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AN IN-FLIGHT SIMULATION OF HANDLING QUALITIES OF THE SV-5P (PILOT) LIFTING BODY WITH VARIOUS FEEDBACK GAINS AND RUDDER TO AILERON INTERCONNECT RATIOS

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Cornell Aeronautical Laboratory, Inc.

TECHNICAL REPORT AFFDL-TR-67-135

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FOREWORD

This report was prepared for the United States Air Force by the Cornell Aeronautical Laboratory, Inc., Buffalo, New York, in partial fulfillment of Contract AF33(615)-3294. It contains material extracted from SV-5P (Pilot)-Preliminary Trim Aerodynamics-(Aero.-Aual(AA-1)-First Revision (title unclassified), Unpublished data from Martin-Baltimore. This data is CONFIDENTIAL (Group 4).

The flight test program reported herein was performed by the Flight Research Department of Cornell Aeronautical Laboratory under sponsorship of the Air Force Flight Dynamics Laboratory, Directorate of Laboratories, Wright-Patterson Air Force Base, Ohio. This in-flight simulation and evaluation of SV-5P handling characteristics was requested by the SV-5P Project Office at Wright-Patterson Air Force Base, Ohio. Mr. Richard Sickeler and Squadron Leader William Smith were project engineers for the Flight Dynamics Laboratory.

This report is also being published as Cornell Aeronautical Laboratory Report No. BM-2238-F-3.

The success of this flight test program is the result of the efforts of a number of members of the Martin Company in Baltimore and the Cornell Flight Research Department. Martin personnel provided wind tunnel data, information on flight conditions, gains, and control characteristics of the SV-5P. This information was the basis of the in-flight simulation. The CAL Program Manager of the T-33 projects is Mr. Robert Kidder. Mr. B. Dolbin of Cornell was responsible for the development and application of the in-flight simulation techniques. Mrs. V. Close was responsible for the IBM 7044 computation programs. Mr. James Meeker aided in some of the original analytic work associated with the in-flight simulation, and also acted as safety pilot and in-flight test conductor during the calibration and evaluation phases of the flight test program. Mr. N. Infanti and R. Harper also acted as safety pilots and in-flight test conductors during various phases of the flight test program. Mr. R. Huber was responsible for modifications, calibration, and maintenance of the T-33 variable stability system. The Cornell evaluation pilot was W. Hall and the Martin evaluation pilot was D. McCracken. Mr. B.A. Peterson of NASA-Edwards and Capt. J.R. Gentry of USAF-Edwards were evaluation pilots for two flights each.

This manuscript was released June 1967 for publication as an AFFDL Technical Report.

This technical report has been reviewed and is approved.

C.B. Westbrook
C.B. Westbrook
Chief, Control Criteria Branch
Air Force Flight Dynamics Laboratory

ABSTRACT

The results of an in-flight simulation program to investigate longitudinal and lateral-directional handling qualities of the Martin SV-5P (Pilot) lifting body are presented and discussed. The in-flight simulation was a point stability simulation at five flight conditions: (1) Re-entry Glide, (2) Boost A, (3) Burnout, (4) Boost B, and (5) Landing Approach. The in-flight simulation was primarily a lateral-directional investigation, the longitudinal characteristics simulated at each flight condition remained fixed. Nine lateral-directional configurations were investigated for each flight condition for a total of 45 different configurations. The nine lateral-directional configurations at each flight condition were obtained by varying the SV-5P rudder to aileron interconnect ratio and the yaw and roll damping feedback gains. The USAF/CAL variable stability T-33 airplane was used as an in-flight simulator. A CAL and a Martin pilot each evaluated 50 configurations. A NASA and a USAF pilot each evaluated 6 configurations. All the configurations were evaluated in straight and level flight. In addition, the landing approach configurations were evaluated during descent at a simulated maximum L/D of the SV-5P. The handling qualities simulated were evaluated by the pilots based on the mission requirements and tasks at each flight condition of the SV-5P. Pilot comments were recorded on each configuration, and the pilots rated the configurations using a new pilot rating scale. The pilot comments and ratings were analyzed and interpreted in the light of the simulated characteristics and their handling qualities. The longitudinal characteristics simulated were considered acceptable except for the objection of some pilots to the large stick force per g during Boost A and B and Burnout. The greatest effect on lateral-directional handling qualities at any flight condition resulted from a change in rudder to aileron interconnect ratio. Too small a value of rudder to aileron interconnect increased the adverse yaw, reduced aileron roll power, and made rudder coordination difficult. Too large a value resulted in an acceleration-ordered p response and a lack of roll damping. In general, increasing the roll and yaw damping improved the aileron response by reducing adverse yaw and improving the roll response.

In addition to security requirements which must be met, this abstract is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the AF Flight Dynamics Laboratory (FDCC), Wright-Patterson AFB, Ohio, 45433.

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TABLE OF CONTENTS

CONTENTS (Cont.)

ILLUSTRATIONS

TABLES

TABLES (Cont.)

SYMBOLS

b Wing span, ft

c Wing chord, ft

$CAP = \frac{\omega_{sp}^2}{n_z/\alpha}$, control anticipation parameter, 1/sec^2

D Airplane drag, lb

C_l Nondimensional rolling moment coefficient

C_L Nondimensional lift coefficient

C_n Nondimensional yawing moment coefficient

C_Y Nondimensional side force coefficient

F_{AS} Aileron stick control force, lb

F_{ES} Elevator stick control force, lb

F_{RP} Rudder pedal control force, lb

g Acceleration of gravity, ft/sec^2

I_x Moment of inertia about airplane x body axis, slug-ft^2

I_y Moment of inertia about airplane y body axis, slug-ft^2

I_z Moment of inertia about airplane z body axis, slug-ft^2

I_{xz} Product of inertia about airplane x and z body axes, slug-ft^2

$K_{AI} = \left(\frac{\delta_r}{\delta_a}\right)_{ss}$, Rudder to aileron interconnect ratio for pilot inputs of δ_a through δ_{AS}

$K_{\dot\theta} = \left(\frac{\delta_e}{\dot\theta}\right)_{ss}$, Pitch damping feedback augmentation gain

$K_{\dot\phi} = \left(\frac{\delta_a}{\dot\phi}\right)_{ss}$, Roll damping feedback augmentation gain

$K_{\dot\psi} = \left(\frac{\delta_r}{\dot\psi}\right)_{ss}$, Yaw damping feedback augmentation gain

$L = C_L q_o S$ Airplane lift, lb

$L = C_l q_o S b$ Rolling moment, ft-lb

$L/D =$ Lift to drag ratio

$L_p = \frac{1}{I_x}\frac{\partial L}{\partial p} = \frac{1}{I_x}\frac{\partial L}{\partial \dot{\phi}}$, sec^{-1}

$L_r = \frac{1}{I_x}\frac{\partial L}{\partial r} = \frac{1}{I_x}\frac{\partial L}{\partial \dot{\psi}}$, sec^{-1}

$L_\beta = \frac{1}{I_x}\frac{\partial L}{\partial \beta}$, sec^{-2}

$L_{\dot{\beta}} = \frac{1}{I_x}\frac{\partial L}{\partial \dot{\beta}}$, sec^{-1}

$L_{\delta_a} = \frac{1}{I_x}\frac{\partial L}{\partial \delta_a}$, sec^{-2}

$L_{\delta_{AS}} = \frac{1}{I_x}\frac{\partial L}{\partial \delta_{AS}}$, sec^{-2} in.$^{-1}$

$L_{\delta_{a(a)}} = L_{\delta_a} + K_{RA} L_{\delta_r}$, sec^{-2}

$L_{\delta_r} = \frac{1}{I_x}\frac{\partial L}{\partial \delta_r}$, sec^{-2}

$L_{\delta_{AP}} = \frac{1}{I_x}\frac{\partial L}{\partial \delta_{AP}}$, sec^{-2} in.$^{-1}$

$L_i' = \left(1 - \frac{I_{xz}^2}{I_x I_z}\right)^{-1}\left(L_i + \frac{I_{xz}}{I_x} N_i\right)$, $i = p, r, \beta, \dot{\beta}, \delta_a, \delta_{a(a)}, \delta_r, \delta_{AS}, \delta_{AP}$

$m = \frac{W}{g}$, mass of airplane, slugs

$M = C_m q_o S c$ Pitching moment, ft-lb

$M_\alpha = \frac{1}{I_y}\frac{\partial M}{\partial \alpha}$, sec^{-2}

$M_{\dot{\alpha}} = \frac{1}{I_y}\frac{\partial M}{\partial \dot{\alpha}}$, sec^{-1}

$M_{\delta_e} = \frac{1}{I_y}\frac{\partial M}{\partial \delta_e}$, sec^{-2}

$M_{\dot{\theta}} = M_{\delta_e} K_{\dot{\theta}}$, sec^{-1}

$n_z =$ normal acceleration, g units

SYMBOLS (Cont.)

$N = C_n q_o S b$ yawing moment, ft-lb

$N_p = \frac{1}{I_z}\frac{\partial N}{\partial p} = \frac{1}{I_z}\frac{\partial N}{\partial \dot{\phi}}$, $\sec^{-1}$

$N_r = \frac{1}{I_z}\frac{\partial N}{\partial r} = \frac{1}{I_z}\frac{\partial N}{\partial \dot{\psi}}$, $\sec^{-1}$

$N_\beta = \frac{1}{I_z}\frac{\partial N}{\partial \beta}$, $\sec^{-2}$

$N_{\dot{\beta}} = \frac{1}{I_z}\frac{\partial N}{\partial \dot{\beta}}$, $\sec^{-1}$

$N_{\delta_a} = \frac{1}{I_z}\frac{\partial N}{\partial \delta_a}$, $\sec^{-2}$

$N_{\delta_{a(a)}} = N_{\delta_a} + K_{RA} N_{\delta_r}$, $\sec^{-2}$

$N_{\delta_{AS}} = \frac{1}{I_z}\frac{\partial N}{\partial \delta_{AS}}$, $\sec^{-2}$ in.$^{-1}$

$N_{\delta_r} = \frac{1}{I_z}\frac{\partial N}{\partial \delta_r}$, $\sec^{-2}$

$N_{\delta_{RP}} = \frac{1}{I_z}\frac{\partial N}{\partial \delta_{RP}}$, $\sec^{-2}$ in.$^{-1}$

$$N_i' = \left(1 - \frac{I_{xz}^2}{I_x I_z}\right)^{-1}\left(N_i + \frac{I_{xz}}{I_z} L_i\right); \quad i = p, r, \beta, \dot{\beta}, \delta_a, \delta_r, \delta_{AS}, \delta_{RP}$$

p Roll rate, rad/sec

q Pitch rate, rad/sec

q_o Dynamic pressure, lb/ft^2

r Yaw rate, rad/sec

s Laplace operator

S Wing area, ft^2

t Time, sec

V Airplane velocity, knots IAS

W Airplane weight, lb

x, y, z Body axes with the x axis in the plane of symmetry, its origin at the c.g., and parallel to waterline zero of the vehicle. The y axis is perpendicular to the plane of symmetry, and the z axis is in the plane of symmetry and perpendicular to the x axis.

$Y = C_Y q_o S$, lb

$Y_p = \frac{1}{mV_o}\frac{\partial Y}{\partial p} = \frac{1}{mV_o}\frac{\partial Y}{\partial \dot{\phi}}$, nondimensional

$Y_r = \frac{1}{mV_o}\frac{\partial Y}{\partial r} = \frac{1}{mV_o}\frac{\partial Y}{\partial \dot{\psi}}$, nondimensional

$Y_\beta = \frac{1}{mV_o}\frac{\partial Y}{\partial \beta}$, sec^{-1}

$Y_{\dot{\beta}} = \frac{1}{mV_o}\frac{\partial Y}{\partial \dot{\beta}}$, nondimensional

$Y_{\delta_a} = \frac{1}{mV_o}\frac{\partial Y}{\partial \delta_a}$, sec^{-1}

$Y_{\delta_{a(a)}} = Y_{\delta_a} + K_{RA} Y_{\delta_r}$, sec^{-1}

$Y_{\delta_{AS}} = \frac{1}{mV_o}\frac{\partial Y}{\partial \delta_{AS}}$, sec^{-1} $in.^{-1}$

$Y_{\delta_r} = \frac{1}{mV_o}\frac{\partial Y}{\partial \delta_r}$, sec^{-1}

$Y_{\delta_{RP}} = \frac{1}{mV_o}\frac{\partial Y}{\partial \delta_{RP}}$, sec^{-1} $in.^{-1}$

$Z_\alpha = -L_\alpha = -\frac{1}{mV_o}\frac{\partial L}{\partial \alpha}$, sec^{-1}

$Z_{\delta_e} = -L_{\delta_e} = -\frac{1}{mV_o}\frac{\partial L}{\partial \delta_e}$, sec^{-1}

$Z_{\dot{\theta}} = Z_{\delta_e} K_{\dot{\theta}}$, nondimensional

α Angle of attack, rad unless otherwise indicated

β Angle of sideslip, rad unless otherwise indicated

γ Flight path angle, rad unless otherwise indicated

δ_a	Aileron deflection, rad unless otherwise indicated
δ_{AS}	Aileron stick deflection, in.
δ_e	Elevator deflection, rad unless otherwise indicated
δ_{ES}	Elevator stick deflection, in.
δ_r	Rudder deflection, rad unless otherwise indicated
δ_{RP}	Rudder pedal deflection, in.
ζ_{AF}	Damping ratio of aileron response to stick force input transfer function
ζ_d	Dutch roll damping ratio
ζ_{EF}	Damping ratio of elevator response to stick force input transfer function
ζ_{SP}	Longitudinal short period damping ratio
ζ_ϕ	Damping ratio of numerator quadratic in roll to aileron input transfer function
θ	Airplane pitch angle, rad unless otherwise indicated
θ_c	Commanded pitch angle
θ_e	Pitch angle tracking error
ρ	Air density, slugs/ft^3
τ_R	Roll mode time constant, sec
τ_{RP}	Time constant of rudder response to rudder pedal force inputs, sec
τ_S	Spiral mode time constant, sec
ϕ	Airplane bank angle, rad unless otherwise indicated
$\left\|\frac{\phi}{\beta}\right\|_d$	Magnitude of roll to sideslip ratio in the Dutch roll mode

ψ	Airplane yaw angle, rad unless otherwise indicated
ω_{AF}	Undamped natural frequency of aileron to stick force input transfer function, rad/sec
ω_d	Undamped natural frequency of the Dutch roll mode, rad/sec
ω_{EF}	Undamped natural frequency of elevator to stick force transfer function, rad/sec
ω_{sp}	Undamped natural frequency of the longitudinal short period mode, rad/sec
ω_ϕ	Undamped natural frequency of the numerator quadratic in bank angle to aileron input transfer function, rad/sec

$(\dot{i}) = di/dt$

$(\ddot{i}) = d^2 i/dt^2$

Subscripts

o	initial value
MAX	maximum value
ss	steady-state value

SECTION I
INTRODUCTION

(U) At the request of the Air Force Flight Dynamics Laboratory, an in-flight simulation and handling qualities investigation of the Martin-USAF SV-5P(Pilot) lifting body was performed by the Flight Research Department of Cornell Aeronautical Laboratory (CAL). The simulation was a point stability simulation performed in the USAF/CAL variable stability T-33 airplane. The program planning began in July 1966, and the flight testing was completed in February 1967.

(U) In July 1966, a meeting was held at Martin Company in Baltimore, Maryland at which the SV-5P simulation program was discussed among Martin, Flight Dynamics Laboratory, and CAL personnel. It was decided that a point stability simulation at a fixed altitude and airspeed was feasible in the variable stability T-33. It was decided that to the extent possible, SV-5P descents would be simulated by extending the T-33 drag petals at the completion of the level flight simulation, and descending and performing a simulated flare at altitude. Figure 1 shows a diagram of the simulated descent.

(C) At the July meeting, Martin Company personnel selected five basic flight conditions that were of particular interest to them from the standpoint of in-flight simulation and handling qualities investigation. These five basic flight conditions represented conditions along the SV-5P flight trajectory and can be described as a Re-entry Glide (RG), Boost A (BA), Burnout (BO), Boost B (BB), and a Landing Approach (LA). The feedback gains ($K_{\theta}, K_{\dot\phi}$, and $K_{\dot\psi}$), and the rudder to aileron interconnect ratios (K_{RA}) were also specified for these basic flight conditions. The flight conditions of the SV-5P vehicle as specified are shown in Table I. In order to investigate the effect of both increased and decreased damping gains, two additional sets of damping gains ($K_{\dot\phi}$ and $K_{\dot\psi}$) were specified for each of the basic flight conditions. To investigate the effect of both an increase and decrease in rudder to aileron interconnect (K_{RA}), two additional K_{RA} values were specified for each set of damping gains. The combinations of gains specified are shown in Table II. The result was a specification of 9 different sets of gains for each flight condition. Thus, a total of 45 configurations was specified for simulation.

(U) The decision was made that the simulation was to be primarily lateral-directional and not longitudinal. At any rate, the longitudinal characteristics simulated were to remain fixed at each of the five flight conditions. A subsequent investigation of the SV-5P longitudinal characteristics at the basic flight conditions indicated that certain of the SV-5P longitudinal characteristics, such as stick force gradients (F_{ES}/n_z), varied greatly between flight conditions. Since the handling qualities investigations could be influenced significantly by such longitudinal characteristics, the decision was made to simulate certain of the important longitudinal as well as the lateral-directional parameters of the SV-5P. The longitudinal parameters simulated are discussed in Section 4.2. The simulated longitudinal parameters varied only with flight conditions.

(U) The important longitudinal and lateral-directional mode characteristics of all 45 configurations were simulated as specified in Section IV. All 45 configurations were evaluated in level flight by both a Martin and a CAL evaluation pilot. In addition, both pilots evaluated the Landing Approach (LA) configurations during descent at maximum L/D. Six of the 45 configurations were also evaluated by a NASA and an AF pilot.

(U) During the evaluation program, the evaluation pilots were not informed of the configuration characteristics simulated in flight except for the flight condition of the SV-5P associated with the configuration such as Re-entry Glide (RG), or Boost A (BA), etc. The pilot was supplied with a Mission and Task card to aid in the evaluation of the configurations at a given flight condition. The pilots commented on and rated each configuration evaluated. The pilot comments were recorded on a wire recorder in flight and were based on a Pilot Card supplied to the evaluation pilot. The pilot numerical rating was based on a new rating scale presented and discussed in Reference 1.

(C) The in-flight calibration part of the program was performed through a series of 29 flights (Flights 728 through 756). The calibration flight period extended from September 30 through December 28, 1966 and was conducted at Buffalo, New York. The evaluation part of the program was transferred to MCAS in Yuma, Arizona on January 3, 1967 because of weather. A total of 106 configurations was evaluated by all of the evaluation pilots during 39 flights (Flight 759 through 797). This flight period extended from January 6 to February 3, 1967. In general, on each flight three configurations were simulated and evaluated in the T-33 in level flight at 23,000 feet and 250 kt indicated airspeed. In addition, the Landing Approach (LA) configurations were also evaluated during the descent from 23,000 feet. This descent was performed at a simulated L/D of 4.7 at 250 kt IAS in the T-33. The final part of the descent consisted of a pilot-initiated flare at 2000 to 3000 feet pressure altitude.

(C) It should be emphasized that the simulation performed and the evaluation program as conducted are based on preliminary information of the SV-5P vehicle as supplied to Cornell Aeronautical Laboratory in July 1966. Since the SV-5P has undergone additional design and analysis, the modal characteristics and handling qualities results presented may not be directly applicable. Since the damping feedback gains (K_ϕ and K_ψ) and the rudder to aileron interconnect ratios (K_{RA}) were varied systematically from the nominal values (Table II), a variety of lateral-directional response characteristics and aileron control characteristics were simulated and evaluated. These results should prove useful in understanding what lateral-directional characteristics are acceptable and objectionable in the SV-5P lifting body when these characteristics are interpreted in the light of the SV-5P mission and task requirements. The results should also be useful as a further understanding of the lateral-directional handling qualities of lifting bodies in general.

SECTION II

POINT STABILITY EQUATIONS OF MOTION FOR SV-5P

2.1 GENERAL DISCUSSION

(C) Before the pertinent longitudinal and lateral-directional characteristics of the SV-5P could be adequately simulated in the variable stability T-33, it was first necessary to settle on a set of adequate longitudinal and lateral-directional equations of motion that would describe the SV-5P dynamic motions for the flight conditions under investigation. From a knowledge of the initial conditions of the SV-5P for each of the five flight conditions under investigation, and the SV-5P feedback gains ($K_{\dot\theta}$, $K_{\dot\phi}$, $K_{\dot\psi}$ and K_{RA}), it was then possible to determine the dimensional stability derivatives required in the equations of motion using wind tunnel data on the static nondimensional derivatives of the SV-5P vehicle. The static nondimensional derivatives were of course determined for the angle of attack, Mach number, and c.g. location appropriate to the flight condition. The dimensional derivatives were determined using the nondimensional derivatives, and the appropriate weight and moments of inertia of the SV-5P vehicle.

(U) From a knowledge of the dimensional derivatives and the equations of motion, the longitudinal and lateral-directional response characteristics of the SV-5P were next determined. The essential SV-5P modal characteristics to be simulated in the T-33 were next determined based on these response characteristics.

2.2 LONGITUDINAL EQUATIONS

2.2.1 Longitudinal Equations of Motion of Vehicle

(U) The two-degree-of-freedom longitudinal short-period equations of motion of the basic unaugmented SV-5P vehicle can be written as

$$(\sec \alpha_0)\,\dot\alpha - Z_\alpha \alpha - (\cos \alpha_0)\,\dot\theta - \frac{g}{V_0}(\sin \theta_0)\,\theta = Z_{\delta_e} \delta_e \qquad (1)$$

$$-M_\alpha \alpha + \ddot\theta = M_{\delta_e} \delta_e \qquad (2)$$

$$n_z = \frac{V_0}{g}(\dot\theta - \dot\alpha) \qquad (3)$$

(C) Equation 3 is not an independent equation of motion, but it relates the normal acceleration of the vehicle in g's to the variables in Equations 1 and 2. Equations 1 and 2 are small perturbation equations of motion from trimmed, unaccelerated flight with initial pitch angle (θ_o), angle of attack (α_o), and flight path angle $(\gamma_o = \theta_o - \alpha_o)$, which are not necessarily small. Equations 1 and 2 are two-degree-of-freedom point stability equations of motion that are only approximately valid for the SV-5P in accelerated climbing or descending flight. Equation 2 contains no pitch damping term $(M_{\dot{\theta}})$ for the unaugmented SV-5P lifting body. No information was available on the inherent damping derivatives of the SV-5P vehicle, hence it has been assumed that the inherent pitch, roll, and yaw damping of the SV-5P are negligibly small, and all the damping of the vehicle results from the stability augmentation system.

(U) In terms of Laplace transforms, Equations 1, 2, and 3 assume the following form:

$$\left[(\sec \alpha_o)\, s - Z_\alpha\right] \alpha(s) - \left[(\cos \alpha_o)\, s - \frac{g}{V_o} \sin \theta_o\right] \theta(s) = Z_{\delta_e}\, \delta_e(s) \tag{4}$$

$$-M_\alpha\, \alpha(s) + s^2 \theta(s) = M_{\delta_e}\, \delta_e(s) \tag{5}$$

$$n_z(s) = \frac{V_o}{g}\left[\dot{\theta}(s) - \dot{\alpha}(s)\right] \tag{6}$$

2.2.2 Longitudinal SAS and Control System Equations

(C) An examination of the longitudinal stability augmentation system (SAS) and control system as it existed in July of 1966 indicated that the elevator control motion of the SV-5P could be adequately described for simulation purposes by an equation of the following form:

$$\delta_e(s) = \frac{3s}{1+3s}\, \frac{\delta_e(s)}{\dot{\theta}(s)}\, \dot{\theta}(s) + \frac{\delta_e(s)}{F_{ES}(s)}\, F_{ES}(s) \tag{7}$$

where

$$\text{washout filter transfer function} = \frac{3s}{1+3s} \tag{8}$$

$$\frac{\delta_e(s)}{\dot{\theta}(s)} = \left(\frac{\delta_e}{\dot{\theta}}\right)_{ss} = K_{\dot{\theta}} \tag{9}$$

$$\frac{\delta_e(s)}{F_{ES}(s)} = \frac{\delta_e(s)}{\delta_{ES}(s)}\, \frac{\delta_{ES}(s)}{F_{ES}(s)} = \frac{\omega_{EF}^2 \left(\delta_e/F_{ES}\right)_{ss}}{s^2 + 2\zeta_{EF}\,\omega_{EF}\, s + \omega_{EF}^2} \tag{10}$$

(C) Equation 8 is the transfer function of a pitch rate washout filter with a corner at 1/3 of a radian per second. The effect of this washout filter is to essentially eliminate the augmented pitch damping feedback gain and all the augmented pitch damping at low frequencies and in steady-state pitch maneuvers. Equation 9 assumes the damping gain is a constant that does not vary with frequency. In view of the high elevator servo frequencies anticipated for the SV-5P compared to the longitudinal short-period frequency, this assumption is reasonable. The anticipated elevator servo frequency is approximately 10 cps, the short-period frequency is of the order of 1/2 to 1/4 cps (see Table VII). Equation 10 assumes that the elevator response to stick force inputs can be represented by an equivalent second-order system with an undamped frequency (ω_{EF}), and damping ratio (ζ_{EF}). This equivalent second-order system is composed of the elevator to elevator stick displacement transfer function, $\delta_e(s)/\delta_{ES}(s)$, and the transfer function of the elevator stick to force inputs, $\delta_{ES}(s)/F_{ES}(s)$. The frequency of the $\delta_e(s)/\delta_{ES}(s)$ transfer function is primarily determined by the elevator servo frequency (approximately 10 cps). The SV-5P stick dynamics are determined by the inertia of a pivoted stick and a simple spring. The spring constant in terms of pounds per inch of stick movement at the pilot's grip (F_{ES}/δ_{ES}) is shown in Table IV. Also shown in Table IV is the approximate stick frequency and damping as measured on a test stand at Martin. Thus, the equivalent frequency of the $\delta_e(s)/F_{ES}(s)$ transfer function will be somewhat below 6 to 8 cps.

2.2.3 Longitudinal Equations with SAS and Washout Filter

(C) Substituting Equation 9 in Equation 7, and Equation 7 in Equations 4 and 5 results in the following longitudinal equations of motion:

$$\left[(\sec\alpha_0)s - Z_\alpha\right]\alpha(s) - \left[\left(\cos\alpha_0 + \frac{3s}{1+3s}Z_{\dot\theta}\right)s - \frac{g}{V_0}\sin\theta_0\right]\theta(s) \tag{11}$$

$$= Z_{\delta_e}\frac{\delta_e(s)}{F_{ES}(s)}F_{ES}(s)$$

$$-M_\alpha\,\alpha(s) + \left[s^2 - \left(\frac{3s}{1+3s}\right)M_{\dot\theta}\,s\right]\theta(s) = M_{\delta_e}\frac{\delta_e(s)}{F_{ES}(s)}F_{ES}(s) \qquad 12)$$

where

$$Z_{\dot\theta} = Z_{\delta_e}K_{\dot\theta}$$

$$M_{\dot\theta} = M_{\delta_e}K_{\dot\theta}$$

Multiplying Equations 11 and 12 by $(1+3s)$ results in the following equations:

$$\left[(3\sec\alpha_0)S^2 + (\sec\alpha_0 - 3Z_{\dot{\alpha}})S - Z_\alpha\right]\alpha(S) - \left[3(\cos\alpha_0 + Z_{\dot{\theta}})S^2 + \left(\cos\alpha_0 - 3\frac{g}{V_0}\sin\theta_0\right)S - \frac{g}{V_0}\sin\theta_0\right]\theta(S)$$

$$= \left(3Z_{\dot{\delta}_e}S + Z_{\delta_e}\right)\frac{\delta_e(S)}{F_{ES}(S)}F_{ES}(S) \qquad (13)$$

$$-(3M_{\dot{\alpha}}S + M_\alpha)\alpha(S) + \left[3S^3 + (1 - 3M_{\dot{\theta}})S^2\right]\theta(S) = (3M_{\dot{\delta}_e}S + M_{\delta_e})\frac{\delta_e(S)}{F_{ES}(S)}F_{ES}(S) \qquad (14)$$

(C) From the above equations, it is possible to derive the transfer functions to control surface inputs, $\alpha(S)/\delta_e(S)$, $\theta(S)/\delta_e(S)$, and $n_z(S)/\delta_e(S)$. The last transfer function is obtained using Equation 6. These transfer functions are quite complex and each contains a fourth-order denominator. If the following assumptions are made, considerable simplification is possible.

$$\frac{g}{V_0}\sin\theta_0 << 1$$

$$Z_{\dot{\theta}} << 1$$

$$M_{\delta_e}Z_{\dot{\delta}} - Z_{\delta_e}M_{\dot{\theta}} = 0$$

The last statement follows from the fact that $Z_{\dot{\delta}} = Z_{\delta_e}K_{\dot{\delta}}$ and $M_{\dot{\theta}} = M_{\delta_e}K_{\dot{\theta}}$. Based on these assumptions, the transfer functions assume the following form:

$$\frac{\alpha(S)}{\delta_e(S)} = \frac{\cos\alpha_0(A_\alpha S^2 + B_\alpha S + C_\alpha)}{S^3 + AS^2 + BS + C} \qquad (15)$$

$$\frac{\theta(S)}{\delta_e(S)} = \frac{\frac{1}{3}(1+3S)(A_\theta S + B_\theta)}{S(S^3 + AS^2 + BS + C)} \qquad (16)$$

$$\frac{n_z(S)}{\delta_e(S)} = \frac{\frac{V_0}{g}(A_{n_z}S^3 + B_{n_z}S^2 + C_{n_z}S + D_{n_z})}{S^3 + AS^2 + BS + C} \qquad (17)$$

where

$$A = \left(\tfrac{1}{3} - M_{\dot{\theta}} - Z_{\alpha} \cos \alpha_0\right)$$

$$B = -\left(M_{\alpha} \cos \alpha_0 + \tfrac{1}{3} Z_{\alpha} - M_{\dot{\theta}} Z_{\alpha}\right) \cos \alpha_0$$

$$C = -\tfrac{1}{3} M_{\alpha} \cos^2 \alpha_0$$

$$A_{\alpha} = Z_{\delta_e}$$

$$B_{\alpha} = \tfrac{1}{3} Z_{\delta_e} + M_{\delta_e} \cos \alpha_0$$

$$C_{\alpha} = \tfrac{1}{3} M_{\delta_e} \cos \alpha_0$$

$$A_{\theta} = M_{\delta_e}$$

$$B_{\theta} = \left(M_{\alpha} Z_{\delta_e} - Z_{\alpha} M_{\delta_e}\right) \cos \alpha_0$$

$$A_{n_z} = -Z_{\delta_e} \cos \alpha_0$$

$$B_{n_z} = M_{\delta_e} \sin^2 \alpha_0 - \tfrac{1}{3} Z_{\delta_e} \cos \alpha_0$$

$$C_{n_z} = \tfrac{1}{3} M_{\delta_e} \sin^2 \alpha_0 + \left(M_{\alpha} Z_{\delta_e} - Z_{\alpha} M_{\delta_e}\right) \cos \alpha_0$$

$$D_{n_z} = \tfrac{1}{3} \left(M_{\alpha} Z_{\delta_e} - Z_{\alpha} M_{\delta_e}\right) \cos \alpha_0$$

2.2.4 Effect of Washout Filter on Longitudinal Response

(C) For a step elevator input $\left[\delta_e(S) = \delta_e / S\right]$, it is possible to evaluate both the initial value at time $t = 0^+$, and the final values at time $t = \infty$ for the variables α, θ, and n_z and their derivatives. The initial values other than zero or infinity are indicated in Table V. As noted in Table V, these initial values are also valid for the SV-5P without the washout filter whose transfer function is $3S/(1+3S)$. The transfer functions of the airplane without the washout filter can be easily determined from Equations 11 and 12 by setting $3S/(1+3S)$ equal to one. The final or steady-state values, both with and without the washout filter, are also shown in Table V. It is interesting to note that some differences do exist in the steady-state values with and without the washout filter. The effect of the washout filter is to eliminate the $Z_\alpha M_{\dot\theta}$ term in the denominator and thus increase all the steady-state variables by the ratio $(Z_\alpha M_{\dot\theta} - M_\alpha \cos\alpha_0)/M_\alpha \cos\alpha_0$. For the flight conditions to be simulated for SV-5P, the effects of the pitch washout filter on steady-state responses were estimated. For the Boost A (BA), Boost B (BB), and Burnout (BO) flight conditions, the effects were insignificant, less than 3 percent. For the Re-entry Glide (RG) and Landing Approach (LA) flight conditions, the washout filter increased steady-state values by approximately 10 and 30 percent respectively.

(C) A check of actual time histories of the pitch responses to a step elevator input (δ_e) with and without the washout filter confirmed these effects. The initial pitch response was the same, the shape of the response curve was similar, and the steady-state response was altered as previously indicated.

2.3 LATERAL-DIRECTIONAL EQUATIONS

2.3.1 Lateral-Directional Equations of Motion of Vehicle

(U) The lateral-directional equations of motion of the basic unaugmented SV-5P vehicle can be written as:

$$\dot\beta - Y_\beta \beta + (\cos\alpha_0)\dot\psi - \frac{g}{V_0}(\sin\theta_0)\psi - (\sin\alpha_0)\dot\phi - \frac{g}{V_0}(\cos\theta_0)\phi = Y_{\delta_a}\delta_a + Y_{\delta_r}\delta_r \tag{18}$$

$$-N'_\beta \beta + \ddot\psi = N'_{\delta_a}\delta_a + N'_{\delta_r}\delta_r \tag{19}$$

$$-L'_\beta \beta + \ddot\phi = L'_{\delta_a}\delta_a + L'_{\delta_r}\delta_r \tag{20}$$

(C) These equations are small perturbation equations about SV-5P body axes. They assumed initially trimmed, unaccelerated flight with initial pitch angle (θ_0), and angle of attack (α_0), which are not necessarily small. It is evident, from the equations, that all the unaugmented rotary derivatives are assumed to be zero. Essentially, all the damping is therefore assumed to come from the stability augmentation system. In comparing these equations to the more conventional small-perturbation equations of motion with the airplane trimmed in level flight, it should be remembered that $\dot\psi = r$ and $\dot\phi = p$ about body axes.

(U) In terms of Laplace transforms, the lateral-directional equations of motion of the unaugmented SV-5P can be written as follows:

$$(s - Y_\beta)\,\beta(s) + \left[(\cos\alpha_0)\,s - \frac{g}{V_0}(\sin\theta_0)\right]\psi(s)$$

$$-\left[(\sin\alpha_0)\,s - \frac{g}{V_0}(\cos\theta_0)\right]\phi(s) = Y_{\delta_a}\,\delta_a(s) + Y_{\delta_r}\,\delta_r(s) \qquad (21)$$

$$-N'_\beta\,\beta(s) + s^2\,\psi(s) = N'_{\delta_a}\,\delta_a(s) + N'_{\delta_r}\,\delta_r(s) \qquad (22)$$

$$-L'_\beta\,\beta(s) + s^2\,\phi(s) = L'_{\delta_a}\,\delta_a(s) + L'_{\delta_r}\,\delta_r(s) \qquad (23)$$

2.3.2 Lateral-Directional SAS and Control System Equations

(C) The lateral-directional SAS and control system of the SV-5P determine the aileron and rudder control motions of the SV-5P vehicle. This system can be adequately described by the following two equations:

$$\delta_a(s) = \frac{\delta_a(s)}{\dot\phi(s)}\,\dot\phi(s) + \frac{\delta_a(s)}{F_{AS}(s)}\,F_{AS}(s) \qquad (24)$$

$$\delta_r(s) = \frac{3s}{1+3s}\,\frac{\delta_r(s)}{\dot\psi(s)}\,\dot\psi(s) + \frac{\delta_r(s)}{\delta_a(s)}\,\frac{\delta_a(s)}{F_{AS}(s)}\,F_{AS}(s) + \frac{\delta_r(s)}{F_{RP}(s)}\,F_{RP}(s) \qquad (25)$$

where

$$\text{washout filter transfer function} = \frac{3s}{1+3s} \qquad (26)$$

$$\frac{\delta_a(s)}{\dot\phi(s)} = \left(\frac{\delta_a}{\dot\phi}\right)_{ss} = K_{\dot\phi} \qquad (27)$$

$$\frac{\delta_r(s)}{\dot\psi(s)} = \left(\frac{\delta_r}{\dot\psi}\right)_{ss} = K_{\dot\psi} \qquad (28)$$

$$\frac{\delta_r(s)}{\delta_a(s)} = \left(\frac{\delta_r}{\delta_a}\right)_{ss} = K_{RA} \qquad (29)$$

$$\frac{\delta_a(s)}{F_{AS}(s)} = \frac{\delta_a(s)}{\delta_{AS}(s)}\,\frac{\delta_{AS}(s)}{F_{AS}(s)} = \frac{\omega_{AF}^2\left(\frac{\delta_a}{F_{AS}}\right)_{ss}}{s^2 + 2\zeta_{AF}\,\omega_{AF}\,s + \omega_{AF}^2} \qquad (30)$$

$$\frac{\delta_r(s)}{F_{RP}(s)} = \frac{\delta_r(s)}{\delta_{RP}(s)} \frac{\delta_{RP}(s)}{F_{RP}(s)}$$

$$= \frac{\left(\frac{\delta_r}{F_{RP}}\right)_{ss}}{\tau_{RP} s + 1} \tag{31}$$

(C) Equation 26 is the transfer function of the yaw rate washout filter and is the same as the pitch rate washout filter. The effect of this filter is to eliminate essentially all the augmented yaw rate feedback gain and all the augmented yaw damping at low frequencies and in steady-state maneuvers. Equations 27, 28, and 29 assume the roll and yaw damping gains and the interconnect ratios are constant and not frequency dependent at any given settings. In view of the high aileron servo frequencies anticipated for the aileron servo (approximately 10 cps), and the small time constant assumed for the rudder servo (.05 sec) the assumptions are reasonable. The validity of these assumptions is further substantiated by the values of Dutch roll frequency and roll mode time constants to be simulated (see Tables XV through XIX).

(C) Equation 30 assumes that the aileron response-to-stick-force inputs can be represented by an equivalent second-order system with an undamped frequency ω_{AF} and damping ratio ζ_{AF}. This equivalent second-order system is composed of the aileron-to-aileron stick transfer function, $\delta_a(s)/\delta_{AS}(s)$, and the transfer function of the aileron stick or stick feel system to force inputs, $\delta_{AS}(s)/F_{AS}(s)$. The frequency of the $\delta_a(s)/\delta_{AS}(s)$ transfer function is primarily determined by the aileron servo frequency. The SV-5P aileron stick dynamics are determined by the inertia of a pivoted stick and a simple spring. The approximate values of aileron stick dynamics, as measured on a test stand at Martin, are 5.5 to 7 cps, as shown in Table IV. The equivalent frequency of the $\delta_a(s)/F_{AS}(s)$ transfer function will be somewhat lower.

(C) Equation 31 assumes that the rudder response to rudder pedal force inputs can be represented by an equivalent first-order system with a time constant (τ_{RP}). During the present simulation, the rudder system of the SV-5P was not sufficiently defined for a more adequate representation. This equivalent first-order time constant is composed of the sum of the equivalent time constant of the rudder-to-rudder pedal transfer function, $\delta_r(s)/\delta_{RP}(s)$, and the rudder pedal to rudder force transfer function, $\delta_{RP}(s)/F_{RP}(s)$. The time constant of $\delta_r(s)/\delta_{RP}(s)$ is of the order of .05 seconds. The SV-5P rudder pedal dynamics are indicated in Table IV. The rudder pedal time constant is of the order of .01 to .02 seconds. The total equivalent time constant τ_{RP} is approximately .06 to .07 seconds.

2.3.3 Lateral-Directional Equations with SAS and Washout Filter

(C) Substituting Equations 26, 27, 28 and 29 into Equations 24 and 25 will give the aileron and rudder inputs to the SV-5P, due to the SAS and the control system of the SV-5P vehicle. Next, substituting Equations 24 and 25 into the lateral-directional equations will give the lateral-directional equations of motion of the SV-5P in body axes. With this substitution, Equations 21, 22, and 23 become:

$$\begin{aligned}(s - Y_\beta)\,\beta(s) &+ \left[\left(\cos\alpha_o - \frac{3s}{1+3s}\,Y_r\right)s - \frac{g}{V_o}(\sin\theta_o)\right]\psi(s) \\ &- \left[(\sin\alpha_o + Y_p)\,s + \frac{g}{V_o}(\cos\theta_o)\right]\phi(s) = Y_{\delta_{a(a)}}\,\frac{\delta_a(s)}{F_{AS}(s)}\,F_{AS}(s) \\ &\qquad + Y_{\delta_r}\,\frac{\delta_r(s)}{F_{RP}(s)}\,F_{RP}(s)\end{aligned} \tag{32}$$

$$\begin{aligned}-N'_\beta\,\beta(s) + \left[s^2 - N'_r\left(\frac{3s}{1+3s}\right)s\right]\psi(s) - N'_p\,s\,\phi(s) &= N'_{\delta_{a(a)}}\,\frac{\delta_a(s)}{F_{AS}(s)}\,F_{AS}(s) \\ &\quad + N'_{\delta_r}\,\frac{\delta_r(s)}{F_{AS}(s)}\,F_{AS}(s)\end{aligned} \tag{33}$$

$$\begin{aligned}-L'_\beta\,\beta(s) - L'_r\left(\frac{3s}{1+3s}\right)s\,\psi(s) + \left[s^2 - L'_p\,s\right]\phi(s) &= L'_{\delta_{a(a)}}\,\frac{\delta_a(s)}{F_{AS}(s)}\,F_{AS}(s) \\ &\quad + L'_{\delta_r}\,\frac{\delta_r(s)}{F_{RP}(s)}\,F_{RP}(s)\end{aligned} \tag{34}$$

where

$$Y_r = Y_{\delta_r}\,K_{\dot\psi}$$

$$Y_p = Y_{\delta_a}\,K_{\dot\phi}$$

$$Y_{\delta_{a(a)}} = Y_{\delta_a} + K_{RA}\,Y_{\delta_r}$$

$$N'_r = N'_{\delta_r}\,K_{\dot\psi}$$

$$N'_p = N'_{\delta_a}\,K_{\dot\phi}$$

$$N'_{\delta_{a(a)}} = N'_{\delta_a} + K_{RA}\,N'_{\delta_r}$$

$$L'_r = L'_{\delta_r}\,K_{\dot\psi}$$

$$L'_p = L'_{\delta_a}\,K_{\dot\phi}$$

$$L'_{\delta_{a(a)}} = L'_{\delta_a} + K_{RA}\,L'_{\delta_r}$$

(C) Multiplying Equations 32, 33, and 34 through by $(1+3s)$ results in the following lateral-directional equations of motion:

$$(1+3s)(s-Y_\beta)\beta(s)+\left[3(\cos\alpha_0-Y_r)s^2+\left(\cos\alpha_0-3\frac{g}{V_0}\sin\theta_0\right)s\right.$$

$$\left.-\frac{g}{V_0}(\sin\theta_0)\right]\psi(s)-(1+3s)\left[(\sin\alpha_0+Y_p)s+\frac{g}{V_0}(\cos\theta_0)\right]\phi(s)$$

$$=(1+3s)Y_{\delta_{a(a)}}\frac{\delta_a(s)}{F_{AS}(s)}F_{AS}(s)+(1+3s)Y_{\delta_r}\frac{\delta_r(s)}{F_{RP}(s)}F_{RP}(s) \qquad (35)$$

$$(1+3s)N'_\beta\beta(s)+s^2\left[3s+(1-3N'_r)\right]\psi(s)-s(1+3s)N'_p\phi(s)$$

$$=(1+3s)N'_{\delta_{a(a)}}\frac{\delta_a(s)}{F_{AS}(s)}F_{AS}(s)+(1+3s)N'_{\delta_r}\frac{\delta_r(s)}{F_{RP}(s)}F_{RP}(s) \qquad (36)$$

$$-(1+3s)L'_\beta\beta(s)-3L'_r s^2\psi(s)+s(1+3s)(s-L'_p)\phi(s)$$

$$=(1+3s)L'_{\delta_{a(a)}}\frac{\delta_a(s)}{F_{AS}(s)}F_{AS}(s)+(1+3s)L'_{\delta_r}\frac{\delta_r(s)}{F_{RP}(s)}F_{RP}(s) \qquad (37)$$

(C) It is possible to derive transfer functions of the β, ψ, and ϕ responses due to control inputs δ_a and δ_r. If this is done using Equations 35, 36, and 37, then the transfer functions with washout filter dynamics will be obtained. Similar transfer functions, excluding washout filter dynamics, can be obtained from Equations 32, 33, and 34 by letting $3s/1+3s$ equal one. One of the essential effects of the washout filter is to raise the order of the response from fourth to fifth order, thus the characteristic equation has five roots, rather than four. The order of the numerator of the transfer functions is also raised by one. The total effect of the washout filter is the introduction of an additional zero and an additional pole to each of the transfer functions which do not cancel one another.

(C) An evaluation of initial and final values of these transfer functions following a step control input (δ_a and δ_r) leads to some interesting results. The initial values of the responses are unaffected by the washout filter. This result is not unexpected, in light of the washout filter transfer function and the similar results obtained longitudinally. Assuming the system to be stable, the final or steady-state results are different with and without washout filter. The initial and final values for aileron inputs (δ_a) are shown in Table VI. It is evident, from the table, that the steady-state values with washout filter can be obtained from the steady-state values without washout filter by setting N'_r and L'_r equal to zero.

(C) An examination of steady-state values of the responses, such as $\dot{\phi}_{ss}$ and β_{ss}, using derivatives for some of the SV-5P configurations to be simulated, indicated considerable differences with and without the washout filter. An examination of actual time histories with and without the washout filter also indicated considerable differences in the response, including the character of the response with time. The washout filter made some stable responses unstable, and in some cases reversed the sign of the responses with the passage of time.

(C) It became clearly evident that the simulation of washout filter dynamics was essential, and the effect of the washout filter was to make the lateral-directional free response of the SV-5P fifth order, rather than fourth order.

SECTION III

SV-5P CONFIGURATIONS TO BE SIMULATED

3.1 FORMULATION OF SIMULATION AND EVALUATION PROGRAM

(C) As previously stated, the simulation was to be primarily a lateral-directional simulation. For each flight condition, the longitudinal characteristics were to remain fixed and the lateral-directional characteristics were to be varied by changes in the feedback gains ($K_{\dot\phi}$ and $K_{\dot\psi}$) and the rudder to aileron interconnect ratio (K_{RA}). At each flight condition, the simulated open-loop characteristics were to be varied with three different sets of $K_{\dot\phi}$ and $K_{\dot\psi}$, one set above and one below the nominal. For each set of SAS gains, three interconnect ratios were also to be investigated, one above and one below the nominal. The 45 configuration designations and the gains associated with each are shown in Table II. The "-1" configuration gains (such as RG-1, BA-1, etc.) are the nominal gains specified for the basic flight conditions in Table I. Examination of Table II indicates that only 15 different open-loop configurations were specified by the 15 sets of SAS feedback gains ($K_{\dot\phi}$ and $K_{\dot\psi}$). The remainder of the configurations are obtained with different rudder to aileron interconnect ratios (K_{RA}).

(U) It was concluded that all of these configurations would be evaluated by two pilots, one from Martin and one from CAL, and an unspecified but limited number of configurations would also be evaluated by an Air Force and a NASA pilot.

(U) Any proper simulation of the SV-5P response characteristics to control inputs involves a knowledge of both the statics and dynamics of the SV-5 control system and their relationship to the dynamic characteristics of the vehicle. The simulation of dynamic characteristics and its limitations will be discussed later. The static characteristics of the SV-5P control system for each of the basic flight conditions are presented in Table III.

3.2 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES

(U) In order to determine the proper basis for a simulation of longitudinal and lateral-directional mode characteristics for the SV-5P, it was first necessary to determine these characteristics. Based on the flight conditions of Table I, and the vehicle gross weight, c.g. position, velocity, and moments of inertia appropriate to those flight conditions, it was possible to compute the dimensional static derivatives of the SV-5P using wind tunnel data supplied by the Martin Co. (Reference 2). The longitudinal static derivatives computed in this way were M_α , L_α or Z_α , Z_{δ_e} and M_{δ_e} . The lateral-directional static derivatives computed from wind tunnel data were Y_β, Y_{δ_a} , Y_{δ_r} , N'_β , N'_{δ_a} , N'_{δ_r} , L'_β , L'_{δ_a} , and L'_{δ_r} .

(C) From a knowledge of the longitudinal feedback gain ($K_{\dot\theta}$ in Table I) and the lateral-directional feedback gains ($K_{\dot\phi}$ and $K_{\dot\psi}$ in Table II), it was possible to compute the rotary derivatives of the SV-5P vehicle for all the configurations. The rotary derivatives computed in this way were $Z_{\dot\theta}$, $M_{\dot\theta}$, Y_r, Y_p, N'_r, N'_p, L'_r, and L'_p.

(C) From a knowledge of the rudder to aileron cross-feed ratios (K_{RA}'s in Table II), it was also possible to compute the augmented aileron control derivatives ($N'_{\delta_{a(a)}}$ and $L'_{\delta_{a(a)}}$).

(U) These dimensional derivatives are defined in the List of Symbols and the method of computing the rotary derivatives, and the augmented control derivatives are defined in Sections 2.2 and 2.3. All the derivatives were derived in SV-5P body axes with the x-axis in the plane of symmetry, its origin at the c.g., and parallel to waterline zero of the vehicle. The y-axis is perpendicular to the plane of symmetry, and the z-axis is in the plane of symmetry and perpendicular to the x-axis.

3.3 LONGITUDINAL MODE CHARACTERISTICS

(U) Using the computed longitudinal stability derivatives, and the longitudinal short period equations of motion, Equations 13 and 14, certain important longitudinal mode characteristics were determined. These computations were made for each of the five basic flight conditions and then modified somewhat based on discussions with Martin personnel. The results are tabulated in Table VII.

(C) From Table VII, it is evident that significant differences in the longitudinal parameters exist between flight conditions, especially in steady-state stick force per g (F_{ES}/n_z). It would be difficult to simulate such low short period frequencies, of the order of 1.6 rad/sec, with any accuracy. The simulation would be very sensitive to small changes in gain settings or small variations in the basic T-33 airplane characteristics with gross weight, c.g. position, and airspeed. In addition, the low n_z/α's of the SV-5P cannot be simulated since the T-33 would need to fly very near or below stall speed. The n_z/α near stall speed of the T-33 is of the order of 6 or 7. Obviously, it is also not possible to simulate the angle of attack changes and pitch angle changes of the SV-5P with control inputs.

(U) As demonstrated in References 3 and 4, the initial pitch acceleration response of an airplane to step control inputs is an important parameter in longitudinal handling qualities and it can be simulated by simulating a control anticipation parameter (CAP) and the steady-state stick force per g (F_{ES}/n_z). In terms of the parameters of Table VII, it is shown in Reference 3 that

$$CAP = \frac{\ddot\theta_o}{n_{z_{ss}}} = \frac{\omega_{sp}^2}{(n_z/\alpha)_{ss}} \tag{38}$$

$$\frac{\ddot\theta_o}{F_{ES}} = \frac{\omega_{sp}^2}{\left(\frac{n_z}{\alpha}\right)_{ss}\left(\frac{F_{ES}}{n_z}\right)_{ss}} \tag{39}$$

(C) It is obvious from Equations 38 and 39 that it is possible to simulate the maximum initial pitch acceleration response of the SV-5P to control force inputs (F_{ES}) and the steady-state maneuver forces (F_{ES}/n_z) by simulating $\omega_{SP}^2/(n_z/\alpha)_{ss}$ and $(F_{ES}/n_z)_{ss}$. Since the minimum $(n_z/\alpha)_{ss}$ that can be simulated in the T-33 are higher than the $(n_z/\alpha)_{ss}$ of the SV-5P, then it is also necessary to simulate a higher ω_{SP} to keep $\omega_{SP}^2/(n_z/\alpha)_{ss}$ the same.

(C) Equations 38 and 39 are reasonably valid only if the longitudinal control system and feel system frequencies are high compared to the airplane short period frequency (of the order of 10 to 1 or higher). This is evidently true for the longitudinal control system of the SV-5P based on the characteristics in Table IV.

(C) A reasonable simulation of the SV-5P longitudinal short period characteristics within the limitations of the T-33 can therefore be performed by simulating CAP $[\omega_{SP}^2/(n_z/\alpha)_{ss}]$, ζ_{SP}, $(F_{ES}/n_z)_{ss}$, and F_{ES}/δ_{ES} . It is also desirable that the attenuating effect of the T-33 control system on the initial pitch response be kept to a minimum.

(C) Since the longitudinal parameters vary significantly with flight condition, especially F_{ES}/n_z, it was felt essential that the appropriate longitudinal parameters be simulated along with the lateral-directional parameters at each flight condition of the SV-5P. The evaluation pilot ratings and comments on a configuration may be influenced as much or more by the longitudinal characteristics as by the lateral-directional characteristics. This is particularly true when some poor longitudinal characteristic detracts from the lateral-directional evaluation.

3.4 LATERAL-DIRECTIONAL MODE CHARACTERISTICS

(C) Using the computed lateral-directional stability derivatives, and the lateral-directional equations of motion adequate for the SV-5P (Equations 35, 36 and 37), it is possible to compute SV-5P mode characteristics and response characteristics in SV-5P body axes. As stated in Section 2.3, the washout filter makes the lateral-directional responses fifth order, and adds an additional pole and zero to the airplane transfer functions. Although the initial responses to control inputs are essentially the same with and without washout filter, the steady-state response, or the response with the passage of time, can be considerably different (see Table VI). Actual studies of SV-5P time histories also confirmed the significant effects of the washout filter on the lateral-directional dynamic characteristics.

(C) Based on these preliminary investigations, it was determined that the essential aspects of the SV-5P fifth-order response characteristics to both δ_{AS} and δ_{RP} inputs must be simulated. Therefore the actual SV-5P fifth-order responses to step inputs of δ_{AS} and δ_{RP} were determined from an IBM 7044 computer program using Equations 35, 36 and 37. The responses were computed for one inch of stick and pedal travel (δ_{AS} = 1.0 in., δ_{RP} = 1.0 in.). The control transfer functions were written in terms of displacements $\delta_a(s)/\delta_{AS}(s)$ and $\delta_r(s)/\delta_{RP}(s)$. Also for reasons of simplicity, and in order to obtain a set of SV-5P responses with a set of consistent inputs, feel system and control system dynamics were neglected. The Laplace transforms of the input transfer functions thus become for step inputs

$$\frac{\delta_a(s)}{\delta_{AS}(s)}\,\delta_{AS}(s) = \frac{1}{s}\left(\frac{\delta_a}{\delta_{AS}}\right)_{ss}\delta_{AS}$$

$$\frac{\delta_r(s)}{\delta_{RP}(s)}\,\delta_{RP}(s) = \frac{1}{s}\left(\frac{\delta_r}{\delta_{RP}}\right)_{ss}\delta_{RP}$$

Step inputs of one inch were assumed for δ_{AS} and δ_{RP}, and $(\delta_a/\delta_{AS})_{ss}$ and $(\delta_r/\delta_{RP})_{ss}$ were obtained from Table III. SV-5P response characteristics, ϕ, p, $\dot{p}$, β, $\dot{\beta}$, r, and $\dot{r}$ for all 45 lateral-directional configurations were obtained, and formed the basis for developing a simulation technique for the variable stability T-33 simulating the SV-5P. The simulation of the SV-5P dynamic feel characteristics to force inputs (F_{AS} and F_{RP}) is discussed later.

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SECTION IV

SIMULATION OF SV-5P CONFIGURATIONS IN T-33 AIRPLANE

4.1 FLIGHT CONDITIONS OF THE T-33 FOR SIMULATION

(C) Based on some preliminary investigations of T-33 gain requirements to simulate the SV-5P mode characteristics, both longitudinal and lateral-directional, it was concluded that a satisfactory simulation was possible with the T-33 airplane flying at 23,000 feet pressure altitude and 250 knots IAS. Adequate normal acceleration increments for maneuvering are possible in the T-33 at this flight condition. From 23,000 feet it is possible to perform spiral descents and flares at L/D = 4.7 for the Landing Approach (LA) configurations simulated. In addition, for the flight condition selected, a considerable amount of calibration data and basic T-33 airplane data exist from previous in-flight simulation programs.

(U) Except for the simulation of LA configurations during descent, all the configurations, including LA configurations, were simulated in straight and level flight. This made the simulation and calibration procedure simpler, since the required T-33 gains for simulating any configuration were only a function of the changes in T-33 dimensional stability derivatives with changes in gross weight as fuel is consumed.

(C) The LA configurations were also simulated and evaluated during descent from 23,000 feet at an L/D = 4.70 and the same constant indicated airspeed, 250 knots (see Figure 1). With the T-33 wing-tip drag petals out to simulate an L/D of 4.7, the basic T-33 stability derivatives are altered. Thus, changes in gains required to simulate LA configurations during descent were determined from descent calibration data obtained in the vicinity of 12,000 feet. The gains and L/D simulated during the descent were verified only in the vicinity of 12,000 feet pressure altitude.

4.2 LONGITUDINAL PARAMETERS SIMULATED

(C) On the basis of the SV-5P longitudinal characteristics discussed in Section 3.3 and listed in Table VII, a reasonable longitudinal simulation of the SV-5P would involve a simulation of the elevator spring rate (F_{ES}/δ_{ES}), the steady-state maneuver forces (F_{ES}/n_y), the initial pitch response parameter [CAP = $\omega_{sp}^2/(n_y/\alpha)$], the damping ratio ($\zeta_{sp}$), and the proper relationship between the airplane and elevator stick dynamic characteristics.

(U) The n_y/α of the T-33 at 250 knots IAS and 23,000 feet altitude was estimated as 21.7 with an average fuel remaining of 350 gallons. Based on this n_y/α and the SV-5P CAP values, the frequencies required in the T-33 to simulate SV-5P CAP values are shown in Table VIII. Table VIII indicates the longitudinal short period parameters of the variable stability T-33 simulating the SV-5P.

(C) From Table IV and Table VII, it is evident that SV-5P elevator stick frequencies are larger than SV-5P short period frequencies by at least a factor of 10. From the results of Reference 3, it is evident that the SV-5P feel system attenuating effects on the initial pitch response will be small. To simulate a similar relationship in the T-33, it is necessary that T-33 feel system frequencies be of the order of 10 cps based on the short period frequencies of Table VIII. To simulate a feel system frequency of 10 cps in the T-33 requires that force commands from the stick be fed directly to a 10 cps elevator servo. If elevator stick position commands are used in the T-33, a feel system frequency of only 2.5 cps is possible with the spring rate of 4.5 lb/in. that is to be simulated.

(U) The calibration phase of the flight program was undertaken using force commands to the elevator servo, but because of noise and structural feedback problems in the force command mode, position commands were used during the actual evaluation phase of the flight test program. Thus, the proper relationship between airplane and feel system frequencies were not simulated during the actual evaluation phase.

4.3 SIMULATION OF LATERAL-DIRECTIONAL CHARACTERISTICS

(C) The importance of the washout filter on the lateral-directional response characteristics has been discussed in some detail in Section 2.3. It was concluded on the basis of some preliminary investigations that the essential aspects of the fifth-order response that resulted from the washout filter must be simulated in the T-33 airplane. In addition, since the SV-5P angles of attack cannot be matched in the T-33, the question naturally arises as to what axis system is to be used as the basis for matching SV-5P and T-33 responses. The T-33 angle of attack at 23,000 feet and 250 knots indicated airspeed is approximately 1.0 degree; the SV-5P angles of attack are shown in Table I.

(U) Although neither a stability nor body axis match is satisfactory, a stability axis match, in which the motions of the aircraft are matched about the initial flight direction, would be more realistic in terms of the motion of the aircraft with respect to its physical environment. The pilot motion cues, especially about the yaw axis, would not be reproduced. The stability axis simulation has been used with reasonably satisfactory results in other simulation programs and was selected for this simulation. Stability axis system as used here is a body fixed axis system with its origin at the c.g. and with the x -axis pointing in the direction of the initial airplane velocity with zero sideslip. The y -axis is perpendicular to the plane of symmetry, and the z-axis is in the plane of symmetry and perpendicular to the x -axis.

(C) Several techniques were investigated for simulation of SV-5P fifth-order lateral-directional responses resulting from the washout filter. One approach investigated was to include a washout filter in the T-33 airplane to have the same characteristics about stability axes as the SV-5P washout filter about stability axes. The roll and yaw equation stability derivatives were next matched about stability axes. The side force derivatives could not be matched since the T-33 has no independent and variable side force control. A second approach also incorporated the washout filter in the T-33, but matched certain lateral-directional parameters about stability axes rather than stability derivatives. The roll rate-to-aileron stick input transfer function (p/δ_{AS}) was matched completely. The other parameters matched were $|\phi/\beta|$ in the Dutch roll, $g/V_o\, N'_r$, $g/V_o\, L'_r$, $N'_{\delta_{AS}}$, $L'_{\delta_{RP}}$, and $N'_{\delta_{RP}}$. Matches of N'_β and L'_β in place of $g/V_o\, N'_r$ and $g/V_o\, L'_r$ were also investigated. The goodness of the matches was determined by comparing SV-5P and T-33 responses about stability axes to δ_{AS} and δ_{RP} step inputs. Both of the above methods showed some promise as a simulation procedure, but would require additional exploration. One important complication was that washout filter dynamics in the T-33 would have to be varied with the SV-5P flight condition being simulated since the SV-5P angle of attack varies with flight condition.

(C) A third simulation technique investigated was to match SV-5P fifth-order responses with washout filter, to a set of fourth-order lateral-directional equations. The fourth-order lateral-directional equations of an airplane in straight and level flight about body axes used in the match took the following form:

$$\dot\beta - Y_{\dot\beta}\dot\beta - Y_\beta\beta + (1 - Y_r)r - (\alpha_o + Y_p)p - \frac{g}{V_o}\phi = Y_{\delta_{AS}}\delta_{AS} + Y_{\delta_{RP}}\delta_{RP} \qquad (40)$$

$$-N'_{\dot\beta}\dot\beta - N'_\beta\beta + \dot r - N'_r r - N'_p p = N'_{\delta_{AS}}\delta_{AS} + N'_{\delta_{RP}}\delta_{RP} \qquad (41)$$

$$-L'_{\dot\beta}\dot\beta - L'_\beta\beta - L'_r r + \dot p - L'_p p = L'_{\delta_{AS}}\delta_{AS} + L'_{\delta_{RP}}\delta_{RP} \qquad (42)$$

(U) The problem was one of matching the fifth-order responses of the SV-5P determined from Equations 35, 36, and 37 to the fourth-order lateral-directional equations of motion by determining the stability derivatives in the fourth-order equations. The best matched stability derivatives were determined by least-square-fitting each of the equations of motion to the SV-5P fifth-order responses to step δ_{AS} and δ_{RP} inputs. Once the least-squares-fit values of the fourth-order derivatives had been determined, these derivatives were used in Equations 40, 41 and 42 to compute fourth-order responses for the same δ_{AS} and δ_{RP} inputs. By comparing these responses to the SV-5P fifth-order responses, the goodness of the fourth-order fit in body axes could be determined.

(C) The comparison of fifth- and fourth-order responses for the SV-5P about body axes was reasonably good. The method is reasonably straightforward and easy to apply using an existing IBM 7044 least-squares-fit program. Since the lateral-directional simulation techniques and computer programs available for the T-33 are based on lateral-directional fourth-order responses, they could be applied directly to the present program to simulate the responses of the SV-5P with washout filter dynamics included. These "equivalent" fourth-order responses and the pseudo derivatives associated with them were the basis for the T-33 simulation of the lateral-directional characteristics of the SV-5P.

(U) Once the "equivalent" fourth-order stability derivatives of the SV-5P had been determined, it was necessary to transform these SV-5P stability derivatives in SV-5P body axes to a set of stability derivatives in T-33 body axes. If these derivatives can be simulated in the T-33, then the responses about stability axes in the T-33 will be identical to the SV-5P fourth-order responses in SV-5P stability axes.

(U) As stated previously, it is not possible to match stability derivative for stability derivative in the T-33, since the T-33 has no independent way of matching side force derivatives. By selecting a limited number of lateral-directional mode characteristics considered to be the most important to match, it is possible to determine a set of T-33 derivatives that will give the desired match.

(U) Several lateral-directional mode characteristic matching criteria were tried. The criterion which gave the best match of overall lateral-directional responses, especially the p and β response to δ_{AS} inputs, is as follows:

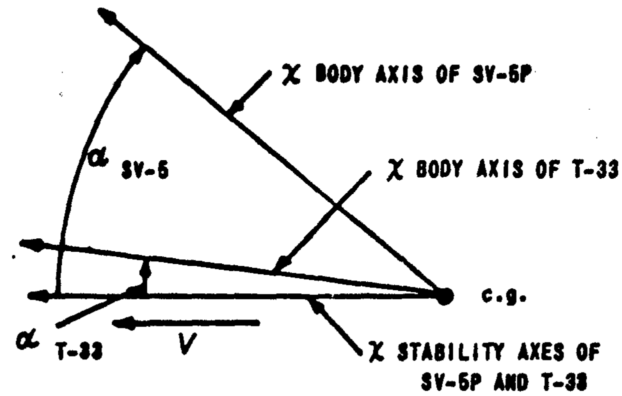
1. The p/δ_{AS} transfer function was matched completely, both numerator and denominator. Thus, $L'_{\delta_{AS}}$, ω_{ϕ} , ζ_{ϕ} , τ_R , τ_S , ω_d , and ζ_d of the SV-5P fourth-order responses were matched.

2. The magnitude of $|\phi/\beta|$ at the Dutch roll, roll, and spiral roots were also matched.

3. The control derivatives $N'_{\delta_{AS}}$, $L'_{\delta_{RP}}$, and $N'_{\delta_{RP}}$ were also matched.

(U) The T-33 stability derivatives required to perform this match were determined from an IBM 7044 program. The essential aspects of the method are discussed in Reference 5. Once these derivatives had been determined for the T-33, they were used in conjunction with the T-33 lateral-directional equations of motion (Equations 40, 41, and 42) to determine the responses to δ_{AS} and δ_{RP} step inputs using a digital computer program. These T-33 responses in T-33 body axes were compared to SV-5P fourth-order responses in T-33 body axes to check the accuracy of the simulation.

(U) The accuracy of the simulation that resulted by following the steps indicated above is shown in Figure 2 for the RG-1 configuration. All the responses are compared in T-33 body axes. If the SV-5P responses and the simulated responses are identical in T-33 body axes, then the comparison of responses of SV-5P and T-33 in stability axes will also be identical. Since the angle of attack of the T-33 in simulating the SV-5P in level flight at 23,000 feet and 250 knots (IAS) is only 1.0 degree, the responses in Figure 2 are very nearly the SV-5P and T-33 responses in stability axes. These conclusions are self evident if the x-stability axes are made to coincide for the SV-5P and the T-33 as indicated below.



(U) It is evident from Figure 2 that the SV-5P least-squares-fit fourth-order response is a reasonably good match of the SV-5P fifth-order response with washout filter dynamics included. The fourth-order match is based on the fifth-order responses up to 10 seconds. A match for this length of time was considered adequate. The T-33 fourth-order simulation of the SV-5P fourth-order response is based on the mode matching criteria previously discussed. The T-33 and SV-5P fourth-order matches are not exact primarily since the T-33 cannot simulate the SV-5P fourth-order side force equation.

(U) Similar comparisons are made in Figures 3 through 6 for the other basic configurations (BA-1, BO-1, BB-1, and LA-1). It can be concluded from these comparisons that the simulation and matching technique was a reasonably good one, especially for the SV-5P response characteristics to δ_{AS} control inputs.

(C) The T-33 "equivalent" fourth-order lateral-directional mode characteristics in simulating the SV-5P are listed in Table IX for all the SV-5P configurations. The denominator mode characteristics are, of course, the same for those configurations where the only differences are the rudder to aileron interconnect (K_{RA}), which affects ω_ϕ, ζ_ϕ and $(\omega_\phi/\omega_d)^2$. Thus, there are only 15 different sets of denominator mode characteristics to be simulated, with three different interconnect ratios for each set of mode characteristics to obtain the 45 lateral-directional configurations of the SV-5P. It is interesting to note that some of the configurations require negative spiral mode time constants to simulate SV-5P fifth-order responses with washout filter dynamics included.

(U) Once the T-33 lateral-directional stability derivatives required to simulate the SV-5P configurations have been determined, it is next necessary to compute the variable stability system gains required to give these derivatives. This is done using an IBM gain setting program for the T-33 presented in Reference 5. These gains take the form of nose gains and knob settings in the rear, safety pilot cockpit of the T-33. The nose gains and knob settings required are based on T-33 calibration curves determined for the T-33 flight condition. The nose gains and knob settings required to perform the simulation are determined by an IBM 7044 computer program. Since the lateral-directional T-33 stability derivatives are a strong function of fuel remaining, the program determines the knob settings required to simulate a configuration for every 25 gallon change in fuel remaining. The knob setting changes are made by the safety pilot as the configuration is being evaluated by the evaluation pilot.

4.4 IN-FLIGHT CALIBRATION OF SIMULATED PARAMETERS

4.4.1 Calibration of Longitudinal Parameters

(U) Once the longitudinal gain settings required to simulate the SV-5P were determined analytically, it was necessary to check out these gain settings by performing in-flight calibrations.

(U) The gain settings used to simulate longitudinal short period frequency (ω_{sp}) and damping ratio (ζ_{sp}) were δ_e/α and $\delta_e/\dot{\theta}$. The longitudinal stick spring rate was simulated directly through the F_{ES}/δ_{ES} gain. The F_{ES}/n_z was simulated by adjusting the δ_e/δ_{ES} gain of the T-33.

(U) The in-flight calibration was conducted at the simulation flight condition of 23,000 feet and 250 knots IAS. Records of the pitch response to several automatic elevator doublets and steps were taken at various fuel remaining conditions with the computed longitudinal gains required to perform the simulation set in the airplane. In addition, the pitch response to manual elevator stick steps (δ_{ES}) of various sizes were also recorded. The control inputs and the airplane responses were recorded in flight on an oscillograph. Short period frequency (ω_{sp}), and damping ratio (ζ_{sp}) were measured from automatic doublet inputs for $\zeta_{sp} < 0.5$ and automatic step inputs for $\zeta_{sp} > 0.5$. The parameter n_z/α was measured from the automatic step inputs. The manual step inputs were used to determine F_{ES}/n_z and F_{ES}/δ_{ES} .

(C) On the basis of this calibration data, adjustments to the longitudinal gains were made to properly simulate $\omega_{sp}^2/(n_z/\alpha)$, ζ_{sp} , F_{ES}/n_z, and F_{ES}/δ_{ES} for the five basic flight conditions shown in Table VIII. The longitudinal parameters simulated vary as a function of fuel remaining in the T-33 for a fixed set of gain settings. It was decided that these variations were not sufficient to warrant the complexity of changing longitudinal gains as a function of fuel remaining.

(U) The actual longitudinal parameters measured during the evaluation phase of the program are shown in Tables X through XIV.

4.4.2 Calibration of Lateral-Directional Parameters

(U) Lateral-directional gain settings required for simulation were determined analytically as previously discussed as a function of the gross weight or fuel remaining in the T-33. The lateral-directional characteristics of the T-33 vary significantly with fuel remaining.

(C) The gains used to simulate the roots of the characteristic equation (denominator terms) were δ_r/r , $\delta_r/\dot{\beta}$, δ_r/β , δ_r/p , δ_a/r , $\delta_a/\dot{\beta}$, δ_a/β , and δ_a/p . The gains used to simulate the proper response to aileron stick control inputs were δ_a/δ_{AS} and δ_r/δ_a . The gains adjusted to simulate rudder pedal inputs were δ_r/δ_{RP} and δ_a/δ_r . Adjustments in only δ_a/δ_{AS} and δ_r/δ_a were necessary when the interconnect ratio of the SV-5P K_{RA} alone was changed. The spring rates of the rudder and ailerons were simulated directly through the gains F_{RP}/δ_{RP} and F_{AS}/δ_{AS}

(U) The computed lateral-directional gains required to simulate the 45 lateral-directional configurations were checked out by performing in-flight calibrations. The in-flight calibrations were conducted at the simulation flight condition of 23,000 feet and 250 knots IAS.

(U) The responses of the airplane to automatic rudder doublet inputs were recorded at various fuel remainings for each of the configurations in Table IX. From the β, p and ϕ oscillograph traces it was possible to identify ω_d, ζ_d and $|\phi/\beta|_d$ for each of the 15 different cases to be simulated.

(C) From the computed δ_a/δ_{AS} and δ_r/δ_a gains a combined simultaneous automatic δ_a and δ_r step input required in the T-33 was determined to simulate SV-5P response to pilot δ_{AS} inputs for the 15 configurations with nominal interconnect ratios (Table IX). The p , β , and r traces obtained in flight were compared to the analytic fourth-order responses desired to simulate δ_{AS} inputs (for example, see Figures 2 through 6). By perturbing or adjusting the relative amount of δ_a and δ_r in the simultaneous automatic input, it was also possible to change the response to δ_{AS} inputs to simulate a change in interconnect ratio (K_{RA}) of the SV-5P. In a similar manner, from the computed δ_r/δ_{RP} and δ_a/δ_r gains a combined automatic δ_r and δ_a step input was determined and used in the T-33 to simulate SV-5P response to a δ_{RP} input. The p , β , and r traces obtained were again compared to the fourth-order responses desired to simulate δ_{RP} inputs (for example, see Figures 2 through 6). By perturbing or adjusting δ_r and δ_a of the automatic δ_{RP} input, it was also possible to determine the effect of δ_r/δ_{RP} and δ_a/δ_r gain changes on the response to δ_{RP} inputs.

(C) From a set of simulated δ_{AS} and δ_{RP} step automatic responses as described above, it was possible to check and obtain the gains required to simulate a set of three configurations whose only difference was interconnect ratio. For example, the simulation of responses to δ_{AS} and δ_{RP} inputs could be checked,and the required gains determined for configurations RG-1, RG-2, and RG-3 or configurations BO-4, BO-5, and BO-6.

(U) When the experimental responses to automatic steps checked the responses desired for δ_{AS} and δ_{RP} inputs reasonably well by visual inspection, the required δ_a/δ_{AS} , δ_r/δ_a , δ_r/δ_{RP} , and δ_r/δ_a gain settings for simulation were determined. When this was not the case, it was necessary to interpolate the gain settings to obtain the desired response from the set of experimental responses. Where possible, the interpolated gains were determined by simple inspection of the response curves. In other cases, the gains were determined by a least-squares fit of the experimental responses to the desired responses.

(U) Changes in gain settings determined as indicated above, were checked out on other calibration flights. When possible, gain setting changes required as a function of fuel remaining were also checked out in flight. Time limitations in general precluded additional checking at other fuel remaining conditions. In such cases, the gain changes with fuel remaining, based on the calibration flight data, were determined analytically.

(U) Manual aileron stick and rudder pedal step inputs were also taken during the calibration flights to check the desired spring rates (F_{AS}/δ_{AS}) and (F_{RP}/δ_{RP}). Adjustments in the spring rate gains were made as required to simulate the SV-5P spring rates. The responses resulting from manual δ_{AS} and δ_{RP} inputs were also used to verify that the simulated responses to cockpit inputs were in fact the same as the automatic step inputs indicated that they should be.

(C) The landing approach configurations (LA-1 through LA-9) were also evaluated during a spiral descent from 23,000 feet at 250 knots IAS. During these spiral descents, it was thought appropriate to simulate the L/D of the LA configurations. Wind tunnel data supplied by Martin indicated that an L/D of 4.7 was attainable for the LA configurations, and this L/D also corresponded very nearly to the $(L/D)_{max}$ of the SV-5P vehicle at Mach numbers less than approximately 0.5. To simulate this L/D at 250 knots IAS it was necessary to extend the drag petals of the wing-tip tanks of the T-33.

(C) Calibration of the airplane with the petals extended was conducted during stabilized descents at 250 knots IAS with idle power (65% rpm). These calibrations were performed with various petal deflection angles. The rate of descent and L/D simulated as the airplane passed through 12,000 feet were determined. This calibration data indicated that a petal deflection angle of 36° would simulate an L/D of 4.7 with idle power at 12,000 feet.

(U) The basic T-33 lateral-directional characteristics also varied with the petals extended. The change in T-33 Dutch roll frequency and damping with the petals extended 36° was determined from rudder doublet inputs in the vicinity of 12,000 feet. Based on this calibration data, appropriate changes were determined in the δ_r/r and δ_r/β gains to keep the Dutch roll frequency and damping of the LA configurations the same during the descent as they were in level flight at 23,000 feet with the petals retracted. No attempt was made to adjust the gain settings of LA configurations as a function of altitude during the descent.

(U) Based on the computed analytic gains, and the calibration flight data, a set of lateral-directional gains required as a function of fuel remaining was determined for each of the 45 lateral-directional configurations to be simulated. Appropriate gain changes for the Landing Approach configurations during the descent were also determined. The longitudinal and lateral-directional variable stability gains, in the form of knob settings, were used by the safety pilot in the rear cockpit to set up the simulated SV-5P configurations flown by the evaluation pilot in the front seat of the T-33 airplane.

SECTION V

IN-FLIGHT INVESTIGATION OF SV-5P HANDLING QUALITIES

5.1 MISSION AND TASKS

(U) Each of the SV-5P configurations simulated was evaluated by each of the pilots based on his interpretation of the mission and task requirements of the configuration. Each of the evaluation pilots was briefed on the mission and task requirements for each of the five flight conditions of the SV-5P that were simulated (Re-entry Glide, Boost A, Burnout, Boost B, and Landing Approach), and provided with a mission and task card to aid him in his evaluation of the configurations. The mission and task requirements shown on the mission and task cards are presented in Figure 7. The evaluation pilot was asked to perform the tasks shown and any others he thought appropriate to the mission. Although the evaluation pilot was aware of the flight condition simulated, and the mission and task requirements, he was not told the longitudinal or lateral-directional characteristics of the configurations he flew.

5.2 PILOT COMMENTS AND PILOT RATING SCALE

(U) Based on the mission and task requirements, the pilot was asked to comment and rate each configuration simulated. As an aid in providing comments, the evaluation pilot was provided with a pilot comment card shown as Figure 8. The pilot was asked to comment on the specific items on the card, but was also free to make any additional comments he thought appropriate. The landing approach comments in Figure 8 apply only to the LA configurations evaluated during the spiral descent and the flare. The pilot comments for each configuration evaluated were recorded on a wire recorder. These comments were later typed, analyzed, and related to the stability characteristics simulated. Similarities and differences of the comments of the various evaluation pilots were also investigated.

(U) As part of the pilot comments, the evaluation pilot was asked to give an overall rating to the configuration in the form of adjectives and a numerical rating based on the mission requirements. The pilot rating scale used is that shown as Figure 9. The basis for the new scale is described in some detail in Reference 1. As explained in Reference 1, the present scale attempts to overcome some of the difficulties experienced with previous scales devised by NASA and CAL. The present scale is clearly mission oriented, that is, it is to be used in rating the airplane or configuration in its performance of a specific mission. In addition, the scale is arranged so that the pilot can make a series of sequential decisions in arriving at a rating. He must first decide whether the airplane is controllable or uncontrollable for the mission. If controllable, the next decision is whether the airplane is acceptable or unacceptable. If acceptable, the next decision is whether it is satisfactory or unsatisfactory. Three degrees of satisfactory, three of unsatisfactory, and three of unacceptable provide for further refinement of the decision. The new scale also provides a better word description of the various categories to aid the evaluation pilot in arriving at a rating.

(U) The present simulation program is the first CAL handling qualities program in which the new rating scale was used.

5.3 TRACKING TASK - BOOST CONFIGURATIONS

(C) During boost, the SV-5P is expected to follow a programmed angle of attack to attain the proper trajectory. It was therefore thought advisable to include a tracking task in the evaluation of the boost configurations, Boost A and Boost B.

(C) As stated previously, the T-33 cannot simulate the angles of attack, and the angle of attack changes of the SV-5P. A realistic simulation of angle of attack tracking is therefore not possible in the T-33. A pitch angle tracking task in which the rate of change of pitch angle to be tracked is comparable to the rate of change of the angle of attack of the SV-5P during boost is possible in the T-33 simulation. Pitch angle tracking was evaluated in lieu of angle of attack tracking for the boost configurations evaluated.

(C) The pitch angle tracking task simulated in the T-33 is not intended to duplicate the angle of attack tracking requirements during boost of the SV-5, but merely to present to the pilot an angle tracking task which is probably equally as demanding in terms of the rate of change of angles with time. The pitch angle to be tracked is plotted as Figure 10. Also shown in the figure is the tracking error (θ_e) displayed on an all-attitude indicator by means of a cross-pointer. The pitch tracking task was a compensatory one in which the pilot was asked to minimize the displayed tracking error, $\theta_e = \theta_c - \theta$. Also shown on the attitude indicator was the actual pitch angle change of the airplane (θ) which occurred from the beginning of the tracking task. Before the pitch angle tracking task was turned on by the safety pilot, the evaluation pilot was able to null the tracking display angles so that the gyro, airplane, and cross-pointer coincided. The pitch angle tracking error displayed was magnified when compared to the actual pitch angle displayed. One inch of tracking error on the attitude indicator represents 5 degrees of pitch angle error. One inch of movement of the gyro horizon represents about 20 degrees of airplane pitch attitude change. This magnification of tracking error was considered reasonable by the evaluation pilot.

5.4 EVALUATIONS WITH RANDOM NOISE

(U) The evaluation pilot was asked to evaluate and comment on the configurations simulated in the presence of natural turbulence, especially the Landing Approach configurations simulated during descent.

(U) Each configuration simulated was also evaluated with random noise signal inputs to all three controls (elevator, aileron, and rudder). A reasonable level of random noise to each control for each of the five SV-5P flight conditions under investigation was selected by the CAL evaluation pilot during the preliminary calibration phase of the program. By "reasonable level" is meant that the evaluation pilot thought that the magnitude of the random noise disturbances of the airplane was what might be expected in normal atmospheric turbulence with the airplane. These random noise levels remained the same for other SV-5P configurations simulated at the same flight conditions such as Re-entry Glide (RG), etc. It is not intended to imply that random noise inputs to the controls are in fact an accurate simulation of the airplane response or sensitivity to atmospheric turbulence, but only an approximation of the airplane's sensitivity to random disturbances.

(U) Figure 11 is an approximate amplitude versus frequency plot of the filtered signal of the random noise generator.

(U) Figure 12 is the instrument display panel as it appeared to the evaluation pilot in the front cockpit during his evaluation of the configurations.

5.5 IDENTIFICATION OF CONFIGURATIONS EVALUATED

(U) Each configuration simulated, usually three per flight, was first assessed and commented upon by the evaluation pilot. At the end of each evaluation, a series of in-flight calibration records, both longitudinal and lateral-directional, was taken. From these records, the stability characteristics and stability parameters actually simulated and evaluated by the pilot were determined. In some cases the simulated stability characteristics differed significantly from those desired.

(U) The safety pilot was supplied with a flight record card which indicated the kinds of control inputs to be used in obtaining longitudinal and lateral-directional airplane responses used for identification. This flight record card is shown as Figure 13.

5.5.1 Longitudinal Identification Records

(U) With the longitudinal gain settings set in to simulate the longitudinal characteristics desired for the configuration, and the characteristics evaluated by the pilot, the airplane was trimmed in straight and level flight both longitudinally and lateral-directionally before each record was taken.

(U) The longitudinal responses to an au matic δ_e doublet and an automatic δ_e step were recorded. For damping ratios (ζ_{sp}) less than 0.5, longitudinal short period frequency was usually measured from these records using the "transient peak ratio method." For configurations with $\zeta_{sp} > 0.5$, frequency and damping were determined from the response to automatic step inputs using the "time ratio method." Both methods are discussed in some detail in Reference 6. The step input data was also used to determine the steady-state n_y/α simulated.

(U) The longitudinal responses to manual step inputs of various magnitudes were also recorded. This data was used to determine the steady-state stick force gradients (F_{ES}/n_y) and spring rates (F_{ES}/δ_{ES}).

(C) Pitch angle tracking was included as a task for the boost configurations simulated (BA and BB configurations). Oscillograph records were taken of the evaluation pilot's tracking performance during his one minute of tracking. Included in these records were the pitch tracking angle (θ_c), and the pilot pitch tracking error (θ_e).

(U) A summary of the longitudinal parameters measured and simulated during the evaluation flights is shown in Tables X through XIV for each of the five flight conditions. The average values and the standard deviations of the simulated parameters are shown in the tables. The desired values are also shown for purposes of comparison. The deviations reflect not only the accuracy of the simulation, but also measurement inaccuracies, especially ω_{sp} and ζ_{sp} for the highly damped cases. Some of the deviations in longitudinal parameters simulated are also attributable to the variation in the basic T-33 airplane stability derivatives with changes in fuel remaining. As explained in Section 4.2, the longitudinal gains were not varied as a function of fuel remaining.

(U) As indicated by Tables X through XIV, the longitudinal simulations for a given flight condition remained reasonably constant. There is no indication in the pilot comment data and the pilot rating data that the pilot assessment of the longitudinal characteristics of a configuration was in any way affected by the deviation shown.

5.5.2 Lateral-Directional Identification Records

(U) With the proper lateral-directional gain settings set in the airplane to perform the lateral-directional simulation of a configuration as evaluated by the pilot, the airplane was trimmed longitudinally and laterally-directionally before each calibration record was taken.

(U) Records of the lateral-directional responses to automatic δ_r doublets were analyzed for Dutch roll undamped frequency (ω_d), damping ratio (ζ_d), and the magnitude of roll to sideslip ($|\phi/\beta|_d$) in the Dutch roll mode. The Dutch roll frequencies and damping ratios were determined by the "transient peak ratio" method applicable for $\zeta_d < 0.5$. In some cases, $|\phi/\beta|_d$ could not be measured directly from the envelope of the ϕ and β traces following a rudder doublet input. In such cases, the value of $|\phi/\beta|_d$ could be approximated reasonably well from $|p/r|_d$ or $(1/\omega_d)|p/\beta|_d$. These alternate methods were also used as a check on the $|\phi/\beta|_d$ measured directly.

(U) Records were taken of a combined and simultaneous automatic step input of δ_a and δ_r in the T-33. The amounts of δ_a and δ_r used in the T-33 were those required to simulate the lateral-directional responses of the SV-5P to a given δ_{AS} input. These responses were compared to δ_{AS} step responses desired for each of the SV-5P configurations simulated. In a similar manner, records were taken of a combined automatic step input of δ_r and δ_a necessary to simulate δ_{RP} inputs of a given magnitude. These responses were also compared to the desired responses to δ_{RP} step inputs for each of the configurations simulated.

(U) Attempts were made to determine the roll mode time constants (τ_R) simulated for each of the lateral-directional configurations using the p response to the simulated δ_{AS} step input. This was not possible since the roll and Dutch roll modes were highly coupled for the configurations simulated (see Table IX). The degree to which τ_R was simulated for the configurations can only be judged qualitatively from a comparison of the measured and desired simulation of the initial p response to δ_{AS} inputs, and the accuracy to which ω_d and ζ_d were simulated. These responses are shown in the Appendix.

(U) No method exists that will easily identify the spiral mode time constant (τ_S) from the lateral-directional records. The simulated τ_S's can only be judged in an approximate qualitative sense by comparing the lateral-directional response tendencies as time increases following a simulated δ_{AS} step input.

(U) The lateral-directional responses to manual δ_{AS} stick and δ_{RP} pedal steps were also recorded for each of the simulated configurations. From these records the spring rates of the stick and rudder pedals (F_{AS}/δ_{AS} and F_{RP}/δ_{RP}) could be easily identified.

(U) The simulated configuration responses, such as p, β, and r, to manual δ_{AS} inputs should agree with the simulated automatic δ_{AS} step responses. They should agree provided that the δ_{AS} and δ_{RP} inputs as a function of time are the same for automatic and manual inputs, and control system attenuating effects are the same in both cases. The simulated δ_{AS} and δ_{RP} automatic inputs are good approximations of step inputs since they are put in as electrical steps and drive relatively fast aileron and rudder servos in the T-33 directly and bypass the feel system of the T-33. The manual δ_{AS} and δ_{RP} steps are inputs of the evaluation pilot and include the T-33 feel system dynamics (see Table IV). It is evident from the table that the T-33 aileron and rudder feel system is only an approximation of the feel system characteristics of the SV-5P. In addition, the manual δ_{AS} inputs of the pilot are not a good approximation of a step as is true of the automatic inputs. The evaluation pilot steps are more like ramp inputs with some variation in the steady-state values of δ_{AS} and δ_{RP}.

(U) Because of all the factors discussed above, it is very difficult to compare directly the lateral-directional responses obtained from both manual and automatic δ_{AS} and δ_{RP} inputs.

(U) Those lateral-directional mode characteristics that could be easily measured from the airplane response characteristics are tabulated and compared to the desired parameters in Tables XV through XIX. Also shown in the tables are the pilot ratings associated with each of the configurations simulated.

(U) The in-flight measured response characteristics (p and β) to simulated automatic δ_{AS} steps and δ_{RP} steps of one inch are shown on Figures A-1 through A-45 in the Appendix. Also shown on these figures are the desired p and β responses for these same inputs. A comparison of simulated and desired mode characteristics is also shown in the small table above each figure.

(U) The degree to which τ_R was simulated can be judged qualitatively from the initial p response to a δ_{AS} input. The degree to which the total response to automatic δ_{AS} and δ_{RP} step inputs was simulated can be judged by a comparison of the measured and desired response curves for each evaluation flight. It is evident from the curves that in some cases the responses to automatic δ_{AS} and δ_{RP} steps were reasonably well simulated; in other cases the comparison was poor. The reasons for the poor simulation of some configurations is not clearly understood. In some cases, this may represent a poor simulation of lateral-directional characteristics with changes in fuel remaining, in the T-33. It was also discovered early in the calibration phase of the program that the response characteristics to automatic δ_{AS} and δ_{RP} inputs were very sensitive to very small changes in the δ_a and δ_r gains. It was therefore difficult to determine δ_a and δ_r gains to simulate δ_{AS} and δ_{RP} inputs with precision.

(U) As explained previously, the automatic δ_{AS} and δ_{RP} step responses do not "truly" represent the response characteristics to manual inputs as experienced by the pilot. The manual inputs contain the attenuating effects of the feel system of the T-33 airplane, and these feel system characteristics do not match those of the SV-5P. In addition, the required manual input gains (δ_a/δ_{AS} and δ_r/δ_{RP}) were determined based on comparison of the responses to automatic input and the desired response characteristics, and calibration curves of the variable stability T-33 control system.

(U) An analysis of the actual simulated response characteristics based on manual δ_{AS} and δ_{RP} inputs would be highly desirable. Such an analysis would require the use of more sophisticated identification techniques such as analog matching or the Equations-of-Motion Method. This SV-5P in-flight simulation program was a highly complex one, and the limited time and funds available precluded any further data analysis.

SECTION VI

ANALYSIS OF PILOT COMMENTS AND PILOT RATING DATA

6.1 BASIS OF COMMENTS AND RATINGS OF VARIOUS EVALUATION PILOTS

(U) The in-flight evaluation phase of the program was conducted at Yuma, Arizona during January and February 1967. A total of 39 evaluation flights was flown during this period. Eighteen evaluation flights were flown by a CAL evaluation pilot, and seventeen by a Martin evaluation pilot. Two flights each were flown by a NASA and USAF pilot. Two CAL pilots acted as rear-seat safety pilots and in-flight test conductors for the entire evaluation phase of the program.

(C) In general, three configurations were simulated and evaluated per flight. On those flights where Landing Approach (LA) configurations were evaluated, the LA configurations were flown as the last configuration of the flight. The LA configurations were then evaluated in level flight at 23,000 ft and 250 kt IAS and during the descent at the same indicated airspeed with idle power and L/D = 4.7. All 45 configurations were evaluated by both the CAL and Martin pilots. In addition, each pilot evaluated 5 of these configurations a second time as repeats. Unfortunately, both the NASA and USAF pilots evaluated only 6 configurations each. They each evaluated the same configurations, and their evaluations acted primarily as checks on CAL and Martin evaluations for these same configurations.

(U) All 4 evaluation pilots participated in a ground simulation of the SV-5P just prior to the flight test program. In the ground simulation program, the pilots did point stability evaluations of the SV-5P, as well as evaluations "flying" complete SV-5P trajectories. The ground simulation was based on more recent design information than that available when the in-flight simulation program was planned in July 1966. No attempt is made to compare this in-flight simulation program and its handling qualities results to the ground simulator program. In their comments during the in-flight simulation of the SV-5P, the pilots occasionally referred to the similarities to or differences from the ground simulation.

(U) All the pilots are test pilots with considerable fighter flight time and some experience in ground or in-flight simulation. The CAL pilot has participated in previous ground and in-flight simulation programs for handling qualities research in the variable stability T-33 airplane. The same is true of the NASA pilot. This is the first experience for the Martin and USAF pilots in an in-flight simulation program using the T-33 airplane. Both the NASA and USAF pilots have actual flight experience in flying lifting-body test vehicles during glide and landing.

(U) All evaluation pilots were briefed on the operation of the variable stability T-33 airplane from the standpoint of the evaluation pilot. The mission and task cards for each SV-5P flight condition simulated were discussed with each of the evaluation pilots. The pilot comment card and the new pilot rating scale were also discussed at the beginning of each pilot's participation in the program. The CAL evaluation pilot often acted as co-pilot during the preliminary calibration flights and also participated in several practice evaluations during this phase of the program. The CAL pilot's learning and adjustment time was therefore less. The USAF pilot flew only two flights, and this was his first experience in an evaluation program with the variable stability T-33. The USAF pilot would therefore be most affected of all the pilots by a lack of familiarity with in-flight handling qualities investigation procedures with the T-33 airplane.

(U) The CAL pilot had very recent experience in the evaluation of handling qualities, both from the standpoint of the evaluation pilot and the engineering analyst engaged in handling qualities research. Based on this experience, he was also aware of the importance of pilot comments as an aspect of handling qualities research. The CAL pilot's comments on three configurations simulated during each flight ran to approximately 45 minutes, 15 minutes per configuration. He described, at some length, the characteristics of each configuration from the pilot's point of view based on the pilot comment card. In general, he refrained from guessing at the numerical values of the stability parameters simulated and attempted to describe the characteristics in purely technical terms. Having "sensed" the bad and good features of the configuration, he attempted to fly the configuration using piloting techniques he thought most appropriate. His overall rating of the configuration was based on all these observations in the light of his interpretation of the mission and task requirements of the configuration.

(U) The Martin pilot's most recent experience was in the SV-5P ground simulator. He interpreted the simulation more as an aid in design of the SV-5P, rather than a program of handling qualities investigation and research. His comments on three configurations per flight ran to approximately 15 minutes, five minutes per configuration. He often used rating numbers in place of words to characterize particular features of the configuration. Thus, he might characterize the pitch response as an A2.0 and the roll control as an A4.0 and the stick force per g as an A6.0. He stated that the word descriptions associated with these rating numbers in the pilot rating scale then applied to the feature given a number rating. The overall longitudinal characteristics were usually given a separate number rating from the lateral-directional characteristics. The Martin pilot stated that his overall numerical rating of a configuration could never be better than the poorest rating given to any particular aspect of the configuration. Although the CAL pilot commented on all the features of a configuration, he assigned only one pilot rating number to a configuration, based on the overall behavior of the vehicle, and the ability of the pilot to accomplish the mission. The pilot rating scale has been used in this manner in all handling qualities research conducted at CAL.

(U) The NASA and USAF pilots were only exposed to two evaluation flights each, and they were therefore somewhat handicapped by learning and adjustment problems associated with any handling qualities research program. On the basis of their brief exposure, it is difficult to assess their particular evaluation techniques.

(U) Individual verbatim comments of each evaluation pilot for each of the configurations flown and evaluated are not presented in this report. These comments are presented in Reference 7 which may be examined for specific details. Summaries of the pilot comments on each configuration simulated are presented in the Appendix. Comparisons of the comments of different pilots on each configuration simulated are also made in the Appendix, and the comments are related to the mode characteristics and the control response characteristics obtained from in-flight oscillograph records.

(U) The reader should refer to the Appendix for detailed summaries of the comments and response characteristics of each configuration simulated. Presented here is a summary of longitudinal and lateral-directional comments for each of the five flight conditions of the SV-5P simulated and an analysis of how these pilot comments and ratings are related to the mode and response characteristics simulated.

6.2 SUMMARY OF PILOT COMMENTS ON RE-ENTRY GLIDE CONFIGURATIONS

6.2.1 Comments on Longitudinal Characteristics

(U) A tabulation and summary of the longitudinal stability parameters simulated is presented in Table X. It is evident from the results that the longitudinal simulation was reasonably good for all the RG configurations simulated.

(C) The comments on longitudinal characteristics were consistent for any given pilot and also among pilots. The RG configurations presented no trim problems. All the pilots felt that longitudinal trim was easy and trim rate adequate. Remarks on pitch response to elevator stick ranged from satisfactory to optimum. Comments on attitude control and n_z control were all favorable. The pilots liked the longitudinal spring ratio (F_{ES}/δ_{ES}), and the steady-state stick force gradients (F_{ES}/n_z). The effects of random noise on the good longitudinal handling qualities was slight and of no great significance.

(C) In viewing the longitudinal parameters in Table X and the results of Reference 4, the good longitudinal comments are not surprising. The short period damping is good, the stick force gradient of 10 to 11 pounds per g is considered satisfactory, and the CAP parameter and the initial pitch acceleration parameter, $\omega_{sp}^2/(n_z/\alpha)(F_{ES}/n_z)$, fall in the satisfactory range based on pilot ratings and comments. The relationship of feel system frequency to short period frequency (approximately 2.5 to 1) in the T-33 simulation is not the same as that of the SV-5P (approximately 12 to 1). The attenuating effects of the feel system on the initial pitch response in the T-33 simulation would be larger than would be the case for the full-scale vehicle. Obviously the initial pitch acceleration response with feel system dynamics included as simulated is too low, but the results of Reference 4 indicate qualitatively that a proper match would not have significantly affected the results.

6.2.2 Comments on Lateral-Directional Characteristics

(C) The best RG configuration tested was RG-3. The pilot comments and ratings of this configuration as flown by the CAL and Martin pilot were quite consistent. The SV-5P damping and cross-feed gains are $K_{\dot{\phi}} = .3$, $K_{\dot{\psi}} = .75$, and $K_{RA} = .4$. The roll rate and roll damping were considered adequate, and the adverse yaw due to ailerons was thought to be small. The precise bank angle control combined with the good directional damping made holding heading and changing heading easy to accomplish. Both aileron and rudder forces and gradients, and feel characteristics were satisfactory to the pilots. Although coordination with the rudder was thought helpful and useful, it was not really required for turn coordination. There were no significant effects of random noise on the handling qualities, and control harmony was compatible about all three axes. The overall numerical rating of the RG-3 configuration was an A1.0 to an A2.0.

(C) It is evident from the data in the Appendix that the mode characteristics and response characteristics to control inputs were reasonably well matched for configuration RG-3. The level of p response to aileron inputs simulated is 30 to 40 percent too high, but the shape of the p responses are very similar to that intended for the configuration. The adverse yaw for a given p response is actually less than what was intended for the configuration. Based on the p response one would expect configuration RG-1 to be rated better than configuration RG-3, since the roll response of RG-1 is less acceleration-ordered, but such was not the case. For configuration RG-1, there was some objection to the lower level of p response from δ_{AS} and the larger level of adverse yaw.

(C) The pilot comments, especially those of an adverse nature, can be summarized for the remaining RG configurations simulated. The single parameter that the pilot was most sensitive to and caused the greatest variation in pilot rating was the interconnect ratio (K_{RA}). In general, as the interconnect ratio was reduced from nominal value ($K_{RA} = .325$), the degree of adverse yaw or sideslip increased, and the increased sideslip resulted in a reduced roll rate for the same aileron input. In some cases, the result was nearly roll rate reversal. The roll rate and adverse yaw could be improved by proper rudder coordination of the pilot, but with large adverse aileron yaw this was often a "tricky" coordination task, and more acceptable to the CAL evaluation pilot than the Martin pilot. As the value of K_{RA} increased, the adverse yaw was reduced, and the roll rate increased. The need for little or no rudder coordination in turns made these configurations much more acceptable to the pilot. The pilot did not object even though the p response was slightly acceleration-ordered, that is, p did not approach a steady-state value but continuously increased with time.

(C) As the damping gains decreased from the nominal values ($K_{\dot\phi}$ = .3 and $K_{\dot\psi}$ = .75) the adverse yaw due to δ_{AS} increased somewhat, and the roll rate was reduced. Also, the p response became more oscillatory. All of these factors tended to make the configurations with reduced damping gains less acceptable to the pilot.

(C) It is difficult to judge the effect of increased damping gains ($K_{\dot\phi}$ = .4 and $K_{\dot\psi}$ = .85) since the response for these configurations (RG-7, RG-8, and RG-9) were in general poorly matched. The poor match is especially evident in the p and β response for δ_{AS} inputs. The greater adverse yaw simulated is probably a strong contributor to the poor p response simulated. The poor match for these configurations is probably associated with the poorer matching criteria in obtaining the T-33 fourth-order simulation of SV-5P. The fourth-order T-33 gains for configurations RG-7, RG-8, and RG-9 were based on a match of $\frac{g}{V_o} N_r'$ and $\frac{g}{V_o} L_r'$ of the SV-5P instead of a match of the magnitude of $|\phi/\beta|$ in the roll and spiral modes. $|\phi/\beta|$ in the roll and spiral modes were better matching criteria and were used for all other configurations simulated.

(C) The sideslip available from the rudder and the resulting roll due to sideslip made the rudder a reasonably powerful sideslip and roll control device. A configuration with significant adverse yaw and resulting poor roll could be improved by eliminating the sideslip and improving the roll with adequate coordination. When the sideslip and roll control of rudder was quite significant, (Conf. RG-7), pilot complaints were directed at the sensitive rudder and the light rudder pedal force gradients. A configuration with low aileron roll and with considerable adverse yaw, coupled with a very sensitive rudder for sideslip and roll control, was especially objectionable to the pilots (Configurations RG-8 and RG-9).

6.3 SUMMARY OF PILOT COMMENTS ON BOOST A CONFIGURATIONS

6.3.1 Comments on Longitudinal Characteristics

(U) The simulated longitudinal characteristics for the BA configurations are listed in Table XI. It is evident that the desired longitudinal characteristics were reasonably well simulated for the BA configurations.

(C) One of the dominant longitudinal characteristics of the BA configurations was the relatively high F_{ES}/n_z (29.4 lb/g). All pilots commented on this longitudinal characteristic. All pilots except the CAL pilot objected to the relatively high F_{ES}/n_z and this characteristic adversely colored their longitudinal evaluation of the BA configurations. The CAL pilot found he could fly the BA configurations satisfactorily with the trim button using the maximum longitudinal trim rate available in the T-33, $d\delta_{ES}/dt$ = 0.6 inches/sec. Using longitudinal trim as a primary longitudinal control technique eliminated the objections to the high longitudinal stick forces.

(C) Because of the high F_{ES}/n_z all pilots except the CAL pilot commented fairly consistently that the pitch response was slow and it required larger than desired stick forces. The same objectionable stick forces made control of attitude and n_z more difficult for the other pilots. In general all pilots reported good performance in the longitudinal pitch tracking task, but the other pilots again objected to the increased difficulties imposed by the high stick forces. Random noise generally did increase somewhat the longitudinal control problem for all pilots.

(C) Using longitudinal trim as a primary longitudinal control, the CAL pilot found the maximum trim rate satisfactory. Using the maximum longitudinal trim rate for trim, the Martin and AF pilots felt that the trim rate should be increased.

(C) Some of the adverse comments associated with slow pitch response to stick forces is also attributable to the slow feel system frequency relative to short period frequency simulation in the T-33 (3 to 1). In the SV-5P the estimated ratio of these frequencies is 12 to 1, and therefore the initial pitch response characteristics should be better than those simulated.

6.3.2 Comments on Lateral-Directional Characteristics

(C) The roll mode time constants of the BA configurations are reasonably large, and the configurations also have an unstable spiral mode (see Table XVI). These characteristics, combined with the other aerodynamic characteristics of the BA configurations, tend to make the roll response to δ_{AS} inputs acceleration-ordered. The roll rate response for a given input in general increases with time. The pilot objections are therefore in general directed first at this characteristic by complaining of low roll damping. When the acceleration-ordered response is also accompanied by a significant amount of adverse yaw, rudder coordination only aggravates the acceleration-ordered roll response. Opposite aileron to arrest the roll then requires opposite rudder to control the sideslip, and the resulting roll and sideslip control is in general difficult.

(U) An examination of the measured and desired mode characteristics (Table XVI) indicates that in general these characteristics were reasonably well matched. Also, an examination of the initial p response in the Appendix indicates a reasonable match of the roll mode time constant (τ_R). Differences do exist, however, and they will be discussed as required.

(C) Configuration BA-7 was flown by all pilots with only 1.5 rating unit differences between the best and poorest ratings. The configuration was acceptable and satisfactory with an average rating between A3 and A3.5. The primary complaint is concerned with the "light" or "low" roll damping. There was also comment about the "fair amount" of sideslip, especially by the CAL pilot. He found rudder coordinations somewhat difficult because of the sensitivity of the rudder in producing both sideslip and roll. It is interesting to note that the p response of the rudder as simulated for the CAL pilot is high after approximately two seconds. Both the Martin and NASA pilots recommend flying aileron alone and accepting the adverse yaw that results.

(C) It is interesting to note that the adverse yaw as simulated was too high. A better simulation of the β response due to δ_{AS} would have made the configuration even more acceptable to all the pilots even though the response to δ_{AS} inputs is slightly acceleration-ordered.

(C) The response characteristics of Configuration BA-9 as simulated, especially the p and β responses to δ_{AS}, were very similar to the responses for Configuration BA-7. The p response is slightly more acceleration-ordered. The pilot comments and ratings were similar for the two configurations. Had the proper adverse aileron yaw been simulated for Configuration BA-9, the pilot comments and ratings of the lateral-directional characteristics would have improved.

(C) The two poorest rated configurations are Configurations BA-4 and BA-6. An examination of the actual response characteristics simulated explains the basis of the pilot complaints. The pronounced acceleration bank angle response is objectionable and the adverse yaw as simulated is also objectionable. Rudder coordination only aggravates the acceleration-ordered p response, because of the acceleration-ordered p response of the rudder as simulated. One must be careful to relate the comments and ratings to the actual simulated response characteristics and not the desired characteristics. It is recommended by the CAL pilot that a reasonably satisfactory bank angle control is possible for these configurations only by reducing aileron gain and using only enough rudder coordination to keep the sideslip within tolerable limits.

(C) The comments about the other configurations simulated follow a similar pattern. In general, decreasing the interconnect ratio (K_{RA}) will improve the p response by making it less acceleration ordered. But this occurs only at the expense of increased adverse yaw. Coordination in the rudder to reduce sideslip will again give an acceleration-ordered p response, especially if the p response of the rudder is acceleration-ordered. Increasing K_{RA} will reduce sideslip but make the p response to δ_{AS} more acceleration-ordered.

(C) The best BA configurations tested were those with the highest damping feedback gains (Configurations BA-7, BA-8, and BA-9).

6.4 SUMMARY OF PILOT COMMENTS ON BURNOUT CONFIGURATIONS

6.4.1 Comments on Longitudinal Characteristics

(U) The simulated longitudinal characteristics for the BO configurations are shown in Table XII. It is evident from the table that in general the desired longitudinal characteristics were reasonably well simulated.

(C) The most dominant longitudinal characteristic was the very high stick force gradient, F_{ES}/n_z = 86.2 lb/g. With an elevator stick spring rate (F_{ES}/δ_{ES}) of 4.44 lb/in. and a stick travel limited to approximately ±6 inches, the maneuver g available to the pilot in the simulation was of the order of ±1/3 g. Obviously the longitudinal maneuverability to the pilot was limited. In the SV-5P vehicle, this limited maneuverability is associated with the low dynamic pressure (q) at burnout and not the inability to change angle of attack. In the T-33 simulation, the very high F_{ES}/n_z was simulated by limiting the angle of attack available as a function of stick force by making the δ_e/F_{ES} gain in the T-33 small. Angle of attack was not matched in the simulation of any of the configurations.

(C) Obviously the initial pitch acceleration response to stick force inputs, $[\omega_{sp}^2/(n_z/\alpha)(F_{ES}/n_z)]$, is low and the steady-state maneuver forces are high because of the high F_{ES}/n_z of the BO configurations. The low pitch response and the excessive maneuver forces were a continual complaint of the Martin, AF, and NASA evaluation pilots. The pilot ratings of BO configurations were never better than A4.5 for these pilots primarily because of the high longitudinal F_{ES}/n_z. The CAL pilot had similar complaints and ratings for BO configurations on Flights 759 and 761.

(C) After Flight 761, the CAL pilot learned to fly BA, BB, and BO configurations satisfactorily through the longitudinal trim button. The excessive stick forces required to maneuver were no longer present, and any degradation of the configurations because of high F_{ES}/n_z disappeared. Although the longitudinal maneuverability of BO configurations was limited to approximately 1/3 g, the CAL evaluation pilot felt this was sufficient in his interpretation of mission requirments of the SV-5P at burnout. Flying Configuration BO-1 using trim control improved the rating from A5.0 to A3.0. The best rating of a BO configuration was the CAL pilot's rating of A2.0 for Configurations BO-1 and BO-7. Thus, these configurations were interpreted to have both good longitudinal and lateral-directional characteristics by the CAL evaluation pilot.

(C) The initial response characteristics of the SV-5P as determined by the simulated parameters CAP $= \omega_{sp}^2/(n_z/\alpha)$ or $\ddot{\theta}_{max}/F_{ES} = \omega_{sp}^2/(n_z/\alpha)(F_{ES}/n_z)$ are attenuated by the T-33 feel system to a larger extent than is the case for the SV-5P. The reason has already been presented in Section 6.3.1. The SV-5P should, therefore, be somewhat more responsive in initial pitch than the T-33 simulation indicates.

6.4.2 Comments on Lateral-Directional Characteristics

(C) The BO configurations with the best lateral-directional response characteristics are Configurations BO-3, BO-6, and BO-4. The CAL pilot ratings for these configurations varied from A2.0 to A2.5. The Martin pilot ratings varied from A4.5 to A5.0. The primary reason for the poorer rating of the Martin pilot is his objection to the longitudinal response characteristics with the high F_{ES}/n_z. The CAL pilot eliminated this objection by flying the configurations with the longitudinal trim button. All of these configurations have the highest damping gains ($K_{\dot{\phi}}$ and $K_{\dot{\psi}}$) and the maximum interconnect ratio (K_{RA}). Both of these gains results in well damped p responses with a reasonably low roll mode time constant and little adverse aileron yaw. Both the Martin and CAL pilots commented on the need for little or no rudder coordination, and the precise bank angle and heading control possible. Both pilots liked the aileron and rudder control forces and feel system characteristics. Good positive control was also possible in the presence of random noise disturbances.

(C) It is interesting to note that when little rudder coordination was required, the pilots found the light rudder control force gradient of 34.4 lb/in. quite satisfactory. The Martin pilot commented several times on Configurations BO-3, BO-6, and BO-9 that he liked the pedal force gradient he had, and preferred this gradient with essentially zero breakout force to a gradient of 28 lb/in. and a ±8 lb breakout force which was used in the ground simulator. Both pilots found the response to rudder pedal inputs on these configurations quite satisfactory. Both pilots commented on the lack of control harmony, that is, the longitudinal forces were high compared to the forces of the aileron and rudder.

(C) Configurations BO-2, BO-5, and BO-8, with the lowest interconnect ratio, resulted in greater adverse yaw and lower roll rates for a given aileron control input. The adverse yaw required greater attention to rudder coordination to obtain an acceptable level of roll response and bank angle control. These effects were especially evident for Configuration BO-8. For these reasons, the pilot ratings were poorer in general for the lowest interconnect ratios. As is true for all the BO configurations, the Martin pilot ratings are poorer in general and heavily weighted by the high longitudinal F_{ES}/n_z.

(C) In examining the response characteristics, comments, and ratings of Configurations BO-1, BO-4, and BO-7, it is possible to examine the effect of changes only in damping feedback gains ($K_{\dot{\phi}}$ and $K_{\dot{\psi}}$). Decreasing these gains from the nominal in going from Configurations BO-1 to BO-4 improved the level of the p response from aileron and rudder inputs, and in general made the response characteristics more oscillatory. These effects are also evident from the increase in $|\phi/\beta|_d$ response and the decrease in Dutch roll damping. Both pilots felt that the improved roll made the lateral-directional response to δ_{AS} inputs satisfactory with little adverse yaw and no strong need for rudder coordination. In increasing the damping gains by going to Configuration BO-7, the changes in pilot comments were predictable. The decrease in adverse yaw made the yaw negligibly small with no requirement for rudder coordination. The configuration could be flown nicely with ailerons alone. The roll response to aileron inputs was considered good, in the sense of adequate roll damping, amplitude, and minimum Dutch roll excitation, but the aileron stick forces were considered slightly heavy. The comment on heavy aileron stick forces is a reflection of the loss in level of roll response for a given δ_{AS} or F_{AS} input, due to the increased roll damping.

6.5 SUMMARY OF PILOT COMMENTS ON BOOST B CONFIGURATIONS

6.5.1 Comments on Longitudinal Characteristics

(C) The simulated longitudinal characteristics of the BB configurations are tabulated in Table XIII. It is evident, from the flight test results, that the desired longitudinal short-period characteristics were reasonably well simulated. The simulated longitudinal parameters differ in no important respects from the longitudinal parameters simulated for the BA configurations. The simulated short-period frequency is somewhat lower in order to simulate a smaller initial pitch response parameter (CAP), as defined by $\omega_{sp}^2/(n_z/\alpha)$. The reduction in CAP from 2.11 to 1.53 is not expected to change the longitudinal handling qualities significantly, based on the results of Reference 3. As explained in Section 6.2.1, the simulated feel system dynamics in the T-33 further attenuate the abruptness of the initial pitch response.

(C) It is not surprising that the overall assessment and comments of the pilots on the BB configurations are similar to those of the BA configurations. The CAL pilot again found the relatively high F_{ES}/n_z of approximately 32 lb/g unobjectionable when he flew the configurations using the longitudinal trim button as a primary longitudinal control. The poor lateral-directional characteristics of many of the BB configurations made assessment of the longitudinal characteristics difficult.

6.5.2 Comments on Lateral-Directional Characteristics

(C) Of all configurations simulated for the various flight conditions, the configurations for the BB flight condition generally had the poorest lateral-directional characteristics from the standpoint of handling qualities. The poor handling qualities were generally associated with the poor roll response, both in magnitude and shape, and the high adverse yaw. These factors were not independent, that is, the poor roll response was often associated with the high adverse yaw. Some of the configurations with especially high adverse yaw led to reversal in the p response with only δ_{AS} inputs. These configurations were especially unacceptable to the pilots. Configurations with high adverse yaw and poor roll could be improved by proper rudder coordination to reduce the adverse yaw and increase the roll, but such a technique was often not too successful. The increased roll resulting from the elimination of adverse yaw sometimes made the roll response acceleration-ordered. This was especially true when the roll response of the rudder was acceleration-ordered.

(C) Although the mode characteristics, such as ω_d, ζ_d, and $|\phi/\beta|_d$ were generally reasonably well matched, the response to control inputs (δ_{AS} and δ_{RP}) were often poorly matched. This was especially true of response to δ_{RP} inputs. Often, the simulated p response was strongly acceleration-ordered, and the desired p response from the rudder was not. The responses to control inputs were generally matched the poorest for the BB configurations. The pilot comments and ratings are applicable to the simulated characteristics and not the desired characteristics, and one must be careful to interpret the comments and ratings in this manner.

(C) Some of the poorest BB configurations were those with the lowest interconnect ratio (K_{RA}), Configurations BB-2, BB-5, and BB-8. All of these configurations display a high degree of adverse yaw and roll reversal in the p response to δ_{AS}. For all of these configurations, the degree of roll reversal in the p response simulated was more severe than that desired, but the adverse yaw was simulated reasonably well. Both pilots found Configuration BO-5 uncontrollable and rated it a 10. The pronounced adverse yaw and roll rate reversal made the airplane very difficult to fly. Continuous concentration was required to simply hold the wings level. The airplane could not be trimmed for hands-off flight. Configurations BB-2 and BB-8 had much the same characteristics. Attempting to obtain adequate roll control with the aileron was a very difficult problem because of the roll reversal tendency and the high adverse yaw. Rudder coordination was very difficult because of the light rudder forces and the acceleration-ordered roll of the rudder. All pilots found lateral-directional trim difficult, requiring a delicate balance between rudder and ailerons. Because of the high roll obtainable from the rudder, both the NASA and CAL pilots found that the best procedure was to use the rudder as the primary roll control device, with small aileron stick inputs for coordination. Using this procedure, the configurations were flyable with considerable pilot effort. Neither the Martin nor AF pilot resorted to this roll technique and found the configurations nearly impossible to deal with; consequently their ratings are significantly poorer.

(C) Configurations BB-3, BB-6, and BB-9 were generally found the most acceptable to the pilots. Pilot ratings for these configurations vary from A5.0 to A6.0. The CAL pilot rating of U8.0 for Configuration BB-6 is not considered, since the adverse yaw rate is much higher and the roll rate significantly poorer than the desired values. These configurations did not exhibit the roll rate reversal tendencies of Configurations BB-2, BB-5, and BB-8. The p response tended to be acceleration-ordered and this factor was accentuated by the high roll mode time constant, 1.18 to 1.39 sec. The adverse yaw due to ailerons was still considered excessive with rudder coordination to reduce sideslip, the acceleration-ordered p response of the rudder made the total airplane p response even more acceleration-ordered. In addition, the p response of the rudder exhibited an initial delay of approximately 1 sec. This delay, coupled with the pronounced acceleration-ordered roll response, made proper rudder coordination and roll control a difficult task. Rudder control and roll control were therefore considered to be sensitive with the low rudder pedal gradient. The effects of random noise were accentuated, and the airplane was difficult to trim lateral-directionally.

(C) The p response to δ_{AS} inputs for Configurations BB-1, BB-4, and BB-7 show no roll reversal tendencies or acceleration-ordered roll responses. The pilots' primary complaints for these configurations were the low level of aileron roll response and the high degree of adverse yaw. For Configurations BB-1 and BB-4, complaints were directed also at the low Dutch roll damping and its effect on roll. The acceleration-ordered p response of the rudder and light rudder forces made coordination and precise bank angle control difficult. The increasing roll rate of the rudder required opposite aileron inputs which, in turn, required opposite rudder pedal inputs. Consequently, there was some complaint, especially by the CAL pilot, of tendencies of a roll PIO. Accurate control of heading and heading changes were not attainable, and lateral-directional trim was always difficult. Pilot ratings for these configurations varied from A6.0 to U9.0.

6.6 SUMMARY OF PILOT COMMENTS ON LANDING APPROACH CONFIGURATIONS

6.6.1 Comments on Longitudinal Characteristics

(C) The longitudinal parameters simulated for the LA configurations are tabulated in Table XIV. Obviously, the longitudinal parameters were simulated reasonably well for all the LA configurations. It is also evident, from the values of ω_{sp}, ζ_{sp}, F_{ES}/n_z, and $\omega_{sp}^2/(n_z/\alpha)$, that the longitudinal short-period dynamics as simulated should be quite acceptable from the standpoint of handling qualities.

(C) The overall comments on longitudinal characteristics were best for the LA flight condition. There was virtual unanimity among all the pilots on the good longitudinal characteristics. There were no difficulties experienced with trim and the trim rate was adequate. Pitch response was considered excellent. Pitch attitude control and n_z control were smooth and precise. All elevator stick feel system characteristics were considered to be satisfactory. The effects of random noise and natural turbulence in the longitudinal handling qualities were considered to be minimal. These comments apply equally as well during the descent. Longitudinal control during the flare at the end of the descent was considered to be smooth, easy, and positive.

(C) There were occasional comments by the Martin, NASA, and USAF pilots that the descent simulation was not realistic from the standpoint of a lifting body. The descent L/D of 4.7 simulated was considered to be too high and probably unrealistic. It was felt that descents would be made at higher speed than 250 kt IAS and lower L/D's than 4.7. Both of these factors would increase the rate of descent over that simulated.

6.6.2 Comments on Lateral-Directional Characteristics

(C) Of all the SV-5P configurations simulated, it is also true that the lateral-directional characteristics of the Landing Approach configurations were generally the most well received.

(C) One of the most recurring and frequent comments on many of the LA configurations was the objectionable abruptness of the initial roll response, or the initial roll sensitivity to aileron stick inputs. This was a more frequent and stronger objection of the Martin pilot than the CAL pilot. There was some objection to the adverse yaw of those configurations with the lowest interconnect ratio (K_{RA}) but, in general, the adverse yaw was not considered excessive. For those configurations with sufficient adverse yaw that rudder coordination was considered necessary, the pilots also commented on the light rudder forces and the sensitivity of rudder control.

(C) The abruptness of the initial roll response is evident from the initial rapid change in p response following a step control input, as shown in the Appendix. The level of p response available, that is, the steady-state p, was always considered adequate and the roll response was considered well damped. The lateral-directional mode characteristics and response characteristics to aileron and rudder inputs were reasonably well simulated for the LA configurations.

(C) Generally, the LA configurations with the highest damping gains ($K_{\dot{\phi}}$ and $K_{\dot{\psi}}$) and the greatest interconnect ratio (K_{RA}) were most acceptable to the pilots, since these configurations tended to reduce the abruptness of the initial roll response and the adverse yaw due to δ_{AS}. Comments on Configuration LA-9 were quite complimentary by both the CAL and Martin pilots. There was little evidence of the abruptness of initial roll response, and the sideslip was considered small enough not to require rudder coordinations. All control forces, gradients, and feel characteristics were considered satisfactory. Random noise inputs had little effect on vehicle response, and lateral-directional damping was considered good. The descent portion of the flight was well received, with good roll and attitude control, no significant effects of turbulence, and excellent flare characteristics. The Martin pilot rated the configuration A1.5. The CAL pilot experienced more adverse yaw due to aileron as the descent progressed and was harsher in his evaluation, rating the configuration an A3.5. No explanation can be offered for the CAL pilot's comment of greater adverse yaw.

(C) Configuration LA-3 was reasonably well received by both the CAL and Martin pilots. The small adverse yaw presented no difficulties to either pilot, but there were some comments about the initial roll response being "a bit abrupt" or "slightly fast." In all other respects, the configuration was considered quite satisfactory. Configuration LA-6 was also highly acceptable to all the pilots except the AF pilot. There were no complaints about roll acceleration, and the adverse aileron yaw was low enough so as not to require rudder coordination. It is interesting to note that the level of p response to δ_{AS} as simulated was too low by approximately 35% for Configuration LA-6. This may explain somewhat the lack of complaints about roll acceleration.

(C) Configurations LA-1 and LA-7 were considered unsatisfactory by both the CAL and Martin pilots. The primary complaint in Configuration LA-1 was the abrupt or rapid roll accelerations to δ_{as} inputs. For Configuration LA-7, the complaints were concerned with the abrupt roll response and the sideslip excursions following δ_{as} inputs. On Configuration LA-8, the adverse yaw and the "abrupt" or "jerky" response to small δ_{as} inputs were complained about the most. It was also felt that rudder coordination was also complicated by the sensitive rudder due to the light pedal forces.

(C) Complaints about the remaining LA configurations are concerned with these same factors: (1) the abrupt roll response, (2) the adverse yaw, and (3) the sensitive rudder during coordination. Details of the comments and response characteristics may be obtained from the Appendix.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

(C) The following conclusions about SV-5P lifting body handling qualities are based on certain assumptions and limitations of the in-flight simulation. The whole simulation was a point stability simulation conducted at constant speed and altitude except for the evaluation of Landing Approach configurations during descent. The simulation is based on preliminary stability and control data supplied by Martin personnel in July 1966. The simulation was performed about stability axes. The simulation assumes that the inherent rotary derivatives of the SV-5P were zero, and all the damping results from feedback gains. Although this assumption is probably conservative from the standpoint of the amount of pitch, roll, and yaw damping that exists, it is not necessarily conservative from the standpoint of an important derivative such as C_{n_p}. The combined effect of the washout filter dynamics with other than zero inherent rotary derivatives has also not been considered in the simulation. The following conclusions about handling qualities are valid, however, based on the longitudinal and lateral-directional characteristics simulated and should prove useful as an aid in design of the SV-5P and other lifting body configurations.

(C) 1. The longitudinal characteristics of the Re-entry Glide (RG) and Landing Approach (LA) configurations were determined to be acceptable and satisfactory by all the evaluation pilots.

(C) 2. The longitudinal characteristics at the other simulated flight conditions were acceptable except for the high F_{es}/n_z at the two boost conditions (29.5 and 32.2 lb/g) and the very high F_{es}/n_z at the burnout condition (86.2 lb/g).

(C) 3. All pilots except the CAL pilot downgraded the longitudinal characteristics of the boost and especially the burnout configurations because of the high F_{es}/n_z. The CAL evaluation pilot discovered that he could successfully fly configurations with high F_{es}/n_z using the longitudinal trim button as a primary longitudinal control with a trim rate of .6 in./sec at the elevator stick. The CAL pilot, therefore, found the boost and burnout longitudinal characteristics acceptable and satisfactory for the missions once the high stick force gradients were eliminated.

(C) 4. No unacceptable handling qualities were found for the basic configurations (RG-1, BA-1, BB-1, BO-1, and LA-1) except that the BB-1 configuration was found to be marginal (PR = A6.0 to U7.0).

(C) 5. Configurations simulated at the Boost B (BB) flight condition presented the most problems to the pilots. The high adverse aileron yaw, the low roll authority and sometimes roll rate reversal associated with δ_{AS} inputs, the high effectiveness of the rudder as a sideslip and roll controller, and the rudder sensitivity associated with low rudder forces all combined to make control of the BB configurations extremely difficult for the pilots. Because of these characteristics, pilots occasionally experienced loss of lateral control with the airplane rolling on its back.

(C) 6. The configurations generally most acceptable to the pilot were those simulated at the Landing Approach (LA) flight condition. Both the longitudinal and lateral-directional characteristics simulated were considered good. The good longitudinal F_{ES}/n_z , the adequate roll authority, the good longitudinal and roll damping, and the small adverse yaw made precise longitudinal and lateral-directional control easy. There was some objection, especially by the Martin pilot, to the abruptness of the initial roll response following a δ_{AS} input.

(C) 7. The most undesirable lateral-directional characteristic simulated was roll rate (p) reversal resulting from a δ_{AS} input. The second most undesirable characteristic was adverse aileron yaw. These two characteristics were often connected, that is, high adverse yaw resulted in a poor aileron roll rate.

(C) 8. A third undesirable characteristic was an acceleration-ordered roll response to δ_{AS} inputs. This condition was often accentuated by a large roll mode time constant. For those configurations accompanied by high adverse yaw and an effective rudder, rudder coordination aggravated the acceleration-ordered roll response excessively and made coordination of ailerons and rudder for roll control difficult. A limited degree of acceleration-ordered roll was not considered objectionable by the pilots.

(C) 9. Variations of K_{RA} (rudder to aileron interconnect) caused greater changes in handling qualities than did the simulated variations in damping gains ($K_{\dot{\phi}}$ and $K_{\dot{\psi}}$). Too small a value of K_{RA} increased the adverse yaw and reduced the roll power of the ailerons. In some cases, the result was a roll rate reversal. Too large values of K_{RA} could lead to acceleration-ordered p response and a lack of roll damping. These effects were most apparent for the BB configurations.

(C) 10. In general, increasing the roll and yaw damping ($K_{\dot{\phi}}$ and $K_{\dot{\psi}}$) improved the response by reducing the adverse yaw and improving the roll response. This was especially the case when the roll response to δ_{AS} inputs tended to roll reversal or an acceleration-ordered response.

(C) 11. For those configurations with high adverse yaw and poor roll response or acceleration-ordered roll responses, the characteristics of the rudder were often objected to when used for coordination. These problems were usually associated with a very effective or acceleration-ordered roll response of the rudder which made coordination of ailerons and rudder difficult. In some cases (Configurations BB-2 and BB-8), the pilot found it better to roll primarily with the rudder and use a slight amount of aileron for coordination.

(C) 12. The most acceptable configurations to both the CAL and Martin pilots based on pilot comments and pilot ratings are shown below with the feedback and cross-feed gains.

CONF.	$K_{\dot{\theta}}$	$K_{\dot{\phi}}$	$K_{\dot{\psi}}$	K_{RA}	Pilot Ratings CAL	MAR	Remarks
RG-3	.3	.3	.75	.4	A2.0	A1.5	————
BA-9	.2	.4	.7	.45	A3.5	A3.0	Simulated δ_{AS} adverse. Yaw too high.
BO-7	.6	.78	1.0	.065	A2.0	A5.0	Martin pilot rating based on high F_{ES}/n_z.
BB-3	.2	.3	.75	.4	A5.0	A5.0	Objectionable adverse yaw. Coordination difficult.
LA-3	.4	.3	.4	.35	A2.0	A3.0	Primary objection is slightly abrupt initial roll response.

REFERENCES

1. Harper, Robert P. and Cooper, George E.: A Revised Pilot Rating Scale for the Evaluation of Handling Qualities, CAL Report No. 153, September 1966.

2. SV-5P (Pilot) - Preliminary Trim Aerodynamics - (Aero. - Aual (AA-1) - First Revision (title unclassified) June 1, 1966 - Confidential Unpublished Data (from Martin-Baltimore).

3. Bihrle, William, Jr.: A Handling Qualities Theory for Precise Flight Path Control, AFFDL-TR-65-198, June 1966.

4. DiFranco, Dante A.: Flight Investigation of Longitudinal Short-Period Frequency Requirements and PIO Tendencies, CAL Report No. TC-2083-F-1, April 1967.

5. Dolbin, B.: Computation of Gains for Matching Lateral-Directional Characteristics with a Variable Stability Airplane, (CAL Report, to be published).

6. Draper, Charles Stark; McKay, Walter; Lees, Sidney: Instrument Engineering - Vol. II, McGraw-Hill Book Company, 1953.

7. Unpublished transcripts of Pilot Comments on SV-5P Simulation in Variable Stability T-33 Airplane.

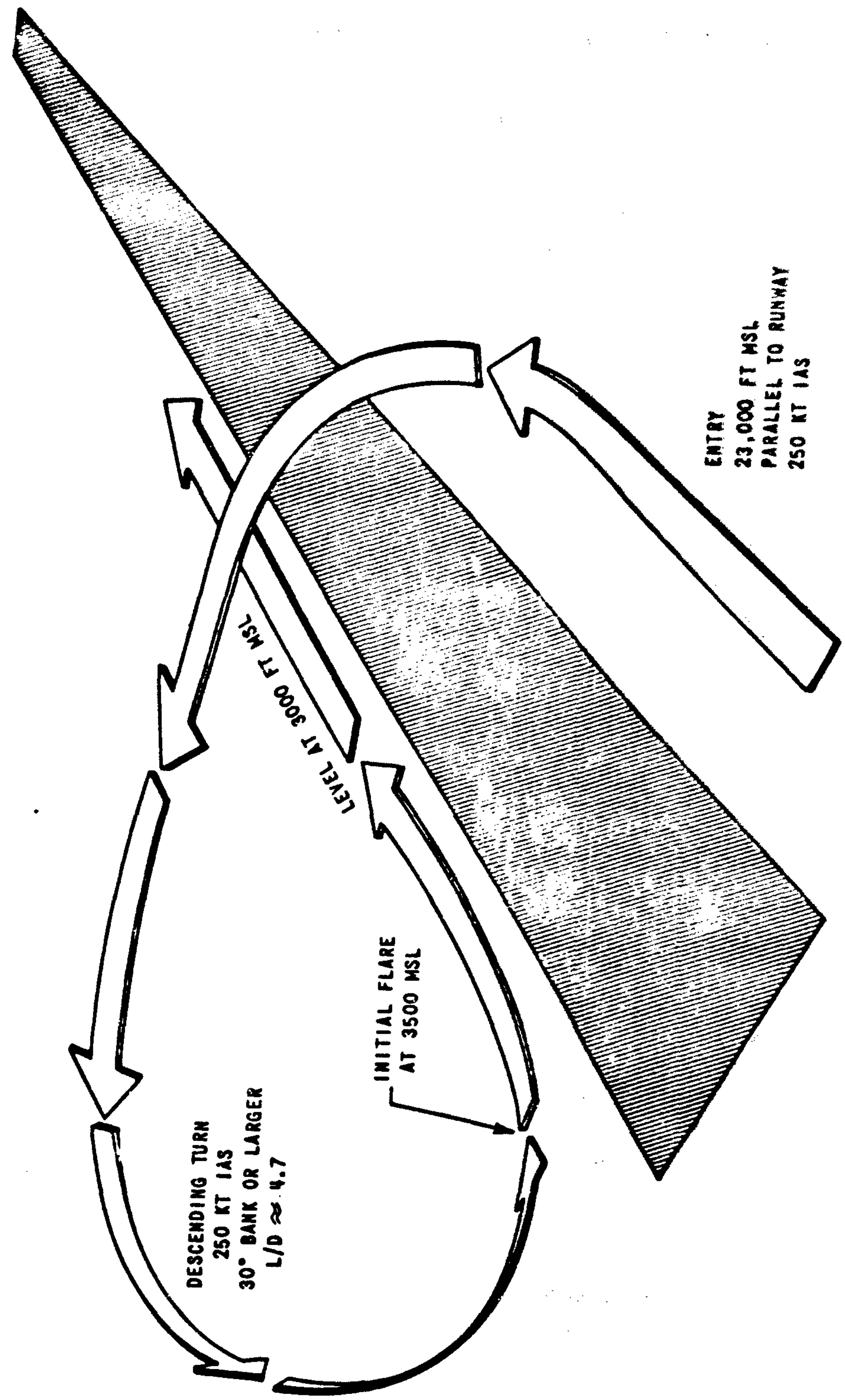


Figure 1 SIMULATED SPIRAL DESCENT

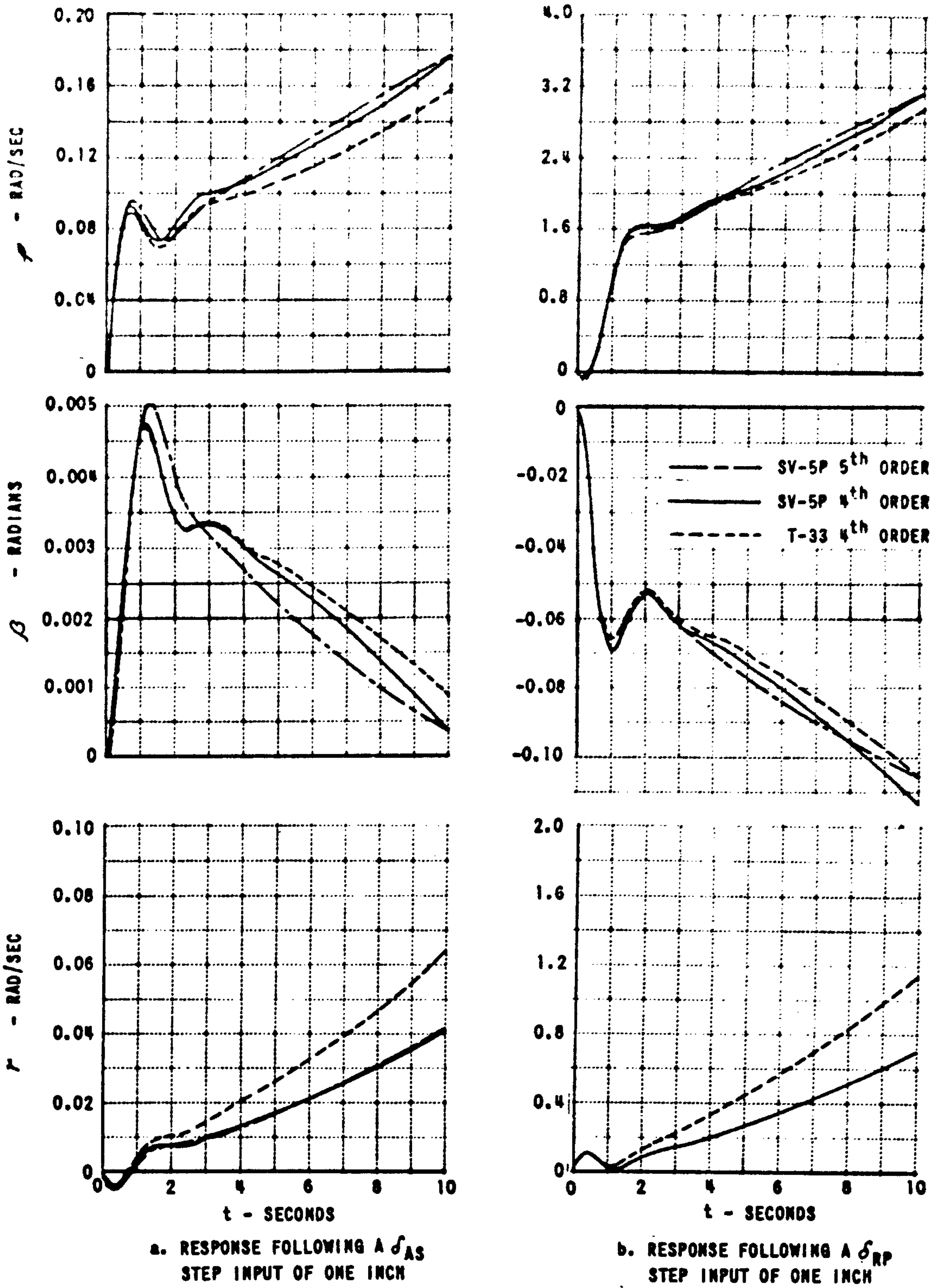


Figure 2 COMPARISON OF DIGITAL COMPUTER RESPONSES DURING VARIOUS STEPS IN THE LATERAL-DIRECTIONAL SIMULATION OF THE SV-5P (CONFIGURATION RG-1)

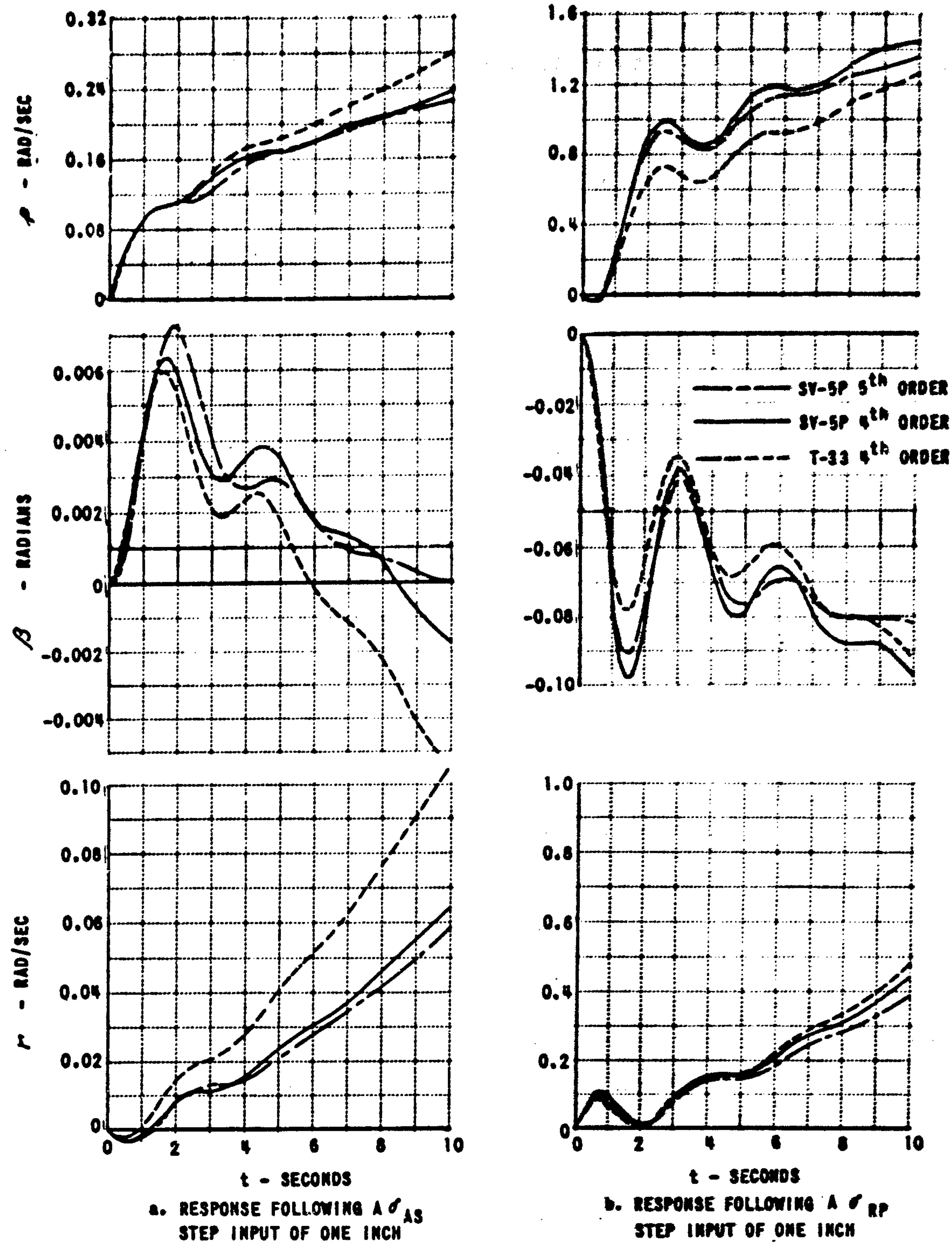


Figure 3 COMPARISON OF DIGITAL COMPUTER RESPONSES DURING VARIOUS STEPS IN THE LATERAL-DIRECTIONAL SIMULATION OF THE SV-5P (CONFIGURATION BA-1)

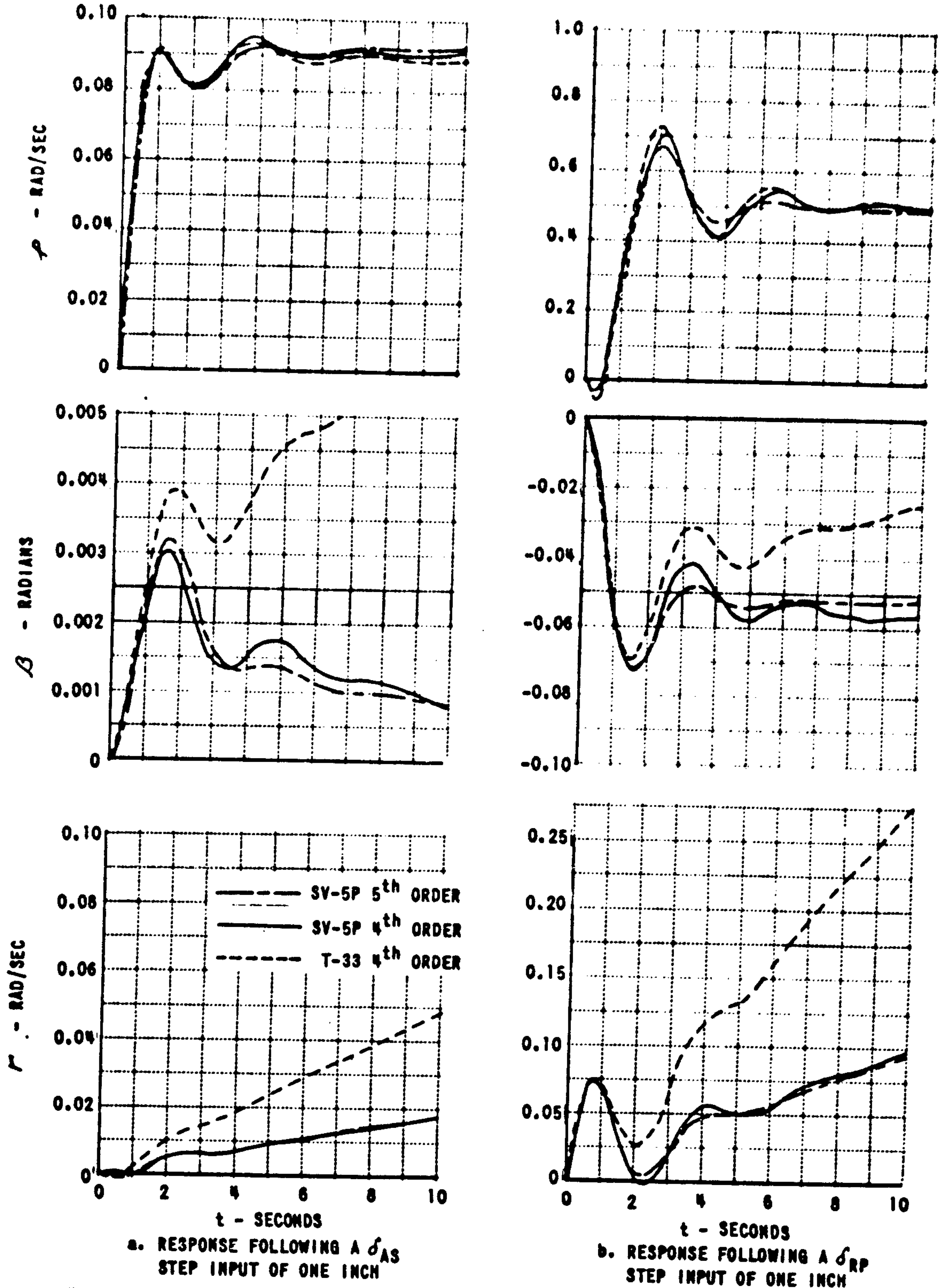
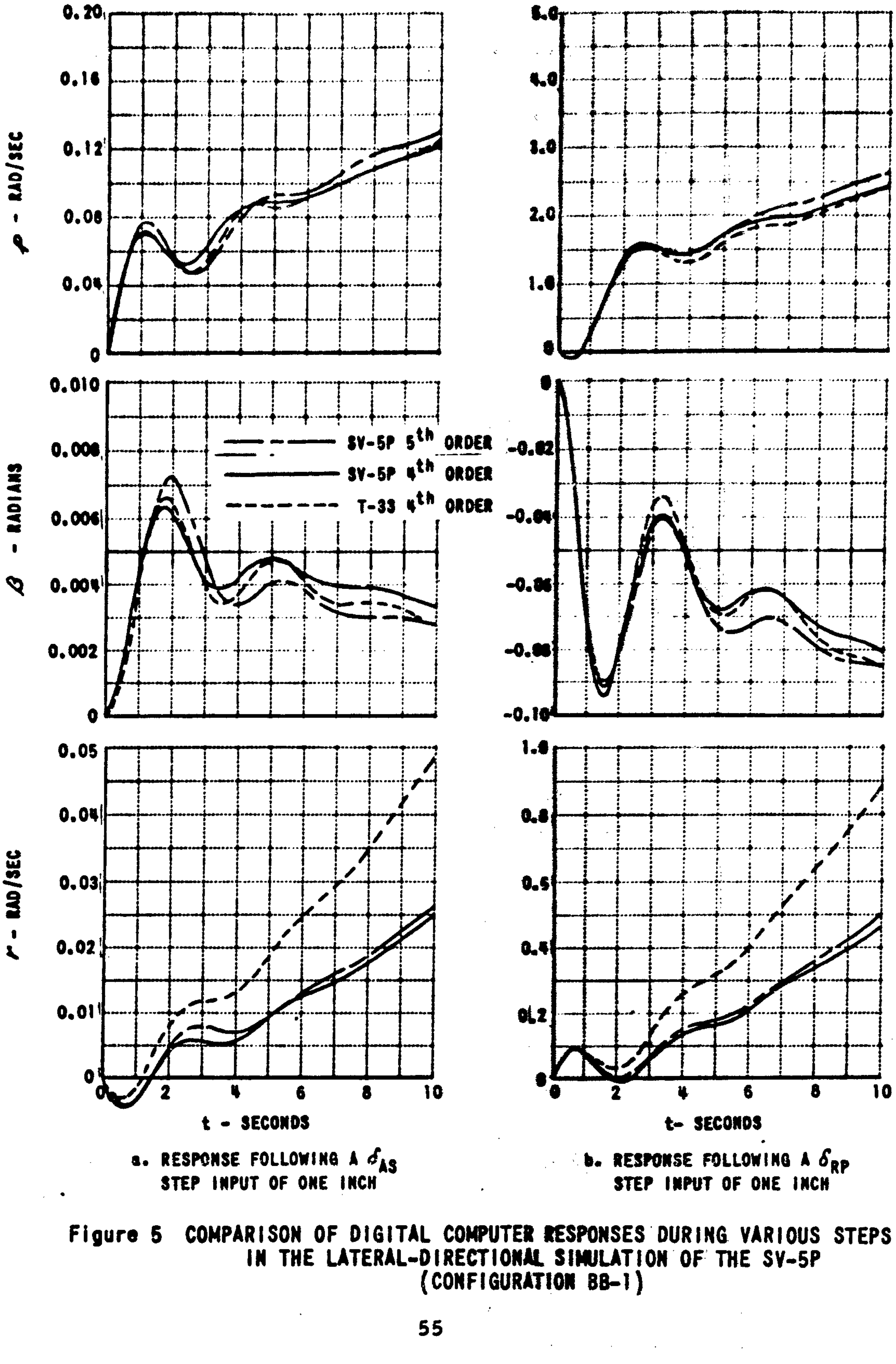


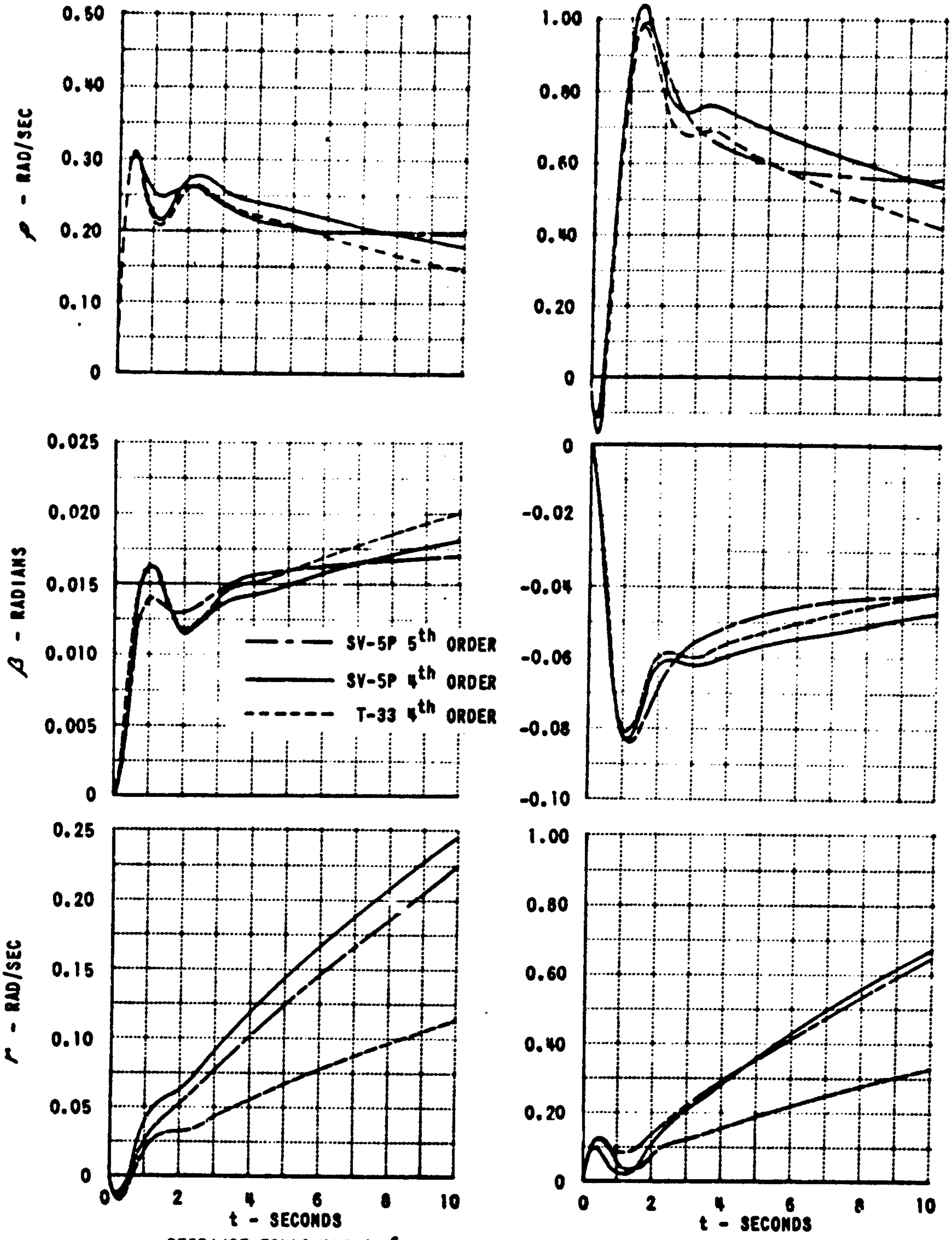
Figure 4 COMPARISON OF DIGITAL COMPUTER RESPONSES DURING VARIOUS STEPS IN THE LATERAL-DIRECTIONAL SIMULATION OF THE SV-5P (CONFIGURATION BO-1)



a. RESPONSE FOLLOWING A δ_{AS} STEP INPUT OF ONE INCH

b. RESPONSE FOLLOWING A δ_{RP} STEP INPUT OF ONE INCH

Figure 5 COMPARISON OF DIGITAL COMPUTER RESPONSES DURING VARIOUS STEPS IN THE LATERAL-DIRECTIONAL SIMULATION OF THE SV-5P (CONFIGURATION BB-1)



a. RESPONSE FOLLOWING A δ_{AS} STEP INPUT OF ONE INCH

b. RESPONSE FOLLOWING A δ_{RP} STEP INPUT OF ONE INCH

Figure 6 COMPARISON OF DIGITAL COMPUTER RESPONSES DURING VARIOUS STEPS IN THE LATERAL-DIRECTIONAL SIMULATION OF THE SV-5P (CONFIGURATION LA-1)

FLIGHT CONDITION		RE-ENTRY GLIDE (RG)	BOOST A (BA) AND BOOST B (BB)	BURNOUT (BO)	LANDING APPROACH (LA)
MISSION DESCRIPTION		RE-ENTRY GLIDE AT ALTITUDE (γ = -18°, R/C = -20,000 FT/MIN) - CORRECT FOR SMALL DISTURBANCES ABOUT TRIM - TURNING FLIGHT - MAKE HEADING CHANGES AND MAINTAIN HEADING.	BOOSTED, ACCELERATED FLIGHT (γ = 40°, R/C = 30,000 FT/MIN) - CORRECT FOR SMALL DISTURBANCES ABOUT TRIM - MAINTAIN CONSTANT HEADING - FOLLOW A PROGRAMMED ANGLE OF ATTACK.	HIGH ALTITUDE LEVEL FLIGHT AFTER BURNOUT (γ = 8°) - CORRECT FOR SMALL DISTURBANCES ABOUT TRIM - MAKE SMALL PITCH CORRECTIONS MAINTAIN HEADING AND MAKE HEADING CHANGES.	LANDING APPROACH (γ = -1°, L/D = 4.70) - SPIRAL DESCENT, ROLL-OUT, FLARE AND LAND - MAINTAIN HEADING - MAINTAIN WINGS LEVEL.
TASKS	1	STRAIGHT AND LEVEL FLIGHT INCLUDING SMALL DISTURBANCES - SMALL PULL-UPS AND PUSH-OVERS - PRECISE CHANGES IN ATTITUDE WHILE MAINTAINING HEADING.	STRAIGHT AND LEVEL FLIGHT INCLUDING SMALL DISTURBANCES - SMALL PULL-UPS AND PUSH-OVERS - PRECISE CHANGES IN ATTITUDE WHILE MAINTAINING HEADING.	STRAIGHT AND LEVEL FLIGHT INCLUDING SMALL DISTURBANCES - SMALL PULL-UPS AND PUSH-OVERS - PRECISE CHANGES IN ATTITUDE WHILE MAINTAINING HEADING.	STRAIGHT AND LEVEL FLIGHT INCLUDING SMALL DISTURBANCES - SMALL PULL-UPS AND PUSH-OVERS - PRECISE CHANGES IN ATTITUDE WHILE MAINTAINING HEADING.
	2	TURNING FLIGHT - SHALLOW LEVEL FLIGHT TURNS (ϕ = 30° OR LESS).	TURNING FLIGHT - SHALLOW LEVEL FLIGHT TURNS CONSISTENT WITH MANEUVER LIMITATIONS (ϕ = 30° OR LESS).	TURNING FLIGHT - SHALLOW BANKED LEVEL FLIGHT TURNS CONSISTENT WITH MANEUVER LIMITATIONS (ϕ = 30° OR LESS)	TURNING FLIGHT - SHALLOW LEVEL FLIGHT TURNS (ϕ = 30° OR LESS).
	3	TURNING FLIGHT - STEEP BANKED LEVEL FLIGHT TURNS CONSISTENT WITH MANEUVER LIMITATIONS (ϕ = 60° OR GREATER).	PRECISE 30° AND 60° BANKED TURNS MAINTAINING CONSTANT ANGLE OF ATTACK (ALTITUDE VARIES) - ROLL REVERSALS TO -30° AND -60° BANK - ROLL TO WINGS LEVEL - TURNS INVOLVING HEADING CHANGES OF 90°.	PRECISE 30° AND 60° BANKED TURNS MAINTAINING CONSTANT ANGLE OF ATTACK (ALTITUDE VARIES) - ROLL REVERSALS TO -30° AND -60° BANK - ROLL TO WINGS LEVEL - TURNS INVOLVING HEADING CHANGES OF 90°.	TURNING FLIGHT - STEEP BANKED LEVEL FLIGHT TURNS (ϕ = 60° OR GREATER).
	4	PRECISE 30° AND 60° BANKED TURNS MAINTAINING CONSTANT ANGLE OF ATTACK (ALTITUDE VARIES) - ROLL REVERSALS TO -30° AND -60° BANK - ROLL TO WINGS LEVEL - TURNS INVOLVING HEADING CHANGES OF 90°.	TRACKING PERFORMANCE - PRECISE TRACKING OF PITCH ANGLE TRACKING TASK.	EVALUATE PERFORMANCE WITH RANDOM NOISE INPUTS ABOUT ALL THREE AXES.	PRECISE 30° AND 60° BANKED TURNS MAINTAINING CONSTANT ANGLE OF ATTACK (ALTITUDE VARIES) - ROLL REVERSALS TO -30° AND -60° BANK - ROLL TO WINGS LEVEL - TURNS INVOLVING HEADING CHANGES OF 90°.
	5	EVALUATE PERFORMANCE WITH RANDOM NOISE INPUTS ABOUT ALL THREE AXES.	EVALUATE PERFORMANCE WITH RANDOM NOISE INPUTS ABOUT ALL THREE AXES.		SPIRAL DESCENT - PERFORM 360° SPIRAL DESCENT FROM 23,000 FT STARTING 90° TO THE RUNWAY WITH PETALS EXTENDED - ROLL OUT AND FLARE ON FINAL AT APPROXIMATELY 3000 FT ABOVE RUNWAY
	6				EVALUATE PERFORMANCE AT ALTITUDE (23,000 FT) WITH RANDOM NOISE INPUTS ABOUT ALL THREE AXES. EVALUATE DESCENT IN NATURAL TURBULENCE.

Figure 7 MISSION AND TASKS APPROPRIATE TO VARIOUS FLIGHT CONDITIONS

LONGITUDINAL CONTROL

1. ARE THERE ANY TRIM DIFFICULTIES?
2. IS PITCH RESPONSE TO ELEVATOR STICK SATISFACTORY?
3. HOW IS ATTITUDE CONTROL? NORMAL ACCELERATION CONTROL?
4. COMMENT ON THE STICK FORCES, STICK GRADIENTS, FEEL CHARACTERISTICS.
5. COMMENT ON PITCH ANGLE TRACKING PERFORMANCE.
6. EFFECTS OF RANDOM NOISE ON PITCH CONTROL.
7. ARE THERE ANY SPECIAL LONGITUDINAL PROBLEMS?

LATERAL-DIRECTIONAL CONTROL

1. IS THE ROLL RESPONSE TO AILERON STICK SATISFACTORY?
2. IS PRECISE BANK ANGLE CONTROL POSSIBLE?
3. COMMENT ON STICK FORCES, STICK GRADIENTS, FEEL CHARACTERISTICS.
4. IS RESPONSE TO RUDDER PEDALS SATISFACTORY?
5. COMMENT ON RUDDER PEDAL FORCES, GRADIENTS, FEEL CHARACTERISTICS.
6. HOW IS RUDDER COORDINATION IN TURNS? INITIAL? STEADY-STATE?
7. IS IT EASY TO MAKE HEADING CHANGES? HOLD HEADING?
8. EFFECTS OF RANDOM NOISE ON LATERAL-DIRECTIONAL CONTROL.

CONTROL DURING LANDING APPROACH

1. IS ROLL CONTROL ADEQUATE?
2. IS RUDDER CONTROL AND RUDDER COORDINATION SATISFACTORY?
3. COMMENT ON CONTROL PRECISION.
4. WHAT ARE EFFECTS OF NATURAL TURBULENCE?
5. DESCRIBE CONTROL DURING FLARE - EASY? DIFFICULT?

OVERALL EVALUATION

1. COMMENT ON CONTROL HARMONY.
2. WHAT ARE THE BAD FEATURES?
3. WHAT ARE THE GOOD FEATURES?
4. ARE THERE ANY SPECIAL PILOTING TECHNIQUES REQUIRED?
5. PILOT RATING BASED ON MISSION - ADJECTIVE - NUMBER.
6. PRIMARY REASON FOR RATING.

Figure 8 PILOT COMMENT CARD

CONTROLLABLE CAPABLE OF BEING CONTROLLED OR MANAGED IN CONTEXT OF MISSION, WITH AVAILABLE PILOT ATTENTION	**ACCEPTABLE** MAY HAVE DEFICIENCIES WHICH WARRANT IMPROVEMENT, BUT ADEQUATE FOR MISSION. PILOT COMPENSATION, IF REQUIRED TO ACHIEVE ACCEPTABLE PERFORMANCE, IS FEASIBLE.	**SATISFACTORY** MEETS ALL REQUIREMENTS AND EXPECTATIONS, GOOD ENOUGH WITHOUT IMPROVEMENT. CLEARLY ADEQUATE FOR MISSION.	EXCELLENT, HIGHLY DESIRABLE	A1
			GOOD, PLEASANT, WELL BEHAVED	A2
			FAIR. SOME MILDLY UNPLEASANT CHARACTERISTICS. GOOD ENOUGH FOR MISSION WITHOUT IMPROVEMENT.	A3
		UNSATISFACTORY RELUCTANTLY ACCEPTABLE. DEFICIENCIES WHICH WARRANT IMPROVEMENT. PERFORMANCE ADEQUATE FOR MISSION WITH FEASIBLE PILOT COMPENSATION.	SOME MINOR BUT ANNOYING DEFICIENCIES. IMPROVEMENT IS REQUESTED. EFFECT ON PERFORMANCE IS EASILY COMPENSATED FOR BY PILOT.	A4
			MODERATELY OBJECTIONABLE DEFICIENCIES. IMPROVEMENT IS NEEDED. REASONABLE PERFORMANCE REQUIRES CONSIDERABLE PILOT COMPENSATION.	A5
			VERY OBJECTIONABLE DEFICIENCIES. MAJOR IMPROVEMENTS ARE NEEDED. REQUIRES BEST AVAILABLE PILOT COMPENSATION TO ACHIEVE ACCEPTABLE PERFORMANCE.	A6
	UNACCEPTABLE DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT. INADEQUATE PERFORMANCE FOR MISSION EVEN WITH MAXIMUM FEASIBLE PILOT COMPENSATION.		MAJOR DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT FOR ACCEPTANCE. CONTROLLABLE. PERFORMANCE INADEQUATE FOR MISSION, OR PILOT COMPENSATION REQUIRED FOR MINIMUM ACCEPTABLE PERFORMANCE IN MISSION IS TOO HIGH.	U7
			CONTROLLABLE WITH DIFFICULTY. REQUIRES SUBSTANTIAL PILOT SKILL AND ATTENTION TO RETAIN CONTROL AND CONTINUE MISSION.	U8
			MARGINALLY CONTROLLABLE IN MISSION. REQUIRES MAXIMUM AVAILABLE PILOT SKILL AND ATTENTION TO RETAIN CONTROL.	U9
UNCONTROLLABLE CONTROL WILL BE LOST DURING SOME PORTION OF MISSION.			UNCONTROLLABLE IN MISSION.	10

Figure 9 REVISED PILOT RATING SCALE

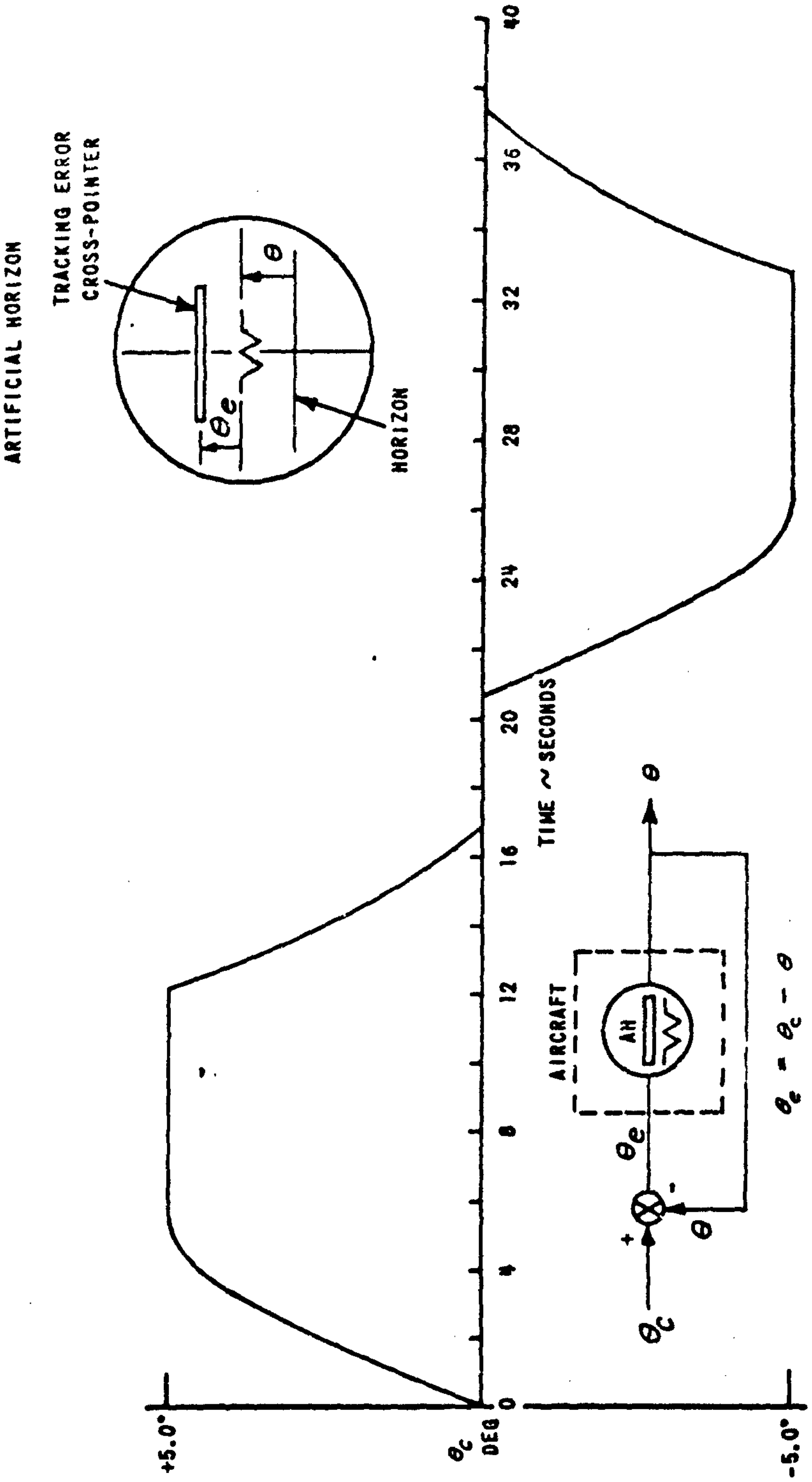


Figure 10 PITCH ANGLE TRACKING TASK COMMAND SIGNAL (ONE CYCLE)

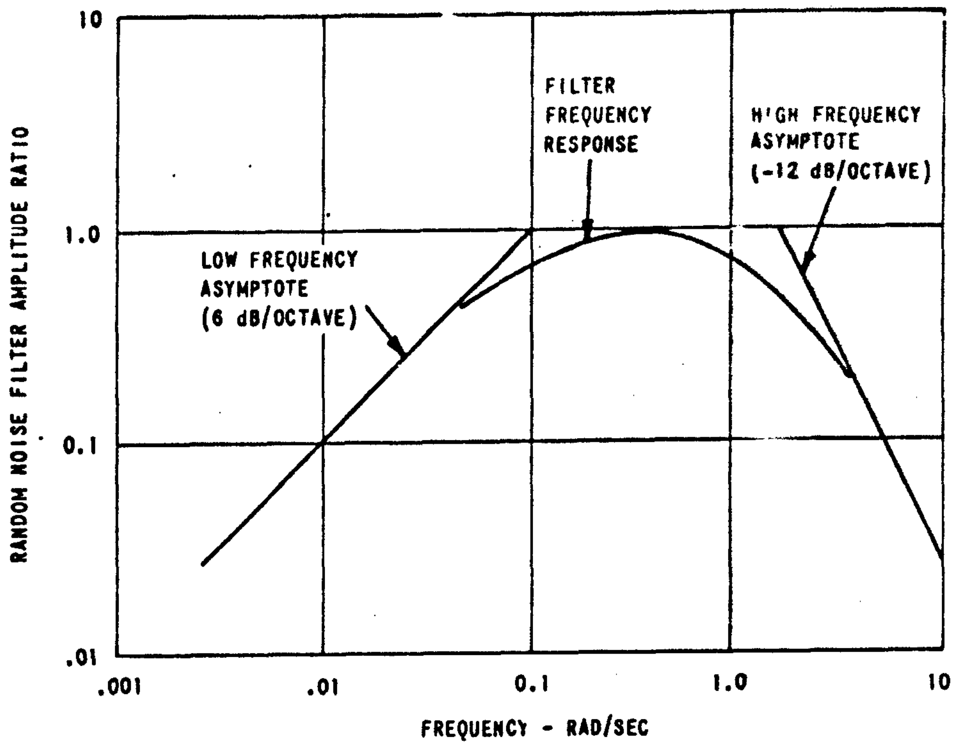


Figure 11 RANDOM NOISE FILTER FREQUENCY RESPONSE

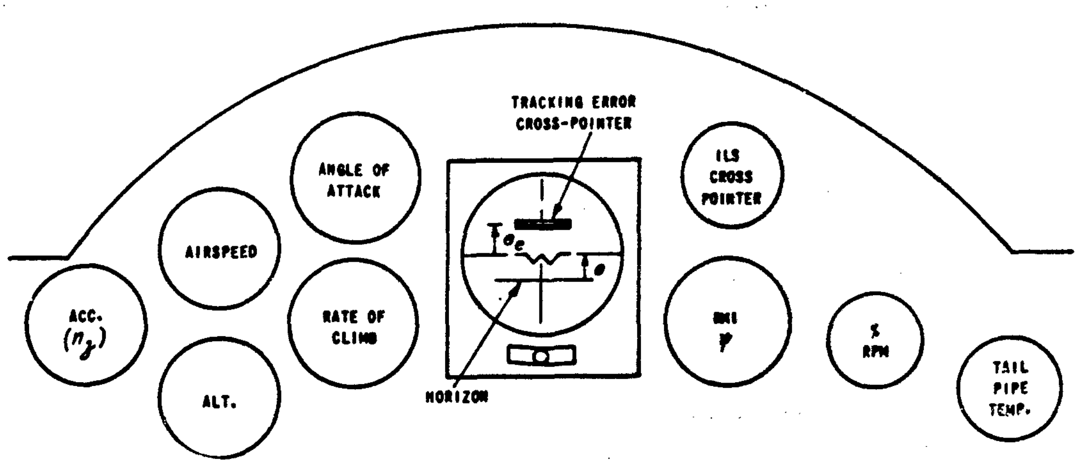


Figure 12 T-33 PANEL ARRANGEMENT WITH TRACKING TASK DISPLAY

LONGITUDINAL RECORDS

1. AUTO δ_e DOUBLETS AND STEPS TO MEASURE ω_{sp}, ζ_{sp}, n_z/α.
2. MANUAL STEPS OF VARIOUS MAGNITUDES TO MEASURE F_{ES}/n_z, F_{ES}/δ_{ES}
3. RECORD OF TRACKING TASK (CONFIGURATIONS 8A AND 8B).

LATERAL-DIRECTIONAL RECORDS

1. AUTO δ_r DOUBLET TO MEASURE ω_d, ζ_d AND $|\phi/\beta|_d$.
2. AUTO δ_a AND δ_r STEPS TO SIMULATE δ_{AS}.
3. AUTO δ_r AND δ_a STEPS TO SIMULATE δ_{RP}.
4. MANUAL δ_{AS} STEPS.
5. MANUAL δ_{RP} STEPS.

Figure 13 CONTROL INPUTS USED FOR FLIGHT RECORDS

Table I

BASIC FLIGHT CONDITIONS OF
SV-5P TO BE SIMULATED

FLIGHT CONDITION	DESCRIPTION	MACH NO.	α_o DEG	θ_o DEG	γ_o DEG	q_o LB/FT^2	$K_{\dot\theta}$	$K_{\dot\phi}$	$K_{\dot\psi}$	K_{RA}
RG	RE-ENTRY GLIDE	0.95	12	-6.5	-18.5	90	0.3	0.3	0.75	0.325
BA	BOOST A	0.80	18	55.5	37.2	40	0.2	0.3	0.6	0.375
BO	BURNOUT	1.76	6	14.8	8.8	60	0.6	0.58	0.8	0.065
BB	BOOST B	0.95	12	51.3	39.3	40	0.2	0.3	0.75	0.325
LA	LANDING APPROACH	0.28	9	8.0	-1.0	115	0.4	0.2	0.4	0.175

WHERE:

α_o = INITIAL ANGLE OF ATTACK

θ_o = INITIAL PITCH ANGLE

γ_o = INITIAL FLIGHT PATH ANGLE

q_o = DYNAMIC PRESSURE

$K_{\dot\theta}$ = PITCH DAMPING FEEDBACK AUGMENTATION GAIN

$K_{\dot\phi}$ = ROLL DAMPING FEEDBACK AUGMENTATION GAIN

$K_{\dot\psi}$ = YAW DAMPING FEEDBACK AUGMENTATION GAIN

K_{RA} = CROSSFEED GAIN = δ_r / δ_a (PILOT)

Table II

CONFIGURATIONS AND LATERAL-DIRECTIONAL GAIN SETTINGS OF SV-5P

CONF.	$K_{\dot{\phi}}$	$K_{\dot{\psi}}$	K_{re}
RG-1*	0.3	0.75	0.325
-2	↓	↓	0.25
-3	↓	↓	0.4
-4	0.2	0.65	0.325
-5	↓	↓	0.25
-6	↓	↓	0.4
-7	0.4	0.85	0.325
-8	↓	↓	0.25
-9	↓	↓	0.4
BA-1*	0.3	0.6	0.375
-2	↓	↓	0.3
-3	↓	↓	0.45
-4	0.2	0.5	0.375
-5	↓	↓	0.3
-6	↓	↓	0.45
-7	0.4	0.7	0.375
-8	↓	↓	0.3
-9	↓	↓	0.45
BO-1*	0.58	0.8	0.065
-2	↓	↓	0
-3	↓	↓	0.13

CONF.	$K_{\dot{\phi}}$	$K_{\dot{\psi}}$	K_{re}
BO-4	0.38	0.6	0.065
-5	↓	↓	0
-6	↓	↓	0.13
-7	0.78	1.0	0.065
-8	↓	↓	0
-9	↓	↓	0.13
BB-1*	0.3	0.75	0.325
-2	↓	↓	0.25
-3	↓	↓	0.4
-4	0.2	0.65	0.325
-5	↓	↓	0.25
-6	↓	↓	0.4
-7	0.4	0.85	0.325
-8	↓	↓	0.25
-9	↓	↓	0.4
LA-1*	0.3	0.4	0.175
-2	↓	↓	0
-3	↓	↓	0.35
-4	0.2	0.3	0.175
-5	↓	↓	0
-6	↓	↓	0.35
-7	0.4	0.5	0.175
-8	↓	↓	0
-9	↓	↓	0.35

CONFIGURATION DESIGNATIONS

RG = RE-ENTRY GLIDE
BA = BOOST A
BO = BURNOUT
BB = BOOST B
LA = LANDING APPROACH

* INDICATES BASIC OR NOMINAL CONFIGURATIONS

Table III

STATIC CONTROL SYSTEM
CHARACTERISTICS OF SV-5P

FLIGHT CONDITION	F_{ES}/δ_{ES} LB/IN.	δ_e/δ_{ES} DEG /IN.	F_{AS}/δ_{AS} LB/IN.	δ_a/δ_{AS} DEG /IN.	F_{RP}/δ_{RP} LB/IN.	δ_r/δ_{RP} DEG /IN.
RG	4.5	-2.5	2	-3.3	28	-6.0
BA				-4.1		
BO				-3.3		
BB				-3.3		
LA		-5.0		-6.6		

Table IV

COMPARISON OF FEEL SYSTEM CHARACTERISTICS
OF SV-5P AND VARIABLE STABILITY T-33

CONTROL	THROW (IN.)		BREAKOUT FORCE (LB)		FORCE GRADIENT (LB/IN.)		FREQUENCY (ω) (CPS)		DAMPING RATIO (ζ)	
	SV-5P	T-33	SV-5P	T-33	SV-5P	T-33	SV-5P	T-33	SV-5P	T-33
ELEVATOR STICK	±6	±6	SMALL	SMALL	4.5	4.5	6 TO 8	~ 2.5	~ .2	APPROX. CRITICAL
AILERON STICK	±6	±6	SMALL	SMALL	2.0	2.0	5.5 TO 7	~ 2.0	~ .3	APPROX. CRITICAL
RUDDER PEDAL	±2.5	±2.5	±8	SMALL	28	28* AND 34	5 TO 8	~ 3.0	~ .2	APPROX. CRITICAL

* 28 LB /IN. USED FOR FIRST THREE EVALUATION FLIGHTS IN T-33 (FLIGHTS 759, 760, AND 761)
34 LB /IN. USED IN REMAINING T-33 EVALUATION FLIGHTS IN LIEU OF THE
SIMULATION OF ±8 LB BREAKOUT FORCE OF SV-5P RUDDER PEDALS

Table X
LONGITUDINAL SHORT PERIOD
INITIAL AND FINAL VALUES AFTER A STEP
ELEVATOR INPUT (δ_e)

	NO WASHOUT FILTER	WITH WASHOUT FILTER
$\dot{\alpha}_o$	$Z_{\delta_e} (\cos \alpha_o)\, \delta_e$	$Z_{\delta_e} (\cos \alpha_o)\, \delta_e$
$\ddot{\theta}_o$	$M_{\delta_e}\, \delta_e$	$M_{\delta_e}\, \delta_e$
n_{z_o}	$-\frac{V_o}{g} Z_{\delta_e} (\cos \alpha_o)\, \delta_e$	$-\frac{V_o}{g} Z_{\delta_e} (\cos \alpha_o)\, \delta_e$
α_{ss}	$\frac{M_{\delta_e} \cos \alpha_o}{Z_\alpha M_{\dot{\theta}} - M_\alpha \cos \alpha_o}\, \delta_e$	$-\frac{M_{\delta_e}}{M_\alpha}\, \delta_e$
$\dot{\theta}_{ss}$	$\frac{Z_{\delta_e} M_\alpha - Z_\alpha M_{\delta_e}}{Z_\alpha M_{\dot{\theta}} - M_\alpha \cos \alpha_o}\, \delta_e$	$\frac{(Z_\alpha M_{\delta_e} - M_\alpha Z_{\delta_e} \sec \alpha_o}{M_\alpha}\, \delta_e$
$n_{z_{ss}}$	$\frac{-\frac{V_o}{g}(Z_\alpha M_{\delta_e} - Z_{\delta_e} M_\alpha)}{Z_\alpha M_{\dot{\theta}} - M_\alpha \cos \alpha_o}\, \delta_e$	$\frac{\frac{V_o}{g}(Z_\alpha M_{\delta_e} - M_\alpha Z_{\delta_e}) \sec \alpha_o}{M_\alpha}\, \delta_e$

Table VI
LATERAL-DIRECTIONAL INITIAL AND FINAL VALUES AFTER A STEP AILERON INPUT (δ_a)

	NO WASHOUT FILTER	WITH WASHOUT FILTER
$\dot{\beta}_o$	$Y_{\delta_{a(a)}} \delta_a$	$Y_{\delta_{a(a)}} \delta_a$
$\ddot{\psi}_o$	$N'_{\delta_{a(a)}} \delta_a$	$N'_{\delta_{a(a)}} \delta_a$
$\ddot{\phi}_o$	$L'_{\delta_{a(a)}} \delta_a$	$L'_{\delta_{a(a)}} \delta_a$
β_{ss}	$\dfrac{\left[\left(N'_{\delta_{a(a)}} L'_r - N'_r L'_{\delta_{a(a)}}\right) + \left(N'_p L'_{\delta_{a(a)}} - N'_{\delta_{a(a)}} L'_p\right) \tan\theta_o\right] \delta_a}{-\left(N'_\beta L'_r - N'_r L'_\beta\right) + \left(N'_\beta L'_p - N'_p L'_\beta\right) \tan\theta_o}$	$\dfrac{\left(N_p L_{\delta_{a(a)}} - N_{\delta_{a(a)}} L'_p\right) \delta_a}{\left(N'_\beta L'_p - N'_p L'_\beta\right)}$
$\dot{\psi}_{ss}$	$\dfrac{-\left(N'_\beta L'_{\delta_{a(a)}} - N'_{\delta_{a(a)}} L'_\beta\right) \delta_a}{+\left(N'_\beta L'_r - N'_r L'_\beta\right) - \left(N'_\beta L'_p - N'_p L'_\beta\right) \tan\theta_o}$	$\dfrac{\left(N'_\beta L'_{\delta_{a(a)}} - N'_{\delta_{a(a)}} L'_\beta\right) \delta_a}{\left(N'_\beta L'_p - N'_p L'_\beta\right) \tan\theta_o}$
$\dot{\phi}_{ss}$	$\dfrac{-\left(N'_{\delta_{a(a)}} L'_\beta - N'_\beta L'_{\delta_{a(a)}}\right)(\tan\theta_o) \delta_a}{-\left(N'_\beta L'_r - N'_r L'_\beta\right) + \left(N'_\beta L'_p - N'_p L'_\beta\right) \tan\theta_o}$	$\dfrac{\left(N'_{\delta_{a(a)}} L'_\beta - L'_{\delta_{a(a)}} N'_\beta\right) \delta_a}{\left(N'_\beta L'_p - N'_p L'_\beta\right)}$

Table VII

SHORT PERIOD LONGITUDINAL CHARACTERISTICS OF SV-5P

FLIGHT CONDITION	DESCRIPTION	ω_{SP} RAD/SEC	ζ_{SP}	n_z/α g/RAD	$\omega_{SP}^2/(n_z/\alpha)$ (CAP)	F_{ES}/δ_{ES} LB/IN.	δ_e/δ_{ES} DEG/IN.	F_{ES}/n_z LB/g
RG	RE-ENTRY GLIDE	2.3	0.6	5.2	1.02	4.5	-2.5	11
BA	BOOST A	1.6	0.4	1.2	2.13	4.5	-2.5	33
BO	BURNOUT	2.3	0.3	2.8	1.89	4.5	-2.5	85
BB	BOOST B	1.6	0.4	1.8	1.42	4.5	-2.5	31
LA	LANDING APPROACH	3.0	0.8	6.0	1.50	4.5	-5.0	9

Table VIII

SHORT PERIOD LONGITUDINAL CHARACTERISTICS OF T-33 SIMULATING SV-5P

FLIGHT CONDITION	DESCRIPTION	CAP $\omega_{SP}^2/(n_z/\alpha)$	n_z/α g/RAD	ω_{SP} RAD/SEC	ζ_{SP}	F_{ES}/n_z LB/g	F_{ES}/δ_{ES} LB/IN.
RG	RE-ENTRY GLIDE	1.02	21.7	4.71	0.6	11	4.5
BA	BOOST A	2.13	21.7	6.64	0.4	33	4.5
BO	BURNOUT	1.89	21.7	6.40	0.3	85	4.5
BB	BOOST B	1.42	21.7	5.55	0.4	31	4.5
LA	LANDING APPROACH	1.50	21.7	5.70	0.8	9	4.5

Table IX

FOURTH-ORDER MODE CHARACTERISTICS
OF VARIABLE STABILITY T-33 SIMULATING
SV-5P CONFIGURATIONS

SV-5P CONF.	ω_d RAD/SEC	ζ_d	τ_R SEC	τ_S SEC	$\left\|\frac{\phi}{\beta}\right\|_d$	ω_ϕ RAD/SEC	ζ_ϕ	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	CONF. WITH SIMILAR DENOMINATOR CHARACTERISTICS*
RG-1	3.05	0.392	0.636	-13.3	5.69	1.92	0.603	0.396	RG-2 RG-3
RG-4	3.12	0.247	0.596	-16.9	5.52	1.96	0.561	0.398	RG-5 RG-6
RG-7	3.13	0.876	1.88	-10.7	4.10	1.07	0.121	0.117	RG-8 RG-9
BA-1	2.08	0.171	1.36	-12.6	2.97	1.75	0.249	0.712	BA-2 BA-3
BA-4	2.07	0.102	1.45	-14.4	3.05	1.76	0.212	0.722	BA-5 BA-6
BA-7	2.09	0.209	1.19	-16.6	2.93	1.74	0.277	0.694	BA-8 BA-9
BO-1	1.967	0.242	0.44	83.2	5.53	1.72	0.275	0.766	BO-2 BO-3
BO-4	2.007	0.153	0.63	-1673	6.25	1.75	0.205	0.76	BO-5 BO-6
BO-7	1.92	0.310	0.34	457.	4.78	1.70	0.332	0.783	BO-8 BO-9
BB-1	1.87	0.20	1.2	-12.8	5.87	1.17	0.434	0.395	BB-2 BB-3
BB-4	1.89	0.137	1.18	-15.6	5.77	1.20	0.382	0.394	BB-5 BB-6
BB-7	1.90	0.366	1.39	-10.1	5.85	1.14	0.487	0.36	BB-8 BB-9
LA-1	3.03	0.426	0.29	13.9	5.61	2.16	0.36	0.509	LA-2 LA-3
LA-4	3.46	0.305	0.41	14.8	5.76	2.26	0.34	0.426	LA-5 LA-6
LA-7	2.71	0.686	0.22	13.5	5.52	2.04	0.61	0.567	LA-8 LA-9

*MODE CHARACTERISTICS THE SAME FOR THESE CONFIGURATIONS EXCEPT FOR ω_ϕ, ζ_ϕ, AND $(\omega_\phi/\omega_d)^2$.

Table X
LONGITUDINAL SHORT PERIOD MODE CHARACTERISTICS SIMULATED FOR RE-ENTRY GLIDE (RG) CONFIGURATIONS

FLIGHT NO.	FUEL RE-MAINING	n_z/α g/RAD	ω_{SP} RAD/SEC	ζ_{SP}	F_{ES}/n_z LB/g	F_{ES}/δ_{ES} LB/IN.	$\frac{\omega_{SP}^2}{(n_z/\alpha)}$	$\frac{\omega_{SP}^2}{(n_z/\alpha)(F_{ES}/n_z)}$
		DESIRED VALUES						
		21.7	4.71	0.6	11.0	4.5	1.02	0.093
759	509	17.35	4.73	0.86	10.5	4.31	1.29	0.123
760	508	20.8	4.65	0.72	11.04	4.47	1.04	0.094
760	380	20.2	5.36	0.89	10.2	4.61	1.42	0.14
764	504	17.3	4.56	0.69	9.04	4.26	1.2	0.133
765	512	17.9	4.86	0.55	11.01	4.61	1.32	0.12
765	380	20.4	4.36	0.59	10.1	4.41	0.93	0.092
768	406	19.6	4.65	0.65	8.78	4.46	1.1	0.126
770	274	22.9	4.36	0.60	8.85	4.46	0.083	0.094
771	—	*	*	*	*	*	—	—
773	424	18.6	4.51	0.64	10.62	4.5	1.094	0.103
780	422	19.8	5.72	0.81	9.3	4.89	1.65	0.177
781	369	20.2	5.25	0.69	10.0	4.4	1.36	0.137
783	376	22.5	5.0	0.73	10.0	4.54	1.11	0.111
785	375	19.6	4.82	0.58	10.6	4.5	1.18	0.112
786	337	22.3	4.27	0.50	10.84	4.42	0.82	0.075
787	480	18.1	4.73	0.86	11.4	4.1	1.24	0.108
788	450	22.6	4.31	0.60	10.34	4.52	0.82	0.076
789	381	21.0	4.11	0.45	10.9	4.43	0.80	0.074
791	498	17.4	5.1	0.83	11.1	4.43	1.49	0.134
792	417	20.9	4.37	0.52	9.93	4.2	0.91	0.092
793	484	16.5	4.33	0.48	11.1	4.48	1.14	0.102
794	451	NO AUTO STEP	5.74	0.79	9.65	4.33	-	-
796	440	NO AUTO STEP	4.5	0.57	10.41	4.28	-	-
AVERAGE		19.8	4.74	0.633	10.28	4.437	1.1	0.111
STANDARD DEVIATION		1.95	0.457	0.133	0.772	0.162	0.332	0.026

*NO SUITABLE RECORDS

Table XI
LONGITUDINAL SHORT PERIOD MODE CHARACTERISTICS SIMULATED FOR BOOST A (BA) CONFIGURATIONS

FLIGHT NO.	FUEL RE-MAINING	n_z/α g/RAD	ω_{SP} RAD/SEC	ζ_{SP}	F_{ES}/n_z LB/g	F_{ES}/δ_{ES} LB/IN.	$\omega_{SP}^2/(n_z/\alpha)$	$\omega_{SP}^2/(n_z/\alpha)(F_{ES}/n_z)$
		DESIRED VALUES						
		21.7	6.64	0.4	33.0	4.5	2.13	0.0645
774	413	18.8	6.24	0.48	30.5	4.6	2.07	0.068
774	266	17.9	6.35	0.33	28.8	4.52	2.25	0.081
774	258	18.8	6.5	0.37	24.8	4.6	2.24	0.091
775	386	19.6	6.56	0.45	29.0	4.7	2.2[illegible]	0.076
775	246	21.2	5.99	0.34	29.7	4.26	1.7[illegible]	0.057
776	396	19.1	6.3	0.51	30.9	4.41	2.08	0.067
777	430	23.3	6.6	0.51	27.5	4.4	1.87	0.068
779	393	18.9	6.52	0.33	31.6	4.35	2.25	0.071
781	476	15.7 †	7.86	0.6†	33.1	4.35	3.94	0.119
782	360	20.0	6.43	0.37	27.8	4.34	2.06	0.074
785	466	21.2	6.86	0.4	32.0	4.42	2.22	0.069
786	191	22.0	7.06	0.46	30.2	4.34	2.26	0.075
788	332	19.8	6.4	0.38	28.7	4.36	2.07	0.072
790	268	27.0	6.22	0.4	29.6	4.33	1.43	0.048
791	373	21.6	6.3	0.30	33.0	4.33	1.84	0.056
792	330	23.1	5.5	0.62	20.9	*	1.31	0.063
795	383	NO AUTO STEP	6.0	0.43	33.2	4.59	-	-
797	454	NO AUTO STEP	6.05	0.45	30.0	4.38	-	-
AVERAGE		20.5	6.43	0.429	29.5	4.43	2.11	0.072
STANDARD DEVIATION		2.62	0.497	0.09	3.05	0.125	0.569	0.016

*NO SUITABLE RECORDS

†BAD TRACE - VALUE IS AN ESTIMATE USING SEVERAL METHODS

Table XII
LONGITUDINAL SHORT PERIOD MODE CHARACTERISTICS
SIMULATED FOR BURNOUT (BO)
CONFIGURATIONS

FLIGHT NO.	FUEL REMAINING	n_z/α g/RAD	ω_{SP} RAD/SEC	ζ_{SP}	F_{ES}/n_z LB/g	F_{ES}/δ_{ES} LB/IN.	$\frac{\omega_{SP}^2}{(n_z/\alpha)}$	$\frac{\omega_{SP}^2}{(n_z/\alpha)(F_{ES}/n_z)}$
		DESIRED VALUES						
		21.7	6.4	0.3	85.0	4.5	1.89	0.0222
759	334	21.5	5.96	0.29	83.2	4.35	1.65	0.02
761	530	15.6	6.34	0.275	85.0	4.33	2.58	0.030
761	412	17.0	6.95	0.42	101.0 †	4.3	2.84	0.028
762	354	20.8	6.17	0.26	92.0	4.61	1.83	0.02
763	508	18.7	6.1	0.21	96.5	4.42	1.99	0.021
767	528	18.0	6.04	0.25	68.4 †	4.55	2.03	0.03
768	268	21.6	6.17	0.28	80.0	4.34	1.76	0.022
770	442	20.8	6.4	0.28	87.6	4.71	1.4	0.016
770	260	22.8	6.46	0.25	73.5	4.38	1.83	0.025
771	—	*	*		*	*	—	—
772	250	17.6	6.15	0.28	84.8	4.39	2.15	0.025
777	320	22.0	6.21	0.27	77.0	4.5	1.75	0.023
778	422	16.1	6.26	0.27	82.5	4.36	2.44	0.03
779	498	17.6	5.98	0.24	116.5 ††	4.49	2.04	0.018
782	474	19.2	6.28	0.27	104.0	4.3	2.05	0.02
784	466	19.8	6.32	0.27	95.0	4.25	2.02	0.021
787	278	15.6	6.23	0.28	82.8 ††	4.15	2.49	0.030
788	241	18.3	6.3	0.25	81.6	4.75	2.17	0.027
789	291	20.8	6.23	0.28	78.5	4.37	1.87	0.024
790	484	21.6	6.58	0.25	86.7	4.37	2.01	0.023
792	500	16.1	6.04	0.27	75.6	4.42	2.27	0.03
794	315	NO AUTO STEP	6.6	0.3	86.4	4.84	-	-
796	325	NO AUTO STEP	6.53	0.275	77.2	4.42	-	-
AVERAGE		19.1	6.29	0.275	86.2	4.44	2.06	0.024
STANDARD DEVIATION		2.33	0.234	0.0386	11.1	0.167	0.341	0.0045

*NO SUITABLE RECORDS
† F_{ES}/n_z VERIFIED
†† EVIDENCE OF HITTING STOPS

Table XIII
LONGITUDINAL SHORT PERIOD MODE CHARACTERISTICS
SIMULATED FOR BOOST B (BB) CONFIGURATIONS

FLIGHT NO.	FUEL RE-MAINING	n_z/α g/RAD	ω_{SP} RAD/SEC	ζ_{SP}	F_{ES}/n_z LB/g	F_{ES}/δ_{ES} LB/IN.	$\frac{\omega_{SP}^2}{(n_z/\alpha)}$	$\frac{\omega_{SP}^2}{(n_z/\alpha)(F_{ES}/n_z)}$
		DESIRED VALUES						
		21.7	5.55	0.4	31.0	4.5	1.42	0.0458
762	534	17.2	5.3	0.38	39.9	4.59	1.63	0.041
763	370	19.8	5.22	0.398	32.5	4.44	1.38	0.042
764	358	18.3	5.22	0.4	40.4	4.72	1.49	0.037
767		19.8	5.6	0.41	30.8	4.35	1.58	0.052
769	406	20.4	5.55	0.425	30.9	4.31	1.51	0.049
771	370	21.0	5.71	0.58	28.9	4.44	1.55	0.054
772	360	20.1	5.49	0.35	29.7	4.46	1.5	0.051
773	258	19.8	5.37	0.41	29.7	4.95	1.45	0.049
778		20.6	5.49	0.42	29.0	4.45	1.46	0.051
780	285	21.6	5.68	0.45	32.7	4.34	1.49	0.046
783	460	21.6	5.72	0.37	35.1	4.76	1.51	0.043
784	344	18.6	5.59	0.4	39.3	4.52	1.68	0.044
786	441	21.9	5.51	0.39	32.3	4.37	1.39	0.043
787	370	22.9	5.85	0.42	28.3	4.37	1.49	0.053
789	468	21.9	5.46	0.42	33.8	4.54	1.36	0.04
790	378	25.9	6.03	0.41	29.4	4.06	1.4	0.048
791	277	21.6	6.35	0.41	32.0	4.4	1.87	0.058
793	387	19.2	5.75	0.37	25.0	4.65	1.72	0.069
795	—	*	*	*	*	*	—	—
797	331	NO AUTO STEP	5.1	0.27	*	*	-	-
AVERAGE		20.7	5.58	0.415	32.2	4.48	1.53	0.048
STANDARD DEVIATION		1.95	0.297	0.074	4.2	0.2	0.131	0.0076

*NO SUITABLE RECORDS

Table XIV
LONGITUDINAL SHORT PERIOD MODE CHARACTERISTICS SIMULATED FOR LANDING APPROACH (LA) CONFIGURATIONS

FLIGHT NO.	FUEL RE-MAINING	n_z/α g/RAD	ω_{sp} RAD/SEC	ζ_{sp}	F_{ES}/n_z LB/g	F_{ES}/δ_{ES} LB/IN.	$\frac{\omega_{sp}^2}{(n_z/\alpha)}$	$\frac{\omega_{sp}^2}{(n_z/\alpha)(F_{ES}/n_z)}$
		DESIRED VALUES						
		21.7	5.70	0.8	9.0	4.5	1.50	0.167
760	240	24.1	5.6	0.65	9.91	4.32	1.3	0.131
761	278	20.7	5.44	0.64	10.7	4.3	1.43	0.134
762	254	22.5	5.15	0.63	9.94	4.23	1.18	0.119
763	224	21.6	6.6	0.91	10.4	4.23	2.02	0.193
764	218	23.5	6.16	0.77	10.0	4.75	1.61	0.161
765	272	16.8	6.55	0.79	9.8	4.76	2.55	0.261
767	252	21.6	4.93	0.42	9.95	4.35	1.12	0.113
768	254	21.6	5.83	0.745	8.75	4.39	1.57	0.18
769	224	21.0	4.96	0.55	9.43	4.23	1.17	0.124
773	216	21.6	6.14	0.8	9.57	4.24	1.75	0.182
777	284	21.0	5.6	0.64	10.8	4.53	1.49	0.156
778	230	24.8	6.2	0.71	10.3	4.36	1.55	0.151
779	236	22.5	6.74	0.915	9.85	4.31	2.02	0.205
780	173	20.0	*	*	10.7	4.37	-	-
781	245	26.2	5.74	0.87	9.43	4.26	1.26	0.118
782	——	23.5	6.4	0.67	9.4	4.3	1.74	0.174
783	280	26.9	6.1	0.87	9.0	4.59	1.38	0.153
784	261	20.6	5.46	0.85	*	*	1.45	-
785	285	20.1	6.08	0.71	10.3	4.25	1.84	0.179
793	283	18.1	6.22	0.73	10.0	4.34	2.14	0.214
794	244	NO AUTO STEP	6.3	0.89	10.8	4.45	-	-
795	187	NO AUTO STEP	6.5	0.77	*	*	-	-
796	224	NO AUTO STEP	6.77	0.95	9.8	4.35	-	-
797	261	NO AUTO STEP	7.6	0.78	10.9	4.37	-	-
AVERAGE		21.9	6.05	0.75	9.99	4.38	1.61	0.164
STANDARD DEVIATION		2.46	0.637	0.128	0.589	0.154	0.377	0.039

*NO SUITABLE RECORDS

Table XV
LATERAL-DIRECTIONAL MODE CHARACTERISTICS SIMULATED DURING EVALUATION FLIGHTS - RE-ENTRY GLIDE (RG) CONFIGURATIONS

CONF.	FLIGHT	PILOT	ω_d		ζ_d		τ_R		τ_s		$\lvert\phi/\beta\rvert_d$		$(\omega_\phi/\omega_d)^2$		F_{as}/δ_{as}		F_{rs}/δ_{rs}		PR
			DESIRED	MEASURED	DESIRED	MEASURED	DESIRED	MEASURED	DESIRED	MEASURED	DESIRED	MEASURED	DESIRED	MEASURED	DESIRED	MEASURED	DESIRED	MEASURED	
RG-1	750	CAL	3.05	-	0.302	-	0.036	-	-13.3	-	5.80	6.01 6.63*	0.396	-	30.0	30.7	2.0	2.08	[illegible]
	780	MARTIN		2.96*		0.475*		-		-		ND		-	30.4	30.4		3.15	[illegible]
	792	MARTIN		3.10		0.78		-		-		ND		-		35.0*		1.60*	[illegible]
	796	NASA		2.63		0.36		-		-		5.49*		-		-		-	[illegible]
RG-2	765	CAL		3.16		0.103*		-		-		0.70**	ND	-		34.0		1.76	[illegible]
	786	MARTIN		-		-		-		-		-		-		30.6*		1.60*	[illegible]
RG-3	765	CAL		3.10		0.65		-		-		ND		-		30.2		2.1	[illegible]
	773	CAL		2.96		0.94		-		-		0.62 0.58**		-		30.0		1.85	[illegible]
	781	MARTIN		-		-		-		-		-		-		32.0*		1.8*	[illegible]
RG-4	760	CAL	3.12	2.73	0.247	0.25	0.506	-	-16.9	-	5.52	0.34 0.94**	0.398	-	28.0	-		2.0	[illegible]
	787	MARTIN		3.37		0.20		-		-		—		-	30.4	31.6*		1.79*	[illegible]
RG-5	770	CAL		2.86		0.21		-		-		0.02**	ND	-		33.2*		1.87	[illegible]
	793	MARTIN		3.30		0.22		-		-		-		-		-		-	[illegible]
RG-6	760	CAL		2.6		0.21		-		-		0.25 0.79**		-		-		1.85	[illegible]
	788	MARTIN		3.40		0.81		-		-		3.66**		-		30.2		2.9*	[illegible]
RG-7	764	CAL	3.13	4.94	0.070	0.06	1.60	-	+10.7	-	4.10	-	0.117	-		33.0		3.5	[illegible]
	785	MARTIN		-		-		-		-		-		-		30.0		2.0	[illegible]
	786 †	MARTIN		-		ND		-		-		ND		-		35.0*		1.8*	[illegible]
RG-8	771 †	CAL		-		-		-		-		-	ND	-		-		-	[illegible]
	791	MARTIN		-		ND		-		-		ND		-		30.0*		3.0*	[illegible]
RG-9	794	CAL		-		-		-		-		-		-		30.0		2.01	[illegible]
	789	MARTIN		-		-		-		-		-		-		34.0*		1.90*	[illegible]

* AVERAGE OF SEVERAL MEASURED VALUES

** MEASURED USING $\left(\frac{1}{\omega_d}\left|\frac{\phi}{\beta}\right|_d\right)$

† LATERAL-DIRECTIONAL GAINS REVISED ON THESE FLIGHTS

HD - RESPONSE HIGHLY DAMPED, PARAMETER COULD NOT BE MEASURED

ND - DESIRED VALUE NOT DETERMINED

Table XVI
LATERAL-DIRECTIONAL MODE CHARACTERISTICS SIMULATED DURING EVALUATION FLIGHTS - BOOST A (BA) CONFIGURATIONS

CONF.	FLIGHT	PILOT	ω_d DESIRED	ω_d MEASURED	ζ_d DESIRED	ζ_d MEASURED	τ_R DESIRED	τ_R MEASURED	τ_s DESIRED	τ_s MEASURED	$\lvert\phi/\beta\rvert_d$ DESIRED	$\lvert\phi/\beta\rvert_d$ MEASURED	$(\omega_\phi/\omega_d)^2$ DESIRED	$(\omega_\phi/\omega_d)^2$ MEASURED	P_{osc}/P_{av} DESIRED	P_{osc}/P_{av} MEASURED	[illegible] DESIRED	[illegible] MEASURED	PR
BA-1	776	CAL	2.00	2.15	0.171	0.22	1.30	-	-12.0	-	2.81	2.76**	0.712	-	34.0	34.7	2.0	1.77	63.5
	777	MARTIN		2.00		0.19		-		-		2.79**		-		35.3		1.67	65.0
BA-2	776	CAL		1.90		0.175		-		-		3.17**	ND	-		34.6		1.66	66.0
	791	MARTIN		1.93		0.17		-		-		3.01**		-		36.5*		2.1*	66.5
BA-3	776	CAL		2.06		0.13		-		-		3.23**		-		32.5		1.70	67.0
	785	MARTIN		2.21		0.12		-		-		2.9**		-		33.6		1.6	66.4
BA-4	775	CAL	2.07	1.91	0.102	0.09	1.45	-	-14.9	-	3.06	3.27**	0.722	-		34.8		1.90	66.0
	784	MARTIN		2.02		0.10		-		-		3.36**		-		34.7		1.86	67.0
	792	MARTIN		1.87		0.075		-		-		4.19**		-		33.0		2.30	66.0
BA-5	776	CAL		2.0		0.00		-		-		3.01**	ND	-		32.7		1.67	66.6
	788	MARTIN		2.1		0.106		-		-		-		-		39.5		2.06	67.5
BA-6	776	CAL		1.81		3.00		-		-		3.5**		-		34.2		1.80	66.0
	790	MARTIN		1.85		0.00		-		-		-		-		33.1		1.60	66.5
BA-7	775	CAL	2.00	1.96	0.200	0.17	1.19	-	-16.0	-	2.93	2.06**	0.696	-		30.7		1.80	64.0
	781	MARTIN		1.75		0.16		-		-		3.05		-		36.9		3.07	62.5
												3.02**							
	795	USAF		2.23		0.106		-		-		2.84**		-		-		-	66.0
	797	NASA		2.05		0.16		-		-		3.12**		-		-		-	66.5
BA-8	776	CAL		1.84		0.17		-		-		2.56**	ND	-		-		-	66.0
	782	MARTIN		2.5		0.12		-		-		-		-		30.0		3.06	65.5
BA-9	775	CAL		1.92		0.2		-		-		2.73**		-		30.1		1.70	64.5
	779	MARTIN		1.78		0.155		-		-		3.94**		-		36.5		1.67	66.0

* AVERAGE OF SEVERAL MEASURED VALUES

** MEASURED USING $\left(\frac{L}{\omega_d}\left|\frac{\phi}{\beta}\right|_d\right)$

† LATERAL-DIRECTIONAL GAINS REVISED ON THESE FLIGHTS

HD - RESPONSE HIGHLY DAMPED. PARAMETER COULD NOT BE MEASURED

ND - DESIRED VALUE NOT DETERMINED

Table XVIII

LATERAL-DIRECTIONAL MODE CHARACTERISTICS SIMULATED DURING EVALUATION FLIGHTS - BURNOUT (BO) CONFIGURATIONS

CONF.	FLIGHT	PILOT	ω_d DESIRED	ω_d MEASURED	ζ_d DESIRED	ζ_d MEASURED	τ_R DESIRED	τ_R MEASURED	τ_s DESIRED	τ_s MEASURED	$\lvert\phi/\beta\rvert_d$ DESIRED	$\lvert\phi/\beta\rvert_d$ MEASURED	$(\omega_\phi/\omega_d)^2$ DESIRED	$(\omega_\phi/\omega_d)^2$ MEASURED	[illegible] DESIRED	[illegible] MEASURED	[illegible] DESIRED	[illegible] MEASURED	PR
BO-1	759	CAL	1.07	1.[illegible]	0.242	0.21	0.44	–	832	–	5.53	[illegible].50 [illegible].33**	0.766	–	[illegible].0	27.[illegible]	2.0	1.72	[illegible]
	760	CAL		1.75		0.20		–		–		[illegible]**		–	[illegible]	[illegible].0		1.[illegible]	[illegible]
	779	MARTIN		1.7		0.14		–		–		[illegible] 5.05**		–		37.0		1.[illegible]	[illegible]
BO-2	761	CAL		1.[illegible]		0.22		–		–		5.27 5.1**	ND	–		–		1.[illegible]	[illegible]
	788	MARTIN		1.[illegible]		0.21		–		–		5.1**		–		[illegible]		1.[illegible]	[illegible]
BO-3	770	CAL		1.[illegible]		0.145		–		–		3.[illegible] 5.25**		–		32.0		2.[illegible]	[illegible]
	777	MARTIN		1.02		0.19		–		–		6.12**		–		35.2		1.[illegible]	[illegible]
BO-4	761	CAL	2.01	1.0	0.153	0.[illegible]	0.62	–	-1.072	–	0.25	5.42 5.0**	0.70	–	[illegible].0	–		1.9	[illegible]
	762	CAL		1.02		0.115		–		–		7.77 7.16**		–		27.2		1.[illegible]	[illegible]
	789	MARTIN		1.96		0.12		–		–		6.72 6.74**		–	[illegible]	31.[illegible]		2.[illegible]	[illegible]
BO-5	772	CAL		1.77		0.14		–		–		6.[illegible]**	ND	–		33.1		1.[illegible]	[illegible]
	784	MARTIN		1.70		0.15		–		–		5.0 5.12**		–		37.7		1.[illegible]	[illegible]
BO-6	771	CAL		1.[illegible]		0.14		–		–		6.66 6.[illegible]**		–		–		1.[illegible]	[illegible]
	782	MARTIN		1.07		0.16		–		–		6.[illegible]*		–		[illegible].2		1.[illegible]	[illegible]
BO-7	783	CAL	1.92	2.[illegible]	0.31	0.2	0.34	–	987	–	0.70	2.5 3.[illegible]**	0.702	–	[illegible].0	[illegible].17		[illegible]	[illegible]
	776	MARTIN		2.07		0.32		–		–		3.90 3.[illegible]**		–	[illegible]	[illegible]		1.[illegible]	[illegible]
	792	MARTIN		1.71		0.17		–		–		[illegible] 3.[illegible]**		–		[illegible].1		[illegible]	[illegible]
	794	USAF		1.74		0.27		–		–		3.[illegible] 3.[illegible]**		–		–		–	[illegible]
	796	NASA		1.[illegible]		0.206		–		–		3.7 [illegible]**		–		–		–	[illegible]
BO-8	778	CAL	*	1.71		0.23		–		–		[illegible] [illegible]**	ND	–		32.0		2.[illegible]	[illegible]
	798	MARTIN		–		–		–		–		–		–		[illegible].1		1.[illegible]	[illegible]
BO-9	767	CAL		1.74		0.23		–		–		3.0 3.10**		–		37.2		1.[illegible]	
	787	MARTIN		1.70		0.245		–		–		[illegible]**		–		–		–	[illegible] [illegible]

* AVERAGE OF SEVERAL MEASURED VALUES

** MEASURED USING $\left(\frac{f}{\omega_d}\left|\frac{\phi}{\beta}\right|_d\right)$

† LATERAL-DIRECTIONAL GAINS REVISED ON THESE FLIGHTS

ND - RESPONSE HIGHLY DAMPED, PARAMETER COULD NOT BE MEASURED

ND - DESIRED VALUE NOT DETERMINED

Table XVIII

LATERAL-DIRECTIONAL MODE CHARACTERISTICS SIMULATED DURING EVALUATION FLIGHTS - BOOST B (BB) CONFIGURATIONS

CONF.	FLIGHT	PILOT	ω_d DESIRED	ω_d MEASURED	ζ_d DESIRED	ζ_d MEASURED	T_R DESIRED	T_R MEASURED	T_S DESIRED	T_S MEASURED	$\|\varphi/\beta\|_d$ DESIRED	$\|\varphi/\beta\|_d$ MEASURED	$(\omega_\varphi/\omega_d)^2$ DESIRED	$(\omega_\varphi/\omega_d)^2$ MEASURED	p_m/δ_{as} DESIRED	p_m/δ_{as} MEASURED	β_m/δ_{rp} DESIRED	β_m/δ_{rp} MEASURED	PR
BB-1	782	CAL	1.07	1.02	0.20	3.17	1.2	—	-12.0	—	5.07	4.96**	0.395	—	28.0	20.4	2.0	1.05	47.0
	783	MARTIN		—		—		—		—		—		—	30.0	15.2		1.02	46.0
BB-2	772	CAL		1.59		0.17		—		—		5.96**	ND	—		34.9		1.05	34.5
	773	CAL		1.65		0.10		—		—		4.89**		—		37.2		1.07	30.0
	776	MARTIN		1.71		—		—		—		—		—		30.0		1.75	30.5
	780	MARTIN		1.90		0.12		—		—		—		—		35.2		1.0	30.0
BB-3	769	CAL		1.07		0.25		—		—		5.03		—		36.6		2.00	45.0
	780	MARTIN		1.0		0.20		—		—		3.92**		—		30.3		2.2	46.0
BB-4	783	CAL	1.80	1.88	0.137	0.155	1.10	—	-15.0	—	5.77	7.0**	0.390	—	28.0	27.2		1.00	40.0
	780	MARTIN		1.77		0.17		—		—		7.10*		—	30.0	30.1		1.0	47.0
BB-5	780	CAL		—		—		—		—		—	ND	—		—		2.12	16.0
	784	MARTIN		1.75		—		—		—		—		—		—		—	16.0
BB-6	772	CAL		1.93		0.12		—		—		6.56**		—		—		—	30.0
	780	MARTIN		1.60		0.17		—		—		—		—		37.0		1.07	45.0
BB-7	784	CAL	1.9	1.50	0.364	0.34	1.30	—	-10.1	—	5.85	7.8**	0.30	—		35.0		1.30	37.0
	780	MARTIN		2.00		0.5						—				35.0		—	37.0
BB-8	771	CAL		1.57		0.4		—		—		0.05**	ND	—		37.2		2.22	46.0
	791	MARTIN		—		—		—		—		—		—		—		—	40.5
BB-9	787	CAL		2.25		0.43		—		—		—		—		31.0		2.35	46.5
	787	MARTIN		1.04		0.45		—		—		—		—		30.1		2.08	46.1

* AVERAGE OF SEVERAL MEASURED VALUES

** MEASURED USING $\left(\frac{1}{\omega_d}\left|\frac{\dot\varphi}{\beta}\right|\right)$

† LATERAL-DIRECTIONAL GAINS REVISED ON THESE FLIGHTS

HD - RESPONSE HIGHLY DAMPED, PARAMETER COULD NOT BE MEASURED

ND - DESIRED VALUE NOT DETERMINED

Table XIX
LATERAL-DIRECTIONAL MODE CHARACTERISTICS SIMULATED DURING EVALUATION FLIGHTS - LANDING APPROACH (LA) CONFIGURATIONS

CONF.	FLIGHT	PILOT	ω_d DESIRED	ω_d MEASURED	ζ_d DESIRED	ζ_d MEASURED	τ_R DESIRED	τ_R MEASURED	τ_s DESIRED	τ_s MEASURED	$\lvert\phi/\beta\rvert_d$ DESIRED	$\lvert\phi/\beta\rvert_d$ MEASURED	$(\omega_\phi/\omega_d)^2$ DESIRED	$(\omega_\phi/\omega_d)^2$ MEASURED	F_{as}/δ_{as} DESIRED	F_{as}/δ_{as} MEASURED	F_{rs}/δ_{rs} DESIRED	F_{rs}/δ_{rs} MEASURED	PR
LA-1	760 780 794 796	CAL MARTIN USAF NASA	3.03	2.54 – 3.14 3.0	0.426	0.36 – 0.7 0.5	0.29	– – – –	13.9	– – – –	5.61	6.4 5.60** – – –	0.509	– – – –	28.0 34.4	25.3 32.2 – –	2.0	1.91 1.80 – –	49.0 49.5 46.0 42.0
LA-2	763 783	CAL MARTIN	↓	3.24 2.76 2.79	↓	0.25 0.42 0.36	↓	– – –	↓	– – –	↓	5.47 6.05** 3.54**	ND	– – –	28.0 34.4	30.0 32.2	↓	2.00 2.1?	49.5 42.0
LA-3	765 777 773	CAL MARTIN CAL	↓	2.62 – 2.82	↓	0.37 – 0.36	↓	– – –	↓	– – –	↓	– – 5.21*	↓	– – –	↓	34.7 35.9 35.4	↓	2.01 1.96 1.80	42.0 43.0 42.0
LA-4	762 779	CAL MARTIN	3.46	3.1 2.89	0.305	0.27 0.33	0.41	– –	14.0	– –	5.76	7.32 6.10** 6.06**	0.426	– –	20.0 34.4	26.0 33.7	↓	1.82 –	43.0 49.0
LA-5	764 781	CAL MARTIN	↓	3.05 4.21	↓	0.3 0.315	↓	– – –	↓	– – –	↓	6.0 5.90** –	ND	– –	↓	34.6 37.0	↓	2.0 1.9	43.0 49.5
LA-6	769 785 793 795 797	CAL MARTIN MARTIN USAF NASA	↓	3.21 3.05 3.01 3.2 3.0	↓	0.36 0.35 0.32 0.34 0.35	↓	– – – – –	↓	– – – – –	↓	5.13 5.34** 5.3** 5.45** 4.90 –	↓	– – – – –	↓	34.0 37.0 31.3 – –	↓	1.01 2.00 2.08 – –	43.0 41.0 41.5 47.5 43.0
LA-7	761 770	CAL MARTIN	2.71	– 3.1	0.606	– 0.67	0.22	– –	13.5	– –	5.52	– –	0.567	– –	20.0 34.4	– 35.0	↓	1.90 2.3	44.3 40.0
LA-8	766 782	CAL MARTIN	↓	2.78 2.3	↓	0.775 0.7	↓	– –	↓	– –	↓	– –	ND	– –	↓	31.6 31.2	↓	2.07 1.80	45.5 43.5
LA-9	767 784	CAL MARTIN	↓	2.60 2.3	↓	0.45 0.61	↓	– –	↓	– –	↓	– –	↓	– –	↓	36.6 34.7	↓	2.06 1.86	43.5 41.5

* AVERAGE OF SEVERAL MEASURED VALUES

** MEASURED USING $\left(\frac{f}{\omega_d}\left|\frac{\phi}{\beta}\right|_d\right)$

† LATERAL-DIRECTIONAL GAINS REVISED ON THESE FLIGHTS

HD - RESPONSE HIGHLY DAMPED, PARAMETER COULD NOT BE MEASURED

ND - DESIRED VALUE NOT DETERMINED

APPENDIX

MODE AND RESPONSE CHARACTERISTICS AND PILOT COMMENT SUMMARIES FOR INDIVIDUAL CONFIGURATIONS

A.1 INTRODUCTION

(U) This Appendix contains: (1) a description of the longitudinal dynamics simulated on the T-33, (2) a summary of pilot comments on the five sets of longitudinal dynamics evaluated in flight, and (3) pilot comments and time history responses for the forty-five lateral-directional configurations.

(U) In Section A.4 (lateral-directional), each case is presented on two facing pages. The left-hand page contains a narrative which summarizes the pilot comments made by all the pilots who flew that particular case. These comments were extracted from the complete comments recorded in flight (and reproduced verbatim in Reference 7). The right-hand page contains: (1) a tabular summary of the lateral-directional mode characteristics, both desired and measured, and (2) roll rate and sideslip responses, desired and measured, for aileron stick step inputs of one inch, and rudder pedal step inputs of one inch. The measured curves are the result of automatic aileron and rudder steps, calculated to simulate δ_{AS} and δ_{RP} steps with the K_{RA} value appropriate to the case. These inputs were not necessarily calculated for the one-inch input, so that the measured responses were scaled to one inch for direct comparison with the desired responses. The flight numbers, pilot, pilot rating, and any remarks pertaining to the curves are also included.

(U) Blanks, or missing curves, indicate that no suitable record could be found for measurement, or that none was taken. Often, turbulence or fuel sloshing effects made analysis impossible, especially in the highly damped cases where measurement is difficult under the best of conditions.

A.2 LONGITUDINAL DYNAMICS

(C) The desired longitudinal response parameters (Table VIII) vary among the five basic flight conditions and not among the subcases. An elevator stick force gradient of 4.5 lb/g was desired for all conditions. The most dramatic parameter variation occurs with elevator stick force per g, which has its lowest value of 9 lb/g in the landing approach, and 85 lb/g in the burnout condition. Similarly, short-period damping is highest (.8) for LA configurations and lowest (.3) for BO cases. Desired short-period frequency has a relatively small variation with flight condition, ranging from 6.64 rad/sec for BA flights, to 4.71 rad/sec for the RG cases.

(C) The values of longitudinal parameters actually achieved on the evaluation flights, as measured from flight records, are presented in Tables X to XIV, along with the desired values. The average value and standard deviation are also given. The usual difficulties in measurement of frequency and damping of highly damped systems were encountered in reading response traces to elevator doublets. There was no indication of system changes or errors in gain settings for any of the cases; therefore, it is felt that the standard deviation is largely a measure of trace reading inaccuracies inherent with highly damped systems. This is indicated by the difference in standard deviation of damping values for LA, where the average value is .75, and BO whose average is .275. Steady-state stick force per g values, as measured from oscillograph time histories, suffer from the dynamic lags of the feel system, the vehicle response time and the inability of the pilot to hold a constant stick force. An elevator stick trim rate of .6 in./sec was maintained on all flights.

(C) Since both the CAL and Martin (MAR) pilots evaluated a given set of longitudinal characteristics at least nine times each, a very complete analysis was possible, including checks on individual pilot consistency and comparisons between pilots. The following summary of pilot comments follows, in general, the format of the pilot comment card, Figure 8.

A.3 SUMMARY OF PILOT COMMENTS – LONGITUDINAL

A. RG Cases

(C) Re-entry glide cases were flown a total of twenty-three times; the CAL pilot flew ten, the MAR pilot eleven, USAF one and NASA one. The comments were quite consistent, both from any given pilot and among pilots.

(C) Trim difficulties were not experienced. All pilots felt trimming was easy and trim rate adequate. On two configurations which were extremely difficult to fly lateral-directionally, the MAR pilot felt that longitudinal trim rate could be a bit higher. Ninety percent of the remarks on RG longitudinal trim were complimentary and it is recommended that no changes be made in this area.

(C) The feelings about pitch response to elevator stick inputs were unanimous in that all pilots were entirely satisfied all of the time. Adjectives range from "satisfactory" to "optimum."

(C) Comments on attitude control and n_z control were all favorable. Pilots felt that they could put the nose where they wanted quite precisely and at a desirable rate. On one flight, the CAL pilot noted a slight tendency to bobble. He tended to use trim to a greater degree in controlling attitude and "g" than did the other pilots, consequently elevator stick forces and gradients were of secondary importance to him. The MAR pilot liked F_{ES}, F_{ES}/δ_{ES} and F_{ES}/n_z most of the time. He felt the gradient could be a bit heavier on two flights, a bit lighter on one other. The CAL, USAF and NASA pilots were in agreement that these features were entirely satisfactory.

(C) Random noise had no significant effect in pitch for over half the flights. The CAL pilot noted a tendency to bobble with random noise on half his flights; the MAR pilot was far less sensitive to it and only once did he indicate that the random noise degraded the longitudinal handling qualities. The USAF pilot felt that random noise had a definite downgrading effect on his flight, while the NASA pilot found it only "slightly annoying." The general impression was that if random noise had any effect at all, it was slight and no particular pilot effort was needed to cope with it.

(C) In summary, then, the longitudinal characteristics in the re-entry glide configuration are quite satisfactory in all respects and no area merits further improvement. Judging from the comments, it is felt that if the longitudinal characteristics were being rated alone, an A 2.0 would be appropriate for the RG case.

B. BA Cases

(C) BA configurations were flown a total of twenty-one times. The CAL pilot flew nine, the MAR pilot ten, USAF one and NASA one. The CAL pilot experienced no difficulties with longitudinal trim on any of his flights, while the MAR pilot felt that the trim rate could be faster on most of his flights. The USAF pilot agreed that this was so, while the NASA pilot, like the CAL pilot, had no comment on it. It was revealed quite often that the CAL pilot used longitudinal trim much more than the others in performing longitudinal maneuvers, and one would guess that the trim rate would be more important and that slow rates would present more of a problem when flying in this manner. This was not the case; however, it may be significant that the CAL pilot <u>initiated</u> pitch response with trim, while the others did so with the stick first, and then trimmed. It would therefore seem reasonable that they would experience an <u>apparent</u> slower trim rate. The rate problem was the only one mentioned in regard to trim. The CAL pilot was generally more satisfied with pitch response than the other pilots who reported fairly consistently that the response was too slow and/or it required larger than desired stick forces and deflections to achieve a desired level of pitch response. The CAL pilot's technique with trim, discussed earlier, could account for this, since his continual use of trim masks the stick forces and gradients. In addition, since he had no complaints about trim rate, it is reasonable that he did not note slow or inadequate pitch rate response.

(C) The difference in technique was again evident in the comments regarding attitude and n_z control. The CAL pilot had virtually no problem with either when using trim continually, while the MAR pilot consistently complained of difficulty due to high stick forces necessary to achieve attitude changes and high stick force per g. The CAL pilot did comment, on occasion, that the elevator stick forces and gradients were high if no trim was used.

(C) With the exception of the USAF pilot, all pilots reported good performance on the tracking task, but considerably more difficulty in achieving this level of performance was experienced by the MAR and NASA pilots, due to the aforementioned high stick forces and the apparent slowness of the pitch response. The CAL pilot had no problem with the task using his trim technique.

(C) Random noise posed no real problem longitudinally for any of the pilots, except the USAF pilot again, who felt the mission could not be accomplished satisfactorily in random noise, due to the inadequacy of pitch authority, especially nose-down. The MAR and NASA pilots felt that random noise accentuated the force and weak response problems, while the CAL pilot did notice a tendency to bobble slightly on a few occasions.

(C) In summary, it appears that no serious problems are encountered in the longitudinal mode for this BA condition. The somewhat slow pitch response and accompanying high elevator stick forces can apparently be masked by using the trim for primary pitch control. It is felt that, with this technique, the tasks required in the boost phase of flight can be accomplished in a satisfactory manner in the presence of turbulence, without excessive demands on pilot skills or attention. The overall pilot rating of A 3.0 would seem appropriate for the longitudinal dynamics of the BA configuration.

C. BO Cases

(C) BO configurations were flown a total of 23 times; the CAL pilot flew eleven, MAR ten, USAF one and NASA one. A sharp difference in rating is obvious between CAL and the other pilots. Consistency among the ratings of any one pilot is excellent.

(C) The pitch response to elevator stick commands is very low in the burnout cases and, since the same stick force gradient and gearing exist as on other cases, it is necessary to have larger than usual stick deflections, with accompanying large forces, in order to achieve even moderate pitch rates. These excessive forces and deflections made pitch control very difficult, a situation aggravated by random noise inputs to the elevator. The same observations and complaints reoccur again and again on the flights of the MAR, USAF and NASA pilots, causing consistent ratings of A4.5 to A6.0. The CAL pilot observed the same effects and interpreted them in a similar manner, giving similar ratings on his first three flights with BO configurations. It was on the fourth flight that he discovered a technique that virtually eliminated all the longitudinal difficulties on subsequent flights, and improved ratings to the A2.0 level. This technique proved so satisfactory that it should be given very careful consideration by future SV-5P pilots. To use the CAL pilot's own words of explanation: "When I was up to Martin, they flew the angle of attack primarily with their trim button and, up to now, I have complained bitterly about the extremely heavy longitudinal forces required to make attitude changes on these burnout configurations, so I put the elevator stick trim gauge up to a gain of 5 and find that considerably more satisfactory when I have an attitude that I wish to achieve to as soon as I start a push or a pull with the elevator, just to get on the trim button and change the attitude with the trim and, very surprisingly, I am happy to say it works quite well for these burnout configurations. Certainly have been able to reduce the stick forces to a satisfactory and very comfortable level. The airplane responds quite well to the trim and I am able to pick an attitude and hold it, so I think that probably this is the way to go and that is certainly realistic and certainly compatible with the SV5 simulation I saw at Baltimore, so I think that probably a very big question comes as far as the ability to trim this airplane and it is certainly excellent. It is a matter of picking an attitude and if I want to hold a 30-degree bank as I roll, I dial in with the amount of trim I need to change the attitude, change it with the trim and you lose the major objection, I think, of the heavy stick forces. The response to the airplane is still slow -- very, very stable longitudinally, so that it is unresponsive, but now I don't find myself fighting the large gradients and I found that I do a much more, much smoother job flying the airplane with the trim as I have it here so that, in general, I am quite pleased with what I see on this BO. I think the pitch response to the elevator is very similar to what I am used to seeing. It starts out with a rather rapid jump and then picks up a very low or slow steady-state attitude change. However, I don't think you will be making extremely rapid attitude changes in the burnout phase of the trajectory, so that attitude control using primarily the trim is good and, when I need a little bit of normal acceleration, I don't have a lot available; don't expect to have a lot, but I can get it with the trim and this rate that I have seems to be compatible with the longitudinal trim rates that they have on their SV5 simulator. So I think I tend to eliminate somewhat my major objections to the heavy feel forces or stick forces and stick gradients by using the trim and the airplane does trim quite nicely in attitude."

(C) From that point on, the CAL pilot had absolutely no significant longitudinal problems. His overall ratings were then largely a function of the lateral-directional dynamics. He did not pass on his technique to the other pilots and none of them discovered it, hence a clear division in ratings was experienced, although excellent repeatability existed in the observations of any one pilot.

D. BB Cases

(C) The longitudinal dynamics of the BB configuration are quite similar to the BA condition, having only a slightly different short-period frequency and stick force per g, and an identical short-period damping and stick force gradient. The comments, therefore, are very much like those for the BA case, except that the bad lateral-directional characteristics of some BB cases often interfered with the accurate assessment of the longitudinal handling qualities.

(C) BB configurations were flown a total of twenty-two times; CAL flew ten, MAR ten, USAF one and NASA one. The CAL pilot again used the trim as his primary longitudinal controller, a technique which tends to mask the feel characteristics of the control system. He had no trim difficulties at any time and found the pitch response satisfactory He felt he had adequate attitude and n_z control for the BB task using trim. Steady-state 60° banked level turns were accomplished without difficulty. He noted consistently the well-damped response and only in the presence of random noise or heavy natural turbulence did he have any tendency to bobble in pitch when making attitude changes or performing the tracking maneuver. On three occasions, the CAL pilot noted that the configuration seemed to exhibit what he referred to as neutral static stability. When the aircraft was displaced in pitch from a trimmed condition, it displayed little or no tendency to return to that trimmed state. No reason for the inconsistency on these three flights was evident. In general, the CAL pilot liked the longitudinal characteristics of the BB case very much and felt it was quite adequate and comfortable for the boost mission.

(C) The MAR pilot consistently complained of a weak pitch response which required large stick deflections for adequate pitch rates, which in turn required high elevator stick forces. He felt that the tracking task could not be performed well without full throw deflections which became very tiring after only a few minutes. He apparently does use the trim, since time after time he notes that the trim rate is too slow. It would appear that the CAL pilot uses the trim as his primary controller, while the MAR pilot uses it in a secondary role to the stick. Random noise consistently aggravated the MAR pilot's force problem. It should be noted that, on one occasion, the CAL pilot tried maneuvers with elevator stick only and agreed that the forces and deflections required for adequate performance were indeed too high. The MAR pilot rates this case A3.0 to A4.0 longitudinally, and notes that it is better than the BO case, but not as good as the RG case. The very bad lateral-directional characteristics of a few BB cases made accurate evaluation of the longitudinal case quite difficult. The USAF pilot was so involved in keeping the wings level on a BB-2 configuration that he had time for only a passing comment that the longitudinal dynamics were "pretty good." The NASA pilot, flying the same configuration much more successfully, found the pitch response low, but adequate for the boost condition, liked the damping, had no trim problems, and felt that the forces and deflections required to keep up to the tracking task were a little high. The impression was very much like the CAL pilot's, and he listed the longitudinal response as the only good feature of BB-2.

(C) In summary, it appears that the overall assessment of the longitudinal characteristics of the BB condition is very much like that for the BA condition, i.e., the somewhat slow pitch response and accompanying high elevator stick forces can apparently be masked by using the trim for primary pitch control. This technique results in satisfactory accomplishment of the boost mission in the presence of turbulence without excessive demands on pilot skills or attention.

E. LA Cases

(C) LA configurations were flown a total of twenty-four times; the CAL and MAR pilots each flew ten, USAF and NASA pilots each flew two. Overall, the comments were more favorable than those received for any other configuration. There was virtual unanimity among all the pilots on the following points:

i. Trim: No difficulties were experienced in any phase of the approach. Trim rate was adequate for the level of response.

ii. Pitch Response to Elevator Stick Inputs: The pitch response was rated good to excellent, being adequate in rate, magnitude and damping. Smooth, positive control at altitude and in the descent was reported.

iii. Attitude and n_z Control: All pilots reported precise, positive control of attitude and normal acceleration throughout the landing approach. The MAR pilot felt, on a few occasions, that the stick force per g could be reduced by one or two pounds.

iv. Stick Force, Gradient and Feel: All elevator feel system characteristics were satisfactory.

v. Random Noise: Very little effect was experienced longitudinally, due to random or natural turbulence and no degradation of handling qualities resulted. Little or no extra pilot effort was required.

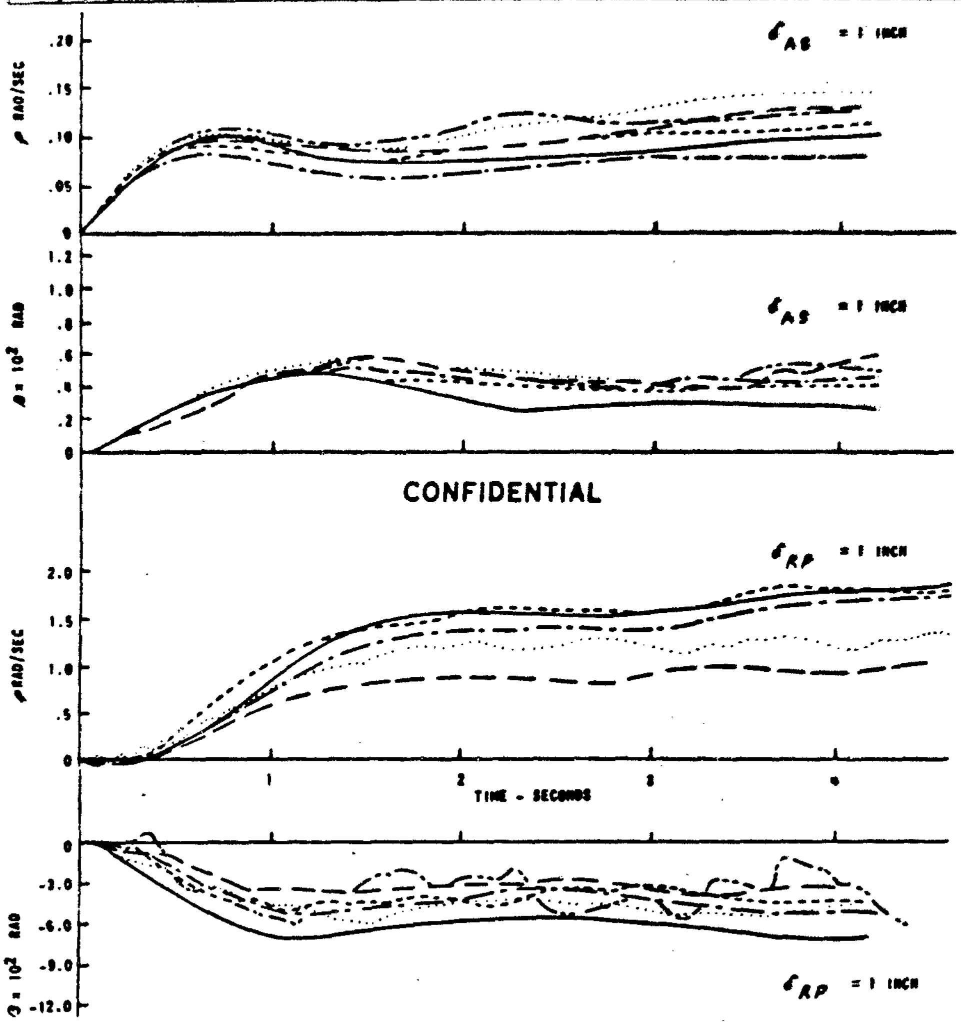
(C) In general, the longitudinal characteristics experienced during the landing approach are very good. The MAR pilot consistently rated it A1.0 to A2.0, the USAF pilot A1.0 to A1.5. Flare control was easy, with smooth and positive control of descent rate. It was felt that there would be absolutely no problems longitudinally and that, in most LA cases, longitudinal control was the best feature of the configuration.

A.4 SUMMARY OF PILOT COMMENTS AND MODE AND RESPONSE CHARACTERISTICS - LATERAL-DIRECTIONAL

RG-1

(C) This case was flown on one occasion by each of the CAL, USAF and NASA pilots, and twice by the MAR Pilot. There were a few inconsistencies among pilots and between the comments on the two MAR flights, but in general, agreement was fair, with a pilot rating spread from A1.0 to A4.0. All pilots felt that the roll response for aileron stick inputs was satisfactory, except the CAL pilot who felt that the response was somewhat sluggish with aileron stick alone, requiring large stick deflections to obtain adequate roll rate. He attributed this partially to the "considerable" adverse yaw due to aileron. The MAR pilot reported "high" adverse yaw on his second flight, but on his first flight agreed with the USAF and NASA pilots that the adverse yaw was low. The recorded ϕ and β responses do not indicate any discrepancies, therefore, there seems to be some difference of opinion as to what degree of sideslip is objectionable. Because of this, the CAL pilot did not feel he had precise bank angle control without some tricky rudder pedal coordination to prevent overshoots. No such difficulty was reported by the other pilots. Aileron stick forces, gradients and feel characteristics were reported "good" by all but the CAL pilot, who had commented earlier that too large forces were required to get desired roll rate using aileron stick alone. The response to rudder pedal inputs was thought satisfactory in roll rate and sideslip, prompting the CAL pilot to remark that the configuration could be flown with rudder alone. The NASA pilot thought that the rudders were too sensitive, making it difficult to correct small angle errors. The magnitude of the response to rudder pedal inputs is related to the comments on the rudder pedals forces and gradients. The CAL and USAF pilots thought that the forces and gradients were too light, while the MAR pilot had no objection to them. All pilots were able to coordinate turns satisfactorily. However, the difference of opinion on adverse yaw due to aileron brought differing judgments on the pilot effort required to accomplish this task. Making heading changes and holding heading were always reported as "easy" tasks, as was control in random noise. No complaints were voiced on control harmony except by the NASA pilot who felt that rudder forces were disproportionately light and that this condition was the only bad feature of the configuration. No other pilots felt that any feature should be labeled as "bad," but the CAL pilot had objections to the adverse yaw, with accompanying coordination problems, and the MAR pilot agreed with him on the second of two RG-1 flights. As reported in Section A.3, the longitudinal characteristics did not downgrade the overall pilot rating since all pilots thought they were "excellent." Similarly, the good roll and directional damping were praised by all pilots. The CAL pilot gave an overall rating of A4.0, based primarily on the amount of adverse yaw due to aileron and the subsequent effort required to coordinate. The MAR pilot gave A1.0 on his first flight, and A3.0 on the second, commenting similarly on adverse yaw on the latter flight, but not on the first one. The USAF and NASA pilots gave A1.5 and A2.0, respectively, there being only minor objection to the rudder pedal gradients by the NASA pilot, and no objections from the USAF pilot.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert\phi/\beta\rvert_d$	[illegible]	[illegible]	[illegible]	P.C.	REMARKS	LEGEND
DESIRED		1.05	.30	[illegible]	[illegible]	[illegible]	[illegible]	2.0	[illegible]			SOLID LINE IS DESIRED
CAL	790	—	—	—	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*DESIRED [illegible]	
[illegible]	790	[illegible]	[illegible]	—	—	—	—	[illegible]	[illegible]	[illegible]		
[illegible]	792	[illegible]	.70	—	—	—	—	[illegible]	[illegible]	[illegible]		
USAF	794	—	—	—	—	—	—	—	—	[illegible]		
NASA	798	[illegible]	.30	—	—	—	[illegible]	—	—	[illegible]		



**All responses, desired and measured, for all configurations, are fourth-order T-33 responses about T-33 body axes while simulating the SV-5P about stability axes. Since the angle of attack of the T-33 during simulation is only one degree, these responses correspond closely to the simulated responses about stability axes.

Figure A-1 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-1 (U)

(C) This configuration was flown once each by the CAL and MAR pilots. Excellent agreement occurred on most points and therefore, little attempt is made to differentiate between pilots in the following assessment. The roll response to aileron stick inputs is unsatisfactory due to the low rate achieved (almost zero after two seconds) and the large amount of side-slip generated in the adverse direction. It is not possible to fly the aircraft laterally with aileron stick alone, and attempting to do so results in the requirement for very large stick deflections and forces to achieve an adequate roll rate. In addition, the sideslip builds up to unacceptable levels. The saving grace of this configuration is the excellent response to rudder pedal inputs, both in roll rate and sideslip. Extra pilot effort is naturally required for adequate turn coordination and bank angle control; however, both these tasks were accomplished satisfactorily by the two pilots, with somewhat more difficulty reported by the MAR pilot. Rudder pedal forces, gradient and feel characteristics are satisfactory, and heading control is also good. The CAL pilot had good control in the presence of random noise while the MAR pilot experienced a little trouble in minimizing β excursions. On the other hand, the CAL pilot found difficulty obtaining the right amounts of aileron and rudder trim to maintain zero sideslip in straight and level flight. No such problem was reported by the MAR pilot. Both pilots were in complete agreement that the single outstanding deficiency of this configuration was the excessive adverse sideslip due to aileron deflection necessitating a high degree of pilot attention to coordinate using the rudder pedals. The CAL pilot commented that the trouble seemed to be directly related to the crossfeed ratio between the rudder and the aileron stick; an effect which shows prominently in comparison to the next case. Again both pilots were pleased with the longitudinal behavior (see Section A.3). Overall ratings were given of A4.5 and A5.0 reflecting primarily the moderately objectional sideslip characteristics.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\lvert\phi/\beta\rvert_d$	$\frac{\omega_\phi}{\omega_d}\lvert\zeta\rvert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.05	.30	.626	-13.3	5.00	5.00	2.0	20.0			SOLID LINE IS DESIRED
CAL	795	3.10	.115/.21	—	—	—	5.70	1.70	26.0	60.0		— — —
WAR	796	—	—	—	—	—	—	1.72/2.00	28.4/28.0	45.0	POOR INITIAL TRIM ON STEPS	- - - - - -

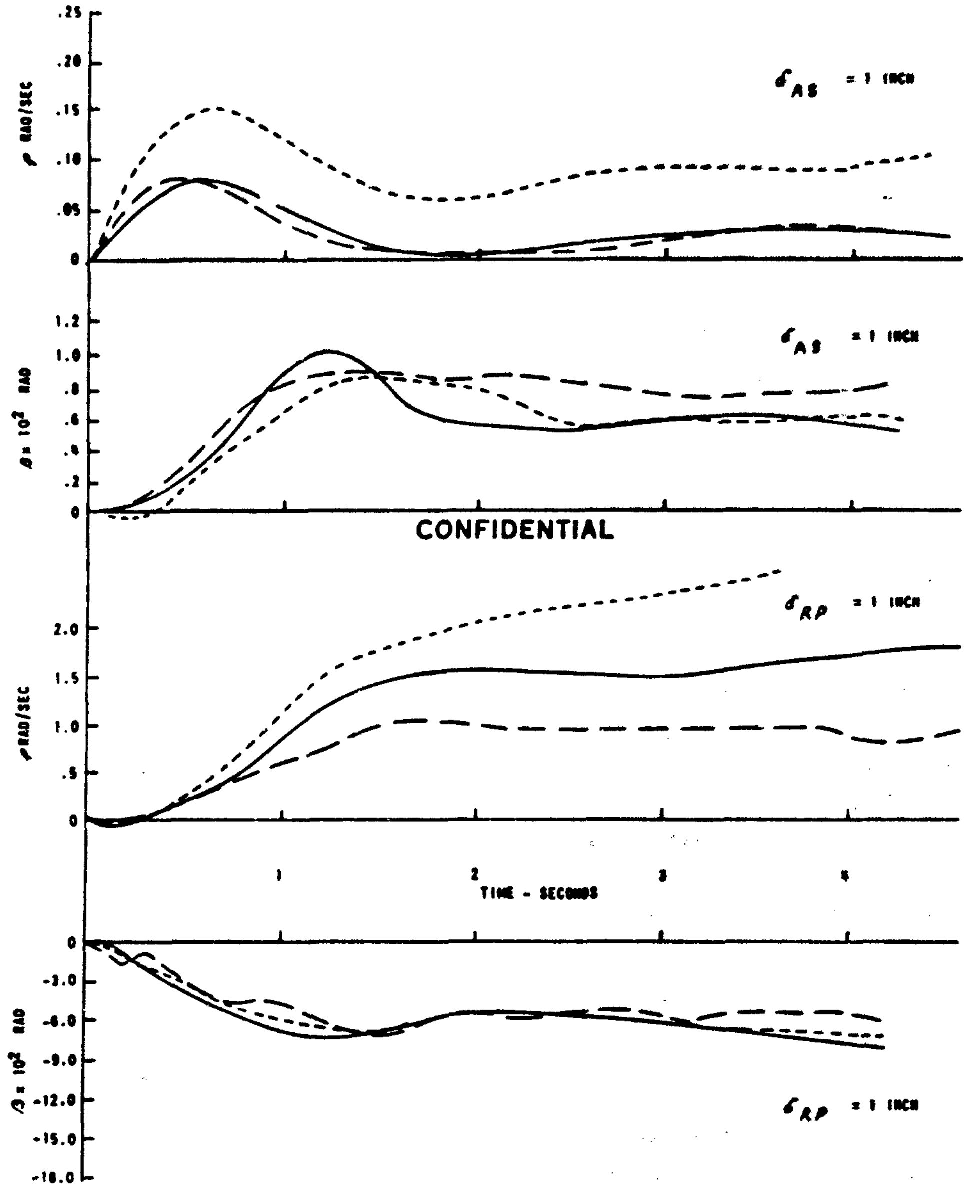


Figure A-2 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-2

RG-3

(C) The comments were consistent in all areas on the three RG-3 flights; two flown by CAL and one by MAR. The roll response to aileron stick inputs was satisfactory, having adequate roll rate, roll damping and only a small amount of adverse yaw (see β/δ_{A_S} curves). Bank angle precision was excellent which, combined with good directional damping, made changing heading and holding heading easy to accomplish. Both aileron and rudder forces, gradients and feel characteristics were satisfactory. The good response to rudder inputs was helpful but not necessary for turn coordination. The sideslip comes back to zero in steady-state turns necessitating only very gentle rudder initially in the direction of turn, if any. Random noise had no significant effect on this configuration and no degradation of handling qualities resulted. Control harmony was compatible among all three axes. No bad features were reported, while good features were the ability to fly the aircraft successfully with aileron alone and the good roll and directional damping. In general, the configuration was well behaved, pleasant to fly and displayed preciseness and ease of control. The excellent longitudinal characteristics (see Section A.3) combined with these lateral-directional qualities to produce pilot ratings of A2.0 on each of the two CAL flights, and A1.5 from the MAR flight.

(C) The effect of K_{RA} in cases RG-1, 2 and 3 is now evident. Adverse yaw due to aileron increases from a low maximum of about 0.003 radians per inch of aileron stick in the RG-3 case, to a high maximum of approximately 0.009 radian per inch in the RG-2 case. RG-1, falling in between RG-2 and RG-3 in this respect, received an average pilot rating between the averages received on the two extremes. Clearly, for this set of dynamics, the minimum amount of sideslip due to aileron is required for best ratings.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert\phi/\beta\rvert_d$	$\frac{1}{K}\lvert\phi/\beta\rvert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.00	.30	.030	-13.3	5.00	5.00	2.0	30.0			SOLID LINE IS DESIRED
CAL	765	3.10	.66	—	—	—	—	2.1	30.2	42.0	TURBULENT	— — —
CAL	772	2.96	.90	—	—	9.02	6.94	1.96	30.0	42.0		- - - - - -
NAG	781	—	—	—	—	—	—	1.80/1.72	30.7/29.4	41.9		— · —

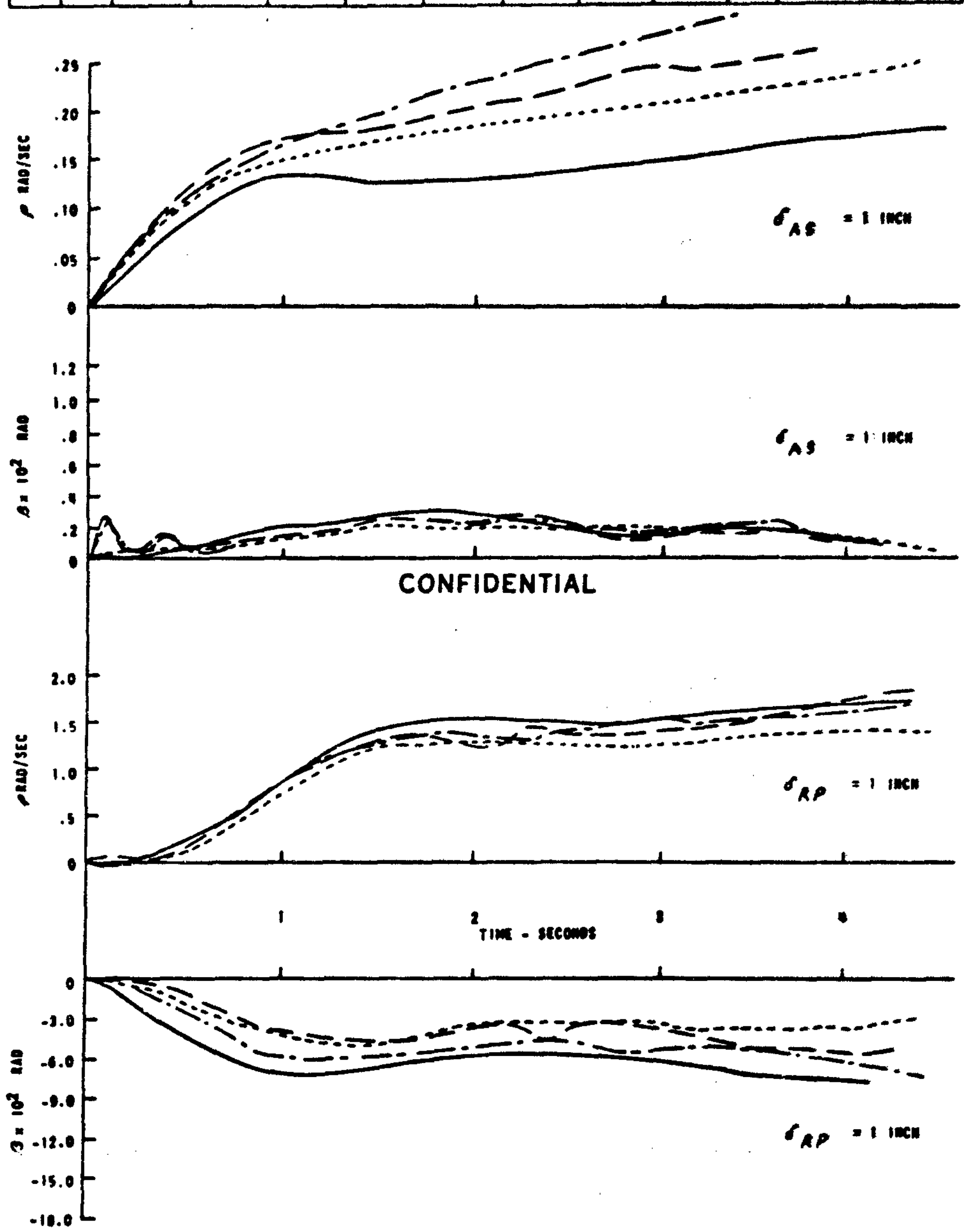


Figure A-3 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS} , δ_{RP}) FOR CONFIGURATION RG-3

(C) The amount of adverse yaw due to aileron stick inputs was again the factor which drew the most frequent objection from the evaluation pilots. The CAL pilot commented that the roll rate due to aileron stick motions was low in comparison to the amount of sideslip generated. The MAR pilot, while concerned by the magnitude of β, thought that the roll rate was adequate. Both pilots had some problems with precise bank angle control due to the fact that the amount of rudder needed to counteract the sideslip excursion excited by the aileron resulted in a sufficiently large rolling velocity that a tendency to overshoot resulted. This effect was accentuated by the relatively low Dutch roll damping. The CAL pilot, after considerable effort, developed a technique for bank angle tasks and turn coordination which he recommends for this configuration. He uses a small amount of rudder into the turn and then, to stop the roll, he smartly neutralized the rudders, perhaps even favoring the opposite direction, when the desired bank angle is achieved. He comments that the light rudder pedal forces make this coordination more difficult than necessary. Neither pilot experienced any difficulty with heading control, experiencing at worst a small symmetric yaw oscillation. The MAR pilot saw no significant effects due to the random noise inputs, however, the CAL pilot did detect a slight roll-sideslip oscillation which, while annoying, did not downgrade the handling qualities. The MAR pilot added "weak roll damping" to his objection concerning adverse yaw in listing the configuration's "bad" features. The excellent longitudinal characteristics in the re-entry glide condition, described in Section A. 3, did not degrade the overall rating of A4. 5 given by the CAL pilot, and A4. 0 given by the MAR pilot.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert \phi/\beta \rvert_d$	$\frac{1}{\omega_\phi}\lvert \phi/\beta \rvert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.12	.207	.596	-16.0	5.52	5.52	2.0	34.0			SOLID LINE IS DESIRED
CAL	760	2.73	.25	—	—	6.94	6.94	2.04	—	[illegible]		— — —
HOR	767	3.37	.20	—	—	—	—	1.87/1.72	31.0/31.2	[illegible]		- - - - - -

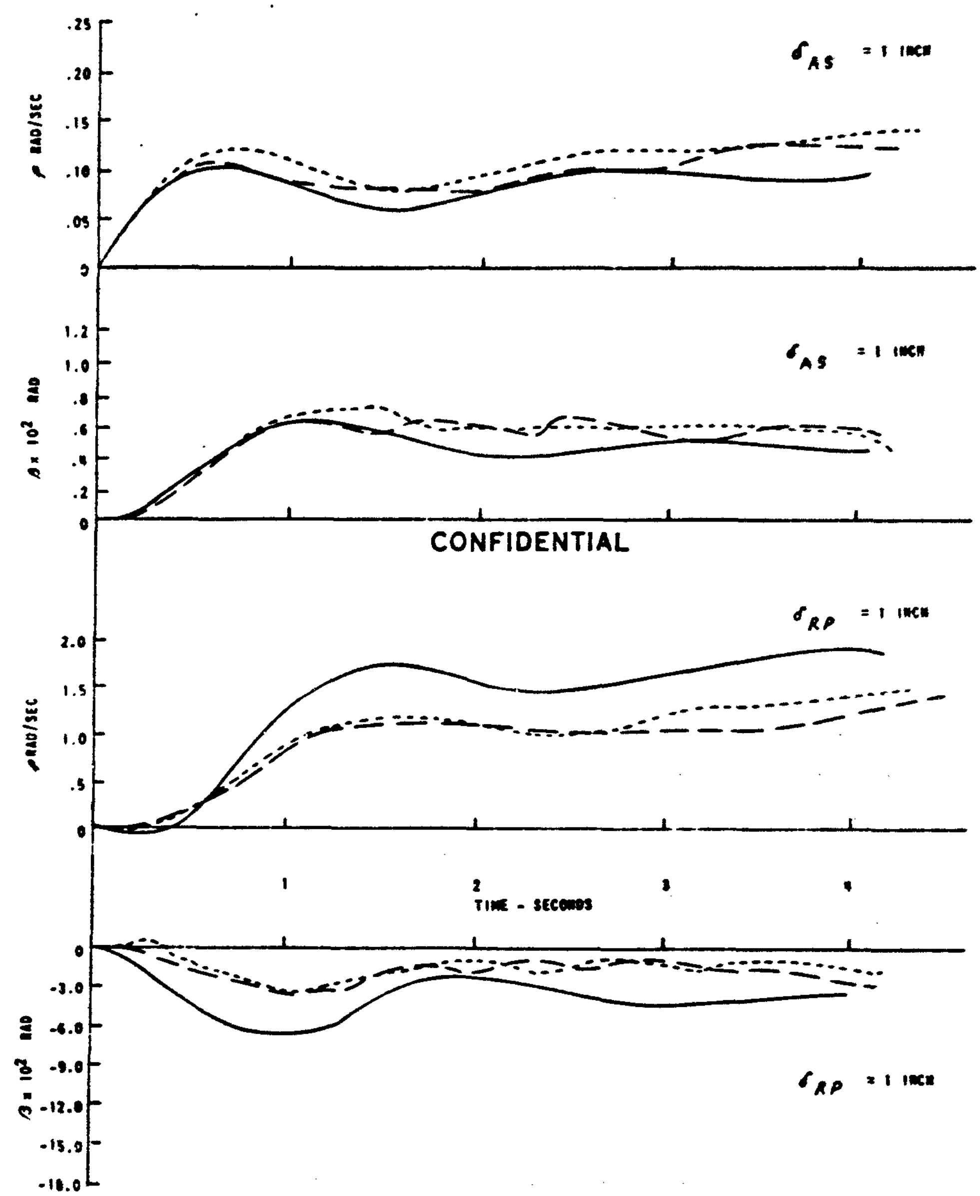


Figure A-4 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-4

RG-5

(C) Once again there was an excellent agreement between the CAL and MAR pilots on the degrading effects of excessive adverse yaw due to aileron. The accompanying graph indicates sideslips on the order of .009 radians per inch of aileron stick were achieved. This level, as indicated by the comments on configuration RG-2, is considered excessive, and with the rudder pedal control available, some very real difficulty in coordination is experienced, requiring a degree of concentration and attention from the pilot, which calls for ratings in the A5 area. This feature makes turn coordination and precise bank angle control quite difficult, especially in light of the roll response to rudder pedal inputs which the CAL pilot described as "slow in roll at first, then increasing rapidly - very difficult to anticipate." This combination of responses tends to be conducive to a pilot-induced roll oscillation. For example, an aileron stick input to the right requires considerable right rudder to keep the ball centered, and the rudder movement results in additional roll rate in the same clockwise direction. This calls for opposite aileron stick to check the roll rate which in turn calls for opposite rudder to keep the sideslip zero. These actions may well cut the roll rate to below the desired level requiring a repeat of the entire cycle. In this particular configuration, the pilots were able to damp this oscillation in a few cycles with some concentration. Both aileron stick and rudder pedal forces, gradients and feel were reported satisfactory. Maintaining a given heading presented no problems while the adverse yaw problem made changing heading somewhat more difficult. The aircraft was easy to trim about all axes. Control harmony was also good. No special techniques are required other than concentration. The mechanism for cc ·dinated, adequate response exists; it simply takes considerable effort to achieve it. The longitudinal characteristics (see Section A. 3) presented no problems. The CAL and MAR pilots both gave an overall rating of A5. 0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	[illegible]	ζ_{AS}/ζ_{AS}	[illegible]	P.R.	REMARKS	LEGEND
DESIRED		2.12	.287	.500	-10.0	5.52	5.52	2.0	26.0			SOLID LINE IS DESIRED
CAL	770	2.06	.21	–	–	–	6.08	1.07	25.0/23.0	59.0		— — —
NAG	793	3.30	.32	–	–	–	–	–	–	45.0		- - - - - -

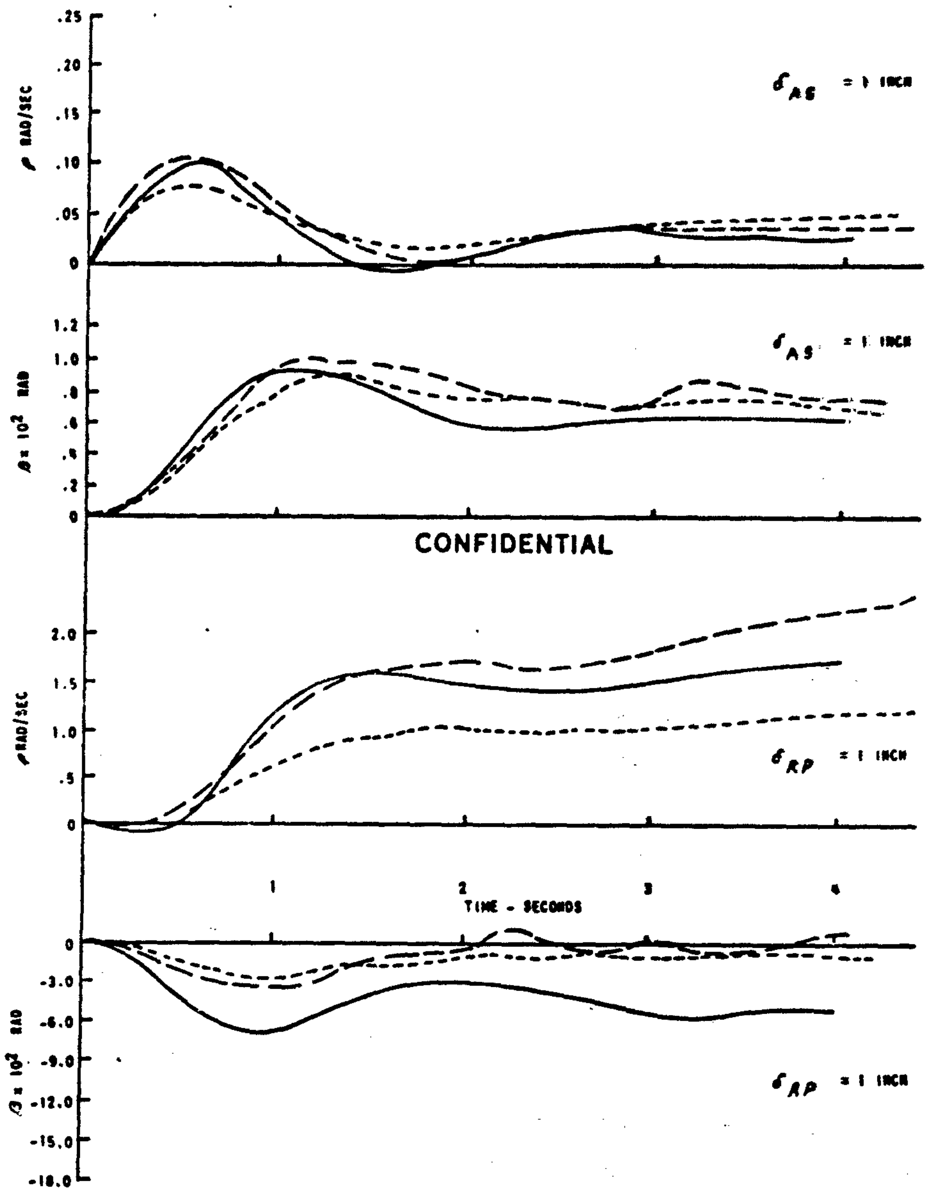


Figure A-5 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-5

(C) A difference of opinion arose with respect to the adequacy of the roll response due to aileron stick inputs. The CAL pilot felt that there was too little roll performance and that the aileron stick produced mostly sideslip. He felt that the rudder was very effective in producing roll rate but that the light rudder pedal force gradient made precise control difficult. He found he had good bank angle control with aileron stick alone but the accompanying slowness of the response was objectionable. The MAR pilot on the other hand had no such objections. He found excellent response in roll and did not note any objections to rudder pedal control. He seemed pleased with every aspect of the vehicle's behavior and gave it an excellent rating of A1.5. An investigation into the gain settings and the responses to both automatic and manual inputs failed to reveal any discrepancies between the two flights and no explanation can be offered for the conflicting pilot comments. The recorded time histories would suggest that RG-6 has more roll authority than RG-4 or RG-5 and less β/δ_{AS}. One would think that this feature would result in slightly better ratings for RG-6, as confirmed by the MAR pilot's rating but not by the CAL rating (A5.0). Both pilots agreed that the longitudinal control was excellent (Section A.3).

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	[illegible]	[illegible]	[illegible]	[illegible]	P.R.	COMMENTS	LEGEND
DESIRED		[illegible]	[illegible]	[illegible]	-10.0	[illegible]	[illegible]	2.0	[illegible]			SOLID LINE IS DESIRED
CAL	700	3.00	.31	–	–	[illegible]	[illegible]	1.00	–	[illegible]	POOR TRIM ON δ_{RP} STEP	— — —
[illegible]	700	[illegible]	.31	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]		- - - - - - -

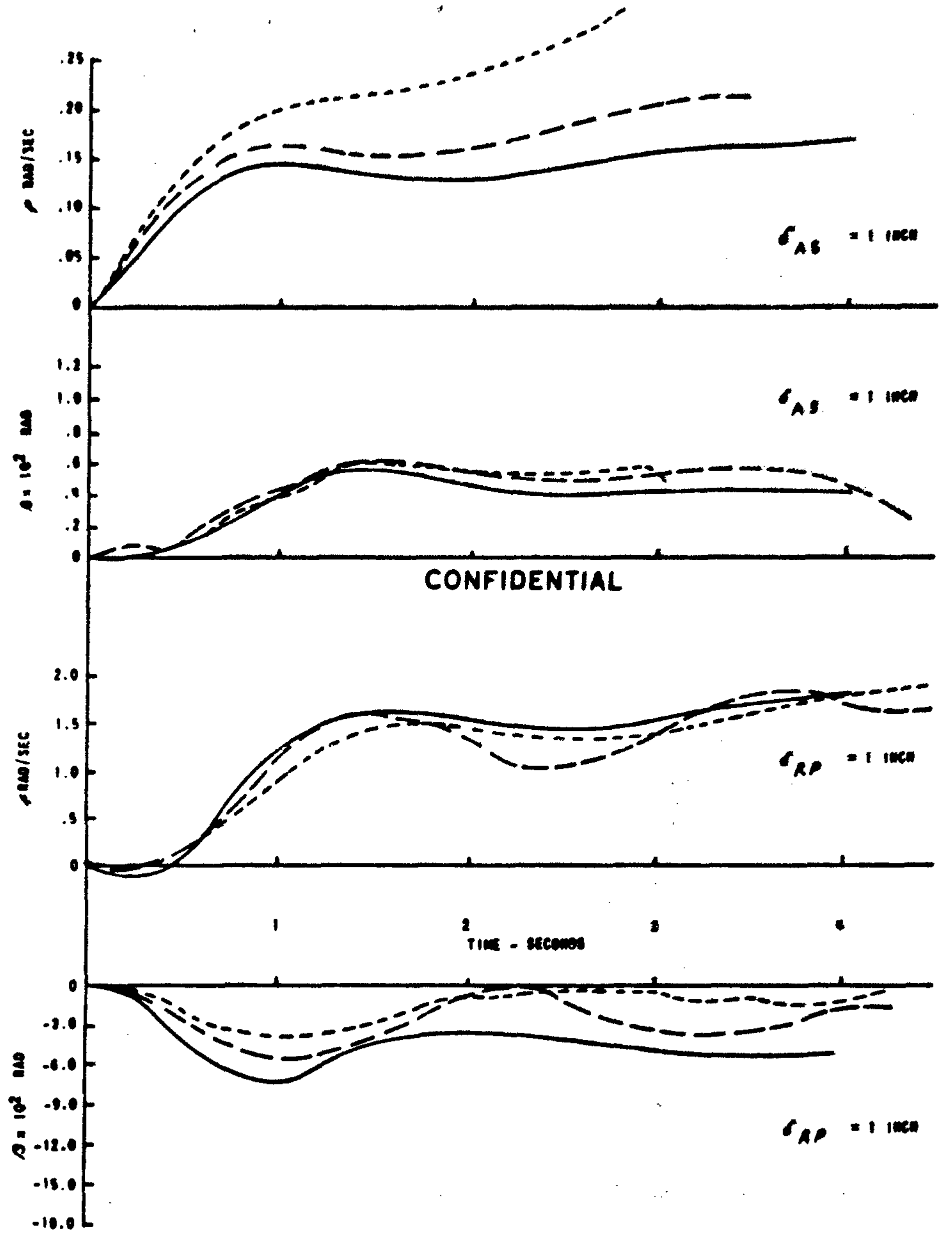


Figure A-6 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-6

(C) The matching technique used for the RG-7, 8, 9 series (as explained in Section IV) was not as successful as the technique used on the other cases. Consequently the fits to the desired curves are not good and the pilot comments must be interpreted in the light of the actual responses obtained. The adverse yaw due to aileron achieved on RG-7 on the CAL flight and first MAR flight is excessive, and increases without bounds for step inputs. The roll rate response starts out in a conventional manner, stops, then reverses. In addition, both the roll and sideslip increase continually for rudder pedal inputs. The sideslip is especially sensitive to rudder pedal inputs -- a situation made more difficult by the very light rudder pedal force gradient. Both pilots found that bank angle precision was extremely low and that undivided attention was required of the pilot in order to achieve any reasonable measure of control. The aircraft was very difficult to trim lateral-directionally, and random noise inputs resulted in continual, large, unacceptable sideslip excursions. The aircraft appeared to have reasonable Dutch roll damping and low ϕ/β ratio. The longitudinal control described in Section A. 3 was good; however, the very poor lateral-directional dynamics made the vehicle unacceptable for the re-entry glide mission. The CAL pilot rated it as U8.0 and the MAR pilot 10.0, although he did not indicate in his comments that the vehicle was uncontrollable. In an attempt to improve the simulation, changes were made to the gain settings and the vehicle reflown by the MAR pilot on Flight 788. The improvement on p and β responses to δ_{AS} inputs is shown on the graphs, and consequently the MAR pilot rated this "new" configuration as U7.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left|\frac{\phi}{\beta}\right|_d$	[illegible]	σ_{AS}/δ_{AS}	σ_{RP}/δ_{RP}	P.O.	COMMENTS	LEGEND
DESIRED		3.13	.076	1.00	-10.7	6.10	9.10	2.0	25.0			SOLID LINE IS DESIRED
CAL	700	6.00	.06	—	—	—	—	2.0	30.0	55.0	HIGHLY DAMPED	
[illegible]	700	—	—	—	—	—	—	2.0	30.0	10.0	AND LARGE	
[illegible]	700	—	—	—	—	—	—	1.08/2.11	57.1/25.0	67.0	DISTURBANCES	

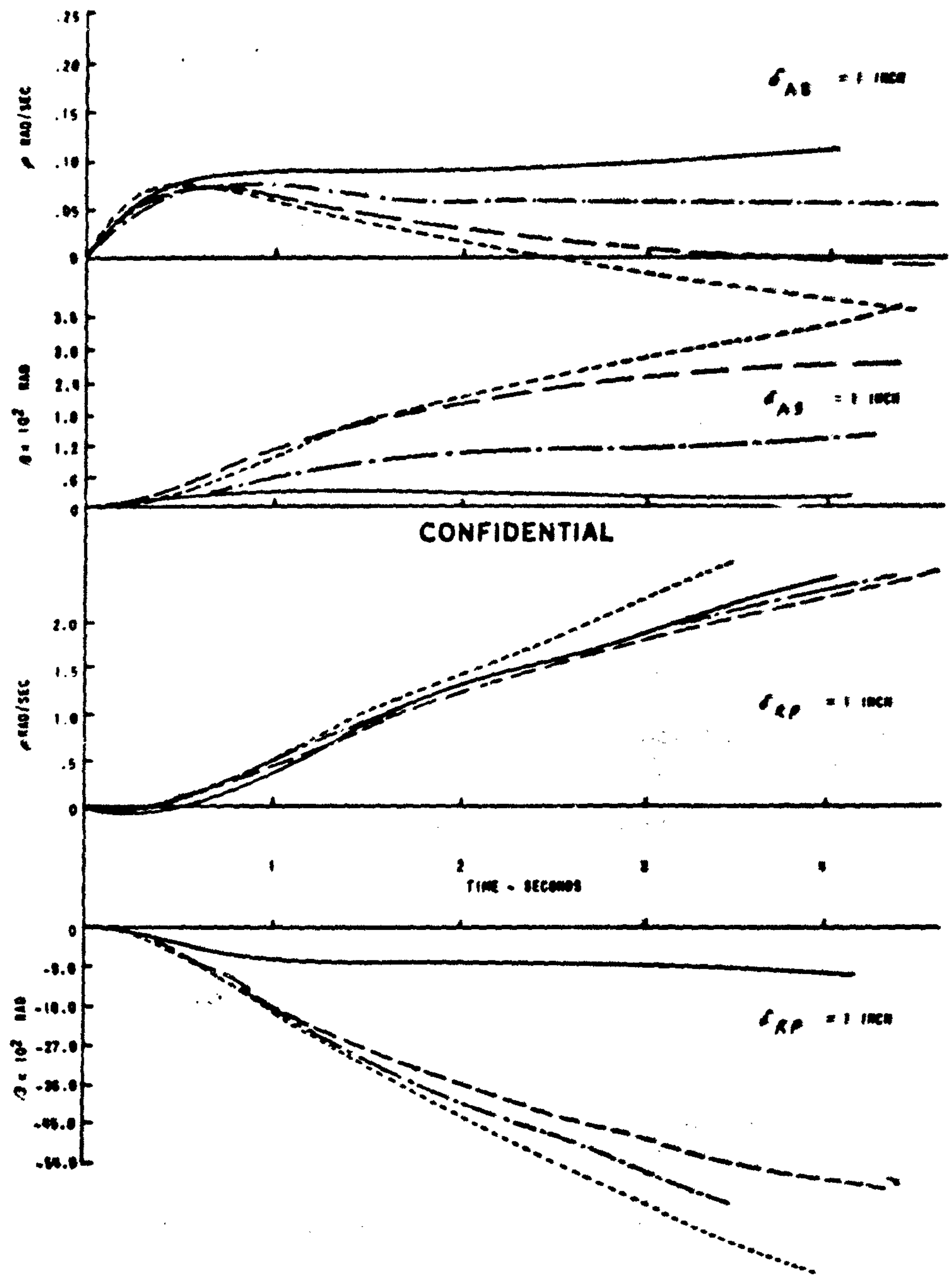


Figure A-7 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (σ_{AS}, σ_{RP}) FOR CONFIGURATION RG-7

(C) This configuration had essentially the same bad features as RG-7, namely very large increasing sideslip response to both aileron stick and rudder pedal inputs. The same difficulties with accurate bank angle and heading control were experienced. The sideslip to rudder response was particularly sensitive. This made coordination quite difficult to achieve, especially with the light rudder pedal force gradient. Again the aircraft was sensitive in sideslip to random noise, and was quite difficult to trim lateral-directionally. Full time pilot attention was required for the simplest maneuvers and it was quite clear to both pilots that the configuration was unacceptable for the re-entry mission. The CAL pilot noted that both aileron and rudder produced large sideslip, so that one could be worked against the other to coordinate. This required considerable effort however, and the least distraction resulted in poor performance. The CAL rating was U7.0 and the MAR rating U8.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert\phi/\beta\rvert_d$	[illegible]	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.13	.076	1.00	-10.7	0.10	0.10	2.0	44.0			DOTTED LINE IS DESIRED
CAL	771	NO RECORDS TAKEN - SEVERE TURBULENCE				—	—	—	—	7.0		
HRB	791	—	—	—	—	—	—	2.06/1.77	34.7/38.6	3.0		

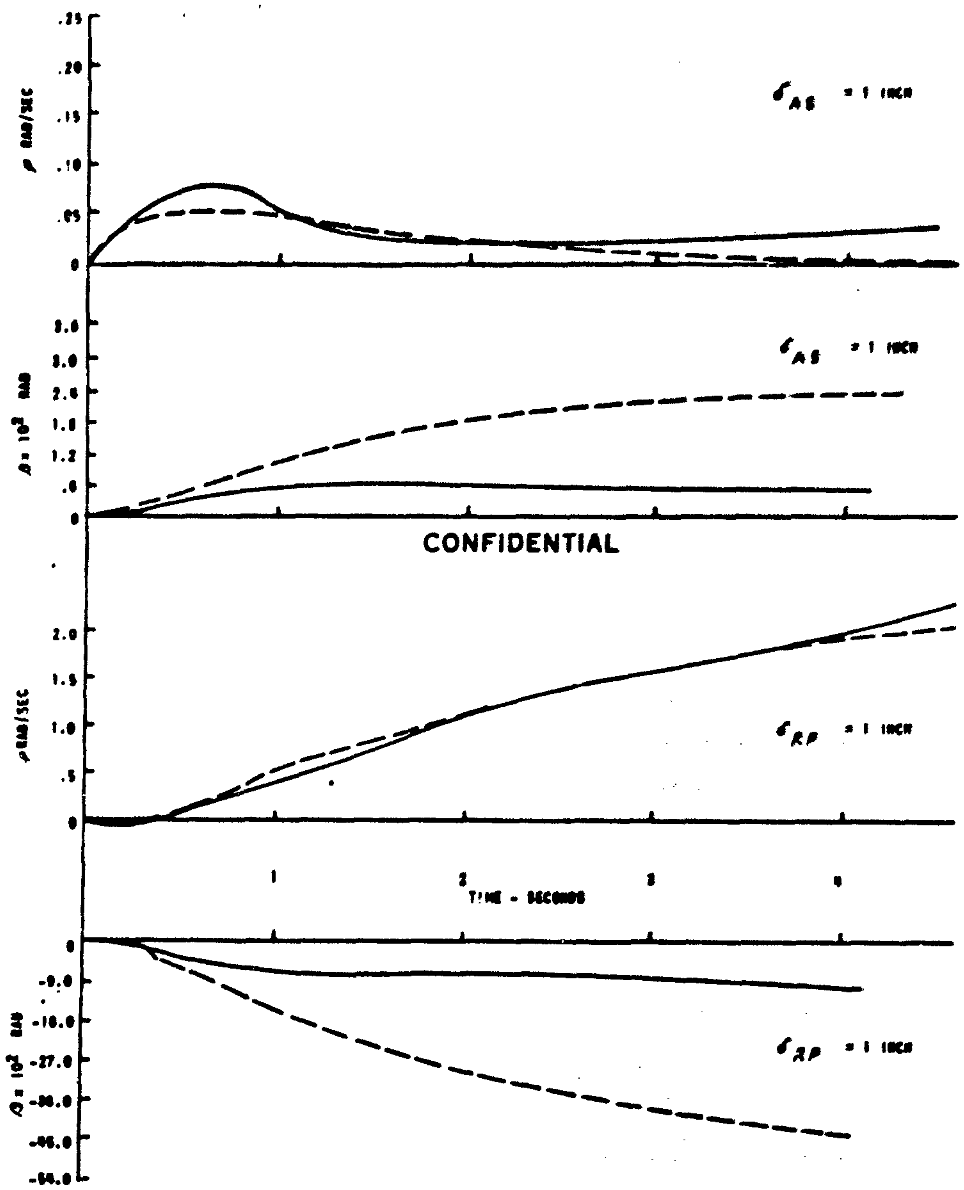


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Figure A-8 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-8

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(C) The same basic problems existed on the simulation of this case as in RG-7 and RG-8. Specifically, far too much adverse yaw is present for aileron stick inputs and the corresponding roll rate is lower. The same rudder pedal responses existed. The CAL pilot again commented on the effectiveness of the rudder pedals in producing sideslip, which, with the very light rudder pedal force gradient, makes it difficult to use effectively, and required continual pilot attention. Sideslip excursions were once more excessive in random noise. The CAL pilot reported that unlike RG-7 and RG-8, the aircraft could be trimmed lateral-directionally if exactly the right combination of rudder and aileron trim were discovered. This took some time and effort. The CAL pilot found that he did have some success in controlling the vehicle and that an A6.0 was a reasonable reflection of his difficulties, and a definite indication that RG-9 was the best of the RG-7, 8, 9 series. The MAR pilot rated it 10.0 as he had done on his first RG-6 flight, although he again failed to indicate anywhere in his comments that the vehicle was uncontrollable.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	[illegible]	[illegible]	[illegible]	[illegible]	P.R.	COMMENTS	LEGEND
DESIRED		3.13	.075	1.00	-10.7	[illegible]	[illegible]	2.0	[illegible]			SOLID LINE IS DESIRED
CAL	700	NO SUITABLE RECORD		–	–	–	–	2.01	[illegible]	45.0		— — —
[illegible]	700	NO SUITABLE RECORD		–	–	–	–	[illegible]	[illegible]	16.0		- - - - -

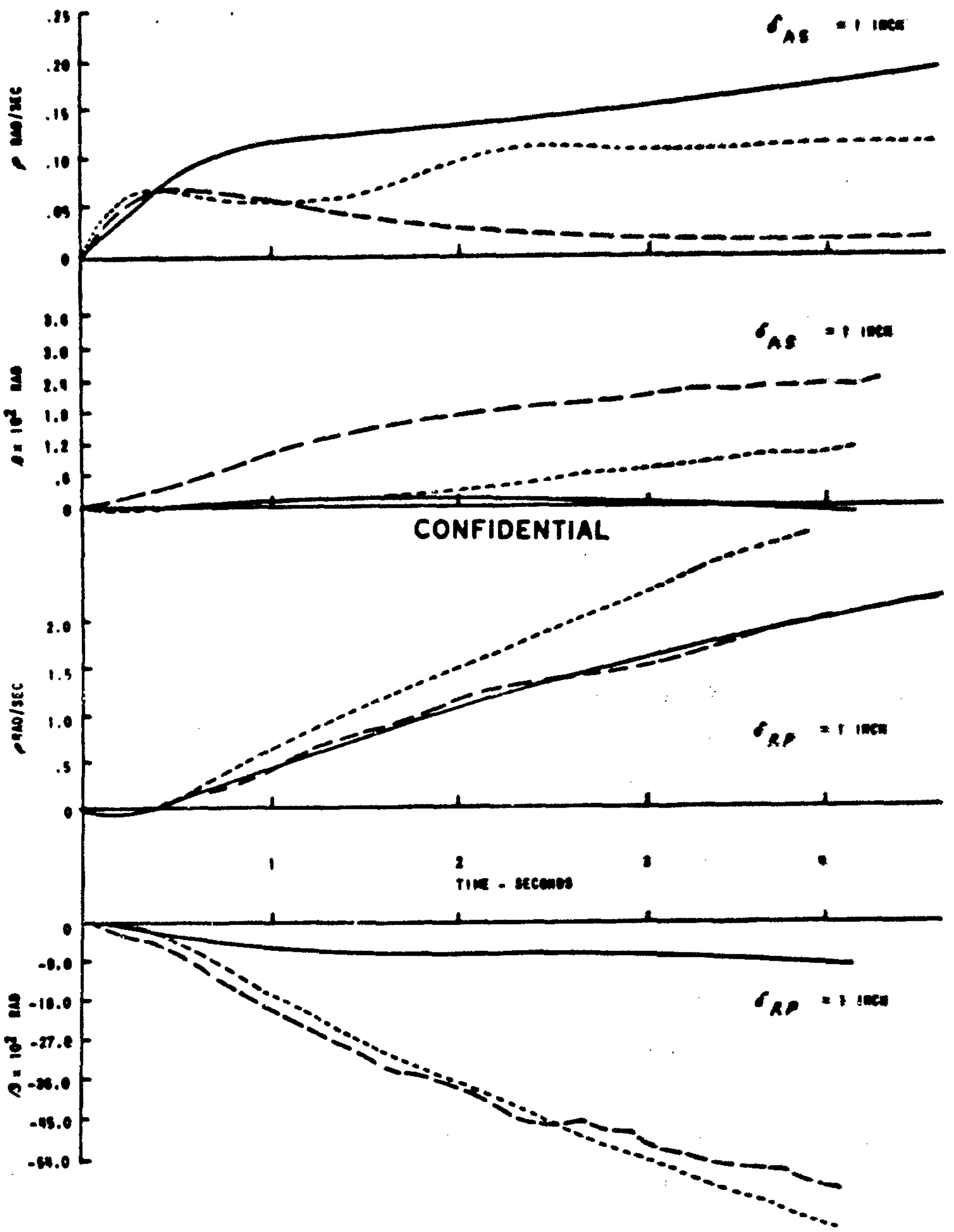
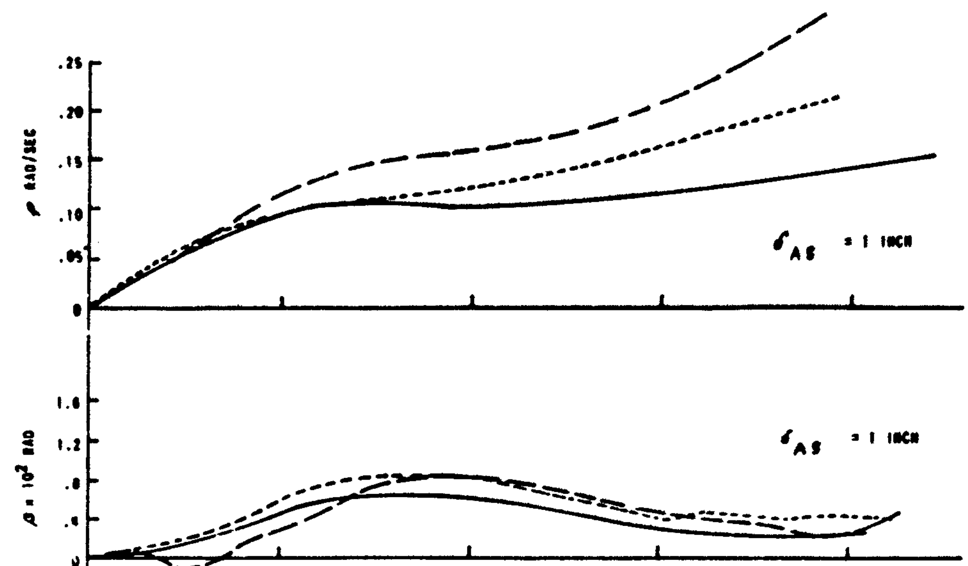


Figure A-9 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION RG-9

(C) The roll mode time constants for the boost configurations are larger than in any other flight conditions, being on the order of 1 1/4 seconds. The spiral mode is unstable, having a time constant of approximately 14 seconds. These two conditions, combined with the low $|\phi/\beta|$ (about 3), result in a roll rate response which makes the aileron stick appear acceleration-ordering. This precipitated pilot comments complaining of low roll damping and the requirement for opposite aileron stick to arrest roll rates. In the case of BA-1, the "fair amount" of adverse yaw is difficult to zero since these opposite aileron stick motions require opposite rudder, and considerable dancing on the rudder pedals results. Luckily, the roll rate and sideslip response to rudder pedals are quite satisfactory (unlike some of the tricky responses in some re-entry glide cases), and this aids the coordination problem. Both pilots noted light roll damping and fair amount of adverse yaw in response to aileron stick inputs. The CAL pilot felt that the magnitude of the roll response was adequate despite the slow rate of growth, while the MAR pilot was particularly displeased with this feature. Both pilots had little difficulty with turn coordination; however, precise bank angle control required careful attention to avoid overshooting due to roll acceleration. This feature had similar effects, but to a lesser degree, on the pilots' ability to change heading precisely. Both aileron stick and rudder pedal forces, gradients and feel were reported satisfactory. The CAL pilot noted that the configuration seemed to be a bit lightly damped directionally. The CAL pilot felt that reasonable attention was required for coordination of the adverse yaw due to aileron, and that the roll acceleration could also be controlled with moderate effort. He gave an overall rating of A3.5. (The longitudinal characteristics, described in Section A.3, posed no particular problems.) The MAR pilot remarked that he would give the configuration a rating of A3.0 to A4.0 if it were not for the roll damping, which annoyed him considerably. There is some suggestion that he was not willing to give this feature the amount of attention it required of him. He felt it should be fixed up. His rating therefore dropped to A5.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\lvert\frac{\phi}{\beta}\right\rvert_d$	$\frac{\omega_\phi}{\omega_d}\left\lvert\frac{\phi}{\beta}\right\rvert_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.07	.17	1.36	-12.6	1.07	1.07	2.0	34.4			SOLID LINE IS DESIRED
CAL	779	2.12/2.10	.22/.22	–	–	–	2.08/2.08	1.77	30.7	43.5		— — —
MDG	777	2.00	.10	–	–	–	2.70	1.07	35.0	45.0		....



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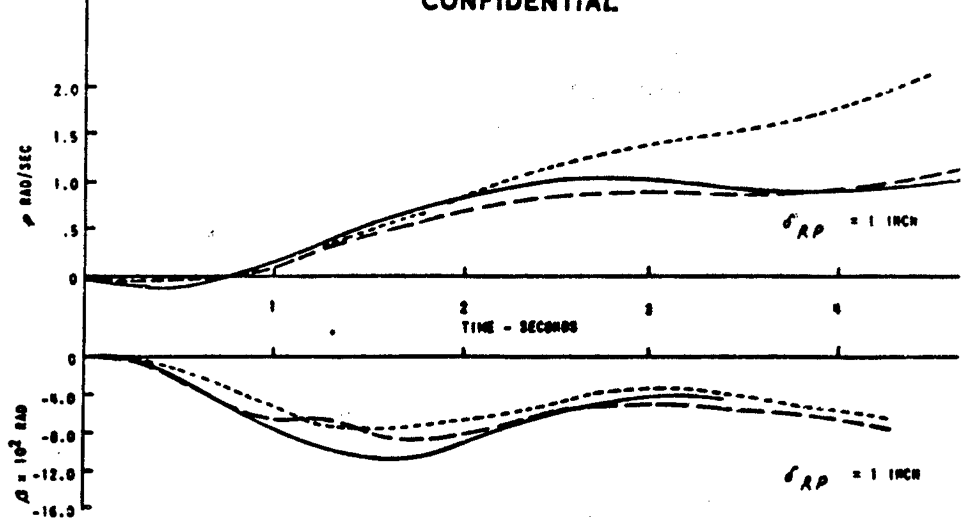

Figure A-10 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-1

(C) The change in interconnect ratio between the rudder and aileron for aileron stick inputs resulted in considerably higher adverse yaw than BA-1. At the same time it helped bring down the roll acceleration, at least after the first second following a δ_{AS} step. Consequently, there were far more complaints about sideslip and less about roll acceleration than in the BA-1 case. The "excessive" sideslip reached .012 rad/inch of aileron stick displacement. The CAL pilot found the response to rudder pedals sufficient in sideslip and roll that by feeding in rudder proportional to aileron, he experienced no problems with coordination, although he had to devote a great deal of his time to it. For small bank angle tasks, the roll response is again acceleration dominant, resulting in the requirement for opposite δ_{AS} inputs to stop the roll rate. These inputs, accompanied by the large adverse yaw, require rudder inputs, and considerable coordination of the two controls is needed. Random noise inputs cause lightly damped oscillations in roll and yaw requiring extra effort and attention by the pilot. The CAL pilot felt that both the aileron stick and rudder pedal forces, gradients and feel characteristics were satisfactory. The MAR pilot felt that the aileron stick forces were a "little bit high" and the rudder pedal forces too light for the sensitivity. He commented that the longitudinal forces were too high (see Section A. 3), resulting in poor control harmony. Turn coordination was easily learned by the CAL pilot making heading control "not at all difficult", while the MAR pilot said that turn coordination was "very difficult" making heading control a definite problem. The high adverse yaw for aileron inputs was the dominant bad feature of this configuration for both pilots. Pilot ratings from the CAL and MAR pilots were A5.0 and A5.5, respectively.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\lvert\phi/\beta\rvert_d$	$\lvert\phi/\beta\rvert_d$	p_{AS}/δ_{AS}	r_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.07	.17	1.36	-12.6	3.07	3.07	2.0	39.4			SOLID LINE IS DESIRED
AL	779	1.99	.175	—	—	—	3.17	1.06	39.6	A5.0		— — —
MAR	791	1.98	.17	—	—	—	3.01	2.02/2.10	37.6/39.4	A5.5		- - - - - -

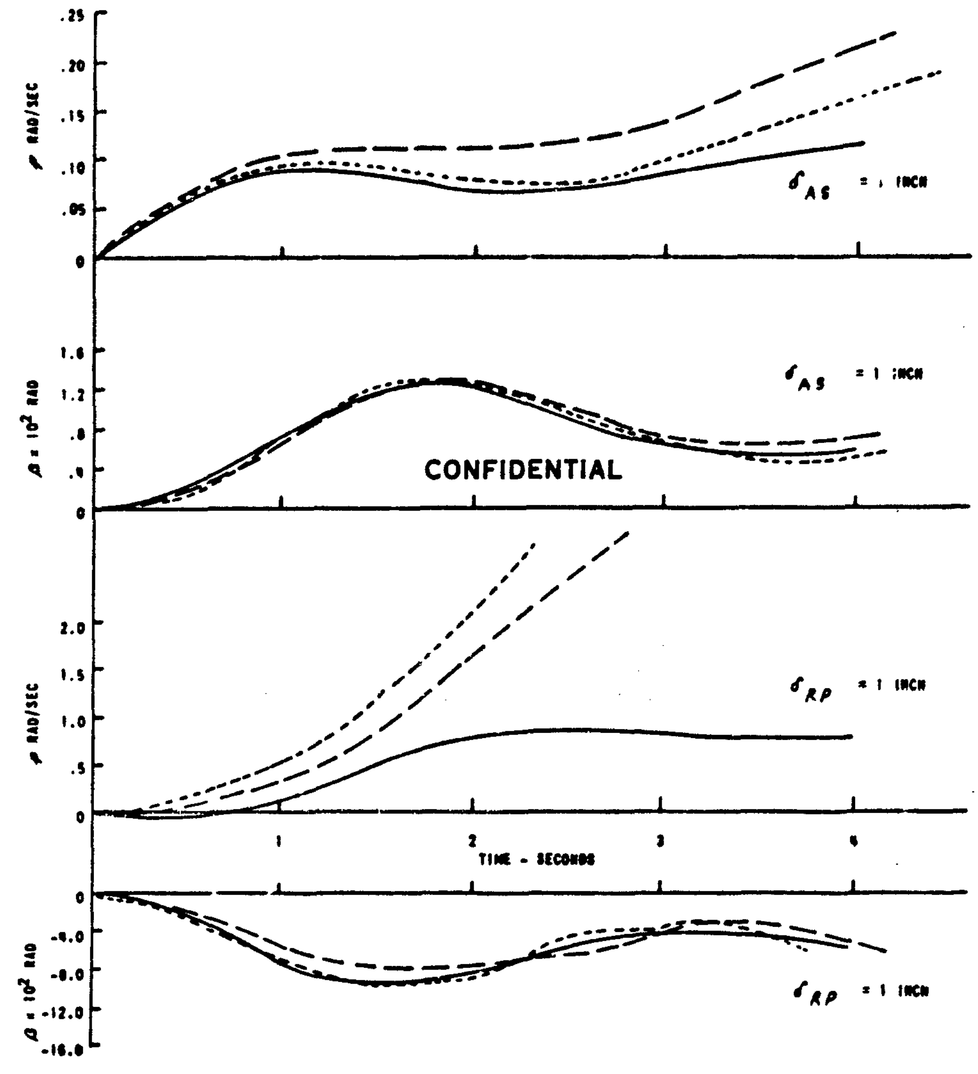

Figure A-11 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-2

(C) The roll acceleration problem is the dominant feature of this configuration. The ever-increasing roll rate for aileron stick inputs (see opposite page) is unsatisfactory to pilots accustomed to rate-ordering controls. Bank angle precision becomes a definite problem, with overshoots being the rule. The frequent aileron stick inputs necessary are accompanied by adverse yaw which adds to the pilot's difficulty. He must apply rudder in the direction of aileron stick in order to null the sideslip. The roll rate generated by the rudder is in the same sense as commanded by the aileron - a situation which aggravates the roll rate problem. The best performance was found by the CAL pilot to be the result of using very low aileron stick gain and phasing out the aileron as a comfortable roll rate is approached. This technique worked well for the CAL pilot when he devoted continuous attention to it. When he had other cockpit duties, or was asked to perform fast bank angle or heading changes, his performance deteriorated sharply. He felt that the aircraft could get away from him in roll when large δ_{AS} inputs were required and he simultaneously put in the rudder pedal deflection necessary for coordination. He also commented that the rudder pedal forces were too light for the sensitivity. This comment keeps recurring whenever a lot of rudder activity is needed, in any flight condition. Random noise accentuated the bank angle control problem for the CAL pilot, requiring even more of his attention. The MAR pilot felt there were no significant effects from random noise. (NOTE: The MAR pilot was particularly silent on this evaluation. He made no attempt to answer many of the questions on the comment card, and those he did answer were often one or two-word judgments. Consequently, the bulk of the information on this configuration comes from the CAL pilot.) Control harmony was not good since the rudders were much lighter than the aileron and elevator forces. The CAL pilot rated this configuration as U7.0, based mainly on the roll problems, while the MAR pilot gave it a rating of A5.0. Longitudinal characteristics were not troublesome (see Section A.3).

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.07	.17	1.36	-12.6	3.07	3.07	2.0	34.4			SOLID LINE IS DESIRED
CAL	774	2.04	.13	–	–	–	3.23	1.76	32.5	U7.0		— — —
MAR	785	2.21	.12	–	–	–	2.90	1.80	33.8	A5.0		--------

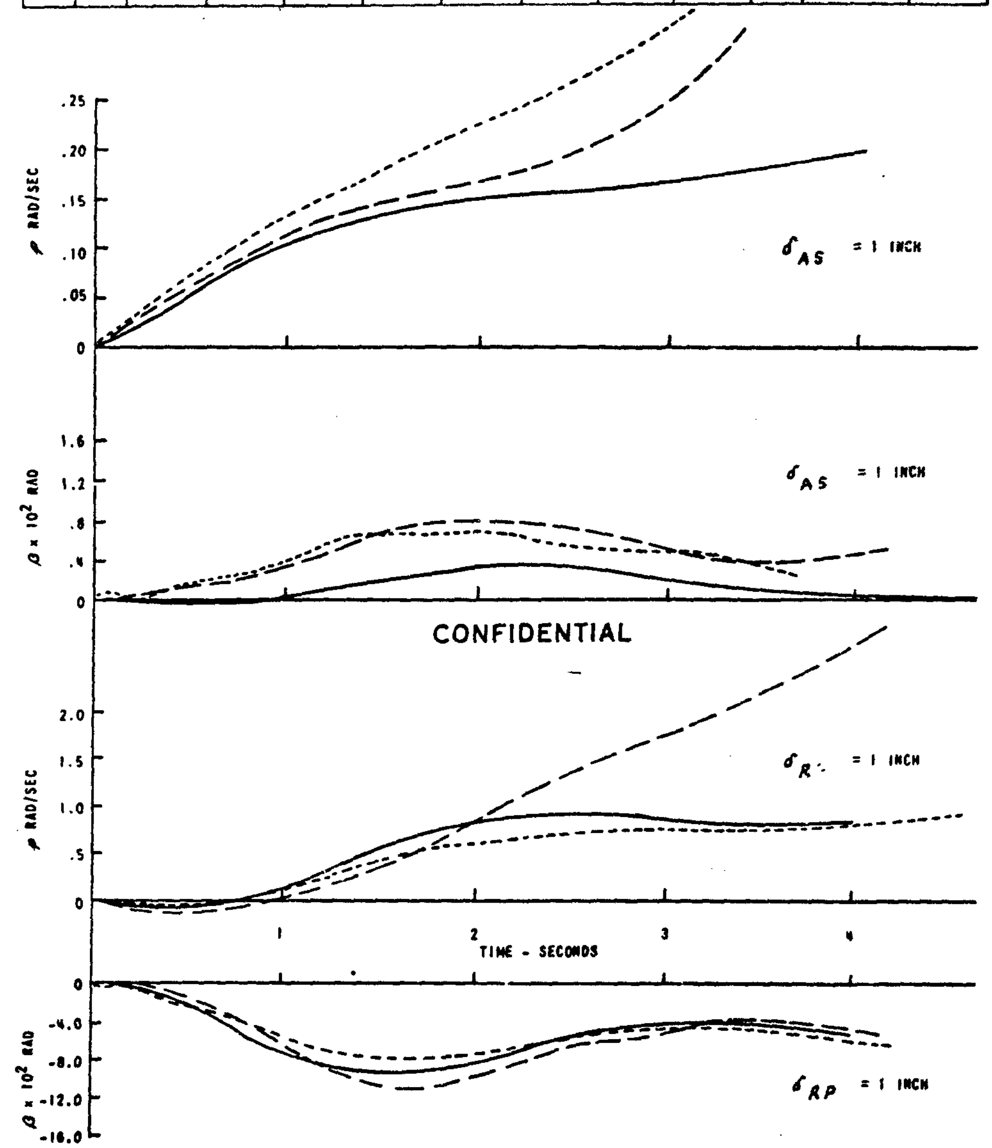

Figure A-12 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-3

(C) Both the roll acceleration and adverse yaw due to aileron problems are again apparent in this configuration to about equal degrees. Aileron stick inputs command roll acceleration and adverse sideslip. Rudder pedal commands, in the direction to null sideslip, result in roll rates which are additive to the initial rates, thus compounding the problem. The light rudder pedal force gradient with this rudder sensitivity makes the situation worse. Consequently, some fancy arm and footwork is called for to achieve adequate coordinated maneuvers. The CAL pilot attempted to lock his rudder pedal inputs to his aileron inputs (with the same sense), and then concentrate on bank angle. This achieved the best compromise between ϕ and β accuracy. Good bank angle control is possible with aileron alone if one is willing to put up with the resulting side accelerations. The weak Dutch roll damping for this case (on the order of .1) does not aid the whole control problem, and is particularly noticeable in natural turbulence or during random noise inputs, where a roll-sideslip oscillation of "bothersome" proportions occurs. The MAR pilot was more annoyed by the roll rates than by the sideslip excursions. Both problems, plus the low directional damping, made heading changes more difficult than desirable, however, maintaining a given heading was not difficult. The CAL pilot gave an overall rating of A4.0 and the MAR pilot gave a U7.5 on his first flight, and an A6.0 on his second flight. It is felt that had the MAR pilot been able to develop a technique similar to the one suggested by the CAL pilot above, he may have been less severe in his ratings. The longitudinal characteristics described in Section A.3 did not contribute significantly to the overall evaluation.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{p}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.07	.102	1.45	-14.4	3.05	3.05	2.0	34.6			SOLID LINE IS DESIRED
CAL	775	1.91	.09	—	—	—	3.27	1.94	34.8	A4.0		— — —
MAR	786	2.02	.10	—	—	—	3.58	1.99/1.92	34.9/34.3	U7.5		-------
MAR	792	1.87	.075	—	—	—	4.19	2.28	33.0	A6.0		— · —

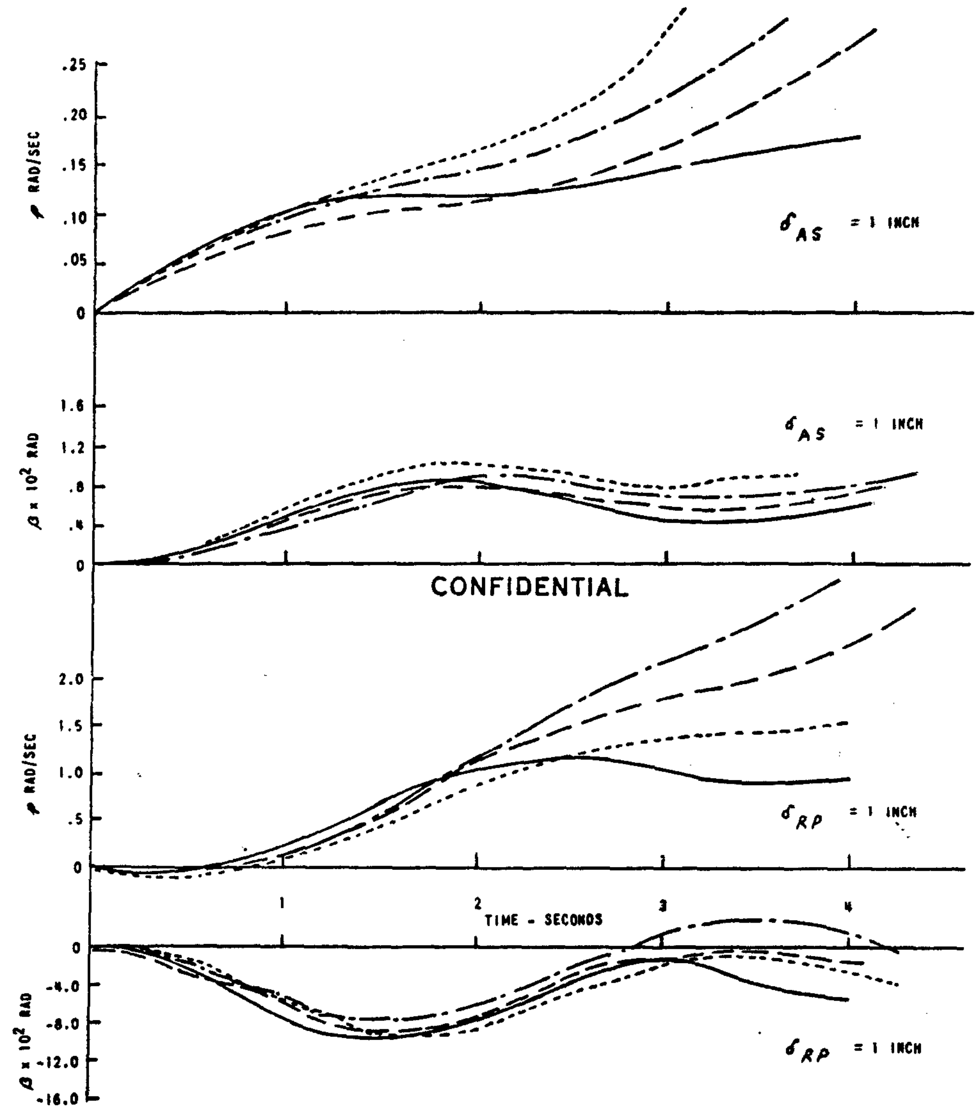

Figure A-13 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-4

(C) The time history p and β responses, compared to the BA-4 case, would indicate some improvement in the roll acceleration problem and a worsening of the adverse yaw problem. The change in interconnect ratio causes more rudder deflection and hence more sideslip for the same δ_{AS} input. This in turn works through L_β to reduce the rolling moment, tending to bring the roll rate down towards a steady-state value rather than an ever-increasing one. For most of the first second, the roll rate is unaffected, however, and the aileron stick still appears to be acceleration ordering. The MAR pilot again commented on his displeasure at this feature. He required full aileron deflections at times to check his roll rate. The resultant high lateral forces, together with the long roll mode time constant, made the lateral system feel "dead," in the words of the MAR pilot. The CAL pilot, using a technique similar to that used in the BA-4 flight, had less difficulty with the configuration and was less severe on its shortcomings. He felt the large amount of adverse yaw was the worst feature, not the roll rates. He also said that the response to rudder pedals was quite good, producing adequate amounts of roll rate and sideslip. He had little difficulty with turn coordination, and recommends keeping the pilot's aileron stick gain low to avoid roll rate problems. He further listed a low $|\phi/\beta|$ ratio and the lateral-directional trimmability as good features. The MAR pilot also recommends keeping the roll rates low in order to concentrate on sideslip coordination. The CAL pilot felt that this configuration had the same degree of unpleasant qualities exhibited by BA-4, and gave it an identical rating of A4.0. The MAR pilot also felt the configuration had similar defects to what he had seen in BA-4 and gave a U7.5 rating as he had on Flight 789. The differences of opinion are consistent.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_\phi}\left\|\frac{\phi}{\beta}\right\|_d$	$\dot{p}_{AS}/\delta_{AS}$	$\dot{p}_{RP}/\delta_{RP}$	P.R.	REMARKS	LEGEND
DESIRED		2.07	.102	1.45	-14.4	3.05	3.05	2.0	34.4			SOLID LINE IS DESIRED
CAL	776	2.0	.09	—	—	—	3.01	1.85	32.7	A4.0		— — —
HAR	788	2.1	.105	—	—	—	—	2.07/2.0	35.2/35.7	U7.5		------

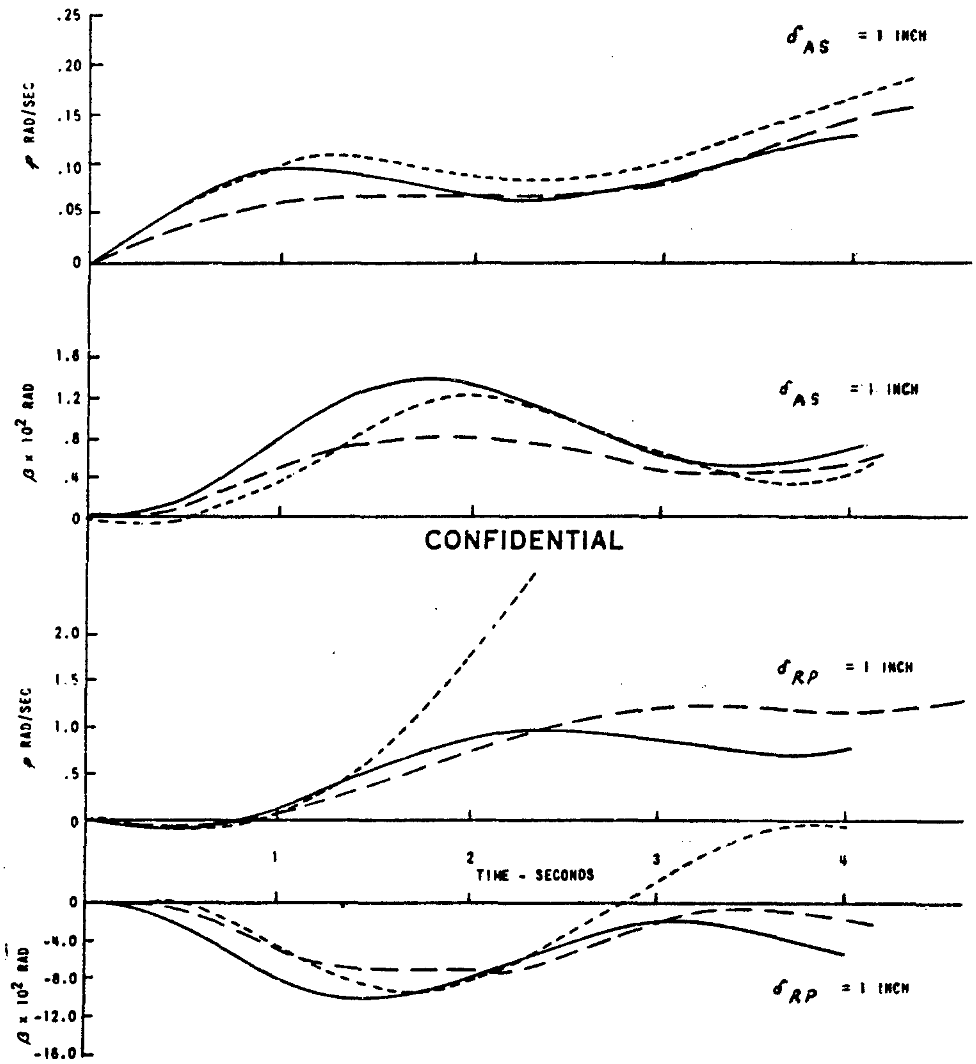

Figure A-14 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-5

(C) Actual time histories of β for this case are very much like BA-4. Likewise the roll rate response is close to BA-4 for the first second and then increases at a faster rate. Both pilots again complained of high adverse yaw due to aileron and acceleration bank angle control. The latter problem drew the loudest complaints mainly in the form of comments on the apparent lack of roll damping. The CAL pilot noted that aileron stick alone produces a "fair" roll rate and a "fair" amount of adverse sideslip. Using rudder pedals to null β results in more roll rate, the combination of which builds p rapidly, often requiring full opposite aileron stick to arrest. Again the MAR pilot's comments were sketchy but there were some indications that he was experiencing the same problem although he did not report any suitable technique for handling the problem. The CAL pilot recommends that the aileron gain should be kept down and enough rudder used to keep β within comfortable limits (not zero since roll rate will build too rapidly) and then aileron stick will be the primary roll controller. Opposite stick inputs are required to check or stop roll rate. The MAR pilot felt precise bank angle control was "not possible," while the CAL pilot, using the above technique, was able to achieve a satisfactory performance on ϕ tasks which are not to be executed quickly. The aircraft holds heading quite well but the roll problem is evident when making heading changes. In random noise, the configuration is "quite rolly" and both pilots felt it downgraded performance and required more pilot concentration. The CAL pilot again commented on the light rudder pedal forces for the amount of sensitivity. The MAR pilot said that the aileron stick forces "seem high." Although there were some differences of opinion on the longitudinal handling qualities (see Section A. 3), the obvious roll problem was the dominant degrading feature of BA-6. The CAL pilot rated it as A6. 0, and the MAR pilot as A6. 5.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.07	.102	1.45	-14.4	3.06	3.05	2.0	34.4			SOLID LINE IS DESIRED
CAL	776	1.81	.09	—	—	—	3.5	1.88	36.2	A6.0		— — —
MAR	780	1.86	.09	—	—	—	—	1.86/1.83	31.0/30.2	A6.5		- - - - - -

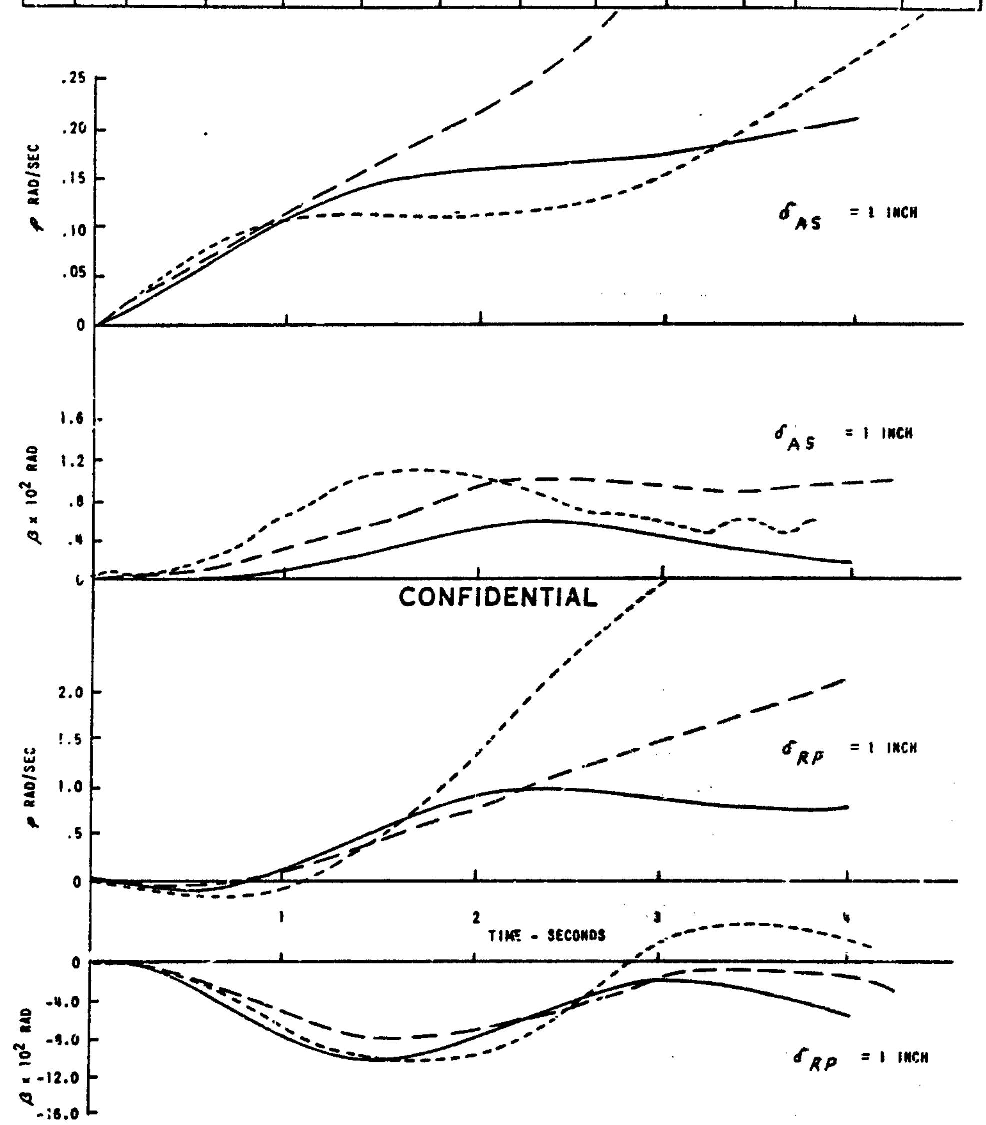

Figure A-15 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-6

(C) This configuration was flown on one occasion by each of the four pilots. The USAF and NASA pilots did not comment as much as other cases, making it difficult for the reviewer to pinpoint the nature of their complaints. The CAL pilot found a lightly damped roll response to aileron stick inputs which was adequate as roll rate but excited a "fair amount" of sideslip. He further found himself operating in an area where opposite aileron stick inputs were required to stop the roll rate and this of course resulted in sideslip of opposite direction. The rudder pedals were found to be quite sensitive in producing both β and φ -- a situation aggravated by low rudder pedal forces and gradient. This resulted in the CAL pilot experiencing some difficulty with good coordination, and resulting loss of precise bank angle and heading control. He recommends flying "with moderation" in respect to roll rate so that large rudder inputs are not required, which would complicate the control problem. The MAR pilot again displays less sensitivity to sideslip excursions and hence he finds it less necessary to use rudders. His main objection is to the low roll damping. He does not explain any techniques he may have used for turn coordination, bank angle or heading control, except to say that these maneuvers are possible with concentration. The NASA pilot mentions that the adverse yaw he experiences is not objectionable, and after trying the rudders, he recommends aileron-alone flight. There was a definite difference of opinion as to the effects of the random noise inputs. The MAR pilot reported "no significant effects"; the CAL pilot observed a roll-sideslip oscillation which definitely increased his workload; the USAF pilot felt the mission could not be accomplished satisfactorily in random noise; and the NASA pilot had no comment. The USAF and NASA pilots did not like the pitch response on this flight (see Section A.3), while the MAR pilot gave the longitudinal characteristics on this flight the best rating of all the BA cases he flew. Despite the differences in verbal opinion, and the difference in pilot evaluation techniques, the ratings were only 1.5 units apart. They were: MAR A2.5, USAF A3.0, NASA A3.5, CAL A4.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{p}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.00	.200	1.19	-16.6	2.02	2.03	2.0	34.4			SOLID LINE IS DESIRED
CAL	775	1.90	.17	—	—	—	2.06	1.90	30.7	A4.0		
MAR	781	1.75	.16	—	—	2.06	3.62	2.05/2.00	38.0/33.0	A2.5		
USAF	705	2.22	.105	—	—	—	2.64	—	—	A3.0		
NASA	707	2.05	.16	—	—	—	3.13	—	—	A3.5		

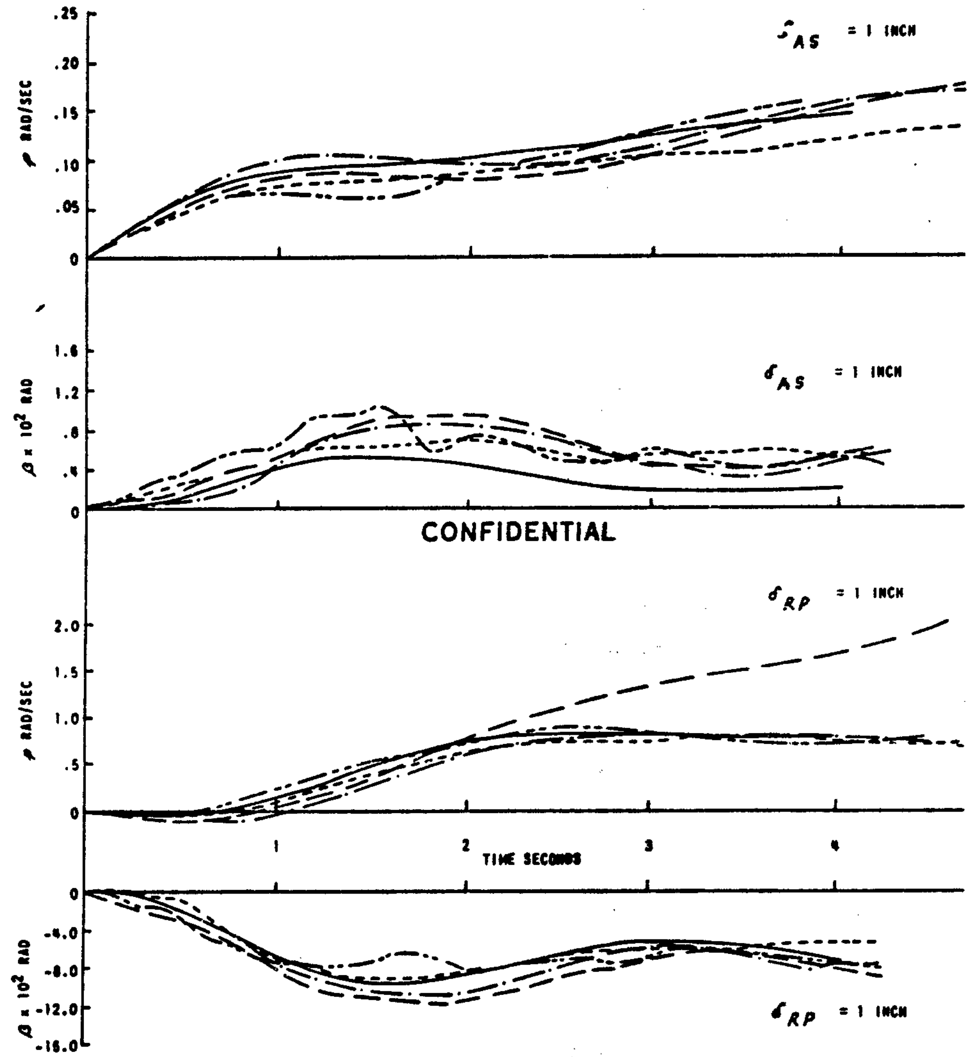

Figure A-16 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-7

(C) The lower roll power compared to BA-7 was noticed by the CAL pilot who found he had to put in large δ_{AS} deflections to achieve adequate roll rate when using aileron stick alone. He felt that with the existing gradient, the resulting aileron stick forces were too heavy. He also found the adverse yaw due to aileron "excessive". Unlike BA-7, he found that coordination of the sideslip was relatively easy, and recommends that one use a "small, pulse-like rudder input with aileron initially--take it out almost immediately, then as roll rate is stopped with opposite aileron, pulse rudder in the opposite direction". The MAR pilot again objected to the low roll damping primarily; however, he did complain of the high adverse yaw due to aileron. He was not as successful at the coordination task and found that the bank angle accuracy and heading control suffered. There was no indication that he had attempted to use rudders to any degree. The comments on random noise response were very much like those on BA-7. The CAL pilot again noticed a small roll-sideslip oscillation, while the MAR pilot felt there were "no significant effects." Control harmony was termed "quite good" by the CAL pilot, and "fair" by the MAR pilot due to the slightly high longitudinal forces (see Section A.3). The CAL pilot listed only the adverse yaw problem under "bad features", while the MAR pilot added low roll damping and the degree of coordination difficulty. Ratings of A4.0 and A5.0 were given by the CAL and MAR pilots, respectively.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.00	.200	1.10	-16.6	2.93	2.83	2.0	30.0			SOLID LINE IS DESIRED
CAL	776	1.94	.17	—	—	—	2.54	—	—	A4.0		— — —
MAR	702	2.5	.12	—	—	—	—	2.05	35.0	A4.5		- - - - - - -

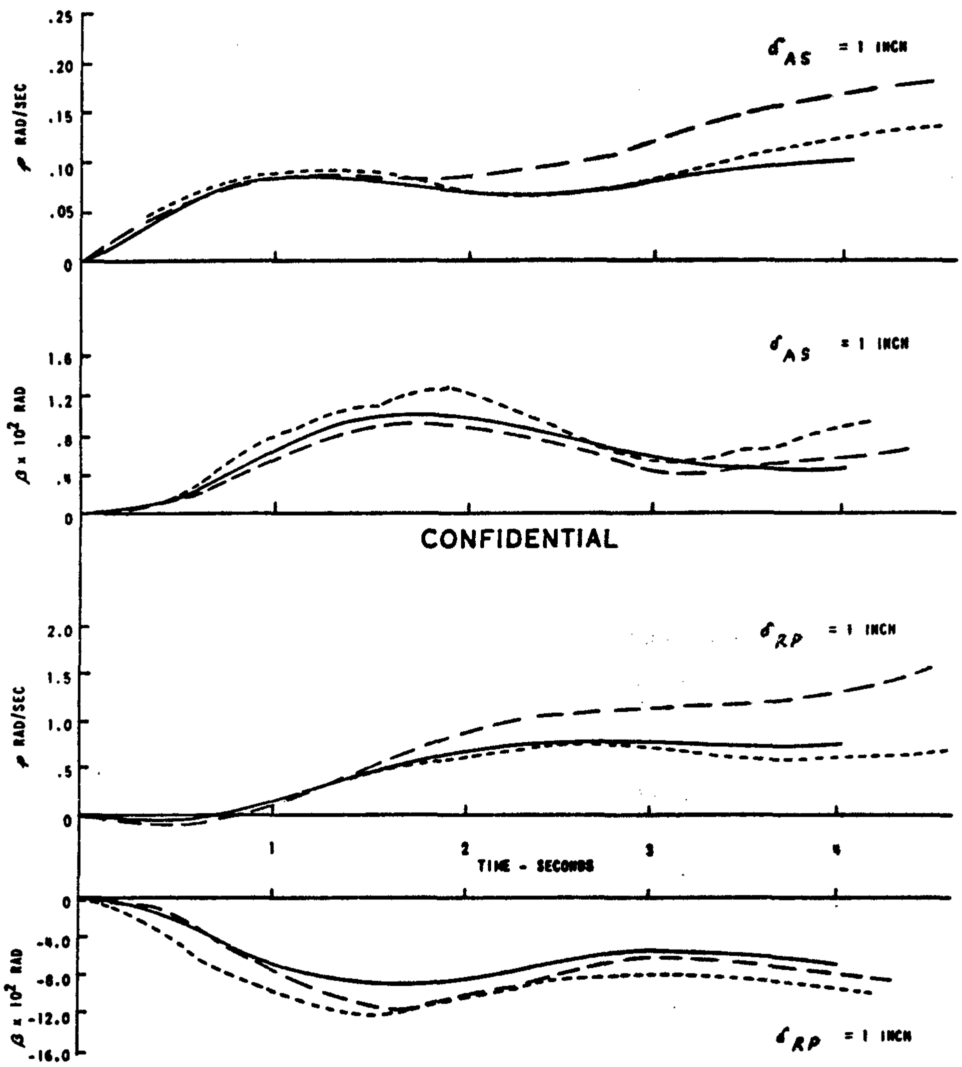

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Figure A-17 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-8

(C) The higher roll power over BA-8 was acknowledged by the CAL pilot, who found that large aileron stick deflections and gradients were no longer required. The amount of adverse yaw due to aileron was again thought to be "large" by the CAL pilot, whereas the MAR pilot did not complain about it, and in fact found that little or no pilot effort was required for satisfactory turn coordination with feet off the rudder pedals. He noted again the weak roll damping. The CAL pilot found that his adverse yaw could be coordinated quite easily by moving the rudder pedals in unison with aileron stick inputs. No rudder was needed in steady-state turns. Heading control and precise bank angle control were performed well with little effort. The CAL pilot once again noted the roll-sideslip oscillation induced by the random noise inputs. The MAR pilot characteristically reported "no significant effect". The aileron and rudder forces were satisfactory, and the CAL pilot felt that good control harmony existed. The MAR pilot thought the elevator stick forces were too high. Both pilots found the aircraft easy to trim for straight and level flight. The CAL pilot thought the longitudinal control (see Section A.3), the rudder control and the control harmony were the "good" features, while the large adverse yaw was the single "bad" feature. The MAR pilot found the high longitudinal forces and the weak lateral and directional damping to be the bad features. Ratings of A3.5 and A3.0 were given by the CAL and MAR pilots, respectively.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\lvert\frac{\phi}{\beta}\right\rvert_d$	$\frac{1}{\omega_d^2}\left\lvert\frac{\phi}{\beta}\right\rvert_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.00	.200	1.19	-10.6	2.93	2.93	2.0	[illegible]			SOLID LINE IS DESIRED
CAL	775	1.92	.2	—	—	—	2.73	1.76	[illegible]	A3.5		— — —
MAR	770	1.70	.155	—	—	—	3.02/4.00	[illegible]	[illegible]	A3.0		- - - - - -

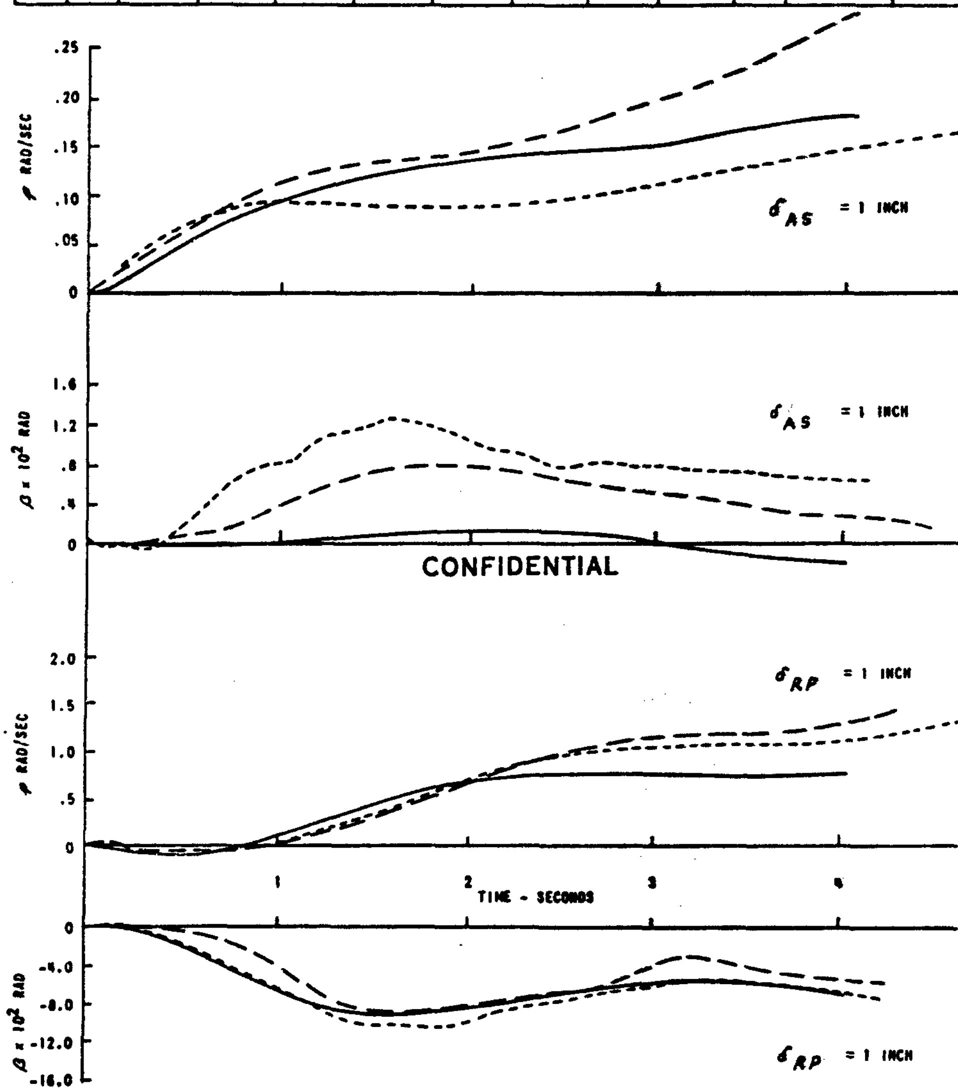

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Figure A-18 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BA-9

(C) As discussed in Section A.3, there was considerable difference in pilot comments concerning the longitudinal characteristics of the burnout flight condition. In addition, the CAL pilot, after three flights, developed a technique which took care of his previous longitudinal problems and vastly changed his rating. Thus, the degree to which the longitudinal characteristics influence the overall evaluation is a function not only of the evaluation pilot, but also the flight number. Care will be taken in the following summaries of the burnout configurations to distinguish between the relative importance of longitudinal and lateral-directional handling qualities to a particular pilot on a particular flight. BO-1 was flown twice by the CAL pilot, and once by the MAR pilot. The first CAL flight was the first experience the pilot had with any BO configurations. His objections were heavily weighted to the longitudinal, and are described in Section A.3. By his second flight, he had developed the longitudinal technique which cancelled his previous objections, and the resulting overall rating is a better indication of the lateral-directional handling qualities. Both pilots found the roll response to aileron stick satisfactory in that the roll damping was quite good, and the amount of adverse yaw generated was not bothersome. The CAL pilot felt that the magnitude of the roll rate could be increased, which would remove the "sluggish" feeling. Both pilots found bank angle precision and heading control very good. Rudders are not really required for turn coordination, however, perfectly coordinated turns are possible with only a little attention to sideslip with the rudder pedals. The response to rudder pedal inputs was found quite satisfactory, and the CAL pilot found he could pick up his sluggish aileron stick roll rate by using a touch of rudder. Rudder sensitivity and the need for rudder were such that no complaints on rudder pedal forces or gradients were received. Random noise had little effect on response, prompting the CAL pilot to remark on the good roll and Dutch roll damping. Control harmony was poor due to the very high elevator stick forces. The overall "stiffness" and trimmability of the configuration were rated as good features. The CAL pilot gave an A5.0 on his first flight, remarking that it was a direct reflection of the longitudinal characteristics. On his second flight, he used a previously developed longitudinal technique, and rated the overall configuration as A3.0, which is a good indication of his opinion of the lateral-directional characteristics. The MAR pilot made it quite clear that his A5.0 rating, like the first CAL flight, was a direct reflection of longitudinal qualities.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\tau_R}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.97	.242	.44	632	5.53	5.33	2.0	34.4			SOLID LINE IS DESIRED
CAL	759	1.97	.21	—	—	4.64	4.36	1.72	27.*	A5.0	*28.6 DESIRED	— — —
CAL	768	1.75	.20	—	—		5..6	1.00	30.6	A3.0		- - - - - - -
MAR	779	1.7	.19	—	—	4.04	5.15	1.06	37.0	A5.0		— - —

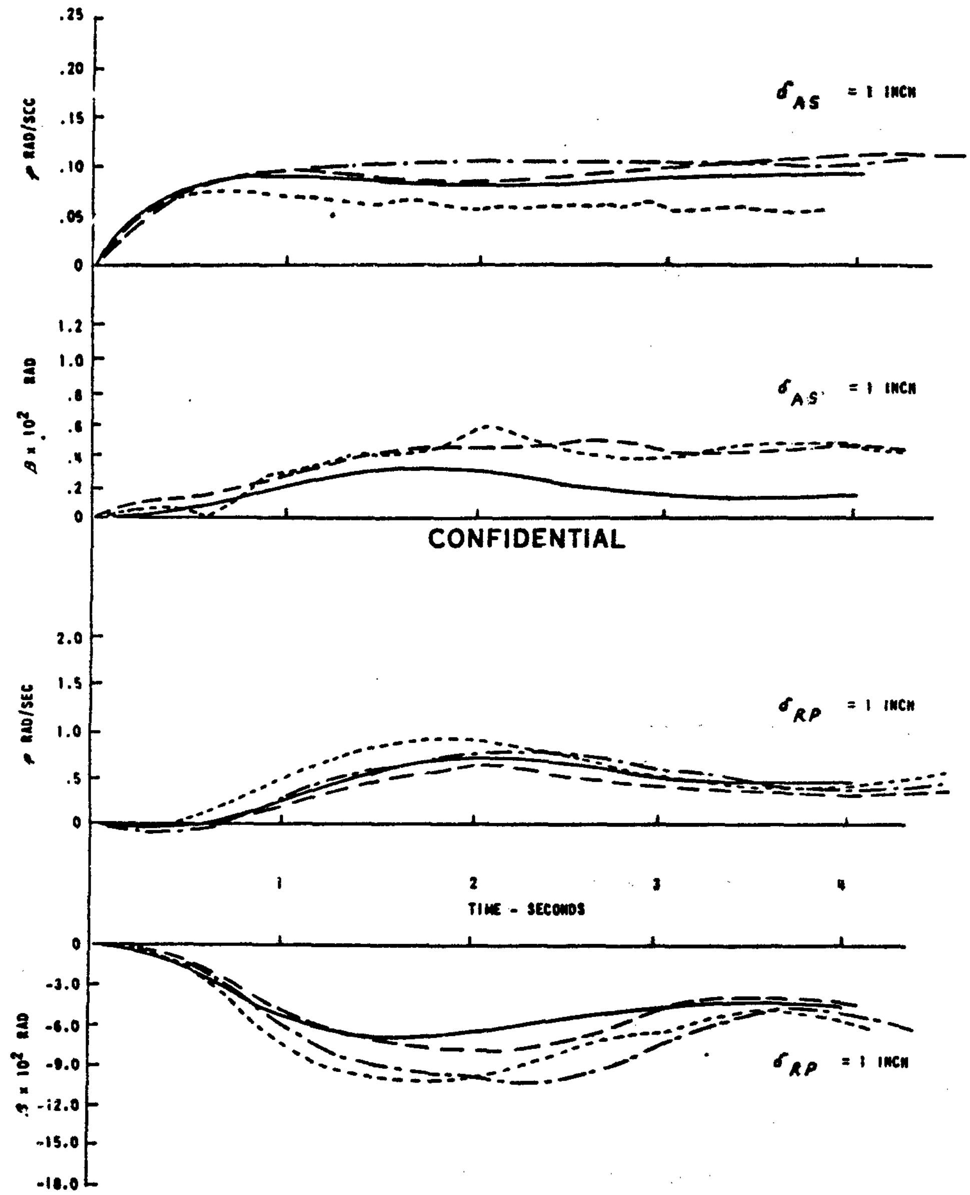


Figure A-19 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-1

(C) The CAL pilot's only encounter with BO-2 was on Flight 761, before he developed the longitudinal technique described in Section A.3. The lateral-directional characteristics are somewhat poorer than BO-1, consequently his overall rating of the configuration of A4.5 is not clearly attributable to either longitudinal or lateral-directional characteristics. The MAR pilot's comments are quite consistent with the CAL pilot on lateral-directional features, however, he (MAR) makes it quite clear that his rating of A6.0 is primarily based on longitudinal considerations. In fact, he independently rated the longitudinal characteristics as A6.0. This method of rating individual features with a number and not giving the overall rating a number better than the lowest of its parts is discussed in Section 6.1. Both pilots noticed the large amount of adverse yaw generated by aileron stick inputs, and the resulting low level of roll power. This low roll rate necessitated larger aileron stick inputs, which, with the existing gradient of 2 lb/in., resulted in "high" lateral forces. Both pilots felt that "considerable" attention to sideslip was necessary to obtain an acceptable degree of bank angle precision, and that turn coordination was difficult. The response to rudder inputs was of sufficient amplitude and sense, both in roll and sideslip, that it was judged "satisfactory". Rudder pedal forces, gradient and feel were likewise satisfactory. Both roll and directional damping were "fair". The CAL pilot thought the random noise disturbances were negligible in roll and yaw; however, the MAR pilot commented that it pointed out the adverse yaw problem. Both pilots disliked the control harmony; the CAL pilot thought the rudders too light in comparison to the elevator and aileron which were compatible, while the MAR pilot thought the elevator stick forces were far heavier than the other two controls. The overall impression from the CAL pilot was that longitudinal and lateral-directional characteristics would each be rated at around A4.5. The MAR pilot definitely gives the longitudinal handling qualities an A6.0 rating, and his general remarks on the lateral-directional handling qualities indicate a rating in the region of A5.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{k}\left\|\frac{\phi}{\delta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.87	.242	.44	832	5.53	5.53	2.0	36.4			SOLID LINE IS DESIRED
CAL	781	1.88	.22	—	—	5.27	5.1	1.82	—	A4.5		————
MAR	788	1.83	.21	—	—	—	5.1	1.94/2.09	38.0/34.0	A6.0		--------

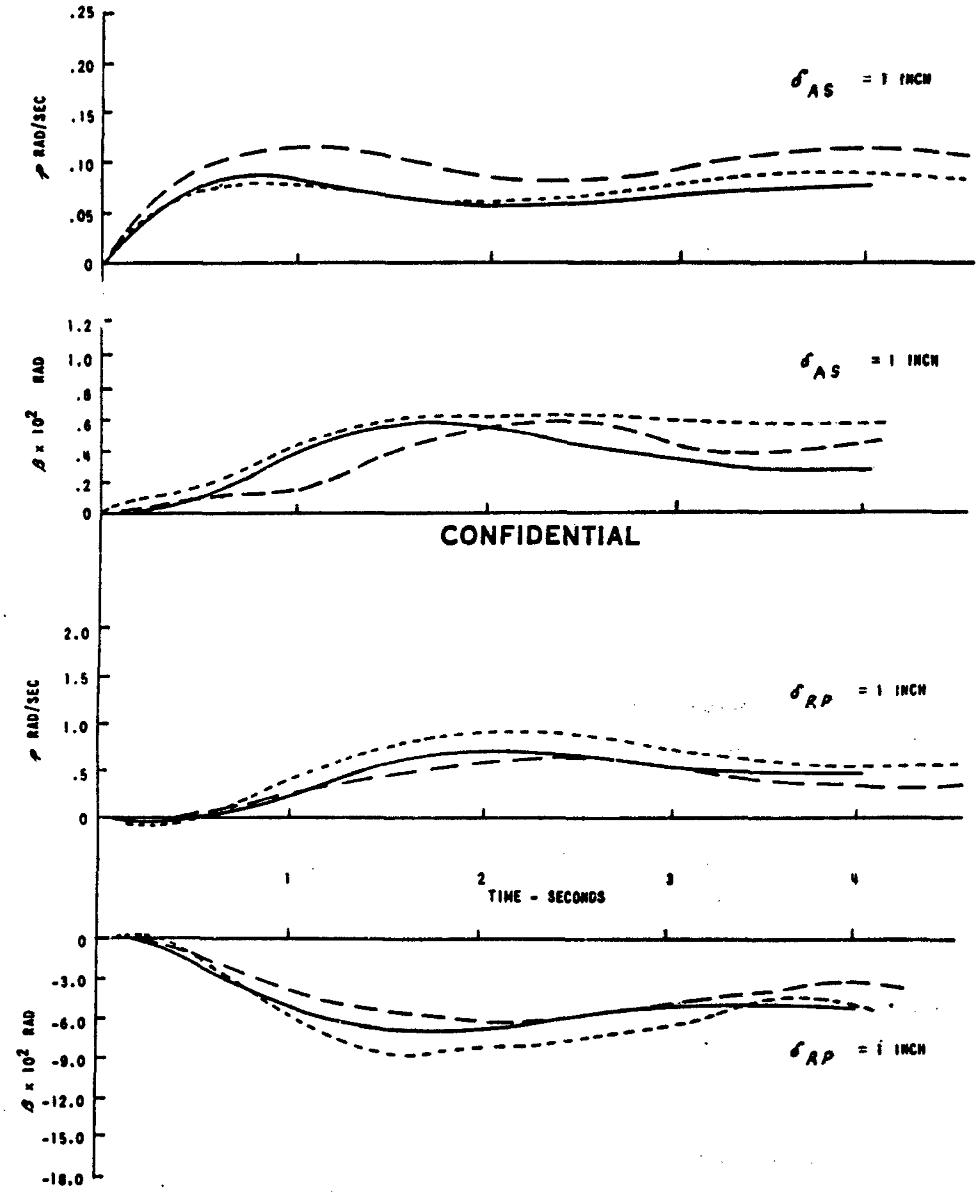


Figure A-20 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-2

(C) The lateral-directional handling qualities of this configuration were found to be excellent by the CAL and MAR pilots, each of whom evaluated it on one occasion. The adverse yaw and sluggish roll rate response present in the BO-2 case have disappeared. The very small amount of sideslip generated by aileron stick inputs does not require coordination with the rudders, although it is quite possible to completely null β with a tiny bit of rudder pressure into the turn. The magnitude of roll rate for lateral inputs is quite adequate. The roll damping is excellent, and what little Dutch roll is excited by aileron stick inputs is quickly damped. Both pilots found these characteristics permitted them excellent bank angle control, excellent heading control, easy turn coordination, and in general, a feeling of good positive control in roll and yaw, even in the presence of the random noise inputs. The CAL pilot mentioned that lateral control forces could be lighter, while the MAR pilot blessed this particular feature with an A2.0. Rudder pedal forces and gradients were liked by the MAR pilot, who incidentally commented that he preferred the higher gradient (34.4 lb/in.) with no breakout force to the lower gradient (28 lb/in.) with an 8 lb breakout force that he had experienced in his company's ground simulation. The response to rudder pedal inputs was "quite satisfactory" to both pilots, but little need for such inputs existed. The CAL pilot did feel that he could increase his roll rate by using a little rudder, and felt this was a desirable feature. The CAL pilot had perfected his longitudinal control technique by the time of his BO-3 flight, so that the longitudinal characteristics were no problem to him, and he was able to give the configuration an overall rating of A2.0. The MAR pilot, on the other hand, still had serious objections to the longitudinal behavior (see Section A.3), and because of this was forced to give an overall rating of A5.0. It is quite clear from his comments praising the lateral-directional case that he was in excellent agreement with the CAL pilot aside from longitudinal characteristics and that the differences in ratings are entirely due to longitudinal differences.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.97	.242	.44	8.12	5.53	5.53	2.0	34.4			SOLID LINE IS DESIRED
CAL	770	1.85	.145	—	—	3.88	5.25	2.36	32.8	A2.0		
MAR	777	1.62	.19	—	—	—	6.12	1.88	35.2	A5.0		

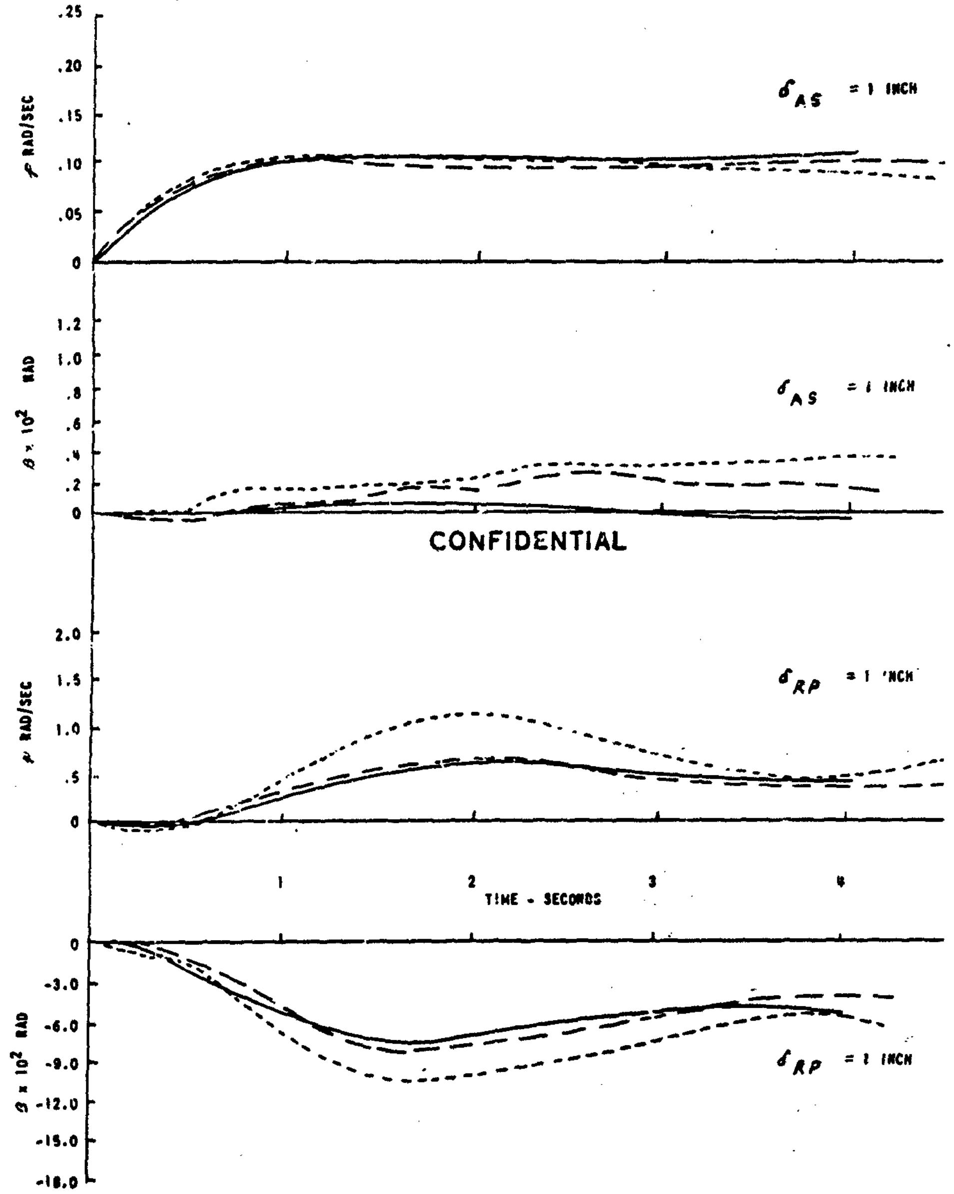
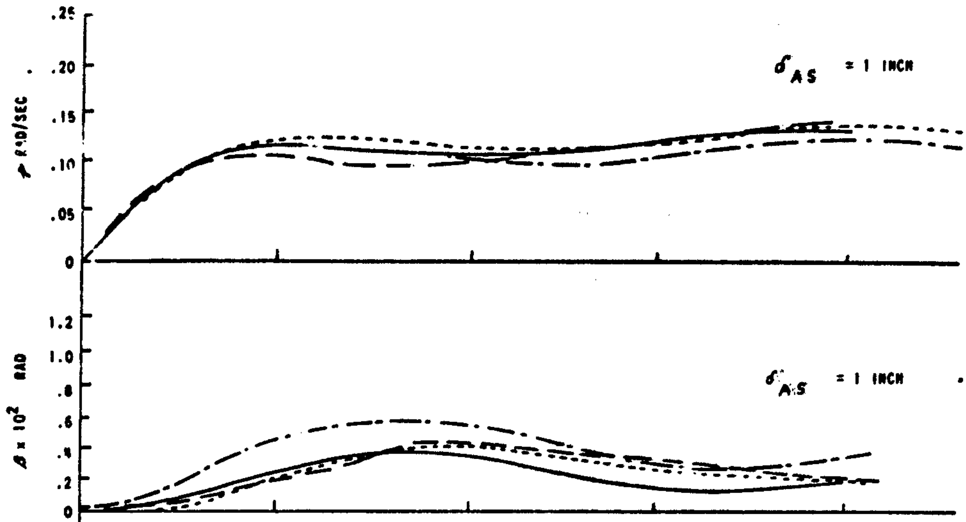


Figure A-21 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-3

BO-4

(C) The CAL pilot flew this configuration on two occasions prior to developing his longitudinal control technique described in Section A. 3. Since the lateral-directional characteristics pose no special problems, the overall ratings are largely a reflection of longitudinal complaints. Both pilots found the roll response to aileron stick inputs satisfactory, being adequate in roll rate (compared to BO-1), roll damping and Dutch roll excitation. The amount of sideslip generated is small allowing the aircraft to be flown quite adequately with aileron alone. Coordination of the small sideslip is difficult and definitely not worth the effort. Precise bank angle control is quite possible, as are making heading changes and maintaining heading. The MAR pilot felt that the aileron forces could be just a bit lighter for optimum feel, and that the rudder pedal gradient could be a bit heavier. The aircraft is fairly unresponsive to the random noise inputs and no extra pilot control effort is required. The MAR pilot liked the roll and directional damping and the $|\phi/\beta|$ ratio. It is not immediately clear what he is observing when he comments on $|\phi/\beta|$ since rudder doublet records indicate that $|\phi/\beta|$ in the Dutch roll is around 6 for this case, which is somewhat higher than many other cases where he makes no comment on it. Control harmony suffers because of the large elevator forces. The chief complaint of both pilots was the longitudinal dynamics, and the overall ratings are governed by these. The CAL rated it A4.0 on two occasions, and the MAR pilot also gave an A4.0 on his one flight. These results indicate excellent agreement on the longitudinal system. It is felt that the lateral-directional system, if being rated separately, would have merited a rating in the A2.0 to A3.0 area.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\lvert \frac{\phi}{\beta} \right\rvert_d$	$\frac{1}{\tau_s} \left\lvert \frac{\phi}{\beta} \right\rvert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.01	.153	.03	-1.673	6.25	6.25	2.0	36.4			SOLID LINE IS DESIRED
CAL	761	1.80	.09	—*	—	5.42	5.80	1.0	—	A4.0		————
CAL	762	1.82	.115	—	—	7.77	7.15	1.83	27.2*	A4.0	*26.0 DESIRED	-------
MAR	7??	1.85	.12	—	—	6.72	6.76	2.00/1.96	31.7/31.0	A4.0		—·—



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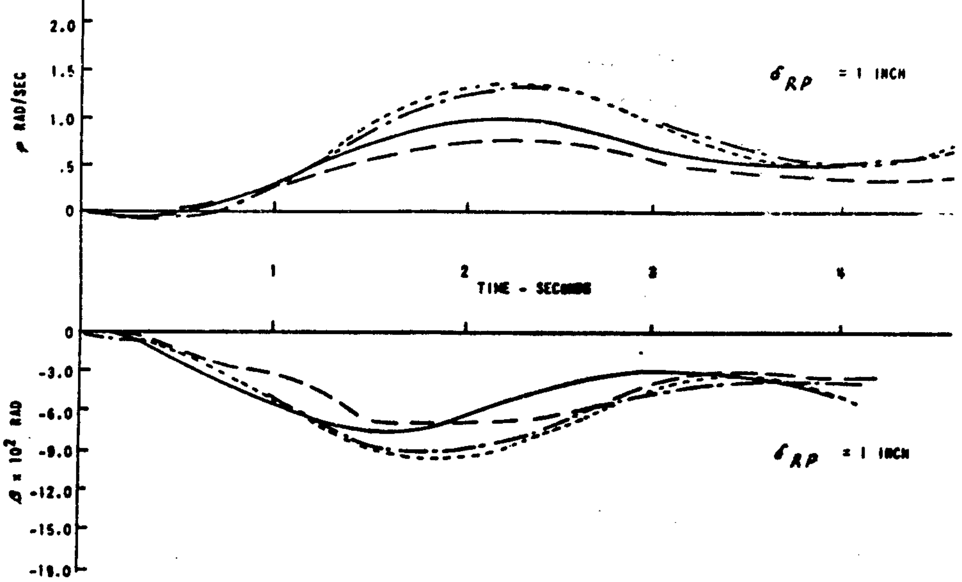


Figure A-22 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-4

(C) This case is very much like BO-4 in that the sideslip response to aileron stick inputs, while greater than BO-4, is still small, and the roll rate response is only slightly reduced. The pilots do not suggest ignoring the sideslip, as they did for BO-4, but find that little effort is required to coordinate. The resulting comments on bank angle control, heading control, and turn coordination were all of a "satisfactory" nature. The excellent roll and directional damping, and the lack of significant response to random noise inputs, make the aircraft a pleasant, stable, easily controlled configuration from the lateral-directional standpoint. The CAL pilot flew this configuration of Flight 772, using the longitudinal control technique described earlier. He rates longitudinal dynamics as a "good" feature, rather than a "bad" feature as he had done on his first three flights. The A3.0 given by the CAL pilot is therefore a good indicator of the BO-5 lateral-directional system being slightly less desirable than BO-4. The A4.0 rating of the MAR pilot is based on the longitudinal characteristics, as he clearly indicates in his remarks, and is consistent with his previous ratings on other BO cases. Section A.3 describes the longitudinal characteristics in detail.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{\omega_\phi}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.01	.153	.63	-1.673	6.25	6.25	2.0	36.4			SOLID LINE IS DESIRED
CAL	772	1.77	.14	–	–	–	6.34	1.85	33.1	A3.0	POOR TRIM ON δ_{RP} STEP	— — —
MAR	784	1.79	.15	–	–	5.0	5.13	1.86/1.8	36.5/36.8	A4.0		- - - - - -

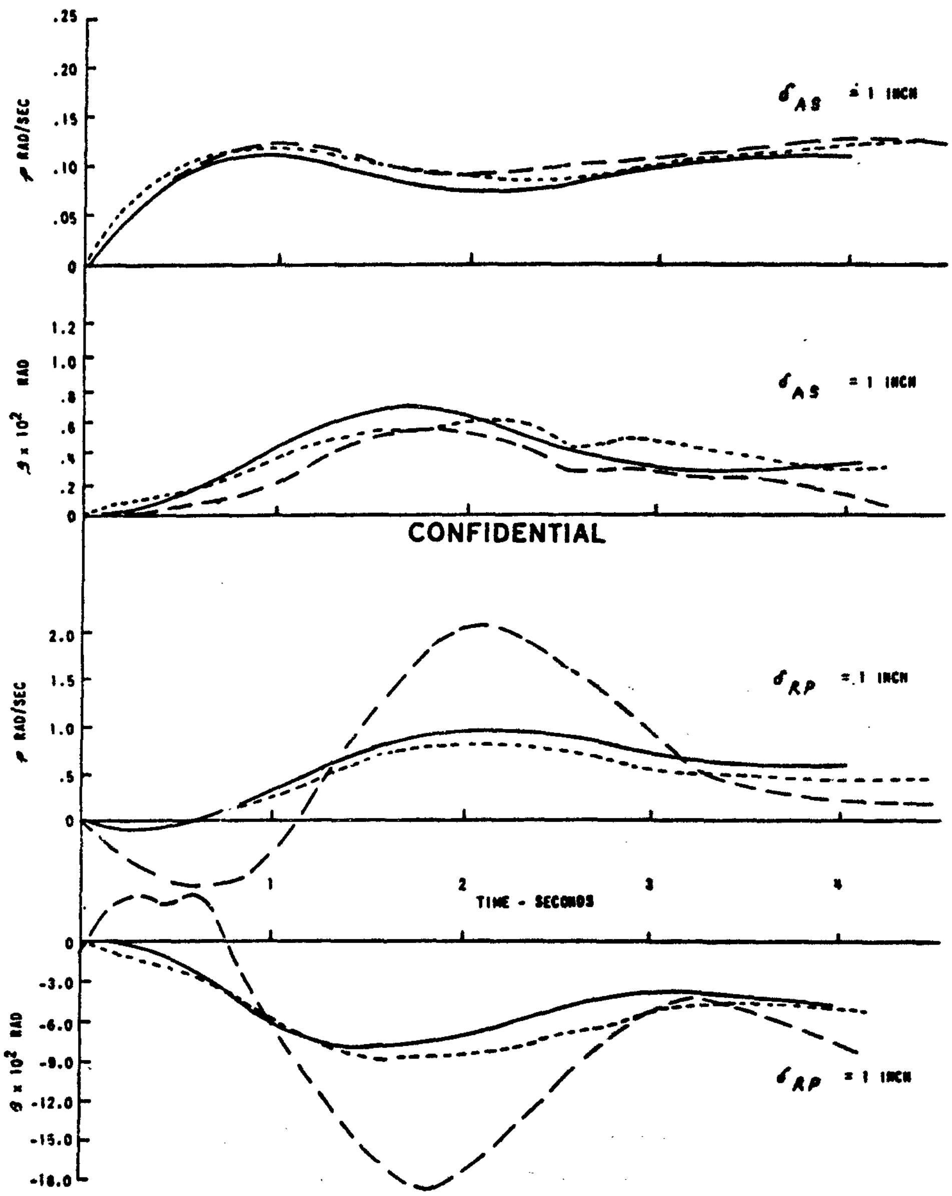


Figure A-23 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-5

(C) The BO-6 configuration has the least adverse yaw due to aileron in the BO-4, 5, 6 series, and since even BO-5, which had the most sideslip, did not come in for much criticism, it is not surprising that this feature received no criticism for BO-6. In fact, it was the single most desirable feature since absolutely no rudder coordination is needed and the aircraft can be flown very satisfactorily with aileron stick alone. The roll rate response to δ_{A_S} inputs has a higher magnitude and less Dutch roll contribution. Coupled with the almost neutral spiral mode (τ_s = -27.9 minutes), and the roll mode time constant of .63 seconds, the ρ response time history appears almost ideal. Both pilots liked the aileron and rudder forces, gradients and feel characteristics. The MAR pilot again commented that he prefers the zero breakout, higher gradient rudder pedals to the characteristics of his company's ground-based simulator. Precise bank angle control, heading control, turn coordination and control in random noise were all reported as very good. The MAR pilot rated the lateral-directional system as A2.0 but was forced, from longitudinal system considerations (see Section A.3), to rate the overall case as A4.5. The CAL pilot used the longitudinal technique referred to earlier, and gave an overall rating of A2.5.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.01	.153	.63	-1.073	6.25	6.25	2.0	35.6			SOLID LINE IS DESIRED
CAL	771	1.06	.15	—	—	6.66	6.05	1.83	—	A2.5	NO AUTO.RECORDS	
MAR	782	1.07	.16	—	—	—	6.36	1.82	35.2	A4.5		— — —

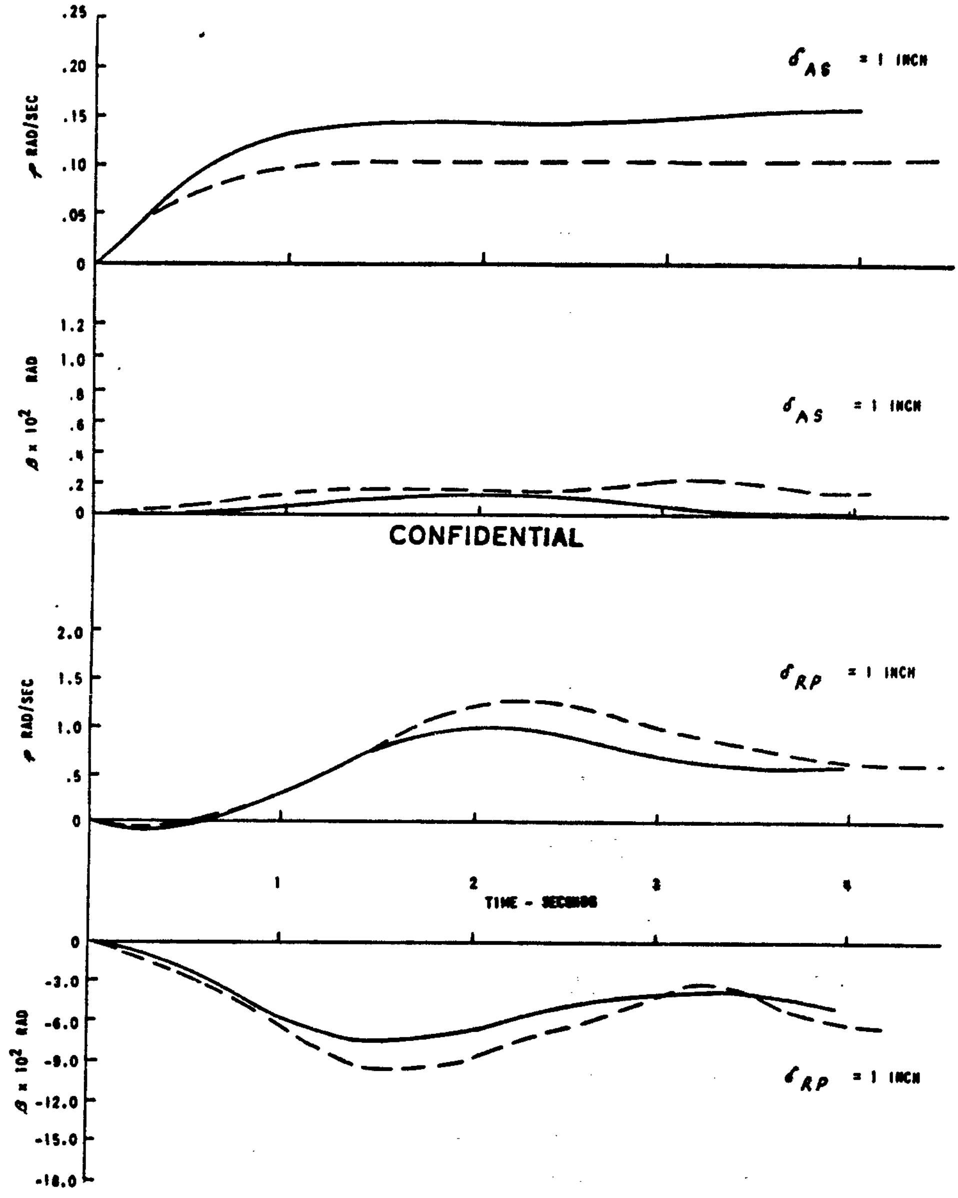


Figure A-24 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-6

(C) There was excellent agreement among the four pilots who flew this configuration on the assessment of the lateral-directional handling qualities. The roll response to aileron stick inputs was very good, displaying adequate roll damping, amplitude, and minimum Dutch roll excitation. In addition, the sideslip generated is of small amplitude in the adverse sense, and does not require the pilot to spend any time trying to coordinate with rudder pedals. Most of the pilots recommended flying with aileron alone. There was a high degree of bank angle accuracy achieved by all pilots. The roll power was thought to be slightly less than optimum by the CAL pilot and by the MAR pilot on one of his two flights. This brought forward comments that the aileron stick forces could be a little lower, since with the existing gradient and requirement for slightly more δ_{AS} than optimum, higher forces are required. The rudder pedal responses were thought to be satisfactory in their production of both roll rate and sideslip. The NASA pilot felt that the rudder pedal gradient was too light for the level of response; however, none of the other pilots had any objections to it. Turn coordination was no problem whatsoever. Most pilots did not bother attempting to null the small sideslip excursions. Likewise, heading control was simple with the low sideslip response and well damped, small Dutch roll excitation. Insignificant responses were observed in natural turbulence or random noise. The CAL pilot used the trimming technique for longitudinal control described in Section A.3. Consequently his overall rating was not downgraded by the longitudinal characteristics and he was able to rate the configuration as A2.0. Longitudinal problems plagued the other pilots however, and their ratings are a direct reflection of these problems (MAR A5.0 and A4.5; USAF A4.5; NASA A6.0). The MAR, USAF and NASA pilots each rated the lateral-directional case alone as A2.0. This correlates well with their comments and the rating of the CAL pilot.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{p}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.92	.31	.34	457	5.70	4.70	2.0	34.5			SOLID LINE IS DESIRED
CAL	783	2.06	.2	—	—	2.50*	3.06*	2.03	25.2 †	A2.0	*FUEL SLOSHING	— — —
MAR	778	2.07	.32	—	—	3.40	3.00	1.83	36.5	A5.0	†28.0 DESIRED	-------
MAR	782	1.71	.17	—	—	5.40	3.90	2.06/2.02	36.5/35.7	A4.5		— - —
USAF	794	1.74	.27	—	—	3.4	3.00	—	—	A4.5		— -- —
NASA	796	1.80	.205	—	—	3.7	4.04	—	—	A6.0		....

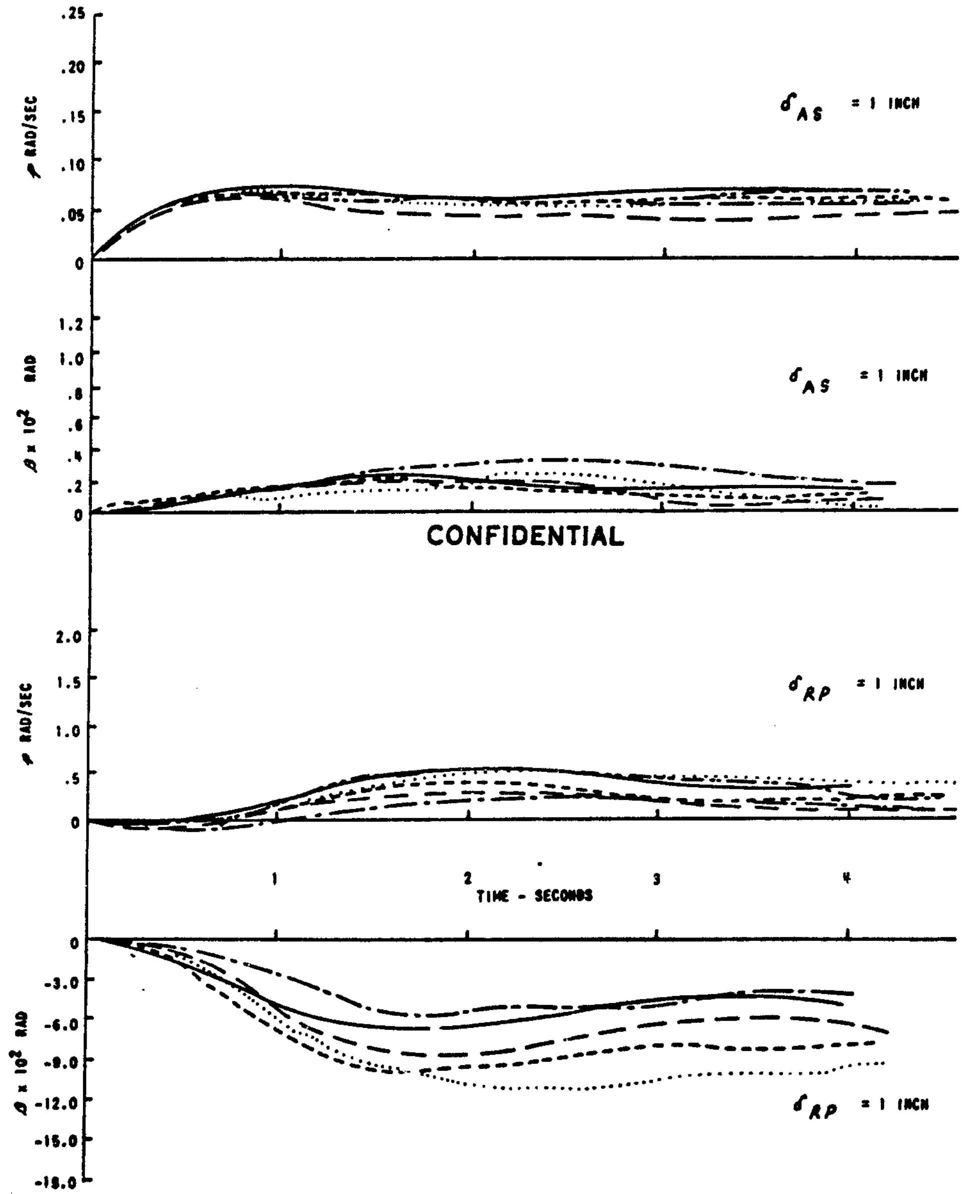
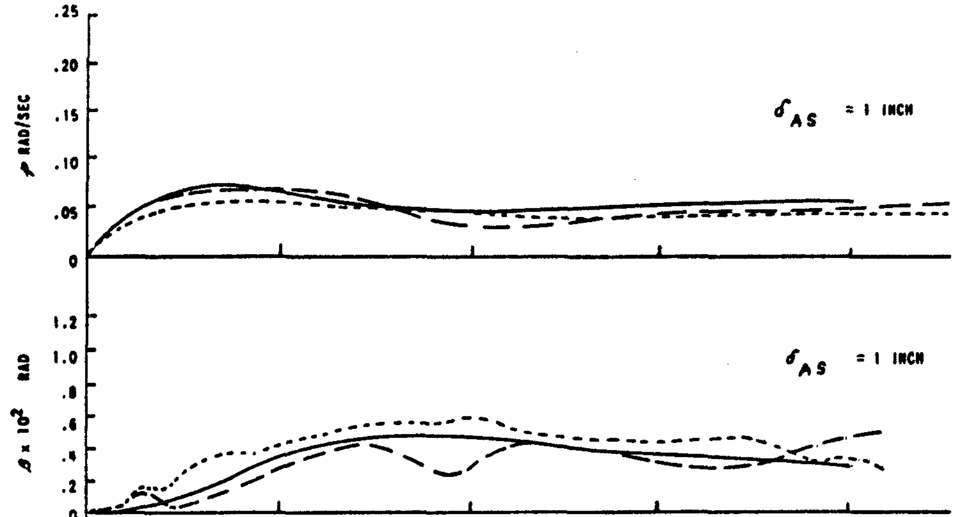


Figure A-25 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-7

(C) The decrease in the rudder-to-aileron interconnect ratio, resulting in the higher adverse yaw and lower roll authority, brought predictable complaints from the CAL and MAR pilots, each of whom flew the configuration on one occasion. The CAL pilot objected to the small roll rate for aileron stick inputs, and found that even by using rudders, the required stick deflections and accompanying forces were too large. Both pilots experienced difficulty with turn coordination, and felt that an undue amount of pilot attention was required. The CAL pilot commented that precise bank angle control was possible only when small aileron inputs were required. He recommends the use of rudder for adequate roll control. Directional damping was thought to be good, which helped the heading control maneuvers. The aircraft was again relatively unresponsive to turbulence and random noise inputs. Trimmability about all three axes was very good. The CAL pilot thought the rudder pedal forces were light in comparison to the aileron stick forces, while the MAR pilot found the elevator forces too high. Both pilots listed the adverse yaw as a "bad" feature. The CAL pilot added the poor roll authority, and the MAR pilot added poor pitch response (see Section A. 3) to the list of bad features. The CAL pilot gave an A5. 5 rating based mostly on his lateral-directional objections, while the MAR pilot rated the lateral-directional separately as A4. 0, but based on longitudinal considerations he rated it overall as A4. 5.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\lvert \frac{\phi}{\beta} \right\rvert_d$	$\frac{1}{\omega_\phi} \left\lvert \frac{\phi}{\beta} \right\rvert_d$	r_{AS}/δ_{AS}	r_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.82	.21	.34	467	4.70	4.70	[illegible]	30			SOLID LINE IS DESIRED
CAL	770	1.71	.23	—	—	4.46	4.45	2.02	22.0	A5.5		— — —
MAR	790	EXCESSIVE TURBULENCE		—	—	—	—	1.07/2.08	30.4/35.0	A4.5	NO δ_{RP} STEP	-------



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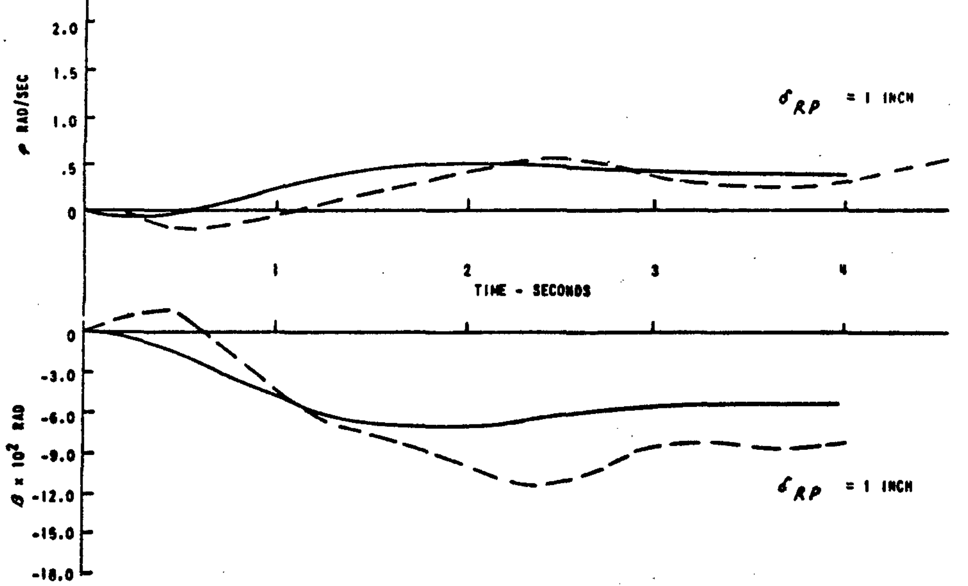

Figure A-26 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-8

(C) This configuration displays improved roll rate magnitude with insignificant Dutch roll excitation for aileron stick inputs. In addition, the yaw due to aileron starts out slightly adverse, and then goes proverse for aileron stick steps. Both the CAL and MAR pilots, each of whom flew this case on one occasion, commented that little or no coordination was required in turns, and that with the roll characteristics, bank angle control was very precise, and heading control was excellent. Both pilots felt that the aileron stick forces could be a little lighter. The response in roll and sideslip due to rudder pedal inputs was satisfactory, although they are not often required for normal maneuvers. Only a slight sideslip oscillation was observed during random noise inputs which did not require pilot compensation. Once again, the CAL pilot commented that the rudder forces were too light in comparison to the stick, while the MAR pilot noted the heavy elevator forces (this is explained in Section A. 3). The overall rating given by the CAL pilot was A2. 5 and the MAR pilot also rated the lateral-directional characteristics as A2. 5 but was forced by his complaints with the longitudinal case to give an overall A5. 0 rating.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\|\phi/\beta\|_d$	$\frac{1}{\omega_d}\|\phi/\beta\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.92	.31	.34	457	4.78	4.78	2.0	36.4			SOLID LINE IS DESIRED
CAL	787	1.74	.23	—	—	3.8	3.10	1.04	37.2	A2.5		— — —
MAR	787	1.78	.245	—	—	—	4.34	—	—	A5.0		-------

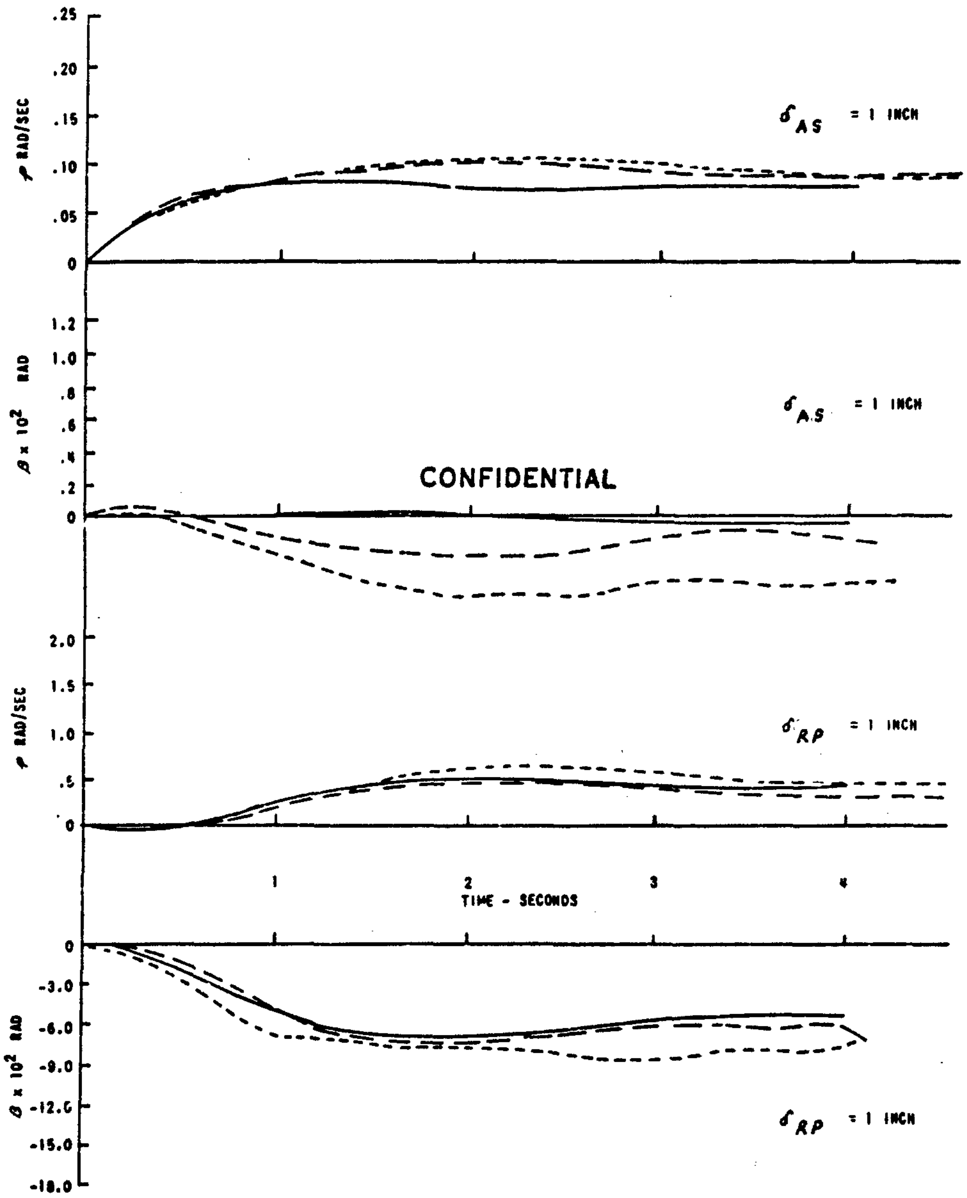

Figure A-27 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BO-9

(C) This case was flown once each by the CAL and MAR pilot. The primary complaint from both was the considerable amount of adverse yaw experienced with aileron stick inputs, compared to the relatively low roll rate produced. The problem is aggravated by the rudder pedal effectiveness in producing roll, and the relatively light Dutch roll damping. The CAL pilot reported that in attempting to coordinate bank angle maneuvers he required a constantly changing amount of rudder pedal inputs in the direction of aileron stick inputs. The resulting increased roll rates required opposite aileron stick inputs which in turn required opposite rudder pedal for sideslip coordination. The result was a pilot-induced oscillation in roll which the pilot found difficult to avoid for reasonable bank angle tasks. Finally the pilot decided to stay off the rudders completely and accept the large sideslip angles and side accelerations, rather than risk the consequences of a roll PIO. The MAR pilot had the same level of difficulty although he did not specifically mention PIO problems. He comments on the low roll and directional damping and his great difficulty with precise bank angle control due to large sideslip excursions. The CAL pilot experienced considerable difficulty in trimming the aircraft for straight and level flight, noting the rudder trim especially was very sensitive. Simply keeping the wings level required an undesirable amount of pilot attention when random noise inputs were fed to the control surfaces. Both pilots indicated that turbulence aggravated an already heavy work load on the pilot. The low roll power required large aileron stick inputs resulting in a complaint from the CAL pilot that these forces were too high and that lateral maneuvering was tiring. The MAR pilot had no objection to the lateral forces. The coordination problem made precise heading control difficult and despite considerable effort, the CAL pilot reported that it was not unusual for him to miss his intended heading by 5 or 10 degrees. Control harmony was thought poor by the MAR pilot because of the large elevator forces, while the CAL pilot thought that both the elevator and aileron stick forces were too high, and incompatible with the rudders. The longitudinal characteristics (see Section A.3) were viewed somewhat differently by the two pilots; however, the lateral-directional characteristics played the most important role in the assessments of each. The CAL pilot gave an overall rating of U7.0 and the MAR pilot A6.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{\omega_\phi}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.07	.2	1.2	-12.8	5.07	5.07	2.0	[illegible]			SOLID LINE IS DESIRED
CAL	782	1.82	.13/.21	—	—	—	4.56	1.05	28.0*	U7.0	*28.0 DESIRED	— — —
MAR	783	—	—	—	—	—	—	1.90/1.75	25.7/25.7	A6.0	POOR δ_{RP} TRIM	- - - - - - -

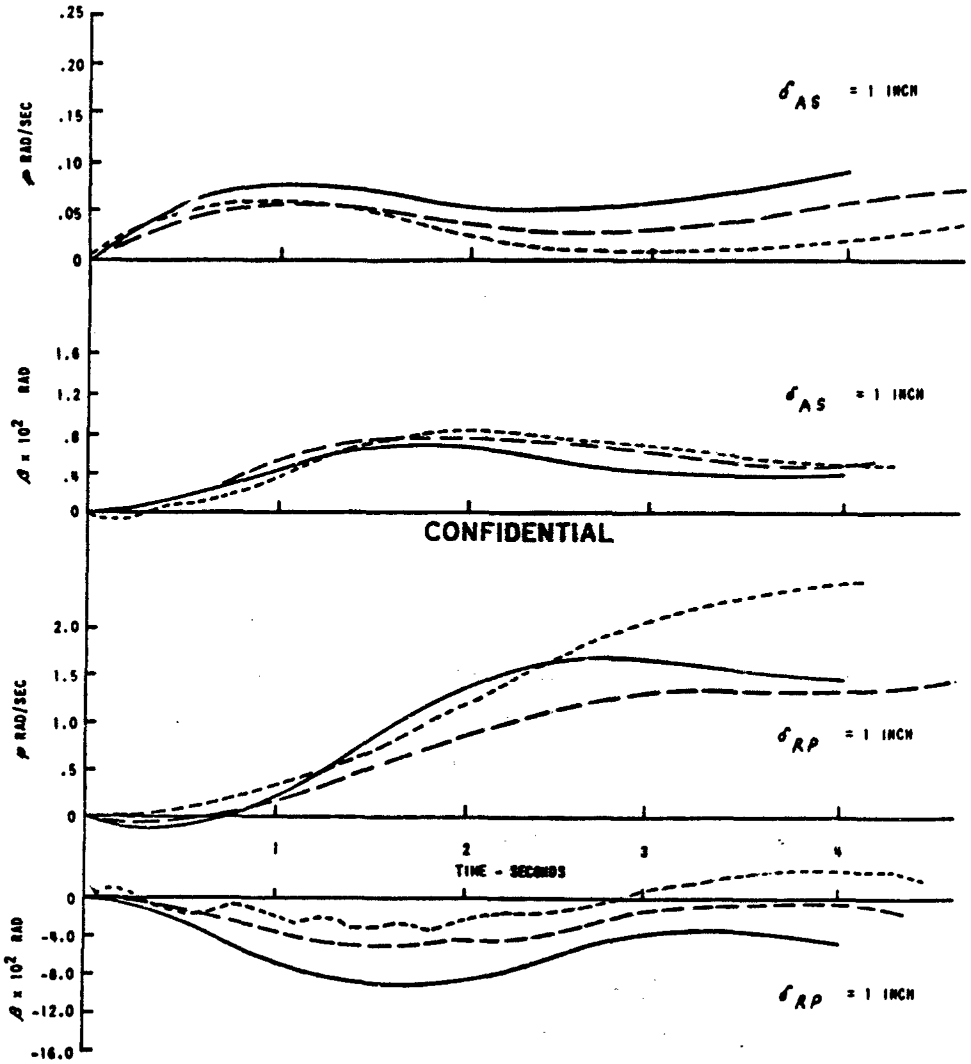

Figure A-28 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-1

(C) The CAL and MAR pilots each flew this configuration on two occasions, the USAF and NASA pilots, once each. The outstanding feature of this configuration is the "excessive" amount of adverse yaw due to aileron and the accompanying roll reversal tendency. Lateral control with aileron alone is virtually impossible. The use of rudder pedals for coordination proved difficult for all the pilots due to the rudder's sensitivity as a roll rate producer. The low roll and directional damping aggravate the situation. The CAL pilot was quick to discover that the key to satisfactory control of this configuration lay in the use of rudder as the primary controller in roll. He found he could initiate, control and stop rolling maneuvers with the rudders, using only very small aileron stick inputs as a coordination device. The rudder pedal deflections required are large, but since the gradient is low, no force problem existed. This unconventional technique allowed for marginal acceptability in bank angle and heading control. Dutch roll oscillations were still evident, and impossible to eliminate. The aircraft is difficult to trim lateral-directionally, there being a very delicate balance between the rudder and aileron trim required. Trim is easily disturbed by turbulence. The NASA pilot also resorted to primary control with rudders, and he too was able to achieve marginal satisfaction. His comments were very much like the CAL pilot, indicating a great deal of pilot effort is required at all times, but that the configuration is indeed flyable. He rated it overall as A6.5 while the CAL pilot gave A4.5 and A6.0 on his two flights. The MAR pilot and USAF pilot did not use this rudder technique, and found the aircraft unacceptable. They commented only briefly on the details of what they were experiencing, but conveyed quite clearly that they had a bad airplane and didn't like it. The USAF pilot was particularly reluctant to answer any of the questions on the card, feeling perhaps that he was dealing with an impossible situation. On occasion his aircraft inadvertently executed uncontrolled 360 degree roll maneuvers. The MAR pilot rated it U9.5 and U9.0; the USAF pilot U9.0. The longitudinal dynamics (see Section A.3) were of secondary importance in these overall evaluations. The variation in pilot ratings from A4.5 to U9.5 is a direct function of the ability of the pilot to recognize and use effectively the rudder pedal responses as his primary mode for acceptable lateral control.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{p}{\beta}\right\|_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.87	.2	1.2	-12.6	5.07	5.07	2.0	30.0			SOLID LINE IS DESIRED
CAL	772	1.50	.17	—	—	—	5.56	1.86	30.0	A6.5		— — —
CAL	773	1.65*	.16	—	—	—	4.86	1.90	37.2	A6.0		- - - - - -
NAR	776	1.71*	—	—	—	—	—	1.76	36.5	U9.5	*DAMPED FREQ.	— - —
NAR	793	1.96	.12	—	—	—	—	1.80/1.71	30.7/35.7	U9.0		— - - —
USAF	795	—	—	—	—	—	—	—	—	U9.0	NO SUITABLE RECORD	
NASA	797	—	—	—	—	—	—	—	—	A6.5	NO SUITABLE RECORD	

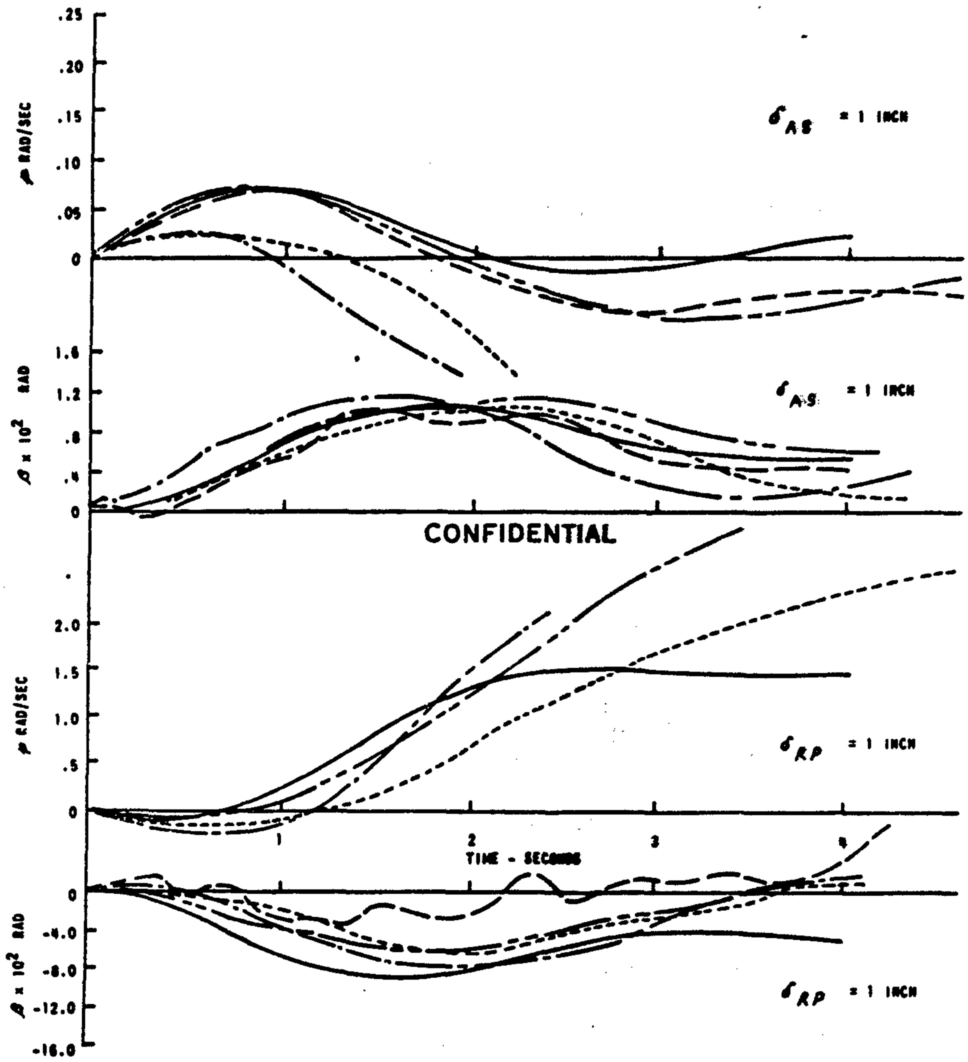

Figure A-29 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-2

(C) The roll response for aileron stick inputs is considerably improved over BB-2, showing no reversal tendencies. However the adverse yaw, although smaller than BB-2, is still felt to be "considerable" by the CAL pilot. This amount of sideslip required rudder inputs which commanded a roll rate which is slow at first, and then builds rapidly. The CAL pilot found that this contribution, added to the ever-increasing roll rate commanded by the ailerons, resulted in an excessive roll acceleration. The weak roll damping is a contributing factor, and both pilots complained about it. Precise bank angle control was exceptionally difficult because of this feature and as a result, accuracy of heading changes suffered. The rudders, being so sensitive, caused rudder pedal forces to feel quite light with the existing gradient of around 34 lb per inch. This lightness was in direct contrast to the "heavy" aileron (when used alone) and elevator forces. Although trimming this configuration lateral-directionally was much more satisfactory than BB-2, random noise still caused lightly damped roll oscillations, which noticeably increased the pilots' workload. Turn coordination is not a problem in steady state since the sideslip returns to zero. The MAR pilot concentrated his objectives on the roll acceleration behavior, and had more tolerance with the sideslip excursions. The longitudinal characteristics (see Section A. 3) were secondary to the lateral problems for the configurations, which both pilots rated as A5. 0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\zeta_d}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.07	.2	1.2	-12.0	5.07	5.07	2.0	34.5			SOLID LINE IS DESIRED
CAL	709	1.07	.25	—	—	5.03	6.90/4.24	2.00	35.6	A5.0		— — —
MAR	706	1.0	.20	—	—	—	3.02	2.27/2.16	34.7/33.6	A6.0		- - - - - - -

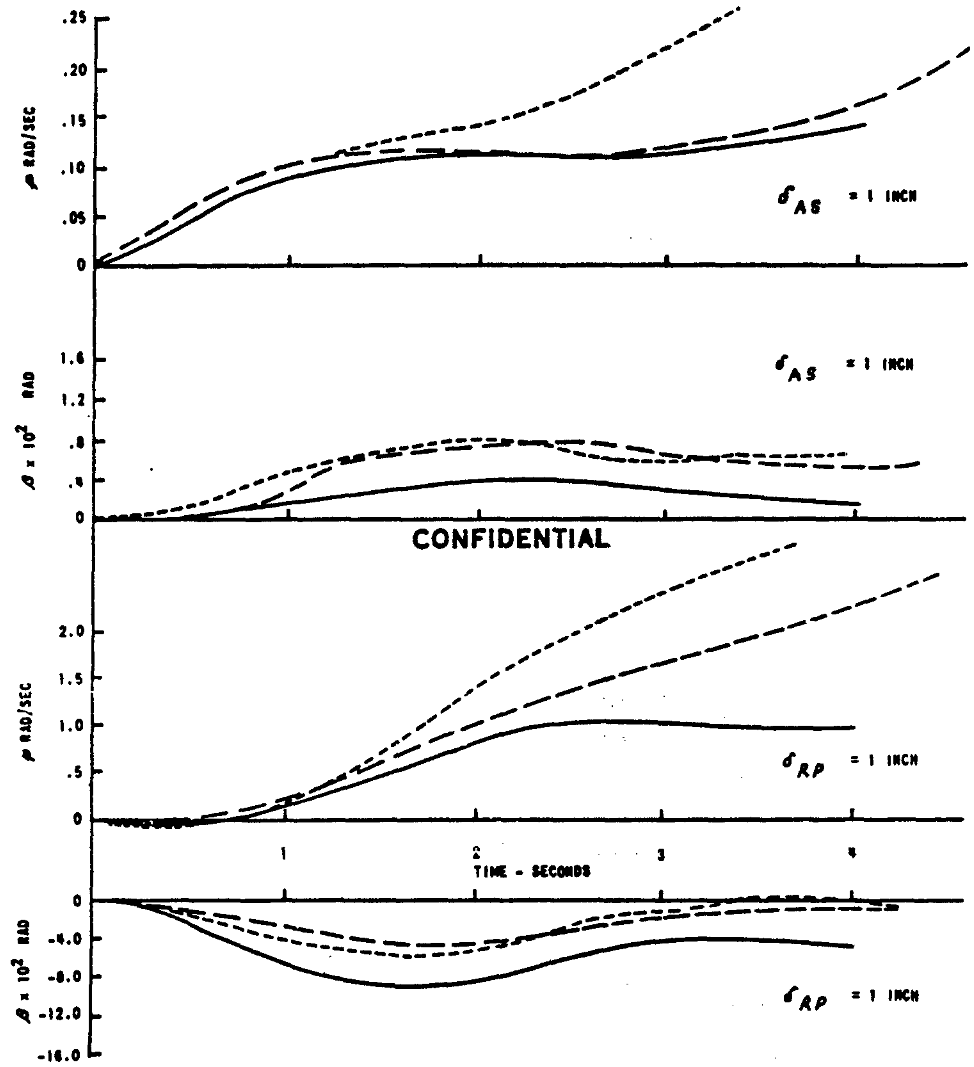

Figure A-30 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-3

(C) Very high adverse yaw, low roll damping and high $|\phi/\beta|$ ratio combined to make this configuration unacceptable to both pilots, who each flew it on one occasion. Bank angle control was particularly difficult and overshoots of thirty to forty degrees were common. It required extreme concentration to achieve a reasonable measure of coordination and any distractions resulted in the aircraft getting away from the pilot. Changing heading was quite difficult because of this and random noise was found to accentuate the roll problem. The configuration felt too sensitive in roll to any type of input. The CAL pilot found that with considerable attention he could dampen out Dutch roll oscillations with the rudders. The MAR pilot felt that both the elevator and aileron stick forces were too high. The longitudinal characteristics were of minor importance to the continually severe rolling problem. The CAL pilot rated the configuration as U9.0 and the MAR pilot as U7.5.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{p}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.89	.137	1.10	-15.6	5.77	6.[illegible]	2.0	29.4			SOLID LINE IS DESIRED
CAL	763	1.65	.156	—	—	—	7.0	1.65	27.2*	[illegible]	*29.0 DESIRED	— — —
MAR	790	1.77	.17	—	—	—	7.0	[illegible]	25.3/[illegible]	[illegible].5	POOR TRIM	- - - - - - -

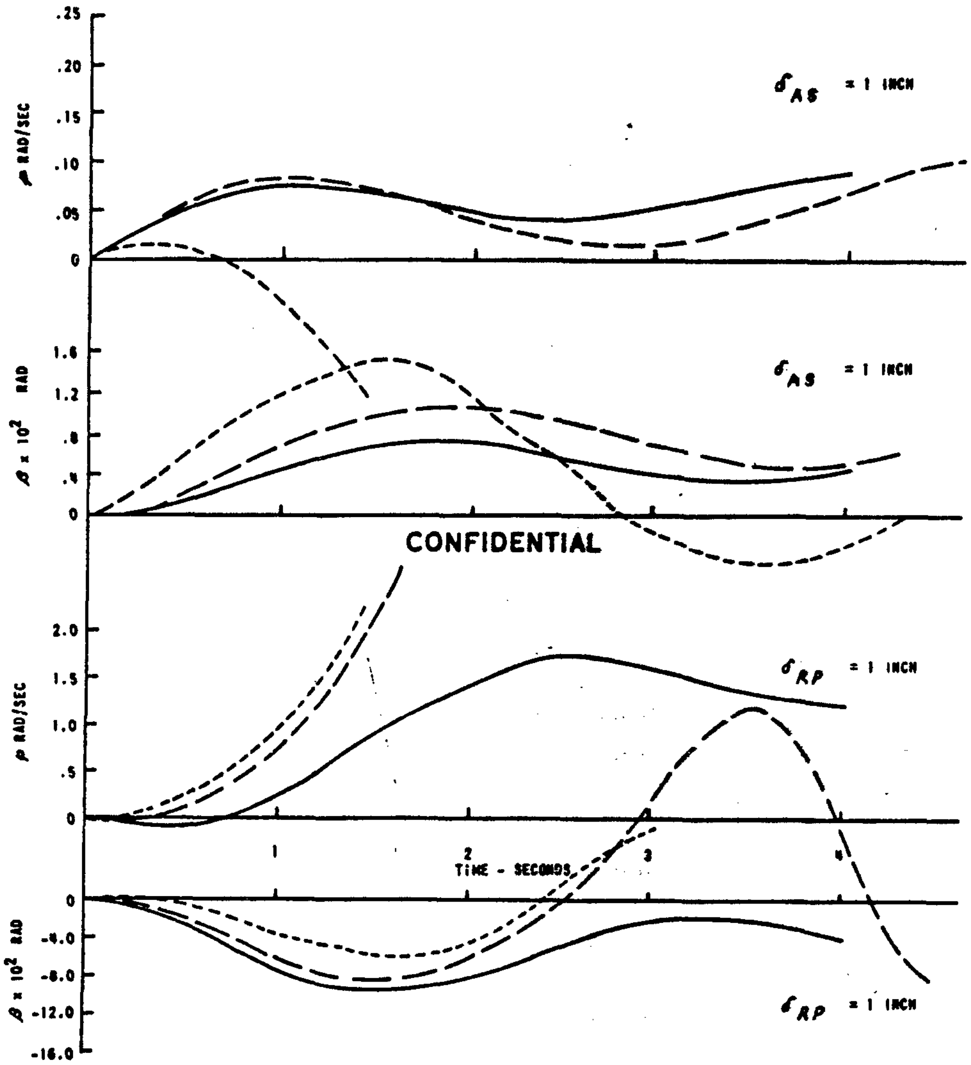

Figure A-31 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION 3B-4

(C) This configuration was uncontrollable. Both pilots found the extreme adverse yaw and roll reversal commanded by aileron stick inputs intolerable. Continuous heavy concentration and effort were required to simply hold the wings level. Any inputs, commanded or external, caused unacceptable roll and yaw excursions. The aircraft could not be trimmed for hands-off flight. Both pilots rated it 10.0.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\lvert\frac{\phi}{\beta}\right\rvert_d$	$\frac{1}{\omega_d}\left\lvert\frac{p}{\beta}\right\rvert_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.89	.137	1.10	-15.6	5.77	5.77	2.0	30.0			SOLID LINE IS DESIRED
CAL	760	—	—	—	—	—	—	2.12	—	10.0		———
MAR	764	1.75*	—	—	—	—	—	—	—	10.0	*DAMPED	

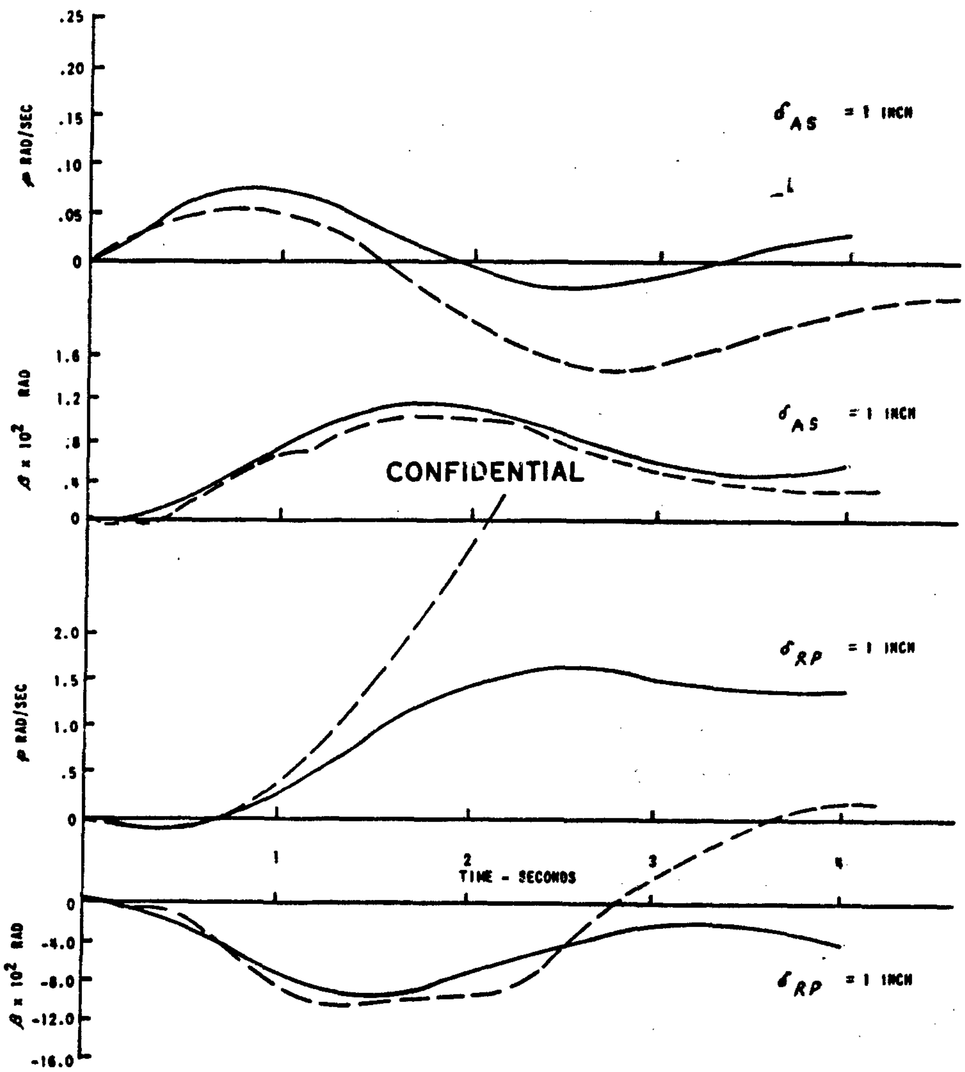

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Figure A-32 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-5

(C) Again we have a rolly configuration that requires a high degree of pilot attention to fly in a controlled manner. The adverse yaw experienced for aileron stick inputs, while not as excessive as BB-5, was still thought to be large, necessitating rudder coordination. The rudder response (the same as BB-4 and BB-5), is divergent in roll, hence the pilots found themselves trading off sideslip problems for roll problems. The high $|\phi/\beta|$ and low Dutch roll damping contributed to the problem, resulting in roll oscillations in natural turbulence and random noise inputs. The aircraft was difficult to trim, and it was not uncommon to experience bank angles up to 60 degrees while attempting to fly straight and level. Naturally, bank angle control was reported poor and changing heading was difficult. The MAR pilot did not seem to be as sensitive to sideslip excursions as the CAL pilot. Consequently his requirement for the use of rudder pedals, with accompanying roll difficulties, was somewhat less. The longitudinal characteristics did not display any very unpleasant characteristics (see Section A.3), hence the ratings of U8.0 by the CAL pilot, and A5.0 by the MAR pilot directly reflect the degree to which each pilot was affected by the roll behavior.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\dot{\phi}}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.80	.137	1.18	-15.6	5.77	5.77	2.0	30.0			SOLID LINE IS DESIRED
CAL	772	1.83	.12	—	—	—	6.50	—	—	U6.0	NO δ_{AS} [illegible]	———
MAR	789	1.60	.17	—	—	—	—	1.00/1.00	35.0/30.2	A5.0		-------

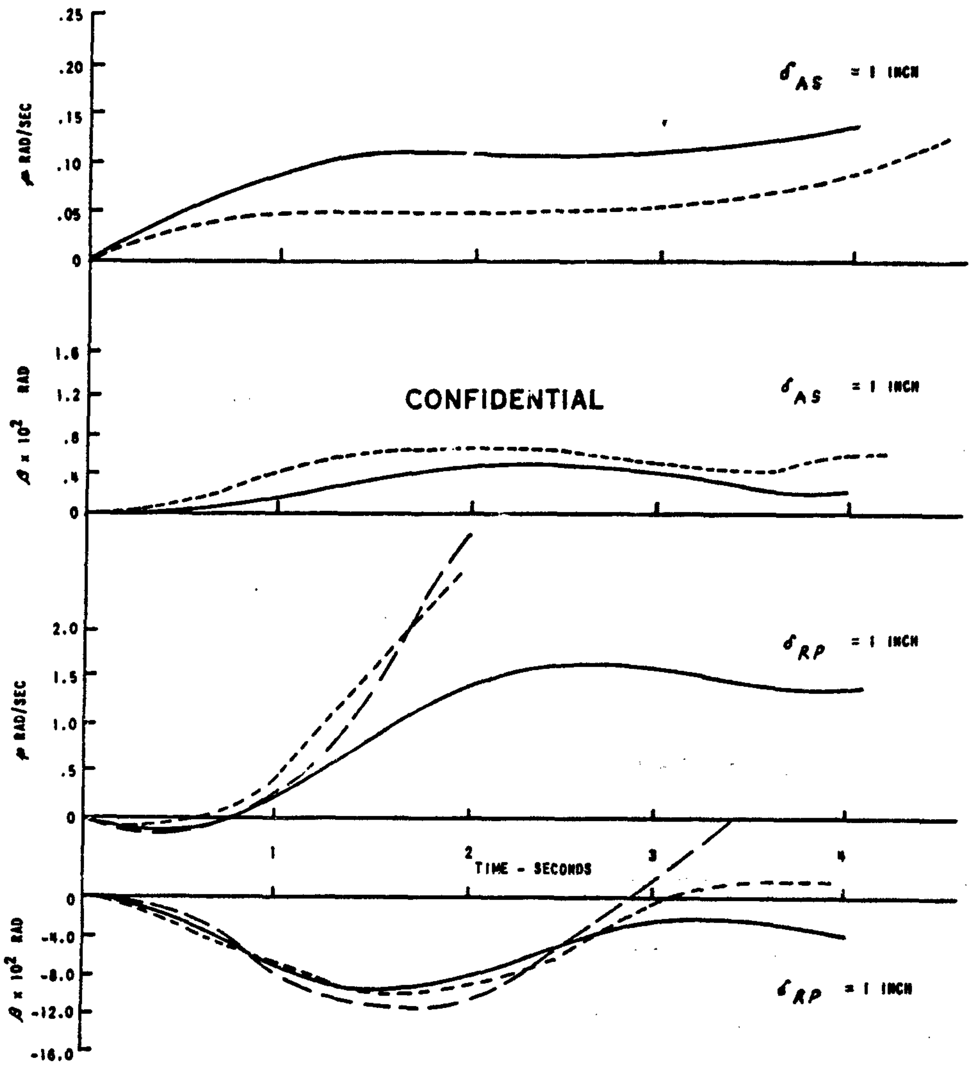


Figure A-33 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-6

(C) Three features combine to make this configuration unsatisfactory lateral-directionally: low roll power, high adverse yaw due to aileron, and high roll rate response to rudder pedal inputs accompanied by a low rudder pedal force gradient. The low roll power means that if the aircraft is to be flown laterally with aileron stick alone, large deflections are required. This results in excessive sideslip excursions demanding rudder coordination. The rudders are extremely effective as roll producers; a situation worsened by the very light rudder pedal force gradient (34.4 lb per inch). This combination of controls required very tricky coordination, requiring constant pilot attention to bank angle control. The high rates of roll commanded by the rudder require excessive aileron inputs to check. Changing heading accurately was a miserable task for both pilots, each of whom flew the configuration on one occasion. It was difficult to trim the aircraft for straight and level flight, and the presence of natural turbulence or random noise always resulted in a continual roll-sideslip oscillation which the pilots, despite full time attention, were unable to control satisfactorally in light of the boost mission requirements. The CAL pilot found it easy to get himself into a pilot-induced oscillation when concentrating on bank angle precision. The MAR pilot felt that the aircraft would easily go out of control if the pilot was distracted only briefly by other cockpit duties. Clearly the configuration is unacceptable, despite the good longitudinal characteristics reported in Section A. 3, and was rated as U7.0 by both pilots.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\vert\phi/\beta\vert_d$	$\frac{\omega_\phi}{\omega_d}\vert\frac{\phi}{\beta}\vert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.83	.306	1.30	-10.1	5.05	5.05	2.0	30.0			SOLID LINE IS DESIRED
CAL	704	1.59	.34	—	—	—	7.95/8.1	1.00	35.0	47.0		
MAR	700	2.00	.4	—	—	—	—	—	35.0	47.0		

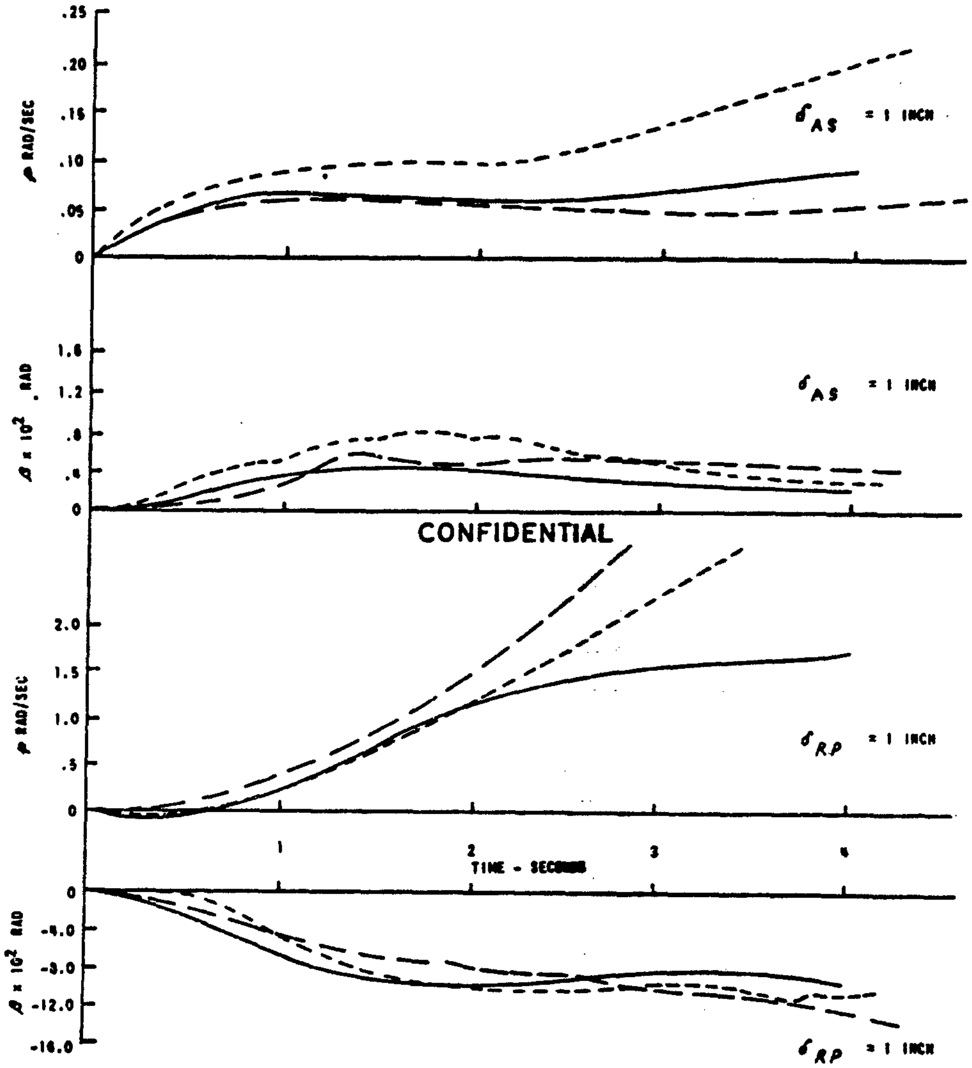


Figure A-34 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-7

(C) There is a "considerable" amount of adverse yaw due to aileron with this configuraticn, and definite roll reversal for aileron stick inputs alone. Rudder is definitely required to achieve adequate roll response and then opposite aileron and rudder to stop it. The coordination of sideslip is extremely difficult, and intense pilot concentration is required to achieve reasonable bank angle accuracy. Both pilots complained of the high lateral forces required, however, rudder pedal forces were satisfactory. There were differences expressed by the pilots with respect to the lateral-directional trimmability and the random noise response. The CAL pilot found that he had good trimmability and listed this as a "good" feature. Also, he felt that there was little response to random noise, and that little downgrading of handling qualities resulted. These statements are in contrast to both the BB-7 and BB-9 cases, where he found some difficulty with both. In addition, it is in conflict with the MAR pilot's observations for the same BB-8 case, who found it "impossible" to trim laterally and quite responsive to random noise. No obvious reason for this discrepancy was found. This difference played an important role in the overall assessment of the vehicle's handling qualities. The CAL pilot thought that an A6.0 was called for, while U9.5 was the MAR pilot's assessment. He commented that with the poor trimming there was a fifty percent chance that a novice pilot would go out of control with this configuration.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\lvert \frac{\phi}{\beta} \right\rvert_d$	[illegible]	σ_{AS}/δ_{AS}	σ_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.90	.366	1.30	-10.1	6.06	6.06	2.0	30.4			SOLID LINE IS DESIRED
CAL	771	1.57	.4	—	—	—	6.06	2.22	27.2	46.0		— — —
MAR	701	—	—	—	—	—	—	—	—	40.5	TRIM POOR	- - - - - -

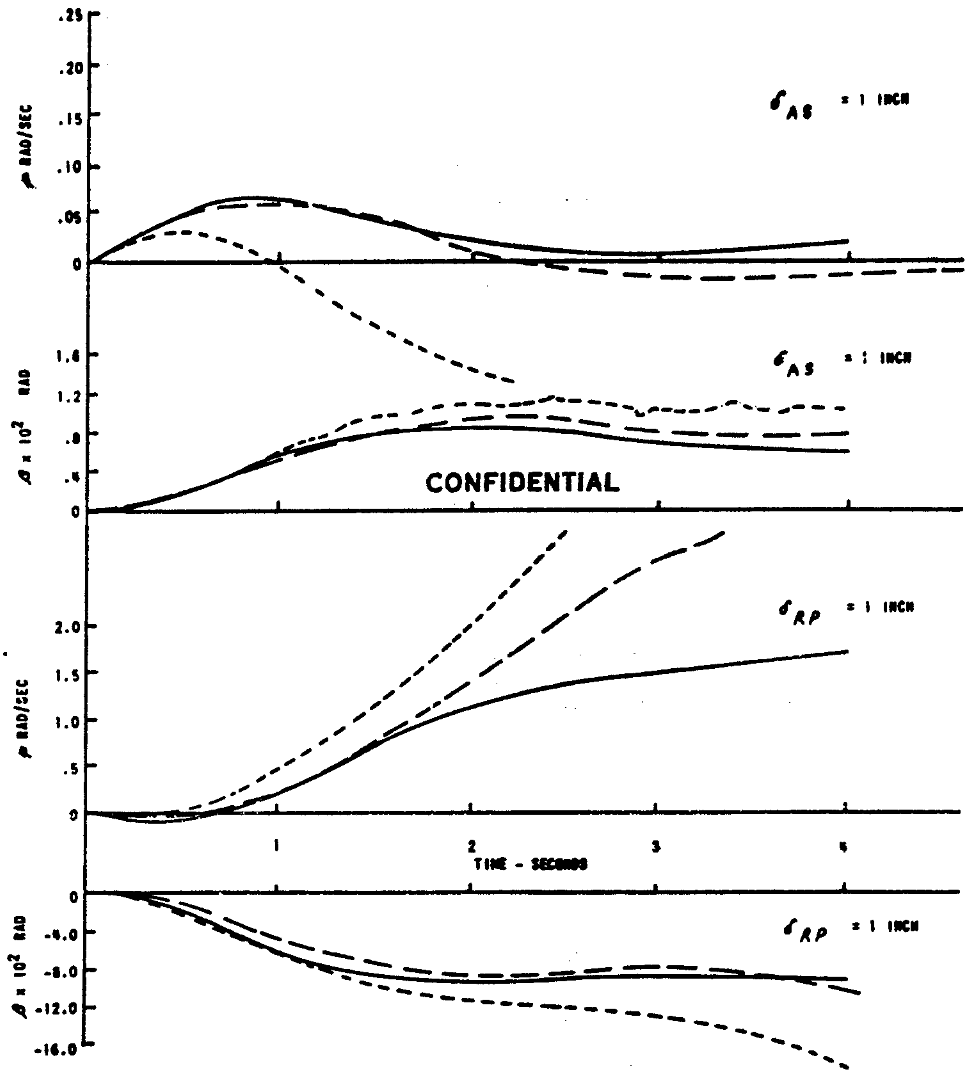


Figure A-35 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-8

(C) The adverse yaw due to aileron was sufficiently low to the CAL pilot on this configuration that he felt one is better off to use aileron stick alone for roll control accepting the sideslip, which will get around the roll response problem for rudder pedal inputs, which was present in BB-7 and BB-8. The roll power is such that reasonably large deflections, with accompanying large lateral forces, will be required. The CAL pilot feels this is not too high a price to pay to avoid the roll problems. The long roll mode time constant accentuates the lateral force problem since the pilot is tempted to put in extra large deflections to initiate a roll maneuver and then take them out quickly--a type of impulse control technique. The configuration is very sensitive, especially in roll, to natural turbulence and random noise inputs. The CAL pilot reported that he simply could not adequately control the roll oscillations. Accuracy in bank angle control was low, as was heading change precision. The higher roll authority with aileron stick and the lower adverse yaw made this configuration the best of the BB-7, 8, 9 series, resulting in ratings from the CAL and MAR pilots of A6.0 and A5.5 respectively.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\lvert\phi/\beta\rvert_d$	$\frac{1}{\omega}\lvert\frac{\phi}{\beta}\rvert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		1.00	.300	1.30	-10.1	5.05	5.05	2.0	30.0			SOLID LINE IS DESIRED
CAL	767	2.25	.43	—	—	—	—	2.55	31.0	A6.0		———
MAR	767	1.04	.96	—	—	—	—	2.00/1.05	33.3/34.9	A5.5		- - - -

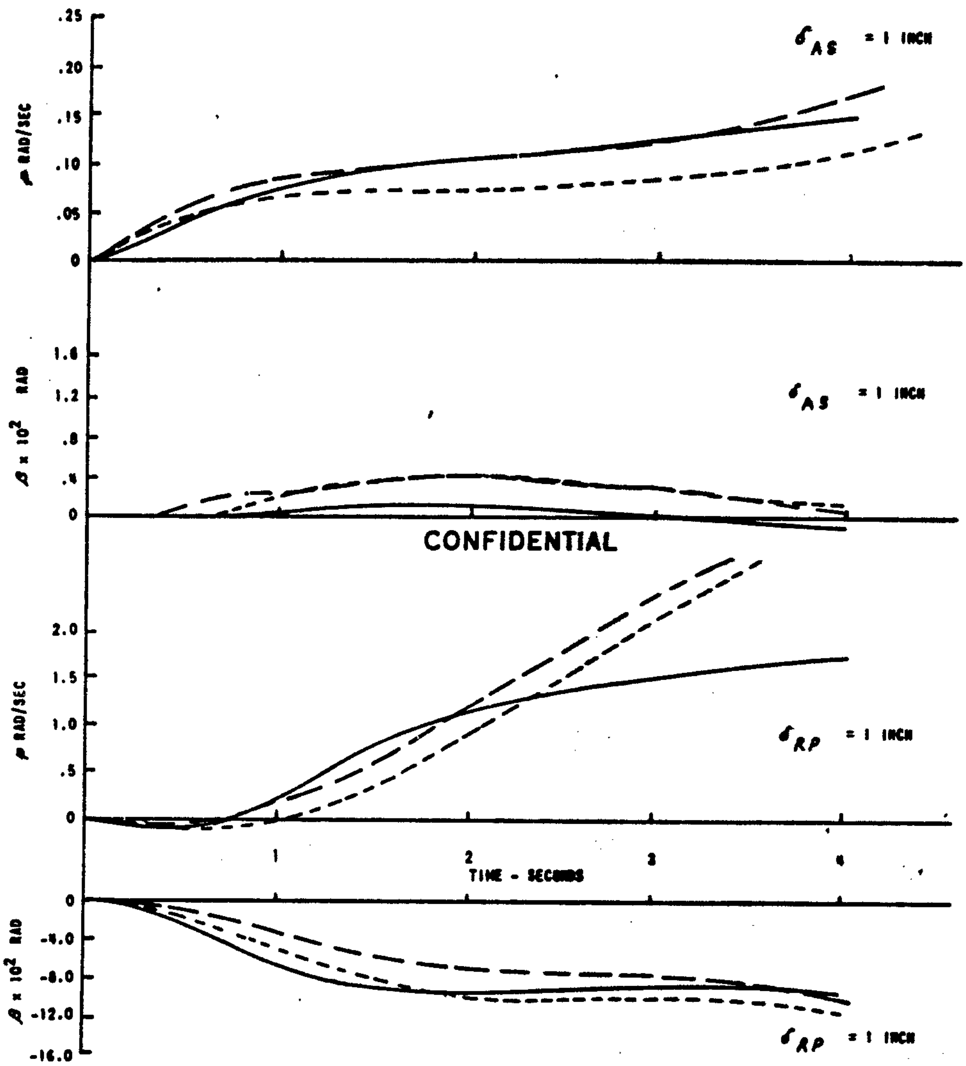
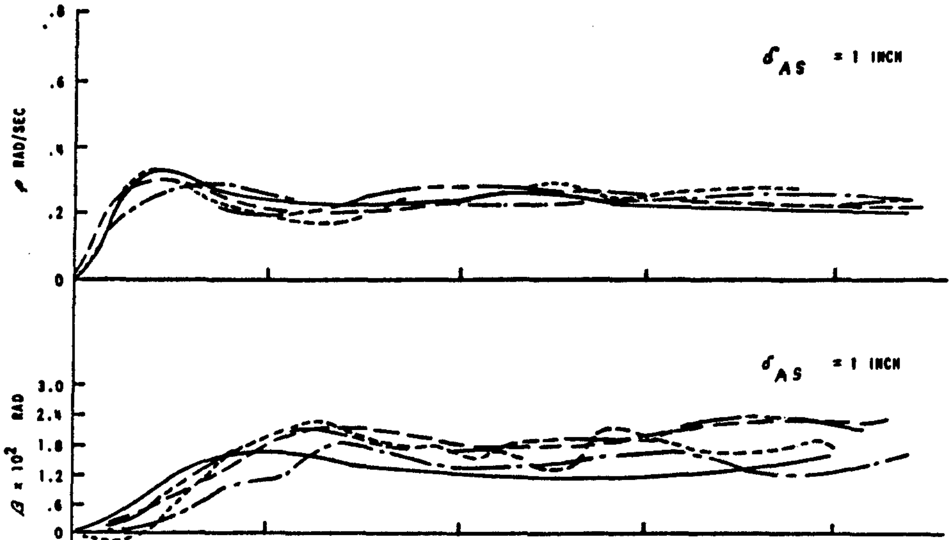


Figure A-36 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION BB-9

(C) The recurring comment from each of the four pilots who flew this configuration concerned the rapid roll acceleration experienced for small, sharp aileron stick inputs. The resulting side accelerations felt at the pilot's head were objected to in varying degrees. In addition, the rudder pedals are sensitive as roll producers, and the Dutch roll frequency is high, giving the overall impression of a very snappy, responsive aircraft. The adverse yaw generated by aileron stick inputs was noticeable but not significant. The CAL pilot preferred to ignore it, since using rudder produced too much sideslip and roll rate than desirable. The low rudder pedal force gradient aggravated this sensitivity. All the pilots felt that bank angle precision suffered because of the initial roll acceleration. Small corrections in ϕ were particularly difficult to accomplish. Heading control was less of a problem if the total change was large enough that a smooth steady-state bank angle maneuver was called for. The aircraft seemed well damped in all respects, making heading maintenance relatively easy. In addition, all pilots found no significant effects were produced by random noise and that no degradation of handling qualities resulted. The CAL and MAR pilots felt that the aileron stick forces were satisfactory, while the USAF and NASA pilots felt they were too low for the roll sensitivity. The CAL pilot thought the rudders were too light, while the NASA pilot, agreeing that they were light, felt they were well matched to the light aileron stick forces. The CAL pilot was the least bothered by the abrupt roll response for small aileron inputs, and complained more about the sideslip produced both by the aileron stick, and rudder pedals. The other pilots all agreed that the roll acceleration problem was the most troublesome. All pilots liked the comfortable descent and flare and felt that there would be little problem in landing this configuration. The longitudinal characteristics were very good (see Section A.3) and often quoted as the best feature of this case. The overall ratings were CAL A4.0, MAR A4.5, USAF A5.0, and NASA A3.0. There was excellent consistency in all the comments; the differences of opinion as to the severity of the complaints is reflected by the different ratings.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert \frac{\phi}{\beta} \rvert_d$	$\frac{1}{\tau_R}\lvert \frac{\phi}{\beta} \rvert_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.03	.420	.29	13.0	5.01	5.01	2.0	30.0			SOLID LINE IS DESIRED
CAL	790	2.94	.38	—	—	6.0	5.08	1.81	25.3*	A4.0	*28.0 DESIRED	— — —
MAR	790	—	—	—	—	—	—	1.81/2.08	32.2	A4.5		-------
USAF	794	3.14	.7	—	—	—	—	—	—	A5.0	δ_{RP} TRIM POOR	—— - ——
NASA	796	3.0	.5	—	—	—	—	—	—	A3.0	TURBULENT	—— - - ——



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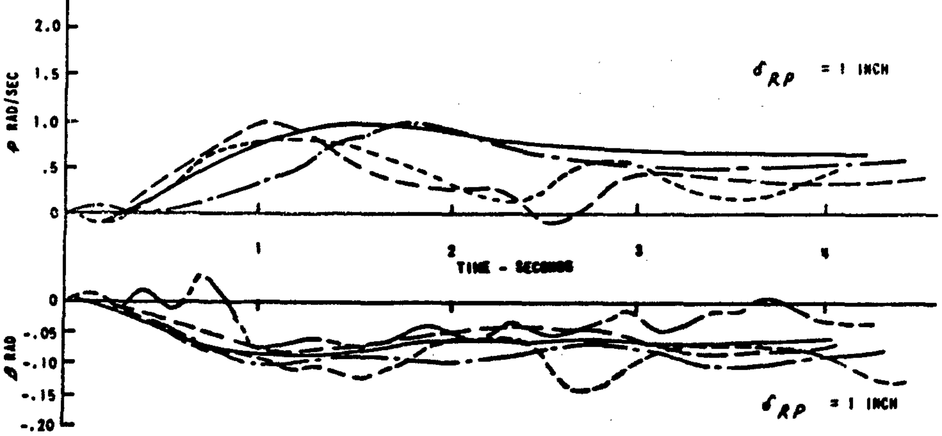

Figure A-37 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-1

(C) The degree of roll acceleration and adverse yaw was in some dispute according to the pilot comments. The CAL pilot felt that a jerky, abrupt roll rate was evident for sharp aileron inputs and that there was a significant amount of accompanying adverse yaw. He found that nulling out the sideslip was difficult since the magnitude and frequency of the β response required large rudder pedal deflections for short periods of time. The MAR pilot commented that the roll response was not as jerky as he had previously encountered and was pleased with this. He again displayed less sensitivity to the adverse yaw and did not experience a requirement for much rudder coordination. Both pilots found the aircraft quite satisfactory in heading control and were satisfied with the aileron stick and rudder pedal forces and gradients. The CAL pilot said that the random noise disturbances accentuated the jerky p response characteristic, while the MAR pilot saw no significant effects. Both pilots agreed that the longitudinal characteristics were good and that handling during the actual descent was very good. The flare maneuver was particularly good. In his closing comments, the MAR pilot noted that he would, in fact, prefer less roll acceleration, but the complaint was not serious enough to downgrade the configuration very much. He rated it as A2.0. The CAL pilot said that the difficuity associated with coordinating the sideslip due to aileron stick motions was his main complaint, and that the jerky p response combined to downgrade the rating to A4.5. There was no indication that any differences in configuration existed between the two flights - the difference in rating seems to be due to a genuine disagreement as to the severity of the above problems.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\tau_R}\left\|\frac{\phi}{\beta}\right\|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.00	.020	.20	13.9	5.61	5.61	2.0	20.0			SOLID LINE IS DESIRED
CAL	703	2.76/2.24	.42/.25	—	—	5.47	6.05	2.00	30.0*	40.5	*20.0 DESIRED	————
HAR	703	2.70	.36	—	—	—	3.54	2.00/2.20	28.6/35.0	42.0		-------

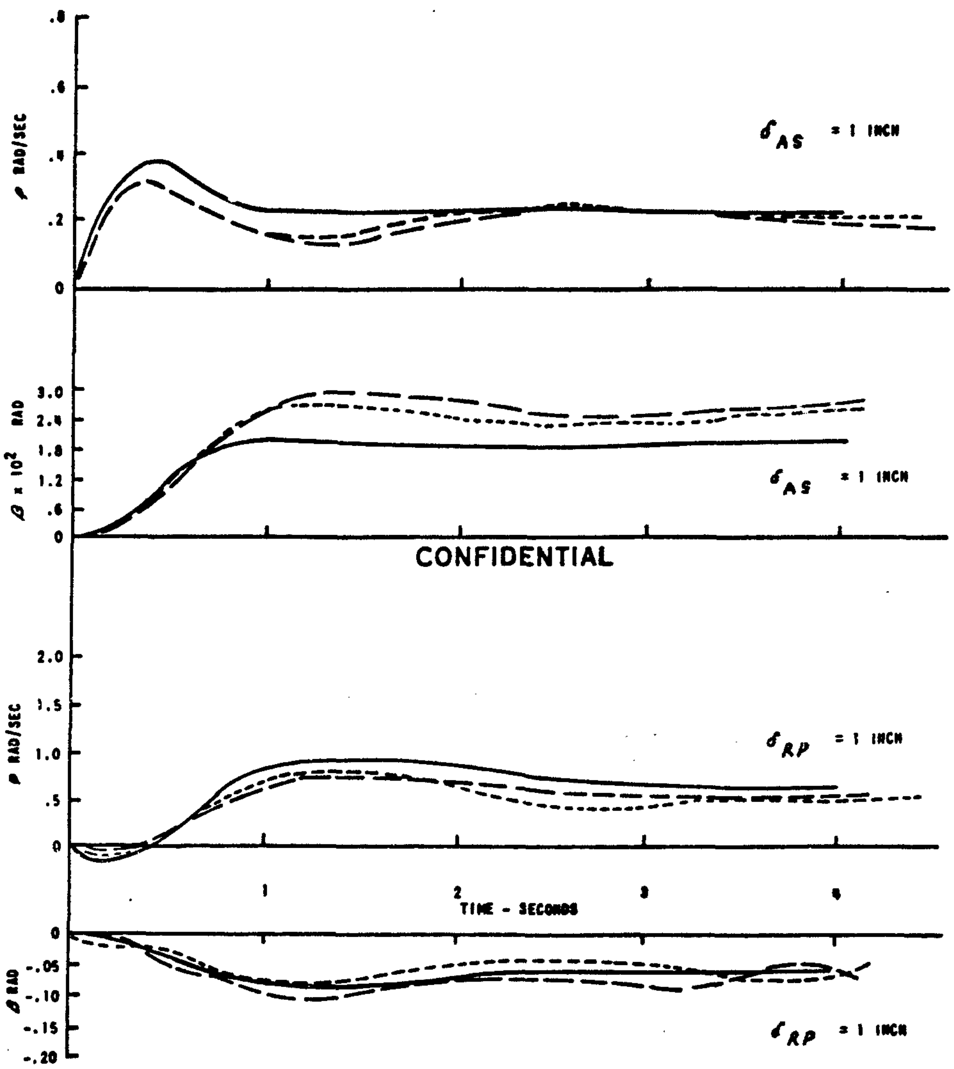

Figure A-38 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-2

(C) Both the initial roll acceleration and sideslip excursions for step aileron inputs are reduced in comparison to LA-1 and LA-2. Roll response was reported "a bit abrupt" by the CAL pilot, and "slightly fast" by the MAR pilot, but was not seriously objected to by either. Likewise neither pilot had difficulty with the adverse yaw. The CAL pilot preferred to use aileron stick alone for lateral control, while the MAR pilot reported no difficulty with coordination. Bank angle control and heading control presented no problem whatsoever. The MAR pilot reported excellent damping about all three axes. All control forces were liked and control harmony was reported as good. The aircraft displayed no significant effect in natural turbulence or random noise. The descent and flare maneuvers were particularly pleasing to both pilots. The aircraft was easy to handle, displayed good roll control, was not affected by turbulence and was easily flared. The CAL pilot flew this configuration on two occasions, rating it as A2.0 both times. The MAR pilot felt A3.0 was merited; the only objection was the initial roll acceleration for small, rapid aileron stick inputs.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\tau_s}\left\|\frac{\phi}{\beta}\right\|_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.03	.426	.29	13.9	5.61	5.61	2.8	39.9			SOLID LINE IS DESIRED
CAL	765	2.62	.37	—	—	—	—	2.06	39.7	A2.0		— — —
CAL	773	2.82	.36	—	—	—	5.21	1.95	35.4	A2.0		------
MAR	777	—	—	—	—	—	—	1.95	35.0	A3.0		— - —

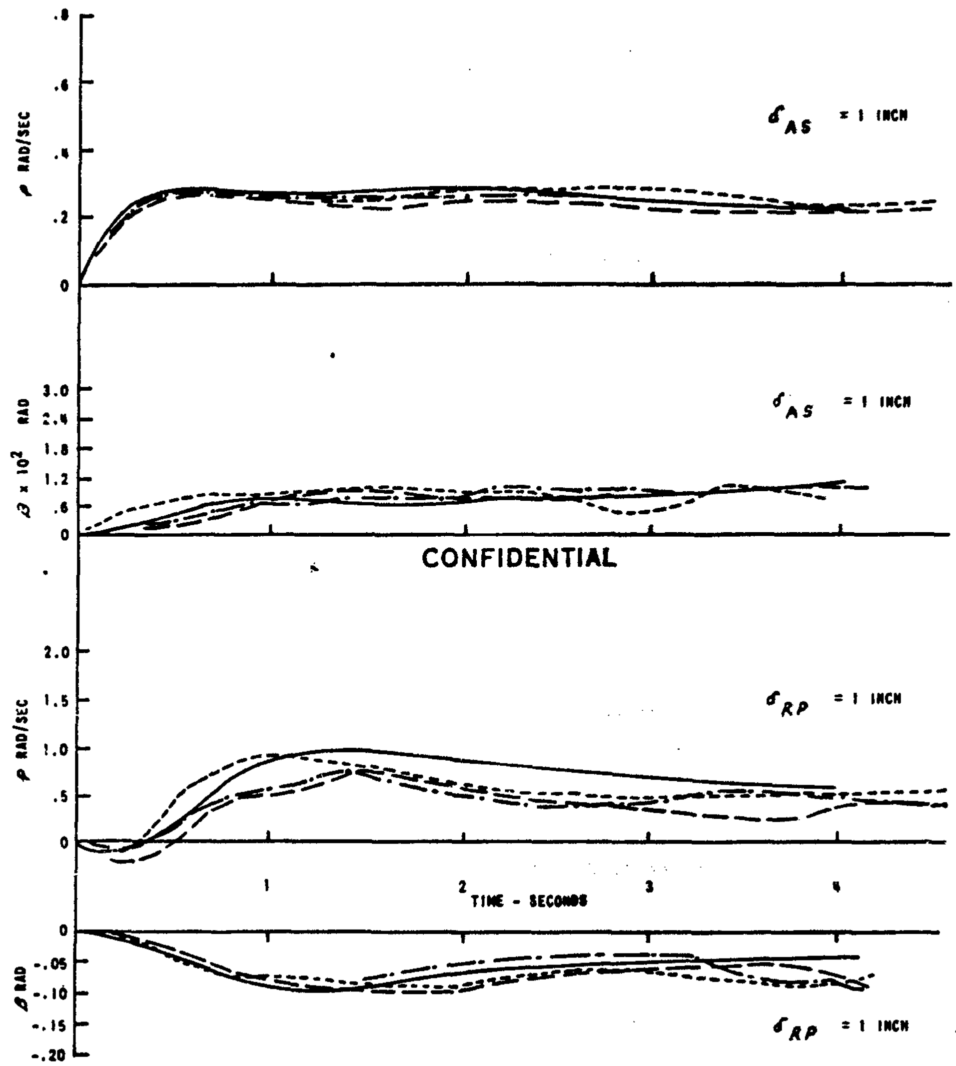

Figure A-39 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-3

LA-4

(C) This configuration again displayed the abrupt roll rate response for small δ_{AS} inputs which was objected to in the LA-1, 2, 3 series. Roll and directional damping were good. Precise bank angle control was possible but not optimum due to the small roll oscillation which inevitably developed whenever small ϕ maneuvers were required. This annoying oscillation is of such high frequency that it damps out before the pilot can put in corrective movements. Neither pilot had trouble with turn coordination and heading control. The MAR pilot preferred to fly it with feet off the rudder pedals, while the CAL pilot found that a little rudder into the turn, followed by a gentle removal as the desired bank angle was approached, did the trick. Sideslip and roll responses to rudder pedal inputs were judged satisfactory. The CAL pilot felt the rudder pedal forces were light in comparison to the elevator and aileron, while the MAR pilot commented that the aileron stick forces were light compared to the elevator stick. The descent and flare were easily performed, smooth and comfortable. The MAR pilot thought that the natural turbulence he experienced aggravated the small δ_{AS} problem since he was continually trying to correct small bank angle displacements. The flare control was excellent and the longitudinal characteristics were also good (see Section A. 3). The difference between the MAR pilot's A4. 0 and the CAL pilot's A3. 0 was the degree of annoyance produced by side accelerations at the pilot's head due to high abrupt roll accelerations.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\omega_d}\left\|\frac{\phi}{\beta}\right\|_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.46	.305	.41	14.0	5.76	5.76	2.0	24.4			SOLID LINE IS DESIRED
CAL	762	3.1	.27	—	—	7.32	6.10	1.82	26.0*	A3.0	*20.0 DESIRED	———
MAR	779	2.09	.33	—	—	—	6.00	—	33.7	A4.0		-------

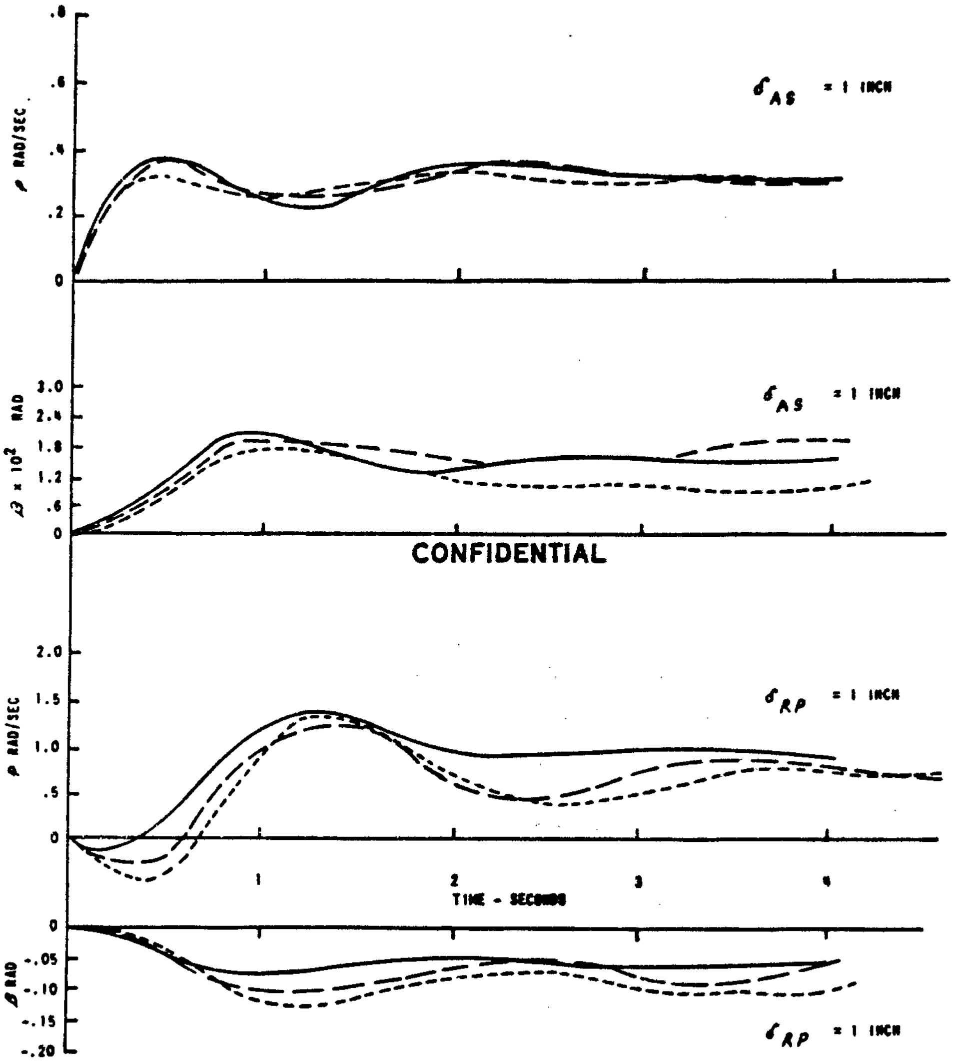

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Figure A-40 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-4

(C) There was little difference in the pilot comments for this case as compared to LA-4. The MAR pilot had the same complaints about the snappy roll for small aileron stick inputs. The CAL pilot again was less bothered by this feature. He did notice more adverse yaw than on LA-4, however, he found that it was still low enough that he did not have to use rudder and could control the aircraft quite well using aileron stick alone. He attempted to use rudder for coordination and experienced no problems in doing so. He recommends using a little δ_{RP} into the turn and easing it out gently as the desired bank angle is approached. The MAR pilot again noted the difficulty with precision of small bank angle or heading changes, but found that larger maneuvers presented no problem. While the CAL pilot thought the responses to random noise were negligible, the MAR pilot again felt that the roll acceleration problem was accentuated by it as he attempted to correct small bank angle disturbances. Directional damping was again reported as excellent. The descent was liked very much by both pilots. Good airspeed, attitude and flare control were experienced. The MAR pilot rated the descent portion separately as an A2.5, overall as A4.5, based primarily on his $\dot{p}$ objections at altitude (he experienced far less problems with this during descent). The CAL pilot gave an A3.0 rating, as he did for LA-4, for which his comments were very similar.

PILOT	FLT	ω_c	ζ_d	τ_R	τ_s	$\left\|\frac{\phi}{\beta}\right\|_d$	$\frac{1}{\tau_s}\left\|\frac{\phi}{\beta}\right\|_d$	r_{AS}/δ_{AS}	r_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.06	.305	.41	14.0	6.70	5.70	2.0	35.4			SOLID LINE IS DESIRED
CAL	764	3.05	.3	—	—	6.0	5.06	2.0	34.6	A5.0		— — —
MAR	781	4.21	.315	—	—	—	—	1.0	37.6	A4.5		- - - - - -

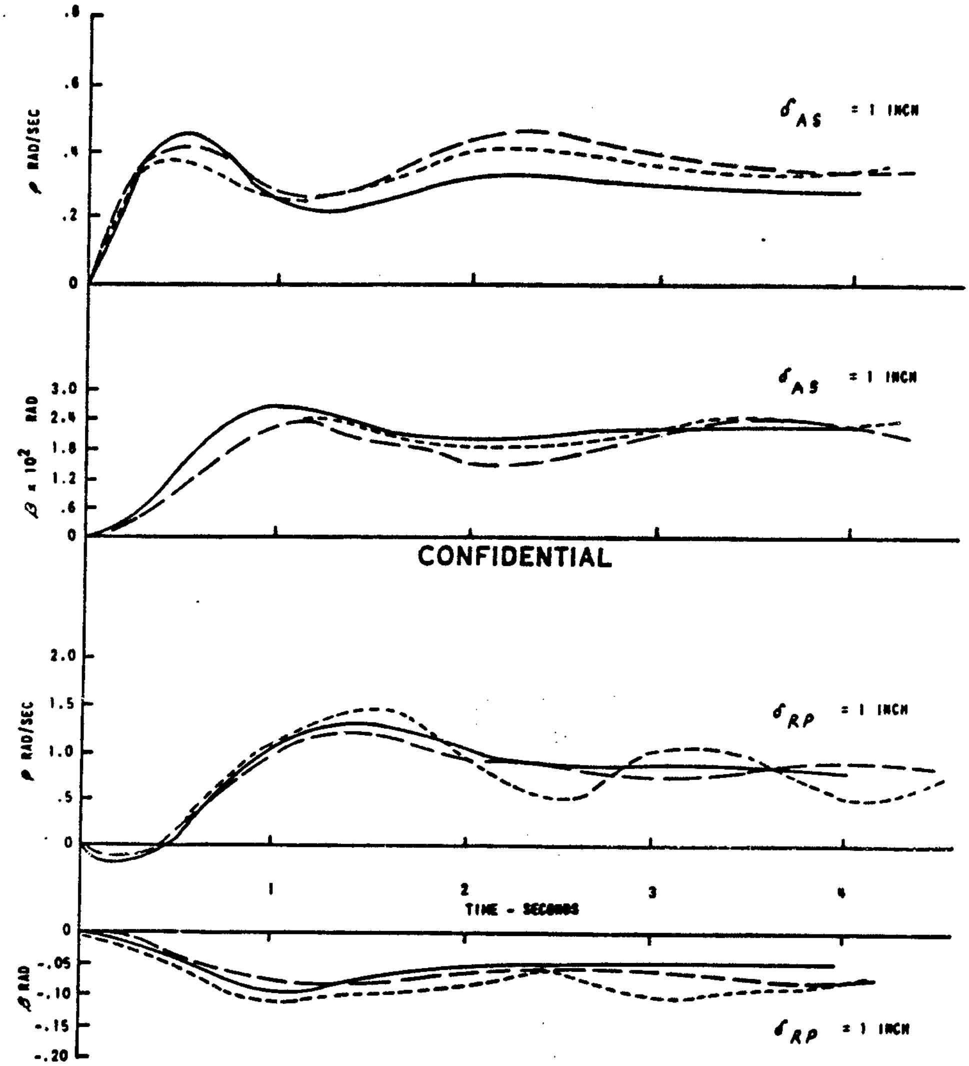

Figure A-41 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-5

(C) This configuration was flown once each by the CAL, USAF and NASA pilots, and twice by the MAR pilot. It was perhaps one of the best overall configurations tested for the landing approach mission. The adverse yaw due to aileron is low, prompting all the pilots to comment that aileron-alone control is quite satisfactory, and that attempts to null the small side-slip are not worth the effort. None of the pilots reported problems with roll acceleration for small stick inputs. The CAL pilot even commented that he would like more roll power than he saw, however, all the other pilots felt the roll power was entirely adequate. The USAF pilot thought that there was perhaps too much roll authority, and he experienced some difficulty with precise bank angle control, due to this sensitivity. The other pilots were in agreement that bank angle control was excellent, with negligible overshoot tendency and oscillation. Three of the pilots felt that the rudders were too sensitive as sideslip producers and that it was easy to overcontrol sideslip maneuvers. The situation is compounded by the rudder pedal force gradient which three of the pilots found "too light" for this sensitivity. The requirement for rudder pedal inputs is low, however, so that this characteristic does not present a big problem. The USAF pilot thought that random noise inputs made his roll sensitivity problem more pronounced. The other three pilots disagreed, remarking that there were no significant effects on vehicle behavior due to these inputs. Both the MAR and CAL pilots thought that a little more roll power would be optimum in the descent, otherwise airspeed, attitude and flare control were excellent. The CAL pilot found he could arrest his rate of descent in only 200 feet, and with definite precision. The excellent longitudinal handling qualities (Section A. 3) combined with the above lateral-directional features to produce ratings of A1.0 and A1.5 from the MAR pilot (he added that A2.5 would be appropriate for the descent portion alone), A3.0 from the CAL and NASA pilots, and A4.5 from the USAF pilot.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert \phi/\beta \rvert_d$	$\frac{\omega_\phi}{\omega_d} \lvert \phi/\beta \rvert_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		3.00	.305	.41	14.0	5.76	5.76	2.0	34.5			SOLID LINE IS DESIRED
CAL	789	3.21	.36	—	—	5.13	5.34	1.91	36.0	A3.0		
NAR	785	3.06	.35	—	—	—	5.3	2.08	37.0	A1.0	δ_{AS} TRIM POOR	
NAR	793	3.01	.32	—	—	—	5.05	2.00/2.00	32.7/29.0	A1.5		
USAF	795	3.2	.34	—	—	4.50	—	—	—	A4.5	δ_{RP} TURBULENT	
NASA	797	3.0	.35	—	—	—	—	—	—	A3.0	EXTREME TURB.	

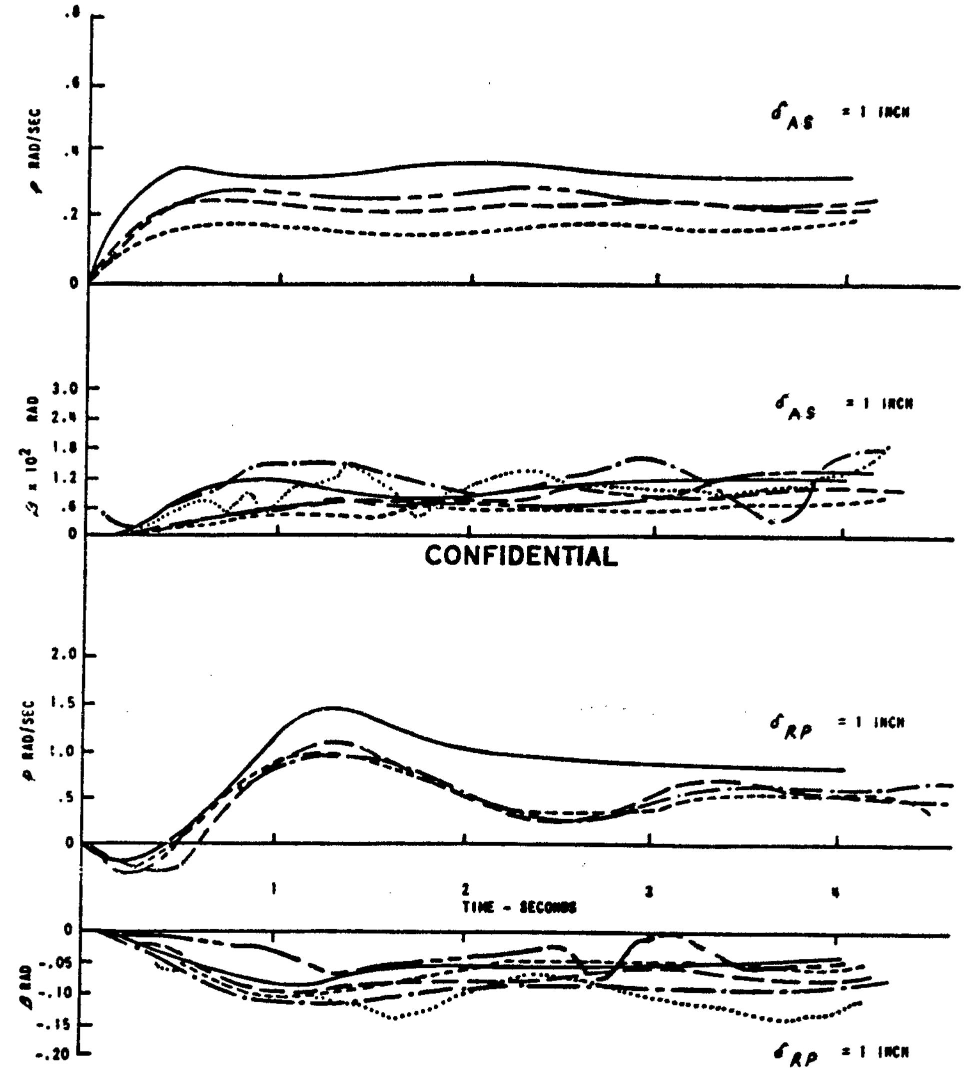

Figure A-42 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-6

(C) Both pilots commented on the high roll accelerations for small aileron stick inputs which caused uncomfortable side forces at the pilot's head. Although the roll damping appears satisfactory for larger aileron inputs, the jerky, abrupt motions for small inputs make precise bank angle control difficult. The random noise inputs accentuated this problem since the disturbances were of an amplitude and frequency such that small rapid corrections were called for. The MAR pilot thought this effect was of a "nauseating" level, while the CAL pilot seemed to be more tolerant of it. The CAL pilot was again more concerned with the sideslip excursions exhibited for aileron stick inputs. He found that the initial excursion during a turning maneuver was large, but returned to zero quite quickly. He found this response hard to null out with rudder pedals, due to the quickness of the response, not the lack of sideslip response for rudder pedal inputs. He would rather use aileron stick alone since coordination requires too much attention for what can be achieved. The MAR pilot also commented that he was unable to coordinate the high frequency β response experienced on turn initiation. The CAL pilot thought control harmony was poor due to the light rudder pedal forces, while the MAR pilot felt that all control forces, gradients and feel characteristics were satisfactory. The descent was again quite well received by both pilots. The aircraft was easy to handle, had good flight path control, minimum response to natural turbulence and excellent flare response. The MAR pilot did feel that his $\dot{p}$ objections at altitude were still valid during the descent. The longitudinal characteristics were very good, as reported in Section A. 3. The CAL pilot gave an overall rating of A4. 0, his prime objection being his difficulty with sideslip coordination. The MAR pilot felt A5. 0 was called for because of his annoying roll acceleration problem.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\lvert \phi/\beta \rvert_d$	$\frac{\omega_\phi}{\omega_d}\lvert \phi/\beta \rvert_d$	ϕ_{AS}/δ_{AS}	ϕ_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.71	.606	.22	13.6	5.52	5.52	2.0	30.0			SOLID LINE IS DESIRED
CAL	761	—	—	—	—	—	—	1.00	—	40.0		———
MAR	778	3.1	.67	—	—	—	—	2.3	45.0	45.0		------

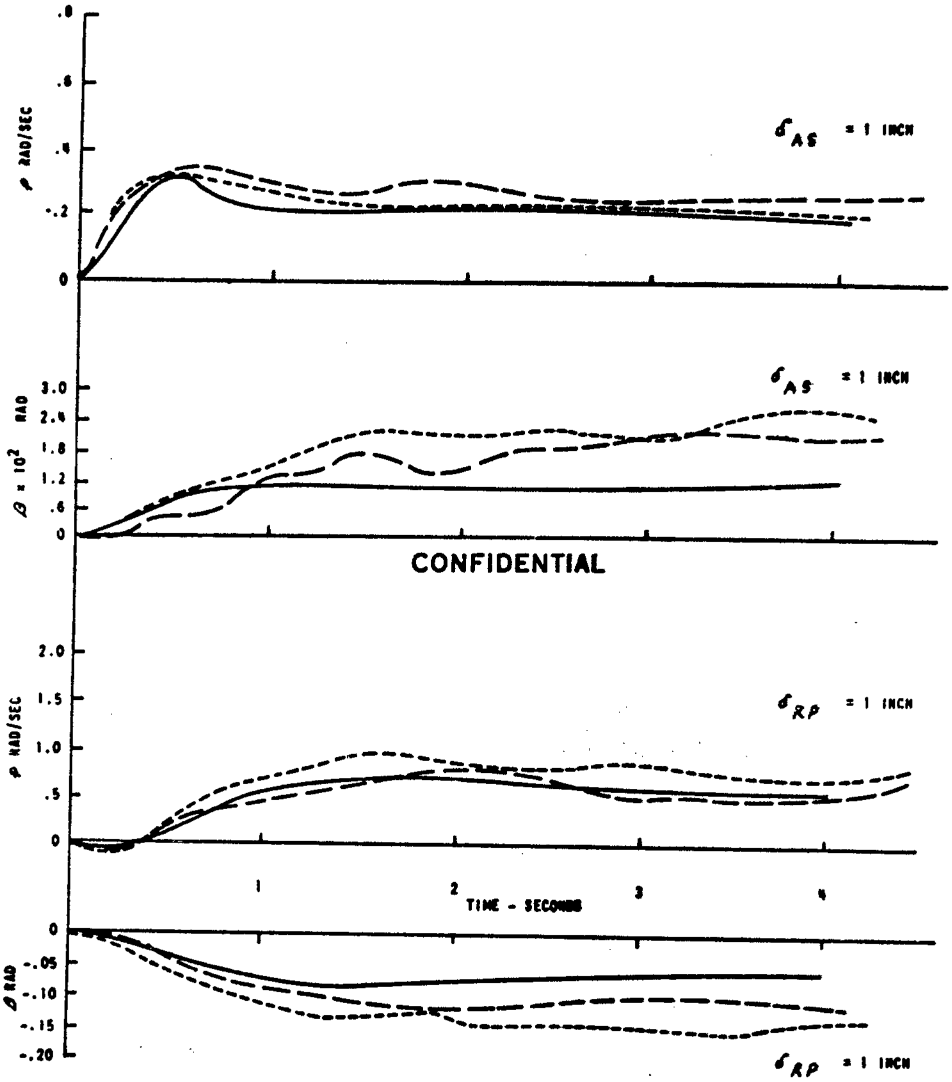

Figure A-43 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-7

(C) The larger sideslip excursions for aileron stick inputs compared to LA-7 solicited a correspondingly higher level of complaint, especially from the CAL pilot who has displayed a sensitivity to it on previous landing approach cases. The MAR pilot also listed the high adverse yaw as a "bad" feature; however, his chronic roll acceleration problem was still the worst single feature to him. He calls the lateral system "nervous" in describing the sensitivity in roll to small δ_{AS} inputs. "Abrupt", "jerky" and "sharp" are other adjectives used to describe this phenomena. He recommends smooth, slow roll inputs as the only suitable technique to avoid head jerks, along with an effort to avoid the necessity for small bank angle maneuvers. Both pilots again discovered that the high rates of change of sideslip on turn tasks made coordination with rudder very difficult, requiring too much of the pilot's attention. The CAL pilot again felt this situation was complicated by the very light rudder pedal forces. The MAR pilot found these forces "satisfactory". The $\dot{p}$ problem was found to be reduced at lower altitudes according to the MAR pilot, however both pilots reported the same difficulties with sideslip control during the descent. The flare control was again reported as "very good", and no significant effects from natural turbulence were encountered. The CAL pilot rated this configuration as A5.5 based mainly on his sideslip complaints, while the A3.5 rating by the MAR pilot reflected primarily the roll acceleration problem.

PILOT	FLT	ω_d	ζ_d	τ_R	τ_S	$\left|\frac{\phi}{\beta}\right|_d$	$\frac{1}{\omega}\left|\frac{\phi}{\beta}\right|_d$	F_{AS}/δ_{AS}	F_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.71	.606	.22	13.6	6.52	6.52	2.0	30.0			SOLID LINE IS DESIRED
CAL	700	2.70	.775	—	—	—	—	2.07	31.6	A5.5		———
MAR	702	2.9	.7	—	—	—	—	1.96	31.2	A3.5		- - - -

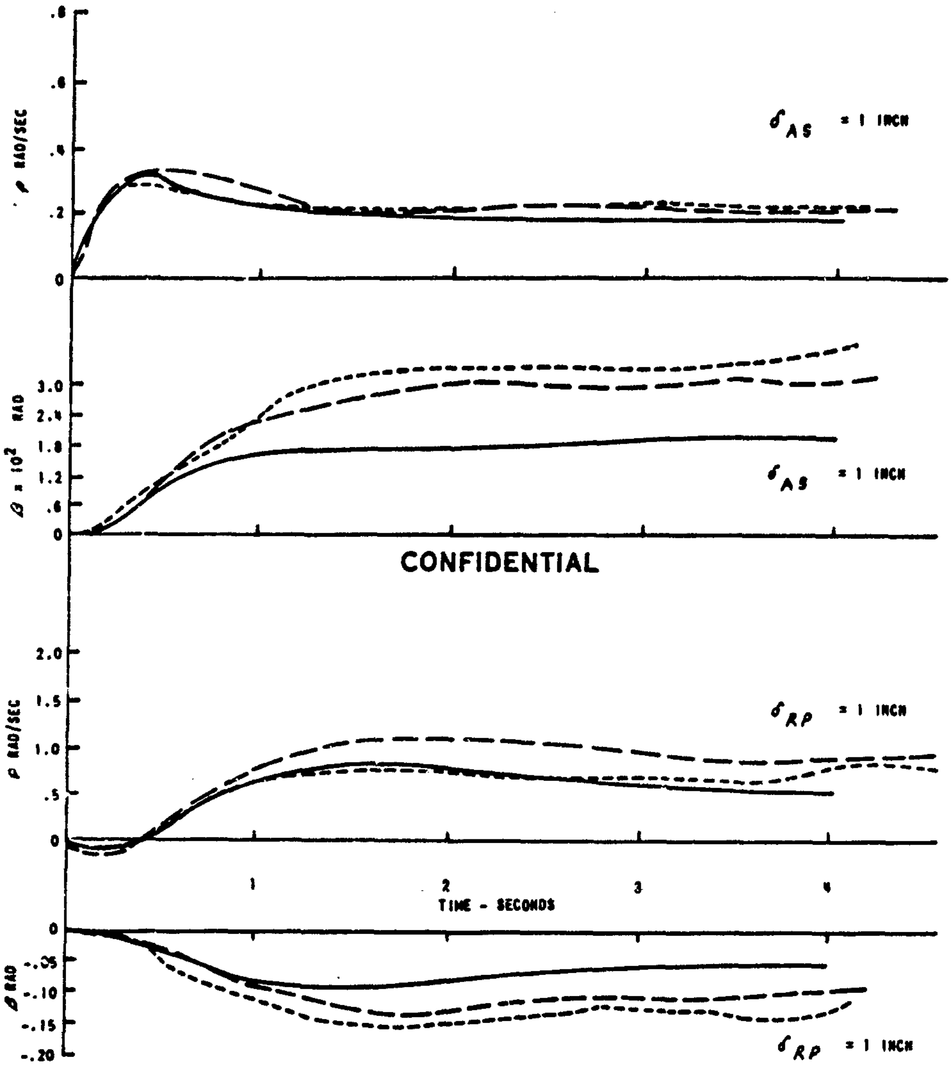

Figure A-44 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS}, δ_{RP}) FOR CONFIGURATION LA-8

(C) A substantial improvement in the sideslip difficulties experienced in LA-8 is effected by the changing of the interconnect ratios to the LA-9 value. The CAL pilot no longer found that he was required to coordinate a fast moving sideslip response to aileron stick inputs - a defect that he showed a dislike for previously. At the same time there was little evidence of the roll rate abruptness present earlier for small, rapid aileron stick inputs. The CAL pilot did report a tendency to abruptness when executing small bank angle changes, but the MAR pilot, usually sensitive to this feature, did not complain of it on his one LA-9 flight. All control forces, gradients and feel characteristics were likewise found satisfactory. Little or no coordination was required on level turns, and no heading control difficulties were experienced. Random noise inputs had little effect on vehicle response and good lateral-directional damping was reported. The descent portion of the flights went well for both pilots. They reported good roll and attitude control, no natural turbulence effects and excellent flare characteristics. The CAL pilot experienced deteriorating sideslip effects at the lower altitude, finding more β response to pure aileron stick inputs than he had at altitude. He became harsher on this feature as the flight terminated, finally rating the configuration as A3.5. The MAR pilot was quite satisfied at all aspects of this configuration and gave an overall rating of A1.5.

[redacted]

PILOT	FLT	ω_d	ζ_d	τ_R	τ_s	$\lvert\phi/\beta\rvert_d$	$\frac{1}{\omega_d}\lvert\phi/\beta\rvert_d$	p_{AS}/δ_{AS}	p_{RP}/δ_{RP}	P.R.	REMARKS	LEGEND
DESIRED		2.71	.086	.22	13.5	5.52	5.52	2.0	39.4			SOLID LINE IS DESIRED
CAL	767	2.60	.45	—	—	—	—	2.06	36.6	A3.5		
MAR	784	2.3	.01	—	—	—	—	1.85	39.7	A4.5		

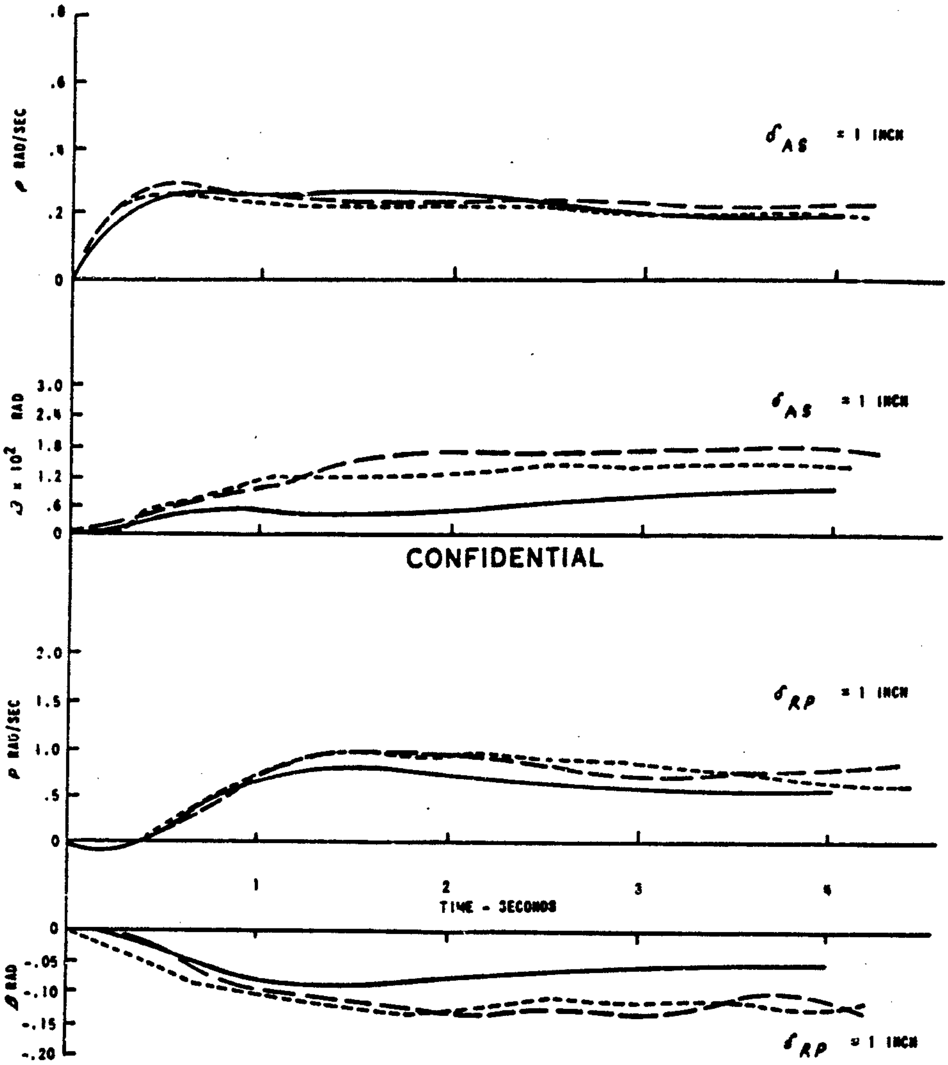

Figure A-45 TIME HISTORY OF RESPONSES TO AUTOMATIC STEP INPUTS (δ_{AS} , δ_{RP}) FOR CONFIGURATION LA-9

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13. ABSTRACT

The results of an in-flight simulation program to investigate longitudinal and lateral-directional handling qualities of the Martin SV-5P (Pilot) lifting body are presented and discussed. The in-flight simulation was a point stability simulation at five flight conditions: (1) Re-entry Glide, (2) Boost A, (3) Burnout, (4) Boost B, and (5) Landing Approach. The in-flight simulation was primarily a lateral-directional investigation, the longitudinal characteristics simulated at each flight condition remained fixed. Nine lateral-directional configurations were investigated for each flight condition for a total of 45 different configurations. The nine lateral-directional configurations at each flight condition were obtained by varying the SV-5P rudder to aileron interconnect ratio and the yaw and roll damping feedback gains. The USAF/CAL variable stability T-33 airplane was used as an in-flight simulator. A CAL and a Martin pilot each evaluated 50 configurations. A NASA and a USAF pilot each evaluated 6 configurations. All the configurations were evaluated in straight and level flight. In addition, the landing approach configurations were evaluated during descent at a simulated maximum L/D of the SV-5P. The handling qualities simulated were evaluated by the pilots based on the mission requirements and tasks at each flight condition of the SV-5P. Pilot comments were recorded on each configuration, and the pilots rated the configurations using a new pilot rating scale. The pilot comments and ratings were analyzed and interpreted in the light of the simulated characteristics and their handling qualities. The longitudinal characteristics simulated were considered acceptable except for the objection of some pilots to the large stick force per g during Boost A and B and Burnout. The greatest effect on lateral-directional handling qualities at any flight condition resulted from a change in rudder to aileron interconnect ratio. Too small a value of rudder to aileron interconnect increased the adverse yaw, reduced aileron roll power, and made rudder coordination difficult. Too large a value resulted in an acceleration-ordered p response and a lack of roll damping. In general, increasing the roll and yaw damping improved the aileron response by reducing adverse yaw and improving the roll response.

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Stability and Control						

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