



**FLIGHT SIMULATOR EXPERIMENTS AND ANALYSES
IN SUPPORT OF FURTHER DEVELOPMENT OF
MIL-F-83300 - V/STOL FLYING QUALITIES SPECIFICATION**

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Approved for public release; distribution unlimited

FOREWORD

This report was prepared for the United States Air Force by the United Aircraft Research Laboratories, East Hartford, Connecticut.

The work reported herein was performed by the United Aircraft Research Laboratories under the sponsorship of the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The research was conducted under Subcontract S-72-4 to Calspan Corporation (formerly the Cornell Aeronautical Laboratory) as part of Air Force Contract F33615-71-C-1722, Project 643A. The AFFDL project engineer was Mr. Terry Neighbor (AFFDL/FGC) and the Calspan project engineer was Mr. David Key.

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ABSTRACT

Fixed- and moving-base flight simulator experiments and analyses were conducted to provide data for use in substantiating, refining and extending the hovering and low-speed-flight portion of MIL-F-83300 - V/STOL Flying Qualities Specification. For longitudinal and lateral control, the following areas were investigated: turbulence intensity, control lags and delays, control-moment limits, control moments through stored energy, inter-axis motion coupling, independent thrust-vector control and rate-command/attitude-hold control. For height and directional control, the effects of damping levels, control lags and delays, and control power limits were investigated. Opinion ratings, pilot comments, and pilot-selected control sensitivities were recorded in the flight simulator experiments; control-power-usage data were also obtained.

The results indicate that the MIL-F-83300 Level 1 requirement for V/STOL dynamic response provides aircraft dynamics which remain controllable for nominal increases in gust intensity. The specification appears to generally exclude pitch and roll control lags, and lags in thrust response, which cause unsatisfactory flying qualities; it admits lags for which pilot opinion does not deteriorate. However, it also excludes directional control lags which do not degrade opinion. The results further indicate that the specification for installed control moments provides levels which are satisfactory but not excessive. Control sensitivities selected by the pilots also generally fall within the boundaries specified, but are much closer to the lower limit than to the upper. Finally, data from the height control study show that minimum Z_w levels of -0.25 to -0.35 are necessary for satisfactory flying qualities with unlimited T/W.

Results for unconventional control techniques evaluated indicate that rotor-propulsion system stored energy can be used to offset limitations in installed control power. Independent thrust-vector control can be used for hovering and maneuvering when properly implemented. Rate-command/attitude-hold control does not appear to provide benefits for hover and low-speed flight.

The exceedance data show that speed stability and damping are the configuration parameters having the greatest effects on control power usage. Control system lags have little effect on pitch and roll control-moment usage, but they increase yaw control-moment and thrust usage somewhat. The largest amounts of control moment were used for the quick stop task; the smallest amounts were used for hover and turn-over-a-spot. The data indicate that the installed total moment for pitch plus roll control must be sufficient to account for simultaneous usage by the pilot; it cannot be assumed that pilots make independent pitch and roll control inputs.

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SYMBOLS

| | |
|-------------------|---|
| BC1-BC6 | Basic V/STOL aircraft configurations 1 through 6 (see Table I) |
| C_1, C_2, C_3 | Coefficients used in nonlinear representation for control moments available through rotor-propulsion system stored energy (see Eq. (1)) |
| CM_m | Maximum pitch, roll and yaw moments available for control, rad/sec ² |
| CM_{SE} | General notation for control moments available through stored energy, rad/sec ² |
| \overline{CM}_5 | Average pitch, roll and yaw control moments exceeded 5-percent of the time with unlimited moments available, rad/sec ² |
| d_e, d_a | Time delays in pitch and roll response, respectively, to control inputs, sec |
| d_n | Time delay in thrust response to collective control input |
| g | Gravitational constant, 32.2 ft/sec ² |
| HOV | Designates hover subtask |
| I_x, I_y, I_z | Moments of inertia in roll, pitch and yaw, slug-ft ² |
| j | $\sqrt{-1}$ |
| L_c | Roll control moment commanded by pilot and SAS divided by I_x , rad/sec ² |
| L_{cm} | Maximum available L_c , rad/sec ² |
| L_{c0} | Reference value of L_c , rad/sec ² |
| \bar{L}_{c0} | Averaged L_{c0} , rad/sec ² |
| L_p | Roll rate damping divided by I_x , per sec |
| L_q | Rolling moment due to pitch rate divided by I_x , per sec |

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SYMBOLS (Cont'd)

| | |
|----------------|---|
| $L_{v\delta}$ | Lateral speed-stability parameter divided by I_x , per sec ³ |
| $L_{\delta a}$ | Lateral control sensitivity divided by I_x , (rad/sec ²)/in. |
| $L_{\delta e}$ | Rolling moment due to longitudinal control stick input, (rad/sec ²)/in. |
| L_{ϕ} | Roll attitude stabilization divided by I_x , per sec ² |
| m | Aircraft mass, slugs |
| MAN | Designates entire maneuvering subtask, i.e., motion in both the x and y directions |
| M_c | Pitch control moment commanded by pilot and SAS divided by I_y , rad/sec ² |
| ΔM_c | Increment to pitch control moment available through rotor-propulsion system stored energy, rad/sec ² |
| M_{cm} | Maximum available M_c , rad/sec ² |
| M_{c0} | Reference value of M_c , rad/sec ² |
| \bar{M}_{c0} | Averaged M_{c0} , rad/sec ² |
| M_{c5} | Pitch control-moment level exceeded 5-percent of the time with unlimited moment available divided by I_y , rad/sec ² |
| M_p | Pitching moment due to roll rate divided by I_y , per sec |
| M_q | Pitch rate damping divided by I_y , per sec |
| \dot{M}_{TS} | Commanded rate-of-change of pitch control moment for thumb switch input, (rad/sec ²)/sec |
| $M_{u\delta}$ | Longitudinal speed-stability parameter divided by I_y , per sec ³ |
| $M_{\delta a}$ | Pitching moment due to lateral control stick input, (rad/sec ²)/in. |
| $M_{\delta e}$ | Longitudinal control sensitivity divided by I_y , (rad/sec ²)/in. |

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SYMBOLS (Cont'd)

| | |
|--------------------|--|
| M_{θ} | Pitch attitude stabilization divided by I_y , per sec^2 |
| N_c | Yaw control moment commanded by pilot and SAS divided by I_z , rad/sec^2 |
| N_{c5} | Yaw control-moment level exceeded 5-percent of the time with unlimited moment available divided by I_z , rad/sec^2 |
| N_{c_m} | Maximum available N_c , rad/sec^2 |
| N_r | Yaw rate damping divided by I_z , per sec |
| N_v | Yaw-due-to-lateral-velocity parameter divided by I_z , $\text{rad}/(\text{ft}\cdot\text{sec})$ |
| N_{δ_r} | Yaw control sensitivity divided by I_z , $(\text{rad}/\text{sec}^2)/\text{in.}$ |
| PR | Pilot opinion rating based on Harper-Cooper scale |
| APR | Degradation in pilot rating |
| P_{LL} | Percent time commanded roll moment exceeded installed roll control moment, percent |
| P_{ML} | Percent time commanded pitch moment exceeded installed pitch control moment, percent |
| P_{NL} | Percent time commanded yaw moment exceeded installed yaw control moment, percent |
| P_{SL} | Percent time simultaneous pitch and roll moment commands exceeded the sum of the installed pitch and roll control moments, percent |
| P_{TL} | Percent time commanded thrust exceeded installed thrust, percent |
| QS | Designates entire quick-stop subtask, i.e., motion in both x and y directions |
| s | Laplace operator, $1/\text{sec}$ |
| SAS | Stability augmentation system |
| S_{u_g}, S_{v_g} | Power spectrum of longitudinal and lateral turbulence components, respectively, ft^2/sec |

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SYMBOLS (Cont'd)

| | |
|--|---|
| $t_{\ddot{\theta}_{\max}}, t_{\ddot{\phi}_{\max}}, t_{\ddot{\psi}_{\max}}$ | Time interval following control input for pitch, roll and yaw, respectively, within which MIL-F-83300 (paragraph 3.2.4, Ref. 1) stipulates that maximum initial angular acceleration shall occur, 0.3 sec |
| TS | Thumb-switch thrust-rotation command, 0 or ± 1 (+1 is aft) |
| TU | Designates ± 180 deg turn subtask |
| T/W | Thrust-to-weight ratio |
| $(T/W-1)_5$ | Five-percent incremental T/W usage level, g's |
| $\Delta T/W$ | Increment to thrust-to-weight ratio, g's |
| UL | Notation for effectively unlimited control moment or thrust level |
| U_m | Mean wind from the north (000 deg true), 10 kts |
| x | Conventional longitudinal axis notation in the body-axis system, ft |
| XM | Designates x-direction part of the maneuver subtask |
| XQS | Designates x-direction part of the quick-stop subtask |
| X_u | Longitudinal drag parameter divided by m, per sec |
| y | Conventional lateral-axis notation in the body-axis system, ft |
| YM | Designates y-direction part of the maneuver subtask |
| YQS | Designates y-direction part of the quick-stop subtask |
| Y_{P_h} | Pilot model transfer function for height control loop |
| Y_{P_θ} | Pilot model transfer function for pitch control loop |
| Y_{P_ψ} | Pilot model transfer function for yaw control loop |
| Y_v | Lateral drag parameter divided by m, per sec |
| Z_w | Height velocity damping divided by m, per sec |

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SYMBOLS (Cont'd)

| | |
|------------------------------|---|
| $Z_{w_a}, Z_{w_s}, Z_{w_T}$ | Notation for aerodynamic, stability augmentation system and total Z_w , respectively, per sec |
| Z_{δ_c} | Height control sensitivity divided by m , (ft/sec ²)/in. |
| $\dot{\gamma}$ | Thrust-vector-rotation rate, deg/sec |
| γ_{δ_e} | Thrust-vector angle per inch of control input, deg/in. |
| δ_c | Collective control displacement, in. |
| ζ | Damping ratio of oscillatory roots |
| ζ_a, ζ_e | Damping ratios of second-order lags in roll and pitch response to control inputs, respectively |
| θ | Euler pitch attitude angle, rad |
| σ_{u_g} | RMS longitudinal turbulence, ft/sec |
| σ_{v_g} | RMS lateral turbulence, ft/sec |
| τ_a, τ_e | Time constant for first-order lag in roll and pitch control response, respectively, sec |
| τ_h | Time constant for first-order lag in thrust response to collective control input, sec |
| τ_{Δ} | Time constant for decay of incremental control power available through stored energy, sec |
| τ_{ψ} | Time constant for first-order lag in yaw response to pedal input, sec |
| ϕ | Euler roll attitude angle, rad |
| ψ | Euler yaw attitude angle, rad |
| ω_d | Damped frequency of the aircraft attitude (pitch or roll) oscillatory roots, rad/sec |
| ω_n | Natural frequency of the aircraft attitude (pitch or roll) oscillatory roots, rad/sec |
| $\omega_{n_a}, \omega_{n_e}$ | Natural frequencies of second-order lag in roll and pitch response to control inputs, respectively, rad/sec |

SECTION I

INTRODUCTION

A specification for V/STOL aircraft flying qualities, MIL-F-83300, has recently been developed under Air Force sponsorship (Ref. 1). It is based on the results of an extensive evaluation of previous V/STOL flying qualities studies as well as the findings of recent experimental and analytical research funded by the Air Force. Most of the latter was conducted as part of the VTOL Integrated Flight Control System (VIFCS) program. The specification and its supporting documentation provide guidance in the design of V/STOL aircraft control systems as well as a standard for flying qualities. They also are the culmination of research which represents a major advance in the understanding of V/STOL flight characteristics.

Additional research is required, however, in the V/STOL hover and low-speed flight regime. In particular, general information is needed on requirements for installed control power, i.e., control moments and thrust-to-weight ratio. Providing appropriate levels of control power for hover and low-speed flight is a critical part of the design of V/STOL aircraft. Despite its importance, there are little general data available which relate flying qualities to installed control power (Refs. 2 through 4). A related factor which has received almost no attention is the incremental control moment or thrust which can be obtained from rotor-propulsion system stored energy. By temporarily converting a part of the rotor-propulsion system angular momentum to control power, it is possible to supplement the installed control powers. Other general areas which should be investigated further are control lags and delays and inter-axis motion coupling. Motion coupling in particular has not been given adequate attention. Control and rate coupling, for example, exist to some degree in almost all V/STOL aircraft and their effects can lead to a significant degradation in flying qualities. In general, however, the specification treats motion coupling only qualitatively.

An uncertainty also exists over the level of height velocity damping, Z_w , needed for satisfactory height control characteristics. MIL-F-83300 indicates that height control will be satisfactory providing that Z_w is not positive, i.e., not destabilizing. Results which support this contention can be found (Ref. 5), but data which indicate a requirement for a significant level of negative Z_w are also available (Refs. 6 and 7). The height control portion of the specification also assumes that a tradeoff exists between the level of height velocity damping present in the aircraft and the required installed thrust-to-weight ratio. Although there are results which support this assumption, it merits further substantiation. Finally, MIL-F-83300 would be more useful if its scope could be extended to encompass

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some unconventional V/STOL control systems. The specifications may already apply to many aspects of hover and low-speed flight with such systems. However, its limitations in this regard are not known and it would be beneficial to examine V/STOL flying qualities with several unconventional systems that might be used on future aircraft. Examples of these types of systems are rate-command/attitude-hold or "stick steering" control and thrust-vector control independent of aircraft attitude.

The study described in this report provides additional information on the hovering and low-speed flying qualities of V/STOL aircraft. The objective of the program was to provide experimental flight simulator data and analyses which will be used to substantiate, refine, and extend the hovering and low-speed flight portion of the V/STOL Flying Qualities Specification.

SECTION II

BACKGROUND OF EXPERIMENTAL PROGRAM

This section contains a description of the studies conducted using the UAC V/STOL Flight Simulator and a discussion of the equipment and procedures used in the experimental program. Most of the equipment and many of the procedures used for the experimental studies were similar to those described in Refs. 7 and 8. Also, the flight simulation for this study was designed to correspond as closely as possible to that implemented at Norair for their previous VIFCS study (Ref. 9). Table A-I is a summary of parameters for cases evaluated and a key to tables in Appendices A, B, C and D that are tabulations of all the data discussed in Sections III through V. Additional details of the flight simulation are contained in Appendix F.

A. Flight Simulator Studies

The experimental program was designed to provide data to substantiate, refine and extend the hovering and low-speed flight portion of the V/STOL Flying Qualities Specification. It included studies of longitudinal and lateral flying qualities, height control and directional control. Emphasis was placed on obtaining information related to requirements for installed control power. The data obtained generally consisted of pilot opinion ratings, pilot-selected control sensitivities and measured control moment and/or thrust usage.

1. Longitudinal and Lateral Control

There were seven different investigations conducted in this part of the program. They were concerned with the effects of (1) turbulence intensity, (2) lags and delays in the response to control inputs, (3) limits on the available control moments, (4) incremental pitch control moment through stored energy, (5) inter-axis motion coupling, (6) thrust-vector control independent of aircraft attitude, and (7) rate-command/attitude-hold control. Six basic V/STOL configurations were selected. A range of values of the parameter being considered was then evaluated for each basic configuration. Also, longitudinal and lateral control were generally evaluated together; only one pilot opinion rating was given for a test case, and this represented the pilot's assessment of the combined longitudinal and lateral flying qualities. In addition, control moments were effectively "unlimited" and pitch, roll and yaw control-moment usage was measured for each study, unless noted otherwise.

a. Basic Configurations

The six basic configurations had conventional rate and attitude stability augmentation, and each was similar to configurations evaluated in the previous Norair and UARL studies (Refs. 7 through 9). They also were symmetrical in that each lateral stability derivative had the same value as the corresponding longitudinal derivative. The directional and vertical stability derivatives were the same for all six configurations. Table I lists their stability derivatives and root locations; roots are also plotted in Fig. 1. It is apparent that the basic configurations span a wide range of dynamic response characteristics. They encompass all three of the levels (1, 2 and 3)* used to characterize aircraft flying qualities in MIL-F-83300, in addition to exhibiting a range of responses to turbulence.

TABLE I

STABILITY DERIVATIVES AND ROOT LOCATIONS FOR UARL BASIC CONFIGURATIONS

| Conf. | Level | Stability Derivatives ^{1,2} | | | | Root Locations | |
|-------|-------|--------------------------------------|-------|-------|------------|----------------|--------------------------------|
| | | $M_{u\dot{g}}$ | X_u | M_q | M_θ | Real Root | $-\zeta\omega_n \pm j\omega_d$ |
| BC1 | 1 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | $-0.81 \pm j 1.85$ |
| BC2 | 2 | 1.0 | -0.05 | -1.1 | -2.5 | -0.5 | $-0.30 \pm j 1.47$ |
| BC3 | 3 | 1.0 | -0.05 | -2.0 | 0 | -2.2 | $0.08 \pm j 0.68$ |
| BC4 | 1 | 1.0 | -0.20 | -3.0 | -1.7 | -2.5 | $-0.35 \pm j 0.64$ |
| BC5 | 1 | 0.33 | -0.20 | -1.7 | -4.2 | -0.29 | $-0.81 \pm j 1.85$ |
| BC6 | 2 | 1.0 | -0.20 | -1.1 | -2.5 | -0.65 | $-0.32 \pm j 1.48$ |

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivatives.

2. Directional derivatives for all configurations: $N_V = 0.002$, $N_r = -1$, $N_{\delta_r} = 0.20$; Vertical derivatives: $Z_w = -1$, $Z_{\delta_c} = -3.2$, $T/W > 1.15$.

*Level 1 flying qualities are "clearly adequate for the mission"; Level 3 are such that the "aircraft can be controlled safely but pilot workload is excessive or mission effectiveness is inadequate, or both"; and Level 2 flying qualities lie between these extremes.

Configurations BC1, BC4 and BC5 are Level 1, but BC4 exhibits a larger attitude response to turbulence ($M_{ug} = -L_{vg} = 1.0$) than BC1 and BC5 ($M_{ug} = -L_{vg} = 0.33$). Also, BC4 and BC5 have greater position responses to turbulence than BC1 ($X_u = Y_v = -0.20$ versus $X_u = Y_v = -0.05$). Configurations BC2 and BC6 are Level 2 with large speed-stability parameters. This feature, combined with the lower levels of damping, results in significant attitude disturbances due to gusts. Configuration BC6 also has the large drag parameters and the attendant large position responses to turbulence. Finally, configuration BC3 is Level 3 with lightly damped dynamics, large speed-stability parameters ($M_{ug} = -L_{vg} = 1.0$), and large attitude disturbances from turbulence. It is important to note also that all of the rate damping and attitude stabilization represented by these derivatives in Table I (i.e., M_q , M_θ and their lateral, vertical and directional counterparts) was assumed to be provided by a stability augmentation system (SAS).

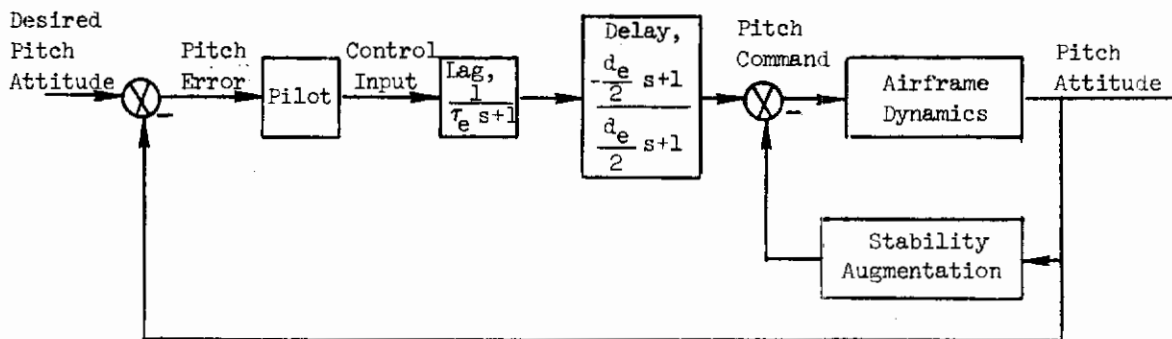
b. Turbulence Intensity

This study was conducted to provide information on the sensitivity of aircraft with different level flying qualities to changes in turbulence intensity and to obtain control-moment usage data. The flying qualities of Level 1 aircraft should be somewhat insensitive to gust level. That is, the MIL-F-83300 definition for V/STOL Level 1 dynamic response must be formulated such that flying qualities remain acceptable for commonly encountered turbulence intensities. Greater deterioration in flying qualities would be expected for Level 2 and 3 aircraft. Each of the six basic configurations was evaluated at three levels of rms longitudinal and lateral turbulence intensity, $\sigma_{ug} = \sigma_{vg} = 3.4, 5.8$ and 8.2 ft/sec. The wind simulation also included a mean wind $U_m = 10$ kt (≈ 17 ft/sec) from the north. Note that only for this study were rms turbulence intensities other than $\sigma_{ug} = \sigma_{vg} = 3.4$ ft/sec evaluated. For the rest of the program the wind simulation consisted of $\sigma_{ug} = \sigma_{vg} = 3.4$ ft/sec and $U_m = 10$ kt. Details of the wind simulation are described in Section II.B.1.

c. Lags and Delays in Attitude Response to Control Inputs

Pitch and roll control lags and delays were evaluated to test the adequacy of the MIL-F-83300 specification for such effects (paragraph 3.2.4, Ref. 1). These lags and delays only operated on the pilot's control stick inputs, i.e., the stability augmentation system (SAS) commands were not affected. The location of the lags and delays in the pitch attitude control loop is shown schematically in Sketch II-A. The implementation was identical for the roll loop. In the specification pitch, roll or yaw lags and delays are presumed to be within acceptable limits if the time to reach the initial maximum angular acceleration is no greater than 0.3 sec. To span this requirement with both acceptable and unacceptable values, first-order lags having time constants of 0.1, 0.3 and 0.6 sec were evaluated for each basic configuration. Also, the longitudinal and lateral lags were always

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SKETCH II-A. Location of Lags and/or Delays Simulated in Pitch Response to Control Inputs

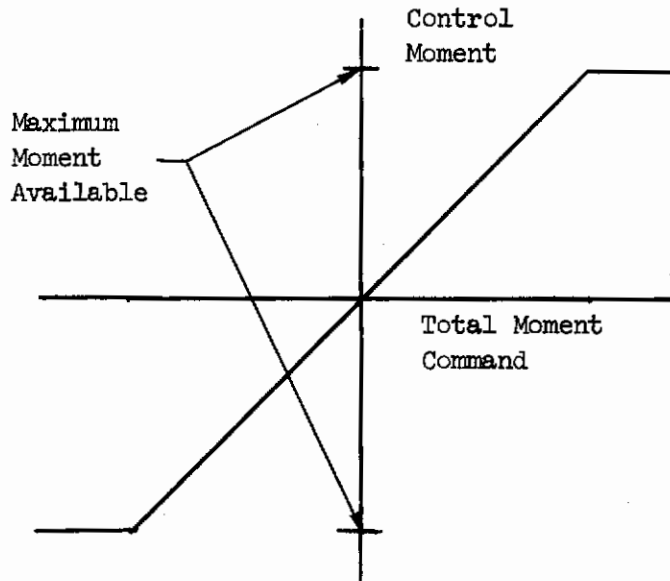
equal ($\tau_e = \tau_a$) for a given test case. In addition, pitch and roll moment delays, $d_e = d_a$, of 0.1 sec were evaluated with and without a combined first-order lag of $\tau_e = \tau_a = 0.3$ sec. Configurations BCl and BC2 were used for these test cases. The effects of second-order control lags were also investigated with configuration BCl to further test the specification. The significance of amplitude versus phase effects was examined by varying the damping ratio and natural frequency of the second-order lags.

d. Limits on Available Control Moments

The purpose of the control-moment-limit study was to investigate the effects of aircraft configuration and control system parameters on the total control moments (i.e., moments commanded by the pilot and the rate damping and attitude stabilization derivatives or SAS) necessary for pilot acceptance. Another objective was to examine whether these required installed control moments correlate with the control moment levels exceeded some given small percent of the time with unlimited moment available, e.g., the 5-percent level. Information on the adequacy of the MIL-F-83300 specification for pitch, roll and yaw control power (paragraph 3.2.3.1) was also provided by comparing it with the results of this study.

Configurations BCl, BC4, BC5 and BC6 were considered initially without control lags or delays. Three to five levels of available total control moment were evaluated for each configuration, and pilot opinion ratings were used to indicate the sufficiency of the levels. Pilots were not aware of the control-moment limits except as they affected flying qualities. The moment limits were applied on an analog computer, not to the physical control stick motion and the maximum control travels available were such that the limits would always be exceeded if the maximum travels were used. The control moment versus moment command characteristics simulated in the moment

limit study for pitch, roll and yaw control are shown in Sketch II-B. Note that the moments available in the pitch, roll or yaw axes were never identical. The reference limits or starting points for the installed control-moment levels (pitch, roll and yaw) were averages of those levels exceeded 5 percent of the time (CM_5) with unlimited moment available. The limits for the remaining test cases were developed by increasing (or decreasing) the reference levels by integral multiples of 10 percent.



SKETCH II-B. Pitch, Roll or Yaw Control Moment Versus Total Control-Moment Command Characteristics for the Moment Limit Study

The effects of control-moment limits were next evaluated with control system lags and delays present. Configurations BC1 and BC5 were used with pitch and roll response delays of $d_e = d_a = 0.1$ sec in combination with first-order lags of either $\tau_e = \tau_a = 0.3$ sec or 0.6 sec. The moment limits evaluated and the procedures for this investigation were unchanged from those for no control lags or delays.

e. Control Moments Through Stored Energy

Several types of V/STOL aircraft derive pitch and roll control moments from cyclic and/or collective changes of rotor system blade angles. Momentary incremental control moments above the installed moment levels can be obtained for such systems by abruptly increasing blade angles to values larger than the normal operating limit. Of course, the aircraft's powerplant will be unable to maintain engine rpm at this large blade angle, and rpm will decay. However, the brief increase in moment may be sufficient

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to compensate for deficiencies in the installed control moments. This study was undertaken to examine whether the stored energy in typical V/STOL rotor-propulsion systems could be used to such advantage.

Preliminary analyses indicate that it may be possible to approximate the control moments available from stored energy, CM_{SE} , by

$$\frac{d(\text{rpm})}{dt} + C_1 (\text{rpm})^2 = C_2 \quad (1)$$

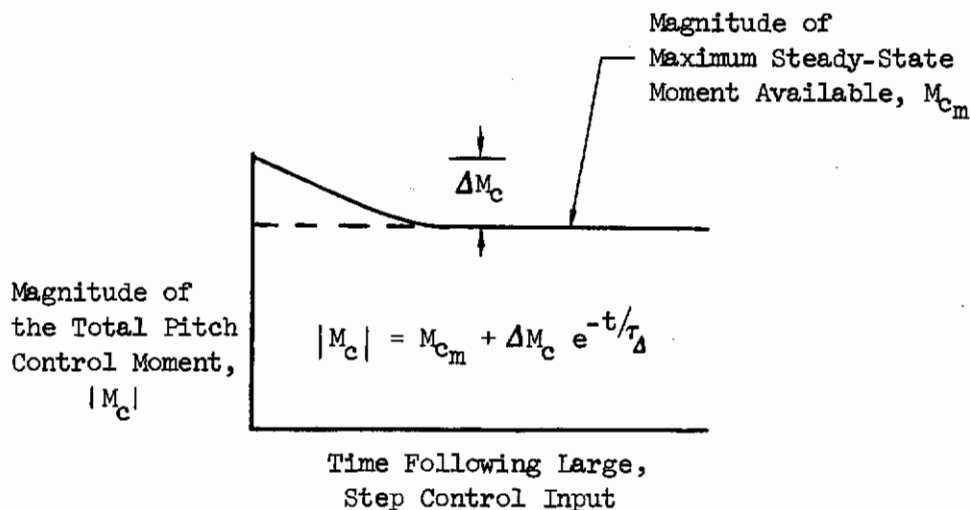
$$CM_{SE} = C_3 (\text{rpm})^2$$

where coefficient C_1 is related to the blade drag, C_2 to the available engine horsepower, and C_3 to the blade lift coefficient. Also, coefficients C_1 and C_3 both change when the pilot moves his control stick. For this study, stored energy effects were simulated for pitch control moments only and a linearized version of Eq. (1) was used to represent stored energy (Eq. (2)).

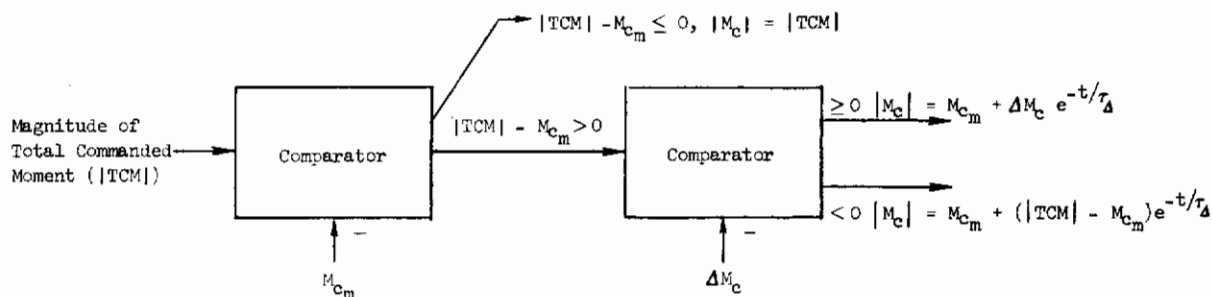
$$\tau_{\Delta} \frac{d}{dt} (CM_{SE}) + CM_{SE} = \tau_{\Delta} \frac{d}{dt} (|\text{Commanded Moment}| - M_{C_m}) \quad (2)$$

In Eq. (2) the parameter τ_{Δ} is the time constant associated with the stored energy decay and M_{C_m} is the steady-state or installed control moment. Also, the maximum control moment increment available from stored energy is defined as ΔM_C and the function $(|\text{Commanded Moment}| - M_{C_m})$ in Eq. (2) cannot be larger than ΔM_C . In addition, the stored energy increment was available for both positive and negative control commands as indicated in Eq. (2). The pitch control-moment step response for the stored energy study is shown in Sketch II-C. The moment response shown there is similar to the maximum pitch control moment the pilot and/or SAS could command if a large, rapid control input was made and sustained. The total moment available, then, consisted of a continuously available installed moment, M_{C_m} , plus a transient term which was excited if the magnitude of the total command exceeded M_{C_m} . The transient gave an abrupt increase related to the $|\text{Commanded Moment}| - M_{C_m}$ (up to the maximum increment of ΔM_C) that decayed with time constant τ_{Δ} . M_{C_m} and ΔM_C are considered to be positive functions in this discussion. The increment from stored energy could be used at any time, but after it decayed the pilot (and/or SAS) had to reduce the commanded moment and wait until the stored energy simulation recovered (the recovery time constant was also τ_{Δ}). This effectively simulated the time it would take a propulsion system to restore rotor rpm. A logic diagram illustrating the stored-energy simulation is shown in Sketch II-D. Representative values for the increment and the rpm decay (and recovery) time were determined from an analysis of the XC-142

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SKETCH II-C. Step-Response Characteristics of the Simulation of Incremental Control Moment Available Through Stored Energy



SKETCH II-D. Schematic Showing Switching Logic for Stored Energy Simulation

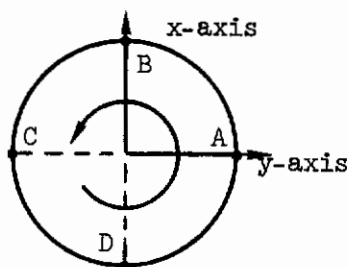
propulsion system. It appears that a moment increment of 30 percent of the installed moment is possible with associated decay time constants of $\tau_\Delta = 0.05$ and 0.10 sec. Values for τ_Δ of as much as 0.2 sec may be possible for helicopters because of the greater rotor-system inertia.

The effects on flying qualities of pitching moment available through stored energy were investigated with the same basic configurations considered in the control-moment limit study, i.e., BC1, BC4, BC5 and BC6. The installed pitch control moment, M_{c_m} , for each configuration was set at a low level

which yielded unsatisfactory pilot ratings without stored energy effects. All other installed control moments were set at satisfactory levels. The effects of the incremental pitch control moments supplied by stored energy were then evaluated for different combinations of ΔM_c and τ_{Δ} . Pilot ratings were used to assess the effects of stored energy. As for the study of control-moment limits, the pilots were not aware of the limits on pitch control power except through aircraft flying qualities. Control-moment data were not measured during the stored energy investigation.

f. Inter-Axis Motion Coupling

This study was performed to determine acceptable values of attitude rate coupling (M_p and L_q) and control coupling (M_{δ_a} and L_{δ_e}). An analysis was conducted initially to determine appropriate polarities and magnitudes for these parameters. The sign convention used for the attitude rate coupling (M_p positive and L_q negative) was derived from a simple analysis of hingeless-rotor aerodynamics. When the rotor tip-path-plane shown in Sketch II-E



SKETCH II-E. Top View of Rotor Tip Path Plane

undergoes pitch rates, one effect gives rise to net rolling moments. For example, if pitch attitude is increased by a positive pitch rate, the angle of attack of a blade in arc DAB will also increase, while that in arc BCD will decrease, causing a negative rolling moment (L_q negative). Similarly, a positive roll rate (increase in roll attitude) results in a positive pitching moment (M_p positive). Data in Ref. 10 indicate that rate coupling levels ranging from $M_p = 0.3$, $L_q = -2.7$ to $M_p = 1.5$, $L_q = -14$ can be present in uncompensated helicopter control systems, depending on rotor design.

The sign convention for control coupling can also be interpreted by reference to Sketch II-E. The maximum control moment for an articulated (hinged) rotor occurs when the blade has moved an additional 90 deg after a blade-angle (cyclic) change, i.e., the maximum pitching moment occurs at point B if the blade angle is changed at A. For a hingeless rotor the

maximum moment occurs after a smaller phase lag, e.g., somewhere in the arc AB for a blade angle change at A. Therefore, a positive pitch control input gives rise to a negative roll moment ($L_{\delta e} < 0$) and a positive roll control command results in a positive pitch moment ($M_{\delta a} > 0$). It should be noted that, with the sign conventions described, the effects of attitude rate and control coupling are additive. For example, a positive pitch control input yields a positive pitch rate and, since both L_q and $L_{\delta e}$ are negative, the induced rolling moments from both sources are negative. However, in the flight simulator evaluation of coupling effects, coefficients having signs which resulted in cancelling moments ($L_q < 0$, $L_{\delta e} > 0$ and $M_p > 0$, $M_{\delta a} < 0$) were also evaluated.

Configurations BC1 and BC2 were considered in this study with rate coupling levels of $M_p = -L_q = 2$ and 4 and control coupling up to $M_{\delta a}/L_{\delta a} = L_{\delta e}/M_{\delta e} = 0.50$. The different types of coupling were evaluated separately and in combination.

g. Thrust-Vector Control Independent of Aircraft Attitude

Independent thrust-vector control (ITVC) enables the pilot to maneuver aircraft having large drag parameters without large attitude changes. Also, with ITVC, large aircraft can be maneuvered near the ground with a reduced probability of tail strikes (and wing strikes, if lateral ITVC is also available). Only longitudinal ITVC was investigated in this study and it was implemented in two ways. In the first approach the longitudinal thrust vector was rotated using a thumb switch which commanded a constant rate of rotation. Pitch attitude was controlled using the conventional control stick. This technique for thrust-vector control was identical to the implementation of the wing tilt (or thrust-vector) control which was used by the evaluation pilots to trim the effects of mean wind acting through the longitudinal drag parameter. The wing tilt capability was available for all test cases evaluated in the UARL study. However, only for the ITVC study was the pilot permitted to use this device for general position control. The second method of implementation involved proportional control of the thrust-vector angle using the control stick while pitch attitude was controlled with the thumb switch. The thumb switch commanded a fixed rate-of-change of pitching moment (\dot{M}_{TS}). In general, the thrust-vector angle was displayed on the contact analog display with a symbol that moved vertically. Thrust-vector angle was also displayed on the instrument panel. For some of the experiments only the instrument panel display was used. Two Level 1 configurations (BC1 and BC4) and a Level 2 configuration (BC2) were used in the ITVC study. These configurations provide a range of position response characteristics with which to test ITVC. Configurations BC1 and BC2 have low drag parameters ($X_u = Y_v = -0.05$) and, consequently, low position stability and low position response to turbulence. Configuration BC4 has large drag parameters which give it greater position stability but also larger gust-induced position disturbances. Attitude control moments were unlimited for this

study and the thrust-vector angle could be rotated through ± 90 deg. Pitch and roll control-moment usage and thrust-vector angle were measured in the ITVC study.

h. Rate-Command/Attitude-Hold Control

The rate-command/attitude-hold or "stick steering" control system has two significant attributes. First, it will hold trim attitudes while allowing the pilot to center the stick and, second, it provides a rate-command control response for higher frequency control motions. A representative attitude transfer function (pitch) for such a system is given by Eq. (3):

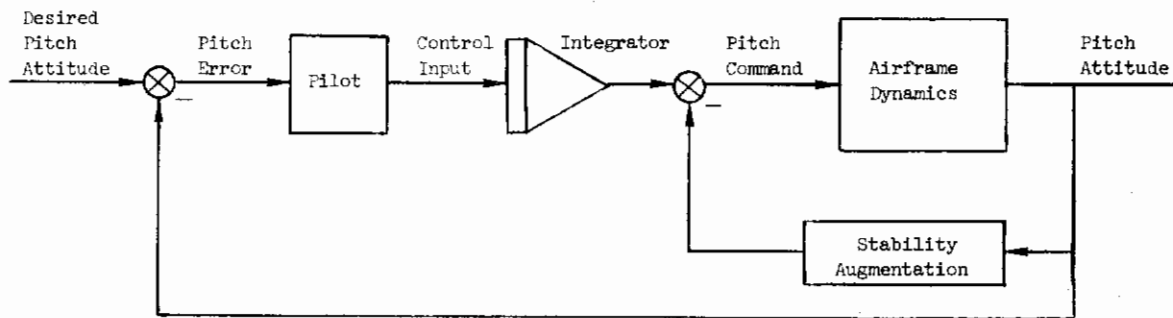
$$\frac{\theta}{\delta_e}(s) = \frac{M_{\delta_e}}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)} \quad (3)$$

This transfer function can be obtained for a rate and attitude stabilized V/STOL aircraft by integrating the control stick input to the attitude control system. This is the feature which enables the pilot to hold trim attitude with no steady-state control input. The attitude stabilization must then be increased to values which drive the real root of the attitude dynamics, i.e., the real root of the hovering cubic, towards zero, where it will be cancelled by the first-order zero related to drag parameter. If the natural frequency of the quadratic term in Eq. (3) is then sufficiently large, the transfer function θ/δ_e at and below the pilot's crossover frequency ($\omega_c \approx 2.5$ to 3.5 rad/sec, Ref. 8) will effectively be

$$\frac{\theta}{\delta_e}(s) \approx M_{\delta_e}/s \quad (4)$$

However, the dynamics still retain the attitude stabilization features. The lead compensation that must be supplied by the pilot for pitch and roll control and, consequently, the longitudinal flying qualities of this control system, are very dependent on the damping ratio, ζ , and natural frequency, ω_n , of the quadratic in Eq. (3). The rate-command/attitude-hold control system for pitch attitude (and also roll) was implemented as shown in Sketch II-F for this study.

For this study the basic longitudinal and lateral airframe derivatives of configurations BC1 and BC4 were used as a base and the rate damping (M_q , L_p) and attitude stabilization (M_θ , L_ϕ) parameters were varied to provide a broad range of ζ and ω_n for the pitch and roll dynamics. The initial parameters chosen were based on a closed-loop analysis of the pilot-aircraft dynamics. Values for ζ and ω_n that could not be obtained with simple



SKETCH II-F. Implementation of Rate-Command/Attitude-Hold Control

attitude and rate feedbacks were not evaluated in this study. Again, the pitch and roll attitude dynamics were identical for each test case.

2. Height Control

The height control program consisted of four studies. They were concerned with the effects on flying qualities of (1) height velocity damping, Z_w , with effectively unlimited thrust, (2) the interaction between Z_w and the installed thrust level, (3) thrust lags and delays, and (4) thrust available through stored energy. The longitudinal, lateral and directional characteristics were defined by the basic configurations and are shown in Table A-I. Pitch, roll and yaw control moments were effectively unlimited. The data obtained consisted of pilot ratings, pilot-selected collective control sensitivities and thrust usage. The measured thrust usage was made up of that which the pilot attempted to command, $Z_{\delta_c} \cdot \delta_c$, and that actually commanded, $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$, where Z_{w_s} is the height damping resulting from stability augmentation.

a. Effects of Height Velocity Damping with Unlimited Thrust

This study was undertaken primarily to provide more information on the minimum acceptable level of height velocity damping, Z_w . The MIL-F-83300 specification (paragraph 3.2.5.4) assumes that Level 1 flying qualities for height control can exist for $Z_w = 0$ provided sufficient thrust is available ($T/W > 1.10$). A previous UARL study (Ref. 7) contains data which indicate that a level of $Z_w \approx -0.5$ is necessary for satisfactory height control. A secondary objective of the study was to measure thrust usage data with effectively unlimited thrust-to-weight ratio ($T/W > 1.15$). Levels of total height damping, Z_{w_T} , ranging from 0 to -0.8 were evaluated with configurations BCl and BC4. The total damping was assumed to consist of equal aerodynamic, Z_{w_a} , and stability augmentation system (SAS), Z_{w_s} , components.

b. Interaction Between Z_w and Installed Thrust Level

The height control power portion of MIL-F-83300 (paragraph 3.2.5.1) is based on the premise that increased height velocity damping reduces the necessary installed thrust. The study described here was conducted to provide more information on this effect. Height control was evaluated with configuration BCl for six or more levels of Z_{wT} , ranging from -0.1 to -0.5, at each of three installed thrust-to-weight ratios ($T/W = 1.02, 1.05, 1.10$). The T/W ratios considered are pertinent to the definition of level boundaries for the height control power specification. Generally Z_{wT} was composed of equal parts of aerodynamic, Z_{wa} , and SAS, Z_{ws} , damping. However, the effects of all Z_{wa} or all Z_{ws} were also investigated.

c. Thrust Lags and Delays

This investigation was designed to test the specification for thrust magnitude control lags (paragraph 3.2.5.2). First-order lags which result in height control response that spans the Level 1 and 2 requirements ($\tau_h = 0.3$ and 0.6) were evaluated with and without 0.1-sec delays. These lags and delays affected both the control and SAS thrust commands. Configuration BCl was used and several values of Z_{wT} , composed of equal Z_{wa} and Z_{ws} components, were simulated for each combination of control lag and delay. Also, the installed T/W was limited to 1.05 for this study.

d. Thrust Available Through Stored Energy

The effects of incremental thrust from rotor-propulsion system stored energy were investigated using configuration BCl with height control characteristics that were unsatisfactory without stored energy ($Z_{wT} = Z_{ws} = -0.35$, $T/W = 1.02$). Two levels of incremental T/W representing momentary thrust increases of approximately 15 percent and 30 percent, i.e., $\Delta T/W = 0.13$ and 0.28 , were evaluated with decay time constants of $\tau_d = 0.05, 0.1$ and 0.2 sec. Stored energy was simulated as described for pitch control in Section II.A.1.e.

3. Directional Control

The three directional control studies investigated (1) the effects of damping on flying qualities and control-moment usage, (2) control lags and delays, and (3) limits on the available control moment. Two of the basic configurations (BC1 and BC2) were used to represent V/STOL longitudinal and lateral control characteristics. The height-control parameters for the directional studies were as shown in Table A-I. Pitch and roll control moments and thrust-to-weight ratio were effectively unlimited. Yaw control moments were also unlimited unless noted otherwise. Pilot ratings, pilot-selected directional control sensitivities and pitch, roll and yaw control-moment usage were recorded.

a. Effects of Yaw Rate Damping

This study was conducted to provide additional information on the relationship between yaw rate damping and flying qualities and to obtain control-moment-usage data. Yaw rate damping values which spanned the Level 1, 2 and 3 specifications (paragraph 3.2.2.2), for directional damping ($N_r = -1, -0.5$ and 0 , respectively) were evaluated for basic configurations BC1 and BC2. For all test cases N_v was 0.005 .

b. Control Lags and Delays

The effects of directional control lags and delays were also investigated to provide results with which to test the control-lag specification (paragraph 3.2.4). First-order control lags (which affected the pedal response only) with time constants $\tau_\psi = 0.3$ and 0.6 were evaluated with and without 0.1 -sec delays in control response. These lag and delay combinations were each evaluated at N_r levels of -0.5 and -1 . Only configuration BC1 was used in this study and N_v remained 0.005 .

c. Yaw Control-Moment Limits

The levels of yaw control moment necessary for satisfactory directional control were determined (1) to provide comparative results for the MIL-F-83300 control power requirement (paragraph 3.2.3.1) and (2) to evaluate the hypothesis that acceptable moment limits correlate with a level exceeded some small percent of the time for unlimited available moments. Configuration BC1 was again used in this study and N_v remained 0.005 . The yaw control-moment limits considered were $N_{cm} = 0.10, 0.13$ and 0.16 and the effects of these limits were evaluated for two values of N_r , -0.5 and -1.0 . The smallest limit considered, $N_{cm} = 0.10$, was based on yaw control-moment data measured in the turbulence study (Section II.A.1.b). It was the average level exceeded 5 percent of the time for the 3.4 ft/sec rms turbulence intensity.

B. Description of Simulation

1. Simulation of V/STOL Aircraft and Winds

The six-degree-of-freedom equations of motion for hovering and low-speed flight were programmed on an analog computer. They were written using a body-axis coordinate system and were linearized assuming small perturbations from hovering flight (Eq. (F-1), Appendix F; Refs. 7 and 8). Also, the angular momentum effects of such spinning masses as propellers and jet engine rotors were not considered. Products of inertia have also been assumed to be negligible and, with the exception of N_v , derivatives which couple motion between axes were generally disregarded. Pitch and roll rate coupling and control coupling were examined in one of the longitudinal and lateral control studies, however. The wind simulation consisted of a 10 kt (≈ 17 ft/sec)

mean wind from the north (000 deg true), U_m , and turbulence which was introduced along the aircraft x and y body axes. Turbulence was simulated by passing the output of a random noise generator, which had a relatively uniform low-frequency power spectral distribution, through a first-order filter with a break frequency of 0.314 rad/sec (Refs. 7 and 8). The simulated turbulence then excited aircraft rotational and translational motion through the aircraft speed-stability and drag parameters and the yaw-due-to-lateral-velocity parameter (see Eq. (F-1), Appendix F). The turbulence intensity was always equal in the x and y axes, and, in general, an rms level of $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec was used. With this turbulence intensity, the wind simulation was the same as that used for much of the previous Norair study conducted under the VIFCS program (Ref. 9). Turbulence intensity levels of $\sigma_{u_g} = \sigma_{v_g} = 5.8$ and 8.2 ft/sec were also considered in the study of turbulence effects.

2. Flight Simulation and Display

Fixed- and moving-base VFR flight simulations were used. For any given study, the moving-base simulations were used to check selected fixed-base data which had been previously obtained. Generally, about half the test cases in a particular study were evaluated in the moving-base mode. The same flight simulator used in the previous UARL VIFCS studies (Refs. 7 and 8) was also used for this program. A motion platform has been added to the device, however (Fig. 2).

The simulator consists of a fully enclosed, two-place Sikorsky S-61 cockpit with a conventional instrument panel, a contact analog display for VFR flight simulation, and the six-degree-of-freedom motion platform. The control system for this simulation was made up of standard helicopter flight controls plus a thumb-switch device which could be used to change the longitudinal thrust-vector angle (or wing-tilt angle) and thereby trim the effects of the mean wind acting through the longitudinal drag parameter. The display (Fig. 3) is composed of a ground grid, horizon line, clouded sky and display symbols. Attitude and coarse position information are obtained from the motion of the ground grid, horizon and sky relative to a cross symbol which represents the nose of the aircraft. The cross may either be the electronic symbol shown in Fig. 3 or simply a marker physically attached to the screen surface. For the independent thrust-vector control and height control studies, the latter method was used and the electronic cross was moved to the right side of the screen to indicate thrust-vector angle and altitude, respectively. Precise aircraft position and velocity information are obtained from the motion of the square symbol which indicates a spot on the ground. At the reference hovering altitude of 40 ft, the dimensions of the contact analog screen represented a hover pad approximately 130 ft (longitudinally) by 150 ft and the square symbol an area about 9 ft on a side.

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Simulator motion is provided by coordinated movement of the six hydraulic actuators on which the cockpit is mounted (Fig. 2). The stroke position of each actuator, commanded in response to the simulation equations of motion, is generally computed using hard-wired analog circuitry. A PDP-8 digital computer is used to set control modes of the motion platform and to monitor system performance. The simulator motion capabilities are summarized in Table II. The amplitude of the motion-platform frequency response is flat to beyond 1 Hz for each type of angular (e.g., pitch, roll or yaw) or linear motion. The phase lag for each type of motion is approximately 30 deg at 1 Hz.

TABLE II

FLIGHT SIMULATOR ANGULAR AND LINEAR MOTION LIMITS

| Axis | Angular Motion | | | Axis | Linear Motion | | |
|-------|----------------|---------------|------------------------------------|--------------|---------------|------------------|-------------------|
| | Attitude, deg | Rate, rad/sec | Acceleration, rad/sec ² | | Position, ft | Velocity, ft/sec | Acceleration, g's |
| Pitch | ±45 | ±1 | ±1 | Longitudinal | ±5 | ±6 | ±0.5 |
| Roll | ±30 | ±1 | ±1 | Lateral | ±5 | ±6 | ±0.5 |
| Yaw | ±45 | ±1 | ±1 | Vertical | ±2.5 | ±6 | ±1.0 |

The platform's motion limits are too small to permit duplication of all low-frequency aircraft motion commanded by the pilot, especially the linear displacements. Consequently, a "washout" logic has been developed to selectively attenuate motion commands which would cause the simulator to exceed its limits (Appendix F; Ref. 11). This system is based on measured frequency response characteristics of the human's vestibular system. It also orients the cockpit relative to the earth's gravity field to simulate low-frequency aircraft linear accelerations which otherwise could not be represented. Several pilots have evaluated the motion system with this washout logic for hovering and low-speed flight and have generally found that it provides a realistic representation of actual flight.

3. Simulated Flight Task

The flight task performed during the longitudinal and lateral and the directional control studies consisted of the following subtasks: vertical

takeoff and climb to a 40-ft hovering altitude, low-speed maneuvers (air taxi; MAN, XM, YM), quick stops (QS, XQS, YQS), turns-over-a-spot (TU), hover (HOV), and landing. The air-taxi maneuvers were conducted in both longitudinal and lateral directions through simulated distances of ± 65 ft and ± 75 ft, respectively. The pilots followed a cross pattern while holding heading constant (at 000 deg true) and hovered momentarily at the cardinal points of the cross. Airspeeds were generally less than 20 ft/sec during the maneuver task. The pilots next performed the longitudinal and lateral quick stops while also holding heading at 000 deg true. Airspeeds were somewhat larger for the quick stops, and, of course, the aircraft's velocities were arrested more abruptly than for the air-taxi maneuvers. The pilots next performed ± 180 deg turns while maintaining hover position and this was followed by a 60-sec precision hover at the center of the simulated hover pad. The pilots then landed the aircraft.

The turn-over-a-spot subtask was deleted for the height control study and a landing sequence (LS) subtask was performed after the hover. The landing sequence consisted of relatively rapid changes in hovering altitude from 40 ft to 20 ft and back to 40 ft. This was followed by a vertical landing.

4. Pilots

The two UARL evaluation pilots were the same pilots A and B who participated in the previous VIFCS studies conducted at UARL (Refs. 7 and 8). Both are licensed private pilots who have flown a variety of fixed-wing aircraft and one has had limited helicopter experience. They also have each accumulated several hundred hours evaluation time on the flight simulator. For each study in this program pilot B generally evaluated all the fixed-base test cases and pilot A approximately half of them. These ratios were reversed for the height control studies, however. Only pilot B performed moving-base evaluations.

Two Calspan test pilots also participated at different times in the UARL program. Each has extensive experience in both helicopters and V/STOL aircraft. Eleven moving-base simulator shifts of at least 4 hours duration each were set aside for Calspan use. Results from the Calspan evaluations are shown only for Calspan pilot B in this report.

5. Comparative Results from UARL and Norair Simulations

The UARL flight simulation was designed to correspond with that used by Norair in their previous VIFCS program (Ref. 9) and thereby provide comparable results. An indication of the success of this effort can be obtained by comparing pilot ratings for similar test cases from the two simulations. Comparable longitudinal and lateral control rating data for the six UARL basic configurations are shown in Fig. 4 and Table III. The UARL fixed-base

TABLE III

COMPARISON OF PILOT RATINGS FROM NORAIR AND CURRENT UARL STUDY

Wind Simulation: $U_m = 10$ kts, $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec for Both Simulations

| Basic Conf. | Simulation Case | Longitudinal Stability Derivatives | | | | Lateral Stability Derivatives | | | | PR | |
|-------------|-----------------|------------------------------------|-----------|-----------|--------------|-------------------------------|-------|-------|------------|------|-----|
| | | M_{u_g} | X_{u_1} | M_{q_1} | M_{θ} | L_{v_g} | Y_v | L_p | L_{ϕ} | FB | MB |
| BC1 | UARL T1 | 0.33 | -0.05 | -1.7 | -4.2 | -0.33 | -0.05 | -1.7 | -4.2 | 2 | 2 |
| | NORAIR 308 | 0.33 | -0.05 | -1.7 | -4.2 | -0.33 | -0.05 | -1.7 | -4.2 | | 3.2 |
| BC2 | UARL T10 | 1.0 | -0.05 | -1.1 | -2.5 | -1.0 | -0.05 | -1.1 | -2.5 | 4.5 | 5 |
| | NORAIR 102 | 1.0 | -0.05 | -1.1 | -2.5 | -0.16 | -0.10 | -5.0 | 0 | | 4.5 |
| BC3 | UARL T16 | 1.0 | -0.05 | -2.0 | 0 | -1.0 | -0.05 | -2.0 | 0 | 5 | 6 |
| | NORAIR 117 | 1.0 | -0.05 | -2.0 | 0 | -0.16 | -0.10 | -5.0 | 0 | | 5 |
| BC4 | UARL T7 | 1.0 | -0.20 | -3.0 | -1.7 | -1.0 | -0.20 | -3.0 | -1.7 | 3.5 | 3 |
| | NORAIR 147 | 1.0 | -0.20 | -3.0 | -1.7 | -0.16 | -0.10 | -5.0 | 0 | | 4 |
| BC5 | UARL T4 | 0.33 | -0.20 | -1.7 | -4.2 | -0.33 | -0.20 | -1.7 | -4.2 | 3.5 | 2 |
| | NORAIR 334 | 0.33 | -0.20 | -2.1 | -3.8 | -0.33 | -0.20 | -2.1 | -3.8 | | 3 |
| BC6 | UARL T13 | 1.0 | -0.20 | -1.1 | -2.5 | -1.0 | -0.20 | -1.1 | -2.5 | 4.75 | 6 |
| | NORAIR 141 | 1.0 | -0.20 | -1.4 | -1.7 | -0.16 | -0.10 | -5.0 | 0 | | 6.2 |

data are averaged over two pilots and the moving-base results are for pilot B only. The Norair ratings for each case have been averaged over several pilots. In general, the ratings from the two programs agree relatively well, generally differing by only about one unit or less. Note, however, that only for configuration BCl were the Norair and UARL test cases completely identical. The comparable longitudinal stability derivatives were always quite similar but the lateral derivatives were generally not.

C. Data Analysis

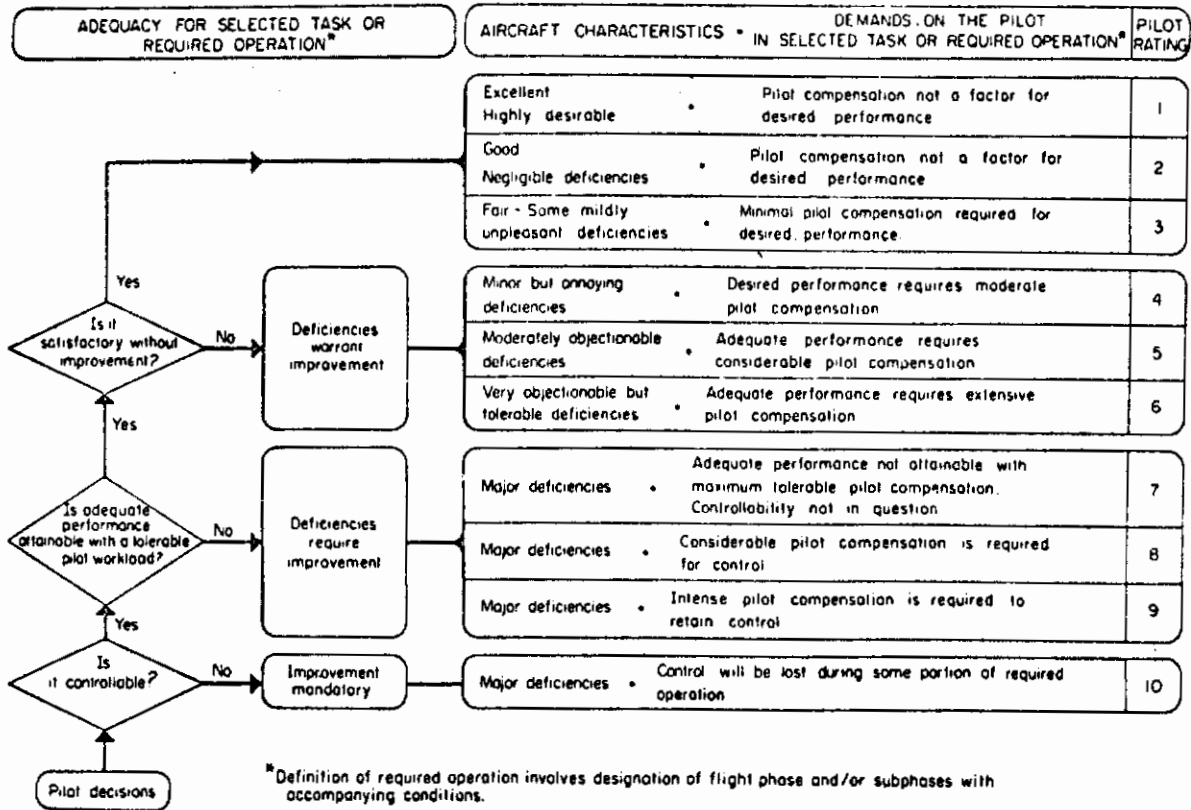
1. Reduction of Experimental Data

a. Flying Qualities Results

Pilot ratings and comments were obtained for each test case. Corresponding pilot-selected control sensitivities were also recorded. For some of the test cases, however, control sensitivities were preset at acceptable levels to save time. The pilot ratings were based on the Cooper-Harper scale (Table IV) and the pilots' comments consisted of responses to the appropriate parts of the questionnaire shown in Table V. The rating scale and questionnaire are very similar to those used in the Norair VIFCS program (Ref. 9). For presentation in the figures the UARL fixed-base rating data and control sensitivity results were each averaged over pilots A and B. The corresponding moving-base data from pilot B are shown separately. Also, Calspan pilot evaluation results were never averaged with the UARL data. Except for height and directional control, the Calspan pilots did not reach the level of control proficiency on the UAC simulator which is necessary to provide valid flying qualities data. This should not be interpreted as a reflection on the capabilities of the Calspan evaluation pilots who were both highly skilled in the control of V/STOL aircraft. Rather, the inability to become proficient, in the somewhat limited time available for Calspan pilot training, was a result of the complex nature of the UAC contact analog display (Fig. 3). This display does not provide a great deal of visual realism and in order to control properly one must rely on the relative motion between the cross and square symbols. The Calspan pilots did not learn to "lead" their control inputs properly using this relative motion information. They also tended to make control inputs of the wrong polarity, because it was difficult for them to determine the proper correlation between the symbol relative motion and the required control input. Valid flying qualities data can be obtained with the UAC display, however, for evaluation pilots who are familiar with its characteristics (e.g., Refs. 7, 8, and 12). For such pilots, the UAC display can provide visual cues (except for peripheral information) which are similar to those in actual VFR flight, and in some aspects possibly better than VFR cues (Ref. 7).

TABLE IV

COOPER-HARPER PILOT RATING SCALE



All the rating and control sensitivity data for the UARL pilots are summarized in Appendix A and the corresponding pilot comments are contained in Appendix B. Similar results from Calspan pilot B are presented in Appendix D.

b. Control Power Data

The total pitch, M_c , roll, L_c , and yaw, N_c , control moments (pilot control inputs plus that from the rate damping and attitude stabilization derivatives, i.e., the stability augmentation system commands) were measured for each test case in the longitudinal and lateral control and the directional control investigations. Pitch control moment and thrust-usage data were measured during the height control study. A representative schematic showing the point at which the pitch control-moment-usage data were measured

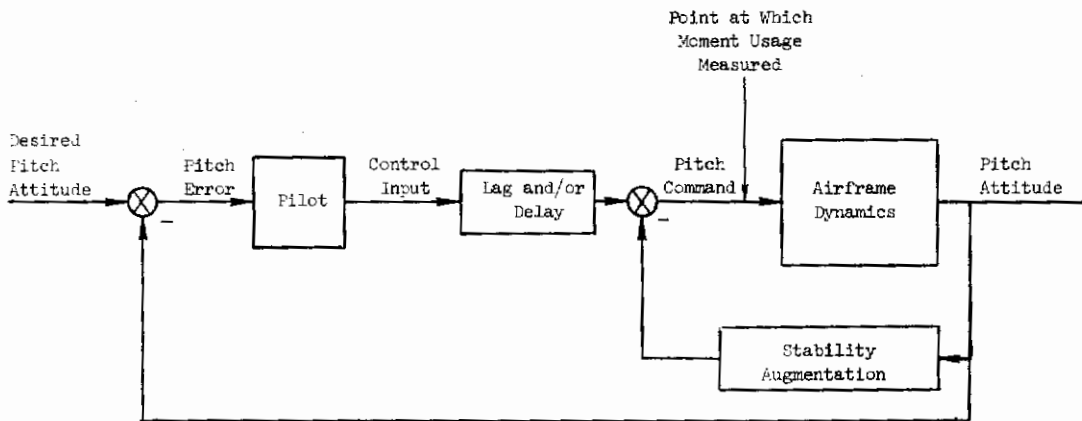
TABLE V
UARL FLYING QUALITIES QUESTIONNAIRE

- I. Comment on selection of control sensitivities.
- II. Comment on the following flying qualities areas.
 - A. Air-taxi-around-the-square.
 - 1. Response to control inputs (all axes).
 - 2. Ability to initiate motion (each direction).
 - 3. Ability to stabilize and hold desired velocities.
 - 4. Ability to stop precisely and come to hover at corners.
 - 5. Are excessive attitude changes (pitch and roll) required?
 - 6. Ability to hold heading, altitude.
 - 7. Control deflections, trim.
 - B. Quick stops.
 - 1. Can you stop as quickly as you would like?
 - 2. Are excessive attitude changes required?
 - 3. Ability to hold heading and altitude.
 - 4. Control motions required.
 - C. Turn-over-a-spot.
 - 1. Ability to remain over spot.
 - 2. Attitude control (pitch and roll), height control.
 - 3. Ability to initiate and hold turn rate.
 - 4. Ability to stop on preselected heading.
 - 5. Comment on use of wing-tilt control.
 - D. Precision hover and vertical landing.
 - 1. Ability to establish and maintain precision hover.
 - a. Attitude and angular rates.
 - b. Position.
 - 2. Adequate for vertical landing?
 - 3. Control activity.
 - E. Secondary dynamics.
 - 1. Did dynamics for one axis affect your control of another axis?
- III. Overall evaluation.
 - A. Objectionable features.
 - B. Favorable features.
 - C. Special piloting techniques.
 - D. Pilot rating; why?

IMPORTANT: PLEASE AVOID ALL REFERENCE AND COMPARISONS TO ANY OTHER FLIGHT. MAKE EACH SET OF COMMENTS INDEPENDENT OF ANY OTHER.

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is shown in Sketch II-G. Control moment for roll and yaw control and thrust usage for height control were measured at corresponding points in the appropriate control loop. These control power data were recorded on an FM tape



SKETCH II-G. Representative (Pitch) Aircraft Control Loop Showing Point at Which Control-Moment Usage was Measured

recorder. Control power usage for the experiments in which effectively unlimited control power was available was characterized by the percent time given moment levels were exceeded for a particular subtask. For those investigations in which control power was limited, the percent time that total control power commands exceeded these limits was of interest. The exceedance percentages were computed off-line from the recorded control power data using an analog computer. Exceedance computations were performed on the magnitudes of the pitch, roll and yaw control moment data; $|M_c|$, $|L_c|$, $|N_c|$, respectively, and the combined pitch and roll moment results, $|M_c| + |L_c|$, from the longitudinal and lateral studies and from the directional control investigations. As indicated by the relationship $(|M_c| + |L_c|)$ the exceedance percentages for the combined pitch and roll signal were performed on the sum of the magnitudes of total pitch and roll control moments. For the height control data, the exceedance computations were performed on $|M_c|$ and on the negative or "up" collective part of $Z_{\delta_c} \cdot \delta_c$ and $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$. It was felt that exceedance percentages computed from the thrust used to ascend or arrest sink rates would be more significant than percentages based on both positive and negative thrust usage about the trim level ($T/W = 1.0$).

Representative plots of exceedance results are shown in Fig. 5. There the percent time that $|M_c|$, $|L_c|$ and $|M_c| + |L_c|$ exceed the given reference levels are shown with subtask as a parameter. These data are for one pilot and are plotted on a probability grid. For the type of plots in Fig. 5, a

straight line indicates that the data can be characterized by a Gaussian probability distribution. There is some tendency for the curves from the hover and turn subtasks to exhibit this characteristic.

To simplify the task of evaluating the effects of a variety of aircraft and task parameter changes on control power usage, the control power level exceeded 5 percent of the time was chosen for comparison. The 5-percent level was selected because it is generally near the upper limit of control power used by the pilot and would presumably be related to the required installed power. A previous UARL study showed some evidence to support this assumption (Ref. 13). On the other hand, it is not such a small percentile that it would be an unreliable indicator of overall control power usage. The data in Fig. 5, for example, indicate that if the 5-percent level is used to rank the subtasks as to control-moment usage, the results are consistent with the trends evident over all percentiles. However, the 5-percent level should be more sensitive to parameter changes than larger percentile levels.

The 5-percent level results presented in this report were averaged over the two pilots participating in the study and over both moving- and fixed-base data to provide the largest possible data sample for a given test point. Averaging the moving- and fixed-base data appeared to be valid since the differences in these two types of data were less than the inter-pilot variation. That is, there was generally no dramatic difference between fixed- and moving-base data. Representative results which support this conclusion are shown in Fig. 6.

2. Analytical Investigations to Interpret the Data

Two types of analytical efforts were undertaken to interpret and rationalize the experimental results. One involved converting the parameters in MIL-F-83300 which specify satisfactory V/STOL response into functions which could readily be compared with the UARL flying qualities and control power data. The computations were performed to permit evaluation of the MIL-F-83300 requirements for control sensitivities, control power and satisfactory levels of control lags and delays.

The second type of analytical investigation was man-machine analysis of the different control loops (longitudinal, lateral, height and directional) closed by the pilot when controlling a V/STOL aircraft. The results of these analyses were used to select parameters to be considered in the experimental studies and to interpret pilot opinion data in terms of the pilot lead and gain compensation required. The closed-loop models and analytical techniques used here are discussed in detail in previous UARL reports (e.g., Refs. 7, 8 and 14).

SECTION III

RESULTS OF LONGITUDINAL AND LATERAL CONTROL STUDIES

This section consists of two parts in which the results of the longitudinal and lateral control studies are discussed. Part A is concerned with flying qualities data and Part B with control-moment usage data. Details of the experimental design, the equipment and procedures and other background material are given in Section II.

A. Flying Qualities Results

Pilot ratings and pilot-selected control sensitivities from the studies of (1) turbulence, (2) control lags and delays, (3) control moment limits, (4) control moments through stored energy, (5) inter-axis motion coupling, (6) thrust-vector control independent of attitude, and (7) rate-command/attitude-hold control are discussed here. The data are interpreted using man-machine analysis methods and, where appropriate, are compared with MIL-F-83300.

1. Turbulence

a. Pilot Ratings

The flying qualities of the six basic configurations were each evaluated at three turbulence intensities ($\sigma_{u_g} = \sigma_{v_g} = 3.4, 5.8$ and 8.2 ft/sec) to determine the sensitivity of representative Level 1, 2 and 3 V/STOL aircraft to changes in turbulence intensity. Pilot ratings from these evaluations (Cases T1 through T18, Table A-II) are presented in Fig. 7. The pilots were not aware of the turbulence intensity level present for a given test case. As might be expected, the ratings generally deteriorated as gust intensity increased. However, it appears that the rate of deterioration may have been greater for configurations with the less stable (Levels 2 and 3) dynamics. For example, there was no degradation in ratings for the Level 1 configurations as rms turbulence intensity was increased from 3.4 to 5.8 ft/sec. A general increase in rating for the Level 1 configurations is evident, however, at the 8.2-ft/sec intensity, although the ratings all remain in the acceptable region (Fig. 7(a)). A much more definite deterioration in ratings is evident for the Level 2 and 3 configurations, especially for the change in turbulence intensity from 3.4 to 5.8 ft/sec.

The degradation in rating is shown more clearly in Fig. 8 where it is plotted versus configuration flying qualities level, with the change in turbulence intensity treated as a parameter. The degradation in fixed-base ratings for Level 2 and 3 configurations is much greater than that for Level 1 configurations over the turbulence intensity interval 3.4 to 5.8 ft/sec. Except for

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BC⁴, which is Level 1 but relatively responsive to gusts, this trend is also evident (to a lesser extent) for the intensity interval 3.4 to 8.2 ft/sec. There is not sufficient moving base data to permit a complete comparison between levels. However, over the turbulence interval 3.4 to 8.2 ft/sec, the degradation in moving-base ratings for Level 1 configurations BC¹ and BC⁴ is less than the corresponding fixed-base degradation. The moving-base degradation for BC⁵ is greater than its fixed-base counterpart but still smaller than the fixed-base degradation for the Level 2 and 3 configurations. In summary, the pilot rating data would tend to indicate (but by no means confirm) that the MIL-F-83300 Level 1 requirement for V/STOL pitch, roll and yaw dynamic response (paragraph 3.2.2) provides aircraft dynamics which remain quite controllable for nominal increases in turbulence intensity.

The rating data can be interpreted by considering the aircraft attitude and position response to turbulence and the phase lags of the attitude dynamics at frequencies critical to pilot control. It has been shown (Refs. 7 and 8) that pilot rating is related to both the workload involved in suppressing turbulence and the lead compensation he must supply to provide good closed-loop attitude characteristics. This lead compensation is inversely dependent on the attitude phase lags over the frequency interval from about 1 to 4 rad/sec (Refs. 7 and 14). The frequency domain characteristics of the open-loop attitude and position response to turbulence for the six basic configurations are shown in Figs. 9 and 10. The phase lags contributed by the pilot and the open-loop attitude dynamics for these configurations are presented in Fig. 11. The pilot's lags are assumed to consist of a pure delay of 0.09 sec in combination with a first-order lag having a 0.2-sec time constant (Refs. 7 and 14). An examination of the phase lag and turbulence response curves will indicate why the Level 1 configurations BC¹ and BC⁵, and to a lesser extent, BC⁴, have generally better flying qualities and are less affected by turbulence than the Level 2 and 3 configurations. The phase lags (Fig. 11) for BC¹, BC⁴ and BC⁵ are all appreciably smaller than those for the Level 2 and 3 configurations over the critical frequencies ($\omega = 1.5$ to 4 rad/sec, Fig. 11). This indicates that the pilot need supply less lead compensation to provide good attitude control characteristics. Also, the normalized open-loop attitude and position power spectral densities for BC¹ and BC⁵ are appreciably smaller than those for the Level 2 and 3 configurations. The power spectral densities for BC⁴, the remaining Level 1 configuration, are comparable to those for BC², BC³ and BC⁶ over the lower frequencies but are smaller at the higher frequencies which are more difficult for the pilot to suppress. Consequently, the opinion ratings for BC⁴ might be expected to exhibit a somewhat smaller sensitivity to gust intensity than BC², BC³ and BC⁶.

b. Control Sensitivities

Longitudinal and lateral control sensitivity data are shown in Figs. 12 and 13, respectively. For most of the six configurations, the longitudinal control sensitivities, $M_{\delta e}$, tend to increase with turbulence intensity. This trend reflects the pilot's requirement for more rapid attitude and position responses to control inputs as he tried to maintain performance in the presence of increasing gust disturbances. For some of the configurations (BC4, BC5 and BC6) the lateral control sensitivities (Fig. 13) tend to increase with turbulence intensity, but this trend is not consistent for all configurations. In fact, the control sensitivities selected for BC3 tend to decrease slightly for the larger gusts. Such inconsistencies are not unexpected, since previous studies have shown that a fairly broad range of control sensitivities are acceptable to most pilots (Refs. 7 and 9). Figures 12 and 13 also contain boundaries for the maximum and minimum control sensitivities permitted under the MIL-F-83300 specification for aircraft attitude response to control inputs (paragraph 3.2.3.2). These sensitivity boundaries were back-calculated using the attitude response specifications and the known aircraft dynamics. It is apparent from the distance between these boundaries that the specification permits appreciable latitude in the installed V/STOL pitch and roll sensitivities. The values of $M_{\delta e}$ and $L_{\delta a}$ selected by the UARL pilots generally fall within these boundaries, but are much closer to the minimum acceptable level than the maximum. In fact, for the Level 1 configurations (BC1, BC4 and BC5), most of the lateral control sensitivities are somewhat below the lower boundary. Larger minimum values are required by MIL-F-83300 for lateral control sensitivities than longitudinal, assuming the pitch and roll dynamics are symmetrical. In studies at UARL, however, $L_{\delta a}$ has generally been found to be smaller than $M_{\delta e}$ (Refs. 7 and 8).

2. Control Lags and Delays

a. Pilot Opinion Ratings

Pilot rating data from the three parts of the control lag and delay investigation are discussed in the following order: (1) first-order control lags, (2) first-order control lags in combination with a 0.1-sec delay, and (3) second-order control lags. The test cases evaluated in these studies were L11-L127 and results of the evaluations are summarized in Table A-III (Appendix A).

The effects of the first-order control lags on ratings are shown in Fig. 14. These lags affected only the pilot's control stick commands and not the SAS inputs. Also, the lags were identical for both pitch and roll. As might be expected, the ratings generally deteriorated as the lag time constant, $\tau_e = \tau_a$, increased. However, the sensitivity of a given configuration's flying qualities to the lag time constant appeared to correlate with

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the flying qualities level (without lags) of the configuration. For example, most of the ratings for the Level 1 configurations at $\tau_e = \tau_a = 0.6$ sec were within one unit of the ratings given for no lags. The Level 2 and 3 configurations generally show a noticeable deterioration in rating at $\tau_e = \tau_a = 0.3$ sec. The degradation in rating is plotted versus flying qualities level in Fig. 15 with the change in lag time constant as a parameter. There is considerable scatter in these results, but the fixed-base data generally show that the degradation in rating was greater for the Level 2 and 3 configurations.

The Level 1 configurations should be somewhat less sensitive to control lags. The primary effect of the control lags is to introduce phase lags (Fig. 16) which increase the need for pilot lead compensation. They do not affect the aircraft response to turbulence. The Level 1 configurations require little lead compensation without lags because their open-loop phase lag is small (Fig. 11). Pilots will tolerate nominal requirements for lead compensation without a significant change in rating (Refs. 7 and 14). Consequently, the ratings for Level 1 configurations do not change appreciably until the lag time constant reaches a relatively large value (e.g., $\tau_e = \tau_a = 0.6$). However, for the Level 2 and 3 configurations the requirements for pilot compensation are at a relatively high level with no lags (Fig. 11). In this situation the pilots appear to be more sensitive to the increased lead requirements, possibly because it is more difficult to supply the needed increment. Note that the magnitude characteristics of the basic configuration-lag combination, which will not be discussed here, may also affect pilot opinion (Refs. 14 and 15).

The specifications for pitch and roll control system lags can be evaluated using the pilot rating data in Fig. 14. The specification (paragraph 3.2.4) is based on the time it takes aircraft attitude to reach the initial maximum angular acceleration, $t_{\dot{\theta}_{\max}}$ and $t_{\dot{\phi}_{\max}}$, after the initiation of the control command. If these times are less than 0.3 sec the attitude dynamics are considered satisfactory. Values of these times have been computed with $\tau_e = \tau_a = 0.1, 0.3,$ and 0.6 sec for each of configurations BC1, BC4 and BC5 and they are summarized in Table VI along with the associated pilot ratings. These results show that the specification permits a $\tau_e = \tau_a = 0.3$ sec for the configurations evaluated; these cases were also generally rated satisfactory. The specification would preclude $\tau_e = \tau_a = 0.6$ sec although the fixed-base ratings remained marginally satisfactory for these cases. However, the moving-base ratings for the first-order control lag evaluation were generally worse than the fixed-base results. Consequently, it would appear that excluding control lags much greater than $\tau_e = \tau_a = 0.3$ sec, as the specification does, is prudent.

TABLE VI

COMPARISON BETWEEN PILOT OPINION RATINGS AND THE
MIL-F-83300 REQUIREMENT FOR ACCEPTABLE ATTITUDE CONTROL LAGS

| Basic Conf. | Lag Time Constant, $\tau_e = \tau_a$, sec | Time to Max. Acceleration, $t_{\theta_{max}} = t_{\phi_{max}}$, sec | Average Pilot Rating | |
|-------------|--|--|----------------------|------------------|
| | | | Fixed Base Mode | Moving-Base Mode |
| BC1 | 0.1 | 0.19 | 2 | 5.5 |
| | 0.3 | 0.31 | 2.75 | |
| | 0.6 | 0.38 | 2.5 | |
| BC4 | 0.1 | 0.15 | 2 | 3.5 |
| | 0.3 | 0.29 | 2.75 | 5 |
| | 0.6 | 0.46 | 3.5 | |
| BC5 | 0.1 | 0.18 | 2 | 3 |
| | 0.3 | 0.30 | 2 | |
| | 0.6 | 0.38 | 3.5 | |

The effects of adding a 0.1-sec time delay in pitch and roll response for Level 1 and 2 configurations (level designation applies for no lags or delays) are shown in Table VII. Such delays also increase the requirements for pilot adapted lead compensation by increasing the phase lags in the attitude response to control inputs. However, as indicated in Fig. 16, a 0.1-sec delay contributes relatively small phase lags over the frequency range (~ 1 to 4 rad/sec) most critical to pilot control of attitude. Time delays greater than 0.1 sec were not considered since the specification (paragraph 3.2.4) excludes them. In this study the time delays ($d_e = d_a$) were added separately and in combination with first-order lags ($\tau_e = \tau_a$) having 0.3-sec time constants. For one of the cases (indicated by the superscript 2 in Table VII) the time delays and lags affected both the pilot's control inputs and the SAS commands. For all other cases the time delays and lags operated only on the control input. For the Level 1 configuration (BC1) the 0.1-sec time delays in the pilot's pitch and roll control inputs had little effect on pilot rating, whether or not the 0.3-sec lags were also present. For example, adding $d_e = d_a = 0.1$ sec with $\tau_e = \tau_a = 0$ did not change the pilot's rating (PR = 2 for both cases). Also, adding $d_e = d_a = 0.1$ with $\tau_e = \tau_a = 0.3$

TABLE VII

EFFECTS OF TIME DELAYS AND CONTROL SYSTEM LAGS ON PILOT RATINGS

BC1 is Level 1 and BC2 is Level 2 Without Lags and Delays

| Basic Conf. | Lag Time Constant, $\tau_e = \tau_a$, sec | Time Delay $d_e = d_a$, sec | Ratings from Pilot B for Fixed-Base Mode |
|------------------|--|------------------------------------|---|
| BC1 ¹ | 0 | 0 | 2 |
| | 0 | 0.1 | 2 |
| | 0.3 | 0 | 2.5 |
| | 0.3 | 0.1 | 3 |
| | 0.3 ² | 0.1 ² | 8 ² |
| BC2 ¹ | 0 | 0 | 5 |
| | 0 | 0.1 | 5 |
| | 0.3 | 0 | 5 |
| | 0.3 | 0.1 | 7 |

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative; pitch and roll lags and delays equal.
2. For this case the lag and delay operated on both the control input and the SAS command. For all the other cases only the control input was affected.

resulted in a pilot rating deterioration of only 0.5 units relative to the rating with only the 0.3-sec lags. However, the results in Table VII show a dramatic change in rating when the lags and delays were relocated so that they affected both the control and SAS commands (PR = 8 versus PR = 3). In this case, the stability augmentation was much less effective and, as a result, the configuration was very difficult to control. The pilot's chief complaint (Case LL25, Table B-II, Appendix B) was that large pitch oscillations developed; it was nearly impossible to damp them and stabilize pitch attitude. The results for the Level 2 configuration (BC2) also show little change when $d_e = d_a = 0.1$ were added with $\tau_e = \tau_a = 0$ sec. However, when the same delays were added to BC2 with $\tau_e = \tau_a = 0.3$ the associated pilot rating was two units worse than for the lags without the delays (PR = 7 versus PR = 5). Note, however, that the rating for the lags alone was somewhat better than would be expected. That is, it is the same rating (PR = 5) as was assigned to BC2 with neither lags nor delays present in the control response. The

results in Table VII, although limited, would tend to indicate that 0.1-sec delays in the pilot's pitch and roll control responses are acceptable, at least for Level 1 configurations. That is, the specification (paragraph 3.2.4) which permits delays in the pitch or roll attitude response to control inputs of up to 0.1 sec, appears to be reasonable.

Second-order lags were also evaluated during this study to provide some information on the generality of the MIL-F-83300 specification for control lags. The specification is based on the results of studies with first-order control lags; however, because it is phrased in terms of an angular acceleration response which must be achieved within a reference time interval, it may also apply to more general lags. Four sets of parameters for the second-order lag were evaluated ($\omega_{n_e} = \omega_{n_a} = 3.33$ rad/sec with $\zeta_e = \zeta_a = 0.22, 0.50,$ and 1.0 and $\omega_{n_e} = \omega_{n_a} = 8.23$ with $\zeta_e = \zeta_a = 1.0$). As for the first-order lag study the lags only affected the pilot's control response and they were identical in pitch and roll. The initial combination of parameters was selected to have the same break frequency ($\omega_n = 3.33$) as that for an acceptable first-order lag ($1/\tau_e = \omega_{n_e}$ where $\tau_e = 0.3$). The damping ratio, $\zeta_e = \zeta_a$, was adjusted to give the same phase lag as that from the first-order lag in the region of the pilot's crossover frequency ($\omega_c = 2.5$ to 3 rad/sec; see Refs. 8 and 14). Consequently, the lead compensation requirements for the two lags would be similar. However, the nature of the control stick response would be quite different because of the lightly damped ($\zeta_e = \zeta_a = 0.22$) oscillations present for the second-order lag. The magnitude and phase characteristics of the open-loop pilot and attitude dynamics, without pilot lead or gain compensation, are shown in Fig. 17.

Results from the evaluation of second-order lags with configuration BCl (Fig. 18) show that the combination of parameters ($\zeta = 0.22, \omega_n = 3.33$) selected for equivalence with $\tau_e = \tau_a = 0.3$ resulted in a pilot rating of 10. Pilot comments indicated that the oscillatory pitch and roll motion was completely unacceptable. The ratings improved with increased damping ratio, but a satisfactory rating was not obtained even with $\zeta_e = \zeta_a = 1.0$. Here the oscillatory dynamics were not a problem, but lead compensation was needed to compensate the phase lags. Pilot rating was satisfactory for this damping ratio, however, with the larger natural frequency, $\omega_{n_e} = \omega_{n_a} = 8.23$ rad/sec. The attitude phase lags in the region of pilot crossover frequency (2.5 to 3.5 rad/sec) were somewhat smaller with these parameters. The pilot rating results from Fig. 18 are compared with $t_{\theta_{max}}^{\dot{}}$ = $t_{\phi_{max}}^{\dot{}}$ values computed for the second-order lag test cases in the following tabulation:

| $\omega_{n_e} = \omega_{n_a}, \text{ rad/sec}$ | $\zeta_e = \zeta_a$ | $t_{\theta_{max}}^{\dot{}} = t_{\phi_{max}}^{\dot{}}$ | PR |
|--|---------------------|---|----|
| 3.33 | 0.22 | 0.61 | 10 |
| 3.33 | 0.50 | 0.58 | 7 |
| 3.33 | 1.0 | 0.55 | 4 |
| 8.23 | 1.0 | 0.33 | 3 |

The only case rated satisfactory also had a time to maximum angular acceleration which was nearly equal (0.33 sec) to that required by the specification (0.30 sec). However, $t_{\delta_{\max}}^{\ddot{\theta}} = t_{\phi_{\max}}^{\ddot{\phi}}$ was almost twice the specification value (0.55 sec) at $\omega_{n_e} = \omega_{n_a} = 3.33$ rad/sec and $\zeta_e = \zeta_a = 1.0$ for a test case rated marginally satisfactory (PR = 4). These very limited results indicate, then, that the control lag specification may not be sufficiently general to apply to second-order control lags.

b. Control Sensitivities

Longitudinal and lateral control sensitivities from the investigation of first-order control lags are presented in Figs. 19 and 20, respectively. It might be expected that pilot-selected control sensitivities would increase somewhat with lag time constants since the lags result in slower attitude response. For the longitudinal sensitivities, M_{δ_e} , there is little evidence of this except possibly for configuration BC3 (Fig. 19). The lateral sensitivities, L_{δ_a} , exhibit some tendency to increase with τ_a and, again, this effect is more pronounced for BC3. Configuration BC3 is Level 3 and very difficult to control as the lags become larger. The pilots may have increased sensitivity in an attempt to more quickly attenuate the large attitude excursions which tended to develop for $\tau_e = \tau_a = 0.3$ and 0.6 sec.

Boundary values for acceptable minimum and maximum longitudinal and lateral control sensitivities developed from the MIL-F-83300 specification for attitude control response (paragraph 3.2.3.2) are shown for the Level 1 configurations in Table VIII. Both the minimum and maximum boundaries increase with $\tau_e = \tau_a$ because the specification is written in terms of an acceptable response after a given time period. Because the lags slow the attitude control response, the sensitivities must increase to satisfy the specification. For the small lag time constants the pilot-selected lateral and longitudinal sensitivities are close to the specification's lower boundaries (M_{δ_e} and L_{δ_a} are averages of fixed- and moving-base data). For the larger time constants the sensitivities fall below the minimum boundaries. Note also that the maximum sensitivity boundaries are very much larger than the UARL selected values. It may be appropriate to lower the minimum boundaries somewhat and it would seem that the maximum boundaries also could be reduced. The maximum allowable sensitivities would, in general, result in extremely "touchy" aircraft pitch and roll response to control inputs and could cause the pilot to overcontrol.

TABLE VIII

COMPARISON OF AVERAGED LONGITUDINAL AND LATERAL CONTROL SENSITIVITIES
FROM THE CONTROL LAG STUDY WITH THE MIL-F-83300 REQUIREMENTS

| Basic Conf. | Lag Time Constant, $\tau_e = \tau_a$, sec | UARL M_{δ_e} | MIL-F-83300 M_{δ_e} Boundaries | | UARL L_{δ_a} | MIL-F-83300 L_{δ_a} Boundaries | |
|-------------|---|---------------------|---------------------------------------|-------|---------------------|---------------------------------------|-------|
| | | | Min. | Max. | | Min. | Max. |
| BC1 | 0 | 0.291 | 0.233 | 1.560 | 0.271 | 0.312 | 1.560 |
| | 0.1 | 0.303 | 0.261 | 1.740 | 0.244 | 0.348 | 1.174 |
| | 0.3 | 0.311 | 0.342 | 2.278 | 0.223 | 0.456 | 2.278 |
| | 0.6 | 0.372 | 0.490 | 3.268 | 0.312 | 0.654 | 3.268 |
| BC4 | 0 | 0.342 | 0.258 | 1.721 | 0.302 | 0.344 | 1.721 |
| | 0.1 | 0.404 | 0.291 | 1.940 | 0.334 | 0.388 | 1.940 |
| | 0.3 | 0.403 | 0.384 | 2.561 | 0.321 | 0.512 | 2.561 |
| | 0.6 | 0.412 | 0.552 | 3.683 | 0.384 | 0.737 | 3.683 |
| BC5 | 0 | 0.293 | 0.233 | 1.560 | 0.243 | 0.312 | 1.740 |
| | 0.1 | 0.304 | 0.261 | 1.738 | 0.241 | 0.348 | 1.738 |
| | 0.3 | 0.283 | 0.343 | 2.288 | 0.220 | 0.458 | 2.288 |
| | 0.6 | 0.324 | 0.489 | 3.263 | 0.301 | 0.635 | 3.263 |

3. Control Moment Limits

In this study the installed control moments required for pilot acceptance were determined for several of the basic configurations (BC1, BC4, BC5 and BC6). The correlation between the requirements for control moment and the levels exceeded some given small percent of the time with unlimited moment available, i.e., the 5-percent level, was also examined. This study was performed with and without control system lags and delays. Also, the pilots were not aware of the control-moment limits except as they affected flying qualities. Results from this study are listed for Cases LMI-LM25 in Table A-IV in Appendix A.

The effects of control-moment limits on pilot rating of the flying qualities of configurations BC1, BC4, BC5 and BC6 are presented in Fig. 21. The reference limits or starting points for the installed control-moment levels (pitch, roll, and yaw) were averages of those levels exceeded 5 percent of the time (\overline{CM}_5) with unlimited moment available (see Section III.B.1.d). These averages were computed over all subtasks, pilots and modes of simulator operation (fixed- and moving-base). The control-moment limits for the remaining test cases were obtained by increasing (or decreasing) the reference

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levels by integral multiples of 10 percent. Also, the limits were applied to the total control moment available for both control inputs and the SAS commands. Note that \overline{CM}_5 is different for each configuration and its magnitude scales approximately with the configuration's speed-stability parameters (see Table C-I, Appendix C).

Only for configuration BC5 did control-moment limits equal to the average 5-percent exceedance level, \overline{CM}_5 , result in ratings equivalent to those of unlimited moments (Fig. 21). Configuration BC5 is a very stable, Level 1 configuration with little response to turbulence. For configuration BC1, which is identical to BC5 except that its drag parameters are one-fourth as large, control-moment limits at least 1.2 times the reference \overline{CM}_5 level were needed to obtain ratings equivalent to those for unlimited moments. For the configurations which were more responsive to turbulence (BC4) or both less stable and more responsive to turbulence (BC6), control-moment limits of 1.3 times the \overline{CM}_5 levels were required for equivalent ratings. For all the configurations examined, a deficiency in control moment was most evident as a momentary inability to control pitch, and to a lesser extent roll, when performing the maneuver and quick-stop subtasks. Pilot comments indicated that the limits on yaw control moment did not affect flying qualities.

Table IX contains a comparison between the control-moment limits found to be necessary for pilot acceptance in this study and the control-moment

TABLE IX

COMPARISON OF UARL ACCEPTABLE CONTROL-MOMENT
LIMITS WITH MIL-F-83300 REQUIREMENTS

| Conf. | Control Moment Source | Installed Control Moment, rad/sec ² | | |
|-------|-----------------------|--|--------------------|-------------------|
| | | Pitch, M_{C_m} | Roll, L_{C_m} | Yaw, N_{C_m} |
| BC1 | UARL | 0.40 | 0.46 | 0.13 |
| | MIL-F-83300 | 0.57 | 0.47 | 0.31 |
| BC4 | UARL | 1.07 | 0.79 | 0.23 |
| | MIL-F-83300 | 1.26 | 0.81 | 0.31 |
| BC5 | UARL | 0.38 | 0.36 | 0.15 |
| | MIL-F-83300 | 0.57 | 0.48 | 0.31 |
| BC6 | UARL | 1.16 | 0.98 | 0.22 |
| | MIL-F-83300 | 1.18 | 0.71 | 0.31 |

requirements in MIL-F-83300. The control moment specification (paragraph 3.2.3.1) stipulates that sufficient control moment must remain at the maneuvering airspeed to simultaneously produce aircraft pitch, roll, and yaw attitude changes of ± 3 deg, ± 4 deg, and ± 6 deg, respectively, within one second. The specification values shown in Table IX were computed assuming longitudinal and lateral maneuvering speeds equivalent to those used in the UARL task (≈ 15 ft/sec). Combining these airspeeds with the mean wind increases the effective longitudinal airspeed to ≈ 32 ft/sec. For the UARL simulation, then, the aircraft must have sufficient pitching moment, M_{cm} , to trim the 32-ft/sec airspeed and also to provide the ± 3 deg pitch change within one second. The roll, L_{cm} , and yaw, N_{cm} , moments need only be sufficient to trim the 15-ft/sec lateral airspeed and provide the required attitude changes (± 4 deg and ± 6 deg, respectively).

The results in Table IX show that for all the Level 1 configurations (BC1, BC4, BC5) the pitch and roll control-moment requirements from MIL-F-83300 equalled or exceeded those found to be necessary in the UARL study. For BC6, a Level 2 configuration which is quite responsive to gusts, the specification value for L_{cm} was about 20 percent low. However, the UARL level for M_{cm} agrees well with the corresponding MIL-F-83300 value. Also, all of the specification levels for N_{cm} were well in excess of the UARL results. It would appear from these relatively limited data that the MIL-F-83300 requirement for pitch and roll control moments is adequate. However, the yaw control-moment requirement seems somewhat excessive. Pilots never noticed a deficiency in yaw control moments during the UARL study even for levels of N_{cm} considerably lower than the UARL data shown in Table IX. Limitations on pitch and roll control moment were predominant in the formation of rating. The MIL-F-83300 yaw control-moment requirement is discussed in more detail in Section V.A.3.

It was pointed out previously that another objective of this study was to determine whether the required levels for installed control moments correlated with the percent time given pitch and roll moment levels were exceeded with unlimited moments available. In particular it was thought that the 5-percent exceedance level might be sufficient. The results in Fig. 21 do not appear to substantiate such an hypothesis. However, it may be that the maximum of the 5-percent exceedance levels measured for the different subtasks should have been used for \overline{CM}_5 instead of the average over all subtasks. These maximum values, averaged over both pilots and fixed- and moving-base simulator modes (Table C-I, Appendix C), are listed in Table X along with the pitch and roll moment levels necessary for pilot ratings approximately equivalent to those for unlimited control moment (Fig. 21).

TABLE X

COMPARISON OF MAXIMUM FIVE-PERCENT EXCEEDANCE MOMENT
LEVELS USED FOR ANY SUBTASK WITH ACCEPTABLE LIMITS
ON INSTALLED ROLL AND PITCH CONTROL MOMENTS

| Basic Conf. | Control Moment | Maximum 5-Percent Level | Acceptable Moment Level |
|-------------|----------------|-------------------------|-------------------------|
| BC1 | M_c | 0.34 | 0.43 |
| | L_c | 0.45 | 0.50 |
| BC5 | M_c | 0.45 | 0.38 |
| | L_c | 0.50 | 0.36 |
| BC4 | M_c | 0.90 | 1.07 |
| | L_c | 0.62 | 0.78 |
| BC6 | M_c | 0.93 | 1.16 |
| | L_c | 0.94 | 0.98 |

The results in Table X show that only for configuration BC5 were the maximum 5-percent exceedance moment levels equal to or greater than those levels which were acceptable to the pilot. It appears, then, that the 5-percent exceedance level, whether it is composed of the average over all subtasks or the maximum for any subtask, does not provide acceptable levels of installed control moment. If configuration BC5 is considered an anomaly, the fact that control-moment levels of 1.2 to 1.3 times \overline{CM}_5 were acceptable may imply that a lower-percentile exceedance level, e.g., the 1 to 2 percent level, would provide acceptable installed control moments. Results related to this possibility are discussed in Section III.B.2.

The control-moment requirements with control system first-order lags ($\tau_e = \tau_a = 0.3$ and 0.6) and delays ($d_e = d_a = 0.1$ for all test cases) were also evaluated in this study for configurations BC1 and BC5. The procedures used and moment levels considered were identical to those for the evaluation of control-moment limits without lags. The effects of the control lags can be seen in Fig. 22. The necessary control-moment levels were increased by

the control lags and delay. For example, control-moment levels for BCl equal to $1.4 \overline{CM}_5$ were required with $\tau_e = \tau_a = 0.3$ and 0.6 and $d_e = d_a = 0.1$ for ratings equivalent to those with unlimited control moments. Control moments equal to only $1.2 \overline{CM}_5$ were sufficient for BCl without lags and delay (Fig. 21). For configuration BC5, $1.2 \overline{CM}_5$ was required with $\tau_e = \tau_a = 0.6$ and $d_e = d_a = 0.1$. Without the lags and delays the corresponding required moment levels were equal to $1.0 \overline{CM}_5$. The control-moment specification (paragraph 3.2.3.1) will account for the additional control moments required with control system lags and delays. It is stated in terms of minimum attitude responses within a certain time and, consequently, requires more installed control moments when control lags or delays are present. It should be noted, however, that the control moments required by MIL-F-83300 for no lags are generally equal to or greater than the UARL levels necessary with lags and delays. This is illustrated in the following list.

| Basic Conf. | MIL-F-83300 Without Lags | | | UARL Acceptable With Lags | | |
|----------------|-----------------------------|----------|----------|------------------------------|----------|----------|
| | M_{cm} | L_{cm} | N_{cm} | M_{cm} | L_{cm} | N_{cm} |
| BC1 | 0.57 | 0.47 | 0.31 | 0.47 | 0.54 | 0.16 |
| BC5 | 0.57 | 0.48 | 0.31 | 0.46 | 0.44 | 0.18 |

Only L_{cm} for configuration BCl from the UARL study is slightly greater than its MIL-F-83300 counterpart. If the control moment specification for L_{cm} is computed with $\tau_a = 0.3$ under the airspeed conditions discussed previously, the MIL-F-83300 requirement for L_{cm} becomes 0.62 rad/sec^2 , an increase of about 35 percent. If the 0.1 sec delay was also considered the percentage increase would be even greater. For $\tau_a = 0.6$ the corresponding level for L_{cm} is 0.81. In fact, the specification control moment requirement for control systems with acceptable lags may be excessive. For example, a control lag of 0.3 sec is permissible under MIL-F-83300 for both configurations BCl and BC5. However, such a lag will increase the specification control moment requirements by approximately 35 percent to levels which are much greater than those the UARL results would indicate are necessary.

4. Incremental Control Moment Through Stored Energy

For this study the pilot could command a pitch control moment (stored energy effects were not simulated for roll) greater than the installed or continuously available total moment. It was assumed that this additional moment was provided by converting angular momentum from a rotor-propulsion

system into an increment which decayed with time (as the angular momentum was dissipated). A more detailed discussion of this effect and a description of the simulation procedures used are given in Section II.B.1.e. Representative values for the present increment and the rpm decay (and recovery) time, determined from an analysis of XC-142 propulsion system data are $\Delta M_c = 0.3 M_{cm}$ and $\tau_\Delta = 0.05$ to 0.10 sec. Values for τ_Δ of 0.2 may be possible for helicopters. Cases LS1-LS3 were evaluated for the stored energy investigation and flying qualities results are summarized in Table A-V in Appendix A.

The results in Fig. 23 were obtained using values for M_{cm} which resulted in flying qualities that were significantly worse than those for unlimited control moments. The effects of stored energy were then evaluated for different combinations of ΔM_c and τ_Δ . Data are presented for basic configurations BC1, BC4, BC5 and BC6 (M_{cm} was different for each). Some general improvement in opinion is evident in Fig. 23 for $\Delta M_c = 0.30 M_{cm}$ and $\tau_\Delta = 0.10$. Definite improvement is evident for all configurations with $\tau_\Delta = 0.20$, although the ratings are poorer than for unlimited pitch control moment. Note that for $\Delta M_c = 0.50 M_{cm}$ and $\tau_\Delta = 0.20$ the flying qualities of BC1 are rated equal to those for unlimited pitch control moment.

Time histories of M_c , the total pitch control moment, which show the effects of stored energy are presented in Fig. 24. These results were measured for the maneuvering subtask with configuration BC1 and $M_{cm} = 0.36$. The stored energy parameters considered are $\Delta M_c = 0.3 M_{cm}$ (0.11 rad/sec^2) with $\tau_\Delta = 0.1$ and 0.2 sec and $\Delta M_c = 0.5 M_{cm}$ (0.18 rad/sec^2) with $\tau_\Delta = 0.2$ sec. These are the parameters used with BC1 to provide the pilot ratings shown in Fig. 23. The stored energy contribution is evident in Fig. 24 as a peak which decays relatively quickly to the M_{cm} level. Note that there is a reduction in the amount of time that the control moment is limited as the contribution from stored energy is increased.

5. Inter-Axis Motion Coupling

a. Pilot Ratings

Attitude rate coupling (M_p, L_q) and control coupling ($M_{\delta_a}, L_{\delta_e}$) were evaluated to determine acceptable limits for such effects (Cases LC1-LC8, Table A-VI, Appendix A). A related objective was to determine whether changes to MIL-F-83300 are needed to account for motion coupling. Background information on this study is contained in Section II.B.1.f. Results from the evaluation of motion coupling are shown in Fig. 25. Pilot ratings and control sensitivities are plotted there versus the level of rate coupling with control coupling shown as a parameter. Configurations BC1 and BC2 were evaluated. For most of the results the coupling effects were additive. For example, a positive pitch control input yields a positive pitch rate and since both L_q and L_{δ_e} were negative, the induced rolling moment was also

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negative. For one test case coefficients having signs which resulted in cancelling moments ($L_q < 0$, $L_{\delta_e} > 0$ and $M_p > 0$, $M_{\delta_a} < 0$) were also evaluated. Note that the pitch and roll rate coupling levels were always equal as were the values for longitudinal and lateral control coupling.

Pilot rating showed a significant, consistent deterioration with rate coupling (Fig. 25(a)). There were no threshold effects evident in pilot rating as control coupling was changed from zero to $M_p = -L_q = 2$. That is, this level of coupling brought about a deterioration in rating of 2 units and the trend continued as rate coupling was increased. Without rate coupling, control coupling ratios up to $M_{\delta_a}/L_{\delta_a} = -L_{\delta_e}/M_{\delta_e} = 0.5$ brought about only a 1 unit decrement in rating (a value of 0.5 indicates a large amount of control coupling). As rate coupling was added the increase in rating (deterioration) caused by control coupling also became somewhat larger. It appears from Fig. 25(a) that a control coupling ratio of 0.25 could be expected to produce a 0.5 to 1 unit deterioration in rating while a ratio of 0.5 results in a 1 to 1.5 unit increase. The deterioration in rating for configuration BC2 caused by $M_p = -L_q = 2$ and $M_{\delta_a}/L_{\delta_a} = -L_{\delta_e}/M_{\delta_e} = 0.25$ was equivalent to that for BC1 with the same coupling parameters. Also, no change in rating occurred for BC2 when the signs of M_{δ_a} and L_{δ_e} were changed such that the rate and control coupling compensated somewhat for each other.

Attitude rate coupling appeared to have a greater effect on rating than control coupling for the levels considered in this study. The results in Fig. 25(a) would tend to indicate that MIL-F-83300 should restrict rate coupling to magnitudes less than about 1 per sec. Also, control coupling ratios greater than about 0.25 should not be permitted.

b. Control Sensitivities

Both the longitudinal and lateral control sensitivities generally tended to increase with rate coupling (Figs. 25(b) and 25(c)). The pilots apparently felt they needed a more rapid attitude response to control the coupling motion. Also, the control sensitivities for the 0.5 control coupling ratio were slightly larger than those for no control coupling. However, as indicated by the MIL-F-83300 reference lines (Fig. 25(b)), the longitudinal control sensitivities for BC1 are within the specification (the maximum boundary is well above the limits of the plot's ordinate scale). Also, the minimum boundary for BC2 is even lower than that for BC1 (not shown). The lateral BC1 sensitivities (Fig. 25(c)) for low rate coupling are somewhat lower than the minimum boundaries. However, the pilots would have had no difficulty controlling with sensitivities corresponding to the specification minimums. The effect of rate and control coupling on control sensitivities is not specifically accounted for by the MIL-F-83300 paragraph on response to control inputs (paragraph 3.2.3.2). However, the range of sensitivities permitted by MIL-F-83300 is sufficiently large that the increase in M_{δ_e} and L_{δ_a} caused by control coupling does not result in their exceeding the upper boundary.

6. Independent Thrust-Vector Control

Pilot ratings from the evaluation of longitudinal thrust-vector control independent of aircraft pitch attitude (ITVC) are shown in Fig. 26 and summarized under Cases L11-L115 in Table A-VII in Appendix A. Lateral ITVC was not considered. The pilots were instructed to rate aircraft flying qualities based on their ability to perform longitudinal-position control tasks using thrust-vector-angle rotation with a minimum of pitch-attitude changes. Note that for the other parts of the UARL program the pilots could change the thrust vector to offset the effects of the mean wind acting through the longitudinal drag parameter. However, he was not permitted to use it for general position control. For the ITVC evaluation he was required to attempt to control longitudinal position exclusively with thrust-vector-angle rotation.

Two Level 1 configurations (BC1, BC4) and a Level 2 configuration (BC2) were evaluated with ITVC.

For configuration BC1, with thumb-switch thrust-vector control and control-stick pitch control and the thrust-vector angle displayed on the contact analog (Fig. 26(a)), the best ratings obtained were nearly as good as those for conventional thrust-vector control through attitude changes (PR = 2 to 2.5 for BC1 with conventional control). The pilots did not find it difficult to control aircraft position with the thrust-vector angle while regulating attitude. The lack of extensive experience with ITVC may have been the major reason for the slightly poorer ratings compared with those for conventional control.

Pilot B also evaluated ITVC (thumb-switch thrust-vector control) for configuration BC1 with only an instrument-panel display of thrust-vector angle. For this case his rating was somewhat poorer because alternating his attention between the contact analog and the thrust-vector-angle panel display increased the difficulty of the control task. With the thrust-vector angle on the contact analog (the cross symbol moved vertically on the right side of the screen to indicate angle) the pilot could derive both longitudinal position and thrust-vector-angle information simultaneously. It should be noted that a thrust-vector-angle display was essential to the performance of the longitudinal maneuvering task. Without such a display longitudinal position could not be stabilized. The pilots apparently controlled thrust-vector angle as an inner loop and aircraft position as an outer loop. This is similar to closure of the pitch-attitude loop as an inner loop for conventional V/STOL aircraft control systems (Ref. 8).

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For configuration BC⁴ the best pilot ratings for ITVC with thumb-switch thrust-vector control (PR ~ 4 for $\dot{\gamma} = 20$ deg/sec, Fig. 26(a)) were slightly poorer than those for conventional control (PR = 3 to 3.5). Configuration BC⁴ (a high-drag configuration) is Level 1 but more responsive to gusts. The larger position disturbances associated with BC⁴ appear to be the reason that the best overall ratings for this configuration were assigned with $\dot{\gamma} = 20$ deg/sec. Rapid thrust-vector angle rates were needed to control position. For BC², the Level 2 configuration (with conventional control), the best rating for thumb-switch ITVC (PR = 4) was slightly better than that for conventional attitude control (PR = 4.5 to 5). Configuration BC² is Level 2 because of its lightly damped attitude dynamics. It may be that control of this configuration was improved with ITVC, because it was not necessary to change attitude to move the aircraft longitudinally. As a result, attitude motion was not excited to the extent that it was for the conventional control system and the pilot's workload may have been reduced.

Results from the evaluation of stick thrust-vector-angle control and thumb-switch attitude control are shown in Fig. 26(b). The thrust-vector-angle change per inch of stick input (or sensitivity) was varied in this study, but the rate-of-change of pitching moment from the thumb switch was fixed at a predetermined satisfactory value. A 0.1-sec lag in thrust-vector-angle response was also simulated. For configuration BC¹ this method of ITVC was satisfactory (Fig. 26(b)), i.e., ratings were similar to those for thumb-switch thrust-vector control. Recall that BC¹ has very stable attitude dynamics and little attitude or position response to turbulence. However, configuration BC⁴ could not be controlled with the stick ITVC and thumb-switch attitude control system. This was due to the difficulty in controlling attitude with the thumb switch for this gust sensitive configuration. The pilot could not pay the necessary attention to attitude control and still control position with ITVC. The result was eventual loss of control. The same comments apply to this type of control for configuration BC².

The UARL evaluation of thrust-vector control independent of aircraft attitude indicates that it could be an acceptable substitute for conventional attitude control, when properly implemented. For large aircraft with Level 1 dynamics the use of ITVC should provide satisfactory flying qualities while enabling the pilot to avoid pitch (or roll) attitudes that could lead to ground strikes. For aircraft having large drag parameters (X_u, Y_v) ITVC would also enable the pilots to control position without the large attitude angles that result for such aircraft with conventional position control through attitude. However, the results from this study for an aircraft with large drag parameter (BC⁴, $X_u = Y_v = -0.2$) indicate that position control for such aircraft remains moderately difficult even with ITVC.

7. Rate-Command/Attitude-Hold Control

The attributes of rate-command/attitude-hold control are that it (1) provides a pitch (roll) rate response proportional to pilot stick commands, and (2) maintains aircraft trim attitudes while enabling the pilot to center his control stick (see Section II.B.1.h. for background). Rate-command/attitude-hold control can be developed with a conventional rate and attitude stabilized V/STOL, by inserting an integration between the pilot's control inputs and the aircraft attitude response. However, to provide satisfactory flying qualities the rate damping and attitude stabilization must be increased to offset the phase lag introduced by the integrator. This can be accomplished by increasing the damping ratio, ζ , of the aircraft's oscillatory roots (with rate damping) and increasing the natural frequency, ω_n , of these roots (with attitude stabilization) beyond the attitude-loop crossover frequency ($\omega_c \approx 2.5$ to 3.5 rad/sec, Ref. 8). Representative effects of changes in ζ and ω_n on the magnitude and phase characteristics of the open-loop pilot-pitch attitude (with no pilot compensation) transfer function are shown in Fig. 27. These results show that increasing ω_n reduces the phase lags near the crossover frequencies $\omega_c \approx 2.5$ to 3.5 rad/sec (and, correspondingly, the pilot lead compensation) more than increasing ζ . Cases LRL-LR15 were evaluated in this study. Flying qualities results for the case are listed in Table A-VIII in Appendix A.

a. Pilot Ratings

The pilot ratings in Fig. 28 for a configuration having the basic air-frame dynamics (i.e., speed stabilities and drag parameters) of BC1 show the effects of both ζ and ω_n for rate-command/attitude-hold control. Ratings are shown in Fig. 28(a) for $\omega_n = 2.80, 3.44, 6.30$ and 7.40 rad/sec. Again, the pitch and roll dynamic characteristics were identical. Several values of ζ were considered for $\omega_n = 2.8$ and 6.3 . The data in Fig. 28(a) indicate that for ω_n in the region of the pitch- and roll-loop crossover frequencies, e.g., $\omega_n = 2.80$ and 3.44 , satisfactory ratings cannot be achieved even with ζ values approaching 1.0. However, for $\omega_n \geq 6.3$ satisfactory ratings resulted for ζ values of 0.5 and possibly lower. Configuration BC4 was evaluated with two natural frequency values ($\omega_n = 4$ and 5 rad/sec) different from those for BC1 to provide a relatively complete map of the effects of natural frequency. There is a significant difference between the moving- and fixed-base data for BC4, but, again, ratings are better for the larger ω_n . It appears, also, that damping ratios in the neighborhood of 0.7 are probably necessary to insure satisfactory flying qualities for these ω_n values. A rate-command/attitude-hold control system was also evaluated for hover and low-speed flight in a previous Boeing study (Ref. 16). In that study an ω_n of 5 rad/sec with $\zeta = 0.9$ resulted in good ratings for lateral flying qualities (PR = 2 to 3 for the optimum control sensitivity) and unsatisfactory ratings were obtained for $\omega_n = 2.5$ rad/sec with $\zeta = 0.9$. These results agree fairly well with the UARL data.

Although the UARL pilots rated a number of the rate-command/attitude-hold test cases satisfactory (LR4, LR6, LR8 and LR15, Table A-VIII, in Appendix A) their comments indicate that it provided no particular benefits for hover and low-speed flight operation. For this type of flight the pilots did not hold given aircraft pitch and roll attitudes sufficiently long to appreciate the fact that trim attitudes could be maintained with the stick centered. Also, the UARL study was conducted without stick centering forces and small offsets from the stick null position resulted in attitude errors when the pilots attention was diverted elsewhere. Finally, it should be noted that the dynamic response portion of MIL-F-83300 (paragraph 3.2.2.1) which stipulates the pitch and roll dynamics necessary for satisfactory flying qualities does not apply to rate-command/attitude-hold control. This paragraph excludes pitch and roll dynamics having an aperiodic root at the origin and admits oscillatory dynamics with $\zeta = 0.3$, providing ω_n is ≥ 1.1 rad/sec. The data from the UARL study show that rate-command/attitude-hold systems are acceptable, although they have an aperiodic root at the origin. However for them to be acceptable, their ω_n must be much greater than 1.1 rad/sec if ζ is only 0.3. Of course, it was not intended that MIL-F-83300 should necessarily apply to rate-command/attitude-hold systems.

b. Control Sensitivities

Longitudinal and lateral control sensitivities from the rate-command/attitude-hold study are shown in Fig. 29. The control sensitivities increase with ω_n but do not show well-defined trends with ζ . The increases in M_{δ_e} and L_{δ_a} with ω_n are to be expected, since larger sensitivities are needed to offset the restoring moments resulting from this large "spring constant". Upper and lower boundary values for control sensitivity, computed from the MIL-F-83300 requirements for control response, are shown in Fig. 29. Two sets of boundary levels, corresponding to two different values of ω_n , are shown for each of the configurations (BC1 and BC4) evaluated. All of the sensitivities affected by the boundary limits shown lie within the acceptable region.

8. Effect of Motion on Pilot Ratings for Longitudinal and Lateral Control

The results of a comparison of pilot ratings for longitudinal and lateral control from moving-base (MB) and fixed-base (FB) evaluations of identical test cases are summarized in Table XI. There the FB-ratings for the different test cases are categorized according to rating level, i.e., satisfactory, unsatisfactory, and unacceptable. The associated MB ratings for the test cases in a given FB rating category are then listed according to whether the MB ratings were better than, equal to, or worse than the corresponding FB rating. The moving-base ratings were consistently no better than, and generally worse than, the fixed-base ratings for the same test

cases. This trend holds for all three of the FB rating categories. Relatively high frequency pitch and roll control inputs must generally be used to control longitudinal and lateral position properly. There may have been a tendency for the pilots to make more abrupt control commands and also to tolerate disagreeable attitude motions (observed on the visual display) more for fixed-base operation. The addition of motion would have made the pilot more aware of undesirable characteristics in test case dynamic responses. This effect could have overshadowed the benefits of added control cues through motion and caused the poorer moving-base ratings.

TABLE XI

EFFECT OF MOTION CUES ON PILOT RATINGS
FOR LONGITUDINAL AND LATERAL CONTROL

| Fixed-Base (FB) Rating-Level, Number of Ratings | Corresponding Moving-Base Rating | | |
|---|--|--|---|
| | Better than FB Number/Percent of Total | Equal FB Number/Percent of Total | Worse than FB Number/Percent of Total |
| Satisfactory, 18 | 4/22 | 3/17 | 11/61 |
| Unsatisfactory, 20 | 7/35 | 1/5 | 12/60 |
| Unacceptable, 6 | 1/17 | 4/66 | 1/17 |

B. Control-Moment Usage

The discussion of the control-moment usage data is presented in four parts. In part 1 the effects of a number of aircraft, control system and task parameters on pitch, roll and simultaneous pitch and roll control-moment usage (as defined by the moment levels exceeded 5 percent of the time) are described. These results were obtained from experiments in which essentially unlimited control moment was available to the pilot. Specifically, the effects of turbulence intensity, aircraft speed stability and drag parameters, flying qualities level, control system lags, motion coupling, and subtask are described. A comparison is also shown between actual simultaneous pitch- and roll-control-moment usage and hypothetical maxima and minima for such simultaneous usage. These results provide insight into the degree to which pilots make simultaneous control commands. In part 2 results from the study of control-moment limits are discussed. The percent time that total control-moment commands exceeded the installed limits are presented

and correlated with the pilot acceptance of the limits. Parts 3 and 4 are concerned with control-moment usage results for the unconventional control systems considered: independent thrust-vector control and rate-command/attitude-hold control, respectively.

In general, comparisons with the MIL-F-83300 specification for control moments are not made in the discussions of control-moment usage. There are two reasons for this: (1) control-moment comparisons were already made in the discussion of the flying qualities results for the control-moment limits study (Section III.A.3) and, (2) the control-moment usage data are described in terms of the 5-percent-exceedance levels which were shown to be lower than the control-moment limits required for pilot acceptance (Section III.A.3). However, the 5-percent-exceedance levels do provide a useful measure for evaluating control-moment usage (see Section II.D.1.b.). Additional control moment usage data are shown in Appendix E. Exceedance plots based on control moment usage in the maneuvering subtasks are presented there which further illustrate the effects of a variety of aircraft and control system parameters.

1. Effects of Aircraft, Conventional Control System and Task Parameters on Control-Moment Usage

- a. Turbulence Intensity

The effects of turbulence intensity ($\sigma_{u_g} = \sigma_{v_g}$) are presented in Figs. 30 and 31 and also listed in Table C-I in Appendix C. The data in Fig. 30 are for configuration BC1 which requires little pilot compensation or "lead" (Level 1) and is relatively unresponsive to turbulence. That is, the configuration has a relatively high level of stability augmentation ($M_{\dot{u}} = L_{\dot{p}} = -1.7$ and $M_{\dot{\theta}} = L_{\dot{\phi}} = -4.2$) and the stability derivatives which describe the moments and forces caused by turbulence, speed stability and drag parameters, respectively, are small ($M_{u_g} = -L_{v_g} = 0.33$, $X_{u_g} = Y_{v_g} = -0.05$). Figure 31 presents results for configuration BC6 which is Level 2, and more responsive to gusts ($M_{u_g} = -L_{v_g} = 1.0$, $X_{u_g} = Y_{v_g} = -0.20$).

For configuration BC1 (Fig. 30) the moment levels corresponding to the 5-percent exceedance level generally increase with turbulence intensity for all tasks, although there is appreciable scatter in the results. Also, none of the 5-percent moment levels (pitch, roll, or combined) scale linearly with turbulence. That is, there is a factor of about 2.4 increase in rms turbulence intensity from 3.4 ft/sec to 8.2 ft/sec but the 5-percent control-moment levels at 8.2 ft/sec are not 2.4 times as great as those for 3.4 ft/sec. The reason the control-moment levels do not scale may be that the control inputs necessary for task performance and the pilot's inadvertent inputs form a bias 5-percent moment level upon which the turbulence

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effects are superimposed. Of course, the 5-percent moment level for pitch has an additional bias due to the 10 kt mean wind acting through M_u . This bias moment is approximately 0.18 rad/sec^2 .

The levels for configuration BC6 (Fig. 31) are significantly larger than those for BC1. This is to be expected because of the greater response of BC6 to gusts, maneuvering airspeeds and the mean wind. For example, the bias moment in pitch for BC6 due to the mean wind is approximately 0.53 rad/sec^2 . The 5-percent roll control-moment levels for BC6 are generally somewhat smaller than those for pitch, probably also because of the increased bias moment in pitch from the mean wind. In addition, the roll moment levels for BC6 show more of a tendency to scale with turbulence than those for configuration BC1. Turbulence has a greater effect on control-moment requirements for BC6 than BC1 because of the greater response of BC6 to gusts. Consequently, it might be expected that in the absence of significant mean-wind effects, as is the case for roll, the control-moment levels for BC6 would exhibit a greater tendency to scale with turbulence.

b. Speed-Stability Parameter

In Fig. 32 and Table C-1 in Appendix C, control-moment results are presented for configurations BC5 and BC4 which show the effects of aircraft speed stability ($M_{u\dot{g}}$, $L_{v\dot{g}}$). Both of these configurations have sufficient stability augmentation to yield Level 1 flying qualities and each has drag parameters of $X_u = Y_v = -0.2$ per sec. Their speed-stability parameters differ by a factor of three, however ($M_{u\dot{g}} = -L_{v\dot{g}} = 0.33$ for BC5 and 1.0 for BC4). The levels in Fig. 32 show an appreciable increase with speed stability for all three control-moment categories. For the individual-axis control moments the increment due to increased speed stability is greater for pitch where the effects of the mean wind are significant. Also, for none of the moment categories does the change in the 5-percent exceedance level scale directly with the factor of three change in speed stability. This would tend to indicate that the control-moment levels required to arrest and initiate position rates and those caused by random pilot inputs are appreciable. If they were not, we might expect 5-percent levels to scale with speed stability because the remaining disturbance moments due to maneuvering airspeed, the mean wind and turbulence all scale with speed stability. It is interesting to note here, also, that MIL-F-83300 accounts, to an appreciable extent, for the effects of speed stability on required control moments. This is accomplished by stating that the required aircraft response must be demonstrated at the airspeeds involved in task performance (paragraph 3.2.3.1, Ref. 1). Also, in the control-moment limit study the specification was found to be adequate for configurations having both large ($M_{u\dot{g}} = -L_{v\dot{g}} = 1.0$) and small ($M_{u\dot{g}} = -L_{v\dot{g}} = 0.33$) speed-stability parameters (Section III.A.3).

c. Drag Parameter

The change in the reference control-moment levels with drag parameter (X_u , Y_v) are shown in Fig. 33 and Table C-I in Appendix C. Configurations BC1 and BC5 are identical except that the drag parameters for BC5 are four times those for BC1 (-0.20 versus -0.05). The results in Fig. 33 show a small general increase in the levels for configuration BC5 which has the larger drag parameters. Increased drag parameters result in larger position disturbances from turbulence. However, maneuvering position rates are generally smaller because of the larger drag forces and these rates are easier to arrest because of the increased position damping. The increased disturbances due to turbulence would probably necessitate larger control-moment levels while the other effects of drag parameter should not increase, and could reduce, the required control levels. That is, the attitude angles and rates-of-change need not be as great to arrest position rates for configurations with larger drag parameters. It appears then, from the results in Fig. 33, that the effects of turbulence may have been dominant since the 5-percent levels increased slightly with drag parameter. The increase would appear to be relatively small, however, for a large change in drag parameter. Certainly, the effects of changes in drag parameter are less than those for the changes in speed-stability parameter that were examined.

d. Level of Flying Qualities

The V/STOL Flying Qualities Specification (MIL-F-83300, Ref. 1) defines three flying qualities levels. Level 1 flying qualities are "clearly adequate for the mission," Level 3 are such that the "aircraft can be controlled safely but pilot workload is excessive or mission effectiveness is inadequate, or both" and Level 2 flying qualities lie between these extremes. The control-moment usage data observed for configurations with Level 1, Level 2, and Level 3 dynamic characteristics are shown on Fig. 34. Results are presented there (and also in Table C-I in Appendix C) for configurations BC4, BC2, and BC3 (Level 1, 2, and 3 configurations, respectively), which have identical speed-stability parameters ($M_{ug} = -L_{vg} = 1.0$). The drag parameters are not identical for each configuration, but drag parameter has a much smaller effect on the 5-percent control-moment level (Fig. 33). There is a general increase in these exceedance moment levels for configurations which fall into the three flying qualities levels of paragraph 3.2.2 in Ref. 1 (Fig. 34) for all three moment categories. That is, as the flying qualities are degraded through reductions in stability augmentation, the control moments used increase. This would indicate that stability augmentation does a more efficient job of compensating the aircraft dynamics and attenuating turbulence inputs than does the pilot. It would appear also that the required levels of installed control moments are decreased with improved aircraft flying qualities.

e. Control System Lags

Control lags appeared to have little effect on control-moment usage. Five percent moment levels for configurations having control system lags are shown in Figs. 35 and 36 (configurations BC5 and BC4, respectively). These data are also summarized in Table C-II in Appendix C. The addition of control lags to BC5, which is Level 1 and has low turbulence response, resulted in a small decrease in the 5-percent levels for pitch and combined control-moment usage, but the levels for roll do not show a consistent change. The effects of control lag on the 5-percent levels for configuration BC4 (Fig. 36) are even less consistent than those for BC5. Configuration BC4 is also Level 1 but more responsive to turbulence than BC5.

f. Inter-Axis Motion Coupling

The effects of both rate and control coupling on the pitch moment levels exceeded 5 percent of the time for configuration BC1 can be seen in Fig. 37 and Table C-IV in Appendix C. Control coupling ($M_{\delta a}/L_{\delta a} = L_{\delta e}/M_{\delta e}$) is treated as a parameter in the three plots of Fig. 37 which correspond to different rate-coupling levels ($M_p = -L_q$). The effects of control coupling alone are shown in Fig. 37(a) where $M_p = -L_q = 0$. These data indicate no significant increase in M_{C5} for a change in control coupling ratios from 0 to $M_{\delta a}/L_{\delta a} = -L_{\delta e}/M_{\delta e} = 0.5$. Recall that for satisfactory pilot ratings control coupling ratios should be kept below 0.25 (Section III.A.5). Consequently, the results in Fig. 37(a) indicate that for acceptable levels of control coupling, the control-moment usage is not changed significantly from that for no control coupling.

However, the results in Fig. 37 show that rate coupling does influence control-moment usage. By comparing the fixed-base data for no control coupling across Figs. 37(a), (b), and (c), it can be seen that pitch control-moment usage increases with rate coupling level. Rate coupling levels greater than $M_p = -L_q = 1$ appear to be unacceptable if satisfactory flying qualities are to be achieved (Section III.A.4). The results in Fig. 37 would indicate that such rate-coupling levels could result in approximately a 10-percent increase control-moment usage.

g. Subtask

Four major subtasks were performed by each pilot during the control-moment-usage study --- maneuvering or air taxi, quick stop, turn-over-a-spot and hover. Two of these, the maneuver and quick-stop subtasks, could be further subdivided according to the direction (longitudinal or lateral) in which the subtask was performed. The effects of each subtask on the 5-percent control-moment-usage level can be seen in Fig. 38 and Table C-I in Appendix C. These data were all obtained for the 3.4 ft/sec turbulence

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intensity level and with the 10-kt mean wind from the north. Note that the aircraft was always headed into the wind except for the turn maneuver.

The subtask for which the pitch and roll 5-percent exceedance level was most often the largest was the quick stop (Fig. 38); the next largest values were for the maneuvering subtask. The lowest levels (pitch and roll) were most often recorded for hover and the next lowest for the turn subtask. The quick stops involve somewhat larger maneuver rates than air taxi and these rates are arrested abruptly. Consequently, it is not surprising that the largest control moments were used there. Hover, on the other hand, generally requires smaller control inputs and the pilots tended to make fewer inadvertent inputs for this subtask. This was generally the situation for turn as well, except that the pilots at times introduced large pitch and roll attitudes for lightly damped configurations, e.g., BC2 and BC3.

The combined control-moment-usage levels are shown with the maneuver and quick-stop subtasks divided into their longitudinal (x) and lateral (y) components. The lateral quick stops resulted in the largest 5-percent-exceedance levels for combined usage and the next largest levels were used for the lateral maneuvers. The combined usage for lateral maneuvering and quick stops may have been larger than that for the same longitudinal subtasks because the lateral subtasks required appreciable control moments while pitch moments were also necessary to compensate for the mean wind. For the longitudinal subtasks pitch moments were needed to perform the maneuvers in the mean wind but roll inputs were small. The lowest levels for simultaneous usage were recorded for the hover task.

h. Simultaneous Usage

An indication of the pilot's tendency to make pitch and roll control inputs simultaneously can be obtained by comparing the sum of the moment levels used for the individual axes with the actual simultaneous usage levels. If the 5-percent-exceedance moment levels for pitch and roll are added, the resulting control moment is that level which would be exceeded 5 percent of the time if the pitch and roll control moments were used simultaneously. The sum of these levels then represents a theoretical maximum for simultaneous moment usage. Also, a practical minimum level for combined usage can be developed if it is assumed that the pitch and roll inputs are independent, i.e., that the pilot does not intentionally correlate his pitch (roll) inputs with the roll (pitch) control motions.

Curves representing the hypothetical maxima and minima for the simultaneous control usage 5-percent exceedance level are shown in Fig. 39 along with the 5-percent moment levels for actual simultaneous usage. The results presented for all six configurations are for the hover subtask only (Table C-I in Appendix C). Similar data were not available in sufficient quantity

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for the other subtasks. The levels representing the upper curve indicate the 5-percent moment levels which would occur if all the pilot's pitch and roll inputs were made simultaneously. The points on the lower curve are the square root of the appropriate sum of the squared 5-percent levels for pitch and roll. That is, it was assumed that the pitch and roll control moments were independent and could be represented by Gaussian probability distributions (the nearly linear curve for hover in Fig. 5 indicates that the Gaussian assumption is reasonable). It can be shown, then, that the square root of the sum of the squares of the individual 5-percent levels represents the simultaneous usage 5-percent level. The remaining curve in Fig. 39 shows the 5-percent levels for actual simultaneous control usage. This curve lies about midway between the two extremes. These results would indicate that, for the hover subtask at least, the minimum total installed control moment for both pitch and roll could be set somewhat less than the sum of the maximum used for individual axis control. However, this total level must still be greater than a level which would be satisfactory for single-axis control.

2. Percent Time Control Moment Commands Exceed Limits

The control-moment limit study (Section III.A.3) was conducted to determine (1) acceptable levels of installed moments for several V/STOL configurations (BC1, BC4, BC5 and BC6) and (2) whether these limits correlated with the 5 percent exceedance levels measured with unlimited control moments. It was found in that study that control moments greater than the 5-percent levels were needed for pilot acceptance. The results presented here give some indication of the acceptability of installed control moments in terms of the percent time the total control command actually exceeds these limits.

Figure 40 contains plots of the percent time total pitch and roll control commands exceeded the installed moments during the maneuvering subtask versus the magnitude of the installed moments (Table C-III in Appendix C). These maximum available control moments, CM_m , are stated as multiples of the average moment levels exceeded 5 percent of the time with unlimited available moments, CM_5 . Note that CM_5 is different for each basic configuration. As would be expected, the percent time the total moment command exceeded the installed moments decreased as CM_m became larger. However, the exceedance percentages become very small as CM_m approaches those levels needed for pilot acceptance ($CM_m \approx 1.2$ to $1.3 CM_5$ for BC1, $\approx 1.0 CM_5$ for BC5 and ≈ 1.2 to $1.3 CM_5$ for BC4 and BC6). For pitch control the exceedance percentages at acceptable CM_m range from about 1.5 percent (average fixed- and moving-base results for BC1) down to almost zero. For roll control the percentages are about the same magnitude. It would appear from these limited results that for pilot acceptability, installed control moments must be set at levels which will not be exceeded often in flight.

3. Control-Moment Usage for Independent Thrust-Vector Control

Independent thrust-vector control might be expected to reduce the requirements for control moments since it eliminates the need to change attitude in order to maneuver the aircraft. However, control moments are still required to attenuate the attitude response to gusts and trim the moments due to airspeeds (developed from maneuvers and the mean wind) acting on the speed-stability parameters. Pitch control-moment- and thrust-vector-angle-usage data are listed in Table C-V in Appendix C.

In Fig. 41 the pitch and control-moment 5-percent exceedance levels for ITVC and conventional pitch attitude control are presented for configurations BC1 and BC4. For both configurations the value of M_{C5} for ITVC is consistently somewhat smaller than that for conventional attitude control.

Exceedance computations were also performed on measured thrust-vector-angle data from the study of ITVC (Table C-V in Appendix C). For the turn maneuver with configuration BC1 the 5-percent thrust-vector-angle exceedance levels ranged from approximately 2 to 8 deg.

4. Control-Moment Usage for Rate-Command/Attitude-Hold Control

Pitch control-moment-usage results for the rate-command/attitude-hold control system are shown in Fig. 42 for three values of the natural frequency of the oscillatory dynamics ($\omega_n = 2.8, 3.44$ and 6.3 rad/sec) and several levels of the damping ratio, ζ . These data are presented for test cases having the basic airframe stability derivatives of configuration BC1. As the damping ratio was increased for both $\omega_n = 2.8$ and 6.3 rad/sec, the configuration became easier to control and the 5-percent exceedance moment level decreased. However, for the two test cases yielding the best fixed-base ratings ($\omega_n = 3.44, \zeta = 0.87, PR = 4$ and $\omega_n = 6.3, \zeta = 0.47, PR = 2.5$) the fixed-base 5-percent moment usage levels were still greater than the corresponding levels for BC1 with conventional attitude control (see Fig. 41).

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SECTION IV

RESULTS OF HEIGHT CONTROL STUDIES

The height control results are discussed in two parts. In part A, the flying qualities data, i.e., pilot opinion ratings and control sensitivities, are discussed and compared with the applicable paragraphs of MIL-F-83300. In part B, the measured thrust-usage data are described. Background material on the experimental design and procedures are contained in Section II. The flying qualities data, pilot comments and measured thrust-usage results from the UARL pilot evaluations are summarized in Appendices A, B and C, respectively. Results from the Calspan pilot evaluations discussed in this section are summarized in Appendix D.

A. Flying Qualities Results

Four separate investigations were conducted during the height control study. These investigations were concerned with (1) the effects of height velocity damping with effectively unlimited thrust-to-weight ratio, (2) the interaction between height velocity damping and thrust-to-weight ratio, (3) lags and delays in the thrust response, and (4) incremental thrust through stored energy.

1. Height Velocity Damping

a. Pilot Opinion Ratings

The effects of height velocity damping, Z_w , on pilot opinion for effectively unlimited thrust-to-weight ratio, $T/W > 1.15$, are presented in Fig. 43 and summarized in Table A-IX (Cases HZ1 through HZ4 and HZ25 through HZ28). Data are shown in Fig. 43 for one Calspan pilot and two UARL pilots. The Calspan pilot evaluations were conducted with no simulated winds and with the simulator in the moving-base mode, while the UARL pilot results were obtained for fixed- and moving-base simulator operation and the standard wind simulation (10-kt mean wind from the north and 3.4 ft/sec gusts along the aircraft x and y body axes). The configurations simulated during these evaluations were BC1 and BC4 which both have Level 1 longitudinal and lateral flying qualities. The ratings from all three pilots are unsatisfactory (and quite similar) for less damping than about $Z_w = -0.35$ per sec. For $Z_w = 0$ the ratings ranged from 8 to 10 and the pilots all commented that stabilizing aircraft vertical motion was extremely difficult. They also indicated that it would probably be impossible to perform any other task, such as a lateral air taxi, in addition to controlling height (see Appendix B, Table B-VIII). The improvement in rating with increased levels of height velocity damping correlates well with the associated reduction in

requirements for pilot lead compensation. The phase lags in the height response to height errors are shown in Fig. 44. Pilots must compensate for these lags at frequencies important to closed-loop height control (0.5 to 1.0 rad/sec; Ref. 7). It is apparent in Fig. 44 that the lead requirements diminish with additional Z_w .

The specification for minimum height velocity damping (paragraph 3.2.5.4) indicates that, for effectively unlimited T/W ($T/W \geq 1.10$), satisfactory height control characteristics can be obtained with $Z_w = 0$. The results in Fig. 43 indicate that the flying qualities are unacceptable without height velocity damping. If the pilot's only task were to control height he may be able to stabilize the altitude loop with $Z_w = 0$. However, the UARL results indicate that if he is also expected to perform tasks involving longitudinal, lateral or directional motion, altitude errors of at least ± 20 ft could be expected. In addition, the precision with which the other tasks could be performed would be seriously degraded by the attention which would have to be given to height control.

b. Collective Control Sensitivities

Pilot-selected control sensitivities from the investigation of height velocity damping are shown in Fig. 45. The sensitivities change little with Z_w although there is a tendency for them to become larger as damping is increased. The minimum permissible MIL-F-83300 boundaries for collective control sensitivity are also plotted in Fig. 45. These boundaries are stated in terms of achieving a climb rate of 100 ft/min 1.0 sec after an abrupt 1-in. control input. Consequently, the boundaries increase as the damping is increased. The control sensitivities from this study all lie well within the allowable range, but they are much closer to the minimum boundary than the maximum. The maximum permissible collective control sensitivities range from $Z_{\delta C} = 12.5$ to 18.1 as Z_w changes from 0 to -0.8.

2. Interaction Between Height Velocity Damping and Thrust-to-Weight Ratio

Figure 46 contains results which demonstrate the interaction between Z_w , T/W and pilot ratings. These data are also listed in Table A-IX, Cases HZ1 through HZ28. In Fig. 46 pilot ratings are presented on a plot of total height velocity damping, Z_{wT} , versus T/W. Similar plots of the results from other height control studies were used to formulate height control power requirements for MIL-F-83300. The data on Fig. 46 were obtained for UARL and Calspan pilots and for fixed- and moving-base flight simulator operation. The basic configuration evaluated was BCl. For most of the data points, Z_{wT} consisted of equal parts of aerodynamic (Z_{wa}) and SAS (Z_{ws}) height velocity damping. However, as indicated in Fig. 46 some of the cases were evaluated with either Z_{wa} or Z_{ws} (but not both) set to

zero. It should be noted that Z_{WS} is provided only within the available T/W. That is, thrust used for damping is instantaneously unavailable for control. Also shown in Fig. 46 are Level 1, 2 and 3 boundaries for height control power from MIL-F-83300.

A definite trade off between the effects of T/W and Z_{WT} on pilot opinion is indicated by the results in Fig. 46. For example, as T/W is increased at constant Z_{WT} , ratings generally improve. Conversely, as the damping is increased for a given T/W, rating also generally improves. These effects tend to justify, to some extent, the shape of the MIL-F-83300 boundaries. However, the data in Fig. 46 are not in complete agreement with these boundaries. One notable exception occurs for the Level 1 boundary at T/W = 1.10 where the UARL results would indicate that total damping greater than -0.25 is necessary for satisfactory ratings. That is, the boundaries in Fig. 46 imply that a T/W > 1.10 is required for a satisfactory rating at $Z_{WT} = 0$. However, the results shown previously in Fig. 45 indicate that even an "unlimited" T/W will not provide satisfactory ratings for $Z_{WT} = 0$. The UARL data would indicate, then, that another boundary line which excludes damping levels smaller than -0.25 should be added to Fig. 46. If this boundary were present the UARL data would also support the movement of the line separating Level 1 and 2 regions to the left. That is, it appears that for a given Z_{WT} less T/W is needed to place a configuration in a Level 1 category than MIL-F-83300 requires.

The interaction between aerodynamic, Z_{WA} , and SAS, Z_{WS} , height velocity damping shown in Fig. 46 merits discussion. A decelerating force which is proportional to descent velocity is available to arrest sink rates in aircraft which have Z_{WA} . Such force may have an appreciable effect on height control for aircraft with limited installed T/W. This increased decelerating force is not available in aircraft with only Z_{WS} . Ratings showing the effects of Z_{WA} and Z_{WS} , with T/W as a parameter, are presented in Fig. 47. For all the cases shown, the total damping was $Z_{WT} = -0.25$, but the relative amounts of Z_{WA} and Z_{WS} were varied. For T/W = 1.02 it appears that the improved ability to arrest sink rates resulting from increased Z_{WA} had a significant impact on flying qualities. As Z_{WA} was changed from 0 to -0.25, pilot rating improved by two units. As T/W was increased the decelerating force from Z_{WA} became less important since the pilot had sufficient T/W to adequately ascend and arrest descents. This is reflected in the smaller change in rating over the same Z_{WA} interval for the larger T/W values. In fact, the moving-base ratings for T/W = 1.10 show almost no variation with Z_{WA} .

3. Lags and Delays in Thrust Response

The effects on pilot rating of first-order lags and a 0.1-sec delay in the thrust response are presented in Fig. 48 and Table A-X (Cases H11 through

HL8). Two values of lag time constant, $\tau_h = 0.3$ and 0.6 sec were evaluated at three levels of Z_{WT} : -0.25 , -0.35 and -0.50 . The thrust-to-weight ratio was held constant at 1.05 and configuration BCl was used for the longitudinal and lateral flying qualities. Except for $Z_{WT} = -0.50$, rating deteriorates with increasing τ_h . The decrement appears to be related to Z_{WT} as well as the change in τ_h (Fig. 48). That is, rating is somewhat less sensitive to τ_h for the higher damping levels. The upward shift in the curves with Z_{WT} is expected since the phase lag in height response at any given τ_h , and hence the pilot's lead compensation, decreases with increasing damping (see Fig. 44). Note also, that the addition of a 0.1 -sec delay had little effect on rating (Fig. 48). Pilot rating for $Z_{WT} = -0.35$ with $d_h = 0.1$ sec and $\tau_h = 0$ is equal to that for no delay, and for $\tau_h = 0.3$ the rating with a 0.1 -sec delay is only a half unit poorer than for no delay.

The specification for lags in thrust response (paragraph 3.2.5.2) is phrased in such a way that, with no delays, a first-order control lag time constant of up to 0.3 sec is permissible. For a $d_h = 0.1$ the specification would permit a lag of $\tau_h \approx 0.2$ sec. The UARL data in Fig. 48 would indicate that the specification is reasonable, providing the aircraft has a Z_{WT} of at least -0.25 to -0.35 per sec. This is the range of minimum values of damping found to be acceptable in the height control studies with no lags. The previous results (e.g., Fig. 43) would indicate that for $Z_{WT} = 0$, $\tau_h = 0.3$ would be completely unacceptable. Also, the specification does not account for the reduction in phase lags contributed by τ_h or d_h , and the associated improvement in rating, which can be achieved with increased levels of Z_{WT} . This effect is illustrated in Fig. 48 and is discussed in detail in Ref. 7.

4. Incremental Thrust Through Stored Energy

The effects of incremental thrust through stored energy (see Section II.A.2.d for background) were investigated with a height control configuration that was unsatisfactory without the stored energy contribution. However, the longitudinal and lateral dynamics were quite easy to control (configuration BCl). For height control the installed T/W was only 1.02 and $Z_{WT} = Z_{WS} = -0.35$, i.e., the pilot had no additional decelerating force from Z_{WA} when descending. Without the incremental thrust from stored energy, height control was unsatisfactory (PR = 4). The change in rating was evaluated for incremental thrust-to-weight ratios of $\Delta T/W = 0.13$ and 0.28 and for decay time constants of $\tau_A = 0.05$, 0.10 and 0.20 sec (Cases HS1 through HS5, Table A-X). With $\Delta T/W = 0.13$, an improvement in rating was not evident until $\tau_A = 0.20$ (Fig. 49). For the larger thrust increment, $\Delta T/W = 0.28$, a general improvement in rating occurred for $\tau_A = 0.10$ sec. For both the $\Delta T/W = 0.13$, $\tau_A = 0.20$ and $\Delta T/W = 0.28$, $\tau_A = 0.10$ combinations, the ratings improved by about one unit to PR = 3.0. For effectively unlimited T/W, the rating was 2.5. The results indicate that for τ_A values which might be typical for helicopters, i.e., $\tau_A = 0.10$ to 0.20 sec, the effects of incremental thrust

through stored energy can be significant. It should be noted, also, that for height control the pilot probably does not use the stored energy effects to their fullest advantage. Height control generally involves low-frequency control motions; consequently, the stored energy in the rotor system is not used as often as it is for pitch and roll control.

5. Effect of Motion and Pilot Ratings for Height Control

Fixed-base (FB) and moving-base (MB) pilot ratings for height control are compared in Table XII. The FB ratings for the different test cases are categorized by general rating level (satisfactory, unsatisfactory and unacceptable). The associated MB ratings are then tabulated according to whether they were better than, equal to, or worse than the FB ratings. The results in Table XII are mixed and only for the unsatisfactory FB rating

TABLE XII

EFFECT OF MOTION CUES ON PILOT
RATINGS FOR HEIGHT CONTROL

| Fixed-Base (FB) Rating Level, Number of Ratings | Corresponding Moving-Base Rating | | |
|---|--|--|---|
| | Better Than FB Number/Percent of Total | Equal FB Number/Percent of Total | Worse Than FB Number/Percent of Total |
| Satisfactory, 4 | 1/25 | 1/25 | 2/50 |
| Unsatisfactory, 7 | 5/72 | 1/14 | 1/14 |
| Unacceptable, 2 | 0/0 | 2/100 | 0/0 |

category is a definite result indicated. For this category the moving-base ratings were generally better than the corresponding fixed-base data. It would appear that motion helped in the control of these more difficult test cases. It may be that the motion was more beneficial for height control than for longitudinal and lateral control because the visual display provides less information on height error than it does for these other two axes.

Consequently, motion cues would have helped more for height control. This effect may not have been evident for unacceptable FB ratings because the rating scale becomes less sensitive to such effects due to its implicit nonlinearities for the unacceptable region. That is, for test cases which are very difficult to control the differences between 7 and 8 or 8 and 9 ratings are not easy to establish and pilots tend to rate such cases similarly.

B. Thrust Usage

Thrust-usage data were obtained which show (1) the effects of Z_w , (2) the percent time that pilots attempted to exceed the installed thrust-to-weight ratio, and (3) the effects of lags. The thrust exceedance results were computed using only the pilot and total thrust commands for which $T/W > 1$. These are the collective inputs which are used to accelerate upward and to arrest sink rates. Also, thrust usage levels are given in terms of incremental thrust-to-weight ratio, i.e., $(T/W-1)$.

1. Height Velocity Damping

The effects of total height velocity damping, Z_{wT} , on the level of incremental thrust-to-weight ratio exceeded 5 percent of the time are shown in Fig. 50 and listed in Table C-VII. Results are shown for both the collective command, $Z_{\delta C} \cdot \delta C$, and the total thrust command, $Z_{\delta C} \cdot \delta C + Z_{wS} \cdot w$. Three levels of Z_{wT} (0, -0.25 and -0.5 per sec) were evaluated for effectively unlimited T/W ($T/W > 1.15$). The data in Fig. 50 show that Z_{wT} has a significant effect on the 5-percent exceedance level, $(T/W-1)_5$. The 5-percent level for $Z_{wT} = 0$ is as much as six times that for Z_{wT} of -0.25 or -0.5. Obviously, the stability augmentation system makes much more efficient use of the installed thrust than the pilot. Also, there generally seems to be little difference between the exceedance levels for $Z_{wT} = -0.25$ and -0.50. It would appear that increasing Z_{wT} above what is a minimum satisfactory level (e.g., $Z_{wT} \sim -0.25$) does not lead to significant changes in thrust usage. Note also that for relatively well damped cases, $Z_{wT} = -0.25$ and -0.50, the largest thrust levels are used for the landing sequence. This is to be expected, since for this subtask the pilot intentionally makes several large altitude changes. For $Z_{wT} = 0$, however, large thrust levels are used for other subtasks in which the pilot is merely attempting to maintain constant altitude. Normally, large values of $(T/W-1)$ are not needed for such control if the height dynamics are acceptable to the pilot.

2. Limits on the Installed Thrust-to-Weight Ratio

The effects of limits on the installed thrust-to-weight ratio are discussed in terms of the percent time pilots attempted to exceed the incremental T/W available. The collective control was not physically constrained at the thrust limits for this study. The thrust limits were evident only in the way they affected height control. Consequently, if the pilot felt he

needed more thrust, he tended to move the collective lever accordingly, whether or not the installed T/W had been exceeded. Results are presented in Fig. 51 for two levels of Z_{wT} (-0.25 and -0.50) with T/W as a parameter. For $Z_{wT} = -0.25$ (note that $\tau_h = 0.3$ for the $T/W = 1.05$ data) the two types of commanded thrust, $Z_{\delta_c} \cdot \delta_c$ and $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$, both exceeded the $T/W = 1.02$ level a large percent of the time. Fifty percent was not uncommon for $Z_{\delta_c} \cdot \delta_c$ and 20 percent was typical for the total commanded thrust. However, the percentages for $T/W = 1.05$ were much smaller. More often than not, the $T/W = 1.05$ level was never exceeded. The results for $Z_{wT} = -0.50$ show the same trends, but the percent time a given level is exceeded is smaller. For example, the maximum percent time that $T/W = 1.02$ was exceeded for any subtask was 30 percent. Also, the only time that $T/W = 1.05$ was exceeded was for the landing sequence and the percentage there was relatively low. These results provide another example of SAS making more efficient use of thrust than the pilot.

3. Thrust Response Lags

Some limited data showing the effects of an acceptable first-order lag in thrust response ($\tau_h = 0.3$) are presented in Fig. 52. For these results Z_{wT} is -0.25 and T/W is 1.10. The 5-percent exceedance levels are generally somewhat larger for $\tau_h = 0.3$ (and appreciably larger for the y-maneuver subtask) than for the no lag case. However, these data are too limited to permit the conclusion that significantly more thrust is needed for height control systems with lags.

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SECTION V

RESULTS OF DIRECTIONAL CONTROL STUDIES

The results of the directional control studies are presented in two parts. Pilot ratings and pilot-selected control sensitivities are discussed and compared with applicable paragraphs of MIL-F-83300 in part A. In part B the measured yaw control-moment data are discussed. Background information related to the directional control experiments is contained in Section II. The flying qualities data, pilot comments, and control-moment data are summarized in Appendices A, B and C, respectively.

A. Flying Qualities Results

Three different studies were conducted during the directional control program. These studies consisted of evaluations of the effects of (1) yaw rate damping, (2) control system lags and delays, and (3) limits on yaw control moment.

1. Yaw Rate Damping

Pilot rating is plotted versus yaw rate damping level, N_r , in Fig. 53(a) for configurations BC1 and BC2. Note that these ratings are for directional control only. Three values of N_r (0, -0.5 and -1 per sec) were evaluated at $N_y = 0.005$. Pilot rating was marginally unacceptable (PR ~6.5) for $N_r = 0$ and marginally satisfactory (PR = 3.5 to 4) for $N_r = -0.5$. Ratings improved to about 2.5 with $N_r = -1$ for both BC1 and BC2. Recall that BC2 has Level 2 longitudinal and lateral characteristics and such dynamics result in an increase in overall pilot workload. It might have been expected, therefore, that a degradation in pilot rating of the directional flying qualities could result. However, this was not the case. The reason for the improvement in rating with damping level can be interpreted in terms of the pilot lead compensation necessary for good closed-loop directional control characteristics. As for height control, the directional lead compensation requirements are related to the open-loop phase lags of the directional dynamics (and the pilot dynamics) in the frequency range of 0.5 to 1 rad/sec (Ref. 7). These phase lags are shown in Fig. 54. It is apparent that the need for lead compensation is diminished as N_r becomes more negative.

The MIL-F-83300 requirement for directional damping (paragraph 3.2.2.2) states that for Level 1 flying qualities the yaw mode must be stable with a time constant no greater than one sec. This is approximately equivalent to specifying $N_r = -1$ for Level 1 flying qualities and the UARL results in Fig. 53(a) show that satisfactory ratings result for such a value. The data also indicate that a somewhat lower damping level of about -0.5 per sec

may provide satisfactory directional control for $N_v = 0.005$. However, the value of N_v can be larger than 0.005 for helicopters and V/STOL aircraft. Since directional flying qualities generally deteriorate with increasing N_v (Ref. 7), the $N_r = -1$ Level 1 requirement appears reasonable.

Control sensitivities selected by the pilots during the yaw rate damping study are shown in the following list along with the minimum and maximum values permitted by MIL-F-83300. The UARL data from the two pilots and the moving- and fixed-base evaluations have been averaged.

| N_r | UARL $N_{\delta r}$ | MIL-F-83300 Boundaries for $N_{\delta r}$ | |
|-------|------------------------|--|---------|
| | | Minimum | Maximum |
| 0 | 0.207 | 0.210 | 0.804 |
| -0.5 | 0.236 | 0.244 | 0.935 |
| -1 | 0.299 | 0.282 | 1.080 |

The UARL control sensitivities almost match the lower boundary values from MIL-F-83300 and, consequently, they are well below the upper limits for $N_{\delta r}$.

2. Control Lags and Delays

First-order lags in yaw response to the pilot's pedal inputs having time constants of $\tau_\psi = 0.1, 0.3$ and 0.6 were evaluated with and without a 0.1-sec time delay. Two values of N_r (-0.5 and -1) were used with configuration BCL providing the longitudinal and lateral dynamics. Pilot ratings from these cases are shown in Fig. 53(b). There is a consistent deterioration in rating with lag time constant for both $N_r = -0.5$ and -1 . Also, the ΔPR due to the different N_r values remains about the same for all τ_ψ , i.e., the ratings for $N_r = -1$ are consistently about 1 unit better. The addition of the 0.1-sec delay did not change the ratings significantly (Fig. 53(b)). The effect of the lags and the different N_r values can once more be rationalized in terms of the required pilot lead compensation. The phase lags encountered in directional control increase with τ_ψ which in turn increases the requirement for pilot lead compensation and this causes pilot rating to deteriorate. Increasing the damping level, N_r , reduces the phase lags and thereby improves the pilot's rating at a given value of τ_ψ .

The results in Fig. 53(b) show that for a Level 1 value of N_r (-1), first-order lags with time constants of up to $\tau_\psi = 0.3$ are acceptable. The

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specification for directional control lags (paragraph 3.2.4) is written in terms of an allowable time within which the initial maximum yaw acceleration must occur ($t_{\dot{\psi}_{max}} \leq 0.3$ sec). The value of $t_{\dot{\psi}_{max}}$ for the lag cases evaluated (with and without $d_{\psi} = 0.1$ sec) with $N_r = -1$ are summarized in the following list.

| <u>N_r</u> | <u>τ_{ψ}</u> | <u>d_{ψ}</u> | <u>$t_{\dot{\psi}_{max}}$</u> | <u>PR</u> |
|-------------------------|---------------------------------|------------------------------|--|-----------|
| -1 | 0.1 | 0 | 0.24 | 3 |
| | | 0.1 | 0.34 | 2 |
| -1 | 0.3 | 0 | 0.51 | 3.5 |
| | | 0.1 | 0.61 | 3.8 |
| -1 | 0.6 | 0 | 0.86 | 4.8 |
| | | 0.1 | 0.96 | 4.7 |

Without delays the specification excludes $\tau_{\psi} = 0.3$ ($t_{\dot{\psi}_{max}} = 0.51 > 0.30$) although this test case was rated satisfactory. Also, the specification permits a 0.1-sec delay which the UARL data indicate is reasonable. However, if $d_{\psi} = 0.1$ is present a 0.1-sec increment is added to $t_{\dot{\psi}_{max}}$. As a result, some combinations of d_{ψ} and τ_{ψ} which are acceptable to the pilot, e.g., $\tau_{\psi} = 0.3$ and $d_{\psi} = 0.1$ are made to appear even more unacceptable in terms of the MIL-F-83300 requirement. That is, $t_{\dot{\psi}_{max}} = 0.61$ for $\tau_{\psi} = 0.3$ and $d_{\psi} = 0.1$ which is twice the allowable $t_{\dot{\psi}_{max}}$ value (0.30), yet the averaged rating for this case is almost on the satisfactory boundary (PR = 3.8). The control lag specification (paragraph 3.2.4) assumes that the time to maximum angular acceleration limit of 0.3 sec is applicable to pitch, roll and yaw motion. It was shown previously (Section III.A.2) that this requirement is adequate for first-order lags in pitch and roll response. However, it appears that a longer time to maximum angular acceleration is appropriate for yaw.

3. Control-Moment Limits

Yaw control-moment limits were evaluated to determine acceptable values of installed yaw moment for the UARL task. The total yaw control moment was limited, but pitch and roll control moments were effectively unlimited. This evaluation was conducted for two values of N_r (-0.5 and -1 sec) with configuration BCl. The reference value for yaw moment was the average level exceeded 5 percent of the time for the turn subtasks conducted during the turbulence intensity study ($\bar{N}_{C5} = 0.10$). Note that this value of \bar{N}_{C5} was appropriate only for configuration BCl. Larger values were recorded for other configurations (see Section III.A.3). Pilot ratings from this study are presented in Fig. 55. For the Level 1 value of N_r (-1) an installed yaw control moment of $N_{Cm} \approx 1.3 \bar{N}_{C5}$ was necessary for pilot

acceptance. With $N_r = -0.5$ the required value for N_{cm} was considerably larger ($\approx 1.6 \bar{N}_{c5}$). If nominal lateral maneuvering velocities of 15 ft/sec are assumed, MIL-F-83300 requires that the installed yaw control moment be approximately 0.31 rad/sec². This level is well in excess of the 0.13 rad/sec² found to be necessary with configuration BC1. However, as mentioned previously, the levels of yaw control moment used varied among the different Level 1 configurations ($\bar{N}_{c5} = 0.175$ for BC4 and 0.15 for BC5). If it were assumed that for configuration BC4 the required installed $N_{cm} = 1.3 \bar{N}_{c5}$, then N_{cm} would have to be 0.228 rad/sec². This value is also less than the 0.31 rad/sec² specified by MIL-F-83300.

4. Effect of Motion on Pilot Ratings for Directional Control

Fixed-base (FB) and moving-base (MB) pilot ratings for directional control are compared in Table XIII. The method of comparison is similar to

TABLE XIII

EFFECT OF MOTION CUES ON PILOT
RATINGS FOR DIRECTIONAL CONTROL

| Fixed-Base (FB) Rating Level, Number of Ratings | Corresponding Moving-Base Rating | | |
|---|--|--|---|
| | Better Than FB Number/Percent of Total | Equal FB Number/Percent of Total | Worse Than FB Number/Percent of Total |
| Satisfactory, 5 | 2/40 | 1/20 | 2/40 |
| Unsatisfactory, 8 | 5/62.5 | 1/12.5 | 2/25 |
| Unacceptable, 1 | 1/100 | 0/0 | 0/0 |

that described previously for the height control ratings. The effect of motion on the rating results is also quite similar to those for height control. That is, motion had little effect for satisfactory FB ratings, but improved the ratings for test cases which were more difficult to control

(i.e., those which were rated unsatisfactory and unacceptable with no motion). As for height control, the reason for the improved ratings with motion may have been the improved cues which resulted for heading. This effect would be expected to be more significant for heading control than for longitudinal and lateral control. This is because the visual display provides much better control cues for longitudinal and lateral control than for directional control.

B. Control-Moment Usage

Two of the three investigations related to yaw control-moment usage were based on data obtained with unlimited yaw moment available. The effects of N_r and control lags were evaluated in these two studies. The third study was concerned with the percent time the total yaw control command exceeded the installed moment. Only results for the turn subtask were considered in the control-moment-usage investigations. Very little yaw control moment was used for the other subtasks.

1. Yaw Rate Damping

The effects of N_r on the 5-percent yaw moment exceedance levels are displayed in Fig. 56(a). As was the case for pitch, roll and height control, the 5-percent level for yaw moment decreases with increased damping. Again, it is apparent that with increased levels of stability augmentation, more efficient use is made of the available control moments.

2. Control Lags

The percent-time reference yaw moment levels were exceeded was computed from the moment data for $\tau_\psi = 0.3$ with $N_r = -0.5$ and for $\tau_\psi = 0.3$ and 0.6 with $N_r = -1$. The moment levels exceeded 5 percent of the time are presented in Fig. 56(b). For both levels of N_r there was a significant increase in the 5-percent-exceedance value, N_{C5} , when a first-order lag of 0.3 sec was added to the control system. A further increase in N_{C5} was observed for a lag of 0.6 sec. The increase in N_{C5} is approximately 50 percent for the addition of $\tau_\psi = 0.3$ sec with $N_r = -1$. The results in Fig. 53(b) indicate that this combination yields satisfactory flying qualities. If satisfactory levels of control lag can cause this large an increase in the yaw control-moment usage, it would appear prudent not to change the MIL-F-83300 specification for installed yaw moments. Without control lags the MIL-F-83300 requirements appeared somewhat larger than the yaw control moments found necessary for pilot acceptance in the UARL studies (Sections V.A.3 and III.A.3).

3. Control-Moment Limits

The percent time that total yaw control-moment commands exceeded the installed moment limits are shown in Fig. 56(c). These percentages were computed from yaw control-moment-usage data for the moment limit values evaluated in the study discussed in Section V.A.3 ($N_{C_m} = 1.0 \bar{N}_{C_5}$, $1.3 \bar{N}_{C_5}$ and $1.6 \bar{N}_{C_5}$ where $\bar{N}_{C_5} = 0.10$). As would be expected, the percentages decreased as the installed yaw control moment increased. Also, these results show that the yaw control-moment level which was acceptable to the pilots, $N_{C_m} = 1.3 \bar{N}_{C_5}$, was exceeded 5 percent of the time. Recall that the reference, $\bar{N}_{C_5} = 0.10$, was the averaged 5-percent exceedance moment level for all the data measured during the turn subtask in the turbulence study (Section III.A.1), when essentially unlimited control moment was available. The larger 5-percent level from the yaw limit study, $N_{C_m} = 0.13$, may have resulted from the pilot's tendency to hold in large pedal inputs which exceeded the yaw control-moment limits. This was done in an attempt to command increased yaw control moment. For unlimited yaw control moments available the aircraft responded to these large inputs and the pilot did not hold the pedal command as long.

SECTION VI

SUMMARY OF PRINCIPAL RESULTS AND RECOMMENDATIONS FOR FURTHER RESEARCH

A. Flying Qualities Results Pertaining to the Development of MIL-F-83300

1. Longitudinal and Lateral Control

a. Turbulence Effects

The Level 1 requirement for V/STOL pitch, roll and yaw dynamic response (paragraph 3.2.2) appears to provide aircraft dynamics which remain quite controllable for nominal increases in turbulence intensity. Pitch and roll control sensitivities selected by the pilots at the largest turbulence intensities considered ($\sigma_u = \sigma_v = 8.2$ ft/sec) remained well within the specification boundaries (paragraph 3.2.3.2) and were much closer to the minimum required levels than to the maximum limit. These results and previous UARL experience would indicate that the upper control sensitivity limits would result in aircraft response which might be difficult to control.

b. Control Lags and Delays

The specification for control lags (paragraph 3.2.4) adequately separated unsatisfactory levels of first-order lags in pitch and roll control response from those which did not significantly degrade pilot ratings for Level 1 configurations (i.e., those that met the Level 1 requirement of paragraph 3.2.2 of MIL-F-83300) evaluated in this study. Pilot ratings also show that permitting a 0.1-sec delay in control response, as the specification does, is reasonable. However, limited results for second-order control lags indicate that the specification may not be sufficiently general to apply to second-order control lags. Control sensitivities selected in this study were generally near, and sometimes below, the minimum MIL-F-83300 boundary. It may be appropriate to lower both the minimum and maximum control sensitivity boundaries somewhat.

c. Control-Moment Requirements

The pitch and roll control-moment requirements from MIL-F-83300 (paragraph 3.2.3.1) generally equalled or exceeded those levels found to be necessary in this program for the Level 1 and 2 configurations considered (without control system lags or delays). Also, the specified control moments were generally not excessive. The addition of control system lags and delays increased the control moments found to be necessary for satisfactory ratings, and the wording of paragraph 3.2.3.1 also provides for this effect. However, the specification control-moment requirements may be excessive for control systems with acceptable lags.

d. Control Moments Through Stored Energy

It appears that rotor-propulsion system angular momentum can be used to offset, to some extent, deficiencies in the installed control moments. However, additional research is required before consideration can be given to accounting for its effects in MIL-F-83300.

e. Inter-Axis Motion Coupling

Pitch and roll rate coupling and control coupling can cause an appreciable deterioration in V/STOL flying qualities. Results from this study indicate that rate coupling levels must be no larger than $M_p = 1$ and/or $L_q = -1$ per sec for satisfactory flying qualities. Control coupling ratios should be limited to $M_{\delta a}/L_{\delta a}$ and/or $L_{\delta e}/M_{\delta e}$ less than about 0.25. The control sensitivity specification does not have to be changed to account for motion coupling.

f. Independent Thrust-Vector Control

Thrust-vector control independent of aircraft attitude can be an acceptable substitute for conventional attitude control when properly implemented. For large aircraft with Level 1 pitch and roll dynamics, the use of ITVC should provide satisfactory flying qualities while enabling the pilot to avoid pitch (or roll) attitudes that could lead to ground strikes. For aircraft having large drag parameters, ITVC would enable pilots to control position without the large attitude changes and trim attitude angles that result for such aircraft with conventional position control through attitude. However, position control for such aircraft would remain moderately difficult, even with ITVC.

g. Rate-Command/Attitude-Hold Control

It appears that rate-command/attitude-hold control as mechanized in this study provides no particular benefits over conventional rate and attitude stabilized control systems for hover and low-speed flight operations. Also, the dynamic response portion of MIL-F-83300 (paragraph 3.2.2.1) does not define characteristics which provide satisfactory dynamic response for rate-command/attitude-hold control systems. However, the specification for control sensitivities (paragraph 3.2.3.2) does encompass those sensitivities needed with rate-command/attitude-hold control.

2. Height Control

a. Z_w and Thrust-to-Weight Ratio

There is a definite interaction between Z_w , T/W and height control flying qualities for T/W less than about 1.05. This result supports to

some extent the method used in MIL-F-83300 to specify Z_w and T/W (paragraph 3.2.5.1). However, MIL-F-83300 permits $Z_w = 0$ for $T/W \geq 1.10$, but results from the UARL program indicate that a minimum $Z_w = -0.25$ to -0.35 is necessary for Level 1 height control. Also, if this Z_w level is present, it would appear that the T/W boundary separating Level 1 and 2 flying qualities could be reduced. Height control sensitivities from this study were within the specification limits (paragraph 3.2.5.3) but were much closer to the minimum boundary than the maximum.

b. Lags and Delays in Thrust Response

The specification for lags and delays in thrust response (paragraph 3.2.5.2) appears reasonable in view of the UARL results. However, it does not account for the ability of increased Z_w to compensate for lag effects.

c. Incremental Thrust Through Stored Energy

Results indicate that the effects of incremental thrust through stored energy can alleviate, to an extent, deficiencies in installed thrust. However, these data are presently too limited to permit consideration of changes in MIL-F-83300 to account for its effects.

3. Directional Control

a. Yaw Rate Damping

Results from this program indicate that the directional damping paragraph in MIL-F-83300 (3.2.2.2) which requires $N_r = -1$ for Level 1 flying qualities is reasonable. Also, the pilot-selected yaw control sensitivities, N_{δ_r} , almost matched the lower boundary values from paragraph 3.2.3.2.

b. Control Lags and Delays

The control lag specification (paragraph 3.2.4) should be modified to permit a longer time to attain maximum yaw acceleration, $t_{\dot{\psi}_{max}}$. For acceptable control lags and delays, $t_{\dot{\psi}_{max}}$ was as much as twice the MIL-F-83300 limit (0.3 sec).

c. Yaw Control-Moment Requirements

The specification for yaw control moment (paragraph 3.2.3.1) requires control moments which are without exception larger than those found to be necessary in this program. However, the yaw control-moment requirements of the specification do not appear to be excessive.

B. Control-Moment Usage

1. Longitudinal and Lateral Control

Pitch and roll control-moment usage increases with turbulence intensity. However, the increase does not scale directly with turbulence intensity, apparently because there is a minimum level of control-moment usage which exists without turbulence due to the moment requirement for task performance, trim of the mean wind, and inadvertent pilot inputs. Speed stability is the aircraft/control system configuration parameter having the greatest effect on control-moment usage. The change in the 5-percent-exceedance moment levels for a threefold increase in speed stability was much greater than that for a factor of four change in drag parameter. Drag parameter may not have to be a consideration in the development of control-moment criteria. The change in control-moment usage with speed stability was also greater than that which resulted when aircraft pitch and roll dynamics deteriorated (accomplished by reducing the level of stability augmentation) from Level 1 to Level 3. Control-moment usage increased with decreasing level of augmentation which confirms that stability augmentation systems make more efficient use of control moment than does the pilot. Control lags had little effect on pitch and roll control-moment usage, and it may be possible to eliminate them from consideration in the development of control-moment specifications. Pitch and roll control coupling also had little effect on control-moment usage, but usage did increase with pitch and roll rate coupling.

The low-speed flight task required of a V/STOL aircraft has been shown to have an appreciable effect on control-moment usage. The 5-percent-exceedance moment levels for the quick stop are as much as 1.5 times as large as those for hover. The expected task must be accounted for when defining requirements for installed control moment. Also, the installed total moment for pitch plus roll control must be sufficient to account for simultaneous control usage by the pilot. It cannot be assumed that pilots make independent pitch and roll control inputs.

Finally, it appears that specifying levels for installed control moment by requiring that they equal those levels which the pilot would be expected to exceed 5 percent of the time is not acceptable. However, it may be that acceptable installed control-moment levels would correlate better with those levels exceeded a smaller percent of the time.

2. Height Control

Thrust usage decreased with increased levels of height velocity damping. Lags in the thrust response increased thrust usage; this contrasts with the effect of lags on pitch and roll control-moment usage. With satisfactory levels of Z_w , installed thrust-to-weight ratios of 1.05 were seldom exceeded and $T/W = 1.10$ was never exceeded.

3. Directional Control

Yaw control-moment usage decreased with increased yaw rate damping for the values of yaw rate damping tested, i.e., $|N_r| < 1.0$. Moment usage increased with lags in the yaw response to control inputs, however.

C. Effects of Flight Simulator Motion Cues on Pilot Ratings

For longitudinal and lateral control the addition of flight simulator motion resulted in poorer pilot ratings than those assigned when the same test cases were evaluated without motion. This trend was evident for all cases, regardless of their flying qualities, i.e., whether or not they had been rated satisfactory, unsatisfactory or unacceptable without motion. For both height and yaw control, however, the addition of motion generally resulted in improved ratings for test cases which were rated unsatisfactory or unacceptable without motion. For cases rated satisfactory fixed base, the addition of simulator motion appeared to have little effect on the pilot's rating of height or directional flying qualities.

D. Recommendations for Further Research

It is recommended that the following research be conducted to obtain information pertinent to the further development of MIL-F-83300.

(1) Additional fixed- and moving-base flight simulator studies of control-power usage should be conducted. In these studies, the significance of aircraft, control system and task parameters would be further evaluated and the control-power specification would be tested in more detail.

(2) The ability of rotor-propulsion system stored energy to compensate for limits in installed control power should be investigated in more detail.

(3) Additional unconventional control systems such as on-off (bang-bang) control and velocity-vector (TAGS) control should be evaluated to determine their attributes. Modifications to MIL-F-83300 to extend its coverage to these systems must be explored. Independent thrust-vector control should also be examined in more detail; it appears to be a promising concept, but was only given limited study in this program.

| LEVEL | | 1 | | 2 | | 3 | |
|-------------|-----|-----|-----|-----|-----|-----|---|
| BASIC CONF. | BC1 | BC4 | BC5 | BC2 | BC6 | BC3 | |
| SYMBOL | ○ | □ | △ | ◇ | △ | ○ | ○ |

LEVEL RELATES FLYING QUALITIES TO PITCH AND ROLL DYNAMIC RESPONSE REQUIREMENTS IN PARAGRAPH 3.2.2 OF MIL-F-83300 (REF. 1)

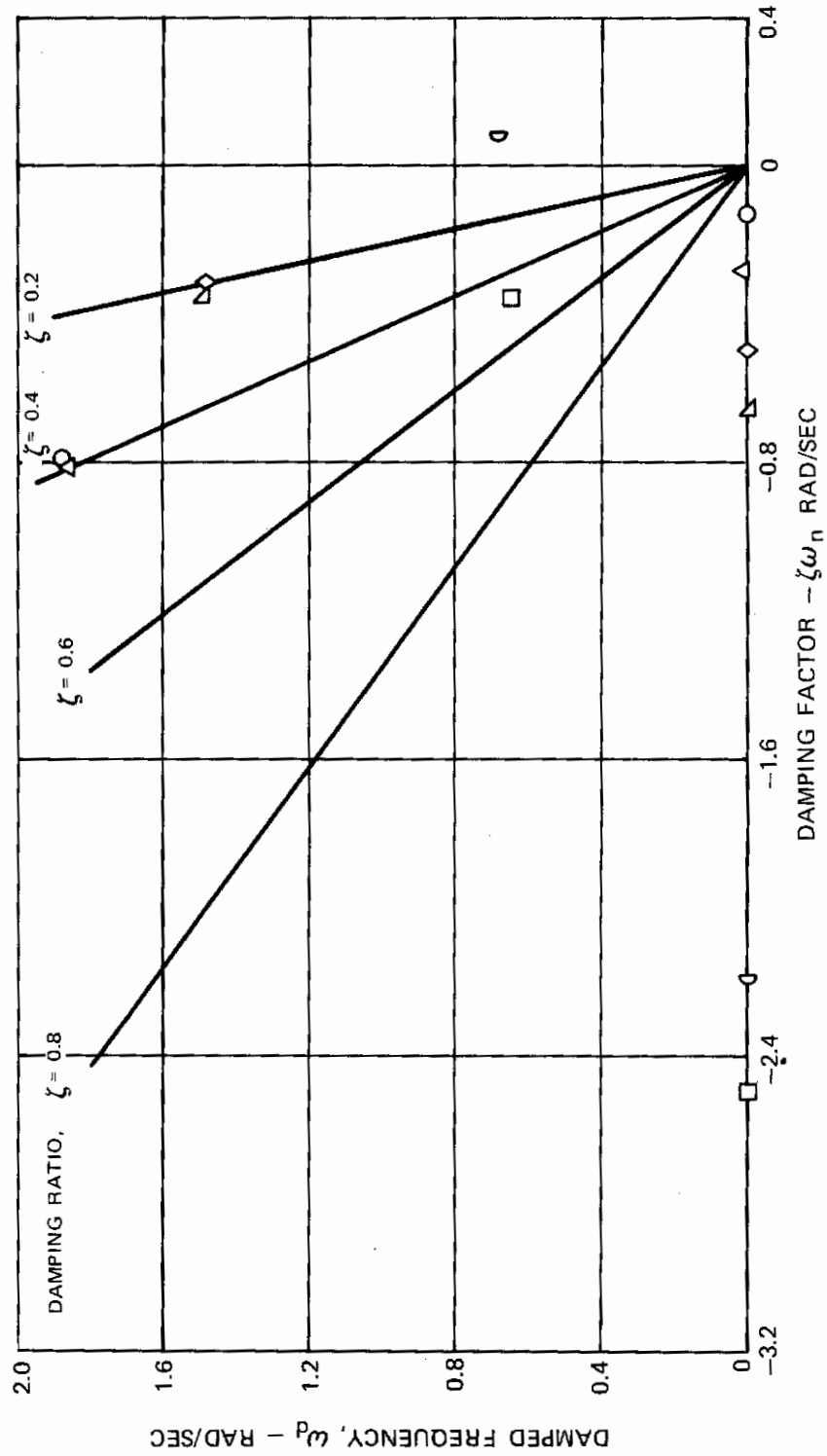


Figure 1. Root Locations for UARL Basic Configurations

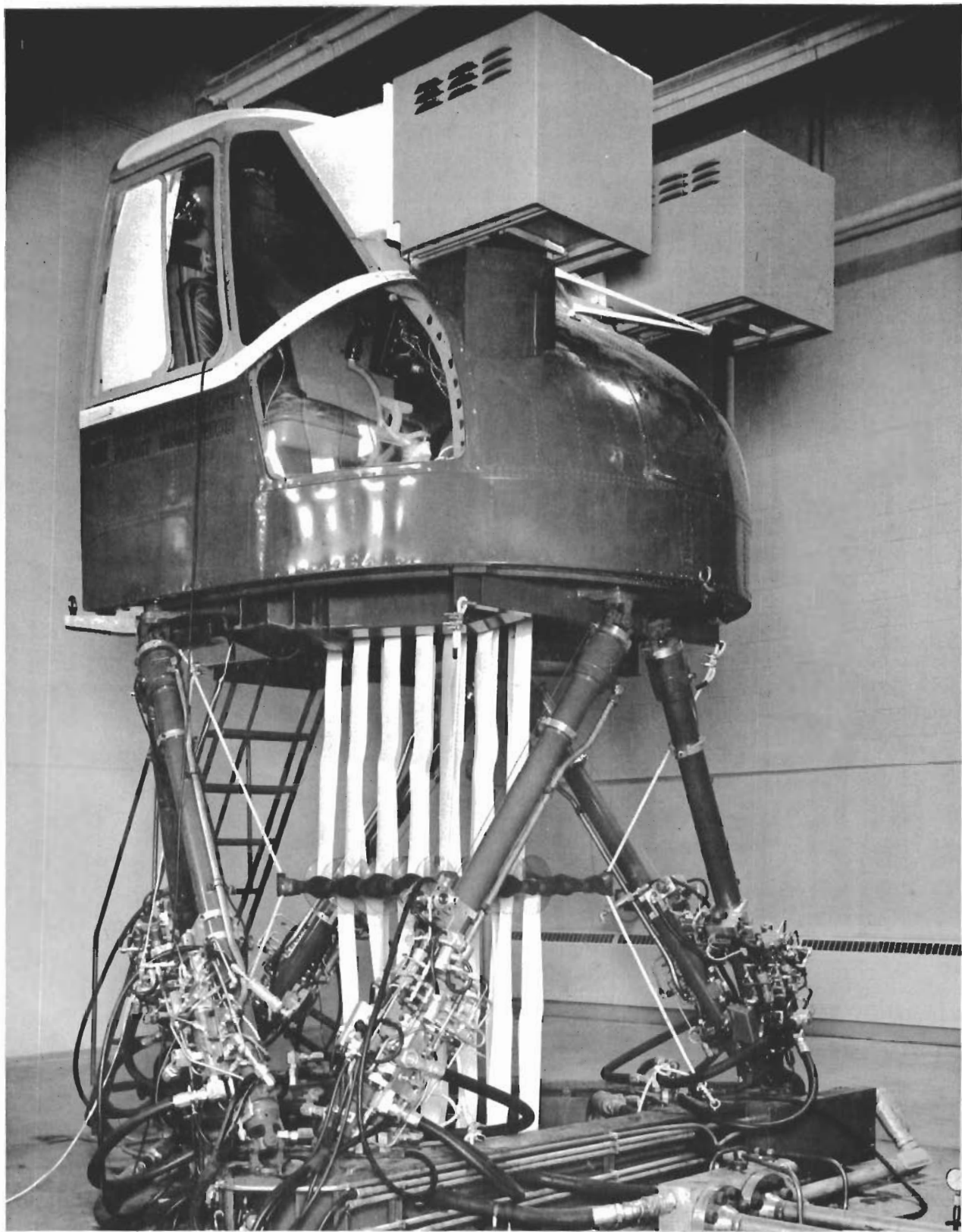


Figure 2. United Aircraft Corporation V/STOL Aircraft Flight Simulator

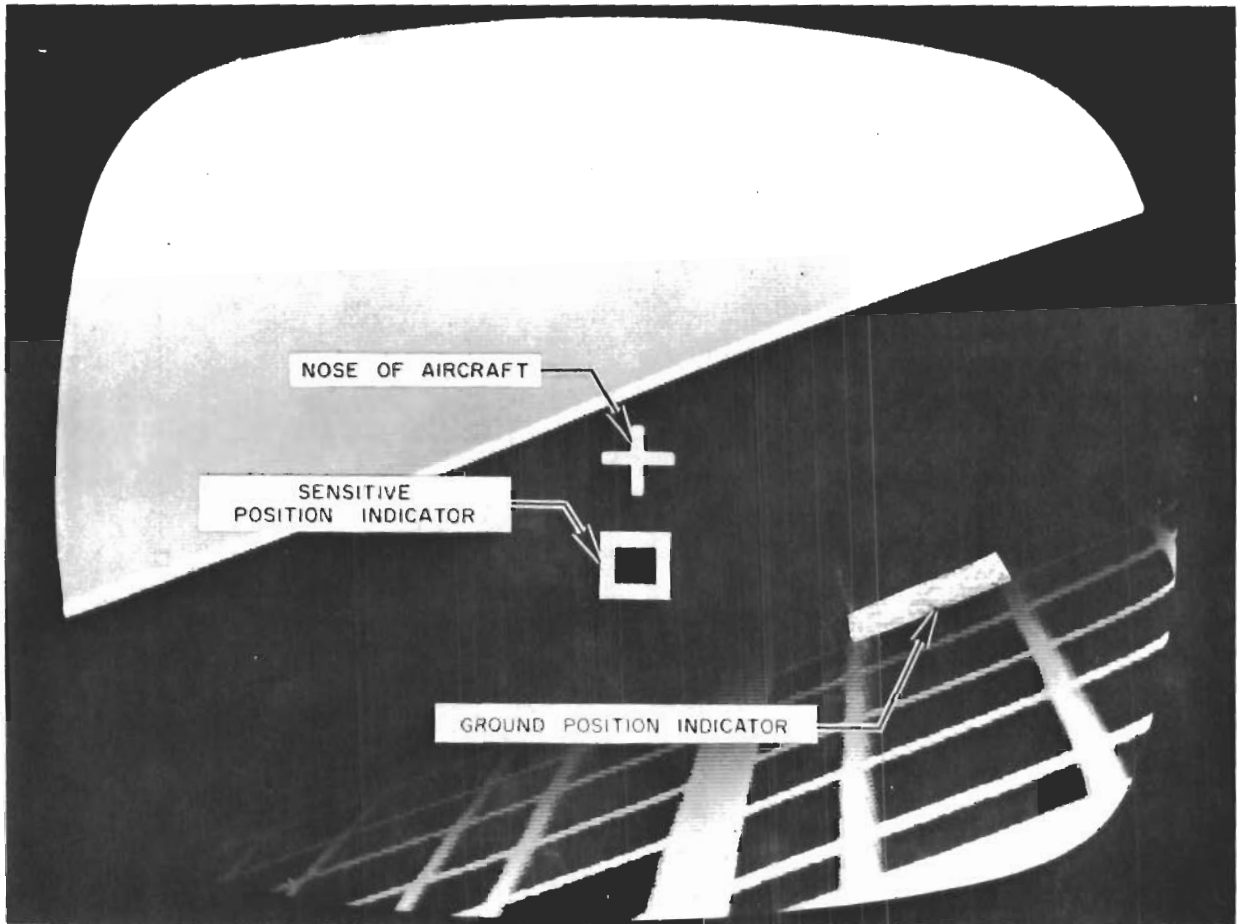


Figure 3. Contact Analog Display for Hovering and Low-Speed Maneuvering Task

| | | | |
|----------------|-------|----|--------|
| SIMULATION | UJARL | | NORAIR |
| SIMULATOR MODE | FB | MB | MB |
| SYMBOL | ○ | ● | ■ |

$$\sigma_{u_g} = \sigma_{v_g} = 3.4 \text{ FT/SEC}$$

$$U_m = 10 \text{ KTS FROM NORTH}$$

*SEE NOTE ON LEVEL DESIGNATION SHOWN ON FIG. 1

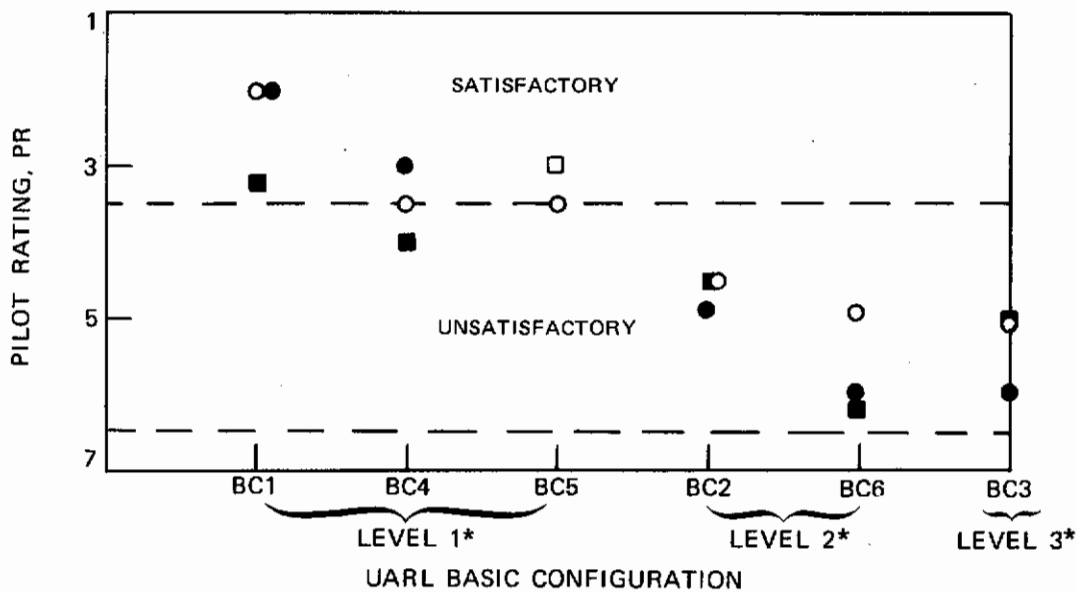


Figure 4. Comparison of Averaged Pilot Ratings from UJARL and Norair Simulations for Similar Configurations

| SUBTASK | MAN | QS | TU | HOV |
|---------|-----|----|----|-----|
| SYMBOL | ○ | □ | △ | ◇ |

CONFIGURATION BC1 PILOT B $\alpha_{u_0} = \alpha_{v_0} = 3.4$ FT/SEC

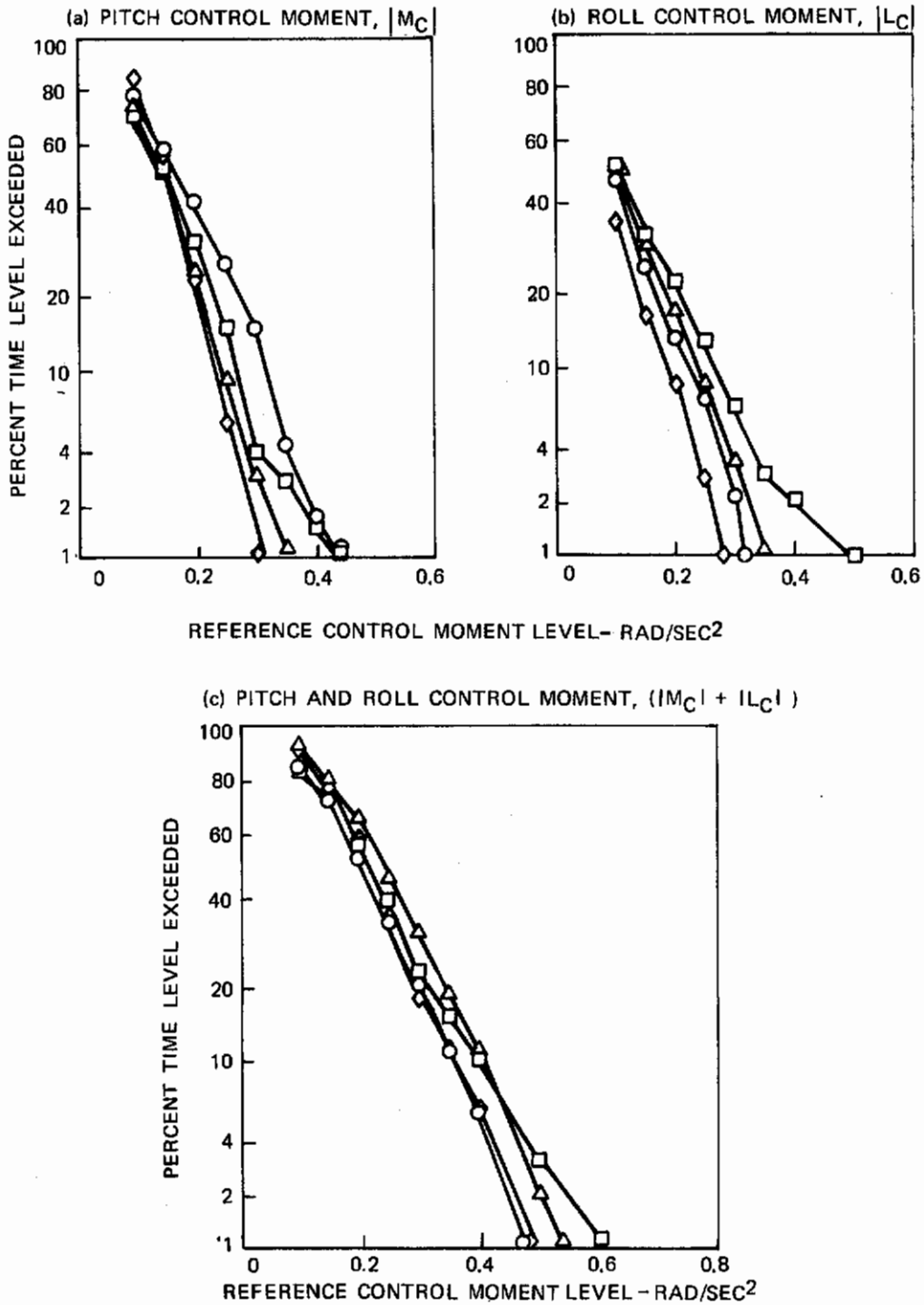


FIGURE 5. Representative Exceedance Plots Showing the Effects of Subtask on Control-Moment Usage

| SIMULATOR MODE, PILOT CONFIGURATION | FIXED, A | | FIXED, B | | MOVING, B | |
|-------------------------------------|----------|-----|----------|-----|-----------|-----|
| | BC4 | BC1 | BC4 | BC1 | BC4 | BC1 |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

BC1, BC4 LEVEL 1 CONFIGURATIONS $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

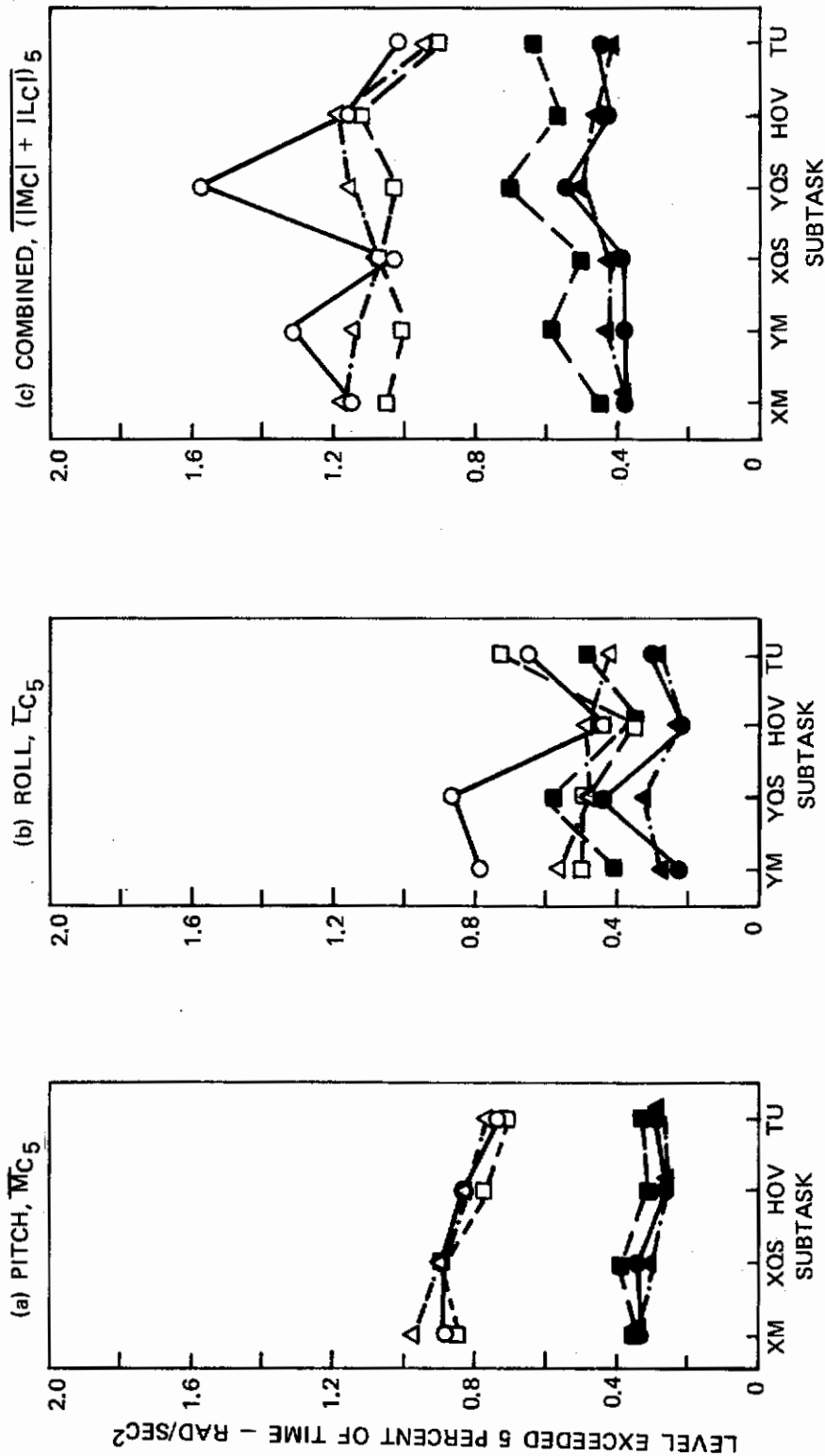


FIGURE 6. Variations in Moment Level Exceeded Five Percent of Time for Two Pilots and Fixed- and Moving-Base Simulator Operation

| LEVEL # | 1 | | | | | | 2 | | | | | | 3 | |
|----------------|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|----|----|
| | BC1 | | BC4 | | BC5 | | BC2 | | BC6 | | BC3 | | FB | MB |
| BASIC CONF. | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | | |
| SIMULATOR MODE | ○ | ● | □ | ■ | ▲ | △ | ◇ | ◆ | ▽ | ▼ | ▲ | △ | ▽ | ▼ |
| SYMBOL | | | | | | | | | | | | | | |

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES

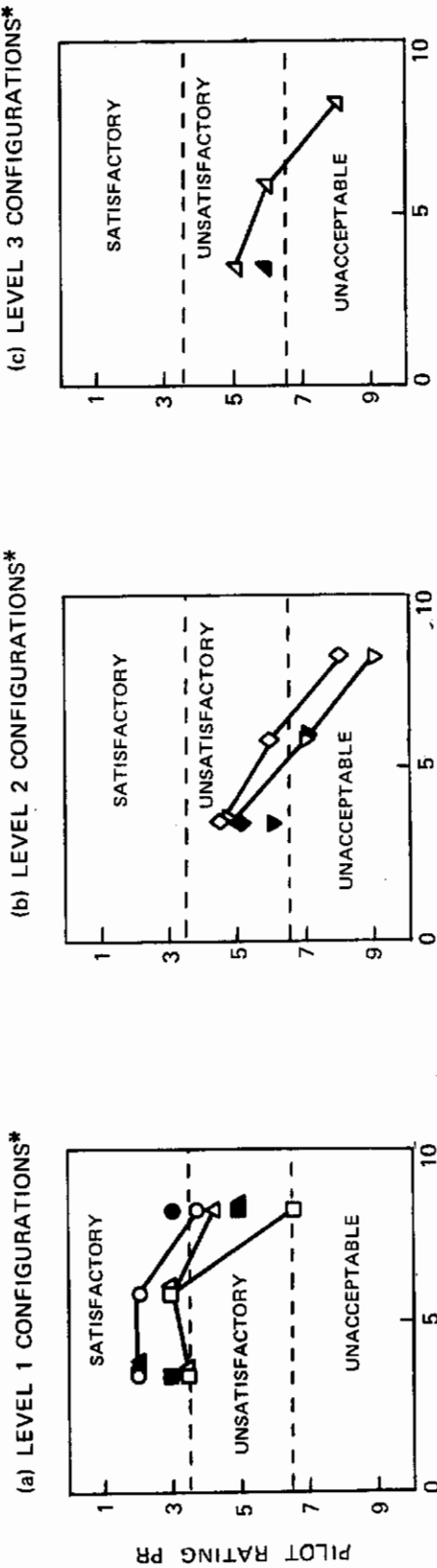


Figure 7. Variation in Pilot Rating with Turbulence Intensity

| TURBULENCE INTENSITY INTERVAL | 3.4-5.8 | | 5.8-8.2 | | 3.4-8.2 | |
|-------------------------------|---------|----|---------|----|---------|----|
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

* LEVEL APPLIED TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

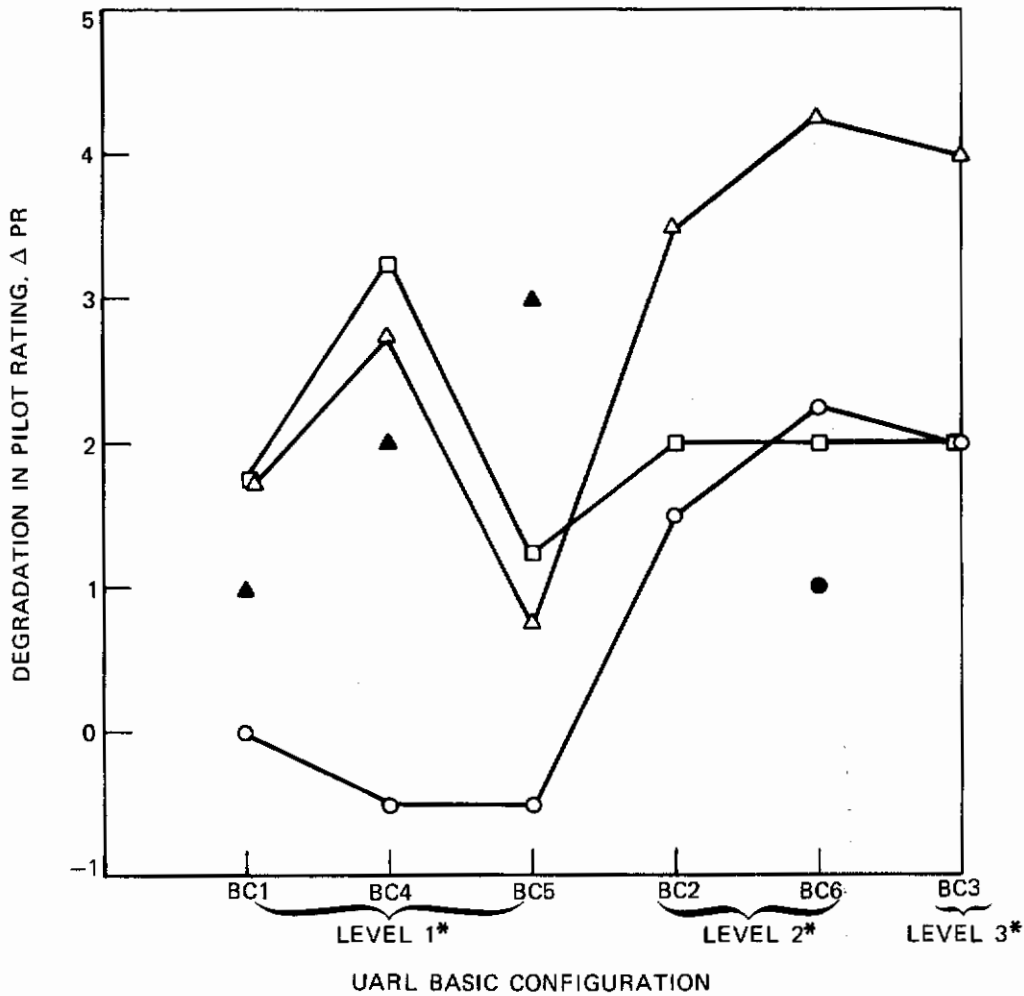


Figure 8. Effect of Pitch and Roll Dynamics Level on Degradation in Pilot Rating with Turbulence Intensity

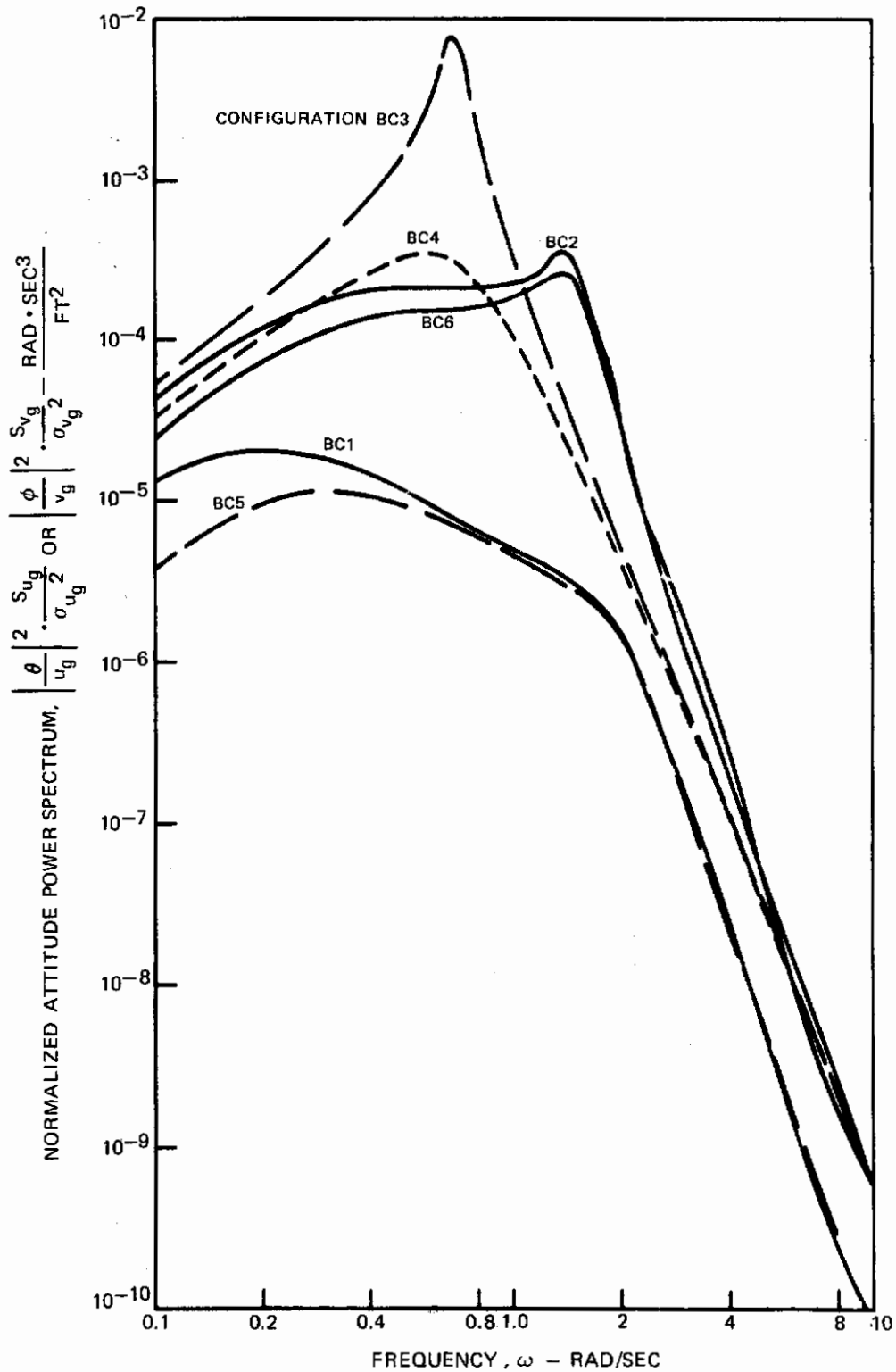


Figure 9. Power Spectrum of Open-Loop Attitude Response to Simulated Turbulence for Basic Configurations

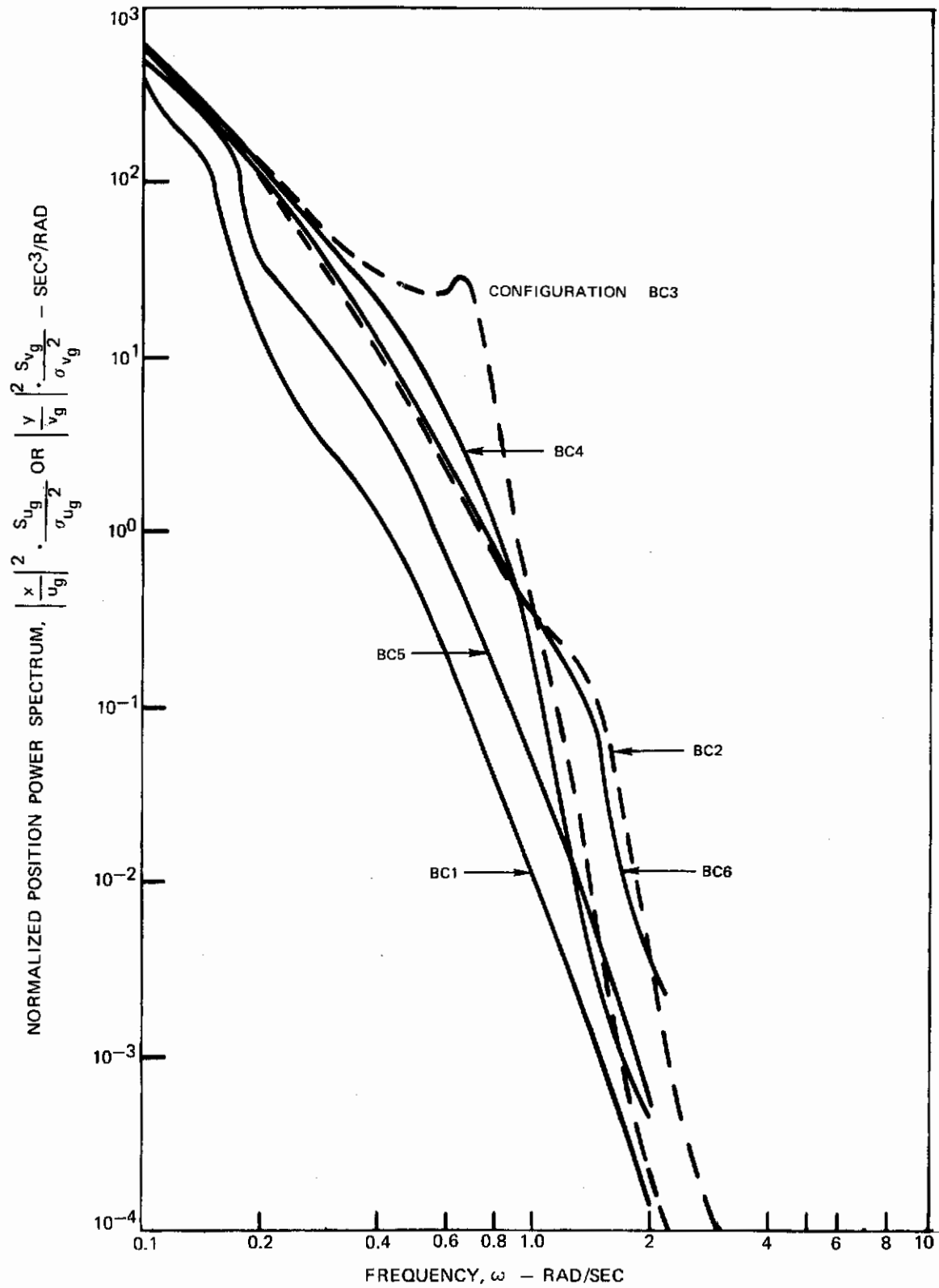


Figure 10. Power Spectrum of Open-Loop Position Response to Simulated Turbulence for Basic Configurations

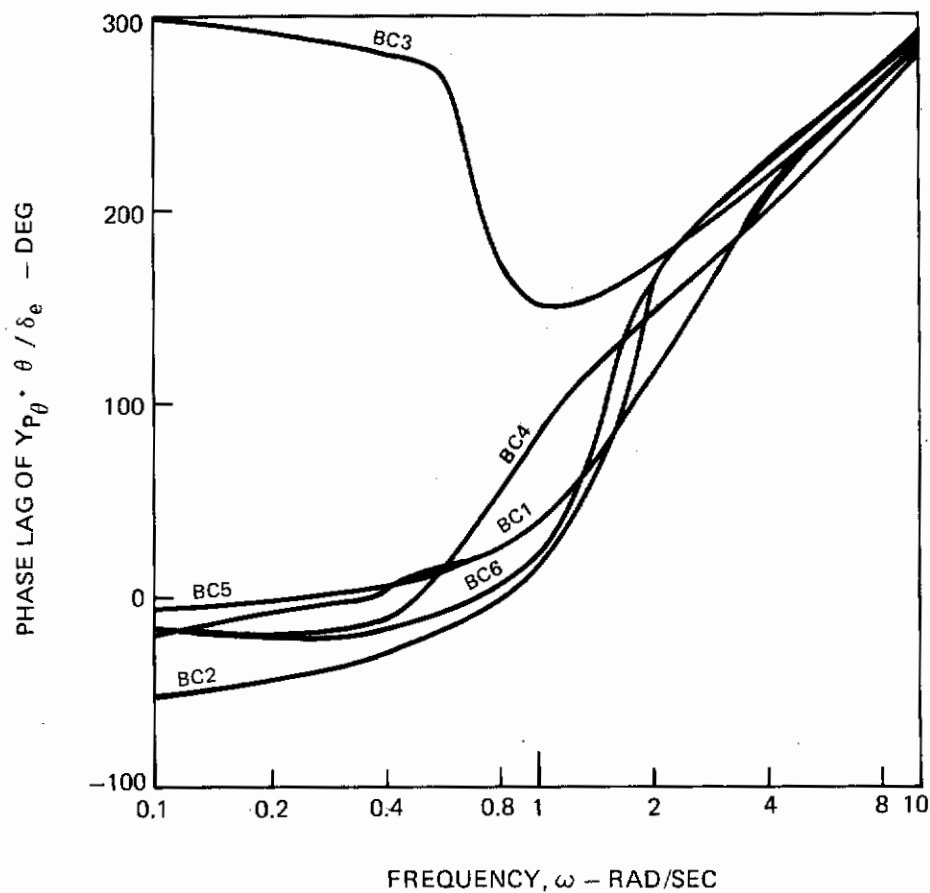


Figure 11. Phase Lag of Pilot-Pitch (Roll) Open-Loop Dynamics for UARL Basic Configurations

| LEVEL* | 1 | | | 2 | | | 3 | | |
|----------------|-------------|----|---|-------------|----|---|-------------|----|---|
| | BASIC CONF. | | | BASIC CONF. | | | BASIC CONF. | | |
| SIMULATOR MODE | BC1 | | | BC2 | | | BC3 | | |
| | FB | MB | ● | FB | MB | ◆ | FB | MB | ▲ |
| SYMBOL | BC4 | | | BC5 | | | BC6 | | |
| | FB | MB | ○ | FB | MB | △ | FB | MB | ▽ |

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

DASHED LINES SHOW MIL-F-83300 BOUNDARIES FOR ACCEPTABLE M_{δ_e} BOUNDARIES BASED ON SPECIFIED MINIMUM AND MAXIMUM ATTITUDE RESPONSE (NORMALIZED WITH CONTROL COMMAND MAGNITUDE) ONE SECOND AFTER CONTROL INPUT

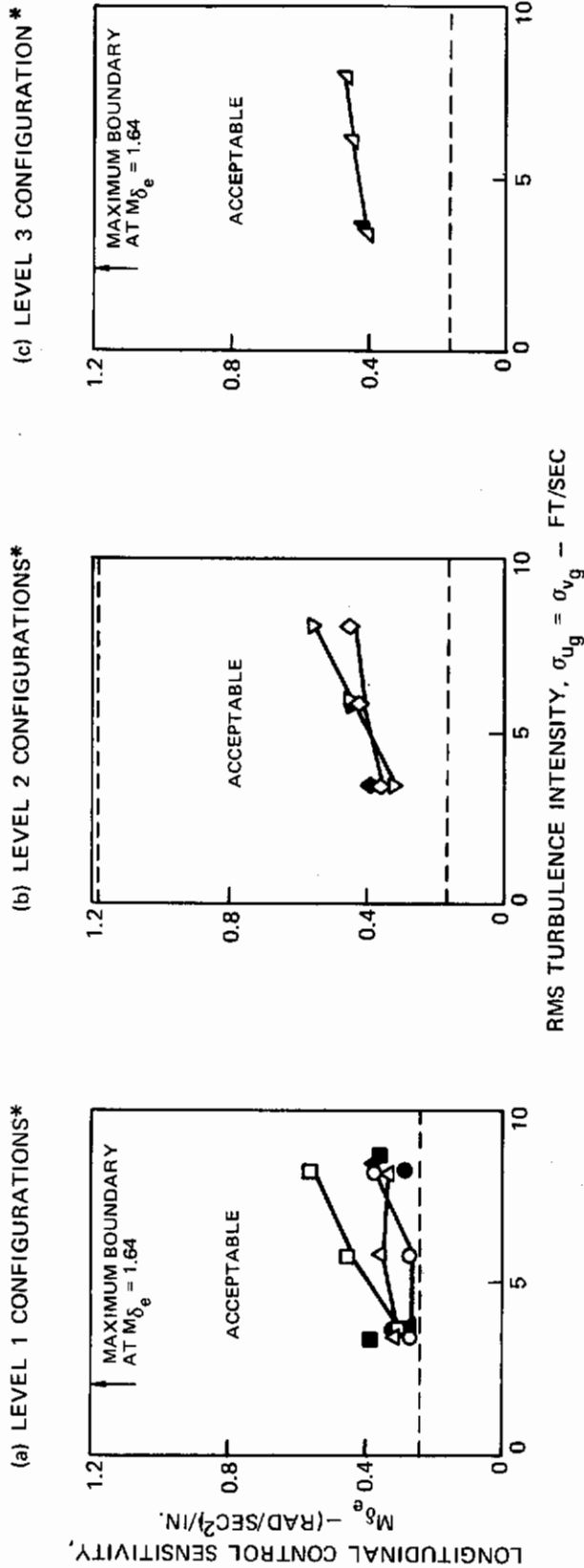


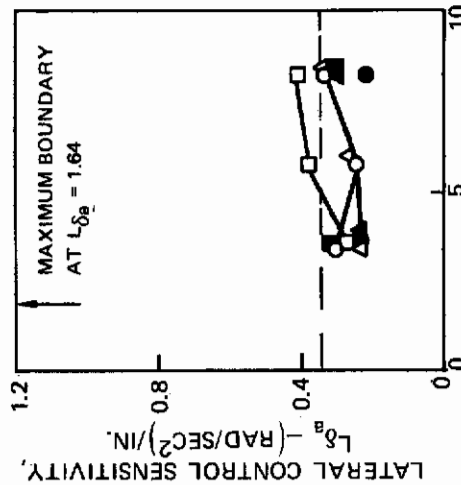
Figure 12. Longitudinal Control Sensitivities from Turbulence Study

| LEVEL * | 1 | | | | | | 2 | | | | | | 3 | |
|----------------|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|---|--|
| | BC1 | | BC4 | | BC5 | | BC2 | | BC6 | | BC3 | | | |
| BASIC CONF. | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | | |
| SIMULATOR MODE | ○ | ● | □ | ■ | △ | ▲ | ◇ | ◆ | ▽ | ▼ | ▷ | ◁ | | |
| SYMBOL | | | | | | | | | | | | | | |

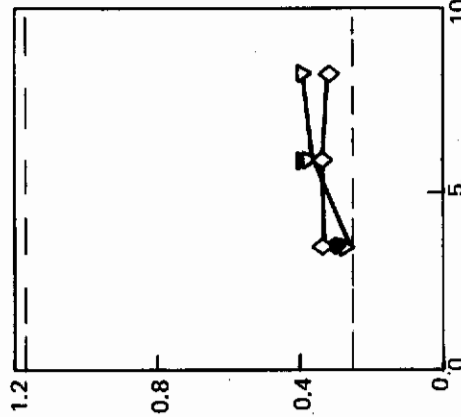
* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

DASHED LINES SHOW MIL-F-83300 BOUNDARIES FOR ACCEPTABLE $L_{\delta a}$. SEE NOTE ON FIG. 12.

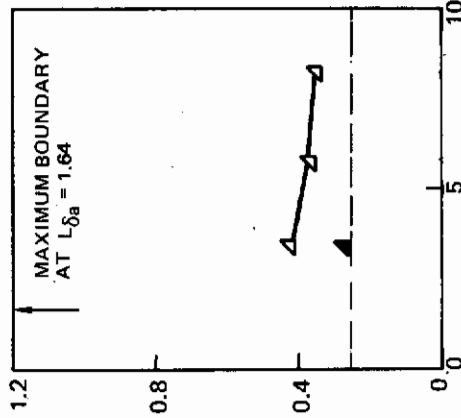
(a) LEVEL 1 CONFIGURATIONS*



(b) LEVEL 2 CONFIGURATIONS*



(c) LEVEL 3 CONFIGURATION*

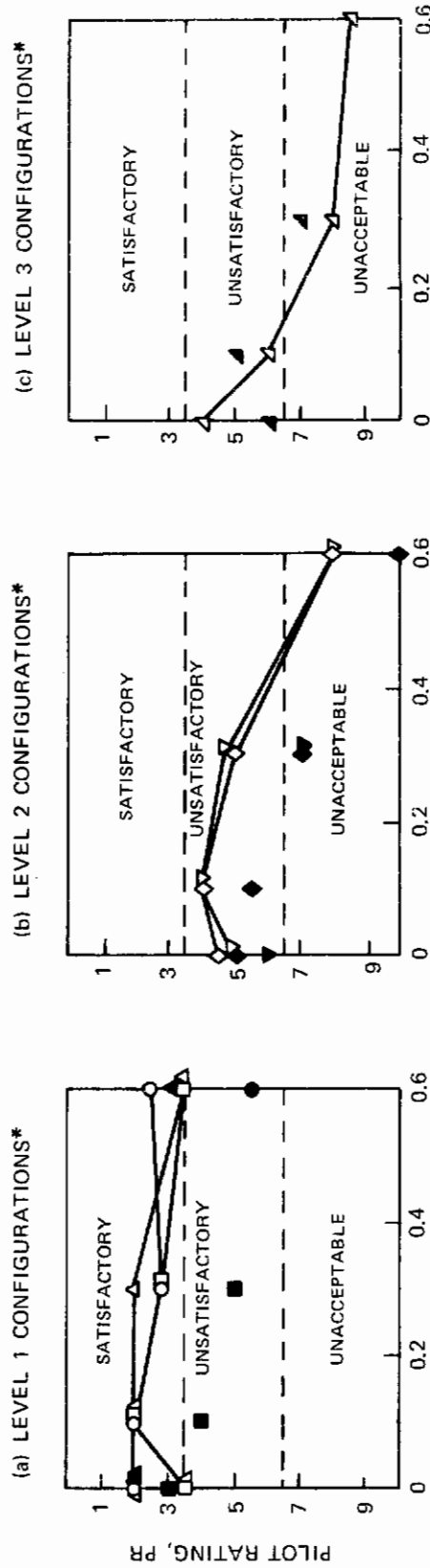


RMS TURBULENCE INTENSITY, $\sigma_{ug} = \sigma_{vg}$ - FT/SEC

Figure 13. Lateral Control Sensitivities from Turbulence Study

| LEVEL * | | 1 | | | | | | 2 | | | | | | 3 | |
|----------------|--|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|----|----|
| BASIC CONF. | | BC1 | | BC4 | | BC5 | | BC2 | | BC6 | | BC3 | | | |
| SIMULATOR MODE | | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB |
| SYMBOL | | ○ | ● | □ | ■ | △ | ▲ | ◇ | ◆ | ▽ | ▼ | ▷ | ▴ | ▷ | ▴ |

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.



FIRST-ORDER LAG TIME CONSTANT, $\tau_g = \tau_g$, SEC

Figure 14. Variation in Pilot Rating with Time Constant of First-Order Lag in Control Response

Contrails

| LAG TIME CONSTANT INTERVAL | 0-0.3 | | 0.3-0.6 | | 0-0.6 | |
|----------------------------|-------|----|---------|----|-------|----|
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

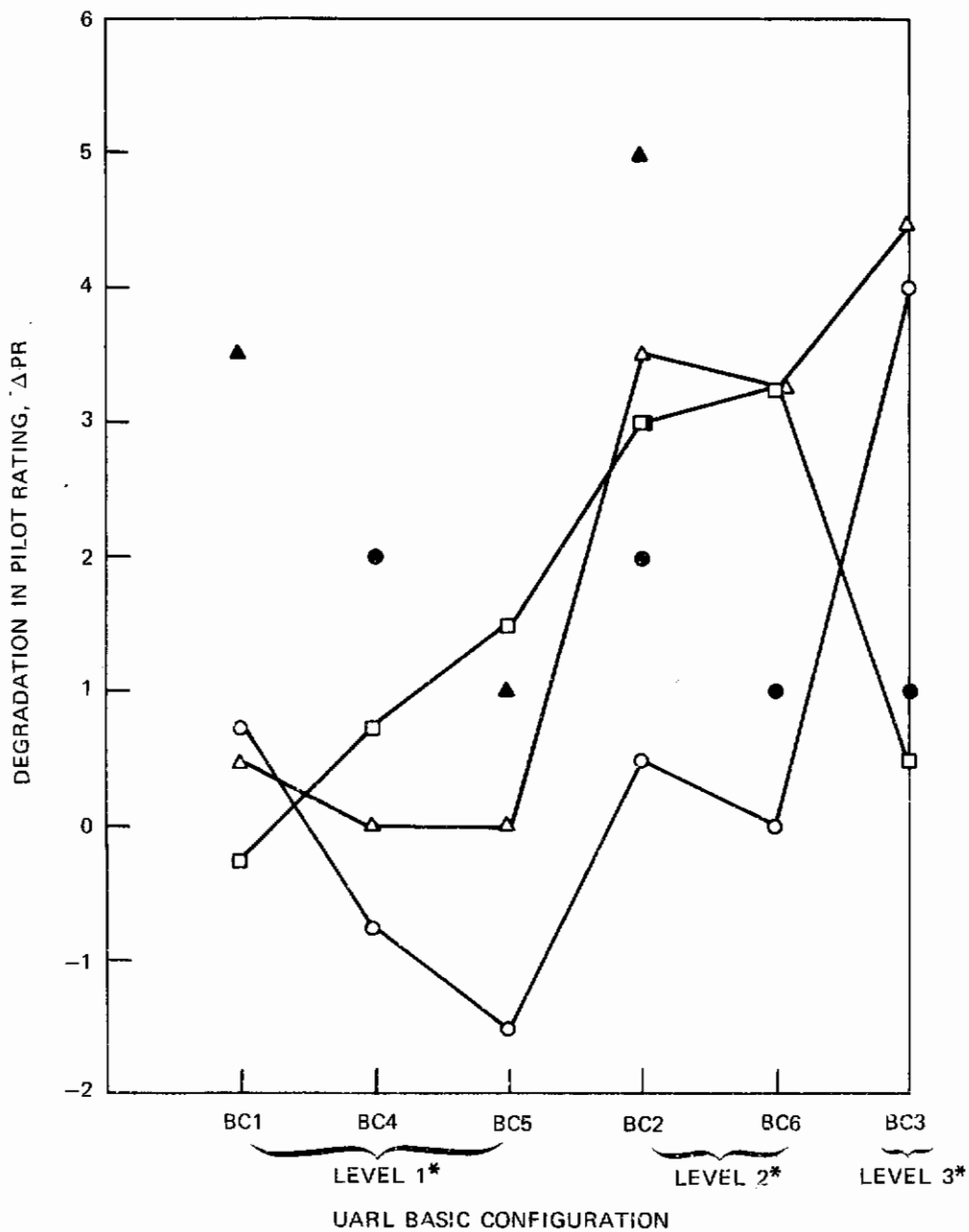


Figure 15. Effect of Pitch and Roll Dynamics Level on Degradation in Pilot Rating with First-Order Lag Time Constant

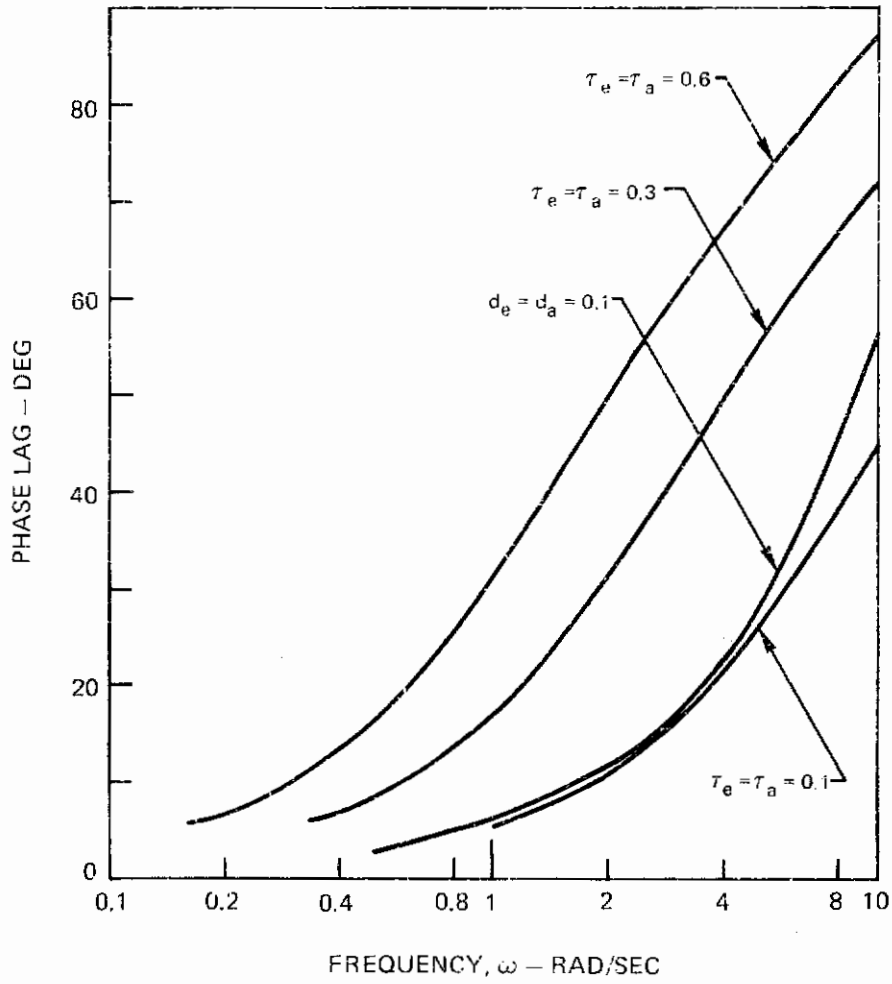


Figure 16. Phase Lags from First-Order Lags and Delays

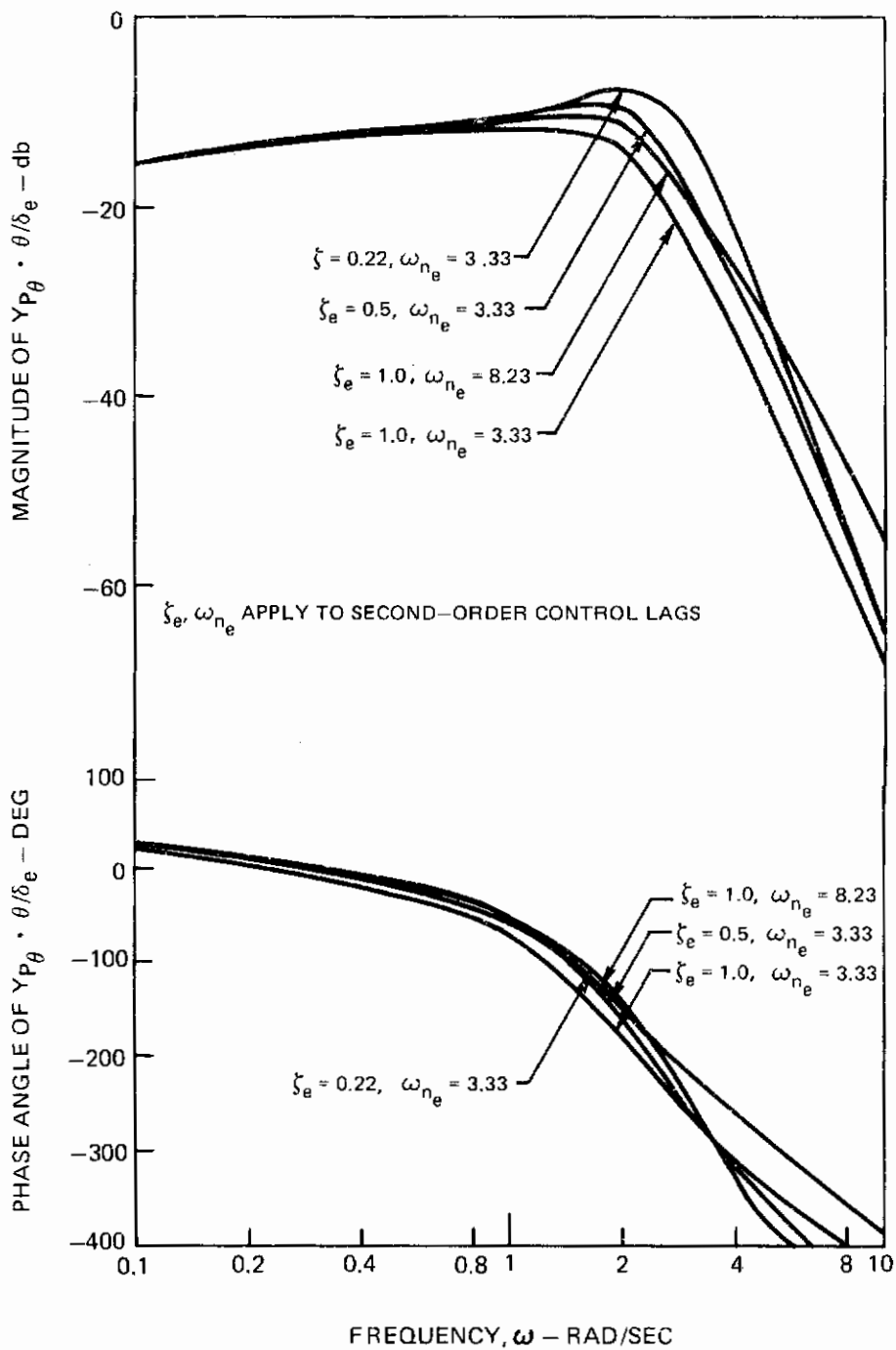


Figure 17. Magnitude and Phase Characteristics for Pilot-Pitch (Roll) Open-Loop Dynamics with Second-Order Control Lags

○ PILOT B, FIXED BASE, CONF. BC1

NATURAL FREQUENCY OF SECOND-ORDER LAG,
 $\omega_{n_e} = \omega_{n_a} = 3.33$ EXCEPT WHERE INDICATED

IDENTICAL LAGS PRESENT IN BOTH PITCH AND ROLL
CONTROL RESPONSE

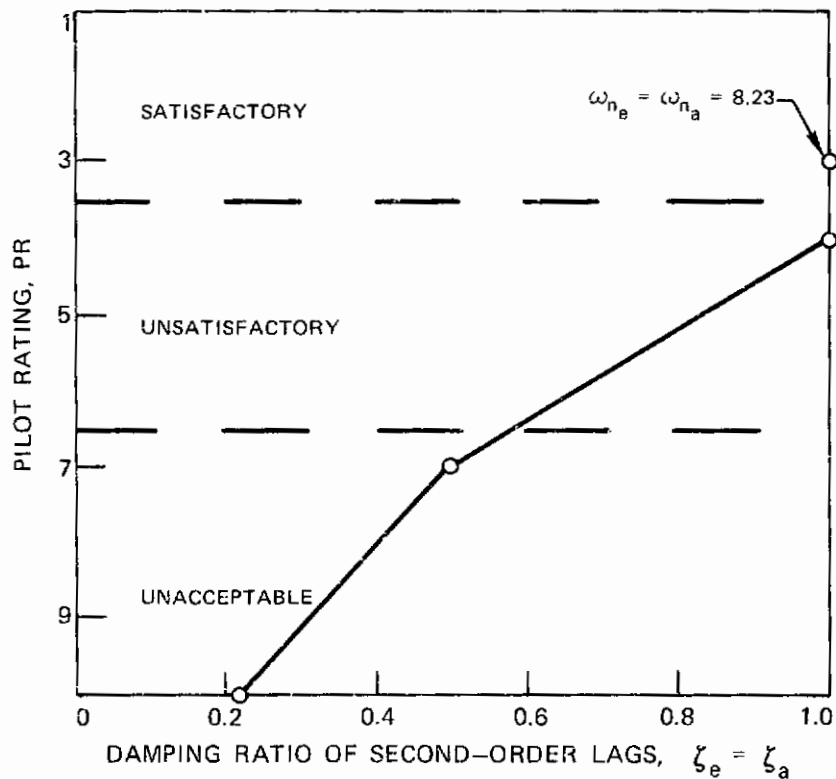


Figure 18. Pilot Ratings for Second-Order Lags in Pitch and Roll Control Response

| LEVEL * | 1 | | | 2 | | | 3 | | | | | | | | | | | | | | |
|----------------|-----|----|---|-----|----|---|-----|----|---|-----|----|---|-----|----|---|-----|----|---|----|----|---|
| | BC1 | | | BC4 | | | BC5 | | | BC2 | | | BC6 | | | BC3 | | | | | |
| SIMULATOR MODE | FB | MB | ○ | FB | MB | □ | FB | MB | ■ | FB | MB | △ | FB | MB | ◆ | FB | MB | ▽ | FB | MB | ▲ |
| SYMBOL | ○ | ● | ○ | □ | ■ | □ | △ | ▲ | ■ | △ | ▲ | △ | ◆ | ▽ | ◆ | ▽ | ▲ | ▲ | ▲ | ▲ | ▲ |

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

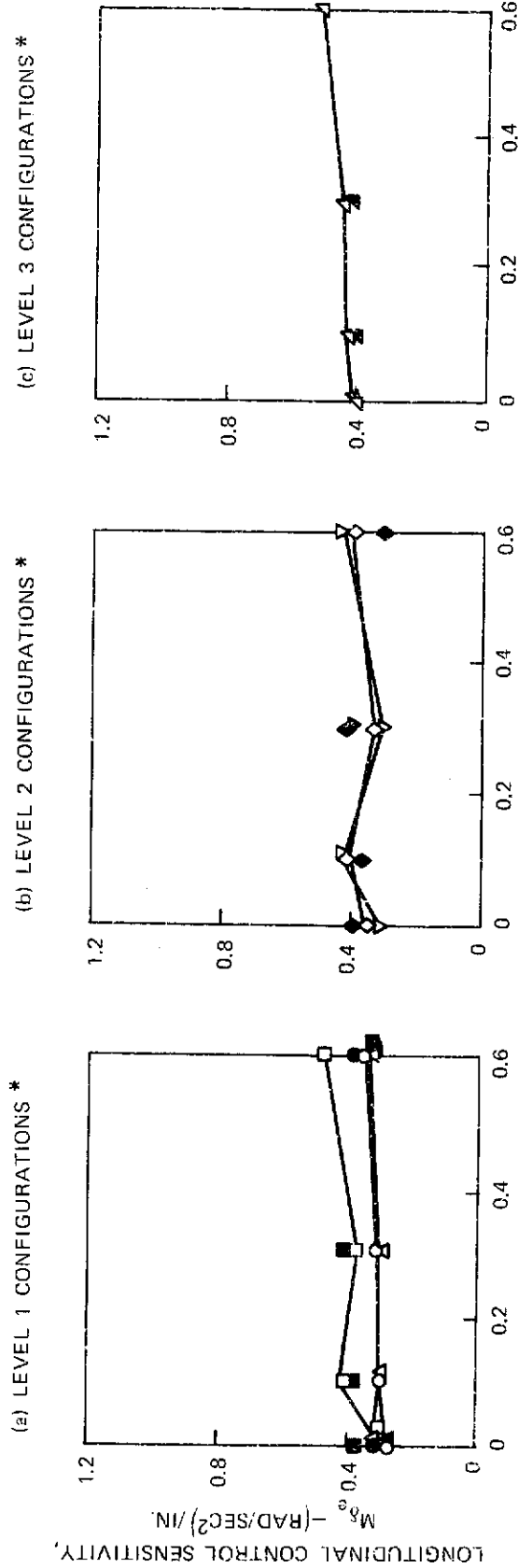


Figure 19. Longitudinal Control Sensitivity Results Showing the Effects of First-Order Control Lag

| LEVEL # | 1 | | | | | | 2 | | | | | | 3 | |
|----------------|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|----|----|
| | BC1 | | BC4 | | BC5 | | BC2 | | BC6 | | BC3 | | | |
| BASIC CONF. | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB | FB | MB |
| SIMULATOR MODE | ○ | ● | □ | ■ | △ | ▲ | ◇ | ◆ | ▽ | ▼ | △ | ▲ | ▽ | ▼ |
| SYMBOL | | | | | | | | | | | | | | |

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

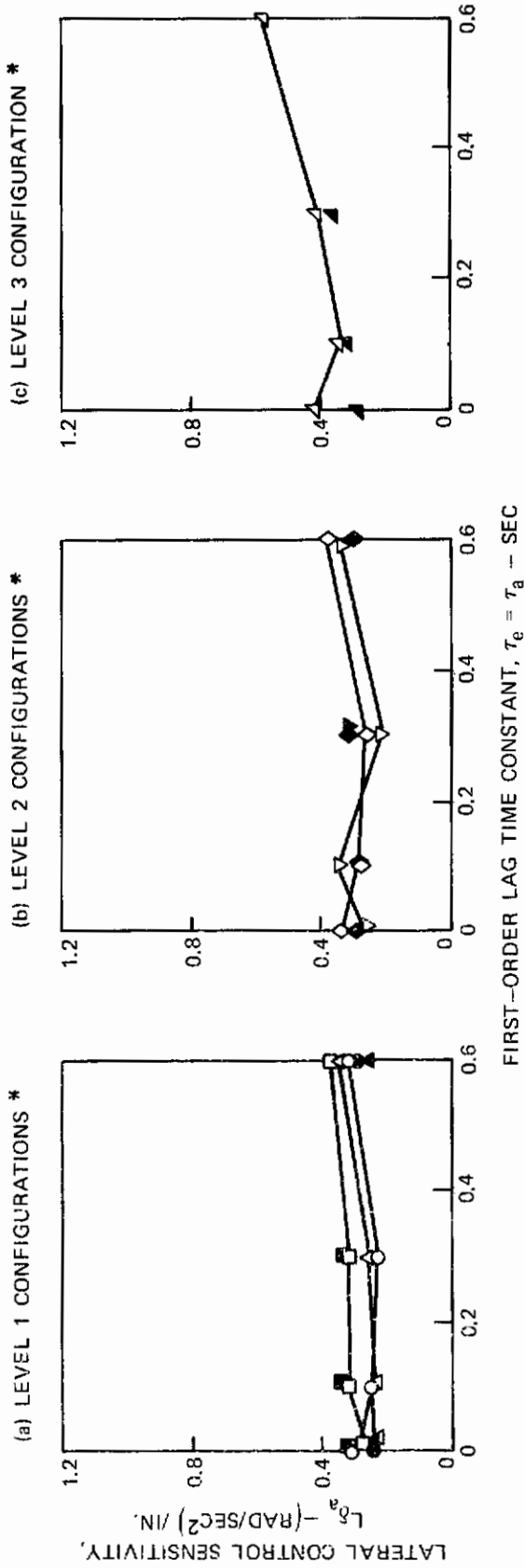


Figure 20. Lateral Control Sensitivity Results Showing the Effects of First-Order Control Lag

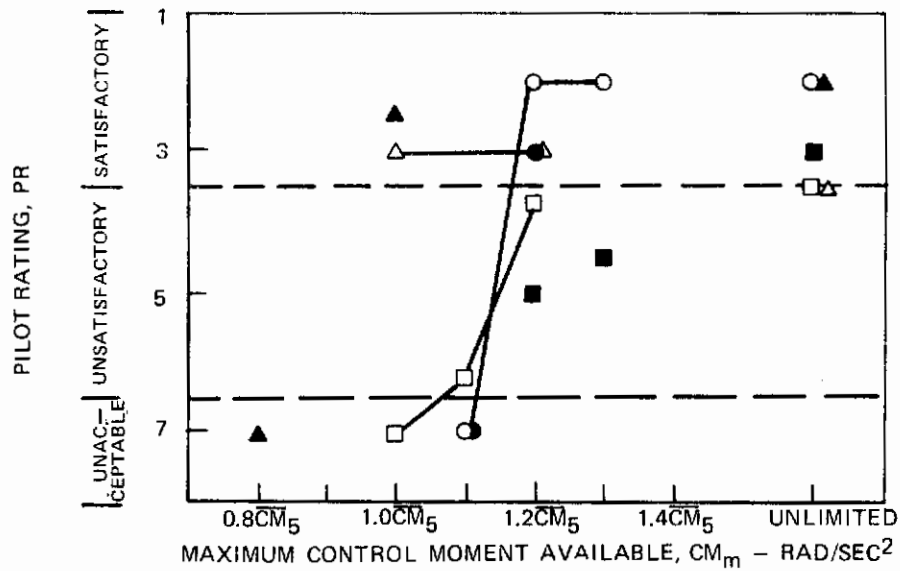
Contrails

| | | | | | | | | |
|----------------|-----|----|-----|----|-----|----|-----|----|
| BASIC CONF. | BC1 | | BC4 | | BC5 | | BC6 | |
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ | ◇ | ◆ |

FIVE PERCENT EXCEEDANCE LEVELS, \overline{CM}_5 FOR PITCH, ROLL, AND YAW, RESPECTIVELY, WERE:

| | | | | |
|-----------------------------|-------|-------|-------|-------|
| BASIC CONF. | BC1 | BC4 | BC5 | BC6 |
| PITCH, \overline{M}_{C_5} | 0.330 | 0.820 | 0.380 | 0.890 |
| ROLL, \overline{L}_{C_5} | 0.380 | 0.605 | 0.360 | 0.750 |
| YAW, \overline{N}_{C_5} | 0.110 | 0.175 | 0.150 | 0.170 |

(a) LEVEL 1 CONFIGURATIONS FOR UNLIMITED CONTROL MOMENTS



(b) LEVEL 2 CONFIGURATION FOR UNLIMITED CONTROL MOMENTS

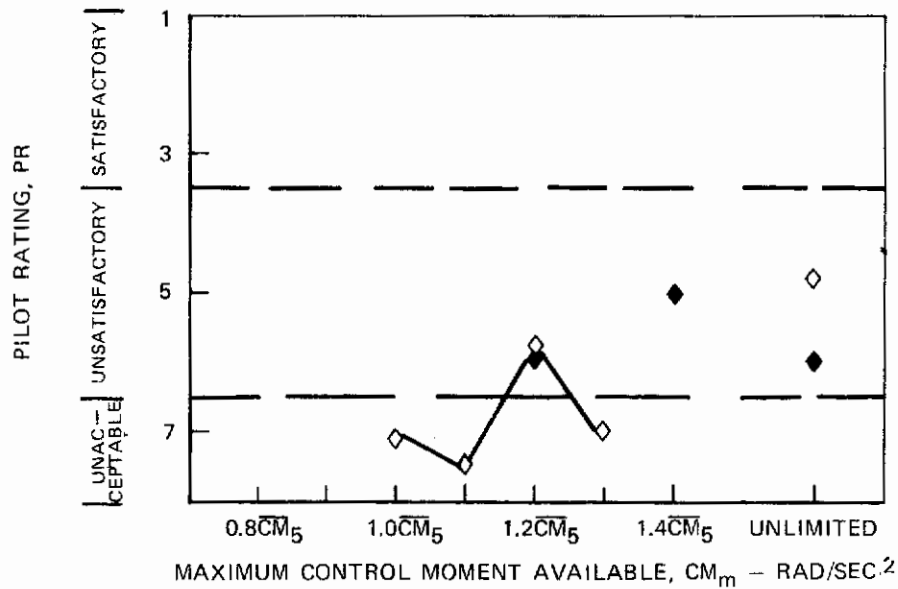


Figure 21. Pilot Rating Results for Control Moment Limits

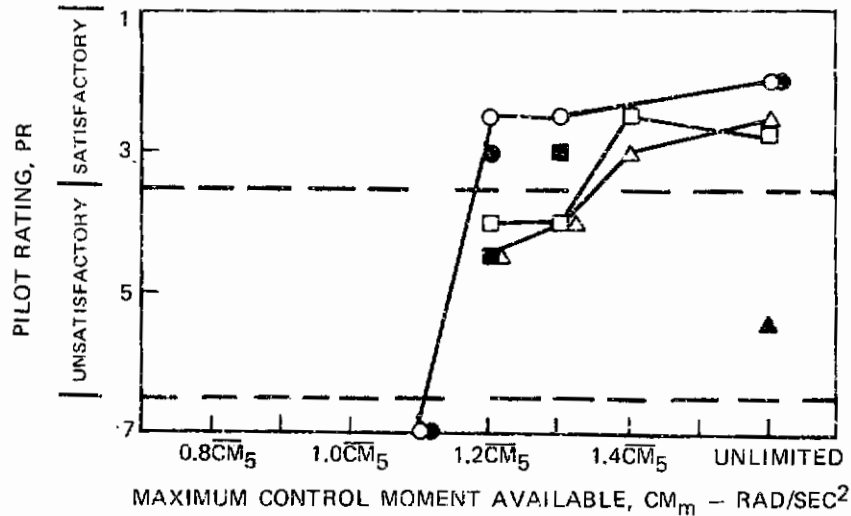
Contrails

| LAG TIME CONSTANT | $\tau_e = \tau_a = 0$ | | $\tau_e = \tau_a = 0.3$ | | $\tau_e = \tau_a = 0.6$ | |
|-------------------|-----------------------|----|-------------------------|----|-------------------------|----|
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

0.1 SEC DELAY IN CONTROL RESPONSE FOR ALL TEST CASES

\overline{CM}_5 : AVERAGED 5 PERCENT EXCEEDANCE MOMENT LEVELS FOR PITCH, ROLL, YAW

(a) BC1 $\overline{CM}_5 = 0.330, 0.380, 0.110$ RAD/SEC² FOR PITCH, ROLL, YAW, RESPECTIVELY



(b) BC5 $\overline{CM}_5 = 0.380, 0.360, 0.150$ RAD/SEC² FOR PITCH, ROLL, YAW, RESPECTIVELY

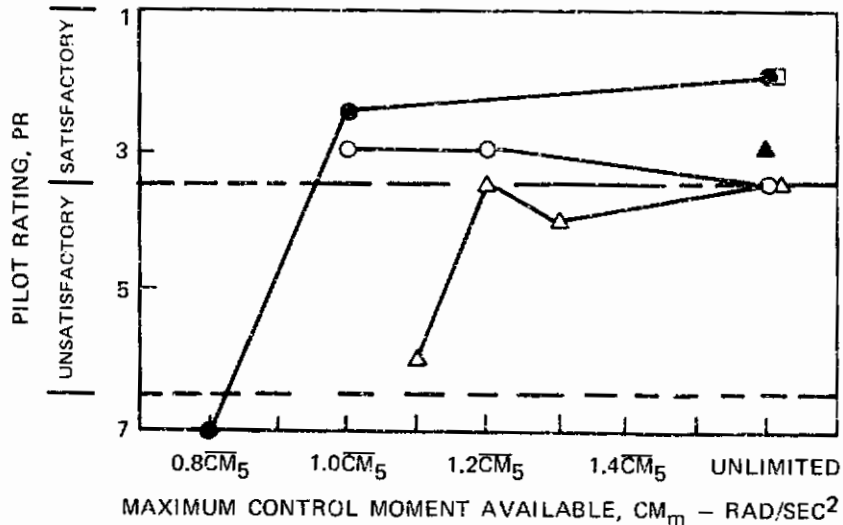


Figure 22. Pilot Ratings Showing the Effects of Control Moment Limits with First-Order Control System Lags

| BASIC CONF. | BC1 | | BC4 | | BC5 | | BC6 | |
|-------------|-----|----|-----|----|-----|----|-----|----|
| | FB | MB | FB | MB | FB | MB | FB | MB |
| SIM. MODE | | | | | | | | |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ | ◇ | ◆ |

ΔM_c : MAXIMUM PITCH CONTROL MOMENT AVAILABLE THROUGH STORED ENERGY.
 EQUAL TO 30 PERCENT OF INSTALLED CONTROL MOMENT, M_{cm} , UNLESS NOTED
 OTHERWISE.

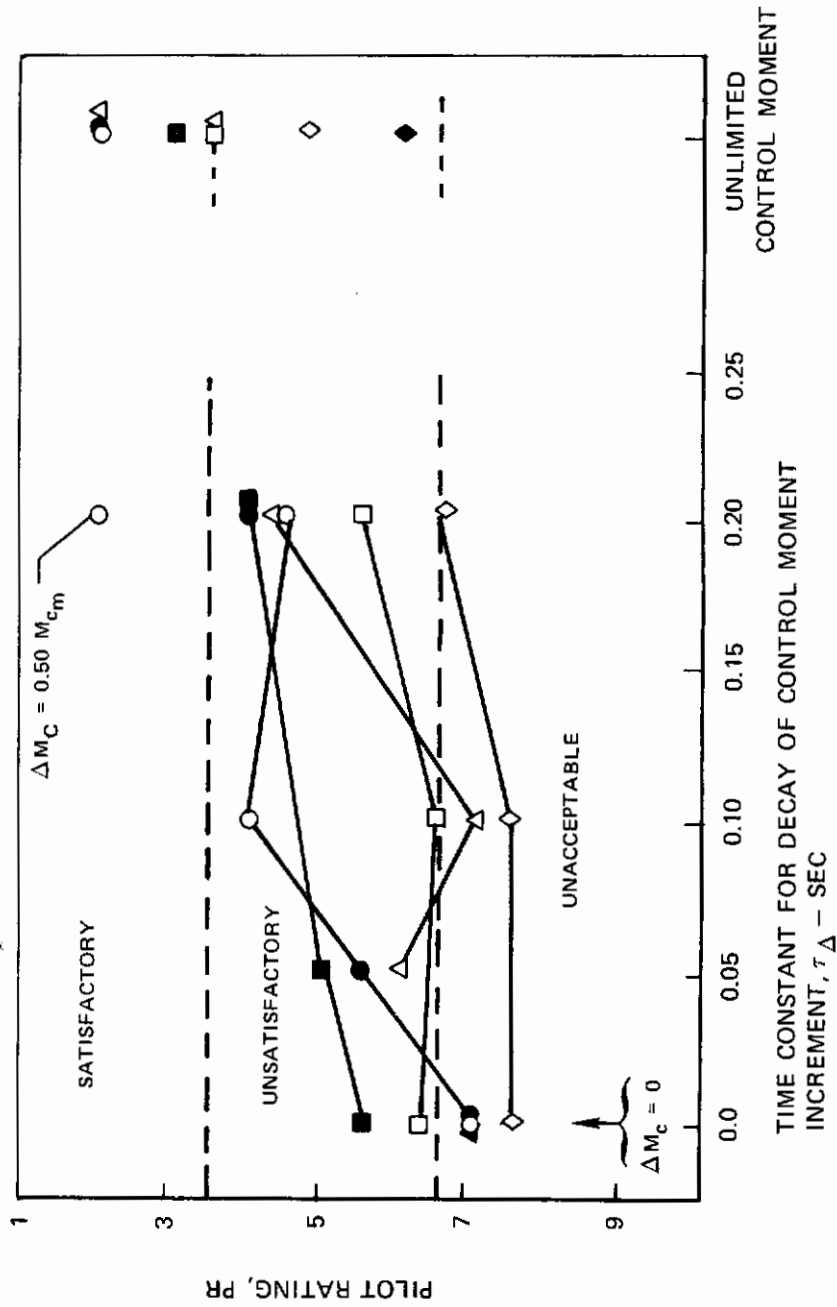


Figure 23. Change in Pilot Rating with Level of Incremental Pitch Control-Moment Available Through Stored Energy

BASIC CONFIGURATION BC1 PILOT B MANEUVERING SUBTASK

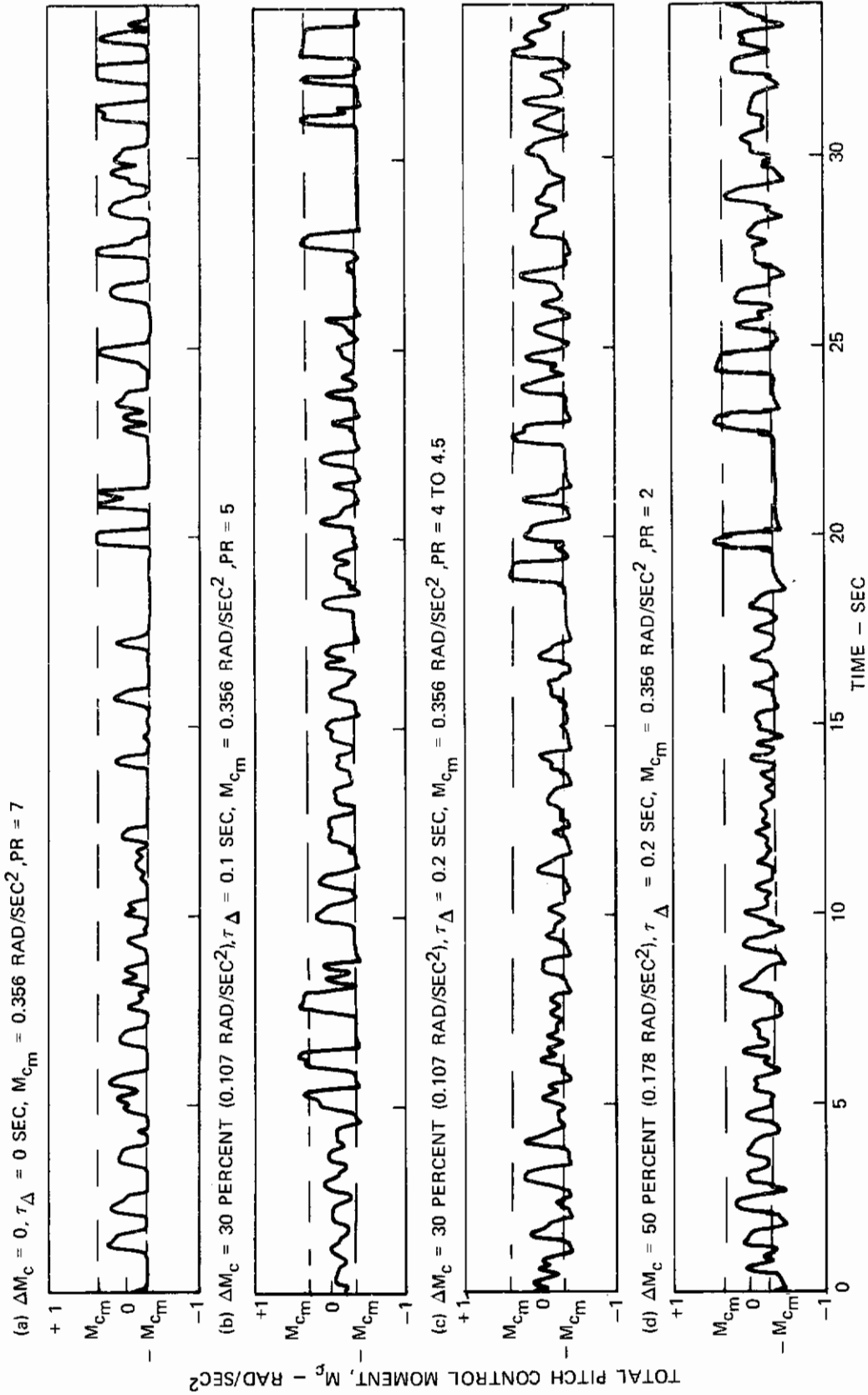


Figure 24. Time Histories of Pitch Control-Moment Usage for the Maneuvering Task with Incremental Moment Available Through Stored Energy

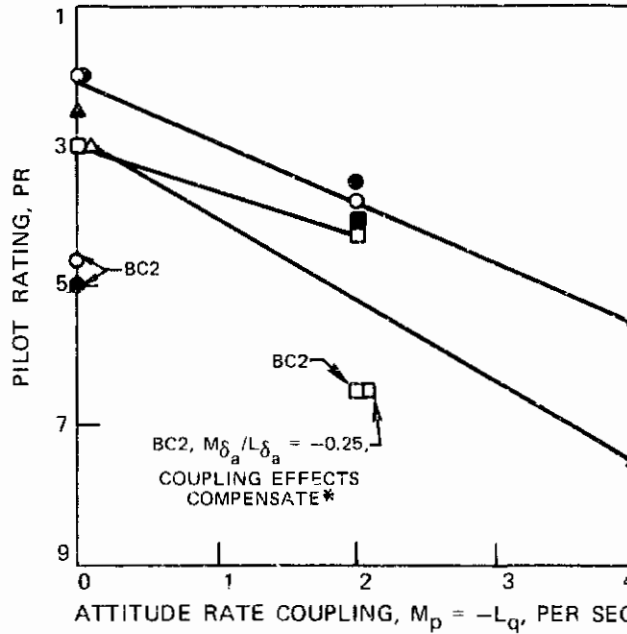
| | | | | | | |
|--|----|----|------|----|------|----|
| $M_{\delta_a}/L_{\delta_a} = -L_{\delta_e}/M_{\delta_p}$ | 0 | | 0.25 | | 0.50 | |
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

CONFIGURATION BC1 EXCEPT WHERE OTHERWISE INDICATED

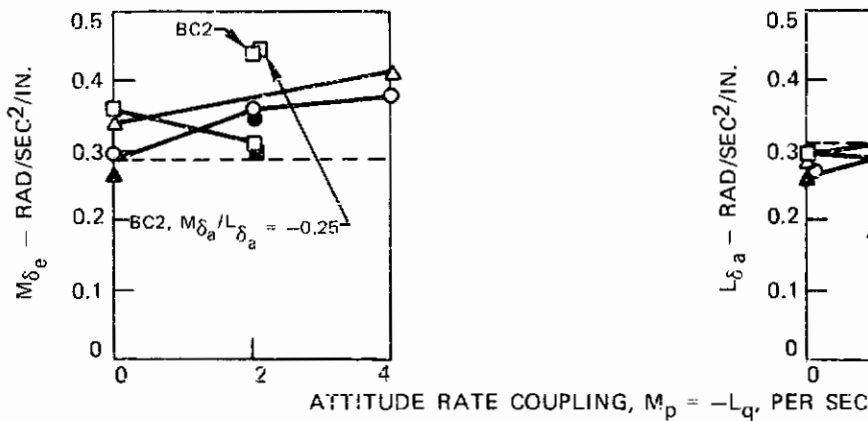
* CONTROL AND RATE COUPLING EFFECTS ADDITIVE, I.E., CONTROL INPUTS CAUSE ATTITUDE RATES WHICH INDUCE COUPLING MOTION IN SAME DIRECTION AS CONTROL COUPLING, UNLESS OTHERWISE NOTED

DASHED LINES INDICATE MIL-F-83300 MINIMUM SENSITIVITY BOUNDARY. SEE NOTE ON FIG. 12.

(a) PILOT RATING



(b) LONGITUDINAL CONTROL SENSITIVITIES, M_{δ_e}



(c) LATERAL CONTROL SENSITIVITIES, L_{δ_a}

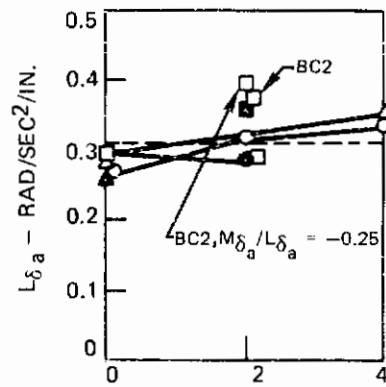


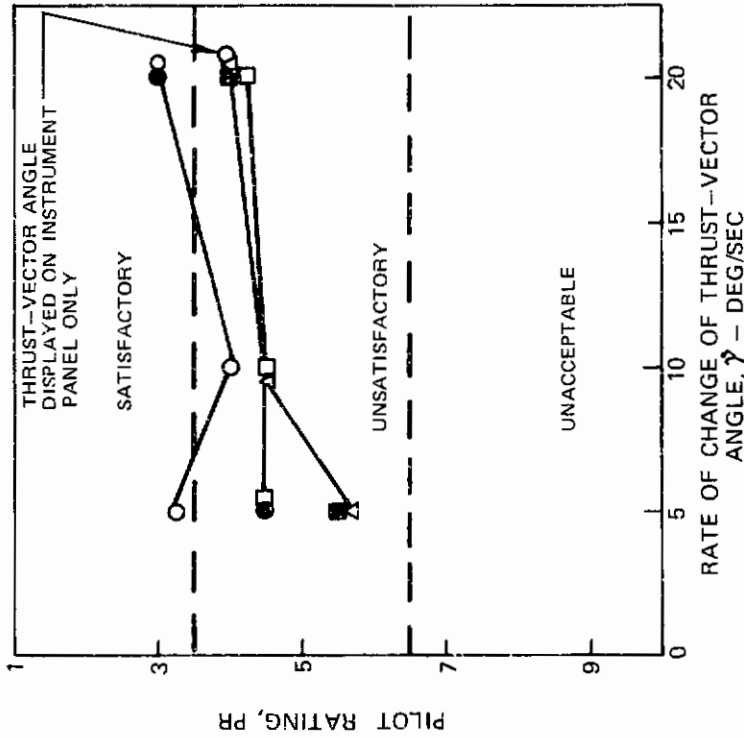
Figure 25. Effects of Inter-Axis Motion Coupling on Pilot Rating and Control Sensitivities

| LEVEL* | | 1 | | 2 | |
|----------------|--|-----|-----|-----|----|
| BASIC CONF. | | BC1 | BC4 | BC2 | |
| SIMULATOR MODE | | FB | MB | MB | MB |
| SYMBOL | | ○ | ● | □ | ▲ |

THRUST VECTOR ANGLE, γ , DISPLAYED ON CONTACT ANALOG AND INSTRUMENT PANEL UNLESS NOTED OTHERWISE

* SEE NOTE ON LEVELS SHOWN ON FIG. 20.

(a) THUMB-SWITCH THRUST-VECTOR CONTROL AND CONTROL-STICK ATTITUDE CONTROL



(b) CONTROL-STICK THRUST-VECTOR CONTROL AND THUMB-SWITCH ATTITUDE CONTROL

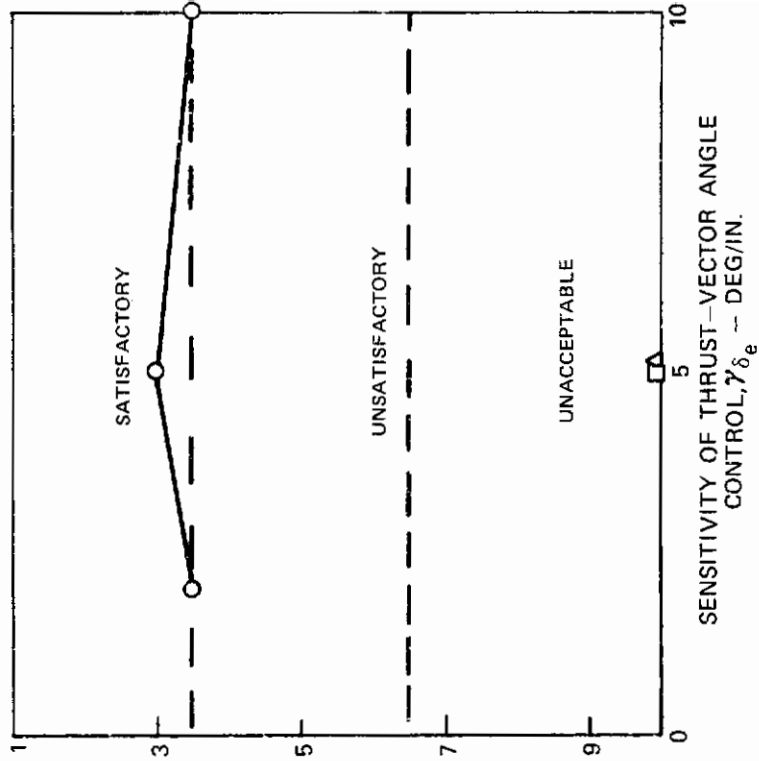


Figure 26. Pilot Rating Results from the Study of Independent Thrust-Vector Control.

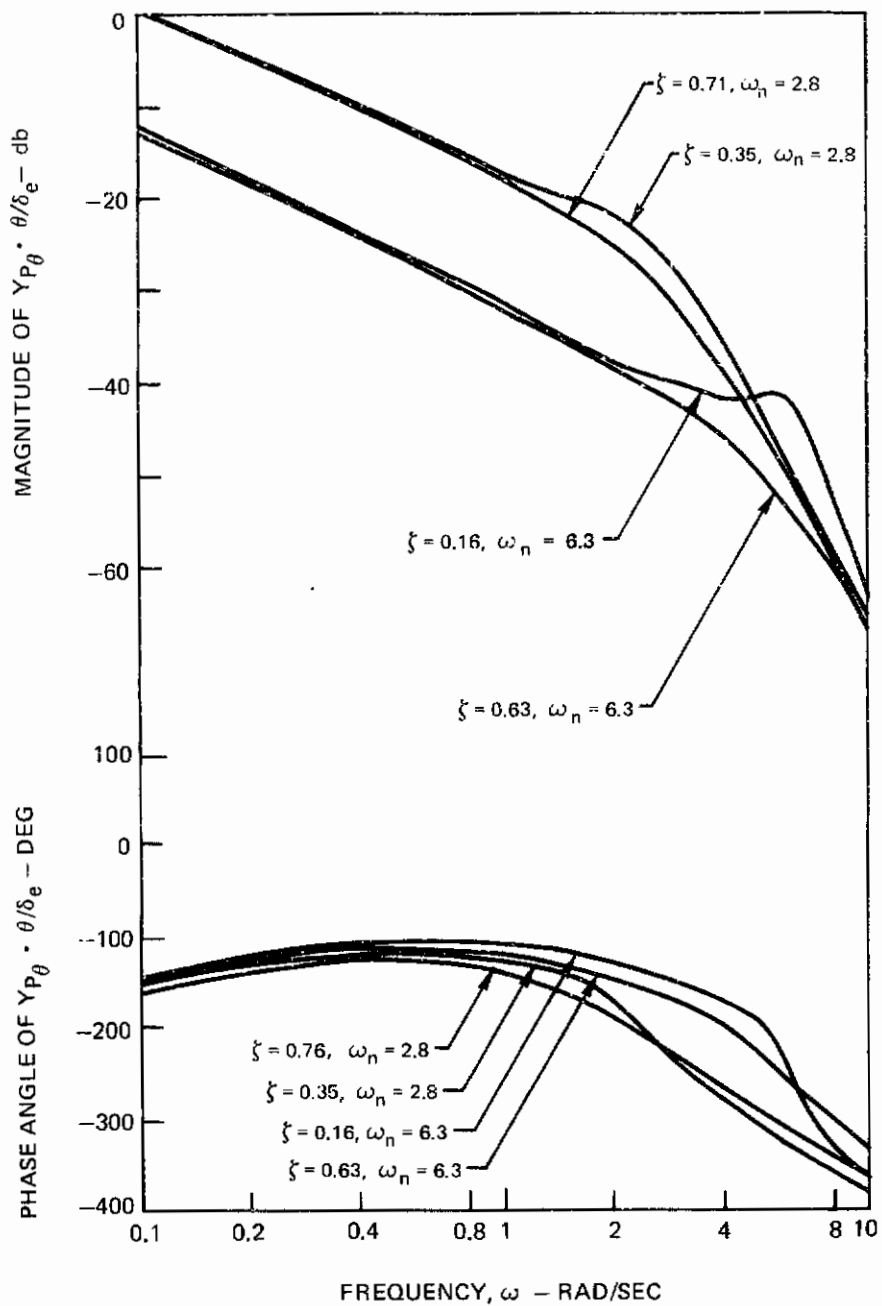
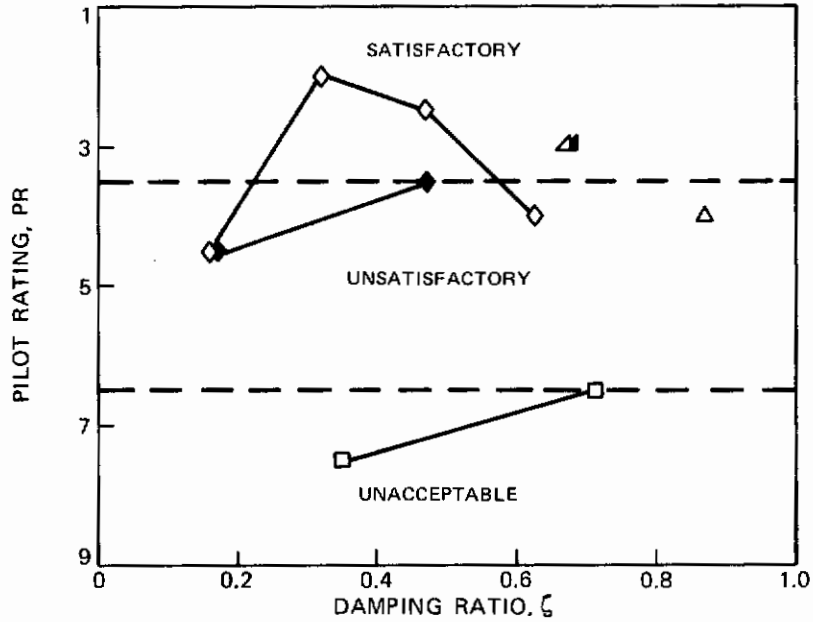


Figure 27. Magnitude and Phase Characteristics for Pilot-Pitch (Roll) Attitude Open-Loop Dynamics with Rate-Command/Attitude-Hold Control

(a) SPEED-STABILITY AND DRAG PARAMETERS OF CONFIGURATION BC1

| | | | | | | | | |
|-------------------------------|------|----|------|----|------|----|------|----|
| NATURAL FREQUENCY, ω_n | 2.80 | | 3.44 | | 6.30 | | 7.40 | |
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB | FB | MB |
| SYMBOL | □ | ■ | △ | ▲ | ◇ | ◆ | ◁ | ▷ |



(b) SPEED-STABILITY AND DRAG PARAMETERS OF CONFIGURATION BC4

| | | | | | | |
|-------------------------------|-----|----|-----|----|-----|----|
| NATURAL FREQUENCY, ω_n | 4.0 | | 5.0 | | 7.4 | |
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

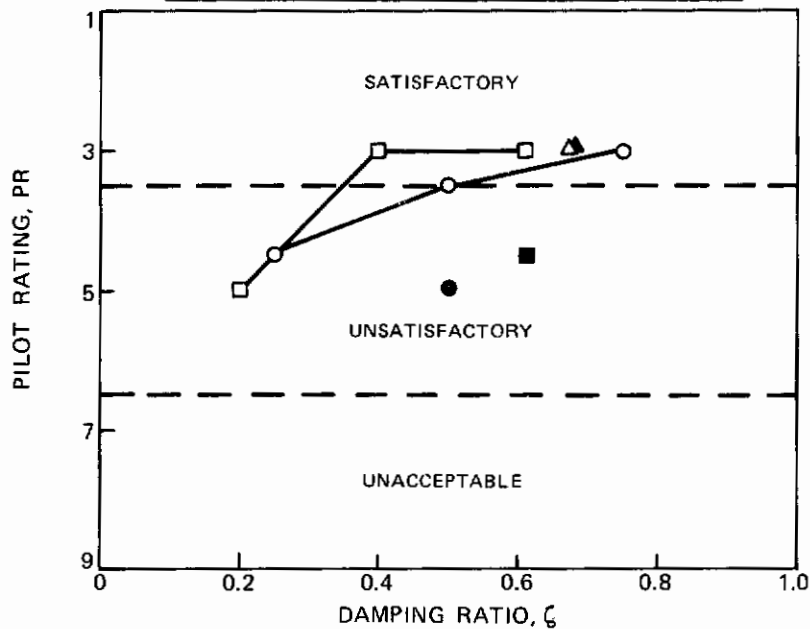
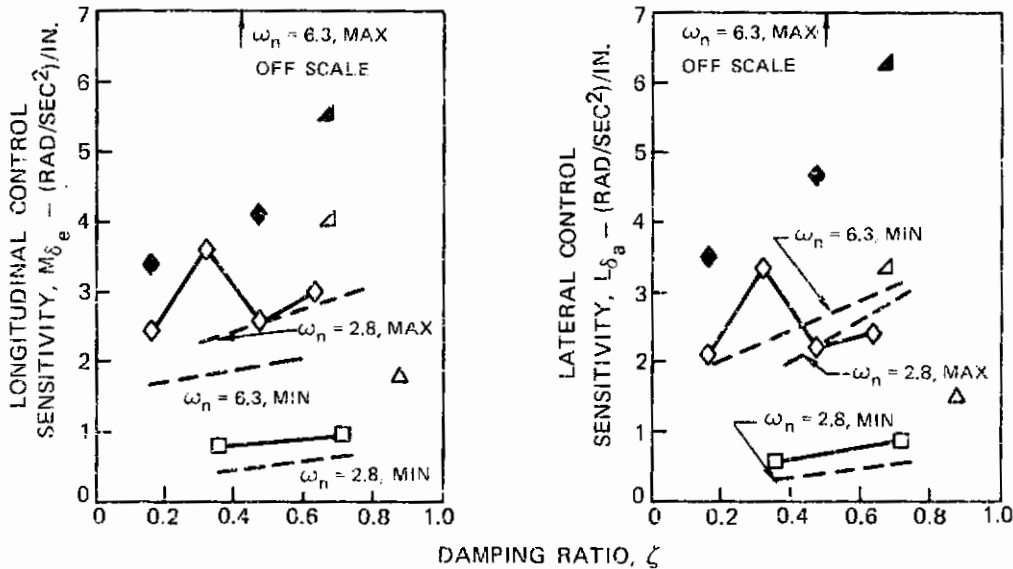


Figure 28. Pilot Rating Results for a Rate-Command/Attitude-Hold Control System

(a) SPEED-STABILITY AND DRAG PARAMETERS OF CONFIGURATION BC1

| | | | | |
|-------------------------------|------|------|------|------|
| NATURAL FREQUENCY, ω_n | 2.80 | 3.44 | 6.30 | 7.40 |
| SIMULATOR MODE | FB | MB | FB | MB |
| SYMBOL | □ | ■ | △ | ▲ |

DASHED LINES SHOW MIL-F-83300 BOUNDARIES. SEE NOTE ON FIG. 12.



(b) SPEED-STABILITY AND DRAG PARAMETERS OF CONFIGURATION BC4

| | | | |
|-------------------------------|-----|-----|-----|
| NATURAL FREQUENCY, ω_n | 4.0 | 5.0 | 7.4 |
| SIMULATOR MODE | FB | MB | FB |
| SYMBOL | ○ | ● | △ |

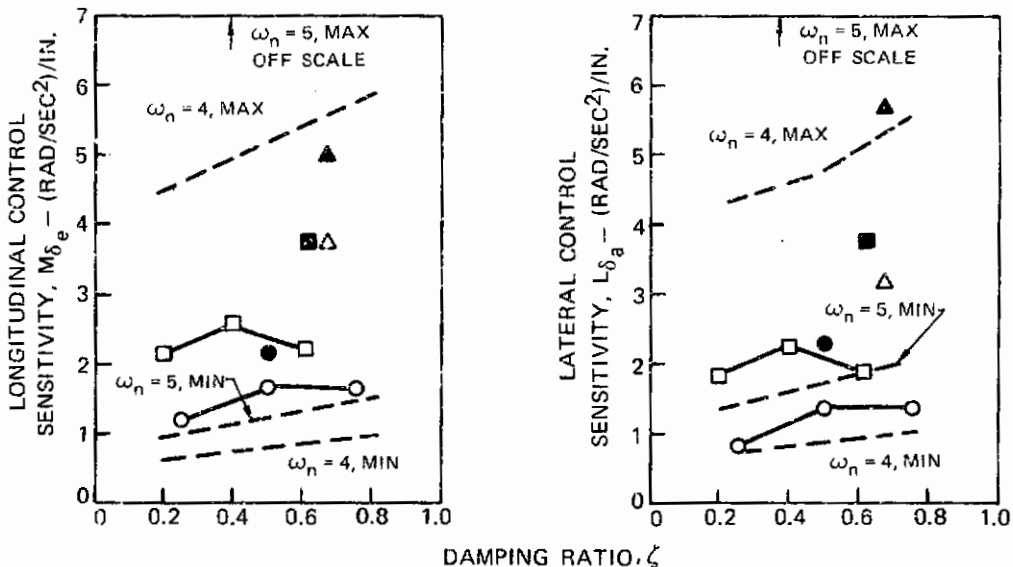


Figure 29. Control Sensitivities from the Study of Rate-Command/Attitude-Hold Control

| | | | |
|----------------------------------|-----|-----|-----|
| RMS TURBULENCE INTENSITY, FT/SEC | 3.4 | 5.8 | 8.2 |
| SYMBOL | O | □ | △ |

CONFIGURATION BC1 $M_{U\beta} = -L_{U\beta} = 0.33$ LEVEL 1*

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

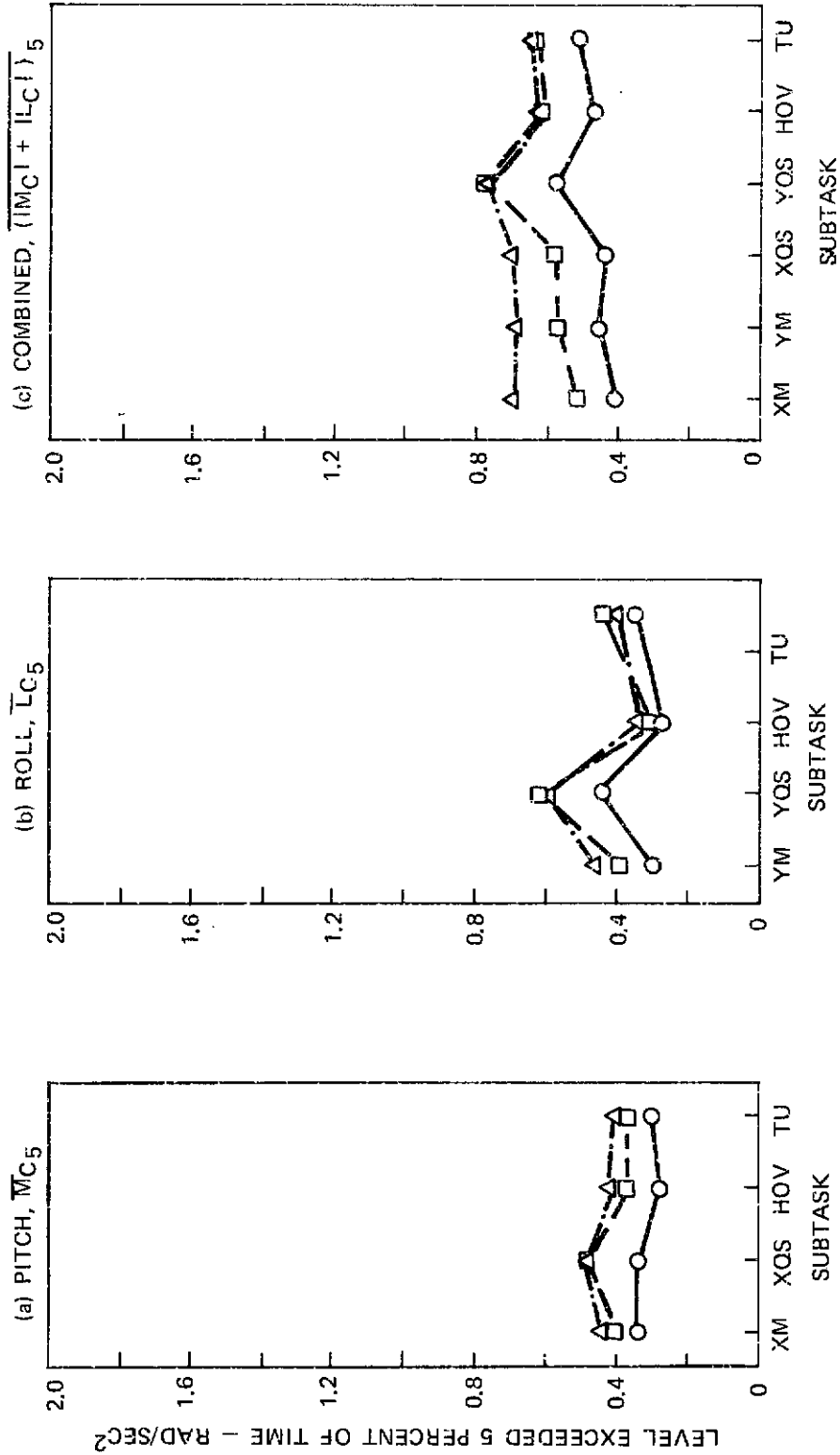


FIGURE 30. Effect of Turbulence on Five-Percent Exceedance Moment Level for a V/STOL Configuration with Small Response to Turbulence

| | | | |
|----------------------------------|-----|-----|-----|
| RMS TURBULENCE INTENSITY, FT/SEC | 3.4 | 5.8 | 8.2 |
| SYMBOL | ○ | □ | △ |

CONFIGURATION BC6 $M_{U\beta} = -L_{U\beta} = 1.0$ LEVEL 2*

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

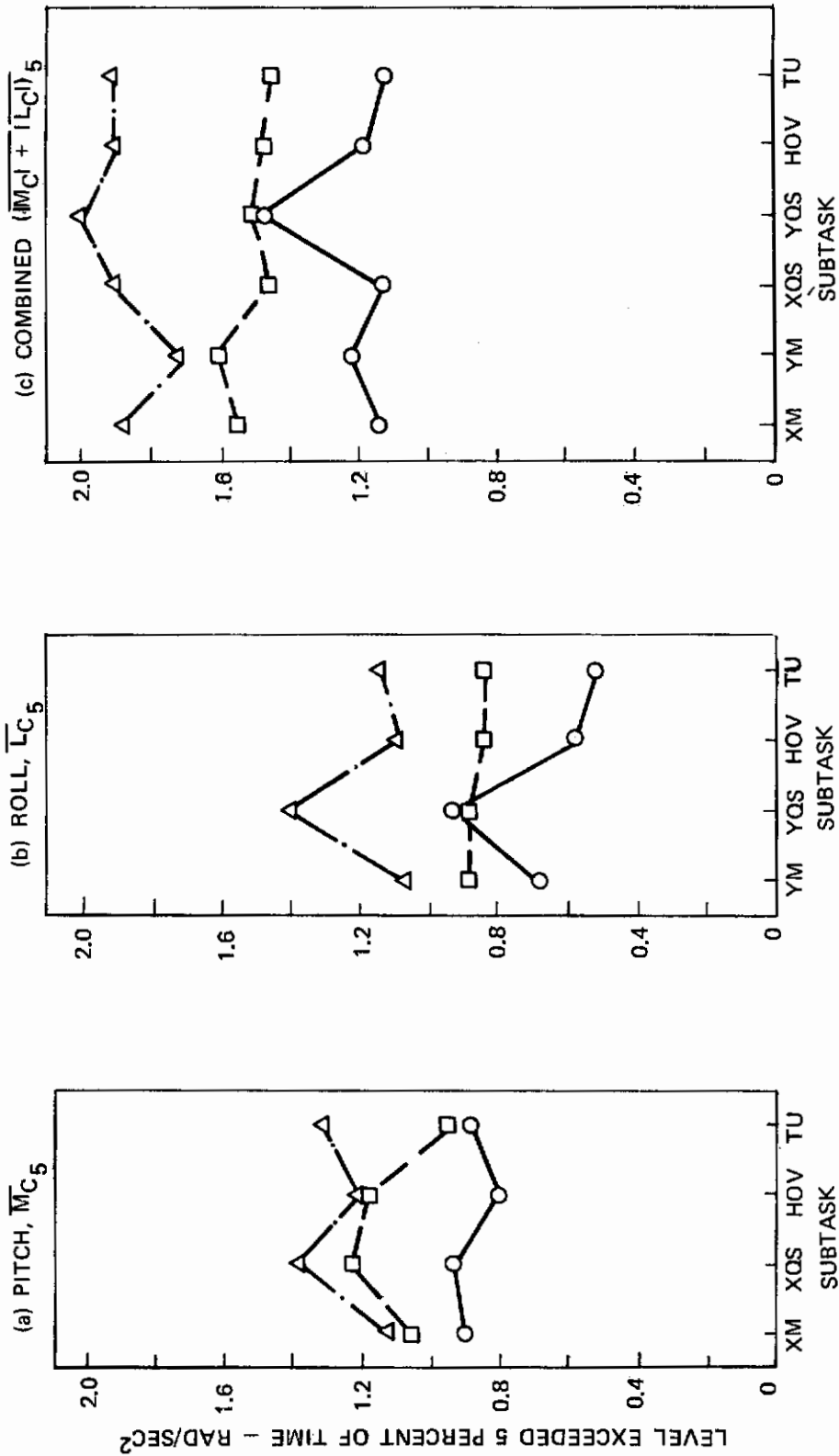


FIGURE 31. Effect of Turbulence on Five-Percent Exceedance Moment Level for a V/STOL Configuration with Large Response to Turbulence

| | | |
|----------------------------|------|-----|
| BASIC CONF. | BC5 | BC4 |
| $M_{u\beta} = -L_{u\beta}$ | 0.33 | 1.0 |
| SYMBOL | ○ | □ |

BC5, BC4 LEVEL 1 CONFIGURATIONS $\alpha_{u_g} = \alpha_{v_g} = 3.4$ FT/SEC

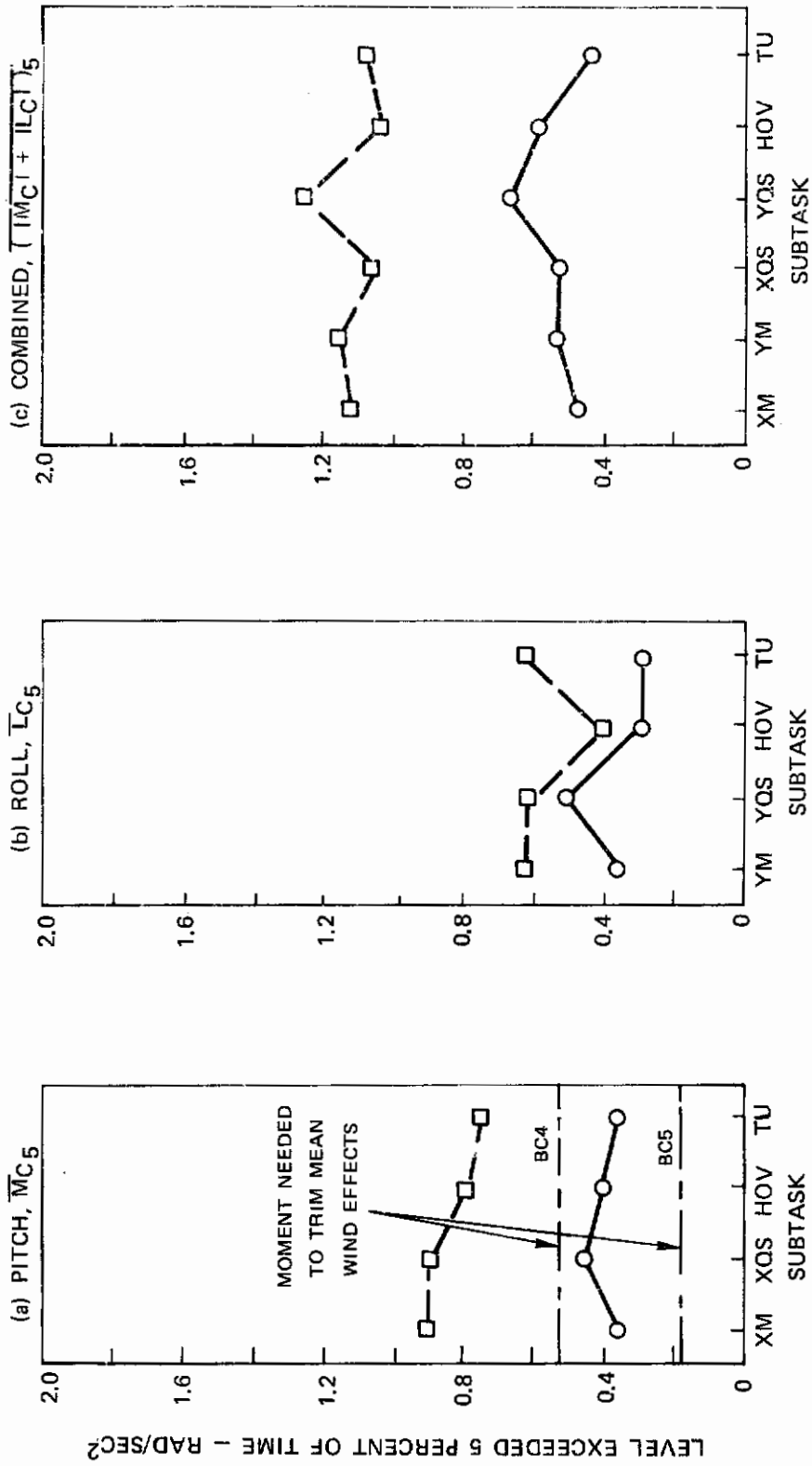


FIGURE 32. Five-Percent Exceedance Moment Levels Showing the Effect of Aircraft Speed-Stability Parameters

| | | |
|-------------|-------|-------|
| BASIC CONF. | BC1 | BC5 |
| $X_u = Y_v$ | -0.05 | -0.20 |
| SYMBOL | O | □ |

BC1, BC5 LEVEL 1 CONFIGURATIONS $\alpha_{u_g} = \alpha_{v_g} = 3.4$ FT/SEC

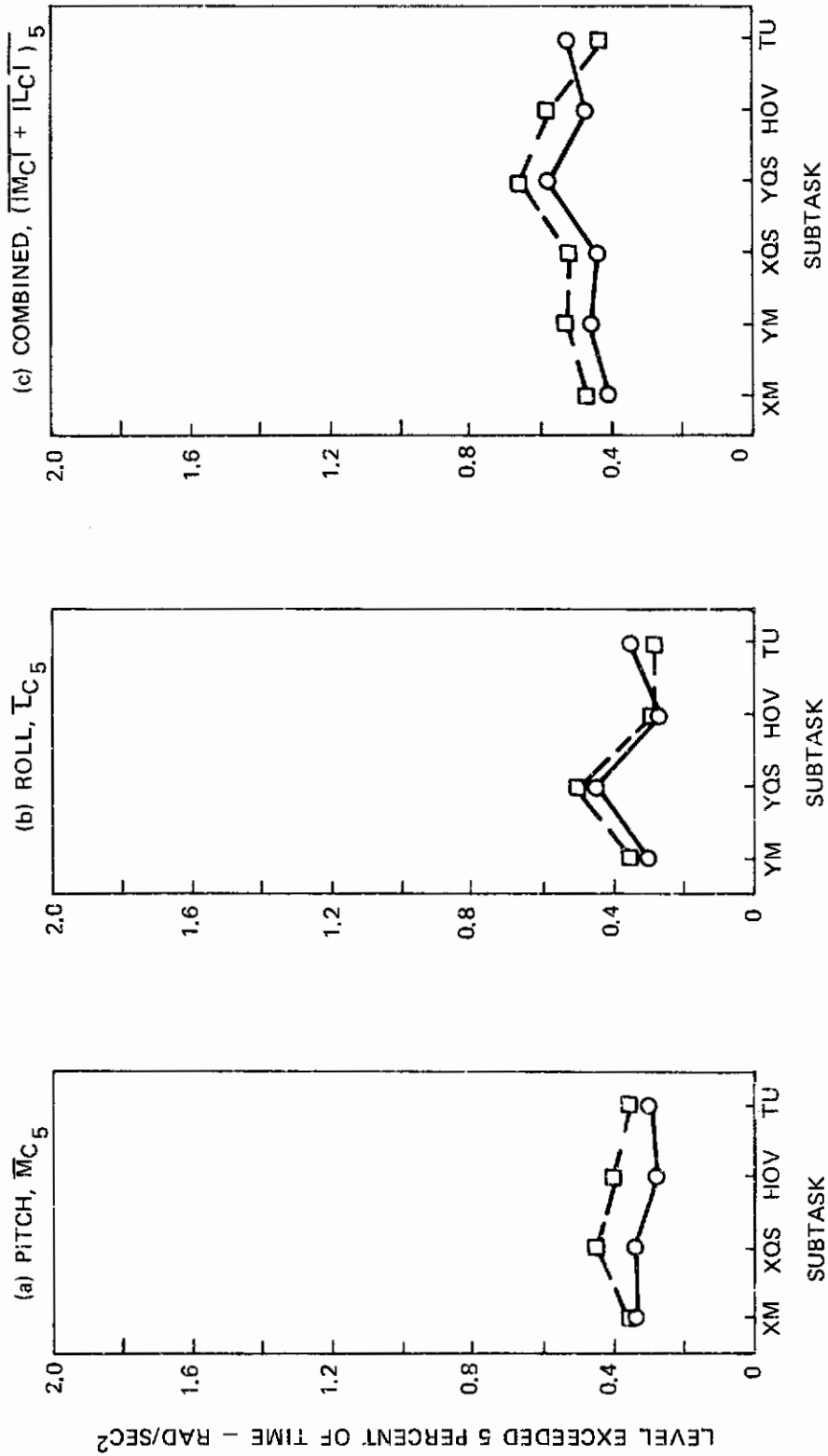


FIGURE 33. Five-Percent Exceedance Moment Levels for V/STOL Configurations Having Different Drag Parameters

| LEVEL | 1 | 2 | 3 |
|-------------|-----|-----|-----|
| BASIC CONF. | BC4 | BC2 | BC3 |
| SYMBOL | ○ | □ | △ |

$M_{y0} = -L_{y0} = 1.0$ FOR BC4, BC2, BC3 $\sigma_{y0} = \alpha_{y0} = 3.4$ FT/SEC

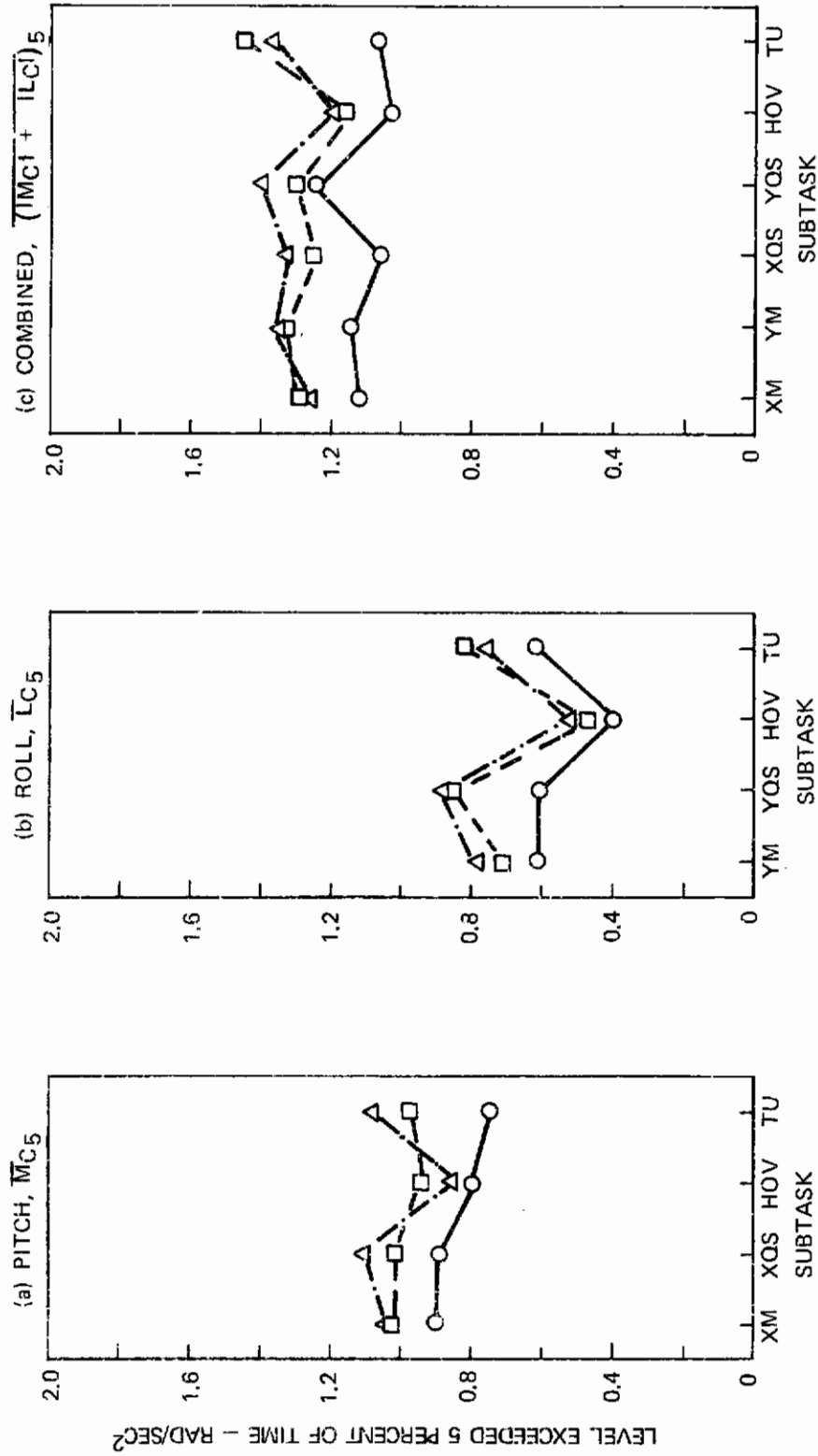


FIGURE 34. Five-Percent Moment Levels for Three V/STOL Configurations Exhibiting the Three MIL-F-83300 Levels of Flying Qualities

| | | | |
|-------------|---|-----|-----|
| CONTROL LAG | 0 | 0.3 | 0.6 |
| SYMBOL | ○ | □ | △ |

CONFIGURATION BC5 LEVEL 1* $M_{1,0} = -L_{v,0} = 0.33$ $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

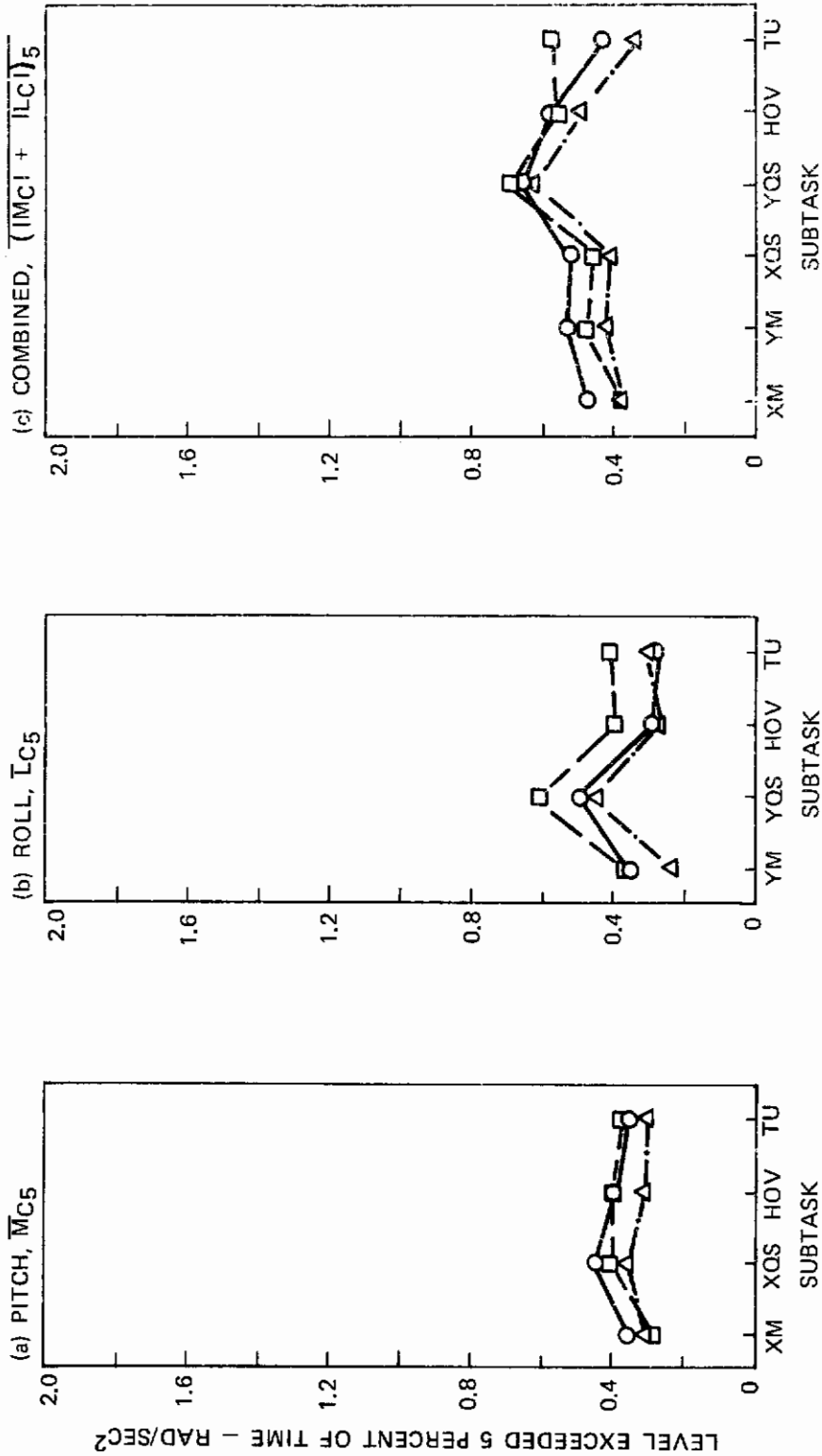


FIGURE 35. Effects of Control lags on Five-Percent Moment Levels for Configuration with Low Response to Turbulence

| | | | |
|-------------|---|-----|-----|
| CONTROL LAG | 0 | 0.3 | 0.6 |
| SYMBOL | ○ | □ | △ |

CONFIGURATION BC4 LEVEL 1 * $M_{u\theta} = -L_{v\theta} = 1.0$ $\sigma_{u\theta} = \sigma_{v\theta} = 3.4$ FT/SEC

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

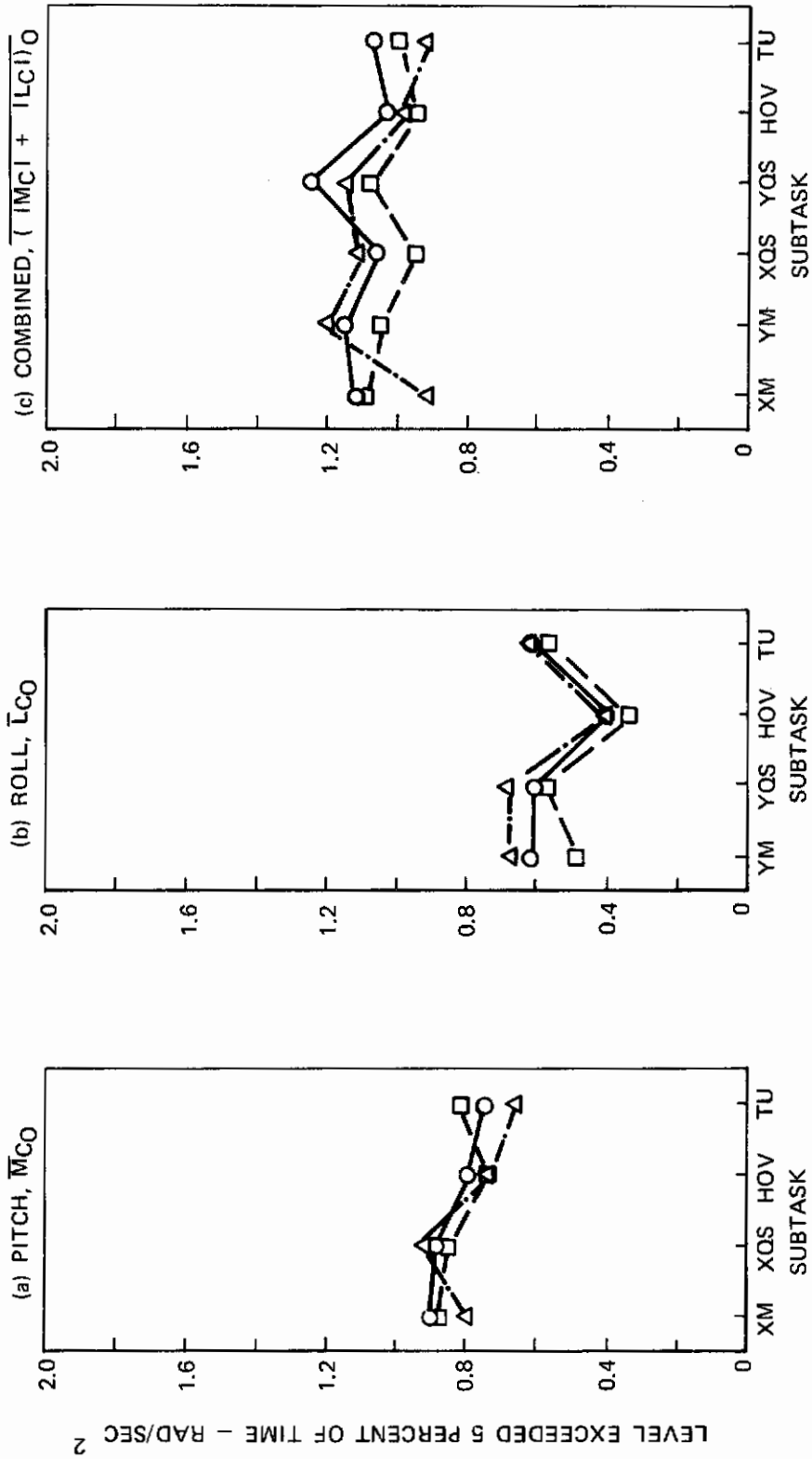


FIGURE 36. Effects of Control lags on Five-Percent Moment Levels for Configuration with Moderate Response to Turbulence

| $M_{\delta} / L_{\delta_a} = -L_{\delta_g} / M_{\delta_g}$ | | 0 | | 0.25 | | 0.50 | |
|--|--|----|----|------|----|------|----|
| SIMULATOR MODE | | FB | MB | FB | MB | FB | MB |
| SYMBOL | | ○ | ● | □ | ■ | △ | ▲ |

CONFIGURATION BC1 CONTROL AND RATE COUPLING EFFECTS ADDITIVE (SEE FIG. 25 FOR EXPLANATION)

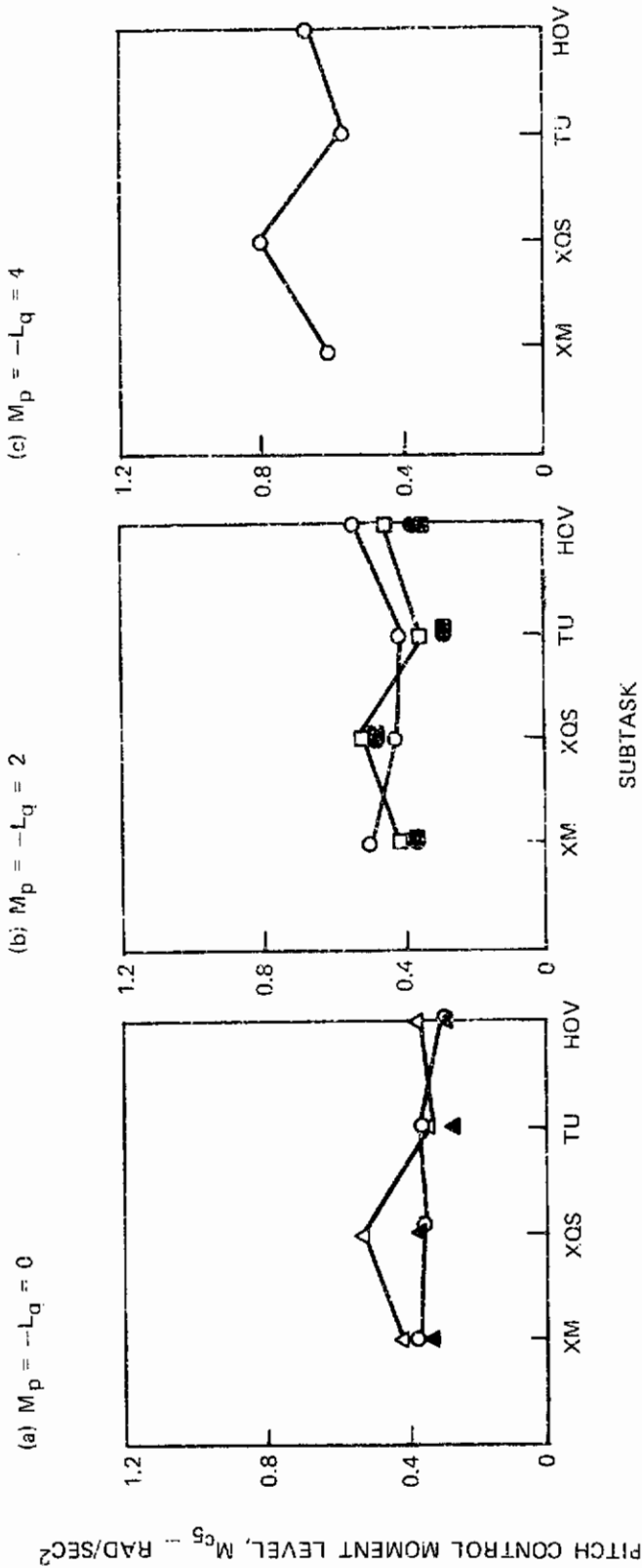


Figure 37. Effect of Rate and Control Coupling on Pitch 5-Percent Exceedance Control-Moment Level

| LEVEL | | 1 | | 2 | | 3 | |
|-------------|-----|-----|-----|-----|-----|-----|--|
| BASIC CONF. | BC1 | BC5 | BC4 | BC2 | BC6 | BC3 | |
| SYMBOL | O | □ | △ | ◇ | △ | D | |

$$\sigma_{U_g} = \sigma_{V_g} = 3.4 \text{ FT/SEC}$$

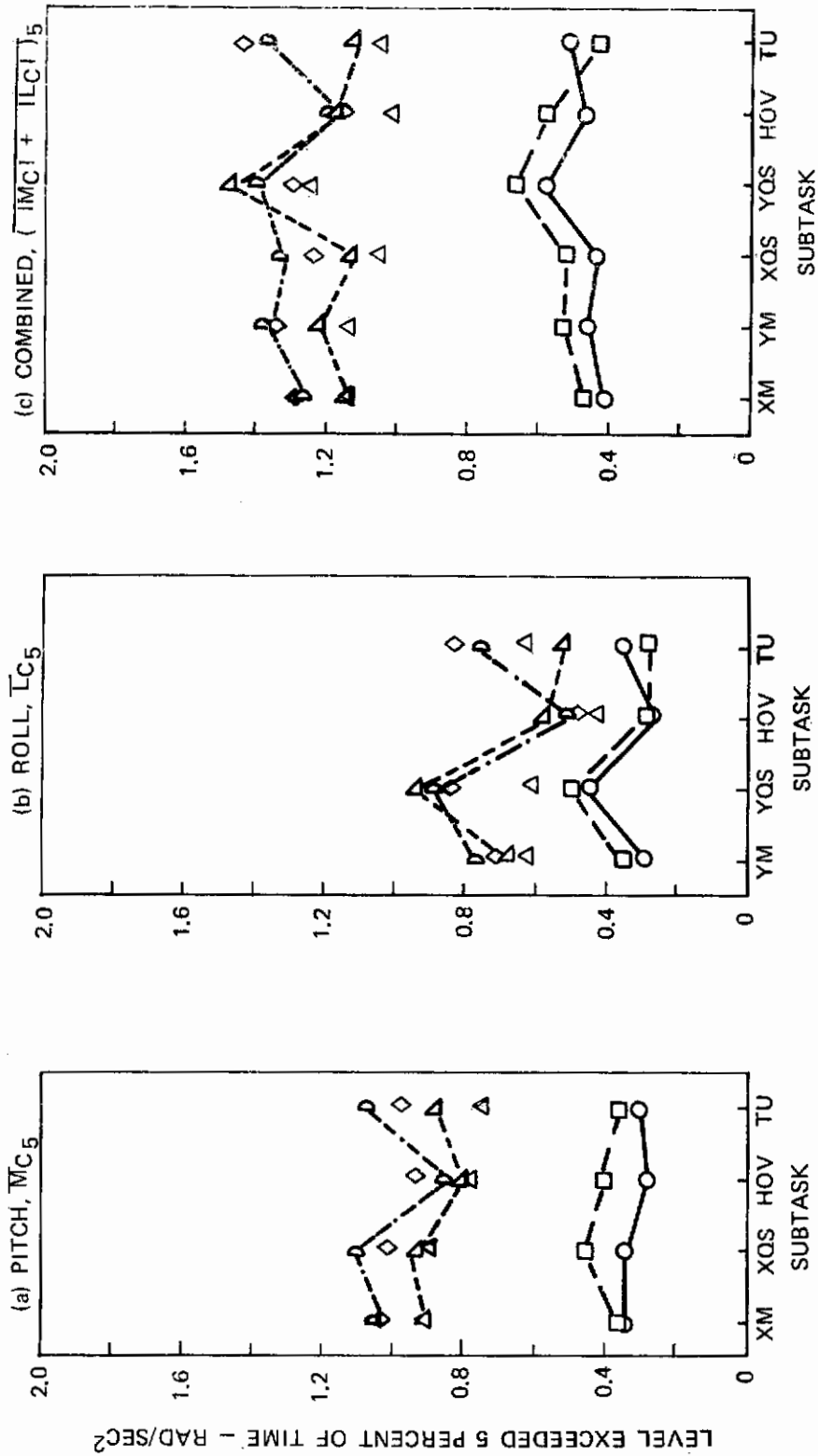


FIGURE 38. Effect of Subtask on Five-Percent Control-Moment-Exceedance Level

| CONTROL MOMENT | $(M_{C1} + 1L_{C1})_5$ | $M_{C5} + L_{C5}$ | $\sqrt{M_{C5}^2 + L_{C5}^2}$ |
|----------------|------------------------|-------------------|------------------------------|
| SYMBOL | O | □ | △ |

HOVER SUBTASK

$$\sigma_{u_g} = \sigma_{v_g} = 3.4 \text{ FT/SEC}$$

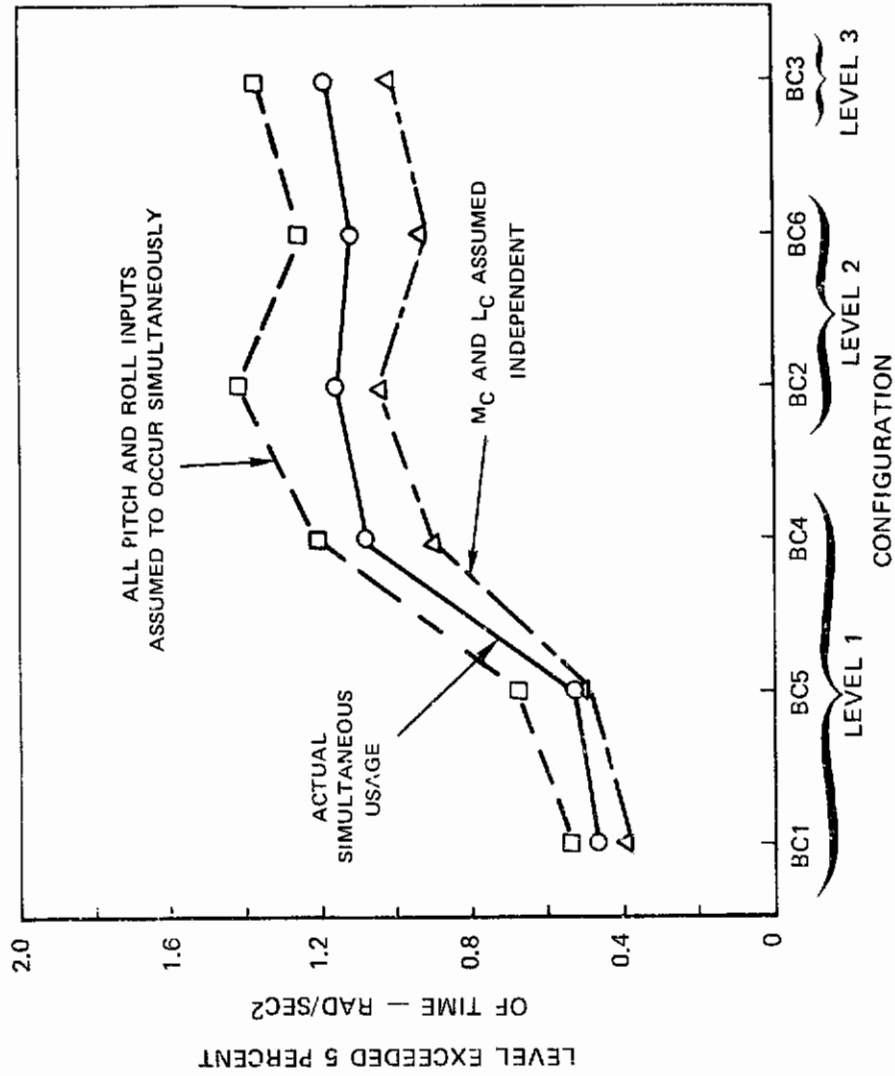
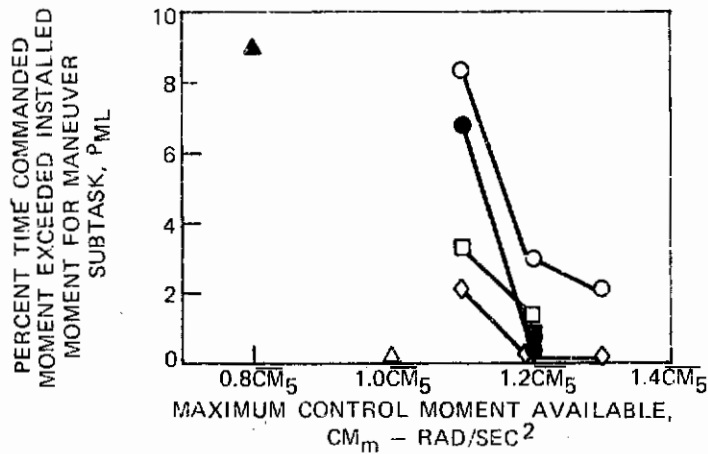


Figure 39. Comparison of Actual Five-Percent Simultaneous Usage Moment Levels for Hover with Hypothetical Maximum and Minimum Values for these Levels

| BASIC CONF. | BC1 | | BC4 | | BC5 | | BC6 | |
|----------------|-----|----|-----|----|-----|----|-----|----|
| SIMULATOR MODE | FB | MB | F2 | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ | ◇ | ◆ |

\overline{CM}_5 : AVERAGED 5-PERCENT EXCEEDANCE MOMENT LEVELS FOR PITCH AND ROLL WITH UNLIMITED CONTROL MOMENT AVAILABLE

(a) PITCH CONTROL



(b) ROLL CONTROL

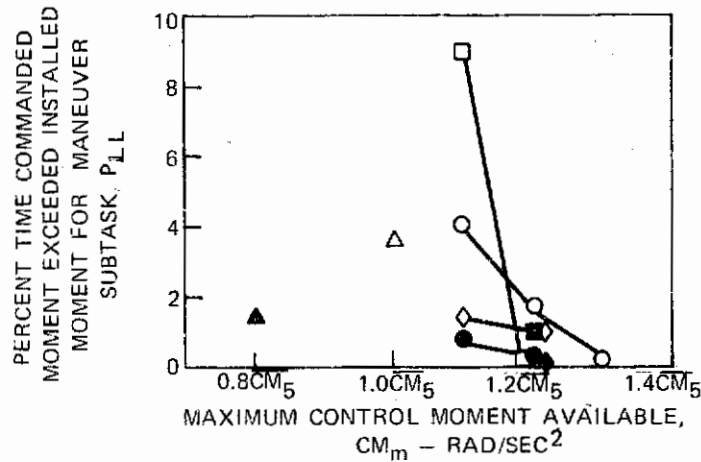


Figure 40. Percent Time Total Moment Command Exceeded Installed Pitch and Roll Control Moments for Flight with Limited Available Moments

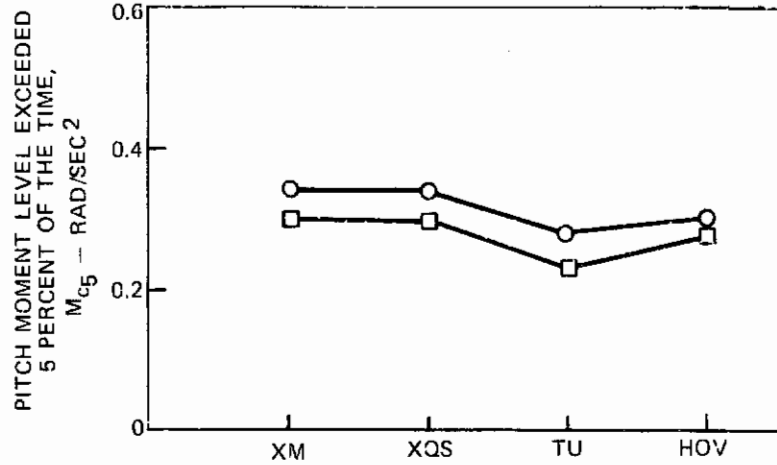
Contrails

| TYPE OF POSITION CONTROL | CONVENTIONAL | INDEPENDENT THRUST-VECTOR CONTROL |
|--------------------------|--------------|-----------------------------------|
| SYMBOL | ○ | □ |

FIXED BASE

THUMB-SWITCH THRUST-VECTOR CONTROL, $\dot{\gamma} = 20$ DEG/SEC, AND CONTROL-STICK ATTITUDE CONTROL FOR INDEPENDENT THRUST-VECTOR CONTROL

(a) CONFIGURATION BC1



(b) CONFIGURATION BC4

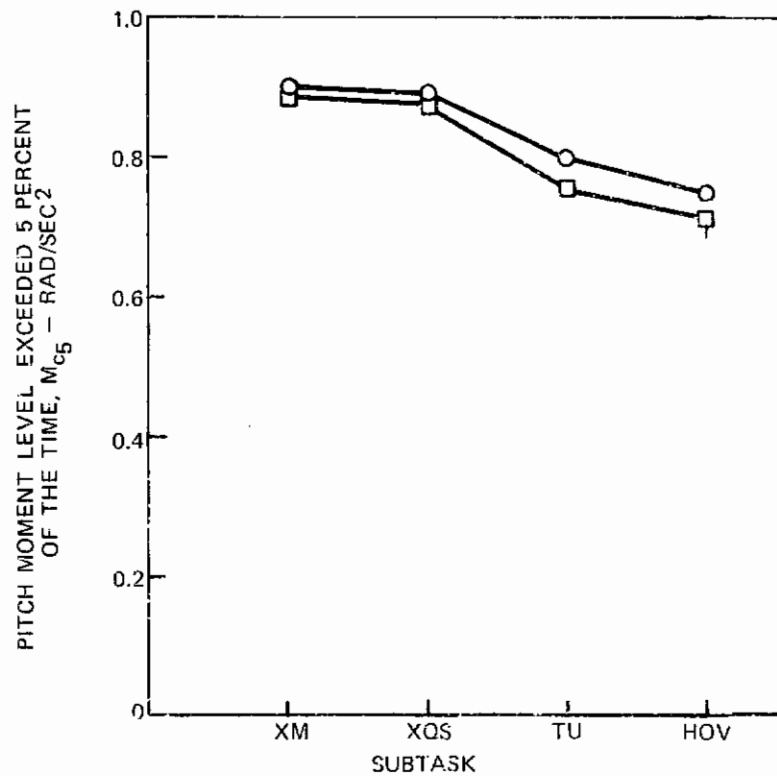
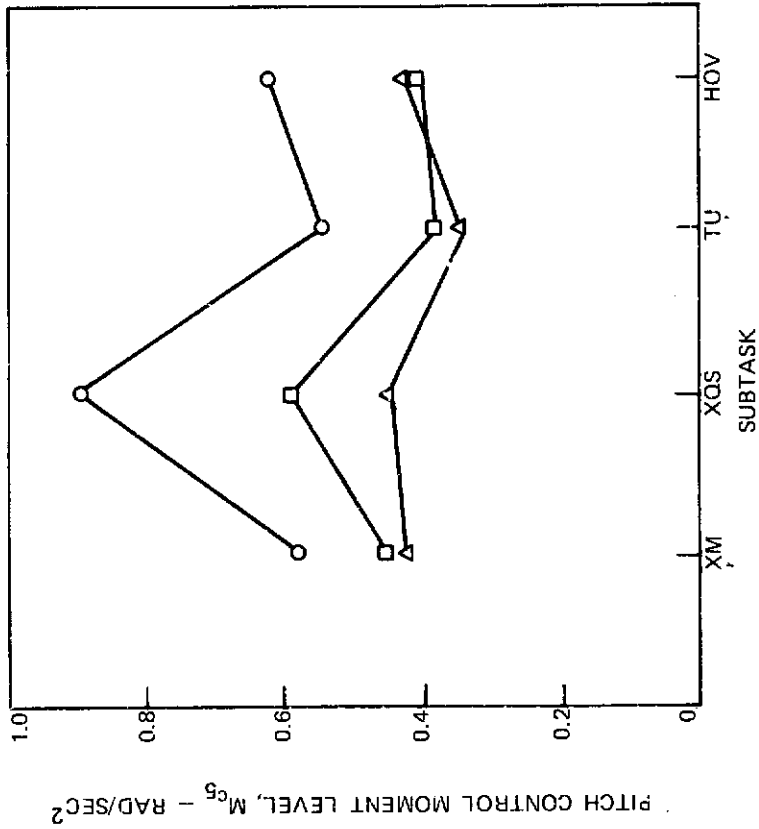


Figure 41. Comparison Between Pitch Control-Moment 5-Percent Exceedance Levels for Independent Thrust-Vector Control and Conventional Position Control

CONFIGURATION BC1

(a) $\omega_n = 2.8$ AND 3.4 RAD/SEC

| ω_n | 2.8 | | 3.4 | |
|----------------|------|------|------|------|
| ζ | 0.35 | 0.71 | 0.87 | 0.87 |
| SIMULATOR MODE | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ▲ |



(b) $\omega_n = 6.3$ RAD/SEC

| ζ | 0.16 | | 0.47 | |
|----------------|------|----|------|----|
| SIMULATOR MODE | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ |

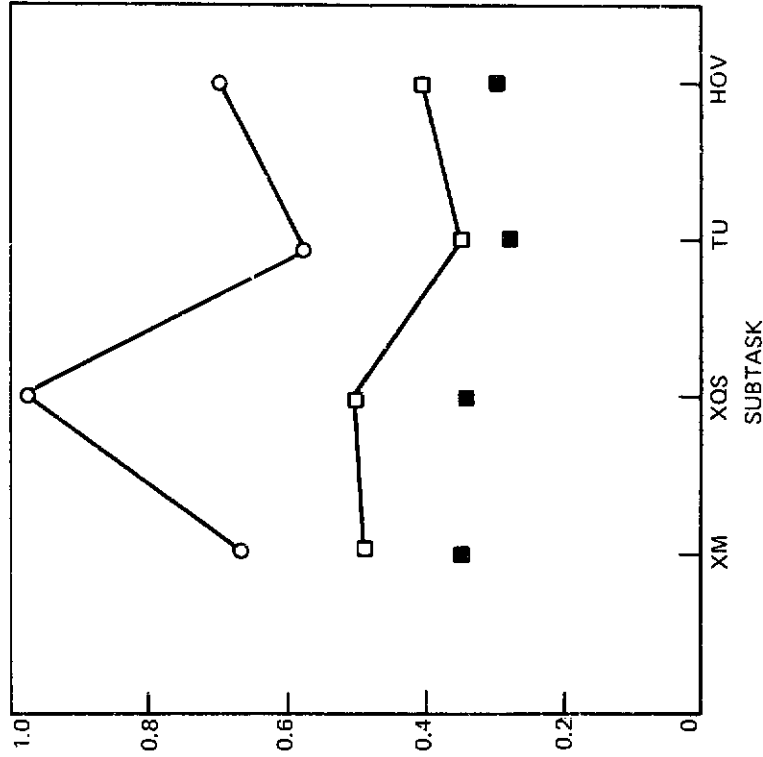


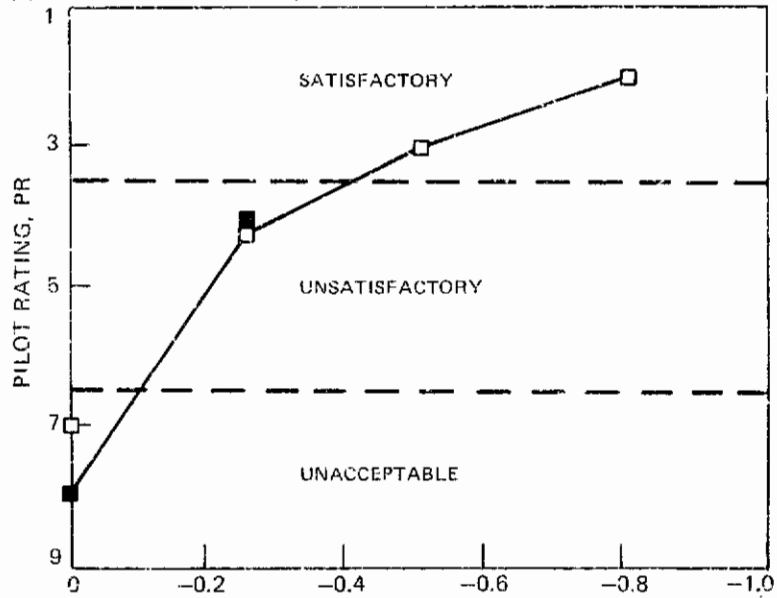
Figure 42. Five-Percent Pitch Control-Moment Exceedance Levels for Rate-Command/Attitude-Hold Control System

Contrails

| PILOT | CALSPAN B* | UARL | |
|----------------|------------|------|----|
| SIMULATOR MODE | MS | FB | MB |
| SYMBOL | ● | □ | ■ |

* NO SIMULATED WINDS FOR CALSPAN PILOT EVALUATION

(a) CONFIGURATION BC1, $T/W > 1.15$



(b) CONFIGURATION BC4, $T/W > 1.15$

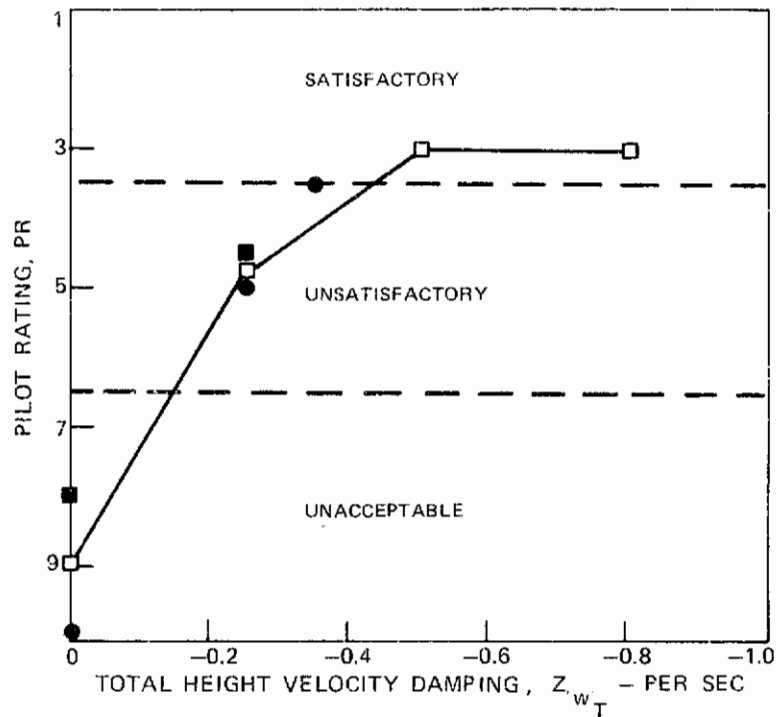


Figure 43. Change in Pilot Rating of Height Control with Height Velocity Damping

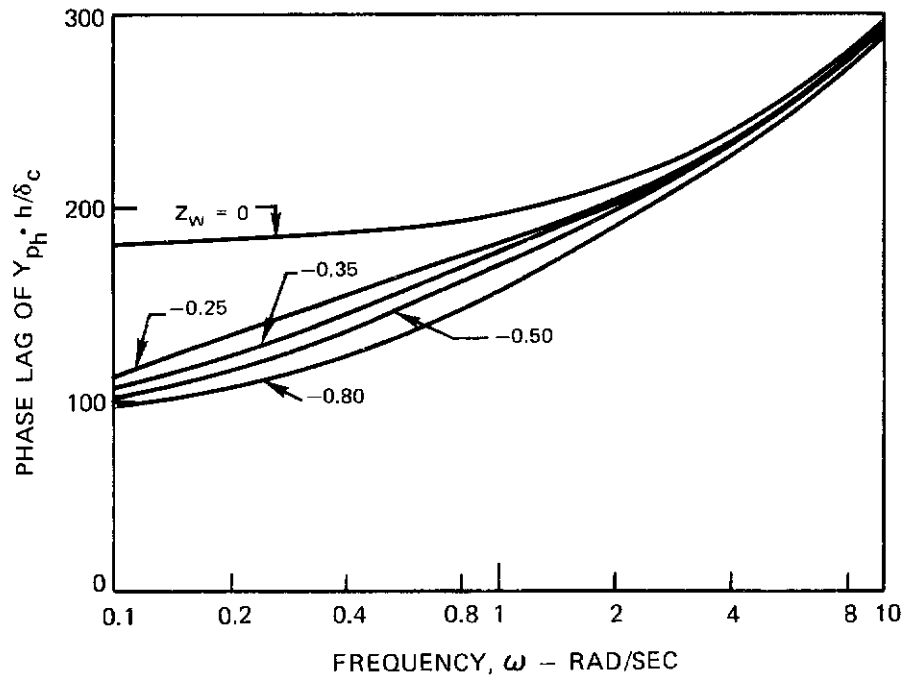
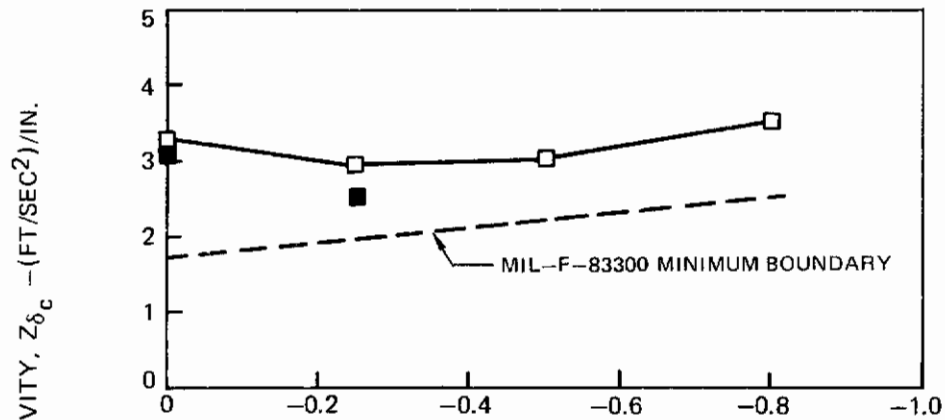


Figure 44. Phase Lags for Pilot-Height Open-Loop Dynamics at Several Z_w Levels

| SIMULATOR MODE | FB | MB |
|----------------|----|----|
| SYMBOL | □ | ■ |

$T/W > 1.15$

(a) CONFIGURATION BC1



(b) CONFIGURATION BC4

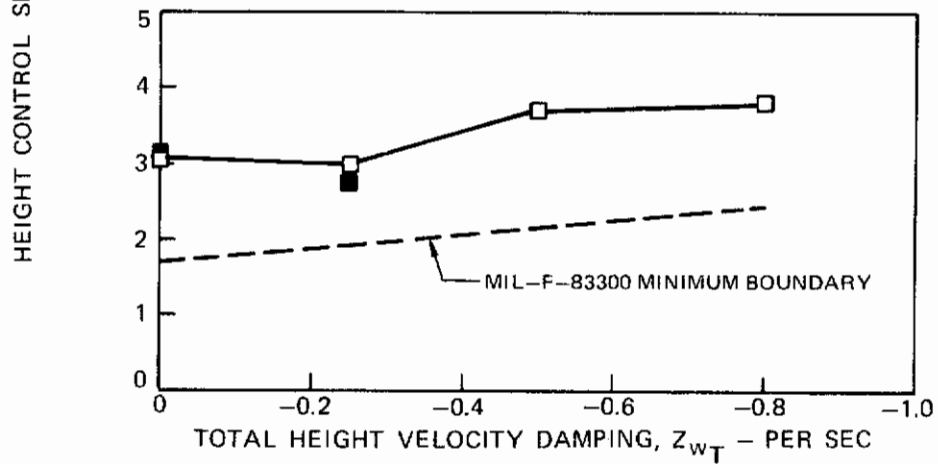


Figure 45. Height Control Sensitivity Results Showing the Effects of Height Velocity Damping

| TYPE OF DAMPING | $Z_{WT} = Z_{Wg} + Z_{Ws}$ $Z_{Wg} = Z_{Ws}$ | | $Z_{WT} = Z_{Wg}$ $Z_{Ws} = 0$ | | $Z_{WT} = Z_{Ws}$ $Z_{Wg} = 0$ | |
|-----------------|---|----|-----------------------------------|----|-----------------------------------|----|
| PILOTS | CALSPAN B* | | CALSPAN B* | | CALSPAN B* | |
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

LEVEL BOUNDARIES FROM MIL-F-83300

Z_{WT} = TOTAL HEIGHT VELOCITY DAMPING Z_{Wg} = AERODYNAMIC HEIGHT VELOCITY DAMPING Z_{Ws} = SAS HEIGHT VELOCITY DAMPING

* $U_m = 0, \sigma, u_g = \sigma, v_g = 1.7$ FT/SEC FOR CALSPAN PILOT EVALUATIONS

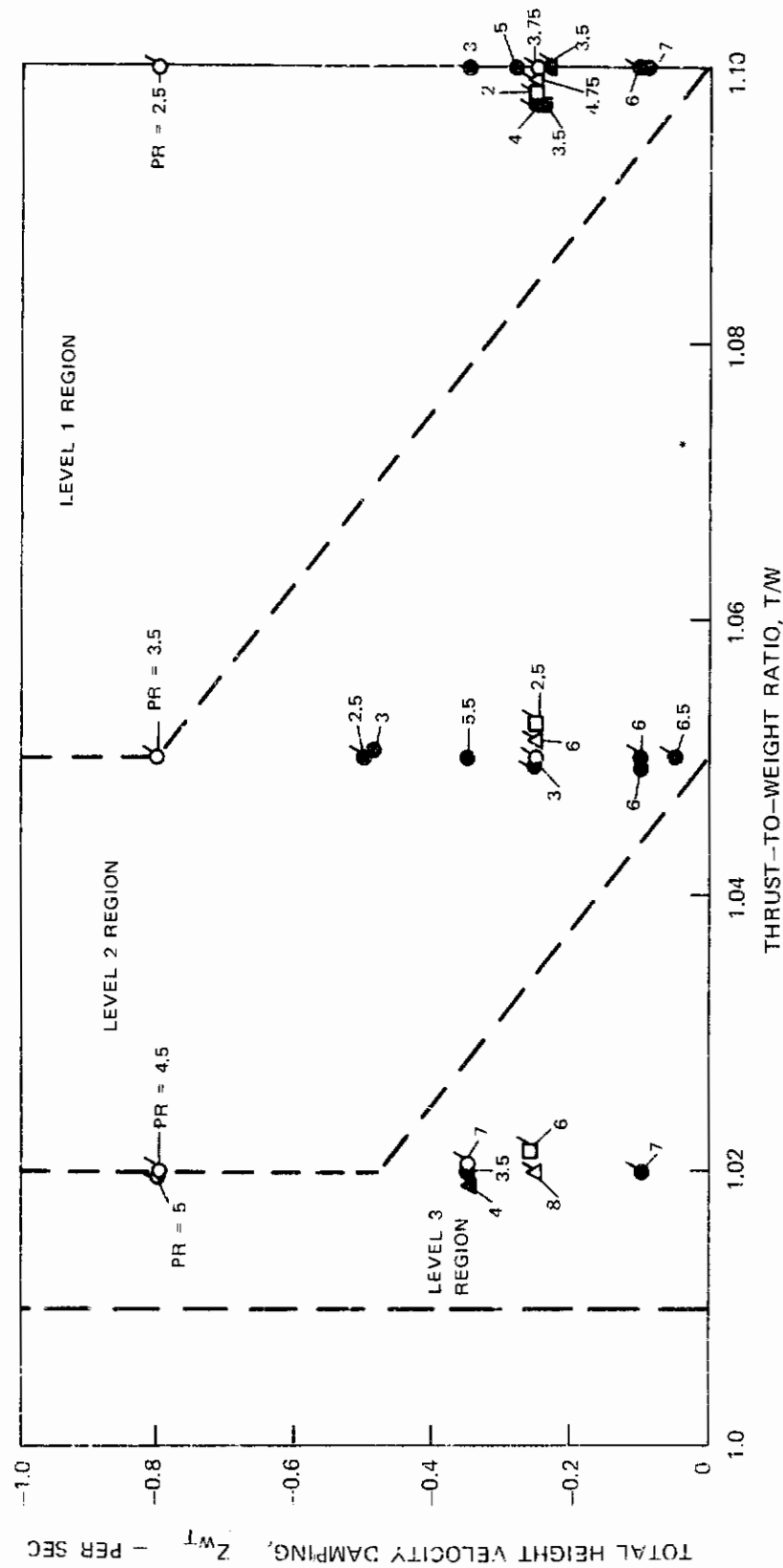


Figure 46. Pilot Rating Results Showing the Interaction Between Height Velocity Damping and Thrust-to-Weight Ratio

Contrails

| | | | | | | |
|----------------|------|----|------|----|------|----|
| T/W | 1.02 | | 1.05 | | 1.10 | |
| SIMULATOR MODE | FB | MB | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ | △ | ▲ |

CONFIGURATION BC1

$$Z_{wT} = Z_{w_a} + Z_{w_s} = -0.25 \text{ FOR ALL CASES}$$

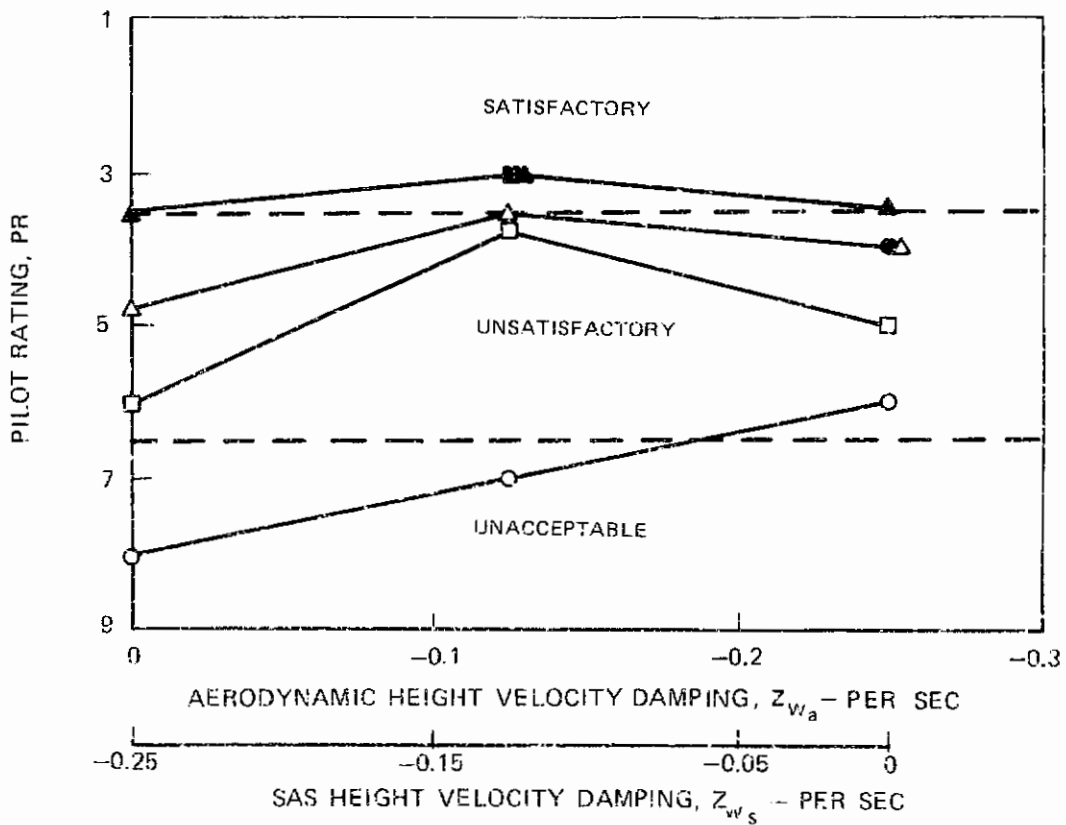


Figure 47. Comparison of Pilot Rating Results for Aerodynamic Versus Stability Augmentation System Height Velocity Damping

Contrails

| | | | | | | |
|-------------------|--------|----|-------|-----|-------|----|
| LEVEL OF Z_{WT} | - 0.25 | | -0.35 | | -0.50 | |
| DELAY, d_h | 0 | | 0 | 0.1 | 0 | |
| SIMULATOR MODE | FB | MB | FB | FB | FB | MB |
| SYMBOL | ○ | ● | □ | ◻ | △ | ▲ |

CONFIGURATION BC1 T/W = 1.05

$$Z_{WT} = Z_{W_2} + Z_{W_5} \text{ WHERE } Z_{W_3} = Z_{W_5}$$

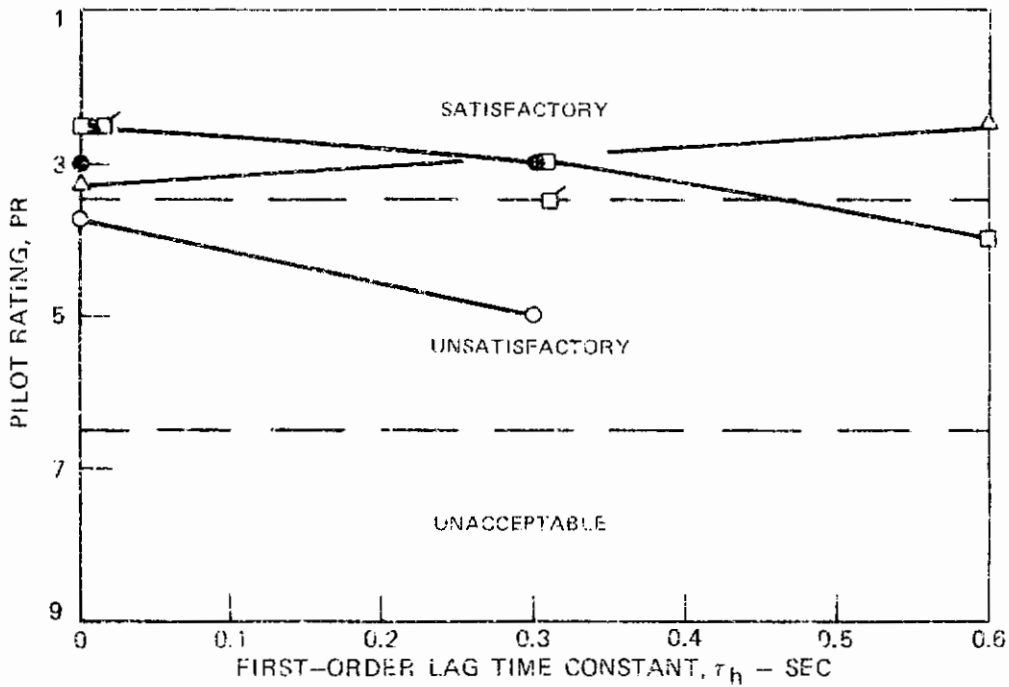


Figure 48. Pilot Rating Results Showing the Interaction Between First-Order Lag Time Constant and Height Velocity Damping

| | | | | |
|----------------|------|----|------|----|
| PILOT | B | | | |
| $\Delta T/W$ | 0.13 | | 0.28 | |
| SIMULATOR MODE | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ |

CONFIGURATION BC1 $Z_{wT} = Z_{ws} = -0.35$ $T/W = 1.02$

$\Delta T/W$: MAXIMUM THRUST INCREMENT AVAILABLE THROUGH STORED ENERGY

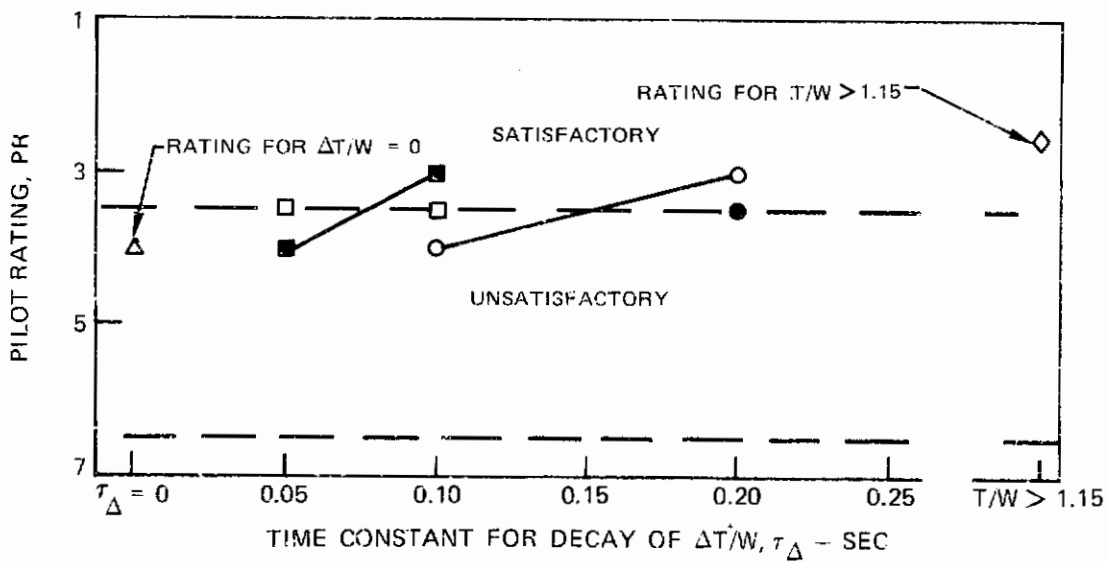


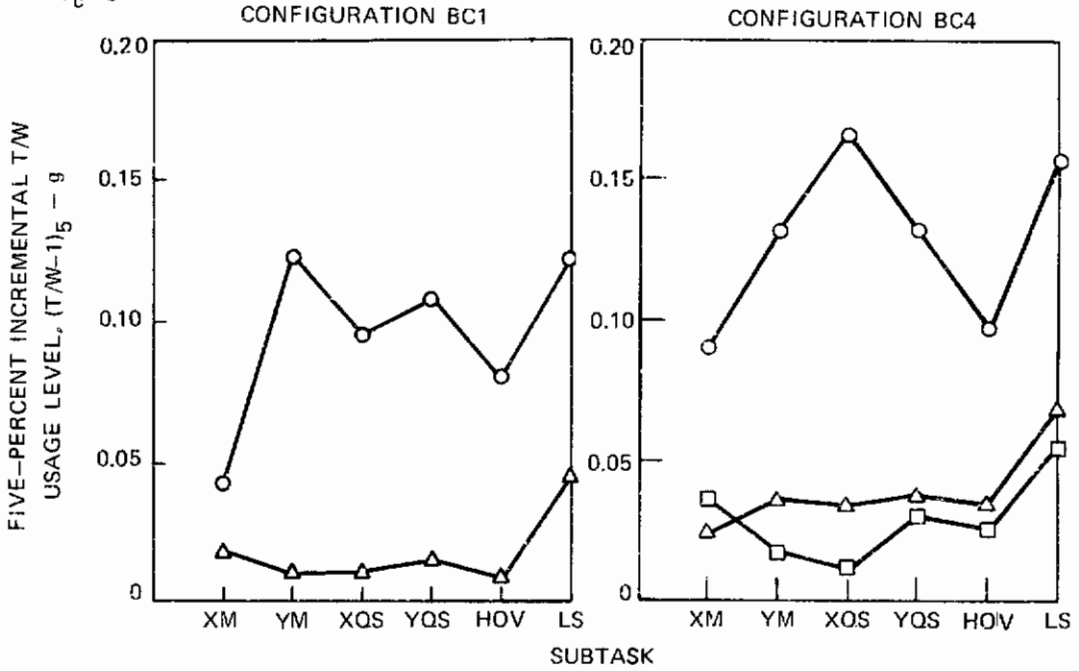
Figure 49. Change in Pilot Ratings Which Results from Incremental Thrust Available Through Stored Energy

| | | | |
|----------------------|---|-------|-------|
| LEVEL OF Z_{WT} | 0 | -0.25 | -0.50 |
| SYMBOL | ○ | □ | △ |

$$Z_{WT} = Z_{wa} + Z_{ws} \text{ WHERE } Z_{wa} = Z_{ws}$$

$T/W > 1.15$

(a) $Z_{\delta_c} \cdot \delta_c$



(b) $Z_{\delta_c} \cdot \delta_c + Z_{ws} \cdot w$

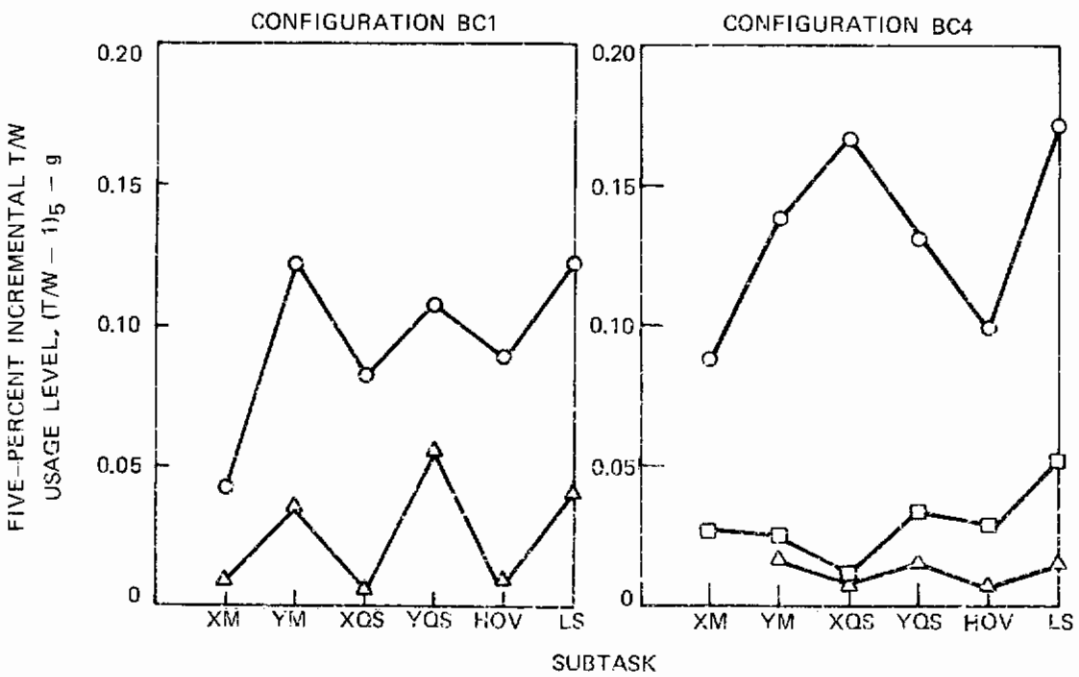


Figure 50. Effect of Z_{WT} on Incremental Thrust 5-Percent Exceedance Levels, $(T/W-1)_5$, Computed for Increased Thrust Commands

Contrails

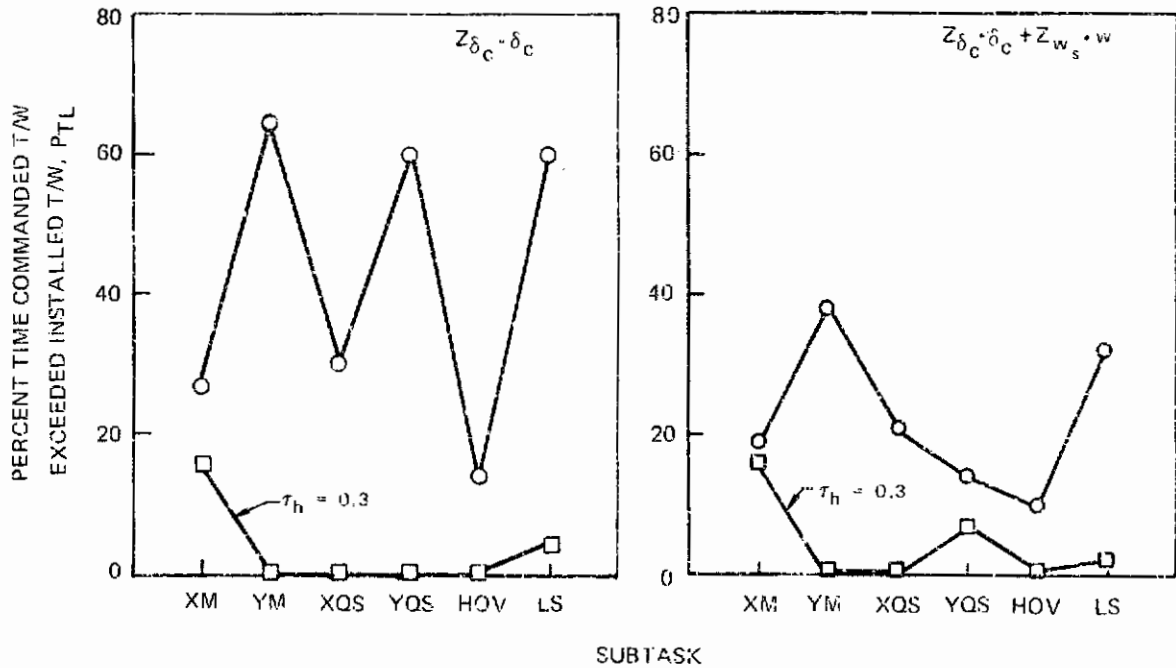
| | | |
|--------|------|------|
| T/W | 1.02 | 1.05 |
| SYMBOL | ○ | □ |

CONFIGURATION BCI

$$Z_{w_T} = Z_{w_a} + Z_{w_s} \quad Z_{w_a} = Z_{w_s}$$

$\tau_h = 0$ EXCEPT WHERE INDICATED

(a) $Z_{w_T} = -0.25$



(b) $Z_{w_T} = -0.50$

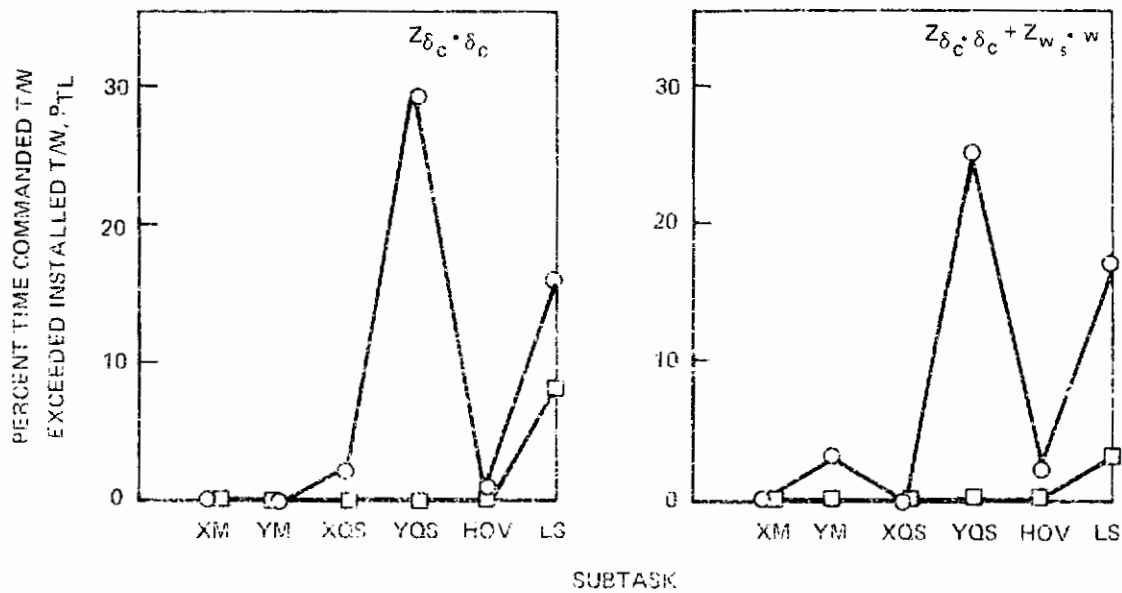


Figure 51. Percent Time Installed Thrust-to-Weight Ratio Limits Exceeded

Contrails

| | | |
|-------------------|---|-----|
| LAG TIME CONSTANT | 0 | 0.3 |
| SYMBOL | ○ | □ |

CONFIGURATION BCI T/W = 1.10 FIXED BASE

$$Z_{w_T} = Z_{w_a} + Z_{w_s} = -0.25 \text{ WHERE } Z_{w_a} = Z_{w_s}$$

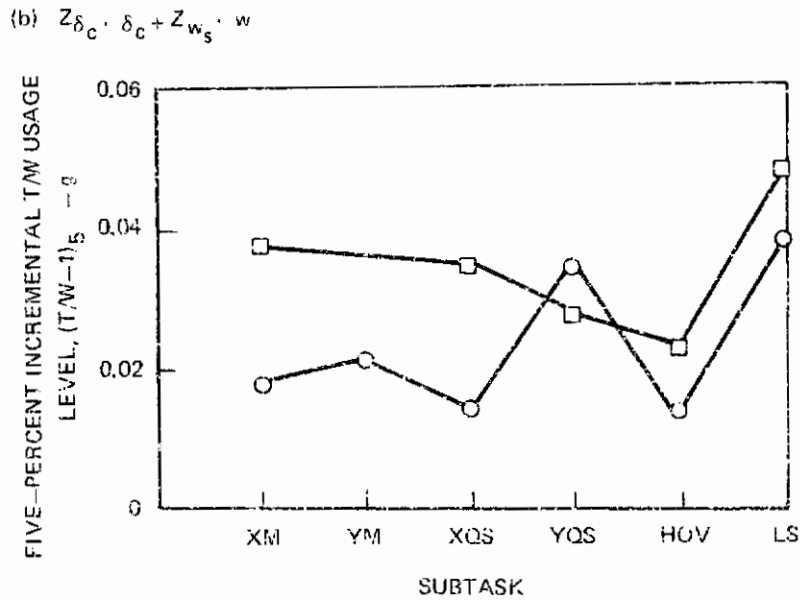
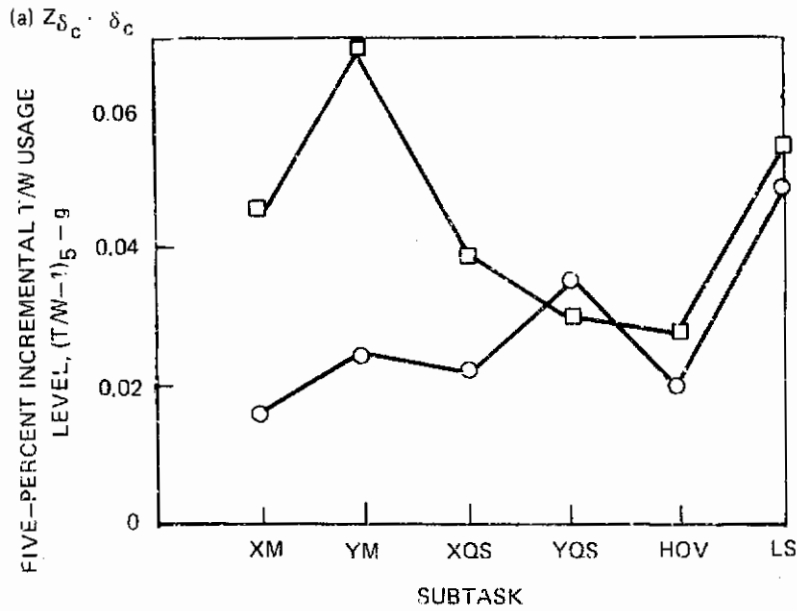


Figure 52. Effect of First-Order Thrust Lags on Incremental Thrust 5-Percent Exceedance Levels Computed for Increased Thrust Commands

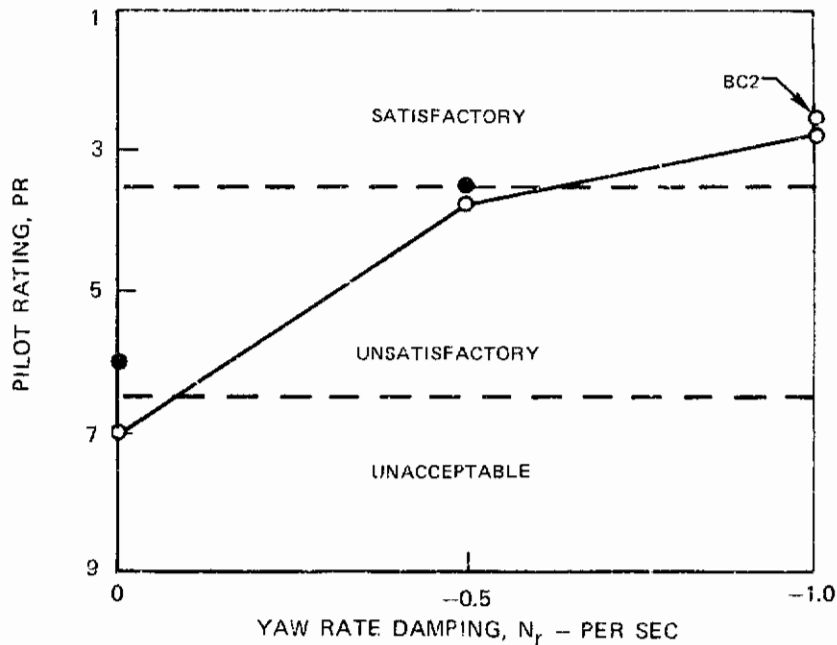
(a) EFFECTS OF YAW RATE DAMPING, N_r

| | | |
|-----------|----|----|
| SIM. MODE | FB | MB |
| SYMBOL | ○ | ● |

$N_V = 0.005$

CONFIGURATION BC1 EXCEPT WHERE INDICATED

UNLIMITED YAW CONTROL MOMENT



(b) COMBINED EFFECTS OF YAW LAGS, τ_ψ , AND DELAYS, d_ψ , AND N_r

| | | | | |
|-----------|------|----|------|----|
| N_r | -0.5 | | -1.0 | |
| SIM. MODE | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ |

UNLIMITED YAW CONTROL MOMENT

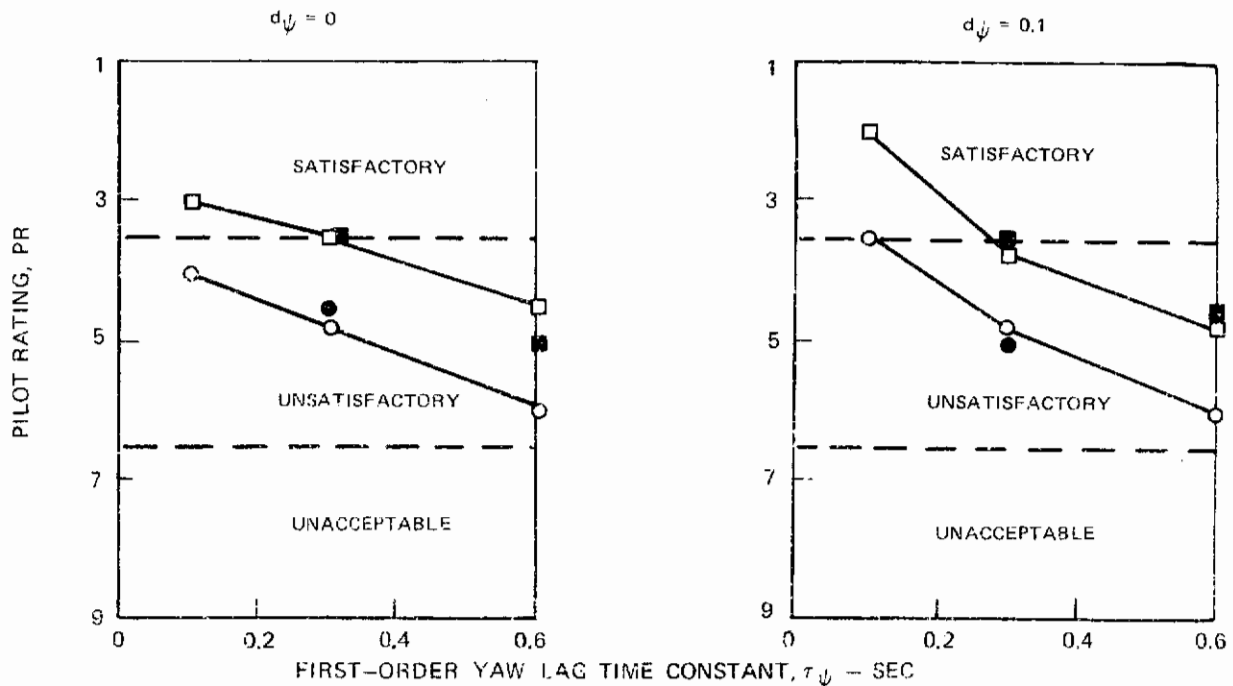


Figure 53. Pilot Rating Results Showing the Effects of Yaw Rate Damping and Lags and Delays in Yaw Control Response

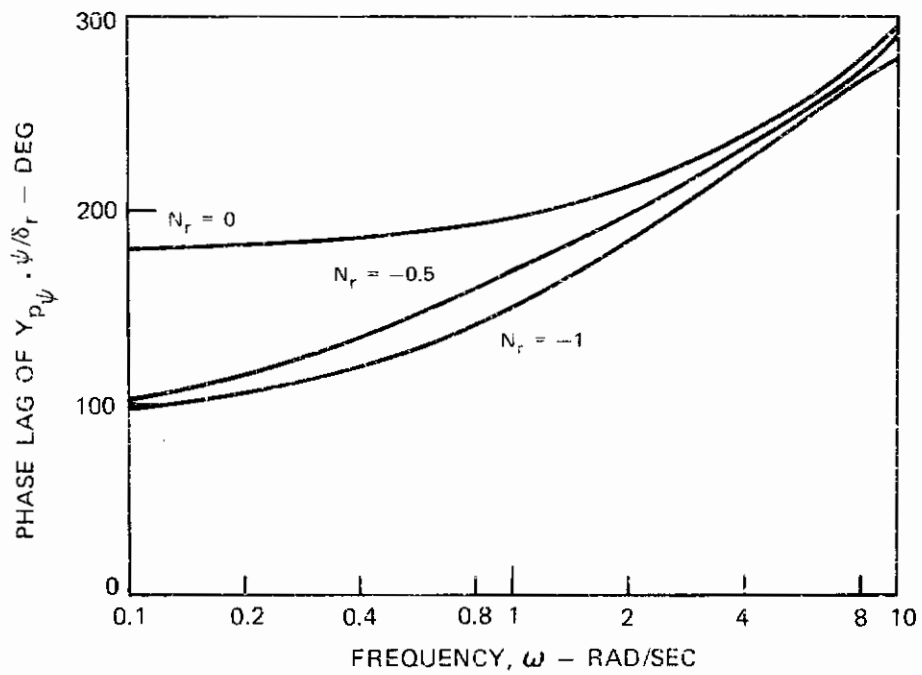


Figure 54. Phase Lag for Pilot-Yaw Open-Loop Dynamics at Several Levels of N_r

| | | | | |
|-----------|------|----|------|----|
| N_r | -0.5 | | -1.0 | |
| SIM. MODE | FB | MB | FB | MB |
| SYMBOL | ○ | ● | □ | ■ |

CONFIGURATION BC1

$\bar{N}_{c5} = 0.10 \text{ RAD/SEC}^2 = \text{YAW CONTROL MOMENT 5-PERCENT EXCEEDANCE LEVEL WITH UNLIMITED MOMENT AVAILABLE}$

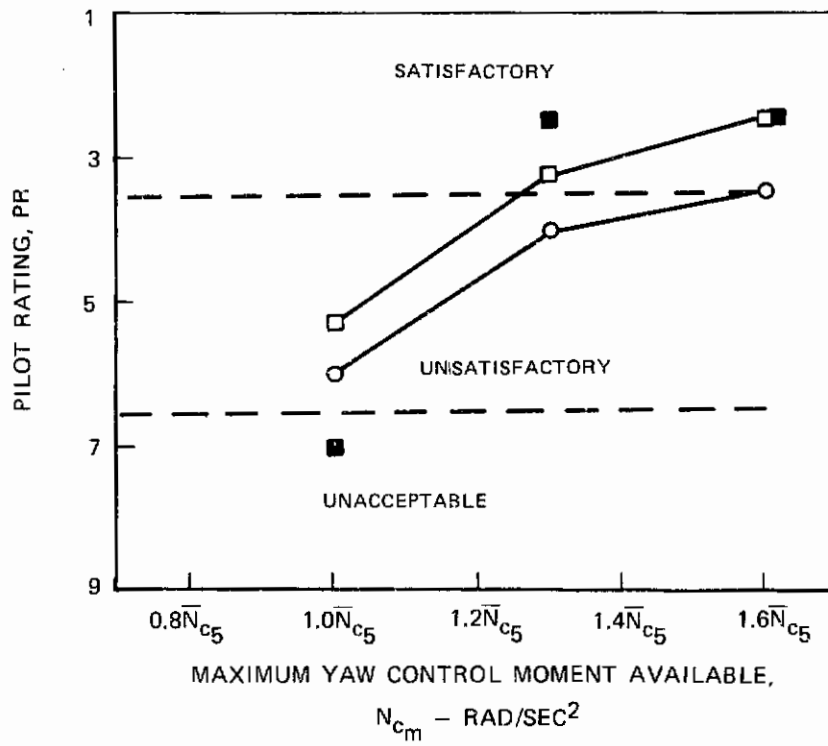


Figure 55. Effects of Yaw Control-Moment Limits on Pilot Rating

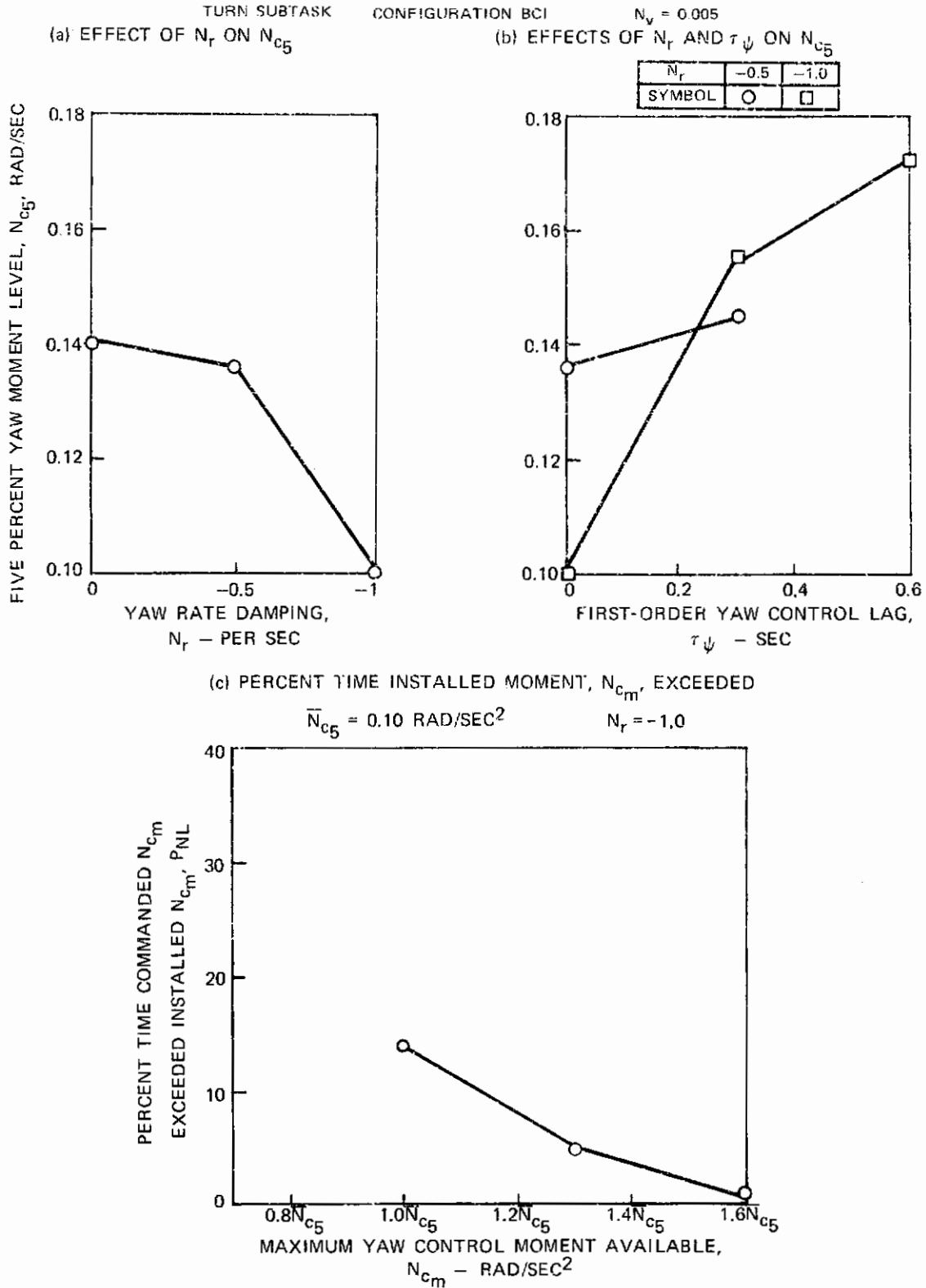


Figure 56. Yaw Control-Moment-Usage Results

Contrails

APPENDIX A

SUMMARY OF FLYING QUALITIES DATA FROM UARL PILOT EVALUATIONS

This Appendix contains a detailed tabulation of the flying qualities data (pilot ratings and pilot-selected control sensitivities) obtained from the flight simulator evaluations with UARL pilots.

Table A-I identifies the studies conducted in the UARL program and lists the parameters for the cases evaluated in each investigation. It also provides a key to the tables which summarize data in Appendices A, B and C. Tables A-II through A-VIII list results from the longitudinal and lateral control studies in the following sequence: A-II, turbulence effects; A-III, control lags and delays; A-IV, control moment limits; A-V, control moments through stored energy; A-VI, inter-axis motion coupling; A-VII, independent thrust-vector control; and A-VIII, rate-command/attitude-hold control. Flying qualities results from the height control studies are listed in Tables A-IX and A-X as follows: A-IX, velocity damping and thrust-to-weight ratio interactive effects; and A-X, thrust lags and delays and incremental thrust through stored energy. Finally, pilot ratings and pilot-selected sensitivities from the directional control studies are summarized in Table A-XI.

TABLE A-I

SUMMARY OF PARAMETERS FOR CASES EVALUATED AND
KEY TO TABLES SUMMARIZING DATA

P: Indicates Parameter Varied During Study F: Control Sensitivity Fixed
S: Control Sensitivity Selected by Pilot UL: Unlimited

| Study | Parameters | Case | Basic Conf. | Longitudinal ¹ | | | | Vertical | | | Directional | | | | Flying Qualities Results Table No. | Pilot Comments Table No. | Control Moment or T/W Usage Table No. | | | |
|---|--|----------|-----------------|---------------------------|-------------|-------------|-------------|----------------|-------------|-------------|-------------|-------------|-------------|-------------|------------------------------------|--------------------------|---------------------------------------|-------------|--------|--------------------------------|
| | | | | \dot{M}_0 | \dot{Z}_0 | \dot{N}_1 | \dot{M}_2 | \dot{X}_0 | \dot{M}_0 | \dot{C}_0 | \dot{Z}_0 | \dot{Y}_0 | \dot{N}_0 | \dot{M}_0 | | | | \dot{N}_0 | | |
| Effects of Turbulence | $\sigma_{u_0} = \sigma_{v_0}^2$ | TI-T18 | B01 | 0.33 | -0.05 | -1.7 | -1.5 | UL | S | F | -1 | 1.15 | -3.2 | 0.005 | -1 | UL | 0.70 | A-II | B-I | C-I |
| | | | B02 | 1.0 | +0.05 | -3.1 | -2.5 | | | | | | | | | | | | | |
| | | | B03 | 1.0 | -0.05 | -2.0 | 0 | | | | | | | | | | | | | |
| | | | B04 | 1.0 | -0.20 | -3.0 | -1.7 | | | | | | | | | | | | | |
| | | | B05 | 0.33 | -0.20 | -1.7 | -1.5 | | | | | | | | | | | | | |
| B06 | 1.0 | -0.20 | -3.1 | -2.5 | | | | | | | | | | | | | | | | |
| Lags and delays in pitch and roll control | $\tau_p = \tau_a^3$ $\tau_r = \tau_a^3$ $\tau_{\dot{p}} = \tau_a^3$ $\tau_{\dot{r}} = \tau_a^3$ | LI1-L127 | B01 through B06 | Same as TI-T18 | | | | UL | S | 3.4 | -1 | 1.15 | -3.2 | 0.005 | -1 | UL | 0.70 | A-III | B-II | C-II |
| Pitch, roll and yaw moment limits | M_{0p}, M_{0q}, M_{0r} $\tau_p = \tau_a$ $\tau_r = \tau_a$ | LI1-L125 | B01 B02 B03 B06 | Same as TI-T18 | | | | P | S | 3.4 | -1 | 1.15 | -3.2 | 0.002 | -1 | P | 0.70 | A-IV | B-III | C-III |
| Pitch control moment through stored energy | M_{0p}, M_{0q}, M_{0r} τ_p | LI1-L133 | B01 B04 B05 B06 | Same as TI-T18 | | | | P ² | S | 3.4 | -1 | 1.15 | -3.2 | 0.002 | -1 | UL | 0.70 | A-V | B-IV | Control moment not measured |
| Inter-axis motion coupling | $M_{0p}, M_{0q}, M_{0r}, M_{0\dot{p}}, M_{0\dot{q}}, M_{0\dot{r}}$ | LI1-L126 | B01 | Same as TI-T18 | | | | UL | S | 3.4 | -1 | 1.15 | -3.2 | 0.002 | -1 | UL | 0.70 | A-VI | B-V | C-IV |
| Independent longitudinal thrust-vector control | δ, γ, θ $\dot{\theta}$ | LI1-L123 | B01 B02 B04 | Same as TI-T18 | | | | UL | S | 3.4 | -1 | 1.15 | -3.2 | 0.002 | -1 | UL | 0.70 | A-VII | B-VI | C-V |
| Rate command/ attitude hold control | $M_{0p}, M_{0q}, M_{0r}, \dot{\theta}, \dot{\gamma}, \dot{\theta}$ | LI1-L115 | B01 | 0.33 | -0.05 | P | P | UL | S | 3.4 | -1 | 1.15 | -3.2 | 0.002 | -1 | UL | 0.20 | A-VIII | B-VII | C-VI |
| | | | B04 | 1.0 | -0.20 | P | P | | | | | | | | | | | | | |
| Velocity damping and thrust-to-weight ratio effects on height control | $\dot{z}_0, \dot{z}_0, \dot{z}_0, \dot{z}_0, \dot{z}_0$ | LI1-RE28 | B01 B04 | 0.33 | -0.05 | -1.7 | -1.7 | UL | F | 3.4 | P | P | S | 0.002 | -1 | UL | 0.20 | A-IX | B-VIII | C-VII |
| Lags and delays in thrust response | τ_h, τ_h | LI1-RE5 | B01 | 0.33 | -0.05 | -1.7 | -1.7 | UL | F | 3.4 | F | P | S | 0.002 | -1 | UL | 0.20 | A-X | B-IX | C-VII |
| Incremental thrust through stored energy | $\Delta T, \dot{T}, \dot{T}$ | LI1-RE5 | B01 | 0.33 | -0.05 | -1.7 | -1.7 | UL | F | 3.4 | F | P | S | 0.002 | -1 | UL | 0.20 | A-X | B-IX | Thrust usage data not measured |
| Directional control studies | τ_p, τ_r | LI-REP | B01 | 0.33 | -0.05 | -1.7 | -1.7 | UL | F | 3.4 | -1 | 1.15 | -3.2 | 0.005 | P | P | S | A-XI | B-X | C-VIII |
| | | | B02 | 1.0 | -0.05 | -1.1 | -2.5 | | | | | | | | | | | | | |

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative. Also, if a longitudinal term is treated as a parameter, the corresponding lateral term is as well.
2. Longitudinal and lateral turbulence levels always equal throughout this program.
3. Pitch and roll control lags always equal. Pitch and roll control delays also always equal.
4. Wind simulation included a mean wind from the north, $U_0 = 10$ kts.
5. Maximum roll moment, M_{0r} , unlimited.

TABLE A-II

FLYING QUALITIES RESULTS FROM THE STUDY OF THE EFFECTS OF TURBULENCE INTENSITY

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-I

| Case | Basic Conf. | Stability Derivatives ¹ | | | | Real Root | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | σ_{ζ}^2 | σ_{ω}^2 | Pilot | Fixed Base | | | Moving Base | | |
|------|-------------|------------------------------------|--------------------|--------------------|--------------------|-----------|---|--------------------|---------------------|-------|--------------------|--------------------|-----|--------------------|--------------------|-----|
| | | $M_{\dot{\omega}}$ | $X_{\dot{\omega}}$ | $M_{\dot{\omega}}$ | $M_{\dot{\omega}}$ | | | | | | $M_{\dot{\omega}}$ | $I_{\dot{\omega}}$ | PR | $M_{\dot{\omega}}$ | $I_{\dot{\omega}}$ | PR |
| T1 | BC1 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | $-0.81 \pm j1.85$ | 3.4 | 3.4 | A | 0.330 | 0.308 | 2.0 | 0.313 | 0.242 | 2.0 |
| T2 | " | " | " | " | " | " | " | 5.8 | 5.8 | B | 0.206 | 0.304 | 2.0 | 0.313 | 0.242 | 2.0 |
| T3 | " | " | " | " | " | " | " | 8.2 | 8.2 | B | 0.268 | 0.239 | 2.0 | 0.313 | 0.242 | 2.0 |
| T4 | " | " | " | " | " | " | " | 8.2 | 8.2 | A | 0.412 | 0.358 | 4.5 | 0.313 | 0.242 | 2.0 |
| T5 | " | " | " | " | " | " | " | " | " | B | 0.341 | 0.306 | 3.0 | 0.289 | 0.221 | 3.0 |
| T6 | BC5 | 0.33 | -0.20 | -1.7 | -4.2 | -0.29 | $-0.81 \pm j1.85$ | 3.4 | 3.4 | A | 0.307 | 0.205 | 4.0 | 0.298 | 0.243 | 2.0 |
| T7 | " | " | " | " | " | " | " | 5.8 | 5.8 | B | 0.306 | 0.248 | 3.0 | 0.298 | 0.243 | 2.0 |
| T8 | " | " | " | " | " | " | " | 8.2 | 8.2 | B | 0.358 | 0.248 | 3.0 | 0.298 | 0.243 | 2.0 |
| T9 | " | " | " | " | " | " | " | 8.2 | 8.2 | A | 0.307 | 0.365 | 4.5 | 0.298 | 0.243 | 2.0 |
| T10 | " | " | " | " | " | " | " | " | " | B | 0.367 | 0.291 | 4.0 | 0.379 | 0.291 | 5.0 |
| T11 | BC4 | 1.0 | -0.20 | -3.0 | -1.7 | -2.5 | $-0.35 \pm j0.64$ | 3.4 | 3.4 | A | 0.333 | 0.331 | 3.0 | 0.380 | 0.301 | 3.0 |
| T12 | " | " | " | " | " | " | " | 5.8 | 5.8 | B | 0.274 | 0.225 | 4.0 | 0.380 | 0.301 | 3.0 |
| T13 | " | " | " | " | " | " | " | 8.2 | 8.2 | B | 0.452 | 0.380 | 3.0 | 0.380 | 0.301 | 3.0 |
| T14 | " | " | " | " | " | " | " | " | " | A | 0.616 | 0.388 | 8.0 | 0.380 | 0.301 | 3.0 |
| T15 | " | " | " | " | " | " | " | " | " | B | 0.513 | 0.434 | 5.0 | 0.375 | 0.297 | 9.0 |
| T16 | BC2 | 1.0 | -0.05 | -1.1 | -2.5 | -0.5 | $-0.30 \pm j1.47$ | 3.4 | 3.4 | A | 0.373 | 0.350 | 4.0 | 0.375 | 0.297 | 3.0 |
| T17 | " | " | " | " | " | " | " | 5.8 | 5.8 | B | 0.343 | 0.350 | 5.0 | 0.375 | 0.297 | 3.0 |
| T18 | " | " | " | " | " | " | " | 8.2 | 8.2 | B | 0.416 | 0.340 | 6.0 | 0.375 | 0.297 | 3.0 |
| T19 | " | " | " | " | " | " | " | " | " | B | 0.445 | 0.322 | 8.0 | 0.375 | 0.297 | 3.0 |
| T20 | BC6 | 1.0 | -0.20 | -1.1 | -2.5 | -0.65 | $-0.32 \pm j1.48$ | 3.4 | 3.4 | A | 0.342 | 0.285 | 4.5 | 0.320 | 0.260 | 6.0 |
| T21 | " | " | " | " | " | " | " | 5.8 | 5.8 | B | 0.298 | 0.242 | 5.0 | 0.320 | 0.260 | 6.0 |
| T22 | " | " | " | " | " | " | " | 8.2 | 8.2 | B | 0.452 | 0.363 | 7.0 | 0.320 | 0.260 | 6.0 |
| T23 | " | " | " | " | " | " | " | " | " | A | 0.581 | 0.352 | 9.0 | 0.320 | 0.260 | 6.0 |
| T24 | " | " | " | " | " | " | " | " | " | B | 0.538 | 0.442 | 9.0 | 0.320 | 0.260 | 6.0 |
| T25 | BC3 | 1.0 | -0.05 | -2.0 | 0 | -2.2 | $0.08 \pm j0.68$ | 3.4 | 3.4 | A | 0.359 | 0.427 | 5.0 | 0.407 | 0.280 | 6.0 |
| T26 | " | " | " | " | " | " | " | 5.8 | 5.8 | B | 0.449 | 0.419 | 3.0 | 0.407 | 0.280 | 6.0 |
| T27 | " | " | " | " | " | " | " | 8.2 | 8.2 | B | 0.439 | 0.373 | 6.0 | 0.407 | 0.280 | 6.0 |
| T28 | " | " | " | " | " | " | " | " | " | B | 0.467 | 0.352 | 8.0 | 0.407 | 0.280 | 6.0 |

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

2. Mean wind, $U_m = 10$ kts.

TABLE A-III

LONGITUDINAL AND LATERAL FLYING QUALITIES RESULTS FROM THE STUDY OF CONTROL SYSTEM LAGS AND DELAYS

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-II

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-d_H \pm j\omega_H$ | First-Order Control Lags | | Second-Order Control Lags | | | Control Delays | | Fixed Base | | | Moving Base | |
|-------------------|-------------|------------------------------------|---------------|--------------------|-----------|---------------------------------------|--------------------------|------------------|--|-------|-------|----------------|---------------|---------------|-------|---------------|----------------|-------|
| | | $M_{\dot{u}}$ | $Y_{\dot{u}}$ | $M_{\dot{\theta}}$ | | | τ_a | ζ_c/τ_a | $\omega_{\dot{u}}/\omega_{\dot{\theta}}$ | d_c | d_a | Pilot | $M_{\dot{u}}$ | $l_{\dot{u}}$ | FR | $\% \delta_e$ | l_{δ_e} | FR |
| LL1 | BC1 | 0.33 | -0.05 | -1.7 | -0.13 | $-0.81 \pm j1.85$ | 0.1 | - | - | - | - | - | - | 0.303 | 0.248 | 2.0 | - | - |
| LL2 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.294 | 0.208 | 3.0 | " | " |
| LL3 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.330 | 0.251 | 2.5 | " | " |
| LL4 | BC5 | 0.33 | -0.05 | -1.7 | -0.29 | $-0.81 \pm j1.85$ | 0.1 | - | - | - | - | - | - | 0.335 | 0.237 | 2.0 | 0.373 | 0.295 |
| LL5 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.302 | 0.242 | 2.0 | " | " |
| LL6 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.296 | 0.254 | 2.0 | " | " |
| LL7 | BC4 | 1.0 | -0.20 | -3.0 | -2.5 | $-0.35 \pm j0.64$ | 0.1 | - | - | - | - | - | - | 0.241 | 0.312 | 3.0 | 0.328 | 0.262 |
| LL8 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.130 | 0.363 | 4.0 | 0.418 | 0.345 |
| LL9 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.424 | 0.319 | 2.0 | 0.421 | 0.329 |
| LL10 | BC2 | 1.0 | -0.05 | -1.1 | -0.5 | $-0.30 \pm j1.47$ | 0.1 | - | - | - | - | - | - | 0.349 | 0.275 | 2.5 | 0.396 | 0.262 |
| LL11 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.349 | 0.275 | 3.0 | 0.421 | 0.329 |
| LL12 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.487 | 0.338 | 4.0 | 0.421 | 0.329 |
| LL13 | BC6 | 1.0 | -0.20 | -1.1 | -0.65 | $-0.32 \pm j1.48$ | 0.1 | - | - | - | - | - | - | 0.161 | 0.404 | 3.0 | 0.396 | 0.262 |
| LL14 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.109 | 0.280 | 4.0 | 0.396 | 0.262 |
| LL15 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.324 | 0.257 | 5.0 | 0.421 | 0.329 |
| LL16 | BC3 | 1.0 | -0.05 | -2.0 | -0.2 | $-0.68 \pm j0.68$ | 0.1 | - | - | - | - | - | - | 0.347 | 0.270 | 5.0 | 0.421 | 0.329 |
| LL17 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.387 | 0.333 | 8.0 | 0.421 | 0.329 |
| LL18 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.414 | 0.374 | 6.0 | 0.396 | 0.262 |
| LL19 | BC1 | 0.33 | -0.05 | -1.7 | -0.13 | $-0.81 \pm j1.85$ | 0.1 | - | - | - | - | - | - | 0.432 | 0.348 | 4.0 | 0.396 | 0.262 |
| LL20 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.314 | 0.193 | 4.5 | 0.396 | 0.262 |
| LL21 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.303 | 0.297 | 5.0 | 0.396 | 0.262 |
| LL22 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.434 | 0.359 | 6.0 | 0.396 | 0.262 |
| LL23 | BC1 | 0.33 | -0.05 | -1.7 | -0.13 | $-0.81 \pm j1.85$ | 0 | - | - | - | - | - | - | 0.427 | 0.351 | 6.0 | 0.396 | 0.262 |
| LL24 | " | " | " | " | " | " | 0.3 | " | " | " | " | " | " | 0.436 | 0.455 | 9.0 | 0.396 | 0.262 |
| LL25 | " | " | " | " | " | " | 0.6 | " | " | " | " | " | " | 0.451 | 0.365 | 7.0 | 0.423 | 0.375 |
| LL26 | BC2 | 1.0 | -0.05 | -1.1 | -0.5 | $-0.30 \pm j1.47$ | 0 | - | - | - | - | - | - | 0.595 | 0.602 | 10.0 | 0.423 | 0.375 |
| LL27 | " | " | " | " | " | " | 0.2 | - | - | - | - | - | - | 0.422 | 0.369 | 7.0 | 0.423 | 0.375 |
| | | | | | | | | | | | | | | 0.295 | 0.226 | 7.0 | | |
| | | | | | | | | | | | | | | 0.300 | 0.272 | 10.0 | | |
| | | | | | | | | | | | | | | 0.352 | 0.310 | 4.0 | | |
| | | | | | | | | | | | | | | 0.317 | 0.257 | 3.0 | | |
| | | | | | | | | | | | | | | 0.297 | 0.260 | 7.0 | 0.307 | 0.255 |
| | | | | | | | | | | | | | | 0.357 | 0.324 | 3.0 | 0.307 | 0.255 |
| | | | | | | | | | | | | | | 0.332 | 0.290 | 3.0 | | |
| | | | | | | | | | | | | | | 0.399 | 0.334 | 5.0 | 0.366 | 0.280 |
| | | | | | | | | | | | | | | 0.363 | 0.334 | 7.0 | 0.372 | 0.317 |

1. Standard wind simulation; $\sigma_{V_H} = \sigma_{V_V} = 3.4$ ft/sec; $U_m = 10$ kts.
 2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
 3. Lag and delay affect both the control and stability augmentation system inputs.

TABLE A-IV
 FLYING QUALITIES RESULTS FROM THE STUDY OF PITCH, ROLL AND YAW CONTROL MOMENT LIMITS
 Vertical and Directional Parameters Listed in Table A-I
 Pilot Comments Given in Table B-III

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta \omega_n \pm j \omega_d$ | Maximum Control Moments Available | | | First-Order Control Lags | | Control Delay d_e | d_a | Pilot | Fixed Base | | | Moving Base | | | |
|-------------------|-------------|------------------------------------|--------------------|--------------------|-----------|---|-----------------------------------|----------------------|----------------------|--------------------------|----------|------------------------|-------|-------|------------|-------|----------------------|----------------------|-------|----------------------|----------------------|
| | | $M_{\dot{\delta}}$ | $X_{\dot{\delta}}$ | $M_{\dot{\gamma}}$ | | | $M_{\dot{\delta}_m}$ | $M_{\dot{\delta}_m}$ | $N_{\dot{\delta}_m}$ | τ_c | τ_a | | | | d_e | d_a | $M_{\dot{\delta}_e}$ | $U_{\dot{\delta}_e}$ | PR | $M_{\dot{\delta}_e}$ | $U_{\dot{\delta}_e}$ |
| IM1 | B01 | 0.35 | -0.05 | -1.7 | -4.2 | -0.13 | -0.81 ± j1.85 | 0.360 | 0.415 | 0.120 | - | - | - | B | 0.301 | 0.256 | 7.0 | 0.301 | 0.254 | 7.0 | |
| IM2 | " | | | | | | | 0.396 | 0.457 | 0.132 | | | | A | 0.307 | 0.261 | 3.0 | 0.317 | 0.256 | 3.0 | |
| IM3 | " | | | | | | | 0.432 | 0.498 | 0.144 | | | | A | 0.296 | 0.243 | 2.0 | 0.317 | 0.256 | 3.0 | |
| IM4 | " | | | | | | | 0.575 | 0.415 | 0.120 | | | | B | 0.327 | 0.200 | 2.0 | 0.303 | 0.218 | 2.5 | |
| IM5 | B05 | 0.33 | -0.20 | -1.7 | -4.2 | -0.29 | -0.81 ± j1.85 | 0.300 | 0.280 | 0.120 | - | - | - | B | 0.350 | 0.359 | 3.0 | 0.320 | 0.268 | 7.0 | |
| IM6 | " | | | | | | | 0.350 | 0.360 | 0.150 | | | | A | 0.270 | 0.233 | 3.0 | 0.297 | 0.218 | 2.5 | |
| IM7 | " | | | | | | | 0.462 | 0.440 | 0.182 | | | | A | | | | | | | |
| IM8 | B04 | 1.0 | -0.20 | -3.0 | -1.7 | -2.5 | -0.35 ± j0.64 | 0.820 | 0.605 | 0.175 | - | - | - | A | 0.260 | 0.194 | 6.0 | 0.426 | 0.348 | 5.0 | |
| IM9 | " | | | | | | | 0.906 | 0.666 | 0.193 | | | | B | 0.413 | 0.395 | 5.0 | 0.428 | 0.334 | 4.5 | |
| IM10 | " | | | | | | | 0.984 | 0.727 | 0.211 | | | | A | 0.215 | 0.244 | 2.0 | 0.393 | 0.325 | 6.0 | |
| IM11 | " | | | | | | | 1.066 | 0.786 | 0.279 | | | | B | 0.431 | 0.404 | 3.0 | 0.400 | 0.336 | 5.0 | |
| IM12 | B06 | 1.0 | -0.20 | -1.1 | -2.5 | -0.65 | -0.32 ± j1.48 | 0.890 | 0.750 | 0.170 | - | - | - | B | 0.387 | 0.351 | 7.0 | 0.400 | 0.336 | 5.0 | |
| IM13 | " | | | | | | | 0.979 | 0.825 | 0.187 | | | | A | 0.215 | 0.182 | 10.0 | 0.393 | 0.325 | 6.0 | |
| IM14 | " | | | | | | | 1.068 | 0.900 | 0.204 | | | | B | 0.387 | 0.351 | 5.0 | 0.400 | 0.336 | 5.0 | |
| IM15 | " | | | | | | | 1.157 | 0.975 | 0.221 | | | | A | 0.228 | 0.182 | 8.0 | 0.393 | 0.325 | 6.0 | |
| IM16 | " | | | | | | | 1.256 | 1.050 | 0.208 | | | | B | 0.367 | 0.353 | 4.5 | 0.400 | 0.336 | 5.0 | |
| IM17 | B01 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | -0.81 ± j1.85 | 0.396 | 0.457 | 0.132 | 0.3 | 0.3 | 0.1 | B | 0.339 | 0.264 | 4.0 | 0.348 | 0.299 | 4.5 | |
| IM18 | " | | | | | | | 0.432 | 0.498 | 0.144 | 0.3 | 0.3 | 0.1 | A | 0.223 | 0.194 | 4.0 | 0.305 | 0.245 | 3.0 | |
| IM19 | " | | | | | | | 0.468 | 0.540 | 0.156 | " | " | " | B | 0.339 | 0.264 | 4.0 | 0.305 | 0.245 | 3.0 | |
| IM20 | " | | | | | | | 0.369 | 0.457 | 0.132 | 0.3 | 0.3 | 0.1 | E | 0.346 | 0.275 | 2.5 | | | | |
| IM21 | " | | | | | | | 0.432 | 0.498 | 0.144 | 0.6 | 0.6 | 0.1 | E | 0.371 | 0.312 | 4.5 | | | | |
| IM22 | " | | | | | | | 0.468 | 0.540 | 0.156 | 0.6 | 0.6 | 0.1 | B | 0.364 | 0.325 | 4.0 | | | | |
| IM23 | B05 | 0.33 | -0.20 | -1.7 | -4.2 | -0.29 | -0.81 ± j1.85 | 0.420 | 0.400 | 0.165 | 0.6 | 0.6 | 0.1 | B | 0.368 | 0.312 | 4.0 | | | | |
| IM24 | " | | | | | | | 0.462 | 0.440 | 0.182 | 0.6 | 0.6 | 0.1 | E | 0.358 | 0.323 | 3.5 | | | | |
| IM25 | " | | | | | | | 0.504 | 0.480 | 0.199 | 0.6 | 0.6 | 0.1 | E | 0.433 | 0.336 | 4.0 | | | | |

1. Standard wind stimulation: $\sigma_{\dot{\delta}} = \sigma_{\dot{\gamma}} = 3.4$ ft/sec, $U_m = 10$ kts.
 2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

TABLE A-V

LONGITUDINAL FLYING QUALITIES RESULTS FROM THE STUDY OF INCREMENTAL CONTROL MOMENTS THROUGH STORED ENERGY

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-IV

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | | Real Root | Complex Roots $-\zeta \omega_n \pm j \omega_d$ | Control-Moment, Stored Energy Parameters ³ | | | Pilot | | Fixed Base | | Moving Base | | |
|-------------------|-------------|------------------------------------|----------------|----------------|----------------|-----------|--|---|--------------|-----------------|----------------|----------------|------------|----------------|----------------|------|-----|
| | | $M_{u\dot{g}}$ | $Y_{u\dot{g}}$ | $M_{q\dot{g}}$ | $M_{p\dot{g}}$ | | | N_{c_m} | ΔM_c | $\gamma \Delta$ | N_{δ_c} | T_{δ_m} | FR | N_{δ_c} | T_{δ_m} | FR | |
| IS1 | BC1 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | $-0.81 \pm j1.85$ | 0.356 | 30% | 0.05 | B | 0.320 | 0.251 | 3.0 | .254 | .192 | 5.5 |
| IS2 | | " | " | " | " | " | " | 0.356 | 30% | 0.10 | A | 0.300 | 0.224 | 5.0 | " | " | " |
| IS3 | | " | " | " | " | " | " | 0.356 | 30% | 0.20 | B | 0.303 | 0.253 | 4.5 | .254 | .192 | 4.0 |
| IS4 | | " | " | " | " | " | " | 0.356 | 50% | 0.20 | B | 0.297 | 0.251 | 2.0 | " | " | " |
| IS5 | BC5 | 0.33 | -0.20 | -1.7 | -4.2 | -0.29 | $-0.81 \pm j1.85$ | 0.300 | 30% | 0.10 | B | 0.310 | 0.255 | 7.0 | " | " | " |
| IS6 | | " | " | " | " | " | " | 0.340 | 30% | 0.05 | B | 0.314 | 0.265 | 6.0 | " | " | " |
| IS7 | | " | " | " | " | " | " | 0.340 | 30% | 0.20 | A | 0.347 | 0.247 | 4.5 | " | " | " |
| IS8 | BC4 | 1.0 | -0.20 | -3.0 | -1.7 | -2.5 | $-0.35 \pm j0.64$ | 0.902 | 0 | 0 | B | " | " | " | .371 | .333 | 5.5 |
| IS9 | | " | " | " | " | " | " | 0.902 | 30% | 0.05 | B | " | " | " | .381 | .342 | 5.0 |
| IS10 | | " | " | " | " | " | " | 0.902 | 30% | 0.10 | A | 0.373 | 0.310 | 8.0 | " | " | " |
| IS11 | | " | " | " | " | " | " | 0.902 | 30% | 0.20 | B | 0.401 | 0.333 | 5.0 | " | " | " |
| IS12 | BC6 | 1.0 | -0.20 | -1.1 | -2.5 | -0.65 | $-0.32 \pm j1.48$ | 0.979 | 30% | 0.10 | A | 0.246 | 0.138 | 9.0 | " | " | " |
| IS13 | | " | " | " | " | " | " | 0.979 | 30% | 0.20 | B | 0.388 | 0.340 | 6.0 | " | " | " |
| " | " | " | " | " | " | " | " | " | " | " | A | 0.254 | 0.134 | 8.0 | " | " | " |
| " | " | " | " | " | " | " | " | " | " | " | B | 0.410 | 0.299 | 5.0 | " | " | " |

- Standard wind simulation; $\sigma_{vg} = 3.4$ ft/sec, $U_m = 10$ kts.
- Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
- Stored energy effects were only simulated in the pitch axis. Roll and yaw control moments were unlimited.

TABLE A-VI

LONGITUDINAL AND LATERAL FLYING QUALITIES RESULTS FROM THE STUDY OF RATE-COMMAND/ATTITUDE-HOLD CONTROL

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-VII

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta \pm j\omega_d$ | Damping Ratio and Natural Frequency | | Pilot | Fixed Base | | | Moving Base | | |
|-------------------|-------------|------------------------------------|-------------|-------|-----------|---|-------------------------------------|------------|-------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | M_{uE} | λ_u | M_q | | | ζ | ω_n | | ζ_{fb} | ζ_{mb} | ζ_{pb} | ζ_{fb} | ζ_{mb} | ζ_{pb} |
| LR1 | B01 | 0.33 | -0.05 | - 8 | -0.092 | -0.92±j2.64 | 0.35 | 2.3 | H | 0.212 | 0.576 | 1.5 | 0.212 | 0.576 | 1.5 |
| LR2 | " | " | " | -40 | -0.050 | -1.00±j6.24 | 0.16 | 6.3 | h | 2.408 | 2.110 | 1.5 | 2.408 | 2.110 | 1.5 |
| LR3 | " | " | " | - 8 | -0.093 | -1.98±j1.98 | 0.71 | 2.3 | A | 0.344 | 0.904 | 3.0 | 0.344 | 0.904 | 3.0 |
| LR4 | " | " | " | - 4 | " | " | " | " | B | 0.984 | 0.884 | 2.0 | 0.984 | 0.884 | 2.0 |
| LR5 | " | " | " | -40 | -0.058 | -2.00±j6.00 | 0.32 | 6.3 | h | 3.640 | 3.340 | 2.0 | 3.640 | 3.340 | 2.0 |
| LR6 | " | " | " | -12 | -0.079 | -2.95±j1.71 | 0.87 | 3.44 | B | 1.792 | 1.528 | 4.0 | 1.792 | 1.528 | 4.0 |
| LR7 | " | " | " | -40 | -0.058 | -3.00±j5.57 | 0.47 | 6.32 | B | 2.588 | 2.268 | 2.5 | 2.588 | 2.268 | 2.5 |
| LR8 | " | " | " | -8 | -0.055 | -4.00±j4.90 | 0.63 | 6.32 | A | 3.044 | 2.440 | 1.0 | 3.044 | 2.440 | 1.0 |
| LR9 | " | " | " | -50 | -0.035 | -5.00±j5.50 | 0.67 | 7.43 | A | 3.960 | 3.344 | 3.0 | 3.960 | 3.344 | 3.0 |
| LR9 | B04 | 1.0 | -0.50 | -16 | -0.28 | -0.99±j3.87 | 0.248 | 4.0 | H | 1.192 | 0.864 | 4.5 | 1.192 | 0.864 | 4.5 |
| LR10 | " | " | " | -2 | -0.26 | -0.99±j5.32 | 0.200 | 5.0 | E | 2.152 | 1.863 | 5.0 | 2.152 | 1.863 | 5.0 |
| LR11 | " | " | " | -4 | -0.27 | -1.97±j3.45 | 0.500 | 4.0 | E | 1.688 | 1.392 | 3.5 | 1.688 | 1.392 | 3.5 |
| LR12 | " | " | " | -4 | -0.24 | -1.97±j4.54 | 0.400 | 5.0 | E | 2.584 | 2.284 | 3.0 | 2.584 | 2.284 | 3.0 |
| LR13 | " | " | " | -6 | -0.27 | -2.97±j2.61 | 0.750 | 4.0 | B | 1.632 | 1.372 | 3.0 | 1.632 | 1.372 | 3.0 |
| LR14 | " | " | " | -6 | -0.25 | -2.98±j4.06 | 0.610 | 5.0 | B | 2.208 | 1.912 | 3.0 | 2.208 | 1.912 | 3.0 |
| LR15 | " | " | " | -10 | -0.22 | -4.99±j5.51 | 0.670 | 7.43 | A | 3.756 | 3.228 | 3.0 | 3.756 | 3.228 | 3.0 |

1. Standard wind simulation; $\sigma_{vg} = \sigma_{vg} = 3.4$ ft/sec, $U_m = 10$ kts.

2. Symmetrical configurations - Lateral derivative has same value as corresponding longitudinal derivative.

TABLE A-VII

LONGITUDINAL FLYING QUALITIES RESULTS FROM THE STUDY OF INDEPENDENT THRUST-VECTOR CONTROL

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-VI

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | Thrust Vector Control Parameters | Pilot | Fixed Base | | Moving Base | | |
|---------------------------------------|-------------|------------------------------------|-------|-------|-----------|--|----------------------------------|-------------|------------------|----------------------------------|----------------------------------|--------------------------|----------------------|
| | | $M_{\dot{\omega}}$ | X_u | M_q | | | | | $\dot{\gamma}$ | γ_e | $\dot{\gamma}_e$ | $I_{\dot{\omega}_a}$ | $I_{\dot{\omega}_e}$ |
| L11 " | BC1 | 0.33 | -0.05 | -1.7 | -4.2 | -0.81 ± j1.85 | 5 " | - | A | 0.329 0.314 0.242 | 0.314 0.242 0.286 | 2.5 4.0 4.0 | 4.5 |
| L12 L13 | | | | | | | 10 20 | | B B | 0.314 0.329 | 0.242 0.286 | 4.0 3.5 | 3.0 |
| L14 L15 L16 " | BC4 | 1.0 | -0.20 | -3.0 | -1.7 | -0.35 ± j0.64 | 5 10 20 | - | B B A B | 0.329 0.329 0.329 0.329 | 0.286 0.286 0.286 0.286 | 4.5 4.5 5.0 3.5 | 5.5 4.0 |
| L17 L18 " | BC2 | 1.0 | -0.05 | -1.1 | -2.5 | -0.30 ± j1.47 | 5 10 " | - | B A B B | 0.338 0.329 0.314 0.338 | 0.335 0.304 0.242 0.335 | 5.0 6.5 4.5 4.0 | 5.5 |
| L19 | | | | | | | 20 | | B | 0.338 | 0.335 | 4.0 | 5.5 |
| L10 ⁵ L11 L12 L13 | BC1 | 0.33 | -0.05 | -1.7 | -4.2 | -0.81 ± j1.85 | 20 - | - | B B | 0.314 N.A. | 0.242 0.242 | 4.0 3.5 | |
| L14 L15 | BC4 | 1.0 | -0.20 | -3.0 | -1.7 | -0.35 ± j0.64 | - | 1 1 1 | B B B | 0.314 N.A. " | 0.242 0.242 0.242 | 4.0 3.0 3.5 | |
| L16 | BC2 | 1.0 | -0.05 | -1.1 | -2.5 | -0.30 ± j1.47 | - | 5 1 | B B | 0.314 N.A. | 0.242 0.335 | 10.0 | |

1. Standard gust simulation; $\sigma_{\dot{\omega}_e} = \sigma_{\dot{\omega}_g} = 3.4$ ft/sec, $\omega_m = 10$ kts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Thrust-vector thumb-switch control, conventional attitude control.
4. Thrust-vector control with stick, thumb-switch attitude control.
5. Thrust-vector angle displayed on instrument panel only.
6. Not applicable - see $\gamma_{\dot{\omega}_e}$ for longitudinal thrust rotation control sensitivity.

TABLE A-VIII
 LONGITUDINAL AND LATERAL FLYING QUALITIES RESULTS FROM THE STUDY OF INTER-AXIS MOTION COUPLING

Vertical and Directional Parameters Listed in Table A-I
 Pilot Comments Given in Table B-V

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | Motion Coupling Parameters | | | | Pilot | Fixed Base | | | Moving Base | | | |
|-------------------|-------------|------------------------------------|----------|-------|-----------|---|----------------------------|-------|-------|-----------------------------|-------|-----------------------------|----------------|----------------|-------------|----------------|----------------|-----|
| | | P_{yy} | X_{yy} | M_q | | | M_θ | M_p | I_q | $M_{\delta_e}/M_{\delta_a}$ | | $I_{\delta_e}/M_{\delta_e}$ | M_{δ_e} | I_{δ_a} | PK | M_{δ_e} | I_{δ_e} | FR |
| LC1 | BCL | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | $-0.61 \pm j1.85$ | 2 | -2 | 0 | 0 | 0 | 0.385 | 0.342 | 4.0 | 0.349 | 0.291 | 3.5 |
| LC2 | " | | | | | | | 4 | -4 | 0 | 0 | 0 | 0.359 | 0.298 | 3.5 | | | |
| LC3 | " | | | | | | | 0 | 0 | 0 | 0 | 0 | 0.386 | 0.356 | 6.5 | | | |
| LC4 | " | | | | | | | 0 | 0 | 0.25 | -0.25 | -0.25 | 0.376 | 0.323 | 4.5 | | | |
| LC5 | " | | | | | | | 0 | 0 | 0.50 | -0.50 | -0.50 | 0.362 | 0.299 | 3.0 | | | |
| LC6 | " | | | | | | | 2 | -2 | 0.25 | -0.25 | -0.25 | 0.322 | 0.308 | 2.5 | | | |
| LC7 | BCL | 1.0 | -0.05 | -1.1 | -2.5 | -0.5 | $-0.30 \pm j1.47$ | 2 | -2 | 0.25 | -0.25 | -0.25 | 0.313 | 0.290 | 4.0 | 0.264 | 0.321 | 2.5 |
| LC8 | " | | | | | | | 4 | -4 | 0.50 | -0.50 | -0.50 | 0.316 | 0.284 | 4.5 | 0.310 | 0.360 | 4.0 |
| | | | | | | | | 2 | -2 | 0.25 | -0.25 | -0.25 | 0.442 | 0.373 | 6.5 | | | |
| | | | | | | | | 2 | -2 | -0.25 | -0.25 | -0.25 | 0.446 | 0.399 | 6.5 | | | |

1. Standard wind simulation; $\sigma_{wg} = \sigma_{vg} = 3.4$ ft/sec, $V_m = 10$ kts.
 2. Symmetrical configurations - Lateral derivative has same value as corresponding longitudinal derivative.

TABLE A-IX

HEIGHT CONTROL FLYING QUALITIES RESULTS FROM THE STUDY OF THE INTERACTION BETWEEN HEIGHT VELOCITY DAMPING AND THRUST-TO-WEIGHT RATIO

Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-VIII

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | Height Damping Thrust-to-Weight Parameters | | | Pilot | Fixed Base | | Moving Base | | |
|-------------------|-------------|------------------------------------|-------|------------|-----------|---|--|-----------|-------|-------|------------|-------|-------------|-------|-----------|
| | | λ_u | M_q | M_θ | | | Z_{w_0} | Z_{w_1} | T/W | | Z_{f_0} | T/R | Z_{f_0} | T/R | Z_{f_0} |
| H21 | B01 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | -0.81 ± j1.85 | 0 | " | C | UL | 3.46 | 3.0 | 3.46 | 3.0 |
| H22 | " | | | | | | | -0.125 | " | " | UL | 3.14 | 7.0 | 3.14 | 7.0 |
| H23 | " | | | | | | | " | " | " | " | 2.98 | 4.0 | 2.98 | 4.0 |
| H24 | " | | | | | | | -0.25 | " | " | UL | 3.12 | 4.5 | 3.12 | 4.5 |
| H25 | " | | | | | | | -0.40 | " | " | UL | 3.04 | 3.0 | 3.04 | 3.0 |
| H26 | " | | | | | | | -0.05 | " | " | " | 3.50 | 2.0 | 3.50 | 2.0 |
| H27 | " | | | | | | | -0.125 | " | " | " | 3.0 | 7.0 | 3.0 | 7.0 |
| H28 | " | | | | | | | 0 | " | " | " | 3.0 | 8.0 | 3.0 | 8.0 |
| H29 | " | | | | | | | -0.25 | " | " | " | 5.0 | 5.0 | 5.0 | 5.0 |
| H30 | " | | | | | | | 0 | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H31 | " | | | | | | | -0.25 | " | " | " | 5.0 | 5.0 | 5.0 | 5.0 |
| H32 | " | | | | | | | -0.40 | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H33 | " | | | | | | | " | " | " | " | 3.0 | 3.0 | 3.0 | 3.0 |
| H34 | " | | | | | | | -0.025 | " | " | " | 4.5 | 4.5 | 4.5 | 4.5 |
| H35 | " | | | | | | | -0.05 | " | " | " | 6.0 | 6.0 | 6.0 | 6.0 |
| H36 | " | | | | | | | -0.125 | " | " | " | 3.01 | 3.01 | 3.01 | 3.01 |
| H37 | " | | | | | | | " | " | " | " | 2.62 | 2.62 | 2.62 | 2.62 |
| H38 | " | | | | | | | 0 | " | " | " | 3.0 | 3.0 | 3.0 | 3.0 |
| H39 | " | | | | | | | -0.25 | " | " | " | 5.0 | 5.0 | 5.0 | 5.0 |
| H40 | " | | | | | | | -0.25 | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H41 | " | | | | | | | " | " | " | " | 2.5 | 2.5 | 2.5 | 2.5 |
| H42 | " | | | | | | | -0.40 | " | " | " | 3.24 | 3.24 | 3.24 | 3.24 |
| H43 | " | | | | | | | -0.05 | " | " | " | 2.5 | 2.5 | 2.5 | 2.5 |
| H44 | " | | | | | | | -0.125 | " | " | " | 2.5 | 2.5 | 2.5 | 2.5 |
| H45 | " | | | | | | | " | " | " | " | 2.62 | 2.62 | 2.62 | 2.62 |
| H46 | " | | | | | | | 0 | " | " | " | 4.5 | 4.5 | 4.5 | 4.5 |
| H47 | " | | | | | | | -0.25 | " | " | " | 5.0 | 5.0 | 5.0 | 5.0 |
| H48 | " | | | | | | | " | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H49 | " | | | | | | | -0.25 | " | " | " | 2.5 | 2.5 | 2.5 | 2.5 |
| H50 | " | | | | | | | -0.40 | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H51 | " | | | | | | | 0 | " | " | " | 2.5 | 2.5 | 2.5 | 2.5 |
| H52 | " | | | | | | | -0.25 | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H53 | " | | | | | | | " | " | " | " | 2.5 | 2.5 | 2.5 | 2.5 |
| H54 | " | | | | | | | -0.40 | " | " | " | 4.0 | 4.0 | 4.0 | 4.0 |
| H55 | " | | | | | | | 0 | " | " | " | 10.0 | 10.0 | 10.0 | 10.0 |
| H56 | " | | | | | | | " | " | " | " | 3.06 | 3.06 | 3.06 | 3.06 |
| H57 | " | | | | | | | -0.125 | " | " | " | 2.60 | 2.60 | 2.60 | 2.60 |
| H58 | " | | | | | | | " | " | " | " | 3.28 | 3.28 | 3.28 | 3.28 |
| H59 | " | | | | | | | -0.25 | " | " | " | 3.71 | 3.71 | 3.71 | 3.71 |
| H60 | " | | | | | | | -0.40 | " | " | " | 3.92 | 3.92 | 3.92 | 3.92 |

1. Standard wind simulation; $\sigma_{u_0} = 3.4$ ft/sec, $h_0 = 10$ kts, no vertical gusts.
 2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
 3. Total height velocity damping, $Z_{w_1} = Z_{w_0} + Z_{w_2}$

TABLE A-X

HEIGHT CONTROL FLYING QUALITIES RESULTS FROM THE STUDIES OF CONTROL LAGS AND DELAYS AND INCREMENTAL THRUST THROUGH STORED ENERGY

Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-IX

(a) Control Lags and Delays

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | Parameters | | | Pilot | Fixed Base | | Moving Base | | | |
|-------------------|-------------|------------------------------------|----------|-------|-----------|--|------------|-----------------|-----------------|-------|------------|-------|-------------|----------------|------|----------------|
| | | $\xi_{u\delta}$ | χ_u | M_q | | | M/θ | $Z_{w\delta}^3$ | $Z_{w\delta}^2$ | | M/W | T_h | d_h | $Z_{\delta c}$ | PR | $Z_{\delta c}$ |
| HL1 | BCL | 0.33 | -0.05 | -1.7 | -4.2 | -0.81 ± j1.85 | -0.125 | -0.125 | 1.05 | 0.3 | 0 | 3.0 | 4.5 | A | 3.0 | 3.0 |
| " | " | | | | | | -0.125 | -0.125 | 1.05 | 0.3 | 0 | 3.0 | 5.5 | E | 3.01 | 3.0 |
| HL2 | " | | | | | | -0.175 | -0.175 | 1.05 | 0 | 0.1 | 3.0 | 2.5 | A | | |
| HL3 | " | | | | | | -0.175 | -0.175 | 1.05 | 0.3 | 0 | 3.0 | 3.0 | A | | |
| HL4 | " | | | | | | " | " | " | " | " | 3.0 | 3.0 | E | | |
| HL5 | " | | | | | | -0.175 | -0.175 | 1.05 | 0.3 | 0.1 | 3.0 | 3.5 | A | | |
| HL6 | " | | | | | | -0.175 | -0.175 | 1.05 | 0.6 | 0 | 4.5 | 4.5 | A | | |
| HL7 | " | | | | | | 0 | 0 | 1.05 | 0.6 | 0 | 4.0 | 4.0 | E | | |
| | | | | | | | -0.25 | -0.25 | 1.05 | 0.6 | 0 | 2.5 | 2.5 | A | | |

(b) Incremental Thrust Through Stored Energy

| Case ¹ | Basic Conf. | Stability Derivatives ² | | | Real Root | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | Parameters | | | Pilot | Fixed Base | | Moving Base | | | |
|-------------------|-------------|------------------------------------|----------|-------|-----------|--|------------|-----------------|-----------------|-------|------------|--------------|-------------|----------------|------|----------------|
| | | $\xi_{u\delta}$ | χ_u | M_q | | | M/θ | $Z_{w\delta}^3$ | $Z_{w\delta}^2$ | | M/W | $\Delta T/W$ | T_A | $Z_{\delta c}$ | PR | $Z_{\delta c}$ |
| HL1 | BCL | 0.33 | -0.05 | -1.7 | -4.2 | -0.81 ± j1.85 | 0 | -0.35 | 1.02 | 0 | 0 | 3.0 | 4.0 | E | 2.67 | 4.0 |
| HS2 | " | | | | | | 0 | -0.35 | 1.02 | 0.13 | 0.10 | 3.0 | 4.0 | B | 2.68 | 3.5 |
| HS3 | " | | | | | | 0 | -0.35 | 1.02 | 0.13 | 0.20 | 3.0 | 3.0 | B | 2.67 | 3.0 |
| HS4 | " | | | | | | 0 | -0.35 | 1.02 | 0.28 | 0.10 | 3.5 | 3.5 | B | 2.67 | 3.0 |
| HS5 | " | | | | | | 0 | -0.35 | 1.02 | 0.28 | 0.05 | 3.5 | 3.5 | B | 2.67 | 4.0 |

- Standard wind simulation; $\sigma_{u\delta} = \sigma_{v\delta} = 3.4$ ft/sec, $U_m = 10$ kts, no vertical gusts.
- Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
- Total height velocity damping, $Z_{w\delta} = Z_{w\delta} + Z_{w\delta}$

TABLE A-XI

DIRECTIONAL CONTROL FLYING QUALITIES RESULTS

Vertical Parameters Listed in Table A-I
Pilot Comments Given in Table B-X

| Case ¹ | Basic Conf. | K _v | Stability Derivatives ² | | | | Real Roots | Complex Roots $-\zeta\omega_n \pm j\omega_d$ | Lag, Leg, Delay and Moment Limit Parameters | | | Pilot | Fixed Base | | Moving Base | |
|-------------------|-------------|----------------|------------------------------------|----------------|----------------|----------------|------------|---|---|-----------------|------------|-------|------------|-----------------|----------------|-----------------|
| | | | N _{uE} | X _u | N _q | M _q | | | N _r | M _{oc} | $\tau\psi$ | | d ψ | F _{gr} | F _z | F _{gr} |
| D1 | B01 | 0.005 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | -0.81±j1.85 | 0 | UL | 0 | 0 | 0.200 | 5.0 | 0.208 | 5.0 |
| D2 | " | " | " | " | " | " | " | " | -0.5 | " | 0 | 0 | 0.225 | 4.0 | 0.229 | 3.5 |
| D3 | " | " | " | " | " | " | " | " | -1.0 | " | 0 | 0 | 0.240 | 3.0 | " | " |
| " | " | " | " | " | " | " | " | " | " | " | " | " | 0.236 | 2.5 | " | " |
| D4 | B02 | 0.005 | 1.0 | -0.05 | -1.1 | -2.5 | -0.50 | -0.30±j1.47 | -1.0 | UL | 0 | 0 | 0.312 | 2.5 | " | " |
| D5 | B01 | 0.005 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | -0.81±j1.85 | -0.5 | UL | 0.1 | 0 | 0.202 | 4.0 | " | " |
| D6 | " | " | " | " | " | " | " | " | -0.5 | " | 0 | 0.1 | 0.270 | 3.5 | " | " |
| D7 | " | " | " | " | " | " | " | " | " | 0.3 | " | " | 0.273 | 4.5 | " | " |
| D8 | " | " | " | " | " | " | " | " | " | " | " | " | 0.181 | 5.0 | 0.259 | 4.5 |
| D9 | " | " | " | " | " | " | " | " | -0.5 | " | 0.3 | 0.1 | 0.235 | 4.0 | " | " |
| D10 | " | " | " | " | " | " | " | " | -0.5 | " | 0.6 | 0 | 0.280 | 5.5 | 0.226 | 5.0 |
| D11 | " | " | " | " | " | " | " | " | -0.5 | " | 0.6 | 0.1 | 0.252 | 6.0 | " | " |
| D12 | " | " | " | " | " | " | " | " | -1.0 | " | 0.1 | 0 | 0.248 | 6.0 | " | " |
| D13 | " | " | " | " | " | " | " | " | -1.0 | " | 0.1 | 0 | 0.306 | 3.0 | " | " |
| D14 | " | " | " | " | " | " | " | " | -1.0 | " | 0 | 0.1 | 0.294 | 2.0 | " | " |
| D15 | " | " | " | " | " | " | " | " | -1.0 | " | 0.3 | 0 | 0.341 | 3.0 | 0.275 | 3.5 |
| D16 | " | " | " | " | " | " | " | " | -1.0 | " | 0.3 | 0.1 | 0.258 | 3.0 | 0.270 | 3.5 |
| D17 | B01 | 0.005 | 0.33 | -0.05 | -1.7 | -4.2 | -0.13 | -0.81±j1.85 | -1.0 | " | 0.6 | 0 | 0.271 | 4.0 | 0.258 | 5.0 |
| D18 | " | " | " | " | " | " | " | " | -1.0 | " | " | " | 0.308 | 4.0 | " | " |
| D19 | " | " | " | " | " | " | " | " | -1.0 | " | 0.6 | 0.1 | 0.300 | 5.5 | 0.284 | 4.5 |
| D20 | " | " | " | " | " | " | " | " | -0.5 | 0.10 | 0 | 0 | 0.233 | 6.0 | " | " |
| D21 | " | " | " | " | " | " | " | " | -0.5 | 0.13 | 0 | 0 | 0.238 | 4.0 | " | " |
| D22 | " | " | " | " | " | " | " | " | -1.0 | " | 0 | 0 | 0.286 | 5.0 | 0.205 | 7.0 |
| " | " | " | " | " | " | " | " | " | " | " | " | " | 0.308 | 5.5 | " | " |
| " | " | " | " | " | " | " | " | " | -1.0 | " | 0 | 0 | 0.236 | 3.0 | 0.244 | 2.5 |
| " | " | " | " | " | " | " | " | " | -1.0 | 0.16 | 0 | 0 | 0.346 | 3.5 | 0.257 | 3.0 |
| " | " | " | " | " | " | " | " | " | -1.0 | " | 0 | 0 | 0.287 | 2.0 | 0.234 | 2.5 |

1. Standard wind simulation: $\sigma_{Vg} = \sigma_{Vg} = 3.4$ ft/sec, $V_{W} = 10$ kts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

APPENDIX B

SUMMARY OF PILOT COMMENTS FROM UARL PILOT EVALUATIONS

This Appendix presents edited pilot comments for the flight simulator test cases evaluated by UARL pilots. The comments are tabulated for each case according to the subtasks performed by the pilots. For each subtask, comments were solicited according to the questionnaire shown in Table IV. Pilots also made additional comments as they felt necessary.

The comment tables parallel the flying qualities data tables of Appendix A. That is, for each data table in Appendix A there is a corresponding comment table in Appendix B. The comments from the longitudinal and lateral control studies are summarized in Tables B-I through B-VIII as follows: B-I, turbulence effects; B-II, control lags and delays; B-III, control-moment limits; B-IV, control moments through stored energy; B-V, inter-axis motion coupling; B-VI, independent thrust-vector control; and B-VII, rate-command/attitude-hold control. Pilot comments for the height control test cases are summarized in Tables B-VIII and B-IX. Table B-VIII contains velocity damping and thrust-to-weight ratio. Comments from the studies of thrust lags and delays and incremental thrust through stored energy are shown in Table B-IX. The pilot comments from the directional control studies are summarized in the last table, B-X.

Contrails

TABLE B-I

PILOT COMMENTS FROM THE STUDY OF TURBULENCE INTENSITY

Flying Qualities Results Given in Table A-II

| Case | Conf. Parameters | Pilot Sim. Mode | $\frac{W_0}{g}$ | PR | Pilot Comments | | | | | |
|------|--|-----------------|-----------------|-----|--|---|--|--|---|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| T1 | $\frac{W_0}{g} = \frac{W_0}{g}$ 3.4 ft/sec | A-FB | 0.330 | 2 | Set to achieve desired roll and pitch response for maneuvering. | Roll affects negligible, could perform the air task with considerable precision. Pilot workload quite low. Control motions were very small and low frequency. | Performed quite easily but required a little anticipation to stop at desired point. | Quite easy, required virtually no thrust trim control. | Hover performance very good, required very little pilot effort. | A very good configuration, little control compensation and effort required to perform the task. |
| | | B-FB | 0.206 | 2 | Selected based on maneuvering and hovering requirements. | Pitch is very easily controlled, don't notice any effects of turbulence. Can initiate motion easily in both lateral and longitudinal directions and can stop precisely. | Can stop quickly but fairly large attitude changes are required. No problem holding attitude and heading for quick stops. | Able to remain over the spot quite well. No problem holding attitude. | Could lower quite accurately. Vertical landing was reasonably precise. Dynamics for one axis didn't affect my evaluation of another axis. | In general, the configuration has no objectionable features. |
| | | B-HB | 0.313 | 1 | Selected to get necessary attitude response. | No problem, could perform this very accurately, very precisely. | Could perform accurately. | Could remain very precisely over the spot and turn quite rapidly while doing so. Wing tilt control was used to small extent. | No problem. Could be done quite precisely. No interference between dynamics. | No objectionable features in this case, except possibly the low drag parameter. Fine attitude characteristics. |
| T2 | B-L $\frac{W_0}{g} = \frac{W_0}{g}$ 3.0 ft/sec | B-FB | 0.268 | 2 | Sensitivity selected primarily for hover. | No difficulty, could stabilize and hold at velocities and stop precisely. | Could stop quite quickly and hold my maneuvering position after stopping. Here drag would be desirable. | Could turn over a spot quite accurately. | Not difficult. Could hold hover position accurately while performing the vertical landing. | Thought this was a good case. |
| | | B-HB | 0.289 | 2 | Sensitivity selected primarily for hover. | No difficulty, could stabilize and hold at velocities and stop precisely. | Could stop quite quickly and hold my maneuvering position after stopping. Here drag would be desirable. | Could turn over a spot quite accurately. | Not difficult. Could hold hover position accurately while performing the vertical landing. | Thought this was a good case. |
| T3 | B-L $\frac{W_0}{g} = \frac{W_0}{g}$ 3.2 ft/sec | A-FB | 0.412 | 4.5 | Set to offset gust effects on pitch and roll. | Had to anticipate stopping point due to low drag. Somewhat difficult to stop. Effect of moderate gust disturbances on attitude and low translational drag necessitated considerable pilot compensation. | Requires considerable anticipation to stop. | Relatively easy but did notice gust disturbances in both position and attitude. Little wing tilt was required. | Performance was good, but it did require some compensation to offset the gust disturbances. | Had objectionable features were moderate gust effects on pitch and roll and the difficulty in stopping. |
| | | B-FB | 0.341 | 3 | Selected for precision hover and climb control because of relatively high level of turbulence. | Somewhat difficult to stabilize desired velocities because of the turbulence. Some problems stopping precisely and hovering. Could perform this part of the task fairly well, though. | No real problem with the quick stop. | Slightly difficult because of the gusts. Good attitude characteristics helped. | Precision hover is moderately difficult, must pay attention to gusts and make appropriate attitude changes. Able to land the spot precisely. | Good configuration with a moderate workload. |
| | | B-HB | 0.258 | 3 | Set to get the attitude response I desired. | Not difficult, good response to all the control inputs. Large speed stability had mixed effects, sometimes blown laterally when maneuvering longitudinally. | No problem, can stop very quickly. | Difficult but again attitude control very fine since at time of concentrate on position. | Could hover quite well, at large tilt. Apparent way. Could land well. No problem. | Drag parameter objectionable. Allow about while maneuvering, made it somewhat difficult to hover and turn-over-a-spot. Had to be pretty adept with my legs when performing the turn-over-a-spot. |
| T4 | B-L $\frac{W_0}{g} = \frac{W_0}{g}$ 3.4 ft/sec | A-FB | 0.307 | 2 | Set mainly for attitude changes during maneuvering. | Somewhat difficult to initiate translational motion, requires rather large attitude changes. Can stop with pretty good degree of precision. | Difficult to perform, just time to get up to speed and then large attitude changes are required to arrest velocity. | Negative trim changes with the wing. Also one gets blown around a lot in position. Requires quite a lot of attention. | Fairly easy, although the trim push was needed in position. Landing and takeoff not difficult. | Slight objection to high drag of aircraft and the associated large attitudes required to maneuver. |
| | | B-FB | 0.306 | 3 | Selected primarily as normal hovering position. | Very responsive to control inputs. Able to initiate motion and hold desired velocities without problems. Always somewhat sluggish in position response. | Couldn't stop as quickly as would like. Somewhat difficult to initiate motion. Intensive attitude changes not really required. | Able to remain over spot fairly well, in spite of the large negative attitude dynamic help. | Could hover precisely without any difficulty and perform vertical landing precisely. No translational effects noticeable. | Only moderately objectionable features were artifacts of the large drag. In hover and take-off approach, favorable features were the good dynamics and the positive damping. |
| | | B-HB | 0.276 | 3 | Selected to get control over attitude. | Easy to control, liked the low pressure barrel to stop nicely. Attitude was well damped. | Could stop quickly, attitude very easy to control and the drag parameter helped to stop. | Can do maneuvering if time is taken. Used wing tilt most. | Could hover precisely and land without too much difficulty. No interference in the dynamics. | Drag parameter made turn maneuver somewhat difficult. Favorable features were good attitude stability and position control. |
| T5 | B-L $\frac{W_0}{g} = \frac{W_0}{g}$ 3.2 ft/sec | A-FB | 0.280 | 2 | Selected to provide proper attitude rates for hover. | Good response to control inputs, able to initiate and hold motion very nicely. No problem stopping precisely and hovering at the same. | Can't stop as quickly as would like, somewhat difficult to build up the speed. | Able to remain over the spot fairly well. Attitude control in position very large drag parameter caused problems. Used with a good deal. | Could hover precisely although very relatively large position disturbances from gusts. Could control hover adequately for vertical landing. No interference between dynamics. | Only objectionable feature was turbulence loading on large drag parameter during hover and turn-over-a-spot maneuver. |
| | | B-HB | 0.297 | 4.5 | Set primarily for trim during maneuvers. | Attitude control very good, little gust disturbances on attitude. However large attitude changes to get desired velocity. Can stop fairly precisely. Some push the aircraft around in position. | Control inputs rather large and stopping no problem. | Difficult only because the gusts push the aircraft around in position, large wing tilt attitude changes are required. | Performance not too good because of gust disturbances in position, some difficulty landing. Control activity relatively low frequency. | Dist effects in position are noticeable. Position well damped. |
| T6 | B-L $\frac{W_0}{g} = \frac{W_0}{g}$ 3.2 ft/sec | A-FB | 0.267 | 4 | Selected to give desired attitude response in hover. | Somewhat position response. Attitude control very live, needed to lose position in air normal to maneuver direction. | Could stop quickly but difficult to hold position after stopping. | Able to perform this approach well. Good attitude characteristics, little significant help. | Somewhat difficult because of large drag effects on drag parameter. Had to make large, rapid attitude changes. No noticeable interference between axes. | Objectable features are turbulence loading on large drag parameter. Attitude control very acceptable. Had to be careful with eye during the hover turn. |

Contrails

TABLE B-I (Continued)

| Case | Def. Parameters | Pilot | V ₀ | T ₀ | Pilot Comments | | | | | |
|------|---|-------|----------------|----------------|--|---|--|--|--|---|
| | | | | | Selection of Control Characteristics | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 76 | B05 $C_{Dg} = 0.015$ $C_{Lg} = 0.8$ 8.2 ft/sec | RMB | 0.379 | 3 | Selected to exhibit control of gusts. | Quite difficult, would get blown off laterally when maneuvering longitudinally and vice versa. When was initially hovering because it was laterally linear with little attitude motion because of dynamics. | Could stop as quickly as would like but aircraft too responsive to position gusts. | Difficult, had to be very, very slowly. Used a lot of wing tilt. Requires concentration. | Couldn't hover particularly accurately. Could hover's position motion, but very difficult to get back to desired lower position. Could land alright, but it was difficult. Used the trim control at high velocities. No problem with secondary dynamics. | Gusts acting on large drag parameters very objectionable. Attitude well coupled, easy to control, however. |
| 77 | B04 $C_{Dg} = 0.015$ $C_{Lg} = 0.8$ 3.4 ft/sec | A-7B | 0.333 | 1 | Selected for hovering and to control roll/gust disturbances. | Response to control inputs good. Stopping at desired point requires a little anticipation in reverse roll. Could maintain ground track fairly well. | No problem generating velocity, stopping velocity was anticipated. | Only problem was effect of wind which requires small changes in wing tilt. Must concentrate to perform the turn. | Performance very good with little control motion required. Landing no problem. | Disturbance fairly good. Gust disturbances on roll and pitch did require a bit of pilot attention. |
| | | B-7B | 0.274 | 4 | Selected to exhibit pilot to move the aircraft around its position. | Control response good. Could stabilize and hold velocities and stop precisely. Some difficulty in initiating motion. | No problem, could stop quite quickly. Attitude was easy to control. | Most difficult unless. The large drag parameters resulted in large position disturbances. Had large trim changes and had to be very careful with them. | Precision hover and vertical landing not difficult. The lateral (longitudinal) drag parameter affected as when trying to control longitudinal (lateral) position. | Major objectionable feature was the effect of winds on the large drag parameters. Favorable feature was that attitude control was quite good. |
| | | B-7B | 0.310 | 3 | Selected to overcome attitude lagging and enable pilot to change attitude rapidly, enough to counteract the effects of drag parameter. | Could maneuver quite accurately. May to stop at the corner because of the large drag parameter and low gusts. | Easy to stop very quickly, the drag parameters helped. | Difficult, but was done slowly and seemed to be able to handle it pretty well. Used a lot of wing-tilt angle. | Could hover fairly precisely. But disturbance for could land quite well, secondary dynamics no problem either. | Objectable feature especially the effects of drag parameter in the turn-over-a-spot annoying. Favorable features - good attitude response, generally low response to the turbulence and the drag parameter helped the maneuvering and quick stop. |
| 78 | B04 $C_{Dg} = 0.015$ $C_{Lg} = 0.8$ 5.2 ft/sec | A-7B | 0.452 | 3 | Selected to achieve the desired attitude response. | Good attitude response, but the ship was kind of sluggish. Could stabilize and hold velocities and stop precisely. | Could stop quite quickly. Relatively large attitude changes were required. | Most difficult of all the subtasks because of the concentration and actively required to counteract the secondary effects through the speed-stability parameter and hold by hovering spot. | Slightly difficult, substantial disturbances in position, large attitude changes required to correct them. No interaction. | Objectable feature - attitude response to gusts through speed stability which lead to large position disturbances. Favorable features - good attitude parameter and hold by hovering spot. |
| 79 | B04 $C_{Dg} = 0.015$ $C_{Lg} = 0.8$ 6.2 ft/sec | A-7B | 0.616 | 8 | Set to control very large gust disturbances. | Difficult to maintain within, hold heading and stop precisely because of gust effects. | Difficult to stop because of gust effects. Large attitude changes required to control position. | Difficult to hold position. Great deal of coordination between wing tilt and control input required. Difficult to perform. | Difficult, requires excessive amount of control input. Large attitude changes result from gusts and control inputs. | Most objectionable feature was the very high gust sensitivity and lack of attitude damping. Very high workload for very high degree of concentration required to maintain control. |
| | | B-7B | 0.513 | 5 | Selected to exhibit turbulence effects on attitude and to correct for the large position displacements introduced by turbulence. | Effects of turbulence on attitude and position were significant, had to work hard to hold desired velocities. Difficult to maintain the position while performing the part of the maneuver and vice versa. Large control deflections required periodically. | Could stop quickly but had to work position carefully afterwards. Rapid control actions required. | Able to remain over the spot because of good attitude dynamics. Even with a large gust, could hover over the spot reasonably well. Had to be careful, used the trim control a good deal. | Attitude dynamics good, allowed pilot to hover fairly well. Biggest problem was effect of turbulence on the drag parameters, made vertical landing difficult. No noticeable interaction. | Objectable features - effects of turbulence on attitude and position. Favorable features - good attitude control response. |
| | | B-7B | 0.470 | 5 | Selected to overcome gust effects on attitude. | When all over, sharp rough gust inputs, attitude oscillates around steady. Can't perform well. | Attitude control work - small overshoot because of gusts. Precise control impossible. | When off position of the large gusts, could not change wing tilt quickly enough to hold it. Made full just controlling pitch, roll attitude. | Couldn't hover precisely, could keep only within 10 ft of square. Landing hazardous, very difficult. Large interactive effects between pitch and roll. | Very difficult to control and dangerous. Feels very drying to reduce response to turbulence. |
| 80 | B04 $C_{Dg} = 0.015$ $C_{Lg} = 0.8$ 11 ft/sec | A-7B | 0.533 | 4 | Set to control gust disturbances on roll and pitch attitude. | No problem initiating or stopping motion. Could remain within the ground track fairly accurately and hold heading and attitude fairly well. | No particular problem, except constant trim had to be held in to maintain velocities. | Performance good, very little wing tilt trim required. Most of the workload from controlling attitude disturbances. | Good performance. | Dynamics were fairly good, more pitch rate and roll rate requiring testable to reduce response to turbulence. |
| | | B-7B | 0.433 | 3 | Selected to exhibit control of gusts. | Unacceptable attitude response to gusts. Difficult to stabilize attitude which also affected ability to stabilize maneuvering velocities. Had to use trim extensively but this caused undesired and excessive attitude motions. | Could perform quick stops without great difficulty, attitude motions were somewhat wild like. | Difficult to control roll attitude for this workload. | Could hover fairly precisely and could control lower position satisfactorily. Had to perform a reasonable landing. Attitude dynamics in roll affected by ability to control pitch and vice versa. | Most objectionable feature was low lack of attitude damping. |
| | | A-7B | 0.379 | 3 | Selected to exhibit control of gusts. | Not too difficult. Did get blown off track, but not frequently. One offense significant re pitch and roll. | No significant problems, drag parameters would hold. Made to concentrate difficult to arrest motion. | Not too difficult because attitude damping sufficient. Noticed gust effects on attitude, though. | Can't hover precisely and in a good jet landing. No interaction between pitch and roll control. | Objectable feature was the gust effect on attitude. Very damping desirable to reduce gust response. Favorable features - the low drag parameters made the hovering and turn attitudes less difficult. |

Contrails

TABLE B-I (Continued)

| No. | Drag Parameters | Pilot-Im. Rate | $\frac{V_{0g}}{V_{0e}}$ | PK | Pilot Comments | | | | | |
|-----|---|----------------|-------------------------|-----|---|--|---|---|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 711 | $\frac{a_{0g}}{a_{0e}} = \frac{a_{0g}}{a_{0e}}$ 5.5 ft/sec | B-73 | 0.436 | 6 | Selected to control attitude response to gusts and to overcome the lack of damping. | Attitude needs more damping. Turbulence really buffeted me about. Able to stabilize and hold velocities fairly well, but required a great deal of attention. Could stop precisely. | Can stop quickly, but very large attitude changes result. Have some difficulty stabilizing attitude. | Able to remain over the spot quite well. Low drag parameters helped. Attitude required a significant amount of attention. | Could hover adequately with effort and could land alright. Attitude wasn't as controllable as it should be. Some interaction between the motion in one axis and my ability to control another axis. | Primary objectionable feature was the lack of attitude damping and its response to turbulence. Favorable feature - low drag parameters helped in hover and turn. |
| 712 | $\frac{a_{0g}}{a_{0e}} = \frac{a_{0g}}{a_{0e}}$ 6.2 ft/sec | B-73 | 0.445 | 8 | Selected to control attitude gust response and control response. | Difficult to initiate and hold velocities because of the attitude characteristics, could not maneuver laterally and hold longitudinal position precisely. Attitude seemed unpredictable. | Could stop relatively quickly but had difficulty holding desired position of the other axis. Large attitude changes involved in this subtask. | Able to maintain position fairly well because of low drag parameters. Attitude control quite difficult. | Able to hover fairly well but large attitude excursions involved. Very difficult to accomplish vertical landing. Pitch attitude control definitely affected my ability to control roll and vice-versa. | Attitude characteristics quite objectionable, springy characteristic annoying. Favorable feature - low drag parameters. |
| 713 | $\frac{a_{0g}}{a_{0e}} = \frac{a_{0g}}{a_{0e}}$ 3.4 ft/sec | A-7B | 0.342 | 4.5 | Set to counteract gust disturbances on attitude. | Considerable effort required to control attitude gust disturbances. Large attitude changes necessary to initiate and sustain motion. Difficult to hold desired velocities, but could stop precisely. | Difficult to generate velocity. Could stop fairly well, although large attitude changes were required. | Gust disturbances on attitude and position annoying, but performance not too bad. Required concentration. | Performance pretty good, but considerable attitude activity due to attitude and position gust disturbances. Landing not too difficult. | Needs attitude damping and high drag characteristics in hover, although it did provide translational damping. |
| | | B-7E | 0.296 | 5 | Selected to control position disturbances and for maneuvering. | Difficult because attitude was underdamped. Could not maintain precise attitude angle or a steady velocity. Could stop fairly precisely. | Difficult to attain velocities, but could stop quickly. | Difficult, had to be very careful with my control inputs and concentrate. Used trim almost constantly. | Could hover fairly accurately. Would like better control over attitude for landing. Lateral drag parameter did affect ability to control longitudinally and vice-versa. | Two objectionable features were the large drag parameters and the low damping levels in pitch and roll. |
| | | B-7E | 0.242 | 6 | Selected to control attitude response to stick inputs and gusts. | Not too difficult, lack of attitude damping affects ability to maintain constant velocity. Lateral speed stability effects very evident through motion. | Can accomplish, but would use more attitude damping. | Very tough, large attitude changes. Have to concentrate too much on pitch and roll to turn precisely. | Can hover well but must pay attention. Motion helps to keep from overcontrolling. Can land adequately. | Motion leads to use of smaller, more precise control inputs. Take-off and landing situations very realistic. |
| 714 | $\frac{a_{0g}}{a_{0e}} = \frac{a_{0g}}{a_{0e}}$ 5.8 ft/sec | B-73 | 0.457 | 7 | Selected to get pitch and roll attitude under control. | Need more damping in both pitch and roll. Difficult to initiate motion and to hover at the same time. Couldn't hold ground track well. | Can stop quickly but large attitude changes result. Difficult to control attitude. | Can't remain over the spot well. Must use wing tilt a great deal. Large pitch and roll angles. | Precision hover is unobtainable, but large attitude angles required. Landing tough because of gusts. Longitudinal dynamics made it difficult to control lateral and vice-versa. | Objectionable feature - the lack of damping. |
| | | B-7E | 0.436 | 7 | Selected to get attitude under control. | Acceleration response to control inputs. Gust response in attitude and position a major annoyance. Couldn't really control precisely. | Could stop fairly quickly, large drag parameters helped. Developed large attitude angles, though. | Could hold position fairly well, but very difficult to land. Must do slowly, use wing tilt constantly. | Could hover without too much difficulty. Lot of attitude motion. Landed alright but had to use wing tilt. Some interaction. | Primary objectionable features - large gust inputs, low damping, gusts acting on the drag parameter. Favorable features - none. |
| 715 | $\frac{a_{0g}}{a_{0e}} = \frac{a_{0g}}{a_{0e}}$ 2.2 ft/sec | A-7B | 0.581 | 9 | Selected to counteract very large gust disturbances and to maintain control. | All aspects of the subtask extremely difficult. Primary effort was in maintaining control. Difficult to stay within boundaries of maneuvering area and to hold heading and attitude. | Very difficult to perform. | Difficult to hold position, height and desired turn rate because of large gust disturbances on pitch and roll. | Impossible. Excessive pilot control activity required. Landing hazardous because of difficulty in holding both position and level attitude. | |
| | | B-73 | 0.556 | 9 | Selected to achieve control over attitude and attenuate gust response. | Disagreeable response to control inputs and gusts, needs much more damping. Tough to initiate, stabilize velocities and difficult to stop. | Can stop quickly, but use large attitudes. Large rapid control actions had also. | Able to remain over a spot but required much effort and attention. Used trim almost constantly. Attitude control was difficult. | Periodically blown off position and large attitude angles required to correct erratic motion. Dynamics aren't adequate for vertical landing. The dynamics from longitudinal axis did affect my control of lateral axis, and vice versa. | Objectionable features - the "step gas" responses in position and attitude and the small levels of damping. No favorable features. |
| 716 | $\frac{a_{0g}}{a_{0e}} = \frac{a_{0g}}{a_{0e}}$ 3.4 ft/sec | A-7B | 0.359 | 5 | Set to counteract annoying gust effects. | Could be performed with considerable concentration. Pitch and roll were slightly underdamped. Could stop fairly well and lower at desired points. | Performed fairly well but must control gust effects. | Some difficulty holding position. Required concentration to perform. Could stop fairly well on preselected heading. | Could perform hover with fair precision, required concentration. | Lack of roll and pitch damping objectionable. |
| | | B-73 | 0.449 | 1 | | Could perform fairly well. Would prefer more damping in both pitch and roll. Had to concentrate more with attitude than desirable. | Required more concentration and attention to perform than would prefer. No large attitude oscillations. | Turned accurately over the spot, low drag parameters helped. Developed some disagreeable large attitudes. | Hovered quite accurately but required concentration. Vertical landing not too difficult. No real interaction. | Objectionable features - lack of damping in pitch and roll, oscillations, response to turbulence more than would like. Favorable features - the low drag parameter. |

TABLE B-I (Concluded)

| Case | Ref. Parameters | Flight Mode | $\frac{d\theta}{dt}$ | Pr | Pilot Comments | | | | | |
|------|---|-------------|----------------------|----|--|--|--|---|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Special Hover, Vertical Landing, Recovery Dynamics | Overall Evaluation |
| T16 | RC3 $\frac{d\theta}{dt} = \frac{d\psi}{dt} = 3.4$ ft/sec | S-WB | 0.407 0.260 | 6 | Selected to overcome lack of damping and control response to turbulence. | Required a significant amount of control activity. Had to maneuver slowly. Lack of position damping annoying. | Need large attitude changes to stop. Had to roll out at just the right moment to stop and stabilize position. Need position damping. | Could perform fairly well because of the low drag parameters. Had to be careful, however. | Could hover fairly well, but attitude motion required attention. Vertical landing not too difficult. Dynamics from one horizontal axis did affect the other. | Objectionable features - low attitude damping, little nose drag parameter needed. |
| T17 | RC3 $\frac{d\theta}{dt} = \frac{d\psi}{dt} = 5.5$ ft/sec | S-FB | 0.439 0.373 | 6 | Selected to overcome lack of damping. | Good position response. Difficult to control attitude, tended to overshoot desired angle, required significant compensation. | Could stop quickly but really had to watch attitude. Some tendency to drift off longitudinally when maneuvering laterally. | Able to remain over the spot because of the small drag parameters. Needed large stick inputs, developed some very large pitch and roll rates. | Could hover quite well, but lots of pitch and roll motion. Couldn't hold position precisely during the landing. Pitch dynamics do affect ability to control roll. | Objectionable features - the low level of attitude damping. Favorable features - the small drag parameters. |
| T19 | RC3 $\frac{d\theta}{dt} = \frac{d\psi}{dt} = 8.2$ ft/sec | S-FB | 0.467 0.352 | 8 | Selected to control attitude gust response. | Disagreeable control response inputs. Needs damping in pitch and roll. Difficult to stabilize, hold velocities and stop precisely. | Can stop quickly, but large attitude changes required. Takes some time to stabilize attitude after coming to a stop. | Able to remain over the spot fairly well because drag parameters were small. Attitude control difficult, had to concentrate. | Could hover fairly well but large control motions required, just concentrate. Difficult to maintain position during vertical landing. Dynamics for roll did affect pitch control and vice-versa. | Lack of attitude damping very objectionable. Difficult to control gust response. However, drag helped in the turn-over-a-spot and hover subtasks. |

Contrails

TABLE B-II

PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL AND LATERAL CONTROL SYSTEM LAGS AND DELAYS
Flying Qualities Results Given in Table A-III

| Case | Conf. Parameters | Pitch-Div. Mech. | δ_a | n | Pilot Comments | | | | | |
|------|--------------------------|------------------|----------------|-----|---|--|---|--|--|---|
| | | | | | Selection of Control Characteristics | Maneuvering | Quick Stops | Turn-Over-a-Bar | Precision Hover, Vertical Landing, Secondary Operations | Overall Evaluation |
| 112 | BC1 $T_a = T_b = 0.1$ | B-FB | 0.304 | 2 | Selected to get the attitude response wanted. | Not difficult. Mostly damped attitude response, able to select and stabilize velocities with no problem. Stop precisely. No lag evident in the attitude response. | Not difficult to perform one control attitude quite precisely. Can perform this task very well. | Not difficult to perform wing tilt control not used much. | No problem, can hover quite precisely with very little control input. Vertical landing also no difficulty. | Fine case. Attitude is very nicely correlated with the stick inputs, no noticeable lags, one control quite well. |
| 113 | BC1 $T_a = T_b = 0.3$ | A-FB | 0.294 | 1 | Set to achieve desired attitude response for air taxi. | Performance was good, only slightly objectionable feature was that commanding an attitude change caused slight oscillation, clear slight lag in attitude response. (That affects minimal), control motions low frequency and small in amplitude. | Performance was good, although slight lag in attitude response when commanding rapid attitude changes. | Very easy and very little throat rotation control required. | Never required very little effort, performance good. | Only slightly objectionable feature was small lag in attitude response and small oscillatory motion when commanding a wide attitude change. |
| | | B-FB | 0.330 0.251 | 2,5 | Selected to get the attitude response to overcome a slight lag. | Air taxi not difficult. Could perform precisely, some slight oscillation when rolling or pitching in and out of maneuvers, but nothing difficult to estimate. No lack of control power. | Could perform precisely, no problem. Again slight oscillation of pitch and roll, but easily damped. | Quite easy to perform. Didn't use wing tilt control much. | Belaxed inputs in hover, could recover quite precisely. Vertical landing also not difficult. | Mostly damped, low response to turbulence, low response to turbulence, nice slight tendency to oscillate in pitch and roll, but easily damped. |
| 114 | BC1 $T_a = T_b = 0.6$ | A-FB | 0.355 0.352 | 2 | Selected to give desired attitude response. | The air taxi relatively easy. Response to control inputs good about all axes. May to initiate maneuver although some anticipation required to stop at a desired position. Could stop and hold hover with good degree of precision. Only small attitude changes required. | No problem, although some position anticipation required to stop at desired point. | Relatively easy, had to use a small amount of wing tilt control to offset the cross wind effects. | Very easy to hover, required only very small control inputs. | Liked the good attitude control and the very low response to turbulence. Pilot workload quite low. |
| | | A-FB | 0.339 0.258 | 3 | Selected to get the attitude response. | Air taxi no problem. Could perform both 1 and 2 maneuvers easily, clearly and hold velocities steady and arrest motion without too much difficulty. Slight tendency to oscillate at the end of maneuvers, had to compensate for this but it wasn't difficult. | Could stop quite accurately, and didn't experience any real large attitude changes. Again, some tendency to oscillate in pitch and roll, had to worry about this a bit. | No difficulty here. Could perform quite well. Wing tilt control wasn't used a great deal. | Could hover very precisely also relaxed slow control motions. Vertical landing easy to perform. | Little bit of oscillation in pitch and roll but not a big problem. Nice relaxed response, low response to turbulence, nicely damped configuration. |
| | | B-FB | 0.375 0.299 | 3 | Selected to control response to turbulence and also pitch oscillations. | Couldn't perform air taxi as precisely or as easily as desired. Difficult to control attitude and to hold a desired velocity. Could not stop very precisely. | Same problem as air taxi, just couldn't seem to control position rates as accurately as desired. | Wasn't problems here concerning position while hovering, did try to use the wing tilt control, but lost position. | Hover wasn't too great a problem because didn't introduce large control inputs. Didn't get into any oscillations. Could land alright. Some interaction between pitch and roll. | The oscillatory response in pitch and roll annoying. Could not seem to stabilize pitch and roll particularly well while maneuvering and doing quick stops. |
| 115 | BC5 $T_a = T_b = 0.1$ | A-FB | 0.308 0.283 | 2 | Selected to give desired response. | Good response to control inputs, very predictable attitude response no problems at all in coming up to a desired velocity and holding it and stopping at desired position. Liked the large cross parameter here. Didn't worry too much about being slow about. | Could stop very quickly and precisely. Had no problem stabilizing on rate. | Attitude so easily controlled and gusts low enough so that even with high drag didn't have difficulty. | No problem in hover. Occasionally would get blown off position some, but no real difficulty. | No real objectionable features. The large drag made it somewhat difficult to obtain lateral and longitudinal velocities. One attitude response, drag made it hard to stop precisely and rapidly. This is a good case. |
| 116 | BC5 $T_a = T_b = 0.3$ | A-FB | 0.295 0.251 | 2 | Selected to see the response for roll and pitch. | Could perform air taxi very well. Attitude was well damped, very predictable and no oscillations. Could stop accurately due to the fairly large lag. Gusts no annoyance. Very good case. | Could stop quite precisely, no problems. Large lag helped stopping. | Performed this quite well. Could take eye off attitude and look at wing tilt indicator with no problem. Could tilt the wing rapidly, this compensated very nicely for the mean wind. | Never no problem, no real vertical landing. | No objectionable features. Because of good attitude characteristics the high drag was no problem when performing the turn. |
| 117 | BC5 $T_a = T_b = 0.6$ | A-FB | 0.281 0.314 | 3 | Selected to get adequate attitude response. | Relatively good position control during air taxi but required relatively large attitude changes to get aircraft response in translation. Could hover fairly well at low corners and could hold heading and attitude accurately because responses in pitch and roll were low. Control deflections were small. | Very easy to perform because of the high drag of the configuration. | Difficult in that considerable wing tilt control had to be used to offset the mean wind effects, but with position performance was fairly good. | Hover was fairly good although with the high drag get pushed around in headwind quite often. This degraded by being slightly. | The only objectionable feature was the large disturbance in position through the drag of the aircraft while hovering. |
| | | B-FB | 0.313 0.264 | 4 | Selected to gain the attitude response needed to overcome lags. | Would perform air taxi fairly well. In attitude that when maneuvering it normally tended to get blown off somewhat in longitudinal position, but headed maneuver fairly well. Some fairly small oscillations in attitude that were difficult to see, but no great problem. | No problem with this case, could seem to do desired job and stop fairly accurately. Extra large lag helped. | Did this quite well. Attitude was sufficiently well damped and compensated that could position vision between wing tilt angle and stick input. | With rapid wind, tilt could rotate throat quickly so as to keep fairly constant control over hover position. Vertical landing no problem. | Only objectionable feature was small lag in response to a stick input to low level, oscillations which were fairly persistent and required some attention. The aspect attitude response was supposed to be response to turbulence and was large one signal in response and quick stops. |

Contrails

TABLE B-II (Continued)

| Case | Conf. Parameters | Pilot Sim. Mode | $\frac{W}{g}$ | JR | Pilot Comments | | | | Overall Evaluation | |
|------|---------------------------|-----------------|----------------|-----|---|---|---|---|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | | Precision Hover, Vertical Landing, Secondary Dynamics |
| LL6 | B5 $T_0 = T_8 = 0.6$ | B-7E | 0.308 0.262 | 3 | Selected to get desired response in pitch and roll. | Could perform air taxi quite precisely. Attitude very well damped, very predictable. Could stop precisely and control hover and maneuvering velocities very well. Had a small problem getting blown off desired track occasionally but that was fairly easy to correct. | No problem. Could perform these quite smoothly and accurately. | Could remain over the spot very well. Did use wing tilt control a good deal because of the high drag. | Hover not difficult. Had to watch the gusts though, tended to get blown off in position. Vertical landing easy. Control activity relatively low during hover and landing. | Only a few objectionable features were getting blown off position periodically when trying to maneuver and hover. Fine attitude characteristics, well damped, low response to turbulence, comfortable case. |
| LL7 | B4 $T_0 = T_8 = 0.1$ | B-7E | 0.424 0.319 | 2 | Selected to get the response needed to overcome damping. Wide range of control sensitivities seemed acceptable. | Air taxi no problem. Good response to the control inputs, low response to turbulence, and the high drag helped in stopping and starting precisely and in holding desired velocity. | No problem. | Good attitude characteristics helped overcome the high drag and also the high rate of change of wing tilt which is now available helped to control hovering position quite accurately. | Could hover quite comfortably. Also, could land without difficulty. | No objectionable features. Favorable features were the good damping and high drag which helped in maneuver and quick stops. |
| | | B-7D | 0.418 0.345 | 4 | Selected to attenuate the gusts. | Air taxi not difficult to perform. Position motions were nicely damped due to large drag parameter, attitude was quite predictable. The effects of gusts were somewhat large but didn't offer any great difficulty. | Could set up a desired velocity and maneuver quite well, stop very precisely without any trouble. Attitude control well damped, very predictable. | Was able to remain over the spot without any difficulty. Had to use wing tilt angle a good deal because of high drag but not difficult to perform this task. | Hover is probably the most difficult task to perform. Could hold position fairly well but it required appreciable control activity. Good deal of control activity needed for vertical landing. | Objectable feature was the somewhat high response to turbulence. Position was nicely damped, attitude dynamics were good. |
| LL8 | B4 $T_0 = T_8 = 0.3$ | A-7B | 0.390 0.349 | 2.5 | Set to get desired attitude response. Attitude dynamics well damped and easily controlled. | Air taxi fairly easy except that fairly large attitudes required to indicate motion, however was stopped fairly precisely at desired point. Control deflections relatively small. | Relatively easy to perform except that large attitudes are required to initiate the action. | Fairly easy except that concentration is required to offset the mean wind. Considerable thrust rotation is required to maintain hovering position in the presence of the mean wind. | Hover performance very good with very little pilot attention required. | Attitude control is good and there is no evidence of control lags in the system. Most objectionable feature is high drag. In particular the gust effects on position disturb the aircraft. |
| | | B-7E | 0.349 0.275 | 3 | Selected to counteract the damping effects. | Air taxi no problem. Did notice some slight oscillation in roll and pitch in response to control inputs, but not large and were easily controlled. Able to perform maneuver quite accurately. | Could stop quite quickly and had no problem setting up and maintaining a constant rate during the quick stop. Large speed stability aided stopping rapidly and precisely. | Able to remain over the spot quite well. No crossed rate on wing tilt helps this maneuver. | Could hover precisely with fairly limited control inputs. Vertical landing no problem. Used wing tilt to help with longitudinal position control. | Only objectionable feature was the slight oscillation in response to roll and pitch inputs, but not particularly bad. Lots of damping, low response to gusts, and the high drag helped maneuvering and didn't seem to degrade hover or the turn maneuver. Had to closely watch wing tilt angle in the turn. |
| LL9 | B4 $T_0 = T_8 = 0.389$ | B-7E | 0.424 0.389 | 5 | Selected to control aircraft response to turbulence. | Response to control inputs would have been fairly predictable and probably acceptable, but the turbulence effects were too large. Could perform the task but really had to concentrate. Difficult, had to constantly be taking care of the effects of gusts and watching to make sure wasn't blown off. Difficult to hold the desired velocity. | Could perform the task but really had to watch for the effects of gusts. | Did this fairly well but had to do it slowly because of the effects of low gusts. Got into some fairly large and relatively oscillatory attitude changes. Used wing tilt control a good deal. | Mixed feelings about ability to hover. Sometimes seemed to be able to do it fairly well, other times not so well. Could land it alright. Lot of control activity in both hover and landing. | Primary objectionable feature was response to turbulence. |
| | | A-7B | 0.467 0.336 | 4 | Set for adequate attitude control. | Air taxi fairly easy except with high drag required relatively large attitudes to initiate motion. Could stop motion relatively easy and hold hover position with very small control deflections. | No problems except in getting the aircraft moving, but could stop very accurately at desired spot. | Required anticipation with thrust position control, attitude control requires just a slight amount of attention. Did use wing tilt control to hold hovering position while making the turn. | Hover performance good, but did get blown around a little bit in position. | Attitude control was fairly good but it did require a little attention to prevent it from becoming oscillatory and from drifting off desired heading. |
| LL10 | B4 $T_0 = T_8 = 0.6$ | B-7E | 0.501 0.404 | 3 | Selected primarily to get the responses desired. Difficult time getting proper attitude response. | In general, could perform the task fairly well. Air taxi was no problem. Attitude seemed predictable, and the high drag helped. | No problem. | Could perform this fairly well. Didn't have to worry too much about attitude and the large rapid wing tilt rate helped in controlling position. | Could hover accurately, no problems. Vertical landing wasn't particularly difficult. Only thing annoying was the difficulty in getting the control response that was needed. | No real objectionable features, some slight oscillation in pitch and roll. The general good attitude characteristics are favorable features. |
| | | B-7E | 0.409 0.280 | 4 | Selected to control the speed-stability effects and the response to turbulence. | Response to control inputs was predictable although it was slightly oscillatory and did notice some response to gusts. Able to initiate motion and to stabilize and hold desired velocities without any problems. Could stop precisely and hover accurately in the course. | No problem here. Did notice a slight response to turbulence and some slight oscillation in pitch and roll. | No problem. Occasionally generated some fairly large and oscillatory roll and pitch motions, but was able to maintain position over the spot very well. | Some difficulty with hover or landing. | The only objectionable feature seemed to be a slight oscillatory tendency in pitch and roll and some response to turbulence. Noticed the effects of speed stability when maneuvering, but these were easily correctable. Attitude response was fairly predictable and could perform all tasks without too much trouble. |

Controls

TABLE B-II (Continued)

| Use | Conf. Parameters | Pilot-Fltn. Mode | M_e V_{20} | R | Pilot Comments | | | | | |
|-----|--------------------------|------------------|-------------------|-----|---|---|--|--|--|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| LLC | DCR $T_e = T_a = 0.1$ | B-FB | 0.390 0.298 | 5.5 | Selected to control attitude because of poor damping and also to control attitude response to turbulence. | Performed air taxi fairly well but there were attitude oscillations; attitude needs more damping for more precision control. | Was able to stop quickly but would prefer more attitude damping. Attitude response to turbulence quite large and difficult to hold velocities. Developed fairly large attitude angles when arresting motion. | Was able to remain over the spot fairly well due to a low drag. However, did develop some fairly large oscillations in attitude. Didn't use wing tilt control too much. | Was able to hover quite precisely, held lower position without too much trouble. However, control activity was reasonably high during hover and landing tasks. Some interaction between dynamics but not too bad. | Would prefer to see more damping in pitch and roll, less response to turbulence, and more predictability in the response to control inputs. Configuration was controllable and could perform the task but not as easily as desired. |
| LLI | DCR $T_e = T_a = 0.3$ | A-FB | 0.324 0.257 | 5 | Get to control and stabilize pitch and roll attitude. | Air taxi maneuver requires some workload in that attitude is highly damped and fairly quiet sensitive. No problem initiating motion but small amount of anticipation required to stop at desired point. Disturbances on attitude seemed to be the biggest problem. | Can be performed readily however some anticipation is required to stop at desired point. | Heaviest workload is in offsetting gust disturbances on attitude and maintaining attitude stability. Very little wing tilt was used in controlling position. | Hover performance was fairly good but attitude control required some attention. | Most objectionable features of this case were (1) the control lag in both pitch and roll and (2) the gust disturbances on pitch and roll. More damping would be desirable. Against performance requires considerable pilot concentration. |
| | | B-FB | 0.347 0.270 | 5 | Selected to control oscillations in pitch and roll to get attitude response desired. | Problem here was oscillatory nature of roll and pitch, although never felt control would be lost. Was able to stop fairly precisely and to control velocities pretty well, but did have to pay a significant amount of attention to pitch and roll. | No great problem here, but attitude tended to wander around and had to pay attention to it. | Was able to remain over the spot quite well, but pitch and roll required attention. Oscillatory nature of pitch and roll was an annoyance. | Hover wasn't any great difficulty, could hold it pretty accurately but did get some moderately large attitudes because of their oscillatory nature. Could land quite well. | Didn't care for the oscillatory characteristics in pitch and roll and it seemed that speed stability and the gust excited oscillations and then would have to damp them. Pitch and roll were still controllable and low drag helped during the hovering and the turn. |
| | | B-FB | 0.424 0.319 | 7 | Selected to control the gusts and also the oscillatory attitude characteristics. | Very difficult. Was constantly seeing in both pitch and roll, trying to keep approximate desired velocity. Couldn't perform this task precisely or in any reasonable time. | Very difficult to stop at desired point and get into some large, oscillatory attitudes. | Again attitude was in constant oscillating motion. Could remain close to the square but really was forcing attitude back and forth. Did use wing tilt a little bit, wasn't really critical. | Couldn't really stay over hover point consistently. However, hover performance not too bad compared to other subtasks. Did manage to land it. Lot of control activity in both hover and landing. Definitely some interaction between roll and pitch. | Objectable features were the oscillatory nature of attitude and response to turbulence. Really had to watch the oscillatory attitude characteristics which were difficult to damp. |
| LLI | DCR $T_e = T_a = 0.6$ | A-FB | 0.387 0.393 | 8 | Get in attitude to maintain attitude stability. | Air taxi very difficult because of difficulty in holding attitude precisely. No problem in initiating desired motion as drag seemed relatively low. Some difficulty holding precision hover at the end of maneuvers. Excessive attitude changes often took place due to inability to control attitude. Control deflections were quite large and at times developed PNO type oscillations. | Maneuver somewhat difficult due to the very poor attitude control. | Required very little wing tilt compensation for zero wind. Most compensation was on maintaining attitude stability. Height control suffered somewhat because of the high workload in pitch and roll. | Hover somewhat difficult because couldn't control attitude accurately. Control activity was large. | Most objectionable feature was inability to control roll and pitch attitude due to the dynamics being oscillatory, lightly damped, and influenced by control lags. Task performance generally quite poor. Considerable compensation required just to maintain control at times. |
| | | B-FB | 0.414 0.374 | 8 | Selected to control gusts and to some extent counteract effects of control lags. | Could just perform the maneuvering task. Was in constant oscillation in both pitch and roll. As control input built up an oscillation which required considerable effort to damp. Difficult to stabilize and hold desired velocity and to stop precisely and hover. Some large attitude excursions occurred. | Same problems as with air taxi. Could stop the aircraft but large attitude excursions occurred. | Managed to remain hover position while turning but attitude went into wild oscillations and just about lost control. Developed one extended PIC in pitch. By stopping control inputs was able to gain control. | Could hover but not as precisely as desired. Attitude oscillations made it difficult. Did manage to land, but it was tough. Lateral dynamics definitely affected longitudinal dynamics and vice-versa. | The attitude characteristics in both roll and pitch are very objectionable. Roll and pitch in constant motion through large angles. |
| | | B-FB | 0.496 0.416 | 10 | | | | | | Uncontrollable. Tried lifting off and hovering. Couldn't remain stationary for more than 5 or 10 sec without developing a PIC. Couldn't start in pitch then, would come in some lateral motion. Tried six or seven different times, but just couldn't keep attitude under control. |
| LLI | DCR $T_e = T_a = 0.7$ | B-FB | 0.432 0.442 | 4 | Selected to give response needed in pitch and roll and also to counteract the effects of turbulence | Could perform this maneuver fairly well although did have to constantly attenuate gust effects to hold selected attitude angle. High drag helps the maneuvering task. Able to stabilize fairly well desired velocities. | No great problem. The high drag helps, mainly have to watch attitude response to turbulence, but attitude seems to be relatively predictable. | Performance fairly good. Don't see significant attitude oscillations. | Hover performed fairly well. Significant amount of attention required to attenuate gusts. Can land fairly well too. | Primary objection is the response to turbulence in pitch. Attitude seemed fairly predictable. Low drag helped in maneuvering and quick stops. |

TABLE B-II (Continued)

| Case | Conf. Parameters | Pilot Sim. Mode | N ₀ - T ₀ | FR | Pilot Comments | | | | | |
|------|--|-----------------|---------------------------------|-----|--|--|---|---|---|---|
| | | | | | Detection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| L114 | S06 T ₀ = T ₀ = 0.3 | A-FB | 0.310 0.193 | 4,5 | Selected for adequate control of the oscillatory attitude dynamics. | Neither large attitude changes required to initiate motion but could stop with great deal of precision and could hover fairly well except for being blown around in position occasionally. | Greatest problem was initiating the motion. Could stop quite easily at desired point. | Got blown around quite a lot, had to use considerable wing tilt control with anticipation in attempt to maintain hovering position. | Hover position wasn't too high although did get blown around in position. Control activity relatively low. | More objectionable feature was that attitude dynamics seemed to need a little more damping. Some response to gusts. Rapid control inputs as during quick stop tended sometimes to overshoot. |
| | | A-FB | 0.303 0.257 | 3 | Selected primarily to get attitude under control and to control attitude in presence of oscillations (which weren't too difficult to control). | Response to control inputs somewhat oscillatory. Better more damping. Able to initiate motion and stabilize and hold desired velocities pretty well, although oscillatory characteristics did somewhat affect ability to hold velocities. | Generally could come to the stop fairly accurately and hold hover without too much difficulty. High drag apparently helped. Blown off a little when trying to come to a desired position. | Dynamics did tend to make it more difficult than if more damping had been available. Rapid wing tilt rate has improved things considerably. | Hover not particularly difficult, although had to control gust effects. Attitude slightly oscillatory. | Objectionable features - slightly oscillatory characteristics in roll and pitch. Ray-stable features - high drag helped during the maneuvering and quick stop. |
| | | B-B | 0.300 0.328 | 7 | Selected to control turbulence and also effects of speed stability during the maneuver. | Could perform the task, but very difficult and not very precisely. Very difficult to control attitude and periodically would develop minor PIO, especially in roll. | Difficult to smoothly transition desired quick stop position. Sometimes got into fairly large attitudes. Poor performance. | Difficult. Got way off in hover position a couple of times. Constantly rolling and pitching and yawing back and forth. Never really stabilized attitude. Used considerable wing tilt control. | Wasn't able to hover particularly well. Periodically oscillated out of position. Landing wasn't very precise. A lot of control activity required significant amount of interaction. | Attitude control very objectionable. Large response to gusts. Large speed-stability effects when maneuvering and very oscillatory attitude characteristics. Very difficult to stabilize once an oscillation started. Had to be very careful about trying to stabilize attitude due to apparent lag effects. |
| L115 | S06 T ₀ = T ₀ = 0.6 | B-FB | 0.334 0.370 | 8 | Selected to control large oscillations which result in pitch and roll. | Response to control inputs is very, very disagreeable. Large oscillations result that need a very great deal of compensation to be able to perform the task at all. Can't perform the task precisely or stabilize and hold velocities. Significant response to turbulence. | Can be performed. Large drag helps as it does in maneuvering, but still quite a difficult task to perform. | Very, very difficult to perform. Try to develop large attitudes and at one point was in an extended PIO, just managed to regain control. | Never very difficult because of oscillatory dynamics. Just a way to stabilize the dynamics. Constant compensating inputs required. Very definitely the lack of damping in roll affected pitch and yaw. | Oscillatory characteristics very objectionable in pitch and roll along with inability to keep them. Sometimes got to grab hold of the stick and hang on as only way able to retain control. Almost lost control once. |
| L116 | S01 T ₀ = T ₀ = 0.1 | B-FB | 0.427 0.381 | 6 | Selected primarily to control aircraft response to turbulence and to compensate for the lack of damping and effects of speed stability in maneuver and quick stop. | Response to control inputs was not particularly good. Large attitude oscillations resulted when attempting to maintain velocity. Missed desired stopping points several times due to the effects of the speed stability, turbulence, and gusts. Attitude control was a problem. | Could stop fairly quickly but attitude control was a problem. | Wasn't particularly difficult to remain over the spot because of the low drag. However, attitude control was a problem. While diverging attention to wing tilt indicator sometimes got into very large attitudes. Needs more damping. | Could hover quite well but it required a good deal of control activity. There was also a problem with interaction of pitch and roll dynamics. | Objectionable feature was lack of attitude damping. Had to be very conscious of the attitude response to turbulence and response to control inputs. |
| | | B-B | 0.377 0.357 | 5 | Selected to control attitude and turbulence. | Performed maneuver pretty well, but prefer to have more damping. Difficult to maintain the desired velocities, have to watch attitude fairly closely and attenuate the response to turbulence. | Could perform task fairly well. Could certainly stay velocity enough. Developed some attitude angles a little larger than desired but could perform the task fairly well. | Remained over the spot quite well. Low drag helped. Didn't use wing tilt control too much. | Could hover quite precisely, no real problem there. Vertical landing was difficult. More control activity than desired. Some interaction between pitch and roll dynamics. | The objectionable features were the low level of damping in attitude (really needs some more and adequate response to turbulence). More pilot control activity required than is acceptable or satisfactory. |
| L117 | S03 T ₀ = T ₀ = 0.3 | A-FB | 0.436 0.455 | 9 | Selected to maintain attitude control to prevent PIO situations. | Using air taxi attitude control very difficult and occasionally got into PIO situations. Had to anticipate desired stopping point. Very difficult to come to precise hover. Sensitive attitude changes caused by gusts. Control deflections rather high frequency and large amplitude. | Difficult because rapid attitude control induced PIO situations in both pitch and roll at times. | Most difficult part of task was to maintain attitude control. Position control difficulty only because of poor attitude control. | Never not too difficult and performance wasn't too bad, however attitude control required intense pilot concentration. Control had but had the attention problems of very poor attitude control. | Most objectionable features were response to turbulence and unpredictable response to control inputs especially related to control lags and lightly damped dynamics. |
| | | B-FB | 0.451 0.365 | 7 | Selected to control response to turbulence oscillations and effects of speed stability when maneuvering. | Could perform maneuver but requires high concentration and constant concern with attitude. Definitely need more damping or less lags, probably tilt. Quite difficult to hold attitude. | Difficult. Could stop and in an imprecise way perform task, but just didn't have desired attitude control. | Tended to lose attitude when attention diverted. Difficult slow control. Difficult slow control. Difficult slow control. Difficult slow control. Difficult slow control. | Really couldn't hold hover position precisely, especially laterally. Vertical landing was difficult. Managed to perform task through. Especially interaction between dynamics (roll on pitch and vice-versa). | Objectionable features - lack of damping, large speed stability, oscillatory characteristics in attitude and lag in attitude response. |
| | | B-B | 0.423 0.375 | 7 | Selected to control attitude oscillations and also attitude response to turbulence. | Difficult to perform maneuver precisely. Difficult to hold the desired attitudes in the presence of low damping and effects of turbulence. Can't maneuver smoothly and stop precisely. | Also difficult because of difficulty in holding desired attitude. | Performed this maneuver fairly well, although there were large oscillations in roll and pitch. Drag was small and stayed over the spot pretty well. Little wing tilt control used. | Could hover fairly well. Not a lot of control activity was required and developed large attitude oscillations. Managed to land alright but again a lot of work required. Didn't perform the task adequately. | Objectionable features - large attitude oscillations, lightly damped attitude characteristics. Large attitude response to turbulence and some oscillations in attitude. |

TABLE B-II (Continued)

| Case | Conf. Parameters | Dist. Sim. Mode | $\frac{M_{de}}{g}$ | FR | Pilot Comments | | | | | |
|------|---|-----------------|--------------------|-----|--|---|--|--|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| L126 | RC3 $\tau_a = \tau_b = 0.6$ | A-FP | 0.595 | 10 | Selected in an attempt to stabilize pitch and roll attitude. | Air taxi maneuver very difficult because it was extremely difficult to stabilize attitude. When attention was diverted from display was momentarily frequently pitch and/or roll would be upset by a gust. Arresting these large attitudes difficult due to control lags and poorly damped dynamics. Very difficult to stay within ground track of the air taxi and control deflections were extremely large. | Very difficult to control due to poor pitch and roll control. | Main attention was devoted to stabilizing pitch and roll, for this reason control of both attitude and direction was very poor due to the high pilot workload. Used very little wing tilt control. | Hover difficult because of difficulty in stabilizing the inner loops. | Most objectionable feature was lightly damped attitude dynamics in combination with what seemed like fairly large control lags. Improvement is mandatory. It has major deficiencies. Near ground feel certain that control could be lost. |
| | | B-FB | 0.422 0.369 | 7 | Selected to control oscillatory characteristics and response to turbulence. | Response to control inputs fairly good. Large oscillations and a significant response to turbulence make control somewhat difficult. Not able to stabilize velocities as well as desired. Ability to stop precisely affected somewhat. Low drag and oscillatory attitude characteristics make precision performance of task difficult. | Can stop quickly but don't care for attitude characteristics. | able to remain over a spot fairly well but can't divert attention from display for very long. Need more damping in pitch and roll. | Can't hover too well, the oscillatory attitude characteristics and response to turbulence tend to make it difficult to maintain hover position. Vertical landing is also difficult. Some interaction between pitch and roll and vice versa. The lack of damping in one tends to lead to upsets in the other. | The objectionable features are lack of damping and oscillatory characteristics in pitch and roll. At no time tended to lose control. |
| L119 | RC1 $\zeta_a = \zeta_b = 0.50$ $\omega_{da} = \omega_{db} = 3.33$ | B-FB | 0.295 0.206 | 7 | Selected to control attitude but not so high as to excite oscillations. | Very difficult to perform with any precision. Attitude response to control inputs very, very difficult. Attitude (especially pitch) in almost constant motion. Tendency to develop PIO in lateral control. Only way could keep attitude under control was to periodically take hand off stick and let pitch damp itself. Couldn't perform air taxi well because of difficulty with attitude. | Difficult to perform because of poor attitude characteristics. | Managed to remain over spot fairly well but attitude difficult to control (in constant oscillation). Used a little wing tilt during turns in coordination with attitude changes. | Hover wasn't difficult, done best by holding stick essentially fixed. Whenever tried to change position developed oscillations that couldn't damp out with control inputs. Some interaction between pitch and roll dynamics. | Attitude characteristics very objectionable. Can't damp out oscillations except to hold stick fixed. Not such control over this case. |
| L128 | RC1 $\zeta_a = \zeta_b = 0.25$ $\omega_{da} = \omega_{db} = 3.33$ | B-FB | 0.300 0.272 | 10 | Selected small control sensitivities in attempt to avoid exciting attitude. Can't make input without exciting attitude motion. | Control must be almost hands off or very, very small inputs. Whenever maneuver attempted low control. Built up large violent oscillations. | | | | Can't control this because of inability to suppress attitude oscillations. |
| L122 | RC1 $\zeta_a = \zeta_b = 1.00$ $\omega_{da} = \omega_{db} = 3.33$ | B-FB | 0.553 0.310 | 4 | Selected to get the response desired to overcome effects of the lags. | Could perform task fairly well. Noticed somewhat irritating oscillations in pitch and roll that had a tendency to sustain themselves, although low level and fairly quickly damped. | Could stop quickly and precisely, the lag was somewhat annoying when attempting to roll out after the y quick stop. | Could perform task fairly well. Reduced pitch and roll oscillations that were sustained for a while. Stayed over the spot fairly well, however. | Could hover quite precisely. Vertical landing was no problem. | Objectionable feature was small amplitude oscillations in pitch and roll which was somewhat irritating. Generally well damped, could control attitude fairly well. |
| L125 | RC1 $\zeta_a = \zeta_b = 1.0$ $\omega_{da} = \omega_{db} = 5.23$ | B-FB | 0.317 0.257 | 3 | Selected to give response needed in attitude. No problems with lags. | Could perform task pretty precisely. Noticed the effects of gusts a little, but it wasn't difficult. Could stabilize and hold velocities. Response to control inputs quite predictable. Heavily damped. | No problem stopping precisely and controlling attitude. | Could remain over the spot quite well. Task fairly easy to perform. Used wing tilt control during the turn. | Hover and landing no problem. | No real objectionable features. Maybe attitude was slightly responsive to turbulence. Noticed some small oscillations. Attitude control was good. |
| L123 | RC1 $\zeta_a = \zeta_b = 0.1$ | B-FB | 0.297 0.266 | 2 | Selected to get desired attitude response. | Response to control inputs quite predictable, well damped. Very steady and noticed very few oscillations. Could initiate motion and stabilize velocities, stop precisely. | Not difficult. | Could remain over a spot very well, attitude nicely damped, no problem with pitch and roll and no problem stopping on preselected headings. Used some small wing tilt. Wing tilt changes were not large. | Can hover very precisely. Vertical landing no problem. | Attitude control very, very good. Nicely damped, easy to control, very predictable and stable. |
| | | B-MS | 0.309 0.252 | 2.5 | Selected to get desired pitch and roll responses. | Easy to perform. Easy to select desired velocity and hold it. Can stop precisely. No problems. | Performed the task quite precisely. Nice positive attitude response to control inputs. No noticeable lags. | Could perform quite precisely and remain over spot. Wing tilt control although not critical, was coordinated with with heading relative to the mean wind. | Hover and vertical landing no problem. No interaction among axes. | Favorable features included good, well-damped, positive pitch response and roll response. |
| L124 | RC1 $\tau_a = \tau_b = 0.3$ $\zeta_a = \zeta_b = 0.1$ | B-FB | 0.397 0.354 | 3 | Selected to get response desired to overcome the lags which were noticeable. | Task wasn't particularly difficult but did notice the effects of lags in response to control inputs. Had to be careful about making control inputs. Had to anticipate changes in attitude a little more than would have to without the lags. However, could perform task fairly well. | Sometimes overshoot position a little bit, some oscillations in position resulted because didn't get attitude reversed quickly enough. | Could do this fairly well, no real problems. Coordinated wing-tilt control with different parts of the turn relative to mean wind. | Hover and vertical landing no problem. | Found the lag in roll and pitch to be an objectionable feature, not really serious but it did result in performing the task less precisely than had previously. |

TABLE B- II (Concluded)

| Case | Conf. Parameters | Pilot- Sim. Mode | V_{be} - V_{ba} | 16 | Pilot Comments | | | | | |
|------|---|------------------|---------------------------|-----|--|---|---|---|--|--|
| | | | | | Detection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landings, Secondary Dynamics | Overall Evaluation |
| 1125 | BC1 $\gamma_a = 0.3$ $\gamma_b = 0.1$ $\gamma_c = 0.$ | B-F3 | 0.332 0.290 | 8 | Selected in an attempt to gain control of pitch and roll oscillations. | Couldn't perform maneuver particularly well because of constant roll oscillations. Some oscillations in pitch, but roll was most annoying. | Difficult to perform task with any precision because of constant roll oscillation. Really large angles (10 deg or more), constant oscillation and relatively high frequency | Came close to losing roll control during maneuver. Couldn't do it particularly well because of roll. Wing tilt control used a little. | Could stabilize aircraft in hover fairly well, but couldn't hover precisely. Could manage to land it but not with precision. Definitely some interaction between pitch and roll. | Roll and pitch oscillations very objectionable, unacceptable. |
| 1126 | BC2 $\gamma_a = \gamma_b = 0.1$ | B-FE | 0.399 0.334 | 5 | Selected to gain control of pitch response to turbulence and speed-stability effects when maneuvering. | Not too difficult to perform. Had to pay close attention to attitude. It was disturbed by turbulence, but fairly controllable. Could stabilize and hold the velocities and stop precisely at the corners fairly well. | Weren't any real problem, could perform task fairly well but had to watch attitude as it was quite responsive to turbulence. | Could perform quite well again having to watch attitude, but remained over the spot fairly well. Only a little wing tilt control used as drag apparently small. | Held position without too much difficulty, although was fairly active with control stick. Vertical landing no problem. | Objectionable features were the attitude response to turbulence and relatively low damping. However, attitude was reasonably predictable but required a good deal of attention and control activity. |
| | | B-ME | 0.366 0.260 | 5.5 | Selected to gain control of attitude oscillations and attitude response to turbulence. | Could perform these maneuvers fairly well, but attitude responsive to turbulence. Some delay in the attitude response. Needs damping. Had to watch attitude fairly closely to perform the maneuver well. | Had to be somewhat cautious in performing this task because didn't want to make too large an attitude change. | Performed this fairly well, but couldn't hold position quite as well as desired. Needed the wing tilt control to correct for mean wind effects. | Performed hover quite well. Vertical landing not too difficult, managed to do it fairly well. Only a little interaction between dynamics. | Objectionable features are lack of adequate attitude damping and attitude response to turbulence. Attitude was controllable but required some effort. |
| 1127 | BC2 $\gamma_a = \gamma_b = 0.3$ $\gamma_c = \gamma_d = 0.1$ | B-FE | 0.383 0.334 | 7 | Selected to gain control of oscillations in attitude. | Response to control inputs undesirable. Roll and pitch in almost constant oscillation of fairly large amplitude. Almost impossible to damp. Could stop fairly well, but difficult to maintain velocity | Lot of attitude motion, difficult or impossible to damp large amplitudes. Affected ability to stop at desired hover position | Again large oscillations especially in pitch. Couldn't control it and occasionally would get a large oscillation in roll too. Very disagreeable. Had to concentrate so much on attitude that it took concentration away from hovering position. | Could hover fairly precisely, but fairly large, constant motion attitude occurred. Could land it alright. Some interaction between roll and pitch due to the oscillatory nature of the dynamics. | Found oscillations in pitch and roll very objectionable, very undesirable. No evidence of lack of control power. |
| | | B-ME | 0.371 0.317 | 7 | Selected in an attempt to get attitude under control. | Very difficult to perform. Can't perform this maneuver precisely, difficult to control attitude, every now and then tend to build up attitude oscillations which are frightening. | Can't really perform a quick stop for fear of losing attitude control. | Did this very slowly and performed the task fairly well, but attitude was in constant oscillation. Needed wing tilt control to help perform the task. | Not too bad, but had to be careful not to make large inputs for fear of setting everything into oscillation again. Can perform the vertical landing. Definite interaction between roll and pitch dynamics. | Objectionable features include lack of damping, very oscillatory lightly damped response in pitch and roll. Very responsive to turbulence. |

*Lag and delay affect both control and SAS inputs.

TABLE B-III

PILOT COMMENTS FROM THE STUDY OF PITCH, ROLL AND YAW CONTROL MOMENT LIMITS

Flying Qualities Results Given in Table A-IV

| Case | Conf. Parameters | Pitch-Trim Mode | $M_{\dot{\alpha}}$ | $M_{\dot{\beta}}$ | SR | Pilot Comments | | | | | |
|------|---|-----------------|--------------------|-------------------|----|---|--|--|--|---|--|
| | | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over- & Spot | Vertical Hover, Vertical Landing, Secondary Maneuvers | Overall Evaluation |
| 1A0 | N1 $M_{\dot{\alpha}}=0.360$ $M_{\dot{\beta}}=0.415$ $M_{\dot{\gamma}}=0.120$ | B-7a | 0.301 | 0.256 | 7 | Selected to get attitude response desired. | Good response to control inputs in pitch and roll generally, however, when maneuvering forward tended to run out of control power occasionally and would pitch so that it was somewhat difficult to stabilize. However, in general could perform task fairly well. | Longitudinal gain strip developed a brief unaccountable attitude excursion due to lack of control power but managed to recover fairly quickly. | Could remain over spot quite well, no difficulty. Well trimmed configuration. | No problem. Could hover precisely, sufficient control power in pitch which showed up periodically during a maneuver and especially during the quick stop. In general configuration well damped. | Only objectionable feature was lack of control power in pitch which showed up periodically during a maneuver and especially during the quick stop. In general configuration well damped. |
| | | B-8E | 0.201 | 0.234 | 7 | Selected to get the desired attitude response. | Generally could perform task fairly well. Didn't have any great difficulty in initial velocity and stopping reasonably precisely. During the X maneuver was disturbed by a gust and couldn't control it due to lack of control power. | Generally no problem. Didn't notice any lack of control power nor had any difficulty during the X maneuver. | Could perform this fairly well but seemed that it lacked a little control power to control roll and pitch. Used the wing tilt controls a little. | Could hover fairly precisely without too much vertical. Vertical landing was no problem. | Objectionable feature was lack of control power, especially in pitch. |
| 1A2 | N1 $M_{\dot{\alpha}}=0.396$ $M_{\dot{\beta}}=0.457$ $M_{\dot{\gamma}}=0.132$ | A-7B | 0.307 | 0.263 | 3 | Set to achieve desired attitude response for maneuvering as there were very little gust effects noticeable. | Maneuvering performance was very good and required very little pilot concentration and very little compensation. Control deflections generally very small and low frequency. | Could perform quite well although a small amount of anticipation required to stop at desired position. Noticed very slight limitation of control power, but this occurred only on a very abrupt control input. | Quite easy, required very little pilot effort and very little thrust to tilt this control. | Hover performance was very good and very little pilot effort required. | Would still consider this a satisfactory configuration, with only slight unpleasant deficiency being the lack of control power when performing quick stop maneuvers. |
| | | B-7D | 0.296 | 0.243 | 2 | Selected to get the attitude response required. | In general this wasn't a particularly difficult task to perform, however once or twice noticed a lack of control power. In two instances attitude pitched up and couldn't do anything to control it until the gust had passed. Limited in control power at an insufficient level. | Didn't have any problems. | Could perform this maneuver quite well remaining over spot very precisely. Used only small amount of wing tilt. | Could hover quite precisely. Vertical landing no problem. Adjusted to low amount of control activity during hover and vertical landing. | Seems some more pitch control power. However, the configuration is nicely damped. |
| | | B-8E | 0.277 | 0.296 | 3 | Selected to get desired attitude response. | No problem performing task. Could initiate and hold velocities and stop precisely. No excessive attitude changes involved. | Could perform this task precisely. | Could do this accurately and rapidly. Didn't have to use wing tilt control too much. | Seemed to have a little bit of trouble holding lateral leveling position out in general this task wasn't particularly difficult. Vertical landing not much of a problem. | Some slight difficulty hovering. Good attitude response, generally the task could be performed well. |
| 1A3 | N1 $M_{\dot{\alpha}}=0.432$ $M_{\dot{\beta}}=0.408$ $M_{\dot{\gamma}}=0.144$ | A-7B | 0.290 | 0.200 | 2 | Set to achieve desired attitude control for maneuvering. | Air and performance was very good with very little pilot compensation and effort required. Control deflections small and generally low in frequency. | Could perform quite well but there was no indication of a limitation on control power. | Performance was good with little pilot effort required. Very little thrust tilt this control required to perform turn maneuvers. | Hover performance very good with a minimum of pilot effort required. | Configuration and virtually no objectionable features. |
| | | B-7B | 0.327 | 0.216 | 3 | Selected to gain control of attitude and attitude response desired. | Could perform maneuver quite accurately, initiate all desired velocities with no problems. No obvious lack of control power. Seemed very easy to control. | No evident lack of control power anywhere. Could perform maneuver and stop precisely. Did not develop any large attitude angles due to lack of control. | No problem performing maneuver. Did it quite accurately, didn't have to rely on wing tilt control too much. | Could hover fairly precisely, but with a little difficulty. Vertical landing no problem. Adjusted to small amount of control activity. | No real objectionable features, except for slight difficulty in hovering. Otherwise it was a good configuration. |
| 1A4 | N1 $M_{\dot{\alpha}}=0.595$ $M_{\dot{\beta}}=0.415$ $M_{\dot{\gamma}}=0.120$ | B-7B | 0.327 | 0.259 | 3 | Selected to get desired attitude response. | Not difficult at all to perform this maneuver. Could do it quite precisely, could initiate and stabilize velocities without any problems and stop precisely without large attitude angles. | Generally had no problem but when performing the roll quick stop once noticed a lack of control power. | No problem, performed this task precisely. Did use wing tilt control a little but wasn't really essential. | Could hover quite precisely without great deal of activity. Vertical landing no problem. | Objectionable feature is possible deficiency in roll control power which was a little annoying. Slightly laced configuration, very responsive and predictable. |
| | | B-8E | 0.303 | 0.238 | 2 | Selected to get response desired in attitude. | No problem. Very predictable response, could hold attitude quite well. Slight tendency to shake off post desired hovering point but that was fairly easily controlled. | No problem, didn't perform these quite well. Very abruptly and could position after the stop without any problems. | Could maneuver quite accurately and was fairly relaxed, no great difficulty. Wing tilt control used only a little during turn. | Could remain over hover point without any problem and didn't have to use too much control activity. Vertical landing not difficult either. | No real objectionable features. Little response desired to help in maneuvering. Didn't notice any absence of control power during maneuvers. |
| 1A5 | N5 $M_{\dot{\alpha}}=0.970$ $M_{\dot{\beta}}=0.280$ $M_{\dot{\gamma}}=0.120$ | B-8E | 0.390 | 0.268 | 7 | Selected to get the response desired in pitch and roll and also in an attempt to overcome control power deficiency. | Would like to see a little more control power as it had some effect on ability to perform the task even when gusts were low. In one instance when maneuvering longitudinally got hit with a gust and just lost control of pitch for several seconds. This degraded task performance. | Went alright, didn't get combination of effects but caused loss of control, but would like to see some control power. Performance lacked precision. | Seems more control power, did use wing tilt a good deal during this task. | Hover alright. Managed to land vertically also. | Definitely needs more control power. |
| 1A6 | N5 $M_{\dot{\alpha}}=0.380$ $M_{\dot{\beta}}=0.450$ $M_{\dot{\gamma}}=0.150$ | A-7E | 0.350 | 0.225 | 3 | Response to control inputs during air taxi very predictable in both pitch and roll. Required somewhat large attitude changes to initiate action during maneuvering but could stop very easily at desired point. Attitude changes not objectionable because of good attitude control. Worked in no control hold leveling and attitude fairly well. | Required large attitude changes. Only disagreeable feature was slight limitation on control power during quick stops but this was only slightly annoying and caused no degradation in performance. | Required somewhat large changes in wing tilt angle in order to hold leveling position but performance was relatively good because of good pitch and roll control. | Hover required very little control action. Most objectionable feature was gust disturbances in the longitudinal and lateral plane during the quick stop maneuvers. | Configuration is probably satisfactory without improvement. Slight annoying lack of pitch control power during the quick stop maneuvers. | |

TABLE B-III (Continued)

| Case | Conf. Parameters | Pilot Sim. Mode | N _{ce} g _a | PR | Pilot Comments | | | | | |
|------|--|-----------------|-----------------------------------|-----|---|--|---|---|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Aviation Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 1M6 | BC K ₀ =0.380 K ₀ =0.360 K ₀ =0.150 | B-M | 0.297 0.218 | 2.5 | Selected to get attitude response desired. | No great difficulty, did notice that when maneuvering laterally tended to get blown off in longitudinal position occasionally. Could correct for it fairly easily. | No difficulty. Could stop quite precisely and remain over spot. Added drag mass maneuvering and quick stopping somewhat easier. | Could perform this fairly accurately but had to watch carefully wing tilt position relative to heading. Used considerable wing tilt to perform task precisely. | Hover no problem, could perform fairly well. Vertical landing not difficult. | No real objectionable features, might be desirable to have somewhat lower drag, but could correct for most effects of drag. No real evidence of a lack of control power. |
| 1M7 | BC K ₀ =0.468 K ₀ =0.440 K ₀ =0.180 | A-FB | 0.270 0.233 | 3 | Set to gain adequate pitch and roll response during air taxi maneuver. | Air taxi relatively easy and performance good. Since attitude control was good had no problem holding heading or altitude. Control deflections relatively small and low frequency. | During rapid attitude changes seemed to notice a slight deficiency in control power. No effect on performance but it did occasionally seem to make roll and pitch slightly oscillatory. | Control easily maintained, no serious effect on task. Wing tilt use was very small. | Hovering, landing and takeoff done with little effort and relatively good precision. | Only mildly unpleasant deficiency was apparent saturation of pitch and roll control during very rapid large attitude changes during the quick stop maneuver. |
| 1M8 | BC K ₀ =0.600 K ₀ =0.600 K ₀ =0.175 | A-FB | 0.260 0.194 | 6 | Set to gain adequate roll and pitch attitude control for the maneuver task. | Good attitude control but did notice control power deficiencies during air taxi. Control deflections relatively low in amplitude and frequency. | Inadequate control power to do a good quick stop. Tended to use some wing tilt to assist in longitudinal quick stop maneuver. | Had some difficulty maintaining position during turn due to the mean wind effects. | Hover, landing and takeoff no difficulty. | Out effects were minimal. The most objectionable feature was inadequate control power for rapid maneuvers and during turn maneuver. This prohibited rapid and precise maneuvering with the speed desired. |
| | | B-FB | 0.413 0.395 | 5 | Selected in attempt to control pitch and roll attitude during gusts. | Difficult to hold maneuvering speed accurately. Pretty much at the edge of the gusts when they get too large. Had to wait till they receded and then attempt to continue. Couldn't perform task precisely. | Precision directly dependent on level of the gusts that happen to be present at any given time. | Lost control once. Began to develop a roll attitude when the gust hit, gave such a large roll attitude had to really make an effort to retain control. | Hover wasn't too bad but every now and then got socked with a gust and have to ride with it. Wing tilt control used fairly heavily to hold hovering position. | Control power inadequacies were hit by a large gust. When the gusts were small configuration seemed to be relatively good but with large gusts difficult to retain control. |
| 1M9 | B-A K ₀ =0.908 K ₀ =0.666 K ₀ =0.193 | A-FB | 0.225 0.244 | 8 | Set to achieve adequate attitude control in pitch and roll. | Not too much difficulty encountered in air taxi as long as speeds kept relatively low and small attitudes used. Attitude control required some compensation although gust disturbances were rather minor. | Presented some difficulty in that occasionally got hit by a gust while trying to maneuver rapidly and maneuver couldn't control attitude too well, although did not lose control. | Had to be done with rather gentle maneuvers and one had difficulty trimming out mean wind due to inadequate control power. Small amount of wing tilt required. | Hover was no problem. Neither was landing or taking off. Control activity was rather low. | Most objectionable feature was limitation on control power in pitch, roll or yaw limitation did not seem to present any problem. Control-ability occasionally in question. High pilot concentration required. Must be flown with small amplitude maneuvers. |
| | | B-FB | 0.432 0.404 | 4.5 | Selected to control turbulence and effects of large speed stability. | In general could perform task fairly well. Every now and then hit with a large gust that disturbed attitude, but was always able to maintain control. | In general could perform task fairly well, but occasionally hit with a large gust that would prevent smooth performance of task. | Performance fairly good. Used wing tilt control a good deal. | No problem hovering, adequate control power. Apparently control power only inadequate when not ground speed, mean wind, and turbulence components were large. | Objectionable feature was deficiency in control power. In general configuration seemed to be fairly well suited. Response to turbulence wasn't that large, fairly low frequency. |
| 1M10 | BC K ₀ =0.984 K ₀ =0.727 K ₀ =0.211 | A-FB | 0.304 0.261 | 4.5 | Attitude control well damped and gust effects minimal. Maneuvering performance is good although relatively large attitude changes required to maneuver. | Attitude control well damped and gust effects minimal. Maneuvering performance is good although relatively large attitude changes required to maneuver. | Noticed control power limitation when making rapid attitude changes although it does not seem to impair performance. | Relatively easy except that large amounts of wing tilt are required to effect same wind effects. | Hover performance is relatively good and control power seems adequate. | Most objectionable features are the gust effects on aircraft position and the noticeable limitation of control power during rapid attitude changes. |
| | | B-FB | 0.431 0.404 | 3 | Selected to control turbulence and speed stability when maneuvering. | Not difficult. Could maneuver precisely and hold attitude quite well and generally had no problem performing task. Noticed just one small deficiency in control power but maybe it was just a large gust. | Could stop precisely and hold desired velocities quite well. Didn't notice any lack of control power. | Performed this quite well. Didn't notice any lack of control power. Did use wing tilt a good deal during the turn. | Could hover precisely. Could also land quite well without any real difficulty. | No real objectionable features, some slight response to turbulence noted but not too bad. Dynamics are quite well damped and workload relatively low. |
| | | B-M | 0.426 0.348 | 5 | Selected to control effects of turbulence acting through speed stability sooty, also to control effects of speed stability while maneuvering. | Moderately difficult to perform. Had to estimate effects of turbulence on pitch and roll. Affected ability to stop precisely to some extent, but could perform the task fairly well. | Didn't get into any un-nerving attitudes and performance relatively good. | Was difficult, couldn't hold hovering attitude particularly well and did develop some fairly large attitude changes. Lot of roll and pitching action. Used wing tilt control a great deal. | Could hover precisely but it involved fairly large attitude changes and a lot of stick motion. Vertical landing alright. Some interference between dynamics, at least during the turn. | The objectionable features were the large response to turbulence in pitch and roll and the lack of damping. Some lack of predictability in the pitch and roll response to stick inputs. Didn't notice any lack of control power, however. |
| 1M11 | BC K ₀ =1.056 K ₀ =0.768 K ₀ =0.239 | B-M | 0.428 0.334 | 4.5 | Selected to get desired response and also to overcome effects of turbulence. | In general could perform this maneuver without any difficulty. Had to estimate the effects of turbulence, however. | Could stop precisely and rapidly without excessive attitude but had to watch the effects of turbulence. | Also could perform this maneuver fairly precisely but again turbulence was significant. Didn't notice any lack of control power in all these maneuvers, however did have to use wing tilt control a good deal in turn because of mean wind. | Required a fair amount of activity as did vertical landing. Use to estimate the effects of turbulence. | Response to turbulence was somewhat too large. However, in general attitude was predictable in response to control inputs. |

Contracts

TABLE B-III (Continued)

| Inst | Conf. Parameters | Pilot Sim. Mode | $\frac{M_{de}}{g}$ | PB | Pilot Comments | | | | | |
|------|--|-----------------|--------------------|-----|--|---|---|---|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 1402 | 805 $M_{de} = -0.590$ $I_{de} = -0.750$ $N_{de} = -0.170$ | B-FB | 0.307 0.351 | 7 | Selected to control attitude response to turbulence and also attitude changes when maneuvering. | Didn't think I could perform this well. There were times when hit by turbulence and would almost come to a stop. Seemed to find attitude bounced around quite a lot. Large attitude changes did result. | Generally could arrest velocity without too much difficulty. Kind of difficult to hold velocity. Also, on the X quick stop when trying to arrest speed got into a large attitude excursion and thought about to lose control. | Attitude control kind of steady. Large attitude oscillations but could hold hovering position fairly well. No problem with directional control power. Wing tilt control used a good deal. | Could hover fairly accurately. As long as attitude changes were fairly small didn't get into too much trouble. Fair amount of control activity. Could land alright. | Objectable features were the uncertainty in ability to control attitude. Got into one large attitude excursion and thought that control might be lost. Many times the attitude response seemed to be fairly well damped. |
| 1403 | 805 $M_{de} = -0.979$ $I_{de} = -0.583$ $N_{de} = -0.187$ | A-FB | 0.215 0.192 | 10 | | Inadequate control power, difficult to establish velocities. At times saturated either pitch or roll control. | Inadequate control power to develop velocities. Fore and aft motion could be controlled using wing tilt, but control seemed inadequate to perform lateral maneuvers. | Lost control once and was unable to recover. Saturated control moment because of turbulence effects. | | Inadequate roll and pitch control moments. Saw control moments OK. |
| | | B-FB | 0.307 0.351 | 5 | Selected to control attitude response to turbulence and the effects of speed stability while maneuvering. | Sometimes maneuvering velocities affected by turbulence through pitch and roll. But in general could maneuver fairly well but lacked desired precision. Once or twice introduced transient which may have been caused by lack of control power. | Could stop fairly quickly and didn't have too much trouble holding maneuvering velocities. | Didn't have too much trouble, but did go through some fairly significant attitude oscillations (particularly in roll). Had to use wing tilt a good deal. | Fair amount of control activity required to hover accurately. Could land without too much difficulty. Secondary dynamics had some interaction but nothing really severe. | Response to turbulence too large and noticed some lack of control power. Used maximum control input once or twice and wasn't able to attenuate gusts. |
| 1404 | 805 $M_{de} = -1.068$ $I_{de} = -0.900$ $N_{de} = -0.204$ | A-FB | 0.266 0.182 | 8 | Set for attitude response for air test. | Inadequate control power to maneuver very rapidly. Infinite deficiency in both roll and pitch. Lateral maneuver was very slow because didn't have lateral thrust trim. | Not possible because initial velocities necessary for quick stops could not be developed. | Required concentration and the wind blew the aircraft quite a bit. Difficult to control because of inadequate control power. Had to make liberal use of wing tilt in an attempt to offset the deficiency in longitudinal control power. | Hovering and landing were no particular problem as control power was adequate for these tasks. | The most objectionable features were (1) deficiency in control power in pitch and roll when maneuvering and turning over a spot and (2) the gust effects on pitch attitude. It required some pilot attention. Must control carefully during maneuver to avoid losing control of the aircraft. |
| | | B-FB | 0.307 0.351 | 4,5 | Selected to control attitude response to turbulence and effects of speed stability during maneuvering. | Generally response to control inputs was acceptable. Could stabilize velocities fairly well and stop without too much difficulty. Attitude kind of responsive to turbulence. Would like a little more damping. | Not too much difficulty. Noticed following abrupt stops there was no tendency to oscillate in pitch or roll. Adequate control power. | Could remain over the spot fairly well but did develop some large attitude changes. Desired more attitude damping. Control power was no better. Wing tilt control used a good deal. | No real problem. Could hover quite precisely although fair amount of control activity required. | A fair amount of attitude response to turbulence and would like to see a little more attitude damping. Control power seemed adequate, noticed no large oscillations and no tendency to lose control. |
| | | B-MB | 0.303 0.325 | 6 | Selected to control response to turbulence and speed stability when maneuvering. | Response to control inputs not quite as predictable as desired, looks like acceleration-type response. Difficult to stabilize velocities and stop precisely. Gust disturbances are overwhelming, very large. | Could stop fairly abruptly but it was difficult to do everything precisely. Didn't notice any lack of control power. | Managed to do this without too much difficulty, but did develop some fairly significant roll and pitch attitudes. Wing tilt control was used a good deal for mean wind effects. | Could hold position pretty well, but was always oscillating back and forth in doing so. Lot of turbulence to overcome when hovering. Vertical landing is moderately difficult. Probably some interactive effect between pitch and roll dynamics. | Objectable features include large response to turbulence with the difficulty it caused in performing task precisely and also the low damping in roll and pitch. Didn't notice any lack of control power. |
| 1405 | 805 $M_{de} = -1.157$ $I_{de} = -0.975$ $N_{de} = -0.221$ | A-FB | 0.266 0.299 | 7 | Workload very high during the air test. Roll and pitch attitude fairly responsive to gusts. Attitude response to control inputs very lightly damped. Aircraft needs more SAS. Considerable gust disturbance in position and fairly large attitude changes required to maneuver. Limitation on control power evident, however, controllability of aircraft not in question. | Difficult to initiate the rapid maneuvers but could be stopped rather quickly. Limitation on control power evident and at times prevented the desired control of attitude. | Fairly difficult because of wind effects on the aircraft position, but control was adequate. Fair amount of wing tilt control required to hold position. | Hover performance fairly good, however pilot workload fairly high. | Most objectionable features were first the lightly damped, gust sensitive dynamics, and second, the limitation on control power. Considerable pilot compensation required, however, controllability not in question. The lack of control power and the insufficient stability augmentation a deficiency that must be improved. | |
| 1406 | 805 $M_{de} = -1.250$ $I_{de} = -1.050$ $N_{de} = -0.230$ | B-MB | 0.400 0.398 | 5 | Selected to control attitude response to turbulence and attitude response to maneuvering velocities. | Could perform this task fairly well and initiate and stabilize velocities although it took some attention. Response to turbulence was fairly sharp, abrupt at times. | Could stop quite quickly and relatively precisely. Tended to introduce some fairly substantial and rapid attitude changes. | Performed this fairly well, including holding hover position. Used wing tilt control a good bit. | Fairly high workload when hovering but performance fairly good. Could land. Not too much interaction between dynamics. | Large attitude response to turbulence and the lack of predictability in the attitude response to stick inputs most objectionable features. Needs more damping. |

Contrails

TABLE B-III (Continued)

| Date | Conf. Parameters | Pilot Size | N_{δ} L_{δ} | FR | Pilot Comments | | | | | | | |
|------|---|------------|------------------------------|-----|---|---|---|--|---|---|---|--|
| | | | | | Selective Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation | | |
| 12A7 | RC1 $N_{\delta} = -0.396$ $L_{\delta} = -0.457$ $N_{\delta} = -0.132$ $T_{\delta} = -0.5$ $\delta_{\delta} = -0.1$ | B-FB | 0.339 0.264 | 4 | Selected to get desired attitude response, seemed a bit sluggish in attitude. | No real problem. Did notice some slight lack of control power though, seemed to get a little larger pitch attitude excursion than wanted, but in general could maneuver quite well. | Could perform task reasonably well, had a little difficulty stopping where desired. | Not too difficult. Do real hard requirements for wing tilt control. | Little disappointed with ability to hover. Would like to have a little more precision. Vertical landing no problem. | Objectionable features include some lack of control power and some apparent effects of lag in attitude control. | | |
| | | | | | B-MB | 0.348 0.299 | 4.5 | Selected to get desired response in pitch and roll; seemed to have to increase control sensitivity to overcome lag effects. | Performed quite well, no problems with initiating and holding desired velocity and didn't get into any particularly large attitudes. | Went fairly well except once during a quick stop seemed to exceed control power limits. Couldn't maneuver attitude as quickly as desired, although nothing serious. | Performed task fairly well. Little use of wing tilt control. | Couldn't hover quite as precisely as desired. Seemed to keep oscillating away from desired position. Could land alright. |
| 12A8 | RC1 $N_{\delta} = -0.432$ $L_{\delta} = -0.498$ $N_{\delta} = -0.144$ $T_{\delta} = -0.3$ $\delta_{\delta} = -0.1$ | B-FB | 0.233 0.294 | 4 | Set for desired attitude response for air taxi. Slight overshoot and oscillation about desired attitude following rapid commands. | Air taxi performance relatively good. Slight lag in attitude control required only small increase in concentration to perform task. Control deflections remain small, however a little reverse high-frequency control required to stabilize desired attitude changes. | Performed fairly well, but some overshoot and oscillation about the desired commanded attitude. | Only small amounts of wing tilt control required. Maneuver was quite easy. | Hover performance very good and required very little pilot concentration. Control power seems to be quite adequate. | The most objectionable feature was the lag in attitude response and then the slight overshoot and oscillation about the commanded attitude change following rapid control inputs. | | |
| | | | | | B-FB | 0.339 0.264 | 4 | Selected to get the response desired in pitch and roll. | Not difficult. Could stop precisely. Could hold velocities without too much difficulty. Minor objection was that pitch and roll seemed to oscillate such that it was slightly difficult to stabilize. | Performance alright but had to damp out oscillations after completing maneuver. | Not difficult, could perform task fairly precisely, but tended to oscillate somewhat in pitch and roll. | Objectionable features were oscillatory nature of pitch and roll after significant attitude change. Would have to follow up to attenuate the overshoot. Configuration seemed fairly well damped, not responsive to turbulence. |
| | | | | | B-MB | 0.306 0.245 | 3 | Selected to get response desired in pitch and roll. | No problem, could perform task very nicely. | Also no problem. No lack of damping, the lags did not seem too annoying. | Could perform quite accurately. Didn't use wing tilt control too much. | Some difficulty here, but not too much, fair amount of control activity required but could hold hover position quite well. |
| 12A9 | RC1 $N_{\delta} = -0.468$ $L_{\delta} = -0.540$ $N_{\delta} = -0.156$ $T_{\delta} = -0.3$ $\delta_{\delta} = -0.1$ | B-FB | 0.346 0.275 | 2.5 | Selected to get attitude response desired. | Response to control inputs acceptable. Seemed to be some slight oscillation following control command, however it was very small very slight and of no major significance. Could stabilize and hold desired velocities, stop precisely and hover at the corners. | Able to stop precisely and hold position, no large attitude angles. Attitude was quite controllable, except for some slight oscillatory characteristics. | No difficulty, didn't have to rely on wing tilt control too much. | Could hover very precisely with a small amount of control activity. Vertical landing no problem. | No real objectionable features. Favorable features included low workload and nice stable response. | | |
| 12A0 | RC1 $N_{\delta} = -0.369$ $L_{\delta} = -0.457$ $N_{\delta} = -0.132$ $T_{\delta} = -0.6$ $\delta_{\delta} = -0.1$ | B-FB | 0.371 0.312 | 4.5 | Selected to get desired attitude response. | Noticed some lack of damping and response to turbulence. Every now and then would overshoot attitude command and couldn't compensate for lag characteristics too well. Could stabilize velocities fairly well, but had problems rolling in and out of maneuvers. | Got into some large attitude motions during a quick stop that weren't easy to damp, nothing dangerous but it was annoying. | Could perform maneuver fairly precisely and didn't use wing tilt control much. | Had a little difficulty in holding lateral hover position. Little more control activity involved and attitude not quite as predictable in hover as would like. Vertical landing no problem. | The oscillatory nature of pitch and roll and the apparent lack of control power or damping made attitude kind of unpredictable in hover as would like. Vertical landing no problem. | | |
| 12A1 | RC1 $N_{\delta} = -0.438$ $L_{\delta} = -0.498$ $N_{\delta} = -0.144$ $T_{\delta} = -0.6$ $\delta_{\delta} = -0.1$ | B-FB | 0.304 0.285 | 4 | Selected to get desired attitude response. Needed control sensitivity to damp out the oscillations that resulted from lags. | In general could maneuver fairly well. Irritating aspect was that attitude tended to oscillate after making a control input, had to make constant attempts to damp it out. This difficulty increased with abruptness of maneuver. | Induced attitude oscillations. Could perform task fairly well, some compensation required to damp attitude. | Performed task fairly well, but did get into some moderate oscillations in pitch and roll that affected task performance somewhat. Wing tilt control used a great deal. | Not too difficult to hover, small relaxed control inputs required. Vertical landing no difficulty. | Isn't care for the oscillatory characteristics in pitch and roll, it seemed to affect control capabilities somewhat. Liked low gust response; fairly relaxed case. | | |
| 12A2 | RC1 $N_{\delta} = -0.468$ $L_{\delta} = -0.540$ $N_{\delta} = -0.156$ $T_{\delta} = -0.6$ $\delta_{\delta} = -0.1$ | B-FB | 0.366 0.297 | 3 | Selected to get desired attitude response. | No difficulty, could perform task very smoothly and precisely. Noticed a little bit of oscillation in roll and pitch but nothing serious. | Could perform task quite precisely, didn't have any problems rolling and pitching in and out of the quick stops. A little bit of oscillation noticeable, but wasn't difficult to attenuate. | No difficulty, again noticed some oscillations in pitch and roll but they weren't particularly large and they weren't all that difficult to attenuate. Wing tilt control not used much. | Could hover precisely with little control activity. Could land with out difficulty. | No real objectionable features except possibly the slight oscillation in roll and pitch that tended to develop in response to control commands, but it was low level. Nicely damped, low response to turbulence, easy to control. | | |
| 12A3 | RC1 $N_{\delta} = -0.480$ $L_{\delta} = -0.400$ $N_{\delta} = -0.165$ $T_{\delta} = -0.6$ $\delta_{\delta} = -0.1$ | B-FB | 0.368 0.312 | 4 | Selected to try to overcome the lack of control power and damping in attitude. | Did this fairly well. Air taxi no problem. Held velocities fairly well and could stop quite precisely. | Did the longitudinal quick stop alright. In lateral quick stop got into an oscillation which was kind of difficult to damp. | Didn't do this very well. Developed some large errors in position. Not sure if that was due to the attitude characteristics or due to not paying close attention to it. Did require the wing tilt a good deal. | Generally could do this fairly well. Did get push at around once or twice, still not happy with the attitude response but it wasn't all that bad. Vertical landing OK. Reasonable amount of control activity in the hover and vertical landing. | Don't think there is quite enough control power in pitch and roll but in general could perform the task alright. | | |

Contrails

TABLE B-III (Concluded)

| Case | Coeff. Parameters | Pilot-Dir. Mode | $\frac{N_e}{\delta_a}$ | PR | Pilot Comments | | | | | |
|------|--|-----------------|------------------------|-----|---|--|--|--|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 1424 | $K_T = 0.462$ $L_{\dot{\alpha}} = 0.440$ $N_{\dot{\alpha}} = 0.182$ $T_{\dot{\alpha}} = 0.6$ $\delta_a \delta_s = 0.1$ | %FB | 0.388 0.323 | 3.5 | Selected to get response desired in attitude to overcome damping. | No problem maneuvering, attitude nicely damped and had sufficient control power to perform it well. | Comments as for maneuvering. | Somewhat difficult to remain over the spot but that was due to large drag rather than any attitude characteristics. Did perform the task reasonably well though. Wing tilt control was used a good deal, absolutely essential for this configuration. Monitored wing tilt angle a good deal. | Could perform this task fairly well. Noted a slight deficiency in control power which is acceptable. Would like to see a little bit more control power however. Vertical landing OK, however amount of control activity involved in hover. | Slightly objectionable feature was a slight deficiency in control power. Good deal of damping, nice response in attitude. |
| 1425 | $K_T = 0.504$ $L_{\dot{\alpha}} = 0.480$ $N_{\dot{\alpha}} = 0.199$ $T_{\dot{\alpha}} = 0.6$ $\delta_a \delta_s = 0.1$ | %FB | 0.433 0.336 | 4 | Selected to overcome the damping and what may have been a lag in attitude response. | Response to control inputs was predictable, well damped. Could develop a smooth consistent velocity and stop precisely. No apparent lack of control power. | Could perform the task quite accurately. Perfectly acceptable behavior here. | Somewhat more difficult because of high drag, but good damping in attitude enabled performance of task fairly well. Did have to use wing tilt a good deal. | Only part of task that had some reservations about. Seemed to be a lag that prevented desired quick responses in attitude needed to overcome gusts. Landing performance adequate. Fair amount of control activity involved. | Objectionable feature was apparent lag in attitude response when hovering which degraded performance slightly. Attitude appeared to be well damped. |

TABLE B-IV

PILOT COMMENTS FROM THE STUDY OF INCREMENTAL
PITCH CONTROL MOMENTS THROUGH STORED ENERGY

Flying Qualities Results Given in Table A-V

| Case | Conf. Parameters | Pilot's Sin. Mode | $\frac{M_0}{V_0}$ | $\frac{V_0}{V_{stall}}$ | Pilot Comments | | | | | |
|------|--|-------------------|-------------------|-------------------------|---|--|--|---|---|---|
| | | | | | Detection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 183 | M1 $M_0 = 0.356$ $\Delta M_0 = 30\%$ $V_0 = 0.05$ | B-WB | 0.294 | 5 | Selected to get the attitude response needed to overcome the effects of damping. Wide range of control sensitivities apparently satisfactory. | No problem laterally, but when going forward at times lost control of pitch attitude to some extent, it would just begin to rise without control. Also noticed lack of control power when pitching up to arrest forward velocity. | Couldn't really perform a accurate quick stop maneuver. Tended to pitch up and just hang there until attitude came back down again after velocity stopped. | No problem. Wing tilt control used a little to help in the turn. | Hover not difficult. Vertical landing no problem. | Objectable feature was noticeable lack of control power during forward maneuvers and forward quick stops. Other than that it was a good configuration. |
| 182 | M1 $M_0 = 0.356$ $\Delta M_0 = 30\%$ $V_0 = 0.10$ | A-FB | 0.380 | 5 | Set for desired attitude response for maneuvering. | Very small attitude change required to maintain velocity. Had to anticipate somewhat the desired stopping position but in general the air taxi performance was good. Pilot worked low, so had no difficulty holding attitude and heading. | Diving maneuver noticed a slight deficiency in control power, pitch particularly, but at no time lost control of the aircraft nor did it require very much pilot attention to avoid getting into that kind of a situation. | Performance was very good. Worked low and virtually no thrust tilt trim was required. | Hovering and landing was excellent with very little control activity required. | Overall the most objectionable feature was the slight limitation of control power during the quick stop maneuvers, but it had very little effect on taxi performance. |
| | | B-FB | 0.300 | 5 | Selected to get the attitude response desired. | Good response to control inputs, no problem initiating and stabilizing velocities, possibly only one or twice noticed a small lack of control power when pitching up after moving ahead longitudinally, but these were relatively minor effects. | Performed these with no difficulty and noticed no lack of control power. | Easy to perform. Used wing tilt only slightly. | Not difficult, didn't notice any lack of control power here. Vertical landing not difficult. | Did notice a slight lack of control power once or twice but nothing serious. Still suspect configuration. |
| 185 | M1 $M_0 = 0.356$ $\Delta M_0 = 30\%$ $V_0 = 0.20$ | B-FB | 0.303 | 4.5 | Selected to get the attitude response needed to overcome the damping. | Generally could perform task well. Once or twice noticed the nose was pushed up slightly by the gusts while maneuvering. Also, there tended to be some slight pitch-up tendency when arresting velocities, but in general could perform this task fairly well. | Didn't encounter any problems here but was aware of pitching up to stop the motion. | Performed this task quite well with little difficulty. Didn't have to use wing tilt control a great deal. | Hover and vertical landing no problem. Could perform both accurately without much control activity. | Were times when lack of control power noticed. Had to watch stick inputs somewhat in order to insure that large pitch attitudes weren't developed. |
| | | B-WB | 0.254 | 4 | Selected to overcome attitude damping and get desired attitude response. | No problem performing task. Noticed some slight shortage of control power when maneuvering forward and attempting to arrest maneuvering velocities, but generally could perform these maneuvers quite accurately. | Generally no problem, especially laterally. When trying longitudinal quick stops noticed slight deficiency in control power when attempting to arrest forward velocities abruptly. | No problem. Wing tilt control was used to a slight extent when turning over the spot. | Precision hover and vertical landing not difficult. No interaction among dynamics. | One slight objectionable feature was the moderate deficiency in control power. Wasn't a real big problem, however. |
| 184 | M3 $M_0 = 0.356$ $\Delta M_0 = 50\%$ $V_0 = 0.20$ | B-FB | 0.297 | 2 | Selected to overcome SAS and get the attitude response wanted. | No difficulty, very predictable attitude response to select and stabilize velocities with no difficulty and stop precisely. | Can stop abruptly with no apparent lack of control moment. No large attitude motions. | Could perform quite well. Don't have to use too much wing tilt. | No problem. Can hover precisely with little control motion. Vertical landing also can be accomplished precisely. Secondary dynamics - No interaction. | No objectionable features. Favorable features - predictable attitude response, low response to turbulence. |
| 185 | M3 $M_0 = 0.300$ $\Delta M_0 = 30\%$ $V_0 = 0.1$ | B-FB | 0.330 | 7 | Selected to get desired attitude response. | Difficult to hold longitudinal velocity because of a lack of control power. Attitude seemed damped, but periodic gust disturbances averaging. Develops large pitch-up attitude when arresting velocity because of deficient control power. | Difficult to control position and velocity precisely. | At times couldn't position pitch attitude as desired because of the gusts. Had to use wing tilt a great deal, difficult to hold position. | Could generally hover position but blown off once or twice. Not too difficult. Secondary dynamics - No interaction. | Objectable feature - serious deficiencies in control power. |
| 186 | M5 $M_0 = 0.360$ $\Delta M_0 = 30\%$ $V_0 = 0.05$ | B-FB | 0.314 | 6 | Selected to overcome the SAS and get desired attitude response. | Could stabilize velocities fairly well, but noticed deficiencies in control power periodically. Had some difficulty controlling pitch attitude, tended to develop large pitch-up angles. | Could perform subtask fairly well, but had to be careful of pitch. Couldn't make inputs too abruptly. | Could perform fairly well. Didn't have any problems with pitch control. Used wing tilt a good bit. | Noticed a lack of control moment. Attitude sluggish in responding. | Noticeable deficiency in control moment. |
| 187 | M5 $M_0 = 0.350$ $\Delta M_0 = 30\%$ $V_0 = 0.2$ | A-FB | 0.347 | 4.5 | Set to achieve attitude control necessary for maneuvering. | Performed fairly well. Relatively large attitude changes were required to overcome the drag of the aircraft. Occasionally got blown off ground track by gusts. Control moment not quite adequate for maneuvering subtask. | Required large attitude changes. Noticeable control deficiency a few times, essentially couldn't hold or arrest attitude motion. | Required some effort and considerable wing tilt for effect the sea, wind effects. Control moment was quite adequate. | Performance was quite good, only a low level of pilot effort required. | Attitude dynamics were basically good. Only problem was that control was periodically deficient. |
| | | B-FB | 0.308 | 4 | Selected to overcome damping and to get desired attitude response. | No difficulty. Could hold desired velocities and stop precisely. Once or twice attitude got blown off and lacked the control moment to recover rapidly, not a major problem. | Performed this task precisely, held attitudes and velocities without difficulty. | Performed quite well without too much control activity or too great a workload. Used wing tilt a good bit, however. | Precision hover and vertical landing could be accomplished precisely with moderate control activity. | Lack of control power was noticeable. Amazing, but not a major deficiency. In general, the configuration was well damped. |

TABLE B-IV (Concluded)

| Case | Conf. parameter | Pilot Sim. Mode | M_{0e} L_{0e} | PR | Pilot Comments | | | | | |
|------|--|-----------------|----------------------|-----|---|---|--|--|---|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| LS8 | B34 $M_{0e} = 0.902$ $\Delta M_c = 0$ $\tau_{\theta} = 0$ | B-MB | 0.371 | 5.5 | Selected to control attitude response to turbulence. | Could perform fairly precisely. Turbulence effects strong, once or twice noticed deficiency in pitch control moment. | Could perform fairly well. Noticed slight deficiency in control power when executing forward velocities. | Difficult to perform. Had to use wing tilt a good bit. Pitch, roll attitude oscillations fairly large. | Not difficult. Vertical landing OK. No major interaction. | Response to turbulence and slight deficiency in control power annoying. Predictable attitude response. |
| | | | 0.333 | | | | | | | |
| LS9 | B34 $M_{0e} = 0.902$ $\Delta M_c = 30\%$ $\tau_{\theta} = 0.05$ | B-MB | 0.381 | 5 | Selected to get desired attitude response and enable to overcome turbulence response. | Could perform fairly well. Noticed slight lack of control power when maneuvering forward. | Could perform fairly well, but slight deficiency in control power. | Moderately difficult to perform. Had to watch effects of mean wind. Like more damping. Used wing tilt control a good bit. | Periodically got blown off desired hovering position. Vertical landing no problem. No interaction. | Response to turbulence objectionable, slight deficiency in control power. |
| | | | 0.342 | | | | | | | |
| LS10 | B34 $M_{0e} = 0.902$ $\Delta M_c = 30\%$ $\tau_{\theta} = 0.1$ | A-FB | 0.373 | 8 | Set to achieve desired attitude changes for maneuvering. | Difficult to maintain large attitudes required to sustain velocity. Noticed no control power deficiencies. Could stop fairly precisely at desired point. Required pilot concentration, and heading and altitude control suffered. | Difficult because of large attitude changes required to start and stop motion. Control power inadequate to maintain desired attitudes during forward motion. | Adequate control power; considerable concentration required because of position disturbances. Considerable wing tilt required. | Performance quite good, gust position disturbances annoying. | Necessary inadequacies in control power during quick stop objectionable. |
| | | B-FB | 0.401 | 5 | Selected to overcome damping and attitude response to turbulence. | Performed without too much difficulty. Noticed slight deficiency in control power. | Could stop fairly precisely and didn't notice any deficiencies in control power. | Moderately difficult due to large drag parameter. Used wing tilt a good deal and had to monitor tilt angle meter closely. | Moderately difficult; developed some fairly large attitudes attempting to hold hover. Could land with no problem; fair amount of control activity. No interaction. | Significant response to turbulence and some deficiency in control power. |
| LS11 | B34 $M_{0e} = 0.902$ $\Delta M_c = 30\%$ $\tau_{\theta} = 0.2$ | A-FB | 0.291 | 7 | Set for maneuvering. | Maneuvering fore and aft difficult because of lack of pitch control moment. Could control ground track fairly well but performance very slow because of lack of attitude control. | Difficult to develop desired speeds. Had inadequate pitch control moment during rapid attitude changes. | Considerable wing tilt to offset mean wind effects. | Hover performance fairly good, control moment seemed adequate. Biggest problem was gusts acting on drag parameters. | Dynamics fairly good. Disturbed by lack of pitch control moment, particularly during quick stop. |
| | | B-FB | 0.381 | 8 | Selected to control turbulence. | No problem performing. Had to counteract effects of turbulence, however. Could stabilize velocities and stop precisely. No noticeable lack of control moment. | Not too difficult. Turbulence affected precision slightly. | Somewhat difficult because of large drag parameters. Performed task fairly well; however, had to use wing tilt a good deal. | Precise hover required; appreciable control activity and concentration. Vertical landing not too difficult. | Response to turbulence noticeable but attitude fairly well damped. |
| | | B-MB | 0.382 | 4 | Selected to get desired attitude response to control turbulence effects. | Could perform quite well and didn't notice any lack of control moment. Pitch and roll somewhat responsive to turbulence, but very predictable. | Could perform without any real difficulty. Even when maneuvering forward and pitching up abruptly noticed no lack of control moment. | No question of controllability, but had to turn slowly to remain over spot. Used wing tilt control carefully and coordinated it closely with direction of mean wind. | Could perform hover quite well; vertical landing no problem. No interaction. | Only objectionable feature is attitude response to turbulence, but not bad case. |
| LS12 | B35 $M_{0e} = 0.979$ $\Delta M_c = 30\%$ $\tau_{\theta} = 0.1$ | A-FB | 0.246 | 9 | Lack of control moment made setting sensitivity meaningless. Used stick as on-off controller. | Very difficult; performance poor because of inadequate control moment. Never lost control of aircraft, however. | Couldn't perform because control moment inadequate. | Difficult; large wing-tilt requirements. | Hover performance quite difficult because of inadequate control moment and effects on aircraft position. | Serious deficiency in pitch control moment. |
| | | B-FB | 0.388 | 6 | Selected to get control over attitude response to turbulence and speed stability effects. | Difficult because had to concentrate on attitude and constantly attenuate turbulence effects. | Had to attenuate attitude turbulence response but could hold velocities relatively well and stop abruptly. | Somewhat difficult. Pitch and roll drifted off during turn because of inadequate damping. Used wing-tilt control a good deal. | Hover difficult, but could be performed well with considerable stick activity. Vertical landing could be accomplished but required attention. Some interaction between longitudinal and lateral dynamics. | Large attitude response to turbulence objectionable, noticed lack of control power once or twice. |
| LS13 | B35 $M_{0e} = 0.979$ $\Delta M_c = 30\%$ $\tau_{\theta} = 0.2$ | A-FB | 0.294 | 8 | Set to control attitude oscillations. | Quite difficult because of gust sensitive and lightly damped attitude dynamics. Pilot workload quite high. Lack of control moment evident in pitch. Heading and altitude control appreciable. | Difficult in longitudinal direction. Noticed control moment limitations in pitch. | | Hover performance adequate but required appreciable pilot effort. | Poor attitude characteristics - high gust sensitivity and limitations on control moment. |
| | | B-FB | 0.430 | 5 | Selected to control attitude response to turbulence. | Could initiate and hold velocities fairly well but constantly attenuated effects of turbulence. | Could stop quite quickly. Had to be careful of turbulence effects. | Could perform quite well. Was tendency for pitch and roll attitudes to drift off. Wing-tilt control used a great deal. | Could hover reasonably well but fair amount of control activity required. Vertical landing could be accomplished accurately. | Needs attitude damping or reduced response to turbulence. |

TABLE B-V

PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL
AND LATERAL INTER-AXIS MOTION COUPLING

Flying Qualities Results Given in Table A-VI

| Case | Conf. Parameters | Pilot Sim. Mode | $\frac{V_{0a}}{V_{0s}}$ | $\frac{V_{0a}}{V_{0s}}$ | FR | Pilot Comments | | | | | |
|------|--|-----------------|-------------------------|-------------------------|-----|--|---|---|--|--|--|
| | | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 121 | $\frac{V_{0a}}{V_{0s}} = 0.5$ $\frac{V_{0a}}{V_{0s}} = 2$ | A-FB | 0.35 | 0.36 | 4 | Set for getting desired response for air taxi maneuver. | Performance during air taxi was good with a minimum of pilot effort. Control deflections were rather small and low frequency. | Noted coupling between pitch and roll when high angular rates were developed. This was somewhat annoying and required control correction. | Performance was good and required very little thrust trim. | Hover performance was very good with very little control effort required. Control activity was low. | Overall quite good except when making rapid attitude changes was hampered by cross coupling between pitch and roll axes. Scemed related to the angular rate of the aircraft and to the control input. |
| | | B-FB | 0.35 | 0.296 | 3.5 | Selected to get desired attitude rates. | Not difficult. Attitude response relaxed, smooth. Reasonably predictable, some coupling evident but no large attitude changes in either pitch or roll resulted. | Generally could perform fairly well, however did notice that when trying to arrest velocities tended to introduce some errors due to attitude coupling. | No difficulty. Did use the wing tilt control a fair amount although it wasn't too necessary. | Precision hover and vertical landing not difficult. The roll and pitch interaction did affect control somewhat in the quick stops. | Only objectionable feature is roll and pitch interaction in quick stops, however, that's not a significant problem. |
| | | B-MB | 0.349 | 0.291 | 3.5 | Selected as a compromise between avoiding excitation of attitude disturbances through coupling and being able to control adequately. | No real difficulty. Coupling effect was there as kind of a high frequency perturbation on control inputs, but generally, it didn't affect ability to control. | Could perform these precisely. Never got into any trouble and could perform them about as precisely as desired. Coupling evident but it didn't seem to take that much effort to control. | No problem. Did use the wing-tilt control to small extent. | Precision hover and vertical landing no problem. Attitude interaction through the coupling. The coupling was evident, but didn't require too much effort to control. | Coupling was evident and required some effort to control. Made somewhat similar control inputs to keep down the effects of coupling, but could still perform task relatively well. |
| 122 | $\frac{V_{0a}}{V_{0s}} = 0.5$ $\frac{V_{0a}}{V_{0s}} = 2$ | A-FB | 0.386 | 0.396 | 6.5 | Set to get desired control response for maintaining aircraft attitude. | During air taxi was annoyed by coupling between pitch and roll axes. This degraded ability to maintain ground track and to stop with precision. Also, because of increased attention required, height control and directional control was degraded. | Pitch and roll coupling was really aggravated. Control of heading was degraded because of this. | Wasn't too difficult and only small amount of thrust rotation was required. | Precision hover performance was fairly good but had to use care to use low frequency, small control inputs. | Most objectionable feature was the coupling between the pitch and roll axes. workload was fairly high and had to use relatively small control inputs. |
| | | B-FB | 0.376 | 0.323 | 4.5 | Selected to get the attitude response desired and also to not excite the coupling. | Could perform task relatively well but pitch and roll in almost constant motion. Fair amount of effort to keep desired attitude, to hold velocity, and to stop precisely. | Longitudinal quick stop wasn't too difficult although tended to put in somewhat lower rates to avoid exciting the coupling. Lateral quick stop somewhat more difficult because of coupling with pitch attitude. | Didn't perform this as precisely as desired due to attitude control difficulty. Did use the wing tilt control. | Precision hover and vertical landing not too difficult. Definitely coupling is evident. | The coupling is objectionable and requires some effort to attenuate it and control adequately. |
| 123 | $\frac{V_{0a}}{V_{0s}} = 0.25$ $\frac{V_{0a}}{V_{0s}} = -0.25$ | B-FB | 0.362 | 0.299 | 3 | Selected to get desired attitude responses. | Noticed some small oscillations in both pitch and roll due to apparent control coupling, but this was low level and no difficulty. Could perform task precisely without excessive attitude changes. | Could be performed precisely. Coupling didn't detract from ability to perform task. | Not difficult. Could keep attitude under control quite well. | Precision hover and vertical landing not difficult. Some interaction between pitch and roll motion here, but at a low level and not difficult to control. | Only mildly objectionable feature is the coupling. |
| 124 | $\frac{V_{0a}}{V_{0s}} = 0.5$ $\frac{V_{0a}}{V_{0s}} = -0.5$ | A-FB | 0.362 | 0.336 | 2.5 | Set to achieve desired response for maneuvering. | Air taxi performance was good. Could hold ground track and stop at desired point quite easily. Control deflections rather small and low frequency. Control about all axes was good. | Presented no particular problems. | Very little trim required for turn over a spot. | Precision hover performance very good with minimal pilot effort required. The dynamics and control inputs of one axis did not affect another axis. | Overall the configuration was very good and had good control response and low cost sensitivity. |
| | | B-FB | 0.372 | 0.283 | 3.5 | Selected to get desired attitude rates. | Attitude control seems fairly low frequency and relaxed, no oscillations. Some coupling evident but low order and doesn't present any real problem. Can maneuver and stop precisely. | Can perform the quick stop precisely. Some small pitch and roll oscillations but they are low frequency, low amplitude. | Performed this quite accurately. Used wing tilt control to some extent. | Precision hover and vertical landing no problem. Secondary dynamics - Unquestionably some interaction between dynamics here but low level, not difficult. | Some minor objection to the coupling but this is not a big problem. |
| | | D-MB | 0.364 | 0.321 | 2.5 | Selected to get the attitude response desired. Coupling didn't have any effect on control sensitivity. | Could perform this precisely in both X and Y directions. No problem holding velocities. No large attitude changes developed. | Can stop quickly and precisely both in X and Y. Notice the slight coupling but it really doesn't affect control inputs. | Not difficult. Can turn rapidly and stay relatively close to the spot. Wing tilt control was used a some extent. | Precision hover and vertical landing no problem. Secondary dynamics - Coupling is evident, but not a big problem. | No real objection to the feature. Coupling is noticeable, but doesn't present any great difficulties. Nicely damped configuration, easy to control. |
| 125 | $\frac{V_{0a}}{V_{0s}} = 0.25$ $\frac{V_{0a}}{V_{0s}} = -0.25$ $\frac{V_{0a}}{V_{0s}} = -0.25$ | A-FB | 0.313 | 0.290 | 4 | Set for maneuvering response of the aircraft. | Had good control characteristics during air taxi. Could hold ground track quite well and stop at desired point. Control motions were relatively low amplitude and low frequency. | Annoyed a little bit by coupling between pitch and roll during rapid control inputs and high angular rates. | Performance was good, little control effort required and very little thrust trim required. | Precision hover performance good and little control activity required. | Most objectionable feature was the control coupling during rapid attitude changes and rapid control inputs. With smooth control inputs and relatively low angular rates, control coupling hardly noticeable. |

Contrails

TABLE B-V (Concluded)

| Case | Conf. Parameter | Pilot- Sim. Mode | $\frac{V_{da}}{V_{da}}$ | PB | Pilot Comments | | | | | |
|------|--|------------------|-------------------------|-----|--|---|---|--|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 125 | BC1 $K_p = 2$ $L_p = -2$ $M_p/L_p = -0.25$ $L_p/M_p = -0.25$ | B-YB | 0.316 | 4.5 | Selected to get desired attitude response. | Attitude response fairly relaxed, but appreciable amount of coupling present. Especially noticed pitch inputs when rolling and vice versa, disturbing and required some attention. Could perform the task adequately, but attitude control required some attention. | Performed fairly well, although not too precisely. Coupling introduced attitude motions that were annoying. | Didn't do this very well for some reason. Not too difficult but should have been able to perform more precisely. | Precision hover and landing no problem. Pitch characteristics affected control of roll and vice versa. | Coupling was significant enough to disturb aircraft and require more attention to attitude control than would like. |
| | | B-AB | 0.310 0.360 | 4 | Selected to get the response desired and to help control the effects of coupling. | Generally not too difficult. Could maneuver longitudinally and laterally with precision, but very definitely some coupling effects that needed corrective inputs. | Coupling quite evident, especially when making rapid attitude changes. | Not difficult. Could perform it rapidly and precisely. Used the wing tilt control to a limited extent. | Precision hover and vertical landing not difficult. Coupling definitely affected control, although it didn't appear to cause a deterioration in performance. | The coupling between roll and pitch was objectionable; looked like rate coupling. This was annoying, but it didn't lead to a loss of precision. |
| 126 | BC1 $M_p = 4$ $L_p = -4$ $M_p/L_p = 0.5$ $L_p/M_p = -0.5$ | B-PB | 0.412 0.358 | 7.5 | Selected as a compromise between that needed to control attitude motions and that which didn't excite pitch and roll response. | Difficult to perform. Lot of somewhat unpredictable attitude motions both in pitch and roll. Apparently a lot of it is due to pitch and roll rates. Got into some fairly large attitudes. Can't perform this with much precision. | Also difficult to perform. Annoyed by coupling. Can't perform this task precisely. | Got into some large attitude motions, a lot of which seems almost unpredictable. Tend to change attitude very abruptly. Difficult to stabilize attitude. | Precision hover and vertical landing not too difficult, but lacks precision. Seems to be a lot of interaction between pitch and roll which is quite disturbing. | Objectionable features are the large amount of coupling and the rapid, fairly unpredictable response that it brings about in pitch and roll. |
| 127 | BC2 $K_p = 2$ $L_p = -2$ $M_p/L_p = -0.25$ $L_p/M_p = -0.25$ | B-PB | 0.442 0.373 | 6.5 | Selected to help get control of attitude oscillations. | Difficult to perform precisely. Pitch and roll in constant oscillation. Significant amount of compensation required to maintain ground velocities and to stop accurately. Some relatively unpredictable motion in pitch and roll due to coupling. | Difficult to perform precisely, must be very careful about control inputs. Have to watch attitudes closely when arresting quick stops. Get into fairly large attitude oscillations. | Remained over the spot fairly well, but went into large pitch and roll oscillations while doing so. Wing tilt control used to limited extent. | Can perform hover, but but the attitude excursions are significant. Fair amount of interaction or coupling due to the light coupling. | Objectionable features - coupling response to turbulence and lack of damping. Difficult ease to control. |
| 128 | BC2 $K_p = 2$ $L_p = -2$ $M_p/L_p = -0.25$ $L_p/M_p = -0.25$ | B-PB | 0.442 0.399 | 6.5 | Selected to get control of the pitch and roll oscillations. | Fairly difficult task. Lot of attention must be paid to attitude control. Difficult to stabilize velocities and stop precisely, but can be done adequately. | Can perform task, stop precisely, but tend to introduce a lot of pitch motion and roll motion. Have to worry about suppressing those oscillations. | Difficult to perform because can't look away from attitude and check the heading indicator without introducing fairly significant attitude errors. Use the wing tilt to moderate extent. | Precision hover and landing not too difficult, but both required attention. | Objectionable features - Response to turbulence, coupling, lack of damping. Difficult case. |

TABLE B-VI

**PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL
INDEPENDENT THRUST-VECTOR CONTROL**

Flying Qualities Results Given in Table A-VII

| Exp | Conf. Parameters | Pitch Slope | Y ₂ / % | PR | Pilot Comments | | | | | |
|-----|------------------|-------------|--------------------|-----|------------------------------------|--|--|---|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-Input | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 111 | 7-5 deg/sec | A-FB | 0.389 | 2.5 | NOT SELECTED | Good control and low gust sensitivity about all axes. Longitudinal air taxi maneuver fairly easy with wing tilt control although it required some anticipation to give a desired pitch. Relatively small thrust rotations required to maneuver longitudinally. | Relatively easy but required anticipation to stop at desired point. | Performance very good and required very little effort. Wing tilt control used sparingly. | Precision hover performance quite good with very little effort required. Not very slight tendency to get into longitudinal position oscillation while controlling position with wing thrust tilt. | Overall, was good configuration, required very little effort. |
| | | B-FB | 0.314 | 4 | | Could perform this task relatively well. Hindered by slow rate of rotation of thrust vector angle, but if maneuvering rates kept small didn't have too much difficulty. | Not into a little trouble here because of slow rate of thrust rotation. Just couldn't get around as quickly as desired and overshoot desired stopping point. | Performed quite relatively well but seemed to be a little on control toward end of maneuver and lost hovering position, but generally recovered over spot relatively well. | Not difficult, one was vertical landing. | Objectivable feature - probably slow rate of change in thrust vector angle. |
| | | B-MB | 0.314 | 4.5 | | Maneuvering not difficult with independent thrust angle control. Could establish velocities and stop relatively precisely. Occasionally thrust rotation rate was inadequate but in general didn't affect ability to maneuver. | Rather difficult due to slow rate of change of thrust vector angle. Had to lead longitudinal motion a great deal with thrust vector angle control to stop where desired. At times resulted in long period of oscillating back and forth in position. | Task wasn't difficult with this man wing tilt control. Very small amplitude motions throughout these tasks. | Precision hover not difficult. Rate of thrust rotation was sufficient. | Objectivable feature - slow rate of change available in thrust vector angle. |
| 112 | 7-10 deg/sec | B-FB | 0.314 | 4 | NOT SELECTED | Could maneuver fairly well with precision. Had to be somewhat nervous about building up rates which were too large because of inadequate rotation rate of thrust. Possibly would like a somewhat larger rate. | More difficult to perform than air taxi. Managed to stop precisely and in hovering thrust vector back and forth got off in position somewhat. | Relatively easy using thrust vector angle. | Quick hover quite well using only thrust vector angle. Vertical landing wasn't difficult. | Objectivable feature - would like to see a little higher thrust rotation rate. In hovering velocities had to lead corrections good bit because of low rotation rate. Favorable feature - attitude slowly damped. |
| | | B-MB | 0.282 | 3.5 | NOT SELECTED | Could maneuver quite precisely and accurately using just thrust vector. Able to slowly velocity desired and stop precisely and hover at one position. Very little attention had to be paid to attitude control. | Could taxi and stop quickly and precisely and hold one position quite easily. | Think this was somewhat easier to perform than when controlling position attitude change. High thrust rotation rate takes a lot. | Also not difficult. Could hold position at all times when fairly released thrust vector angle inputs. Vertical landing also not difficult. | Not real objectionable feature - one slight drawback was that thrust rotation rate may have been somewhat large. It was difficult to command a small change in thrust angle. |
| 113 | 7-10 deg/sec | B-MB | 0.314 | 5 | | Could maneuver forward and aft without difficulty. Like increased thrust rotation rate, but it's to the point where it's almost too quick. Can stop precisely and hold forward position quite well. Don't introduce attitude changes when thrust rotated but can feel longitudinal accelerations. | No difficulty. Don't have to lead inputs by operating on heading or position, rates as much as with low rotation rates. Can wait until about last moment until at desired position and then rotate thrust angle. | It's difficult to perform. | Precision hover and landing not difficult. | Slightly objectionable feature is the thrust rotation rate is somewhat too high. Attends precision with which thrust vector angle can be commanded, but in general is good configuration. |
| | | B-FB | 0.389 | 4.5 | NOT SELECTED | Could perform maneuver relatively well, although had to watch effects of pitch setting on position. Tended to get them off in position a little because but could generally hold it without too much error. Would like a little higher thrust rotation rate. Somewhat difficult to correct for small errors with this slow rate. | Performed maneuver relatively well. Would prefer somewhat larger thrust rotation rate. | Not too difficult to perform. Think it's somewhat easier than if no independent thrust vector control. | Not difficult, could remain within the square relatively well. Prefer higher thrust rotation rate. | Slow rate change of thrust vector angle was objectionable. Also high drag made it difficult to control, although task performance not too bad. |
| 114 | 7-10 deg/sec | B-MB | 0.389 | 5.5 | | Could perform maneuver relatively well and hold velocities without much trouble. Didn't get into any trouble but didn't have much reserve capability. Would like little larger thrust rotation rate. | Could perform task relatively well. High drag requires large changes in thrust vector angle to change velocity. Tended to overshoot desired stopping point because of low rotation rate, then oscillate back and forth in position. | Could perform task as precisely because of high drag and wind effects. | Precision hover not too bad, but would like a larger thrust rotation rate. Vertical landing not too difficult. | Objectivable feature - high drag makes control somewhat difficult in combination with low thrust rotation rate. One advantage of lower thrust rotation rate is that little pitching motion is introduced when thrust rotated. |
| | | B-FB | 0.329 | 4.5 | NOT SELECTED | Could maneuver longitudinally quite precisely, when fairly accurately, and hold hover without too much difficulty. Had a pretty good command of thrust vector angle to control position. | Could perform quite precisely and hold position with thrust angle control, although some difficulty holding position after stopping. Used thrust vector control almost exclusively. | Able to perform more accurately using thrust vector angle than could have using attitude control plus wing tilt. Relatively easy to correct position changes, however, could not remain within square the whole time. | Precision hover was not difficult part of task. Couldn't really stay within square the whole time, but close to it. | Not able to control as accurately as could have with pitch attitude because wing tilt rate was somewhat too slow for this high drag. |

Controls

TABLE B-VI (Continued)

| Date | Conf. Parameters | Milt. Sta. Mode | $H_{\dot{\theta}}$ % /s | FR | Pilot Comments | | | | | |
|------|---|-----------------|-------------------------------|-----|------------------------------------|--|--|--|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 116 | BC4 $\dot{\theta} = 20 \text{ deg/sec}$ | A-FB | 0.329 | 5 | NOT SELECTED | Quite gust sensitive in all axes. Air taxi maneuver somewhat difficult and requires constant attention. Being able to independently control longitudinal position with thrust vector somewhat helpful; however, tilt rate was too high, tended to lead position control with an attitude change, then follow up with thrust tilt change. | Maneuvering longitudinally required considerable anticipation and could not stop very accurately at desired point. | Workload quite high due to gust and sea wind effects on high aircraft drag. Thrust vector control helped somewhat but still difficult task. | Precision hover performance fairly good; however, required moderate workload. Used thrust vector control to control longitudinal position during hover. | Most objectionable feature was high gust sensitivity in pitch, roll and position control of aircraft. Independent thrust vector control may have helped somewhat but still required considerable pilot workload. |
| | | B-FB | 0.329 | 5.5 | | Could perform longitudinal maneuvers quite accurately, stop precisely and hold position fairly well. Made few attitude changes. Almost all control input came using just thrust vector angle. Liked high thrust rotation rate. | Could perform quite well. Could maneuver rapidly and stop quite precisely and hold new position relatively well. Some difficulty judging just exactly when to initiate thrust rotation. | Could perform this better than controlling position with attitude changes. Could correct position across quite rapidly. | Could stay within square most of time. Slipped out slightly every now and then, but generally could hover precisely. No problems landing. | Might like a little more attitude stability. Attitude every now and then drifted off and introduced some error. Gust effects on attitude were significant. High rate of thrust angle rotation made it quite easy to control position. |
| | | B-MB | 0.329 | 4 | | Could maneuver longitudinally relatively well and stop precisely, but bushed by large drag, particularly laterally, and by effects of gusts acting on attitude. | Not much difficulty. Could stop precisely and hold position relatively well. However, had to make very large thrust angle changes and tended to induce fair amount of attitude motion. | Could hold longitudinal position quite well, can perform task better with TVC than without it. | Can hover relatively well and land OK. Bushed somewhat by roll attitude response. | Disliked attitude response to turbulence and high drag. In general, TVC helped; could perform task relatively well. Thrust rotation rate adequate. |
| 117 | EC2 $\dot{\theta} = 5 \text{ deg/sec}$ | B-FB | 0.338 | 5 | FOC SELECTED | Could perform air taxi quite precisely. Although at times desired high thrust rotation rate. Could hold velocities relatively well and stop and hold hover position. | Moderately difficult because of lead time involved in making inputs to arrest motion. Difficult to predict when to initiate corrective inputs. | Generally not too difficult. Felt it was easier with TVC than with attitude. With TVC didn't disturb attitude so much as attitude was lightly damped, responsive to gusts. Want higher thrust rotation rate. | Not too difficult, could perform accurately with this thrust rotation rate. Vertical landing OK. Some interaction between pitch and roll dynamics. | Disliked lightly damped attitude response and slow rate of thrust rotation. |
| | | | 0.335 | | | | | | | |
| 118 | EC2 $\dot{\theta} = 10 \text{ deg/sec}$ | A-FB | 0.389 | 5.5 | NOT SELECTED | Attitude very lightly damped, quite sensitive to gusts. Fairly high workload for air taxi to control gust disturbances. Some deterioration in heading and attitude control because of attention on attitude. | Could stop and start quickly, maintain higher velocities and stop abruptly without too much difficulty. | Not too difficult because of low drag; however, constant attention is required to maintain pitch and roll control. | Precision hover performance fairly well but requires constant control effort to offset gust disturbances on attitude. TVC does aid longitudinal maneuver. | Most objectionable features are gust disturbances and lightly damped pitch and roll dynamics. TVC does aid longitudinal maneuver. |
| | | B-FB | 0.334 | 4.5 | | Longitudinal air taxi fairly easy. Could maneuver fairly well, hold velocities and stop and hover at desired point. Pitch required some attention because it was lightly damped. TVC improvement; without it would have excited attitude motion because of lightly damped dynamics. | Could stop and start quickly, maintain higher velocities and stop abruptly without too much difficulty. | Not difficult. Maintained some attitude motion, but in general could hold hover position relatively well. TVC certainly helps. | Not difficult. Could hold position. During landing had to control pitch and roll fair amount. Again TVC helped. Some interaction between pitch and roll. | Objected to lightly damped attitude dynamics. TVC helped this configuration. |
| 119 | EC2 $\dot{\theta} = 10 \text{ deg/sec}$ | B-FB | 0.338 | 4 | NOT SELECTED | Could maneuver precisely, stop without too much difficulty and hold hover position. Adequate thrust rotation rate. Attitude not too well damped, would have excited attitude more without TVC since only small attitude corrections needed. | Could stop and start precisely using TVC. | Also not difficult. Could hold hover position quite accurately while controlling attitude disturbances. | Hover not too difficult. Could maintain position within square at all times. Attitude oscillations did require some attention. Landing no problem. A little interaction between pitch and roll, but nothing major. | Felt pitch and roll could use a little more drag. TVC helped a good bit. |
| | | B-MB | 0.338 | 5.5 | | Longitudinal maneuver performed relatively well. Gusts tended to disturb attitude and that would affect position. Noticed a fair amount of coupling between thrust angle and attitude changes. Workload considerably high. | Somewhat difficult to stop precisely and then hold new position in presence of attitude disturbances. Noticed some significant inputs to pitching moment due to thrust rotation. | TVC improved performance. Could hold position quite precisely. | Precision hover and landing not too difficult. Lateral control affected ability to control longitudinally. | Objected primarily to lack of attitude damping. Thrust vector rate was high, but needed it. TVC definite asset. |
| 1110 | EC1 $\dot{\theta} = 20 \text{ deg/sec}$ | B-FB | 0.314 | 4 | NOT SELECTED | Air taxi not too difficult. Could maneuver with desired velocities and stop precisely. Didn't have too much difficulty monitoring thrust angle and display in control of position. | Somewhat more difficult. Had tendency to overshoot desired stopping point, but again could be performed adequately. | Got into some difficulty in that thrust rotation was over-controlled; perhaps thrust rotation rate was too high. | Hover and landing not difficult. | Somewhat difficult to monitor both thrust angle meter and display during quick stop and turn maneuver. Generally could perform tasks fairly well and switching attention didn't present problem. |
| 1111 | EC1 $X_{\dot{\theta}} = 2.0 \text{ deg/in.}$ $Y_{\dot{\theta}} = 1.0 \text{ rad/sec}^2$ | B-FB | N.A. | 3.5 | NOT SELECTED | In air taxi could control position and velocity quite precisely, stop accurately and hold position with no difficulty. Didn't make any pitch attitude control inputs. Acceptable control mode. | Could start and stop very precisely and quickly without difficulty. Noticed some larger attitude changes as speed built up, but learned to essentially neglect them and concentrate on position control. | Not difficult, although did correct for some attitude changes and once momentarily lost control of position. Kind of difficult to control attitude precisely. | Could hold position very precisely. Little attention to attitude, just controlled position. Vertical landing no difficulty. | Kind of difficult to control attitude, but requires little control as it is quite stable. Position control very easy, can control quite precisely, but might like a little more stick sensitivity. |

Contrails

TABLE B-VI (Concluded)

| Case | Conf. Parameters | Pilot Sim. Mode | $\frac{N_e}{\theta_e}$ | FR | Pilot Comments | | | | | |
|------|---|-----------------|----------------------------|-----|------------------------------------|--|---|---|---|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| L112 | BC1 $\gamma_e = 5.0$ deg/in. $\dot{\gamma}_e = 1.0$ rad/sec ² | B-FB | N.A. ¹ 0.242 | 3 | NOT SELECTED | Easy to perform precisely and hold velocities accurately, stop precisely and hold hover position with no problem. | Not difficult, can develop large velocities and stop very abruptly with precision. Develop some small attitude oscillations, but just ignored them. | Not difficult to control hover position, but when turning relative to mean wind have to correct for pitch motion; this distracts slightly from position control. | Hover control easy, once hover and land precisely. | Attitude control during turns can be somewhat difficult, although there is a learning process. Very easy to control position. Like thrust vector sensitivity. |
| L113 | BC1 $\gamma_e = 10.0$ deg/in. $\dot{\gamma}_e = 1.0$ rad/sec ² | B-FB | N.A. ¹ 0.242 | 3.5 | NOT SELECTED | Not difficult to maneuver and stop precisely. Can hold desired velocities without difficulty. Thrust tilt control sensitivity has gotten somewhat high, notice attitude motion following thrust rotation. | Can stop precisely. Can build up large velocities and arrest them very abruptly and precisely. High control sensitivity induces some attitude motion. | Task somewhat difficult. Position control no problem, but once more have some difficulty in controlling mean wind effects on attitude. Must share attention between attitude and longitudinal position. | Precision hover and landing no problem. | Thrust rotation control sensitivity somewhat high, causes some attitude motion and tends to induce errors in position. Generally can control longitudinal position quite precisely. |
| L114 | RC4 $\gamma_e = 5.0$ deg/in. $\dot{\gamma}_e = 1.0$ rad/sec ² | B-FB | N.A. ¹ 0.296 | 10 | NOT SELECTED | Can't really control it. Attitude changes are too high frequency to follow with thumb switch. When trying to reduce large attitude errors, position errors get large. Can't control attitude. | Can't perform quick stops. | | Can't hover and tend to lose control quite often. Tend to get confused with inputs and can't coordinate inputs well enough. Practice doesn't seem to help. | Inconsistencies between direction that thumb switch pushed to change attitude and direction that control stick pushed to correct for position errors. Can't control sufficiently well to avoid inducing large position disturbances. |
| L115 | RC2 $\gamma_e = 5.0$ deg/in. $\dot{\gamma}_e = 1.0$ rad/sec ² | B-FB | N.A. ¹ 0.335 | 10 | NOT SELECTED | Effectively uncontrollable. Can probably stabilize it and not lose control during hover, but when maneuvering the accelerations in position induce such large attitude changes that can't control them rapidly enough. | Difficult to control attitude in any high frequency sense with this control arrangement. | | Large attitude changes induced when attempting to hold hovering position. Can't correct attitude rapidly enough and stabilize it well enough to control with any precision or even to retain control of aircraft. | Eventually get into a large attitude oscillations and lose control, even just at hover. Extremely difficult to control attitude and stabilize it. |

Controls

TABLE B-VII

PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL AND
LATERAL RATE-COMMAND/ATTITUDE-HOLD CONTROL

Flying Qualities Results Given in Table A-VIII

| Exp. | Conf. Parameters | Pilot-Exp. Code | $N_{\dot{\theta}}$ | $N_{\dot{\phi}}$ | PR | Pilot Comments | | | | | |
|------|---|------------------------|--------------------|--|--|--|--|--|--|--|--|
| | | | | | | Selection of Control Sensitivity | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Comments |
| 121 | BC1 $N_{\dot{\theta}} = -2$ $N_{\dot{\phi}} = -8$ | B-FB | 0.812 | 0.975 | 7.5 | Selected to gain control of attitude oscillations and also get desired response. | Very difficult to perform because of large attitude oscillations. Difficult to stabilize pitch and roll, couldn't perform task precisely. Got into some relatively large attitudes. | Some problem. Couldn't stop quickly or precisely and very difficult to control attitude within desired limits. | Couldn't perform precisely because of difficulty in controlling pitch and roll attitude. Did use the wing tilt control to small extent. | Hover was easiest of all tasks, but drifted around. Unquestionably the roll dynamics affected pitch control and vice versa. | Objectable features - large oscillatory motions in pitch and roll and the lags in response to control inputs. |
| 122 | BC1 $N_{\dot{\theta}} = -2$ $N_{\dot{\phi}} = -40$ | B-FB | 2.406 | 2.140 | 4.5 | Selected to get pitch and roll rates needed. | Could perform this maneuver fairly well but a high frequency oscillation in pitch and roll was annoying. Too high frequency to control and it affected precision. Still annoyed somewhat by sluggishness in roll response. | No problem with longitudinal quick stop, except for annoying high frequency oscillation; however, lateral quick stop difficult to perform precisely because of sluggishness in roll. | Could perform task fairly well, although the high frequency attitude oscillations were annoying. Used some wing tilt control. | Hover and landing not particularly difficult. | Objectable features - high frequency oscillation in pitch and roll. Also, roll sluggishness. |
| | | B-DB 3.434 3.468 | 4.5 | Selected to overcome the lags in pitch and roll response. | X-maneuver no difficulty. Y-maneuver also not too difficult. Had to avoid building up rates which were too large because it was difficult to attenuate them due to lag in roll response. | Y-quick stop quite difficult. Couldn't stop precisely and hold position easily. Tended to overshoot and then oscillate back and forth. | Didn't perform task particularly well - had difficulty holding position. Attitude lags might have been a problem. May have been overconstraining somewhat. Used wing tilt control a fair amount. | Hover not difficult. Vertical landing also no problem. No interaction. | Objectable features - lag in attitude response and the fact that attention diverted from display. | | |
| 123 | BC1 $N_{\dot{\theta}} = -4$ $N_{\dot{\phi}} = -8$ | A-FB | 0.944 | 0.904 | 0 | Selected sensitively to maintain PIO tendencies. | Required considerable attention because of difficulty in stabilizing command attitudes. Required considerable lead compensation to stabilize and anticipation of desired stopping point to arrest velocities. Ability to remain within ground track rather poor because of attention required to control heading, heading and altitude control deteriorated. Control deflections had to be very small and low in frequency to avoid getting into PIO situations. | Difficult because of difficulty remaining large rapid attitude changes. Needs more rate damping. | Required considerable concentration because of difficulty in maintaining pitch and roll control. Very little wing tilt required. | Hover only moderately difficult but some difficulty establishing a precise hover position. | Most objectionable feature was large amount of lead compensation required to control and stabilize attitude. Had considerable tendency toward PIO's, particularly in pitch. |
| | | B-FB | 0.994 | 0.834 | 5 | Selected to get control of attitude oscillations and develop desired pitch and roll rates. | Could perform task with only moderate precision. Attitude oscillations made it difficult to stabilize on ground track precisely and stop precisely. | Again found it difficult to stop precisely and roll out as precisely as desired because of oscillatory pitch and roll response. | Generally able to do this alright. Wing tilt control used a fair amount. | Not too difficult, but again a fair amount of pitch and roll oscillations. Very little interaction. | Objected to oscillatory pitch and roll characteristics. |
| 124 | BC1 $N_{\dot{\theta}} = -4$ $N_{\dot{\phi}} = -40$ | B-FB | 3.364 | 3.340 | 2 | Selected to get necessary pitch and roll rates. | No problem, could perform precisely. Very agreeable case. | No problem, could perform precisely, no undesirable attitude oscillations. | Not difficult. Did use wing tilt control to a small extent. | Neither hover nor landing was difficult. Both performed precisely, although had a little difficulty in hover, maybe because of high sensitivities. Difficult to stabilize on given position. | No objectionable features. Good case. |
| 125 | BC1 $N_{\dot{\theta}} = -6$ $N_{\dot{\phi}} = -32$ | B-FB | 1.799 | 1.526 | 4 | Selected to get attitude rates desired and also to help control slight oscillatory tendency in pitch and roll. | No problem longitudinally. Laterally generally no problem except some tendency to oscillate when rolling out, although these oscillations are relatively easy to control. | No problem in longitudinal; however, when making lateral quick stop have tendency to develop some undesirable oscillations when trying to roll out rapidly. | No problem. Did use wing tilt control to some small extent during turn. | Precision hover and vertical landing performed precisely. No interaction. | Objectable features - tendency to oscillate when making abrupt roll changes. |
| 126 | BC1 $N_{\dot{\theta}} = -6$ $N_{\dot{\phi}} = -40$ | B-FB | 2.588 | 2.228 | 2.5 | Selected to get attitude response desired. | Could perform maneuver quite well. Attitude very stable, no attitude oscillations noticeable. Didn't get into large attitudes. In general could perform fairly well. | One story, although attitude quite stable. Slightish. Seemed to have to anticipate things a bit more and couldn't make large rapid changes in roll. | Not difficult because attitude quite stable. Seemed to have some trouble with lags in response to control commands. Used wing tilt control to slight extent. | Hover and vertical landing no difficulty. No interaction between axes. | Objectable features - perhaps slight sluggishness in pitch and roll, especially roll. However, attitude very stable, highly damped. |
| | | B-DB 4.142 4.690 | 3.3 | Could perform relatively well. Somewhat somewhat by sluggishness in control response. Also had to concentrate to avoid developing attitude errors. | Couldn't perform particularly well. Annoying lag in attitude response. Had to pay close attention to attitude. | Not too difficult, had significant use of wing tilt control. | Could hover fairly well. Landing not difficult. No real interaction between pitch and roll. | lags in pitch and roll response affected control. Also attitude errors integrate rapidly when attention is diverted. | | | |
| 127 | BC1 $N_{\dot{\theta}} = -8$ $N_{\dot{\phi}} = -40$ | A-FB | 3.054 | 2.240 | 4 | Set control sensitivity to achieve desired response to control inputs. | Fairly easy to perform although anticipation was required to stop at desired hover point due to low transverse drag. Could hold heading and altitude quite well during air taxi maneuver. | Performance fairly good although could not achieve real rapid attitude changes without large control inputs. | Had a little difficulty trying to maintain hover position because of concentration required to hold attitude. Very little wing tilt control required. | Hover and landing performance very good and required very little work. Load on control motions. | Most objectionable feature was if a control input were held, it resulted in attitude changes if attention diverted elsewhere. May need more training with this control system. |
| 128 | BC1 $N_{\dot{\theta}} = -10$ $N_{\dot{\phi}} = -50$ | A-FB | 3.050 | 3.344 | 3 | Responded almost as rate command system so set sensitivity to achieve desired rate response. | Relatively easy and performance was quite good. Could hold heading and altitude quite well during maneuver and control deflections relatively small and low frequency. | Slightly annoying, couldn't change attitude as rapidly as desired without rather large control inputs. | Wasn't too difficult. Very little wing tilt control required, but did require concentration because of low drag. | Precision hover relatively easy. Performance good and slight disturbances hardly noticeable. | Slightly objectionable control during quick stops. |

Contrails

TABLE B-VII (Concluded)

| No. | Conf. Parameters | Mach | H ₀ - '000 | R ₀ - ° | Pilot Comments | | | | Overall Evaluation | |
|------|---|------|-----------------------|--------------------|---|---|--|---|--|--|
| | | | | | Direction of Control Sensitivities | Maneuvering | Quick Stops | Turn-On-a-Spot | | Position Error, Vertical Landing, Secondary Dynamics |
| 128 | BC1 M ₀ = -10 M ₀ = -50 | B-FB | 5,530 6,300 | 3 | Selected to overcome sluggishness in pitch and roll response. | Not at all difficult. Didn't get into any large attitude changes and didn't have any problem holding velocity and stopping at desired point. | Quick stop no problem. Could stop precisely. 7-g stop seemed more difficult. Had a little difficulty stopping but didn't seem to oscillate too much. | Could perform relatively well. Not too difficult. Used wing-tilt control to some extent. | Hover and vertical landing not difficult. | Still a little sluggishness in attitude response. Everything well damped. Suffered by fact that when looking at heading indicator, tended to drift away in attitude. |
| 129 | BC4 M ₀ = -2 M ₀ = -16 | B-FB | 1,190 0,004 | 4-5 | Selected to get control of attitude oscillations and to get desired attitude response. | Not too difficult. Some annoying tendency to oscillate in pitch and roll; however, these are low frequency. | Generally not too difficult. Attitude oscillations, although low frequency, large enough amplitude to affect ability to control. | Difficult. Must account for high drag with wing tilt control. Attitude oscillations make difficult to concentrate on position. | Hover and vertical landing not too difficult. | Oscillatory attitude characteristics and high drag which makes it difficult to "turn over" spot probably are objectionable. |
| 1210 | BC9 M ₀ = -2 M ₀ = -25 | B-FB | 2,150 2,666 | 5 | Selected to get rate of response desired to overcome effects of attitude stabilization. | Somewhat difficult to perform because of higher frequency oscillations in pitch and roll. Not large enough amplitude or low enough frequency to affect position, but was a distraction and made attitude control a problem. | Difficult to stabilize attitude at times following roll-out during lateral quick stop. | Some difficulty due to distractions in attitude, high frequency oscillations. Wing tilt control, used a good bit. | Couldn't hover too precisely due to high frequency attitude oscillations. Vertical landing no problem. Some interaction between pitch and roll dynamics. | Fairly continuous, high frequency oscillations in attitude objectionable. |
| 1211 | BC9 M ₀ = -4 M ₀ = -16 | B-FB | 1,688 1,390 | 3-5 | Selected to get desired attitude rates. | Generally could perform maneuvers quite precisely. Nice response in pitch and roll. Possibly slight tendency toward low-level oscillations, but presents no problem. Good attitude characteristics. | No real difficulty performing. Could stop accurately. Attitude quite controllable, predictable. | Performed reasonably well. Could concentrate on position without developing large attitude errors. Wing tilt control used a great deal. | Hover and vertical landing no problem. No interaction between pitch and roll. | Objectionable features were high drag in pitch and roll and perhaps some lack of damping. |
| | | B-MD | 2,173 2,274 | | | | | | | |
| 1212 | BC9 M ₀ = -4 M ₀ = -25 | B-FE | 2,504 2,804 | 3 | Selected to get the attitude response needed to overcome attitude stabilization. | Not difficult except for effects of rather large drag. Good attitude response characteristics, well damped. No oscillations and didn't get into unexpected attitudes. | Generally could perform fairly well, although high drag held low forward velocity. | Handled this alright. Have to take it slow because of high drag and have to be careful with wing tilt. Attitude presented no distraction. | Hover and vertical landing not difficult. | High drag objectionable, but attitude characteristics very good. |
| 1213 | BC9 M ₀ = -6 M ₀ = -16 | B-FB | 1,632 1,372 | 3 | Selected to get desired rates of change in pitch and roll. | Not particularly difficult to maneuver. Attitude quite predictable, well damped. Very slight tendency toward some low frequency oscillations but no problem controlling. | Generally no problem, although probably could have used a little more sensitivity in roll. Sensitivity a compromise between that needed to roll out in lateral quick stop vs requirements for hover. | Not difficult. Not time and used wing tilt control extensively. | Hover and landing not difficult. No real interaction. | Only objectionable feature might be high drag and slight tendency toward low frequency oscillations in pitch and roll. |
| 1214 | BC4 M ₀ = -2 M ₀ = -26 | B-FE | 2,200 4,512 | 3 | Selected to get desired attitude rates. | No difficulty regarding attitude control. Good attitude characteristics, but high drag tends to make it somewhat difficult to maneuver precisely. | Attitude control great. Generally can perform quick stop precisely. | Good attitude characteristics, not really as difficult because of large drag. Have to take it slow and use wing tilt control good bit. | Hover and vertical landing no problem. No interaction between pitch and roll. | Objectionable feature effect of imbalance on high drag characteristics. Excellent attitude characteristics. |
| | | B-MD | 3,750 3,692 | | | | | | | |
| 1215 | BC4 M ₀ = -10 M ₀ = -50 | B-FB | 3,750 3,280 | 1 | Set to achieve desired response in pitch and roll for maneuvering task. | Fairly good performance; could stay quite well within ground track. Used pulse-type control inputs to command desired pitch and roll. Control inputs relatively small and low frequency. | Not too difficult but required rather large attitude changes to get quick-stop type action. | Required considerably attention to offset gust and spin effects on drag. This required considerable wing tilt control in turn. | Hover relatively easy, but gust disturbances required continuous control. Performance quite good. | Configuration relatively good. Only slightly objectionable features were main wing and gust effects on position response of aircraft. |
| | | B-ME | 5,010 5,594 | | | | | | | |

TABLE B-VIII

PILOT COMMENTS FROM THE HEIGHT CONTROL STUDY OF THE INTERACTION BETWEEN
HEIGHT VELOCITY DAMPING AND THRUST-TO-WEIGHT RATIO

Flying Qualities Results Given in Table A-IX

| Case | Conf. Parameters | Pilot-Std. Note | h ₀ | V ₀ | Pilot Comments | | | | |
|------|---|-----------------|----------------|----------------|---|--|--|--|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamics | Overall Evaluation |
| H21 | SC1 T ₀ =T ₀₀ +0.0 T/W=UL | A-FB | 3.46 | 9 | Set height control sensitivity in an attempt to stabilize altitude. | Very difficult because of difficulty in controlling altitude. Altitude was very, very lightly damped and required extreme concentration to gain even minimal altitude stability. As a result, the remainder of the task suffered considerably. | Also difficult to perform because the large altitude changes produced attitude errors which were difficult to control and often resulted in PIO-type situations in altitude. | Hover difficult because of altitude control. Had difficulty holding altitude within 10 ft of the desired level. Altitude control activity high. | Most objectionable feature was the lack of damping in altitude. Intense pilot compensation was required to retain control. |
| | | B-FB | 3.14 | 7 | Selected in an attempt to get height under control. | Quite difficult. Can't perform the task as precisely as desired because have to pay so much attention to height control. Altitude varies 200 ft upward to 200 ft. Difficult to keep under control. | Cannot be performed precisely because must pay so much attention to height. | Could perform fairly well. Didn't disturb height too much while hovering. Configuration was good enough such that could hold hover position fairly well. The landing sequence performed reasonably well, at least in height; however, neglected hovering position somewhat. Could land it safely. | Definitely needs more height damping. |
| | | B-ND | 3.03 | 7 | Selected in an attempt to gain control of altitude oscillations. | Could maneuver longitudinally without too much difficulty, however, height oscillated 150 ft. Lateral maneuvering was difficult. | Performing lateral quick stops was quite difficult. Tended to have altitude go up to 100 ft or more. | Could hold altitude within 10 ft in hover. Difficulty interaction between height and particularly lateral control. Could change altitude, but tended to oscillate a fair amount about it. | Needs more height damping. |
| H22 | SC1 T ₀ =T ₀₀ +0.195 T/W=UL | A-FB | 2.90 | 4 | Set height control sensitivity to get desired altitude response for air taxi and landing sequence. | Altitude control fairly good, could devote attention to control of other areas during the air taxi and quick stop maneuvers. Relatively easy and very little wing tilt was required during turn. | | Precision hover required very little control activity and altitude could be held fairly well. The landing sequence maneuver required a little anticipation to stop at desired altitude, but otherwise was not too difficult. | A little more altitude damping needed to make it a satisfactory configuration. |
| | | B-FB | 3.12 | 4.5 | Selected to get desired altitude response. | Could perform task while holding height fairly well, although height required attention. Held height within say 25 ft. | Could hold height if considerable amount of attention paid to it. Probably quick stop performance suffered somewhat and height tended to slip away. | Could hover quite accurately. Didn't have any problems holding height. Hover position wasn't affected too much by turbulence; consequently, there was little to disturb height, so large altitude changes necessary to correct hover position. In landing sequence, going from 40 ft down to 20 ft, had difficulty arresting the descent rate and holding it. Had a tendency to overshoot desired altitude. Could land without too much difficulty, but had to do it cautiously. | Think h ₀ level is a little too low, would like to be able to take attention off height a little more. Can't hold altitude much better than 20 ft at best. |
| | | B-ND | 2.57 | 4 | Selected to get desired rate of response in height. | Generally could perform this task fairly well, at least longitudinally. When maneuvering laterally, developed some height oscillations which were somewhat difficult to damp out. Paying attention to these and trying to get height under control did detract from ability to perform the lateral maneuver. | Generally could perform these relatively well. Had some trouble with the lateral quick stop and the resulting lateral height. Would like to see a little more height damping. | No problem hovering and holding hover altitude. Could come down and stop fairly well at 20 ft and then come back up to 40 ft. Had to lead inputs somewhat, but this wasn't any great problem. Some interaction between height and control of roll. | Didn't like tendency to build up height oscillations when attempting to maneuver laterally. Had to pay attention to height but the damping was just slightly inadequate. |
| H23 | SC1 T ₀ =T ₀₀ +0.25 T/W=UL | A-FB | 3.04 | 3 | Selected height control sensitivity to obtain desired altitude response for takeoff and landing. | Air taxi was relatively easy as altitude required only moderate amount of attention to hold during the maneuver. Air taxi required relatively small pitch and roll changes, however, due to low drag, stopping position had to be anticipated. | Had no particular problems and altitude control was no problem as long as height control was coordinated with large altitude changes. | Control actions and pilot effort during precision hover were very low. Had very little trouble arresting sink rate during the landing sequence and the subsequent climb back to 40 ft. | A little more height damping might be desirable but this level is quite adequate. |
| H24 | SC1 T ₀ =T ₀₀ +0.4 T/W=UL | A-FB | 3.00 | 2 | Selected to get desired response to collective inputs for changing altitude. | Air taxi was relatively easy because very little attention was required to control altitude. | Quick stop maneuver quite easy. | Precision hover required virtually no inputs on the altitude control to maintain the altitude within a few feet of the nominal hovering altitude. | Very good height control, has adequate damping. |
| H25 | SC1 T ₀ =T ₀₀ +0.25 T/W=1.02 | B-ND | 3.05 | 7 | Selected in an attempt to control altitude oscillations. | Developed coupling between height and both longitudinal and lateral axes when attempting to maneuver. Seemed to have difficulty holding height during the longitudinal maneuver. | During the longitudinal quick stop just about touched down because of the low thrust and lack of damping. Height was consistently going into relatively large oscillations, 20 ft or so. | This wasn't too bad. Could stabilize height fairly well and keep hovering position under control quite well. During landing sequence almost touched down during descent to 20 ft. Had to be very careful because of the low control power. We able to stabilize fairly well after desired altitude achieved. Needs more thrust and more damping. Definite interaction between the height dynamics and roll and pitch dynamics. | One objectionable feature is the distinct lack of height damping and low thrust. |
| H26 | SC1 T ₀ =T ₀₀ +0.125 T/W=1.02 | A-FB | 3.0 | 7 | Had adequate thrust for takeoff but had difficulty stopping at desired maneuvering altitude of 40 ft. Had some problems controlling altitude during the air taxi and turn-over-a-spot maneuvers. | Control of altitude required considerable pilot attention in quick stops. | Control of altitude required some attention to control altitude. Had a great deal of difficulty in arresting sink rate during the descent to 20 ft. Thrust was clearly quite inadequate and the configuration lacked height damping. | Aircraft needs to be increased thrust and increased height damping. | |
| H27 | SC1 T ₀ =T ₀₀ +0.25 T/W=1.07 | A-FB | 3.0 | 8 | Climb-out following takeoff was very slow due to lack of thrust. Had some difficulty stopping and maintaining desired maneuvering altitude at 40 ft. Air taxi requires considerable pilot concentration on altitude control. Somewhat difficult to stay within 25 ft of the desired altitude. | Particularly difficult due to the upset in altitude. During the lateral quick stop briefly touched down. | Precision hover not too difficult after the desired altitude was established. We stabilizing this altitude was a matter of a problem and required considerable effort. Arresting sink rate during the landing sequence maneuver required that only small sink rates could be developed. | There were two equally objectionable features (1) the lack of thrust for arresting sink rates and climbing out and (2) the insufficient altitude damping. Considerable effort required to avoid developing high sink rates. | |
| H28 | SC1 T ₀ =T ₀₀ +0.45 T/W=1.02 | A-FB | 3.0 | 8 | Configuration very sluggish during lift-off, could not establish very high rate of climb; however, had no difficulty at all establishing desired altitude. During the air taxi had no problem controlling altitude. | Altitude was upset a little more and did not have a limitation on thrust in arresting sink rate. | Hovering performance was very good and was not bothered by lack of either thrust or altitude damping. During landing sequence had to be careful not to develop too high a sink rate, but didn't have too much difficulty arresting sink rate as long as care was used. Climb out again to 40 ft. was very slow and sluggish. | Most objectionable features were (1) lack of thrust which was particularly annoying during a climb out and (2) annoyance in arresting sink rate, although this problem was not too severe. | |

Contracts

TABLE B-VIII (Continued)

| Case | Conf. Parameters | Pilot's Exp. Mode | G | SP | Pilot Comments | | | | |
|------|---|-------------------|------|-----|---|--|--|---|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamics | Overall Evaluation |
| H209 | BC1 $Z_{\dot{w}} = -0.35$ $Z_{\dot{w}} = -0.35$ $T/N = 1.02$ | B-FB | 3.0 | 4 | | Had to pay fairly close attention to height control when maneuvering. Had to lead inputs a fair amount in order to arrest descents and had to be careful about building up descent rates that were not too large. Couldn't take attention off height control. Although I could perform the maneuvers fairly well, it affected their precision somewhat. Also, don't think height held any better than about ± 10 ft on the average, maybe somewhat less. | Required considerable attention to control altitude. | Hover was not too difficult to perform and could stabilize altitude fairly well. Had difficulty going down to 20 ft and stabilizing there. Tended to oscillate up and down. Also, had to be very careful with collective inputs. Significant amount of time before reaching desired 20 ft position. Could land safely, however. | Would prefer to see a little more $Z_{\dot{w}}$ and also more thrust. |
| H210 | BC1 $Z_{\dot{w}} = -0.25$ $T/N = 1.02$ | A-FB | 3.0 | 4 | | Adequate thrust for takeoff. Had no problem stopping at desired hovering altitude. All constant altitude maneuvers were relatively easy to perform. Did not have to concentrate much on altitude and held altitude relatively constant. | No problems. | Precision hover performance was very good and there was very little control activity required. Thrust was slightly deficient when attempting to arrest sink rate so had to anticipate the desired altitude while descending by applying thrust with anticipation. | Only slightly objectionable feature was the limitation on thrust which was noticed only when arresting sink rates. |
| H211 | BC1 $Z_{\dot{w}} = -0.4$ $T/N = 1.02$ | A-FB | 3.0 | 5 | | Climb out following takeoff was very slow as there was inadequate thrust to develop any significant rate of climb. However, damping seemed quite good so had no trouble stopping at desired maneuvering altitude. Altitude control was quite easy during all of the constant altitude maneuvers, including air taxi and turn-over-a-spot. | No problem controlling altitude. | Hover performance good, little effort required. Didn't seem to have much trouble arresting sink rate during the landing sequence. However, had difficulty climbing back up to 40 ft, there was just inadequate thrust available. Landing was not particularly difficult as long as sink rate wasn't allowed to get too high. | Slightest objections were (1) lack of thrust for developing suitable climb rates for backing off and climbing to desired altitudes and (2) inadequate thrust for arresting high rates of sink. |
| | | B-FB | 3.0 | 4 | | No difficulty, quite easy to hover and maneuver and to stop precisely both vertically and laterally. Could hold height quite accurately while doing this little attention required. | Can perform without difficulty and can go to relatively large altitudes without having altitude affected significantly. | No difficulty, can hover precisely and hold altitude without difficulty. In landing maneuver can ease down to 20 ft without too much difficulty. Must perform this task relatively slowly because can't arrest large sink rates; however, the large $Z_{\dot{w}}$ aids in performing task. Very difficult to climb back up to 40 ft altitude because of low thrust. Can land quite easily, but again have got to do it relatively slowly. | Only objectionable feature is that it is very difficult to climb to any altitude. Response is much too slow and there some difficulty arresting sink rates, but this is not a significant problem. |
| | | B-MB | 2.98 | 5 | Selected to get desired response to control inputs in height. | Could maneuver quite well. Some coupling between height and roll inputs, but generally height very stable, very well damped. Only complaint with height control is lack of thrust. It takes a long time to climb out. However, can descend and arrest descent very abruptly and precisely. | No problem, but during the lateral quick stop did couple in some height motion. | No problem. Landing sequence not difficult to perform, but annoyed by inability to climb out as quickly as desired. Much too sluggish in climbing. | Only objectionable feature is lack of thrust which restricts rate of climb, but well damped and can arrest descents precisely. |
| H212 | BC1 $Z_{\dot{w}} = -0.025$ $T/N = 1.05$ | B-MB | 3.07 | 6.5 | Selected primarily in attempt to control height oscillations. | Could perform the longitudinal maneuver fairly accurately and hold hover within ± 10 ft. Lost precision in lateral maneuver because of concentration required on holding height. Definite interaction between height control and ability to control laterally. | Again longitudinal was not too bad. Laterally didn't build up too many large errors but still feel that height control is much too poorly damped to control adequately. | Hover wasn't too difficult. Height remained in constant oscillation, but not particularly large amplitudes or as large as they were during the maneuvering portions of the tasks. Could descend to about 20 ft and hover there with relatively small altitude oscillations and then go back up to 40 ft. Height dynamics definitely affected ability to control lateral position. | Definitely needs more height damping to reduce attention required on height control. |
| H213 | BC1 $Z_{\dot{w}} = -0.05$ $T/N = 1.05$ | B-MB | 3.02 | 6 | Selected to get desired rate of change of height and to help get the height oscillations under control. | Air taxi not difficult. Holding height within ± 10 ft while maneuvering longitudinally, but when maneuvering laterally tended to develop larger height oscillations as much as 20 ft or so. Think height control did affect ability to perform maneuvering task to some extent. Difficult to stabilize height. Height was in almost continuous oscillation. | Longitudinal quick stops could be performed better than lateral ones, however, in both introduced some upsets in height. These were especially pronounced for lateral quick stop when altitude diverged by about 30 ft. Unfortunately, height was in pretty much constant oscillation during performance of quick stops. | Hover not too difficult. Could keep the height oscillations to within 25 ft. Had sufficient control power to perform landing sequence, but needed some damping. Had to lead height control to arrest climb and descent rates. Could perform vertical landing safely. Height dynamics did affect ability to control during the lateral quick stop. Tendency to let height diverge and concentrate on the lateral maneuver. | Objectionable feature was the lack of height damping. Control power seemed adequate. |
| H214 | BC1 $Z_{\dot{w}} = -0.125$ $T/N = 1.05$ | A-FB | 3.0 | 3 | | Thrust adequate for takeoff and didn't have too much trouble stopping at the desired altitude following climb out. Height control required a little bit of attention while performing the constant altitude maneuvers, but both thrust and damping seemed to be adequate. | No problem with this task. | Precision hover performance was quite good and required very little attention. During the landing sequence maneuvers seemed to have adequate thrust for arresting sink rate and for climbing back to the 40-ft altitude hover. | |
| | | B-FB | 3.0 | 4.5 | | Air taxi could be performed reasonably well, but had to pay significant amount of attention to altitude. Tended to drift away and had to correct and lead control corrections to stabilize on altitude. | Could be performed fairly well. Could go to large altitude changes without abrupt changes in altitude. However, again altitude tended to creep off and needed stabilization. | Could hover fairly well but had to pay fair amount of attention to altitude. Had some difficulty stabilizing on new altitudes when descending and in coming back up to 40 ft. Had to lead control inputs to stabilize height. Also had to approach the landing somewhat cautiously. | Didn't feel that altitude could be changed easily enough. Had to be somewhat careful with altitude control. Idea to see more height damping. |

Contracts

TABLE B-VIII (Continued)

| No. | Test Parameters | Flight Mode | Z ₀ | T ₀ | Pilot Comments | | | | |
|------|--|-------------|----------------|----------------|--|--|--|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamics | Overall Evaluation |
| 2214 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.125$ $\frac{T_{00}}{T_{01}} = 1.05$ | B-ND | 2.62 | 3 | Selected to get desired height response. | No problem performing maneuver longitudinally; laterally might have excited a little height motion, but apparently height is sufficiently well damped that did not get into any significant height position changes. | Could perform both longitudinal and lateral quick stops fairly well without upsetting height. Height is relatively easy to control, stable. | No problem holding hover position or altitude. No problem performing landing sequence. Could stop abruptly with only a slight amount of compensation. Height position well damped. No real interaction between different axes. | No real objectionable features. Sufficient damping, an apparent lack of control power. |
| 2215 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.25$ $\frac{T_{00}}{T_{01}} = 1.05$ | A-FB | 3.0 | 6 | | Because of inadequate thrust, takeoff was relatively sluggish, but had no difficulty establishing desired maneuvering altitudes. During constant altitude maneuver, performance was fairly good. Lack of altitude damping was not a particular problem. Roving turn required only a small amount of wing tilt trim. | Upset altitude somewhat but the only deficiency is a lack of thrust for arresting these altitude disturbances. | Precision hover performance was excellent and required very little effort. Damping was fairly good during the landing sequence; the only problem was arresting high sink rates quickly, this required caution to develop only minimal sink rates. | About only objectionable feature seemed to be lack of thrust for arresting sink rates and for developing desired climb rates. Requires extensive attention to avoid getting into problems during high sink rates. |
| 2216 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.25$ $\frac{T_{00}}{T_{01}} = 1.05$ | A-FB | 3.0 | 3 | | Thrust more than adequate for takeoff. Required a little anticipation to give at desired maneuvering altitude. During air taxi and turn-over-a-spot moderate pilot attention was required to control altitude, but performance was not degraded. | Some tendency to upset altitude, but had more than adequate thrust to arrest the motion. | Adequate thrust and damping for precision hover. During landing sequence had adequate thrust to arrest sink rate and did not have to place any limitation on sink rate for fear of not being able to arrest it. | Only moderately objectionable feature was that it could use a little more height damping. |
| 2217 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.25$ $\frac{T_{00}}{T_{01}} = 1.05$ | A-FB | 3.0 | 4 | | Not much difficulty in performing constant altitude maneuvers. Altitude required small amount of attention but seemed to have adequate damping, and thrust for maintaining constant altitude. | No altitude control problems. | Precision hover performance was very good and required very little pilot concentration. There was adequate thrust for climbing but stopping at desired altitude required some pilot anticipation. | At this damping level thrust seemed adequate, but a little more height damping would be desirable. |
| | | B-FB | 3.0 | 2.5 | | Could perform air taxi with precision and hold altitude quite accurately. Altitude very stable, easy to correct and generally did not stray much from desired altitude. No need to lead inputs. | Could perform this task easily and precisely and could make fairly large altitude changes without affecting height control. | Could hover very precisely, very little need to monitor altitude. In the landing maneuver could descend quite precisely to 20 ft and come back up. The vertical response was positively good, didn't seem to lack control power and the damping was more than adequate. No difficulty arresting sink rate, no great need to lead altitude inputs. Could land quite precisely. | No real objectionable features to this case. |
| | | B-ND | 3.06 | 2.5 | Selected to get test-1 response in height. | Maneuvering no problem. Could perform the task precisely and had no real problem with holding height during either the longitudinal or lateral maneuvers. | Could perform these precisely. Did see some decrease in altitude slow during very abrupt lateral stops with large roll angles, but easily corrected. | Precision hover no problem. In landing sequence could change altitude very abruptly and stop quite precisely with no noticeable overshoot. Could also climb fairly rapidly. | Might like to see a little more control power, but not much. No real objectionable features. |
| 2218 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.40$ $\frac{T_{00}}{T_{01}} = 1.05$ | A-FB | 3.0 | 3.5 | | During takeoff had adequate thrust for climb out. No difficulty stopping at maneuvering altitude of 40 ft. During constant altitude maneuvers altitude required very little effort to control and altitude control was good. Height dynamics seemed well damped and to have a rate-type response. | No problem with task. | Hovering performance good and required very little effort. Could not develop real high rate of climb or rate of descent due to limitation on thrust and/or high damping. A little more thrust would have been desirable to develop higher rates of climb and to insure arresting sink rate during descent. | Only slightly objectionable feature was perhaps being a little sluggish in response to altitude due to the lack of control power. |
| 2219 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.05$ $\frac{T_{00}}{T_{01}} = 1.10$ | B-ND | 3.24 | 6 | Selected to help in stabilizing height oscillations. | Could maneuver longitudinally without too much trouble. When maneuvering laterally introduced a fairly large longitudinal displacement error while concentrating on height. Height required a lot of pilot compensation to stabilize, was in almost constant oscillation up and down, as much as 20 ft. | Longitudinal quick stops performed fairly well while holding height within 15 to 20 ft. Lateral quick stops quite difficult because of the lack of height damping. | No difficulty hovering. Could keep height oscillations small while hovering accurately. Could perform landing sequence fairly accurately. Could descend relatively quickly to 20 ft and stabilize and rise again to 40 ft, then land gently. Height dynamics satisfactory. Ability to control other axes (particularly roll). | Height dynamics objectionable, need more damping. |
| 2220 | BC1 $\frac{Z_{00}}{Z_{01}} = 0.125$ $\frac{T_{00}}{T_{01}} = 1.10$ | A-FB | 3.0 | 2.5 | | Had more than adequate thrust for takeoff and had little difficulty stopping at desired altitude following climb out. During the constant altitude maneuvers had to devote only a small amount of attention to the control of altitude. | | Precision hover required very little concentration or control activity. During landing sequence maneuver had no difficulty arresting sink rate, however, small amount of anticipation required to stop at desired altitude. | Only improvement desired might be a slight increase in altitude damping. Otherwise configuration is quite satisfactory. |
| | | B-FB | 3.0 | 2.5 | | In general could perform air taxi relatively well. Did have to pay attention to altitude, however, did make fairly constant corrections. Had to take concentration away from horizontal position a good deal to control altitude. Had to lead altitude control somewhat. Would like to see a little more altitude damping. Had adequate control power. | Could perform this maneuver without too much difficulty. Didn't notice a lack of control power and went to relatively large altitudes without affecting altitude too much. Rather occasionally by the fact that altitude would tend to change unnoticed. | Hover performed quite accurately, but altitude required attention. Landing sequence performed fairly well. Could maneuver vertically at satisfactory rates, but had to lead inputs somewhat when arresting vertical rates. | Would like to see a little more altitude damping, although it is not all that bad. Think control power is adequate. |

Controls

TABLE B-VIII (Continued)

| No. | Conf. Parameters | Altitude (ft) | V ₀ (ft/s) | TR | Pilot Comments | | | | |
|------|--|---------------|-----------------------|-----|--|--|--|--|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamic | Overall Evaluation |
| 8220 | BC1 $Z_{\dot{w}} = -0.125$ $Z_{\ddot{w}} = 1.10$ | B-FB | 2.52 | 3 | Selected to get desired height control response. | Not too much difficulty with lateral maneuvering. In lateral maneuvers noticed some coupling between altitude and roll. Had to be kind of careful maneuvering laterally because could build up some fairly substantial height variations if not watched closely. | Had to be careful with lateral roll outs to make sure that height wasn't disturbed. Had to watch height closely, definitely some coupling between roll and height. | No problem, could hold height fairly well, 78 to 83 ft. Could descend to 70 ft and stop rapidly. Some control compensation required, but could stabilize relatively well at desired height and then climb to 40 ft without too much difficulty. | Slight lack of height damping, but seemed to be plenty of thrust. |
| 8221 | BC1 $Z_{\dot{w}} = 0$ $Z_{\ddot{w}} = -0.25$ $T/W = 1.10$ | A-FB | 3.0 | 4.5 | | More than adequate thrust for takeoff. Had good rate of climb but had to anticipate desired maneuvering altitude a little. During air taxi and hovering runs maneuver general performance was fairly good but had to direct moderate attention to control of altitude. | Tended to upset altitude but had adequate thrust margin to arrest sink rates. | Precision hover performance was very good and required very little effort or concentration. No problem arresting sink rates as there was more than adequate thrust and even didn't seem too much difficulty stopping at desired altitude. | Only objectionable feature was a slight deficiency in altitude damping, but thrust seemed more than adequate. |
| | | B-FB | 3.0 | 5 | | Altitude tended to wander when maneuvering and when performing quick stops. Had to monitor altitude a good bit in order to hold altitude precisely. Could perform the task fairly well. | Performance fairly good, but altitude needed attention and tended to overshoot periodically when making corrections. | Could hover precisely, had to monitor altitude again, but altitude control not too difficult. The landing sequence was performed fairly well. Had some difficulty arresting altitude, some tendency to overshoot desired altitude. | Needs more altitude damping. |
| | | B-ND | 2.82 | 3.5 | Selected to get desired height response. | No problem with air taxi. Had to watch height while maneuvering laterally, but could control this to within about 23 ft. | Had to keep attention on height when making lateral quick stops and make some compensating inputs, but height didn't change rapidly. No problem with longitudinal quick stop. | Hover no problem. In landing sequence could change altitude fairly abruptly and stop without too much difficulty. Had to compensate for overshoot a little but didn't require too much effort. | Maybe would like to see a little more damping, but the ease is relatively easy to control. |
| 8222 | BC1 $Z_{\dot{w}} = -0.25$ $Z_{\ddot{w}} = 0$ $T/W = 1.10$ | A-FB | 3.0 | 4 | | Good input for takeoff and developed good rate of climb, stopping at desired altitude was not too much of a problem. Constant-altitude maneuvers required moderate attention to altitude control but performance was fairly good. | These maneuvers upset altitude the most and required the most attention. | Precision hover performance was very good and required very little effort. Had no difficulty at all arresting sink rates or stopping at desired altitudes. | Only annoying feature seemed to be attention required to control altitude during constant altitude maneuvers. |
| | | B-ND | 2.76 | 3.5 | Selected to get desired height response. | No problem with longitudinal maneuvers. Could perform task precisely and hold hover altitude relatively well, 72 to 83 ft. Had to pay somewhat more attention to height during lateral maneuvers. | Could perform fairly well, introduced slightly larger height errors during lateral than longitudinal maneuvers, but height didn't change rapidly and it was reasonably easy to correct. | Hover no problem. Could descend relatively rapidly and arrest descent accurately, and quickly. Had to use some small compensating control inputs but fairly easy to do. | Might like to see a little more height damping, but this is not a bad case. |
| 8223 | BC1 $Z_{\dot{w}} = -0.25$ $T/W = 1.10$ | A-FB | 3.0 | 2.5 | | More than adequate thrust for takeoff and had no difficulty at all stopping at desired altitude. Followed climb out. Altitude control during all of the constant altitude maneuvers was relatively easy and required very little effort. | No problem. | Precision hover performance was very good and required very little effort. With thrust and height damping seemed adequate. During the landing sequence maneuvers had no difficulty arresting sink rate or stopping at desired altitude. | Good configuration. |
| | | B-FB | 3.0 | 4 | | Air taxi could be performed with fair precision, although it would have been aided by a little more altitude damping. Altitude tended to creep away periodically. Altitude control required was low. However, one disagreeable factor was that it tended to drift off when attention not paid to it almost constantly. | Could perform this task relatively well. Could go to fairly large attitude angles without having attitude change abruptly, but attitude tended to drift away. | Not difficult, but had to pay attention to altitude. Could change altitude relatively quickly and stop without too much difficulty. Needed to lead inputs a little but not a great deal. Landing 3-sec precisely. Generally, had no complaint about ability to maneuver vertically, but was bothered by lack of altitude stability. Don't think altitude held any better than about 25 ft or more. | Needs a little more altitude damping. |
| 8224 | BC1 $Z_{\dot{w}} = -0.40$ $T/W = 1.10$ | A-FB | 3.0 | 2.5 | | Air taxi maneuver and turn-over spot relatively easy to perform and had relatively good performance. Control of altitude required very little attention. Height seemed adequately damped and to have adequate thrust for control. | Relatively easy to perform. | Precision hover required very little effort and could control all error quite well. Adequate thrust for climbing and changing altitude and arresting sink rates. There may have been very small amount of compensation required to stop aircraft at desired altitude. | Good configuration. |
| 8225 | BC4 $Z_{\dot{w}} = 0$ $T/W = 1.10$ | A-FB | 3.0 | 10 | | Out range of sensitivities in an attempt to obtain closed-loop control over altitude. | Had an extremely difficult time controlling altitude. It required extreme anticipation to arrest vertical motion and at times got into vicious PIO's that usually resulted in hitting the ground. Found it extremely impossible to perform the task because when attention diverted from strictly altitude control but altitude control through either pure diversion or PIO tendencies. | | It is mandatory that this configuration have more height damping. Control would be lost during some portion of the required task. |

Contrails

TABLE B-VIII (Concluded)

| Case | C.G. Characteristics | Pilot-Inst. Points | T _h | T _h | Pilot Comments | | | | |
|------|---|--------------------|----------------|----------------|---|---|---|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamics | Overall Evaluation |
| H225 | RC4 $T_{\text{th}} = T_{\text{th}}^* + 0.1$ T/W=0.1 | B-FB | 3.02 | 8 | Selected in an attempt to stabilize height control. | Very difficult to perform because of attention needed to stabilize height. Couldn't perform any maneuvering task precisely because of concern about possible ground strike. Height accuracies must have been up to -60 to 70 ft. Very difficult to keep height under control and attempt to perform task. | Very difficult to perform the task with any precision because of very poor height control. | This wasn't quite as bad, could hover fairly well but had some difficulty stabilizing height. The landing sequence was next to impossible to perform. Couldn't stabilize on either 20 or 40 ft altitudes. The vertical landing also difficult, got close to the ground and then just dropped it in to prevent oscillating once more. | Definitely needs more damping in height; this is completely unacceptable. |
| | | B-MB | 3.06 | 8 | Selected in an attempt to gain control of altitude oscillations. | Very difficult to perform. Can't do it with any precision. Must concentrate on altitude control, then this degrades maneuver performance. Altitude control no better than 140 ft. | Had simulator emergency during the lateral quick stop because of the difficulty in controlling altitude. Can't perform any task with precision. | Couldn't hover precisely or hold hovering position while landing. Concerned mainly with height control and stabilizing it to some extent. The landing sequence was a bit and also operation. Just had to let hovering precision deteriorate and very cautiously get altitude down to 20 ft. Had to lead control inputs a great deal. | Difficult to control height -- certainly the most objectionable feature. Extremely difficult to keep height anywhere in bounds. Needs height damping. |
| H226 | RC4 $T_{\text{th}} = T_{\text{th}}^* + 0.125$ T/W=0.1 | A-FB | 2.60 | 5 | Set height control sensitivity for both altitude response and altitude stability. | Controlling altitude requires moderate pilot concentration, that is, required some anticipation to stop at desired altitude. Air taxi maneuver required moderate concentration on altitude control. | Required moderate concentration to perform it. | Precision hovering required moderate pilot concentration both to offset mean wind effects on aircraft position and to control altitude. Because of the divided attention it was generally held only within 710 ft of the desired altitude. | Most objectionable feature was the slightly low damping in altitude. Feel more damping would be required to make this a satisfactory configuration. |
| | | B-FB | 3.28 | 4.5 | Selected for desired control response in height. | Air taxi not too difficult. Could perform it reasonably well with some precision while holding altitude within about 25 ft. Had to pay a good deal of attention to height, more than desired. | Could perform lateral and longitudinal quick stops with reasonable precision but had to fairly constantly keep attention on height. | Precision hover not too difficult. Could hover precisely, but occasionally altitude would drift off. The landing sequence wasn't too difficult. Would like to see some more height damping, however. Difficult to stabilize and hold altitude precisely. Approached landing cautiously, but performed it OK. | Objectionable feature was primarily the lack of height damping. Would like to see a little more. |
| | | B-MB | 2.70 | 4.5 | Height control sensitivity selected to control height oscillations. | Generally could maneuver relatively well, but think that lack of damping in height affected ability to perform maneuver. Could hold height within about 110 ft, but altitude was in constant motion. Couldn't really stabilize on any given altitude particularly well. | No real difference in remarks compared to maneuvering. | Could hover fairly well while holding altitude without too much effort, but hovering position was degraded somewhat. Had to make fairly continuous inputs to height to keep stabilized and to keep within 710 ft. In landing sequence could decrease altitude to about 20 ft fairly well, but every now and then would have to make an abrupt input to control hovering position. | Would like to see a little more damping in height, although this isn't critical. |
| H227 | RC4 $T_{\text{th}} = T_{\text{th}}^* + 0.25$ T/W=0.1 | A-FB | 3.71 | 2 | Selected height control sensitivity for desired altitude response during takeoff and landing. | Air taxi wasn't too difficult, except that relatively large altitude changes were required to initiate and sustain velocity. Could hold heading and altitude fairly accurately with only a moderate control effort. | Most objectionable feature of quick stops was the large altitudes required to initiate the translational motion. | Was annoyed somewhat by gust disturbances during precision hover in both position and a little in altitude. This was a mildly unpleasant characteristic. Altitude control required very little activity and seemed to be fairly well damped. | Generally good configuration. |
| H228 | RC4 $T_{\text{th}} = T_{\text{th}}^* + 0.14$ T/W=0.1 | A-FB | 3.32 | 3 | Selected height control sensitivity to get desired response for making altitude changes. | Air taxi was relatively easy to perform because very little attention was required to control altitude. Turn-over-a-spot required pilot effort only because of the mean wind effects on position such that relatively large changes in wing tilt trim were required. | Relatively easy to control. | Precision hover was very easy from the standpoint of controlling altitude, most attention was required to offset drag effects on the airplane. Height control was very good. | Would rate it 2.6, but because of mean wind effects on the aircraft, will rate the overall configuration 3.0. |

TABLE B-IX

PILOT COMMENTS FROM THE STUDIES OF HEIGHT CONTROL SYSTEM
LAGS AND DELAYS AND INCREMENTAL THRUST THROUGH STORED ENERGY
Flying Qualities Results Given in Table A-X

| Case | Conf. Parameters | Pitch Mode | g ₀ | PR | Pilot Comments | | | |
|------|--|------------|----------------|-----|--|--|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamics |
| HL1 | SC1 $Z_{\dot{w}} = 0.125$ $T/N = 1.05$ $T_w = 0.3$ $K_v = 0$ | A-FB | 3.0 | 4.5 | Takeoff performance quite good, but had to anticipate desired hovering altitude of 40 ft. During air taxi altitude required considerable attention, and altitude deviated more than desired. | Altitude performance was fairly good during turn maneuver, but during quick stop there was considerable variation in altitude. | Hovering performance was fairly good, but had to devote some attention to control of altitude. During landing sequence maneuver had no problem arresting sink rate but required some attention to stabilize altitude. This applied to the landing, too. | Most objectionable feature seemed to be a combination of either light damping in altitude or perhaps lag in the thrust response. |
| | | B-FB | 3.0 | 3.5 | Altitude required considerable attention and compensation during both the maneuvering and quick stop portion of the task. Could not descend altitude even for a moment. Had to lead inputs and make fairly continual control inputs. | Considerable pilot effort required. Performance not too good. | Could hover fairly precisely, but had to make relatively continuous altitude control inputs to hover accurately. Could perform landing sequence but had to be very careful about descending too rapidly and overshooting desired altitude. Same applied to ascending. Had to anticipate desired altitude. Couldn't land smoothly because of thrust lags. | Altitude needs more damping or lower thrust lag. |
| | | B-ND | 3.01 | 3 | Selected to get desired height response. | No difficulty performing air taxi while holding height within fairly close tolerance, say about 25 ft. Height seemed to be relatively stable. Fairly well damped and didn't change abruptly when performing the lateral maneuvers. | No problem holding height during the longitudinal quick stop; during the lateral quick stop several degrees altitude lagged which were large enough to introduce height errors and cause some difficulty in height control, but really nothing extreme. | No problem, could hover quite accurately and hold height very steady. In landing sequence could descend at fairly rapid rates and stop quite precisely. No oscillations evident. Could land normally. No worries about oscillating in height near the ground. |
| HL2 | SC1 $Z_{\dot{w}} = 0.175$ $T/N = 1.05$ $T_w = 0.2$ $K_v = 0.1$ | A-FB | 3.0 | 2.5 | Very good takeoff performance, had no difficulty stopping at and holding 40-ft altitude during constant altitude maneuvers. In fact, very few control inputs were required while performing air taxi, quick stops and turn-over-a-spot maneuvers. | | Thrust response seemed fairly good when arresting sink rate during the landing sequence maneuver and stopping at the 20-ft altitude. Thrust control was also adequate for landing. | Good altitude control. |
| | | A-FE | 3.0 | 3 | Climb out performance was good and had no problems stopping at desired altitude. Very little effort required to hold altitude while performing the air taxi, turn-over-a-spot, and quick stop maneuvers. | | Hovering performance was very good and required very little effort to control altitude. There was either a slight limitation or delay in thrust when attempting to arrest sink rate, but this was no particular problem. | Only objectionable feature was the slight limit or delay in thrust when arresting sink rate. |
| HL3 | SC1 $Z_{\dot{w}} = 0.175$ $T/N = 1.05$ $T_w = 0.2$ $K_v = 0$ | A-FB | 3.0 | 3 | Air taxi and quick stop maneuvers could be performed while holding altitude relatively constant. Altitude not difficult to maintain during these maneuvers. Tendency to change somewhat but not too rapidly, easily compensated. | | Hover could be performed quite precisely while holding altitude within very close tolerance of about 1 ft. The landing sequence also was not difficult to perform. Some small tendency to overshoot when ascending and descending but easy to compensate. | Would probably like to see a little more damping and a little less lag, but in general is not a bad height-control configuration. |
| | | B-FB | 3.0 | 3 | | | | |
| HL4 | SC1 $Z_{\dot{w}} = 0.175$ $T/N = 1.05$ $T_w = 0.2$ $K_v = 0.1$ | A-FB | 3.0 | 3.5 | Climb out was satisfactory following takeoff and had no difficulty stopping at maneuvering altitude of 40 ft. Altitude control required very little attention while performing air taxi, quick stops and turn-over-a-spot maneuvers. | | Altitude control during precision hover was very good. During landing sequence did notice a little lag in thrust response in trying to arrest sink rate, so had to anticipate desired altitude. Again, during climb out thrust was adequate but noticed a slight lag in thrust response while performing the final landing. | A slightly objectionable feature seemed to be a small lag in thrust when attempting to land or arrest sink rate. |
| | | A-FE | 3.0 | 4.5 | Had adequate thrust for takeoff and climb out to desired altitude. Only small amount of effort required to stabilize at desired altitude. During constant altitude maneuvers had to give some attention to controlling altitude as there was some tendency to oscillate about desired maneuvering altitude of 40 ft. | Required a little more altitude control but did not see a particular problem. | During precision hover noticed tendency to oscillate and maintain altitude slightly, but in general performance was fairly good. During landing sequence noticed a lag in thrust when attempting to arrest sink rate, but this was only a moderate problem. Thrust response was slightly slow during landing. | Most objectionable feature seemed to be a slight lag or delay in thrust response when attempting to arrest sink rate. |
| HL5 | SC1 $Z_{\dot{w}} = 0.175$ $T/N = 1.05$ $T_w = 0.6$ $K_v = 0$ | A-FB | 3.0 | 3.5 | Generally could perform air taxi precisely and hold altitude fairly constant. Some small tendency for altitude to drift off but this was relatively easily compensated. Had to pay some attention to altitude but really it didn't tend to get away. | Could be performed with precision and without about changes in altitude. Had to monitor altitude. | Precision hover could be performed easily and altitude presented no great problem. Could descend and ascend without too much difficulty. Did have to land smoothly, however. Had to be concerned about overshoot, especially when descending altitude. Vertical landing could be performed quite precisely, but had to be careful in arresting sink rate. | Some thrust lag effects evident. Might like to see a little more damping, but this is not a particularly bad one. |
| | | B-FB | 3.0 | 3.4 | | | | |
| HL6 | B-1 $Z_{\dot{w}} = 0.25$ $T/N = 1.05$ $T_w = 0.6$ $K_v = 0$ | A-FB | 3.0 | 4 | Air taxi so great difficulty. Some coupling between height and roll motion but didn't have to make particularly large or rapid inputs to correct for it. Hovering pretty relaxed. | No difficulty, could hold altitude fairly well even while performing the lateral quick stop, but a little there was some coupling noticeable there. | Hover so difficult. Could hold both longitudinal and vertical position quite well. Landing sequence was a little wobbly, had to be careful not to build up descent rates which were too large because of a tendency to develop some oscillations in height. Had to avoid abrupt inputs though. | Objectionable feature was slight oscillatory behavior in height, although this wasn't a problem. |
| | | A-FB | 3.0 | 2.5 | Good climb-out performance following takeoff. Very little altitude control was required. | These maneuvers induced some altitude error. However, control was relatively easy. | Virtually no altitude control was used during the precision hover. There was adequate thrust and damping during the landing sequence maneuver and any thrust lag was not noticeable. | Good altitude control. |
| HL7 | SC1 $Z_{\dot{w}} = 0.15$ $Z_{\ddot{w}} = 0.75$ $T/N = 1.05$ $T_w = 0.5$ $K_v = 0$ | A-FB | 3.0 | 2.5 | Selected to get desired height response. | Not difficult. Could maneuver accurately while holding height relatively well. Height tended to increase during the lateral maneuvers, however. | Could not control altitude precisely during lateral quick stop. | Hover not difficult. Could perform more thrust for ascending or rate of descent, can't climb without MC interaction. |
| HL8 | SC1 $Z_{\dot{w}} = 0.15$ $T/N = 1.05$ $T_w = 0.5$ $K_v = 0$ | B-ND | 2.67 | 4 | | | | Adequate loss of thrust. |

Contrails

TABLE B-IX (Concluded)

| No. | Comp. Parameters | Pilot Mode | V ₀ | FR | Pilot Comments | | | | |
|-----|--|------------|----------------|-----|--|---|--|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Precision Hover, Landing Sequence and Secondary Dynamic | Vertical Control |
| H8C | BCL $Z_{\dot{h}} = 0$ $Z_{\dot{h}} = -0.35$ $T/W = 1.09$ $\Delta T/W = 0.13$ $T_{\dot{h}} = 0.10$ | A-FB | 3.0 | 4 | | Height control required attention. No abrupt changes in altitude but tended to drift off. Had to lead collective inputs and avoid building up large descent rates. | Developmental height errors of 25 ft. | Hover not too difficult. Could hold altitude precisely. Moderately difficult to arrest my descent at 20 ft and stabilize altitude there. Lack of available thrust. Could land safely, however. | Needs more installed thrust-to-weight ratio and possibly more damping. |
| H8D | BCL $Z_{\dot{h}} = 0$ $Z_{\dot{h}} = -0.35$ $T/W = 1.02$ $\Delta T/W = 0.13$ $T_{\dot{h}} = 0.2$ | A-FB | 3.0 | 3 | | Height control required some attention but only low-frequency corrections needed. Didn't have to lead inputs much. | Height control not difficult. | Could hover precisely with only small variations in altitude. Relatively easy to perform landing sequence. Could build up appreciable altitude rates, sustain them, and arrest height changes quickly. | |
| | | B-MB | 2.68 | 3.5 | Selected to get desired rate of height change. | No problem either laterally or longitudinally. Could maneuver and stop precisely. No difficulty holding altitude quite precisely. | No problem even in lateral quick stops. Could stop abruptly and hold altitude quite precisely. | Hover no problem. Generally could handle landing sequence fairly well. A little concerned with ability to stop rate of descent. At times overshoot altitude a little, so had to descend with some care. Think thrust is adequate. | Objectionable features - A slight objection to lack of thrust that was evident when trying to stop rate of high descent rates. |
| H8E | BCL $Z_{\dot{h}} = 0$ $Z_{\dot{h}} = -0.35$ $T/W = 1.02$ $\Delta T/W = 0.28$ $T_{\dot{h}} = 0.10$ | A-FB | 3.0 | 3.5 | | Altitude required attention when maneuvering. However, generally could control it fairly well. Some tendency to creep off and increase altitude but it happened relatively slowly. Could build up fairly significant rates and arrest them without too much difficulty. | Required some attention, but could control altitude fairly well. | Hover no problem. Could perform this precisely and hold altitude quite accurately. The landing sequence also not too difficult. Could go down to 20 ft at a relatively rapid rate and arrest altitude without too much difficulty. Did have some problems stabilizing it out nothing too significant. | Fairly good case. |
| | | B-MB | 2.67 | 3 | Selected to get desired response in height and desired rate of change of altitude for a comfortable control input. | Generally no problems with air taxi. Could maneuver precisely and hold altitude accurately. | Performed quick stops precisely and had no problem holding height. | Hover was not difficult. Some lack of thrust when arresting descent. Concerned with building up too large a descent rate, however, seemed to be able to ascend as rapidly as desired. Seemed to have adequate thrust available. | Objectionable feature was the slight lack of thrust when descending. A little concerned with inability to arrest descent rates, but with care can keep them well under control. |
| H8F | BCL $Z_{\dot{h}} = 0$ $Z_{\dot{h}} = -0.35$ $T/W = 1.02$ $\Delta T/W = 0.28$ $T_{\dot{h}} = 0.05$ | A-FB | 3.0 | 3.5 | | During maneuver had to watch altitude reasonably closely. Tended to increase slightly, but didn't seem to be difficult to control and it was reasonably creditable. Don't recall having to lead inputs too greatly. | No problem with altitude control. | Could hover precisely and hold altitude closely. Landing sequence was not difficult to perform. Could hover precisely and descend to the 20-ft altitude with no difficulty. Didn't seem to have any real problems arresting descent rates. | Couldn't let descent rates build up too large but air normal descent could arrest altitude precisely. |
| | | B-MB | 2.67 | 4 | Selected to get desired altitude response. | Air taxi not difficult. Height control didn't affect ability to control longitudinal or lateral motion while maneuvering. Had a little difficulty holding altitude. Would drift up and down about 25 ft or so. | Could stop quickly and precisely, at least longitudinally, without having altitude change too much. Did lose some altitude during the lateral quick stop. May have lacked a little thrust to recover altitude. | Hover not difficult. Had to be a little careful about rate of descent. Couldn't descend rapidly and stop abruptly. Had to slow down relatively easily. | Objectionable feature - Slight lack of thrust during descent and when trying to recover height during lateral quick stops. |

Controls

TABLE B-X

PILOT COMMENTS FROM THE STUDY OF DIRECTIONAL CONTROL
Flying Qualities Results Given in Table A-XI

| Case | Conf. Parameters | Pilot. Cim. Code | ξ_{ϕ} | IS | Pilot Comments | | | | | |
|------|---|------------------|--------------|-----|---|---|--|---|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Vertical Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| D1 | RC1 $\xi_{\phi} = 0$ $\xi_{\psi} = 0.1$ $\xi_{\theta} = 0$ $\xi_{\phi} = 0$ | B-FB | 0.206 | 7 | Selected to attenuate heading oscillations and gain some control over directional motion. | Had difficulty holding heading. Heading was in almost constant oscillation through as much as 110 to 135 deg. Could perform task but performance was affected by attention required on direction. Just couldn't take attention off direction and pay proper attention to performing the maneuvers precisely. | Again, holding heading took too much attention away from the remainder of the task; it affected ability to perform quick stops as precisely as desired. | Had to do this very, very carefully, had to really be hesitant in developing directional changes and rates because of the difficulty in stopping and stabilizing heading. However, by going so slowly, managed to stop just about where desired and could hold heading 110 deg. Had more heading damping. | Could never fairly precisely, but heading was constant oscillation of about 110 deg. Poor dynamic in heading affected ability to control the other axes. | Really need some more damping in heading. The level of the configuration is relatively easy to control so can afford some attention on heading, but still heading control requires too much time. |
| | | B-NB | 0.206 | 6 | Selected to help control yaw oscillations. | Seemed to have constant oscillations in yaw when maneuvering both longitudinally and laterally. Heading to thought it was quite difficult to hold heading while maneuvering laterally. | Could perform three maneuvers alright, but oscillations in yaw developed. This diversion of attention affected ability to control longitudinal and lateral motion. Worried about losing yaw when doing lateral quick stop. | Could turn and stop fairly precisely if active attention paid to yaw maneuver. Tended to lose horizontal position; it was difficult to look away any length of time and stabilize yaw. Definitely need more yaw damping. | Hover not too difficult, but was in a fairly constant small oscillation in yaw. The yaw dynamic definitely affected ability to control pitch, roll and height. | Objectionable features - lack of yaw damping. Definitely need more. |
| D2 | RC1 $\xi_{\phi} = 0.5$ $\xi_{\psi} = 0.1$ $\xi_{\theta} = 0$ $\xi_{\phi} = 0$ | A-FB | 0.227 | 4 | Set to get desired response in heading. | Heading control requires a moderate amount of attention due to gust effects on direction. Longitudinal performance was good but lateral taxi maneuvers required considerable attention to direction. | Focused on particular problems that were not present with air taxi maneuvers. | Response to pedal inputs was fairly good but required a little anticipation to stop at desired heading. Gust effects added some uncertainty to directional control during this task. Very little wing tilt control used. | Hover performance was good but a small amount of effort was required to control the gust effects on heading. | Most objectionable feature was the gust effects on heading. Think a little more damping under these conditions would be necessary to take a satisfactory configuration. |
| | | B-FB | 0.255 | 3.5 | Selected to get heading response desired for a comfortable amount of pedal input. | Could maneuver quite accurately longitudinally. Had to pay reasonable amount of attention to heading control during lateral maneuvers, probably somewhat more than desirable. Noticed that heading tended to oscillate a little although it was fairly well damped and the oscillations were relatively small, generally less than 3 deg. | Could perform fairly well. Every now and then distracted from primary task because of the heading control requirements. | Could turn and control rates quite accurately and stop where desired with fair precision. Also could hold heading fairly accurately. Wing tilt control was used a little. | Didn't think heading control requirements affected ability to hover. Vertical landing also performed precisely and heading control no problem. Only time heading control affected ability to perform different maneuvers was in lateral maneuver. | Would like to see a little more damping in heading, although heading is not particularly difficult to control. |
| | | B-NB | 0.259 | 3.5 | Selected to get the rate response needed in yaw. | A problem during this longitudinally, laterally had to pay some attention to heading, but seemed to have adequate damping. Some minor oscillation in heading. | In yaw difficult here. Could perform the quick stops quickly, however did have to pay attention to heading during the lateral quick stops. | Not difficult. Can turn rapidly and stop fairly precisely. | Hover not difficult. No really noticeable interaction between dynamics. | Highly like to see a little more damping. But the damping is adequate. |
| D3 | RC1 $\xi_{\phi} = 1.0$ $\xi_{\psi} = 0.1$ $\xi_{\theta} = 0$ $\xi_{\phi} = 0$ | A-FB | 0.286 | 3 | Set to get desired response in heading to pedal inputs. | Air taxi relatively easy but during lateral maneuvers did have to correct for coupling of lateral velocity to heading. Could hold heading fairly well during maneuvers. | Focused on particular problems but required a little anticipation to stop at desired point. | Had good directional control, required very little anticipation to stop at desired heading, but effects slightly annoying in direction. Used virtually no wing tilt control. | Hover performance was very good and directional control activity was very small. | Only slightly objectionable feature was the gust effects on direction and the coupling of direction to lateral velocity during lateral maneuvering tasks. |
| | | B-FB | 0.290 | 2.5 | Selected to get response in heading needed for turning. | Could perform task while holding heading very accurately. Heading didn't detract from ability to perform this task. Could keep heading within 12 or 13 deg. Allowed some lateral-directional coupling while maneuvering laterally but it was easy to handle. | No difficulty in controlling heading while performing quick stops. Heading control didn't detract from ability to perform quick stops. | Could perform quite accurately, set turn rates easily, stop precisely and hover accurately at a given heading. | Could hover accurately. Could hold heading precisely while hovering. Same is true for vertical heading. | No objectionable features. Heading well damped, nice rate response, very controllable. |
| D4 | RC2 $\xi_{\phi} = 1.0$ $\xi_{\psi} = 0.1$ $\xi_{\theta} = 0$ $\xi_{\phi} = 0$ | B-FB | 0.312 | 2.5 | Selected to get desired rate of change of heading with comfortable pedal input. | Somewhat difficult to perform because of reduced damping in roll and pitch and higher speed sensitivities. Heading is well damped and can take attention away from it sufficiently long to control the other axes. | Heading control is easy, sufficiently well damped that can concentrate on the other axes. | Can perform subtask precisely, quite easy to control. Wing tilt control is used to take out effects of mean wind. | No problem in hover as respect to heading control. That is somewhat difficult because of low damping in pitch and roll. In heading must exercise considerable control of pitch and roll, but can hold heading. | Favorable feature is that heading is quite easy to control. |
| D5 | RC1 $\xi_{\phi} = 0.5$ $\xi_{\psi} = 0.1$ $\xi_{\theta} = 0.1$ $\xi_{\phi} = 0$ | B-FB | 0.202 | 4 | Selected to control heading oscillations. | Heading control affected performance. Had to concentrate on heading to hold it within 110 to 115 deg, and the amount of attention that it took degraded precision of maneuvers. Good damping or less lag in heading. | Heading control detracted from ability to perform quick stop maneuvers, especially the lateral maneuvers. | Seemed to be able to establish a heading rate fairly well, but had to be careful about stopping on preselected heading, tended to develop oscillations in heading when trying to stop abruptly. Heading control seemed to detract from ability to hold hover position. | Managed hover fairly well, but there were some heading oscillations and had to concentrate a fair amount on heading. Landing no problem. Heading dynamic affected ability to perform tasks in other axes. | Objectionable features - lack of heading damping and the lag effects in heading. |

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TABLE B-X (Continued)

| Case | Conf. Parameters | Pilot-ALS Mode | N_p | FR | Pilot Comments | | | | | |
|------|--|----------------|-------|-----|--|--|--|---|--|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| D6 | ECI $K_p = -0.5$ $K_{\dot{\omega}} = -0.1$ $T_D = 0$ $\zeta_D = 0.1$ | B-FB | 0.270 | 3-5 | Selected to get desired heading rate of change. | No problem. Relatively easy to hold heading. Had to make some corrective heading inputs when maneuvering laterally but heading was well damped. Didn't develop any heading oscillations. | No difficulty in performing these tasks. Some corrective inputs required when maneuvering laterally, but could make a good sharp lateral quick stop. | Relatively easy to set up and hold a heading rate and stop precisely at new heading. Wing tilt control was used a small extent. | Hover not difficult. No interaction between heading dynamics and control of other axes. | No objectionable features, this is a good case. Heading is well damped, no evident lags. |
| D7 | ECI $K_p = -0.5$ $K_{\dot{\omega}} = -0.1$ $T_D = 0.3$ $\zeta_D = 0$ | A-FB | 0.273 | 4-5 | Set to maintain directional control in presence of gusts and lags in the directional control. | Performance fairly good, but had some difficulty controlling heading during lateral maneuvers due to gust effects and directional coupling to lateral speed. | Only difficulty was associated with heading control during changes in lateral velocity. | Heading was very responsive to pedals but required anticipation to stop at desired heading due to lags in directional control. Used a small amount of wing tilt control. | Hover performance good but did require attention on direction. | Most objectionable features were related to slightly low headings in direction, gust effects on direction and lag in response to directional control inputs. |
| | | B-FB | 0.181 | 5 | Selected to control heading oscillations, especially when trying to hold heading precisely during maneuver or hover. | Ability to maneuver was affected by difficulty in holding heading. Heading tended to oscillate 35 deg about constantly. Heading was never really stable. Lateral maneuver especially difficult. | Could perform these tasks, but heading required a fair amount of attention. Difficult to control height because of attention required for heading. | Could turn over the spot fairly well and stop heading precisely. Didn't seem to get into heading oscillations. Wing tilt control used to some extent. | Had some difficulty hovering because of heading control. Vertical landing heading did affect ability to control in other axes. | Objectable features - the lack of damping in heading and/or the lags. |
| | | B-HB | 0.259 | 4-5 | Selected to get heading to desired heading and also to control heading oscillations. | In lateral maneuver had a tendency to develop heading errors and oscillations. Oscillations generally were low level and not too difficult to control, but annoying. | In lateral quick stops had to watch heading fairly closely and make corrections which could develop into oscillations. | If performed slowly could turn and stop precisely, but if heading rates built up and tried to arrest heading abruptly, tended to develop significant heading oscillations. Difficult to damp. | Hover and landing no problem. Think heading affected ability to control roll and lateral motion. | Objectable features - Don't like the oscillatory characteristics in heading. The lag is apparently present. |
| D8 | ECI $K_p = -0.5$ $K_{\dot{\omega}} = -0.1$ $T_D = 0.3$ $\zeta_D = 0.1$ | B-FB | 0.280 | 5-5 | Selected to get desired turn rate for heading control. | Found it difficult to stabilize heading when maneuvering laterally. Built up fairly significant oscillations in heading (about 310 to 325 deg) that affected ability to perform lateral maneuver. | Only lateral quick stop was difficult. Ability to perform quick stop affected by the heading control difficulty. | Could develop and hold turn rate fairly well, but had difficulty stopping on desired heading and stabilizing it. Wing tilt control used to some small extent. | No problem with hover. Had to be light on heading oscillations relatively small. Landing no difficulty. Heading control definitely affected ability to perform lateral maneuvers. | Heading control objectionable, the lags are simply too large. Tend to develop oscillations. |
| | | B-HB | 0.226 | 5 | Selected to control heading oscillations. | Developed heading oscillations when maneuvering both laterally and longitudinally. Somewhat difficult to control heading. Tends to stray away, very oscillatory. | Especially during lateral quick stops heading was oscillatory and required significant amount of attention. | Had to be careful not to slide by desired heading. Very easy to do with this case. | Hover and vertical landing not difficult. Heading control affected ability to control pitch, roll and to some extent height. Took attention away from these other axes. | Objectable features - Lack of damping and lag in heading control. |
| | | A-FB | 0.235 | 4 | Set for desired response while making heading changes. | Relatively easy except lateral maneuver required attention to maintain heading. Performance relatively good however. | Required a little more attention on heading. | Performance fairly good although couldn't maintain a constant turn rate very accurately. Required a little anticipation to stop at desired heading and some difficulty stabilizing it. | Precision hover and landing performance good and required very little effort. | Only objectionable feature was that directional damping was slightly low. |
| D9 | ECI $K_p = -0.5$ $K_{\dot{\omega}} = -0.1$ $T_D = 0.6$ $\zeta_D = 0$ | B-FB | 0.252 | 6 | Selected to get desired turn rate for an acceptable pedal input and also in an attempt to hold control heading oscillations. | Performance affected by lack of damping and lags in heading. Tended to develop fairly constant heading oscillations during maneuver. This was more pronounced while maneuvering laterally. | Ability to perform this task also affected by the lack of damping in heading. | Could turn fairly well and control turn rate without much difficulty, but it was tough to hold a heading. Wing tilt used a little. | While hovering was oscillating in heading. Could hover fairly well, but at times hover position was affected by attention being diverted to heading. Had to watch heading while landing. Lack of damping and lag in heading affected ability to control roll pitch and height. | Needs some more damping in heading or reduction in lags. Almost impossible to damp out heading oscillations; ability to control other axes is affected. |
| D10 | ECI $K_p = -0.5$ $K_{\dot{\omega}} = -0.1$ $T_D = 0.6$ $\zeta_D = 0.1$ | B-FB | 0.248 | 6 | Selected to get turn rate desired for a given pedal input. | Could perform the longitudinal maneuver relatively well, but lateral maneuver was more difficult. Had to be very careful to avoid exciting heading oscillations. Could not control heading too tightly. Very definite tendency to build up PIO's in heading. | Difficult to perform. Had to be careful about heading control. | Not too difficult, but it was tough to stop on a given angle precisely. Tendency to oscillate to fairly large heading angles. | Could perform hover and landing fairly well, but heading did tend to wander. Very definite lack of damping, the lags in heading affect ability to control pitch and especially roll. | The PIO tendency in heading due to lags and lags are objectionable. All cases with large lags are somewhat unusual in that if control inputs kept small they aren't that bad, but one can develop large oscillations so quickly that they must be regarded as undesirable. |
| D11 | ECI $K_p = -1.0$ $K_{\dot{\omega}} = -0.1$ $T_D = 0.1$ $\zeta_D = 0$ | B-FB | 0.306 | 3 | Selected to get the desired turn rate. | Could perform this maneuver quite well, heading control no problem. Noticed some very slight oscillations in heading, but not difficult to control. | Noticed some slight oscillatory tendency in heading, very, very slight, easily correctable. | Could turn precisely, select turn rate desired without too much trouble. Wing tilt control used a little to correct the effects of mean wind. | No problem. Some slight tendency to oscillate heading and turn in heading but didn't affect ability to hover or land precisely. | No real objectionable features. Slight tendency for heading to oscillate, but not difficult to control. |

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TABLE B-X (Continued)

| Case | Conf. Parameters | Mach. Cim. Mode | β_{sp} | FR | Pilot Comments | | | | | |
|------|---|-----------------|--------------|-----|---|--|--|--|---|---|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| D12 | BC1 $\beta_{sp} \sim 1.0$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ | B-FB | 0.294 | 2 | Selected to get desired turn rate response to pedal inputs. | Could perform both lateral and longitudinal maneuvers precisely while paying very little attention to heading control. Heading quite stable, no tendency towards oscillations. | No difficulty. | Could turn quite precisely, stop abruptly and remain there without oscillation. Heading control no problem. | Could hover quite accurately, hold position well without having to worry about heading. | No objectionable features. All axes well damped. Comfortable aircraft to fly. |
| D13 | BC1 $\beta_{sp} \sim 1.0$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ | A-FB | 0.341 | 3 | Set to get desired heading response. | During air taxi heading response was relatively easy and gust effects and coupling to lateral velocity were rather minimal. | Required some attention to control heading due to lateral velocity coupling during the lateral quick stop maneuvers. | May to maintain a constant turn rate and to stop at desired heading. May have noticed a very slight lag in directional response but because of the relatively slow control in direction this was of no particular problem. | Hover and landing no problem. | Good directional control characteristics. |
| | | B-FB | 0.313 | 4 | Selected to get desired turn rate response to pedal inputs. | Could perform task fairly well. Annoyed at times by the slight oscillation that built up in heading, say 15 deg. Seemed to excite it more often than maneuvering laterally, required some attention to damp it. | Could perform the quick stops rather well but at times had some problems with the heading oscillations. | Could perform task quite well. Could turn at desired rate, stop precisely, and hold heading without too much trouble. Remained over the spot fairly well. | Could hover quite accurately and land without too much trouble. Some interaction between the heading control requirements and ability to control other axes. | Slight oscillation that built up in heading periodically was probably the only objectionable feature in heading. |
| | | B-NB | 0.275 | 3.5 | Selected to get desired turn rates. | No problem either laterally or longitudinally. Laterally did develop some small heading noise but no real oscillations and easily controlled. | No problem longitudinally. Laterally had to watch heading a little but it was quite easy to stabilize. | No real problem stabilizing heading after the turn. | Precision hover and vertical landing not difficult. Heading control did not affect other axes. | No significant objectionable features. Heading a little oscillatory. |
| D14 | BC1 $\beta_{sp} \sim 1.0$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ | A-FB | 0.298 | 3 | Set for desired heading response to pedal inputs | Relatively effortless but had to give a little attention to heading control during lateral maneuvers. Gust effects on direction were minimal. | Task posed no particular problems. | Turn rate control quite good and would stop at desired heading with relatively little anticipation. Used relatively little wing tilt control. | Performance was good and required very little effort. | Mildly annoying characteristics here were slight gust effects and control lags in heading, however, only slightly noticeable and little attention required. |
| | | B-FB | 0.305 | 4.5 | Selected to get desired rate of heading change. | Task not difficult longitudinally; laterally had some difficulty holding heading and developed heading oscillations that at times affected ability control lateral displacement. | Lateral quick stops required attention in heading; feel performance degraded by lags in heading control. | Could hold and develop a turn rate fairly well but tended to develop some oscillations after attempting to arrest the heading. Wing tilt control was used a little. | Hover and landing presented no problems. Heading dynamics did affect ability to control laterally somewhat. | Objectionable feature was the lag in heading, although it could have been worse. |
| | | B-NB | 0.270 | 3.5 | Selected to get desired turn rates. | Noticed some slight heading oscillations for both lateral and longitudinal maneuver, but in general could control them while paying only moderate attention. | Heading oscillations were evident for both lateral and longitudinal quick stops, but it was not particularly difficult to control. Possibly ability to perform the task was degraded slightly due to attention devoted to heading. | Not too difficult, some tendency to slide by desired heading and then develop oscillations when attempting to recover. | Precision hover and vertical landing not difficult. Heading dynamics did affect ability to control pitch and roll to some small extent. | Would like more damping or less lag in heading. |
| D15 | BC1 $\beta_{sp} \sim 1.0$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ | A-FB | 0.271 | 4 | Set to get desired heading response. | Had to give some attention to directional control, especially during lateral maneuver due to some gust effects and due to directional coupling to lateral velocity. | During the lateral transition had to give some attention to heading control. | Turn rate control wasn't quite as good as desired and it required a little anticipation to stop at desired heading. Lags were not particularly noticeable. | Hover performance was good only direction required a small amount of attention. | Most objectionable feature seemed to be a slight deficiency in damping in direction needed to suppress gust disturbances and minimize disturbances due to lateral maneuvering velocity. |
| | | B-FB | 0.237 | 5 | Selected to control some what unstable heading when attempting to hold it closely, used reduced value so that wouldn't excite motion. | Could be performed, but heading affected precision, this was especially true when maneuvering laterally. Couldn't keep from exciting heading oscillations which were about 7/10 deg. | Too much attention necessary for heading control to keep it from oscillating. | Could perform task alright. Turn was performed relatively slowly but quite accurately. Wing tilt control was used. | Could hover fairly well, didn't have too much difficulty holding heading in hover and landing. Heading dynamics affected ability to control during lateral maneuvers and quick stops. | Objectionable features were lack of heading damping and/or the lags in heading. |
| | | B-NB | 0.258 | 5 | Selected to get turn rate and also to help in controlling heading oscillations. | During lateral maneuvers had to watch heading but didn't seem to get into any large oscillations. Some annoyance since had to pay more attention to it than desired. | Had to watch heading in lateral quick stop. Possible to get into fairly substantial oscillations in heading. | Approached turns very carefully. Didn't want to develop large oscillations which could happen if rapid turn attempted. | Precision hover and vertical landing no problem. Heading dynamics affected ability to control somewhat. | The lag in heading control which led to heading oscillations during the turn and lateral maneuvers was objectionable. |
| D16 | BC1 $\beta_{sp} \sim 1.0$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ $\beta_{sp} \sim 0.1$ | A-FB | 0.306 | 4 | Selected to stabilize heading control. | Had some trouble during lateral maneuvers holding heading and at times almost had a PIO-type situation in controlling heading. Heading was disturbed to some extent by gusts and by the coupling with lateral velocity. Had some difficulty commanding and holding heading without overshooting the desired heading. | Had heading control problems similar to those in air taxi. | Wasn't too difficult, but it required some anticipation to stop at desired heading. Very little wing tilt control used. | Hover wasn't too bad, although had to provide some concentration on heading to hold within 25 deg. | Biggest problem was commanding and holding at desired heading. Seemed to be some lag in the response and at times almost got into a PIO-type situation. |

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TABLE B-X (Continued)

| No. | Conf. Parameters | Pilot's Sin. Mode | N _z | P _z | Pilot Comments | | | | | |
|-----|--|-------------------|----------------|----------------|--|--|---|---|---|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 116 | K1 N _z =-1.0 N _z =UL T _z =0.6 Q _z =0.1 | B-7E | 0.300 | 5.5 | Selected to get desired turn rate response. | Had some difficulty stabilizing heading. Heading would tend to oscillate through fairly large angular swings, 15 to 15 deg, during lateral maneuvers. Had to keep pedal inputs as small as possible. | Lateral quick stops did present somewhat of a problem, had to watch heading closely and keep correcting it as it tended to oscillate some. | Could turn over the spot fairly accurately and stop fairly well. Kind of difficult to hold turn rate; rates would tend to build up and then taper off. | Precision hover and vertical landing presented no problem. Large lag in heading affected ability to control laterally. | The oscillatory characteristic in heading and the lag in response was objectionable. |
| | | B-ME | 0.264 | 4.5 | Selected to get desired turn rates. | No real problem. Could perform both laterally and longitudinally without difficulty. Had to watch heading a little during the lateral maneuvers and correct for some heading action. | Again no problem. Had to correct for heading changes during lateral maneuvers but not difficult. | Could turn precisely and stop fairly quickly. Every now and then developed a small oscillation but not difficult. | Precision hover and vertical landing no problem. Heading control didn't affect ability to control other axes. | Objectionable features - small oscillatory tendency in heading. |
| 117 | K1 N _z =-0.5 N _z =0.10 T _z =0. Q _z =0. | B-7E | 0.238 | 6 | Selected to get desired turn rate for a given pedal input. | Laterally ran into difficulties. Didn't have enough control power to counteract the effects of N _z when maneuvering laterally; this was bad to oscillations. Had to be very careful to keep heading as close to zero as possible because if a yaw error developed there was no way to get heading back during maneuver. | Same situation during the lateral quick stops and some got into some moderate oscillations during the lateral quick stop. | Not difficult. At a low turn rate can stop precisely and hold heading relatively well. Wing tilt control used to a small extent. | No problem with heading during hover or landing. The lack of control power in heading coupled with the low damping affected ability to control roll and lateral position. | The lack of directional control power and damping is the primary objectionable feature. |
| 118 | K1 N _z =-0.5 N _z =0.13 T _z =0. Q _z =0. | B-7E | 0.230 | 4 | Selected to get desired turn rate response. | Not difficult. Laterally somewhat more difficult as could introduce some relatively small heading oscillations. Rubbed a little when maneuvering laterally by the lack of control power and damping, but in general could perform these tasks without much difficulty. | Could perform the lateral quick stop fairly precisely and make a large heading change to stop abruptly, but had to watch heading somewhat. | No difficulty except had to avoid building up high turn rates so as to not overshoot desired heading. | Hover and vertical landing not difficult. Some rime interaction between heading dynamics and roll control, lateral position control. | Control power is just marginal, would like to see a little more damping in heading, but the case isn't too bad. |
| 119 | K1 N _z =-0.5 N _z =0.16 T _z =0. Q _z =0. | B-7E | 0.239 | 3.5 | Selected to get desired turn rate. | Really no great difficulty in performing air task. Some oscillatory characteristics in heading during lateral maneuvers, but easily controlled. | Could perform reasonably precisely, but again some oscillations characteristic in heading when trying to perform the lateral quick stop. | Generally not difficult, but must avoid building up high turn rates so as to not overshoot heading and go into oscillations. | Hover and vertical landing no problem. Lack of damping in heading had slight effect on ability to control laterally. | Would like to see a little more damping in heading, but the case isn't too bad. |
| 120 | K1 N _z =-1.0 N _z =0.10 T _z =0. Q _z =0. | A-7E | 0.208 | 3 | Set for desired directional response. | Performance fairly good and noticed no deficiencies in control power or damping. | Noticed a little lack of directional control power when maneuvering laterally while trying to hold heading. | Could not turn at a very high rate due to inadequate directional control power. Practically allowed to a stop when 90 deg to the wind. Had to anticipate desired heading because of insufficient control power. | Precision hover performance was good and there were no difficulties. | Most objectionable feature was the insufficient directional control power. Could perform the task but it required some additional compensation and workload. |
| | | B-7E | 0.206 | 5.5 | Selected to get desired turn rate response. | Was out of control power during lateral maneuvers, couldn't counteract the effect of N _z in lateral maneuver to left the nose rotated to the left and couldn't bring it back. | No problem longitudinally but developed some heading oscillations during the lateral quick stop because of deficiency in control power. | Could perform this relatively well, but could not turn particularly fast. Had to be careful to turn slowly to avoid overshooting desired heading. | No problem with hover and landing. The lack of heading control power did affect ability to control laterally during lateral quick stop and during the lateral maneuvers. | The lack of directional control power was objectionable, really need some more to perform the tasks adequately. |
| | | B-ME | 0.293 | 7 | Selected to get desired turn rates. | Longitudinal maneuver no problem. In lateral maneuvers tended to run out of yaw control power when large turn rates built up. Affected ability to hold heading. | Generally not difficult, some tendency to develop larger than desirable heading angles when maneuvering laterally. | Difficult to control heading. Could arrest turn rate, but when at 90 deg to the mean wind it was difficult to stabilize heading. Need more control power. | These tasks not difficult. Lack of directional control power definitely affected ability to control pitch and roll. | Lack of directional control power in heading was very objectionable. |
| 121 | K1 N _z =-1.0 N _z =0.23 T _z =0. Q _z =0. | A-7E | 0.236 | 3 | Set for desired directional response. | Directional damping was good and had no problem performing the air task maneuver or holding heading during that maneuver. | Quick stop maneuvers no problem. | Had good rate control, however, when 90 deg to the mean wind noticed a lack of control power as relatively slow turn rate didn't degrade performance and only slightly objectionable. | Hover performance good and directional control quite adequate. | Only slightly objectionable feature was a noticeable reduction in directional control power when 90 deg to the mean wind. |
| | | B-7E | 0.306 | 3.5 | Selected to get turn rates that were desirable. | Could perform without difficulty. Had to be somewhat careful to avoid developing large heading rates. As long as directional inputs were moderate, could control quite well, but noticed the lack of control power every now and then when heading rates got a little large. | Could perform these tasks quite well, both lateral and longitudinal. | Not difficult, but had to avoid developing turn rates which were too large. If turn too rapid would overshoot and it would be difficult to get heading under control again. With small turn rates no problem. | Hover and landing no problem. No noticeable interaction of heading with roll and pitch. | Just a slight lack of yaw control power. Would like to see a little more in case of large heading rates or an emergency. |
| | | B-ME | 0.254 | 2.5 | Selected to get desired turn rates. | No problem with lateral or longitudinal maneuvers. No apparent shortage of control power. | Could perform these maneuvers fairly precisely. No loss of control power evident. Had to be concerned to a limited extent with heading, but it was well damped. | No difficulty, could turn rapidly, stop precisely. Again no evidence of a lack of control power even when 90 deg to the mean wind. | No difficulty with hover and landing. No interaction of heading with other axes. | No real objectionable features. Good characteristics in heading. |

TABLE B-X (Concluded)

| Case | Conf. Parameters | Pilot Sim. Mode | $\frac{V}{V_T}$ | FR | Pilot Comments | | | | | |
|------|--|-----------------|-----------------|-----|--|---|---|--|---|--|
| | | | | | Selection of Control Sensitivities | Maneuvering | Quick Stops | Turn-Over-a-Spot | Precision Hover, Vertical Landing, Secondary Dynamics | Overall Evaluation |
| 720 | $K_1 = -1.0$ $K_2 = -0.16$ $\tau = 0.0$ $\zeta = 0.0$ | A-FB | 0.287 | 1 | Set for desired response to pedal inputs. | Good control during air taxi, only slight attention required to control heading during the lateral maneuver. Good damping and adequate control power about all axes. | No particular problems, but lateral quick stop required some attention. | Turn rate could be held quite accurately and there was no problem in stopping at desired heading. Adequate directional control power to control mean wind effects. | Hover performance was very good and required very little attention. | Noticed no deficiency in control power and could perform the tasks quite well. |
| | | B-FB | 0.366 | 2 | Selected for desired heading response for turns. | No problem laterally or longitudinally. Could perform these tasks precisely and didn't have to compensate much for heading changes. Heading quite stable, not affected much at all during lateral maneuvers. Plenty of control power. | Same type of comments as for maneuvering. | No problem, could turn precisely and rapidly and still stop accurately. Wing tilt control used to a small extent. | Not at all difficult to hover and land, could perform these tasks precisely and they weren't at all affected by the heading dynamics. | No objectionable features. Good case. |
| | | L-WB | 0.294 | 2.5 | Selected to get desired turn rate response. | Lateral and longitudinal maneuvers no problem. Well damped. Fine heading control, no indication of a lack of control power. | No problem. Could perform the lateral quick stop precisely, small compensatory inputs in heading. | Also no problem, can turn rapidly, stop precisely. | Precision hover and vertical landing not difficult. No interaction among the dynamics. | No objectionable features. Good case. |

Contrails

APPENDIX C

SUMMARY OF CONTROL-POWER-USAGE DATA

Control-power-usage data, which generally consist of the control power levels exceeded five percent of the time, are listed in this Appendix. For some of the studies concerned with control-power limits, the percent times that the control power command exceeded these limits are also presented. Data are shown in this Appendix only for selected test cases, i.e., the exceedance computations were not performed on all the cases considered in the UARL program.

The control-power-usage data tables also generally parallel the tables in Appendices A and B. Control-moment data from the longitudinal and lateral control studies are summarized in Tables C-I through C-VI as follows: C-I, turbulence effects; C-II, control lags and delays; C-III, control-moment limits; C-IV, inter-axis motion coupling; C-V, independent thrust-vector control; and C-VI, rate-command/attitude-hold control. Thrust-usage data from the height control study are presented in Table C-VII. Results from the studies of the interactive effects of height velocity damping and thrust-to-weight ratio and thrust lags and delays are shown there. Control-moment-usage data from the directional control studies are contained in the last table, C-VIII.

TABLE C-1

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT
OF THE TIME FROM THE STUDY OF TURBULENCE INTENSITY

Vertical and Directional Parameters Listed in Table A-1
See End of Table for Explanation of Notes

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Turbu- lence, $\alpha_k = \sigma_{v_k}$ | Sub- task ³ | Fixed Base | | | | | | | | Moving Base | | | | |
|--|---------------------------------------|---------------|---------------|--------------------|---|---------------------------|------------|-----------|--------------------|-----------|-----------|-----------|--------------------|-----------|-------------|-----------|--------------------|-----------|--|
| | | | | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | | |
| | $M_{\dot{\delta}}$ | $X_{\dot{u}}$ | $M_{\dot{v}}$ | $M_{\dot{\theta}}$ | | | M_{c_5} | I_{c_5} | $\Delta \dot{m}^4$ | N_{c_5} | M_{c_5} | I_{c_5} | $\Delta \dot{m}^4$ | N_{c_5} | M_{c_5} | I_{c_5} | $\Delta \dot{m}^4$ | N_{c_5} | |
| T1 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 3.4 | XM | 0.33 | | 0.38 | | 0.35 | | 0.45 | | 0.35 | | 0.39 | | |
| | | | | | | YM | | 0.22 | 0.38 | | | 0.40 | 0.58 | | | 0.27 | 0.43 | | |
| | | | | | | XQS | 0.34 | | 0.39 | | 0.39 | | 0.50 | | 0.30 | | 0.42 | | |
| | | | | | | YQS | | 0.44 | 0.54 | | | 0.58 | 0.70 | | | 0.32 | 0.50 | | |
| | | | | | | TU | 0.28 | 0.30 | 0.45 | 0.07 | 0.33 | 0.48 | 0.64 | 0.05 | 0.28 | 0.28 | 0.42 | 0.03 | |
| | | | | | | HCV | 0.26 | 0.22 | 0.43 | | 0.31 | 0.35 | 0.57 | | 0.26 | 0.23 | 0.47 | | |
| T2 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 5.8 | XM | | | | | 0.40 | | 0.52 | | | | | | |
| | | | | | | YM | | | | | | 0.39 | 0.57 | | | | | | |
| | | | | | | XQS | | | | | 0.48 | | 0.58 | | | | | | |
| | | | | | | YQS | | | | | | 0.62 | 0.70 | | | | | | |
| | | | | | | TU | | | | | 0.27 | 0.44 | 0.63 | 0.15 | | | | | |
| | | | | | | HCV | | | | | 0.79 | 0.30 | 1.01 | | | | | | |
| T3 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 8.2 | XM | 0.48 | | 0.78 | | 0.41 | | 0.70 | | 0.43 | | 0.63 | | |
| | | | | | | YM | | 0.46 | 0.66 | | | 0.57 | 0.80 | | | 0.34 | 0.61 | | |
| | | | | | | XQS | 0.44 | | 0.62 | | 0.56 | | 0.87 | | 0.44 | | 0.60 | | |
| | | | | | | YQS | | 0.73 | 0.55 | | | 0.48 | 0.81 | | | 0.38 | 0.65 | | |
| | | | | | | TU | 0.37 | 0.45 | 0.69 | 0.08 | 0.46 | 0.51 | 0.71 | 0.09 | 0.37 | 0.25 | 0.52 | 0.07 | |
| | | | | | | HCV | 0.43 | 0.30 | 0.60 | | 1.38 | 0.38 | 1.56 | | 0.38 | 0.30 | 0.60 | | |
| T4 - BC5 | 0.33 | -0.20 | -1.7 | -4.2 | 3.4 | XM | 0.40 | | 0.47 | | 0.39 | | 0.50 | | 0.29 | | 0.43 | | |
| | | | | | | YM | | 0.39 | 0.57 | | | 0.39 | 0.58 | | | 0.29 | 0.45 | | |
| | | | | | | XQS | 0.53 | | 0.57 | | 0.45 | | 0.59 | | 0.37 | | 0.40 | | |
| | | | | | | YQS | | 0.63 | 0.72 | | | 0.54 | 0.73 | | | 0.34 | 0.53 | | |
| | | | | | | TU | 0.44 | 0.26 | 0.55 | 0.11 | 0.35 | 0.38 | 0.56 | 0.11 | 0.29 | 0.20 | 0.40 | 0.07 | |
| | | | | | | HCV | 0.35 | 0.19 | 0.46 | | 0.44 | 0.39 | 0.65 | | 0.40 | 0.28 | 0.53 | | |
| T5 - BC4 | 1.0 | -0.20 | -3.0 | -1.7 | 3.4 | XM | 0.86 | | 1.15 | | 0.85 | | 1.05 | | 0.97 | | 1.17 | | |
| | | | | | | YM | | 0.79 | 1.32 | | | 0.50 | 1.01 | | | 0.56 | 1.14 | | |
| | | | | | | XQS | 0.89 | | 1.03 | | 0.89 | | 1.07 | | 0.90 | | 1.07 | | |
| | | | | | | YQS | | 0.87 | 1.58 | | | 0.49 | 1.03 | | | 0.48 | 1.15 | | |
| | | | | | | TU | 0.73 | 0.65 | 1.02 | 0.20 | 0.71 | 0.73 | 1.12 | 0.13 | 0.76 | 0.48 | 0.94 | 0.05 | |
| | | | | | | HCV | 0.83 | 0.44 | 1.16 | | 0.77 | 0.35 | 0.90 | | 0.83 | 0.42 | 1.15 | | |

TABLE C-I (Concluded)

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Turbu- lence, $\sigma_{u_s} = \sigma_{q_s}$ | Sub- task ³ | Fixed Base | | | | | | | | Moving Base | | | | |
|--|------------------------------------|---------------|---------------|---------------|---|---------------------------|------------|-----------|-------------------|-----------|-----------|-----------|-------------------|-----------|-------------|-----------|-------------------|-----------|------|
| | | | | | | | Pilot A | | | | Pilot B | | | | Pilot S | | | | |
| | $M_{\dot{u}}$ | $X_{\dot{u}}$ | $M_{\dot{q}}$ | $M_{\dot{r}}$ | | | X_{c_5} | Y_{c_5} | Sim. ⁴ | N_{c_5} | M_{c_5} | L_{c_5} | Sim. ⁴ | N_{c_5} | M_{c_5} | L_{c_5} | Sim. ⁴ | N_{c_5} | |
| T6 - BC2 | 1.0 | -0.05 | -1.1 | -2.5 | 3.4 | XM | 1.09 | | 1.46 | | 0.59 | | 1.18 | | 1.07 | | 1.24 | | |
| | | | | | | YM | | 0.75 | 1.37 | | | 0.64 | 1.25 | | | 0.74 | 1.36 | | |
| | | | | | | XQS | 0.95 | | 1.13 | | 1.0 | | 1.28 | | 1.09 | | 1.29 | | |
| | | | | | | YQS | | 1.14 | 1.47 | | | 0.68 | 1.22 | | | 0.74 | 1.22 | | |
| | | | | | | TU | 0.73 | 0.74 | 1.20 | 0.12 | 0.91 | 0.94 | 1.40 | 0.11 | 1.28 | 0.79 | 1.75 | 0.05 | |
| | | | | | | HOV | 0.07 | 0.54 | 1.29 | | 0.98 | 0.45 | 1.01 | | 0.98 | 0.43 | 1.18 | | |
| T13 - BC6 | 1.0 | -0.20 | -1.1 | -2.5 | 3.4 | XM | 0.87 | | 1.05 | | 0.92 | | 1.30 | | 0.90 | | 1.07 | | |
| | | | | | | YM | | 0.31 | 1.31 | | | 0.65 | 1.30 | | | 0.58 | 1.06 | | |
| | | | | | | XQS | 0.92 | | 1.05 | | 0.99 | | 1.32 | | 0.67 | | 1.01 | | |
| | | | | | | YQS | | 1.37 | 1.90 | | | 0.80 | 1.39 | | | 0.62 | 1.11 | | |
| | | | | | | TU | 0.81 | 0.68 | 1.08 | 0.09 | 0.95 | 0.75 | 1.32 | 0.13 | 0.89 | 0.52 | 1.14 | 0.13 | |
| | | | | | | HOV | 0.85 | 0.58 | 1.30 | | 0.77 | 0.37 | 0.98 | | 0.79 | 0.42 | 1.07 | | |
| T14 - BC6 | 1.0 | -0.20 | -1.1 | -2.5 | 5.3 | XM | | | | | 1.13 | | 1.60 | | 1.09 | | 1.50 | | |
| | | | | | | YM | | | | | | 0.92 | 1.64 | | | 0.83 | | | |
| | | | | | | XQS | | | | | | 1.31 | | | | 1.13 | 1.30 | | |
| | | | | | | YQS | | | | | | | 0.86 | | | 0.72 | 1.39 | | |
| | | | | | | TU | | | | | | 1.00 | 1.13 | 1.63 | 0.13 | 0.90 | 0.70 | 1.27 | 0.05 |
| | | | | | | HOV | | | | | | 1.31 | 0.97 | | | 1.03 | 0.54 | 1.21 | |
| T15 - BC6 | 1.0 | -0.20 | -1.1 | -2.5 | 8.2 | XM | 1.17 | | 1.90 | | 1.08 | | 1.85 | | | | | | |
| | | | | | | YM | | 1.21 | 1.87 | | | 0.93 | 1.58 | | | | | | |
| | | | | | | XQS | 1.57 | | 2.20 | | 1.18 | | 1.70 | | | | | | |
| | | | | | | YQS | | 1.51 | 2.00 | | | 1.29 | | | | | | | |
| | | | | | | TU | 1.53 | 1.07 | 1.90 | 0.18 | 1.09 | 1.21 | | 0.12 | | | | | |
| | | | | | | HOV | 1.21 | 1.14 | 1.90 | | 1.19 | 1.04 | 1.87 | | | | | | |
| T16 - BC3 | 1.0 | -0.05 | -2.0 | 0 | 3.4 | XM | 0.97 | | 1.28 | | 0.98 | | 1.13 | | 1.14 | | 1.31 | | |
| | | | | | | YM | | 0.82 | 1.35 | | | 0.97 | 1.41 | | | 0.55 | 1.33 | | |
| | | | | | | XQS | 1.02 | | 1.27 | | 1.03 | | 1.21 | | 1.24 | | 1.50 | | |
| | | | | | | YQS | | 1.32 | 1.80 | | | 0.80 | 1.24 | | | 0.54 | 1.16 | | |
| | | | | | | TU | 0.91 | 0.80 | 1.35 | 0.11 | 1.35 | 0.83 | 1.60 | 0.13 | 0.98 | 0.65 | 1.16 | 0.01 | |
| | | | | | | HOV | 0.81 | 0.60 | 1.24 | | 0.88 | 0.60 | 1.29 | | 0.87 | 0.35 | 1.04 | | |

1. Wind simulation included mean wind, $U_m = 10$ kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.

4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function $(|M_c| + |L_c|)$.

TABLE C-II

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT
OF THE TIME FROM THE STUDY OF CONTROL SYSTEM LAGS AND DELAYS

Vertical and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Lag T _e , T _a | Delay d _e , d _a | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | | | | | | | |
|--|---------------------------------------|----------------|----------------|----------------|--|--|---------------------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|--|--|--|--|--|--|--|--|--|
| | M _u g | X _u | M _q | M _θ | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | | | | | | | | |
| | | | | | | | | M _{C5} | L _{C5} | Sim. ⁴ | N _{C5} | M _{C5} | L _{C5} | Sim. ⁴ | N _{C5} | M _{C5} | L _{C5} | Sim. ⁴ | N _{C5} | | | | | | | | | |
| LL5 - BC5 | 0.33 | -0.20 | -1.7 | -4.2 | 0.31 | 0 | XM | | | | | 0.29 | | 0.38 | | | | | | | | | | | | | | |
| | | | | | | | YM | | | | | 0.37 | 0.48 | | | | | | | | | | | | | | | |
| | | | | | | | XQS | | | | | | | | 0.40 | | 0.45 | | | | | | | | | | | |
| | | | | | | | YQS | | | | | | | | | 0.58 | 0.69 | | | | | | | | | | | |
| | | | | | | | TU | | | | | | | | | 0.37 | 0.41 | 0.57 | 0.02 | | | | | | | | | |
| | | | | | | | HOV | | | | | | | | | 0.40 | 0.40 | 0.56 | | | | | | | | | | |
| LL6 - BC5 | 0.33 | -0.20 | -1.7 | -4.2 | 0.60 | 0 | XM | 0.29 | | 0.33 | | 0.33 | | 0.42 | | 0.31 | | 0.39 | | | | | | | | | | |
| | | | | | | | YM | | 0.20 | 0.37 | | | 0.32 | 0.49 | | | 0.20 | 0.41 | | | | | | | | | | |
| | | | | | | | XQS | 0.36 | | 0.40 | | 0.39 | | 0.42 | | 0.33 | | 0.40 | | | | | | | | | | |
| | | | | | | | YQS | | 0.62 | 0.75 | | | 0.47 | 0.67 | | | 0.27 | 0.47 | | | | | | | | | | |
| | | | | | | | TU | 0.29 | 0.28 | 0.52 | 0.02 | 0.28 | 0.36 | 0.50 | 0.02 | 0.32 | 0.26 | 0.45 | 0.02 | | | | | | | | | |
| | | | | | | | HOV | 0.28 | 0.18 | 0.37 | | 0.36 | 0.42 | 0.64 | | 0.30 | 0.21 | 0.46 | | | | | | | | | | |
| LL8 - BC4 | 1.0 | -0.20 | -3.0 | -1.7 | 0.31 | 0 | XM | 0.89 | | 1.13 | | 0.81 | | 0.94 | | 0.93 | | 1.21 | | | | | | | | | | |
| | | | | | | | YM | | 0.39 | 1.09 | | | 0.53 | 1.01 | | | 0.54 | 1.04 | | | | | | | | | | |
| | | | | | | | XQS | 0.88 | | 1.04 | | 0.85 | | 0.88 | | 0.82 | | 0.94 | | | | | | | | | | |
| | | | | | | | YQS | | 0.60 | 1.05 | | | 0.68 | 1.20 | | | 0.44 | 0.98 | | | | | | | | | | |
| | | | | | | | TU | 0.85 | 0.57 | 0.99 | 0.15 | 0.84 | 0.53 | 0.98 | 0.02 | 0.74 | 0.60 | 1.04 | 0.02 | | | | | | | | | |
| | | | | | | | HOV | 0.66 | 0.28 | 0.87 | | 0.73 | 0.36 | 0.92 | | 0.84 | 0.37 | 1.06 | | | | | | | | | | |
| LL9 - BC4 | 1.0 | -0.20 | -3.0 | -1.7 | 0.60 | 0 | XM | 0.73 | | 0.85 | | 0.88 | | 0.99 | | | | | | | | | | | | | | |
| | | | | | | | YM | | 0.71 | 1.27 | | | 0.64 | 1.14 | | | | | | | | | | | | | | |
| | | | | | | | XQS | 0.98 | | 1.14 | | 0.88 | | 1.08 | | | | | | | | | | | | | | |
| | | | | | | | YQS | | 0.68 | 1.13 | | | 0.69 | 1.17 | | | | | | | | | | | | | | |
| | | | | | | | TU | 0.63 | 0.56 | 0.86 | 0.02 | 0.70 | 0.67 | 0.98 | 0.02 | | | | | | | | | | | | | |
| | | | | | | | HOV | 0.66 | 0.41 | 0.89 | | 0.82 | 0.39 | 1.09 | | | | | | | | | | | | | | |
| LL14 - BC6 | 1.0 | -0.20 | -1.1 | -2.5 | 0.31 | 0 | XM | 0.73 | | 1.03 | | 0.93 | | 1.15 | | 0.82 | | 1.11 | | | | | | | | | | |
| | | | | | | | YM | | 0.82 | 1.09 | | | 0.52 | 1.07 | | | 0.62 | 1.12 | | | | | | | | | | |
| | | | | | | | XQS | 0.96 | | 1.27 | | 0.90 | | 1.09 | | 0.79 | | 1.07 | | | | | | | | | | |
| | | | | | | | YQS | | 0.84 | 1.19 | | | 0.64 | 1.16 | | | 0.56 | 1.15 | | | | | | | | | | |
| | | | | | | | TU | 0.87 | 0.55 | 1.09 | 0.07 | 0.79 | 0.63 | 1.11 | 0.07 | 0.79 | 0.69 | 1.15 | 0.05 | | | | | | | | | |
| | | | | | | | HOV | 0.66 | 0.44 | 0.94 | | 0.90 | 0.49 | 1.19 | | 0.75 | 0.49 | 1.12 | | | | | | | | | | |

TABLE C-II (Concluded)

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | $\frac{L_{a_1}}{\tau_e, \tau_a}$ | Delay d_e, d_a | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | |
|--|---------------------------------------|-------|---------------|--------------------|----------------------------------|---------------------|---------------------------|------------|-----------|-------------------|-----------|-----------|-----------|-------------------|-----------|-------------|-----------|-------------------|-----------|
| | | | | | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | |
| | M_{u_5} | X_u | $M_{\dot{q}}$ | $M_{\dot{\theta}}$ | | | | M_{c_5} | L_{c_5} | Sim. ⁴ | N_{c_5} | M_{c_5} | L_{c_5} | Sim. ⁴ | N_{c_5} | M_{c_5} | L_{c_5} | Sim. ⁴ | N_{c_5} |
| LL15 - BC6 | 1.0 | -0.20 | -1.1 | -2.5 | 0.60 | 0 | XM | | | | 0.81 | | 1.13 | | | | | | |
| | | | | | | | YM | | | | | 0.59 | 1.28 | | | | | | |
| | | | | | | | XQS | | | | | 0.78 | | 1.04 | | | | | |
| | | | | | | | YQS | | | | | | 0.68 | 1.29 | | | | | |
| | | | | | | | TU | | | | | | 0.96 | 0.72 | 1.37 | 0.08 | | | |
| | | | | | | | HOV | | | | | | 0.94 | 0.58 | 1.18 | | | | |
| LL 23 - BC1 | 0.33 | -0.20 | -1.7 | -4.2 | 0 | 0.1 | XM | | | | 0.34 | | 0.48 | | | | | | |
| | | | | | | | YM | | | | | 0.29 | 0.47 | | | | | | |
| | | | | | | | XQS | | | | | 0.35 | | 0.42 | | | | | |
| | | | | | | | YQS | | | | | | 0.53 | 0.67 | | | | | |
| | | | | | | | TU | | | | | | 0.29 | 0.34 | 0.52 | 0.12 | | | |
| | | | | | | | HOV | | | | | | 0.31 | 0.35 | 0.57 | | | | |
| LL-24 - BC1 | 0.33 | -0.20 | -1.7 | -4.2 | 0.3 | 0.1 | XM | | | | 0.33 | | 0.41 | | | | | | |
| | | | | | | | YM | | | | | 0.25 | 0.48 | | | | | | |
| | | | | | | | XQS | | | | | 0.33 | | 0.39 | | | | | |
| | | | | | | | YQS | | | | | | 0.37 | 0.56 | | | | | |
| | | | | | | | TU | | | | | | 0.25 | 0.24 | 0.39 | 0.11 | | | |
| | | | | | | | HOV | | | | | | 0.29 | 0.19 | 0.41 | | | | |
| LL-25 - BC1 | 0.33 | -0.20 | -1.7 | -4.2 | 0.3, 0 | 0.1, 0 | XM | | | | 0.59 | | 1.24 | | | | | | |
| | | | | | | | YM | | | | | 1.10 | 1.29 | | | | | | |
| | | | | | | | XQS | | | | | 0.85 | | 1.33 | | | | | |
| | | | | | | | YQS | | | | | | 1.14 | 1.34 | | | | | |
| | | | | | | | TU | | | | | | 0.68 | | | 0.09 | | | |
| | | | | | | | HOV | | | | | | 0.55 | 0.95 | 1.27 | | | | |

1. Wind simulation included mean wind, $U_m = 10$ kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, = 180 deg turn-over-a-spot; HOV, precision hover.
4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function $(|M_c| + |L_c|)$.

TABLE C-III

PERCENT TIME PITCH, ROLL AND YAW CONTROL-MOMENT
COMMANDS EXCEEDED INSTALLED MOMENT LIMITS

Vertical and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Maximum Control Moment Available | | | Lag $\tau_{\theta}, \tau_{\phi}$ | Delay d_{θ}, d_{ϕ} | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | |
|--|---------------------------------------|-------|-------|--------------------|--|----------|----------|-------------------------------------|---------------------------------|---------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|--|--|
| | | | | | | | | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | |
| | $M_{q\theta}$ | X_u | M_q | $M_{\dot{\theta}}$ | M_{cm} | L_{cm} | M_{cm} | | | | F _{ML} | F _{LL} | F _{SL} | F _{YL} | F _{ML} | F _{LL} | F _{SL} | F _{YL} | F _{ML} | F _{LL} | F _{SL} | F _{YL} | | |
| LM1 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 0.360 | 0.415 | 0.120 | 0 | 0 | YM | | | | 7.6 | | 1.6 | | 14.9 | | 0 | | | | |
| | | | | | | | | | | YM | | | | | 4.4 | 0.4 | | | 0 | 0 | | | | |
| | | | | | | | | | | XQS | | | | 21.4 | | 13.0 | | | 9.7 | | 0 | | | |
| | | | | | | | | | | YQS | | | | | 8.6 | 4.0 | | | 0 | 0 | | | | |
| | | | | | | | | | | TU | | | | 1.2 | 2.3 | 0 | 3.1 | 2.0 | 1.3 | 0 | 2.8 | | | |
| | | | | | | | | | | HOV | | | | 3.0 | 1.1 | 0.2 | | 0.8 | 0.2 | 0 | | | | |
| LM2 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 0.396 | 0.457 | 0.132 | 0 | 0 | XM | 0 | 0 | | 0.9 | | 0 | | 0 | | 0 | | | | |
| | | | | | | | | | | YM | | 0 | 0 | | 0.5 | 0 | | | 0 | 0 | | | | |
| | | | | | | | | | | XQS | 0 | | 0 | | 8.1 | | 0 | | 0.7 | | 0 | | | |
| | | | | | | | | | | YQS | | 0 | 0 | | | 4.3 | 0 | | | 0.2 | 0 | | | |
| | | | | | | | | | | TU | 0 | 0 | 0 | 0 | 0.9 | 1.5 | 0 | 0 | 0.3 | 0.4 | 0 | 0 | | |
| | | | | | | | | | | HOV | 0 | 0 | 0 | | 2.0 | 0.3 | 0 | | 0.2 | 0 | 0 | | | |
| LM3 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 0.432 | 0.498 | 0.144 | 0 | 0 | XM | | | | 2.3 | | 0 | | | | | | | | |
| | | | | | | | | | | YM | | | | | 0.1 | 0 | | | | | | | | |
| | | | | | | | | | | XQS | | | | 2.0 | | 0 | | | | | | | | |
| | | | | | | | | | | YQS | | | | | 2.8 | 0 | | | | | | | | |
| | | | | | | | | | | TU | | | | 0 | 1.6 | 0 | 0 | | | | | | | |
| HOV | | | | 1.9 | 0.3 | 0 | | | | | | | | | | | | | | | | | | |
| LM5 - BC5 | 0.33 | -0.20 | -1.7 | -4.2 | 0.300 | 0.280 | 0.120 | 0 | 0 | XM | | | | | | | | 1.02 | | 0 | | | | |
| | | | | | | | | | | YM | | | | | | | | | 1.6 | 0 | | | | |
| | | | | | | | | | | XQS | | | | | | | | 0 | | 0 | | | | |
| | | | | | | | | | | YQS | | | | | | | | | 2.0 | 0 | | | | |
| | | | | | | | | | | TU | | | | | | | | 0.6 | 1.7 | 0 | 0 | | | |
| HOV | | | | | | | | 0 | 0.3 | 0 | | | | | | | | | | | | | | |
| LM6 - BC5 | 0.33 | -0.20 | -1.7 | -4.2 | 0.350 | 0.360 | 0.150 | 0 | 0 | XM | 0 | | 0 | | | | | | | | | | | |
| | | | | | | | | | | YM | | 3.7 | 0 | | | | | | | | | | | |
| | | | | | | | | | | XQS | 3.5 | | 0 | | | | | | | | | | | |
| | | | | | | | | | | YQS | | 18.3 | 0 | | | | | | | | | | | |
| | | | | | | | | | | TU | 1.6 | 2.2 | 0 | 0 | | | | | | | | | | |
| HOV | 0 | 1.9 | 0 | | | | | | | | | | | | | | | | | | | | | |
| LM9 - BC4 | 1.0 | -0.20 | -3.0 | -1.7 | 0.902 | 0.666 | 0.193 | 0 | 0 | XM | | | | 1.8 | | 0 | | | | | | | | |
| | | | | | | | | | | YM | | | | | 0 | 0 | | | | | | | | |
| | | | | | | | | | | XQS | | | | 2.4 | | 0 | | | | | | | | |
| | | | | | | | | | | YQS | | | | | 0.1 | 0 | | | | | | | | |
| | | | | | | | | | | TU | | | | 0.5 | 6.1 | 0 | 0 | | | | | | | |
| HOV | | | | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | |

TABLE C-III (Concluded)

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Maximum Control Moments Available | | | Lag τ_e, τ_a | Delay τ_e, τ_a | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | |
|--|---------------------------------------|----------------|----------------|----------------|---|----------------|----------------|-------------------------|---------------------------|---------------------------|------------|----------|----------|----------|----------|----------|----------|----------|-------------|----------|----------|----------|
| | | | | | | | | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | |
| | $X_{u\dot{g}}$ | $X_{u\dot{u}}$ | $X_{u\dot{q}}$ | $X_{u\dot{g}}$ | $N_{c\dot{m}}$ | $L_{c\dot{m}}$ | $N_{c\dot{m}}$ | | | | F_{ML} | F_{LL} | F_{SL} | F_{PL} | F_{ML} | F_{LL} | F_{SL} | F_{PL} | F_{ML} | F_{LL} | F_{SL} | F_{PL} |
| LML0 - BC4 | 1.0 | -0.20 | -3.0 | -1.7 | 0.954 | 0.727 | 0.211 | 0 | 0 | XM | 0.3 | 0 | 0 | 0 | 2.3 | 0 | 0 | 0 | 0.2 | 0.2 | | |
| | | | | | | | | | | YM | 0.1 | 0 | 0 | 0 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | XQS | 1.7 | 0 | 0 | 0 | 0.8 | 0 | 0 | 3.2 | 0.0 | 0 | 0 | 0 |
| | | | | | | | | | | YQS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.06 | 0.0 | 0 | 0 |
| | | | | | | | | | | TU | 0 | 0 | 0 | 0 | 0 | 7.7 | 0 | 0 | 0.5 | 2.7 | 0 | 0 |
| | | | | | | | | | | HOV | 0 | 0 | 0 | 0 | 1.6 | 0 | 0 | 0.2 | 0 | 0 | 0 | |
| LML3 - BC6 | 1.0 | -0.2 | -1.1 | -2.5 | 0.979 | 0.825 | 0.187 | 0 | 0 | XM | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | | |
| | | | | | | | | | | YM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | XQS | 0 | 0 | 0 | 0 | 6.2 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | YQS | 0 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | TU | 0 | 0 | 0 | 0 | 0 | 0.2 | 2.6 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | HOV | 0 | 0 | 0 | 0 | 1.4 | 0.6 | 0 | 0 | 0 | 0 | 0 | |
| LML4 - BC4 | 1.0 | -0.2 | -1.1 | -2.5 | 1.068 | 0.900 | 0.204 | 0 | 0 | XM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | | | | | | | | | | YM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | XQS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | TU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0 | 0 |
| | | | | | | | | | | HOV | 0 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | |
| LML5 - BC6 | 1.0 | -0.2 | -1.1 | -2.5 | 1.157 | 0.975 | 0.221 | 0 | 0 | XM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | | | | | | | | | | YM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | XQS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | YQS | 0 | 3.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | TU | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | HOV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| LML7 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 0.396 | 0.457 | 0.132 | 0.3 | 0.1 | XM | 0 | 0 | 0 | 0 | 0.6 | 0 | 0 | 0.1 | 0 | 0 | | |
| | | | | | | | | | | YM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | XQS | 0 | 0 | 0 | 0 | 1.5 | 0 | 0 | 2.1 | 0 | 0 | 0 | |
| | | | | | | | | | | YQS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | TU | 0 | 0 | 0 | 0 | 0 | 0.3 | 0.3 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | HOV | 0 | 0 | 0 | 0 | 1.2 | 1.1 | 0 | 0 | 0.4 | 0.2 | 0 | 0 |
| LML8 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 0.432 | 0.498 | 0.144 | 0.3 | 0.1 | XM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | | | | | | | | | | YM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | XQS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0 | 0 | |
| | | | | | | | | | | YQS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | TU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | | HOV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | |

1. Wind simulation included mean wind, $U_m = 10$ kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.
4. F_{SL} : Percent time that commanded moments exceeded installed limit on simultaneous control moment usage, $(N_{cM} + L_{cM})$.

TABLE C-IV

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT
OF THE TIME FROM THE STUDY OF INTER-AXIS MOTION COUPLING

Vertical and Directional Parameters Listed in Table A-I

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Motion Coupling Parameters | | | | Sub- Task ³ | Fixed Base | | | | Moving Base | | | | | | | | | | | |
|--|---------------------------------------|----------------|----------------|----------------|----------------------------------|----------------|----------------------------|----------------------------|---------------------------|----------------------------|----------------------------|----------------------------|----------------------------|------------------|----------------------------|----------------------------|----------------------------|------------------|----------------------------|------|------|------|------|------|------|
| | | | | | | | | | | Pilot A | | Pilot B | | Pilot B | | | | | | | | | | | |
| | M _u E | Y _u | M _q | M _θ | M _p | L _q | M _{δ₁} | M _{δ₂} | | M _{δ₃} | M _{δ₄} | M _{δ₅} | L _{δ₅} | Sim ⁴ | N _{δ₅} | M _{δ₅} | L _{δ₅} | Sim ⁴ | N _{δ₅} | | | | | | |
| LC1 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 2 | -2 | 0 | 0 | XM | | | | 0.48 | | 0.67 | | 0.36 | | 0.43 | | | | | | |
| | | | | | | | | | YM | | | | | 0.39 | 0.66 | | | | 0.24 | 0.49 | | | | | |
| | | | | | | | | | XQS | | | | | | | | 0.43 | | 0.64 | | | 0.48 | | | 0.59 |
| | | | | | | | | | YQS | | | | | | | | | 0.56 | 1.03 | | | | 0.35 | | 0.75 |
| | | | | | | | | | TU | | | | | | | | 0.41 | 0.36 | 0.66 | 0.17 | 0.29 | 0.30 | 0.44 | | |
| | | | | | | | | | HOV | | | | | | | | 0.54 | 0.41 | 0.86 | | | 0.37 | 0.19 | 0.47 | |
| LC2 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 4 | -4 | 0 | 0 | XM | | | | 0.61 | | 0.88 | | | | | | | | | | |
| | | | | | | | | | YM | | | | | 0.54 | 0.96 | | | | | | | | | | |
| | | | | | | | | | XQS | | | | | | | | 0.81 | | 1.29 | | | | | | |
| | | | | | | | | | YQS | | | | | | | | | 0.91 | 1.57 | | | | | | |
| | | | | | | | | | TU | | | | | | | | 0.57 | 0.47 | 0.87 | 0.16 | | | | | |
| | | | | | | | | | HOV | | | | | | | | 0.68 | 0.47 | 1.01 | | | | | | |
| LC4 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 0 | 0 | 0.50 | -0.50 | XM | 0.40 | | 0.58 | | 0.39 | | 0.64 | | 0.34 | 0.42 | | | | | | |
| | | | | | | | | | YM | | 0.40 | 0.56 | | 0.38 | 0.54 | | | 0.24 | 0.45 | | | | | | |
| | | | | | | | | | XQS | 0.58 | | 0.79 | | 0.47 | | 0.68 | | 0.36 | | 0.42 | | | | | |
| | | | | | | | | | YQS | | 0.70 | 1.00 | | | 0.65 | | | | 0.31 | 0.54 | | | | | |
| | | | | | | | | | TU | 0.36 | 0.40 | 0.58 | 0.11 | 0.28 | 0.30 | 0.47 | 0.23 | 0.27 | 0.24 | 0.38 | | | | | |
| | | | | | | | | | HOV | 0.37 | 0.29 | 0.51 | | 0.37 | 0.34 | 0.65 | | 0.29 | 0.18 | 0.38 | | | | | |
| LC5 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 2 | -2 | 0.25 | -0.25 | XM | 0.37 | | 0.47 | | 0.43 | | 0.57 | | 0.35 | 0.48 | | | | | | |
| | | | | | | | | | YM | | 0.37 | 0.66 | | 0.39 | 0.69 | | | 0.33 | 0.53 | | | | | | |
| | | | | | | | | | XQS | 0.53 | | 0.70 | | 0.49 | | 0.72 | | 0.47 | | 0.62 | | | | | |
| | | | | | | | | | YQS | | 0.72 | 1.23 | | | 0.63 | 1.10 | | | 0.33 | 0.61 | | | | | |
| | | | | | | | | | TU | 0.32 | 0.33 | 0.53 | 0.06 | 0.40 | 0.39 | 0.65 | 0.17 | 0.29 | 0.24 | 0.42 | 0.05 | | | | |
| | | | | | | | | | HOV | 0.39 | 0.29 | 0.54 | | 0.53 | 0.39 | 0.78 | | 0.35 | 0.19 | 0.46 | | | | | |
| LC8 - BC2 | 1.0 | -0.05 | -2.5 | -0.5 | 2 | -2 | -0.25 | 0.25 | XM | | | | 0.87 | | 1.08 | | | | | | | | | | |
| | | | | | | | | | YM | | | | | 0.71 | 1.28 | | | | | | | | | | |
| | | | | | | | | | XQS | | | | | 0.85 | | 1.09 | | | | | | | | | |
| | | | | | | | | | YQS | | | | | | 0.70 | 1.32 | | | | | | | | | |
| | | | | | | | | | TU | | | | | 0.90 | 0.68 | 1.34 | 0.17 | | | | | | | | |
| | | | | | | | | | HOV | | | | | 0.77 | 0.47 | 1.03 | | | | | | | | | |

1. Wind simulation included mean wind, $U_m = 10$ kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.
4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function $(|M_c| + |L_c|)$.

TABLE C-V

PITCH CONTROL-MOMENT AND THRUST-VECTOR-ANGLE LEVELS EXCEEDED 5 PERCENT
OF THE TIME FROM THE STUDY OF INDEPENDENT THRUST-VECTOR CONTROL

Vertical and Directional Parameters Listed in Table A-I

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Thrust- Vector Control Param. | | | Sub- Task ³ | Fixed Base | | | | Moving Base | |
|--|---------------------------------------|----------------|----------------|----------------|--|------------------------------|------------------------------|---------------------------|-----------------|------|-----------------|------|-----------------|------|
| | | | | | | | | | Pilot A | | Pilot B | | Pilot B | |
| | M _u g | X _u | M _q | M _θ | γ ⁴ | γ _{de} ⁵ | M _{TS} ⁵ | | M _{cs} | TV | M _{cs} | TV | M _{cs} | TV |
| LI1 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 5 | - | - | XM | 0.33 | | 0.29 | | 0.25 | |
| | | | | | | | | XQS | 0.29 | | 0.34 | | 0.33 | |
| | | | | | | | | TU | 0.27 | 2.77 | 0.31 | 7.86 | 0.21 | 2.00 |
| | | | | | | | | HOV | 0.29 | | 0.30 | | 0.25 | |
| LI3 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | 20 | - | - | XM | | | 0.32 | | 0.28 | |
| | | | | | | | | XQS | | | 0.33 | | 0.27 | |
| | | | | | | | | TU | | | 0.22 | 5.50 | 0.24 | 2.50 |
| | | | | | | | | HOV | | | 0.29 | | 0.27 | |
| LI6 - BC4 | 1.0 | -0.20 | -3 | -1.7 | 20 | - | - | XM | 0.93 | | 0.93 | | 0.80 | |
| | | | | | | | | XQS | 0.88 | | 0.89 | | 0.86 | |
| | | | | | | | | TU | 0.79 | 9.15 | 0.81 | 10.6 | 0.67 | 4.20 |
| | | | | | | | | HOV | 0.72 | | 0.75 | | 0.68 | |
| LI12 - BC1 | 0.33 | -0.05 | -1.7 | -4.2 | - | 5 | 1 | XM | | | 0.35 | | | |
| | | | | | | | | XQS | | | 0.39 | | | |
| | | | | | | | | TU | | | 0.29 | 20.6 | | |
| | | | | | | | | HOV | | | 0.32 | | | |

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.
2. Symmetrical Configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; XQS, longitudinal quick stop; TU, ±180 deg turn-over-a-spot; HOV, precision hover.
4. Thumb switch thrust vector angle control, conventional attitude control.
5. Control stick thrust vector control, thumb switch attitude control.

TABLE C-VI

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT OF
THE TIME FROM THE STUDY OF RATE-COMMAND/ATTITUDE-HOLD CONTROL

Vertical and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

| Case ¹ Basic Conf. | Stability Derivatives ² | | | | Params. for Second- Order Dynamics | | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | |
|-------------------------------------|---------------------------------------|----------------|----------------|----------------|--|------------|---------------------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|------|--|--|
| | | | | | | | | Pilot A | | | | Pilot B | | | | Pilot D | | | | | | |
| | M _{us} | N _u | M _q | N _q | ξ | ω_n | | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | | | |
| 1A1 - BC1 | 0.35 | -0.05 | -2 | -8 | 0.35 | 2.8 | XM | | | | 0.58 | | 0.65 | | | | | | | | | |
| | | | | | | | YM | | | | | 0.58 | 0.90 | | | | | | | | | |
| | | | | | | | XQS | | | | | 0.89 | | 0.98 | | | | | | | | |
| | | | | | | | YQS | | | | | | | 0.75 | 1.01 | | | | | | | |
| | | | | | | | TU | | | | | | 0.54 | 0.45 | 0.75 | 0.11 | | | | | | |
| | | | | | | | HCV | | | | | | | 0.62 | 0.50 | 0.86 | | | | | | |
| 1B2 - BC1 | 0.33 | -0.05 | -2 | -40 | 0.16 | 6.3 | XM | | | | 0.66 | | 0.84 | | 0.30 | | 0.39 | | | | | |
| | | | | | | | YM | | | | | 0.58 | 0.93 | | | 1.27 | 0.46 | | | | | |
| | | | | | | | XQS | | | | | 0.97 | | 1.06 | | 0.34 | | 0.38 | | | | |
| | | | | | | | YQS | | | | | | | 0.74 | 1.17 | | | 0.28 | 0.45 | | | |
| | | | | | | | TU | | | | | | 0.57 | 0.47 | 0.88 | 0.17 | 0.24 | 0.34 | 0.44 | | | |
| | | | | | | | HCV | | | | | | | 0.69 | 0.68 | 1.07 | | 0.77 | 0.21 | 0.40 | | |
| 1B3 - BC1 | 0.33 | -0.05 | -4 | -8 | 0.71 | 2.8 | XM | | | | 0.45 | | 0.59 | | | | | | | | | |
| | | | | | | | YM | | | | | | 0.42 | 0.72 | | | | | | | | |
| | | | | | | | XQS | | | | | | 0.59 | | 0.82 | | | | | | | |
| | | | | | | | YQS | | | | | | | 0.66 | 1.00 | | | | | | | |
| | | | | | | | TU | | | | | | | 0.37 | 0.39 | 0.63 | 0.13 | | | | | |
| | | | | | | | HCV | | | | | | | 0.41 | 0.44 | 0.73 | | | | | | |

TABLE C-VI (Continued)

| Case ¹ - Basic Conf. | Stability ² Derivatives | | | | Params. for Second- Order Dynamics | | Sub- task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | | |
|--|---------------------------------------|----------------|----------------|----------------|--|----------------|---------------------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|--|--|--|--|
| | | | | | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | | | |
| | M _{u8} | X _u | M ₁ | M _θ | ξ | ω _r | | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | | | | |
| LR5 - BC1 | 0.33 | -0.05 | -6 | -12 | 0.87 | 3.44 | XM | | | | 0.44 | | 0.58 | | | | | | | | | | |
| | | | | | | | YM | | | | | 0.42 | 0.60 | | | | | | | | | | |
| | | | | | | | XQS | | | | | 0.45 | | 0.60 | | | | | | | | | |
| | | | | | | | YQS | | | | | | 0.81 | 1.02 | | | | | | | | | |
| | | | | | | | TU | | | | | 0.35 | 0.42 | 0.55 | 0.12 | | | | | | | | |
| | | | | | | | HOV | | | | | 0.43 | 0.41 | 0.62 | | | | | | | | | |
| LR6 - BC1 | 0.33 | -0.05 | -6 | -40 | 0.47 | 6.32 | XM | | | | 0.48 | | 0.62 | | 0.34 | | 0.37 | | | | | | |
| | | | | | | | YM | | | | | 0.44 | 0.69 | | | 0.28 | 0.47 | | | | | | |
| | | | | | | | XQS | | | | | 0.50 | | 0.65 | | 0.35 | | 0.38 | | | | | |
| | | | | | | | YQS | | | | | | 0.56 | 0.77 | | | 0.26 | 0.44 | | | | | |
| | | | | | | | TU | | | | | 0.34 | 0.35 | 0.51 | 0.13 | 0.27 | 0.24 | 0.39 | | | | | |
| | | | | | | | HOV | | | | | 0.40 | 0.38 | 0.66 | | 0.29 | 0.20 | 0.40 | | | | | |
| LR6 - BC1 | 0.33 | -0.05 | -10 | -50 | - | - | XM | 0.29 | | 0.35 | | | | | | | | | | | | | |
| | | | | | | | YM | | 0.20 | 0.40 | | | | | | | | | | | | | |
| | | | | | | | XQS | | | 0.44 | | | | | | | | | | | | | |
| | | | | | | | YQS | | | 0.47 | 0.59 | | | | | | | | | | | | |
| | | | | | | | TU | 0.30 | 0.28 | 0.39 | 0.59 | | | | | | | | | | | | |
| | | | | | | | HOV | 0.28 | 0.19 | 0.37 | | | | | | | | | | | | | |

TABLE C-VI (Concluded)

| Case ¹ - Basic Conf. | Stability Derivatives ² | | | | Params. for Second- Order Dynamics | | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | |
|--|---------------------------------------|----------------|----------------|----------------|--|----------------|---------------------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|--|--|--|
| | | | | | | | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | | |
| | M _{qs} | X _u | M _q | M _θ | ξ | ω _n | | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | M _{cs} | L _{cs} | Sim. ⁴ | N _{cs} | | | |
| LR10 - BC4 | 1.0 | -0.20 | -2 | -25 | 0.20 | 5 | XM | | | | 1.40 | | 1.93 | | | | | | | | | |
| | | | | | | | YM | | | | | 1.06 | 1.60 | | | | | | | | | |
| | | | | | | | XQS | | | | 1.37 | | 1.90 | | | | | | | | | |
| | | | | | | | YQS | | | | | 1.03 | 1.67 | | | | | | | | | |
| | | | | | | | TU | | | | 1.03 | 1.01 | 1.61 | 0.18 | | | | | | | | |
| | | | | | | | HOV | | | | 1.19 | 0.83 | 1.75 | | | | | | | | | |
| LR11 - BC4 | 1.0 | -0.20 | -4 | -16 | 0.50 | 4 | XM | | | | 1.13 | | 1.50 | | 0.53 | | 1.09 | | | | | |
| | | | | | | | YM | | | | | 0.90 | 1.53 | | | 0.53 | 1.13 | | | | | |
| | | | | | | | XQS | | | | 1.15 | | 1.49 | | 0.83 | | 1.02 | | | | | |
| | | | | | | | YQS | | | | | 0.99 | 1.75 | | | 0.48 | 1.05 | | | | | |
| | | | | | | | TU | | | | 0.86 | 0.79 | 1.27 | 0.19 | 0.62 | 0.64 | 1.39 | | | | | |
| | | | | | | | HOV | | | | 1.16 | 0.64 | 1.65 | | 0.60 | 0.29 | 0.50 | | | | | |
| LR14 - BC4 | 1.0 | -0.20 | -6 | -26 | 0.61 | 5 | XM | | | | 1.24 | | 1.93 | | 0.80 | | 0.99 | | | | | |
| | | | | | | | YM | | | | | 0.92 | 1.76 | | | 0.57 | 1.07 | | | | | |
| | | | | | | | XQS | | | | 1.05 | | 1.28 | | 0.75 | | 0.90 | | | | | |
| | | | | | | | YQS | | | | | 0.71 | 1.22 | | | 0.59 | 1.13 | | | | | |
| | | | | | | | TU | | | | 0.84 | 0.82 | 1.37 | 0.18 | 0.69 | 0.66 | 1.02 | | | | | |
| | | | | | | | HOV | | | | 1.01 | 0.69 | 1.59 | | 0.67 | 0.30 | 0.85 | | | | | |

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot, HOV, precision hover. bcp;
4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function (iM_c + iN_c!).

TABLE C-VII

PILOT COMMANDED AND TOTAL THRUST USAGE RESULTS FROM HEIGHT CONTROL STUDY

Longitudinal, Lateral and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

(a) Five-Percent Exceedance Levels for Pitching Moment, M_{C5} , and Incremental Thrust Increase Levels, $(T/W-1)_5$

| Case ¹ - Basic Conf. | Parameters ² | | | lag, τ_L | Delay, d_h | Sub- task ³ | Fixed Base | | | | | |
|--|---|------------------------------|-------|---|------------------------------|---------------------------|------------|------------------|-------|----------|------------------|-------|
| | | | | | | | Pilot A | | | Pilot B | | |
| | | | | | | | M_{C5} | $(T/W-1)_5$ for: | | M_{C5} | $(T/W-1)_5$ for: | |
| | $\% \delta_c \cdot \delta_c + \% w_B \cdot w$ | $\% \delta_c \cdot \delta_c$ | | $\% \delta_c \cdot \delta_c + \% w_B \cdot w$ | $\% \delta_c \cdot \delta_c$ | | | | | | | |
| H220 - BC1 | -0.125 | -0.125 | 1.10 | 0 | 0 | XM | 0.36 | 0.007 | 0.010 | 0.34 | 0.023 | 0.022 |
| | | | | | | YM | | 0.017 | 0.024 | | 0.025 | 0.024 |
| | | | | | | XQS | 0.36 | 0.009 | 0.020 | 0.37 | 0.019 | 0.024 |
| | | | | | | YQS | | 0.034 | 0.035 | | 0.034 | 0.034 |
| | | | | | | HOV | 0.30 | 0.010 | 0.016 | 0.36 | 0.017 | 0.023 |
| | | | | | | LS | 0.29 | 0.052 | 0.062 | 0.36 | 0.024 | 0.033 |
| H221 - BC1 | 0 | -0.25 | 1.10 | 0 | 0 | XM | 0.34 | 0.031 | 0.023 | 0.39 | 0.057 | 0.057 |
| | | | | | | YM | | 0.055 | 0.057 | | 0.048 | 0.045 |
| | | | | | | XQS | 0.47 | 0.030 | 0.029 | 0.37 | 0.026 | 0.029 |
| | | | | | | YQS | | 0.069 | 0.043 | | 0.047 | 0.034 |
| | | | | | | HOV | 0.29 | 0.029 | 0.036 | 0.33 | 0.014 | 0.023 |
| | | | | | | LS | 0.69 | 0.067 | | 0.32 | 0.061 | 0.067 |
| H222 - BC1 | -0.25 | 0 | 1.10 | 0 | 0 | XM | 0.36 | 0.024 | 0.018 | | | |
| | | | | | | YM | | 0.057 | 0.054 | | | |
| | | | | | | XQS | 0.47 | 0.047 | 0.047 | | | |
| | | | | | | YQS | | 0.050 | 0.048 | | | |
| | | | | | | HOV | 0.30 | 0.022 | 0.021 | | | |
| | | | | | | LS | 0.30 | 0.070 | 0.060 | | | |
| H223 - BC1 | -0.25 | -0.25 | 1.10 | 0 | 0 | XM | 0.37 | 0.008 | 0.006 | | | |
| | | | | | | YM | | 0.015 | 0.007 | | | |
| | | | | | | XQS | 0.46 | 0.007 | 0.008 | | | |
| | | | | | | YQS | | 0.026 | 0.018 | | | |
| | | | | | | HOV | 0.30 | 0.009 | 0.009 | | | |
| | | | | | | LS | 0.30 | 0.030 | 0.052 | | | |
| H21 - BC1 | 0 | 0 | >1.15 | 0 | 0 | XM | 0.39 | 0.042 | 0.042 | | | |
| | | | | | | YM | | 0.123 | 0.116 | | | |
| | | | | | | XQS | 0.32 | 0.082 | 0.095 | | | |
| | | | | | | YQS | | 0.108 | 0.108 | | | |
| | | | | | | HOV | 0.26 | 0.088 | 0.080 | | | |
| | | | | | | LS | 0.34 | 0.122 | 0.121 | | | |
| H23 - BC1 | -0.25 | -0.25 | >1.15 | 0 | 0 | XM | 0.34 | 0.009 | 0.017 | | | |
| | | | | | | YM | | 0.035 | 0.010 | | | |
| | | | | | | XQS | 0.39 | 0.006 | 0.010 | | | |
| | | | | | | YQS | | 0.054 | 0.015 | | | |
| | | | | | | HOV | 0.29 | 0.008 | 0.008 | | | |
| | | | | | | LS | 0.26 | 0.028 | 0.045 | | | |

Contrails

TABLE C-VII (Continued)

| Case ¹ Basic Conf. | Parameters ² | | | Lag, T_h | Delay, δ_h | Sub- task ³ | Fixed Base | | | | | |
|-------------------------------------|-------------------------|-----------|-------|---------------|----------------------|---------------------------|---|-------------------------------|-----------|---|-------------------------------|-----------|
| | | | | | | | Pilot A | | | Pilot B | | |
| | Z_{w_a} | Z_{w_s} | T/W | | | | $(T/W-1)_5$ for: | | | $(T/W-1)_5$ for: | | |
| | | | | | | | $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$ | $Z_{\delta_c} \cdot \delta_c$ | M_{c_5} | $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$ | $Z_{\delta_c} \cdot \delta_c$ | M_{c_5} |
| H225 - BC4 | 0 | 0 | >1.15 | 0 | 0 | XM | | | | 1.027 | 0.089 | 0.091 |
| | | | | | | YM | | | | | 0.139 | 0.133 |
| | | | | | | XQS | | | | 0.88 | 0.167 | 0.167 |
| | | | | | | YQS | | | | | 0.132 | 0.133 |
| | | | | | | HGV | | | | 0.78 | 0.098 | 0.098 |
| | | | | | | LS | | | | 0.83 | 0.169 | 0.158 |
| H226 - BC4 | -0.125 | -0.125 | >1.15 | 0 | 0 | XM | 0.89 | 0.025 | 0.028 | 0.85 | 0.029 | 0.045 |
| | | | | | | YM | | 0.028 | 0.019 | | 0.023 | 0.017 |
| | | | | | | XQS | 0.96 | 0.015 | 0.015 | 0.98 | 0.010 | 0.009 |
| | | | | | | YQS | | 0.043 | 0.039 | | 0.024 | 0.024 |
| | | | | | | HGV | 0.74 | 0.034 | 0.030 | 0.87 | 0.027 | 0.023 |
| | | | | | | LS | 0.84 | 0.070 | 0.069 | 0.87 | 0.034 | 0.043 |
| H227 - BC4 | -0.25 | -0.25 | >1.15 | 0 | 0 | XM | 0.85 | | 0.025 | | | |
| | | | | | | YM | | 0.017 | 0.039 | | | |
| | | | | | | XQS | 0.84 | 0.009 | 0.034 | | | |
| | | | | | | YQS | | 0.016 | 0.038 | | | |
| | | | | | | HGV | 0.72 | 0.008 | 0.035 | | | |
| | | | | | | LS | 0.76 | 0.016 | 0.079 | | | |
| H12 - BC1 | -0.125 | -0.125 | 1.10 | 0.3 | 0 | XM | | | | 0.30 | 0.038 | 0.045 |
| | | | | | | YM | | | | | | |
| | | | | | | XQS | | | | 0.37 | 0.035 | 0.038 |
| | | | | | | YQS | | | | | 0.028 | 0.029 |
| | | | | | | HGV | | | | 0.30 | 0.023 | 0.027 |
| | | | | | | LS | | | | 0.29 | 0.048 | 0.053 |

TABLE C-VII (Concluded)

(b) Five-Percent Exceedance Levels for Pitching Moment, M_{C5} , and Percent Time Commanded T/W of Pilot and SAS Exceeds Installed T/W

| Case ¹ - Basic Conf. | Parameters ² | | | Lag, τ_h | Delay, d_h | Sub- task ³ | Fixed Base | | | | | |
|--|-------------------------|-----------|------|------------------|-----------------|---------------------------|------------|---|---|----------|---|---|
| | | | | | | | Pilot A | | | Pilot B | | |
| | Z_{W_a} | Z_{W_s} | T/W | | | | M_{C5} | P_{TL} for $Z_{\delta_c} \cdot \delta_c + Z_{W_s} \cdot w$ | P_{TL} for $Z_{\delta_c} \cdot \delta_c$ | M_{C5} | P_{TL} for $Z_{\delta_c} \cdot \delta_c + Z_{W_s} \cdot w$ | P_{TL} for $Z_{\delta_c} \cdot \delta_c$ |
| HZ6 - BCL | -0.125 | -0.125 | 1.02 | 0 | 0 | XM | 0.36 | 19.0 | 27.0 | | | |
| | | | | | | YM | | 38.0 | 65.0 | | | |
| | | | | | | XQS | 0.48 | 21.0 | 30.0 | | | |
| | | | | | | YQS | | 14.0 | 60.0 | | | |
| | | | | | | HCV | 0.32 | 10.0 | 14.0 | | | |
| | | | | | | LS | 0.34 | 32.0 | 60.0 | | | |
| HZ10 - BCL | -0.25 | -0.25 | 1.02 | 0 | 0 | XM | 0.33 | 0.0 | 0.0 | | | |
| | | | | | | YM | | 3.0 | 0.0 | | | |
| | | | | | | XQS | 0.39 | 0.0 | 2.0 | | | |
| | | | | | | YQS | | 25.0 | 29.0 | | | |
| | | | | | | HCV | 0.29 | 2.0 | 1.0 | | | |
| | | | | | | LS | 0.28 | 17.0 | 16.0 | | | |
| HZ17 - BCL | -0.25 | -0.25 | 1.05 | 0 | 0 | XM | | | | 0.34 | 0.0 | 0.0 |
| | | | | | | YM | | | | | 0.0 | 0.0 |
| | | | | | | XQS | | | | 0.39 | 0.0 | 0.0 |
| | | | | | | YQS | | | | | 0.0 | 0.0 |
| | | | | | | HCV | | | | 0.36 | 0.0 | 0.0 |
| | | | | | | LS | | | | 0.32 | 3.0 | 8.0 |
| HZ11 - BCL | -0.125 | -0.125 | 1.05 | 0.3 | 0 | XM | 0.39 | 16.0 | 16.0 | | | |
| | | | | | | YM | | 0.0 | 0.0 | | | |
| | | | | | | XQS | 0.43 | 0.0 | 0.0 | | | |
| | | | | | | YQS | | 7.0 | 0.0 | | | |
| | | | | | | HCV | 0.34 | 0.0 | 0.0 | | | |
| | | | | | | LS | 0.34 | 2.0 | 4.0 | | | |

1. Wind simulation included mean wind, U_m : 10 kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical Configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; LS, landing sequence; HCV, precision hover.

TABLE C-VIII

YAW, PITCH AND ROLL CONTROL-MOMENT RESULTS FROM THE DIRECTIONAL CONTROL STUDY

Longitudinal, Lateral and Vertical Parameters Listed in Table A-I
See End of Table for Explanation of Notes

(a) Five-Percent Exceedance Control-Moment Levels

| Case ¹ - Basic ² Conf. | N _V | Directional Parameters Varied | | | | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | | | |
|---|----------------|-------------------------------------|-----------------|----------------|----------------|---------------------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|-------------------|-----------------|------|------|------|------|------|
| | | R _r | N _{cm} | r _ψ | d _ψ | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | | | | |
| | | | | | | | M _{c5} | L _{c5} | Sim. ⁴ | N _{e5} | M _{c5} | L _{c5} | Sim. ⁴ | N _{e5} | M _{c5} | L _{c5} | Sim. ⁴ | N _{e5} | | | | | |
| D1 - BC1 | 0.005 | 0 | UL | 0 | 0 | XM | | | | | | | | | | 0.40 | | 0.50 | | | | | |
| | | | | | | YM | | | | | | | | | | | | 0.26 | 0.43 | | | | |
| | | | | | | XQS | | | | | | | | | | | | | | 0.43 | | 0.51 | |
| | | | | | | YQS | | | | | | | | | | | | | | | 0.27 | 0.49 | |
| | | | | | | TU | | | | | | | | | | | | | | 0.30 | 0.28 | 0.46 | 0.14 |
| | | | | | | HOV | | | | | | | | | | | | | | | 0.35 | 0.18 | 0.40 |
| D2 - BC1 | 0.005 | -0.5 | UL | 0 | 0 | XM | 0.39 | | 0.52 | | 0.42 | | 0.57 | | 0.38 | | 0.47 | | | | | | |
| | | | | | | YM | | 0.29 | 0.56 | | | 0.38 | 0.58 | | | 0.26 | 0.48 | | | | | | |
| | | | | | | XQS | 0.46 | | 0.55 | | 0.48 | | 0.59 | | 0.38 | | 0.46 | | | | | | |
| | | | | | | YQS | | 0.46 | 0.67 | | | 0.37 | 0.61 | | | 0.30 | 0.56 | | | | | | |
| | | | | | | TU | 0.29 | 0.29 | 0.46 | 0.13 | 0.31 | 0.33 | 0.49 | 0.14 | 0.28 | 0.22 | 0.39 | 0.14 | | | | | |
| | | | | | | HOV | 0.35 | 0.22 | 0.45 | | 0.38 | 0.38 | 0.64 | | 0.37 | 0.23 | 0.50 | | | | | | |
| D7 - BC1 | 0.005 | -0.5 | UL | 0.3 | 0 | XM | 0.33 | | 0.41 | | 0.40 | | 0.56 | | 0.46 | | 0.59 | | | | | | |
| | | | | | | YM | | 0.29 | 0.44 | | | 0.44 | 0.68 | | | 0.34 | 0.62 | | | | | | |
| | | | | | | XQS | 0.30 | | 0.41 | | 0.40 | | 0.50 | | 0.46 | | 0.58 | | | | | | |
| | | | | | | YQS | | 0.38 | 0.57 | | | 0.44 | 0.62 | | | 0.32 | 0.63 | | | | | | |
| | | | | | | TU | 0.29 | 0.29 | 0.43 | 0.15 | 0.33 | 0.37 | 0.59 | 0.12 | 0.35 | 0.27 | 0.49 | 0.17 | | | | | |
| | | | | | | HOV | 0.29 | 0.18 | 0.39 | | 0.38 | 0.33 | 0.58 | | 0.40 | 0.25 | 0.62 | | | | | | |
| D8 - BC1 | 0.005 | -0.5 | UL | 0.3 | 0.1 | XM | | | | | | | | | | 0.42 | | 0.63 | | | | | |
| | | | | | | YM | | | | | | | | | | 0.31 | 0.64 | | | | | | |
| | | | | | | XQS | | | | | | | | | | 0.40 | | 0.53 | | | | | |
| | | | | | | YQS | | | | | | | | | | | 0.29 | 0.59 | | | | | |
| | | | | | | TU | | | | | | | | | | 0.30 | 0.24 | 0.45 | 0.16 | | | | |
| | | | | | | HOV | | | | | | | | | | | 0.39 | 0.24 | 0.56 | | | | |
| D13 - BC1 | 0.005 | -1 | UL | 0.3 | 0 | XM | | | | | | | | | | 0.43 | | 0.55 | | | | | |
| | | | | | | YM | | | | | | | | | | | 0.28 | 0.59 | | | | | |
| | | | | | | XQS | | | | | | | | | | | 0.39 | | 0.53 | | | | |
| | | | | | | YQS | | | | | | | | | | | | 0.29 | 0.56 | | | | |
| | | | | | | TU | | | | | | | | | | | 0.35 | 0.26 | 0.40 | 0.16 | | | |
| | | | | | | HOV | | | | | | | | | | | | 0.39 | 0.27 | 0.55 | | | |

TABLE C-VIII (Concluded)

(a) Five-Percent Exceedance Control-Moment Levels

| Case ¹ - Basic ² Conf. | N _v | Directional Parameters Varied | | | | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | | | |
|---|----------------|-------------------------------------|-----------------|----------------|----------------|---------------------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|------------------|-----------------|------|------|------|------|--|
| | | N _r | N _{cm} | T _ψ | δ _ψ | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | | | | |
| | | | | | | | M _{c5} | L _{c5} | Sim ⁴ | N _{c5} | M _{c5} | L _{c5} | Sim ⁴ | N _{c5} | M _{c5} | L _{c5} | Sim ⁴ | N _{c5} | | | | | |
| D14 - ECL | 0.005 | -1 | UL | 0.6 | 0 | XM | | | | | | | | | | 0.42 | | 0.56 | | | | | |
| | | | | | | YM | | | | | | | | | | | | | 0.28 | 0.52 | | | |
| | | | | | | XQS | | | | | | | | | | | | | 0.42 | | 0.57 | | |
| | | | | | | YQS | | | | | | | | | | | | | | 0.30 | 0.61 | | |
| | | | | | | TU | | | | | | | | | | | | | 0.35 | 0.25 | 0.44 | 0.17 | |
| | | | | | | HOV | | | | | | | | | | | | | 0.39 | 0.22 | 0.56 | | |

(b) M_{c5}, L_{c5} and Percent Time Yaw Control-Moment Command Exceeded Installed Limit, P_{NL}

| Case ¹ - Basic ² Conf. | N _v | Directional Parameters Varied | | | | Sub- Task ³ | Fixed Base | | | | | | | | Moving Base | | | | | | | | |
|---|----------------|-------------------------------------|-----------------|----------------|----------------|---------------------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|------------------|-----------------|------|------|------|-------|--|
| | | N _r | N _{cm} | T _ψ | δ _ψ | | Pilot A | | | | Pilot B | | | | Pilot B | | | | | | | | |
| | | | | | | | M _{c5} | L _{c5} | Sim ⁴ | P _{NL} | M _{c5} | L _{c5} | Sim ⁴ | P _{NL} | M _{c5} | L _{c5} | Sim ⁴ | P _{NL} | | | | | |
| D20 - ECL | | -1 | 0.10 | 0 | 0 | XM | | | | | | | | | | 0.40 | | 0.50 | | | | | |
| | | | | | | YM | | | | | | | | | | | | | 0.28 | 0.48 | | | |
| | | | | | | XQS | | | | | | | | | | | | | 0.38 | | 0.48 | | |
| | | | | | | YQS | | | | | | | | | | | | | | 0.30 | 0.53 | | |
| | | | | | | TU | | | | | | | | | | | | | 0.30 | 0.29 | 0.45 | 13.20 | |
| | | | | | | HOV | | | | | | | | | | | | | 0.38 | 0.26 | 0.54 | | |
| D21 - ECL | | -1 | 0.13 | 0 | 0 | XM | 0.39 | | 0.56 | | 0.40 | | 0.29 | | | 0.38 | | 0.47 | | | | | |
| | | | | | | YM | | 0.28 | 0.48 | | | | 0.34 | | | | | | 0.27 | 0.48 | | | |
| | | | | | | XQS | 0.50 | | 0.59 | | 0.39 | | 0.38 | | | | | | | | | | |
| | | | | | | YQS | | | | | | 0.22 | 0.40 | | | | | | 0.31 | 0.55 | | | |
| | | | | | | TU | 0.30 | 0.29 | 0.47 | 7.50 | 0.33 | | 0.31 | 1.00 | 0.28 | 0.26 | 0.39 | 6.70 | | | | | |
| | | | | | | HOV | 0.32 | 0.22 | 0.47 | | 0.39 | | | | | | | | 0.36 | 0.25 | 0.50 | | |
| D22 - ECL | | -1 | 0.16 | 0 | 0 | XM | | | | | | | | | | 0.40 | | 0.58 | | | | | |
| | | | | | | YM | | | | | | | | | | | | | 0.28 | 0.50 | | | |
| | | | | | | XQS | | | | | | | | | | | | 0.47 | | 0.58 | | | |
| | | | | | | YQS | | | | | | | | | | | | | 0.29 | 0.57 | | | |
| | | | | | | TU | | | | | | | | | 0.34 | 0.26 | 0.44 | 1.19 | | | | | |
| | | | | | | HOV | | | | | | | | | | 0.39 | 0.22 | 0.52 | | | | | |

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ±180 deg turn-over-a-spot; HOV, precision hover.
4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function (|M_{c5}| + |L_{c5}|).

Contrails

APPENDIX D

SUMMARY OF FLYING QUALITIES DATA AND PILOT COMMENTS FROM CALSPAN PILOT EVALUATIONS

Flying qualities data (pilot ratings and pilot-selected control sensitivities) for the flight simulator evaluations with Calspan pilot B are summarized in Table D-I. Another Calspan pilot participated briefly in the UARL program but did not perform flying qualities investigations. Calspan pilot B evaluated both lateral and longitudinal control test cases and height control cases. Turbulence effects, control lags and delays and control-moment limits were evaluated in the longitudinal and lateral control investigation (Table D-I(a)). The interactive effects of height velocity damping and thrust-to-weight ratio were evaluated in the height control study (Table D-I(b)).

Edited pilot comments from the Calspan pilot B evaluations are summarized in Table D-II. Comments for the longitudinal and lateral control test cases are shown in Table D-II(a) and those for the height control test cases are contained in D-II(b).

TABLE D-I
FLYING QUALITIES RESULTS FROM CALSPAN PILOT EVALUATIONS
Height and Directional Parameters Contained in Table A-I
Pilot Comments Given in Table D-II

(a) Longitudinal and Lateral Control

| Case | Basic Cont. | Stability Derivatives ^a | | | Real Root | Complex Root $-ζ_0 ± jω_0$ | Maximum Control | | | Disturbance $σ_{DG} = σ_{VG}$ | Yaw $τ_0 = τ_1$ | Delay $k_{DG} = k_{VA}$ | Moving Base | | |
|------|-------------|------------------------------------|----------|----------|-----------|----------------------------|-----------------|----------|----------|-------------------------------|-----------------|-------------------------|-------------|-------|-----|
| | | $ζ_{aE}$ | $ζ_{aC}$ | $ζ_{aθ}$ | | | $ζ_{aδ}$ | $ζ_{aδ}$ | $ζ_{aδ}$ | | | | $ζ_{aδ}$ | | |
| 201 | 201 | 0.33 | -0.05 | -1.7 | -4.2 | -0.31 ± j1.85 | UL | VL | UL | 1.7 | 0 | 0 | 0.24 | 0.230 | 7.0 |
| 202 | 202 | 1.0 | -0.05 | -1.1 | -6.5 | -0.30 ± j1.17 | UL | VL | UL | 0 | 0 | 0 | 0.300 | 0.320 | 3.0 |
| 203 | 203 | 1.0 | -0.05 | -2.0 | 0 | 0.38 ± j0.65 | UL | VL | UL | 1.7 | 0 | 0 | 0.330 | 0.290 | 3.0 |
| 204 | 204 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.64 | UL | VL | UL | 0 | 0 | 0 | 0.331 | 0.365 | 3.0 |
| 205 | 205 | 0.33 | -0.05 | -1.7 | -4.2 | -0.31 ± j1.85 | UL | VL | UL | 1.7 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 206 | 206 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.310 | 3.0 |
| 207 | 207 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 208 | 208 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 209 | 209 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 210 | 210 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 211 | 211 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 212 | 212 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 213 | 213 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 214 | 214 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 215 | 215 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 216 | 216 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 217 | 217 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 218 | 218 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 219 | 219 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 220 | 220 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 221 | 221 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |

(b) Height Control

| Case | Basic Cont. | Stability Derivatives ^a | | | Real Root | Complex Root $-ζ_0 ± jω_0$ | Height, Height, Thrust-to-Height Parameters | | | Moving Base | | | | | |
|------|-------------|------------------------------------|----------|----------|-----------|----------------------------|---|----------|----------|-------------|---|---|-------|-------|-----|
| | | $ζ_{aE}$ | $ζ_{aC}$ | $ζ_{aθ}$ | | | $ζ_{aδ}$ | $ζ_{aδ}$ | $ζ_{aδ}$ | | | | | | |
| 201 | 201 | 0.33 | -0.05 | -1.7 | -4.2 | -0.31 ± j1.85 | UL | VL | UL | 1.7 | 0 | 0 | 0.24 | 0.230 | 7.0 |
| 202 | 202 | 1.0 | -0.05 | -1.1 | -6.5 | -0.30 ± j1.17 | UL | VL | UL | 0 | 0 | 0 | 0.300 | 0.320 | 3.0 |
| 203 | 203 | 1.0 | -0.05 | -2.0 | 0 | 0.38 ± j0.65 | UL | VL | UL | 1.7 | 0 | 0 | 0.330 | 0.290 | 3.0 |
| 204 | 204 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.64 | UL | VL | UL | 0 | 0 | 0 | 0.331 | 0.365 | 3.0 |
| 205 | 205 | 0.33 | -0.05 | -1.7 | -4.2 | -0.31 ± j1.85 | UL | VL | UL | 1.7 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 206 | 206 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.310 | 3.0 |
| 207 | 207 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 208 | 208 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 209 | 209 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 210 | 210 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 211 | 211 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 212 | 212 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 213 | 213 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 214 | 214 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 215 | 215 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 216 | 216 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 217 | 217 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 218 | 218 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 219 | 219 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 220 | 220 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |
| 221 | 221 | 1.0 | -0.05 | -3.0 | -1.7 | -0.35 ± j0.65 | UL | VL | UL | 0 | 0 | 0 | 0.330 | 0.365 | 3.0 |

1. Use $σ_{DG} = 0$ for all Calspan pilot evaluations. For height control $σ_{DG} = σ_{VG} = 0$ for cases 201-213 and $σ_{DG} = σ_{VG} = 3.7$ ft/sec for cases 214-221.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

TABLE D- II

PILOT COMMENTS FROM CALSFAN PILOT EVALUATIONS

(a) Longitudinal and Lateral Control

Case C11 BC1 $N_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 1.7$ $M_{\delta_e} = 0.447$ $L_{\delta_e} = 0.260$ PR = 6

Control sensitivities - I did get adequate roll control; however, the configuration is such that it's difficult to stop it where you want, so you have to anticipate quite a bit. Adjusted sensitivities to give enough quickness of response so I would attempt to stop without having to anticipate as much. Then there was a tendency to oscillate so I finally compromised and accepted the sensitivities that I have now. Air taxi around the square - It's very difficult to remain over the spot on the ground, primarily because I'm behind the airplane or I'm overcontrolling in attempting to maintain a position. It does seem that pitch response and bank angle response are quite good but the aircraft response in translation is very sluggish in both directions, both in trying to get it started and in stopping it. Once you get it started it's quite difficult to stop it with any precision at all. You approximate the task and that's about all you can do. There is a low level of precision here. If I concentrate very hard I can usually stay within the 10-ft square. Holding heading is no problem. There is some change in altitude, but not very much -- maybe ± 7 or 8 ft. Quick stops - Don't really have any precision, you just have to make some pretty large inputs. I managed to do it a couple of times fairly well, but it was strictly a hit-or-miss proposition. Turning over a spot - That's a problem; the big difficulty is to stay within ± 10 to 20 ft of the center of the square. Hover - The ability to maintain precision hover is quite poor as far as attitude and angular rates are concerned; however, it's not bad. As usual, have quite a bit of trouble laterally. Seems that I'm sliding back and forth all the time. The motion starts quite subtly, but once it starts it is difficult to stop. Overall evaluation - The major objectionable features are the sluggishness in response and control of the displacements. Favorable features include the fact that height control is pretty good, heading control is no problem and there are really no oscillatory tendencies at all in any direction.

Case C12 BC2 $N_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_e} = 0.380$ $L_{\delta_e} = 0.320$ PR = 7

Case C13 BC2 $N_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 1.7$ $M_{\delta_e} = 0.380$ $L_{\delta_e} = 0.320$ PR = 9

With turbulence (C13) I would say, for all practical purposes, that the aircraft is unflyable. I can maybe keep it in the sky but the excursions are very large and I get the feeling I really don't have much control over the aircraft. I didn't get a chance to do anything in the way of maneuvering. All I was trying to do was to hover over a spot, and I wasn't able to do that. So I tried various gains on the cyclic both in pitch and roll and just didn't feel it was very good. I think it improved some when I went up to higher sensitivities, but not sufficiently that I would accept the airplane. This cut down the level or magnitude of the excursions, but I still didn't think it was a flyable or acceptable airplane and I couldn't do the task. So then I flew it without turbulence (C12). Without the turbulence I was able to do the maneuvers to some extent. I get the impression that, even without turbulence, there are some external disturbances. These may be inadvertently pilot-induced. Certainly it's a tremendous difference between turbulence in and turbulence out. With turbulence (C13) I would have to reject the configuration completely because at some point you probably will lose it, especially if the turbulence were any higher. Now, in smooth air, it did seem there was some lag in response to control inputs, about all axes, in spite of the fact that the height control is pretty good. I'd have to move the collective only a number of times. I think I was able to initiate the motion alright but precision of stabilizing velocities, etc., wasn't very good at all. I don't think my hover capability was real good although I did manage to make some turns in both directions and most of the time stayed within the square. There seems to be quite a bit of change in attitude, pitch primarily. Tried some quick stops. The airplane responds sluggishly; there seems to be a fair amount of lead required to either stop lateral motions or longitudinal motions. In turning over a spot, no real problems stopping or a heading. There is apparently no cross-coupling between the rudder and the cyclic. Probably would have been able to land this, at least in smooth air. In regard to secondary dynamics, in the higher rate maneuvers there was some cross-coupling. The major objectionable feature was the lack of precision with which I can initiate and stabilize velocity and position over the surface. I did manage to do some 360's fairly good in hover, but that's about the only thing I was able to do fairly well.

Case C14 BC3 $N_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_e} = 0.320$ $L_{\delta_e} = 0.365$ PR = 5.5

Case C15 BC3 $N_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 1.7$ $M_{\delta_e} = 0.320$ $L_{\delta_e} = 0.365$ PR = 10

Tried it with turbulence (C15) and found it completely unacceptable, probably a 10 rating. I flew it for a couple of minutes. In smooth air (C14) I tried quite a few gearings and I thought that might help but it didn't. It looks like lightly damped roll modes and I'm not sure about pitch. There were times where it almost felt like the airplane wanted to go on its own, but in any case didn't have precision of control. I had more trouble in roll than in pitch. Maneuvers not very successful. Regardless of control sensitivities, I never really felt I had good lateral control. I didn't have nearly as much trouble in pitch as in roll. Not able to establish any decent bank angle; very easy to overcontrol. I didn't like it, couldn't really stop or hover precisely. Not really able to stay within ground track limits. Quick stops - Not really very good at all; I tried some but seems like the airplane wants to take off, especially in the lateral quick stops. Turning over a spot - Didn't look real bad. It does seem that, once you get the airplane under reasonable control and get everything steadied out reasonably well, it can be held reasonably well.

Contrails

TABLE D-II(a) (Continued)

| | | | | | | | | |
|----------|-----|-----------------------|-----------------------|-----------------------|---|------------------------|------------------------|----------|
| Case CL7 | BC4 | $M_{C_{\delta}} = UL$ | $L_{C_{\delta}} = UL$ | $N_{C_{\delta}} = UL$ | $\sigma_{u_{\delta}} = \sigma_{v_{\delta}} = 0$ | $M_{\delta_e} = 0.321$ | $L_{\delta_a} = 0.365$ | PR = 3 |
| Case CL7 | BC5 | $M_{C_{\delta}} = UL$ | $L_{C_{\delta}} = UL$ | $N_{C_{\delta}} = UL$ | $\sigma_{u_{\delta}} = \sigma_{v_{\delta}} = 1.7$ | $M_{\delta_e} = 0.321$ | $L_{\delta_a} = 0.365$ | PR = 4.5 |

It was quite a bit more effort to try to do the task in turbulence (CL7) but I was able to do that and even hover, say, fair. I could even keep within the 7-ft square. Lot of control activity in the turbulence, however. The configuration does seem to have reasonable stability and damping and the responses to control inputs appear to be reasonable with the particular gearings I chose. In smooth air the response to control inputs was fair. It does still seem that there are some lags in the initial responses to control inputs. I also did a fair amount of height control power inputs. I was able to establish displacements and velocities with reasonable precision in smooth air. Hovering capability was reasonably good. Could do the turns over a spot reasonably well. I really don't see anything strongly objectionable; the biggest thing probably are some lags in response to control inputs, but they are not really so bad. Could do it fairly well. Have some difficulty with bank angle, but it's probably me. So in smooth air I would say the aircraft was pretty good. I think performance in smooth air was satisfactory without improvement. In turbulence the work level certainly goes up quite a bit and maybe this is just a matter of proficiency. In turbulence the pilot compensation and workload are really fairly high.

| | | | | | | | | |
|----------|-----|-----------------------|-----------------------|-----------------------|---|------------------------|------------------------|--------|
| Case CL8 | BC5 | $M_{C_{\delta}} = UL$ | $L_{C_{\delta}} = UL$ | $N_{C_{\delta}} = UL$ | $\sigma_{u_{\delta}} = \sigma_{v_{\delta}} = 0$ | $M_{\delta_e} = 0.370$ | $L_{\delta_a} = 0.341$ | PR = 3 |
| Case CL9 | BC5 | $M_{C_{\delta}} = UL$ | $L_{C_{\delta}} = UL$ | $N_{C_{\delta}} = UL$ | $\sigma_{u_{\delta}} = \sigma_{v_{\delta}} = 1.7$ | $M_{\delta_e} = 0.386$ | $L_{\delta_a} = 0.402$ | PR = 7 |

Flew this in smooth air first (CL8) and I thought overall it was an excellent configuration. The only thing I noticed was a tendency to bobble the airplane a little in pitch. Whether there is lightly damped pitch oscillation here I don't know. Could have just been closed-loop. Noticed this particularly when I tried to make a fairly rapid attitude change. The control sensitivities seemed to be adequate in smooth air. I then flew short time in turbulence (CL9) and felt the need to increase the control sensitivity to be able to offset some of the gusts. Not really sure which was better; without the higher sensitivity it seemed that I just didn't have sufficient control to keep the aircraft excursions small enough. On the other hand, with the higher gearings it did seem that I got into more high-frequency PIC's. Wasn't sure which to take, but it did seem that this gearing I chose in turbulence (CL9) is better suited for precision control in doing the hover. The following comments are in smooth air. Response to control input seemed to be reasonable, although there were times when I felt it was a little sluggish, but I did seem to be able to stop the thing without needing a lot of lead, so maybe the damping is pretty good. The controllability of position and velocity seemed reasonable. Could hover very well. Could do turns over a spot very well. Very rarely went outside the 7-ft square. Could do the quick stops quite well although it did seem that I couldn't really generate high enough velocities with the control power I had. In other words, for the quick stop I would have expected to get a little higher speed going and make it much quicker, but this may be a function of the gearing I chose or it may just be a function of the dynamics of the aircraft. In any event, I was able to do all of the tasks with what I considered to be pretty good precision. The only possible objectionable feature is that the response, maybe initial response, to control inputs could be a little slow and possibly control power maybe was a little low. This may be my fault, going with the gearing I had. I don't really see that there is anything objectionable about it. In smooth air I certainly would rate it satisfactory without improvement for the task I was doing, with only negligible deficiencies or some mildly unpleasant deficiencies. In turbulence, I had quite a bit of trouble. The performance in turbulence certainly was not what I would consider very good so that the airplane would go into the deficiency-warrant-improvement category.

| | | | | | | | | |
|-----------|-----|-----------------------|-----------------------|-----------------------|---|------------------------|------------------------|--------|
| Case CL10 | BC5 | $M_{C_{\delta}} = UL$ | $L_{C_{\delta}} = UL$ | $N_{C_{\delta}} = UL$ | $\sigma_{u_{\delta}} = \sigma_{v_{\delta}} = 0$ | $M_{\delta_e} = 0.498$ | $L_{\delta_a} = 0.273$ | PR = 3 |
|-----------|-----|-----------------------|-----------------------|-----------------------|---|------------------------|------------------------|--------|

No comments due to defective recording.

| | | | | | | | | | |
|-----------|-----|-----------------------|-----------------------|-----------------------|---|-------------------------|------------------------|------------------------|--------|
| Case CL11 | BC4 | $M_{C_{\delta}} = UL$ | $L_{C_{\delta}} = UL$ | $N_{C_{\delta}} = UL$ | $\sigma_{u_{\delta}} = \sigma_{v_{\delta}} = 0$ | $\tau_e = \tau_a = 0.3$ | $M_{\delta_e} = 0.623$ | $L_{\delta_a} = 0.110$ | PR = 3 |
|-----------|-----|-----------------------|-----------------------|-----------------------|---|-------------------------|------------------------|------------------------|--------|

I didn't feel any great need to try a range of control sensitivities, so I left them where they were initially. Air taxi around the square - Response to control inputs seemed a little sluggish about all axes, but was able to stabilize and hold desired velocities. However, with these gearings the rates were generally rather small for fairly large inputs, but I felt comfortable with it. Some lag in initiation of the motion. Was able to stop the motion rather rapidly but it did take fairly large attitude changes to do it. Could actually overcontrol quite a bit and still be able to stop the motion pretty close to where I wanted it. Was able to come to a hover at the corners fairly well. Attitude changes required were fairly large, but mainly because I would wait quite awhile before I would try to stop it. Ability to remain within ground track was pretty good. Was able to hold heading well. Control deflections were very often on the fairly large side. Ability to hold heading wasn't bad at all. Control motions were fairly large. Turn over a spot - I thought my performance was very good as far as making turns and hovering; height control was no particular problem. Could initiate and maintain the turn rate. It seems to me it's strictly mechanical; you push the rudder in a certain amount, set up some kind of yaw rate and that's it. You can practically take your foot off the rudder and it will just stay there, and when you get within 5 or 10 degs of where you want to stop, just put in the opposite rudder. Doesn't seem to be any particular trouble as I can stop at a preselected heading very well. No wing tilt control used. Certainly I could establish hover quite well. Control was adequate for vertical landing. I would probably say the most objectionable feature was that the aircraft wasn't very responsive. The favorable feature is that I can do all the maneuvers with good precision.

Contrails

TABLE D-II(a) (Continued)

Case CL12 BC4 $M_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $\tau_e = \tau_a = 0.6$ $M_{\delta_e} = 0.509$ $L_{\delta_a} = 0.237$ $PR = 5$

Once you establish a velocity while maneuvering, it can be held reasonably well. The problem was in initiating it in such a way that the pilot didn't oscillate or develop a PIO. Ability to stop precisely was a little problem because of the dynamics and the necessity for the pilot to reduce his gains so he didn't get into a PIO. I think there are times when the attitude changes are rather large, especially in pitch, but in fact the attitude changes are really fairly small. Would rate the ability to remain within ground track limits, to hold headings and to hold altitude as fair. Seemed like the altitude control was not quite as precise as desired, mainly because I was concentrating more on attitude inputs because of this tendency to get into a PIO. Did seem that I was making some fairly large control deflections in pitch and roll. To get large bank angle (10 deg max) rapidly and then try to stop it resulted in getting behind the oscillation. That part of the problem was strictly pilot-induced. For small corrections, didn't have that trouble at all. Really noticed this only in the large inputs and when I required large, high rates. Don't think I was able to accomplish what you might consider a quick stop maneuver. If I tried I just felt that I didn't know whether I could stop the motion, because I got into a pilot oscillation. Don't think there were any excessive attitude changes; was just cautious about getting the aircraft to move laterally and maintain reasonable rates so I could avoid oscillation. Ability to hold heading and altitude was somewhat degraded, I think mainly because I was more worried about stopping it. Turning over a spot didn't provide much trouble. Would be drifting a little but could make corrections. Only time I felt in trouble was when attitude rates got high. The objectionable feature was that large attitude changes had to be made slowly to avoid getting into an overcontrol situation and PIO. However, for small amplitudes and small corrections, and when things were fairly well stabilized, the precision of control wasn't bad at all. Special piloting technique is to make control inputs so as to stay away from oscillatory tendency.

Case CL13 BC4 $M_{C_m} = UL$ $L_{C_m} = UL$ $N_{C_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $\tau_e = \tau_a = 0.1$ $M_{\delta_e} = 0.355$ $L_{\delta_a} = 0.341$ $PR = 2.5$

Tried higher lateral and longitudinal sensitivities and rapid, large amplitude maneuvers. With the higher sensitivities I could do a pretty good job although I seemed to be a little more oscillatory, so I decided to reduce the gains to roughly the initial values. Air taxi around the square - Response to control inputs seems a little sluggish. However, it's not really difficult to stabilize and hold desired velocities even though a little on the slow side. Ability to stop precisely not too bad. Seemed to be a relatively easy thing to stop precisely. Attitude changes may be a little on the high side. Ability to remain within ground track limits was quite good. Could hold heading and altitude quite well. Control deflections at times seemed to be on the large side with this gearing. For example, to get 5 deg of bank angle requires almost full throw, although I'm not hitting the stops. Didn't use any trim. Quick stops - With this gear ratio you don't really pick up very large velocities. After making an input it takes a little while for the velocity to pick up. To determine how much to lead it to stop didn't seem to be a very difficult thing. Ability to hold heading and altitude was quite good. Control motions required are substantial but manageable. Ability to hover over a spot was very good. Height control no problem. Pitch and roll control quite good. Ability to initiate and hold turn rates no problem and stopping on a pre-selected heading no problem. I was very happy with the precision of the hover, precision of the turns, ability to stop the motions; even though there are some lags in the system they were still quite noticeable. Control activity for vertical landing is probably fairly normal for a VSTOL airplane. The basic good feature is that the performance is quite good without excessive workload. No particular piloting techniques. I think it's acceptable and satisfactory, probably doesn't need any improvements unless you are looking for a highly responsive aircraft.

Case CL14 BC1 $M_{C_m} = 0.106$ $L_{C_m} = 0.154$ $N_{C_m} = 0.046$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_e} = 0.604$ $L_{\delta_a} = 0.234$ $PR = 10$

There is no question that this is an unacceptable configuration. I tried a range of longitudinal control sensitivities because I got into a longitudinal PIO which was so large and I was so far behind it that I in effect lost control. Increased the sensitivity; this seemed to improve things somewhat as long as I flew the airplane very tightly and with small amplitude displacements. Could be the pitch rate and attitude both couple in here to get me into trouble. If I got the aircraft moving forward pretty fast in trying to quick stop, it required very large pitch attitude to stop it. This is when I got into what appeared to be a very large amplitude situation where, in effect, I lost control. Did this about three or four times and went back to initial conditions. One can control the aircraft and do the maneuver task but you have to do it with small amplitudes and slow rates in pitch attitude. Once you get into large amplitude displacements and high pitch rates, then, in effect, control was lost. Would have to rate this an unacceptable configuration. It felt like control power was way down and so I just can't accept the airplane.

Case CL15 BC1 $M_{C_m} = 0.216$ $L_{C_m} = 0.248$ $N_{C_m} = 0.096$ M_{δ_e} and L_{δ_a} Unknown $PR = 0$

A pretty lousy configuration; not nearly as bad as the one I just had (CL14), but had similar characteristics, although the biggest problem with this one appears to be in controlling longitudinal position. Don't seem to have much control of forward and alt velocities or of being able to stop it with any degree of precision. Lateral control is not very good, but does seem to be a little better than longitudinal. Initial response to control inputs seems to be slow; however, once you get it started you do seem to have difficulty establishing a particular rate. It does seem to take a large pitch attitude change to get it moving and to stop it. Don't seem to have any idea when to make control reversals to stop it precisely. Don't think my ground track was very good in any case. Always had some heading problems here because I'm very often inadvertently putting rudder in when I'm trying to turn or bank. Where it stopped in the quick stops was unpredictable. Can't stop it where I wanted it. Then trying to hold it was also a problem. Turning over a spot was quite ragged; errors were on the order of ± 15 or 20 ft from the center. Tried flying it very tightly but just wasn't really able to accomplish it. Performance

Contrails

TABLE D-II(a) (Continued)

was quite poor. Trying to maintain a hover resulted in position errors on the order of 10 to 15 ft. Not sure I have adequate control for vertical landing. I suppose you might have some velocity, and just go ahead and land it, but trying to hit a spot is quite difficult. Lots of control activity. Objectionable features are the fact I just don't seem to know what kind of inputs to make to stop motions or initiate motions of the magnitude and the precision desired. No real special piloting techniques except that you try to second-guess or anticipate the inputs. Basically it's a very poor configuration from the standpoint of precision of control and performance.

Case 0116 BCL $M_{C_m} = 0.216$ $L_{C_m} = 0.249$ $N_{C_m} = 0.006$ $\sigma_{u_G} = \sigma_{v_G} = 0$ $M_{\delta_e} = 0.460$ $L_{\delta_e} = 0.361$ PR = 3.5

I tried several control sensitivities. At the higher values, got into some PIO problems and some overcontrol problems, so I reduced them a little. There is some lag in the response to control inputs and it does take a fair amount of attitude change to get things moving, but it's not excessive. Can maintain velocities once I've established them as long as they are not too high. I do seem to run into some problems if I increase my gain and make larger inputs; in other words, if the rates are fairly high and it takes large amplitude attitude changes to stop the motion. Then I get into some overcontrol and oscillatory tendencies. For low and moderately low velocities I can stop fairly well on the corners. Performance on ground track wasn't too bad. Holding heading was OK. Quick stops - Couldn't say these are really good quick stops. The main problem is that I relate the quick stop with high rate velocities and large amplitude pitch or bank angles, where I get into trouble. So I've been a little hesitant to get it going too fast. I did get into some PIO laterally one time when I made a fairly rapid quick stop. Turn over a spot - That actually went very well as long as I had a good stable rate of turn and not too fast. Was able to stay just about in the center of the spot most of the time. At the higher rates I went a little outside the square, maybe about 5 ft or so. I was fairly happy with the hover and turns, fairly happy with the low rates, both lateral and longitudinal, not too happy with the quick stop. Generally, it takes a moderate amount of concentration. I think I did induce some sort of lateral oscillation at times, especially when I felt I had to make some pretty rapid inputs.

Case 0117 BCL $M_{C_m} = 0.266$ $L_{C_m} = 0.332$ $N_{C_m} = 0.128$ $\sigma_{u_G} = \sigma_{v_G} = 0$ $M_{\delta_e} = 0.447$ $L_{\delta_e} = 0.280$ PR = 4

Didn't do too much on the gearings. I seemed to be able to fly the airplane pretty well so I only changed the longitudinal sensitivity a little. Response to control inputs seems to be pretty fair. Was able to initiate motions but it's not as responsive as I would like it. As long as I maintain u and v to moderately low values, there is no problem in maintaining desired velocities. There is a lag in the response in u and v to control inputs, but the attitude changes required to get the airplane to move in the x and y direction seem to be only moderate. Pitch attitude changes and roll attitude changes to stop the motions seem what I would rate as moderate. Would prefer to have smaller changes required but it's not really too bad. Precision to stay over ground track was fair also. Did take some effort, but performance was not too bad. Holding heading was not a problem and altitude control was good and control deflections were moderate. Quick stops - Don't think it's as good as I would like to see it but it's really not too bad either. Does take pretty large attitude changes to perform a quick stop. Turn over a spot - Was fair to good; at least I didn't have to work too hard and I could probably stay within about 10 ft of the center of the square. No problems initiating and stopping the turn. Again I did not push the rate. In the hover the performance was pretty good. Did have to work fairly hard but not excessively hard to do a reasonable job, although you're always making inputs. Certainly adequate for vertical landing and control activity would be considered as moderate to moderately high. Some slight cross-coupling between lateral and longitudinal modes. I guess the only objectionable feature I could see was the lack of responsiveness of the airplane in the u and v velocities, ability to stop precisely, and the small lag in response of the aircraft to moderate control inputs. Also, the attitude changes are maybe a little higher than would like. You can make some improvements on the airplane. Desired performance requires moderate pilot compensation.

Case 0118 BCL $M_{C_m} = 0.1$ $L_{C_m} = 0.1$ $N_{C_m} = 0.1$ $\sigma_{u_G} = \sigma_{v_G} = 0$ $M_{\delta_e} = 0.447$ $L_{\delta_e} = 0.280$ PR = 5

Tried several values of control sensitivity. Increased the sensitivity and didn't particularly like it because I got into some sort of pilot-induced oscillation, mainly in roll. There is still some lag in the response in the displacements and velocities of the aircraft. This was a sort of moderately difficult configuration to fly. Was able to do some things with pretty good precision, but it did take a lot of concentration. It did have a tendency to lag the control inputs; you had to anticipate stopping the motion of the aircraft laterally and longitudinally. Pitch response, roll response, yaw response all pretty good. Responsiveness in the initiation of motion and the stopping of the motion in the x and y directions was affected by lags in the system. Was difficult to stabilize and hold desired velocities. Then to try to stop it at any precise point was also somewhat difficult. I was able to hover pretty well, but it did take quite a bit of concentration. In doing so, there were some excursions in height but that was easily compensated with collective inputs. Height control was quite adequate; good damping in height. There is sort of a corkscrew effect when you start turning, depending on the rate at which you turn. There is a tendency to drop down in altitude. Sure there is a loss of lift as it does require some noticeable power input to maintain altitude. Had a tendency to lose altitude in the turn over a spot. Also seemed to be power required when I made some rapid lateral and longitudinal displacements. As far as precision around the ground track, x and y was sort of rough, especially in the y direction. I was either too far ahead or too far behind the spot. Quick stops - It's sort of a hit-or-miss proposition, although I managed to stop at the spot fairly well, but trying to hold it there was not easy. There did seem to be some fairly large control motions required. Turning over a spot - I think the ability to stay over the spot was only fair; I was always making corrections. Didn't make very fast turns. With these moderate turn rates I was able to stop it within about 15 deg of desired heading. Hover precision was fair, but I had to work fairly hard at it. Certainly adequate for vertical landing and control activity was almost constant. There were some x cross-coupling effects between longitudinal motions and lateral or bank angles; I always had that problem. I guess the most objectionable feature is the fact that you do have to anticipate stopping of x and y motions and pitch attitude changes. Pitch attitude changes seem to be fairly large to maneuver. Overall, it does require moderate to considerable pilot compensation to do most of the tasks, especially the quick stops.

TABLE D-II(a) (Continued)

Case C119 BCL $M_{c_m} = UL$ $L_{c_m} = UL$ $N_{c_m} = UL$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $K_{g_e} = 0.500$ $L_{g_a} = 0.320$ FR = 7

This was not a very good configuration. I played around a little with the gearings, but the final values are essentially like the previous configuration. Even for relatively small amplitude displacements and rates, I just didn't think the precision of control and the precision of the task were adequate. Don't believe I ever felt I completely lost control, but there were times when very large excursions were obvious. Quick stops - I could stop it, but then I couldn't maintain position at the stopping point. Then trying to bring it back to hover was quite a problem. Could probably stop the turn on a heading within about 45 deg. Precision of hover was fair, but it did take a pretty fair amount of concentration. I would probably be able to land, although I'd have to be quite careful with it. Height control, however, didn't seem to be a big problem, although there was one maneuver where I think I let the altitude go all the way down to 20 ft. I guess the primary objection is the initiation of translational motion is sluggish and once you get the motion started it's difficult to stop it. Pitch control is certainly quite adequate. Lateral control seemed a little sluggish. The attitudes required to stop the airplane once you get it moving are fairly large, especially in pitch. Didn't see anything too favorable about the configuration. There is no pitch or lateral oscillation that is highly objectionable, so the damping in pitch and roll is pretty good. The problem is along the axes in translation and also the large displacements in bank angle and pitch attitude that are required to get the airplane to move and stop.

Contrails

TABLE D-II(b) (Continued)

(b) Height Control

Case G11 $Z_{\omega_A} = Z_{\omega_E} = 0$ $T/W = UL$ $Z_{\delta_C} = 4.20$ $PR = 10$

Primary task was to evaluate ability to maintain height control while doing basic tasks. It's quite obvious you've absolutely no stability, no damping in height control, so the pilot starts off chasing altitude. The task is very, very severe. I was overcontrolling very, very much with the collective. I tried it again much more carefully and was actually able to get off the ground and establish about 50 ft and had pretty good control of altitude for a short time, maybe on the order of a minute or two, and was also able to hover over the spot at the same time fairly well, but was spending much time controlling altitude. So everything looked good; then I tried to start the maneuver. As soon as I did this, the altitude changed a little, so I tried to chase it with larger and larger collective inputs. Was going down to about 40 ft and up to about 80 or 90 ft. That's pretty poor. It was obvious that practically all my time would have to be devoted to height control and there would be very little time to do anything else with the aircraft. On the basis of height control alone, I would have to rate this configuration completely unacceptable. Control will be lost in some portion of required operation.

Case G12 $Z_{\omega_A} = Z_{\omega_E} = -0.25$ $T/W = UL$ $Z_{\delta_C} = 3.20$ $PR = 5$

Required a fair amount of monitoring of height control. The best I could do was to maintain altitude about 120 to 140 ft, but this took a fair amount of effort. I did all of the maneuvers. Didn't really think that these maneuvers were too bad. Some degrading might have occurred in performance due to time spent monitoring height control. Always shooting for 15 ft, but this time I doubled that on the average to 40 ft. Air taxi around the square response to controls really wasn't too bad. Was able to initiate motion in each direction. General comments - Essentially, I had a fair amount of monitoring on height control with rather large excursions. Saw as much as 20 ft high and about 15 ft low from the nominal 50 ft that I'm shooting for. On the average, however, height control was about 40 ft. Required reasonable amount of monitoring. Didn't choose any control sensitivity, just accepted what was here as being reasonable. Could do all the maneuvers reasonably well. However, during the more rapid and larger amplitude maneuvers I had to monitor the height a little more carefully because it would tend to either climb or descend as I made these large amplitude inputs. Most objectionable feature would be the height control; I would certainly like to have it be better. Favorable feature, I think, was the fact that, in spite of height control, I was still able to do all maneuvers reasonably well.

Case G13 $Z_{\omega_A} = Z_{\omega_E} = -0.35$ $T/W = UL$ $Z_{\delta_C} = 3.20$ $PR = 3.5$

Control sensitivity - Finally chose this one, which is a little lower gain than would have really liked from a standpoint of initial response. With higher sensitivities, got into other little problems like a tendency to overcontrol some, so I finally backed off. Taxi around the square response to inputs was fair. Ability to stabilize and hold desired velocities was fair. Could stop and come to a hover at the corners reasonably well, although again it takes fairly large and rapid inputs to stop. It does take fairly large pitch and roll attitudes; the bank angles are usually less than 5 deg and in pitch less than 5 deg. However, was able to maintain ground track quite well and no problem in holding heading because you just keep your foot off the rudders in effect, and the friction holds it once you establish that you have no rate of turn. Altitude control - Spent some time on it; could maintain altitude if I wanted to within 15 ft for normal maneuvering. Not true when I went into large amplitude, very rapid or at least attempted to make very rapid inputs to establish higher rates. Here height control problem became a little more obvious. Quick stops - Could stop quickly but, considering that rates are fairly low, the attitude changes appeared to be fairly high. So altitude control doesn't seem to be much of a problem; height control a little bit of a problem, definitely noticeable that you do have to spend some time on it. Can initiate and hold turn rates without problem; can stop on prescribed heading even at very high rates. Didn't use any of the wing tilt control. Precision hover - Vertical landing - Was able to establish and maintain precise hover quite well, a little skidderish but not really too bad; could generally stay well within the 7-ft square. The dynamics of one axis did not affect the evaluation of another. Overall evaluation - Somewhat objectionable feature was that you have to look at the height control, but it really wasn't that big a feature. Was reasonably satisfied that I could meet my criterion of 15 ft, but to do that it requires maybe a little more time and cross reference than is desirable. Favorable features - The fact that I can do all the maneuvers with reasonable precision in a fairly good way. No special piloting technique.

Case G14 $Z_{\omega_A} = Z_{\omega_E} = -0.175$ $T/W = 1.00$ $Z_{\delta_C} = 5.20$ $PR = 3.5$

Control sensitivities - Added a little sensitivity; it seemed to be a little better. I would say generally this was a fair configuration. Air taxi - The precision of control is still not really as good as I would like it. The small sensitivity change helped some. Still get the feeling there are appreciable lags from collective input and in stopping the rates of descent or rates of climb I can find a fairly well stabilized altitude with some effort. It takes several power inputs and cross-checking between the display and altimeter to find it. After a while you sort of mechanically put the power in and get the rates of descent. To set the rates of descent under control, you make a fairly large input and then hold it in for a second or two and take part of it out again and then cross-check the altimeter and display. It seemed to me that maybe 2 ft/sec is about as high as I would like to see or like to go with this thing. One time I had a fairly high rate of descent going and got down to about 12 ft on the altimeter. Was wondering whether I would be able to stop the rate of descent before touching down. Touchdown is about 9 ft. I still think there is some limitation here. It's probably a combination of limited thrust available plus aerodynamic damping and artificial damping. I can't differentiate; it's a combination, I think. As far as height control is concerned, you could do a fair job of flying the airplane. You can get adequate performance; is it satisfactory without improvement? Maybe you have some moderate pilot compensations to get the precision you want. There are again limits to how fast you can go up and down and still be able to control the rate of climb or the rate of descent. Precision of control, again, does take a certain amount of pilot effort to get the proper power setting, so frequency of collective input is maybe a little higher than you would like.

Contrails

TABLE D-II(b) (Continued)

| | | | | | |
|--|------------------------------|-------------------|-----------------------|-----------------------|----------|
| Case CH5 | $Z_{w_B} = 0$ | $Z_{w_S} = -0.35$ | $T/W = 1.07$ | $Z_{\delta_C} = 0.00$ | $FR = 4$ |
| <p>The hover performance was reasonable. Tried quite a few control sensitivities. I was having some lags in height control response to collective which I could improve by increasing the sensitivity. I had a tendency to blow overcontrol, so I went back toward the lower sensitivity. I wasn't too happy with the precision of height control. Had to spend a fair amount of time at it and almost invariably when I did I had trouble trying to maintain my position over the spot. However, it was not really that horrendous. It was one of those configurations that, if the rates of change in height were kept to a low level, I was able to establish a steady-state height reasonably well, but again with quite a number of collective inputs. At the higher rates, did overcontrol quite a bit. When I reduced rates to fairly low levels, maybe a half-foot per second or something in that order, it gets reasonable as far as precision, with some effort you maybe can establish a hover height about 45 ft. It's certainly controllable. I can get adequate performance with tolerable workload. I would think you should improve this some; I wasn't too happy with the precision of control only because it took quite a bit of effort, a lot of collective inputs to finally establish a steady-state hover height. I would probably think it's at least a moderate compensation required. I'm not really sure whether I ran out of thrust. Had the feeling that possibly at the higher rates it took a large amount of collective to stop the rate of sink.</p> | | | | | |
| Case CH6 | $Z_{w_B} = Z_{w_S} = -0.00$ | $T/W = 1.05$ | $Z_{\delta_C} = 3.20$ | $FR = 6$ | |
| <p>Selection of the gearing was predicated primarily on reducing overcontrol tendencies. Ended up I think with the minimum gearing available. I had gone up fairly high with it; however, there is a very strong tendency to overcontrol, so I was going up and down like a yo-yo for a while. I was spending a fair amount of time on the height control when I was trying to be precise with it; that deteriorated the performance on the X-Y plane. The overall impression is that it is not a very good configuration. I suspect that it's a damping problem primarily, but I couldn't care less whether it is damping or the fact that I may have lags in the power application, or that there is a lack of excess thrust available. The end result is the same. The precision of height control is just not there. I could probably land it as long as I can keep the rates down. Have to work pretty hard, though, to establish exactly 20 ft or exactly 40 ft within, say, 1/2 ft; that's a fairly difficult task. It does warrant improvement. It has very objectionable but tolerable deficiencies. Adequate performance requires extensive pilot compensation.</p> | | | | | |
| Case CH7 | $Z_{w_B} = Z_{w_S} = -0.175$ | $T/W = 1.05$ | $Z_{\delta_C} = 1.51$ | $FR = 5.5$ | |
| <p>I didn't change the sensitivities on collective, just accepted what I had, mainly because it seemed adequate. I did a little better in hover, but I'm still having tough time flying longitudinal and lateral modes so I concentrated more on the hover in evaluating the height control. It's a matter of rates, I think. If I keep the rates reasonably low, I have some precision. If I try to speed up the response, I'm way behind the airplane in trying to recover it. I think the objectionable features are the lead time required in stopping the motion once you get it moving, the lag in getting some noticeable movement when you make the input and the fact that the precision of control in all axes was rather poor. If I set up high rates of descent and high rates of climb, then the precision just isn't there. You get an overshoot of at least 10 ft or more in the climb direction. I'm a little more hesitant to allow it to drop below 20 ft so I tend to make sharper, faster, larger inputs when the rate of descent is fairly high and I'm approaching 20 ft. It's like bang-bang control, you just put it in and say take some of it out because you know you probably have overcontrolled. Think it is controllable. Adequate performance with a tolerable workload? Not if you're talking about the overall task.</p> | | | | | |
| Case CH8 | $Z_{w_B} = Z_{w_S} = -0.25$ | $T/W = 1.05$ | $Z_{\delta_C} = 1.51$ | $FR = 3$ | |
| <p>It is still not very good, but I managed to hover at times almost within the square, which is pretty good. The same things bother me in longitudinal and lateral control: the lags, the turbulence, possibly the gearing is involved in there also. On the precision of vertical control, I was able to go down to 20 ft and hold it there while I attempted to do some maneuvers, went back up to 40 ft and hit it fairly well. For long periods of time the height control required no attention. Also attempted some high rates of descent and climb. The time that I have to concentrate on the height control is fairly minimal. Precision of height control was pretty good and the fact that you can pretty much set the collective and the height stays fairly close to where you put it, certainly within the 5 ft; that's pretty good. It seemed that there was always somewhat of a lag, but I think that's probably built into the altimeter. Possibly some of this hunting for the proper collective position may be caused by that lag in the altimeter. Only minor or minimal pilot compensation required.</p> | | | | | |
| Case CH9 | $Z_{w_B} = Z_{w_S} = -0.05$ | $T/W = 1.10$ | $Z_{\delta_C} = 5.24$ | $FR = 7.5$ | |
| <p>I played around with the collective sensitivity quite a bit and was not able to find anything I liked. As I increased the sensitivity, I overcontrolled very badly. I had started out with the sensitivity to the minimum position on the lever and went up just a little, but that gave me all kinds of trouble. I picked something halfway between. I was still having troubles so I finally settled on having minimum sensitivity and that still gave me the same kinds of problems I had on the previous configuration (CH11) except more accentuated. To get the thing moving it seems to take quite a bit of thrust; once you get it moving, though, to stop it takes quite a bit of collective change so I suspect we have some degradation in the height damping, plus the fact that possibly we have low excess thrust available for height control. End result is that performance on the tasks, longitudinal and lateral, was quite bad. Didn't even try the lateral displacements; I was having enough trouble with pitch.</p> | | | | | |

TABLE D-II(b) (Concluded)

Used a good portion of time just trying to keep the airplane at proper altitude or at least trying to stay close to the 20 ft or 40 ft altitude. I was overshooting at least 10 ft. Have a tendency to fly tighter when I'm going down than when I'm going up. Main objection was that I did not have precision of height control. I think there were times when I did manage to have the power lever just about right but then every time you maneuver the airplane to some extent you do have quite a bit of activity with the collective.

Case CH10 $Z_{w_a} = Z_{w_c} = -0.125$ $T/W = 1.10$ $Z_{\delta_c} = 1.51$ $PR = 5$

The initial control sensitivity on the collective was a little high and I overcontrolled very badly, so I put the sensitivity down some. Was having more problems with hover than anything else on this configuration. Seems to be substantial lead required both in pitch and roll but it's more obvious in the pitch axis. The dynamics are also a problem. I had to make reasonable number of collective inputs to maintain 40 ft. However, it seemed to be a reasonable task. On the other hand, when I started to make climbs and descents to about 20 ft and back up to 40 ft, still had a tendency to overcontrol with the collective because there seemed to be a lack of thrust or there was a lag in the response of the thrust; either way you would get the same effect. Overall performance of the tasks was quite poor, especially the hover; I really had trouble with that. As long as I did things at reasonably low rates, I could manage to do the task. If I tried to push the airplane and force it to respond at higher rates, then everything seemed to go to pot. I don't really think I could do a quick stop with this thing too well. I didn't try any turns over the spot. Precision of hover, I thought, was quite poor and I had difficulty in establishing reasonable rates of descent and climbs so I could stop the height exactly where I wanted it. I think it was probably adequate for vertical landing as far as height control was concerned, but I'm not too sure about being able to hit a spot with any degree of precision. Control activity was quite large; I was continuously making inputs. Overall, there wasn't anything I particularly liked about it, but I thought it was flyable with a fairly large amount of effort. It takes quite a bit of concentration.

Case CH11 $Z_{w_a} = Z_{w_c} = -0.175$ $T/W = 1.10$ $Z_{\delta_c} = 6.30$ $PR = 3$

Don't have the feeling I have very precise control of the aircraft; however, I managed to keep reasonable control. It's just concentrating on height control that's a problem. By using low rates for take-off and changing altitude by 20 ft from 40 ft to 20 ft and back to 40 ft, did seem to have reasonable precision within about 1 or 2 ft. However, I did do a couple of maneuvers where I increased the rates fairly high and did have some overshoot problems. Got the impression that it was because I needed more collective displacement than I would normally like to use; it seemed I was using quite a bit of power. The excess power available is not as much as I would like. I don't think it was associated with damping per se because generally I could stabilize pretty well at 40 ft and 20 ft with just a moderate amount of hunting. Objectionable feature - I think it was just at the higher rates; too much collective displacement was required. Favorable features were that, by keeping the rates reasonably slow, I was able to have pretty precise control of altitude. No special piloting techniques except that, because of lags in the lateral and longitudinal dynamics, you have to lead the power application if your rates of descent or rate of climb get too high. It's hard to say exactly what those rates are, but if you're going to change 20 ft in more than about 30 sec, then you may get into some power application problems. I suspect it was probably lack of sufficient excess thrust available for control.

APPENDIX E

CONTROL-MOMENT EXCEEDANCE PLOTS FOR THE MANEUVERING SUBTASK

Pitch, roll, yaw and height control power exceedance data computed for a range of reference moment levels are contained in this Appendix. Initially, exceedance plots are present for pitch, roll and combined pitch and roll control moment data measured during the maneuvering subtask. The effects of turbulence intensity, aircraft speed stability and drag parameter, level of aircraft pitch and roll dynamics, control lags, rate and control coupling, and independent thrust-vector control can be seen in these exceedance data. The change in thrust-usage exceedance values with height velocity damping are presented next, and the final figure in this Appendix contains the yaw control-moment-usage exceedance results. In general, the effects of the different parameters examined on control-power usage, as defined by the exceedance data in this Appendix, are consistent with the effects noted (for the maneuvering subtask) by comparing the 5-percent exceedance levels.

| RMS TURBULENCE INTENSITY, FT/SEC | 3.4 | 5.8 | 8.2 |
|----------------------------------|-----|-----|-----|
| SYMBOL | ○ | □ | △ |

CONFIGURATION BC1 $M_{0.9} = -L_{0.9} = 0.33$ MANEUVERING SUBTASK

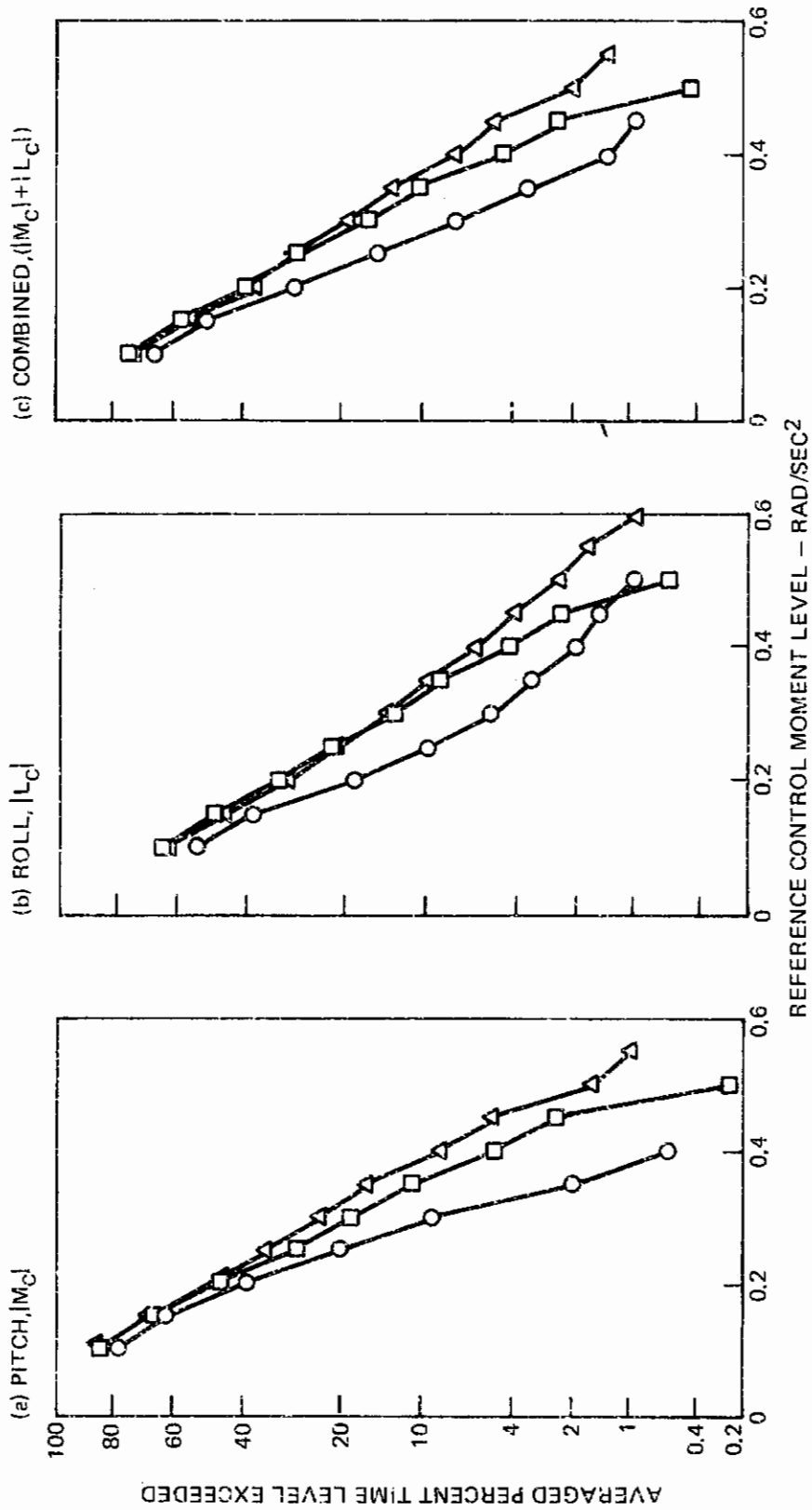


FIGURE E-1.1. Effect of Turbulence on Exceedance Results for a V/STOL Configuration with Small Response to Turbulence

| RMS TURBULENCE INTENSITY, FT/SEC | 3.4 | 5.8 | 8.2 |
|----------------------------------|-----|-----|-----|
| SYMBOL | ○ | □ | △ |

CONFIGURATION BC6 $M_{0.9} = -L_{0.9} = 1.0$ MANEUVERING SURTASK

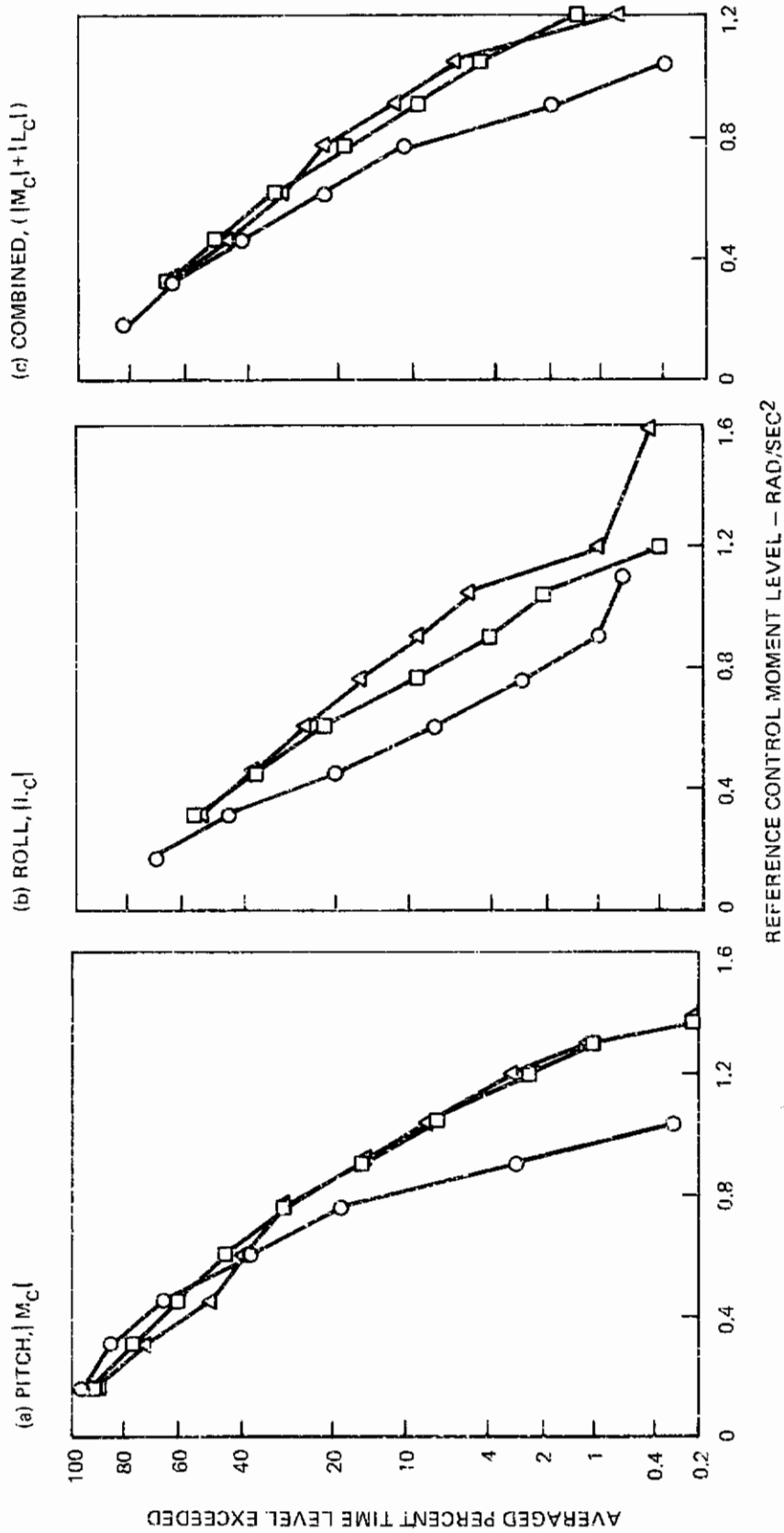


FIGURE E-2. Effect of Turbulence on Exceedance Results for a V/STOL Configuration with Large Response to Turbulence

| BASIC CONFIGURATION | BC5 | BC4 |
|----------------------------|------|-----|
| $M_{u\beta} = -L_{v\beta}$ | 0.33 | 1.0 |
| SYMBOL | □ | ○ |

$\sigma_{u\beta} = \sigma_{v\beta} = 3.4 \text{ FT/SEC}$ MANEUVERING SUBTASK

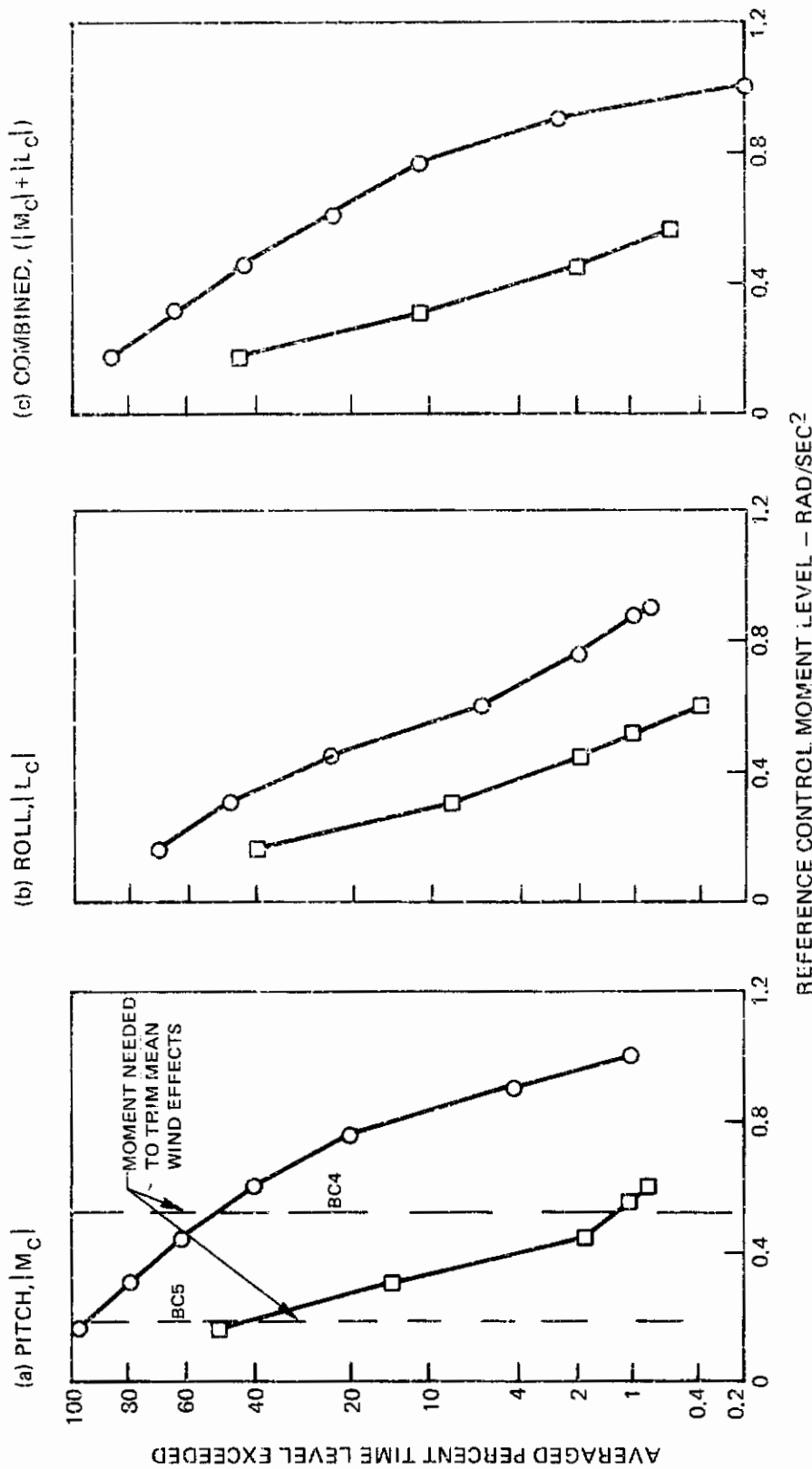


FIGURE E-3. Exceedance Results Showing the Effect of Aircraft Speed-Stability Parameters

| BASIC CONFIGURATION | BC1 | BC5 |
|---------------------|-------|-------|
| $X_u = Y_v$ | -0.05 | -0.20 |
| SYMBOL | ○ | □ |

$\sigma_{u_{ig}} = \sigma_{v_{ig}} = 3.4 \text{ FT/SEC}$ MANEUVERING SUBTASK

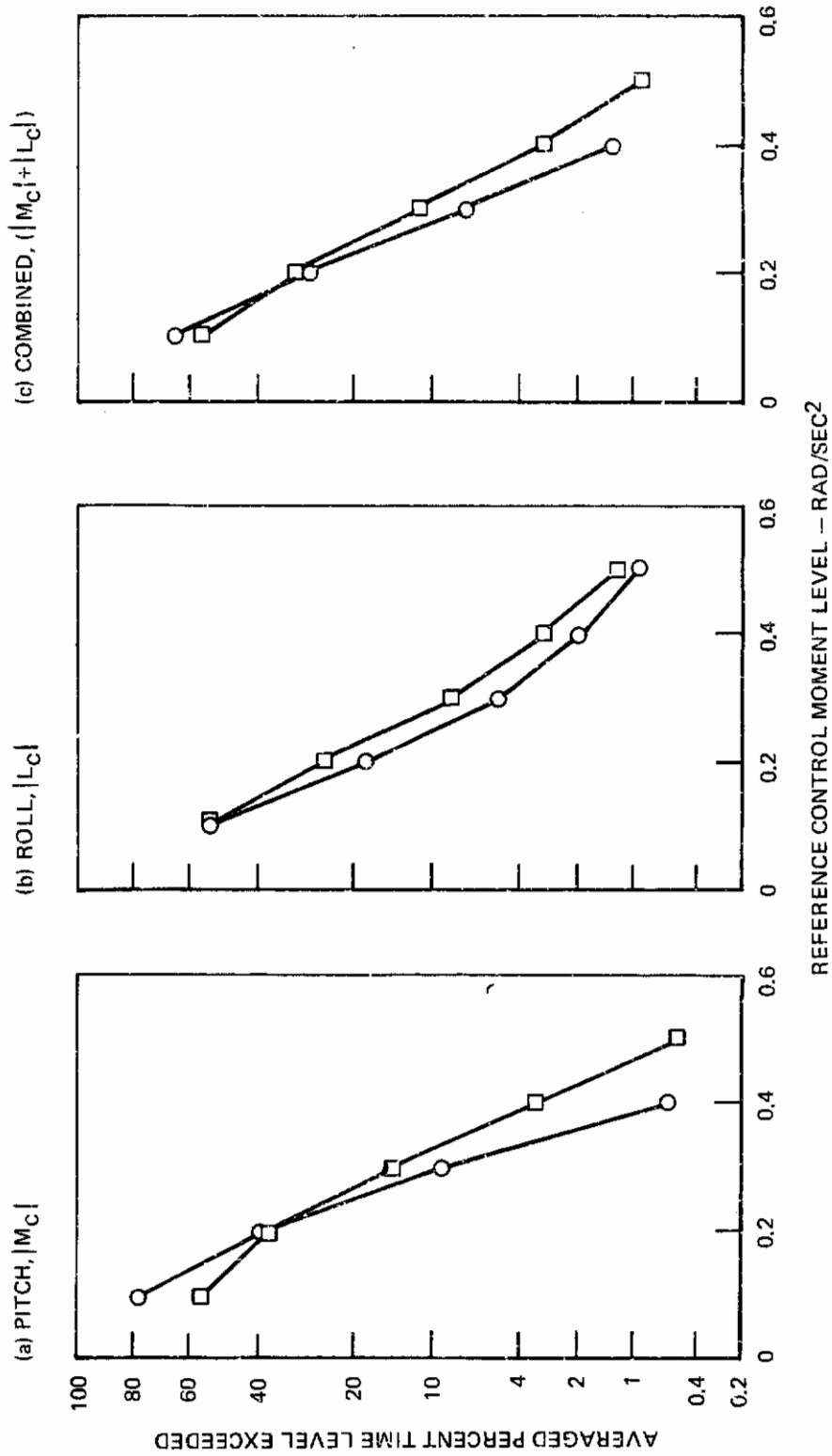


FIGURE E-4. Exceedance Results for V/STOL Configurations Having Different Drag Parameters

| LEVEL | 1 | 2 | 3 |
|---------------------|-----|-----|-----|
| BASIC CONFIGURATION | BC4 | BC2 | BC3 |
| SYMBOL | ○ | □ | △ |

$M_{Ug} = -L_{Ug} = 1.0$ FOR BC4, BC2, BC3 $\sigma_{Ug} = \sigma_{Ug} = 3.4$ FT/SEC MANEUVERING SUBTASK

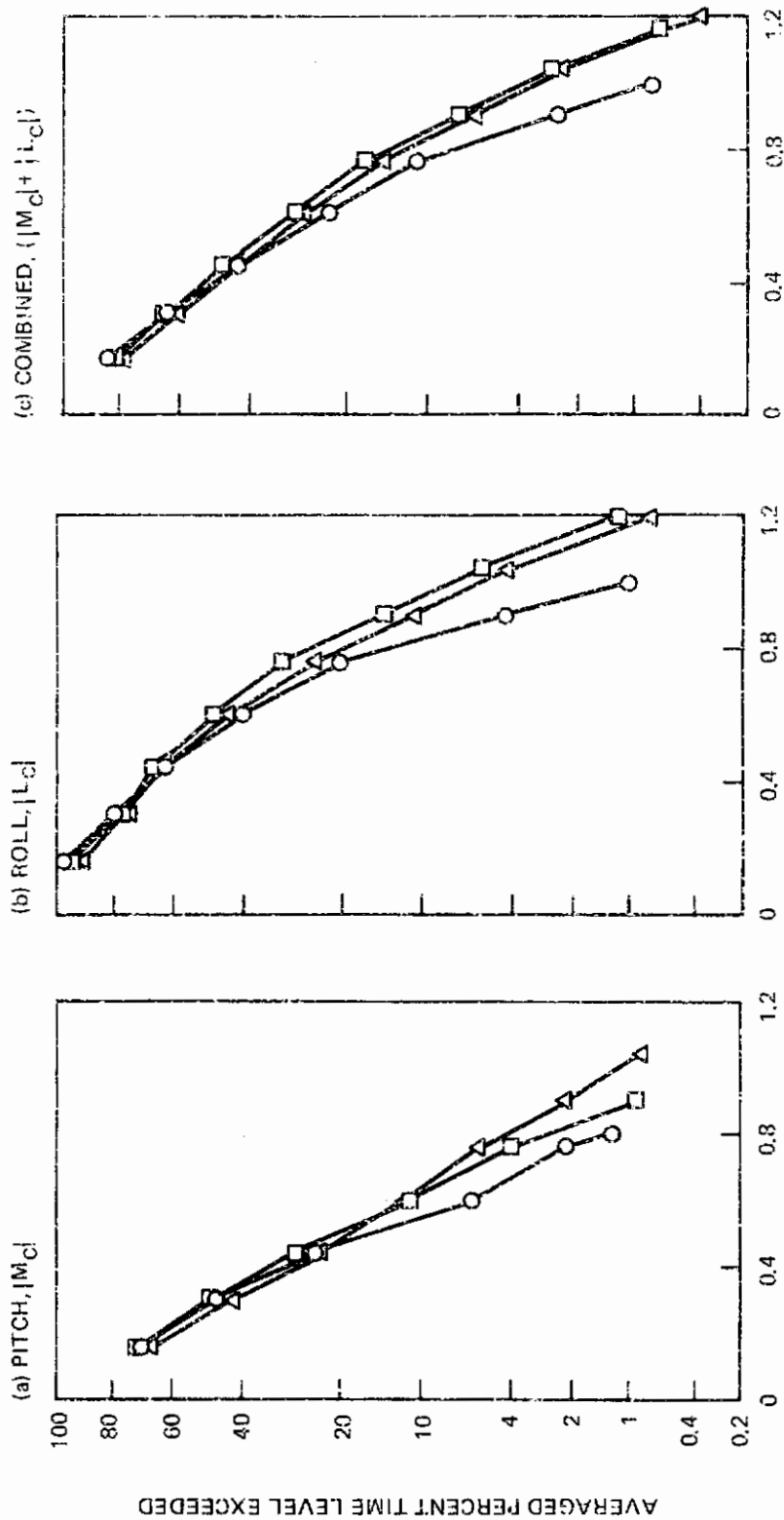


FIGURE E-5. Exceedance Data for Three V/STOL Configurations Exhibiting the Three MIL-F-83300 Levels of Flying Qualities

| | | | |
|-------------|---|-----|-----|
| CONTROL LAG | 0 | 0.3 | 0.6 |
| SYMBOL | ○ | □ | △ |

CONFIGURATION BC4 $M_{0\beta} = -L_{0\beta} = 1.0$ $\sigma_{u_{0\beta}} = \sigma_{v_{0\beta}} = 3.4$ FT/SEC MANEUVERING SUBTASK

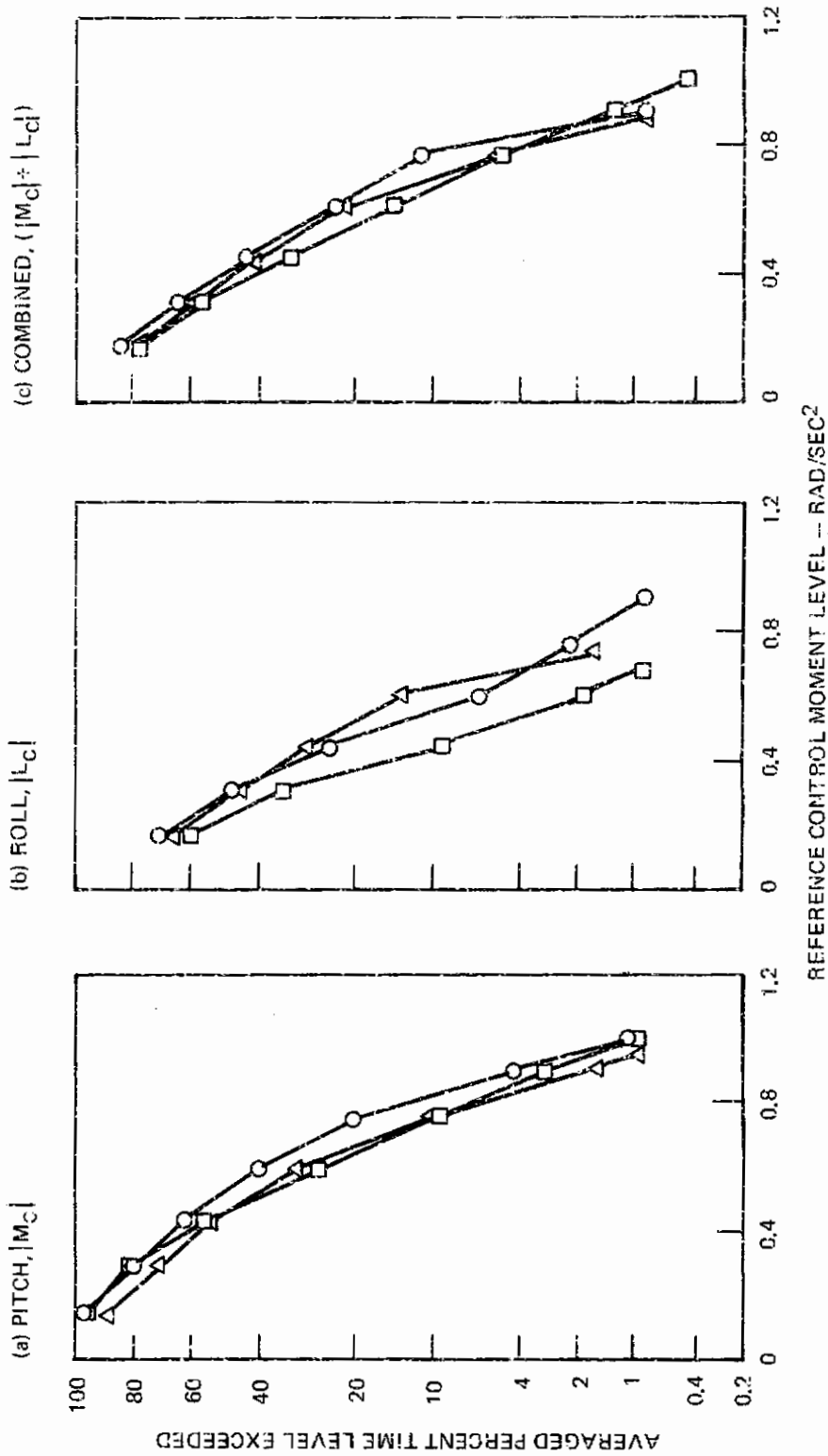


FIGURE E-6. Effects of Control Lags on Exceedance Results for a Configuration with Moderate Response to Turbulence

| | | | | | | | |
|--|--|----|----|------|----|------|----|
| $M_{\delta_a} / L_{\delta_a} = -M_{\delta_e} / L_{\delta_e}$ | | 0 | | 0.25 | | 0.50 | |
| SIMULATOR MODE | | FB | MB | FB | MB | FB | MB |
| SYMBOL | | ○ | ● | □ | ■ | △ | ▲ |

CONFIGURATION BC1 $a_{u\beta} = a_{v\beta} = 3.4$ FT/SEC $M_{u\beta} = -L_{v\beta} = 0.33$ MANEUVERING SUBTASK

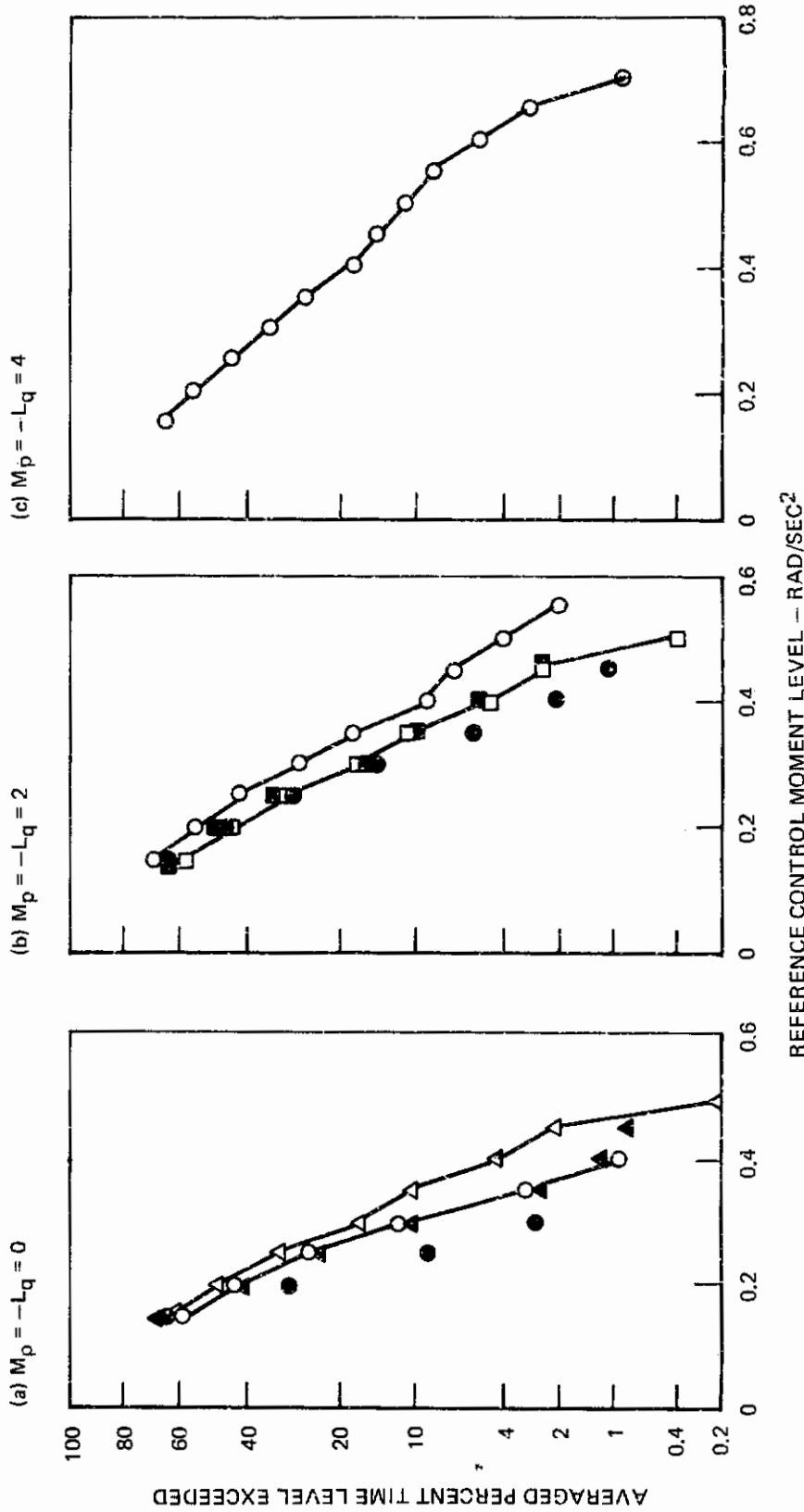


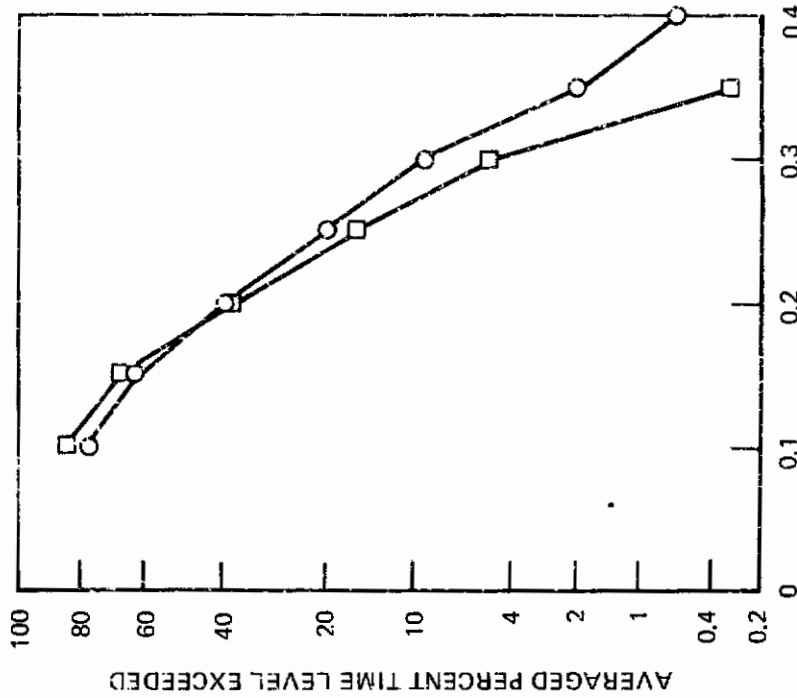
FIGURE E-7. Effect of Rate and Control Coupling on Pitch Exceedance Results

| TYPE OF POSITION CONTROL | CONVENTIONAL | INDEPENDENT THRUST-VECTOR CONTROL |
|--------------------------|--------------|-----------------------------------|
| SYMBOL | ○ | □ |

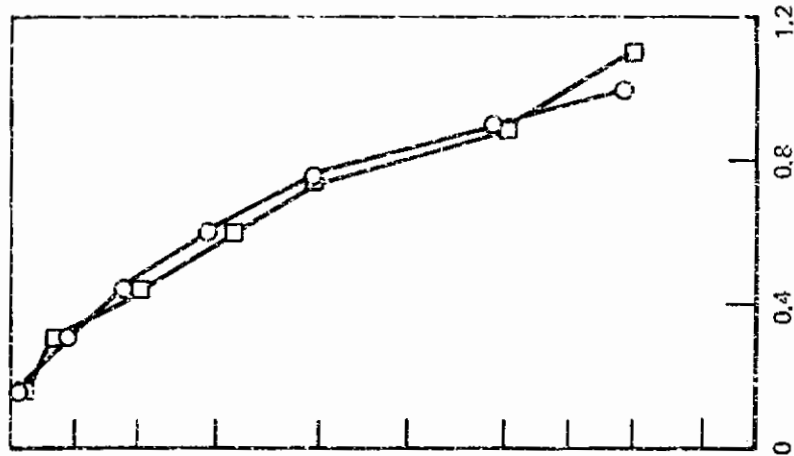
FIXED BASE MANEUVERING SUBTASK

THUMB-SWITCH THRUST-VECTOR CONTROL, $\dot{\gamma} = 20$ DEG/SEC, AND CONTROL-STICK ATTITUDE CONTROL FOR INDEPENDENT THRUST-VECTOR CONTROL

(a) CONFIGURATION BC1



(b) CONFIGURATION BC4



REFERENCE PITCH CONTROL MOMENT LEVEL -- RAD/SEC²
 FIGURE E-8. Comparison Between Pitch Control-Moment Exceedance Data for Independent Thrust-Vector Control and Conventional Position Control

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| | | | |
|--------------------|---|-------|-------|
| LEVEL OF Z_{W_T} | 0 | -0.25 | -0.50 |
| SYMBOL | ○ | □ | △ |

$Z_{W_T} = Z_{W_B} + Z_{W_s}$ WHERE $Z_{W_B} = Z_{W_s}$ $T/W > 1.15$

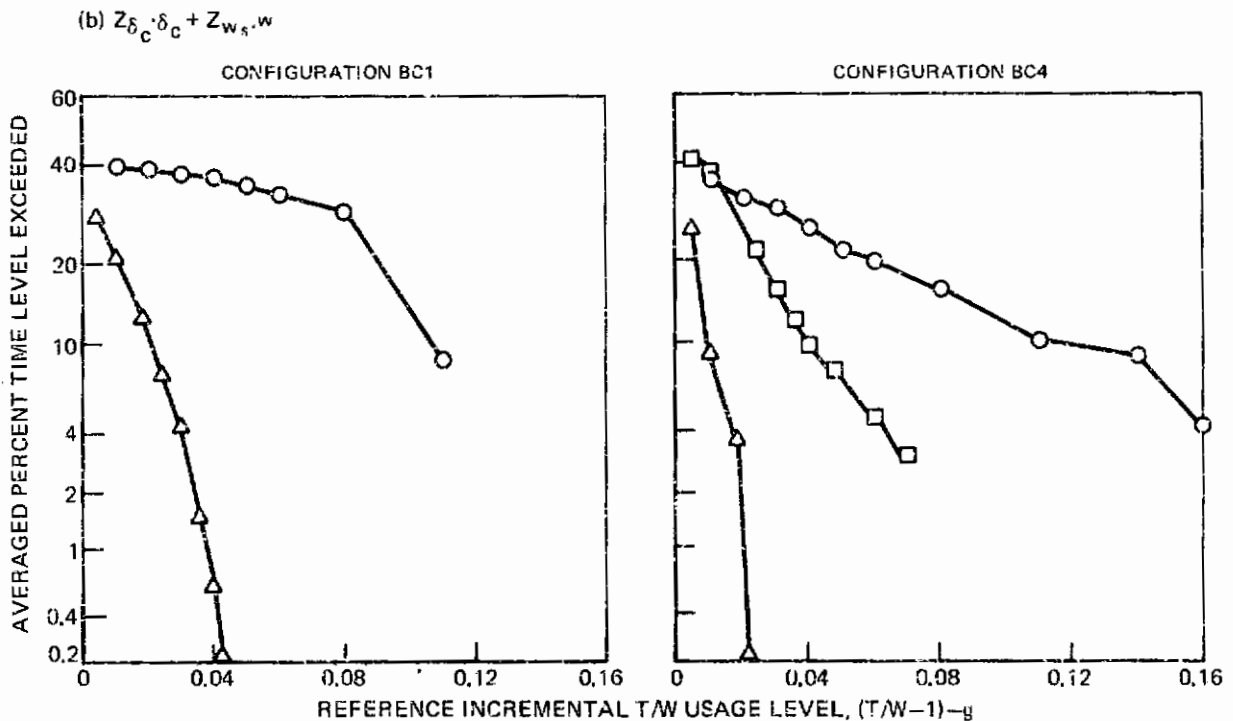
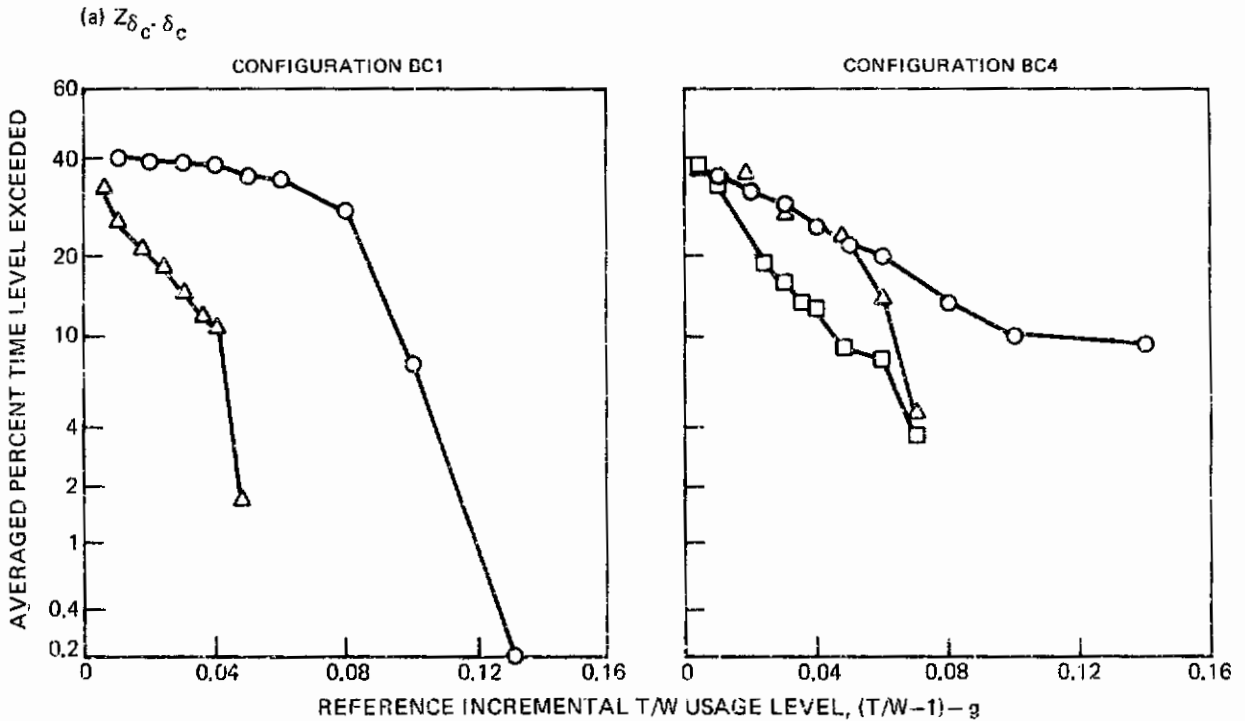
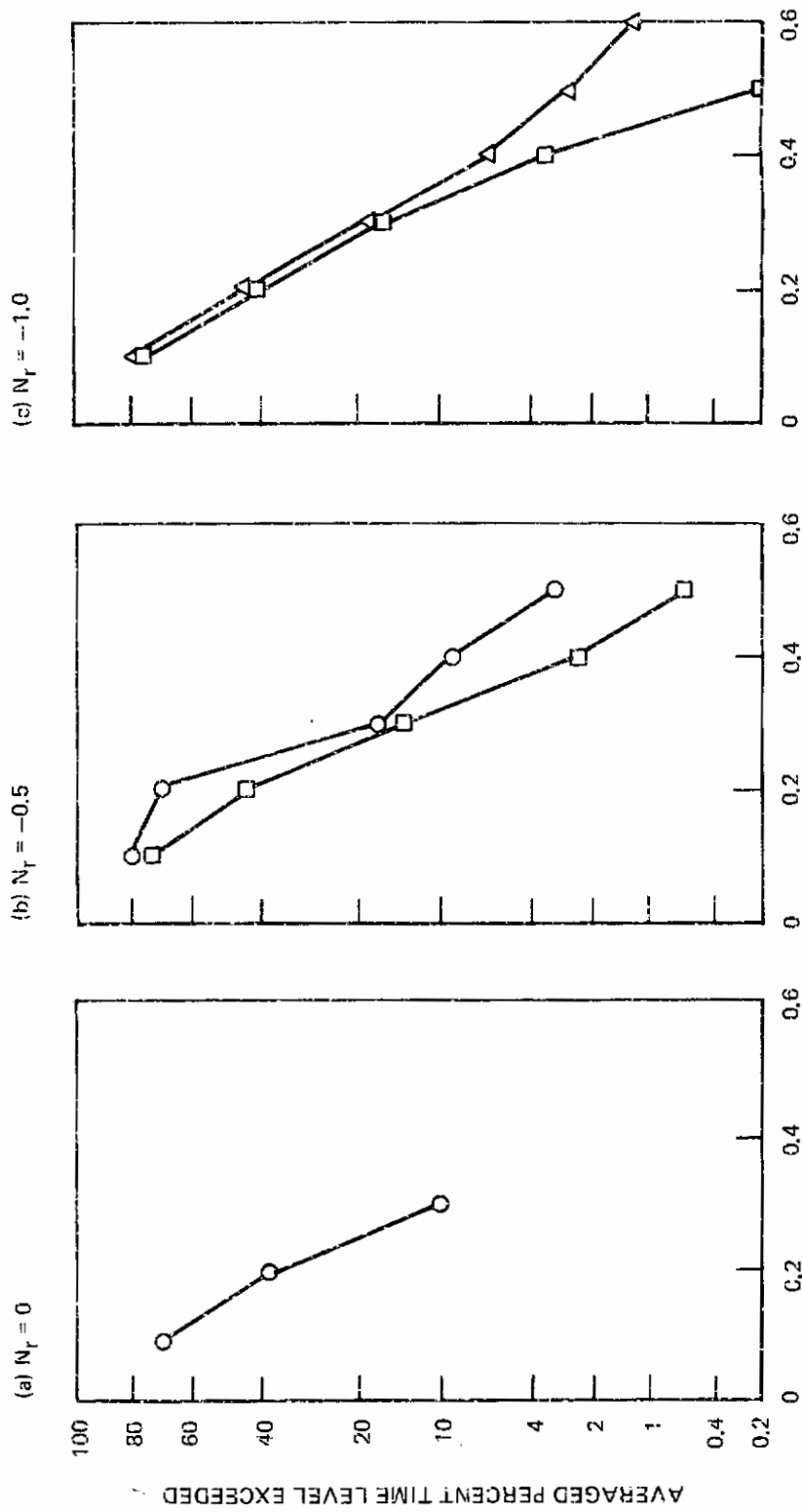


FIGURE E-9. Effect of Z_{W_T} on Incremental Thrust, $(T/W-1)$, Exceedance Results Computed for Increased Thrust Commands

| FIRST ORDER CONTROL LAG, T_{ψ} | 0 | 0.3 | 0.6 |
|-------------------------------------|---|-----|-----|
| SYMBOL | ○ | □ | △ |

TURN SUBTASK CONFIGURATION BC1 $N_V = 0.005$



REFERENCE YAW CONTROL MOMENT LEVEL, N_{CO} - RAD/SEC²

FIGURE E-10. Yaw Control-Moment Usage Exceedance Results

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APPENDIX F

ADDITIONAL DETAILS OF THE UARL FLIGHT SIMULATION

This Appendix is a supplement to the description of the UARL flight simulation contained in this report (Section II.B). Details of the equations used to represent V/STOL aircraft motion in hovering and low-speed flight are discussed initially, here. The characteristics of the flight simulator controls are detailed next and the motion washout logic is described in the final section of this Appendix.

A. Equations of Motion

The general form of the six-degree-of-freedom perturbation equations of motion for V/STOL hovering and low-speed flight are given in Eq. (F-1).

$$\begin{aligned}
 M_u u + M_\theta \dot{\theta} + M_q \dot{q} - \dot{q} &= -M_{\delta_e} \delta_e - M_u (u_g + U_m \cos\psi) \\
 L_v v + L_\phi \dot{\phi} + L_p \dot{p} - \dot{p} &= -L_{\delta_a} \delta_a - L_v (v_g - U_m \sin\psi) \\
 N_v v + N_r \dot{r} - \dot{r} &= -N_{\delta_r} \delta_r - N_v (v_g - U_m \sin\psi) \\
 X_u u - q w + r v - g (\sin\theta + \sin\gamma) - \dot{u} &= -X_u (u_g + U_m \cos\psi) - X_{\delta_e} \delta_e \\
 Y_v v - r u + p w + g \sin\phi \cos(\theta + \gamma) - \dot{v} &= -Y_v (v_g - U_m \sin\psi) - Y_{\delta_a} \delta_a \\
 Z_w w - p v + q u + g(1 - \cos\phi \cos\theta - \cos\psi \cos\gamma) - \dot{w} &= -Z_{\delta_c} \delta_c \\
 \dot{\gamma} &= 0.087 TS \\
 \dot{\theta} &= q \cos\phi - r \sin\phi \\
 \dot{\phi} &= p + q \sin\phi \tan\theta + r \cos\phi \tan\theta \\
 \dot{\psi} &= (q \sin\phi + r \cos\phi) \sec\theta
 \end{aligned}
 \tag{F-1}$$

The various terms and symbols are described in the List of Symbols. The equations are for a body axis coordinate system and have been normalized with aircraft mass and moments of inertia. Stability derivatives on the left side of the equations describe the aerodynamic, propulsive and stability augmentation forces and moments. Terms on the right side describe the forces and moments induced by control inputs, the simulated turbulence and the mean wind. With the exception of N_v , the derivatives which couple motion between axes have generally been assumed to be negligible. However,

Controls

pitch and roll rate coupling and control coupling were examined in one of the longitudinal and lateral control studies (Sections II.A.1.f. and III.A.5.). For this investigation the terms $M_{\dot{p}p}$ and $L_{\dot{q}q}$ were added to the left side of the pitch and roll moment equations, respectively, and the terms $M_{\delta_a} \delta_a$ and $L_{\delta_e} \delta_e$ were added to the right side of these respective equations. Also, it should be noted that the mean wind, U_m , was from 000 degrees true and it therefore affected the lateral and directional forces and moments, especially during the ± 180 deg turn subtask. Finally, the relationship for $\dot{\gamma}$ describes the rate-command, thumb-switch control characteristic for the thrust-vector angle, γ . The parameter TS was either 0 or 11 and, consequently, the pilot could command a 5 deg/sec rate-of-change of thrust-vector angle (or wing-tilt angle) to trim the effects of the mean wind acting on the aircraft longitudinal drag parameter. For the study of independent thrust-vector control the rate-of-change of thrust-vector angle was treated as a parameter (Section III.A.6.).

B. Characteristics of the Flight Simulator Controls

A conventional floor-mounted control stick (the cyclic pitch control stick of the S-61) was used for attitude control. It was used without a force gradient and the inherent friction present was negligible. The full longitudinal and lateral travels of the control stick were ± 6.63 in. and ± 6.50 in., respectively. For height control, a conventional, floor-mounted helicopter-type collective control with adjustable friction was used (7.5 in. total travel). The rudder pedals (± 3.2 in. total travel) for yaw control did not have a force gradient and the inherent friction was negligible. An on-off thumb-switch control was also used to command a fixed rate-of-change of thrust-vector angle (5 deg/sec). For the study of independent-thrust-vector control (Section III.A.6.) different commanded rates-of-change were considered. Also, for one part of that study the thumb switch was used to control pitch attitude and the cyclic stick controlled thrust-vector angle (Section III.A.6.).

C. Flight Simulator Motion Washout System

A schematic flow diagram for the motion washout interface between the simulated V/STOL aircraft motion (from the equations of motion implemented on an analog computer) and the commanded flight simulator motion is shown in Fig. F-1. This washout system insures that the flight simulator remains within its motion limits. The characteristics of the washout system have been tailored as much as possible to the frequency response features of the human vestibular system (Ref. 11). First-order roll-offs (20 dB/decade) are used to attenuate the low-frequency flight simulator attitude motion. This roll-off at low frequencies is similar to the frequency response of the attitude motion sensors in the vestibular system (the semi-circular canals). Second-order roll-offs are used for the translational motion.

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Crossfeeds between low-frequency longitudinal and lateral accelerations and pitch and roll attitude, respectively, are used to simulate these accelerations with components of the earth's gravity vector. Because of this feature these low-frequency aircraft accelerations are also subtracted from the simulator translational motion commands. A more complete description of the washout system is contained in Ref. 11.

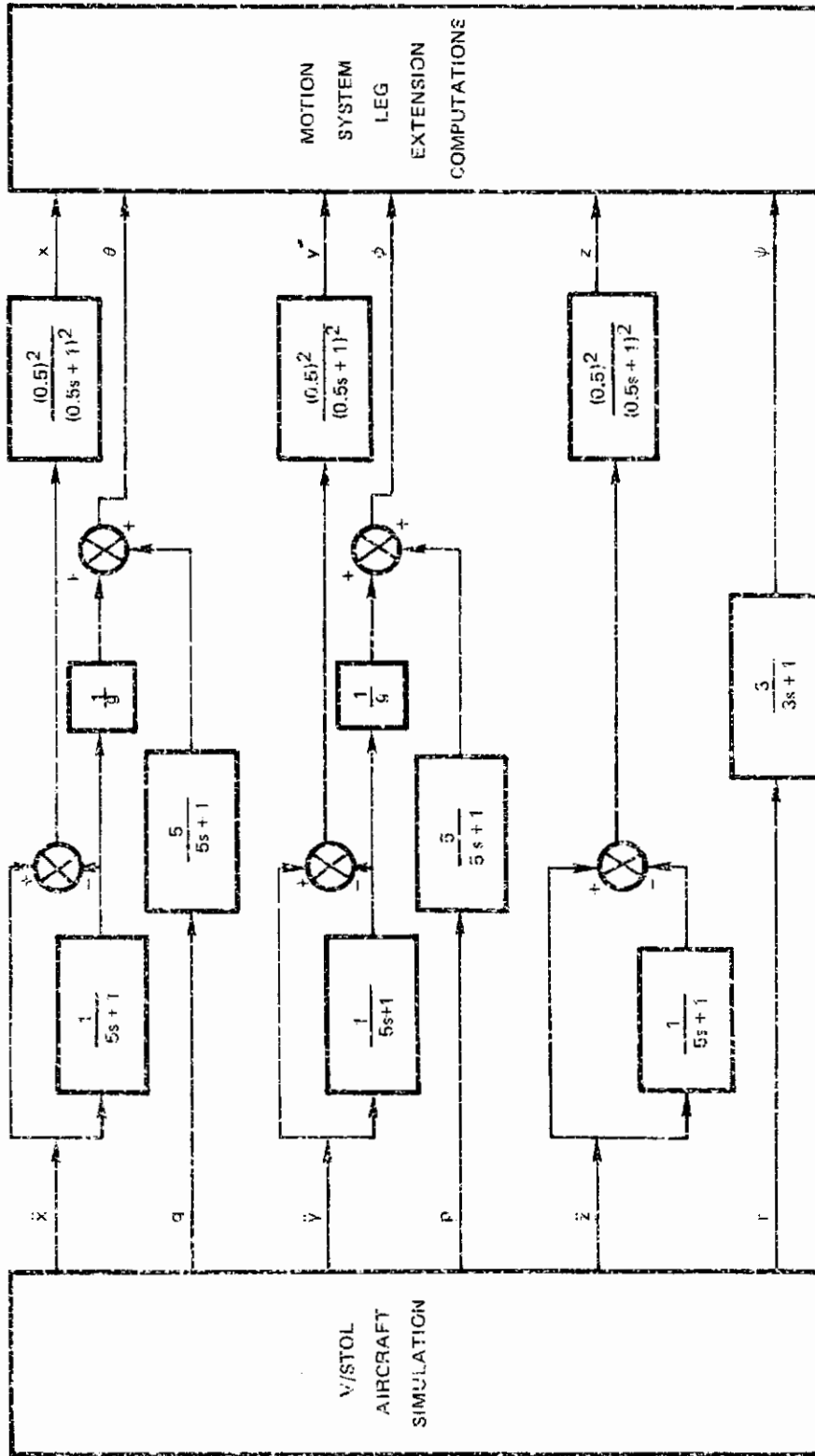


FIGURE F-1. Schematic Diagram of UAC V/STOL Flight Simulator Motion Washout System

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| 13. ABSTRACT Fixed- and moving-base flight simulator experiments and analyses were conducted to provide data for use in substantiating, refining and extending the hovering and low-speed-flight portion of MIL-F-83300 - V/STOL Flying Qualities Specification. For longitudinal and lateral control, the following areas were investigated: turbulence intensity, control lags and delays, control-moment limits, control moments through stored energy, inter-axis motion coupling, independent thrust-vector control and rate-command/attitude-hold control. For height and directional control, the effects of damping levels, control lags and delays, and control power limits were investigated. Opinion ratings, pilot comments, and pilot-selected control sensitivities were recorded in the flight simulator experiments; control-power-usage data were also obtained. The results indicate that the MIL-F-83300 Level 1 requirement for V/STOL dynamic response provides aircraft dynamics which remain controllable for nominal increases in gust intensity. The specification appears to generally exclude pitch and roll control lags, and lags in thrust response, which cause unsatisfactory flying qualities; it admits lags for which pilot opinion does not deteriorate. However, it excludes directional control lags which do not degrade opinion. The results further indicate that the specification for installed control moments provides levels which are satisfactory but not excessive. Control sensitivities selected by the pilots also generally fall within the boundaries specified, but are much closer to the lower limit than to the upper. Finally, data from the height control study show that minimum Z_w levels of | | |

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13. Abstract (Continued) -0.25 to -0.35 are necessary for satisfactory flying qualities with unlimited T/W.

Results for unconventional control techniques evaluated indicate that rotor-propulsion system stored energy can be used to offset limitations in installed control power. Independent thrust-vector control can be used for hovering and maneuvering when properly implemented. Rate-command/attitude-hold control does not appear to provide benefits for hover and low-speed flight.

The exceedance data show that speed-stability and damping are the configuration parameters having the greatest effects on control power usage. Control system lags have little effect on pitch and roll control-moment usage, but they increase yaw control-moment and thrust usage somewhat. The largest amounts of control moment were used for the quick stop task; the smallest amounts were used for hover and turn-over-a-spot. The data indicate that the installed total moment for pitch plus roll control must be sufficient to account for simultaneous usage by the pilot; it cannot be assumed that pilots make independent pitch and roll control inputs.

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|---|--------|----|--------|----|--------|----|
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