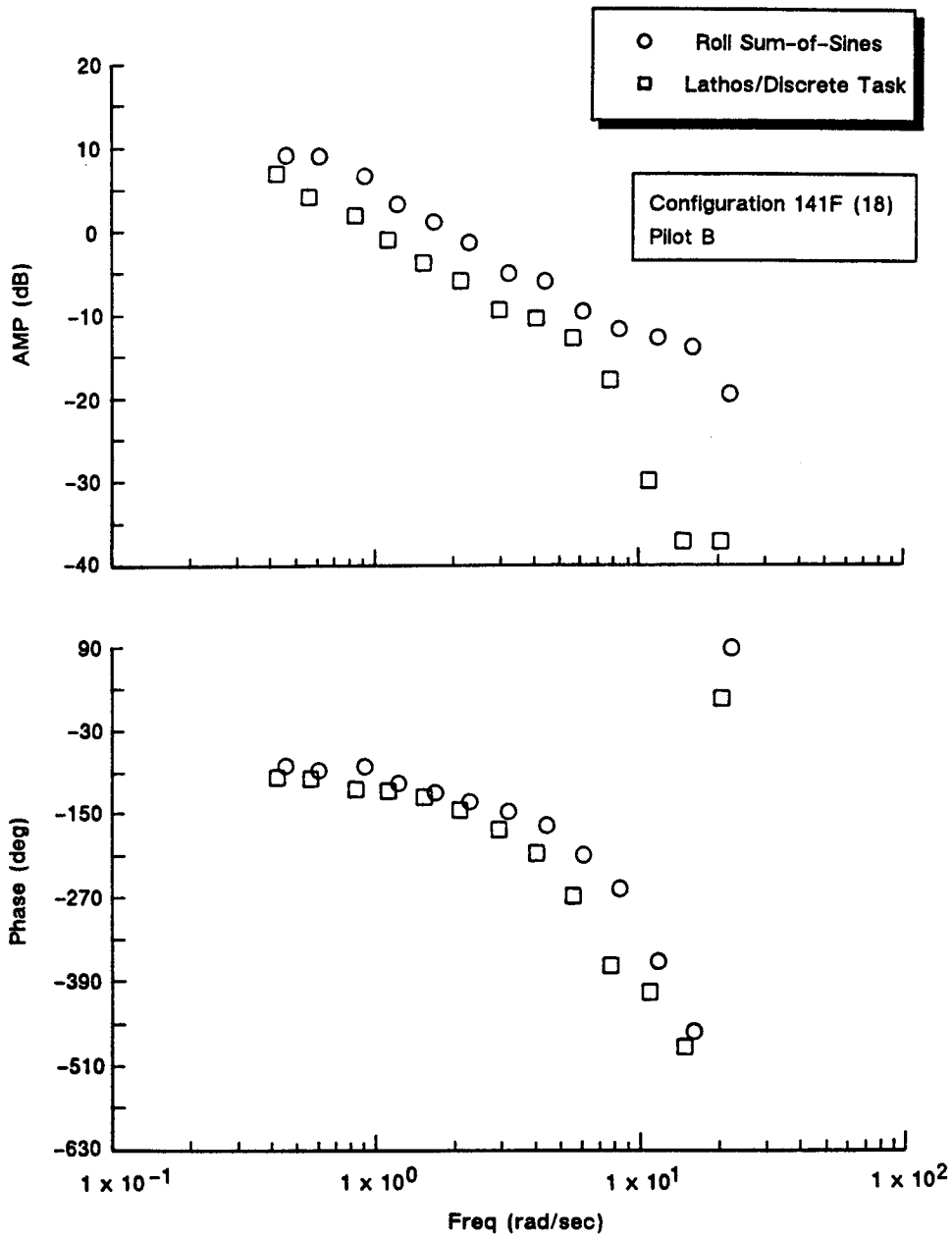


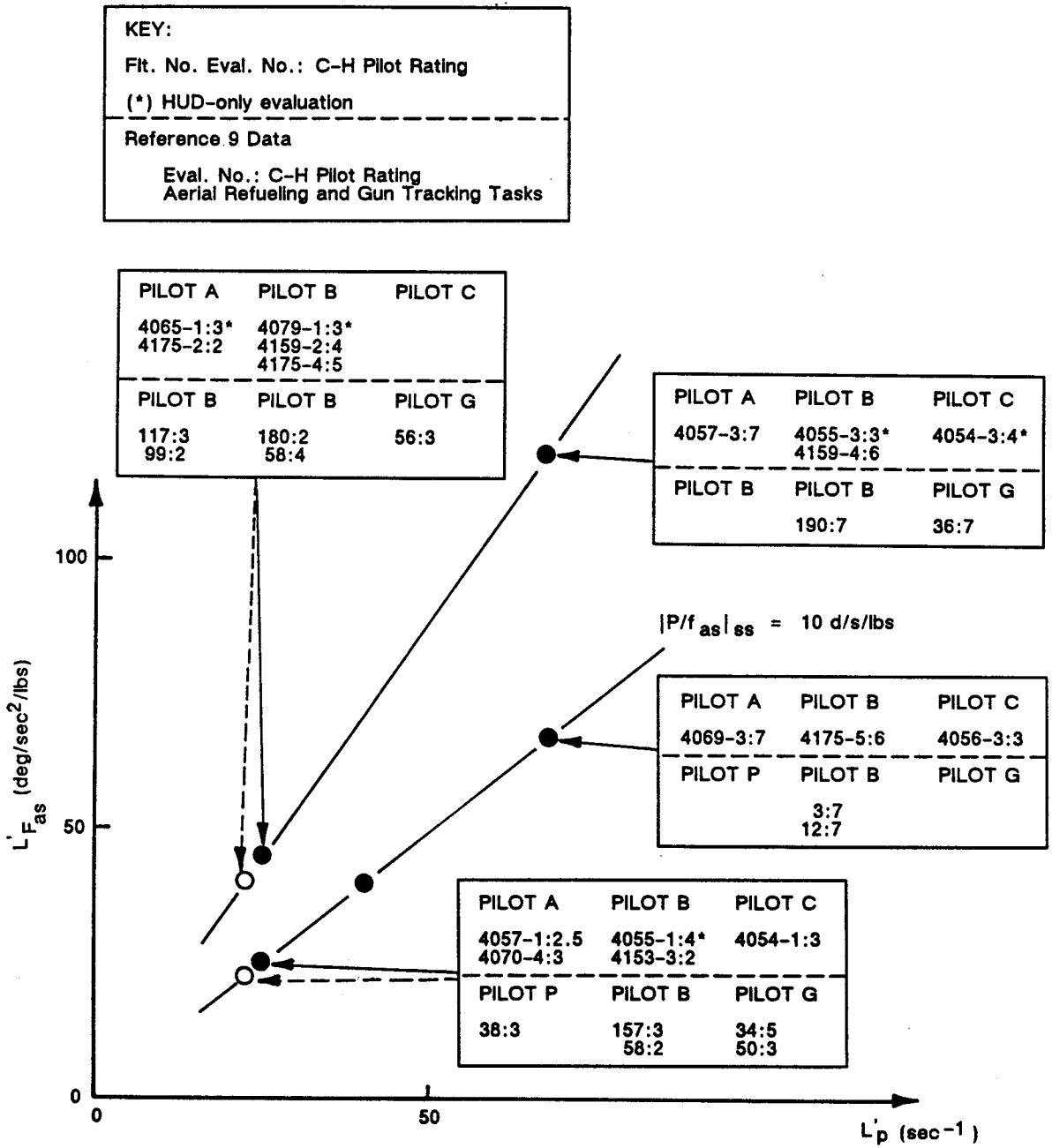
Figure 46 EFFECT OF  $Y_p Y_c$  DESCRIBING FUNCTION; PILOT B

Finally, the pilot rating results from this mini-experiment are compared to the LATHOS (Reference 9) data in Figure 47. Overall, very good agreement is attained. The pilot commentary from the two separate experiments are also quite similar. In particular, the subjective trade-off between task performance and pilot acceptance of roll abruptness for control inputs is consistent in both data bases at the short roll mode time constant values (high roll damping). This favorable comparison of subjective pilot evaluations lends credence to the results of this experiment and substantiates the database for a larger pilot population (6 evaluation pilots).

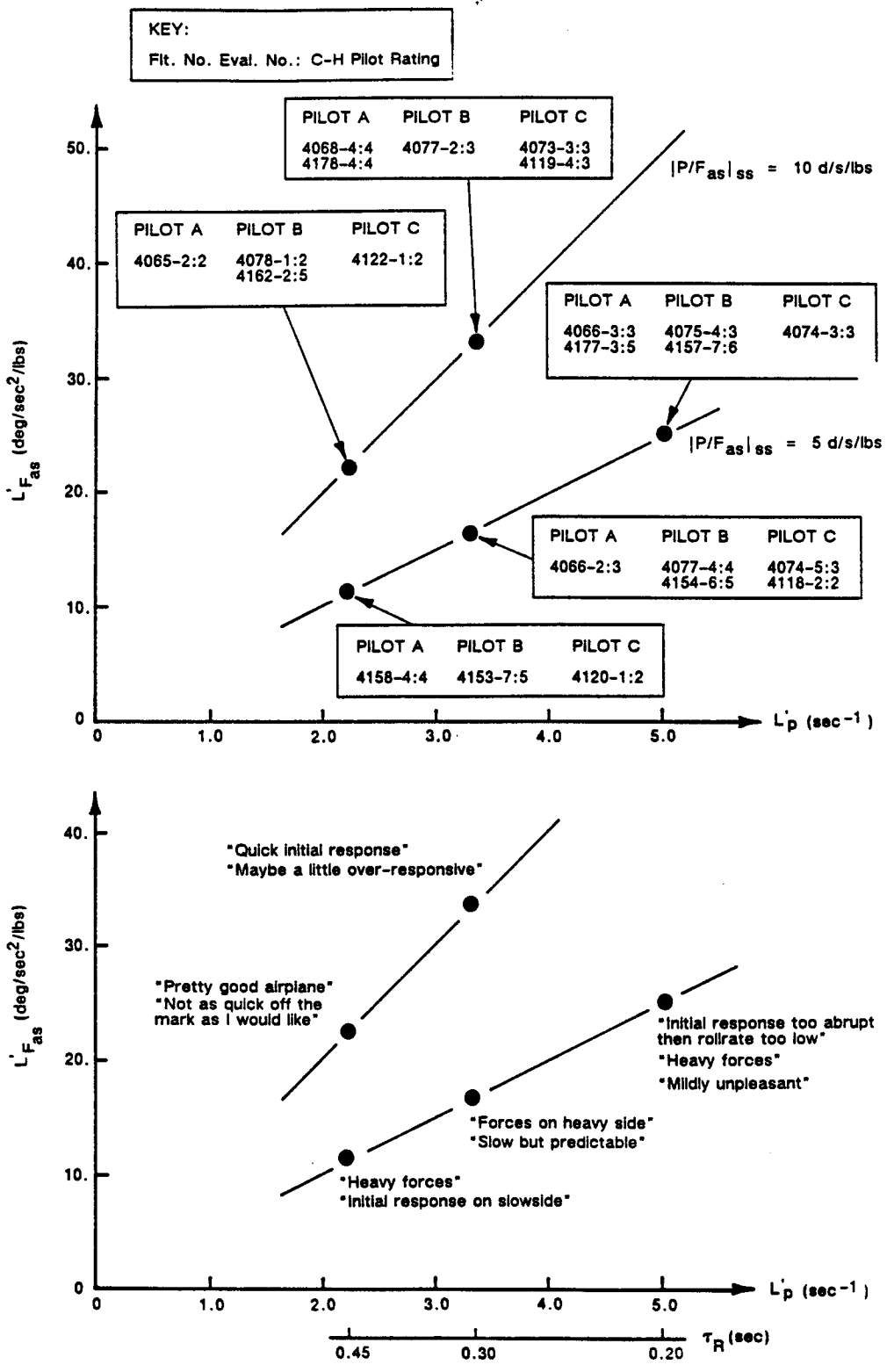
### 5.1.2 Power Approach Task Results

The pilot rating data obtained in the power approach task is presented in Figure 50 for Mini-Experiment #1. A synopsis of the pilot commentary is also given. In this trade-off between roll damping and roll command authority, Level 1 (pilot ratings  $\leq 3\frac{1}{2}$ ) flying qualities were generally witnessed. The Level 2 ratings that were given highlight the roll response extremes represented by these configurations and, thus, indicate where flying qualities degradation begins. For instance,

- At  $|p/F_{as}|_{ss} = 5$  deg/sec/lbs, heavy forces are a general comment and complaint. With this control authority at the longest roll mode time constant, the roll response is too slow and Level 2 ratings predominate.
- As the roll mode time constant decreases along this constant steady-state performance level, the roll response becomes improved but then degrades again as a mismatch between the initial and final responses occurs. At the .20 roll time constant value, the pilot complaint is that the initial roll response is abrupt but the sustained roll rate of 5 deg/sec/lbs is too low. Greater stick force inputs to increase the roll rate performance are needed but this aggravates the initial abruptness; hence, a mild (Level 2) flying qualities conflict arises between steady-state and initial roll response requirements.
- At the 10 deg/sec/lbs steady-state roll performance level, the control forces in the task are relatively light. As the roll mode time constant decreased to .30 sec, Pilot A complained of over-responsiveness in roll and downgraded the configuration accordingly.



**Figure 47 COMPARISON OF MINI-EXPERIMENT NO. 1 RESULTS TO LATHOS (REFERENCE 9) EXPERIMENT DATA; FLIGHT PHASE CATEGORY A**



**Figure 48 PILOT RATING DATA FOR MINI-EXPERIMENT #1, POWERED APPROACH TASK**



These results are compared to the LATHOS data (Reference 9). The pilot rating comparison, shown in Figure 49, indicates good agreement between the two data bases on the average. Level 2 flying qualities were given in Reference 9 only at the high roll damping, low sustained roll rate configuration from Reference 9. The data from this experiment corroborate these ratings. There does appear to be some pilot preferences/rating differences for the lower roll command gains and longer roll mode time constants, although the disagreement is mild.

## 5.2 LATHOS EXTENSION

Nineteen evaluations of 6 configurations from Mini-Experiment #2 provide data for clarification of design criteria established from the LATHOS program. Using a force command architecture, pure delay was added to the control system of three augmented aircraft configurations performed.

The pilot rating data are plotted in Figure 50 according to the total equivalent time delay. The experiment configurations are labeled as appropriate. Pure delay was added experimentally to three configurations although, for Configuration L241F(5), only one time delay point was investigated.

The pilot rating data show degrading effects of control system time delay; however, some anomalous ratings distort the trends. For both Configurations 241F(10) and L141F(5), no rating degradation occurs from the addition of 55 msec delay. (In fact, some anomalous rating improvements are shown by this experimental variation.) At 175 msec total time delay (110 msec added delay), the ratings degrade but the variation in ratings is substantial. The ratings vary between 4 and 8 for Configuration L241F(10) and between 4 and 7 for Configuration L141F(5). Clearly, flying qualities at this delay level are not Level 1 but, depending upon the pilot control techniques or level of aggressiveness exhibited by the different pilots, Level 3 flying qualities characteristics may or may not occur. For Configuration L141F(5), 175 msec of delay (240 msec total delay) was added and evaluated. Pilots A and C gave Level 3 ratings; in fact, Pilot C was not able to perform a landing out of the lateral offset maneuver. Pilot B anomalously indicated flying qualities improvement by the addition of delay from 175 to 240 msec total equivalent delay. (The evaluation configurations were not known by the pilot and, therefore, they had no knowledge of the configuration characteristics or their previous ratings) The Level 2 ratings are anomalous and are not considered to be indicative of the configuration flying qualities.

KEY:  
 Flt. No. Eval. No.: C-H Pilot Rating  
 -----  
 Reference 9 Data  
 Eval. No.: C-H Pilot Rating

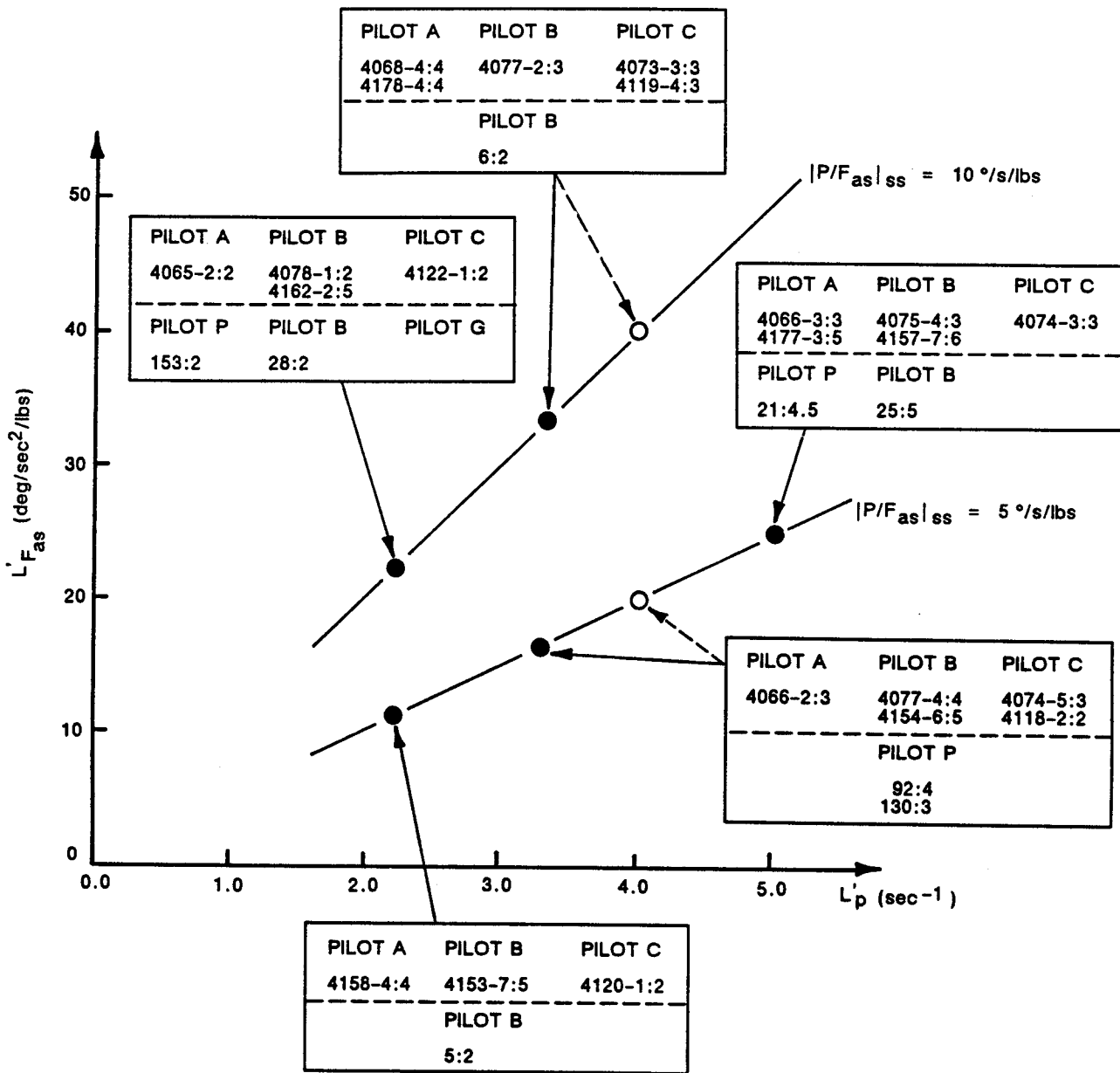
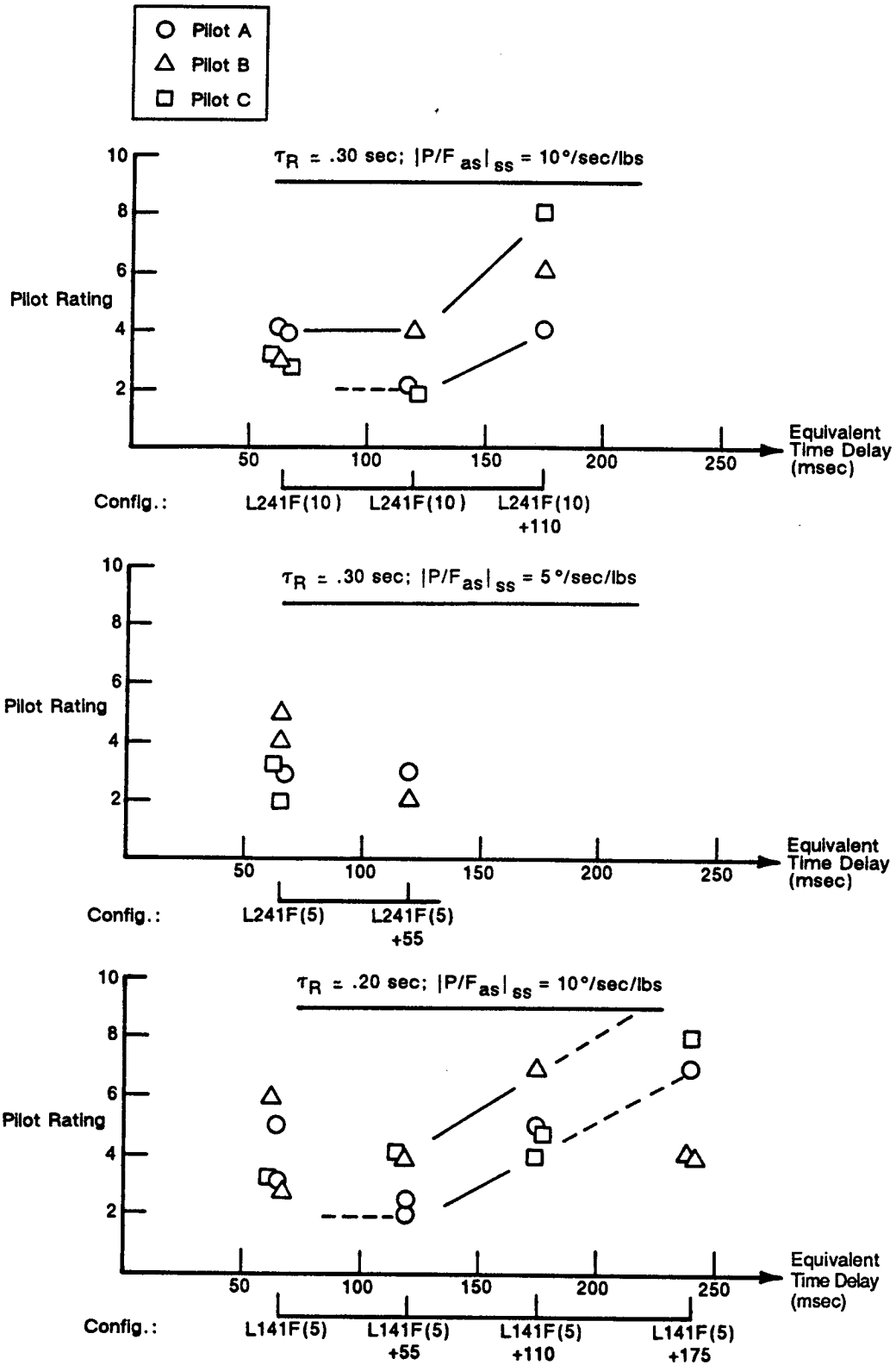
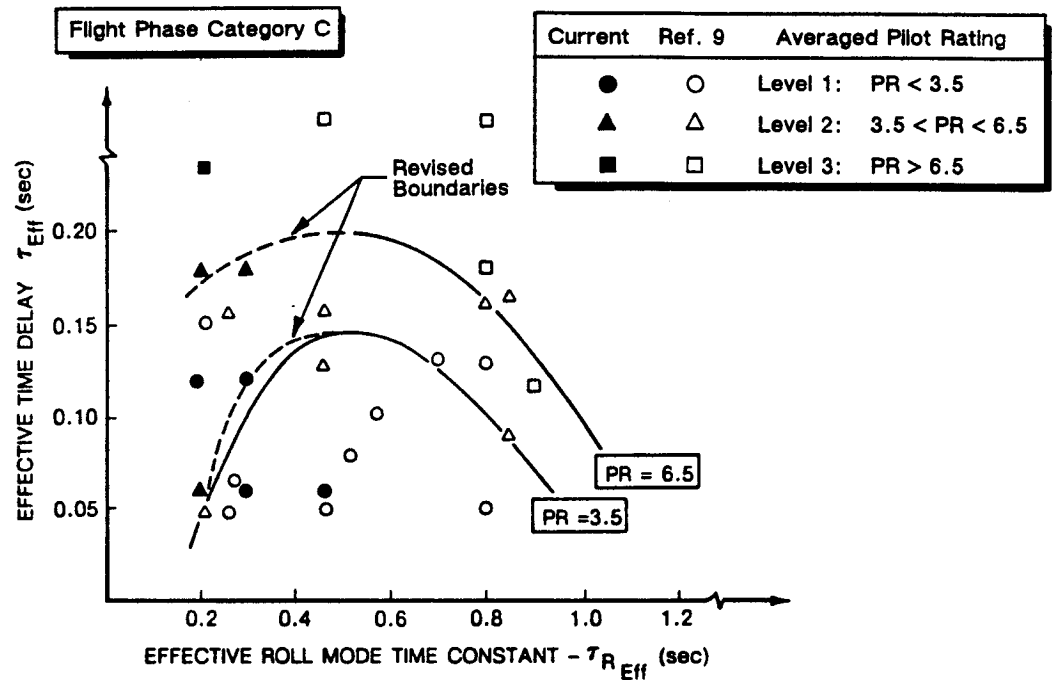


Figure 49 COMPARISON OF MINI-EXPERIMENT NO. 1 RESULTS TO LATHOS (REFERENCE 9) EXPERIMENT DATA; FLIGHT PHASE CATEGORY C



**Figure 50 PILOT RATING DATA FOR MINI-EXPERIMENT #1, CATEGORY C, ACCORDING TO TOTAL EQUIVALENT DELAY**

These data are compared to the flying qualities criterion developed in the LATHOS program in Figure 51. Averaged pilot rating data determined the flying qualities levels plotted for comparative purposes - however, the underlying data (ratings and comments) must be referenced and understood. For instance, both the LATHOS and current program data, by using averaged pilot rating, show an anomalous rating improvement at the .20 effective roll mode time constant with increased time delay. By review of the pilot rating and comments, these data points actually represent borderline Level 1/Level 2 flying qualities characteristics.



**Figure 51 DATA COMPARISON TO LATHOS (REF. 9) DESIGN CRITERION WITH PROPOSED REVISIONS**

Revision to the design criterion of Reference 9 can be proposed based on these data: (1) the Level 1 ( $PR=3\frac{1}{2}$ ) boundary can be extended to show more tolerance to short roll mode time constants; and (2) a Level 2 boundary definition can be extended to include the latest data. Good separation of the data are drawn by the proposed boundaries with the exception of the anomalous rating improvements for added time delay at the .20 roll mode time constant value.

This design criterion establishes the dynamic shape of the roll response to a cockpit control step input but the criterion does not specify the roll command authority or any command shaping gradient. This criterion specifies the roll dynamic response shape for best roll flying qualities assuming "optimum" command gains. This criterion is, therefore, a necessary but perhaps not sufficient prerequisite for good roll flying qualities. Additional criteria are needed as

well. Also, the criterion is founded from data using a force command architecture with "fast" and thus, transparent feel system characteristics. The influence of these factors is addressed in the following sections.

### **5.3 EFFECT OF FEEL SYSTEM DYNAMICS**

The effect of feel system dynamics were investigated when the feel system was either in series or in parallel with the forward command path. A force command architecture (parallel feel system), identical to the control system of the first two mini-experiments, was employed in Mini-Experiment #3. These results are presented in the next section, followed immediately by the effects of feel system dynamics when the feel system is in series with the forward command path (Mini-Experiment #5).

#### **5.3.1 Feel System Dynamics in a Force Command System**

Eighteen evaluations of 8 configurations aid in establishing the influence of feel system dynamics on flying qualities when the feel system is not cascaded in series with the forward command path. The force command system architecture of the two previous mini-experiments was therefore, retained but the feel system natural frequency was reduced to either 13 or 8 rad/sec; thus, the identical forward command path dynamics were flown but the tactile (position) cues transmitted to the pilot from his force input were altered.

##### **5.3.1.1 Up-and-Away Task Results**

The pilot comments during up-and-away evaluations suggest that the feel system variation was not consciously evident to the pilots. No comments were made to the effect that they noticed the feel system characteristics. The pilot rating data, shown in Figure 52, generally substantiates the absence of subjective influence. The comments and ratings were essentially identical for the "slow" as well as "fast" feel system frequencies. The rating changes that did occur were within the expected rating variation or the evaluation tasks were different. The rating data are not plentiful, however, for this flight phase.

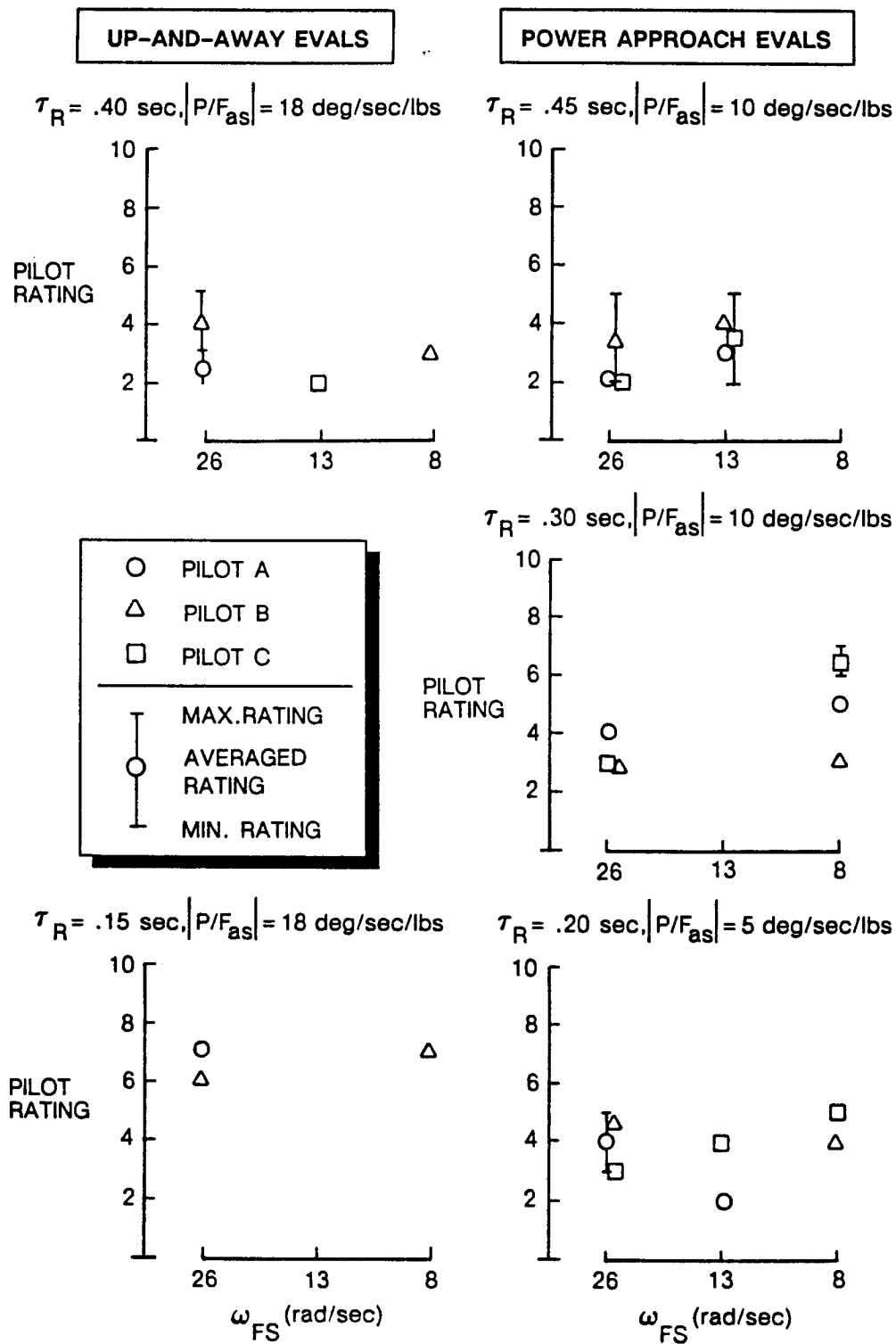
It was hypothesized before testing that reduced feel system frequencies could physically filter pilot inputs; if this is true, abrupt airplane roll responses, often observed for extremely short roll mode time constants, might be ameliorated by the cockpit controller dynamics rather than by use of flight control system filtering. This hypothesis, however, is not supported by the data of

this program for the force command system architecture. For example, the feel system change from 26 rad/sec to 8 rad/sec with the up-and-away evaluation of the .15 sec roll mode constant aircraft (Figure 52) produced a rating degradation for Pilot B from 6 to 7. The feel system variation from 26 to 8 rad/sec actually produces a greater, not lower, tendency for abrupt roll acceleration characteristics and an increased propensity for roll ratchet tendencies based on the subjective pilot comments. The time history comparison in Figure 53 also shows a greater high frequency oscillatory character ("roll ratchet" tendency) with the slow feel system configuration than with the faster, "transparent" feel system for the same task. This tendency is most evident in the stick force and roll angular acceleration traces. In analyzing the sum-of-sines tracking data, however, the tendencies for roll ratchet are not apparent in the open-loop frequency response ( $\phi/\phi_e$ ) of the compensatory tracking situation, as illustrated in Figure 54. The frequency responses show little difference at high frequency and only a slight change in crossover frequency (1.50 vs. 1.85 rad/sec for the 8 rad/sec feel system compared to the 26 rad/sec feel system). These data do not support the frequency response roll ratchet criteria of Reference 11 since the ( $\phi/\phi_e$ ) amplitude response of 26 rad/sec system looks very nearly the same as the amplitude response of the 8 rad/sec system even though the 8 rad/sec system had greater roll ratchet tendencies.

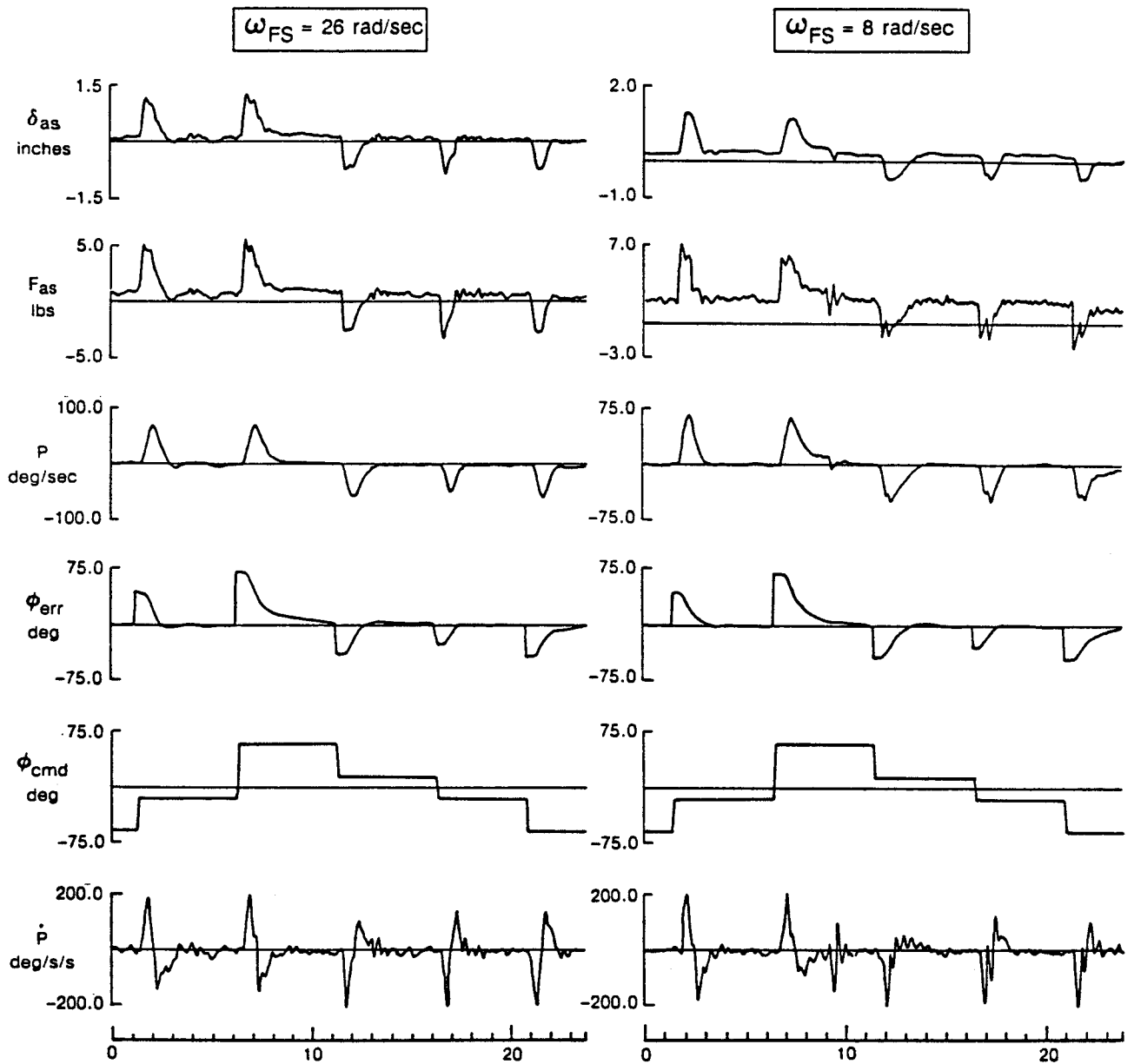
At the slower, .40 sec roll mode time constant, the feel system variation was, again, perceptually transparent. Neither the pilot ratings (Figure 52) nor comments describe any flying qualities changes because of feel system variations.

### 5.3.1.2 Power Approach Task Results

For power approach evaluation tasks, reduced feel system frequencies generally produced a flying qualities degradation. One case (Configuration L141F(5), Pilot A) showed an improvement in a 13 rad/sec feel system over a faster feel system. With a 13 rad/sec feel system, the pilot comments do not note any abnormal feel system characteristics nor any objectionable response of the stick displacements with pilot-applied force inputs. For the 8 rad/sec feel system frequency, however, comments were made concerning the strange "feel" of the stick. The pilots

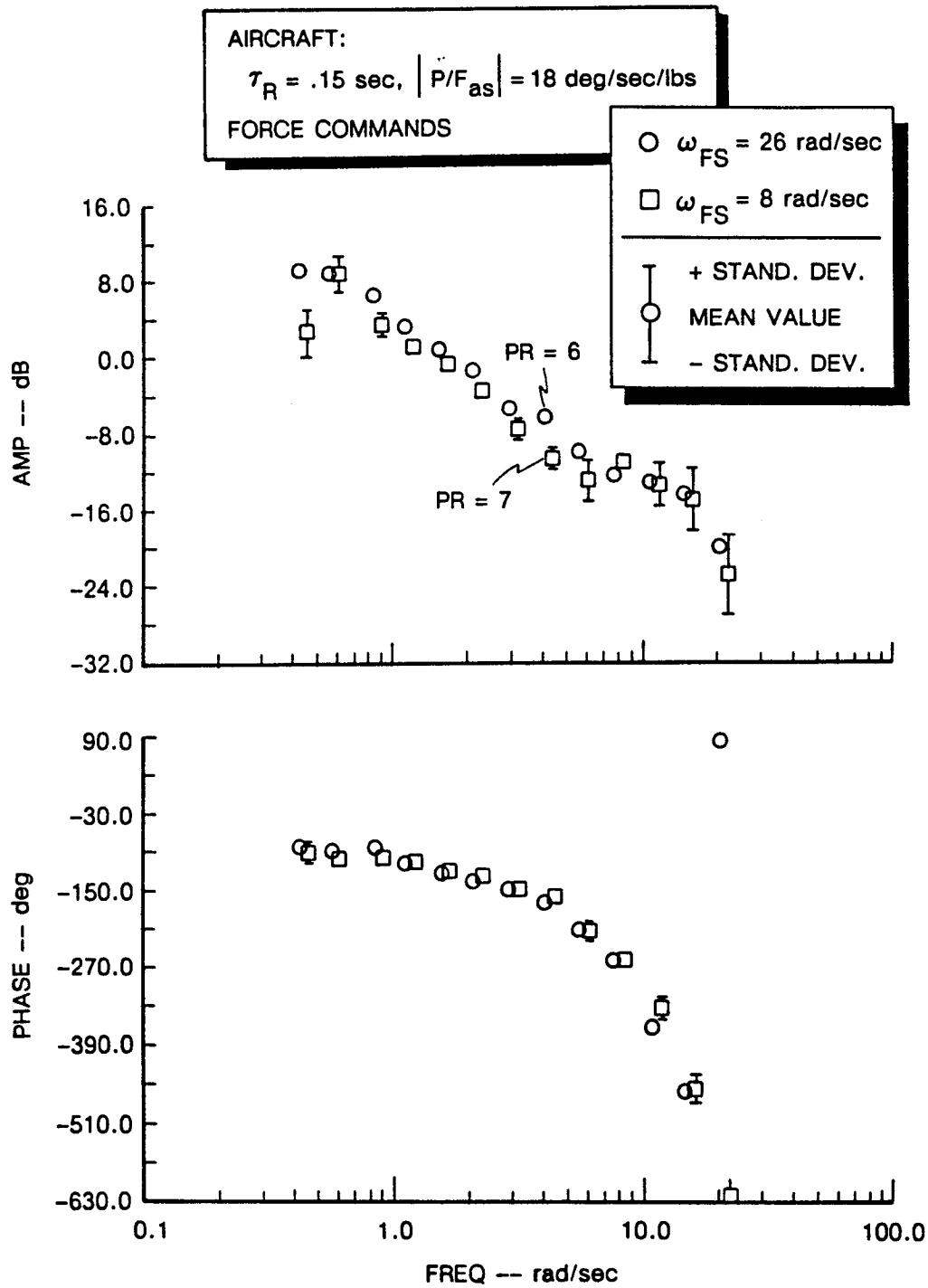


**Figure 52 EFFECT OF FEEL SYSTEM FREQUENCY WITH FORCE COMMAND CONTROL SYSTEM**



**Figure 53 HUD TRACKING TASK TIME HISTORY FOR PILOT B  
WITH  $\tau_R = .15$  sec,  $|P/F_{as}| = 18$  deg/sec AIRCRAFT  
CONFIGURATION, FORCE COMMANDS**





**Figure 54 OPEN-LOOP ( $\phi/\phi_e$ ) FREQUENCY RESPONSE DATA FOR PILOT B DURING SUM-OF-SINES TRACKING TASK**

sometimes described the characteristics as a "bobweight" effect in the stick itself. The flying qualities of these configurations were generally degraded from the fast feel system dynamics although the degree of degradation varies by pilot. Pilot C rated the slowest feel system characteristics as being very degraded from the fastest feel system.

These data highlight how flying qualities can be affected by changes in feel system or controller characteristics. Even though the dynamics of these systems are not part of the "controlled" element, the pilot was affected by the tactile feedback although not always very dramatically. The feel system influence in the power approach was a function of pilot preference.

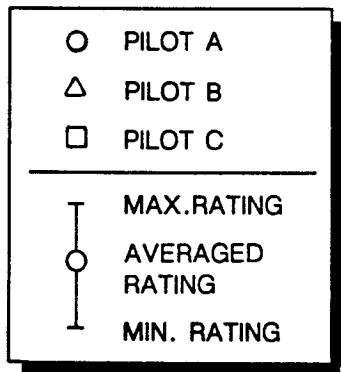
### **5.3.2 Effect of Feel System Dynamics - Position Command Control System**

The results of Mini-Experiment #5 and some configurations from Mini-Experiment #6 are also applicable in investigating the effects of feel system dynamics changes. In these cases, the feel system is cascaded in series with the forward command path (part of the system under pilot control) by virtue of the position command architecture.

#### **5.3.2.1 Up-and-Away Task Results**

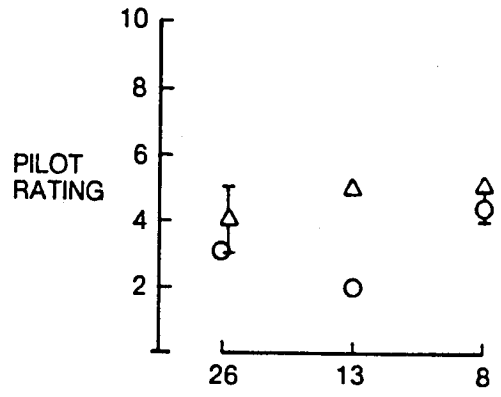
The pilot rating data are plotted in Figure 55 for up-and-away evaluations in which the feel system frequency was varied in position commands. The rating and comment data indicate that:

- As the feel system frequency decreases to 13 rad/sec from 26 rad/sec, no significant change in pilot rating data occurs. Only subtle changes in the pilot commentary are evident which show that some change was noticed. However, pilots were not consciously aware that the change was produced by the slower feel system dynamics.
- As the feel system frequency decreases further to 8 rad/sec, adverse pilot opinions and ratings occur. The pilot comments note a "funny" stick feel for which they object and peculiar closed-loop response characteristics, such as nonlinear response to control inputs. PIO was a concern.



UP-AND-AWAY EVALS

$$\tau_R = .40 \text{ sec}, |P/F_{as}| = 18 \text{ deg/sec/lbs}$$



$$\tau_R = .25 \text{ sec}, |P/F_{as}| = 18 \text{ deg/sec/lbs}$$

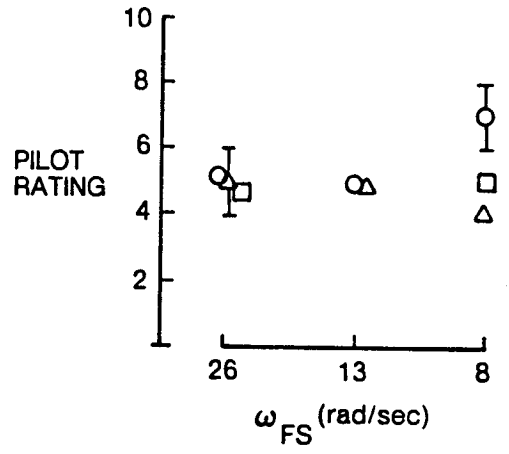
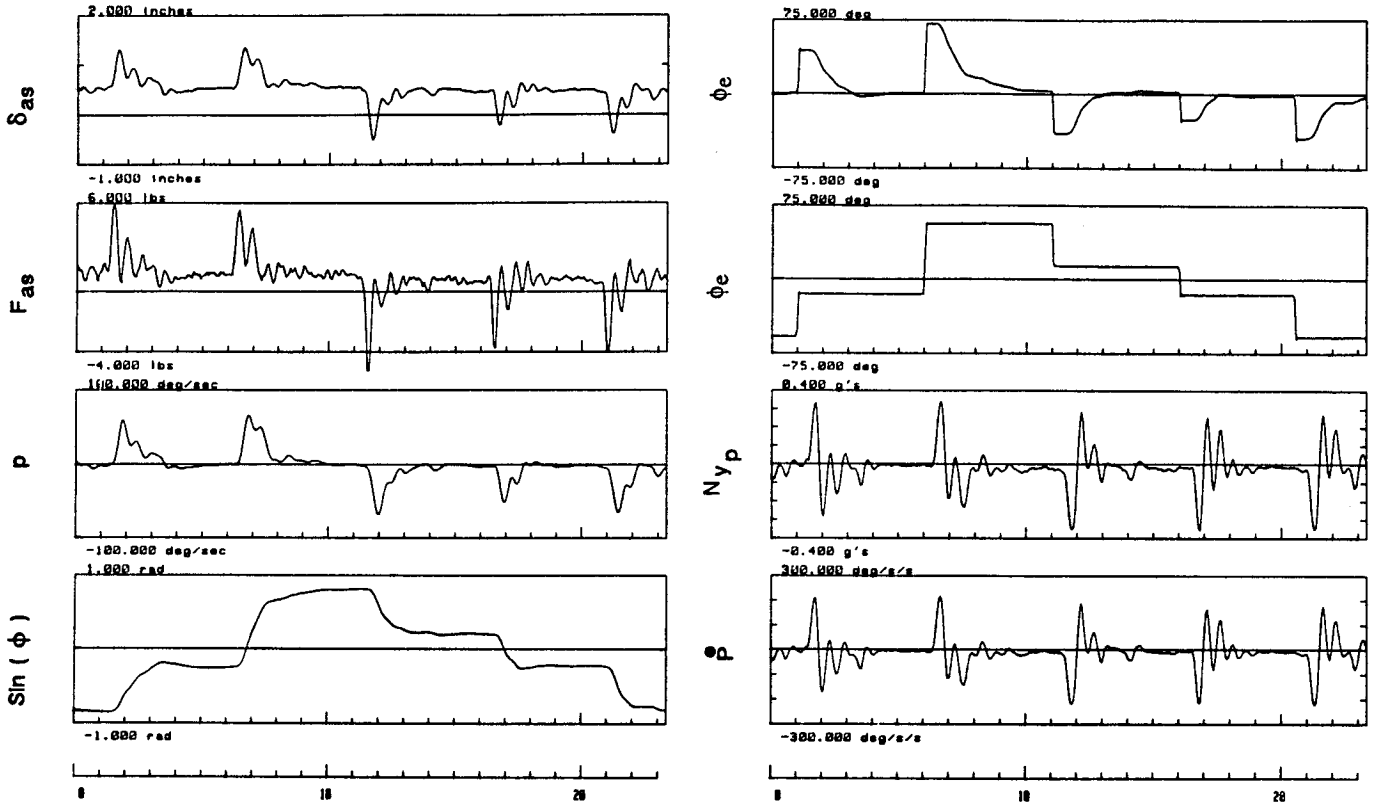


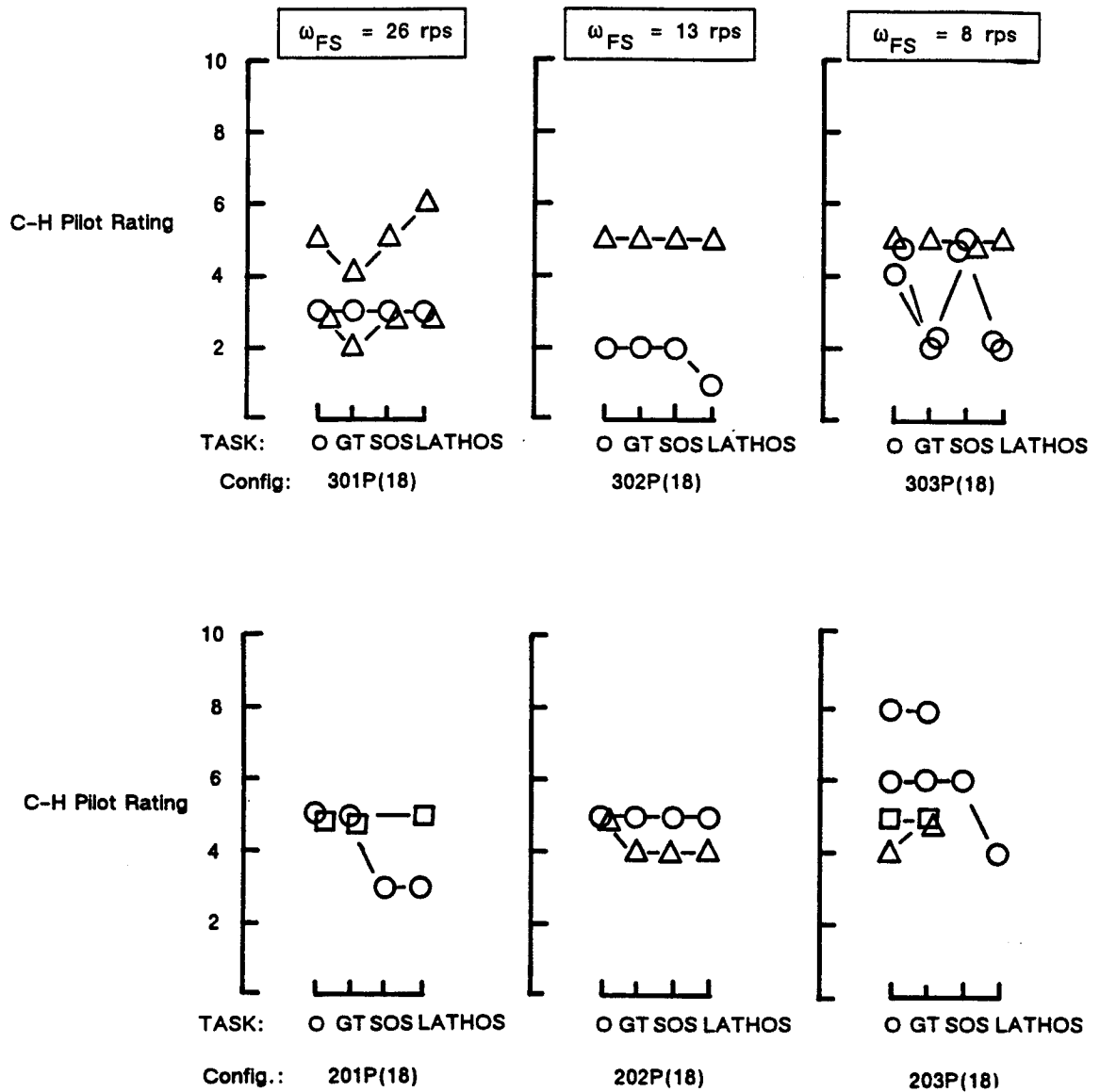
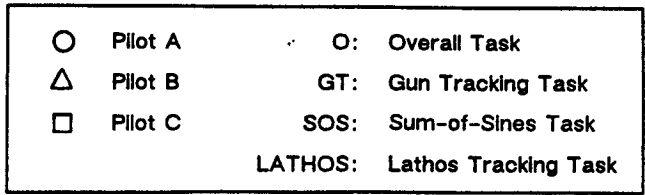
Figure 55 EFFECT OF FEEL SYSTEM FREQUENCY WITH POSITION COMMAND CONTROL SYSTEM FOR UP-AND-AWAY TASK

- The effect of the feel system variation was without apparent influence from the aircraft roll mode time constant.
- A slower feel system dynamic response does not ameliorate abrupt roll response by physically filtering the pilot inputs as was initially hypothesized. Configuration 143P(18) was twice rated as having control in question because the roll ratchet was so severe. In fact, the 8 rps stick may have exasperated the roll ratchet tendencies. The LATHOS tracking time history of Figure 56 shows severe "bursts" of pilot induced oscillation occurring during the roll deceleration toward a roll command. The oscillations, at a frequency of about 16 rad/sec, were described as an "unavoidable roll ratchet."
- The feel system influence may be dependent upon pilot preference, pilot technique, and task. The pilot rating data for the individual up-and-away tasks show inconsistent trends across both pilot and task. For Pilot A, the roll SOS task dictated the overall configuration rating for 303P(18). Conversely, the overall rating for 201P(18) was derived primarily from the air-to-air task. Pilot B showed different tendencies.

The influences of the feel system are illustrated using the open-loop describing function data ( $Y_p Y_c$ ) for Configurations 301P(18) and 303P(18) from the roll SOS tracking task (Figure 58). As the frequency response data show, very similar low frequency characteristics and task performance were attained (crossover frequency of 1.8 rad/sec versus 1.4 rad/sec for Configuration 301P(18) and 303P(18), respectively). However, the high frequency, pilot-vehicle system characteristics are altered by the feel system change. In particular, an oscillatory (PIO) potential at approximately 8 rps is apparent in the frequency response data due to by the feel system reduction from 26 rps to 8 rps. The data show a gain in the  $Y_p Y_c$  frequency data of 0.0 dB with a phase lag of greater than 180 degrees. The pilot ratings do not, however, reflect a PIO tendency or extremely adverse flying qualities.



**Figure 56 FLIGHT #4176, RECORD #16; CONFIGURATION 143P (18); LATHOS TRACKING**



**Figure 57 EFFECT OF FEEL SYSTEM DYNAMICS AND TASK ON PILOT RATINGS**

### 5.3.2.2 Power Approach Task Results

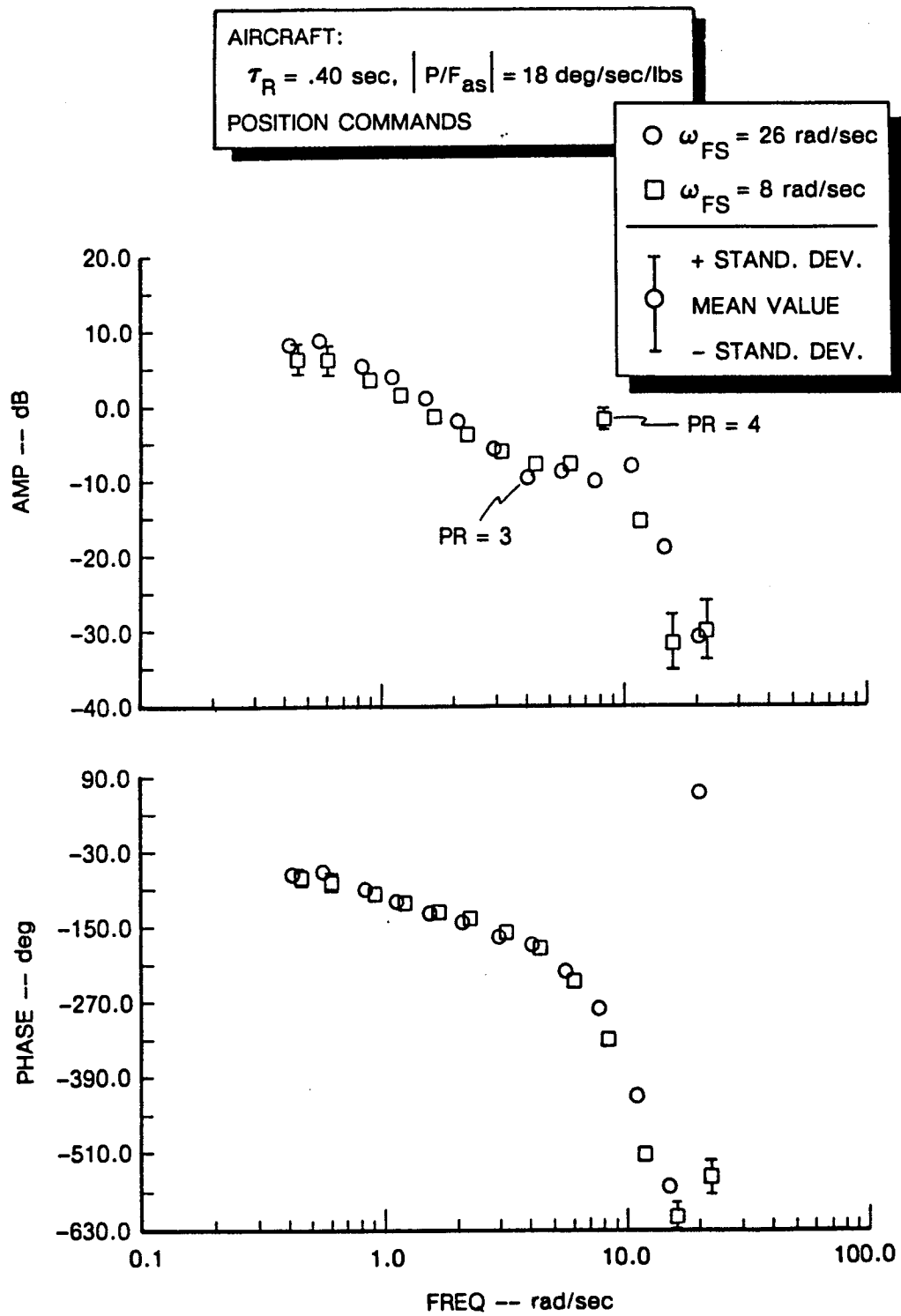
In the power approach evaluations, the acceptability of the slower feel system dynamics was again highly dependent upon the pilot. One possible determinant could well have been the pilot control activity. The greater the stick activity and the less "predictable" the pilot during the task, the worse flying qualities would result for the slow feel systems.

The pilot rating data for parametric feel system dynamic changes in the power approach task are presented in Figure 59. Pilot A, in general, found that he could do the lateral offset landing task, with even the slowest feel system frequency (8 rps) at adequate or desired performance levels. The peculiar feel system characteristics, such as a nonlinear or bobweight effect, were noticeable but not obtrusive. Level 1 ( $PR \leq 3\frac{1}{2}$ ) and borderline Level 1/Level 2 ( $PR = 4$ ) ratings were given. One exception to this trend occurred during very gusty wind conditions. A pilot rating of 8 was given for Configuration 243P(10) whereas, two ratings of 4 were given for an almost identical configuration (Configuration 203P(10)) during days with less severe environmental conditions.

Pilot C, on the other hand, was more sensitive to feel system dynamic effects and gave Level 3 ratings almost uniformly for the slowest feel system dynamics. Although quantitative evidence is not shown here, Pilots A and C had very different control techniques. Pilot A could be considered a "smoother" controller than Pilot C; thus, different flying qualities evaluations may have resulted for the feel systems variations according to control input activity. Both pilots are representative of the general pilot population; therefore, this variation in acceptability of these feel system characteristics can be expected, and should be designed for.

The rating data exhibits more scatter, both in terms of both inter- and intra-pilot rating variability. It is believed that the experimental variation is causing a large portion of the variability. Review of the task performance records and comments support this contention. In summary, the feel system was, not unexpectedly, found to be a substantial influence on flying qualities.

- The 26 rad/sec feel system is essentially transparent to the pilot, in that, the position response of the stick to a pilot applied force input is not noticeable.

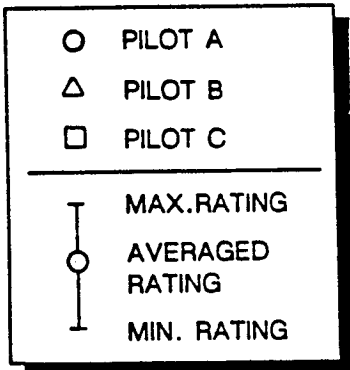
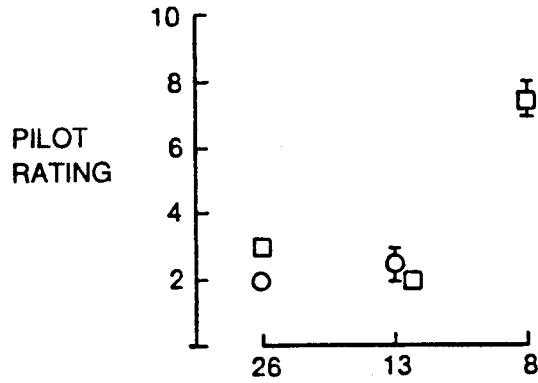


**Figure 58 OPEN-LOOP ( $\phi/\phi_e$ ) FREQUENCY RESPONSE DATA FOR PILOT A DURING SUM-OF-SINES TRACKING TASK**

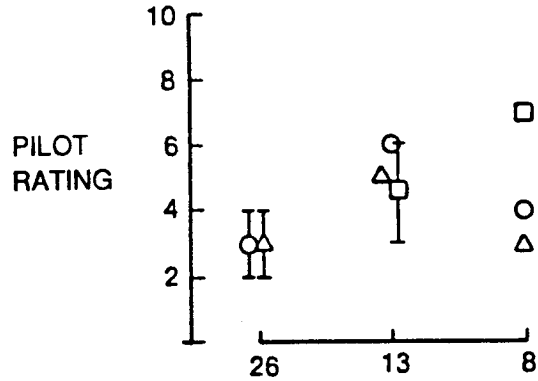


**POWER APPROACH EVALS**

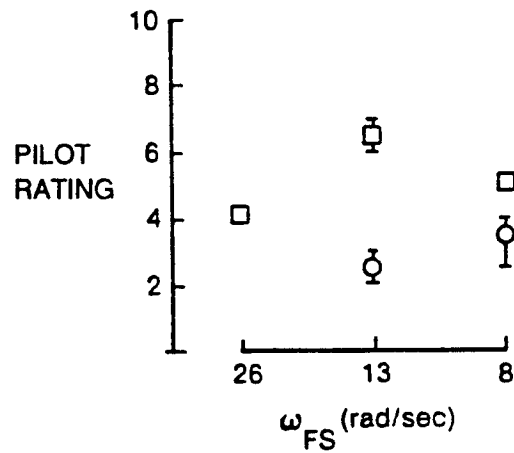
$\tau_R = .45 \text{ sec.}, |\bar{p}/F_{as}| = 10 \text{ deg/sec/lbs}$



$\tau_R = .30 \text{ sec.}, |\bar{p}/F_{as}| = 10 \text{ deg/sec/lbs}$



$\tau_R = .20 \text{ sec.}, |\bar{p}/F_{as}| = 5 \text{ deg/sec/lbs}$



**Figure 59 EFFECT OF FEEL SYSTEM DYNAMICS IN POSITION COMMANDS FOR POWER APPROACH EVALUATIONS**

- The 13 rad/sec feel system essentially defines the borderline between transparent and obtrusive feel systems. If the control activity or frequency content of the control activity is high, then the 13 rad/sec feel system becomes noticeable and accordingly, flying qualities degrade. The 13 rad/sec feel system was transparent otherwise. The pilot rating scatter for this condition is indicative of this variation.
- The 8 rad/sec feel system frequency is clearly noticeable and degrading. The pilot comments note a peculiar stick feel that is described as being a bobweight effect.
- Laboratory research has shown that "augmented" feel system characteristics can improve tracking performance (e.g., References 14 and 15). These feel systems are obtrusive cues of "plant" response characteristics. These systems are, consequently, of low frequency. Although explicit data were not taken to test these algorithms, the data that do exist would suggest that these "augmented" feel systems would be unacceptable to the pilots. The feel system characteristics would be annoying and peculiar. The likely reason that these "augmented" feel systems are of benefit in the laboratory would be the absence of aircraft acceleration cues. The augmented feel systems provide an additional cue of the plant response in the laboratory tracking of a visual display task. In flight, the aircraft motion cue response predominates the tracking task and any auxiliary cues which are not in concert with the motion and visual cues would be distracting and degrading. Thus, augmented feel systems are hypothesized to not be beneficial in the flight environment.

#### **5.4 EFFECT OF POSITION COMMANDS**

The effects of changing from a force to a position command architecture can be drawn from comparing evaluations from the previous Mini-Experiment data. The force control system architecture results of the Mini-Experiments #1 and #3 are compared to the data of Mini-Experiments #5 and #6 for a position command system. The command path gain was changed to provide identical  $|p/F_{as}|_{ss}$  configurations whether force or position commands were used. The feel system dynamics and controlled element dynamics are identical with the exception that the flight control system command is changed. The pilot rating data for this comparison are shown in Figures 60 and 61 for up-and-away and power approach evaluations, respectively.

The data in the up-and-away flight phase are sparse and no conclusions can be drawn. If anything, pilot ratings indicate that flying qualities degrade for the position command systems in comparison to a force command system.

For the power approach task, the degradation in flying qualities by going to the position command system is more evident. As will be discussed in detail later, these data define whether a potential time delay penalty may result from having the feel system dynamics in the command path. The comparison of time responses in Figure 62 illustrates this potential penalty using a step input of cockpit control force for Configurations L142P(5) and L142F(5). Configuration L142F(5) responds quickly and with the minimal delay to the force step command; whereas, the step command of force is filtered by the feel system dynamics with the position command system in Configuration L142P(5). The roll time response is smoother and less abrupt for this canned input example but the "penalty" is the additional delay due to the feel system. The data of Figure 61 show that Pilot A rated the control law change to position commands as being an insignificant flying qualities influence. Conversely, Pilot B rated the different configurations as having significantly different characteristics. The position command system was borderline Level 2/Level 3 whereas a rating of 4 (borderline Level 1/Level 2) was given for the force command system.

## **5.5 EFFECT OF FORCE - DEFLECTION GRADIENT**

Four evaluations of 2 configurations briefly examined the effect of different roll centerstick force-per-deflection gradients. One configuration was evaluated in the up-and-away and one in the power approach flight phase. The nominal force-deflection gradient was 4.0 lbs/inch; a 2.75 lbs/inch was evaluated. A force command system architecture was employed, thus, the feel system variation was an element in parallel to the roll command path but directly apparent to the pilot. The feel system natural frequency was 26 rad/sec.

The pilot rating data are shown in Figure 63 in comparison to the nominal configurations. In the up-and-away evaluation, the rating data from Pilot A indicates a significant improvement in flying qualities because of the increased deflection gradient (greater stick motion). The pilot ratings improve to Level 1 (PR = 3,2) from Level 3 (PR=7). The nominal configuration (141F(10)) received a Level 3 evaluation by Pilot A due to its abrupt roll response character. Pilot B rated the configuration similarly. With the increased deflection-per-unit stick force, the airplane closed-loop response under closed-loop pilot control was significantly improved. The quick augmented aircraft roll response was still apparent but the controllability with the pilot-in-the loop was significantly improved. Response predictability was also significantly enhanced. The roll

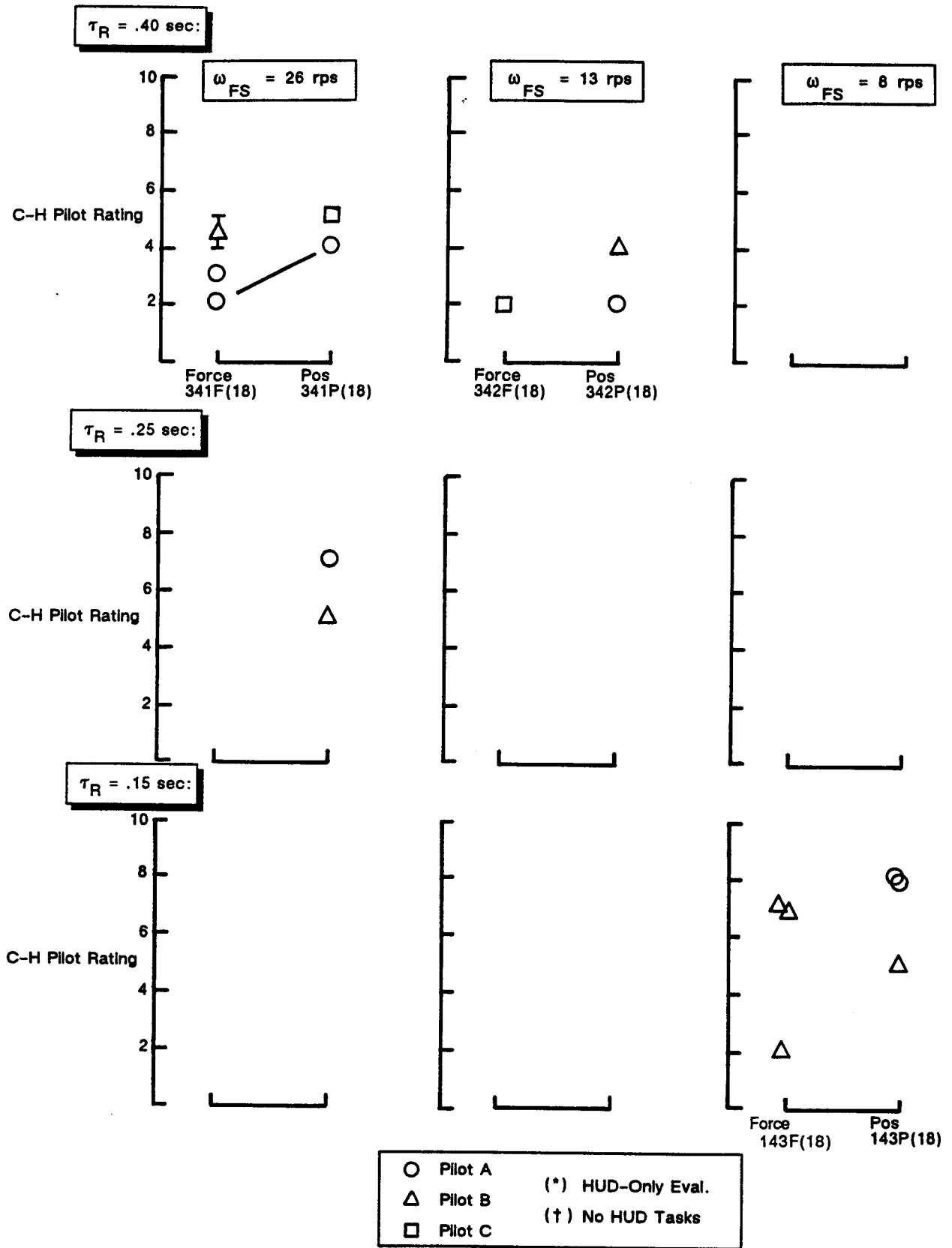


Figure 60 EFFECT OF CONTROL SYSTEM COMMAND TYPE ON UP-AND-AWAY EVALUATIONS

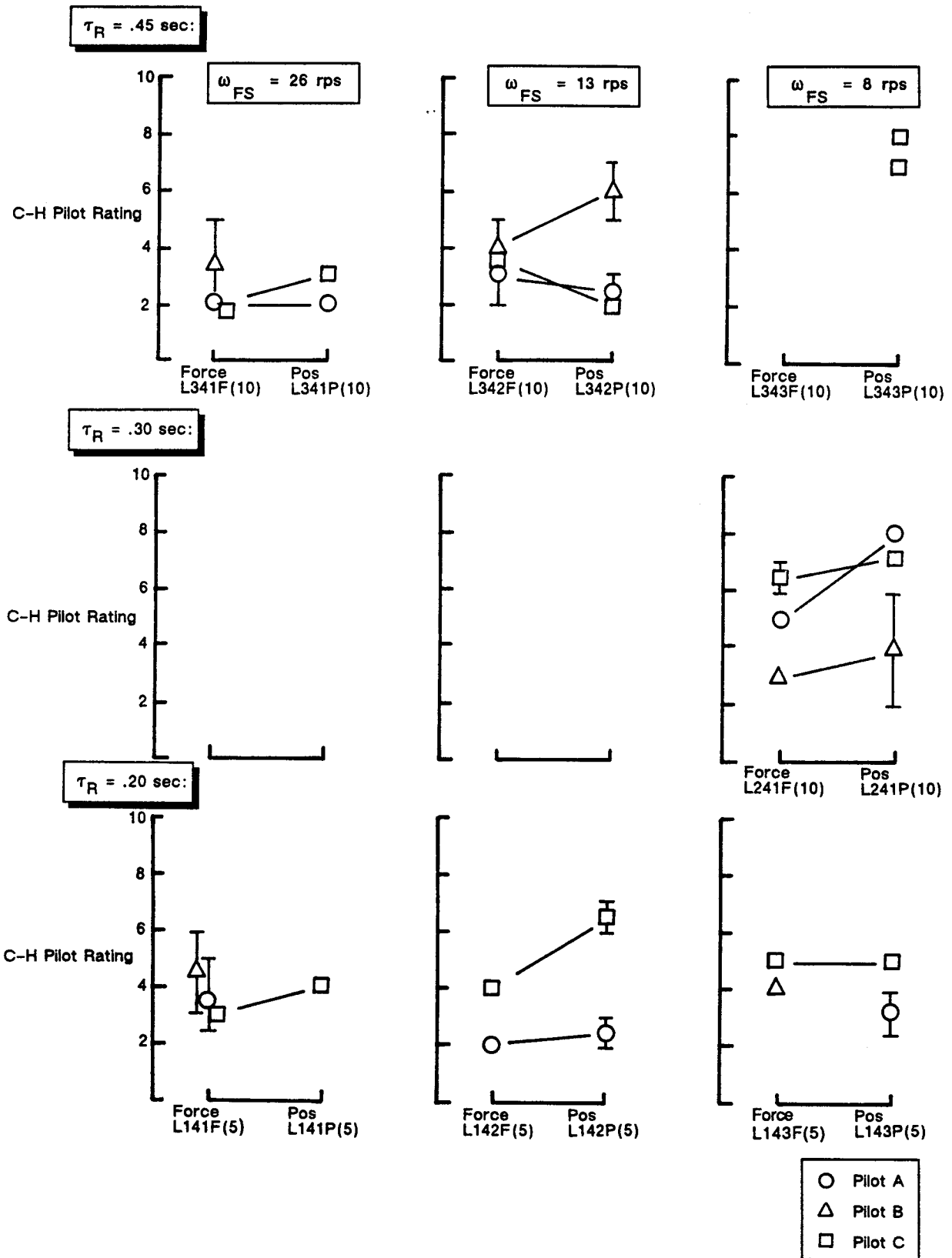


Figure 61 EFFECT OF POSITION COMMANDS ON POWER APPROACH EVALUATIONS

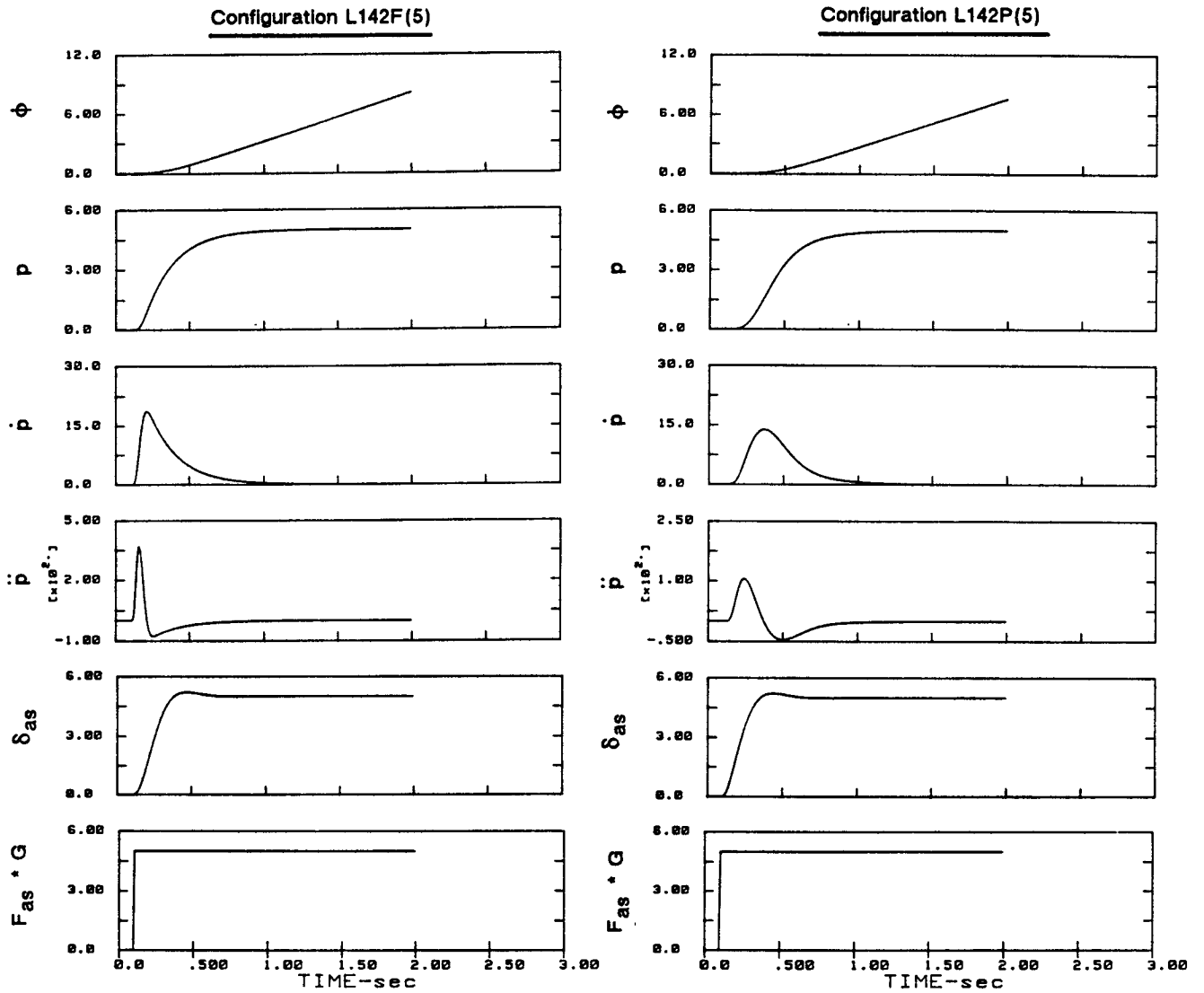
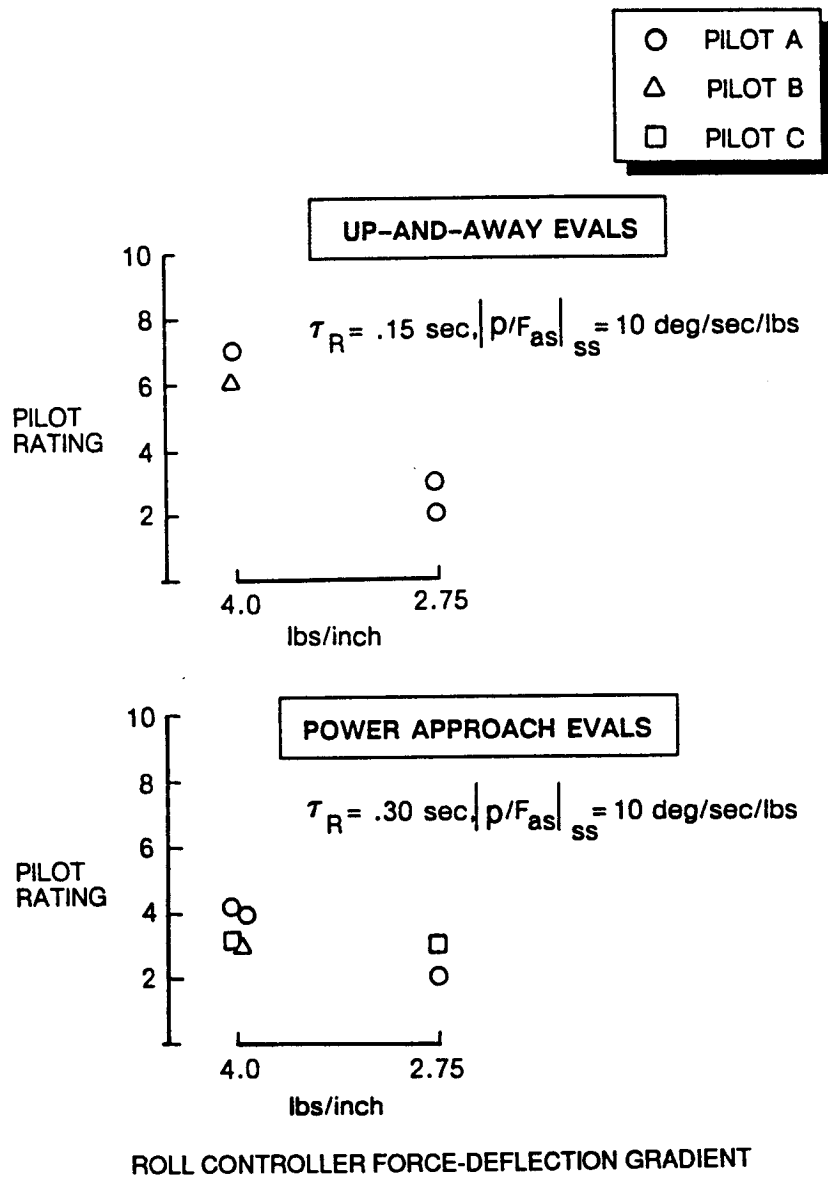


Figure 62 COMPARISON OF POSITION AND FORCE COMMAND SYSTEM TIME RESPONSE TO FORCE STEP INPUT



**Figure 63** EFFECT OF FORCE-DEFLECTION GRADIENT, FORCE COMMANDS,  $\omega_{FS} = 26 \text{ rad/sec}$

response was precise and during the task, the greater stick motions were noticeable but not excessive.

Unfortunately, this same experimental variation was not performed on the most roll ratchet-prone configurations (141F(18)).

In power approach, the flying qualities improvement was not as dramatic. The ratings do, however, show an overall improvement. Configuration L241F(10) is rated as being borderline Level 1/Level 2 because it is slightly over-responsive. Pilot A gave two ratings of 4 and Pilot C gave two ratings of 3. With a decreased force-deflection gradient, Pilot A awarded a rating of 2. The airplane did not exhibit any noticeable deficiencies in flying qualities. Pilot C gave a Level 1 rating of 3 with the decreased force-deflection gradient but stipulated that a better rating was not possible because he objected to the unusual feel of the stick.

The tracking statistics from the up-and-away HUD tasks are very similar despite the change in feel system gradient and the large difference in flying qualities:

- For both the roll sum-of-sines and LATHOS tasks, the open-loop crossover frequency and phase margins were almost identical. The open-loop frequency response comparison for the roll SOS task is shown in Figure 64. The crossover frequency occurs at 1.35 rad/sec for each configuration.
- For the decreased force-deflection gradient, the amplitude peaking tendency at high frequency is reduced but not significantly (~2 dB reduction in peak amplitude). The frequency at which the amplitude peak occurs is also reduced.
- Tracking error performance statistics are, of course, very similar. In the LATHOS tracking task, the cumulative time that the roll error was within the desired performance standard of 8 degrees was approximately 52 sec for the decreased force-deflection gradient versus 55 sec for the nominal configuration (141F(10)).

## 5.6 "HIDDEN" TIME DELAYS

Significant emphasis was placed on the evaluation of "Hidden" time delays (Mini-Experiment #6) since it embodies almost all of the experimental objectives. 81 evaluations of 28 configurations were performed. The configurations were created from three augmented aircraft



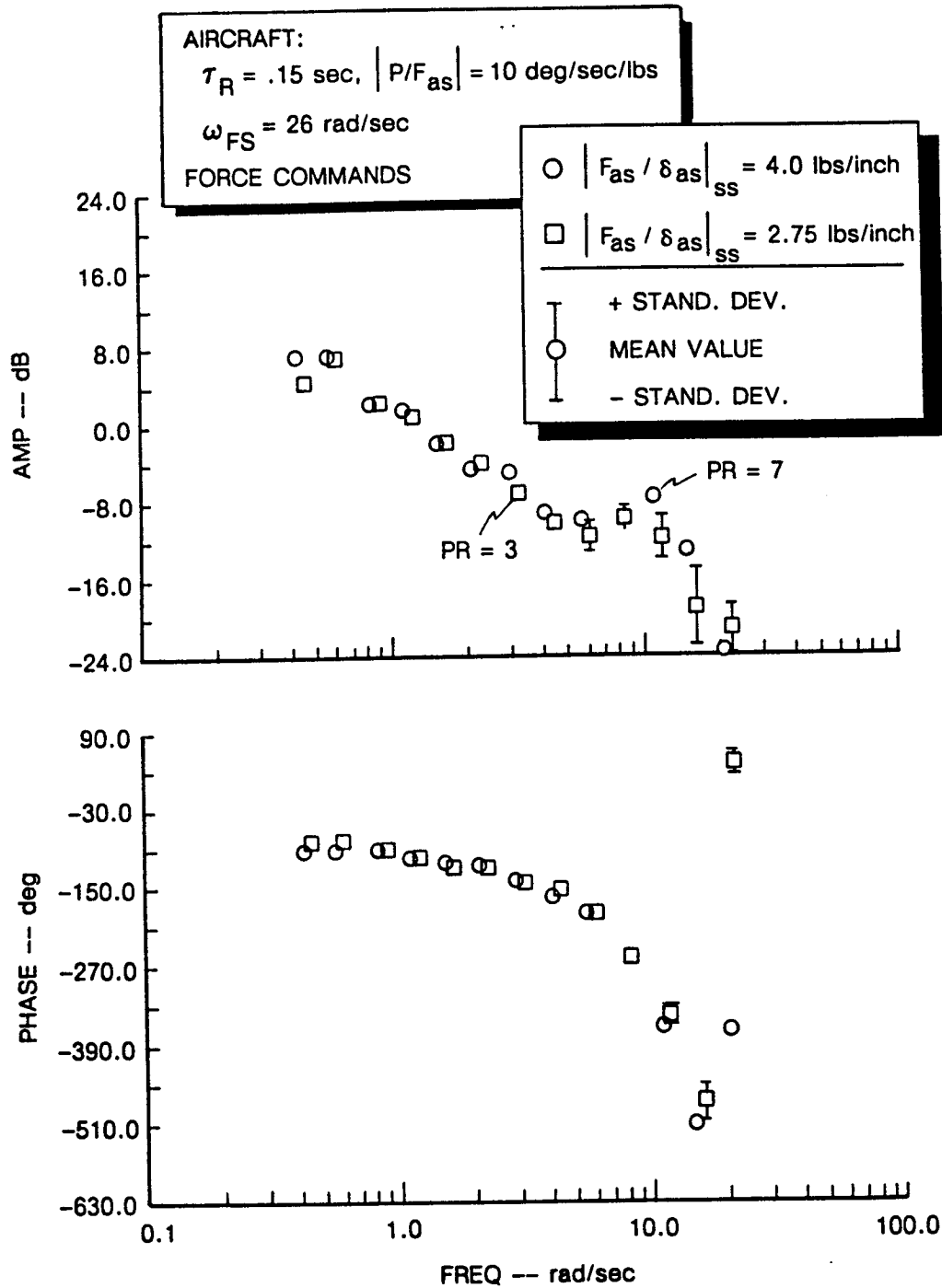
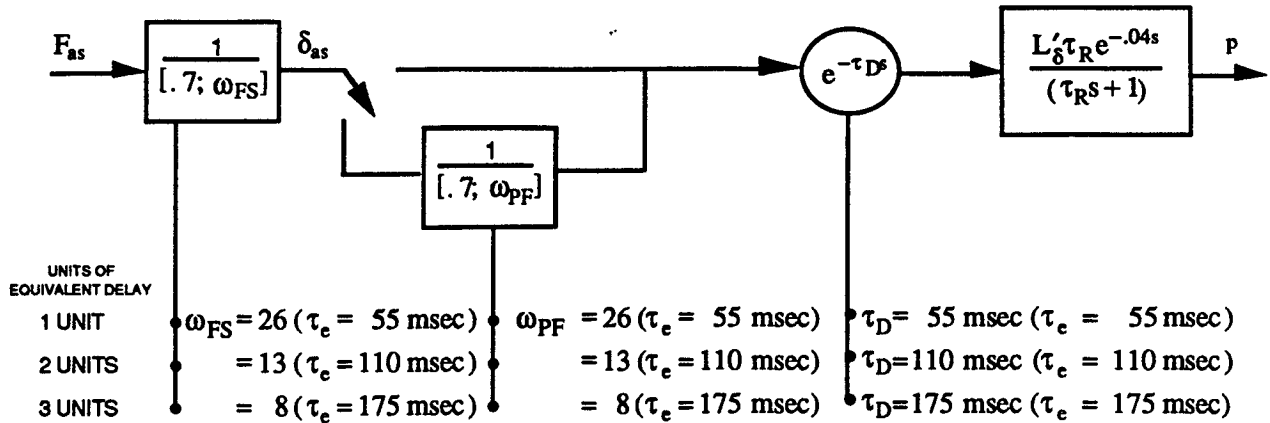


Figure 64 OPEN-LOOP ( $\phi/\phi_0$ ) FREQUENCY RESPONSE DATA FOR PILOT A DURING SUM-OF-SINES TRACKING TASK



**Figure 65 FLIGHT CONTROL SYSTEM SET-UP FOR MINI-EXPERIMENT NO. 6**

configurations (one power approach and two up-and-away configurations). A position command architecture was used. Time delay was added to these configurations in "units" of equal equivalent time delay, where the units of equivalent time delay were developed from either pure transport time delay in the control system, or equivalent time delay introduced by the feel system or identical control system filters (see Figure 65.) In this scheme, the delay was either "pure" or "equivalent" and either accessible or inaccessible ("hidden") from the pilot.

As a matter of convenience, the comparison of time delay elements that were added experimentally were "equated" by units of equivalent time delay. The quoted equivalent time delays are not exact; rather, their approximate added equivalent delay were used for experiment configuration development only. For instance, the 8 rad/sec prefilter and feel system frequency can be approximated as 175 msec of equivalent delay using the  $2\zeta/\omega$  equivalent delay approximation. However, these systems contribute amplitude attenuation as well as phase lag in the low frequency ranges of interest (<10 rad/sec) and, therefore, are not completely describable as a time delay element only. Exact equivalent delays for each configuration are presented in Appendix A using various input and time delay measurement definitions.

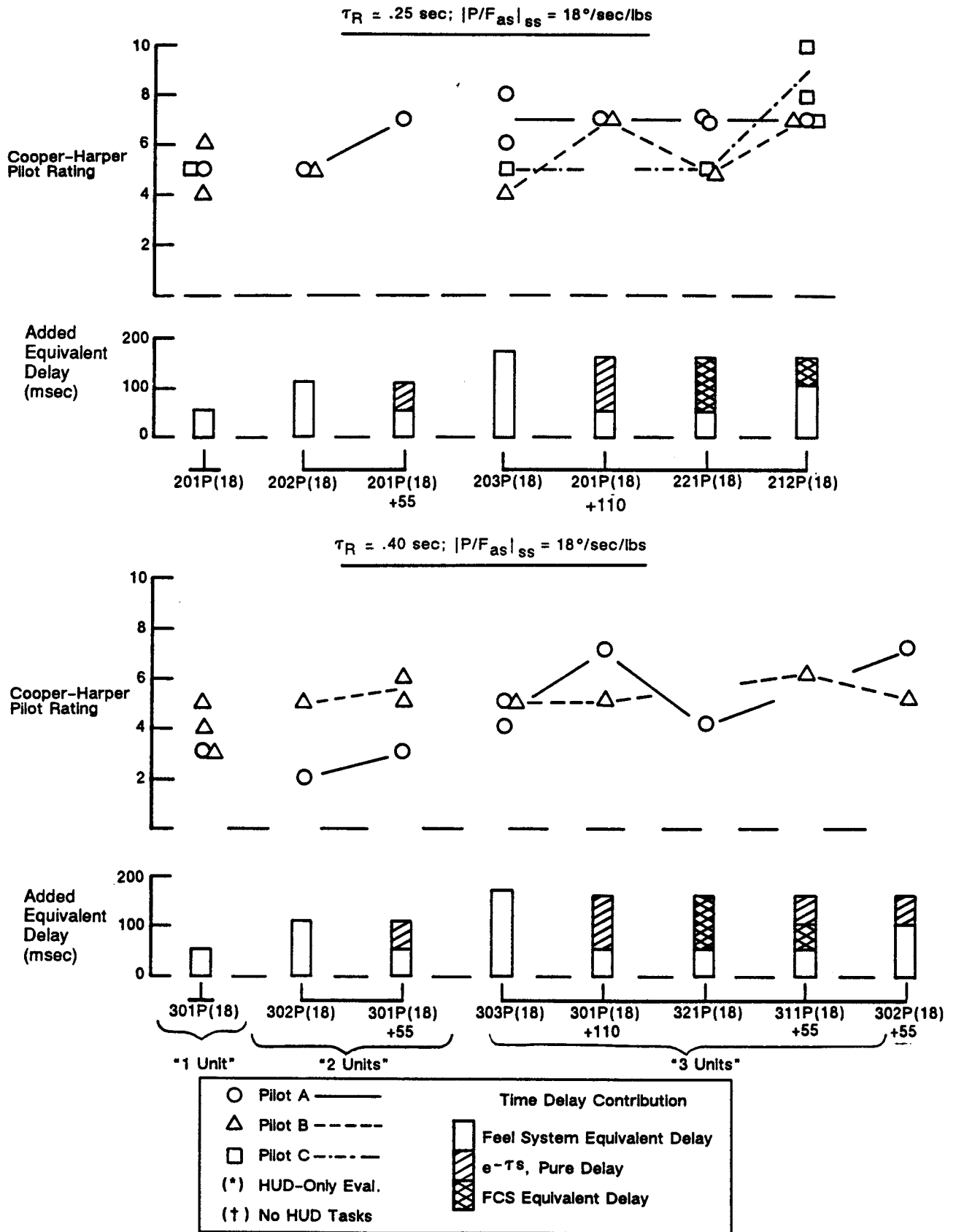
### 5.6.1 Up-and-Away Task Results

The pilot rating data from this mini-experiment are plotted in Figures 66 for the up-and-away evaluation tasks. A bar graph of added equivalent delay is also shown to illustrate the delay source. Two configurations were used in the time delay variation during up-and-away evaluations.

With the augmented aircraft configuration of a .25 sec roll mode time constant and 18 deg/sec/lbs steady-state roll rate (Config. 201 P(18)), Level 2 flying qualities were evaluated with a minimum of time delay in the position command control system. (For this reason, this configuration was not emphasized in the experimental time delay variation. Evaluations were later shifted to the .40 sec roll mode time constant configuration.) Configuration 201P(18) received two ratings of 5. Both Pilots A and C objected to the abrupt roll response of the airplane that created controllability problems. The added delay evaluations for this configuration produced the following results:

- Two "units" of time delay were created by either reducing the feel system natural frequency to 13 rad/sec or adding a pure delay of 55 msec. In terms of pilot ratings only, the reduction in feel system did not produce a degradation. However, the lower frequency feel system clearly changed the aircraft's flying qualities. Pilot A, for instance, commented that the airplane was mysterious with the 13 rad/sec feel system. Conversely, the addition of 55 msec created a Level 3 airplane primarily because of severe "roll ratchet" problems. The addition of pure time delay was clearly degrading and also clearly different than a feel system change of nearly equal added phase lag proportions.
- Four different configurations were evaluated which had 3 "units" of equivalent delay added. For Pilot A, the source or location of the delay was not a factor. All configurations were Level 3 as each received an averaged pilot rating of 7 from Pilot A. In contrast to Pilot A, Pilot B gave two of the configurations Level 2 ratings (4 and 5 for Configurations 203P(18) and 221P(18), respectively). Pilot C also gave Level 2 ratings (two ratings of 5) for those same two configurations. Configurations 201P(18) + 110 and 212P(18) were rated Level 3 by all pilots.

The evaluations of the 3 "units" of added delay highlight important roll control system design properties that may be lost if equivalent time delay descriptions are used "blindly". For these configurations, the pilot comments describe different closed-loop aircraft characteristics for 3 "units" added delay even for the evaluations by Pilot A who used almost identical pilot ratings to characterize the flying qualities. Configuration 201P(18)+110 exhibited the worst flying qualities; PIO and poor predictability were evident and these problems were common to all tasks as defined



**Figure 66 PILOT RATING DATA FOR MINI-EXPERIMENT #6, UP-AND-AWAY FLIGHT PHASE**

by the individual task pilot ratings. The peculiar feel system characteristics of Configuration 203P(18) produced degraded flying qualities although the pilot ratings varied by both pilot and task because the acceptability of low frequency feel system characteristics are dependent upon the required control activity of the task and upon the preferred pilot technique for these evaluations. Interestingly, the worse flying qualities rating (Level 3) were given the configuration with the moderate feel system frequency (13 rad/sec) and the "fast" prefilter dynamics (26 rad/sec). Conversely, various Level 2/Level 3 ratings were given for the fast feel system and moderate prefilter (Configuration 221P(18)). The 13 rad/sec prefilter helped to smooth the roll abruptness and the fast feel system is transparent and unobtrusive. In the reverse order (Configuration 212P(18)), the 26 rad/sec prefilter does not significantly filter the roll response. The prefilter is essentially an equivalent delay.

A better basis for evaluations of time delay was provided by using an augmented aircraft with a .40 sec roll mode time constant because of improved flying qualities for the baseline aircraft. With only 1 "unit" of added delay, the baseline aircraft was essentially Level 1, although some over-driving of the airplane was required to get the initial performance required in some tasks, particularly for the HUD tasks. Pilot B rated this aspect as borderline Level 1/Level 2. At two units of added time delay, flying qualities were essentially equivalent and unchanged for Pilot A whether the delay was a "hidden", pure time delay or "accessible" to the pilot through a reduced feel system frequency. The data for Pilot B suggest that two units of delay produced a slight flying qualities degradation. A lack of precision in roll control, such as roll overshoots, was noticed. Again, the pilot comments were slightly different depending upon where the delay was encountered.

With "3 units" of added delay, flying qualities varied depending upon the delay source. Essentially borderline Level 2/Level 3 flying qualities ratings were given for each configuration with additional pure time delay (Configurations 301P(18)+110, 302P(18)+55, and 311P(18)+55). When the delay was due solely to the feel system or a combination of feel system and FCS filters, a degradation to only Level 2 flying qualities resulted.

In a trade-off between types and locations of time delay, pure delay in the control system is clearly degrading. Changes to the feel system characteristics are not always obvious and their degradation potential is dependent upon the task and individual pilot control techniques. Also, the degradation with the slowest feel system tends to be worse with the quicker roll response configurations. When a filter is placed in the control system, flying qualities improvement is generally seen compared to a feel system of the same frequency (e.g., Configuration 221P(18))

versus 212P(18)) because the filter provides beneficial smoothing of the response which was not evident through the feel system.

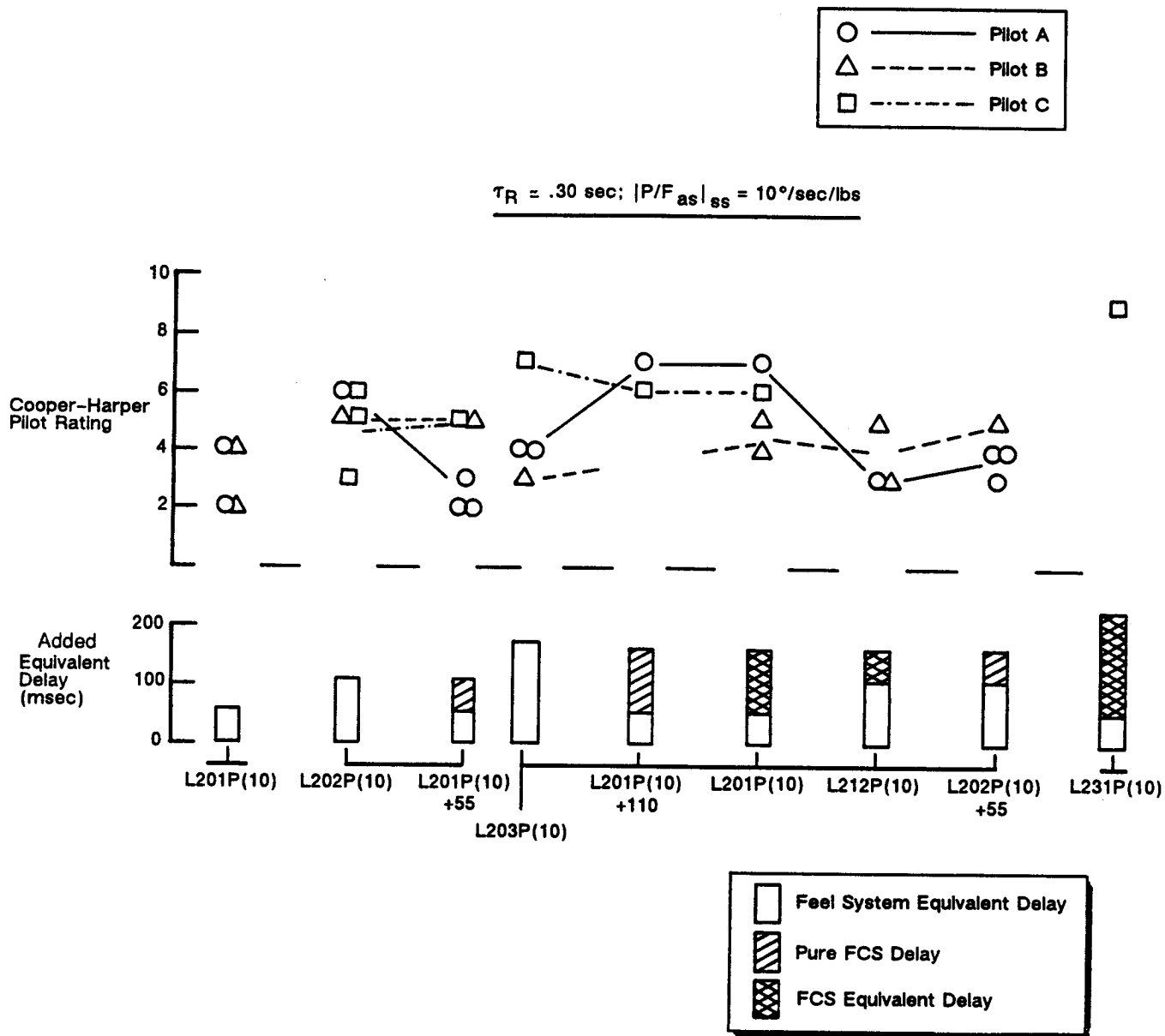
### **5.6.2 Power Approach Task Results**

For power approach evaluations, Configuration L201P(10) was used as the baseline configuration for experimental time delay variations. The pilot rating data for this mini-experiment is presented in Figure 67. Again, a bar graph of time delay is added below the ratings to illustrate the delay source in each configuration. This base configuration exhibited Level 1 flying qualities on the average. Its only deficiency was a slightly over-responsive roll response.

With "2 units" of delay, the rating data of Pilots B and C highlight a degradation to Level 2 flying qualities from the baseline. The flying qualities degradation as essentially independent of the type of time delay introduced. Conversely, the addition of pure time delay did not produce a rating degradation from the baseline according to Pilot A. However, the slower feel system did create Level 2 flying qualities. These ratings run counter to the previous findings but the repeat ratings substantiate the evaluations.

At three units of delay, Pilot B gave borderline Level 1/Level 2 for each configuration. Conversely, Pilot A rated significant flying qualities differences depending upon the delay source and type. Configurations L203P(10), L212P(10), and L202P(10)+55 were rated Level 1/Level 2. The pilot comments indicate that Pilot A noticed the slower feel system dynamics, particularly for Configuration L203P(10). Yet, despite the peculiar feel characteristics, Pilot A got desired performance with, at worst, a moderate level of pilot compensation. On the contrary, Pilot C gave the same configuration a Level 3 rating of 7 primarily because of PIO and controllability problems.

Pilot A, in his comments and during the debriefing, suggested that the lateral offset task as flown in the NT-33 was not as demanding or as rigorous a flying qualities task as others tasks had been. For whatever reason, the task lended itself to predictive pilot inputs that were not felt to be sufficient to expose flying qualities "cliffs." These observations were made despite the severe task demands (300 ft lateral offset corrected at 200 ft AGL) that are much greater than normally encountered. For instance, Configuration 201P(10)+110 was given a Level 3 rating of 7 but this rating was based primarily on a lurking, but unseen PIO tendency. This tendency was mostly



**Figure 67 PILOT RATING DATA FOR MINI-EXPERIMENT, NO. 6 IN POWER-APPROACH FLIGHT PHASE**

witnessed through Pilot A's sampling of the configuration on downwind and during the visual approach. Adequate, and even desired performance was achieved on the actual landings. This task deficiency may have also contributed to the relatively good ratings for Configuration 201P(10)+55. To elevate the task demands, unpredictable task elements would be necessary, such as varying crosswind, gusts, and wind shears. Due to safety and simulation limitations, however, the task demands could not be increased further.

In brief summary, the source and type of time delay influence flying qualities. For instance:

- In up-and-away evaluations, slower feel system dynamics were not as degrading as equal amounts of pure delay. The slower feel system dynamics are not, however, equivalent in terms of flying qualities influences nor as beneficial as a control system filter. Configuration 221P(18) with its 13 rad/sec FCS filter and 26 rad/sec feel system exhibited better flying qualities than the rearrangement of these elements in Configuration 212P(18). This latter configuration was too roll responsive, whereas, the former configuration had a much improved roll response to pilot inputs derived from the smoothing by the 13 rad/sec control system filter.
- Conversely, in power approach evaluations, the flight control system filtering proved degrading. The roll responsiveness of the power approach configurations is significantly less than the up-and-away configuration and therefore, they do not benefit from control system smoothing. The slower feel systems, while still not as degrading as additional pure delay, are less degrading in flying qualities effects than the identical FCS filter.

## **5.7 EFFECT OF CONTROLLER TYPE**

Mini-Experiment #7 obtained data investigating lateral flying qualities and time delay effects with a sidestick controller. This mini-experiment was designed and conducted by a USAFTPS student test team as a student project using the USAF NT-33 aircraft. The test plan, experiment design, and conduct was performed by the students with USAFTPS staff direction. Safety pilots and aircraft calibration and maintenance were provided by Calspan under USAF contract. The results of this project are briefly summarized and comparisons to the Calspan data



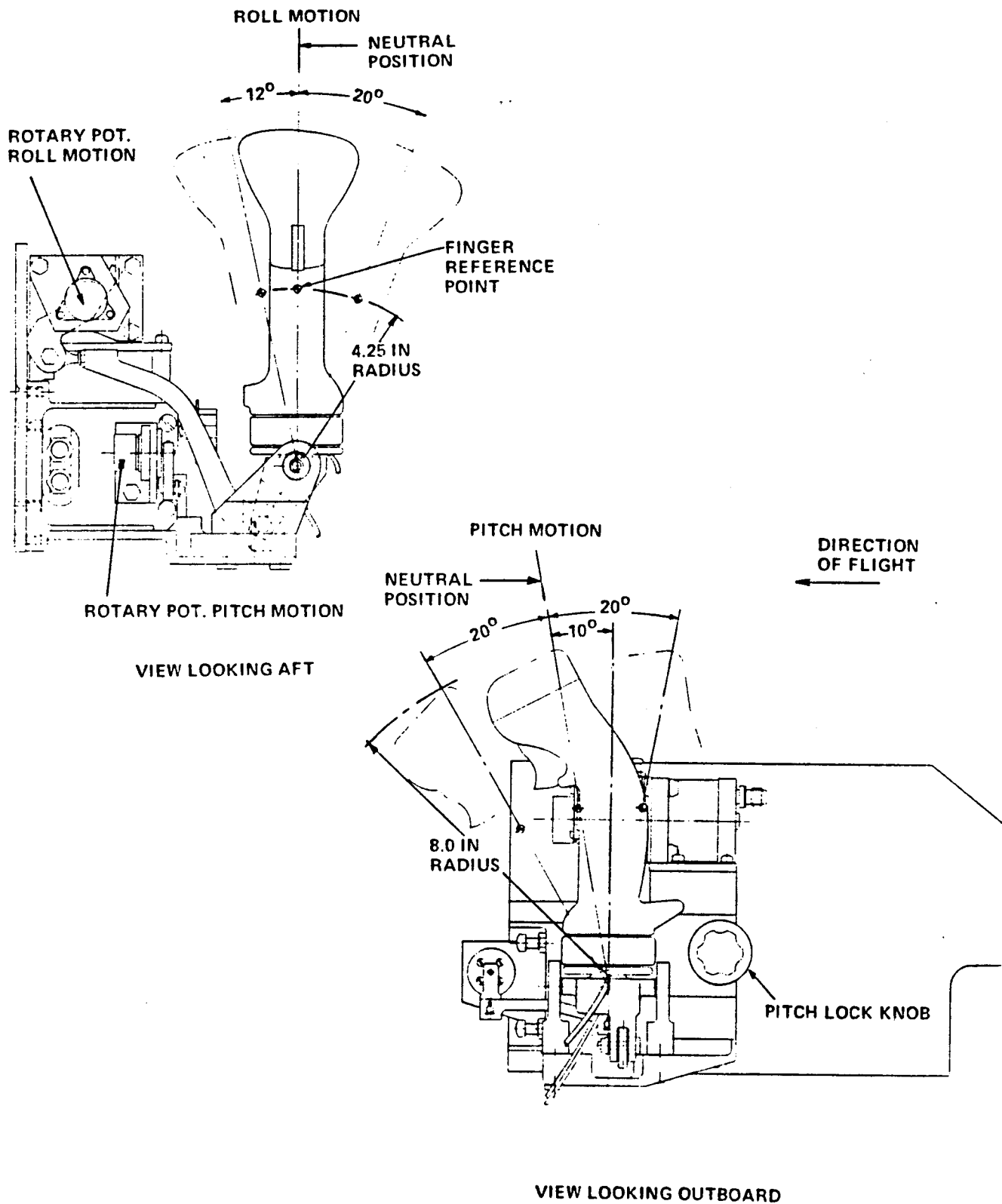
are made to view the effects of controller type. The technical report, from which the sidestick data were obtained, is cited as Reference 16. Test details are also provided therein.

A slightly different experiment design was performed by the USAFTPS test team so direct comparison of centerstick and sidestick controller can not be made. The USAFTPS design added pure control system time delay to the selected feel system dynamics in a position command system such that three values of effective time delay were simulated. The effective time delay is calculated using the maximum slope intercept method (Reference 2). Three values of roll mode time constant were evaluated. The configurations and pilot rating results are presented in Appendix A. The steady-state roll command was held constant at 19 deg/sec/degree of sidestick deflection. (The sidestick characteristics are shown in Figure 68.) This experiment mirrors, but does not mimic, the design of Mini-Experiment #6.

Three project pilots participated in the test. During up-and-away evaluations, both HQDT (Handling Qualities During Tracking) of an airborne target and HUD evaluation tasks were performed.

The HUD tasks were identical to the Calspan tests. For power approach evaluations, the visual offset approach and landing task was used. All TPS evaluations were conducted at Edwards AFB.

Pilot D of the sidestick evaluation program was quite critical of highly responsive, abrupt roll characteristics. In some cases, Pilot D gave ratings of 7 because an excessively abrupt roll response was considered an aircraft deficiency that required improvement. This Level 3 rating indicated that the aircraft exhibited major deficiencies despite the fact that desired performance could be attained with moderate or better levels of pilot compensation. Pilot F, who was not critical of abrupt roll response characteristics, gave the same configurations a significantly better rating based strictly on task performance and workload without calling the abrupt roll response a deficiency which required improvement. Conversely, a similar situation existed with regard to feel system characteristics. Pilot F was more critical of feel system characteristics than the other pilots. His ratings were downgraded with respect to the others because of the unusual feel characteristics rather than a degradation in task performance.



**Figure 68 SIDESTICK MOTION LIMITS**

Once again, these individualistic factors are valid flying qualities concerns and illustrate the influence of the experiment factors on the general pilot population. These influences must be taken into consideration in development of general design criteria.

The pilot rating data obtained from sidestick evaluations are compared to the pilot rating data for centerstick evaluations of very similar augmented aircraft configurations. Averaged pilot ratings and maximum rating deviations are shown to illustrate flying qualities. Up-and-away evaluation data are plotted in Figure 69. Power approach evaluation data are plotted in Figure 70.

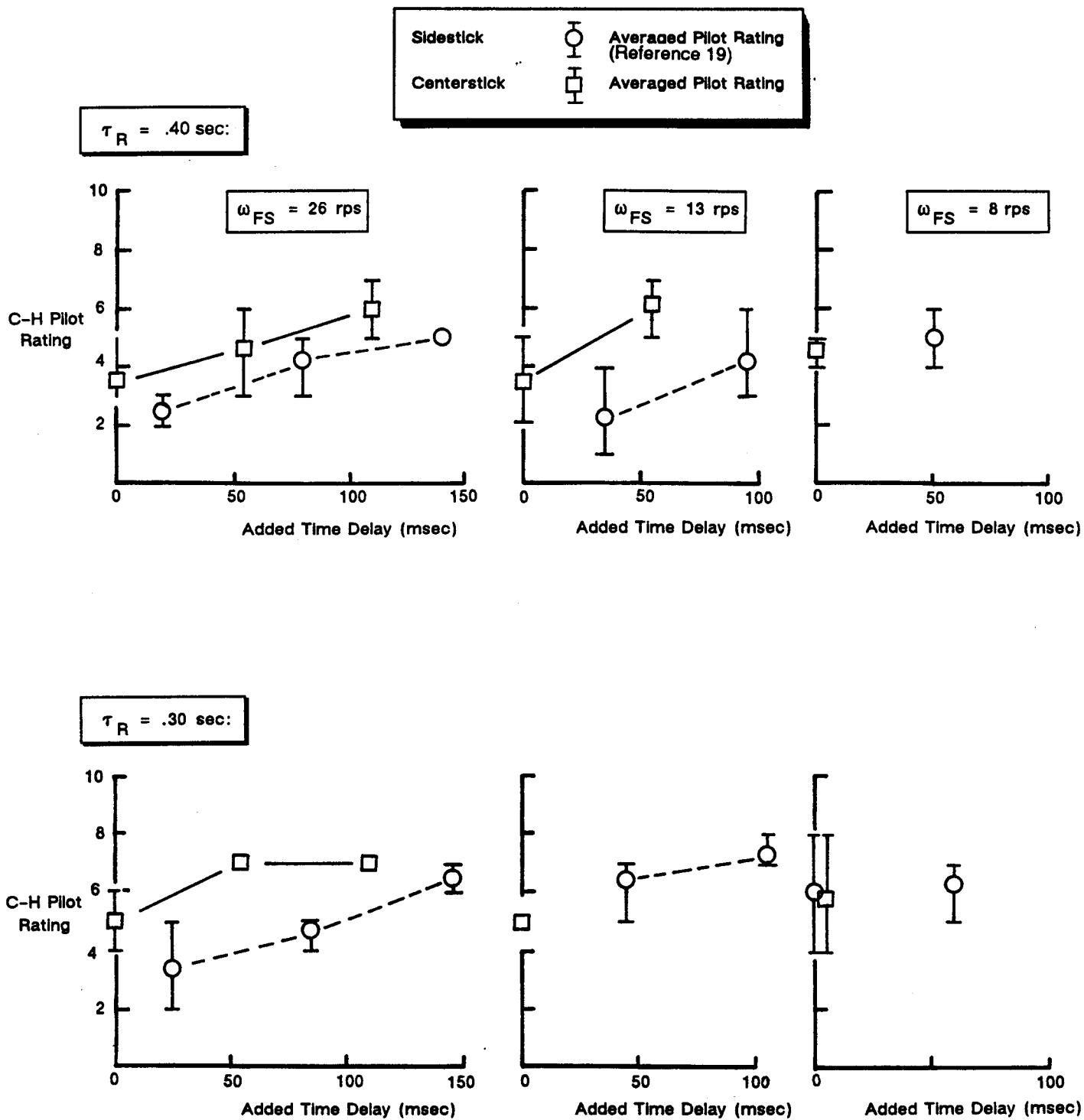
For up-and-away evaluations of a .4 roll mode time constant configuration, the change to a sidestick controller shows general flying qualities improvement in the range of one-to-two rating units with the fastest feel system. Greater differences in flying qualities occurred for the .30 roll time constant configuration.

The sidestick evaluations showed that the 13 rps feel system frequencies were essentially transparent to the pilots; thus, no rating degradation occurred at a given added delay due to reduced feel systems. At the slowest feel system frequency (8 rad/sec), the flying qualities the controller type is inconsequential. The pilot comments for sidestick evaluation note a peculiar stick feel and "odd" motion characteristics just as were experienced in the centerstick evaluations.

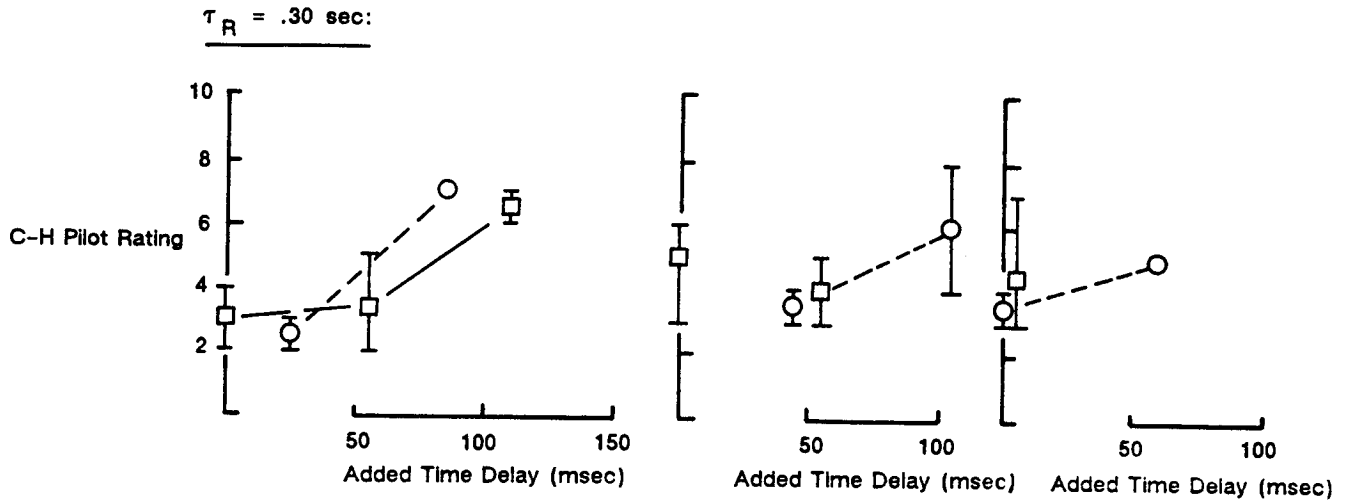
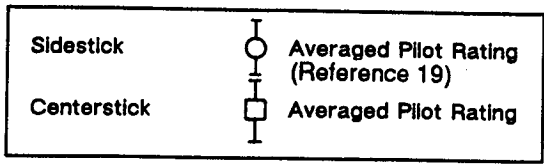
At the .30 sec roll mode time constant, the pilot rating data from sidestick controller evaluations is improved over the centerstick evaluations. Roll quickness was noted in the sidestick evaluations, but the accelerations were not judged to be as excessive as the centerstick evaluations. One probable cause for this improvement could be the command gradient difference. Note, however, that as the roll mode time constant decreased further to .15 sec, the rating data for the sidestick evaluation indicate Level 3 flying qualities just as that for the centerstick data.

In power approach evaluations, the centerstick and sidestick pilot rating data are nearly identical. No significant differences can be discerned.

The data comparing sidestick and centerstick controllers are not substantial and the experiment designs to make this comparison, were slightly different; therefore, conclusions cannot be easily drawn. However, in general, the evaluation data suggest that the flying qualities influences mapped out by the centerstick evaluation data carry-over closely to the sidestick controller. Subtle differences in desired command gradients and roll mode time constants are shown. The significant difference is in the feel system frequency at which the motion response is



**Figure 69 PILOT RATING COMPARISON FOR CENTERSTICK AND SIDESTICK CONTROLLER; UP-AND-AWAY APPROACH EVALUATIONS**



**Figure 70 PILOT RATING COMPARISON FOR CENTERSTICK AND SIDESTICK CONTROLLER; POWER APPROACH EVALUATIONS**

noticeable. In up-and-away evaluations, the centerstick data indicate that 13 rad/sec is approximately the frequency at which the feel system motion becomes a factor in the flying qualities evaluation. For the sidestick evaluations, the 13 rad/sec feel system is still transparent to the pilots. For both controllers, the 8 rad/sec is objectionably obtrusive. Thus, the frequency at which the motion of the sidestick feel system is noticeable is less than the frequency for the centerstick (13 rad/sec) but greater than 8 rad/sec. The small motions of the sidestick, in comparison to the centerstick, may be the cause of the difference.

## Section 6 DATA ANALYSIS

Selected analyses and correlations are presented wherein the data are considered in its entirety rather than in terms of mini-experiments. In this manner, general design criteria for roll flight control and flying qualities are considered. Averaged pilot ratings were calculated and are used in these analyses (Appendix A). The average ratings are used merely for convenience. The individual ratings and comments must be and are fully recognized to provide the intuitive basis for any design criteria. The averaged ratings are used as a convenience.

### 6.1 EQUIVALENT SYSTEMS ANALYSIS

The current military specification for piloted vehicle flying qualities, MIL-F-8785C, allows the application of equivalent systems in demonstrating requirement compliance. For the time delay requirement, cockpit control force is defined as the input. The experiment data are examined against this requirement. The experimental manipulation of command architectures (force and position) and feel system dynamics provides a definitive basis for this comparison and should indicate whether the force input is the proper input definition in these situations. The analysis is restricted to examining the time delay requirement from MIL-F-8785C. The other pertinent roll flying qualities requirements are essentially met for each configuration, therefore, flying qualities compliance is defined by the delay requirement alone.

Equivalent systems models were calculated for each configuration (Appendix A) using both force and position as the transfer function input. The low order model form was:

$$(p/\delta_{as}) \text{ or } (p/F_{as}) = \frac{Ke^{-\tau_e s}}{(\tau_r s + 1)}$$

The equivalent match was calculated over a frequency range of .1 to 10 rad/sec. In the case of a force command system, equivalent models were not calculated using position inputs since the controller position output is in parallel to, rather than cascaded in series with, the control system command. Because of this architecture, fatuous equivalent system models can result if the lag or delay in the feel system is greater than the lag or delay of the augmented aircraft. For instance, for low frequency feel systems, negative time delay (i.e., time "lead") will be calculated for the  $(p/\delta_{as})$  equivalent systems transfer function if the augmented aircraft response  $(p/F_{as})$  exhibits less

equivalent delay than the equivalent delay due to the feel system ( $\delta_{as}/F_{as}$ ). Therefore, these models were not even considered.

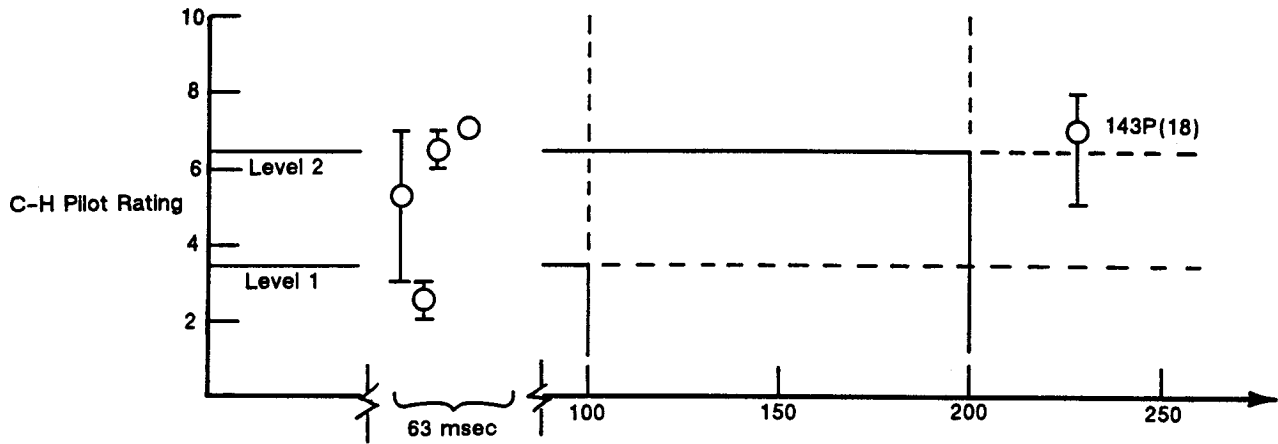
Most equivalent models had negligible cost or mismatch functions ( $\text{cost} \leq 2.0$ ) where the cost was calculated as the weighted sum-squared error difference between the model and actual frequency response. The exceptions were the 8 rad/sec filter or feel system configurations. For these configurations, the resultant high order response cannot be adequately matched with the first-order low order equivalent model shown above. The cost functions for these equivalent models hovered around a value of 20. This level of mismatch is not significant but neither is it insignificant (see, for example, Reference 23 and 24).

The compliance of the .15 sec roll mode time constant configurations in the up-and-away evaluation tasks to the MIL-F-8785C time delay requirement is shown in Figure 71. In Figure 71a, the force signal is used as the input definition for the time delay (independent of control command system type). In Figure 73b, the time delay requirement is evaluated using the position signal as a time delay measurement input for position command systems and using the force signal as the time delay measurement input for force command systems. Level 1 is defined in this figure as a maximum pilot rating of  $3\frac{1}{2}$  and Level 2 is defined by the maximum rating of  $6\frac{1}{2}$ . The following observations can be made:

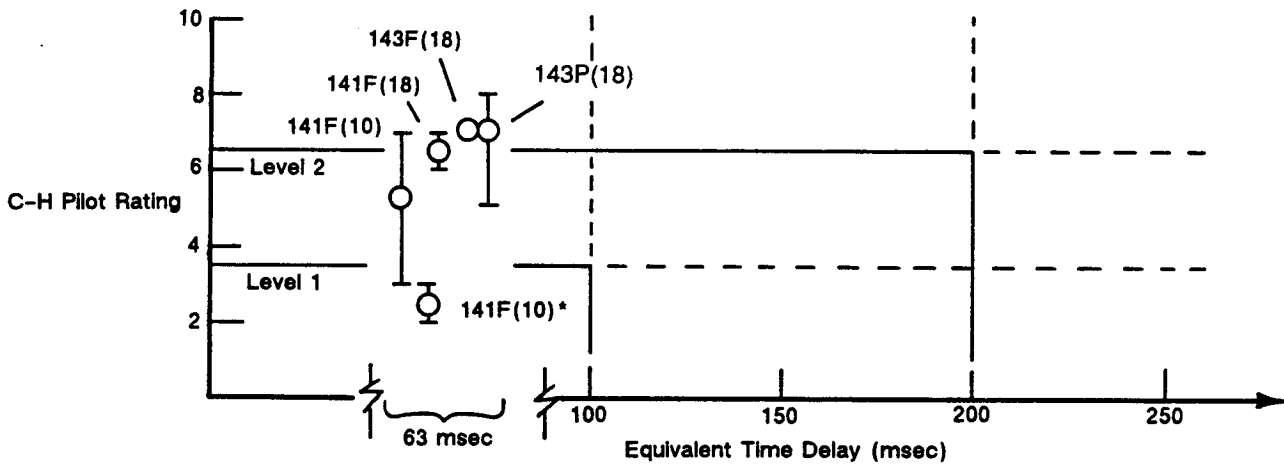
- Four configurations with force command systems are shown which have the same level of equivalent time delay independent of the force or position time delay input definition. However, the configurations have very different flying qualities. This result suggests that the MIL-F-8785C requirement may be insufficient in defining roll flying qualities completed. These configurations, with the exception of Configuration 141F(10)\*, were too roll responsive. MIL-F-8785C defines minimum levels of roll response and maximum values of roll time constant. The poor flying qualities of these configurations are produced primarily by the combined effects of minimum values of roll mode time constant and maximum levels of roll control authority to meet steady-state roll requirements. No MIL-F-8785C requirements exist to govern maximum acceptable roll accelerations for pilot-in-the-loop controllability demands.



a) Force Input Only:



b) Force or Position Input:



Up-and-Away $\tau_R = .15 \text{ sec}$	
	Max Rating Averaged Pilot Rating Min Rating

**Figure 71** COMPARISON OF .15 ROLL MODE TIME CONSTANT CONFIGURATIONS TO MIL-F-8785C TIME DELAY REQUIREMENT

- The good configuration, 141F(10)\*, differed from the others by force-deflection gradient (2.75 lbs/inch versus 4.0 lbs/inch). No quantitative requirement currently exists which discerns the flying qualities improvement provided by this force-deflection variation.

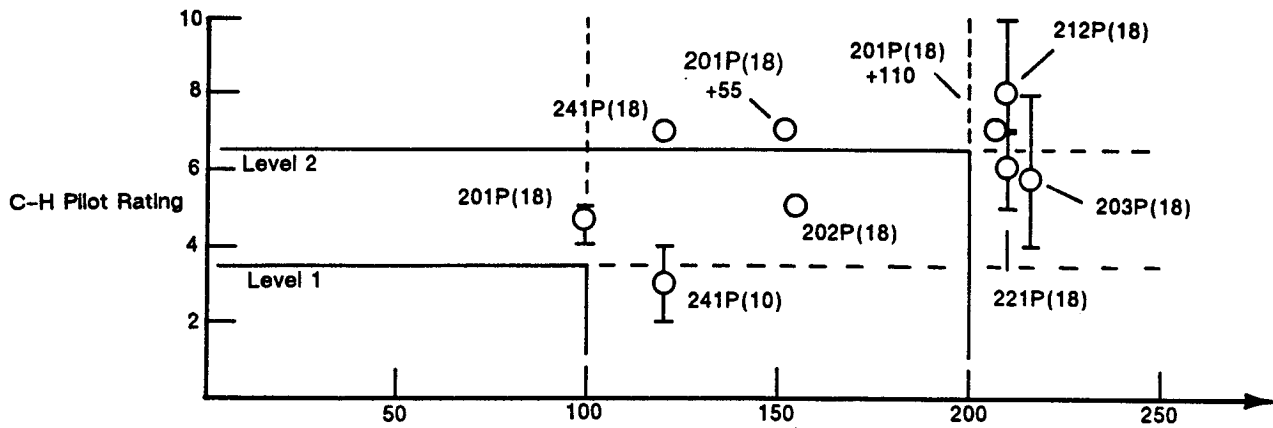
A comparison of pilot rating data obtained for the .25 sec roll mode time constant configurations in up-and-away evaluations is made against the MIL-F-8785C time delay requirements in Figure 72a. In this figure, the control force signal is used exclusively as the input basis.

In Figure 72b, a position input is used as the input definition for position command systems and the force signal measurement is retained for force command architectures.

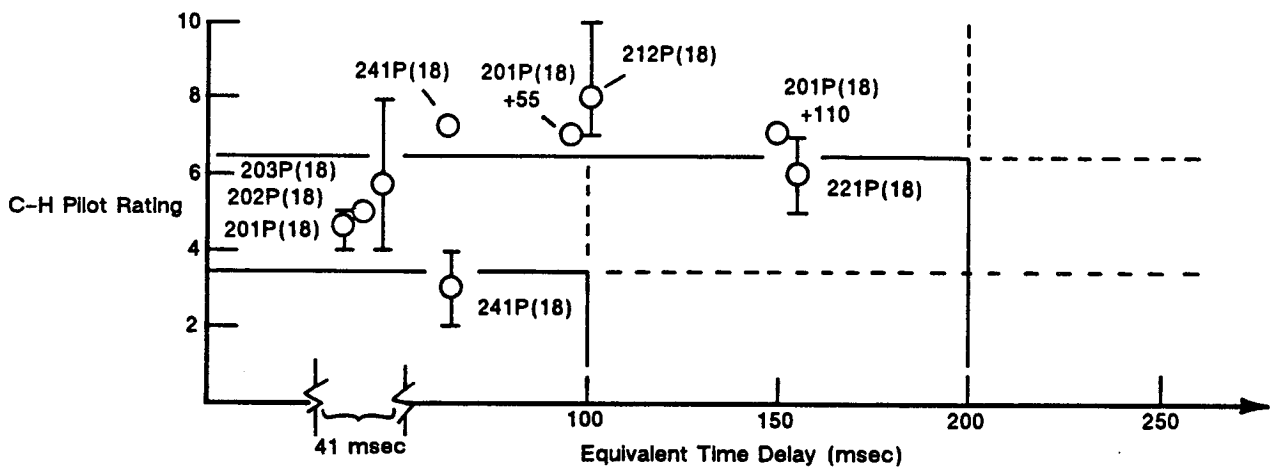
These figures demonstrate that:

- The MIL-F-8785C requirements are, again, insufficient to define lateral flying qualities. For instance, a change in command gain produces very improved flying qualities (e.g., Configuration 241P(10) versus 241P(18)), yet these configurations are identical in their compliance with MIL-F-8785C since each meets the minimum roll authority requirements.
- The best discrimination of the data against the time delay requirement is provided by the current "force input" definition for time delay calculations although neither demonstration technique is very accurate nor completely sufficient. For instance, if position inputs are used for position command systems, then no discrimination of flying qualities due to feel system differences are predicted. The poor flying qualities due to 8 rad/sec feel system dynamics are not considered to be bad designs in this case. Also, Configuration 212P(18) is "predicted" to be better than Configuration 221P(18) but, in actuality, the opposite is true. Configuration 221P(18) is superior in flying qualities because the 13 rps control system filter smooths the roll response and the feel system is transparent. Conversely, Configuration 212P(18) exhibits a slow feel system which produces no "filtering" effects nor does the 26 rps control system prefilter provide attenuation. With the force input definition, MIL-F-8785C requirements for time delay do not "predict" any flying qualities differences, whereas differences truly exist.

a) Force Input Only:



b) Force or Position Input:



Up-and-Away $\tau_R = .25 \text{ sec}$	
	Max Rating Averaged Pilot Rating Min Rating

Figure 72 COMPARISON OF .25 ROLL MODE TIME CONSTANT CONFIGURATIONS TO MIL-F-8785C TIME DELAY REQUIREMENT

The comparison of the .40 sec roll mode time constant pilot rating data is again made against the two proposed alternative methods of compliance to the MIL-F-8785C time delay requirement. These up-and-away evaluation data provide the best test for these alternatives since the augmented aircraft configurations were essentially Level 1 without the experimental variations being included (i.e. added control system delay, slow feel system dynamics, or added control system filtering).

In Figure 73a, the configurations are plotted with the time delay calculated from a force command input. Fairly good discrimination of data by the flying qualities level requirements is shown, with the exception of the Level 3 area. In this region (greater than 200 msec equivalent delay), six configurations are predicted to be Level 3 but each is rated Level 2 on the average.

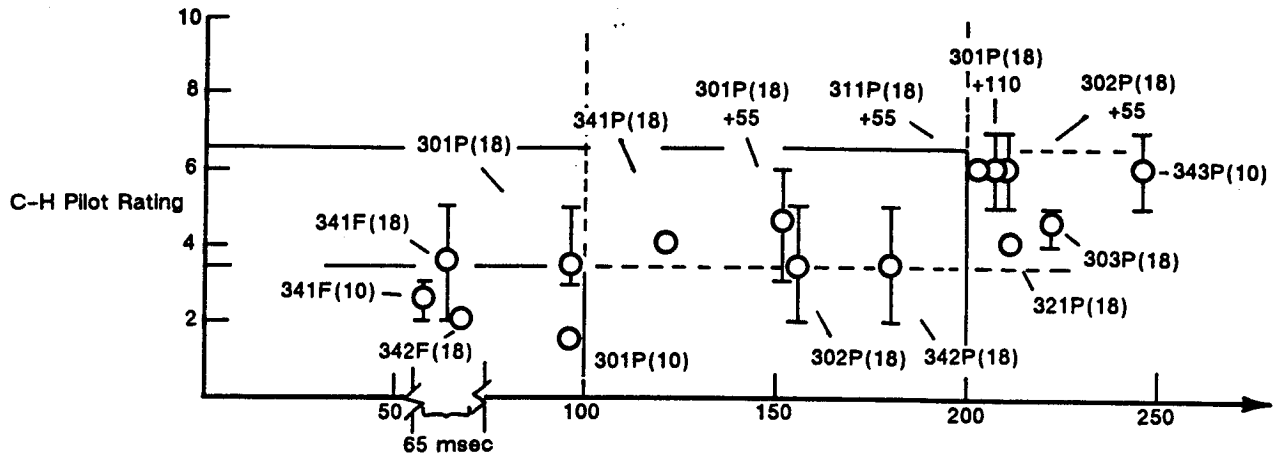
However, only two configurations (Configuration 303P(18) and 321P(18)) are really significant violations of the Level 3 prediction since the other four are borderline Level 2/Level 3. Only a single evaluation of configuration 321P(18) was performed so this data point is not well substantiated. The evaluation of Configuration 303P(18) did not note significant time delay-induced problems, but rather, Level 2 flying qualities resulted from the peculiar feel system characteristics. The Level 3 prediction for this case is, consequently, extreme.

In Figure 73b, a position input was used in the determination of a configuration time delay when a position command system was used. The correlation of pilot rating with the flying qualities levels of the time delay requirement are different than Figure 73a, but they are also reasonable. The area of disagreement with the requirement, however, shifts to the Level 1 region. With the new input definition, the slowest feel systems are now predicted to be Level 1 but the evaluation data represent Level 2 flying qualities.

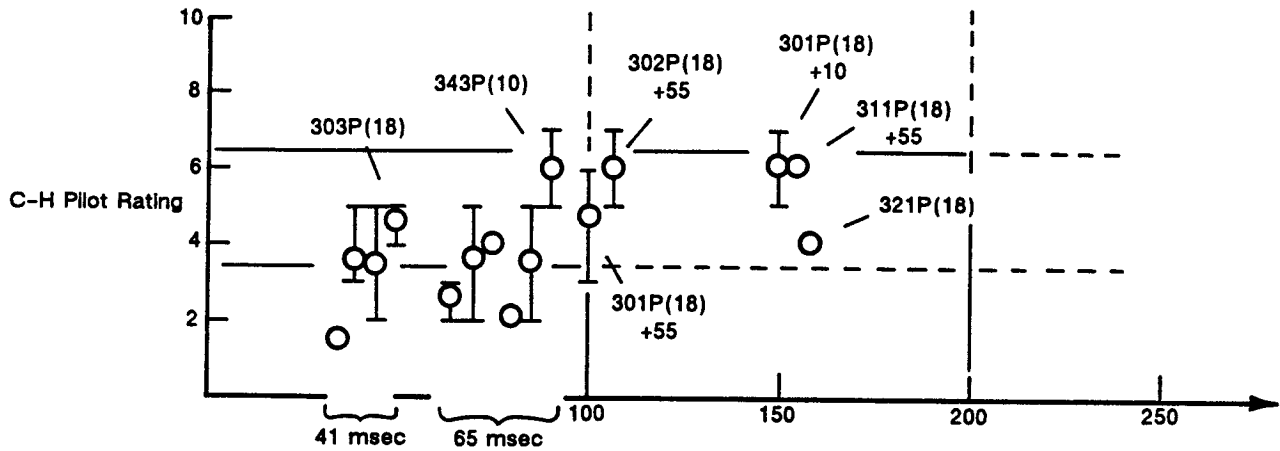
These comparisons clearly demonstrate that neither methodology is completely accurate in discriminating the flying qualities data from the up-and-away evaluations.

The pilot rating data for the power approach evaluations are plotted against the equivalent time delay in Figures 74 and 75. The .20 and .45 roll mode time constant configurations are illustrated in Figure 74 and the .30 sec roll mode configurations are plotted in

a) Force Input Only:



b) Force or Position Input:



Up-and-Away $\tau_R = .40 \text{ sec}$		Max Rating Averaged Pilot Rating Min Rating
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Figure 73 COMPARISON OF .40 ROLL MODE TIME CONSTANT CONFIGURATIONS TO MIL-F-8785C TIME DELAY REQUIREMENT

75. Both force input only and force or position input equivalent time delays (depending upon whether a force or position command architecture was used) are employed.

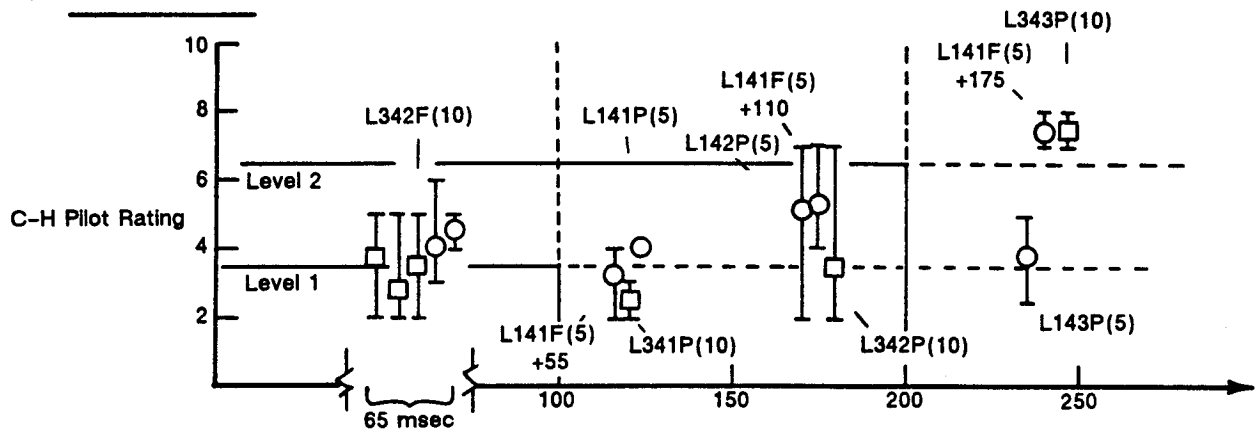
The comparisons show that:

- When the force input is used exclusively to define the equivalent time delay measurement, fairly good flying qualities definition is achieved except that numerous position command configurations are predicted to be Level 3 but are Level 2, in actuality. Also, the flying qualities deficiencies associated with short roll mode time constants (i.e., roll abruptness) and slow feel systems in a force architecture (e.g., Configuration L243F(10)) could not be appropriately defined.
- When position or force inputs are used to define the equivalent time delay, a good interpretation of Level 2 and Level 3 flying qualities is provided. Predicted Level 2 and Level 3 configurations received Level 2 and Level 3 pilot ratings, respectively, on the average. However, numerous configurations are predicted to be Level 1 in this correlation but received Level 2 and Level 3 pilot ratings. This correlation is not satisfactory since a criterion should not provide a Level 1 prediction when poor flying qualities can result. Rather, it is a better criteria approach to "predict" poor flying qualities and be conservative in having actual Level 1 flying qualities.

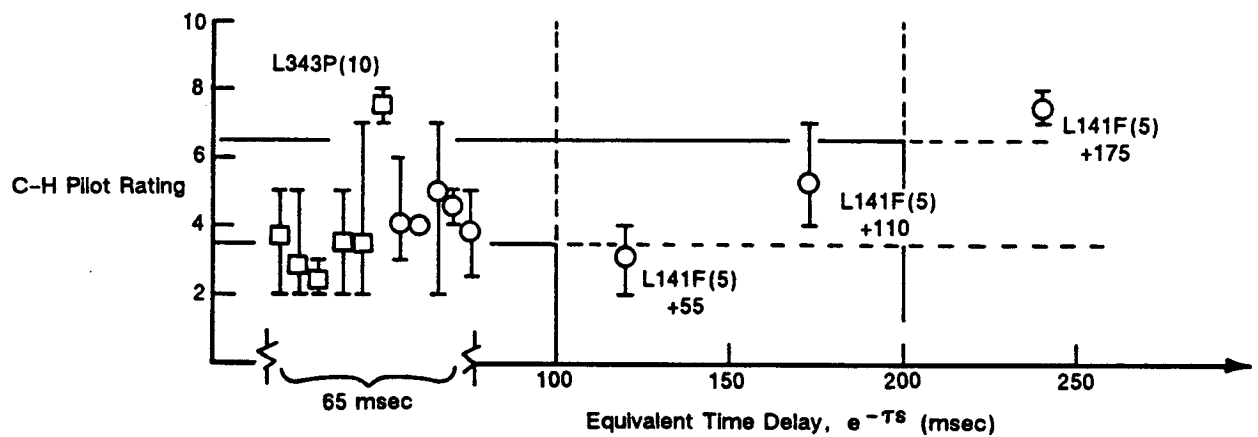
In summary, these data indicate three primary deficiencies in MIL-SPEC requirements:

1. Neither a force nor position input definition for time delay measurement is completely sufficient or accurate.
2. Maximum roll acceleration requirements based on pilot-in-the-loop controllability demands need to be established and imposed.
3. Flying qualities influence from feel system effects, such as low frequency dynamics or force-deflection changes, are not equivalent to time delay effects and should not be characterized as such.

a) Force Input Only:



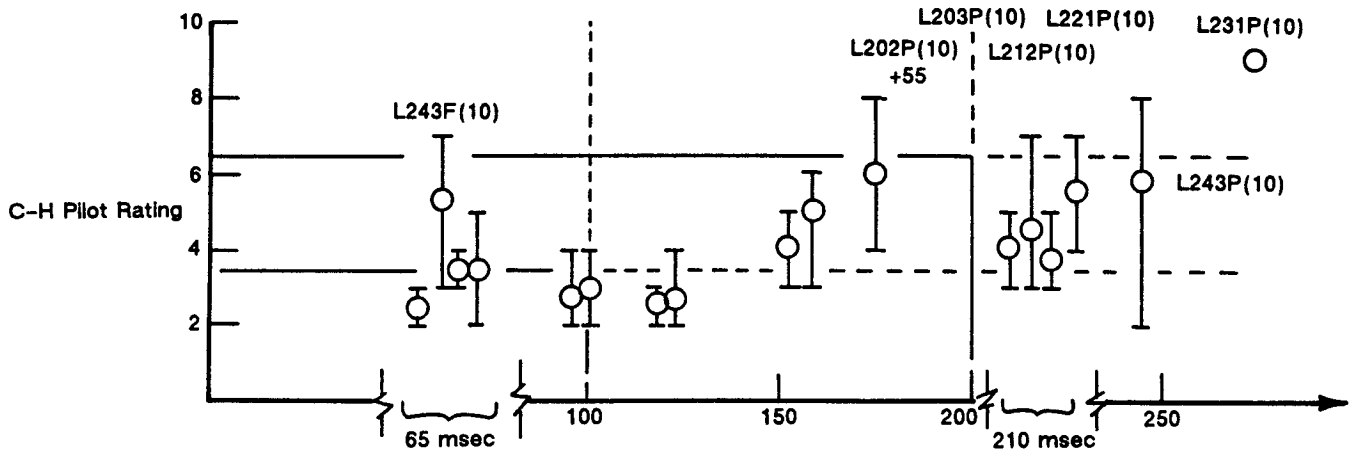
b) Force or Position Input:



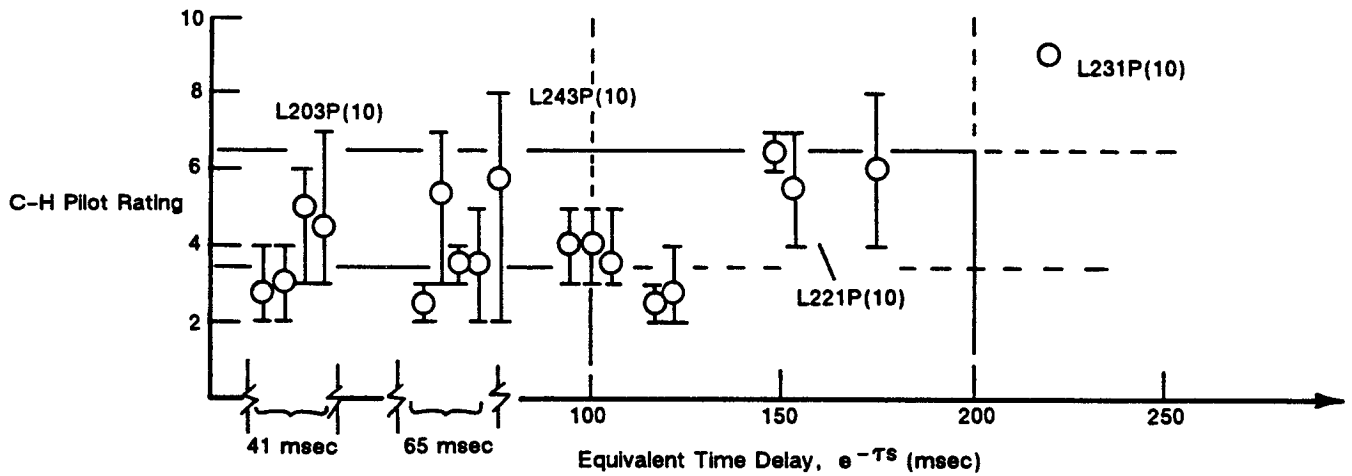
Power Approach		
○	$\tau_R = .20 \text{ sec}$	
□	$\tau_R = .45 \text{ sec}$	

Figure 74 COMPARISON OF .20 AND .45 sec ROLL MODE TIME CONSTANT CONFIGURATIONS TO MIL-F-8785C TIME DELAY REQUIREMENT

a) Force Input Only:



b) Force or Position Input:



Power Approach $\tau_R = .30 \text{ sec}$	 Max Rating Averaged Pilot Rating Min Rating
--	---

Figure 75 COMPARISON OF .3 sec ROLL MODE TIME CONSTANT CONFIGURATIONS TO MIL-F-8785C TIME DELAY REQUIREMENTS



## 6.2 TIME DOMAIN CRITERIA

The roll response of an aircraft to a step input command can be segmented for characterization into its initial, transient, and final response. From a cockpit view, the pilot desires a minimum of delay between his input and the initial response with a quick, yet not abrupt transient response to an adequate level of steady-state roll performance with reasonable stick forces. The response should be predictable and not noticeably nonlinear in time or in response to command input amplitude. With these desired flying qualities attributes in mind, criteria are developed for incorporation into MIL-SPEC requirements. The deficiencies of the current MIL-SPEC requirements are also addressed.

As the previous section has shown, the current MIL-F-8785C requirements are not complete in defining roll flying qualities. Minimum roll control authorities and maximum roll mode time constants and stick force levels are specified adequately by the current MIL-SPEC requirements. These requirements essentially define and are sufficient for the minimum steady-state and minimum transient performance levels in roll. However, with full authority, fly-by-wire flight control systems, maximum roll response extremes can be reached. As a great deal of experimental data has shown, poor pilot-in-the-loop control and predictability characteristics result. For instance, poor Level 3 flying qualities occur with short roll mode time constants which are erroneously predicted to be Level 1.

As has been shown, three areas need to be addressed. These are:

- Time delay definition and specification
- Maximum roll acceleration limits
- Artificial feel system requirements

The current time delay requirement is incomplete and inadequately defined. Maximum roll acceleration limits are needed because the roll acceleration capabilities of current and future aircraft outstrip the pilot's ability to precisely control the aircraft roll rates. Finally, a separate requirement on feel system design is needed, in addition to the current force, breakout, and friction requirements, because of their significant influence on flying qualities. Since inappropriate and inaccurate to incorporate the feel system dynamics as a time delay contributor the feel system

dynamics are neglected in defining the subsequent delay or roll acceleration requirements. A separate requirement is proposed instead.

The maximum roll acceleration or transient roll performance limits are currently independent of the time delay requirements. In analyzing the LATHOS data (Reference 9), time domain criteria were defined using effective roll mode time constant and time definitions (Figure 4). This criterion basis is used as a starting point for new criteria as shown to be necessary by this data and others.

Pilot ratings are compared to the LATHOS results on Figure 47 and Figure 49 for the up-and-away and power approach evaluations, respectively. A proposed revision to the power approach criteria is shown on Figure 51 reflecting the additional data provided by this experiment. A cockpit force step input was used exclusively in defining the effective parameters. The LATHOS correlations are limited in these figures to the fast (26 rad/sec) feel system dynamics only with a force command system.

The correlation of pilot rating data and the  $PR = 3\frac{1}{2}$ ,  $PR = 6\frac{1}{2}$  boundaries is quite good. Note that revision to the  $PR = 6\frac{1}{2}$  boundary in power approach flight phase category at the lower roll mode time constants was made. In making this comparison, an "optimum" control gearing is assumed (Reference 9).

Despite the good correlation of pilot rating data and the time domain criteria from Reference 9, two deficiencies in the current criteria are evident and require remedies; these are:

1. Feel system influences are not properly accounted. Only the "transparent" fast feel system dynamics were compared against the criteria. The feel system was completely neglected.
2. Command gain differences are not adequately defined. The current criterion parameter plane establishes the necessary but perhaps not sufficient prerequisites for good roll response dynamics and good flying qualities. One missing flying qualities ingredient is an adequate definition for command gain influences, given good roll dynamics, or roll acceleration requirements from pilot control inputs.

These additional flying qualities criteria are outlined with following sections.

## Feel System Requirements

The current MIL-F-8785C specification for feel system design are appropriate but not sufficient. For instance, the control centering, breakout, friction, and freeplay requirements must be met for good handling qualities. These requirements are adequate for Class IV aircraft. Minimum allowable feel system frequencies and dampings are essentially specified by the maximum allowable phase lag requirements. However, this requirement is not complete.

The current MIL-F-8785C requirement based on allowable phase lag is not sufficient nor an adequate depiction of the influence of feel system dynamics effects using the flight phase Category A and C requirements. For instance:

- In Table VIII, the phase lag requirement suggests that an 8 rad/sec feel system frequency would be acceptable for roll mode time constants greater than or equal to 0.40 sec. The pilot rating data from this program do not show an improvement to Level 1 flying qualities as the roll time constant is increased about 0.40 sec with the 8 rad/sec feel system. Indeed, the slow 8 rad/sec feel system produced unacceptable or annoying feel characteristics for almost all configurations.
- The damping ratio as well as natural frequency determine the phase lag limits. The current requirement, therefore, encourages low feel system damping ratios to meet the requirement (see Table VIII) for a given roll mode time constant. For instance, a roll mode time constant of .15 sec and a 13 rad/sec feel system natural frequency corresponds to Level 3 flying qualities by the phase lag requirement. Decreasing the damping ratio to .2 from .7 changes the phase lag requirement correlation from Level 3 to Level 1 ( $-44.3^\circ$  to  $-15.6^\circ$ ). Unfortunately, past experience, such as on the F-18 development (Reference 13), have shown adverse handling qualities due to low damping feel systems. Low stick damping creates problems such as "bobweight" coupling between the stick and pilot arm which results in a closed-loop, undamped resonance between the pilot arm mass and the aircraft. Constant attention with hands-on-the-stick was required to prevent inadvertent oscillations caused by vibration or aircraft motion (e.g., turbulence) which introduces undamped stick motion of the absence of stick damping.

A specification for allowable frequency and damping could be developed from this data base. Rather than using a phase lag requirement, a minimum equivalent frequency of 13 rad/sec

and a damping ratio of .6 is proposed. (Data substantiating the feel system damping ratio requirement are sparse). This requirement assumes a second-order feel system. From Reference 25, however, the F-14 is shown to have third-order feel system dynamic characteristics with a first-order lag root at 3.37 rad/sec and a second-order complex pair around 40 rad/sec. This low frequency real root dominates the feel system response and creates a system which violates the proposed 13 rad/sec lower frequency limit. The difference between the F-14 feel system and the second-order equivalent feel system requirement is the phase lag relationship. The F-14 cockpit control deflection lags the force input by 90° at most up to 13 rad/sec; whereas, second-order feel systems can lag by up to 180 degrees. The first-order system would probably not exhibit the same out-of-phase, "bobweight" deficiencies that the evaluation pilots from this program objected to with the slow, 8 rad/sec feel system. To accommodate these different feel system characteristics, the feel system requirement should more properly be stated quantitatively as "the cockpit control deflection shall not exhibit a phase lag of greater than 90° at 13 radians per seconds nor shall the cockpit deflection exhibit amplification above the steady-state value for any frequency less than 13 radians per second".

The phase angle requirement limits the feel system frequency of a second-order system to be at least greater than 13 rad/sec and does not prohibit lower frequency, first-order feel systems. For instance, the F-14 feel system would not violate this proposed specification requirement. The amplification requirement restricts the minimum damping ratio of the second-order feel system. Undesired amplification of the control deflection for frequencies up to the range of the pilot neuro-muscular dynamics of around 13 rad/sec (Reference 19) would be disallowed.

Unfortunately, this proposed requirement does not treat nonlinearities since the requirement is based in the frequency domain. Also, lower limits on a first-order feel system dynamic response are not specified. Further, the sometimes degrading influence of the 13 rad/sec feel system frequency, particularly for power approach tasks, is neglected and the requirement does not reflect the influence of piloting task or pilot control technique on acceptable feel system characteristics. The argument could be made that the feel system should be designed to the most stringent task and piloting demands since a physical feel system variation cannot be "scheduled" as easily as control system changes can be scheduled in digital fly-by-wire aircraft.

#### Roll Acceleration ("Sensitivity") Criteria

The influence of control system time delay on flying qualities appears to be dependent upon the shape of the transient response after the initial response delay. This interrelationship is

**Table VIII**

**CORRELATION OF CONTROLLER PHASE LAG AGAINST MIL-F-8785C REQUIREMENTS**

PHASE LAG AT UPPER FREQUENCY (rps)  
AS DEFINED BY MIL-F-8785C

FEEL SYSTEM DYNAMICS	$\tau_R$ :	0.15	0.20	0.25	0.30	0.40	0.45
	UPPER FREQUENCY ( $1/\tau_R$ )	6.77	5.00	4.00	3.33	2.50	2.22
$\zeta = .7; \omega_n = 26$ rps		-21.0 °	-15.6 °	-12.4 °	-10.3 °	-7.7 °	-6.9 °
$\zeta = .7; \omega_n = 13$ rps		-44.3 °	-32.3 °	-25.4 °	-21.0 °	-15.6 °	-13.9 °
$\zeta = .7; \omega_n = 8$ rps		-75.4 °	-55.1 °	-43.0 °	-35.2 °	-25.9 °	-22.8 °
$\zeta = .2; \omega_n = 13$ rps		-15.6 °	-10.2 °				
$\zeta = .2; \omega_n = 8$ rps		-47.6 °	-22.3 °				

LEVEL 3

**ALLOWABLE COCKPIT CONTROL DEFLECTION LAGS DUE TO COCKPIT CONTROL FORCE INPUTS**

From MIL-F-8785C

LEVEL	ALLOWABLE LAG ~ deg		CONTROL	UPPER FREQUENCY ~ rad/sec
	CATEGORY A AND C FLIGHT PHASES	CATEGORY B FLIGHT PHASES	ELEVATOR	$\omega_{n_{sp}}$
1 and 2	30	45	RUDDER & AILERON	$\omega_{n_d}$ or $1/\tau_R$
3	60			(whichever is larger)

implied in the effective time domain by the "inverted-U" shape of the pilot rating boundaries. A third ingredient, the command gain, is not an integral criterion parameter but should be to completely specify the transient response shape. Also, the command gain and effective roll mode time constant help to define the roll acceleration response which must also be specified.

To address these issues, the data are examined using the maximum rate of roll acceleration change or "jerk" response ( $\ddot{p}$ ) of the configurations for a step input. This parameter has shown good preliminary results in Reference 7. In this evaluation, the maximum value of "jerk" is calculated from a step position input of 1 inch of cockpit control deflection for a position command architecture or from a step force input of a magnitude sufficient to achieve a 1 inch steady-state roll control deflection for a force command system. The influence of the feel system dynamics are, therefore, not included. Feel system static force-deflection characteristics, however, do impact the criterion.

For the up-and-away data, the maximum roll "jerk" parameter is plotted with the effective time delay for each configuration in Figure 76. Averaged pilot rating levels are, again, used to illustrate flying qualities trends. The data used to develop this correlation is presented in Appendix A.

The averaged pilot rating trends are fairly well separated by the  $\ddot{p}$  and  $\tau_{\text{eff}}$  parameters. In Figure 76, the correlation is expanded to include Reference 9 data as well. Time delay tolerance is greatest for lower values of  $\ddot{p}$ . This substantiates the conjecture that a greater time delay tolerance is present for slower, less abrupt transient responses. Conversely, less time delay is tolerable with high roll "jerk" configurations in this criterion. Feel system effects are not apparent in this criterion due to the input definition. The influence of the feel system should be determined separately. Also, the effective roll mode time constant and time delay criteria should be referenced simultaneously with this "jerk" criterion since both criterion define important flying qualities characteristics (that is, the roll acceleration defines the maximum value of the rate of acceleration change due to pilot commands while the time constant describes the shape of the transient response).

The same criteria and others were examined with the power approach flying qualities data. The results show that time delay tolerance is not a strong function of the maximum acceleration rate, rather, the best correlation of flying qualities data was formed using the maximum roll rate. This correlation suggests that the current criterion based on effective roll mode and time delay parameters are sufficient in predicting roll flying qualities for fighter aircraft in power

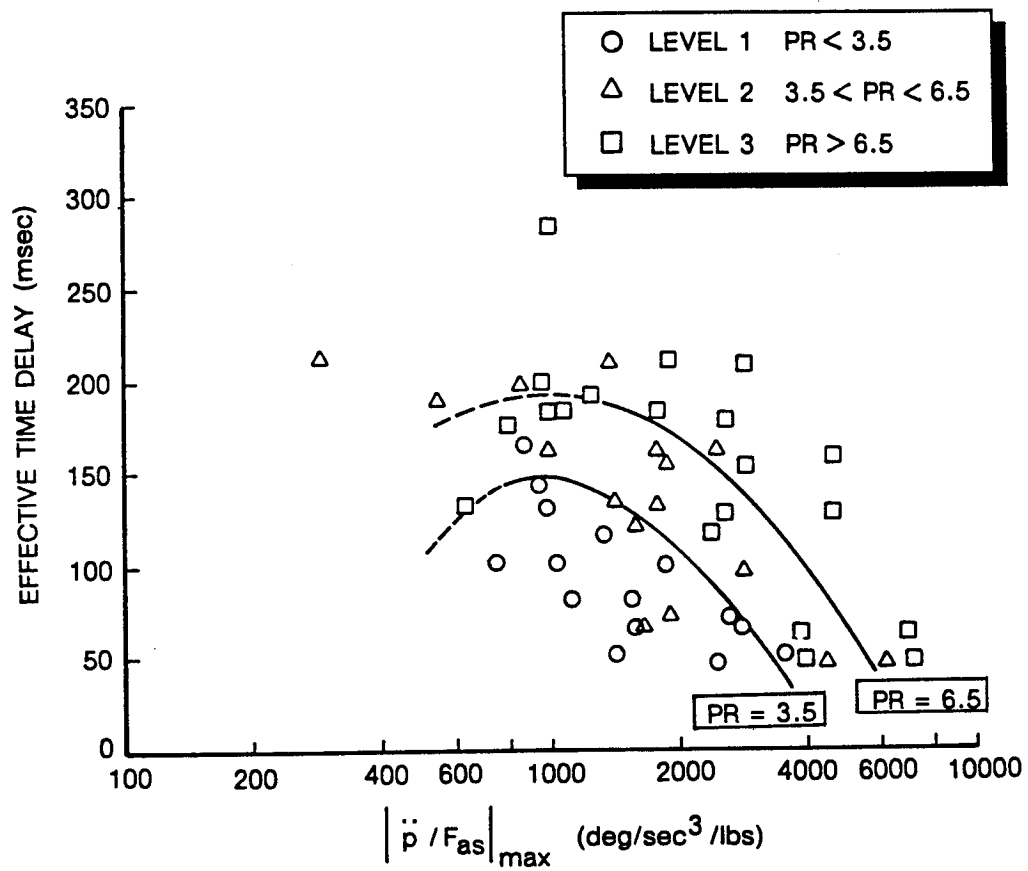


Figure 76 HANDLING QUALITY LEVELS AS A FUNCTION OF EFFECTIVE TIME DELAY AND ROLL JERK

approach. Nonlinear gearing effects need to be introduced but the lack of a suitable database prohibits this formulation at the present time.

### 6.3 EFFECT OF MOTION CUES

A series of fixed-based ground simulations were performed which mimicked the in-flight experiment performed here. These experiments are documented in References 11 and 12. Comparison against these experiments are not made due to the great disparity between the experimental motion cues, visual cues, and evaluation tasks. For instance, the nominal Reference 11 and 12 configuration from which experimental control system variations were made was rated Level 1 in the ground-based simulations. Conversely, a very similar configuration was rated Level 3 in this experiment because of objectionally abrupt roll accelerations. Therefore, comparison of the data bases is fatuous. Motion cues are critical in roll flying qualities evaluations. To illustrate the differences, the results of the ground simulator evaluations (References 11 and 12) show pilot reference for:

- high roll damping ( $\tau_R \leq .15$  sec).
- high roll command gain ( $p/F_{as} = 20$  deg/sec/lbs), particularly as control system time delay is added.
- no-motion cockpit controllers.

In sharp contrast, the results of this in-flight experiment have demonstrated very different trends:

- optimum roll damping is between  $\tau_R = .30$  to  $.60$  sec.
- moderate roll command gains (steady-state roll rates between 10 and 18 deg/sec/lbs) with a reference for decreasing command gain (or sensitivity) as delay increases.
- cockpit controllers with motion.

In Reference 23, a similar flight and ground based experiment was documented which also showed the same dichotomous flying qualities preference depending upon the motion cue environment.



These differences dramatically illustrate the powerful influence of the in-flight, full motion environment. Therefore, airplane motion cuing cannot be neglected in the evaluation of lateral flying qualities designs for fighter aircraft and reliance on ground-based simulation for lateral control law definition should be avoided.

## **Section 7**

### **CONCLUDING REMARKS**

An in-flight investigation was performed examining the influence of feel system characteristics on lateral fighter flying qualities. Subjective pilot evaluation and quantitative tracking data were examined. These data showed:

- The feel system is a unique flight control system element that affects flying qualities whether the system is employed in a force command architecture or a position command architecture. Although the command to the flight control system differs in the two situation, the feel system effect on the pilot is similar.
- A feel system with a natural frequency of 26 rad/sec and a damping ratio of .7 is transparent to the pilot; that is, the position response of the stick from a his force input is essentially instantaneous and unobtrusive to his control actions. As the feel system frequency is reduced to 13 rad/sec, the influence of the feel system on pilot flying qualities is subtle. At 8 rad/sec, the change is obvious and degrading. The "sluggish" stick response is described as a bobweight effect resulting in a nonlinear pilot/vehicle closed-loop response.
- Variations in feel system dynamics are not equivalent to the same variations in "downstream" flight control system elements. Downstream variations are "hidden" from the pilot since the changes are only apparent in the resultant aircraft motion and visual response. Significant phase lag contributions in these elements, for instance, cause severe control problems such as PIO. The identical phase lag in the feel system causes a flying qualities degradation, but of less severity because the source of the degradation is directly sensed by the pilot.
- A decreased force-deflection gradient (more motion-per-unit of input force) centerstick controller greatly alleviated roll ratchet tendencies. The reduction from 4.0 lbs per inch to 2.75 lbs per inch improved very abrupt aircraft response characteristics from Level 3 to Level 1 in up-and-away evaluations.
- Frequency response analyses of tracking data were not sufficiently indicative of roll flying qualities or roll ratchet tendencies.

- Flying qualities criteria are proposed for the design of roll flight control systems. The requirements specify a satisfactory range of effective roll mode time constant, effective time delay, feel system frequency response characteristics, and maximum roll acceleration capabilities. These criteria are suggested to augment the current MIL-F-8785 requirements which specify only minimum roll capabilities.
- Accurate motion cues were shown through data base comparison to be critical to the accurate evaluation of roll flying qualities.

## Section 8

### REFERENCES

1. Chin, J., Berman, H., and Ellinwood, J., "X-29A Flight Control System Design Experiences," AIAA Paper No. 82-1583, August 1982.
2. Smith, R.E., and Bailey, R.E., "Effect of Control System Delays on Fighter Flying Qualities," AGARD Conference Proceedings No. 333 on Criteria for Handling Qualities of Military Aircraft.
3. Military Specification: "Flying Qualities of Piloted Airplanes," MIL-F-8785C, 1980.
4. Hodgkinson, J., Berger, R.L., and Bear, R.L., "Analysis of High Order Aircraft Flight Control System Dynamics Using an Equivalent Systems Approach," McAir Report No. 76-009, Seventh Annual Pittsburg Conference on Modeling and Simulation, 1976.
5. Meyer, R.T., Knox, J.R., and Tingas, S.A., "Suggested Revisions to MIL-F-8785C for Large (Class III) Aircraft," AFWAL-TR-83-3015, February 1983.
6. Berry, D.T., Powers, B.G., Szalai, K.J., and Wilson, R.J., "A Summary of an In-Flight Evaluation of Control System Pure Time Delays During Landing Using the F-8 DFBW Airplane," AIAA Paper No. 80-1626, August 1980.
7. Smith R.E., and Sarrafian, S.K., "Effect of Time Delay on Flying Qualities: An Update," AIAA Paper No. 86-2202, August 1986.
8. Weingarten, N.C., and Chalk, C.R., "In-Flight Investigation of Large Aircraft Flying Qualities for Approach and Landing," AFWAL-TR-81-3118, September 1981.
9. Monagan, S.J., Smith, R.E., and Bailey, R.E., "Lateral Flying Qualities of Highly Augmented Fighter Aircraft," AFWAL-TR-81-3171, June 1982.
10. Cooper, G.E., and Harper, R.P., Jr., "The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities," NASA TN D-5153, April 1969.

11. Johnston, D.E., and McRuer, D.T., "Investigation of Interactions Between Limb-Manipulation Dynamics and Effective Vehicle Roll Control Characteristics," NASA CR-3983, May 1986.
12. Johnston, D.E., and Aponso, B.L., "Design Considerations of Manipulator and Feel System Characteristics in Roll Tracking," NASA CR-4111, February 1988.
13. Moran, W.A., "Operational and Developmental Experience With the F/A-18 Digital Flight Control System," AGARD Conference on Active Control Systems: Review, Evaluation, and Projections, March 1985.
14. Herzog, J.H., "Manual Control Using the Matched Manipulator Control Technique," IEEE Transactions of Man-Machine Systems, Volume 9, No. 3, pp. 56-60, September 1968.
15. Merhav, S.J., and Ya'acov, O.B., "Control Augmentation and Workload Reduction by Kinesthetic Information from the Manipulator," IEEE Transactions on Systems, Man, and Cybernetics, Vol. 6, No. 12, pp. 825-835, December 1976.
16. Brown, S.W. et al., "NT-33A Lateral Flying Qualities Evaluation: Effects of Time Delay, Artificial Feel System Dynamics, and Roll Mode Time Constant on Lateral Flying Qualities," USAFTPS-TR-87A-S02, December 1987.
17. Bailey, R.E., Knotts, L.H., and Levison, W.A., "An Investigation of Time Delay During In-Flight and Ground-Based Simulation," Calspan Report No. 7205-16, Vols. I and II, August 1987.
18. Onstott, E.D., and Faulkner, W.H., "Prediction, Evaluation, and Specification of Closed Loop and MultiAxis Flying Qualities, AFWAL-TR-78-3, February 1978.
19. McRuer, D.T., and Magdaleno, R.E., "Human Pilot Dynamics With Various Manipulators," AFFDL-TR-66-138, December 1966.
20. Van Cott, H.P., and Kinkade, R.G., "Human Engineering Guide to Equipment Design," American Institutes for Research, Washington, D.C., 1972.
21. Hall, G.W., and Smith, R.E., "Flight Investigation of Fighter Side-Stick Force-Deflection Characteristics," AFFDL-TR-75-39, May 1975.

22. Wood, J.R., "Comparison of Fixed-Base and In-Flight Simulation Results for Lateral High Order Systems," AIAA Paper No. 83-2105, August 1983.
23. Smith, R.E., Hodgkinson, J., and Snyder, R.C., "Equivalent System Verification and Evaluation of Augmentation Effects on Fighter Approach and Landing Flying Qualities," AFWAL-TR-81-3116, Vols. I and II, September 1981.
24. Wood, J.R., and Hodgkinson J., "Definition of Acceptable Levels of Mismatch for Equivalent Systems of Augmented CTOL Airplanes," McDonnell Douglas Report A6792, December 1980.
25. Bischoff, D.E., "Development of Longitudinal Equivalent System Models for Selected Navy Aircraft," NADC-81069-60, August 1981.

## Appendix A TABULATED DATA

Relevant program data are tabulated in this appendix.

In Table A-I, a summary of evaluations is presented. For each configuration, the evaluation flight and pilot ratings are tabulated. This table lists the configuration identifier ("CONFIG"), the evaluation pilot ("Pilot"), the flight number and evaluation number of that flight ("Flt-Eval"). The data are the Cooper-Harper Pilot Ratings ("PR") assigned to the configuration overall ("overall PR") and to the individual tasks. The individual task ratings were not always given nor were all the tasks flown for each configuration (see Section 4.5). "HUD" is entered in the overall PR Summary if only HUD tasks were used in the flying qualities evaluations. The individual rating task data are defined for the formation flying task ("Form"), air-to-air target tracking ("A-A"), the discrete pitch and roll HUD-generated tracking task ("SAAB"), the HUD-displayed sum-of-sines roll tracking task taken from the time delay study program ("SOS (TD)"), the roll sum-of-sines task specifically designed for this program ("SOS(NASA)"), and the HUD-displayed, roll-only discrete tracking task identical to that of the LATHOS program ("LATHOS").

In Table A-II, time history response parameters are listed. The metrics were calculated from a time history simulation computer program using a 1 lbs step roll stick force input or a 1 inch step roll stick position input. Both inputs are used for position command system configurations whereas only force inputs are calculated for the force command system, since the controller position, in this situation, is in parallel rather than series to the roll command. The metrics are illustrated on the time history response as shown in Figure A-1. In this table, the overall configuration pilot ratings are given. Simple means of this data are taken for illustration purposes and flying qualities levels, used for the criteria of Section 5 were assigned.

In Table A-III, equivalent systems parameters are shown. Equivalent roll mode time constants,  $\tau_{R_e}$ , and equivalent time delays,  $\tau_e$ , were calculated using the low order model:

$$(p/x) = \frac{K_e e^{-\tau_e s}}{(\tau_{R_e} s + 1)}$$

where "x" was either  $\delta_{as}$  or  $F_{as}$  depending upon whether force or position commands was used as the input definition. Position commands were never used as the delay definition input for force command systems. The high order transfer function models were matched over a frequency range of .1 to 10 rad/sec using 21 points equi-spaced on a logarithmic scale. No frequency weightings were used to "bias" the match. The mismatch or cost functions are tabulated with the equivalent models, where the cost function was:

$$\text{Cost} = \sum_{i=1}^{21} (\Delta\text{dB}_i^2 + .01745 \Delta\phi_i^2)$$

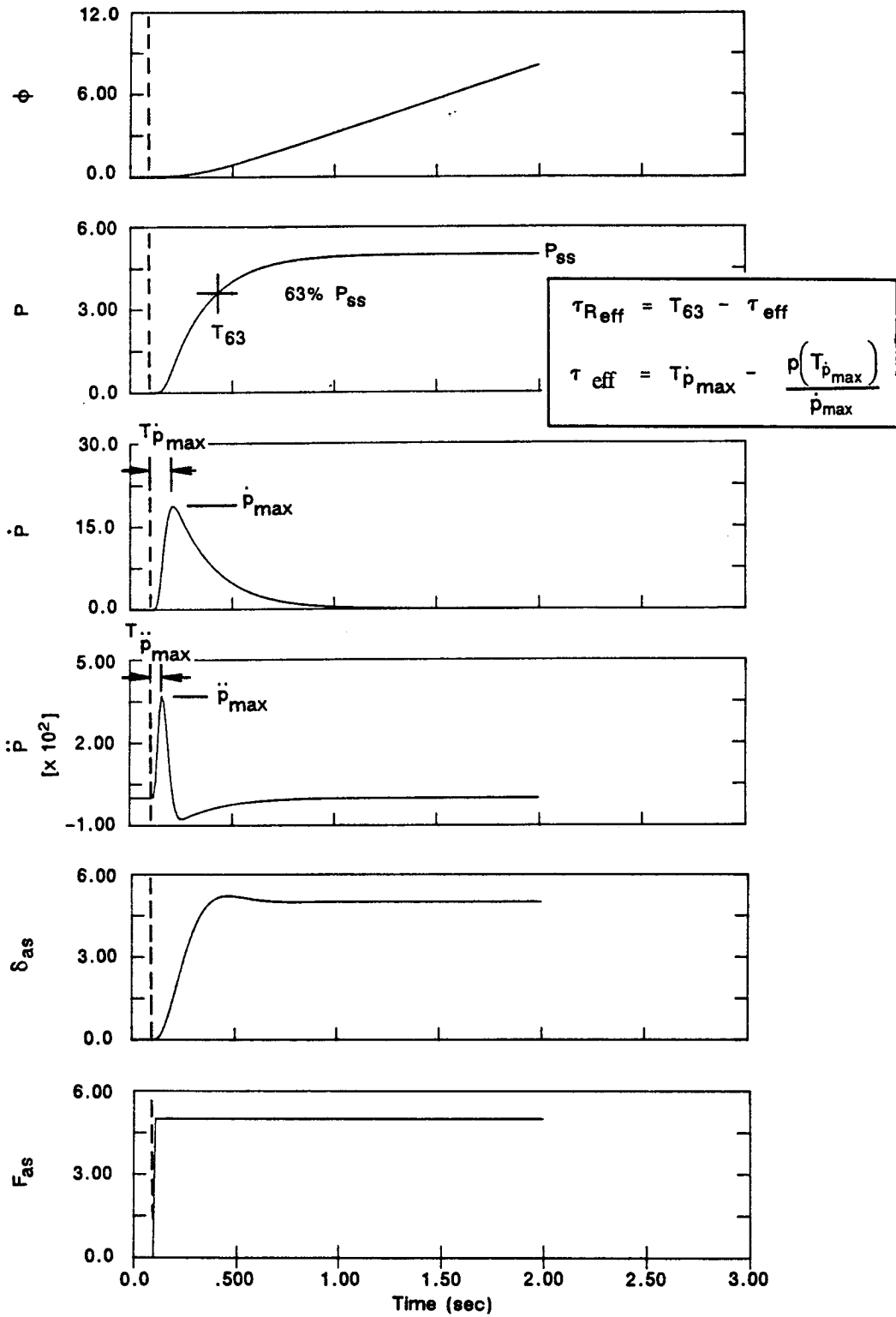
where  $\Delta\text{dB}_i$  = difference in amplitude ratio between HOS and LOS, in dB, at each ith frequency point

$\Delta\phi_i$  = difference in phase angle between HOS and LOS, in degrees, at each ith frequency point

The equivalent and effective time delays are compared in Figure A-2 for several configurations. In general, the calculated equivalent and effective time delay are identical; however, in several instances, they are not equal. Equality is dependent upon numerous items, such as the absence or presence of nonlinearities, the frequency range of the equivalent system match compared to the frequency of high order elements, and the assumed order of the low order equivalent model. One direct indicator of a potential difference between the equivalent and effective time delay measurements is the equivalent system cost function. As shown in Figure A-2, the deviation from perfect correlation between equivalent and effective time delay is significant when the cost function is not negligible (i.e., cost > .1). These comparisons are discussed further in References 2 and 24.

In Table A-IV, the pilot rating results from Reference 16 are presented. Details of the summary results can be found in Reference 16; they are presented here for convenience since the pilot rating results were shown in this report.





CONFIG: L142F(5)

Figure A-1 ILLUSTRATION OF TIME HISTORY RESPONSE METRICS

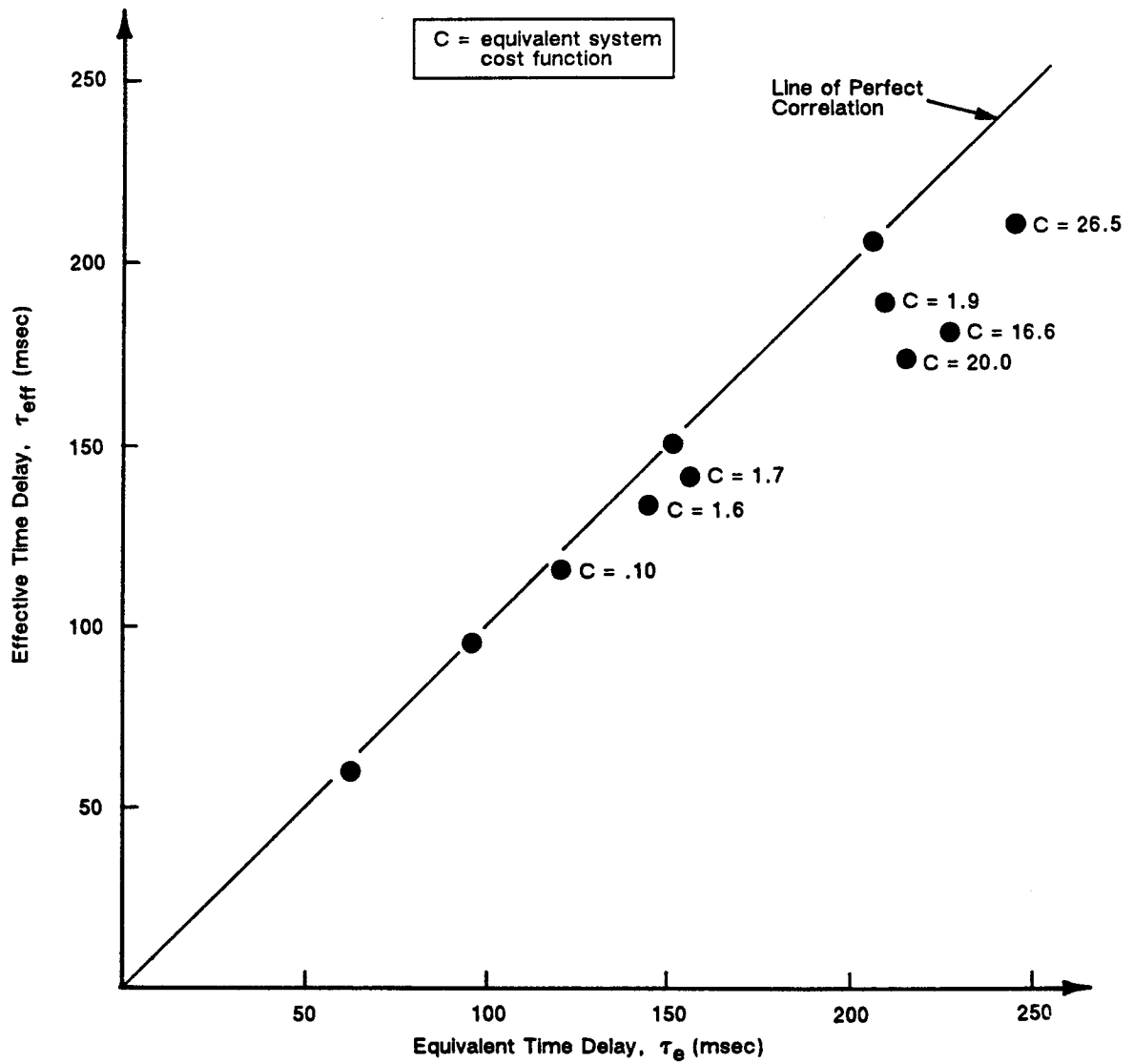


Figure A-2 COMPARISON OF EQUIVALENT AND EFFECTIVE TIME DELAY MEASUREMENTS

**Table A-I  
EVALUATION SUMMARY**

CONFIG.	PILOT	FLT-EVAL	OVERALL PR	FORM. PR	A-A PR	SAAB PR	SOS (TD) PR	SOS NASA PR	LATHOS PR	REMARKS	
141F (10)	C	4056-3	3	2	3	2	2	7	4		
	A	4069-3	7		5						
	B	4175-5	6		4						
141F (10)*	A	4160-4	2	2	2	3	2	1	*F <sub>as</sub> /δ <sub>as</sub> = 2.5 lbs/in		
	A	4161-4	3	2							
141F (18)	C	4054-3	4 (HUD)	4	4	4	4	6			6
	B	4055-4	3 (HUD)								
	A	4057-3	7								
	B	4159-4	6								
141F (18) +25	B	4153-4	4	-	-	-	-	-			
142F (18)	A	4160-5	3 (HUD)	-	-	-	5	3			
143F (18)	B	4055-5	2 (HUD)	6	2	7	7	7			
	B	4154-5	7								
	B	4155-5	7								
143P (18)	A	4069-4	8	7	7	8	8	7	HUD tasks not flown		
	B	4153-5	5								
	A	4176-4	8								
201P (18)	A	4070-3	5	5	5	3	3	3		HUD tasks not flown	
	C	4127-2	5								
	B	4153-1	4								
	B	4157-2	6 (HUD)								
201P (18) +55	A	4161-3	7	5	7	7	7				
201P (18) +110	B	4154-1	7	6	7	-	-	-			
	A	4161-5	7								
202P (18)	A	4156-2	5	5	4	5	4	5			
	B	4159-1	5								
203P (18)	B	4053-2	4	2	5	2	2	6	4		
	C	4056-1	5								
	A	4057-2	8								
	A	4160-2	6								
212P (18)	A	4052-3	7	3	4	3	5	8	8		
	C	4054-2	10								
	C	4127-1	8								
	C	4126-3	7 (HUD)								
	B	4155-2	7								
221P (18)	A	4052-2	7	5	7	3	4	-	-		
	B	4055-2	3 (HUD)								
	C	4056-2	5								
	B	4154-4	5								
	A	4176-1	7								

**Table A-1  
EVALUATION SUMMARY**

CONFIG.	PILOT	FLT-EVAL	OVERALL PR	FORM. PR	A-A PR	SAAB PR	SOS (TD) PR	SOS NASA PR	LATHOS PR	REMAF
222P (18)	B	4055-3	2 (HUD)			2	2			
231P (18)	B	4079-2	5 (HUD)					4	4	
241P (10)	A	4070-2	2		1 1/2			2	2	
	A	4160-1	4		5			4	4	
241P (18)	A	4069-2	7		2			7	4	
	C	4126-2	5 (HUD)					5	4 1/2	
301P (10)	A	4070-5	1 1/2		1 1/2			1 1/2	1 1/2	
301P (18)	A	4156-1	3		3			3	3	
	B	4155-3	5		4			5	6	
	B	4157-1	4 (HUD)					4	4	
	B	4175-1	3		2			3	3	
301P (18) +55	A	4160-3	3		2			4	3	
	B	4159-3	5		-			-	-	
	B	4155-1	6		5			5	5	
301P +110	A	4161-1	7		4			7	6	
	B	4155-4	5		4			5	5	
302P (18)	B	4154-2	5		5			5	5	
	A	4161-2	2		2			2	1	
302P (18) +55	A	4156-3	7		2			7	4	
	B	4175-2	5		5			5	5	
303P (18)	A	4156-4	4		2			5	2	
	B	4175-3	5		5			5	5	
	A	4176-2	5		2			5	2	
311P (18) +55	B	4154-3	6		6			-	-	
321P (18)	A	4176-5	4		4			4	3	
341F (10)	C	4054-1	3	2	4	2	2			
	B	4055-1	4 (HUD)			4 1/2	4			
	A	4057-1	2 1/2	2	3	2 1/2	2			
	A	4070-4	3		2 1/2			3	2	
	B	4153-3	2		-			-	-	
341F (18)	A	4065-1	3 (HUD)			2		4	3	
	B	4079-1	3 (HUD)					4	2	
	B	4159-2	4		2			2	4	
	B	4175-4	5		3			5	-	
	A	4176-3	2		2			2	1	
341P (18)	A	4052-1	4	3	4	2	5			
	C	4126-1	5 (HUD)					5	4	
342F (18)	C	4127-3	2		2		2	2		
342P (18)	A	4069-1	2		2			2	2	

**Table A-I  
EVALUATION SUMMARY**

CONFIG.	PILOT	FLT-EVAL	OVERALL PR	FORM. PR	A-A PR	SAAB PR	SOS (TD) PR	SOS NASA PR	LATHOS PR	REMARKS
	B	4153-2	5		5					HUD tasks not flown
343F (18)	B	4079-3	3 (HUD)					3	3	
343P (10)	A	4070-1	5		4			5	4	
	B	4156-5	7		6			7	6	
L141F (5)	A	4066-3	3							
	C	4074-3	3							
	B	4075-4	3							
	B	4157-7	6							
	A	4177-3	5							
L141F (5) +55	A	4067-4	2 1/2							
	A	4068-3	2							
	C	4073-4	4							
	B	4077-3	4							
L141F (5) +110	C	4126-6	5							
	C	4118-4	4							
	B	4162-6	7							
	A	4178-5	5							
L141F (5) +175	A	4066-4	7							
	B	4078-2	4							
	B	4076-3	4							
	C	4122-4	8							
L141P (5)	C	4128-3	4							
L142F (5)	A	4065-5	2							
	C	4123-4	4							
L142P (5)	A	4067-5	2							
	C	4126-7	6							
	C	4120-4	7							
	A	4158-3	3							
	B	4162-4	7							
L143F (5)	B	4076-2	4							
	C	4074-4	5							
L143P (5)	A	4068-5	2 1/2							
	C	4073-5	5							
	A	4177-4	4							
L201P (5)	A	4067-3	2							
	C	4123-1	2							
	A	4160-7	NR							
	B	4157-3	4							
L201P(10)	A	4068-1	4							
	B	4155-7	4							
	B	4153-6	2							

**Table A-1  
EVALUATION SUMMARY**

CONFIG.	PILOT	FLT-EVAL	OVERALL PR	FORM. PR	A-A PR	SAAB PR	SOS (TD) PR	SOS NASA PR	LATHOS PR	REMARKS
L201P(10) +55	A	4158-1	2							
	C	4127-5	5							
	A	4156-5	4							
	B	4155-6	5							
	A	4177-6	3							
	A	4178-2	3							
L201 (10) +110	C	4122-2	6							
	A	4158-5	7							
L202P(10)	A	4067-2	6							
	C	4119-2	5							
	C	4126-4	6							
	C	4127-4	3							
	B	4162-1	5							
L202P(10) +55	B	4157-5	5							
	A	4158-2	3							
	A	4177-2	4							
	A	4178-6	4							
L203P(10)	A	4066-1	4							
	B	4078-4	3							
	C	4118-3	7							
	A	4160-6	4							
L212P(10)	B	4075-2	3							
	B	4175-7	5							
	A	4178-7	3							
L221P(10)	C	4074-2	6							
	B	4075-3	4							
	B	4162-3	5							
	A	4078-1	7							
L231P(10)	C	4074-1	9							
L241F (5) +55	A	4066-2	3							
	C	4074-5	3							
	B	4077-4	4							
	C	4118-2	2							
	B	4154-6	5							
L241F (5) +55	A	4065-3	3							
	B	4076-1	2							
L241F(10)	A	4068-4	4							
	C	4073-3	3							
	B	4077-2	3							
	A	4178-4	4							
	C	4119-4	3							
L241F (10)*	C	4122-3	3							
	A	4156-6	2							

\*( $F_{as}/\delta_{as}$   
2.5 lbs/

**Table A-1  
EVALUATION SUMMARY**

CONFIG.	PILOT	FLT-EVAL	OVERALL PR	FORM. PR	A-A PR	SAAB PR	SOS (TD) PR	SOS NASA PR	LATHOS PR	REMARKS
L241F(10) +55	C	4128-4	2							
	A	4161-7	2							
	B	4162-5	4							
L241F(10) +110	C	4127-6	8							
	B	4153-8	6							
	A	4177-5	4							
L243F(10)	A	4068-2	5							
	B	4075-5	3							
	C	4119-3	6							
	C	4120-3	7							
L243P(10)	A	4070-6	8							
	C	4073-2	7							
	B	4077-1	2							
	B	4157-6	6							
L341F(5)	C	4120-1	2							
	B	4153-7	5							
	A	4158-4	4							
L341F(10)	A	4065-2	2							
	B	4075-1	1*							Low Approach Only
	B	4078-1	2							
	C	4122-1	2							
	B	4162-2	5							
	C	4118-1	3							
L341P(10)	A	4177-1	2							
	C	4118-1	3							
L342F(10)	C	4073-1	2							
	C	4120-2	5							
	B	4175-6	4							
	A	4178-3	3							
L342P(10)	C	4128-1	2							
	A	4067-1	2							
	A	4069-5	NR							
	C	4119-1	2							
	B	4157-4	5							
	B	4159-6	7							
	A	4161-6	3							
L343P(10)	C	4123-3	7							
	C	4128-2	8							

Table A-II  
UP-AND-AWAY CONFIGURATIONS

CONFIG	1 lb $F_{as}$ STEP INPUT							1 inch $F_{as}$ STEP INPUT							PILOT RATINGS				
	$\tau_{R\text{eff}}$	$\tau_{\text{eff}}$	$\ddot{p}_{\text{max}}$	$\dot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	$\dot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	$\tau_{R\text{eff}}$	$\tau_{\text{eff}}$	$\ddot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	$\dot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	A	B	C	$\overline{\text{PR}}$	Level Rating	
141F (10)	0.165	0.06	3832	958	0.055	46.8	0.105	N/A						7	6	3	5.3	3 <sup>‡</sup>	
141F (10)*	0.165	0.06	2634	958	0.055	46.8	0.105	N/A						2,3			2.5	1	
141F (18)	0.165	0.06	6896	1724.4	0.055	84.2	0.105	N/A						7	6		6.5	3	
142F (18)	0.165	0.06	6896	1724.4	0.055	84.2	0.105	N/A						3			-	-	
143F (18)	0.165	0.06	6896	1724.4	0.055	84.2	0.105	N/A							7,7		7	3	
143P (18)	0.26	0.18	1060	265.3	0.16	45	0.335	0.165	0.06	6898	0.055	337	0.105	8,8	5		7	3	
201P (18)	0.26	0.095	2840	710.1	0.09	55.3	0.17	0.25	0.044	6851	0.04	254.8	0.08	5	4	5	4.7	2	
201P (18) + 55	0.26	0.150	2840	710.1	0.145	55.3	0.225	0.25	0.099	6851	0.095	254.8	0.135	7			7	3	
201P (18) + 110	0.26	0.205	2840	710.1	0.2	55.3	0.28	0.25	0.154	6851	0.15	254.8	0.19	7	7		7	3	
202P (18)	0.28	0.133	1401	350.3	0.115	44.5	0.255	0.25	0.044	6851	0.04	254.8	0.08	5	5		5	2	
203P (18)	0.33	0.173	784	195.8	0.145	36	0.35	0.25	0.044	6851	0.04	254.8	0.08	8,6	4	5	5.75	3	
212P (18)	0.28	0.189	1228	307.1	0.185	44.6	0.315	0.26	0.095	2840	0.09	221.2	0.17	7	7	10,8	8	3	
221P (18)	0.28	0.189	1228	307.1	0.185	44.6	0.315	0.28	0.133	1401	0.115	178	0.255	7,7	5	5	6	3	
241P (10)	0.26	0.115	1320	329.9	0.11	29.3	0.195	0.26	0.062	2418	0.055	125.6	0.115	2,4			3	1	
241P (18)	0.26	0.115	2376	593.8	0.11	52.7	0.195	0.26	0.062	4352	0.055	226	0.115	7			7	3	
301P (10)	0.4	0.098	1030	258.9	0.09	21.2	0.175	0.4	0.045	2432	0.04	93.6	0.085	1.5			1.5	1	
301P (18)	0.4	0.098	1864	466	0.09	38.2	0.175	0.4	0.045	4377	0.04	168.4	0.085	3	5,3		3.6	1	
301P (18) + 55	0.4	0.153	1864	466	0.145	38.2	0.23	0.4	0.1	4377	0.095	168.4	0.14	3	5,6		4.7	2	
301P (18) + 110	0.4	0.208	1864	466	0.2	38.2	0.285	0.4	0.155	4377	0.15	168.4	0.195	7	5		6	3	
302P (18)	0.41	0.141	940	235.3	0.12	32.5	0.28	0.4	0.045	4377	0.04	168.4	0.085	2	5		3.5	1	
302P (18) + 55	0.41	0.196	940	235.3	0.175	32.5	0.335	0.4	0.1	4377	0.095	168.4	0.14	7	5		6	3	
303P (18)	0.45	0.188	540	134.8	0.155	27.7	0.385	0.4	0.045	4377	0.04	168.4	0.085	4,5	5		4.6	2	
311P (18) + 55	0.4	0.208	1364	341.1	0.205	37.4	0.305	0.4	0.098	1864	0.09	152.8	0.175		6		6	2	
321P (18)	0.41	0.197	844	210.6	0.19	32.8	0.335	0.41	0.141	942	0.12	130	0.28	4			4	2	
341F (10)	0.41	0.064	1564	390.9	0.06	21.2	0.12	N/A						2,5,3	2	3	2.6	1	
341F (18)	0.41	0.064	2816	703.6	0.06	38.1	0.12	N/A						2	4,5		3.6	1	
341P (18)	0.41	0.119	1576	393.5	0.115	36.7	0.205	0.41	0.064	2814	0.06	152.4	0.12	4			4	2	
342F (18)	0.41	0.064	2816	703.6	0.06	38.1	0.12	N/A								2	2	1	
342P (18)	0.42	0.163	864	216.5	0.15	32.1	0.305	0.41	0.064	2814	0.06	152.4	0.12	2	5		3.5	1	
343F (18)	0.41	0.064	2816	703.6	0.06	38.1	0.12	N/A							3 <sup>‡</sup>		-	-	
343P (10)	0.45	0.211	288	72	0.185	15.3	0.41	0.41	0.064	1564	0.06	84.4	0.12	5	7		6	2	

† HUD only evaluation

‡ Level different than  $\overline{\text{PR}}$



Table A-II  
POWER APPROACH CONFIGURATIONS

CONFIG	← 1 lb F <sub>as</sub> STEP INPUT →						← 1 inch F <sub>as</sub> STEP INPUT →						PILOT RATINGS				
	$\tau_{R\text{eff}}$	$\tau_{\text{eff}}$	$\ddot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	$\dot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	$\tau_{R\text{eff}}$	$\tau_{\text{eff}}$	$\ddot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	$\dot{p}_{\text{max}}$	$T_{\dot{p}_{\text{max}}}$	A	B	C	$\overline{\text{PR}}$	Level Rating
L141F (5)	0.21	0.061	370.80	0.055	18.80	0.11	N/A						3,5	3,6	3	4	2
L141F (5) + 55	0.21	0.116	370.80	0.11	18.80	0.165	N/A						2.5, 2	4	4	3.1	1
L141F (5) + 110	0.21	0.171	370.80	0.165	18.80	0.22	N/A						5	7	5,4	5.3	2
L141F (5) + 175	0.21	0.236	370.80	0.23	18.80	0.285	N/A						7	4,4	8		3 <sup>‡</sup>
L141P (5)	0.21	0.113	198.90	0.11	17.20	0.19	0.21	0.061	1483.20	0.055	75.20	0.11			4	4	2
L142P (5)	0.24	0.151	105.60	0.14	13.90	0.27	0.21	0.061	1483.20	0.055	75.20	0.11	2,3	7	6,7	5	2
L143F (5)	0.21	0.061	370.80	0.055	18.80	0.11	N/A							4	5	4.5	2
L143P (5)	0.30	0.189	60.80	0.17	11.10	0.36	0.21	0.061	1483.20	0.055	75.20	0.11	2.5,4		5	3.8	2
L201P (5)	0.30	0.096	168.00	0.09	13.40	0.17	0.3	0.045	1598.00	0.04	60.40	0.084	2	4	2	2.7	1
L201P (10)	0.30	0.096	336.00	0.09	26.80	0.17	0.3	0.045	3196.00	0.04	120.80	0.084	4,2	4,2		3	1
L201P (10) + 55	0.30	0.151	336.00	0.145	26.80	0.225	0.3	0.1	3196.00	0.095	120.80	0.139	4,3,3	5	5	4	2
L201P (10) + 110	0.30	0.206	336.00	0.2	26.80	0.28	0.3	0.155	3196.00	0.15	120.80	0.194	7		6	6.5	3
L202P (10)	0.32	0.136	167.40	0.12	22.00	0.265	0.3	0.045	3196.00	0.04	120.80	0.084	6	5	5,6,3	5	2
L202P (10) + 55	0.32	0.191	167.40	0.175	22.00	0.32	0.3	0.1	3196.00	0.095	120.80	0.139	4,3,4	5		4	2
L203P (10)	0.37	0.179	94.50	0.15	18.20	0.365	0.3	0.045	3196.00	0.04	120.80	0.084	4,4	3	7	4.5	2
L212P (10)	0.32	0.192	147.90	0.185	22.10	0.325	0.3	0.096	1344.00	0.09	106.80	0.265	3	3,5		3.6	2
L221P (10)	0.32	0.192	147.90	0.185	22.10	0.325	0.32	0.136	670.00	0.12	88.00	0.17	7	4,5	6	5.5	2
L231P (10)	0.37	0.234	91.50	0.22	18.30	0.42	0.37	0.179	378.00	0.15	72.80	0.365			9	9	3
L241F (5)	0.31	0.063	255.50	0.06	13.50	0.115	N/A						3	4,5	3,2	3.4	1
L241F (5) + 55	0.31	0.118	255.50	0.115	13.50	0.17	N/A						3	2		2.5	1
L241F (10)	0.31	0.063	511.00	0.06	27.00	0.115	N/A						4,4	3	3,3	3.4	1
L241F (10)*	0.31	0.063	511.00	0.06	27.00	0.115	N/A						2		3	2.5	1
L241F (10) + 55	0.31	0.118	511.00	0.115	27.00	0.17	N/A						2	4	2	2.7	1
L241F (10) + 110	0.31	0.173	511.00	0.17	27.00	0.225	N/A						4	6	8	6	2
L243F (10)	0.31	0.063	511.00	0.06	27.00	0.115	N/A						5	3	6,7	5.3	2
L243P (10)	0.37	0.202	90.40	0.18	18.10	0.39	0.31	0.063	2044.00	0.06	108.00	0.115	8	2,6	7		3 <sup>‡</sup>
L341F (5)	0.46	0.064	174.90	0.06	9.60	0.125	N/A						4	5	2	3.7	2
L341F (10)	0.46	0.064	349.80	0.06	19.10	0.125	N/A						2	2,5	2	2.8	1
L341P (10)	0.46	0.120	196.50	0.115	18.50	0.21	0.46	0.064	699.60	0.06	38.40	0.125	2		3	2.5	1
L342F (10)	0.46	0.064	349.80	0.06	19.10	0.125	N/A						3	4	2,5	3.5	1
L342P (10)	0.46	0.166	108.70	0.15	16.40	0.31	0.46	0.064	699.60	0.06	38.40	0.125	2,3	5,7	2,2	3.5	1
L343P (10)	0.49	0.215	65.30	0.185	14.20	0.42	0.46	0.064	699.60	0.06	38.40	0.125			7,8	7.5	3

† HUD only evaluation

‡ Level different than  $\overline{\text{PR}}$

Table A-III

EQUIVALENT <sup>†</sup> SYSTEMS - POWER APPROACH CONFIGURATIONS

CONFIG	← "FORCE" INPUT →			← "POSITION" INPUT →		
	$\tau_{R_e}$	$\tau_e$	COST	$\tau_{R_e}$	$\tau_e$	COST
L141F (5)	0.2	0.065	0.04	N/A	-	-
L141F (5) + 55	0.2	0.12	0.04	N/A	-	-
L141F (5) + 110	0.2	0.175	0.04	N/A	-	-
L141F (5) + 175	0.2	0.24	0.04	N/A	-	-
L141P (5)	0.2	0.12	0.09	0.2	0.065	0.04
L142P (5)	0.22	0.178	1.9	0.2	0.065	0.04
L143F (5)	0.2	0.065	0.04	N/A	-	-
L143P (5)	0.27	0.235	19.7	0.2	0.065	0.04
L201P (5)	0.3	0.098	0.03	0.3	0.041	0
L201P (10)	0.3	0.098	0.03	0.3	0.041	0
L201P (10) + 55	0.3	0.153	0.03	0.3	0.096	0
L201P (10) + 110	0.3	0.208	0.03	0.3	0.151	0
L202P (10)	0.31	0.156	1.6	0.3	0.041	0
L202P (10) + 55	0.31	0.211	1.6	0.3	0.096	0
L203P (10)	0.37	0.218	21.9	0.3	0.041	0
L212P (10)	0.32	0.211	1.9	0.3	0.098	0.03
L221P (10)	0.32	0.211	1.9	0.31	0.156	1.6
L231P (10)	0.37	0.274	22.8	0.37	0.218	21.9
L241F (5)	0.3	0.065	0.04	N/A	-	-
L241F (5) + 55	0.3	0.12	0.04	N/A	-	-
L241F (10)	0.3	0.065	0.04	N/A	-	-
L241F (10)*	0.3	0.065	0.04	N/A	-	-
L241F (10) + 55	0.3	0.12	0.04	N/A	-	-
L241F (10) + 110	0.3	0.175	0.04	N/A	-	-
L243F (10)	0.3	0.065	0.04	N/A	-	-
L243P (10)	0.38	0.243	23.9	0.3	0.065	0.04
L341F (5)	0.46	0.065	0.05	N/A	-	-
L341F (10)	0.46	0.065	0.05	N/A	-	-
L341P (10)	0.46	0.121	0.11	0.46	0.065	0.05
L342F (10)	0.46	0.065	0.05	N/A	-	-
L342P (10)	0.47	0.181	2.3	0.46	0.065	0.05
L343P (10)	0.54	0.247	27.4	0.46	0.065	0.05

†21 Points; .1-10 rps, No frequency weighting

Table A-III

## EQUIVALENT † SYSTEMS - UP - AND - AWAY CONFIGURATIONS

CONFIG	← "FORCE" INPUT →			← "POSITION" INPUT →		
	$\tau_{Re}$	$\tau_R$	COST	$\tau_{Re}$	$\tau_R$	COST
141F (10)	0.15	0.063	0.03	N/A	-	-
141F (10) †	0.15	0.063	0.03	N/A	-	-
141F (18)	0.15	0.063	0.03	N/A	-	-
142F (18)	0.15	0.063	0.03	N/A	-	-
143F (18)	0.15	0.063	0.03	N/A	-	-
143P (18)	0.22	0.228	16.6	0.15	0.063	0.03
201P (18)	0.25	0.097	0.02	0.25	0.041	0
201P (18) + 55	0.25	0.152	0.02	0.25	0.096	0
201P (18) + 110	0.25	0.207	0.02	0.25	0.151	0
202P (18)	0.26	0.155	1.6	0.25	0.041	0
203P (18)	0.32	0.216	20	0.25	0.041	0
212P (18)	0.26	0.21	1.9	0.25	0.097	0.02
221P (18)	0.26	0.21	1.9	0.26	0.155	1.6
241P (10)	0.26	0.121	0.1	0.26	0.065	0.04
241P (18)	0.26	0.121	0.1	0.26	0.065	0.04
301P (10)	0.4	0.097	0.02	0.4	0.041	0
301P (18)	0.4	0.097	0.02	0.4	0.041	0
301P (18) + 55	0.4	0.152	0.02	0.4	0.096	0
301P (18) + 110	0.4	0.207	0.02	0.4	0.151	0
302P (18)	0.41	0.156	1.7	0.4	0.041	0
302P (18) + 55	0.41	0.211	1.7	0.4	0.096	0
303P (18)	0.48	0.222	24.3	0.41	0.041	0
311P (18) + 55	0.4	0.207	0.07	0.4	0.152	0.02
321P (18)	0.41	0.212	2	0.41	0.157	1.7
341F (10)	0.41	0.065	0.05	N/A	-	-
341F (18)	0.41	0.065	0.05	N/A	-	-
341P (18)	0.41	0.121	0.11	0.41	0.065	0.05
342F (18)	0.41	0.065	0.05	N/A	-	-
342P (18)	0.42	0.18	2.3	0.41	0.065	0.05
343F (18)	0.41	0.065	0.05	N/A	-	-
343P (10)	0.48	0.246	26.5	0.41	0.065	0.05

†21 Points; .1-10 rps, No frequency weighting

Table A-IV  
**SIDE-STICK PROGRAM PILOT  
 RATING RESULTS**  
 From Reference 16

Configuration	Roll Mode Time Constant $\tau_R \sim$ [sec]	Feel System Natural Freq. $\omega_{FS} \sim$ [rad/sec]	Added Pure Delay $\tau \sim$ sec	Effective* Roll Mode Time Constant $\tau_{R_{eff}} \sim$ [sec]	Effective* Time Delay $\tau_{eff} \sim$ [sec]	COOPER-HARPER PILOT RATINGS**								
						HUD EVALS			HQDT EVALS			PA EVAL		
						D	E	F	D	E	F	D	E	F
301P (-) +20	0.45	26	0.02	0.45	0.12	3,3		2			2			2
+80	"	"	0.08	"	0.18	4	5	3		5				
+140	"	"	0.14	"	0.24	5		5		5	5			7
302(P) (-) +35	"	13	0.035	0.46	0.18	2		1		4		5	3	3
+95	"	"	0.095	"	0.24	3, 4		5		6	3		3,4	
303(P) (-) +50	"	"	0.05	0.49	0.24	5	5	5		5,6	4	6	2	3
201(P) (-) +25	0.3	26	0.025	0.3	0.12	2,3,3				4,5		2	3,3	2
+85	"	"	0.085	"	0.18		5	5,4		5		7		
+145	"	"	0.145	"	0.24	6				7				
202(P) (-) +45	"	13	0.045	0.31	0.18	7		5,6,7		7	7	8	4	3
+105	"	"	0.105	"	0.24	7				7	8	8	4	
203(P) (-) +60	"	8	.0	0.32	0.18	4		6		7	8	3	3	4
+150	"	"	0.06	"	0.24	7				5,7			5	
101P (-) +30	0.15	26	0.03	0.16	0.12	8				6,6				7
+90	"	"	0.09	"	0.18	7				7	4			8
+150	"	"	0.15	"	0.24	7		7				10		8
102P (-) +55	"	13	.0	0.2	0.12				7				4,4	
+115	"	"	0.055	"	0.18	7					4	5	2	2
+115	"	"	0.115	"	0.24	5				7	7			
103P (-) +25	"	8	0.025	0.26	0.18	5					7		4	7
+85	"	"	0.085	"	0.24			7				10		

\*Effective parameters defined in Figure A-1 using a force step input.

\*\*Pilots D, E, and F are pilots A, B, and C respectively of Reference 16

## **Appendix B**

### **SIMULATION MECHANIZATION**

This experiment was performed using the variable stability NT-33 aircraft, modified and operated by Calspan under the USAF contract. The aircraft configurations were simulated by using the variable stability response feedback system in the NT-33. The feel system dynamics were mechanized using an electrohydraulic servo-actuator with position and rate feedbacks to control the frequency and damping.

#### **Response Feedback Simulation**

A simplified schematic diagram of the experiment elements is shown in Figure B-1. A response feedback simulation was used to mechanize the augmented aircraft configurations. The closed-loop response feedback system includes the NT-33A control surface actuators, motion sensors, and signal conditioning dynamics. With the feedback loops closed, these dynamics will migrate somewhat. Their movement is not considered to be significant, however. The variable stability system gains are controlled by analog potentiometers located in the rear seat safety cockpit of the NT-33. The dynamics of the variable stability system sensors and signal conditioning filters are described in Reference 17.

Speed variations can affect the response feedback simulation since automatic gain scheduling with airspeed is not provided. During the evaluation tasks, the safety pilots assisted in controlling the NT-33 throttles to keep the airspeed within bounds. This procedure was implemented in order to allow the evaluation pilot to concentrate on the lateral flying qualities evaluation and not the intricacies of the NT-33 throttle response. Variations in simulated dynamics occur with airspeed variation as shown in Section 3. Also, the lateral-directional VSS gains were scheduled with fuel remaining and hence, inertia, to maintain the simulated aircraft dynamics within acceptable bounds. Gain changes were manually set by the safety pilots.

Good, Level 1 longitudinal flying qualities were simulated using the NT-33 response feedback simulation. The airspeed and phugoid responses of the NT-33 were essentially unmodified but were satisfactory and not detracting from the evaluation of lateral flying qualities.

The roll flight control system is illustrated in Figure B-2. Four switches were created to control the flight control system architecture. Switch positions were dictated by the

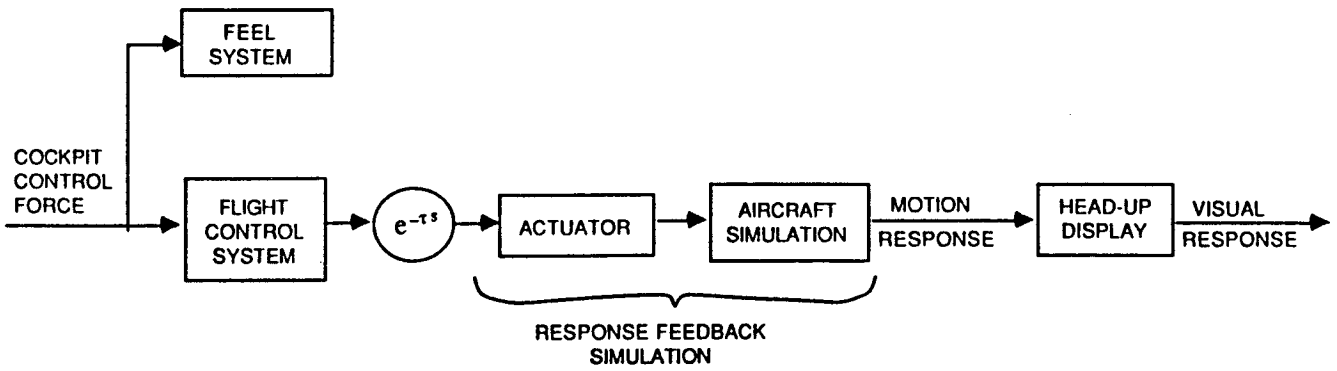
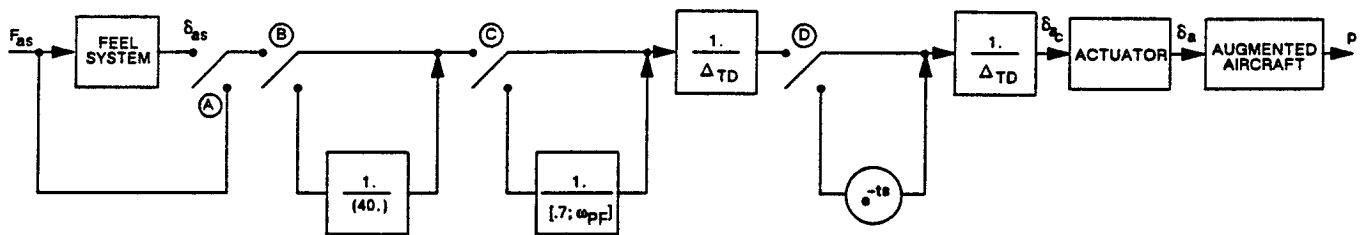


Figure B-1 ROLL FLIGHT CONTROL SYSTEM SCHEMATIC



- SWITCH (A) : FORCE OR POSITION COMMAND  
 (B) : FIRST-ORDER FILTER  
 (C) : SECOND-ORDER FILTER ( $\omega_{PF} = 26, 13, \text{ or } 8$ )  
 (D) : TIME DELAY,  $t$   
 $\Delta_{TD}$  : (300) [5,300]

Figure B-2 EXPERIMENTAL ROLL FLIGHT CONTROL SYSTEM

experiment/configuration designs. Shorthand motion is employed in the control system description.

The time delay circuit switch was mechanized to introduce only a pure digital time delay. To accommodate this, two high frequency filters are always in the experimental flight control system. The filters are needed for anti-aliasing and filtering of the digital delay circuit. The filter characteristics are shown in Figure B-2. They introduce approximately 15 msec of equivalent delay to all configurations but the introduction of delay adds only pure digital delay and no "equivalent, phase lag" lag delay as had been the case in previous NT-33 simulations (see for instance, Reference 9).

The aileron actuator dynamics were nominally:

$$\frac{\delta_a}{\delta_{a_c}} = \frac{60^2}{s^2 + 2(.7)(60)s + 60^2}$$

This actuator added approximately 25 msec of equivalent delay (using a  $2\zeta/\omega$  approximation); thus, the minimum simulated equivalent delay by the NT-33 was 40 msec for this program.

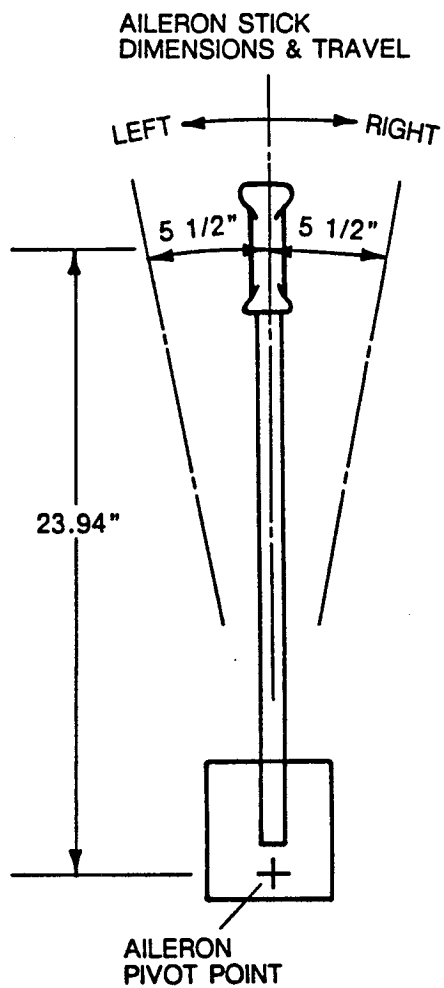
### Feel System

A centerstick and sidestick controller were used. Both are operated by artificial feel systems. The geometries of the controllers are shown in Figures B-3 and B-4.

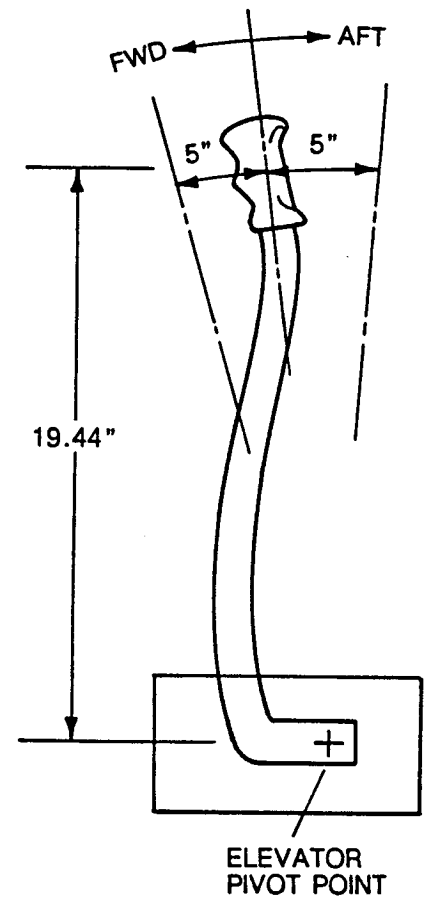
Position and rate feedbacks control the frequency and damping of the electro-hydraulic feel system. Calibrations of the feel system were made to obtain the desired frequency, damping, and deflection gradients. Calibration procedures included dynamic and static checks. Time and frequency domain techniques were used. Manual frequency sweeps were flown to check the data by transforming the time domain data to frequency data via Fast Fourier Transfers (FFT). As an example, the frequency domain-derived flight data of the  $\delta_{as}/F_{as}$  transfer function are compared to the nominal feel system models.

In Figure B-5, the flight data-desired frequency responses are compared to the transfer function:

a) Pitch Centerstick Dimensions



ELEVATOR STICK DIMENSIONS & TRAVEL



b) Roll Centerstick Dimensions

Figure B-3 ROLL FLIGHT CONTROL SYSTEM SCHEMATIC



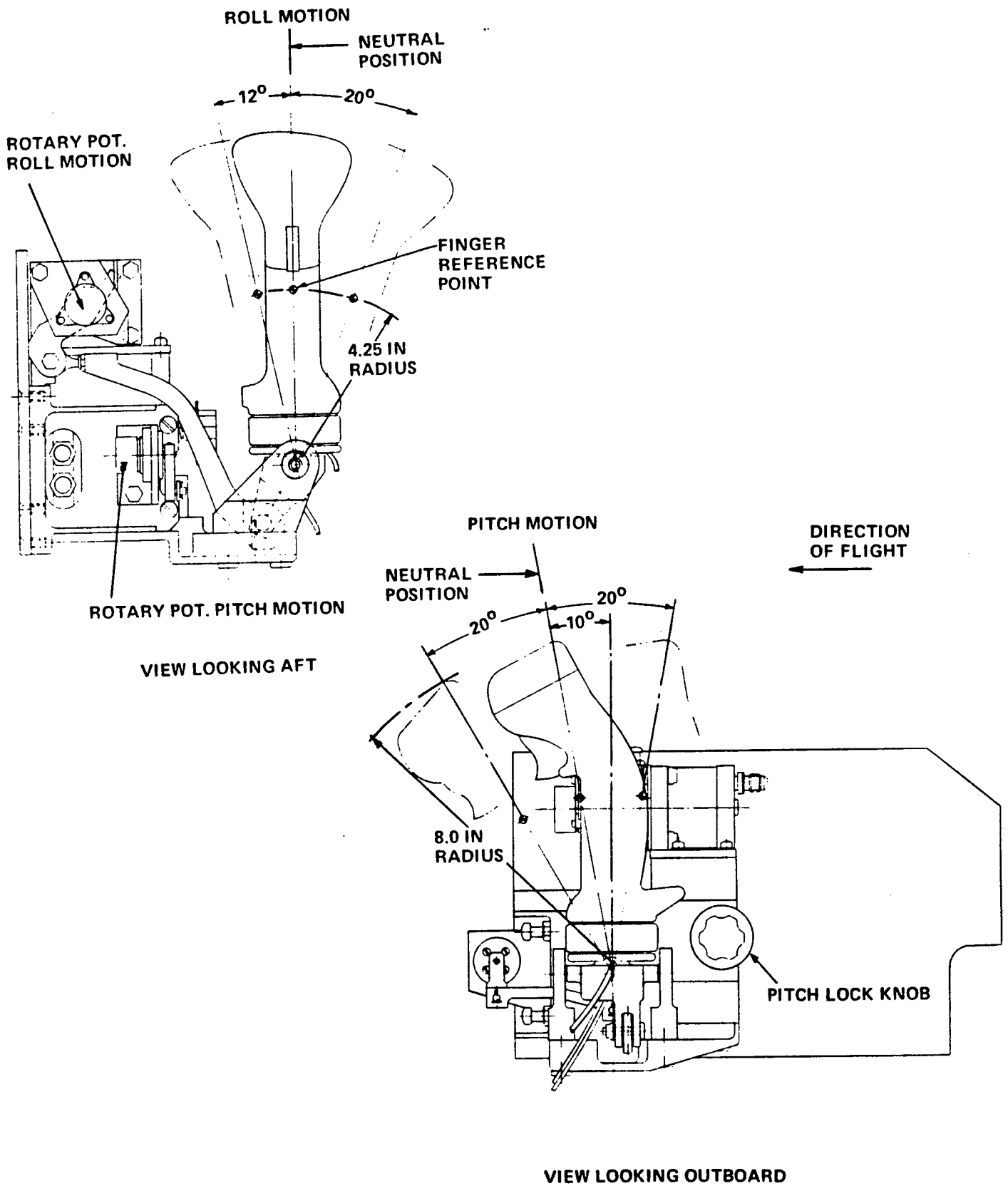


Figure B-4 SIDESTICK MOTION LIMITS

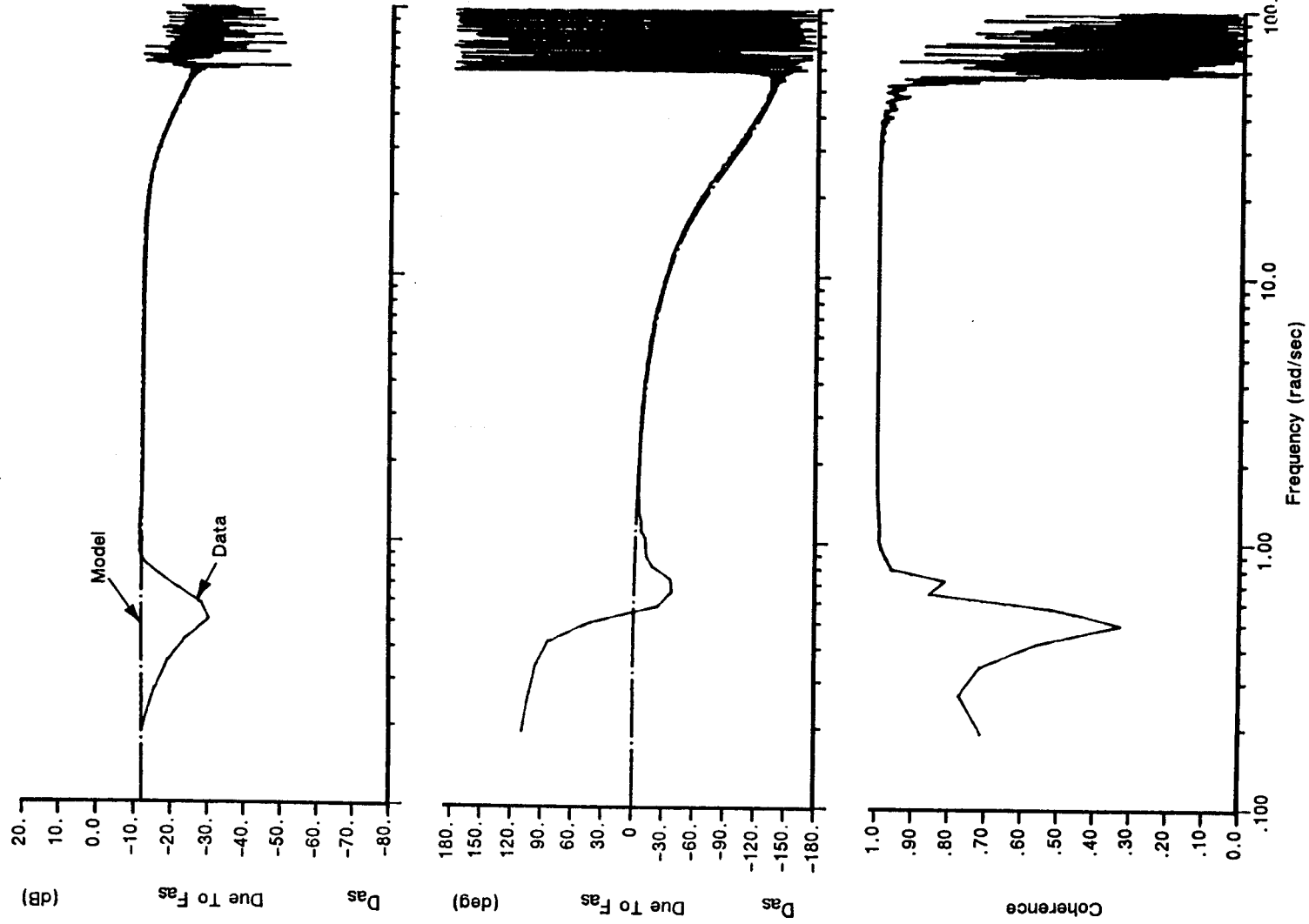


Figure B-5 COMPARISON OF FLIGHT DATA AND MODEL FOR 26 RAD/SEC FEEL SYSTEM

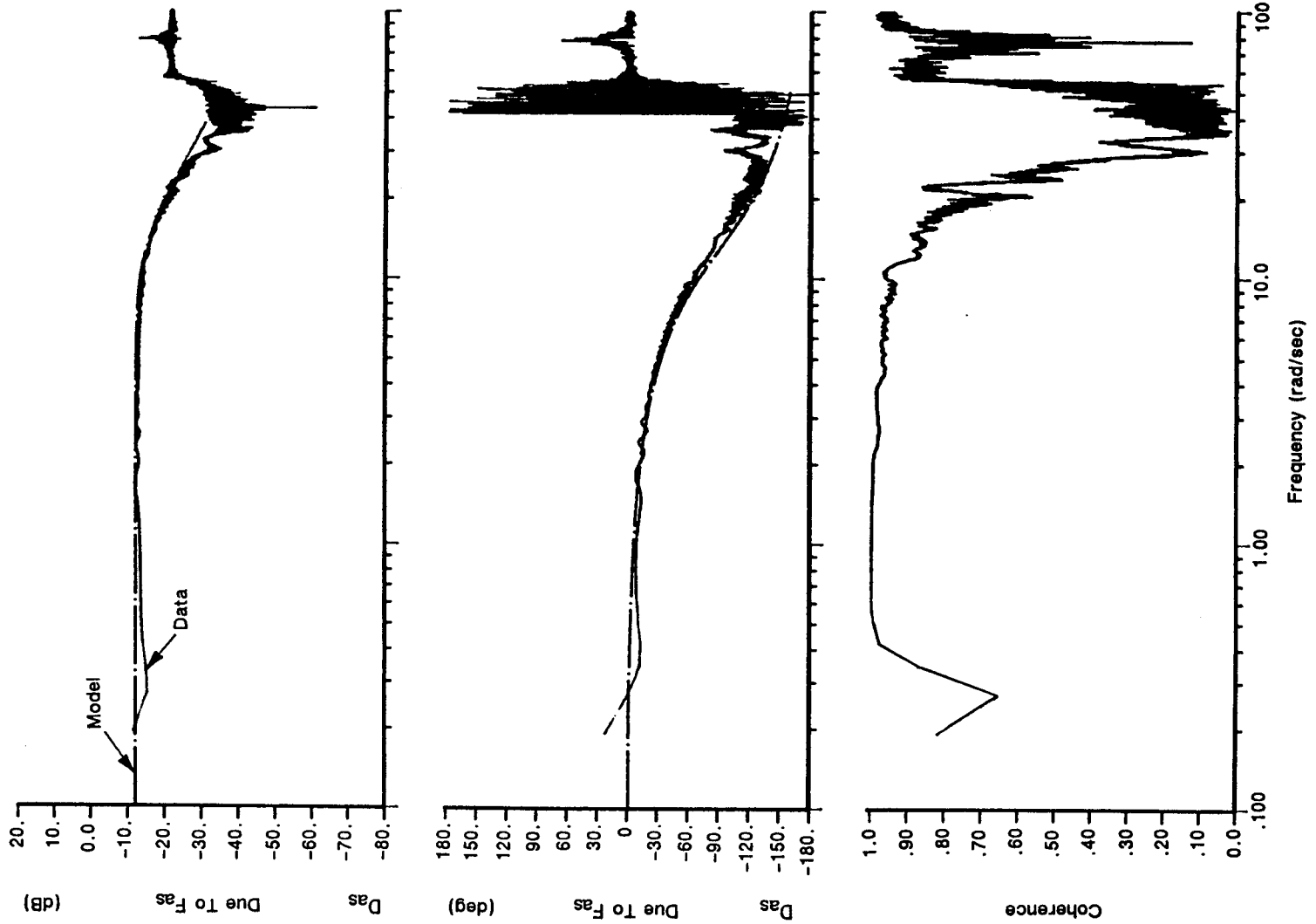


Figure B-6 COMPARISON OF FLIGHT DATA WITH MODEL FOR 13 RAD/SEC FEEL SYSTEM

$$\frac{.25(26^2)}{s^2 + 2(.7)(26)s + 26^2}$$

In Figure B-6, the flight data are compared to the transfer functions:

$$\frac{.25(13^2)}{s^2 + 2(.7)(13)s + 13^2}$$

In Figure B-7, the flight data are compared to the transfer function:

$$\frac{.25(8^2)}{s^2 + 2(.7)(8)s + 8^2}$$

The coherence function indicates the validity of the flight data. Simply speaking, values of coherence less than unity indicate that the FFT-derived transfer function data are not completely accurate. As these figures show, the overlay of the model and flight data demonstrate that the nominal feel system models are indeed accurate.

### **Display System**

The head-up display (HUD) was used to program two evaluation tracking tasks. As highlighted in Figure B-1, the head-up display system follows the vehicle "motion" response. The processing of the aircraft state parameters for head-up display consists of four functional elements:

- sensor and signal conditioning
- anti-aliasing
- computer processing unit
- programmable display generation

These system components sense the vehicle's attitude (during in-flight simulation), filter and condition the signals by removing noise and structural interactions, perform anti-aliasing, quantify the analog inputs, calculate the task commands and error signals, and project these quantities on the head-up display. The transfer functions, using a shorthand notation, between the pitch or roll attitude states and the same quantities displayed head-up are given by:

$$\left(\frac{\theta_d}{\theta}\right), \left(\frac{\phi_d}{\phi}\right) = \frac{e^{-.035s}}{(500)[.5, 500](140)}$$

The 35 msec pure delay component arises from the sampling of an analog quantity and the digital processing associated with the creation of the HUD tracking tasks and its display. The assumption was made that the pure delay due to a discrete, sampling process equals one-half the sampling interval. This transfer function translates into an equivalent time delay of approximately 45 msec. This delay between the aircraft motion and visual responses of the HUD was not felt to be significant.

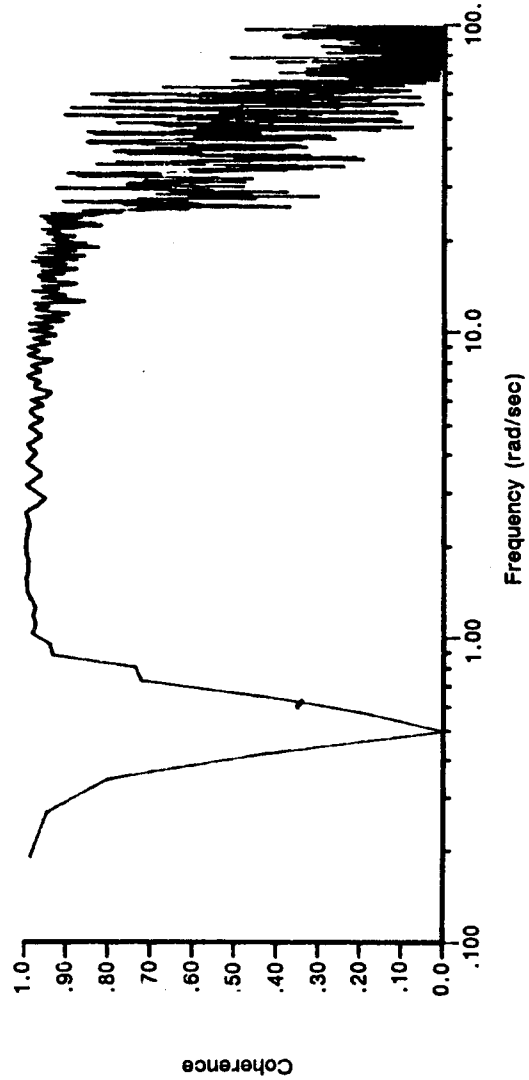
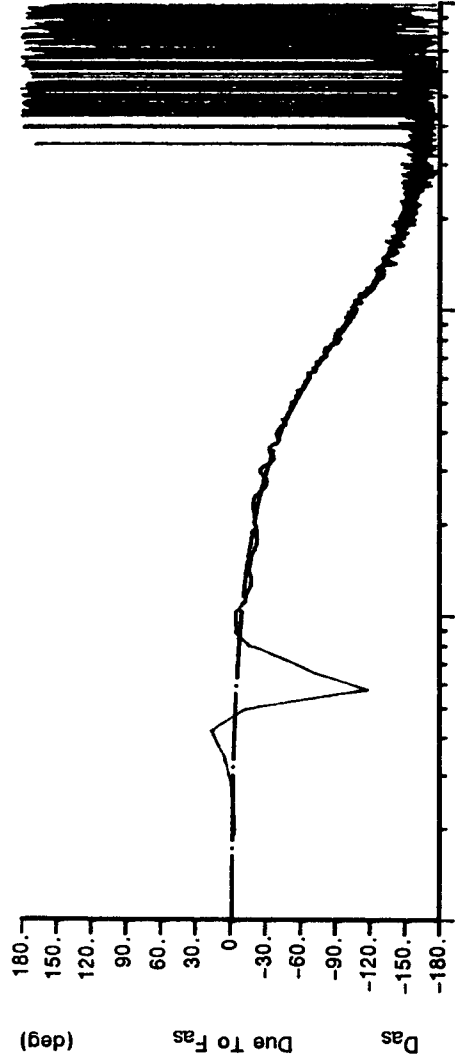
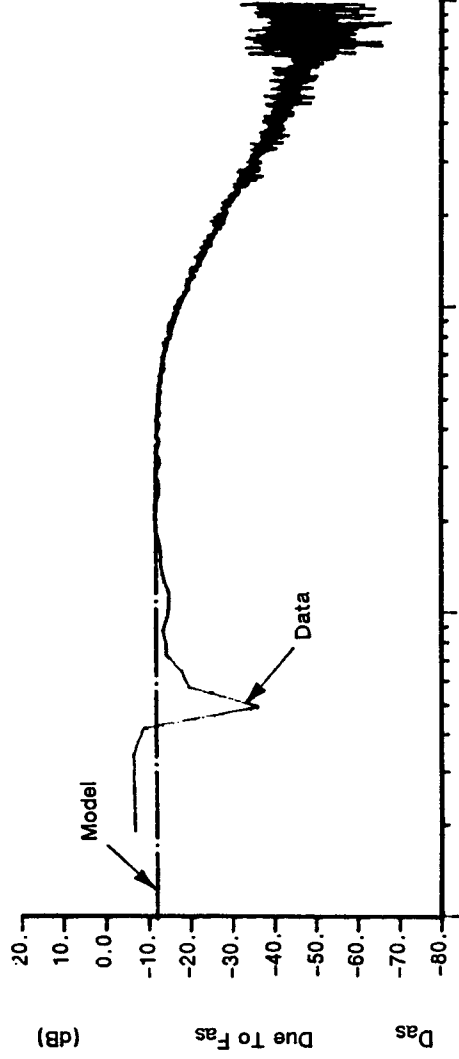


Figure B-7. COMPARISON OF FLIGHT DATA WITH MODEL FOR 8 RAD/SEC FEEL SYSTEM

**Appendix C**  
**PILOT COMMENTS**

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4026-7	C	.2	5	-	13	(40)	P	PA	6	L142P(5)

TASK COMMENTS:

Not satisfactory without improvement. It's pretty bad in terms of predictability, but what helps it are the heavier than normal forces. Between a 5 and a 6. Call it a 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not extremely heavy but on the heavy side.
- o Roll Sensitivity? Not overly sensitive
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Response was smooth, maybe a little slow. Predictability was poor, seemed like a bunch of lag. Not abrupt, just unpredictable.
- o PIO Tendency? Yes, but not extreme because of smoother initial response and heavy forces.
- o Any Special Piloting Techniques? Could not get into loop very tight.

TASK COMPARISON:

Not extreme differences between approach and landing.

SUMMARY:

Still debating between a 5 and a 6. Call it a "good" 6.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4052-1	A	.40	18	-	26	(40)	P	UA	4	341P(18)

TASK COMMENTS:

Airplane is quite responsive to roll. Fingertip like airplane but still quite smooth. A 3.

In gun tracking, one or two bobbles when aggressive. Have to be smooth because of sensitivity - a 4.

In SAAB, didn't seem sensitive, a 2.

In roll SOS, a 5 because of the initial abruptness was really felt, especially for the small crisp inputs.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticeable. Very tiny displacements required.
- o Roll Sensitivity? On the high side. Flight is smooth, however.
- o Harmony? None

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initially, crisp, high. Predictability was reasonable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Had to be smooth on the stick, because of responsiveness

TASK COMPARISON:

SUMMARY:

Overall, a rating of 4 due to high sensitivity.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4052-2	A	.25	18.	-	26	13	P	UA	7	221P(18)

TASK COMMENTS:

In formation, some bobbling felt. A 5 - very responsive, typically abrupt.

In gun tracking, almost desired performance. Really only adequate. A 7 due to excessive initial abruptness.

In SAAB task, achieved desired performance. "video-gamelike" handling qualities. A 3.

In roll SOS task, fast initial response. A 4 due to abruptness.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?                      Very high.
- o Harmony?                                  No problem. Roll more responsive than pitch.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    initial response:    excessive
- o Predictability:                      suffered with small amplitude overcontrol.
- o PIO Tendency?                      occasional small amplitude bobble.
- o Any Special Piloting Techniques?    no.

TASK COMPARISON:

SUMMARY:

Initial response too abrupt. Requires improvement - a 7. Ride qualities, initial abruptness problem.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4052-3	A	.25	18.	-	13	26	P	UA	7	212P(18)

TASK COMMENTS:

In formation, initial response was quick. Predictability no problem. Abrupt sensitivity. A 3 in gun tracking, again a quick initial response. No real problems noted in task. A 4 due to high roll sensitivity.

SAAB tracking task: a video game. Roll sensitive but in context of task, good. Initial response was crisp and predictable, a 3.

In roll SOS, abruptness with this task shows up more than in others. A 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Small
- o Roll Sensitivity? Very sensitive
- o Harmony? Problems in tendency to overcontrol in pitch due to oversensitivity in pitch.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Abrupt initially, adequate performance
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

Some turbulence

SUMMARY:

Initial response was too high. Aircraft overall requires improvement. A 7.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4053-1	B	.25	18.	-	13.	26.	P	UA	4	212P(18)

TASK COMMENTS:

Satisfactory airplane in formation task. Abrupt roll acceleration noted however. A 3 for the task alone.

In gun tracking, quick lateral movements caused bank overshoots.

A 4½, Only adequate performance in gross acquisition.

SAAB: pilot was able to keep up with the command bar. Desired performance, a 2.

In roll SOS, close approximation of formation task, a 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall rating of a 4.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4053-2	B	.25	18.	-	8	-	P	UA	4	203P(18)

TASK COMMENTS:

Form: easy to acquire position. Desired performance. Control system is very good. Aggressive moves caused slight overshoot, a 2.

AA: small pitch bobble; nose moving left to right. a 5. difficulty keeping target airplane in plane.

SAAB: more of a sinusoidal-like task. This control system has no problems. became more abrupt - easier to control. No problems, a 2.

Roll SOS: well suited to SOS task. Highly desirable system for this task, a 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? good
- o Displacements?
- o Roll Sensitivity?
- o Harmony? good - P/R harmony

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall rating of 4.

Flt No.-Eval	Pilot	$\bar{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4053-2	B	.40	18	-	13	(40)	P	UA	5	342P(18)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light
- o Roll Sensitivity? satisfactory
- o Harmony? Not a problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was good - nice and quick. However, I could not predict where I was going to stop the pipper as well as I would have liked. I got oscillations when going from wing-tip-to-wing-tip that I didn't like.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Back off on aggressiveness to avoid overshoot.

TASK COMPARISON:

(No HUD tracking tasks.)

SUMMARY:

Not satisfactory without improvement. Gross acquisition was not predictable. A 5.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4054-1	C	.40	10	-	26	(40)	F	UA	3	341F(10)

TASK COMMENTS:

Roll on sensitive side. Roll bobble. On the quick side, a little bobble is present.

Form: Gross response is a little low, but otherwise it feels good. Sensitive roll response. A 2.

A-A: a 4. Pitch bobbles, roll sensitivity bobble.

SAAB: Bobble in pitch. Easier to do than A-A, a 2.

Roll SOS: good, a 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Good airplane, good sensitivity in roll axis.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4054-2	C	.25	18.	-	13.	26.	P	UA	10	212P(18)

TASK COMMENTS:

Plane has hesitation and is abrupt. Very unpredictable.

Form: ( $F_R = 405$  gains set for 400). Sensitive A/C. Bobbles in roll. Lateral PIO. an 8.

A-A: PIO! a 10.

SAAB: a little bobble - PIO, a 5.

Roll SOS: a 6 - PIO

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

A 10 due to poor air-to-air handling qualities.



Flt No.-Eval	Pilot	$\bar{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4054-3	C	.15	18.	-	26.	(40)	F	UA	4*	141F(18)

TASK COMMENTS:

SAAB: a 5 - PIO's still there with smaller amplitude but the PIO less easy to excite.

Roll SOS: - jerky, a 4. Initial response is quick & annoying. No PIOs.

Overall, a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Displacements?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: Predictability?
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

\*HUD only tasks

SUMMARY:

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4055-1	B	.40	10.	-	26	(40)	F	UA	4	341F(10)

TASK COMMENTS:

SAAB: Pitch was noticeably quicker than roll axis. It was more likely that the pitch seemed to be okay with the roll axis slower. A 4½ - roll axis is too slow.

Roll SOS: (light turbulence) Same roll axis problem, but aircraft was easier to handle. A 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Roll forces high with low roll rate.
- o Roll Sensitivity? satisfactory.
- o Harmony? Not good. Lateral axis not as quick as longitudinal axis.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: slow. Predictable.
- o PIO Tendency?
- o Any Special Piloting Techniques? Had to lead the plane once the direction of turn was seen.

TASK COMPARISON:

SAAB required quicker control inputs. Roll SOS - easier to track for this system.

SUMMARY:

Tendency to bobble on target - detracted from lateral handling quality. A 4 overall.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4055-2	B	.25	18.	-	26.	13.	P	UA	3*	221P(18)

### TASK COMMENTS:

SAAB: Quick control configuration, not absolutely predictable, but okay. A 3. Tendency to overshoot in pitch & roll, due to sensitivity of both axes.

Roll SOS: Good job. Very quick. Pilot should (1) not be aggressive on the initial start and (2) anticipate the roll out a little bit. A 3.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? high.
- o Roll Sensitivity? high. Overshoots if you outguess target.
- o Harmony? Good.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: initial response - good; predictable.
- o PIO Tendency? no.
- o Any Special Piloting Techniques? Yes. (1) couldn't be overly aggressive in the start (2) anticipate the roll out and not be too abrupt.

### TASK COMPARISON:

On SOS, had to concentrate on being smoother and not be aggressive, any aggressive attempt would result in overshoot in roll.

\*HUD evaluation only.

### SUMMARY:

Sensitive in pitch. Very quick. Had to be careful not to overcontrol. Nice, quick acceleration and roll rate. A little too sensitive in pitch and roll. A 3.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4055-3	B	.25	18.	-	13	13	P	UA	2*	222P(18)

TASK COMMENTS:

SAAB: Good. Light forces. Quick accelerations and rates in pitch and roll. Easy to track. Minimal overshoot tendency. A 2.

Roll SOS: Easily accomplished. Quickness in acceleration and sustained rates. Have to watch for aggressiveness; tendency to overshoot with aggressive moves. a 2.

Overall: good acceleration and good rates.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques? Not to overdrive it. Anticipate roll outs.

TASK COMPARISON:

\*HUD only task evaluation

SUMMARY:

HQR: 2

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4055-4	B	.15	18.	-	26	(40)	F	UA	3	141F(18)

TASK COMMENTS:

SAAB: Easy to get on target. No tendency to overshoot. Good harmony between pitch & roll. Initial response is slower than desired; due to time delay from control system, or slow roll acceleration. A 3. Less than optimal initial response.

Roll SOS: good, slow initial response. Didn't matter as much. Easy to track target. A 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? (roll) pitch - light
- o Displacements? small.
- o Roll Sensitivity? good
- o Harmony? very good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: slower than desired. Predictability? Yes, easy to adapt. Good sustained roll rate.
- o PIO Tendency? No
- o Any Special Piloting Techniques? had to anticipate - allow high rates to work. Not overly aggressive.

TASK COMPARISON:

w/SAAB: had to be more careful w/aggressiveness. slow initial response was less evident w/Roll SOS.

SUMMARY:

A 3 overall.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4055-5	B	.15	18.	-	8	(40)	F	UA	2*	143F(18)

TASK COMMENTS:

SAAB: Very predictable. Initial response good. Rate was okay. Good harmony. A 2.

Roll SOS: Very good for this task. A 2.

FEEL SYSTEM CHARACTERISTICS: satisfactory

- o Forces? light and
- o Displacements? small, respectively
- o Roll Sensitivity? good
- o Harmony? good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: satisfactory. Predictability? yes.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

No differences between tasks and pilot maneuvers

\*HUD only tasks

SUMMARY:

A 2 overall. Plane did lack sustained roll response; could be quicker.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4056-1	C	.25	18.	-	8.	-	P	UA	5	203P(18)

### TASK COMMENTS:

A little bit sensitive - some wing walking.  
 Feels like the dynamics of the roll mode are not a problem - just sensitive.  
 Hard to evoke fine tuning corrections around neutral.

Formation: PR=4, desired performance but moderate compensation because of light forces. I'm careful because I'm aware of sensitivity. No delays, no dynamic response-type problems. No PIO - not unpredictable.

Air-to-air: wing walking is more pronounced for this task. Adequate performance, PR=5. A large amplitude bobble - not a PIO. Can feel an annoying, low frequency "ringing" in airplane.

SAAB task: Good tracking accuracy; desired performance. PR=3. Bobble not really seen in this task - only occasionally.

SOS task: PR=4 because of loping along for smooth rolls.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? light forces, small displacement.
- o Roll Sensitivity? Yes, it's sensitive
- o Harmony? Pitch was good, harmony was good.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was not quick. Predictability was good initially. Got loping in controlling steady rolls.
- o PIO Tendency? Not really, bobbling in aggressive tasks.
- o Any Special Piloting Techniques? Can't stop bobble. Too sensitive to lead rolls - maybe backed off a little.

### TASK COMPARISON:

SOS: "loping" problems. A-A: bobble problems. No different piloting techniques in the other tasks.

### SUMMARY:

Problems are loping along during steady rolls, bobbling trying to maintain accurate bank angles, and high sensitivity. That's a 5 overall.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4056-2	C	.25	18.	-	26.	13.	P	UA	5	221P(18)

TASK COMMENTS:

Formation: desired performance but a 4. A little sluggish, unpredictable forces were heavier than last time, as I could handle those problems with moderate compensation.

Air-to-Air: Can't get precision I wanted. Unpredictable for fine tracking. Can't get desired performance. A 6.

SAAB task: desired performance - a 4. No bobbles or PIOs but an unpredictable response to inputs.

SOS task: Not desired performance because of slow PIO in fine tuning tracking corrections - a 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK, displacements good.
- o Roll Sensitivity? good.
- o Harmony? ok

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was a tad on the slow side but not too bad. Predictability was no good. Some time delay in roll.
- o PIO Tendency? Yes, for fine tracking.
- o Any Special Piloting Techniques? Back off a little.

TASK COMPARISON:

Not as significant of differences as I've seen. No control differences.

SUMMARY:

A 5 overall - unpredictable.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4056-3	C	.15	10.	-	26	(40.)	F	UA	3	141F(10)

### TASK COMMENTS:

Stick feels sluggish but dynamics are smooth - not too sensitive. If anything its on the sluggish side.

Formation: PR=2. Compensation was not a factor. Could be confident with airplane. No problems.

Air-to-air: PR=3. Stick felt a little heavy. Good sensitivity but roll axis stick for large inputs felt sluggish like I was dragging something - mildly unpleasant.

SAAB task: PR=2. Stick forces felt heavier in this task. Compensation not a factor.

SOS task: PR=2.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nice but heavy for aggressive changes in attitude
- o Roll Sensitivity? Good
- o Harmony? Nice

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good. Seemed like a long time constant. Not an abrupt response. Predictability was good.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

### TASK COMPARISON:

Sluggishness noted for quick tasks.

### SUMMARY:

Overall, a 3. Stick forces on heavy side - mildly unpleasant for quick changes.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4057-1	A	.40	10	-	26	(40)	F	UA	2½	341F(10)

### TASK COMMENTS:

Very nice airplane. Excellent sensitivity. Good initial roll response and very good predictability. No overshoot tendency in bank captures. PR=2. Solid airplane.

Formation: a 2 also. Very good attitude control. Very precise.

Air-to-air: Roll quite good. Maybe need a little more roll performance for gross maneuvering. A 3 because it needed more roll control power. Otherwise a very good airplane to fly.

Discrete task: Only deficiency was that the forces could be less, or more roll for higher roll maneuvers. PR=2½.

SOS task: Maybe a tendency to relax and be less aggressive in task because the airplane is so easy to fly. A good, solid 2.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Roll forces noticed for large bank angle changes. Minor deficiency.
- o Roll Sensitivity? OK except I could use more roll control power for some maneuvers.
- o Harmony? Some pitch sensitivity. Small problem.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response and predictability were excellent.
- o PIO Tendency? No
- o Any Special Piloting Techniques? No

### TASK COMPARISON:

Air-to-air and SAAB task showed minor deficiency of lacking roll authority.

### SUMMARY:

Slight pitch bobbles/turbulence during air-to-air tracking. Very smooth and easy to fly. Overall a 2½ to reflect the less than perfect roll control power; otherwise an excellent airplane.

Flt No.-Eval	Pilot	$\bar{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4057-2	A	.25	18.	-	8	-	P	UA	8	203P(18)

### TASK COMMENTS:

Stick feels funny in my hand. Abrupt airplane with a bobweight effect in the stick/my hand. Very precise roll but abrupt. Peculiar feeling in fake cue. A 5 for general performance.

Formation: uncomfortable airplane on edge of PIO. Very quick airplane. Strange combination of an abrupt yet precise airplane with a peculiar lateral stick feel: easy to get force/feel out of phase. PR=8 for this task. Air-to-air: very poor airplane. Very jerky. Easy to overcontrol and small amplitude PIO. The force/feel problems noted before were not a problem in this task. PR=8 for high frequency lateral PIO. SAAB task: PR=6; abruptness problems did not show up in this task. Occasional overcontrol tendencies. SOS task: PR=4. Not too bad in this task.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticed
- o Roll Sensitivity? Very high
- o Harmony? Small pitch bobble. Both pitch and roll too sensitive.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response too abrupt. Predictability was poor depending upon task. On large airplane tracking tasks, it was easy to couple up with.
- o PIO Tendency? Yes, in several of the tasks.
- o Any Special Piloting Techniques? Perhaps I was getting smoother but it could be task dependent.

### TASK COMPARISON:

No technique differences between tasks.

### SUMMARY:

Air-to-air and formation stand out. Overall PR of 8.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4057-3	A	.15	18	-	26	(40)	F	UA	7	141F(18)

### TASK COMMENTS:

Airplane has an abrupt initial response and stops exactly where you want it. Predictability therefore is good and performance is excellent; however, ride qualities are not good. Despite sensitivity, formation task was flown smoothly without overcontrol. But I was aware of sensitivity so that's a factor. PR=4 as it warrants improvement.

Air-to-air: not a good look at it but I could compensate for initial response and make plane adjustments without overcontrolling. PR=4. In free form flight, very precise but too abrupt, requiring improvement, a 7. SAAB task: I achieved desired performance. Not too many problems. PR=4 because of sensitivity. SOS task showed up the abruptness. Initial response was really head knocking. PR=7-requires improvements. Small amplitude wing rock, ratcheting.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?                      Too high
- o Harmony?                                      Both pitch and roll too sensitive

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:      Initial response too high. It's a very abrupt stopper so in that sense predictability is good.
- o PIO Tendency?                      Yes, in fine tracking.
- o Any Special Piloting Techniques?      Be smooth - you can do that in the majority of the tasks.

### TASK COMPARISON:

No technique differences.

Additional Factors: Some turbulence today. Some pitch bobbling in fine tracking.

### SUMMARY:

PR=7 because ride qualities require improvement although desired performance could be attained.

Flt No.-Eval	Pilot	$\bar{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4065-1	A	.40	18	-	26	(40)	F	UA	3*	341F(18)

TASK COMMENTS:

Free play: Roll too sensitive - very abrupt; desired performance however. PR=4. No noticeable lateral accelerations.

SOS: Was compensating for task. Very accurate (performance) but pilot compensation was needed to tone down initial response. PR=4.

LATHOS: Only problem was a pitch bobble. Overall PR=3 but roll itself was a 2.

Discrete: Aircraft was outstanding. Good harmony. PR=2

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nothing noticed
- o Roll Sensitivity? High - less a problem during discrete task.
- o Harmony? OK except for some task

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Quick initial response and outstanding final response
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

Pitch bobble and some aileron buzz were slight factors but not a problem  
 \*HUD only task evaluation.

SUMMARY:

Overall a 3.



Flt No.-Eval	Pilot	$\hat{\tau}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4065-3	A	.30	5	.055	26	(40)	F	PA	3	L241F(5)+55

TASK COMMENTS:

Adequate performance is obtainable. A 3. Some mildly unpleasant deficiencies.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? lateral forces are on the heavy side. Displacements not noticed.
- o Roll Sensitivity? On the low side.
- o Harmony? roll - heavier than pitch

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: slow but predictable
- o PIO Tendency? none
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4065-5	A	.2	5	-	13	(40)	F	PA	2	L142F(5)

TASK COMMENTS:

1st PA: satisfactory rating of 2.  
 2nd PA: a little long - but no complaints.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? normal
- o Roll Sensitivity? average, good.
- o Harmony? pleasant harmony on 1st PA - not a factor.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: about what you would like to see  
 predictability is good.
- o PIO Tendency? No
- o Any Special Piloting Techniques? No

TASK COMPARISON:

SUMMARY:

Pleasant airplane to fly. Overall a 2.



Flt No.-Eval	Pilot	$\hat{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4066-1	A	.30	10	-	8	-	P	PA	4	L203P(10)

TASK COMMENTS:

Very responsive airplane - no sharp edges to response. Controllable.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                      Could feel some lateral displacement, as if the stick was a bob weight in hand.
- o Roll Sensitivity?                         Sensitive but not sharp edged, pleasant to fly in.
- o Harmony?                                    No problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    Initial response: crisp. Predictability: good.
- o PIO Tendency?                 A little hunting in the bank angle of control while in crosswind. (he considered this part of the PIO)
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Didn't achieve desired performance on both PA's, therefore overall a 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4066-2	A	.30	5	-	26	(40)	F	PA	3	L241F(5)

TASK COMMENTS:

Adequate performance was obtainable.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                      Responsiveness is down if you try to make aggressive maneuvers, so you notice the forces
- o Roll Sensitivity?                              For large inputs, a little low. For normal inputs it was fine.
- o Harmony?                                        Not a factor.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:                      Initial response satisfactory for task. Final response: predictable. The overall roll authority was low for the inputs, but not required for these tasks.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

A little more roll response is desired; therefore, a 3 overall.

Flt No.-Eval	Pilot	$\zeta$ <sub>R</sub>	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4066-3	A	.2	5	-	U	(40)	F	PA	3	L141F(5)

**TASK COMMENTS:**

Pilot is messing up the touchdown location in the L to R having to adjust to the crosswind w/the power. Floating a lot.

Adequate performance is obtainable.

1st landing a 2

2nd landing, a 5 - landing went long, on basis of landing performance.

**FEEL SYSTEM CHARACTERISTICS:**

- o Forces? & displacements: not noticed
- o Roll Sensitivity? good
- o Harmony? not a problem

**AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:**

- o Roll Attitude Response: initial response is good. Predictability is good (on roll).
- o PIO Tendency? None
- o Any Special Piloting Techniques?

**TASK COMPARISON:**

**SUMMARY:**

Overall, a 3.

Flt No.-Eval	Pilot	$\tilde{\tau}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4066-4	A	.2	5	.175	26	(40)	F	PA	7	L141F(5)+175

TASK COMMENTS:

Airplane is overly sensitive. Tendency to be jerky. With aggressive maneuver, a little PIO resulted.

Yet, plane is controllable. Due to second landing, plane requires improvement. A 7 overall because of PIO susceptability w/aggressive inputs in close.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? No force displacements noticed.
- o Roll Sensitivity? Too high. It was jerky, and sharp edged laterally.
- o Harmony? More roll than pitch. It was a factor.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was high (in roll). Predictability was good if you could be predictable w/the airplane; kinda groove it down.
- o PIO Tendency? If you make aggressive inputs, overcontrol and PIO's, small PIO's resulted. Be smooth is how to get rid of it.
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4067-1	A	.45	10	-	13	(40)	P	PA	2	L342P(10)

TASK COMMENTS:

Airplane was responsive yet smooth.  
 Desired performance was achieved.  
 Stick feels like there is a little motion in it, but controllable.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Responsive yet smooth
- o Roll Sensitivity? High side of nominal
- o Harmony? Nothing noted

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response is quick yet quite predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall a 2.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4067-2	A	.30	10	-	13	-	P	PA	6	L202P(10)

TASK COMMENTS:

Achieved desired performance.  
 However, sensitivity is objectionable, a 5.  
 Objectionable but tolerable ... a 6 overall.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticeable.
- o Roll Sensitivity? Extremely high.
- o Harmony? Roll more sensitive than pitch. No problem overall.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Roll initial response was excessive. Predictability was marginal.
- o PIO Tendency? None. No overcontrol.
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall a 6.

Flt No.-Eval	Pilot	$\hat{t}_R$	P/F <sub>as</sub>	Delay..	Feel	Filter	Cmd	Flt Phase	PR	Config
4067-3	A	.3	10	-	26	13	P	PA	2	L201P(5)

TASK COMMENTS:

Two touch and go's going alternate sides; slight crosswinds.

Achieved desired performance.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Pleasant airplane to fly, no problems noticed.
- o Roll Sensitivity? Satisfactory
- o Harmony? None

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response - good. Final response was totally predictable. No problem.
- o PIO Tendency? None
- o Any Special Piloting Techniques? No problem.

TASK COMPARISON:

SUMMARY:

2 overall

Flt No.-Eval	Pilot	$\tilde{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4067-4	A	.2	5	.055	26	(40)	F	PA	2½	L141F(5)+55

TASK COMMENTS:

Two touch and go's - 1 from each side.  
 Airplane has just a touch of jerkiness, subtle though.  
 Abrupt on occasion - needs higher sensitivity.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Takes and displacements seem pleasant
- o Roll Sensitivity? a little above nominal
- o Harmony? no problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: a little jerky
- o PIO Tendency? no, predictability is good
- o Any Special Piloting Techniques? none

TASK COMPARISON:

SUMMARY:



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4067-5	A	.2	5.0	-	13	(40)	P	PA	2	L142P(5)

TASK COMMENTS:

Two touch and go's - pleasant airplane to fly

Satisfactory - overall a 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? No problem
- o Roll Sensitivity? Pleasant
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good, no problem with predictability. Initial response: good
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4068-1	A	.30	10	-	26	-	P	PA	4	L201P(10)

TASK COMMENTS:

Controllable. Desired performance was obtainable.

A 4 because too sensitive.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticeable, very responsive laterally
- o Roll Sensitivity? On the high side; quite sensitive
- o Harmony? No problems, can observe the harmony differences

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was high, a little on the excessive side, predictability was good.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4068-2	A	.3	10	-	8	(40)	F	PA	5	L243F(10)

TASK COMMENTS:

No problem flying the plane  
 Desired performance was obtainable. However moderately objectionable deficiencies;  
 therefore it is a 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? 'bit' strange, lateral stick feels like a bobweight, feels like there's a weight in my hand, forces slightly out of phase.
- o Roll Sensitivity? quick
- o Harmony? some noticeable disharmony, can make some inadvertant roll inputs

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: good, predictability is good. Initial response is good.
- o PIO Tendency? no tendencies, just a little strangeness about it
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4068-3	A	.2	5	.055	26	(40)	F	PA	2	L141F(5)+55

TASK COMMENTS:

Desired performance easily obtained.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Forces and displacements felt a little on the heavy side.
- o Roll Sensitivity? satisfactory, medium valued.
- o Harmony? none

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was reasonable, slow in contrast with others, predictability was good.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

ADDITIONAL FACTORS:

Crosswind from North, 060 at 11 contributed to pilot's landings.

SUMMARY:

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4068-4	A	.30	10	.055	26	(40)	F	PA	4	L241F(10)+55

**TASK COMMENTS:**

Desired performance, a 3. A little over-responsive, a 4 overall.

**FEEL SYSTEM CHARACTERISTICS:**

- o Forces? Nothing really noticeable.
- o Roll Sensitivity? A little bit high
- o Harmony? A little something noticeable. More sensitive in roll then pitch.

**AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:**

- o Roll Attitude Response: Abrupt initial response was too high. Predictability was too high.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

**TASK COMPARISON:**

**SUMMARY:**

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4068-5	A	.2	5	-	8	(40)	P	PA	2½	L143P(5)

TASK COMMENTS:

Slight x-wind.

If you move the stick laterally you feel a little force feedback. In context of task, it was ok. A little more aggressive in tasks.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? A little bob-weighting effect was felt. Displacement: "giving"
- o Roll Sensitivity? Reasonable, felt sensitive but smooth.
- o Harmony? No problem.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response - good, smooth & predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Overall a 2½. Rating reflects lateral motion and lateral bobweight effect.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4069-1	A	.40	18	-	26	(40)	P	UA	2	342P(18)

TASK COMMENTS:

A/A: A solid 2, very predictable, responsive - good airplane

SOS: some lateral accelerations noted but not a problem - a 2.

LATHOS: A 2 also. Responsive airplane with occasional lateral accelerations at cockpit noted. Overall a good airplane.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? No problems
- o Roll Sensitivity? On high side but quite manageable
- o Harmony? None

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response fast; predictability quite good.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4069-2	A	.25	18.	-	26.	(40)	P	UA	7	241P(18)

TASK COMMENTS:

A/A: Good airplane in air-to-air tracking - quick and predictable - a 2.

SOS: Desired performance but too abrupt - too much lateral acceleration. Deficiencies require improvement - a 7.

Lathos: Abruptness did not show through. A 4 for some initial abruptness.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? No complaints
- o Roll Sensitivity? high
- o Harmony? No problem noted except roll sensitivity higher than pitch.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response quick and abrupt; predictability did not really suffer but ride qualities suffered in SOS task in particular. Jerkiness in cockpit.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

An overall rating of 7 because of sum of sines task but hard to generalize because of different task ratings.



Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4069-3	A	.15	10.	- ..	26.	(40)	F	UA	7	141F(10)

TASK COMMENTS:

- A/A: Not satisfactory without improvement - too abrupt. Moderately objectionable even though I got desired performance - a 5.
- SOS: Really poor. I got desired performance but lateral accelerations were unacceptable and require improvement - a 7.
- Lathos: Not nearly as bad as SOS. Desired performance - abruptness noticeable but not a factor - a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?                      Much more sensitive in roll than pitch but it did not bother me in the tasks.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:      Extremely sensitive, abrupt airplane. Initial response was quick and sharp-edged. Predictability is good except their abruptness shows through.
- o PIO Tendency?                      Not in roll attitude
- o Any Special Piloting Techniques?      Try to smooth it down but you can't you do that in SOS task in particular.

TASK COMPARISON:

SUMMARY:

Overall a 7 due to abruptness problems.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4069-4	A	.15	18.	-	8.	(40)	P	UA	8	143P(18)

TASK COMMENTS:

A/A: PR=7 because of abruptness and overcontrol tendencies.

SOS: unable to not roll ratchet during SOS. Constant PIO - an 8.

LATHOS: Bursts of oscillations requiring improvement. A 7.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony? Disharmony not noticed during tasks.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Very sensitive abrupt airplane - almost ridiculous. Initial response abrupt, quick. Predictability poor with classic roll ratchet.
- o PIO Tendency? Roll ratchety type PIO
- o Any Special Piloting Techniques? Try to be smooth

TASK COMPARISON:

SUMMARY:

Overall, a 8.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4069-5	A	.45	10	-	13	(40)	P	PA	NR	L342P(10)

TASK COMMENTS:

NO COMMENTS

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Flt No.-Eval	Pilot	$\widehat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4070-1	A	.40	10	-	8	(40)	P	UA	5	343P(10)

TASK COMMENTS:

Noticeable initial response; have to overdrive the airplane a little bit.

A/A: desired performance. A 4, because of motion and forces.

SOS: not adequate performance - lag, couldn't keep up with task - a 5 because of forces.

LATHOS: easy to do but a sloppy stick - there's a bobweight feel to it. A 4 due to large motions.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Displacements are noticeable.
- o Roll Sensitivity? Responsive but lag to start with.
- o Harmony? No problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: OK. Initially have to overdrive response. Predictability is good.
- o PIO Tendency? No
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall a 5.

Flt No.-Eval	Pilot	$\zeta_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4070-2	A	.25	10.	-	26.	(40)	P	UA	2	241P(10)

TASK COMMENTS:

SOS: initial abruptness, satisfactory. A 2.

A-A: easy to do, good airplane, responsive yet predictable. A 1½. Satisfactory.

LATHOS: good performance, controllable, easy to do, a 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Very satisfactory.
- o Roll Sensitivity? Good, responsive
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was good. Predictability was excellent.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Overall rating a 2.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4070-3	A	.25	18.	-	26.	-	P	UA	5	201P(18)

TASK COMMENTS:

Force displacement not a factor, a very responsive airplane, a little on the abrupt side.

AA: satisfactory but abrupt initially. a 5. (due to abruptness)

LATHOS: outstanding, a 3. Turn down abruptness.

SOS: Easy to do, initial abruptness but no overcontrolling or ratchets. Excellent & desired performance, a 3.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony? no problem. Much more responsive to roll than pitch.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Roll initial response was on abrupt side, quick.
- o PIO Tendency? none.
- o Any Special Piloting Techniques? desire to be smooth but can be flown.

TASK COMPARISON:

SUMMARY:

Overall a 5, due to tracking against F-4.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4070-4	A	.40	10	-	26	(40)	P	UA	3	341F(10)

### TASK COMMENTS:

Airplane sensitivity lower than desirable

A-A: controllable, a 2½. Should be a little more responsive.

Roll SOS: have to get it moving, had to overdrive it to get it going, A 3. No abruptness - nice.

LATHOS: quite pleasant and easy to do. a 2. No problems and smooth. Airplane tuned.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Noticed
- o Roll Sensitivity? Lower than desirable
- o Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initiate response medium to slightly slow. No problems w/predictability. However, it made a difference with tasks.
- o PIO Tendency?
- o Any Special Piloting Techniques? None

### TASK COMPARISON:

### SUMMARY:

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4070-5	A	.40	10.	-	26.	-	P	UA	1½	301P(10)

TASK COMMENTS:

A-A: a 1½

LATHOS: better ones, quite nice, 1½  
well tuned with task

R SOS: pinball task, 1½. Yet consistent.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? nice combination
- o Roll Sensitivity? good, could make it more with reasonable precision
- o Harmony? not effective

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: initial response and final response are well tuned
- o PIO Tendency? none
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Plane was fairly consistent. Overall 1½. A "rare" configuration in that I got the same (good) performance on all tasks. Best configuration yet.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4070-6	A	.30	10	-	8	(40)	P	PA	8	L243P(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Small displacements
- o Roll Sensitivity? Extremely sensitive
- o Harmony? An observed disharmony but not a problem during tasks.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Abrupt, too responsive initially. Not predictable.
- o PIO Tendency? Yes, particularly during sidestep. Bursts of PIO when closed loop.
- o Any Special Piloting Techniques? Try to back out of loop.

TASK COMPARISON:

ADDITIONAL FACTORS:

Gusting to 28 knots down runway.

SUMMARY:

Controllable but barely. PR=8 overall.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4073-1	C	.45	10	-	13	(40)	F	PA	2	L342F(10)

TASK COMMENTS:

1st Landing: Landed a little long. Good lateral correction. No lateral directional problems. Crisp roll response, degradingly quick, good command gain.

2nd Landing: A 2. Quick in roll axis response.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nothing abnormal; stick motions were smaller than some airplanes but good.
- o Roll Sensitivity?
- o Harmony? Pitch-roll harmony was good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good. Initial response: Noticeably sharper but predictable.
- o PIO Tendency? No
- o Any Special Piloting Techniques? No

TASK COMPARISON:

ADDITIONAL FACTORS:

Right cross wind - 10 knots.

SUMMARY:

A good airplane, a 2 overall.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4073-2	C	.30	10	-	8	(40)	P	PA	7	L243P(10)

TASK COMMENTS:

1ST LANDING: was hard (not much flare) because pilot had to try & keep out of the roll loop. Small oscillation onto the ground.

2ND LANDING: in loop, bobbling on short final. T.D. early with not much pitch control.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK. Displacements: okay
- o Roll Sensitivity? OK. Feeling of sluggishness somewhere (not sure if it was the feel system or dynamics)
- o Harmony? Pitch harmony: good. Not as good as before.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response had a mushy feeling. Delay or sluggish, then it picks up more. It was unpredictable.
- o PIO Tendency? Yes, A bobble more noticeable when you get in the tight end of loop.
- o Any Special Piloting Techniques? Tried to stay out of loop.

TASK COMPARISON:

Approach - the problems are noticeable.  
Landing: the problems get more noticeable as you get closer to the ground

SUMMARY:

Not adequate response - a 7 overall.

Flt No.-Eval	Pilot	$\hat{v}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4073-3	C	.30	10	-	26	(40)	F	PA	3	L241F(10)

TASK COMMENTS:

1st Landing: Quick initially but it's sluggish on final. Seemed predictable but different with a nonlinear feel to it, in the sense that the initial response was like the first ones but final response felt heavier. Landing performance had no problem, no lateral problems in close.

2nd landing: Good. On the white mark. No problems noticed, but nonlinear character of response noticed. a 3.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good. Displacements more than last time. Seemed heavier after initial response
- o Roll Sensitivity? OK initially, but heaved up a little bit
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: A little less predictable. Initial response: quick. Predictability: good.
- o PIO Tendency? None
- o Any Special Piloting Techniques? A little bit of factor for heavier force at final roll rate

TASK COMPARISON:

SUMMARY:

Smooth flight. Could be a 4 but a 3 overall.

Flt No.-Eval	Pilot	$\tilde{v}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4073-4	C	.2	5	.055	26	(40)	F	PA	4	L141F(5)+55

#### TASK COMMENTS:

1st landing - heavier forces but no adverse. Landed long but due to not pulling back on power. No problems on roll other than having to put on heavier forces.

2nd landing: distracted on final, wondering if there is a low freq. oscillation after correction from 4th evaluation in lateral stick. If so, it was on last min.

Throughout corrections, heavier forces were put in but plane was still smooth. Response: No degradation of putting in corrections.

#### FEEL SYSTEM CHARACTERISTICS:

- o Forces? heavier
- o Roll Sensitivity? smooth & slower
- o Harmony? ok

#### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: had to overdrive it a little bit, because of the heavy forces on the roll, slow response. Initial response: slower (not sluggish) predictability: had to put lead compensation once you did it was predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Overdrive a little bit

#### TASK COMPARISON:

Low frequency feel/oscillation on stick on close-in short final on 2nd landing.

#### SUMMARY:

Mildly unpleasant. Does require improvement, in roll forces, a 4. Rating primarily because of low, slower & heavier forces.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4073-5	C	.2	5	-	8	(40)	P	PA	5	L143P(5)

TASK COMMENTS:

1st landing: adequate. Deficiencies which require improvement. A 5 or 6. A 5. Moderately objectionable.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK, the same as before.
- o Roll Sensitivity? Same
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Less predictable because of initial delay & sluggish response. Wasn't scary.
- o PIO Tendency? Tendency was there but you didn't get into any because of the slow response of airplane, you'd back off before getting into it.
- o Any Special Piloting Techniques? Yes, some required to back off.

TASK COMPARISON:

Approach/Landing: No major differences. Some in small and large inputs can be noticed. Big input: delay & sluggish behavior - you have to compensate.

SUMMARY:

Sluggish w/a little delay; slight PIO, a 5.

Flt No.-Eval	Pilot	$\hat{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4074-1	C	.30	10	-	26	8	P	PA	9	L231P(10)

TASK COMMENTS:

Quick initially - slow finally. Somewhat unpredicable.

1st PA: dumped it off on size of input. In final portion of landing, Chuck took it and we had some sort of right bank upset.

2nd PA: same thing except PIO tendency is more pronounced.

Not adequate performance, a 9.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                      fairly light
- o Roll Sensitivity?                            quick
- o Harmony?                                     okay

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    very quick initially, response is very sluggish. Unpredictable.
- o PIO Tendency?                              Fairly strong.
- o Any Special Piloting Techniques?    had to back off

TASK COMPARISON:

SUMMARY:

wind from south, 5 knots. A 9. Very disconcerting. Had to have smooth conditions to land.

Flt No.-Eval	Pilot	$\hat{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4074-2	C	.30	10	-	26	13	P	PA	6	L221P(10)

#### TASK COMMENTS:

Adequate performance, somewhat tolerable, but warrants improvement. Small amplitude bobble on short final everytime.

#### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nothing out of the ordinary noticed. Forces tend to be sensitive initially with quick initial responses.
- o Roll Sensitivity? No delays or lags noticed
- o Harmony? Okay

#### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response very quick, unduly quick. Predictability: not good because of quick initial response, particularly for final corrections.
- o PIO Tendency? Yes, small amplitude PIO fairly high frequency. But only in final portion of landing.
- o Any Special Piloting Techniques? Compensation required. Very difficult to get out of the loop and do it. Tried to back off but difficult w/light & sensitive forces.

#### TASK COMPARISON:

Approaches: annoyingly quick but no problem. Landing tasks: PIO talked about above.

#### SUMMARY:

Cross wind out of south, a 6. Abruptness and small amplitude PIO.



Flt No.-Eval	Pilot	$\tilde{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4074-3	C	.2	5	-	26	(40)	F	PA	3	L141F(5)

TASK COMMENTS:

1st landing: good, solid smooth. Feel of roll control. Stiffer feeling stick. Short final had a little hunting in bank control prior to td.

Fairly good airplane.

A 3, mildly unpleasant deficiencies.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Stick felt tighter
- o Roll Sensitivity? Nice, more linear feel
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: good, smooth roll rate command. Initial response: fast enough but not too quick. Predictability: response was good.
- o PIO Tendency? None, other than slight undesirable motion prior to touchdown on 1st landing.
- o Any Special Piloting Techniques? No. Very slight back-off on first PA.

TASK COMPARISON:

SUMMARY:

A 3 , good but slight deficiency on something that's causing some hunting.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4074-4	C	.2	5	-	8	(40)	F	PA	5	L143F(5)

TASK COMMENTS:

More than minor deficiencies, a 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Fairly tight stick.
- o Roll Sensitivity? Too sensitive initially, a quick airplane.
- o Harmony? OK, although not as good as before.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Quick. Predictability = somewhat unpredictable, slower finally.
- o PIO Tendency? Slight one on short final. "Springiness" in stick is annoying. Contributes to non-linearity of motion due to stick inputs. Quick initially/sluggish finally.
- o Any Special Piloting Techniques?

TASK COMPARISON:

Non-linear response is noticed in both approaches and landings.

SUMMARY:

A 5. Moderately objectionable.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4074-5	C	.30	5	-	26	(40)	F	PA	3	L241F(5)

TASK COMMENTS:

Excellent performance, but stick forces are heavier than desired.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? On heavy side; displacements - okay.
- o Roll Sensitivity? Smooth initially & finally, very predictable.
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial - smooth input. Very predictable & same on final response.
- o PIO Tendency? No
- o Any Special Piloting Techniques? No

TASK COMPARISON:

None

SUMMARY:

a 3

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4075-1	B	.45	10	-	26	(40)	F	PA	1	L341F(10)

TASK COMMENTS:

(low approaches only)

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light. Displacements: satisfactory
- o Roll Sensitivity? Good. Not overly sensitive
- o Harmony? Excellent

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick but not overly so. Quite Predictable. Very useful for task assigned.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

None

SUMMARY:

No wind or turb. factors. A 1. Very good.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4075-2	B	.30	10	-	13	26	P	PA	3	L212P(10)

TASK COMMENTS:

Low approach only

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory
- o Roll Sensitivity? Little high, more than desired
- o Harmony? Reduced harmony between pitch and roll, with roll being quicker of the two.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was a little too fast. Was predictable, especially on 2nd landing.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Had to be less aggressive with roll.

TASK COMPARISON:

No T.D. - low approach only

SUMMARY:

Slightly high roll sensitivity. A 3.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4075-3	B	.30	10	-	26	13	P	PA	4	L221P(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Aileron & Pitch forces were light. Displacement was satisfactory.
- o Roll Sensitivity? A little more sensitive than preferred.
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response good. Predictable response.
- o PIO Tendency? None. A tendency for lateral overshoot in close in the flare.
- o Any Special Piloting Techniques? Some, in the flare, had to be careful with how aggressive the controls were input.

TASK COMPARISON:

No

SUMMARY:

Adequate performance, desirable. Changed his mind, too sensitive laterally, fair, a 4.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4075-4	B	.2	5	-	26	40	F	PA	3	L141F(5)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, well meshed for task at h;and. Displacements: satisfactory.
- o Roll Sensitivity? Satisfactory
- o Harmony? Very good. The two were closely matched.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was a little slower than desired. Check predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None. Maybe a little bit of pilot anticipation of when to make the input.

TASK COMPARISON:

No

SUMMARY:

Fair, anticipation of when to make Roll input. A 3.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4075-5	B	.30	10	-	8	(40)	F	PA	3	L243F(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory. Displacements: satisfactory
- o Roll Sensitivity? A little bit high, preventing an aggressive maneuver on the initial correction.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick, predictable
- o PIO Tendency? None
- o Any Special Piloting Techniques? Not to be overly aggressive on initial corection or on short final.

TASK COMPARISON:

SUMMARY:

adequate performance, too much roll sensitivity, a 3.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4076-1	B	.30	5	.055	26	(40)	F	PA	2	L241F(5)+55

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory. Stick displacements: satisfactory
- o Roll Sensitivity? excellent
- o Harmony? very good. No problems.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initially was good. Airplane turned the way the pilot felt it should. No real corrections required.
- o PIO Tendency? No. Predictability and response was good.
- o Any Special Piloting Techniques? None

TASK COMPARISON:

No

SUMMARY:

Overall a 2. Good

Flt No.-Eval	Pilot	$\hat{c}_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4076-2	B	.2	5	-	8	(40)	F	PA	4	L143F(5)

TASK COMMENTS:

Overall, a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Lateral stick forces: too light at times. Displacement: appeared to be correct. No problems with longitudinal force or displacements.
- o Roll Sensitivity? Too sensitive. Very small movement required to move plane to where you want to go. Roll axis much quicker and sensitive than pitch.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response for line up was adequate. Predictability was good initially, however. For in-close corrections a little problem w/predictability, especially 1st landing in terms of making too large of an input for the control system he had.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Some compensation in (1) anticipating how much control input to make and (2) how quickly to make the input in lateral axis again.

TASK COMPARISON:

No

SUMMARY:

Controllable. Adequate performance, a minor deficiency - being excessive roll sensitivity.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4076-3	B	.2	5	.175	26	(40)	F	PA	4	L141F(5)+175

TASK COMMENTS:

In close, predictability was not good.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light & satisfactory for this task in pitch & roll.
- o Roll Sensitivity? Satisfactory
- o Harmony? Satisfactory w/good relationship

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response revealed some time delay between input and roll response of airplane. Moved adequately but was unpredictable.
- o PIO Tendency? No
- o Any Special Piloting Techniques? Yes, on downwind, time delay was discovered & had to compensate for that. Light on controls so as to not overdrive the airplane.

TASK COMPARISON:

None

SUMMARY:

Have to make corrections for the apparent time delay in lateral axis, a 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4077-1	B	.30	10	-	8	(40)	P	PA	2	L243P(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory. Displacements: satisfactory
- o Roll Sensitivity? satisfactory
- o Harmony? good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was adequate. Predictable roll response for fine lateral corrections in close was good.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

N/A

SUMMARY:

Good, a 2.

Flt No.-Eval	Pilot	$\hat{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4077-2	B	.30	10	-	26	(40)	F	PA	3	L241F(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory, although the roll forces felt slightly higher.
- o Roll Sensitivity? Good
- o Harmony? Satisfactory, but not quite perfect. Roll channel feeling more sluggish than pitch channel.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial roll attitude response: adequate, but would like to see a little bit quicker. Predictable. Rate was slower.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Pilot had to be more aggressive to compensate for the slower roll rate

TASK COMPARISON:

N/A

SUMMARY:

Desired, fair rating, a 3 due to pilot compensation of sluggish roll rate.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4077-3	B	.2	5	.055	26	(40)	F	PA	4	L141F(5)+55

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                      Roll Forces: higher than desired.      Displacements: satisfactory
- o Roll Sensitivity?                           Satisfactory
- o Harmony?                                    Adequate, but roll channel was more sluggish & heavier than pitch channel.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:      Initial response: slow w/combination of heavier forces & slower roll rate, forcing pilot to overdrive airplane. Response not as predictable as desired.
- o PIO Tendency?                              None
- o Any Special Piloting Techniques?      Pilot had to overdrive because of the high forces & sluggish roll rate.

TASK COMPARISON:

N/A

SUMMARY:

Desirable performance, heavier forces & sluggish roll rate. Give it a 4.

Flt No.-Eval	Pilot	$\tilde{\tau}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4077-4	B	.30	5	-	26	(40)	F	PA	4	L241F(5)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Displacements: roll forces were adequate but higher than desired, displacements were satisfactory.
- o Roll Sensitivity? lower than desired. Did contribute to extra pilot workload.
- o Harmony? Adequate. Roll axis appears more sluggish than pitch.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: too slow. Gave problem in terms of initial line-up correction, didn't reverse back to the right quick enough, overshoot.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Yes. Deal with sluggish airplane. Airplane appeared to be a little slow with forces a little heavier.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. A 4. Apparent sluggish roll axis and heavier forces and sustained roll rate.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4078-1	B	.45	10	-	26	(40)	F	PA	2	L341F(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, appropriate for this configuration on both axes.
- o Roll Sensitivity? Very good
- o Harmony? Very good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: quick. Predictable
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

N/A

SUMMARY:

Good, a 2.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4078-2	B	.2	5	.175	26	(40)	F	PA	4	L141F(5)+175

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Roll forces are adequate but high. Displacements: satisfactory.
- o Roll Sensitivity? Less than desired
- o Harmony? Adequate

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too slow. Problem with predictability.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None. Compensate for slow roll rate.

TASK COMPARISON:

SUMMARY:

Controllable. Desired performance but slow roll rate w/higher roll forces and lower sensitivity than desired, a 4.

Flt No.-Eval	Pilot	$\tilde{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4078-4	B	.30	10	-	8	-	P	PA	3	L203P(10)

TASK COMMENTS:

1 landing

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light Displacements: satisfactory
- o Roll Sensitivity? Initially, U/A was thought to be good, but following close corrections it appeared to be too sensitive. Tendency to overcontrol.
- o Harmony? satisfactory.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: very good. Crisp with high sustained roll rate. Predictable. In close, tendency to overshoot. Too roll sensitive in this case.
- o PIO Tendency? No
- o Any Special Piloting Techniques? Small smooth corrections in close to avoid overcorrection.

TASK COMPARISON:

No

SUMMARY:

Fair, tendency to overcontrol with small, in close corrections, due to excessive roll sensitivity, a 3.

Flt No.-Eval	Pilot	$\bar{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4079-1	B	.40	18	-	26	(40)	F	UA	3*	341F(18)

TASK COMMENTS:

LATHOS: Tendency to overshoot because of rapid roll rate, a 4.

SAAB task, HQR of 2

On combined task, relaxed on stick, therefore smoother.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good and light
- o Roll Sensitivity? SAAB: good. Others: a little high and caused some problems with overshoots
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good on initial acceleration and sustained roll rate. Predictability was a little problem, causing overshoots due to sensitivity.
- o PIO Tendency? No
- o Any Special Piloting Techniques? Avoid overshoots in making small, quick corrections laterally.

TASK COMPARISON:

Pure roll tasks were more difficult due to roll sensitivity. Handling qualities on pure roll tasks were less optimized.  
\*HUD only evaluation.

SUMMARY:

Fair, excessive roll sensitivity, causing overshoots when making small and smooth lateral corrections. A 3.

Flt No.-Eval	Pilot	$\hat{\lambda}_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4079-2	B	.25	18.	-	26	8	P	UA	5*	231P(18)

TASK COMMENTS:

LATHOS: a 4. Airplane is "ratchety" probably due to time delay.

SAAB: a 4. Due to roll axis time delay and/or longer roll mode time constant.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light. Displacements: nominal - both satisfactory.
- o Roll Sensitivity? Satisfactory
- o Harmony? Satisfactory

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response showed evidence of either a long roll mode time constant or excessive time delay. Roll rates could have been higher for task. Plane seemed to constantly accelerate in roll and not get to sustained steady state. Predictability is poor, especially in tasks emphasizing lateral.
- o PIO Tendency?
- o Any Special Piloting Techniques? Be smooth with controls. Anticipate the moves of the aircraft, overdrive somewhat.

TASK COMPARISON:

Not much difference in handling qualities between tasks. Lateral axis is poor.

\*HUD only task evaluation

SUMMARY:

Adequate performance, a 5.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4079-3	B	.40	18	-	8	(40)	F	UA	3*	343F(18)

TASK COMMENTS:

SAAB: A 3, abrupt roll acceleration

LATHOS: a 3, abrupt roll acceleration

SAAB task was easier to accomplish, because task was not as demanding in roll axis.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Roll forces were nice. Displacements were small.
- o Roll Sensitivity? Roll Sensitivity too high slightly, abrupt in its acceleration; felt ratchety.
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response: acceleration was very good. Sustained roll rate was fine. Problem with predictability due to too high roll sensitivity.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Forced to allow system to work for you and not overdrive it, & overanticipate and take out the control too quickly. Resulted in lateral overshoots on target.

TASK COMPARISON:

No real differences.  
\*HUD eval. only.

SUMMARY:

Fair, too much roll sensitivity causing overshoots in UA and lateral corrections, a 3.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4118-1	C	.45	10	-	26	(40)	P	PA	3	L341P(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Slightly on sensitive side
- o Roll Sensitivity? A little too sensitive
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: No problems with roll control. Quick initial response and no problems with predictability.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

ADDITIONAL FACTORS:

17 knot direct crosswind made it a tough task.

SUMMARY:

No problems with roll. Good airplane, slightly on sensitive side, PR=3.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4118-2	C	.30	5	-	26	(40)	F	PA	2	L241F(5)

#### TASK COMMENTS:

Landed short, but in desired on first landing  
 Landed long, but in desired area on second.  
 Airplane feels softer in roll, less abrupt than last one, I like that.  
 Maybe even a little on slow side.

#### FEEL SYSTEM CHARACTERISTICS:

- o Forces? A little heavier
- o Roll Sensitivity? Better than last one, not as sensitive
- o Harmony? Good

#### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: No problems. Corrections could be made in close without any problem. Initial response was smooth, predictability was good.
- o PIO Tendency? None
- o Any Special Piloting Techniques? No

#### TASK COMPARISON:

#### SUMMARY:

Strong left crosswind but not a factor. A 2.

Flt No.-Eval	Pilot	$\hat{R}$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4118-3	C	.30	10	-	8	-	P	PA	7	L203P(10)

### TASK COMMENTS:

Notice abrupt and quick response initially and then a secondary oscillation in my hand. A sluggishness or lag that I can feel that makes it unpredictable. Got a PIO even though I tried to back out of task.

Uneasy to fly because you really have to stay out of loop. Controllability is not in question because I could stay out of loop and not PIO. But workload is not tolerable. R=7.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Felt light initially - not too light.
- o Roll Sensitivity? On sensitive side - but not a problem.
- o Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: A problem. Quick initial response followed by second, sluggish unpredictable response. Almost a two-mode response.
- o PIO Tendency? Yes
- o Any Special Piloting Techniques? Stay out of the loop

### TASK COMPARISON:

PIO when you get into loop

### SUMMARY:

Unpredictable airplane. Slightly sensitive initially and then unpredictable. A 7.



Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4118-4	C	.2	5	.110	26	(40)	F	PA	4	L141F(5)+110

TASK COMMENTS:

Steady-state seems fine but I don't like initial abruptness. Noticed it most making fine corrections just prior to landing. Really just annoying. Maybe satisfactory without improvement but I would rather it didn't do that.

Don't notice abruptness on lateral correction where the input is in for a longer time. You notice it on short final making small corrections. More than mildly unpleasant. No compensation, just jerkiness.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK
- o Roll Sensitivity? Good. I can't say that abruptness was really due to roll sensitivity
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: A little quick initially. Predictability was good though.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None required

TASK COMPARISON:

SUMMARY:

PR=4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4119-1	C	.45	10	-	13	(40)	P	PA	2	L342P(10)

TASK COMMENTS:

Satisfactory without improvement. It would be a 1 except it needed to be toned down in sensitivity just a tad. It was very predictable throughout. Sensitivity not a problem but just a little high.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good
- o Roll Sensitivity? Slightly light
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Very predictable. Great initial response.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

A 2. A good airplane.

Flt No.-Eval	Pilot	$\tilde{z}_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4119-2	C	.30	10	-	13	-	P	PA	5	L202P(10)

#### TASK COMMENTS:

This one wasn't as bad on the second approach as the first. Not satisfactory without improvement. Debating between a 4 and a 5.

Did not notice pilot compensation on second approach but I did on first. Overall a 5, weighing the first approach more than the second.

#### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Acceptable
- o Roll Sensitivity? A little sensitive
- o Harmony? OK

#### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Abrupt initial response. Starting to get unpredictable  
Final response was somewhat in question.
- o PIO Tendency? Not noticed
- o Any Special Piloting Techniques? Had to lead the input for final corrections particularly close to ground.

#### TASK COMPARISON:

Problems noted only close to ground

#### SUMMARY:

A good 5.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4119-3	C	.30	10	-	8	(40)	F	PA	6	L243F(10)

TASK COMMENTS:

PR=6. Not desired performance. Workload was high but not intolerable. PIO tendency was there but not divergent. Problems were not apparent on approach.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? Quick, abrupt
- o Harmony? Roll more sensitive

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Somewhat unpredictable. Quick initial response. Steady state roll rate was not a problem. Seemed to be a lag there that hurt my predictability.
- o PIO Tendency? Yes, small amplitude but I felt I could control it and stop it.
- o Any Special Piloting Techniques? Back out of task/loop

TASK COMPARISON:

Problems occurred on short final in close

SUMMARY:

A 6. Slightly unpredictable and much too abrupt.

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Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4119-4	C	.30	10	-	26	(40)	F	PA	3	L241F(10)

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**TASK COMMENTS:**

I thought it was a pretty good airplane but there was something subtle about it. There was an abruptness or steady-steady response that was not as good as I would have liked. Call it a 3.

**FEEL SYSTEM CHARACTERISTICS:**

- o Forces?                                Felt crisp but may be too abrupt initially.
- o Roll Sensitivity?
- o Harmony?

**AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:**

- o Roll Attitude Response:    Good. Predictable. Initial response was slightly on sensitive side but not abrupt.
- o PIO Tendency?                None
- o Any Special Piloting Techniques?    None, fly normally and had no problems.

**TASK COMPARISON:**

**SUMMARY:**

A 3. Good airplane. Maybe a slight abruptness problem.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4120-1	C	.45	5	-	26	(40)	F	PA	2	L341F(5)

TASK COMMENTS:

That's a 2. If anything, forces were a hair on the heavy side so I can't give it a 1. Felt very confident with it.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? good, on high side maybe, heavy. Not a problem.
- o Roll Sensitivity?
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Very good. Not abrupt at all. Very smooth. Very predictable roll response
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Good airplane. smooth response

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4120-2	C	.45	10	-	13	(40)	F	PA	5	L342F(10)

TASK COMMENTS:

Not satisfactory without improvement.  
 I didn't get desired performance. Give it a 5. Considerable compensation because of abruptness rather than predictability. No real PIO tendency.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light
- o Roll Sensitivity? sensitive
- o Harmony? Acceptable but I've seen better

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Quite quick initially. Predictability was not good but not terrible. More of an abruptness problem.
- o PIO Tendency? Not a significant one.
- o Any Special Piloting Techniques? None really. Just used smaller inputs to avoid abruptness.

TASK COMPARISON:

SUMMARY:

A 5. Abruptness, sensitivity and a slight predictability problem.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4120-3	C	.30	10	-	8	(40)	F	PA	7	L243F(10)

**TASK COMMENTS:**

Requires improvement. Almost a 6, but it's a 7. There's a definite delay, PIO, problem that causes unpredictable behavior. It's not that scary because it's slow aircraft dynamics. The airplane doesn't jump out at you and you can get out of the loop.

**FEEL SYSTEM CHARACTERISTICS:**

- o Forces? On heavy side
- o Roll Sensitivity? Low
- o Harmony? Acceptable

**AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:**

- o Roll Attitude Response: Moderate initial response, not extremely long nor abrupt. Predictability was bad.
- o PIO Tendency? Yes, low frequency
- o Any Special Piloting Techniques? Had to back out to stop PIO

**TASK COMPARISON:**

Worse task was small corrections just prior to touchdown

**SUMMARY:**

A good 7.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4120-4	C	.2	5	-	13	(40)	P	PA	7	L142P(5)

TASK COMMENTS:

Requires improvement. It's a 7.

PIO tendency was there. Delay seemed to be more in my stick than the flight control. It was annoying. It felt like a sluggish stick. More annoying than last 7 but same PIO tendency. Annoying stick characteristics. Not an abrupt airplane so it wasn't that scary.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? On heavy side
- o Roll Sensitivity? Not real bad, not real sensitive
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was acceptable - not real abrupt or sluggish, not good predictable.
- o PIO Tendency? A slow PIO tendency. Not an explosive PIO tendency with a sensitive airplane that I would really be worried about.
- o Any Special Piloting Techniques? Had to lead the airplane a little. I could compensate enough to do the corrections.

TASK COMPARISON:

No factors

SUMMARY:

A 7. More annoying than last eval (a 7) because of stick characteristics.

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Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4122-1	C	.45	10	-	26	(40)	F	PA	2	L341F(10)

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TASK COMMENTS:

Feels like a comfortable airplane.  
Good airplane. PR=2  
A little light on stick but easy to adjust.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? A little light
- o Roll Sensitivity? A little sensitive but after a while it felt nice
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was just right - not too quick, not too sluggish. Response was very predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

A little choppy turbulence, no factor. A 2, good airplane.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4122-2	C	.30	10	.16	26	-	P	PA	6	L201P(10)+110

TASK COMMENTS:

Not satisfactory without improvement. I could do all right with it but I just can't put anything big in quickly.

Too unpredictable for that - that's a 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK, but light
- o Roll Sensitivity? Very sensitive
- o Harmony? Roll more sensitive than pitch

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick but final response was unpredictable.
- o PIO Tendency? Yes, low amplitude PIO problem
- o Any Special Piloting Techniques? PIO was there throughout except if I backed out.

TASK COMPARISON:

Final portion of landing or lateral offset correction was where I could surprise myself.

SUMMARY:

Sensitive and unpredictable - a 6.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4122-3	C	.30	10	-	26	(40)	F	PA	3	L241F(10)*

$$*F_{as}/das = 2.75 \text{ lbs/inc}$$

#### TASK COMMENTS:

Landed long on second landing because I forgot the throttle. I couldn't find anything wrong with the lateral flying qualities.

It's satisfactory without improvement.

Initially, when I flew it, there was something about the feel that wasn't nice and crisp and linear. But is a 3. Why I felt like I initially did I don't know.

#### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good; on low, heavy side
- o Roll Sensitivity? Less
- o Harmony? OK

#### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good, smooth and predictable
- o PIO Tendency? No
- o Any Special Piloting Techniques?

#### TASK COMPARISON:

No problems with approach or landing

#### SUMMARY:

A 3 and not better because there was a slight unusual feel in the stick.

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Flt No.-Eval	Pilot	$\tilde{\nu}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4122-4	C	.2	5	.175	26	(40)	F	PA	8	L141F(5)+175

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TASK COMMENTS:

Took one to a low-go and as I got closer I got more and more PIO.  
 It was controllable but I didn't do the task. Give it an 8.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? Sensitive airplane, roll ratchet, but problems were not just due to sensitivity.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Unpredictable. Initial response was quick and then you got stair-stepping and PIO.
- o PIO Tendency? Definite, even when turning base turn and it got aggravated when closer to the ground.
- o Any Special Piloting Techniques? Stay out of loop.

TASK COMPARISON:

SUMMARY:

Did not try to touch down because of safety concerns but I don't feel it was uncontrollable. I'll stick with the 8.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4123-1	C	.30	5	-	26	-	P	PA	2	L201P(5)

TASK COMMENTS:

1st approach touchdown short  
 2nd approach touched down long  
 Both within desired performance  
 I liked the airplane, it feels nice  
 PR=2, touchdown deviations due to throttle technique.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nice, not sensitive or abrupt at all.
- o Roll Sensitivity? Nice
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Precise. Initial response was smooth. Predictability was good.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

No differences noticed

SUMMARY:

Slight left crosswind, no problem. Good airplane, a 2. Can't see anything wrong with it.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4123-3	C	.45	10	-	8	(40)	P	PA	7	L343P(10)

TASK COMMENTS:

That's not adequate performance with a tolerable workload. Not worrying about control. Not as bad as last one. I could back out of the loop to get two good touchdown points. But it was very clear that I had to back out of the loop to avoid the PIO. A 7.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK, a little more sensitive than last one. Acceptable. Not the big problem
- o Roll Sensitivity? OK
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was acceptable. Predictability was bad. That was the problem.
- o PIO Tendency? Yes
- o Any Special Piloting Techniques? Quick inputs start PIO. I had to back out to stop the PIO. I could back out of the loop, unlike the last configuration.

TASK COMPARISON:

SUMMARY:

PR=7

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4123-4	C	.2	5	-	13	(40)	F	PA	4	L142F(5)

TASK COMMENTS:

Not satisfactory without improvement.

Abruptness was objectionable. Noticed a small amplitude PIO particularly doing fine corrections close in. Not unpredictable but its hard to stop.

Call it a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good. Airplane felt tight and stiff in force.
- o Roll Sensitivity? OK
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick. Not bothersome in approach phase but in close it was. It was predictable. What was unpredictable was how to stop the small amplitude PIO.
- o PIO Tendency? Yes in final portions of landing, PIO was a "wing-walk" - a degree or two oscillation in bank.
- o Any Special Piloting Techniques? I found none that changed anything.

TASK COMPARISON:

SUMMARY:

A 4.



Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4126-1	C	.40	18	-	26	(40)	P	UA	5	341P(18)

TASK COMMENTS:

Very sensitive in roll but not exceedingly so.

Roll SOS: hard to get desired error performance. Give it a 4½ because of more than minor deficiencies - no, give it a 5. Desired performance at times, but overall only adequate.

LATHOS: Not much of a problem with this task. Slight overshoot tendency PR-4. Not satisfactory without improvement but I think I got desired error tracking performance.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good
- o Roll Sensitivity? OK. At first it seemed sensitive but it was ok in the task.
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was good. Not too quick or slow. Slight predictability problem, however, causes overshoot and overcontrol.
- o PIO Tendency? Slight although you can stop it right away.
- o Any Special Piloting Techniques? Back out a little and shape inputs.

TASK COMPARISON:

A little easier in LATHOS task because it wasn't a continual rapid rate. Predictability and overcontrol problems were more apparent in the SOS task.

\*HUD evaluation only.

SUMMARY:

A 5 overall because primarily of SOS task.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4126-2	C	.25	18	-	26.	(40)	P	UA	5*	241P(18)

TASK COMMENTS:

Roll SOS: better than last evaluation but PIO trying to track is still there. Not desired performance. A 5.

Lathos: Easier than SOS task. Not as easy as first eval step and ramp task. Noticed a searching for final correction and have problems stopping, although (oscillations) are within desired performance. Has a PIO that you have to back out of. A 4½.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK
- o Roll Sensitivity? Not a problem
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: A little abrupt initially. Predictability for fine corrections was not real good.
- o PIO Tendency? Yes, small amplitude, higher frequency.
- o Any Special Piloting Techniques? Backed out of task.

TASK COMPARISON:

\*HUD only evaluation

SUMMARY:

A 5 overall, very similar to last one.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4126-3	C	.25	18.	-	13.	26.	P	UA	7*	212P(18)

TASK COMMENTS:

Roll SOS: a doggy airplane. That's a 7. Not adequate performance with a tolerable workload.

LATHOS: a 7 also.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? very light.
- o Roll Sensitivity? too sensitive.
- o Harmony? did not notice a problem but could have been improved.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was abrupt with very poor predictability.
- o PIO Tendency? Definite PIO, if I tried to close the loop tightly.
- o Any Special Piloting Techniques? Backed out helped but consequently error scores got worse.

TASK COMPARISON:

Step and ramp task tended to be harder because errors didn't seem to get worse when I backed out of task.

\*HUD eval. only.

SUMMARY:

Not a good airplane.

Flt No.-Eval	Pilot	$\tilde{r}_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4126-5	C	.30	10	-	13	-	P	PA	6	L202P(10)

TASK COMMENTS:

Much more sensitive than last airplane. Unpredictable for tight control. No problem with small inputs or staying out of loop.

Call it adequate performance with tolerable workload - but only a 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? Much too sensitive
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick. Unpredictable for big or quick inputs. Not obvious that its unpredictable for small inputs.
- o PIO Tendency? Yes, although more of an overcontrol than PIO tendency.
- o Any Special Piloting Techniques? Don't use big, quick inputs

TASK COMPARISON:

SUMMARY:

Tolerable but very objectionable - a 6.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4126-6	C	.2	5	.110	26	(40)	F	PA	5	L141F(5)+110

TASK COMMENTS:

Call it a 4. Desired performance but not satisfactory without improvement. Don't like heavy forces and quick initial response. Noticed on second landing that I lost the predictability when I got in close. Not terrible but not what I want - call it a 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Heavy, stiff
- o Roll Sensitivity?
- o Harmony? Not a problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick. Predictability was ok except when I used tight corrections just prior to touchdown.
- o PIO Tendency?
- o Any Special Piloting Techniques? Fly smoothly but don't overpower it or you get into problems

TASK COMPARISON:

ADDITIONAL FACTORS:

15-18 knots down runway.

SUMMARY:

C-4

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4127-1	C	.25	18.	-	13.	26.	P	UA	8	212P(18)

TASK COMMENTS:

Roll SOS: very sensitive airplane with delay. Strong PIO tendency.

A-A: continual PIO.

LATHOS: overall a PR of 8. All tasks were similar in flying qualities.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light forces, displacements were ok.
- o Roll Sensitivity? sensitive
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Not real quick in initial response; not abrupt but fast. unpredictable.
- o PIO Tendency? very strong.
- o Any Special Piloting Techniques? almost a divergent PIO unless stick was released. Low amplitude, continual PIO in fine tracking.

TASK COMPARISON:

SUMMARY:

Bad airplane.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4127-2	C	.25	18	-	26	-	P	UA	5	201P(18)

TASK COMMENTS:

Roll SOS: A slight PIO problem.

A-A: Pretty good in gross acquisition. Only problem is a low amplitude "dither" during time tracking. PR=5. Not desired performance because of the "bobble".

LATHOS: Deficiency is "ringing" in roll. PR=5. Backed out to stop ringing. It's more than annoying.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not bad.
- o Roll Sensitivity? sensitive.
- o Harmony? ok

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: quick, too quick initially. Poor predicability. Particularly during fine tracking.
- o PIO Tendency? Yes, not divergent but during fine corrections. A closed loop, small amplitude ringing.
- o Any Special Piloting Techniques?

TASK COMPARISON:

Noticed small amplitude bobble more in HUD tasks than in air-to-air except when going wing tip to wing tip.

SUMMARY:

Overall a 5.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4127-3	C	.40	18	-	13	(40)	F	UA	2	342F(18)

TASK COMMENTS:

A-A: Good precision. Some dutch roll nose wandering with 'g', however, not too bad. Desired tracking. PR=2

Roll SOS: PR=2 No problems at all. Good lateral-directional characteristics.

LATHOS: PR=2. Nothing wrong with the airplane.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good
- o Roll Sensitivity? Good
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Quick initial response but ok. Response just right. Good predictability.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

Airplane was very similar in all tasks. Dutch roll with 'g' making nose wander. Not considered to be a significant factor.

SUMMARY:

Overall a 2.



Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4127-4	C	.30	10	-	13	-	P	PA	3	L202P(10)

TASK COMMENTS:

No problems noted with airplane. Landed long on first approach primarily due to crosswind problems.

May be a little bit of uncertainty in roll axis when making final corrections.

PR=3, not a 2, because of the wing dip just prior to touchdown.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Middle of the road
- o Roll Sensitivity? Not too sensitive, ok
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response good, not too quick, not too sluggish. Slight uncertainty near touchdown.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Strong crosswind from left. Pretty good airplane, but not perfect.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4127-5	C	.3	10	.055	26	-	P	PA	5	L201P(10)+5!

TASK COMMENTS:

A slight uncertainty or unpredictability for bigger inputs.

Not a real bad airplane but there was an unpredictability about it that warranted improvement. Not desired performance because of PIO. A 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK
- o Roll Sensitivity? OK
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was ok. Predictability was lacking for big inputs. Not noticeable for small inputs.
- o PIO Tendency? Yes
- o Any Special Piloting Techniques? Fly smoothly to avoid PIO. Avoid big corrections or fine corrections in final stages of landing.

TASK COMPARISON:

SUMMARY:

A 5.

Flt No.-Eval	Pilot	$\hat{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4127-6	C	.30	10	.110	26	(40)	F	PA	8	L241F(10)+110

### TASK COMMENTS:

Sensitive initially. Didn't think it was going to be a problem until I got into a PIO. No touchdown on first approach. VSS dump on short final due to PIO making final corrections. Didn't notice lag in system until after PIO.

Control was in question because you have to consciously back out of the loop to avoid PIO. I did it once by avoiding lateral inputs so that's considerable compensation for control.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? light
- o Roll Sensitivity? Quick, abrupt, very sensitive
- o Harmony? Not a factor

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Very quick initial response with light steady-state forces. Bad predictability
- o PIO Tendency? Very strong
- o Any Special Piloting Techniques? Can't get into the loop and avoid lateral inputs.

### TASK COMPARISON:

PIO during landing task but not in approach. Slight crosswind.

### SUMMARY:

A "gotcha" airplane. PIO when you get into the loop.

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4128-1	C	.45	10	-	13	(40)	P	PA	2	L342P(10)

TASK COMMENTS:

Responsive airplane, not adversely so.  
 PR = 2  
 Not a lot wrong with this airplane, felt nice.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good
- o Roll Sensitivity? Good
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good initial response. No predictability problems.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

Same in both approach and landing.

ADDITIONAL FACTORS:

Wind was a little troublesome. Gusty with a left crosswind.

SUMMARY:

Good airplane, a 2.

Flt No.-Eval	Pilot	$\hat{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4128-2	C	.45	10	-	8	(40)	P	PA	8	L343P(10)

TASK COMMENTS:

Somewhat unpredictable. Initial forces are heavy and then they get light. Nonlinear feel, almost disconcerting.

Unacceptable PIO on short final. Heavy initial forces then light forces gives a surprising roll rate after putting in a bigger input. Really fools you.

Concerned about control. You really have to stay out of the loop. Not a PIO due to a time delay, it's different, nonlinear forces.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Heavy forces then light
- o Roll Sensitivity? too sensitive
- o Harmony? Not harmonious

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was ok. Dynamics of the response seemed ok. Predictability was terrible due to nonlinear feel.
- o PIO Tendency? Yes particularly in correcting for gustiness on short & final.
- o Any Special Piloting Techniques? Use as few inputs as possible.

TASK COMPARISON:

ADDITIONAL FACTORS:

Gusty winds

SUMMARY:

An 8 particularly in these conditions. Very nonlinear feel was the problem.

Flt No.-Eval	Pilot	$\tilde{\tau}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4128-3	C	.2	5	-	26	(40)	P	PA	4	L141P(5)

TASK COMMENTS:

Heavier stick forces than last one. A little abrupt.

Desired performance, but I don't like heavy stick forces and the airplane is abrupt in initial response for fine corrections. You get high accelerations that jerk you. That's annoying. A minor but annoying deficiency.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Heavy
- o Roll Sensitivity? Don't notice abruptness until in higher gain control close to ground.
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was abrupt. Predictability was not a problem.
- o PIO Tendency? Not in a classic sense. For small amplitude oscillations in a high frequency sense. Out of phase with airplane due to abruptness.
- o Any Special Piloting Techniques? None except to expect abrupt response.

TASK COMPARISON:

SUMMARY:

A 4- not a bad airplane but minor but annoying deficiencies.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4128-4	C	.30	10	.055	26	(40)	F	PA	2	L241F(10)+55

TASK COMMENTS:

Roll rate is fairly responsive and forces seem to be linear, feels pretty good so far.

Good airplane. Only problem may be the sensitivity. Call it a 2.  
Sensitivity complaints that I may have had may be due to prejudice from last eval.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good, maybe a tad light
- o Roll Sensitivity? Good
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good initial response. Predictability was good.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

No differences

ADDITIONAL FACTORS:

Gusty conditions.

SUMMARY:

A 2 - a good airplane

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4153-1	B	.25	18.	-	26.	-	P	UA	4	201P(18)

TASK COMMENTS:

No trouble tracking and holding pipper on target.

It was satisfactory without improvement but only fair. That's a 3.

Slight tendency to over control on the roll-in. Change rating to a 4.  
Slight lateral PIO and overshoot when I rolled in hard on gross acquisition. I had to back off slightly. No problem with fine tracking.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light.
- o Roll Sensitivity? Maybe a little too responsive initially. A little sensitive for gross acquisition but fine in fine tracking.
- o Harmony? pretty good.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: fairly predictable.
- o PIO Tendency? slight.
- o Any Special Piloting Techniques? Compensation was to not overcontrol when you made the gross lateral move.

TASK COMPARISON:

No HUD-tracking tasks

SUMMARY:

HQR of 4.



Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4153-3	B	.40	10	-	26	(40)	F	UA	2	341F(10)

TASK COMMENTS:

Slower responding laterally than last config.  
 Pretty easy to track with this one.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Felt higher but ok.
- o Roll Sensitivity? Good. Not as sensitive as last two airplanes but certainly adequate to do the job.
- o Harmony? I liked it.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial roll response was satisfactory and predictable.
- o PIO Tendency? No PIO tendencies.
- o Any Special Piloting Techniques? None really needed

TASK COMPARISON:

(No HUD Tracking tasks).

SUMMARY:

Desired performance in both fine tracking and gross acquisition. I was very able to move the pipper easily from wing tip to wing tip and hold it exactly where I wanted it. HQR=2.

Flt No.-Eval	Pilot	$\bar{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4153-4	B	.15	18.	.025	26	(40)	F	UA	4	141F(18)+25

TASK COMMENTS:

A little bit more abrupt than I would like, but it's not causing me problems so far.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? satisfactory, but light.
- o Roll Sensitivity? satisfactory.
- o Harmony? good.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: quick and predictable. One thing, however, if you tried to make several small corrections in rapid succession, it felt that the airplane was roll ratchety. It would have been interesting to see that in formation.
- o PIO Tendency? None
- o Any Special Piloting Techniques? You could not be overly aggressive in small lateral inputs otherwise you get the roll ratcheting.

TASK COMPARISON:

(No HUD tracking tasks)

SUMMARY:

Not satisfactory without improvement because of the abruptness or roll ratchet with small displacements. I'll call that moderate compensation for an HQR of 4. I did get desired performance.

Flt No.-Eval	Pilot	$\hat{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4153-5	B	.15	18.	- "	8.	(40)	P	UA	5	143P(18)

TASK COMMENTS:

Maybe a little time delay - not sure, we'll see if it's a player. A little oscillation that I don't like. Anything quick and you're in trouble.

Gross acquisition is fine but once you get close it's a problem.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Adequate. Light forces and small displacement.
- o Roll Sensitivity? Good
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: In gross tracking, the initial response was good and predictable. It was desired performance. However, in fine tracking, I felt the airplane had poor predictability and it was overshooting. It felt like a time delay was giving me problems.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

(No Hud tracking tasks performed)

SUMMARY:

Not satisfactory without improvement. Considerable compensation to shape control inputs. That's an HQR of 5.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4153-6	B	.30	10.	-	26	-	P	PA	2	L201P(10)

TASK COMMENTS:

On first approach, I was late on the power and we floated although I didn't see any roll problems.

On the second approach, I got desired performance.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good
- o Roll Sensitivity? Good
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: I liked it. Good response
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Satisfactory without improvement. HQR of 2. Pilot compensation not a factor.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4153-7	B	.45	5	-	26	(40)	F	PA	5	L341F(5)

TASK COMMENTS:

One objectionable deficiency of this airplane was that on the offset correction, the airplane was very slow laterally.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Heavy forces, heavier than I like for a fighter type airplane
- o Roll Sensitivity? Not sensitive enough
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too slow. Because of that, I didn't anticipate when to correct back to centerline on the first approach and overshoot the centerline
- o PIO Tendency? none
- o Any Special Piloting Techniques? Lead turns and put in more control initially than you may have wanted

TASK COMPARISON:

SUMMARY:

Desired landing performance but it was not satisfactory without improvement. I'll rate that a 5 for considerable pilot compensation required.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4153-8	B	.30	10	.110	26	(40)	F	PA	6	L241F(10)+110

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? Too high with maybe some time delay. I did not like it whatever it was
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick. It was predictable for a gross acquisition of the runway. However, in fine tracking the centerline there was a tendency to overshoot and possibly PIO.
- o PIO Tendency?
- o Any Special Piloting Techniques? Small, smooth responses had to be used and the more I stayed out of the loop, the better I was.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement because of the overshoots and borderline PIO. That's an HQR of 6.

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Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4154-1	B	.25	18	.110	26.	-	P	UA	7	201P(18)+110

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TASK COMMENTS:

In air to air, constant roll oscillations and overshoots. Really have to work at getting the performance. I'll give it an HQR of 6 so far.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?   Extremely light, too light.
- o Roll Sensitivity?                                   Extremely sensitive.
- o Harmony?    Poor. Roll much more sensitive than pitch.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:                       Initial response for both acquisition and fine tracking was unpredictable, too quick, and there were a lot of overshoots by what appeared to be a time delay.
- o PIO Tendency?                                     Yes.
- o Any Special Piloting Techniques?            You have to fly the airplane with just two fingers so that you always use fine, smooth inputs to do any tracking at all.

TASK COMPARISON:

SUMMARY:

Got adequate performance I think. That's a 6 due to lots of overshoots due to sensitivity and time delay requiring extensive compensation. No, change rating to a 7. :That was not a tolerable workload. Really terrible airplane.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4154-2	B	.40	18	-	13.	-	P	UA	5	302P(18)

### TASK COMMENTS:

A little bit of a problem with overshoots. A little lateral stick movement that I didn't like. No problem fine tracking. Desired performance - maybe not as quick as I would like. I have to overdrive it a little bit. Give gun tracking a 5.

In the roll SOS, I can get the performance but it's a lot of work. Some overshoots due to having to overdrive my inputs. Give it a 5.

Discrete task isn't that bad. The continuous movement is the problem.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, fighter-type forces.
- o Roll Sensitivity? satisfactory
- o Harmony? adequate

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was adequate but I didn't like the overshoots I got when I aggressively tracked. I had to overdrive airplane to start and to stop. Particularly bad during continuous tracking maneuvers.
- o PIO Tendency? Small tendency that could be avoided.
- o Any Special Piloting Techniques? Lead target and avoid rudder starts and stops to avoid overshoots.

### TASK COMPARISON:

On continuous, jinking target, you got into lateral overshoots.

### SUMMARY:

Adequate performance on all tasks. Not satisfactory without improvements. Considerable compensation required to avoid overshoots especially for quick inputs. HQR = 5.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4154-3	B	.40	18	.055	26.	26.	P	UA	6	311P(18)+55

TASK COMMENTS:

In gun tracking, I'm having problems when going rapidly from wing tip to wing tip. Not as precise of an airplane as I would like. Not a super good airplane. Just adequate performance. Give that an HQR = 6.

Quick and rapid motions really show up the bad features of this airplane. Not a good, fine tracker either.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light but satisfactory
- o Roll Sensitivity? A little lighter than I wanted
- o Harmony? Roll a little quicker than pitch

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response for gross acquisition was quick enough. Not as predictable as I would like. Hard to judge when to put in input or take it out. Got worse in fine tracking particularly for rapid maneuvers.
- o PIO Tendency? Yes
- o Any Special Piloting Techniques? Be light on the stick and be careful on how much lead you use. Be smooth.

TASK COMPARISON:

Airplane handled best for just slow sinusoidal commands. Rapid, small steps with no time in between were the hardest.

SUMMARY:

Not satisfactory without improvements. Large overshoots for an HQR of 6.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4154-4	B	.25	18.	-	26.	13.	P	UA	5	221P(18)

TASK COMMENTS:

In gun tracking, it was pretty good, certainly better than last ones. Give it an HQR of 4. It did have some deficiencies where you could get some overshoots when you got aggressive.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? A little too light. Displacements were a little small.
- o Roll Sensitivity? OK
- o Harmony? Satisfactory

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was a little slower than I would have liked. Also, the roll rate response for gross tasks could have been a little quicker. Not as good as I would have liked in true tracking. Not that predictable. Overshoots.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Had to be very light with stick, using two fingers for fine tracking. Avoid overdriving and ramp out input once on target to avoid overshoots.

TASK COMPARISON:

Gross acquisition was easier than fine tracking tasks. Gun tracking was actually easier than the HUD tasks, because the HUD tasks tended to command small, quicker commands that slowed the overshoots.

SUMMARY:

Not satisfactory without improvement. Not desired performance all the time. It was considerable compensation in the fine tracking so I'll call it an HQR of 5.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4154-5	B	.15	18.	-	8.	(40.)	F	UA	7	143F(18)

TASK COMMENTS:

You have to be gentle with this airplane. Roll response is very fast. I think I can stay with the target with desired performance but it's very uncomfortable to compensate for this ratcheting. HQR=6.

In roll SOS, I'm really having a lot of trouble, not in "matching wings", but in keeping the airplane from shaking back and forth in what I think is an incipient PIO. Very uncomfortable. I don't like this at all. HQR=7

FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                   Extremely light forces.    Didn't seem to be any displacement at all.
- o Roll Sensitivity?                       Way too sensitive.
- o Harmony?                                Poor. Roll very sensitive.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:   Initial roll response was very sharp. Not smooth in any respect. The only thing that was predictable about this airplane was that it was going to be very jerky especially during fine tracking.
- o PIO Tendency?                         Very strong.
- o Any Special Piloting Techniques?   Work as hard as you could be to be light on the stick.

TASK COMPARISON:

Gun tracking and HUD tasks showed equally poor qualities. Roll SOS was particularly tough because of the continual rapid attitude changes.

SUMMARY:

Terrible airplane. Controllable but not adequate performance with a tolerable pilot workload. Lateral overshoots and incipient PIO were major deficiencies. HQR of 7.

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Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4154-6	B	.30	5	-	26	(40)	F	PA	5	L241F(5)

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TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? A little heavier than I like
- o Roll Sensitivity? Satisfactory
- o Harmony? Adequate

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response on correction was slow. No real closed loop problems, maybe one overshoot of desired roll attitude.
- o PIO Tendency? Not really
- o Any Special Piloting Techniques?

TASK COMPARISON:

Got desired landing performance on first approach but floated on second landing

SUMMARY:

Not satisfactory without improvement fairly considerable workload to compensate for slow roll response and heavy forces. Call it an HQR of 5.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4155-1	B	.40	18.	.055	26.	-	P	UA	6	301P(18)+55

TASK COMMENTS:

Give that a 5 for the gun tracking task. I had some overshoots of the target but I don't know why.

For the roll SOS, give that an HQR of 5 as well, due to the overshoots in initially trying to track the target.

A rating of 5 for the discrete task as well.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, satisfactory.
- o Roll Sensitivity? Satisfactory.
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response in gross acquisition was certainly too slow. I'm not sure if that was a roll mode time constant problem or if it was just low max. roll rate. Continuous roll response was too slow also. Not good predictability because you had to overdrive the airplane.
- o PIO Tendency? Thought I saw a small incipient PIO.
- o Any Special Piloting Techniques?

TASK COMPARISON:

Airplane handled better in gun tracking than HUD tasks since the fine tracking handling was not bad.

SUMMARY:

Not satisfactory without improvement. Extensive compensation to overcome sluggish roll and to compensate for roll overshoots. That's an HQR of 6 overall, even though I gave 5's for the individual tasks. The workload was extensive rather than considerable.

Flt No.-Eval	Pilot	$\uparrow$ R	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4155-2	B	.25	18.	-	13.	26.	P	UA	7	212P(18)

TASK COMMENTS:

An HQR of 5 for the gun tracking task because I don't like the fine tracking task performance (overshoots)

An HQR of 6 bordering on 7 - no go to a 7 because I certainly wouldn't buy that airplane. Tendency to overshoot.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light
- o Roll Sensitivity? adequate
- o Harmony? ok

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was a bit sluggish and I had to overdrive the response. It was not predictable in terms of stopping or starting.
- o PIO Tendency? Not really, certainly overshoot tendencies.
- o Any Special Piloting Techniques? You had to anticipate start of roll and force airplane to get it up to a steady roll rate.

TASK COMPARISON:

Lateral overshoot was brought out more by the HUD task especially the discrete ordering rapid commands. You had to anticipate more in the aerial gunnery.

SUMMARY:

Not adequate performance with a tolerable workload. Major deficiencies in attempting to execute fine and rapid lateral control tasks, you got constant overshoot and almost an incipient lateral PIO. I got adequate performance but I can't buy that. That's a 7.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4155-3	B	.40	18.	-	26	-	P	UA	5	301P(18)

TASK COMMENTS:

For gun tracking, that's a 4.

For roll SOS, that's a 5.

For LATHOS, it's a 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light, no problem.
- o Roll Sensitivity? satisfactory
- o Harmony? ok

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was adequate. For the discrete task in the gross acquisition task, with rapid roll rates, the initial response was too slow and the max roll rate was too low. You need to overdrive the airplane and predictability suffered.
- o PIO Tendency? None
- o Any Special Piloting Techniques? You had to overdrive the airplane to get the roll rate and anticipate the roll stops.

TASK COMPARISON:

Tougher airplane with the HUD task than the gun tracking because there's more anticipation to get the max roll rate and then stop.

SUMMARY:

Not satisfactory without improvements. Moderately objectionable deficiencies to compensate for slow start, max roll, roll rate, and also a slight overshoot. Call it overall a 5.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Phase	PR	Config
4155-4	B	.40	18.	.110	26.	-	P	UA	5	301P(18)+11

TASK COMMENTS:

For the gun tracking, I liked the airplane. That's a 4 although I did see some lateral oscillation. We'll see what happens in the HUD tasks.

Tendency to overshoot and I had to work hard because of it particularly when making small, rapid corrections. That's a 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light.
- o Roll Sensitivity? Too high.
- o Harmony? Adequate

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial roll rate and sustained roll rate were high and I liked that. I was able to track well.
- o PIO Tendency? None really; overshoot tendencies when stoping, I didn't like that.
- o Any Special Piloting Techniques? You had to anticipate the roll step and avoid the roll overshoot.

TASK COMPARISON:

Better airplane during gun tracking, really nice airplane, during fine tracking phase. In the HUD task, some inferior characteristics showed up - the overshoots that required some pilot controls.

SUMMARY:

Not satisfactory without improvement. I didn't like overshoot tendency - not a PIO but I didn't like it. It could have been a 6 but based on the good gun tracking, I'll give it an overall rating of 5.



Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4155-5	B	.15	18.	-	8.	(40.)	F	UA	7	143F(18)

TASK COMMENTS:

A real problem in fine gun tracking due to constant overshoots. Call it a 7.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Forces were too light.
- o Roll Sensitivity? too high.
- o Harmony? A little below satisfactory; roll too sensitive.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was oversensitive. Any type of input at all seemed to make the airplane move. There was a nice high sustained roll rate so you could watch large wing movements. But a constant lateral overshoot trying to stop or make small lateral corrections. The pilot's head was moved around the cockpit noticeably.
- o PIO Tendency? Not really.
- o Any Special Piloting Techniques? Try to make inputs as smoothly as possible.

TASK COMPARISON:

HUD tasks were more demanding in requiring small smooth inputs. Control techniques in all tasks were the same.

SUMMARY:

Not adequate performance with a tolerable pilot workload. Major deficiency was the constant lateral PIO. HQR of 7.

Flt No.-Eval	Pilot	$\tilde{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4155-6	B	.30	10	.055	26	-	P	PA	5	L201P(10)+5

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory
- o Roll Sensitivity? Very good
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Nice and quick initial response. Fairly predictable. Maybe a slight roll oscillation tendency in making the final correction to touchdown.
- o PIO Tendency?
- o Any Special Piloting Techniques? Needed anticipation to avoid roll oscillation

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement because of lateral overshoots making corrections on final. HQR of 5.

Flt No.-Eval	Pilot	$\tilde{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4155-7	B	.30	10	-	26	-	P	PA	4	L201P(10)

TASK COMMENTS:

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory
- o Roll Sensitivity? Adequate
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initially it looked good and predictable. However, I did see some overshoots due to a combination of the control system and crosswind gusts.
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. Minor deficiencies. Slight tendency for lateral overshoot on final and also a little difficulty in determining when to turn back. Not sure what that's due to. I liked it but moderate compensation and desired performance for an HQR of 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4156-1	A	.40	18.	-	26.	-	P	UA	3	301P(18)

TASK COMMENTS:

In gun tracking, no real problems. Small degree of abruptness when making corrections but really not too bad. That's a 3.

In roll SOS, certainly adequate performance and likely desired performance. Interestingly, in this task, I would have liked a little quicker initial response whereas on the last task I thought it was maybe too quick. A 3.

It was a smooth airplane in general. A 3 in LATHOS task and a 3 overall.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? I noticed the force requirement to drive it a bit initially. That's why it's a 3.
- o Roll Sensitivity? Not sensitive
- o Harmony? Quick in pitch compared to roll.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: A little slow or off-nominal initial response although I complained the other way in the air-to-air. Predictability was good.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Overall a 3.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4156-2	A	.25	18.	-	13.	-	P	UA	5	202P(18)

### TASK COMMENTS:

Very strange, difficult airplane to evaluate. The initial impression is extreme abruptness yet I really have to muscle it around to get it from wing tip to wing tip. Only adequate performance. Initial abruptness was a problem on occasion, but it was a whole lot better than I thought when I first put my hands on the airplane. A 5 in gun tracking.

In roll SOS, it was a borderline airplane in that the hard-knocking ride qualities problem is about to become objectionable. However, it is acceptable and the performance is reasonable. Give it a 5 although I got desired performance, the deficiencies were more than in discrete task, good performance again but too quick, so it's a 5.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticed.
- o Roll Sensitivity? Extremely sensitive at first but it got better. It had that side acceleration, ride qualities problem.
- o Harmony? More sensitive in roll than pitch.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was abrupt and it affected the predictability at times, although when you wanted to stop, it stopped just right where you wanted it to.
- o PIO Tendency? Not really.
- o Any Special Piloting Techniques? None.

### TASK COMPARISON:

### SUMMARY:

A mysterious airplane in air-to-air tracking. It had a jerkiness problem but it never exploded into a control problem. Overall rating, a 5.

Flt No.-Eval	Pilot	$\tilde{r}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4156-3	A	.40	18	.055	13	-	P	UA	7	302P(18)+55

### TASK COMMENTS:

In gun tracking, it was desired performance and satisfactory without improvement. Quick but precise airplane. That's a 2.

In roll SOS, interesting that it's quite different than the gun tracking. There was a constant small amplitude PIO or ratchet in roll rate throughout. I couldn't get rid of it yet I was able to be precise in tracking. Desired performance (in pipper tracking error) yet I don't like what I see (the ratchet) so that's a 7 in that it requires improvement.

Very strange airplane; different in every task. Really good performance in discrete task. I could almost use open-loop inputs and it would stop where I wanted it to with just a little abruptness initially. A 4 in this task. Only deficiency was a ringing, tiny oscillation, due to a sharp input.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nothing there.
- o Roll Sensitivity? Nothing stood out.
- o Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Roll response seemed to be three different sets depending on the task. Generally a quick, almost too quick initial response. Predictability was never really bad but the residual small amplitude oscillation was bad, an unpredictability.
- o PIO Tendency?
- o Any Special Piloting Techniques?

### TASK COMPARISON:

Very different airplane characteristics in tasks.

### SUMMARY:

Overall rating would be a 7 based on roll ratchet problems although I didn't see it in the airplane or discrete tracking tasks - just the roll SOS - but I couldn't stop it.



Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4156-5	A	.30	10	.055	26	-	P	PA	4	L201P(10)+:

TASK COMMENTS:

Satisfactory without improvement; that's a 3.  
 It had a little sensitivity but I never saw it in the task.  
 I was expecting worse but it never showed up during task.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK
- o Roll Sensitivity? Not a problem
- o Harmony? No problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Quick but predictable
- o PIO Tendency? None
- o Any Special Piloting Techniques? I didn't feel that I was compensating although I thought the sensitivity was lurking.

TASK COMPARISON:

SUMMARY:

A 3 overall with some reservations in the background but that doesn't count. Change rating to 4 after a little thought because the quickness was really there.



Flt No.-Eval	Pilot	$\hat{U}_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4156-5	B	.40	10	-	8.	(40)	P	UA	7	343P(10)

### TASK COMMENTS:

In gun tracking, that's an HQR of 6 because the airplane was very sluggish. HQR of 7 in roll SOS, the airplane is too slow to do the job that you have to overdrive it and it is so unacceptable that no one should buy the airplane.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Seemed high. Displacements were too large.
- o Roll Sensitivity? Low
- o Harmony? Poor. Roll was slow.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response and sustained roll rate was way too low. Unusable for fighter. Although it was only evident in the gross acquisition phase of the gun tracking task. Predictability problems.
- o PIO Tendency? Incipient low frequency PIO
- o Any Special Piloting Techniques? You have to use lead, overdrive the airplane

### TASK COMPARISON:

No problems with fine tracking. SOS was the most demanding because it was always moving.

### SUMMARY:

Pretty bad airplane. Not acceptable performance with a tolerable pilot workload. Controllability not in question so that's an HQR of 7.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4156-6	A	.30	10	-	26	(40)	F	PA	2	L241F(10)*

\*F<sub>as</sub>/das) = 2.75 lbs/inch

TASK COMMENTS:

Good airplane. No complaints. A 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK
- o Roll Sensitivity? About right
- o Harmony? None

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was good and it was predictable
- o PIO Tendency? None
- o Any Special Piloting Techniques? None. Easy to be quite aggressive with it.

TASK COMPARISON:

SUMMARY:

A 2 overall. Good airplane.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4157-1	B	.40	18	-	26	-	P	UA	4	301P(18)

**TASK COMMENTS:**

(HUD-only tracking evaluation)

Initial SOS, HQR of 4. Deficiency was a slight tendency to overshoot while trying to track the target.

**FEEL SYSTEM CHARACTERISTICS:**

- o Forces? Satisfactory
- o Roll Sensitivity? Satisfactory
- o Harmony? Good

**AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:**

- o Roll Attitude Response: Good. Initial response was quick enough for the HUD tasks. It was fairly predictable.
- o PIO Tendency? None, however there was a slight overshoot tendency when I tried to stop or when making quick, abrupt corrections. Not a strong overshoot tendency.
- o Any Special Piloting Techniques? You had to roll out as smoothly as you could.

**TASK COMPARISON:**

The discrete task required higher roll rates and you had to be careful in taking the input out to avoid the roll overshoot.

**SUMMARY:**

Not satisfactory without improvement. Moderate compensation to stop the roll overshoot. That's an HQR of 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4157-2	B	.25	18	-	26.	-	P	UA	6*	201P(18)

TASK COMMENTS:

HUD-only tracking evaluation.

In roll SOS, that's an HQR of 6. It was fairly tough to compensate for due to tendency for overshoots and high lateral sensitivity.

In the discrete task, that's an HQR of 5. The airplane feels a little too light so I'm being tentative to compensate although I was able to get the performance.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Too light.
- o Roll Sensitivity? Too high.
- o Harmony? A little off.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick and the sustained roll rate was quick enough to track the target. Predictability was not so good. The airplane was very abrupt and it tended to overshoot when trying to stop.
- o PIO Tendency?
- o Any Special Piloting Techniques? You had to extra smooth when trying to start and stop. You need to ramp out input to stop and avoid abruptness and overshoot.

TASK COMPARISON:

I went to school on the SOS task so I was smoother and could do better on the discrete task  
 \*HUD tracking only.

SUMMARY:

It was oversensitive in roll, forces were too light, and there was a tendency to overshoot in stopping, particularly for constant corrections; that's an HQR of 6 for tolerable but major deficiencies.



Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4157-4	B	.45	10	-	13	(40)	P	PA	5	L342P(10)

TASK COMMENTS:

Nice initial response but a little too sensitive for in-close corrections. I don't like those kinds of problems. That's not where you want to be fooling around with the airplane. Call is initially an HQR of 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory
- o Roll Sensitivity? Satisfactory
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response for gross correction was very nice with a good initial and sustained roll rate. No problems there. It was fairly predictable in stopping.
- o PIO Tendency? Not really. Rapid corrections in close caused some overshoots that I did not like.
- o Any Special Piloting Techniques? In close, fine corrections, you had to be very smooth.

TASK COMPARISON:

Final corrections showed lateral sensitivity

SUMMARY:

Not satisfactory without improvement. Moderate compensation in making fine corrections. HQR=5.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4157-5	B	.30	10	.055	13	-	P	PA	5	L202P(10)+55

TASK COMMENTS:

Airplane felt fairly good although there was something I didn't like about the final correction. Maybe too much oversensitivity. Call it a 5 initially.

I liked the second landing, call that an HQR of 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light and satisfactory
- o Roll Sensitivity? Satisfactory
- o Harmony? Adequate

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick and predictable on the initial move; however, on the correction back, I had problems both times.
- o PIO Tendency? No
- o Any Special Piloting Techniques? Sensitivity required compensation to not overwork the airplane laterally.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. Adequate performance required considerable compensation in two areas. One, I had difficulties in correcting back after initial move. And two, the sensitivity required you to be light on the stick. HQR of 5.





Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4157-7	B	.2	5	-	26	(40)	F	PA	6	L141F(5)

### TASK COMMENTS:

Airplane is a little strange. You got a very abrupt initial roll acceleration and then very low sustained roll rates so the gross correction is as problem. Call it a 5 on the first landing.

On the second one, it wasn't much different than the first. Call it a 6 on the second one.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Too high
- o Roll Sensitivity? Satisfactory
- o Harmony? Poor, roll was sluggish

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Too abrupt initially. Almost a step-type response. Sustained roll rate was too slow, forcing some severe compensation to start it, stop it and estimate when to reverse. I didn't like that.
- o PIO Tendency? None
- o Any Special Piloting Techniques? You had to anticipate roll in and reverse. You also have to be smooth initially.

### TASK COMPARISON:

### SUMMARY:

Not satisfactory without improvements. Initial response was too abrupt and the sustained roll rate was too low. This airplane was aggravating. Overall rating a 6.

Flt No.-Eval	Pilot	$\tilde{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4158-1	A	.30	10	-	26	-	P	PA	2	L201P(10)

TASK COMMENTS:

Give it a 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticed
- o Roll Sensitivity? Very responsive airplane. Up-and-away if you're playing with it it feels quite sensitive, but in the pattern, it's nice and smooth and you can do the task without a problem.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response is fast but predictable. No tendency to PIO or overcontrol.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

It's sensitive at altitude but in context of the task, the sensitivity was not a problem. Stick with a 2.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4158-2	A	.30	10	.055	13	-	P	PA	3	L202P(10)+55

TASK COMMENTS:

Give it a 3. There was a tiny, tiny overcontrol but it's still satisfactory without improvement.

A different character than the last airplane. Just a nibble of unpredictability.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not a factor.
- o Roll Sensitivity? Quick
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick. Predictability was generally good except for a little wing wobble on occasion.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

Nothing stands out.

SUMMARY:

A decent airplane. Quick, with perhaps a minor lack of precision. Stick with a 3.



Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4158-4	A	.45	5	-	26	(40)	F	PA	4	L341F(5)

TASK COMMENTS:

On downwind, this configuration seemed downright sluggish. But in context of the task, it didn't bother me.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Noticeable forces. You have to overdrive the airplane and muscle it around a bit.
- o Roll Sensitivity? On the lowside
- o Harmony? Sluggish in roll compared to pitch

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response on low side. You can overdrive it and get where you want to go and not overshoot so its predictable.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Achieved desired performance but not satisfactory without improvement because of its roll sluggishness. Give it a 4.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4158-5	A	.30	10	.110	26	-	P	PA	7	L201P(10)+11

### TASK COMMENTS:

Achieved desired landing performance, but it's a very sensitive, responsive, PIO-prone airplane although I never saw any PIOs. The task just doesn't seem to discriminate latent problems like this one has.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Very small
- o Roll Sensitivity? High
- o Harmony? roll was more sensitive

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too high. Predictability was ok in terms of the landing task. On the approach or in general maneuvering, it was less predictable with a tendency to oscillate and for overcontrol.
- o PIO Tendency? A latent PIO tendency although I didn't see any, so I didn't like it. I was surprised by the smoothness that you could fly the offset and landing.
- o Any Special Piloting Techniques?

### TASK COMPARISON:

### SUMMARY:

I thought it would be much worse close to the ground, but it wasn't. Adequate performance even desired landing performance however, I didn't like the airplane. I think it requires improvement so I'll give it a 7. That's peculiar but it was way too sensitive even though I could do the landing task.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4159-1	B	.25	18.	-	13.	-	P	UA	5	202P(18)

TASK COMMENTS:

Call it initially a 4. I thought it had some overshoot problems during one of the gross acquisitions.

Call that an HQR of 4 for the roll SOS task. I saw overshoots and you had to ramp out the input to stop the airplane to avoid the overshoots because of the sensitivity.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory fighter-type light forces
- o Roll Sensitivity? Satisfactory
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick in terms of acceleration and the sustained roll rate was satisfactory. I was able to track all the targets, both the gun tracking and HUD tasks. The airplane was fairly predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Only real problem I had was to ramp out the input at the end. No problem putting the input in except that it tended to drop off. The control system tended to drop out if I made a rapid input.

TASK COMPARISON:

No real difference between the tasks.

SUMMARY:

Not satisfactory without improvement. Tough decision but I'll say the overall HQR is a 4. If the maneuvering were a little more rapid, it might bring out the overshoots more. So I'll call it a 5 overall instead.

Flt No.-Eval	Pilot	$\bar{C}_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4159-2	B	.40	18	-	26	(40)	F	PA	4	341F(18)

TASK COMMENTS:

Pretty good airplane. Not too much to say. Give it a 2. I liked that one alot.  
That task (Roll SOS) really went well. Call it a 2 as well.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Certainly light and satisfactory, very fighter-like.
- o Roll Sensitivity? excellent
- o Harmony? good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Roll response was a little slower than I would like both in terms of initial acceleration and sustained roll rate. I felt myself overdriving the airplane during the discrete HUD tracking task in the big gross acquisition maneuvers. Airplane was very predictable. No problems with overshoots.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Only compensation that was necessary was in the discrete where I had to overdrive the input to get the desired roll response for the big moves.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement because two minor deficiencies were the initial roll acceleration and final roll rate were a little too slow for making big roll attitude changes. This showed up in the discrete task. HQR of 4 overall.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4159-3	B	.40	18.	.055	26.	-	P	UA	5	301P(18)+55

### TASK COMMENTS:

In the gun tracking task, I liked that airplane but I did notice a low roll acceleration or a time delay when I was sampling.

I didn't like the initial roll acceleration during the SOS task. I started seeing some overshoot and ratcheting. That's a HQR of 5.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory
- o Roll Sensitivity? Not sure if the problems were due to sensitivity or time delay or what. I think it was due to something of the sensitivity.
- o Harmony? OK

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too slow. The acceleration response was slow. Also the final roll rate was less than I would like. I had some predictability problems in that I had to ramp the input out.
- o PIO Tendency? None but there were overshoots. Overshoots were apparent in the roll so saved the small corrections in the discrete HUD task.
- o Any Special Piloting Techniques? Had to overdrive the input a little and ramp out the input.

### TASK COMPARISON:

I liked it in the gun tacking. The roll SOS was demanding. Discrete task was the most demanding. I had to ramp out the input much more in the discrete task.

### SUMMARY:

Certainly not satisfactory without improvement. Problems were the slow roll acceleration coupled with a low sustained roll rate. There was a tendency to roll overshoot. These deficiencies required considerable compensation. Give it an HQR of 5.

Flt No.-Eval	Pilot	$\hat{U}_R$	R/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4159-4	B	.15	18.	-	26	(40)	F	UA	6	141F(18)

### TASK COMMENTS:

In the air-to-air, I saw a little roll ratcheting that I didn't like. HQR of 5.

I liked the roll SOS task even less than gun tracking task. Call that an HQR of 6 for now due to overshoots, abrupt roll acceleration, and a low sustained roll rate.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, satisfactory.
- o Roll Sensitivity? Too high.
- o Harmony? Off a bit.

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too abrupt and the sustained roll rate was too low. It was not predictable which required that you ramp the input out, especially for small, quick corrections.
- o PIO Tendency? An incipient PIO tendency, although it didn't develop into a PIO.
- o Any Special Piloting Techniques? Overdrive the airplane a little to get the roll rate you want and then rampout the input at the end. You also have to be careful not to upset the airplane during a steady-state control position due to the sensitivity.

### TASK COMPARISON:

### SUMMARY:

Not satisfactory without improvement. Extensive compensation for adequate performance because of high initial roll rate, slow sustained roll rate and it will overshoot if you don't rampout your input. Some ratcheting and an incipient PIO. Overall HQR of 6.

Flt No.-Eval	Pilot	$\hat{t}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4159-6	B	.45	10	-	13	(40)	P	PA	7	L342P(10)

TASK COMMENTS:

Airplane is pretty quick off the mark, pretty sensitive. Saw an incipient PIO. Give it a 5 after the first approach.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? light
- o Roll Sensitivity? too high
- o Harmony? a little less than desired

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: initial response was quick and it was reasonably predictable for the gross correction. It was too quick.
- o PIO Tendency? Definite low amplitude, medium frequency. PIO in close corrections. You had to be light on the airplane and that was a problem.
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Turbulence caused some corrections to be made. Overly sensitive in roll. Due to PIO in close, I'll call that a 7. That's a major deficiency. Control was not in question, however.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4160-1	A	.25	10	-	26.	(40)	P	UA	4	241P(10)

TASK COMMENTS:

The rating for gun tracking..it was an excellent airplane for tracking but it was a little sluggish in terms of the roll performance. For fine tracking it was a 2 but with the gross acquisition, it was only adequate performance for a rating of 5.

For the roll SOS, it was not satisfactory without improvement. It was just on the sluggish side initially. That's a 4.

For the discrete task, it was similar to the other task. You have to overdrive to get it going. A minor but annoying deficiency. I got desired performance so that's a 4. It's very solid in stopping. Quite nice.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Forces noticed during gross acquisition.
- o Roll Sensitivity? On low side.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Slow initial response. Predictability is excellent. It really stops where you want it.
- o PIO Tendency? None
- o Any Special Piloting Techniques? No

TASK COMPARISON:

Fine tracking was excellent but getting it moving is not so good.

SUMMARY:

Overall rating a 4.

Flt No.-Eval	Pilot	$\zeta_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4160-2	A	.25	18	-	8.	-	P	UA	6	203P(18)

### TASK COMMENTS:

In gross tracking, it was a strange feeling airplane. The stick kind of wobbles in your hand. It feels responsive yet you notice the stick motions. You can get adequate performance - at least for now. Right now its a 6. You get a low frequency, lateral acceleration in cockpit - not a high frequency roll ratchet, it's just objectionable.

In roll SOS, it's the same characteristics as before. It's abrupt but it has a low frequency ride qualities problem. You can learn to get away from the problems, but it's still a 6. Very objectionable. I was learning to be smooth with it. In the discrete task, I was getting better. You could do it reasonably well. Still not satisfactory without improvement. Give it a 4 because it was easier to do.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                      Noticed the stick displacements
- o Roll Sensitivity?                            Reasonable
- o Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:                Initial response seemed quick.        Predictability was marginal.
- o PIO Tendency?                            Yes, in some tasks particularly if going wing tip to wing tip.
- o Any Special Piloting Techniques?    I was learning to be smoother and got better performance. If you got aggressive, particularly in reversals you got in trouble.

### TASK COMPARISON:

### SUMMARY:

Overall, a 6.



Flt No.-Eval	Pilot	$\bar{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4160-4	A	.15	10.	-	26.	(40)	F	UA	2	141F(10)*

\*F<sub>as</sub>/das = 2.75 lbs/inch

TASK COMMENTS:

In gun tracking, its a pretty good airplane. It was a good, well-rounded airplane. A good compromise between gross acquisition and fine tracking. It didn't have any of those rough edges, so I'll give a 2.

In roll SOS, it was a pretty fine airplane. It was precise, but smooth. That's a pilot rating of 2.

In the discrete task, it's a good airplane. It's quick and exact. That's a 1 in that task.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Well tuned.
- o Roll Sensitivity? About right. When you wanted the response you could get it and it was still predictable.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick, but predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Overall rating is a 2.





Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4160-6	A	.30	10	-	8	-	P	PA	4	L203P(10)

TASK COMMENTS:

Could get adequate performance and I think I could get desired performance. Airplane had some peculiar characteristics that I could notice flying around but not in the task. There was a little wing wobble on occasion. Call it a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Displacements were noticeable. There seemed to be a peculiar relationship between displacements and the response.
- o Roll Sensitivity? Nothing noted
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Quick initial but something was peculiar. Predictability was ok.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

No problems in the landing task but I noticed some roll imprecision during the approach.

SUMMARY:

Wind and turbulence were not a factor. Stick with a 4. You could get the job done but I have some reservations.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4160-7	A	.30	5	-	26	-	P	PA		L201P(5)

**TASK COMMENTS:**

Forgot comments & ratings.

**FEEL SYSTEM CHARACTERISTICS:**

- o Forces?
- o Roll Sensitivity?
- o Harmony?

**AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:**

- o Roll Attitude Response:
- o PIO Tendency?
- o Any Special Piloting Techniques?

**TASK COMPARISON:**

**SUMMARY:**

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4161-1	A	.40	18	.110	26	-	P	UA	7	301P(18)+110

TASK COMMENTS:

In gun tracking, it was a sensitive airplane but not too bad. Desired performance was attainable. Just a little oversensitivity. I could track precisely but a little abrupt. That's a 4.

In roll SOS, it's a ratchety airplane. On this one, it was a constant ratchet, bobbling, head-knocking in cockpit. Requires improvement. Therefore, it's a 7.

Control was never in question. It's amazing the task differences for this one.

In the discrete task, I noticed an initial delay. I got barely adequate performance. I did not have the continuous ratchet that was in the SOS. I'll rate that a 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Forces and sensitivity depended upon the task.
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Attitude response and predictability were also task dependent.
- o PIO Tendency? Yes, considering ratchet as a PIO. Overcontrolling in task.
- o Any Special Piloting Techniques? I was able to tone down my inputs in the last task so it was smoother but less accurate.

TASK COMPARISON:

SUMMARY:

Overall rating is a 7.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4161-2	A	.40	18.	-	13.	-	P	UA	2	302P(18)

TASK COMMENTS:

In gun tracking, I could achieve very good tracking. Quite precise. I could move the pipper to any part of the target airplane and stop it there. Desired performance. I can't complain about it.

In roll SOS, its a pretty good airplane. You can pretty much get any kind of performance out of it that you want. If you want to move fast, you can. If you want to be smooth, you can. Yet you have control over the whole thing. A 2.

In discrete, it's a pleasure to fly it. You get the initial response and stop it where you want it. Give it a 1. A 2 overall.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticed
- o Roll Sensitivity? Near ideal
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was what you wanted to make it and without penalty to the final response. Predictability was good.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

All tasks were easy tasks.

SUMMARY:

PR of 2

Flt No.-Eval	Pilot	$\hat{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4161-3	A	.25	18.	.055	26	-	P	UA	7	201P(18)+55

### TASK COMMENTS:

In air-to-air tracking it's not satisfactory without improvement. There was an insidious roll ratchet, a ringing when trying to be aggressive. However, it wasn't as bad as I expected because you could stop it. Give it a 5.

In roll SOS, it is almost impossible not to ratchet continuously. You really had to lag behind the task. Give it a 7. But if you look at the errors, the performance was probably as good as any. A ratcheting monster.

I really didn't like that airplane. Just as bad in the discrete task. Even ratcheted following a ramp command. Adequate or even desired performance could be attained, but the ride qualities or rates or what were unacceptable and require improvement. It is a 7.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces?                                        Nothing noticed.
- o Roll Sensitivity?
- o Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    Initial accelerations were a problem, ridiculous.
- o PIO Tendency?                                Constant ratchet.
- o Any Special Piloting Techniques?

### TASK COMPARISON:

### SUMMARY:

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4161-4	A	.15	10.	-	26.	(40)	F	UA	3	141F(10)*

\*F<sub>as</sub>/das = 2.75 lbs/inch

TASK COMMENTS:

In air-to-air, when I first took it, I thought it was going to be a "ratchet" airplane again, but there was something about it that made it quick and precise. It seems solid yet different than the others, it's quite responsive initially but it's solid in stopping. So it's accurate. That's a 2.

In the roll SOS, it was interesting. You noticed the displacements to get it moving but it had the quickness to do the job but not so bad to be objectionable. A 3 for this task.

In the discrete task, it's a pretty good airplane. It had a different character than some I've flown. A 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? I noticed the stick motions on occasion. It was not objectionable.
- o Roll Sensitivity? Reasonable. Adequate roll control power.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was there. You had to drive it a little to do some of the task. Predictability was excellent.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

A 3 overall.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4161-5	A	.25	18.	.110	26.	-	P	UA	7	201P(18)+110

### TASK COMMENTS:

In air-to-air, it was a jerky airplane, not ratchety. Too abrupt. You can't be aggressive with it without some ridiculous accelerations. But you don't get a high frequency dither. Jerky is the best word. Give it a 7.

In the roll SOS, it was better than I thought it would be. You can smooth it out and get the job done. I could achieve good performance in terms of error. I'll give it a 6. Objectionable characteristics.

In discrete task, I really didn't like it. It was unbelievably abrupt. In the game-playing sense of that task, this airplane is almost ideal because you can smash into it and get the initial response and generally the final response is ok. I got desired performance but I'll give it a 5. Overall, it's unacceptable.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticed
- o Roll Sensitivity? Very sensitive
- o Harmony?

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response is spell binding. Predictability is okay at times but not so at others.
- o PIO Tendency? It's there in short bursts when you are aggressive in a closed-loop fashion.
- o Any Special Piloting Techniques? Trying to be smooth helps.

### TASK COMPARISON:

### SUMMARY:

The ratings are trying to differentiate the differences in the tasks. Overall it's a 7, however. Lousy airplane.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4161-6	A	.45	10	-	13	(40)	P	PA	3	L342P(10)

TASK COMMENTS:

Give it a 3. A little sensitive but no problems related to that.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? No problem.
- o Roll Sensitivity? On high side to medium sensitivity
- o Harmony? No problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick but predictability was good.
- o PIO Tendency? No
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall PR of 3.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4161-7	A	.30	10	.055	26	(40)	F	PA	2	L241F(10)+55

TASK COMMENTS:

Seemed like a pretty good airplane. A 2.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? OK
- o Roll Sensitivity? OK
- o Harmony? Not a problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response seemed to be well blended with the final. Lots of control power. No predictabilty problems.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None, easy airplane to fly.

TASK COMPARISON:

SUMMARY:

Overall rating of 2.

Flt No.-Eval	Pilot	$\uparrow$ R	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4162-1	B	.30	10	-	13	-	P	PA	5	L202P(10)

TASK COMMENTS:

Initial rating was an HQR of 5. Some roll overshoots particularly during final corrections. Nice light forces but there were sensitivity problems in close.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light. I liked that.
- o Roll Sensitivity? Too high, some problems in close
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was very good. In close was where the problem was. I got more airplane response than I bargained for.
- o PIO Tendency? None
- o Any Special Piloting Techniques? You have to be careful not to excite the airplane in close.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. Considerable compensation to not excite the airplane because the sensitivity is too high and airplane was too quick. An HQR of 5.



Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4162-3	B	.30	10	-	26	13	P	PA	5	L221P(10)

TASK COMMENTS:

In that particular landing, there wasn't too much to gripe about. Call that a 4. But there was something in there that I thought was going to cause problems. We'll look at that on the second landing.

I got worried about the overshoot on the second landing and I let it float. Very interesting.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? Satisfactory
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was a little slow. It looked like a long roll mode time and constant. It was predictable however.
- o PIO Tendency? None although there was an overshoot tendency in the second runway alignment correction.
- o Any Special Piloting Techniques? you had to be careful to damp out the input in close to avoid the overshoot.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. HQR of 5. Considerable compensation to avoid the overshoot.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4162-4	B	.2	5	-	13	(40)	P	PA	7	L142P(5)

TASK COMMENTS:

Real slow airplane. Call it an HQR of 4. It doesn't bite you but it doesn't come around too quick.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Apparent forces were high. Airplane was sluggish.
- o Roll Sensitivity? Too low
- o Harmony? Not quite satisfactory

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial roll response was too slow. Overall sustained roll was too low. It was predictable, however.
- o PIO Tendency? None
- o Any Special Piloting Techniques? You have to overdrive the input and take the corrections out earlier.

TASK COMPARISON:

SUMMARY:

I don't know if I'd buy that for a fighter. I think that the airplane's too slow for a fighter and I wouldn't buy it. It's really max compensation. It's a major deficiency that requires improvement. Controllability not in question. Maybe a 5 but really have to give it a 7.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4162-5	B	.30	10	.055	26	(40)	F	PA	4	L241F(10)+5.

TASK COMMENTS:

Call that a 3. I didn't find too much wrong with that one.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? A little low
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was ok for both the initial and final corrections. Although I had the impression that I was pushing the airplane a lot. It was predictable.
- o PIO Tendency? None. No overshoots
- o Any Special Piloting Techniques? Not really except maybe a little overdriving

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. A minor deficiency being the overdriving compensations. It was only moderate compensation. AN HQR of 4. Not too bad.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4162-6	B	.2	5	.110	26	(40)	F	PA	7	L141F(5)+110

TASK COMMENTS:

That airplane was slow initially, I had to overdrive it. There were overshoots both on gross and final corrections. That's a 6 so far.

We'll do one more on that one. I don't like that, it's too slow. A 7.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Too high for a fighter
- o Roll Sensitivity? Too low
- o Harmony? Not satisfactory

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was so slow that's unacceptable. Overall sustained roll rate was too low. It was predictable, however.
- o PIO Tendency? No but I did see some roll overshoots when I rolled briskly.
- o Any Special Piloting Techniques? You had to overdrive it to get it to where you want it.

TASK COMPARISON:

SUMMARY:

You can't say that adequate performance was attainable with a tolerable pilot workload, lateral roll performance was too low to be adequate for a fighter-type airplane. Give it a 7.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4175-1	B	.40	18	-	26	-	P	UA	3	301P(18)

TASK COMMENTS:

In air-to-air, that's a 2. Really nice airplane. In roll SOS, I had a little tendency to go past target when trying to match wings. That's a 3 so far. I could stop but it seemed to slide past him.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light forces, good
- o Roll Sensitivity? Very nice
- o Harmony? Excellent

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response for all tasks except LATHOS was very, very good. Airplane was a little slow for the LATHOS task. Predictability was good in all cases.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Pushing airplane a little on last task to get it rolling as fast as I wanted.

TASK COMPARISON:

SUMMARY:

Rate it a 3. Only deficiencies I didn't like were the slightly less desired roll performance on the LATHOS task and the sliding past the target in the SOS task. It was easily compensated for. HQR of 3 overall.



Flt No.-Eval	Pilot	$\tau$ R	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4175-2	B	.40	18	-.55	13	-	P	UA	5	302P(18)+55

TASK COMMENTS:

In air to air, call that a 5. I don't like the way it rocked around and it tended to wander.

In roll SOS, there was ratcheting and overshoots for an HQR of 5.

In LATHOS tracking, HQR of 5.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, satisfactory.
- o Roll Sensitivity? Satisfactory
- o Harmony? Satisfactory

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too slow. It was fairly predictable but it was sluggish so I had to overdrive it.
- o PIO Tendency? None
- o Any Special Piloting Techniques? On discrete task more than the others, you had to overdrive it to start and ramp out the input to stop it without overshooting

TASK COMPARISON:

SUMMARY:

Moderately objectionable deficiencies were that it was laterally slow, initially and the response overshoots and ratchets. Overall an HQR of 5.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4175-3	B	.40	18	-	8	-	P	UA	5	303P(18)

TASK COMMENTS:

In air-to-air, that's an HQR of 5. I didn't like the way that one wandered around. Again, that's an HQR of 5. Slow roll rate and overshoots.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light and satisfactory.
- o Roll Sensitivity? Satisfactory
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was too slow. Sustained roll rate was too low. You had to overdrive the airplane especially in the discrete task. Predictability gave problems. You had to ramp out the input.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Overdrive initially and ramp out input when getting to target. Roll ratchet if small amplitude, quick inputs.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. That's an HQR of 5 in summary.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4175-4	B	.40	18	-	26	(40)	F	UA	5	341F(18)

TASK COMMENTS:

In the air-to-air task, that's a 3.

In the SOS task, that's a 5. Two problems: a little roll overshoot in small fine maneuvers, and I'm having predictability problems.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light
- o Roll Sensitivity? Adequate, maybe a little more sensitive than I would have liked.
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was adequate. For discrete task, the starts were a little abrupt. Some predictability problems.
- o PIO Tendency? None. Some overshoots.
- o Any Special Piloting Techniques? Use smooth inputs.

TASK COMPARISON:

Discrete task was the toughest.

SUMMARY:

Not satisfactory without improvement. Abrupt roll accelerations and prediction problems. Neither were really too bad but overall it was aggravating. A 5 for a summary of things rather than any one objectionable thing.

Flt No.-Eval	Pilot	$\hat{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4175-5	B	.15	10.	-	26	(40)	F	UA	6	141F(10)

TASK COMMENTS:

In air-to-air, performance was pretty good. A 4. Certainly not perfect.

In roll SOS, that's an HQR of 6 for slow roll rate, heavy force and ratchety.

In the discrete task, that's a 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Too high.
- o Roll Sensitivity? Satisfactory.
- o Harmony? Not satisfactory.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Too slow initially, although depending on input, it could be abrupt starting. You had to overdrive it particularly in discrete task. Predictability not bad except for small, quick movements that gave overshoots and roll ratchet.
- o PIO Tendency?
- o Any Special Piloting Techniques? Ramp out big inputs and be smooth on discrete input to avoid accelerations.

TASK COMPARISON:

Discrete task highlighted problems. It required smooth starts and overdriving to get roll performance. No real problems in air-to-air.

SUMMARY:

Very objectionable deficiencies. Overall HQR of 6.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4175-6	B	.45	10	-	13	(40)	F	PA	4	L342F(10)

TASK COMMENTS:

I thought I was going to have an overdriving problem in fine corrections but I didn't see any at all.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Satisfactory
- o Roll Sensitivity? Satisfactory
- o Harmony? Good

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was adequate. It was quick enough and predictable.
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Not really satisfactory without improvement. I compensated for this configuration mentally because of the overshooting potential I saw on the first approach. Overall HQR of 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4175-7	B	.30	10	-	13	26	P	PA	5	L212P(10)

TASK COMMENTS:

Initially HQR of 5 because of an overshooting tendency

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Light, satisfactory
- o Roll Sensitivity? Too high
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initially quick and predictable. Small corrections however created overshoots.
- o PIO Tendency? None
- o Any Special Piloting Techniques? Make smooth, small corrections in close.

TASK COMPARISON:

SUMMARY:

Not satisfactory without improvement. HQR of 5 overall.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4176-1	A	.25	18	-	26	13	P	UA	7	221P(18)

### TASK COMMENTS:

Interesting airplane. Did better than I thought. Very sensitive airplane. Not satisfactory without improvement. Too jerky. Almost desired performance. A 6 overall. Adequate performance but sensitivity was too high.

In roll SOS task, it's very ratchety. You really have to back off to get the ratcheting to moderate levels. Requires improvement. A 7.

In discrete task, it's an ATARI game task. You can really get it there and stop. A 5 for this task.

### FEEL SYSTEM CHARACTERISTICS:

- o Forces? Not noticed
- o Roll Sensitivity? High
- o Harmony? No problems

### AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response too sensitive but predictable
- o PIO Tendency? Certainly in roll SOS, in roll ratchet sense
- o Any Special Piloting Techniques? None developed

### TASK COMPARISON:

### SUMMARY:

Clear-cut 7 overall for reasons of requiring improvement.





Flt No.-Eval	Pilot	$\bar{C}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4176-3	A	.40	18	-	26	(40)	F	UA	2	341F(18)

TASK COMMENTS:

In air-to-air task, no problems. It's a 2.

In the roll SOS task, it's a pretty good airplane. Nice, crisp initially response without the head-knocking. An HQR of 2.

In the discrete task, that's a good airplane. A 1.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Good
- o Roll Sensitivity? About Ideal
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Good
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Rating overall is a 2.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4176-4	A	.15	18.	-	8	(40)	P	UA	8	143P(18)

TASK COMMENTS:

Poor airplane. It's jerky in air-to-air tracking. Larger amplitude lower frequency ratchet-type problem. A 7. requires improvement and I could not get adequate performance.

In roll SOS, barely controllable. That's an 8. Bad airplane.

In LATHOS, that's a lousy airplane. A 7.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?                      Sensitive.
- o Harmony?                                No problems.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    Initial response was quick. Predictability was not too bad in the discrete task but it was not there at all in the SOS task.
- o PIO Tendency?                      Yes, in all tasks and particularly in SOS task.
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Overall an 8.

Flt No.-Eval	Pilot	$\bar{U}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4176-5	A	.40	18	-	26	13	P	UA	4	321P(18)

TASK COMMENTS:

Interesting airplane. It wasn't as good as I thought it would be, but then it got better. Not satisfactory without improvements. A little sloppy. Desired performance however, A 4.

In roll SOS, there was something a little laggy about it. It was smooth and predictable however. A 4.

In LATHOS task, it was a good initial response. Give it a 3.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?                      Good
- o Harmony?                                No problems

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    A little confused about the problems I had. Precision of final response was lacking for this one
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Strangeness that caused a lack of precision. Overall rating of a 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4177-1	A	.45	10	-	26	(40)	P	PA	2	L341P(10)

TASK COMMENTS:

Some difficulties with tailwind, but no difficulties with airplane

FEEL SYSTEM CHARACTERISTICS:

- o Forces? I saw nothing there
- o Roll Sensitivity? About right
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response and predictability were good
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

No problems with airplane. A 2.

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Flt No.-Eval	Pilot	$\tilde{R}$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4177-2	A	.30	10	.055	13	-	P	PA	4	L202P(10)+55

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TASK COMMENTS:

You could get desired performance. A little sensitivity at the edge so that's a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity? Starting to get a little sensitive
- o Harmony? Not a problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was getting to be on the high side. Predictability was reasonable.
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

Tail wind was a factor but we adjusted for it. Overall a 4.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4177-3	A	.2	5	-	26	(40)	F	PA	5	L141F(5)

TASK COMMENTS:

Satisfactory without improvement if terms of performance but in terms of aircraft characteristics I would say it was moderately objectionable. It feels like there's a very stiff spring in the stick. When I get the response, the forces feel very heavy.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Noticeable and heavy.
- o Roll Sensitivity? On low side.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Airplane seems to respond all right but it seems like there's a limiter in the stick - it feels very heavy. Predictability was no problem.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

A 5 due to heavy lateral forces although I could get the job done.

Flt No.-Eval	Pilot	$\tilde{z}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4177-4	A	.2	5	-	8	(40)	P	PA	4	L143P(5)

TASK COMMENTS:

You could achieve desired performance so I'll call it a 4. It had some unusual characteristics that you had to adapt to. The stick feels springy like you had a weight or a pendulum in your hand. The motion seemed a bit excessive. But you could do the task quite nicely.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: You get used to the largest motions of the stick and it doesn't seem to bother you, certainly predictable.
- o PIO Tendency?
- o Any Special Piloting Techniques? You learn how to adapt to it. But its in need of some improvement.

TASK COMPARISON:

SUMMARY:

A 4 overall due to the large stick motion.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4177-5	A	.30	10	.110	26	(40)	F	PA	4	L241F(10)+11

TASK COMMENTS:

Not satisfactory without improvement although I got desired performance. A little oversensitive, a little jerky so I'll give it a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? A little sensitive but it stops exactly where you want it to.
- o Roll Sensitivity? On high side
- o Harmony? OK

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was quick but predictable
- o PIO Tendency? No
- o Any Special Piloting Techniques? None

TASK COMPARISON:

SUMMARY:

A 4 because it was a little too sensitive. I would like it tuned down a little.



Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4177-6	A	.30	10	.055	26	-	P	PA	3	L201P(10)+55

TASK COMMENTS:

It's satisfactory without improvement, but it's mildly unpleasant. A little sensitive but it's precise, so it's a 3.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?                      On the high side
- o Harmony?                                      No problems

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    Initial response was a bit on the high side but it was very predictable.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

a 3

Flt No.-Eval	Pilot	$\tilde{r}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4178-1	A	.30	10	-	26	13	P	PA	7	L221P(10)

TASK COMMENTS:

Very sensitive. No real problems with it but I felt I was eventually compensating for it. I felt like I could couple in with it in close. Although I did get desired performance it had objectionable but tolerable deficiencies for a rating of 6.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Very light
- o Roll Sensitivity? High
- o Harmony? No problems

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was very quick. It was predictable however. But I felt there was a lurking PIO.
- o PIO Tendency? Didn't see any PIOs but I saw evidence of them.
- o Any Special Piloting Techniques? Compensated mentally quite a bit, I was afraid of this one.

TASK COMPARISON:

SUMMARY:

Change it to a 7. I think it requires improvement because it could hurt someone someday.

Flt No.-Eval	Pilot	$\hat{L}_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4178-2	A	.30	10	.055	26	-	P	PA	3	L201P(10)+55

TASK COMMENTS:

It's a near ideal airplane in many respects. Maybe a little too sensitive at times that causes some overcontrol. But I was confident with it. Desired performance was easily obtainable. It's a 3.

Not a 2 because you need to turn down the sensitivity a notch.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? No problems.
- o Roll Sensitivity? On the high side
- o Harmony? No problems.

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Initial response was good, just a little on the high side. Predictability was diminished because of the sensitivity and overcontrol potential.
- o PIO Tendency? A couple nibbles of overcontrol for fine corrections in close.
- o Any Special Piloting Techniques?

TASK COMPARISON:

ADDITIONAL FACTORS:

Wind Calm

SUMMARY:

a 3.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4178-3	A	.45	10	-	13	(40)	F	PA	3	L342F(10)

TASK COMMENTS:

I got desired performance but there was a couple things I didn't like.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?                      Noticed displacements but they weren't objectionable. Forces not a factor.
- o Roll Sensitivity?           Seemed a little slow initially but I got the performance.
- o Harmony?

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:    At first I thought there was something different about the initial response. Predictability: good.
- o PIO Tendency?              No PIO tendency and I could be aggressive with it.
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

Satisfactory without improvement - it's a 3. The 3 reflects something going on that I had to adapt to in the stick motion and initial response.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4178-4	A	.30	10	-	26	(40)	F	PA	4	L241F(10)

TASK COMMENTS:

Desired performance was easily attainable. I could be aggressive with it. Give it a 4.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Noticeable. Seemed very springy laterally. You could get the performance you wanted but you noticed the springiness and the forces.
- o Roll Sensitivity?
- o Harmony? Not a problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Predictability was excellent
- o PIO Tendency? None
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

I could get the response if I tolerated the forces. Overall rating of a 4, I would like to see the springiness improved but I could get the performance.

Flt No.-Eval	Pilot	$\zeta_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4178-5	A	.2	5	.110	26	(40)	F	PA	5	L141F(5)+1

TASK COMMENTS:

I can't work it as well as I wanted. It was slow. Maybe desired performance but really only adequate. Call it a 5 for now.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Stringy feeling. Noticeable forces.
- o Roll Sensitivity?
- o Harmony? No problem

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Rates build after input. Delayed response. Can't get the rates going. Predictability impaired.
- o PIO Tendency?
- o Any Special Piloting Techniques?

TASK COMPARISON:

SUMMARY:

A 5.

Flt No.-Eval	Pilot	$\tau_R$	P/F <sub>as</sub>	Delay	Feel	Filter	Cmd	Phase	PR	Config
4178-6	A	.30	10	.055	13	-	P	PA	4	L202P(10)+55

TASK COMMENTS:

I could get desired performance but it seems nonlinear in the beginning. You get more response out of it than you would expect. You can occasionally get overcontrol because of it. A 4. Its a minor but annoying deficiency that should be improved.

FEEL SYSTEM CHARACTERISTICS:

- o Forces?
- o Roll Sensitivity?                      Initially too responsive.
- o Harmony?                                      No problems

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response:
- o PIO Tendency?                              No
- o Any Special Piloting Techniques?      You could learn to live with this but it should be improved

TASK COMPARISON:

SUMMARY:

Overall a 4.

Flt No.-Eval	Pilot	$\tau_R$	P/Fas	Delay	Feel	Filter	Cmd	Flt Phase	PR	Config
4178-7	A	.30	10	-	13	26	P	PA	3	L212P(10)

TASK COMMENTS:

Can't complain too much. Satisfactory without improvement. A 3.

It felt a little strange about neutral on the first one but nothing became of it.

FEEL SYSTEM CHARACTERISTICS:

- o Forces? Nothing there
- o Roll Sensitivity? Reasonable
- o Harmony? No problems

AIRCRAFT RESPONSE UNDER CLOSED-LOOP CONTROL:

- o Roll Attitude Response: Something was not completely linear with the initial response but I could get good performance
- o PIO Tendency? None
- o Any Special Piloting Techniques? None

TASK COMPARISON:

ADDITIONAL FACTORS:

Wind's calm

SUMMARY:





## Report Documentation Page

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			15. Supplementary Notes This report was prepared for the Flight Dynamic Laboratory, Wright Patterson AFB and NASA Ames Research Center, Dryden Flight Research Facility. NASA Technical Monitor was Mary F. Shafer, NASA Ames Research Center, Dryden Flight Research Facility, Edwards, California. This report was also released as Calspan Report No. 7205-26.		
16. Abstract An experimental investigation of the influence of lateral feel system characteristics on fighter aircraft roll flying qualities was conducted using the variable stability USAFNT-33 aircraft. Forty-two evaluation flights were flown by three engineering test pilots. The investigation utilized the power approach, visual landing task, and up-and-away tasks including formation, gun tracking, and computer-generated compensatory attitude tracking tasks displayed on the Head-Up Display. Experimental variations included the feel system frequency, force-deflection gradient, control system command type (force or position input command), aircraft roll mode time constant, control system prefilter frequency, and control system time delay. The primary data were task performance records and evaluation pilot comments and ratings using the Cooper-Harper scale. The data highlight the unique and powerful effect of the feel system of flying qualities. The data show that the feel system is not "equivalent" in flying qualities influence to analogous control system elements. A lower limit of allowable feel system frequency appears warranted to ensure good lateral flying qualities. Flying qualities criteria should most properly treat the feel system dynamic influence separately from the control system, since the input and output of this dynamic element is apparent to the pilot and thus, does not produce a "hidden" effect.					
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