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EVALUATION OF LATERAL-DIRECTIONAL HANDLING QUALITIES OF PILOTED RE-ENTRY VEHICLES UTILIZING FIXED-BASE AND IN-FLIGHT EVALUATIONS

by J. I. Meeker

Prepared by
CORNELL AERONAUTICAL LABORATORY, INC.
Buffalo, N. Y.
for Flight Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1967

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and AF 33(615)-1253 by
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FOREWORD

The work reported herein was undertaken as a joint effort among the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio; the Flight Research Center, NASA, Edwards, California; and the Flight Research Department, Cornell Aeronautical Laboratory, Inc., Buffalo, New York.

The report was prepared by Cornell Aeronautical Laboratory in fulfillment of Contract AF 33(615)-1253 S/A 5(65-1619), AFFDL (RTD) Project No. 6392OE0812. The work was sponsored by the Flight Research Center, NASA and was administered by the Air Force Flight Dynamics Laboratory. Mr. F. VanLeynseele was NASA project engineer for the Flight Research Center. Mr. L.W. Taylor and Mr. K.W. Iliff designed the experiment for the Flight Research Center. The program was monitored for the Flight Dynamics Laboratory by Capt. J.R. Pruner and Flt. Lt. T.M. Harris.

Evaluation pilots for the program were: F.W. Haise, B.A. Peterson and M. O. Thompson, all from the Flight Research Center, NASA, and R. P. Harper from the Flight Research Department, CAL. The safety pilot on all flights was J. I. Meeker.

The program was conducted under the technical direction of C.R. Chalk, project engineer for the Flight Research Department, CAL. The following members of the Flight Research Department made significant contributions to the engineering effort: B.H. Dolbin, who developed the simulation methods and procedures for calculating variable stability gains; R.W. Huber, who was responsible for modification, calibration and operation of the T-33 variable stability system and ground simulation equipment; G.W. Hall, who assisted in analysis of pilot comment data and in the report preparation; D.L. Key, who authored the appendix on ground simulation of the T-33 and contributed to the initial flight calibration procedures. The following members of the Department's computing group were responsible for the digital computer programming required for the simulation and gain calculations: V.D. Close, W.H. Shed and C.L. Mesiah.

ABSTRACT

The final results of a fixed-base and in-flight research program to investigate lateral-directional handling qualities in the re-entry mission are reported and discussed. Most evaluations were for the up-and-away phase of the re-entry mission, but a small number of configurations were evaluated in a spiral descent to a landing approach.

Three different groups of lateral-directional flight characteristics were investigated and the results are presented in three parts. Part I evaluation configurations were selected from a previous re-entry vehicle evaluation program performed by Cornell Aeronautical Laboratory, Part II configurations were based on a general lateral-directional handling qualities investigation conducted by Flight Research Center, NASA, and Part III configurations were directly applicable to lifting body investigations performed by Flight Research Center, NASA. All of the configurations were evaluated for their suitability to the re-entry mission.

The vehicle used for both the fixed-base and in-flight simulations was a three-axis variable stability T-33 airplane.

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LIST OF SYMBOLS

α - angle of attack, radians

β - angle of sideslip, radians

$\dot{\beta}$ - sideslip rate, radians/sec

δ_a - aileron deflection, radians

δ_{AS} - aileron stick deflection, inches

δ_r - rudder deflection, radians

δ_{RP} - rudder pedal deflection, inches

ζ_ϕ - damping ratio of numerator quadratic in roll to aileron input transfer function

ζ_d - Dutch roll damping ratio

ζ_{RS} - roll spiral damping ratio

θ - angle of pitch, radians

λ_r - roll mode root

σ - real part of $s = \sigma + j\omega$

τ_R - roll mode time constant, seconds

τ_S - spiral mode time constant, seconds

ϕ - bank angle, radians

ψ - heading angle, degrees

ω - imaginary part of $s = \sigma + j\omega$

ω_ϕ - undamped natural frequency of numerator quadratic in roll to aileron input transfer function, radians/sec

ω_d - Dutch roll undamped natural frequency, radians/sec

ω_{RS} - roll spiral undamped natural frequency, radians/sec

F_{AS} - aileron stick force, pounds

F_{RP} - rudder pedal force, pounds

g – acceleration of gravity, feet/sec^2

h – altitude, feet

I_x – moment of inertia about x axis

I_y – moment of inertia about y axis

I_z – moment of inertia about z axis

I_{xz} – product of inertia

$j = \sqrt{-1}$

L – rolling moment, ft-lb

$$L_\beta = \frac{1}{I_x} \quad \frac{\partial L}{\partial \beta}$$

$$L_{\dot\beta} = \frac{1}{I_x} \quad \frac{\partial L}{\partial \dot\beta}$$

$$L_{\delta_a} = \frac{1}{I_x} \quad \frac{\partial L}{\partial \delta_a}$$

$$L_{\delta_{AS}} = \frac{1}{I_x} \quad \frac{\partial L}{\partial \delta_{AS}}$$

$$L_{\delta_r} = \frac{1}{I_x} \quad \frac{\partial L}{\partial \delta_r}$$

$$L_{\delta_{RP}} = \frac{1}{I_x} \quad \frac{\partial L}{\partial \delta_{RP}}$$

$$L_p = \frac{1}{I_x} \quad \frac{\partial L}{\partial p}$$

$$L_r = \frac{1}{I_x} \quad \frac{\partial L}{\partial r}$$

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

$m = W/g$

N – yawing moment, ft-lb

$$N_\beta = \frac{1}{I_z} \quad \frac{\partial N}{\partial \beta}$$

$$N_{\dot\beta} = \frac{1}{I_z} \quad \frac{\partial N}{\partial \dot\beta}$$

$$N_{\delta_a} = \frac{1}{I_z} \frac{\partial N}{\partial \delta_a}$$

$$N_{\delta_{AS}} = \frac{1}{I_z} \frac{\partial N}{\partial \delta_{AS}}$$

$$N_{\delta_r} = \frac{1}{I_z} \frac{\partial N}{\partial \delta_r}$$

$$N_{\delta_{RP}} = \frac{1}{I_z} \frac{\partial N}{\partial \delta_{RP}}$$

$$N_p = \frac{1}{I_z} \frac{\partial N}{\partial p}$$

$$N_r = \frac{1}{I_z} \frac{\partial N}{\partial r}$$

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

n_y - side force acceleration, g units

n_z - normal acceleration, g units

p - roll rate, radians/sec

p_{ss} - steady state roll rate, radians/sec

PR - pilot rating

R/C - rate of climb

RN - random noise

s - Laplace operator

V - true velocity, feet/sec

Y - side force, lb

$$Y_{\beta} = \frac{1}{mV} \frac{\partial Y}{\partial \beta}$$

$$Y_{\dot{\beta}} = \frac{1}{mV} \frac{\partial Y}{\partial \dot{\beta}}$$

$$Y_{\delta_a} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_a}$$

$$Y_{\delta_{AS}} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_{AS}}$$

$$Y_{\delta_r} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_r}$$

$$Y_{\delta_{RP}} = \frac{1}{mV} \frac{\partial Y}{\partial \delta_{RP}}$$

$$Y_{p} = \frac{1}{mV} \frac{\partial Y}{\partial p}$$

$$Y_{r} = \frac{1}{mV} \frac{\partial Y}{\partial r}$$

x, y, z - STABILITY AXES (i.e., a right hand orthogonal body axis system with origin at the C.G., the z axis in the plane of symmetry and the x axis aligned with the relative wind at zero sideslip trim flight.)

SECTION 1
INTRODUCTION

The specific mission of a manned space vehicle re-entering the atmosphere is to descend and land safely without exceeding the limitations of the vehicle or pilot. The lifting body is being studied as a possible vehicle to accomplish this mission. The requirement for maneuverability during the descent and landing gives increased importance to the stability and control characteristics of the vehicle.

The research program reported herein was undertaken as a joint effort to investigate lateral-directional handling qualities. This work was sponsored by the NASA Flight Research Center and performed under contract with the Air Force Flight Dynamics Laboratory by the Flight Research Department of Cornell Aeronautical Laboratory. An Air Force T-33 airplane modified to incorporate a three-axis variable stability system was employed for the handling qualities evaluations.

The principal objective of this investigation was to evaluate the lateral-directional handling qualities for the re-entry mission of selected ranges of dynamic flight characteristics. Three groups of configurations were evaluated during the program and these are reported as Part I, Part II and Part III configurations. The Part I configurations were selected from a previous re-entry vehicle evaluation program performed by Cornell Aeronautical Laboratory; Part II configurations were based on configurations evaluated in a general lateral-directional handling qualities investigation conducted by Flight Research Center, NASA; Part III configurations were selected because of their application to lifting body investigations performed by Flight Research Center, NASA. The same re-entry mission task was used in evaluating the configurations in all three parts. The configurations were evaluated with both fixed-base and in-flight simulation. One objective of the program was to obtain data for a comparison of evaluation results using in-flight and fixed-base simulation. The variable stability T-33 was used for both fixed-base and in-flight evaluations. The same configurations were also evaluated in a fixed-base simulator using a contact analog display at Flight Research Center, NASA. The results of the NASA simulation are not included in this document but will be reported in a forthcoming NASA report.

The major effort of this investigation was devoted to evaluating vehicle configurations in the up-and-away phase of the re-entry mission. However, some configurations were also evaluated in a spiral descent to a landing approach. The longitudinal characteristics were held constant for each part of the program so that the lateral-directional evaluations would not be influenced by varying longitudinal handling qualities. Each evaluation pilot was required to perform and evaluate the suitability of a series of maneuvers which were representative of those that he might be called upon to perform during an actual re-entry and descent.

For each configuration evaluated, the pilot recorded his observations on the handling qualities and his subjective evaluation of the suitability of these characteristics for the accomplishment of the mission. The pilot then assigned rating numbers to the configuration. The evaluation was performed a second time in the presence of a random noise disturbance, comments recorded and another pilot rating assigned. The pilot comment data was studied extensively and played an important part in the data analysis.

This report includes a detailed description of the experiment, explaining the evaluation procedure, the test program and the equipment used. It discusses the maneuvers performed, the airplane parameters varied and defines the vehicles simulated. The results are presented for both the fixed-base and in-flight simulations in the form of pilot comments and pilot ratings.

A secondary objective of the test program was to collect data on magnetic tape for the purpose of defining pilot describing functions for the task of bank angle tracking with aileron. The airplane was disturbed by a recorded signal consisting of the sum of ten sine waves which was injected into the aileron summing amplifier during this tracking task. The analysis of this data is being conducted by NASA Flight Research Center and by CAL under separate contract and is not reported here. Results of the NASA analysis were presented by Harriet J. Smith of NASA Flight Research Center in a paper entitled "Human Describing Functions Measured In Flight and On Simulators" at the MIT-NASA Working Conference on Manual Control, Cambridge, Massachusetts, February 28-March 2, 1966.

SECTION 2
DESCRIPTION OF EXPERIMENT

2.1 TEST PROGRAM

The test program included both fixed-base ground simulator and in-flight evaluations of three groups of configurations, Part I, Part II, and Part III. The Part I configurations were selected from configurations evaluated in a previous in-flight simulation program performed by the Cornell Aeronautical Laboratory (Reference 1); Part II configurations were based on configurations evaluated in a fixed-base ground simulation program using a contact analog display performed by the Flight Research Center, NASA (Reference 2) in a general investigation of lateral-directional handling qualities; Part III configurations were selected because of their application to lifting body investigations conducted by the Flight Research Center, NASA. In most cases, "good" longitudinal dynamics, i.e., well-damped, fast-responding short period mode, were selected so that poor longitudinal handling qualities would not contaminate evaluation of the lateral-directional handling qualities. Spring-type feel was used for the pilot's controls. The configurations, including the longitudinal and feel system characteristics, are defined in detail and tabulated in Section 3.

The fixed-base evaluations were accomplished at Buffalo during January and February 1965. All of the in-flight evaluations were flown at Edwards AFB, California during February to May 1965.

Four evaluation pilots were used in the program. Pilots A and B evaluated the Part I, II, and III configurations for both fixed-base and in-flight simulations. Pilot C evaluated all of the Part III in-flight configurations and Pilot D was used primarily for evaluating the Part III in-flight descent configurations. A brief resume of each evaluation pilot's background is given in Table 1.

Prior to his taking part in the evaluation program, the overall reentry mission was thoroughly discussed with each evaluation pilot. The evaluation maneuvers, rating scale (Table 2) and comment card (Table 3) were also discussed with each evaluation pilot in an effort to insure that they all evaluated the configurations against a common criterion.

The evaluation pilots were given no prior information about the configurations and had the configurations presented to them in a random manner. Repeat evaluations were also included in the program for each pilot, but here again, he did not know ahead of time if it was a repeat.

The comments recorded by the evaluation pilot each time he evaluated a configuration were of major importance in this program. When transcribed, the comments were generally three to six double spaced typewritten pages in length for each evaluation of an in-flight configuration. The comments were approximately 50 percent longer for the fixed-base evaluations where the pilot could take all the time he desired. The comment data provided considerable insight in determining why a pilot liked or disliked a particular configuration and why he rated it the way he did. The comments were examined in detail and were given major consideration in arriving at the pilot rating curves discussed in the Results and Analysis section. A summary of pilot comments is presented for each configuration. The summary is an extract of the significant comments of all the pilots who evaluated each configuration. The correlation of the different pilots' comments on any particular configuration was, in general, quite good with respect to describing its characteristics. There was, however, less agreement on the pilot rating numbers assigned to the configurations.

2.2 EQUIPMENT

The vehicle used for both the in-flight and fixed-base simulation was a three-axis variable stability T-33. This airplane was modified by Cornell Aeronautical Laboratory for the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command. The variable stability and variable drag equipment are described in

References 3, 4, 5, and 6. Details of the capabilities of this equipment as a fixed-base simulator are given in Reference 7. Figures 1, 2, 3, and 4 depict the airplane in flight, the drag petal installation and the evaluation pilot's cockpit for the fixed-base and in-flight simulations.

The airplane is a standard T-33 which has been modified so that the system operator, who also serves as safety pilot, in the rear cockpit may vary the handling characteristics about all three axes by changing the settings of gain controls located on his right-hand console. The evaluation pilot in the front cockpit has no knowledge as to how the gain controls are changed to set up the desired evaluation configurations. The only information he has concerning the configurations he is evaluating is the knowledge he obtains from the evaluation maneuvers. This eliminates the possibility of biased pilot opinion that could result from the evaluation pilot's prior knowledge of the configurations being evaluated. The gain controls are varied as a function of fuel load during the in-flight evaluation of a configuration to keep the handling characteristics of the simulated configuration constant.

The fixed-base evaluations in this investigation were conducted in simulated instrument flight with the cockpit canopy covered so the only cues available were those displayed on the cockpit instruments. The same cockpit displays were used for the in-flight evaluations in addition to the outside visual observations and motion cues experienced by the evaluation pilot. The variable stability system was used to vary the stability and control characteristics on the fixed-base simulator the same as it was in flight. The essential difference was that an analog computer was used to simulate the T-33 for the fixed-base evaluations as described in Appendix D. The block diagrams in Figure 5 illustrate the mechanization of the in-flight and fixed-base simulations.

A conventional center stick and rudder pedals were used for control inputs. Control feel was provided by electrically-controlled hydraulic feel servos which provided opposing forces proportional to the control stick and rudder deflections (i.e., a simple linear spring feel system). The feel system spring rates and friction characteristics for the different phases of the program were as shown in the data. Control stick and rudder pedal positions were used as pilot control inputs to the control surface servo channels.

The normal T-33 throttle was used for thrust control for the in-flight simulation with the tachometer and exhaust gas temperature gauges depicted in Figure 4 for thrust indications. A special throttle lever (see Figure 3) was provided for thrust control for the fixed-base simulation. This lever controlled a voltage which was fed through a suitable lag to the X-force summing amplifier of the analog computer. This voltage was also used to drive a meter calibrated in percent rpm for a cockpit indication of thrust.

The cockpit display instruments used in this program were as follows:

1. Lear remote attitude-direction indicator, type ARU-2/A. This instrument presents pitch attitude as the rotation of a sphere which appears as a vertical translation of a horizontal white line with respect to the instrument case. Roll angle is presented as the rotation of this same sphere which appears as a rotation in the vertical plane of the horizontal white line. Sideslip is presented as the horizontal translation of a vertical bar. A rate-of-turn indicator at the bottom of the instrument presents yaw rate. Side acceleration as indicated by a displacement of the black ball is available for in-flight simulation but not for fixed-base operation.
2. Airspeed, altitude and rate-of-climb. The normal T-33 pitot-static instruments were used for the in-flight simulation and electrical instruments driven by analog computer outputs were used for the fixed-base simulation.
3. Normal acceleration was indicated by an electrical instrument which was driven by an accelerometer for in-flight simulation and by the analog computer for fixed-base simulation.

4. Angle of attack was indicated by an electrical instrument which was driven by an angle of attack vane for in-flight simulation and by the analog computer for fixed-base simulation.

5. Heading angle was presented on the radio magnetic indicator (RMI) which was driven by a magnetic sensor for in-flight simulation and by the analog computer for fixed-base simulation.

The airplane simulated on the TR-10 analog computers for the fixed-base simulation was the T-33 at 23,000 feet, 250 knots IAS, and a weight of 12,400 pounds. Two drag configurations were simulated -- drag petal closed configuration for the level flight evaluations, and drag petal full-open configuration for the descent evaluations. The airplane equations of motion simulated on the analog computer are listed in Appendix D along with the assumptions that went into the equations. Variation of the lateral stability derivatives of the basic T-33 as a function of angle of attack was included in the simulation.

A source of random disturbances was used for both the fixed-base and in-flight simulations to provide a more realistic evaluation environment. This was not a true simulation of turbulence. However it did provide an external disturbance to aid the pilot in evaluating the configuration. The random disturbance was obtained by driving the T-33 elevator, aileron and rudder actuators by a random noise signal. The signal was generated by a gas tube white noise source passed through a bandpass filter. The filter had a frequency response as shown in Figure 6 with a first order break point at 0.1 rad/sec and a second order break point at 1.7 rad/sec. The amplitudes of the disturbance signal going to the control surface actuators could be varied independently and this was done for both the fixed-base and the in-flight evaluations. For each configuration, the evaluation pilot was allowed to choose the intensities of the disturbance signals that he felt provided a realistic external disturbance for evaluation of the handling characteristics.

2.3 EVALUATION PROCEDURE

The mission of the pilot-vehicle combination must be defined before any meaningful evaluation of handling qualities can be accomplished. The specific mission of a vehicle re-entering the atmosphere is to descend and land safely without exceeding the limitations of the vehicle or pilot. This mission may require many tasks but an evaluation of the vehicle handling characteristics regarding their suitability for the mission can be accomplished by having the evaluation pilot perform selected representative tasks. The major effort of this investigation was devoted to evaluating configurations in the up-and-away phase of the re-entry mission. The piloting tasks used to evaluate the configurations in this phase were performed at nominal flight conditions of 23,000 feet and 250 knots IAS and consisted of:

1. Straight flight, including small turns and pitch corrections about level flight.
2. Turning flight. Shallow (up to 30°) and medium (up to 60°) banked turns involving heading changes of at least 90° with particular attention to the control of nose position with bank angle while holding constant angle of attack.
3. Rolling flight. Slow and rapid rolling maneuvers including 180° rolls when handling characteristics permitted.

The evaluation pilot performed these maneuvers in order, making general comments as desired on the wire recorder. At the end of the maneuvers, he completed his comments as called for on the Pilot Comment Card, Table 1, and assigned a rating to the configuration. The random disturbance signal was then turned on and adjusted to provide what he believed to be a realistic disturbance level for the evaluation and the maneuvers were repeated. Additional comments were then made with emphasis on any significant changes of the flying qualities in the presence of disturbances. Another rating was then assigned to the configuration for the evaluation with disturbance inputs.

The other task employed to evaluate some configurations was a 270° spiral descent and landing approach (see Figure 7). This maneuver was performed at 250 knots IAS with the power at idle, and the drag petals extended. It started on a heading 90° to the left of the runway heading and ended with the initiation of flare approximately 1000 feet above the runway. The drag configuration provided an L/D of approximately 2.5. A pilot rating was assigned to each descent configuration and evaluation pilot comments were recorded on the wire recorder. The pilot ratings assigned to the descent configurations for the in-flight simulation were assigned for the atmospheric turbulence that was encountered during the descent with no attempt to extrapolate a rating for a smooth air environment. However, appropriate remarks were recorded concerning the turbulence that was encountered during the evaluation descent. Comments are found in Table III-5.

A ten point rating scale, (see Table 2), was used to assign pilot ratings to all configurations. The rating scale consists of numbers that correspond to one or more adjectives. The evaluation pilots relied upon the words completely to determine which numerical rating should be assigned to the configuration. The numbers have meaning only because of the adjectives associated with the numbers and are used in this report as a convenient shorthand to discuss the ratings.

In order to arrive at the rating number, the evaluation pilot first assigned the configuration to either the acceptable or unacceptable category. If acceptable, it was then determined to be either satisfactory or unsatisfactory and then further broken down according to the adjectives on the chart. If unacceptable, it was then placed in either the flyable or unflyable category with a further break-down within the unacceptable but flyable category. If a configuration was judged to be unflyable, it does not necessarily mean that the pilot could not keep control of the airplane but it does mean that it was unflyable while attempting to perform the tasks required for the mission.

The fixed-base simulation evaluations were conducted with reference to instruments only and the in-flight evaluations were conducted as visual flying but with the pilot paying close attention to the instruments. The evaluation pilots were permitted to use as much time as desired to evaluate the configuration during the fixed-base simulations. They took an average of 50 minutes to an hour to evaluate and record comments on each configuration. It was not feasible to allow that much evaluation time for the in-flight simulations and complete the required evaluations. A time limit was not set for the in-flight evaluations but they were generally completed in 20 to 30 minutes for each configuration.

Smooth air and good initial trim conditions are essential for good calibration records but it was not always feasible to use valuable flight time to find a patch of smooth air and take the time required to get a good initial trim (this was especially true of some of the "wilder" configurations). As a result, readable records were not always obtained but enough records were obtained for each configuration to insure identification of the configuration. The valid in-flight calibration records were read and averages of the readings are presented in the Section 3 as Nominal Measured Modes. Similar records were taken for the fixed-base configurations and the data are also presented.

Some of the characteristics could not always be directly obtained from the calibration records. These included the numerator terms of the aileron stick to bank angle transfer function which were calculated as shown in Appendix B.

In addition to the in-flight recordings, transient responses were generated by a digital computer for aileron stick steps, rudder pedal steps and gust inputs. These responses are also presented in Section 3.

TABLE 1
EVALUATION PILOTS

Pilot A	R.P. HARPER -- Cornell Aeronautical Laboratory evaluation pilot. Over 3500 hours of diversified flying time. Extensive experience as evaluation pilot in handling qualities investigations employing variable stability airplanes and ground simulators.
Pilot B	F.W. HAISE -- Flight Research Center, NASA, research pilot. Over 4900 hours of diversified flying time. Extensive experience in the qualitative evaluation of airplane flying qualities and ground simulator evaluation of space vehicles.
Pilot C	B.A. PETERSON -- Flight Research Center, NASA, research pilot. Over 4200 hours of diversified flying time including flight experience in the M2-F1 lightweight lifting body. Extensive experience in the assessment of airplane flying qualities and ground simulator evaluations of space vehicles.
Pilot D	M.O. THOMPSON -- Flight Research Center, NASA, research pilot. Over 3800 hours of diversified flying time including flight experience in the X-15 and the M2-F1 lightweight lifting body. Extensive experience in the qualitative evaluation of airplane flying qualities and ground simulator evaluation of space vehicles.

TABLE 2

PILOT'S RATING SCALE

Category	Adjective description within category		Numerical rating
	Satisfactory	Excellent	1
		Good	2
		Fair	3
Acceptable	(ask that it be fixed)		
	Unsatisfactory	Fair	4
		Poor	5
		Bad	6
	(won't buy it)		
	Flyable	Bad	7
		Very bad	8
		Dangerous	9
Unacceptable	(won't fly it)		
	Unflyable	Unflyable	10

7 ~ required major portion of pilot's attention

8 ~ controllable only with a minimum of cockpit duties

9 ~ aircraft just controllable with complete attention

TABLE 3
PILOT'S COMMENT CARD

I. Make general comments as desired

II. Following maneuvers without random noise and again after random noise

1. Pilot's Controls
   - a. Aileron - feel-response to aileron
   - b. Rudder - feel-response to rudder
   - c. Elevator - feel-response to elevator
2. Roll Control
   -- Maintaining ϕ , Changing ϕ , Techniques used.
3. Heading Control
   -- Maintaining ψ , Changing ψ , Techniques used.
4. Pitch Control
   -- Maintaining θ , Changing θ , Techniques used.
5. Interaction
   - a. Control - roll due to rudder
     - yaw due to aileron
   - b. Response - roll due to sideslip
     - yaw due to roll rate
     - roll due to pitch

Following Completion of Maneuvers -

1. Summarize major objections/favorable features.
2. Comment on primary instruments and information cues used.
3. Comment on any special piloting technique required.
4. Numerical/adjective rating.
5. Comment on adequacy of simulation.
6. Comment on existing atmospheric conditions.

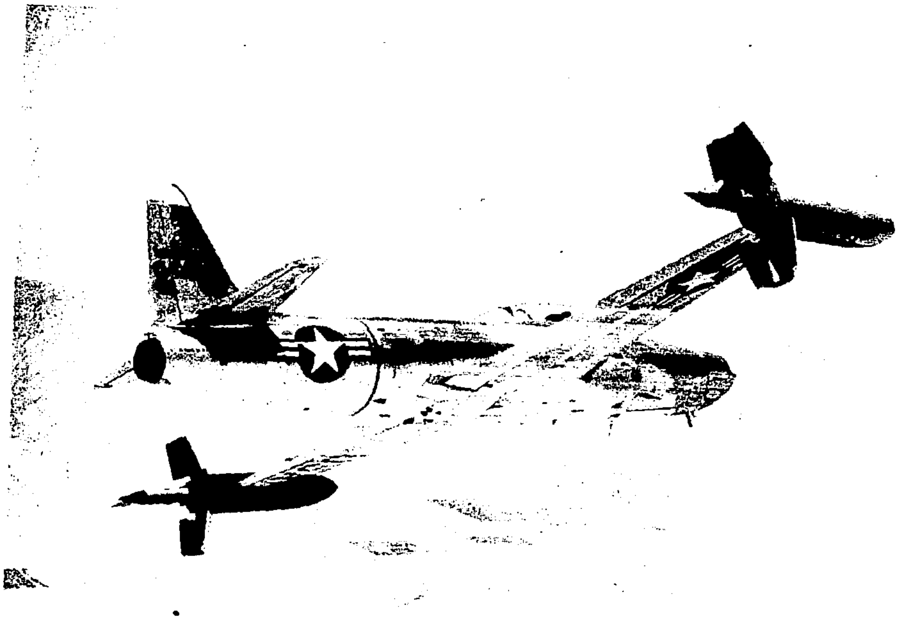


Figure 1 Variable Stability T-33

Figure 2 T-33 Drag Petal Installation

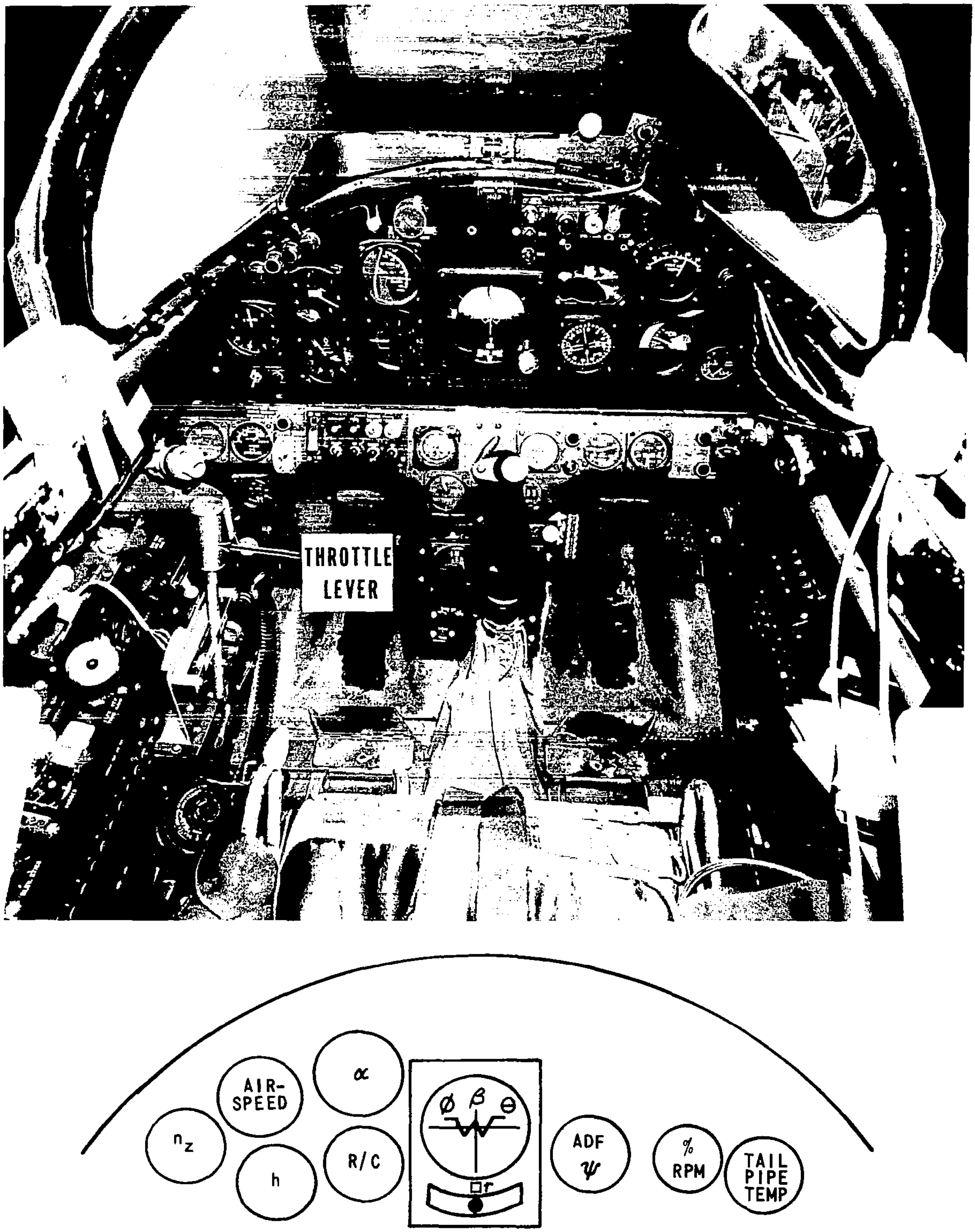


Figure 3 Fixed-Base Simulation T-33 Cockpit

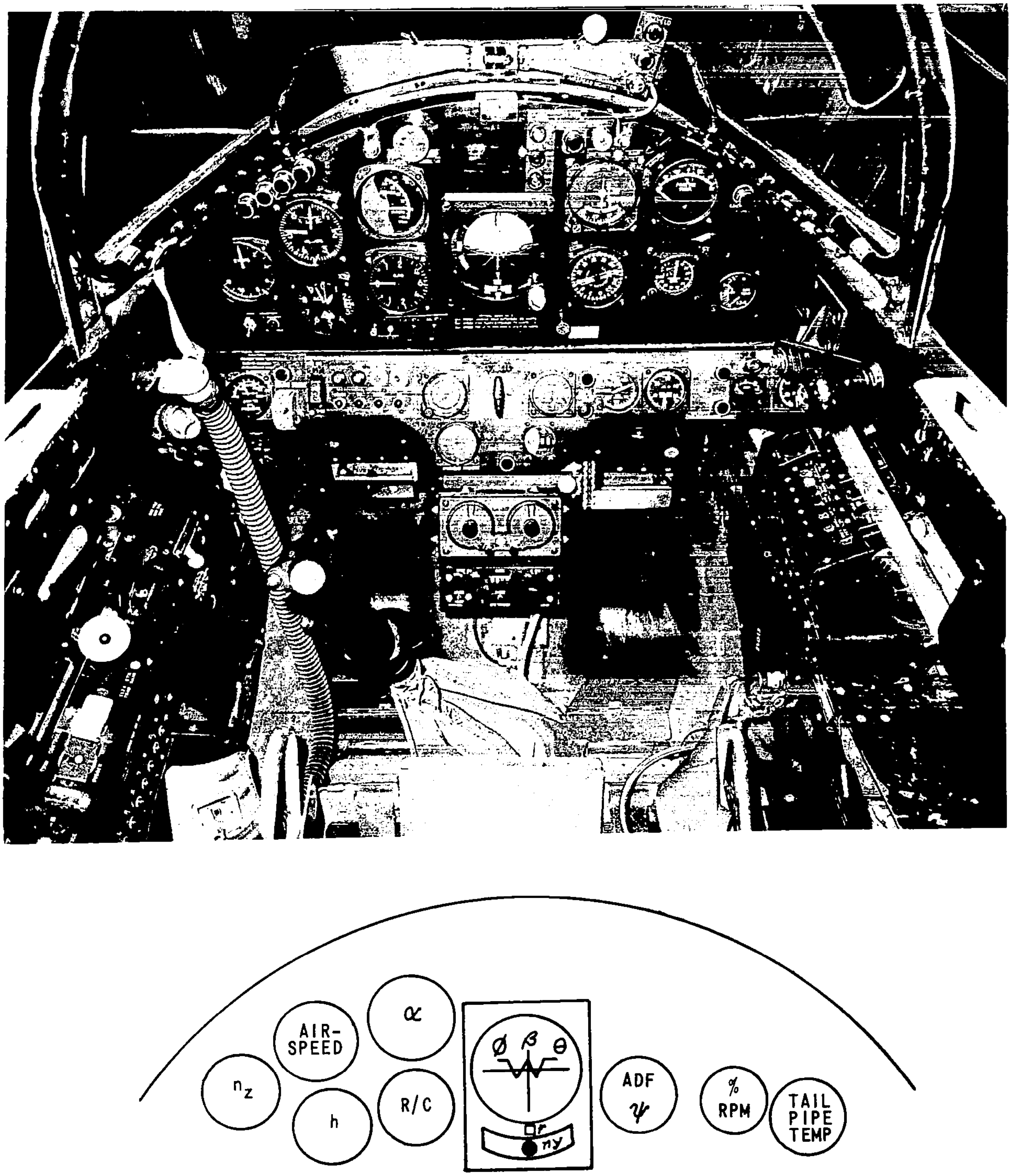
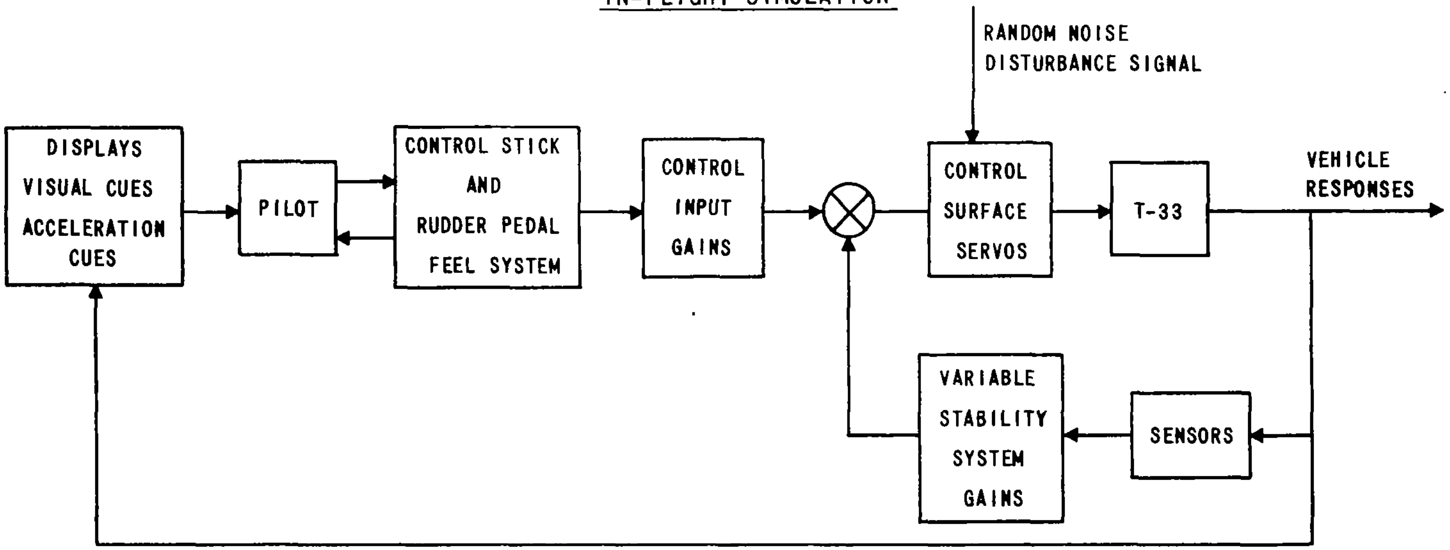


Figure 4 In-Flight Simulation T-33 Cockpit

IN-FLIGHT SIMULATION



FIXED-BASE SIMULATION

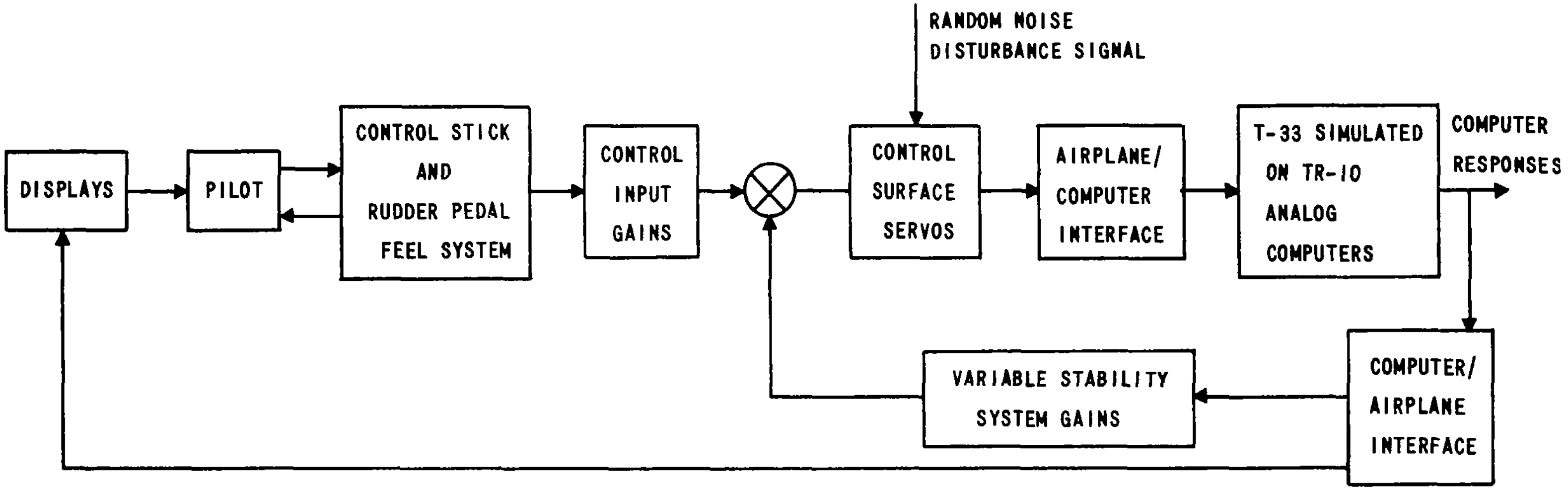


Figure 5 SIMULATOR BLOCK DIAGRAMS

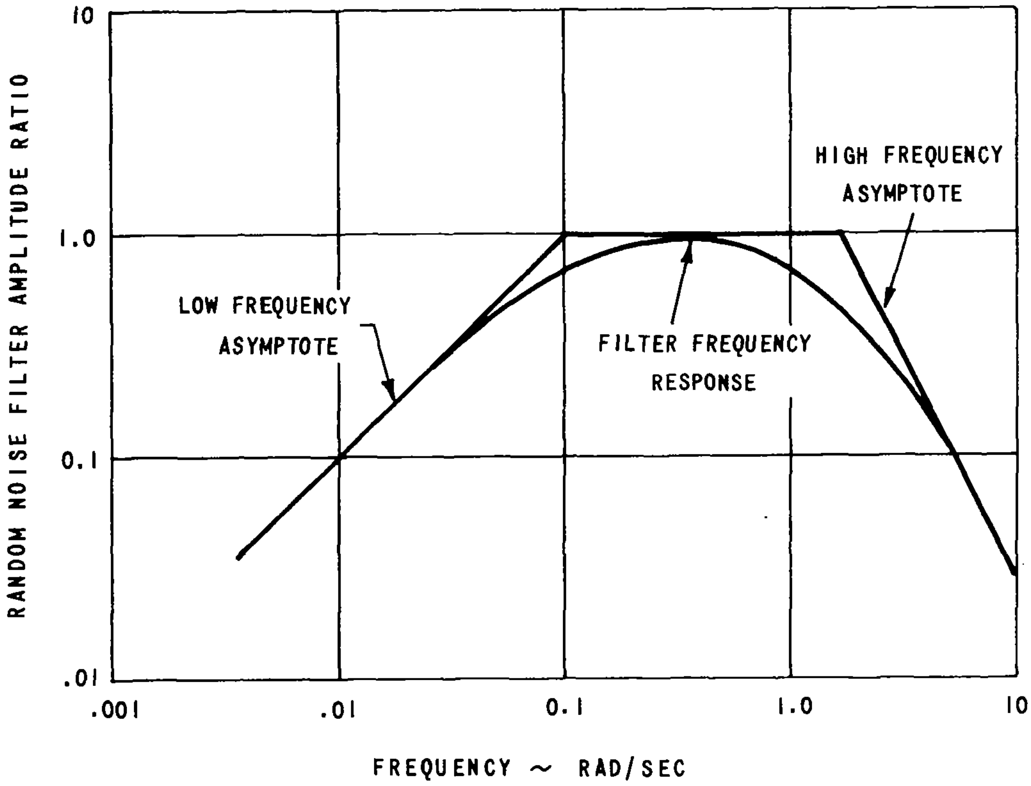
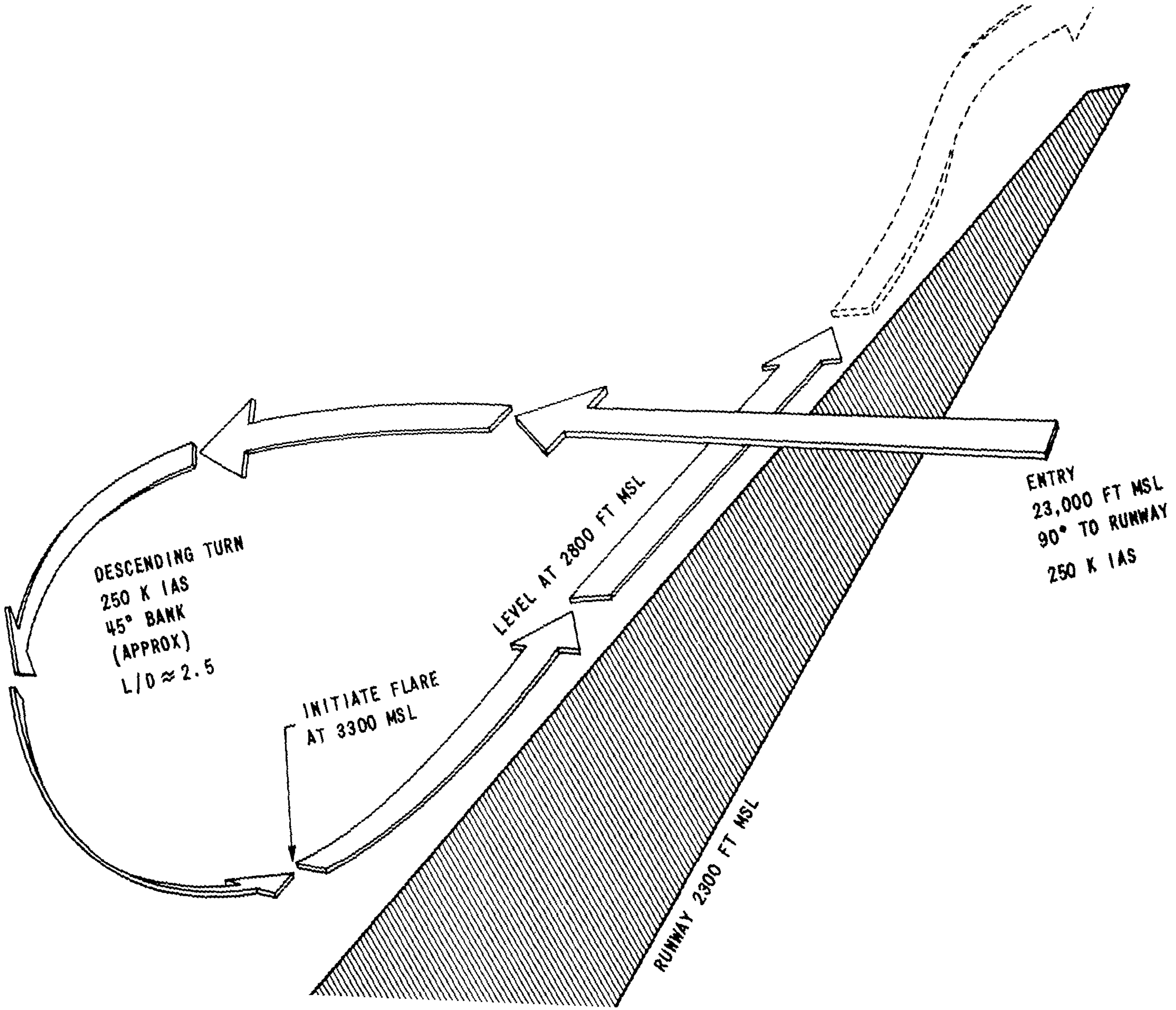


Figure 6 FREQUENCY RESPONSE OF NOISE GENERATOR FILTER


DESCENDING TURN
250 K IAS
45° BANK
(APPROX)
L/D ≈ 2.5
INITIATE FLARE
AT 3300 MSL
LEVEL AT 2800 FT MSL
ENTRY
23,000 FT MSL
90° TO RUNWAY
250 K IAS
RUNWAY 2300 FT MSL

SECTION 3

ANALYSIS AND RESULTS

3.1 GENERAL

The results of this experiment were the pilot comment data and the pilot ratings. These data provide the means for identifying handling qualities parameters which reflect the pilot's control difficulties. The pilot rating is interpreted as an overall measure of the acceptability or "goodness" of the handling qualities for the defined task. In the case of lateral-directional handling qualities there are a large number of effects which, depending on the circumstances involved, can be troublesome. Thus, the pilot comment data must be relied upon to provide insight into the difficulties experienced and to help pinpoint the root causes of poor handling qualities which are indicated by the pilot ratings.

The manner in which an evaluation pilot combines his impressions of the handling qualities to arrive at an adjective description and pilot rating number is not well defined. The pilot rating assigned a configuration is primarily based on the amount of effort required to accomplish the mission. He evaluates the effort, skill, concentration and the practicability of any special control techniques required relative to the precision of flight path control actually achieved. In arriving at the rating, the pilot considers the response of the configuration to turbulence as well as to control inputs. The rating also reflects whether or not a configuration possessed any characteristic which the pilot considered potentially dangerous. In view of the complexity of the process, some variation in the ratings can be expected when the same configuration is evaluated by different pilots or evaluated more than once by the same pilot. The individual pilot ratings of each configuration for each time it was evaluated are presented in this section. However, composite pilot ratings are used for the purpose of discussing the way in which the handling qualities changed with variation of the parameters in the experiment.

A composite pilot rating was determined for each configuration, in lieu of an average pilot rating, because of the limited number of evaluations for each configuration. Since extensive pilot comments were recorded for each evaluation along with the pilot rating numbers, it was possible to determine a composite pilot rating for each configuration that was more representative of the handling qualities than a simple numerical average. The composite pilot ratings were determined after examining the pilot rating numbers in detail, both with and without random disturbances, and the pilot comments for each evaluation.

In arriving at the composite pilot ratings, consideration was given to several factors: What was the evaluation pilot's confidence in his rating? Was he rushed during his evaluation? Was the evaluation hampered by weather or turbulence? Were system or airplane difficulties a factor? Was air traffic a problem? Was this an early evaluation or had the pilot already evaluated several configurations? Was his evaluation influenced by a previous configuration which may have been exceptionally good or bad? Was this the pilot's first evaluation of the configuration or was it a repeat? Was the evaluation pilot generally optimistic or pessimistic? Was the pilot evaluating the handling qualities for a specialized research vehicle role which would be piloted only by a highly trained pilot under ideal conditions or was he considering it for an operational role which would be flown by pilots with less experience under less than ideal conditions? All of these factors could influence the pilots evaluation of a configuration and the composite pilot ratings are the result of attempting to eliminate these factors. The composite pilot ratings are based on all the available information and on the analyst's judgement. They are, in his opinion, the numbers which best represent the manner in which the handling qualities changed with the parameters in the experiment.

The pilot comment data in general showed very good agreement in the pilot's evaluations of the configurations. The agreement was good not only for a single pilot's successive evaluations of a configuration, but also for other pilot's evaluations of the same configuration. The comments showed that the pilots were noting the same characteristics and were experiencing the same difficulties for a given configuration. The variations in pilot rating numbers that were obtained for some configurations indicate that all the pilots were not always weighting the observed characteristics in the same manner to arrive at a pilot rating number for the handling qualities of the configuration in the re-entry mission.

3.2 DATA

Discussion of results and test data are presented separately in this section for each part of the program. The data format is generally similar for each part, and is described below.

3.2.1 Table of Pseudoderivatives and Mode Characteristics

These tables include the stability derivatives of the vehicle or configuration being simulated and the pseudoderivatives, i.e., the set of derivatives that can be simulated with the T-33 and will match the important modes of the configuration being simulated. The pseudoderivatives and the methods used to obtain them are discussed in more detail in Appendix C. The lateral-directional modes were obtained from a digital computer program for both the simulated sets and the pseudo sets of derivatives and are presented in the tables. Calibration records were generally obtained each time a configuration was set up for evaluation. The mode characteristics were read from these records and the averages are listed in the tables as the nominal measured modes. (Usable readings could not be obtained from all of the records because of turbulent flight conditions or difficulty in obtaining a good initial trim condition. The obviously erroneous readings were excluded in determining the nominal values.)

3.2.2 Table of Control Derivatives and Numerator Zeros

The control derivatives listed in these tables include the specified values for the vehicle or configuration, the calculated pseudo values, and the values that were actually set up for the evaluations. These set-up values were determined from the control gain settings used in the evaluations and the final revised T-33 control derivatives determined during the program. They represent the best estimate of the control derivatives that were actually set up for the evaluations. The aileron stick to bank angle transfer function numerators were calculated as described in Appendix B for the in-flight and fixed-base configurations. They were obtained from a digital computer program for both the simulated vehicle and pseudo sets of derivatives.

3.2.3 Root Locus Diagrams

These diagrams show the poles and zeros of the aileron stick-to-bank-angle transfer function and the locus of roots for a varying pilot gain closure of the loop, i.e., the pilot moves the stick in direct proportion to the bank angle error. The poles were obtained from the nominal measured modes of the configurations and the zeros from the calculated numerator zeros as described in Appendix B.

3.2.4 Transient Responses to Aileron Stick Step

These plots were either calculated or obtained from flight records as specified on the plot. The calculated responses were generated and plotted by a digital computer program using simulated airplane derivatives or the pseudoderivatives and the actual in-flight or fixed-base control derivatives. In-flight oscillograph recordings were made of the response to a sharp step input to the T-33 ailerons and rudder equivalent to an aileron stick step. These records were digitized on punched cards and fed into a digital computer program which converted the sideslip vane recording to true β , scaled the responses to an equivalent standard size input and plotted them.

3.2.5 Transient Responses to Rudder Pedal Step

These responses were generated and plotted by a digital computer program using pseudoderivatives and the actual in-flight or fixed-base control derivatives.

3.2.6 Transient Responses to Side Gusts

These responses were generated and plotted by a digital computer program as described in Appendix E. Simulated vehicle and pseudoderivatives were used to obtain these responses.

3.2.7 Tables of Pilot Comment Data

The pilot comment data obtained for each evaluation of a configuration was examined in detail and the significant comments are summarized in the tables. All of the pilot's comments were used in making the summary tables and as might be expected, there were sometimes conflicting comments which are reflected in the summary tables.

3.3 PART I EXPERIMENT

The purpose of this part of the experiment was to repeat a portion of a previous lateral-directional handling qualities experiment which was done under Air Force sponsorship by Cornell Aeronautical Laboratory in 1960 and to extend this work to include larger values of $|\phi/\beta|$. Some of the data in Figure 5 of Reference 1 was selected to be repeated because recent investigations, conducted mainly in ground simulators, had produced results which were in disagreement with the data for $|\phi/\beta| \approx 9$ reported in Reference 1. It was of interest to determine whether the disagreement in results was caused by the method of simulation (i.e., in-flight or ground simulation) or whether the interpretation of the data in Reference 1 for $|\phi/\beta| \approx 9$ was erroneous.

Thus, the configurations in this part of the experiment were evaluated in the T-33, both as a ground simulator (where the information available to the pilot was displayed on cockpit instruments) and in flight (where, in addition to the instrument display, the pilot had available motion cues and visual reference to the outside world).

There were three sets of configurations in Part I that differed primarily by the roll to sideslip ratio of the Dutch roll mode. Within each of the three sets, the ratio of yaw acceleration to roll acceleration for aileron control, $N'_{\delta_{AS}}/L'_{\delta_{AS}}$, was varied from large adverse to large proverse. The roll acceleration due to aileron control, $L'_{\delta_{AS}}$, was varied to compensate for the change in $\left(\frac{\omega_\phi}{\omega_d}\right)^2$ and thus the uncoordinated steady state roll rate per inch of aileron stick was maintained constant for all configurations within a set. The configurations are defined in detail and the data are presented in the data tables.

3.3.1 Effects of N'_p

After the Part I configurations had been calibrated for in-flight evaluation and the evaluations had been started, errors were discovered in the roll and yaw rate channels of the T-33 variable stability system. This did not have an effect on the mode characteristics which had been set up by in-flight calibrations, but it did indicate that the mode characteristics were being obtained with something other than the desired pseudoderivatives. In view of these calibration errors and what was considered to be a refined knowledge of the basic T-33 airplane derivatives, it was decided to recompute the gains for the Part I configurations and to have at least one pilot evaluate as many of them as possible. This was done and when in-flight dynamic responses were obtained, it was found that the Dutch roll damping was much too high and the roll mode was also wrong for the cases where $|\phi/\beta| = 9$ and 13. After some consideration, it was decided that the value of N'_p used for the T-33 airplane was probably inaccurate and could be the source of the errors. The following approximations for Dutch Roll damping and the roll mode time constant indicate the importance of N'_p for configurations with a large value of the ratio L'_β/N'_β.

$$2\zeta_d\omega_d \approx N'_{\dot\beta} - N'_r - Y_\beta - \frac{L'_\beta}{N'_\beta}\left(N'_p - \frac{g}{V}\right) \qquad (1)$$

$$\frac{1}{\tau_R} \approx -L'_p + \frac{L'_\beta}{N'_\beta}\left(N'_p - \frac{g}{V}\right) \qquad (2)$$

When the calculated gains were again set up in flight and the $\delta_{r/p}$ gain was varied, it was found that it did indeed have a very powerful effect on the Dutch roll damping and the roll mode time constant. Thus, in setting up the AA-4, 5, 6 and AA-7, 8, 9 series, calculated gains were used as the starting point and the $\delta_{r/p}$ gain was iterated to get the right

Dutch roll damping (the $\delta_{r/p}$ gain that gave the right Dutch roll damping also improved the match of the roll mode time constant).

The "AA" configurations are identified in Tables 1-1, 2, 3, and 4. These configurations were evaluated by pilot A. Pilot C also evaluated AA-2A and AA-7.

The above discussion serves not only to identify the differences between the two sets of in-flight configurations in Part I, but also serves to point out the uncertainties in knowledge of specific derivatives, such as N'_p, N'_β, N'_r, L'_p and L'_r which were achieved in flight. This is not of much importance if one is only interested in the values of the characteristic roots because the characteristic roots can be determined quite easily from flight responses to calibration inputs. These derivatives, however, affect the transfer function numerator terms (such as $2\zeta_\phi\omega_\phi$ in the bank angle to aileron transfer function) and it is not as easy to determine from the flight records what values were achieved in flight.

Values of ω_ϕ and $2\zeta_\phi\omega_\phi$ were first calculated for the Part I configurations by using pseudoderivatives and calibrated values of $N'_{\delta_{AS}} / N'_{\delta_{AS}}$, together with the approximate equations developed in paragraphs 2 and 3 of Appendix B. However, when the time histories of the responses to aileron stick inputs were examined it was obvious, from the amplitude and phase of the Dutch roll excited by the input, that the calculated values of ω_ϕ and $2\zeta_\phi\omega_\phi$ were not correct for the in-flight configurations. More accurate values of ω_ϕ and $2\zeta_\phi\omega_\phi$ were determined by matching the roll rate responses to aileron stick inputs obtained in flight with responses generated by an analog computer. The method used is described in paragraph 4 of Appendix B and the values of ζ_ϕ and ω_ϕ determined by this method are presented in Tables 1, 2, 3, and 4.

The incorrect values of $2\zeta_\phi\omega_\phi$ calculated by the method of paragraph 3 of Appendix B were the result of poorly known values of the stability derivatives N'_β, N'_r, L'_r. The incorrect values of ω_ϕ

calculated by the method of paragraph 2 of Appendix B were the result of the assumption that $\omega_d^2 \approx N'_\beta$ This assumption is not valid when L'_β / N'_β is large. This was demonstrated by flight records taken for various values of the δ_r/p gain during the set-up of the "AA" configurations. From these records, it was observed that the Dutch roll frequency and damping ratio were both strongly affected by the variation of N'_p when L'_β / N'_β was large.

It is of interest to determine the conditions on the stability derivatives that will cause the zero to lie on the Dutch roll pole in the ϕ/δ_{AS} transfer function.

The following expression for $2\zeta_\phi \omega_\phi$ of the ϕ/δ_{AS} transfer function is developed in Appendix B.

$$2\zeta_\phi \omega_\phi \approx \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}\left(L'_r - L'_{\dot\beta}\right) + \frac{Y_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_\beta + \left(N'_{\dot\beta} - N'_r - Y_\beta\right) \tag{3}$$

Comparison of Equation 3 with Equation 1, the approximate expression for $2\zeta_d \omega_d$, indicates that both are a function of $(N'_{\dot\beta} - N'_r - Y_\beta)$; however, the Dutch roll damping is also a function of $(L'_\beta/N'_\beta)(N'_p - g/V)$ and $2\zeta_\phi \omega_\phi$ contains rolling moment and control derivatives not in the expression for Dutch roll damping. From these approximate expressions it is evident that $\zeta_\phi \omega_\phi$ will equal $\zeta_d \omega_d$ if

$$N'_{\delta_{AS}} = Y_{\delta_{AS}} = \left(N'_p - g/V\right) = 0$$

The other condition that must be satisfied for the zero to lie on the Dutch roll pole is that $\omega_\phi = \omega_d$ or $(\omega_\phi / \omega_d = 1)$. It became apparent, from examination of the in-flight recorded transient responses, that the following approximation developed in Appendix B was not adequate for defining the configurations.

$$\left(\omega_\phi / \omega_d\right)^2 \approx 1 - \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} \frac{L'_\beta}{N'_\beta} \tag{4}$$

This approximation was based on the following approximations:

$$\omega_\phi^2 \approx \left(N'_\beta + Y_\beta N'_r\right) - \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_\beta \tag{5}$$

$$\omega_d^2 \approx N'_\beta + Y_\beta N'_r \approx N'_\beta \tag{6}$$

The expression for ω_ϕ^2 was valid for the Part I configurations, but Equation 6, which is a common approximation for ω_d, bears further examination.

For a neutrally stable spiral mode, the lateral directional characteristic equation can be written as:

$$s\left(s+\lambda_R\right)\left(s+\lambda_1\right)\left(s+\lambda_2\right) = s\left(s^3 + a_2 s^2 + a_1 s + a_0\right) \tag{7}$$

where λ_1, λ_2 are a coupled conjugate pair that represents the Dutch roll mode and λ_R represents the roll mode. Expanding the left side of Equation 7 and substituting from the expansion of the characteristic equation in Reference 10 for stability axes gives:

$$\lambda_R \lambda_1 \lambda_2 = \frac{\omega_d^2}{\tau_R} = a_0 = N'_p L'_\beta - N'_\beta L'_p + Y_\beta\left(N'_p L'_r - N'_r L'_p\right) + g/V\left(N'_r L'_\beta - N'_\beta L'_r - L'_\beta\right) \tag{8}$$

$N'_r L'_\beta$ and $N'_\beta L'_r$ terms are normally small compared to L'_β . When these terms are removed (which was valid for this program), the expression becomes:

$$\frac{\omega_d^2}{\tau_R} \approx -N'_\beta L'_p + Y_\beta\left(N'_p L'_r - N'_r L'_p\right) + \left(N'_p - \frac{g}{V}\right) L'_\beta \tag{9}$$

If the assumption is made that $1/\tau_R \approx -L'_p$, the expression reduces to

$$\omega_d^2 \approx N'_\beta + Y_\beta N'_r - \frac{L'_\beta}{L'_p}\left(N'_p - \frac{g}{V}\right) - \frac{Y_\beta N'_p L'_r}{L'_p} \tag{10}$$

Equation 10 shows that $\omega_d^2 \approx N'_\beta + Y_\beta N'_r$ is not a good approximation if L'_β is large and $\left(N'_p - g/V\right)$ is not zero, which was the situation with the Part I in-flight configurations. Zero aileron yaw therefore did not produce $\left(\omega_\phi / \omega_d\right) = 1$ and minimum Dutch roll excitation for aileron inputs.

The following expression for the β/δ_{AS} transfer function can be obtained from page 99 of Reference 9 by assuming $Y_{\delta_{AS}} \approx \alpha_o \approx 0$ and by noting that the sideslip response to an aileron stick step in Figures I-12 to I-16 has a steady state. Since the spiral root was at the origin for these configurations, the steady-state sideslip implies that the constant term in the numerator cubic of the β/δ_{AS} transfer function was essentially zero and thus we can write:

$$\frac{\beta}{\delta_{AS}} \approx \frac{-N'_{\delta_{AS}}\, s + N'_{\delta_{AS}} L'_p - L'_{\delta_{AS}}\left(N'_p - g/V\right)}{\left(s+\lambda_R\right)\left(s^2 + 2\zeta_d\,\omega_d\, s + \omega_d^2\right)} \tag{11}$$

From this expression, it is seen that the steady-state sideslip for aileron inputs is zero for

$$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_p \approx \left(N'_p - g/V\right) \tag{12}$$

Equation 11 also indicates that the sideslip excited by aileron stick inputs is zero for all frequencies when $N'_{\delta_{AS}} = \left(N'_p - g/V\right) = Y_{\delta_{AS}} = 0$. For the case of $\left|\phi/\beta\right| \neq 0$, this result implies that the zero lies on the Dutch roll pole in the ϕ/δ_{AS} transfer function when $N'_{\delta_{AS}} = \left(N'_p - g/V\right) = Y_{\delta_{AS}} = 0$.

In the following paragraphs, the results of Part I of the experiment are discussed in some detail.

3.3.2 $\left|\phi/\beta\right|$ Less Than One (Configurations A and AA-1, -2, -3)

The composite rating curves in Figure I-1 for low roll to sideslip configurations, $\left|\phi/\beta\right| = .64$ to $.89$, show good agreement for the in-flight and fixed-base configurations. Reference to the pilot comments shows that, for the adverse yaw case, the pilots object to the Dutch roll excitation of sideslip with rapid aileron inputs and the difficulty in coordinating well; there are no major objections for the near-zero aileron yaw case; for proverse aileron yaw, the pilots object to the Dutch roll excitation of sideslip with rapid aileron inputs and for large rolling maneuvers. The comments also show that, for the fixed-base simulation of the proverse yaw case, there is a tendency to set up a divergent sideslip oscillation with aileron control.

The root locus diagrams, Figures I-20 and I-21, show that the light Dutch roll damping becomes even lighter when the pilot acts as a high gain proportional bank angle controller with proverse yaw. This tendency to oscillate was not noted for the in-flight simulations, but the maximum in-flight $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ was only 85% of the maximum fixed-base value. This is reflected in the higher ω_ϕ/ω_d value for the fixed-base proverse aileron yaw configuration. Other factors to be considered are the additional motion and visual cues available to the pilot in flight. There is also the possibility that the pilot uses lower gain in the bank angle to aileron loop in flight. The comments also showed that the steep turning performance was a good feature of the proverse yaw case and, for the fixed-base evaluation, the sideslip oscillations would damp out when the pilot was controlling pitch attitude with bank angle. Using bank angle to maintain a desired pitch angle is a common technique in steep turns, where the pilot maintains an essentially constant elevator stick force and increases the pitch angle by decreasing the bank angle or decreases the pitch angle by increasing the bank angle. It was also noted that there was no tendency to "dish-out" (i.e., for the nose to drop) when rolling out of steep turns. This was considered a good feature for the proverse yaw configuration.

The evaluation pilots noted the heavier rudder pedal forces for the "A" in-flight configurations and objected to this for the adverse yaw case. There was also an objection to the light rudder pedal forces for the adverse yaw "AA" configuration. There was, however, nothing to indicate that the rudder control characteristics were a major factor in the evaluation of this group of configurations.

Examination of the transient responses to aileron stick steps, Figure I-12, shows that there is very little Dutch roll oscillation on the bank angle and roll rate responses. There is, however, considerable Dutch roll oscillation on the sideslip and yaw rate responses, which becomes minimum and reverses phase as the aileron yaw changes from adverse to proverse. It is also apparent that the pilots prefer the configurations that have minimum sideslip excitation with aileron control.

The random disturbance input pointed up the lack of Dutch roll damping and the attention required to coordinate the rudder with aileron inputs. When the aileron yaw was proverse, the pilots noted that there was often a conflict in use of the rudder to suppress disturbances and for coordination of aileron inputs. The following expression was developed in Reference 15 for the rudder pedal deflection required to coordinate, i.e., keep $\beta = 0$ in a rolling maneuver:

$$\delta_{RP} = \frac{\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}\ddot{\phi} + \left(N'_p - \frac{g}{V} - \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_p\right)\dot{\phi} + \frac{g}{V}\left(N'_r - \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_r\right)\phi}{-N'_{\delta_{RP}} - Y_{\delta_{RP}} N'_r + \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}\left(L'_{\delta_{RP}} + L'_r Y_{\delta_{RP}}\right)} \qquad (13)$$

This expression was developed by equating $\beta = 0$ in the equations of motion and eliminating the yaw rate and aileron stick terms. In developing the expression, it is assumed that $Y_{\delta_{AS}} = \alpha_0 = 0$ and that $Y_{\delta_{RP}} \dot{\delta}_{RP}$ can be neglected. The expression indicates that $N'_{\delta_{AS}} / L'_{\delta_{AS}}$ and $\left(N'_p - \frac{g}{V}\right)$ are important factors in determining how the pilot must operate the rudders to keep the aircraft coordinated while maneuvering the aircraft in bank angle. Coordination can be a difficult process and depends upon relative magnitudes of the coefficients of $\ddot{\phi}$, $\dot{\phi}$, ϕ and the pilot's ability to determine what should be done. With proverse aileron yaw, opposite rudder pedal inputs are required to coordinate aileron inputs. This is opposite to what pilots are normally accustomed to doing and tends to make the coordination task more difficult.

3.3.3 $|\phi/\beta|$ Between 9 and 10 (Configurations A and AA-4, -5, -6)

There is less agreement between these composite pilot rating curves for the different simulations, Figure I-1, than for the low $|\phi/\beta|$ configurations, but they clearly show the trend that pilots do not like large yaw due to aileron control, either adverse or proverse.

A basic complaint about all of the configurations in this group is the large roll response to sideslip and the consequence of miscoordination. With large adverse yaw, the roll response to aileron is "jerky" and the Dutch roll mode is excited. The pilot opinion improves as the adverse yaw decreases and peaks after the aileron yaw has become proverse. As the aileron yaw is made more proverse, the pilot rating deteriorates with the major complaint being a closed-loop oscillation when precise bank angle control is attempted. The root locus diagrams show this possibility for closed-loop oscillation for proverse aileron yaw when the pilot acts as a proportional controller in closing the bank angle loop.

The transient responses to aileron stick step inputs, Figure I-13, show that the minimum sideslip excitation occurs for the slightly proverse aileron yaw configurations. This indicates that the instrumentation X axis was not aligned with the flight path, i.e., $\alpha_o \neq 0$, or that $\left(N'_p - \frac{g}{V}\right)$ was negative.

The configurations with minimum sideslip excitation also had the best pilot ratings. The pilots considered the initial roll response abrupt and too large for the adverse aileron yaw configurations. It should be noted that as $(\omega_\phi/\omega_d)^2$ became smaller (as the aileron yaw became more adverse) $L'_{\delta_{AS}}$ was increased to keep the steady state roll rate per aileron control input constant. The abrupt initial roll response can be attributed to the larger $L'_{\delta_{AS}}$ values for the adverse aileron yaw configurations.

The pilot comments are helpful in explaining the differences in the in-flight pilot rating curves for the "A" and "AA" configurations. With the high $|\phi/\beta|$, the configurations are quite susceptible to miscoordination and the "AA" configurations were considered to have far too much rudder sensitivity for good control. This probably accounts for the generally better ratings for the "A" configurations for ω_ϕ/ω_d near one. For larger and smaller values of ω_ϕ/ω_d ($\omega_\phi/\omega_d < .6$ and $\omega_\phi/\omega_d > 1.3$) the pilot comments show closer correlation between the in-flight A and AA configurations than is indicated by the pilot rating numbers.

Although the rudder sensitivity in the fixed-base evaluations was the same as it was for the AA in-flight evaluations, it did not cause as large a deterioration in pilot ratings. The major objection to the large proverse aileron yaw configurations (fixed-base configuration A-6A and in-flight configurations A-6B and AA-6) was the closed-loop bank angle oscillations. The objections occurred at similar levels of sideslip excitation and values of ω_ϕ/ω_d for both the fixed-base and the in-flight evaluations, but $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ was more than twice as large for the in-flight configurations. This can be attributed to a difference in $\left(N'_p - \frac{g}{V}\right)$.

The random input again pointed up the lack of Dutch roll damping. The roll response to sideslip disturbances was greatly increased relative to the previous group. Mistakes in coordination caused large bank angle responses.

3.3.4 $|\phi/\beta|$ Between 12 and 13 (Configurations A and AA-7, -8, -9)

Only one in-flight pilot rating curve is presented in Figure I-1 for these high $|\phi/\beta|$ configurations. Only one "AA" configuration was evaluated because of limited time in the flight program. The pilot rating curves show that the best pilot rating occur near $\omega_\phi/\omega_d = 1$ for both the fixed-base and in-flight evaluations. Reference to the transient responses in Figure I-11 and I-14 shows that the configurations with minimum sideslip excitation in the Dutch roll mode for aileron stick inputs are also the configurations with the best pilot ratings. The best ratings for the in-flight configurations were experienced when the aileron yaw was proverse. This can be attributed to $(N'_p - \frac{g}{V})$ making $\omega_\phi \neq \omega_d$ and $\zeta_\phi \neq \zeta_d$ with $N'_{\delta_{AS}}$ zero.

A major objection to these configurations was the large rolling response to sideslip disturbances from either rudder miscoordination or external disturbances. For the large adverse yaw cases, the pilots object to the "jerky" roll response to aileron. The response is initially abrupt, but then slows down because of the sideslip generated by the adverse yaw. They also note that the steady state roll rate is quite high when the sideslip is kept at a minimum with rudder coordination, but is low without coordination. A comparison of in-flight configurations A-7B and AA-7 shows that $L'_{\delta_{AS}}$ was 27% higher for AA-7 and the steady state roll rate per aileron input was more than twice as large for AA-7. This is in agreement with the pilot comments which were more critical of the initial abrupt roll response of AA-7. Another factor that made AA-7 more objectionable was the "tremendous decrease in apparent directional stiffness when going closed loop" noted in the pilot comments. Reference to the ϕ/δ_{AS} transfer function zero locations of A-7B in Figure I-21 and of AA-7 in Figure I-22 shows the possibility for a closed-loop low frequency oscillation at high airplane-pilot gain. The airplane control gain was higher for AA-7 where the comments on low directional stiffness indicated a low frequency oscillation.

The pilot ratings improved as the adverse aileron yaw was decreased and reached a crest when sideslip excitation became minimum. As the aileron yaw became more proverse, the pilots objected to closed-loop roll oscillations and the pilot ratings deteriorated. They objected to the oscillations more in the fixed-base evaluation than in the in-flight evaluations. The objections also occurred with less proverse aileron yaw for the fixed-base simulations than for the in-flight simulations. Reference to the root locus diagrams in Figures I-20 and I-21 shows that the zeros of the ϕ/δ_{AS} transfer function pass to the left of the Dutch roll pole for the in-flight configurations, which causes the closed-loop root loci to remain in the left half plane until ω_ϕ becomes significantly greater than ω_d . The zeros of the fixed-base configurations are farther to the right and the closed-loop root loci cross over into the right half plane when ω_ϕ is only slightly larger than ω_d . This is in agreement with the pilot comments that indicated closed-loop oscillations in configurations with lower values of ω_ϕ/ω_d for the fixed-base evaluations. The pilots also objected to the low roll acceleration at large proverse aileron yaw for both the fixed-base and in-flight simulations. They did, however, comment that the flight characteristics of the proverse yaw configurations improved in steep turns.

It should be noted that the rolling moment due to rudder pedal was not set to the planned value for the in-flight configurations because of an error in calculating a gain setting ($L'_{\delta_{RP}}$ was slightly positive instead of slightly negative). This was not, however, considered significant in the evaluations because the pilot comments indicated that any $L'_{\delta_{RP}}$ effects could not be distinguished from the large L'_β effects. The comments also indicated that the rudders were objectionably sensitive in causing sideslip and thus rolling moments for the fixed-base evaluations. The in-flight rudder sensitivity, which was only 40% of the fixed-base values, was considered about right. This could help account for the difference between the fixed-base and in-flight pilot ratings.

The random input again pointed up the lack of Dutch roll damping and caused considerable roll disturbance. In natural turbulence the roll accelerations were excessive.

3.3.5 Summary of Part I Results

The longitudinal control characteristics were selected to provide good handling qualities and were kept constant for the Part I configurations. There were no significant objections in the pilot comments concerning the longitudinal control so it can be assumed that the lateral-directional evaluation results were not altered by longitudinal considerations.

The transient responses to a side gust shown in Figure I-19 are essentially the same in sideslip and yaw rate for all three groups. The magnitude of the bank angle and roll rate responses are proportional to L'_β or $|\phi/\beta|$. This supports the pilot comment data where the pilots objected to the higher roll response to sideslip disturbances with high L'_β or $|\phi/\beta|$ and down-rated these configurations more after evaluating them in the presence of random disturbances. See Appendix E for a more detailed discussion of the roll response to sideslip disturbances.

Calculated transient responses for a standard rudder pedal step are shown in Figures I-17 and I-18. These responses verify the pilot comments that the high $|\phi/\beta|$ configurations were quite responsive in roll to rudder inputs and that alarming roll response could result from miscoordination. The responses also show that the rudder pedals were much less sensitive for the "A" in-flight configurations than for the "AA" and the fixed-base configurations.

From the time histories of Figures I-9 through I-16 it is observed that minimum sideslip did not occur at $N'_{\delta_{AS}} = 0$, particularly for the A-7, -8 and -9 set of Figure I-14. It must be concluded that ($N'_p - g/V$), α_0 or $Y_{\delta_{AS}}$ was not zero for these configurations.

A comparison of the results obtained in this program with those obtained in Reference 1 shows reasonable agreement for the low $|\phi/\beta|$ configurations (see Figure I-1, configurations A-1, -2, -3). The pilot ratings for $|\phi/\beta| \approx 9$ obtained in this program do not agree with the data of Figure 5 in Reference 1 for $|\phi/\beta| \approx 9$. In attempting to resolve this disagreement, the pilot comments and transient response records for configurations 67, 68, 69 and 70 of Reference 1 were reexamined. It was found that the Dutch roll damping ratio as read from the transient responses ranged from $\zeta_d \approx .06$ to .03 for these configurations. Thus the damping ratio values used to identify configurations 67 - 70 in Reference 1 have been found to be in error and direct comparison of the results of Reference 1 for $|\phi/\beta| \approx 9$ with the results of this program for $|\phi/\beta| \approx 9$ cannot be made because the Dutch roll damping ratio was much higher in the current program.

The effect of the lower damping ratio in the Reference 1 evaluations would be to enhance the desirability of adverse yaw ($\omega_\phi/\omega_d < 1$). The improvement in closed-loop Dutch roll damping that is attendant to adverse yaw due to aileron control is much more important when the open-loop Dutch roll damping is low. For cases where the lack of Dutch roll damping is an overwhelming objection to the configuration, one would expect the improvement in closed-loop damping with small amounts of adverse yaw to be a more significant factor to the pilot's rating than the detrimental effects of induced sideslip and rudder coordination. Hence, the pilot rating versus ω_ϕ/ω_d would be expected to reach a peak for $\omega_\phi/\omega_d < 1.0$ when the Dutch roll damping is quite low. Thus, the results of the present program are not inconsistent with the results of Reference 1, once the error in indentification of ζ_d in Reference 1 is taken into account.

From the pilot ratings and pilot comments obtained in this program it is apparent that the pilots like the configurations best when the sideslip excited by aileron control is minimum. When $|L'_\beta|$ is large, they object to the large rolling motions that resulted from sideslip rather than the sideslip itself and to the consequences of miscoordination.

For configurations with the spiral root at the origin, a possible handling qualities parameter which reflects the importance of sideslip to the lateral directional handling qualities is the ratio of steady state sideslip (under the assumptions of Equation 5) to steady state roll rate, for aileron inputs.

$$\left.\frac{\beta}{p}\right|_{\substack{S.S.\\ \delta_{AS}}} = \frac{N'_{\delta_{AS}} L'_p - L'_{\delta_{AS}} \left(N'_p - \frac{g}{V}\right)}{L'_{\delta_{AS}} \omega_\phi^2}$$

$$= \frac{1}{\omega_\phi^2} \left[\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_p - \left(N'_p - \frac{g}{V}\right) \right] \qquad (14)$$

This parameter includes the effect of ($N'_p - \frac{g}{V}$).

TABLE I-1 PSEUDODERIVATIVES AND MODE CHARACTERISTICS

	Config.	A-1, -2, -3	A-4, -5, -6	A-7, -8, -9
Pseudo-derivatives	g/V	.0525	.0525	.0525
	L'_β	-5.36	-77.1	-102.2
	$L'_{\dot\beta}$	0	0	0
	L'_p	-2.55	-3.26	-2.65
	L'_r	.203	1.55	9.24
	N'_β	5.16	4.91	5.67
	$N'_{\dot\beta}$	-.041	.068	0
	N'_p	-.00846	.0770	.0608
	N'_r	-.374	-.406	-.513
	Y_β	-.171	-.167	-.14
	Y_p	0	0	0
	Y_r	0	0	0
Calculated modes	ω_d	2.30	2.17	2.30
	ζ_d	.103	.177	.1305
	$\left\lvert\frac{\phi}{\beta}\right\rvert$	.656	9.19	13.00
	$\measuredangle\frac{\phi}{\beta}$	44.38	46.89	48.0
	τ_R	.389	.331	.370
	τ_S	270.5	11.4	10^6
Fixed-base nominal measured modes	ω_d	2.30	2.11	2.24
	ζ_d	.092	.18	.14
	$\left\lvert\frac{\phi}{\beta}\right\rvert$	.65	9.7	12.8
	τ_R	.35	.29	.53
In-flight nominal measured modes "A" configurations	ω_d	2.20	2.35	2.61
	ζ_d	.092	.18	.13
	$\left\lvert\frac{\phi}{\beta}\right\rvert$	.64	9.6	12.0
	τ_R	.39	.298	.288
In-flight nominal measured modes "AA" configurations	ω_d	2.20	2.10	2.41
	ζ_d	.099	.18	.12
	$\left\lvert\frac{\phi}{\beta}\right\rvert$	.89	9.7	14.7
	τ_R	.321	.311	.446

TABLE I-2 CONTROL DERIVATIVES AND NUMERATOR ZEROS

	config.	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{deg/sec}{inch}$	$N'_{\delta_{RP}}$	$L'_{\delta_{RP}}$	$Y_{\delta_{RP}}$
Pseudo configuration	A-1	-.120	.954	0	-.126	.858	.926	2.13	.1112	18.23	.60	-.50	---
	A-2	-.00668	.782	0	-.00854	.982	.991	2.28	.110	17.12	↓	↓	---
	A-3	.0803	.685	0	.117	1.10	1.05	2.42	.110	16.83	↓	↓	---
Fixed base configuration	A-1	-.131	.974	.00134	-.135	.869	.932	2.14	.109	17.0	.604	-.494	-.00604
	A-2	-.007	.789	.0000906	-.00888	.991	.996	2.29	.110	15.7	↓	↓	↓
	A-3	.0862	.679	-.000859	.127	1.123	1.065	2.44	.110	15.3	↓	↓	↓
In-flight configuration	A-1	-.0798	.867	.00116	-.092	.9099	.953	2.099	.100	19.2	.235	-.190	-.00293
	A-2	.00355	.709	.0000932	.005	1.005	1.003	2.206	.100	15.9	↓	↓	↓
	A-3	.0717	.664	-.00075	.108	1.106	1.05	2.313	.100	16.4	↓	↓	↓
In-flight configuration	AA-1	-.0706	.917	.00116	-.077	.870	.932	2.05	.099	14.7	.601	-.502	-.00748
	AA-2	.000778	.788	.000131	.001	.965	.977	2.16	.099	14.0	↓	↓	↓
	AA-2A	.0283	.778	-.000204	.036	1.00	1.00	2.20	.099	14.3	↓	↓	↓
	AA-3	.0685	.665	-.000702	.103	1.06	1.03	2.27	.105	13.02	↓	↓	↓

TABLE I-3 CONTROL DERIVATIVES AND NUMERATOR ZEROS

	Config.	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{deg/sec}{inch}$	$N'_{\delta_{RP}}$	$L'_{\delta_{RP}}$	$Y_{\delta_{RP}}$
Pseudo configuration	A-4	-.0245	1.09	0	-.0225	.686	.828	1.08	.1688	14.18	.60	-.50	---
	A-5	.00039	.861	0	.000453	1.06	1.03	2.24	.143	17.32	↓	↓	---
	A-6	.00766	.706	0	.0107	1.23	1.11	2.41	.137	16.50	↓	↓	---
Fixed base configuration	A-4	.0257	1.10	.000286	-.0234	.582	.764	1.61	.181	10.62	.604	-.494	-.00604
	A-5	.00174	.843	0	.00206	1.04	1.019	2.15	.150	14.51	↓	↓	↓
	A-6	.0131	.715	-.000112	.0183	1.33	1.15	2.43	.142	15.71	↓	↓	↓
	A-6A	.0232	.532	-.000218	.0437	1.78	1.331	2.82	.133	15.75	↓	↓	↓
In-flight configuration	A-4B	-.0968	2.69	.00179	-.036	.166	.408	.960	.53	7.68	.234	-.191	-.00299
	A-4	-.00996	.996	.000334	-.01	.469	.685	1.61	.31	8.00	↓	↓	↓
	A-5	.0129	.806	-.0000137	.016	.843	.918	2.16	.22	11.65	↓	↓	↓
	A-6	.0214	.668	-.000125	.032	1.00	1.000	2.35	.20	11.42	↓	↓	↓
	A-6A	.0298	.497	-.00026	.060	1.33	1.152	2.71	.17	11.30	↓	↓	↓
	A-6B	.0318	.303	-.000335	.105	1.83	1.352	3.18	.17	9.50	↓	↓	↓
In-flight configuration	AA-4	-.0828	2.30	.00161	-.036	.25	.50	1.05	.18	10.23	.601	-.503	-.00769
	AA-5	0	.904	.000207	0	.656	.81	1.70	.18	10.53	↓	↓	↓
	AA-5A	.0162	.579	-.000112	.028	1.20	1.095	2.30	.14	12.35	↓	↓	↓
	AA-6	.0341	.325	-.000358	.105	2.05	1.43	3.00	.11	11.80	↓	↓	↓

TABLE I-4 CONTROL DERIVATIVES AND NUMERATOR ZEROS

	Config.	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{deg/sec}{inch}$	$N'_{\delta_{RP}}$	$L'_{\delta_{RP}}$	$Y_{\delta_{RP}}$
Pseudo configuration	A-7	-.0255	1.34	0	-.01855	.722	.85	1.955	.1235	20.52	.60	-.50	---
	A-8	-.00426	.974	0	-.004375	1.0	1.0	2.30	.1331	20.65	↓	↓	---
	A-9	.00890	.735	0	.0121	1.32	1.15	2.645	.1445	20.61	↓	↓	---
Fixed base configuration	A-7	-.0264	1.34	.000298	-.0197	.609	.780	1.75	.127	24.8	.604	-.494	-.00604
	A-8	-.00472	.963	.00007	-.0049	.903	.951	2.13	.141	26.4	↓	↓	↓
	A-9	.0105	.736	-.0000859	.0143	1.28	1.13	2.52	.160	28.6	↓	↓	↓
	A-9A	.0176	.616	-.00016	.0286	1.57	1.252	2.81	.170	29.3	↓	↓	↓
In-flight configuration	A-7B	-.0669	3.04	.00156	-.022	.187	.433	1.13	.58	9.40	.238	.00252	-.00299
	A-7	-.0026	1.30	.000323	-.002	.53	.728	1.90	.37	11.40	↓	↓	↓
	A-8	.01348	.898	.0000304	.015	.81	.900	2.35	.29	12.02	↓	↓	↓
	A-9	.0214	.668	.000315	.032	1.07	1.034	2.70	.25	11.80	↓	↓	↓
	A-9B	.0261	.249	.000276	.105	2.09	1.445	3.77	.19	8.58	↓	↓	↓
In-flight configuration	AA-7	-.0851	3.87	.00199	-.022	.255	.505	1.21	.09	25.0	.601	-.503	-.00769

TABLE I-5 CONTROL FEEL AND PITCH DYNAMICS

	Fixed Base	In Flight
Aileron stick spring rate ~ lb/in	2.3	2.3
Aileron stick breakout force ~ lb	±.7	±.71
Rudder pedal spring rate ~ lb/in	190*	180*
Rudder pedal breakout force ~ lb	±11.7	±11.4
Elevator stick spring rate ~ lb/in	40	40
Short period frequency, ω_n ~ rad/sec	2.95*	3.8*
Short period damping ratio, ζ	.48*	.6*
Stick force per "g" ~ lb/g	8	8
$\delta_{ES\ MAX}$ ~ in.	+7.75, -3.5	+7.75, -3.5
$\delta_{AS\ MAX}$ ~ in.	±6	±6
$\delta_{RP\ MAX}$ ~ in.	±4	±4

*nominal values from flight and ground simulator records

TABLE I-6 SUMMARY OF PILOT COMM
FOR FIXED-BASE CONFIGU

CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABLE FEATURES	SPEC
	GENERAL	AILERON YAW	COORDINATION	FEEL			T
A-1	TENDENCY TO EXCITE SIDESLIP WHEN I MANEUVER ABRUPTLY. DIFFICULT TO DAMP OUT OSCILLATION WITH AILERON. SLIGHT DIFFERENCE IN RUDDER-AILERON PHASING SEEMS TO EXCITE DUTCH ROLL. GOOD CONTROL WITH SMOOTH INPUTS. POOR HEADING CONTROL. SIDESLIP INDUCED WITH EVEN SMALL INPUTS.	QUITE A BIT OF ADVERSE.	TRIED BOTH COORDINATING AND NOT COORDINATING - NOT SURE WHICH IS BEST. REQUIRES CONCENTRATION AND LEAD WITH RUDDERS TO COORDINATE WELL. CAN COORDINATE SLOW SMALL INPUTS WELL.	POOR RESOLUTION. ADEQUATE FOR MISSION BUT A LITTLE ON THE SLOW SIDE. LIGHT FORCE GRADIENT. A SMALL DEAD BAND.	NONE.	SIDESLIP INDUCED BY AILERON WHICH DOES NOT INTERFERE WITH CONTROL OF AIRPLANE. CANNOT COORDINATE IN RAPID ROLLING. DUTCH ROLL MODE WITH SIZABLE SIDESLIP INDUCED BY RAPID AILERON INPUTS.	FLY BANK AN STEADY INPU WITH RUDDER WITH $\dot{\beta}$ TEC
A-2	GOOD AILERON CONTROL. GOOD ROLL RESPONSE. SOME SLOSHING DUTCH ROLL EXCITATION WITH AILERON. QUITE ADEQUATE FOR THE MISSION. RESPONSE IS A LITTLE BIT SLOW BUT THAT IS GOOD. GOOD HEADING CONTROL.	ADVERSE BUT RELATIVELY SMALL. NOT OBJECTIONABLE. NOT NOTICEABLE FOR SMALL INPUTS.	EASY TO COORDINATE. TENDENCY TO EXCITE SIDESLIP WITH IMPROPER COORDINATION. CAN'T COORDINATE REAL WELL FOR RAPID ROLLING MANEUVERS.	BREAKOUT FORCES AFFECT MY ABILITY TO FIND ZERO ROLL RATE. ONLY SLIGHTLY OBJECTIONABLE. STICK DOESN'T CENTER BY ITSELF BUT THIS IS NOT A PROBLEM.	THE SIDESLIP OSCILLATIONS THAT DID OCCUR DID NOT CREATE BANK ANGLE CONTROL PROBLEM. GOOD PITCH CHARACTERISTICS.	LIGHT DUTCH ROLL DAMPING. LATERAL CONTROL BREAKOUT FORCES.	USE RUDDER WITHOUT COO TO MATCH TEC RAPID RESPO
A-3	BANK ANGLE CONTROL GOOD FOR SLOW INPUTS. DUTCH ROLL EXCITED WITH LARGE INPUTS. EASIER TO MINIMIZE SIDESLIP WITH AILERONS THAN WITH RUDDER. CAN MINIMIZE SIDESLIP WITH AILERON PULSES. SIDESLIP OSCILLATIONS DAMP OUT RAPIDLY AT STEEP BANK ANGLES. I USE AILERON TO MAINTAIN PITCH ATTITUDE IN STEEP TURNS WHICH WITH PROVERSE AILERON YAW DAMPS OUT SIDESLIP OSCILLATIONS. GOOD FOR ROLLING OUT OF STEEP TURNS - NO DISH OUT. OSCILLATORY IN MAINTAINING HEADING BUT NO PROBLEM. TENDENCY FOR SIDESLIP OSCILLATIONS TO DIVERGE UNLESS YOU USE LEAD IN APPLYING AILERON INPUTS. WOULD LIKE TO SEE HIGHER ROLL RATE FOR GIVEN INPUT. WOULD BE SATISFACTORY FOR ROLLING MANEUVERS IF PILOT KEPT HIS GAIN DOWN AND MADE ONLY SMALL SLOW INPUTS. DUTCH ROLL READILY EXCITED BY AILERON INPUTS. RESIDUAL OSCILLATION FROM AILERON INPUTS DAMPS OUT BY ITSELF UNLESS YOU TRY TO FIGHT IT.	PROVERSE. OBJECTIONABLE BUT HAS SOME GOOD FEATURES.	CROSS COORDINATION WORKS IN KEEPING SIDESLIP SMALL BUT I TEND TO DO THE WRONG THING FOR SUDDEN AILERON INPUTS. I TEND TO IGNORE THE SMALL SIDESLIP DISTURBANCES UNLESS I SEE THEM IN PITCH ATTITUDE AT LARGE BANK ANGLES. TEND NOT TO COORDINATE. PILOT ATTEMPTS AT COORDINATION DID NOT MEET WITH SUCCESS.	GOOD IN STEEP TURNS. SMALL EFFECT OF SIDESLIP ON ROLL CONTROL. GOOD ROLL RESPONSE.	NOT QUITE PERFECT CENTERING. SMALL BREAKOUT FORCE BUT DOESN'T BOTHER MUCH. ATTEMPTS AT CROSS COORDINATING DIFFICULT.	EASILY INDUCED SIDESLIP WITH AILERON CONTROL AND TENDENCY FOR PILOT TO ENFORCE SIDESLIP OSCILLATION IF HE ISN'T CAREFUL WITH AILERON CONTROL. THE DEGREE OF PROVERSE YAW NOTED FOR RAPID LARGE AILERON INPUTS.	AILERON ONLY CAN DAMP BUT INVERSE $\dot{\beta}$ PULSING THE OF SIDESLIP PASSES THROU
A-4	GOOD FOR SLOW MANEUVERING. SIDESLIP GETS EXCITED FOR RAPID MANEUVERING. LOW ROLL RATE RESPONSE IF YOU DON'T COORDINATE. ROLL RESPONSE VERY DEPENDENT UPON SIDESLIP. ROLL CONTROL SLUGGISH. DUTCH ROLL OSCILLATION EXCITED BY AILERON INPUTS.	CAUSES SMALL AMOUNT OF ADVERSE SIDESLIP.	DOESN'T TAKE MUCH RUDDER TO COORDINATE. DIFFICULT TO PUT IN THE RIGHT AMOUNT. USED RUDDER TO GET DESIRED ROLL RESPONSE. NO PROBLEM FOR SLOW MANEUVERING. DESIRED FOR RAPID ROLLING.	CAN FIND THE POSITION FOR ZERO ROLL RATE PRETTY EASILY. HEAVY. LOW BREAKOUT FORCE. LIGHT GRADIENT. GOOD HARMONY.	FAIRLY LOW ADVERSE YAW DUE TO AILERON. GOOD FOR SLOW MANEUVERING. GOOD FOR MAINTAINING HEADING AND BANK ANGLE.	ROLL DUE TO SIDESLIP OBJECTIONABLY LARGE, CONSEQUENCES OF MISCOORDINATION ARE SEVERE IN TERMS OF BANK ANGLE ERRORS.	CAREFUL CO
A-5	VERY LITTLE SIDESLIP INDUCED BY ROLL CONTROL. ROLL CONTROL SEEMS QUITE GOOD. AILERON ORDERS ROLL RATE. ROLL RATE A LITTLE ON THE LOW SIDE BUT DESIRABLE FOR THE MISSION. EASY TO MAINTAIN AND CHANGE BANK ANGLE AND HEADING. WOULD LIKE A LITTLE MORE ROLL POWER. JUST A LITTLE DUTCH ROLL EXCITATION WITH AILERON.	SEEMS NONEXISTENT. I WOULD CALL IT ZERO. PRACTICALLY NO SIDESLIP GENERATED WITH AILERON.	PRACTICALLY NO RUDDER REQUIRED FOR COORDINATION. DIDN'T EVEN USE RUDDER.	I NOTICE BREAKOUT FORCES BUT THEY PRESENT NO PROBLEM. LIGHT BREAKOUT FORCE, LIGHT GRADIENT, GOOD CENTERING. I WOULD LIKE BETTER CENTERING.	LACK OF YAW DUE TO AILERON. LACK OF SIDESLIP EXCITATION. GOOD PITCH CONTROL.	LARGE ROLL DUE TO SIDESLIP. WOULD LIKE A LITTLE LARGER ROLL ACCELERATION.	AILERON ONLY FOR RUDDER
A-6	AILERONS INDUCE VERY LITTLE SIDESLIP. GOOD ROLL PRECISION. QUITE GOOD FOR CHANGING BANK ANGLE AND AT STEEP BANK ANGLES. DUTCH ROLL OSCILLATIONS DAMP OUT WHEN I RELAX BUT PERSIST WHEN I TRY TO CONTROL BANK ANGLE CLOSELY. WOULD LIKE HIGHER ROLL RATE FOR GIVEN AILERON INPUT.	ESSENTIALLY ZERO. WHEN I LOOK AT YAW RATE AFTER A SHARP AILERON INPUT, IT LOOKS PROVERSE. SMALL PROVERSE.	DIDN'T USE RUDDER PEDALS. SINCE CROSS COORDINATION WOULD BE REQUIRED, THE SMALL SIDESLIP GENERATED BY AILERON WAS NOT SIGNIFICANT ENOUGH TO JUSTIFY COORDINATION. COORDINATION NOT REQUIRED.	HAVE TO SEARCH FOR ZERO ROLL RATE POSITION. CAN NOTICE BREAKOUT FORCE BUT IT DOESN'T BOTHER ME. LIGHT CONTROL.	LITTLE SIDESLIP EXCITATION WITH AILERON. GOOD PRECISION IN CONTROL OF BANK ANGLE AND HEADING.	LARGE BANK ANGLE RESPONSE TO RUDDER. LARGE BANK ANGLE RESPONSE TO SIDESLIP. BANK ANGLE OSCILLATION TENDS TO PERSIST WHEN YOU TRY TO DAMP IT OUT. WOULD LIKE BETTER AILERON CENTERING. WOULD LIKE HIGHER ROLL RATE RESPONSE FOR AILERON INPUT.	AILERON ON OVERCONTROL
A-6A	AILERON EFFECTIVENESS SEEMS SLOW BUT ADEQUATE FOR THE MISSION. DUTCH ROLL DAMPS OUT BY ITSELF WHEN EXCITED BUT YOU HAVE A TENDENCY TO PROLONG IT IF YOU TRY TO DAMP IT OUT. BANK ANGLE NOTICEABLY OSCILLATORY AT ZERO G. CONTROL IN STEEP TURNS IS BETTER. WOULD LIKE HIGHER ROLL RATE FOR AILERON INPUT VERY LITTLE SIDESLIP GENERATED.	PROVERSE BUT APPEARS TO DECREASE AT HIGHER ANGLES OF ATTACK.	NOT NECESSARY TO COORDINATE FOR SLOW MANEUVERING. CROSS COORDINATION TO KEEP SIDESLIP ZERO IS DIFFICULT.	BREAKOUT FORCES NOTICEABLE BUT DON'T SEEM TO BOTHER TOO MUCH. HARMONY IS NOT TOO GOOD - ELEVATOR STICK MOVEMENTS ARE SMALL AND AILERON STICK MOVEMENTS ARE LARGE.	EASY TO FLY IT, SLOW MANEUVERING RATES WITHOUT DISTURBANCES.	CLOSED-LOOP BANK ANGLE OSCILLATIONS. BANK ANGLE OSCILLATIONS ARE DIVERGENT WHEN I ACT AS PROPORTIONAL CONTROLLER. WOULD LIKE HIGHER ROLL RATE FOR AILERON INPUT.	MANEUVER S OSCILLATION AILERON PU OSCILLATIO

RY OF PILOT COMMENTS
ED-BASE CONFIGURATIONS

	OBJECTIONABLE FEATURES	SPECIAL PILOTING TECHNIQUES	CONTROL IN PRESENCE OF DISTURBANCES	OVERALL OPINION	RUDDER CONTROL	LATERAL-DIRECTIONAL FREE RESPONSE	LONGITUDINAL HANDLING
	SIDESLIP INDUCED BY AILERON WHICH DOES NOT INTERFERE WITH CONTROL OF AIRPLANE. CANNOT COORDINATE IN RAPID ROLLING. DUTCH ROLL MODE WITH SIZABLE SIDESLIP INDUCED BY RAPID AILERON INPUTS.	FLY BANK ANGLE WITH AILERONS. SLOW STEADY INPUTS. KEEP SIDESLIP ZERO WITH RUDDERS. CAN STOP OSCILLATIONS WITH $\dot{\beta}$ TECHNIQUE.	CONSTANTLY AGGRAVATING DISTURBANCES WITH ROLL CONTROL.	UNACCEPTABLE BUT FLYABLE.			
. N- R-	LIGHT DUTCH ROLL DAMPING. LATERAL CONTROL BREAKOUT FORCES.	USE RUDDER FOR COORDINATION BUT OK WITHOUT COORDINATION. YOU DON'T HAVE TO WATCH TECHNIQUES. USE RUDDER WHEN RAPID RESPONSE IS DESIRED.	I WAS ABLE TO DO THE REQUIRED MANEUVERS IN THE PRESENCE OF DISTURBANCES. LACK OF DIRECTIONAL DAMPING IS MORE AGGRAVATING WITH DISTURBANCES.	GOOD CONFIGURATION. ACCEPTABLE AND SATISFACTORY. I WOULD LIKE TO SEE IT IN THE AIR TO FEEL THE SIDE ACCELERATIONS.	WOULD LIKE BETTER FEEL. BREAKOUT FORCES ADVERSELY AFFECT MY ABILITY TO COORDINATE. WOULD LIKE A LITTLE MORE EFFECTIVENESS. VERY LITTLE ROLL DUE TO RUDDER. SOME FRICTION. GOOD FORCE FEEDBACK FOR WHAT I'M PUTTING IN. PEDALS QUITE STIFF. FORCES HEAVY BUT DESIRABLY SO. I DON'T NOTICE FRICTION GIVING ME ANY TROUBLE.	VERY LITTLE ROLL INDUCED BY SIDESLIP. LIGHT DUTCH ROLL DAMPING. DUTCH ROLL IS ALMOST ENTIRELY A SNAKING MOTION. GOOD ROLL DAMPING. MODERATELY STIFF DUTCH ROLL.	SIDESLIP DISTURBANCES SHOW UP IN θ IN STEEP TURNS. NO BREAKOUT FORCE. FEEL SEEMS ADEQUATE. SHORT PERIOD DAMPING GOOD. STICK FORCE GRADIENT SEEMS HIGHER FOR HIGHER θ. QUITE SATISFACTORY AND DID NOT ENTER INTO LATERAL-DIRECTIONAL PROBLEM. GOOD FEEL AND GOOD RESPONSE.
I	EASILY INDUCED SIDESLIP WITH AILERON CONTROL AND TENDENCY FOR PILOT TO ENFORCE SIDESLIP OSCILLATION IF HE ISN'T CAREFUL WITH AILERON CONTROL. THE DEGREE OF PROVERSE YAW NOTED FOR RAPID LARGE AILERON INPUTS.	AILERON ONLY. MANEUVER SLOWLY. CAN DAMP DUTCH ROLL OSCILLATION WITH INVERSE $\dot{\beta}$ TECHNIQUE ON AILERON I.E., PULSING THE AILERON IN THE DIRECTION OF SIDESLIP NEEDLE MOVEMENT AS IT PASSES THROUGH ZERO.	TEND TO REDUCE SIDESLIP DISTURBANCES WITH RUDDERS WHICH IS IN CONFLICT WITH REQUIREMENT TO CROSS COORDINATE WITH AILERON INPUTS AND THIS DOESN'T HELP MATTERS. STEEP TURNS NOT AS GOOD	CONTROL OF PITCH ANGLE AND ROLLING OUT OF STEEP TURNS EASIER WITH PROVERSE YAW. THE SIDE ACCELERATIONS THAT WOULD RESULT IN FLIGHT FROM THE OBSERVED SIDESLIP ANGLE WOULD PROBABLY BE UNCOMFORTABLE.			
RON. OR .	ROLL DUE TO SIDESLIP OBJECTIONABLY LARGE. CONSEQUENCES OF MISCOORDINATION ARE SEVERE IN TERMS OF BANK ANGLE ERRORS.	CAREFUL COORDINATION.	ROLLING DISTURBANCES WERE QUITE LARGE. DIFFICULT TO CONTROL IN PRESENCE OF SIDESLIP DISTURBANCES. DUTCH ROLL CONTINUALLY EXCITED.	ACCEPTABLE BUT UNSATISFACTORY FOR THE RE-ENTRY MISSION.			
OF	LARGE ROLL DUE TO SIDESLIP. WOULD LIKE A LITTLE LARGER ROLL ACCELERATION.	AILERON ONLY. I FOUND LITTLE USE FOR RUDDER PEDALS.	SIDESLIP DISTURBANCES PRODUCED SIZABLE ROLL DISTURBANCES. HAD TO USE LARGE AILERON DEFLECTIONS.	SATISFACTORY, GOOD. I WOULD LIKE TO SEE IT IN FLIGHT TO SEE IF THE ROLLING DISTURBANCES BOTHER ME.	HEAVY BUT GIVES YOU GOOD FEEL FOR WHAT YOU ARE PUTTING IN. WOULD BE NICER WITHOUT THE BREAKOUT FORCES I FEEL. VERY LARGE ROLLING RESPONSE TO RUDDER. BREAKOUT FORCES LOW. QUITE SENSITIVE IN THAT SMALL INPUTS GIVE LARGE ROLLING MOTIONS. WOULD LIKE BETTER CENTERING IN VIEW OF THE LARGE ROLL RESPONSE. TEND TO PUT IN TOO LARGE RUDDER INPUTS. ROLL DUE TO RUDDER LARGE AND INSEPARABLE FROM ROLL DUE TO SIDESLIP.	LARGE ROLL DUE TO SIDESLIP. HIGH $\|\phi/\beta\|$. ADEQUATE ROLL DAMPING. DIRECTIONAL DAMPING LOW. LOW DUTCH ROLL DAMPING. MODERATE DIRECTIONAL STIFFNESS.	GOOD FEEL AND GOOD RESPONSE. WELL DAMPED SHORT PERIOD. I SEE PITCHING MOTION ONLY FOR ELEVATOR INPUT.
L-	LARGE BANK ANGLE RESPONSE TO RUDDER. LARGE BANK ANGLE RESPONSE TO SIDESLIP. BANK ANGLE OSCILLATION TENDS TO PERSIST WHEN YOU TRY TO DAMP IT OUT. WOULD LIKE BETTER AILERON CENTERING. WOULD LIKE HIGHER ROLL RATE RESPONSE FOR AILERON INPUT.	AILERON ONLY. BE CAREFUL NOT TO OVERCONTROL WITH RUDDER.	CAUSES LARGE ROLLING MOTIONS. REQUIRES CLOSE ATTENTION TO FLY. TEND TO OVERCONTROL WITH RUDDERS WHEN USING THEM TO CONTROL DISTURBANCES	ACCEPTABLE AND SATISFACTORY.			
	CLOSED-LOOP BANK ANGLE OSCILLATIONS. BANK ANGLE OSCILLATIONS ARE DIVERGENT WHEN I ACT AS PROPORTIONAL CONTROLLER. WOULD LIKE HIGHER ROLL RATE FOR AILERON INPUT.	MANEUVER SLOWLY AND LET DUTCH ROLL OSCILLATION DAMP OUT BY ITSELF. USE AILERON PULSES TO DAMP ROLL OSCILLATIONS.	DIVERGENT BANK ANGLE OSCILLATION WHEN I TRY TO CONTROL BANK ANGLE DISTURBANCES WITH AILERON. REQUIRES MORE PILOT ATTENTION.	BAD CHARACTERISTICS SHOW UP PRIMARILY IN THE PRESENCE OF DISTURBANCES.			

TABLE I-8 SUMMARY OF PILOT C
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CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABLE FEATURES	SPE
	GENERAL	AILERON YAW	COORDINATION	FEEL			
A-1	DUTCH ROLL ALMOST CONTINUOUSLY EXCITED BY AILERONS. RESPONSE VERY GOOD EXCEPT AILERON STICK EXCITES THE DUTCH ROLL. I HAVE PLENTY OF AUTHORITY. JUST A LITTLE TOO MUCH FOR THE MISSION. BOTHERSOME DUTCH ROLL EXCITATION FOR ABRUPT AILERON INPUTS.	LARGE ADVERSE YAW. AGGRAVATING. GIVES DUTCH ROLL OSCILLATION.	REQUIRES HEAVY RUDDER PEDAL FORCES TO COORDINATE. CAN'T FIND THE RIGHT COMBINATION. HAVE TO COORDINATE TO DO MANEUVERS. CAN MANAGE PRETTY WELL IF I DO IT SLOWLY. UNSUCCESSFUL IN COORDINATING FOR RAPID ROLLING AND STEEP TURNS.	LITTLE TOO SENSITIVE. HARD TO FIND STICK POSITION FOR ZERO BANK ANGLE WITH THE EXISTING BREAKOUT FORCE. LIGHT FORCE GRADIENT.	LOW $\|\phi/\beta\|$ OF DUTCH ROLL OSCILLATION.	LARGE YAW DUE TO AILERON REQUIRING COORDINATION AND HARD TO COORDINATE WELL. I GOT TIRED OF STOMPING ON THE RUDDER PEDALS EVERY TIME I USED THE AILERONS.	WORKING THE DUTCH ROLL T INPUTS. STOPPING OSC
A-2	DOESN'T EXCITE MUCH IN THE WAY OF SIDESLIP. PLENTY OF ROLL RESPONSE. RAPID ROLLING MANEUVERS TENDED TO EXCITE SOME SIDESLIP. QUITE SATISFACTORY LATERAL CONTROL POWER. SOME DUTCH ROLL EXCITATION. I LIKE THE LATERAL CONTROL.	SOME ADVERSE - I COORDINATE RUDDER WITH THE AILERON AND IT'S AT AN ACCEPTABLE LEVEL.	RUDDER FORCES WELL IN LINE WITH COORDINATION REQUIREMENTS. COORDINATE JUST SLIGHTLY TO KEEP SIDESLIP ZERO. REQUIRES COORDINATION FOR LARGE ABRUPT AILERON INPUTS BUT COORDINATION MORE DIFFICULT.	LIGHTER THAN IT NEEDS TO BE. HARMONY WITH ELEVATOR COULD BE BETTER. QUITE ADEQUATE FOR MISSION. BREAKOUT FORCES NOTICEABLE BUT LOW. GOOD CENTERING.	CAN MAKE IT DO WHAT I WANT IT TO DO. GOOD LATERAL CONTROL. NO PARTICULARLY UNDESIRABLE DUTCH ROLL CHARACTERISTICS.	WOULD LIKE A LITTLE BETTER AILERON CENTERING. WOULD LIKE TO HAVE A LITTLE MORE ROLLING IN DUTCH ROLL OSCILLATION. NO MAJOR OBJECTIONS.	NONE. A LIT
A-3	QUITE CONTROLLABLE FOR SMALL MANEUVERS. LESS DESIRABLE FOR RAPID ROLLING MANEUVERS. NOT TOO GOOD FOR MAINTAINING HEADING. TAKES A LITTLE ANTICIPATION TO STOP ON DESIRED BANK ANGLE WHEN CHANGING BANK ANGLE.	PROVERSE. OBJECTIONABLY HIGH IN LARGER ROLLING MANEUVERS.	SIDESLIP GENERATED BY RAPID ROLLING MANEUVERS IS NOT THE TYPE I CAN COORDINATE. WASN'T VERY SUCCESSFUL AT CROSS COORDINATING.	A LITTLE SENSITIVE. BREAKOUT FORCES NOT OBJECTIONABLE. DIFFICULT TO FIND ZERO ROLL RATE POSITION. STICK CENTERING OK.	CONTROL OF BANK ANGLE QUITE GOOD IN STEEP TURNS. SIDESLIP DOESN'T DO TOO MUCH TO BANK ANGLE CONTROL.	NOT SUCCESSFUL IN COORDINATING PROVERSE YAW. EXCITATION OF SIDESLIP WITH AILERON CONTROL AND CAN'T DO ANYTHING ABOUT IT.	AILERON ONL
A-4B	LARGE AMOUNT OF SIDESLIP WHEN YOU PUT IN AILERON WITHOUT COORDINATING. YOU INITIALLY GET VERY HIGH ROLLING ACCELERATION BUT THEN IT SLOWS DOWN AS A LOT OF, SIDESLIP COMES IN. THE AILERON REQUIRED IS VERY VERY SMALL WHEN YOU COORDINATE. ROLL CONTROL NOT TOO HIGH AS LONG AS YOU DO THINGS SLOWLY. TERRIBLE WHEN YOU TRY TO ROLL RAPIDLY. DUTCH ROLL EXCITATION WITH AILERON INPUTS.	EXTREMELY LARGE AND ADVERSE.	YOU THINK YOU CAN HANDLE IT WHEN YOU WORK HARD ON THE RUDDER PEDALS AND COORDINATE. DIFFICULT TO COORDINATE EXACTLY. VERY LARGE SIDESLIP GENERATED WHEN YOU MISCOORDINATE.	VERY SENSITIVE, ABRUPT INITIAL RESPONSE, BREAKOUT FORCES BOTHER ME. AILERON BREAKOUT FORCES HELP ME WHEN I USE RUDDERS FOR ROLL CONTROL. LOW BREAKOUT, FRICTION, AND FORCE GRADIENT.		CONSEQUENCES OF MISCOORDINATION ARE ALARMING. ADVERSE YAW GENERATION WITH AILERON INPUTS.	A LOT OF CO SMOOTH AIL
A-4	RESPONSE PLENTY FAST. MAINTAINING BANK ANGLE GOOD. ROLL ACCELERATION LOOKS GOOD BUT I HAVE A DEFINITE SLOWDOWN WITH GENERATION OF SIDESLIP. EXCITATION OF DUTCH ROLL MODE.	ADVERSE.	REASONABLY HEAVY RUDDER FORCES REQUIRED TO COORDINATE BUT EASY TO DO. YOU REALIZE WHEN YOU MISCOORDINATE BECAUSE IT ROLLS TOO FAST OR NOT FAST ENOUGH. ABLE TO KEEP SIDESLIP ZERO.	LIGHT BUT NOT TOO LIGHT. LIGHT BREAKOUT FORCE, LIGHT FORCE GRADIENT, NO APPRECIABLE FRICTION BAND, GOOD STICK CENTERING.	NICE BANK ANGLE AND HEADING CONTROL AS LONG AS YOU COORDINATE WELL.	GIVES YOU A LITTLE BIT OF TROUBLE IF YOU DON'T COORDINATE PERFECTLY. LARGE RATHER OVERPOWERING ROLL DUE TO SIDESLIP - ROCKED YOUR HEAD QUITE A BIT IN TURBULENCE.	NONE EXCEPT
A-5	RESPONSE TO AILERONS IS PROMPT AND GOOD. PRETTY GOOD AT MAINTAINING AND CHANGING BANK ANGLE. SOME DUTCH ROLL EXCITATION WITH AILERON INPUTS. SATISFACTORY LATERAL CONTROL POWER. ADEQUATE ROLL DAMPING.	VERY LOW ADVERSE. NOT OBJECTIONABLE. ADVERSE, JUDGING FROM COORDINATION REQUIREMENTS BUT CAN'T SAY WHETHER IT'S ADVERSE OR PROVERSE FROM YAW RATE NEEDLE RESPONSE TO AILERON STEP.	EASILY COORDINATED. COULD COORDINATE NATURALLY. NOT SUSCEPTIBLE TO MISCOORDINATION. COORDINATION NOT REQUIRED FOR ROLLING MANEUVERS.	COULD STAND A LITTLE LESS CONTROL SENSITIVITY FOR THE MISSION. BREAKOUT FORCES OBJECTIONABLE BUT NOT ENOUGH TO BE CALLED UNSATISFACTORY.	GOOD POSITIVE CONTROL. PREDICTABLE. GOOD LATERAL CONTROL POWER AND ROLL DAMPING.	NO STRONG ONES. RESPONSIVENESS IN BANK ANGLE TO DISTURBANCES. HIGH $\|\phi/\beta\|$ OF DUTCH ROLL MODE.	NONE. HELP
A-6	GOOD RESPONSE TO AILERON. NO SIGNIFICANT DUTCH ROLL EXCITATION OR SIDESLIP GENERATION WITH AILERON INPUTS. VERY SLIGHT DUTCH ROLL OSCILLATION IS INCURRED.	CLOSE TO ZERO BASED ENTIRELY ON SIDESLIP - DIDN'T LOOK AT YAW RATE NEEDLE.	WHEN I USED RUDDERS, I ENDED UP WITH PROVERSE SIDESLIP IN ROLLS. NO COORDINATION REQUIRED.	OBJECT TO AILERON FRICTION. COMFORTABLE ROLL SENSITIVITY. BREAKOUT FORCE LOW. FORCE GRADIENT LIGHT. WOULD LIKE A LITTLE MORE ROLL RATE FOR FOR GIVEN INPUT.	PRECISENESS OF BANK ANGLE AND HEADING CONTROL. ALL-AROUND GOOD LATERAL CONTROL. LACK OF YAW GENERATION AND DUTCH ROLL EXCITATION WITH AILERON CONTROL.	ROLLING MOTION DUE TO DISTURBANCES. NO MAJOR OBJECTIONS.	AILERON ONL
A-6A	A LITTLE SIDESLIP IS INDUCED WITH FULL AILERON. PULLING "G" SEEMS TO STABILIZE THE DUTCH ROLL. ROLL CONTROL EFFECTIVE AND ADEQUATE FOR MISSION.	I THINK PROVERSE, BUT THE SIDESLIP INDUCED IS ESSENTIALLY ZERO.	NOT REQUIRED.	THE CONFIGURATION IS GOOD ENOUGH THAT I NOTICE AND OBJECT TO THE BREAKOUT FORCES. PRETTY GOOD. TOO MUCH AILERON STICK MOTION FOR GOOD HARMONY.	GOOD ROLL CONTROL.	SUSCEPTIBILITY TO ROLLING DISTURBANCES.	AILERON ONL
A-6B	ROLL CONTROL BECOMES OSCILLATORY WHEN I TRY TO MAINTAIN A PRECISE BANK ANGLE. BETTER FOR SLOW MANEUVERING RATES. IMMEDIATE RESPONSE. CONTROL IS OK WHEN PILOT IS RELAXED OR USING LOW GAIN. GOOD IF YOU DO THINGS SLOWLY. SOME DUTCH ROLL EXCITATION WITH AILERONS.	SOME PROVERSE BUT SIDESLIP STAYS NEAR ZERO FOR SLOW MANEUVERING.	HAVE TO CROSS COORDINATE TO KEEP SIDESLIP ZERO SO I FLY WITH AILERON ALONE. COORDINATION NOT REQUIRED.	LOW SIDE ON SENSITIVITY. LOW ROLL ACCELERATION FOR AILERON INPUT. NO SIGNIFICANT FRICTION.	REASONABLE FLYING AIRPLANE FOR SLOW AILERON INPUTS. PROVERSE YAW HAS GOOD FEATURE OF HOLDING THE NOSE UP FOR YOU WHEN YOU ROLL OUT OF STEEP TURNS.	OSCILLATION WHEN YOU TRY TO MAINTAIN PRECISE ROLL CONTROL. LOW AILERON CONTROL SENSITIVITY.	CAN GET RID RELAXING.
A-7B	I FELT A LARGE ROLL ACCELERATION WHEN I USED THE AILERONS ABRUPTLY. ABRUPT INITIAL AILERON RESPONSE. VERY HIGH ROLL RATES IF COORDINATED BUT LOW IF NOT COORDINATED.	PRETTY LARGE MAGNITUDE ADVERSE.	YOU HAVE TO USE QUITE A BIT OF RUDDER FOR COORDINATION. NOT TOO DIFFICULT WHEN YOU APPLY AILERON SLOWLY AND SMOOTHLY. MORE SUCCESSFUL WHEN I USED THE AILERON TO COORDINATE RUDDER INPUTS RATHER THAN USE THE RUDDER TO COORDINATE AILERON INPUTS.	ROLL SENSITIVITY TOO HIGH. BREAKOUT FORCES OBJECTIONABLE FOR ABRUPT RESPONSE.	IT'S PRETTY GOOD IF YOU COORDINATE PROPERLY.	ABRUPTNESS IN ROLL RESPONSE AND THE ABRUPT MANNER IN WHICH ROLL RESPONSE WAS ALTERED IF I MISCOORDINATED. THE CONSEQUENCES OF MISCOORDINATION.	USED AILERO INPUTS. US AILERON CO
A-7	VERY SNAPPY IN INITIAL ROLL RESPONSE THEN SUDDENLY SLOWS DOWN. FEELS NORMAL WHEN I COORDINATE WITH RUDDER. AILERON INPUTS EXCITE THE DUTCH ROLL MODE.	ADVERSE IN MODERATE AMOUNT. CAN FEEL IT AS SIDE FORCE.	I DO MUCH BETTER WHEN I COORDINATE. QUITE A CHANGE IN THE ROLL RATE YOU GET BETWEEN WHEN YOU COORDINATE AND WHEN YOU DON'T. I TRY BASICALLY TO MAKE THE ROLL RATE COME OUT RIGHT IN COORDINATING.	BREAKOUT FORCE NOTICEABLE AND OBJECTIONABLE DUE TO THE ABRUPT AILERON CONTROL. PRETTY SENSITIVE. LIGHT FORCE GRADIENT.	NOT A BAD CONFIGURATION IF YOU COORDINATE AND DO EVERYTHING SMOOTHLY.	ABRUPT INITIAL ROLL RESPONSE THAT SUDDENLY SLOWS DOWN. SUSCEPTIBLE TO COORDINATION ERRORS ON THE PART OF THE PILOT. TOO MUCH ROLL RESPONSE TO DISTURBANCES.	COORDINATI APPLIED AI
A-8	VERY GOOD IN STEEP TURNS. GOOD ROLL CONTROL. NO TENDENCY TO OSCILLATE. NO COORDINATION REQUIRED FOR SLOW SMALL INPUTS. OSCILLATIONS THAT I GET FOR ABRUPT INPUTS ARE ANNOYING RATHER THAN CAUSING A DETERIORATION IN PERFORMANCE.	YAW DUE TO ROLL CONTROL MOSTLY NEAR ZERO, SIDESLIP DUE TO ROLL CONTROL ADVERSE. IT SEEMS LESS THAN IT IS FROM THE STANDPOINT OF DUTCH ROLL EXCITATION.	EASY TO COORDINATE. REQUIRES A LITTLE COORDINATION TO KEEP SIDESLIP ZERO.	GOOD FEEL. LOW BREAKOUT FORCE, NO SIGNIFICANT FRICTION BAND. FORCE GRADIENT LIGHT. A LITTLE BIT OF A PROBLEM WITH STICK CENTERING.	GOOD FOR MANEUVERING.	DON'T LIKE THIS MUCH ROLL RESPONSE TO SIDESLIP. EXCITATION OF LOW DAMPED HIGH $\|\phi/\beta\|$ DUTCH ROLL WITH ABRUPT AILERON INPUTS.	NONE REQU
A-9	CAN DO GOOD STEEP TURNS. GOOD POSITIVE CONTROL OF BANK ANGLE IN STEEP TURNS. PRETTY SENSITIVE AROUND LEVEL FLIGHT. IMMEDIATE RESPONSE TO AILERON. ABRUPT USE OF AILERONS GIVES HALTING ROLL RATE. SMALL DUTCH ROLL OSCILLATION EXCITED WITH AILERON. DESIRE GREATER LATERAL CONTROL POWER.	IF YOU LOOK AT THE SIDESLIP NEEDLE, YOU CONCLUDE IT'S A LITTLE ADVERSE, BUT IF YOU LOOK AT THE YAW RATE NEEDLE, YOU CONCLUDE IT'S PROVERSE. FROM A PILOTING VIEWPOINT, IT'S ESSENTIALLY ZERO BECAUSE YOU DON'T NEED TO COORDINATE.	CAN SPEED UP THE ROLL RATE BY COORDINATING BUT I DON'T NEED TO.	A LITTLE SENSITIVE IN LEVEL FLIGHT. BREAKOUT FORCES NOTICEABLE BUT LOW. FORCE GRADIENT LIGHT. GOOD CONTROL HARMONY.	VERY GOOD IN STEEP TURNS. QUITE SATISFACTORY USING LATERAL CONTROL ALONE. ONLY MINOR DUTCH ROLL EXCITATION WITH AILERONS.	HIGH ROLL RATES WHEN SIDESLIP IS DISTURBED. DESIRE GREATER LATERAL CONTROL POWER.	NONE. AI
A-9B	RESPONSE TO AILERON SEEMS QUICK. OSCILLATORY WHEN TRYING TO MAINTAIN 30° BANK ANGLE - WORSE ON INSTRUMENTS. OSCILLATORY WHEN YOU TRY TO PIN BANK ANGLE DOWN. BANK ANGLE CONTROL TAKES FAIR AMOUNT OF ATTENTION. GOT INTO DIVERGENT BANK ANGLE OSCILLATION WHEN TRYING TO TRACK BANK ANGLE. AILERON PULSES WORKED PRETTY WELL. LESS OSCILLATION AT HIGH "G". SLOWING UP OF ROLL RATE. WING ROCKING.	PROVERSE.	COORDINATION NOT REQUIRED. ROLL RATE LOWER THAN DESIRED WHEN I TRY TO COORDINATE.	A LITTLE ON THE HEAVY SIDE. LOW BREAKOUT FORCE, FORCE GRADIENT LOW, SENSITIVITY LOW.		DIFFICULT TO FLY TIGHT BANK ANGLE CONTROL. LACK OF LATERAL CONTROL POWER. CONSTANT EXCITATION OF HIGH ROLLING MOTION DUTCH ROLL.	AILERON ON

MMARY OF PILOT COMMENTS)R IN-FLIGHT CONFIGURATIONS

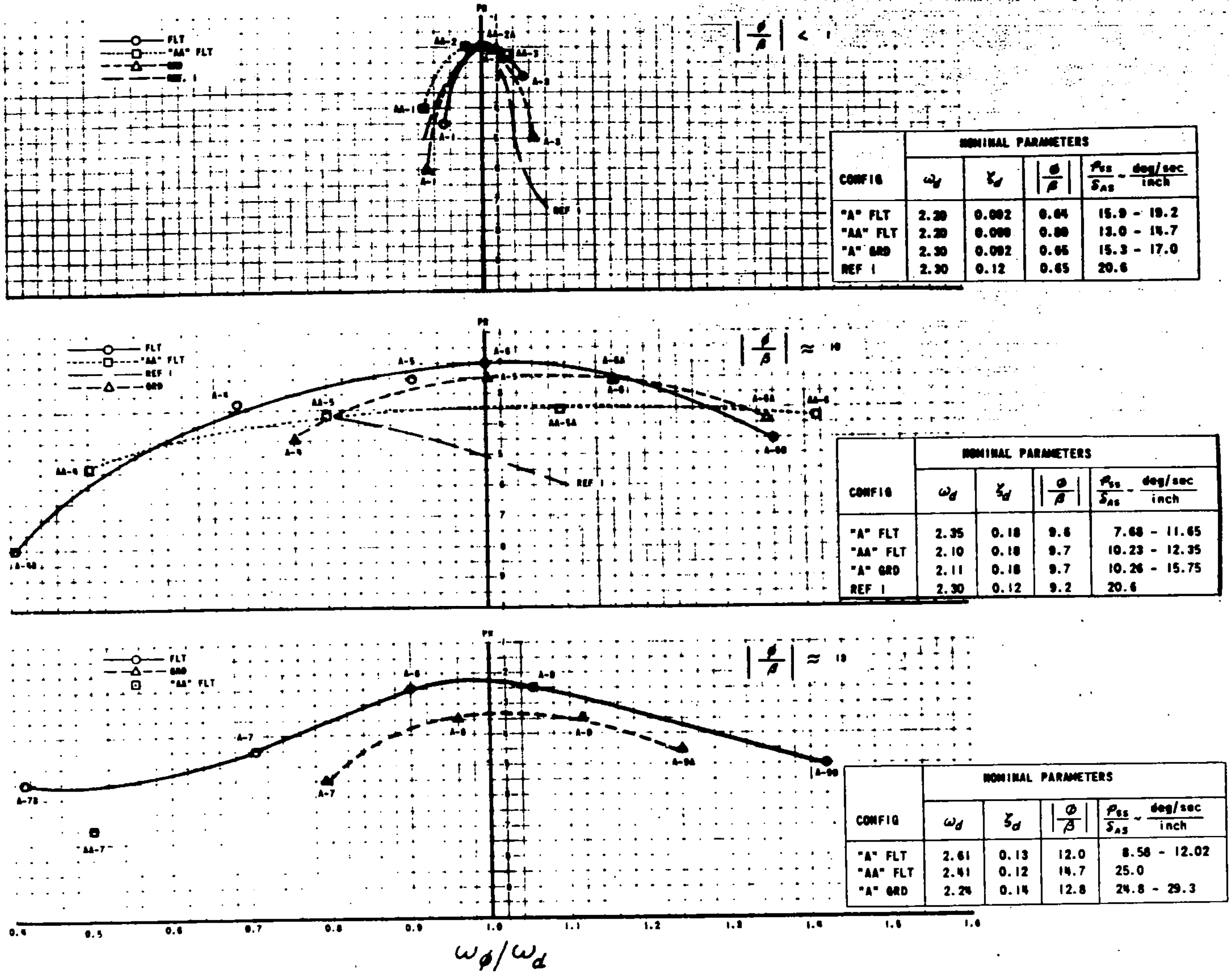
	OBJECTIONABLE FEATURES	SPECIAL PILOTING TECHNIQUES	CONTROL IN PRESENCE OF DISTURBANCES	OVERALL OPINION	RUDDER CONTROL	LATERAL-DIRECTIONAL FREE RESPONSE	LONGITUDINAL HANDLING
.	LARGE YAW DUE TO AILERON REQUIRING COORDINATION AND HARD TO COORDINATE WELL. I GOT TIRED OF STOMPING ON THE RUDDER PEDALS EVERY TIME I USED THE AILERONS.	WORKING THE RUDDER PEDALS TO DAMP THE DUTCH ROLL THAT'S EXCITED WITH AILERON INPUTS. β TECHNIQUE EFFECTIVE IN STOPPING OSCILLATION.	SUSCEPTIBLE TO BEING DISTURBED BY NOISE AND BY MY CORRECTIVE INPUTS. COORDINATION TAKES A LOT OF ATTENTION. RESTRICTED FROM MAKING LARGE ABRUPT AILERON INPUTS.	ACCEPTABLE BUT UNSATISFACTORY. FAIR TO POOR. SLOSHY-TYPE AIRPLANE.	BREAKOUT FORCE TENDS TO BOTHER ME. FORCES PRETTY HEAVY. RESPONSE TO RUDDER OSCILLATORY. ROLL DUE TO RUDDER ESSENTIALLY ZERO. GET GOOD FEEDBACK FROM RUDDER FORCES I PUT IN. SMALL FRICTION BAND. PRIMARILY GENERATE SIDESLIP WITH RUDDERS. ON THE HEAVY SIDE AND DESIRABLY SO. LOW BREAKOUT FORCES. SMALL PROBLEM IN CENTERING. ONLY SMALL BANK ANGLE CHANGES WITH RUDDER INPUT.	RATHER LIGHT DUTCH ROLL DAMPING. ROLL DUE TO SIDESLIP IS PRETTY SMALL. OSCILLATION IS APPARENTLY SNAKING. MODERATELY STIFF DUTCH ROLL. FLAT DUTCH ROLL OSCILLATION. ADEQUATE DUTCH ROLL DAMPING. ROLL DAMPING QUITE SATISFACTORY. NO APPARENT DIHEDRAL EFFECT.	PITCH CHARACTERISTICS GOOD. ELEVATOR FORCES A LITTLE ON THE HEAVY SIDE. WELL SUITED TO MISSION. HEAVILY DAMPED SHORT PERIOD, HEAVIER THAN IT NEEDS TO BE *FOR THE MISSION.* MAINTAINING PITCH ANGLE EASY.
	WOULD LIKE A LITTLE BETTER AILERON CENTERING. WOULD LIKE TO HAVE A LITTLE MORE ROLLING IN DUTCH ROLL OSCILLATION. NO MAJOR OBJECTIONS.	NONE. A LITTLE BIT OF COORDINATION.	I HAD GOOD POSITIVE CONTROL. KIND OF AGGRAVATING BUT DOESN'T REALLY JOSTLE THE AIRPLANE THE WAY TURBULENCE DOES. HAVE TO WORK A LITTLE BIT HARDER.	GOOD AIRPLANE - HARD TO FIND FAULT WITH IT. ACCEPTABLE SATISFACTORY GOOD. FAIR TO GOOD. EXCELLENT TO GOOD.			
·O	NOT SUCCESSFUL IN COORDINATING PROVERSE YAW. EXCITATION OF SIDESLIP WITH AILERON CONTROL AND CAN'T DO ANYTHING ABOUT IT.	AILERON ONLY.	NOT TOO BAD.	FOR SLOW SMALL MANEUVERING INPUTS, IT'S A GOOD CONFIGURATION. WOULD RATE IT LOWER FOR MISSION REQUIRING MORE MANEUVERING.			
	CONSEQUENCES OF MISCOORDINATION ARE ALARMING. ADVERSE YAW GENERATION WITH AILERON INPUTS.	A LOT OF COORDINATION AND MIGHTY SMOOTH AILERON INPUTS.	DISTURBANCE IN RUDDER CHANNEL QUITE HIGH.	I DON'T LIKE IT. UNACCEPTABLE. I DID THE WORST WHEN I WAS KIND OF EXCITED.	HEAVY FORCES PROVIDE GOOD FEEDBACK BUT I WOULD PREFER A LITTLE LESS FORCE. HAVE GOOD ROLL RATE CONTROL WITH RUDDER PEDALS BUT CAN'T CONTROL BANK ANGLE VERY WELL. BREAKOUT FORCE AND FRICTION LOW. CENTERING OK. HEAVY AND SATISFACTORY. ROLL DUE TO RUDDER INSEPARABLE FROM ROLL DUE TO SIDESLIP AND QUITE LARGE. RESPONSE TO RUDDER PREDICTABLE.	LOW DUTCH ROLL DAMPING. MEDIUM $\|\phi/\beta\|$. LARGE ROLL DUE TO SIDESLIP. FEELS STIFF DIRECTIONALLY. $\|\phi/\beta\|$ APPEARS TO BE ABOUT 10 TO 1. WELL DAMPED DUTCH ROLL. GOOD ROLL DAMPING.	ELEVATOR FEEL GOOD. PITCH CONTROL IS OK. GOOD SHORT PERIOD DAMPING. ADEQUATE CONTROL POWER, STICK CENTERING GOOD. A LITTLE HEAVY IN TURNS. SPEED CONTROL GOOD.
AS	GIVES YOU A LITTLE BIT OF TROUBLE IF YOU DON'T COORDINATE PERFECTLY. LARGE RATHER OVERPOWERING ROLL DUE TO *SIDESLIP - ROCKED YOUR HEAD QUITE A* BIT IN TURBULENCE.	NONE EXCEPT COORDINATION.	BANK ANGLE QUITE RESPONSIVE TO TURBULENCE. OBJECTIONABLE IN TURBULENCE. MORE PILOT EFFORT REQUIRED FOR PITCH *CONTROL WITH RANDOM NOISE.*	NICE AS LONG AS YOU COORDINATE WELL.			
.	NO STRONG ONES. RESPONSIVENESS IN BANK ANGLE TO DISTURBANCES. HIGH $\|\phi/\beta\|$ OF DUTCH ROLL MODE.	NONE. HELPFUL TO COORDINATE.	CREATED ROLL DISTURBANCES BUT WAS ABLE TO COUNTER WITH AILERON. LESS DESIRABLE WITH RANDOM NOISE. VERY RESPONSIVE IN BANK ANGLE TO SIDESLIP DISTURBANCES.	A SMOOTH NICE FLYING AIRPLANE. GOOD FOR THE MISSION.			
NG ON-	ROLLING MOTION DUE TO DISTURBANCES. NO MAJOR OBJECTIONS.	AILERON ONLY FOR ROLL WAS BEST.	A LOT OF ROLLING MOTION DUE TO DISTURBANCE. REQUIRES LARGE AILERON STICK DEFLECTION TO COUNTER.	ALL-AROUND GOOD LATERAL CONTROL.			
	SUSCEPTIBILITY TO ROLLING DISTURBANCES.	AILERON ONLY.	QUITE RESPONSIVE IN ROLL TO RANDOM DISTURBANCES. REQUIRES A LOT OF AILERON TO COUNTER DISTURBANCES.	ACCEPTABLE AND SATISFACTORY FOR THE MISSION.			
- P	OSCILLATION WHEN YOU TRY TO MAINTAIN PRECISE ROLL CONTROL. LOW AILERON CONTROL SENSITIVITY.	CAN GET RID OF OSCILLATION BY JUST RELAXING.	A LOT OF ROLLING MOTION FROM DISTURBANCES. TAKES LARGE AILERON INPUTS TO GET DESIRED ACTION IN RETURNING TO STRAIGHT AND LEVEL.	SEEMS TO BE A DIFFERENT AIRPLANE WHEN I TRY TO PIN THE BANK ANGLE DOWN - BECOMES OSCILLATORY.			
	ABRUPTNESS IN ROLL RESPONSE AND THE ABRUPT MANNER IN WHICH ROLL RESPONSE WAS ALTERED IF I MISCOORDINATED. THE CONSEQUENCES OF MISCOORDINATION.	USED AILERON TO COORDINATE FOR RUDDER INPUTS. USE THE BEST POSSIBLE RUDDER-AILERON COORDINATION.	HAS LARGE ROLLING MOTION FOR SIDESLIP DISTURBANCES.	UNSATISFACTORY, FAIR TO POOR.	FORCES PRETTY HIGH. ROLL DUE TO RUDDER INSEPARABLE FROM ROLL DUE TO SIDESLIP AND LARGE. A LITTLE DIFFICULT TO RESOLVE EXACTLY THE CORRECT INPUTS I NEED ON THE RUDDER PEDALS. SLIGHT FRICTION BAND CAUSES SMALL PROBLEM IN CONTROL CENTERING. RUDDER CONTROL JUST ABOUT RIGHT.	VERY HIGH ROLL TO SIDESLIP RATIO. DUTCH ROLL OSCILLATION APPEARED TO BE LIGHTLY DAMPED. DIRECTIONALLY STIFF. GOOD ROLL DAMPING.	A LITTLE ON THE HEAVY SIDE AND GOOD. SATISFACTORY. GOOD RESPONSE TO ELEVATOR. GOOD CONTROL POWER. BREAKOUT FORCE LOW, NO SIGNIFICANT FRICTION. SHORT PERIOD WELL DAMPED.
DI-	ABRUPT INITIAL ROLL RESPONSE THAT SUDDENLY SLOWS DOWN. *SUSCEPTIBLE TO* COORDINATION ERRORS ON THE PART OF THE PILOT. TOO MUCH ROLL RESPONSE TO DISTURBANCES.	COORDINATION IN THE DIRECTION OF *APPLIED AILERON.*	AIRPLANE RESPONDS QUITE A BIT TO DISTURBANCES. IT'S A ROUGH RIDE IN TURBULENCE. ROLL ACCELERATION IN TURBULENCE IS SUBSTANTIAL. RANDOM NOISE IS NOT LIKE TURBULENCE.	MISSION COULD BE PERFORMED BUT IT IS NOT A GOOD CONFIGURATION. GOOD AIRPLANE IN SMOOTH AIR.			
	DON'T LIKE THIS MUCH ROLL RESPONSE TO SIDESLIP. EXCITATION OF LOW *DAMPED HIGH* $\|\phi/\beta\|$ *DUTCH ROLL WITH* ABRUPT AILERON INPUTS.	NONE REQUIRED.	CONTROL OF RESPONSE TO TURBULENCE PRETTY GOOD. ROLL CONTROL IN PRESENCE OF *RANDOM NOISE INCREASED* WORK LOAD.	IT'S PRETTY GOOD. ACCEPTABLE, SATISFACTORY.			
T- NE. ITH	HIGH ROLL RATES WHEN SIDESLIP IS DISTURBED. DESIRE GREATER LATERAL CONTROL POWER.	NONE. AILERON ONLY.	DISTURBANCES APPEARED PRIMARILY IN ROLL. REQUIRES INCREASED PILOT *EFFORT.*	ACCEPTABLE SATISFACTORY.			
	DIFFICULT TO FLY TIGHT BANK-ANGLE *CONTROL. LACK OF LATERAL CONTROL* POWER. CONSTANT EXCITATION OF HIGH ROLLING MOTION DUTCH ROLL.	AILERON ONLY.	NOT TOO BAD. DEFINITE INCREASE IN *PILOT WORKLOAD - HAVE TO MAKE ALMOST* CONTINUOUS LATERAL INPUTS.	FLYABLE, BUT JUST BARELY. ALL RIGHT *FOR THE MISSION. I END UP FEEDING* THE LATERAL OSCILLATION WHEN I TRY TO DAMP IT OUT.			

TABLE I-7 SUMMARY OF PILOT
FOR FIXED-BASE CO

CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABLE FEATURES
	GENERAL	AILERON YAW	COORDINATION	FEEL		
A-7	ROLL RATE ORDERING. PARTICULARLY IF I KEEP SIDESLIP ZERO WITH RUDDER. LARGE DUTCH ROLL EXCITATION FOR SHARP INPUTS. BANK ANGLE OSCILLATIONS DAMP OUT WHEN I FLY A TIGHT BANK ANGLE-AILERON LOOP. GOOD RESPONSE FOR GOOD COORDINATION - POOR RESPONSE FOR POOR COORDINATION. ADEQUATE ROLL ACCELERATION. ROLL RATE SLOWS DOWN AS SIDESLIP BUILDS UP. TENDENCY TO OVERCONTROL.	ADVERSE AND LARGE.	ROLL RATE QUITE LOW IF I DON'T COORDINATE. TEND TO COORDINATE TO GET DESIRED ROLL RATE BECAUSE OBSERVED SIDESLIP DISTURBANCES ARE TOO SMALL FOR GOOD COORDINATION. LARGE BANK ANGLE ERRORS RESULT FROM MISCOORDINATION. SENSE OF RUDDER REQUIRED FOR COORDINATION IS EASY TO DETERMINE BUT CORRECT MAGNITUDE DIFFICULT TO ATTAIN.	NOTICEABLE BREAKOUT FORCE CAUSES ME TO FISH FOR ZERO ROLL RATE. AILERON FORCES LIGHT COMPARED TO ELEVATOR FORCES IN STEEP TURNS.	IT'S NOT BAD WHEN YOU MANEUVER SLOWLY. GOOD FOR MAINTAINING BANK ANGLE.	I CAN'T DO RAPID ROLLING MANEUVERS WITH PRECISION BECAUSE LARGE BANK ANGLE DUTCH ROLL OSCILLATIONS ARE EXCITED. I CAN'T CONTROL BANK ANGLE WITH THE DESIRED PRECISION. SLOWING DOWN OF ROLL RATE.
A-8	MODERATE BUT DESIRABLE ROLL RATE RESPONSE TO AILERON. LITTLE OR NO SIDESLIP INDUCED BY SMALL AILERON INPUTS. CAN MAINTAIN DESIRED BANK ANGLE QUITE WELL. LARGE BANK ANGLE RESPONSE WHEN SIDESLIP IS DISTURBED IN RAPID ROLLING MANEUVERS.	VERY NEARLY ZERO.	CAN KEEP SIDESLIP EVEN CLOSER TO ZERO IF YOU APPLY A LITTLE RUDDER A SHORT TIME AFTER YOU APPLY AILERON BUT YOU RUN THE RISK OF MISCOORDINATING AND GETTING A LOT OF ROLLING MOTION. VERY LITTLE NEED FOR RUDDER CONTROL.	BREAKOUT FORCE IS A LITTLE BIT OBJECTIONABLE BECAUSE IT IS DIFFICULT TO PIN DOWN ZERO ROLL RATE. LIGHT FORCE GRADIENT.	ONLY VERY SMALL SIDESLIP IS INDUCED BY ROLL CONTROL.	THE LARGE BANK ANGLE DISTURBANCES THAT RESULT WHEN SIDESLIP IS DISTURBED DURING MANEUVERING. LARGE BANK ANGLE ERRORS THAT RESULT FROM MISCOORDINATION. DIFFICULTY IN LOCATING ZERO ROLL RATE AILERON POSITION.
A-9	TENDENCY TO OSCILLATE IN BANK ANGLE. WHEN TRYING TO MAINTAIN A PRECISE BANK ANGLE - I TEND TO FEED THE OSCILLATION. I COULD DAMP IT OUT BY APPLYING LEAD. AILERON CAUSES ONLY SLIGHT SIDESLIP AND DUTCH ROLL EXCITATION. OSCILLATION DAMPS OUT WHEN I REDUCE MY GAIN. GOOD CONTROL FOR SLOW INPUTS. LESS OSCILLATORY AT STEEP BANK ANGLES. LONG ROLL MODE TIME CONSTANT.	NO SIGNIFICANT YAWING MOMENT IN TERMS OF SIDESLIP INDICATION. I WOULD SAY THAT IT IS PROBABLY PROVERSE BASED ON THE YAW RATE NEEDLE.	TEND NOT TO USE RUDDER FOR COORDINATION. NOT REQUIRED.	SLIGHT BREAKOUT FORCE CAUSES ME TO FISH A LITTLE TO FIND THE POSITION FOR ZERO ROLL RATE. LIGHT FORCE GRADIENT.	LACK OF YAW DUE TO ROLL CONTROL.	THE OSCILLATORY TENDENCY. TOO MUCH ROLL DUE TO SIDESLIP DISTURBANCES. THE TENDENCY TO OSCILLATE WHILE TRYING TO MAINTAIN BANK ANGLE PRECISELY. WOULD LIKE MORE ROLL ACCELERATION.
A-9A	GOOD FOR SLOW INPUTS. MUCH LIGHTER DUTCH ROLL DAMPING CLOSED LOOP. OSCILLATORY. AILERONS TEND TO EXCITE DUTCH ROLL OSCILLATION, ESPECIALLY IN TRYING TO MAINTAIN ZERO BANK ANGLE. LESS OSCILLATORY IN STEEP TURNS. WOULD LIKE HIGHER ROLL RATE FOR GIVEN AILERON INPUT.	SLIGHTLY PROVERSE. LESS PROVERSE IN STEEP TURNS.	CAN USE RUDDERS TO DAMP SIDESLIP OSCILLATIONS IF AILERON CONTROL PRODUCES DIVERGENT OSCILLATION. COORDINATION NOT DESIRED. EASY TO OVERCONTROL WHEN ATTEMPTING TO COORDINATE.	NOTICEABLE BREAKOUT FORCES. STICK CENTERING POSES SMALL PROBLEM IN THAT CONTINUAL JOCKEYING OF AILERON STICK RESULTS FROM TRYING TO MAINTAIN BANK ANGLE.	GOOD FOR SLOW CAREFUL MANEUVERING AILERON INPUTS. GOOD IF SIDESLIP DOES NOT GET DISTURBED.	TENDENCY TO OSCILLATE WHEN CONTROLLING BANK ANGLE. LARGE ROLLING MOMENTS FROM SMALL SIDESLIP DISTURBANCES. WOULD LIKE MORE ROLL POWER.

UMMARY OF PILOT COMMENTS
OR FIXED-BASE CONFIGURATIONS

IURES	OBJECTIONABLE FEATURES	SPECIAL PILOTING TECHNIQUES	CONTROL IN PRESENCE OF DISTURBANCES	OVERALL OPINION	RUDDER CONTROL	LATERAL-DIRECTIONAL FREE RESPONSE	LONGITUDINAL HANDLING
NEUVER SLOWLY. K ANGLE.	I CAN'T DO RAPID ROLLING MANEUVERS WITH PRECISION BECAUSE LARGE BANK ANGLE DUTCH ROLL OSCILLATIONS ARE EXCITED. *I CAN'T CONTROL BANK* ANGLE WITH THE DESIRED PRECISION. SLOWING DOWN OF ROLL RATE.	MAKE SLOW INPUTS AND DON'T ATTEMPT TO MANEUVER RAPIDLY.	PITCH DISTURBANCES ARE AGGRAVATING. SIDESLIP DISTURBANCES CAUSE LARGE BANK ANGLE ERRORS. INCESSANT USE OF AILERON REQUIRED TO CONTROL BANK ANGLE.	I DON'T HAVE THE PRECISION OF BANK ANGLE CONTROL THAT IS DESIRABLE AND NECESSARY.	ROLL DUE TO RUDDER AND ROLL DUE TO SIDESLIP ARE LARGE AND INSEPARABLE. JUST A *LITTLE BIT OF RUDDER CAUSES* LARGE ROLLING MOTIONS. RESOLUTION IS NOT GOOD ENOUGH FOR SMALL BANK ANGLE CORRECTIONS. FEEL IS A LITTLE ON THE HEAVY SIDE BUT GIVES GOOD INDICATION OF YOUR INPUT WHICH IS REQUIRED. TEND TO OVERCONTROL WITH RUDDERS IN MINIMIZING SIDESLIP. RUDDER PEDAL RESOLUTION IS A LITTLE BIT OBJECTIONABLE IN THAT IT AFFECTS THE APPARENT *ROLL TRIM*.	MODERATE STIFFNESS. VERY LARGE ROLL DUE TO SIDESLIP. LIGHTLY DAMPED DUTCH ROLL. *ROLL DAMPING APPEARS ADE*QUATE. WOULD LIKE A SHORTER ROLL MODE TIME CONSTANT.	GOOD RESPONSE, GOOD FEEL. WELL DAMPED SHORT PERIOD. PITCHING MOMENTS ONLY FOR *ELEVATOR INPUTS. NO INTER*ACTION WITH LATERAL-DIRECTIONAL MODES. FIGHTER-LIKE STICK FORCES. EASY TO HOLD ALTITUDE AND AIRSPEED IN LEVEL FLIGHT. EASY TO HOLD G AND AIRSPEED IN TURNING FLIGHT.
IS INDUCED	THE LARGE BANK ANGLE DISTURBANCES THAT RESULT WHEN SIDESLIP IS DISTURBED DURING MANEUVERING. LARGE *BANK ANGLE ERRORS THAT RESULT FROM* MISCOORDINATION. DIFFICULTY IN LOCATING ZERO ROLL RATE AILERON POSITION.	ESSENTIALLY AILERONS ONLY. SOME RUDDER COORDINATION HELPFUL FOR LARGE ROLLING MANEUVERS.	LARGE BANK ANGLE RESPONSE FROM SIDESLIP DISTURBANCES WHICH ARE DEMANDING OF PILOT'S ATTENTION. ROLL CONTROL *MUCH MORE DIFFICULT. RUDDER PEDALS* CAN BE USED TO MINIMIZE LARGE SIDESLIP DISTURBANCES.	A REASONABLY GOOD AIRPLANE.			
CONTROL.	THE OSCILLATORY TENDENCY. TOO MUCH ROLL DUE TO SIDESLIP DISTURBANCES. THE TENDENCY TO OSCILLATE WHILE TRYING TO MAINTAIN BANK ANGLE PRECISELY. WOULD LIKE MORE ROLL ACCELERATION.	AILERON ONLY. TRY TO DECREASE MY GAIN WHENEVER I GOT INTO THIS OSCILLATION.	MAINTAINING BANK ANGLE QUITE DIFFICULT IN PRESENCE OF NOISE. BANK ANGLE QUITE OSCILLATORY.	ACCEPTABLE FOR THE MISSION.			
NEUVERING F SIDESLIP	TENDENCY TO OSCILLATE WHEN CONTROLLING BANK ANGLE. LARGE ROLLING MOMENTS FROM SMALL SIDESLIP DISTURBANCES. WOULD LIKE MORE ROLL POWER.	DEVELOP LEAD IN USING AILERONS. USE AILERON PULSES TO DAMP DISTURBANCES.	TENDED TO DEVELOP A DIVERGENT OSCILLATION WHEN I WAS CONTROLLING BANK ANGLE DISTURBANCES WITH AILERON. VERY RESPONSIVE TO RANDOM NOISE.	PRETTY GOOD CONFIGURATION FOR SMALL SLOW AILERON INPUTS BUT AGGRAVATING. PILOT SUSTAINED OSCILLATION WHEN SIDESLIP IS DISTURBED.			



CONFIG	NOMINAL PARAMETERS			
	ω_d	ζ_d	$\left\lvert\frac{\phi}{\beta}\right\rvert$	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{\text{deg/sec}}{\text{inch}}$
"A" FLT	2.20	0.002	0.64	15.9 - 19.2
"AA" FLT	2.20	0.000	0.80	13.0 - 14.7
"A" GRD	2.30	0.002	0.66	15.3 - 17.0
REF I	2.30	0.12	0.65	20.6

CONFIG	NOMINAL PARAMETERS			
	ω_d	ζ_d	$\left\lvert\frac{\phi}{\beta}\right\rvert$	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{\text{deg/sec}}{\text{inch}}$
"A" FLT	2.35	0.18	9.6	7.68 - 11.65
"AA" FLT	2.10	0.18	9.7	10.23 - 12.35
"A" GRD	2.11	0.18	9.7	10.26 - 15.75
REF I	2.30	0.12	9.2	20.6

CONFIG	NOMINAL PARAMETERS			
	ω_d	ζ_d	$\left\lvert\frac{\phi}{\beta}\right\rvert$	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{\text{deg/sec}}{\text{inch}}$
"A" FLT	2.61	0.13	12.0	8.58 - 12.02
"AA" FLT	2.41	0.12	14.7	25.0
"A" GRD	2.24	0.14	12.8	24.8 - 29.3

Figure I-1 Composite Pilot Ratings

SUMMARY OF PILOT COMMENTS FOR INFLIGHT CONFIGURATIONS

ES	OBJECTIONABLE FEATURES	SPECIAL PILOTING TECHNIQUES	CONTROL IN PRESENCE OF DISTURBANCES	OVERALL OPINION	RUDDER CONTROL	LATERAL-DIRECTIONAL FREE RESPONSE	LONGITUDINAL HANDLING
RUDDERS.	COORDINATION REQUIREMENTS. SIDESLIP THAT RESULTS FROM MISCOORDINATION WITH LIGHT DUTCH ROLL DAMPING. DIFFICULT TO COORDINATE PERFECTLY.	APPLY RUDDER WITH AILERON. JUDICIOUS USE OF RUDDER.	DOESN'T RESPOND MUCH TO DISTURBANCES.	ACCEPTABLE BUT UNSATISFACTORY.	FEEL IS LIGHT AND SENSITIVE. FEEL IS ADEQUATE BUT A LITTLE ON THE LIGHT SIDE, SOME TENDENCY TO OVERCONTROL FEEL GOOD, GRADIENT GOOD. ABLE TO DAMP THE DUTCH ROLL WHEN IT APPEARED. ROLL DUE TO RUDDER & ROLL DUE TO SIDESLIP SMALL AND INSEPARABLE. BREAKOUT FORCES LOW, FRICTION BAND MEDIUM TO LOW, PEDAL CENTERING GOOD.	LOW ROLL TO SIDESLIP RATIO. LIGHTLY DAMPED DUTCH ROLL. WHEN DISTURBED IN SIDESLIP, JUST OSCILLATES BACK AND FORTH WITH VERY LITTLE INDUCED ROLLING. DID NOT LIKE DIRECTIONAL OSCILLATIONS WHEN EXCITED. ROLL DUE TO SIDESLIP ALMOST ZERO.	GOOD FEEL, GOOD RESPONSE AND GOOD PITCH CONTROL. FORCES A LITTLE HEAVY BUT OK FOR MISSION. FORCE GRADIENT MEDIUM, APPROXIMATELY 7 LB PER G. BREAKOUT FORCES LOW, VERY SMALL FRICTION BAND, GOOD STICK CENTERING.
N'T SEEM G. COULD	TENDENCY TO OSCILLATE DIRECTIONALLY WHEN DISTURBED REQUIRING RUDDER PEDALS FOR DAMPING. LIGHTLY DAMPED DUTCH ROLL. AILERON BREAKOUT FORCES. CAN DAMP D.R. ONLY WITH RUDDERS.	AILERON ONLY. DON'T COORDINATE WITH RUDDER - YOU DON'T NEED TO.	DOES NOT CAUSE ME TO DOWNRATE IT.	PRETTY GOOD CONFIGURATION. ACCEPTABLE AND SATISFACTORY.			
D SLOW	NO SERIOUS ONES. LIGHT DUTCH ROLL DAMPING AND TENDENCY TO EXCITE SOME SIDESLIP IN RAPID ROLLING MANEUVERS.	AILERON ONLY FOR ROLL CONTROL AND USE RUDDERS TO DAMP THE DUTCH ROLL WHEN EXCITED.	DOESN'T RESPOND MUCH TO TURBULENCE.	ACCEPTABLE SATISFACTORY GOOD.			
NO PROB- GOOD IN	AILERON CONTROL DOES EXCITE LIGHTLY DAMPED DUTCH ROLL.	AILERON ONLY. ATTEMPTS AT CROSS COORDINATION WERE SOMETIMES SUCCESSFUL. SOMETIMES UNSUCCESSFUL.	NOT RESPONSIVE TO DISTURBANCES. RESPONSE TO DISTURBANCES STAY BOUNDED.	ACCEPTABLE, SATISFACTORY, FAIR TO GOOD			
	NECESSITY FOR RUDDER COORDINATION. CANNOT COORDINATE WELL AND EFFECTS OF NOT COORDINATING SIGNIFICANT BECAUSE OF LARGE EFFECT ON BANK ANGLE CONTROL.	SMOOTH AILERON CONTROL.	DISTURBANCES IN BANK ANGLE LARGE IN MAGNITUDE AND IT FELT LIKE THE SIDESLIP WAS GOING REAL FAR OUT WHEN I CORRECTED WITH AILERON AND DIDN'T GET THE RUDDER PEDALS JUST RIGHT. ALARMING.	IT'S JUST NOT A VERY GOOD CONFIGURATION. ACCEPTABLE BUT DEFINITELY UNSATISFACTORY. WHEN YOU DO SOMETHING WRONG, IT RESPONDS RAPIDLY.	RUDDER PEDALS TOO SENSITIVE. RATHER POOR RUDDER CONTROL BUT CAN DO NICE JOB BY REALLY COORDINATING. TOO SENSITIVE IN TERMS OF SIDESLIP THEY PRODUCE. YOU DON'T HAVE MUCH FEEDBACK OF THE RUDDER INPUTS YOU ARE PUTTING IN. RUDDER PEDAL FORCE GRADIENT QUITE STIFF BUT THEY'RE PRETTY LIGHT IN TERMS OF ABILITY TO PRODUCE SIDESLIP CHANGES. THE RUDDER PEDAL REQUIRED TO MAKE THE ROLL RATE WHAT YOU EXPECT TO GET FROM THE AILERONS IS VERY TOUCHY. LOT OF ROLL RATE FOR A LITTLE BIT OF RUDDER PEDAL. ROLL DUE TO RUDDER AND SIDESLIP TOGETHER WAS LARGE.	LARGE ROLL TO SIDESLIP WITH LIGHT DAMPING OF DUTCH ROLL. ROLL DUE TO RUDDER AND ROLL DUE TO SIDESLIP VERY LARGE. DUTCH ROLL MODERATE TO LIGHTLY DAMPED. DAMPING OF DUTCH ROLL NOT TOO BAD. FAIRLY STIFF DIRECTIONALLY.	PITCH CONTROL BASICALLY GOOD. A LITTLE BIT ON THE HEAVY SIDE. OK FOR THE MISSION.
A PRETTY	USE OF AILERONS REQUIRES COORDINATION TO GET A GOOD PREDICTABLE ROLL RESPONSE. RAPID MANEUVERS BECOME OBJECTIONABLE. SENSITIVITY TO MISCOORDINATION. RUDDER PEDALS TOO LIGHT FOR COORDINATION REQUIREMENTS.	EITHER USING A LITTLE COORDINATION OR NOT COORDINATING AT ALL. COORDINATION IN RAPID ROLLING MANEUVERS.	QUITE SUSCEPTIBLE TO RANDOM DISTURBANCES.	SATISFACTORY FOR SLOW MANEUVERING, UNSATISFACTORY FOR RAPID MANEUVERING.			
ADEQUATE	RESPONSE TO AILERON JUST A LITTLE BIT UNPREDICTABLE.	NONE.	VERY RESPONSIVE TO RANDOM NOISE. REQUIRES LARGE AILERON INPUTS TO COUNTER.	DOES NOT EXHIBIT WHAT YOU'D REALLY TERM GOOD FLYING QUALITIES BUT OK FOR MISSION. ACCEPTABLE AND SATISFACTORY.			
AY DURING IFF FEELING	TENDENCY TO OSCILLATE THE AIRPLANE UNDER CERTAIN CONDITIONS IN BANK ANGLE.	I DID NOT COORDINATE AT ALL. USED AILERON TO CONTROL BANK ANGLE OSCILLATIONS.	ROLLED SHARPLY ONE WAY OR THE OTHER IN TURBULENCE BUT NOT UNBOUNDED. VERY RESPONSIVE TO RANDOM NOISE.	BORDERLINE BETWEEN SATISFACTORY AND UNSATISFACTORY. OBJECTIONABLY OSCILLATORY IN LEVEL FLIGHT AND SHALLOW BANKS.			
	TREMENDOUS DECREASE IN APPARENT DIRECTIONAL STIFFNESS WHEN GOING CLOSED LOOP. ABRUPT INITIAL RESPONSE. DIFFICULTY IN COORDINATING. VERY HIGH DIHEDRAL EFFECT.	LOTS OF COORDINATION AND SMOOTHNESS.	VERY RESPONSIVE TO RANDOM NOISE.	PILOT A - UNACCEPTABLE FOR MISSION. PILOT C - HOWEVER, AS A RE-ENTRY VEHICLE INITIAL FAR OUT APPROACH, IT WOULD BE ACCEPTABLE.	FEEL IS NOT TOO BAD. IT'S A LITTLE ON THE SENSITIVE SIDE. DIFFICULT TO PHASE THE RUDDER WITH SIDESLIP. ROLL DUE TO SIDESLIP AND RUDDER EXTREMELY LARGE. FRICTION BAND LOW, PEDAL CENTERING GOOD.	LARGE ROLL DUE TO SIDESLIP. MODERATE TO LIGHT DUTCH ROLL DAMPING. PRETTY STIFF DUTCH ROLL OPEN LOOP. VERY HIGH L_β EFFECT MAKES IT VERY UNDESIRABLE LATERAL-DIRECTIONALLY.	ELEVATOR FEEL OK. PITCH CONTROL OK. NO PARTICULAR OBJECTIONABLE CHARACTERISTICS. GOOD LONGITUDINAL CONTROL AIDS IN BEING ABLE TO ACCOMPLISH A RE-ENTRY MISSION.

TABLE I-9 SUMMARY
FOR INFLI

CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABL
	GENERAL	AILERON YAW	COORDINATION	FEEL		
AA-1	SIDESLIP INDUCED BY AILERON DISTURBS CONTROL OF AIRPLANE. RESPONSE IS OBJECTIONABLE WITHOUT COORDINATION. MAINTAINING BANK ANGLE OK BUT CHANGING BANK ANGLE OBJECTIONABLE.	ADVERSE. FAIRLY LARGE.	DIFFICULT. SIDESLIP BECOMES SIZABLE IF YOU DON'T COORDINATE. BANK ANGLE DOES NOT PROVIDE INFORMATION TO AID COORDINATION.	LITTLE INSENSITIVE BUT DESIRABLE FOR MISSION. BREAKOUT FORCES SLIGHTLY BOTHERSOME.	CAN MINIMIZE SIDESLIP WITH RUDDERS.	COORDINATION REQUI THAT RESULTS FROM WITH LIGHT DUTCH RO DIFFICULT TO COOR
AA-2	AILERON ONLY AIRPLANE. ONLY SMALL D.R. OSCILLATIONS EXCITED IN SIDESLIP WITH AILERONS. COULD CHANGE AND MAINTAIN BANK ANGLE WELL. RESPONSE TO AILERON GOOD. PRETTY MUCH ZERO SIDESLIP DUE TO ROLL CONTROL.	ESSENTIALLY ZERO	VERY LITTLE COORDINATION REQUIRED AND COULD NOT BE IMPROVED BY USING RUDDER. SOME SIDESLIP INDUCED BY RAPID ROLLING MANEUVERS BUT NOT ENOUGH THAT I WOULD TRY TO COORDINATE.	AILERON FRICTION NOTICEABLE AND OBJECTIONABLE.	DIRECTIONAL OSCILLATIONS DIDN'T SEEM TO BOTHER BANK ANGLE TRACKING. COULD MANEUVER WELL.	TENDENCY TO OSCILL WHEN DISTURBED REQU PEDALS FOR DAMPING. DUTCH ROLL. AILERON CAN DAMP D.R. ONLY
AA-2A	GOOD CONTROL OF BANK ANGLE. GOOD RESPONSE TO AILERON. SMALL SIDESLIP INDUCED BY AILERON.	PROVERSE AND OF SMALL MAGNITUDE.	NOT NECESSARY TO CROSS COORDINATE.	JUST ABOUT RIGHT - WELL ADAPTED TO MISSION. DID NOTICE AILERON BREAKOUT FORCES - SLIGHTLY OBJECTIONABLE. STICK CENTERING NOT QUITE GOOD.	QUITE GOOD IN STEEP TURNS AND SLOW MANEUVERING.	NO SERIOUS ONES. DAMPING AND TENDENC SIDESLIP IN RAPID
AA-3	ROLL CONTROL EXCITES DUTCH ROLL BUT IMPORTANT ONLY WHEN MANEUVERING RAPIDLY. DOESN'T BOTHER ROLL CONTROL BUT EXCITES SIDESLIP. OVERSHOOTS DURING FAST CHANGE OF HEADING.	PROVERSE. MODERATE IN MAGNITUDE. SOMEWHAT OBJECTIONABLE.	CAN MINIMIZE SIDESLIP BY CROSS COORDINATING BUT AFTER DOING RIGHT 3 OR 4 TIMES, I THEN PUT IN WRONG RUDDER INPUT.	GOOD FOR MISSION.	BASICALLY EASY TO CONTROL. NO PROBLEMS FOR SLOW MANEUVERING. GOOD IN STEEP TURNS.	AILERON CONTROL DOES DAMPED DUTCH ROLL.
AA-4	INITIAL ROLL RESPONSE ABRUPT AND TOO LARGE. FINE FOR MAINTAINING LARGE BANK ANGLES BUT ABRUPT AND JERKY WHEN CHANGING BANK ANGLES. OBJECTIONABLE FOR RAPID MANEUVERING. VERY SUSCEPTIBLE TO SIDESLIP DISTURBANCES.	CONSIDERABLE ADVERSE YAW.	NEED TO COORDINATE WITH ROLL CONTROL. EITHER UNDERCONTROL OR OVERCONTROL WITH RUDDERS. LARGE ROLL RESPONSE TO SIDESLIP WHEN NOT COORDINATED. SUBSTANTIAL ROLL ACCELERATIONS IF YOU DON'T COORDINATE WELL.	ABRUPT AND SENSITIVE.		NECESSITY FOR CANNOT COORDINATE OF NOT COORDINATING CAUSE OF LARGE EFFE CONTROL.
AA-5	THE DUTCH ROLL IS EXCITED AND THIS ALTERS THE WAY THE ROLL GOES AS A FUNCTION OF AILERON INPUTS. YOU CAN MANEUVER SLOWLY QUITE WELL. LARGE INPUTS AND RAPID INPUTS GET YOU IN TROUBLE.	SOME ADVERSE AND MODERATELY LARGE IN ITS EFFECT ON ROLL RESPONSE.	REQUIRED TO MAKE ROLLING PERFORMANCE WHAT YOU WANT AND TO KEEP SIDESLIP ZERO. IF YOU DON'T COORDINATE OR COORDINATE IMPERFECTLY, THE SIDESLIP THAT IS INDUCED CREATES SOME LARGE ROLLING MOMENT WHICH INTERFERES WITH WHAT YOU EXPECT THE AILERONS TO BE PRODUCING. MISCOORDINATION IS APPARENT IN BOTH SIDE ACCELERATION AND IN ROLL CONTROL.	AILERON FEEL IS HEAVY IF YOU DON'T COORDINATE AND ALMOST TOO LIGHT IF YOU DO COORDINATE.	FOR SLOW MANEUVERING, IT'S A PRETTY GOOD CONFIGURATION.	USE OF AILERONS REQU TO GET A GOOD PRED SPONSE. RAPID MANE JECTIONABLE. SENS ORDINATION. RUDDER FOR COORDINATION RE
AA-5A	A LITTLE SQUIRMY IN BANK ANGLE CONTROL. A LITTLE UNPREDICTABLE. IN RAPID ROLLING IT SLOWS DOWN, THEN SPEEDS UP. DIDN'T ALWAYS GO EXACTLY THE WAY I EXPECTED. SPENDING MORE TIME AND ATTENTION THAN NORMAL ON BANK ANGLE CONTROL.	QUITE SMALL AND PROVERSE IN DIRECTION.	INDUCES PROVERSE SIDESLIP WHEN USING RUDDERS FOR COORDINATION. YOU DON'T COORDINATE WITH THE RUDDER PEDALS NORMALLY BECAUSE SIDESLIP APPEARS TO BE ZERO. GOT MUCH HIGHER ROLL RATES IF I APPLIED RUDDERS. MADE ERRORS IN COORDINATION.	BASICALLY PRETTY GOOD.	STAYS UNDER CONTROL AND IS ADEQUATE FOR THE MISSION.	RESPONSE TO AILERON UNPREDICTABLE.
AA-6	A VERY ROLLY TYPE OF CONFIGURATION. IF YOU MANEUVERED SLOWLY IN SMOOTH AIR, YOU DIDN'T EXCITE SIDESLIP AND DUTCH ROLL AND YOU COULD MANEUVER QUITE WELL. OSCILLATED IN BANK ANGLE WHEN I TRIED TO KEEP IT LEVEL. EXCITED D.R. WHEN REVERSING AILERON INPUTS.	PROVERSE - MODERATE.	CAN'T COORDINATE WELL ENOUGH TO WANT TO ACCEPT THE RATHER STRONG ROLLING ERRORS DUE TO MY COORDINATION ATTEMPTS.	BASICALLY PRETTY GOOD.	LATERAL OSCILLATION GOES AWAY DURING STEEP BANK ANGLE TURNS. STIFF FEELING DIRECTIONALLY.	TENDENCY TO OSCILLA UNDER CERTAIN CONDIT ANGLE.
AA-7	VERY ABRUPT ROLL RESPONSE. TEND TO OSCILLATE IN HEAD SHAKING FASHION. CONSIDERABLY IMPROVED BY COORDINATION. IT'S VERY DIFFICULT TO MAINTAIN A PRECISE BANK ANGLE EVEN THOUGH ROLLING INTO SMALL ANGLES.	LARGE AMOUNT OF ADVERSE.	YOU NEED TO COORDINATE. VERY DIFFICULT TO PHASE IT PROPERLY AND COORDINATE WELL. RUDDER MORE POWERFUL THAN AILERON IN ROLL.	AILERON FRICTION BOTHERED ME AND PROBABLY MADE ME MORE ABRUPT. BREAKOUT FORCES LOW, FRICTION BAND LOW, STICK CENTERING GOOD, FORCE GRADIENT VERY LOW, SENSITIVITY MUCH TOO HIGH		TREMENDOUS DECREASE RECTIONAL STIFFNESS LOOP. ABRUPT INITIA DIFFICULTY IN COORD HIGH DIHEDRAL EFFECT

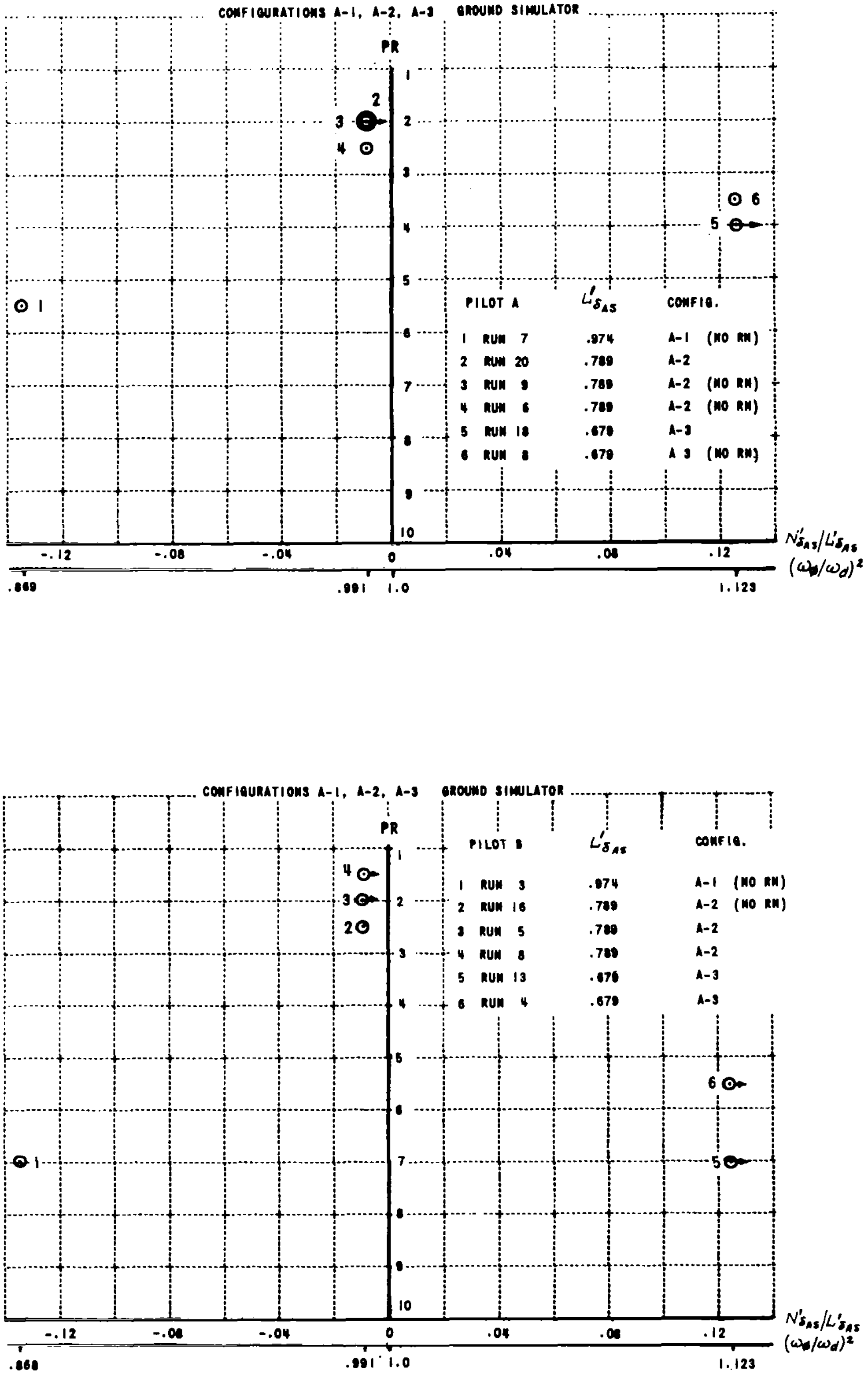


Figure I-2 Fixed-Base Pilot Ratings

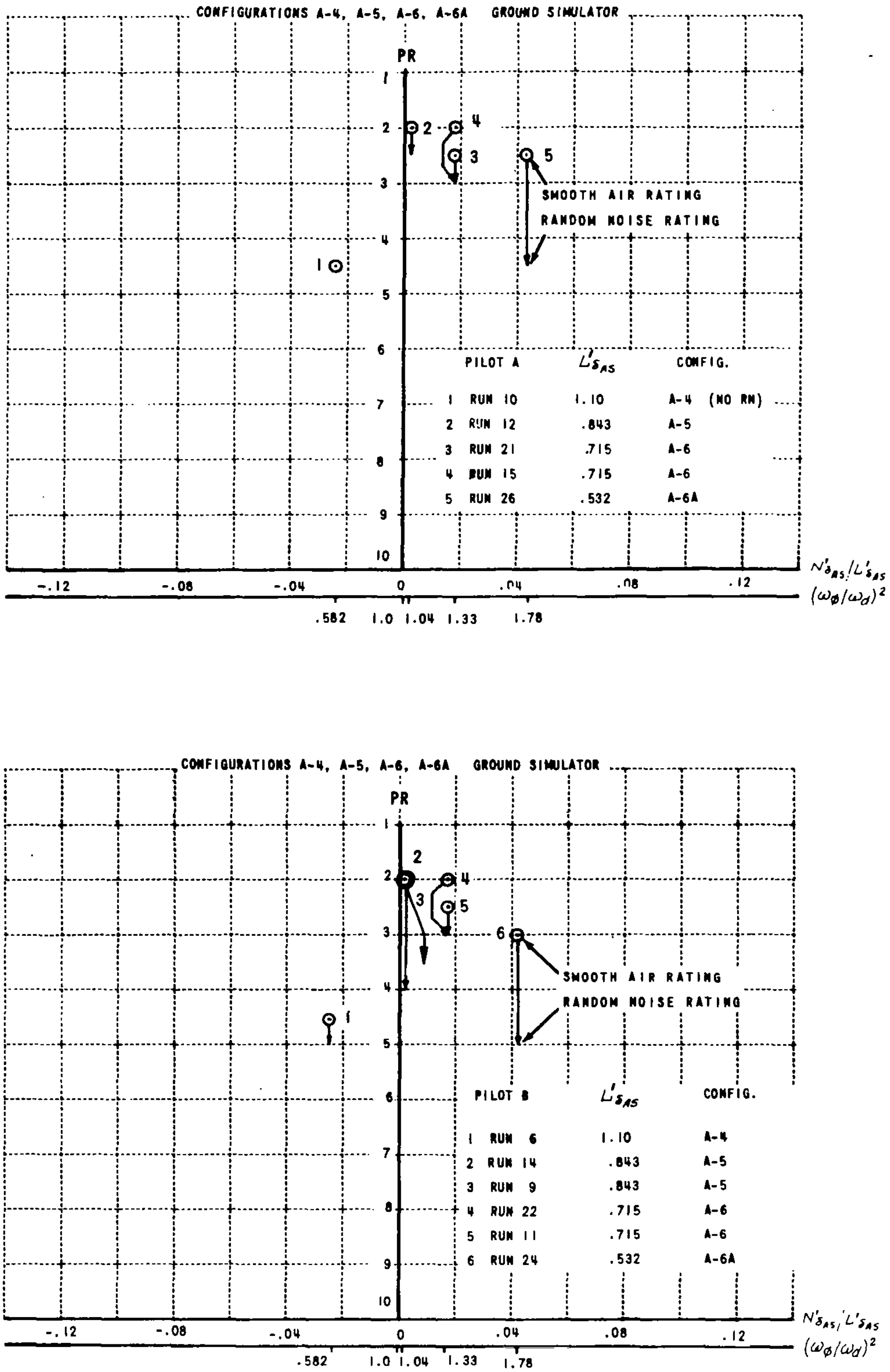


Figure I-3 Fixed-Base Pilot Ratings

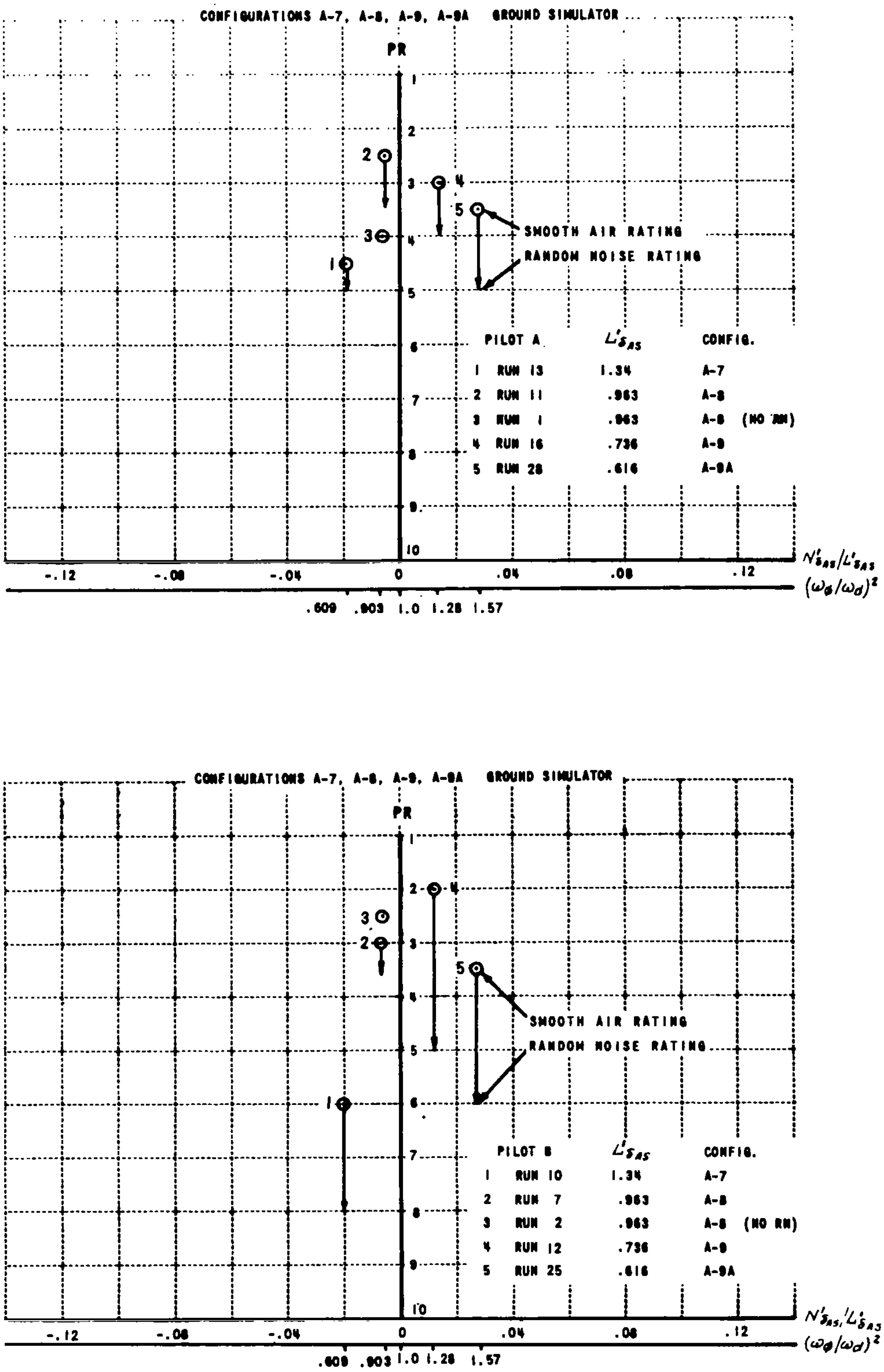


Figure I-4 Fixed-Base Pilot Ratings

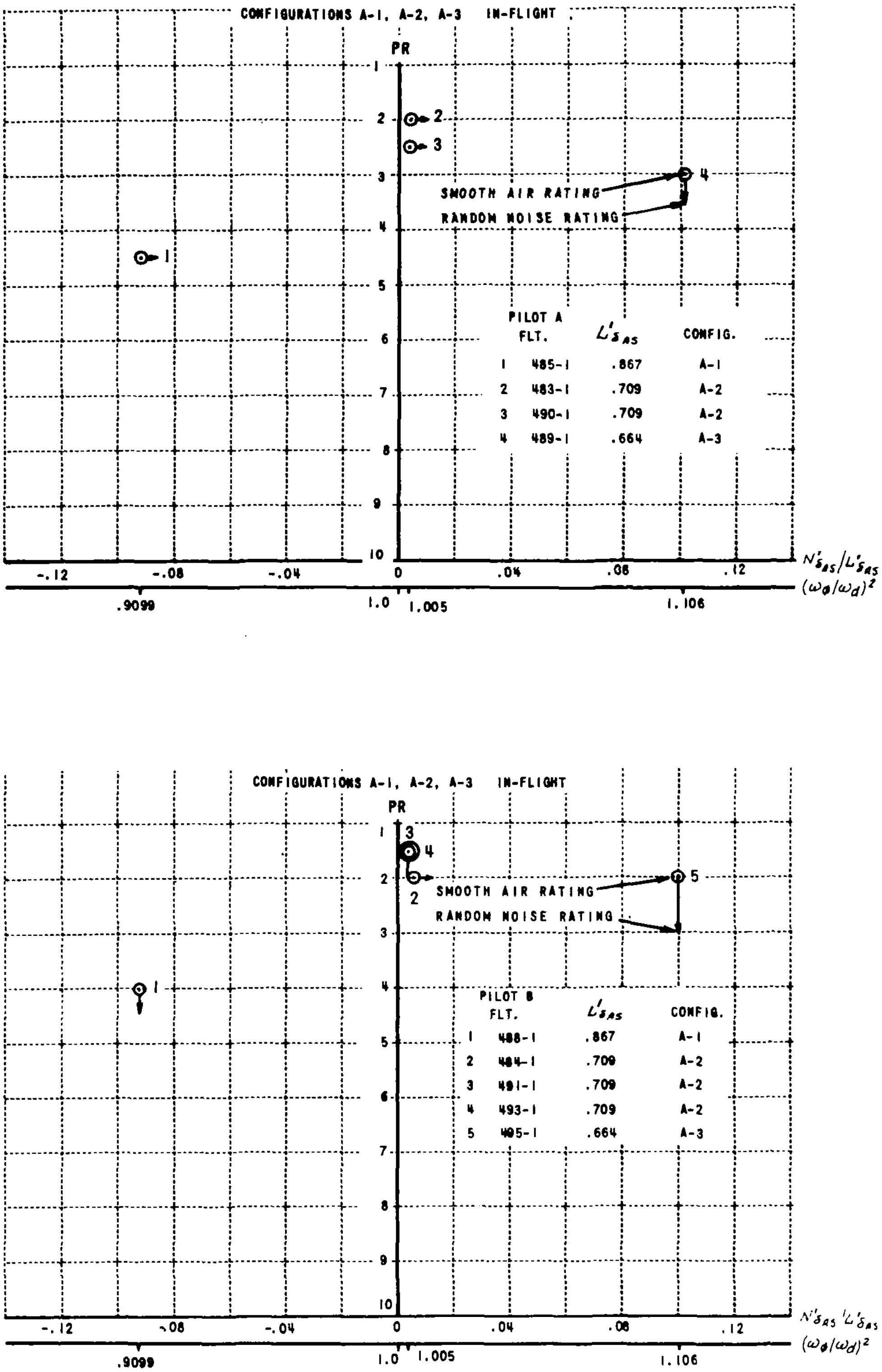


Figure I-5 In-Flight Pilot Ratings

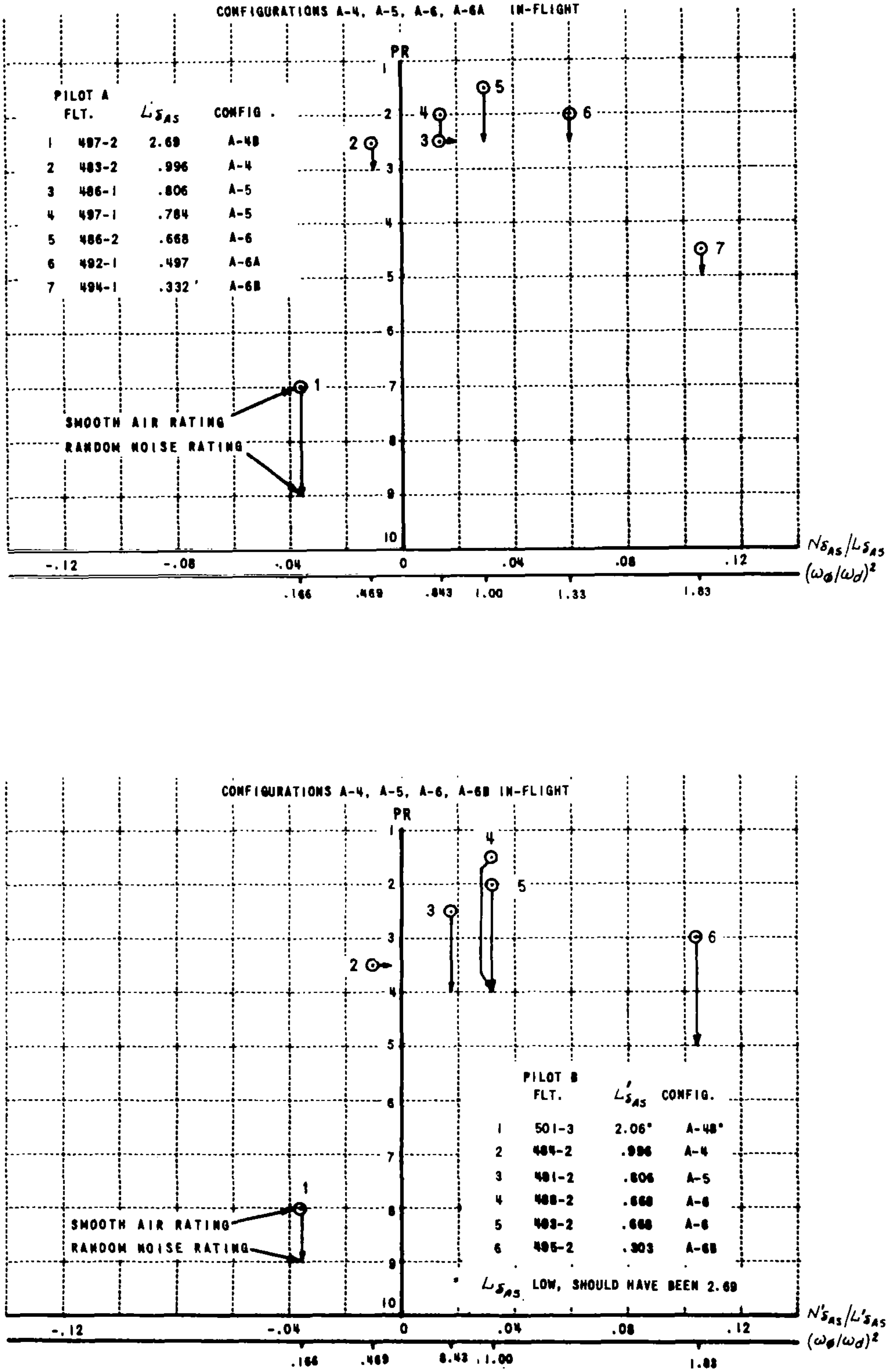


Figure I-6 In-Flight Pilot Ratings

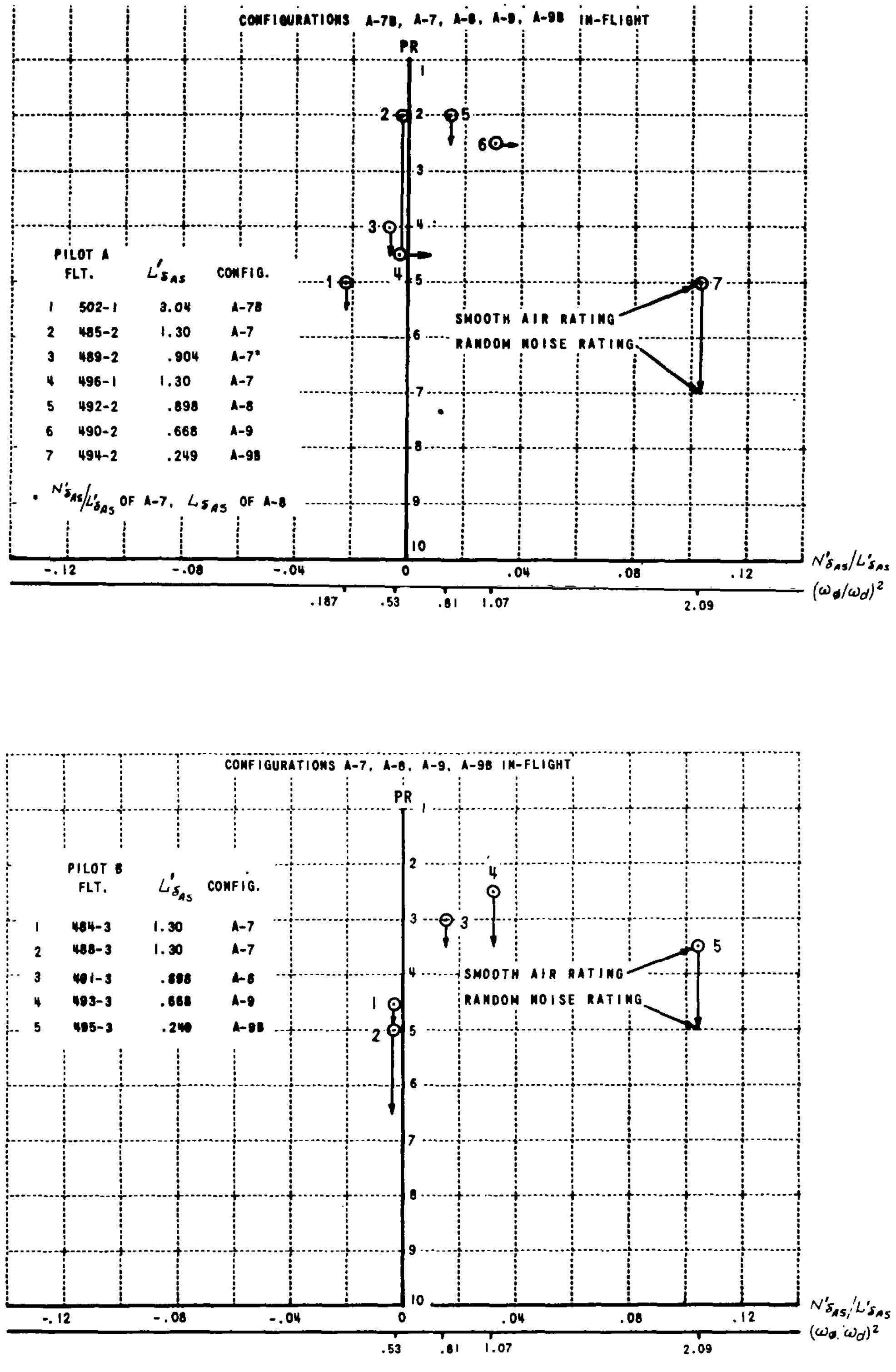


Figure I-7 In-Flight Pilot Ratings

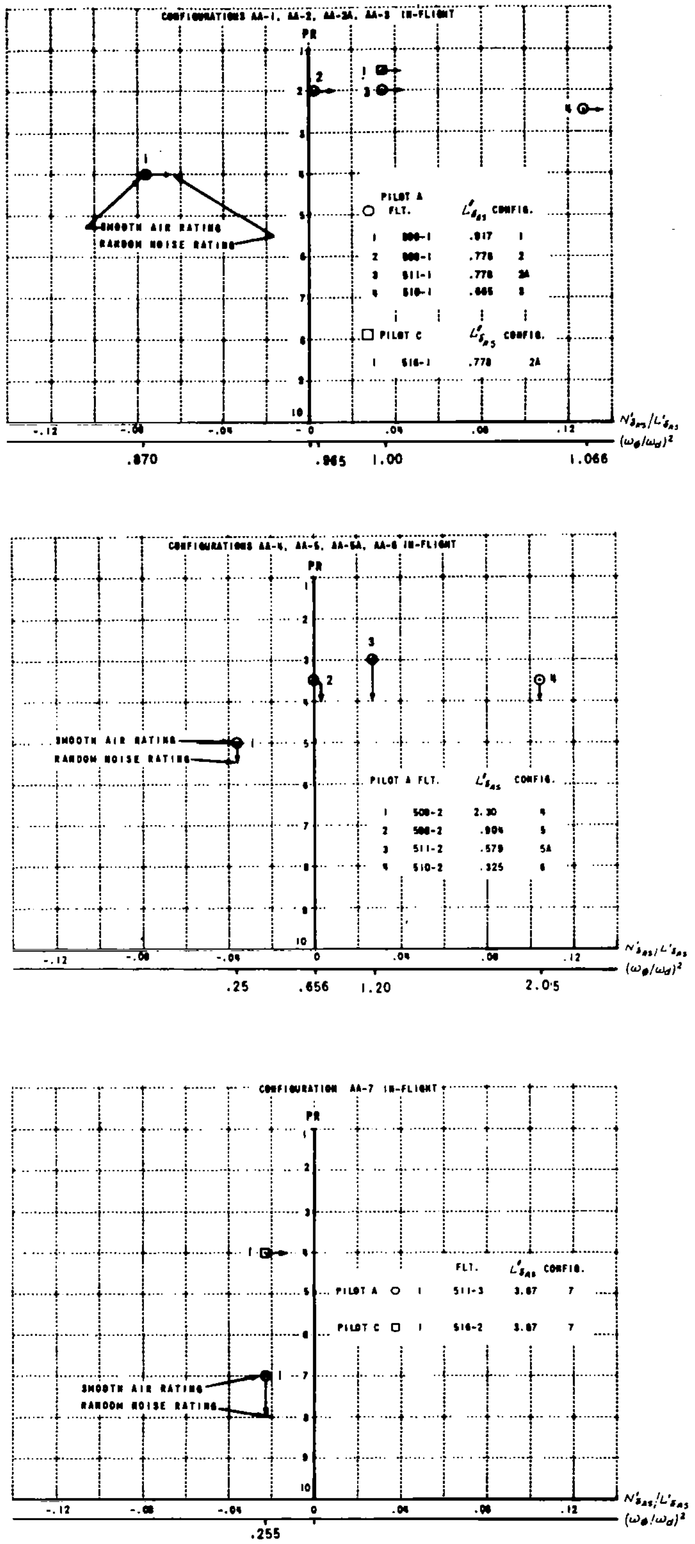


Figure I-8 In-Flight Pilot Ratings

ϕ and β ~ degrees

p and r ~ deg/sec

δ_{AS} Step = .5 inch

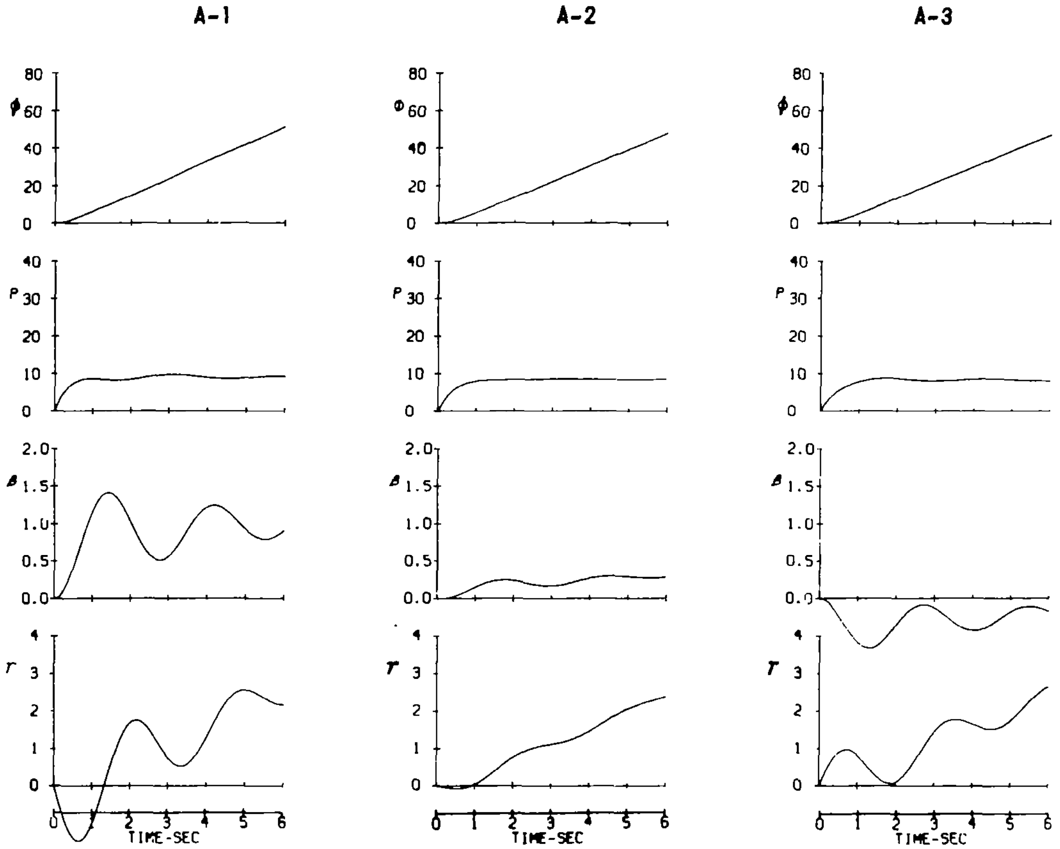
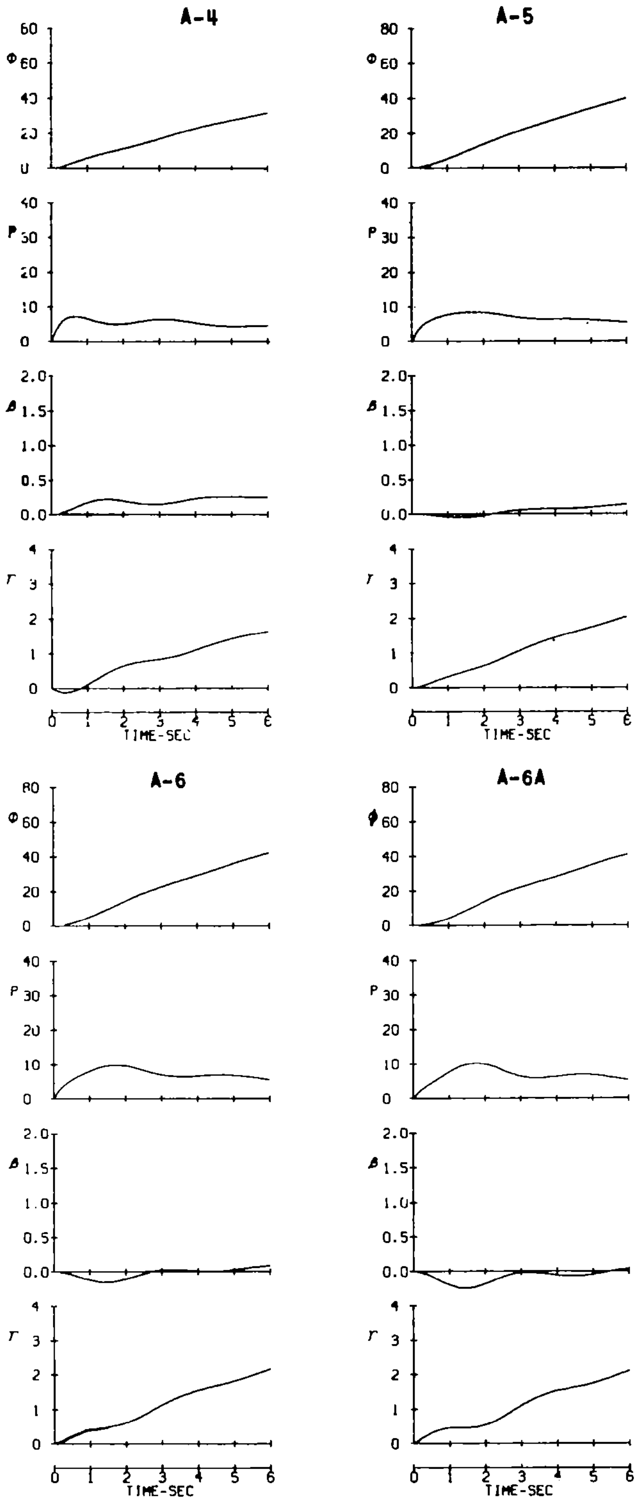
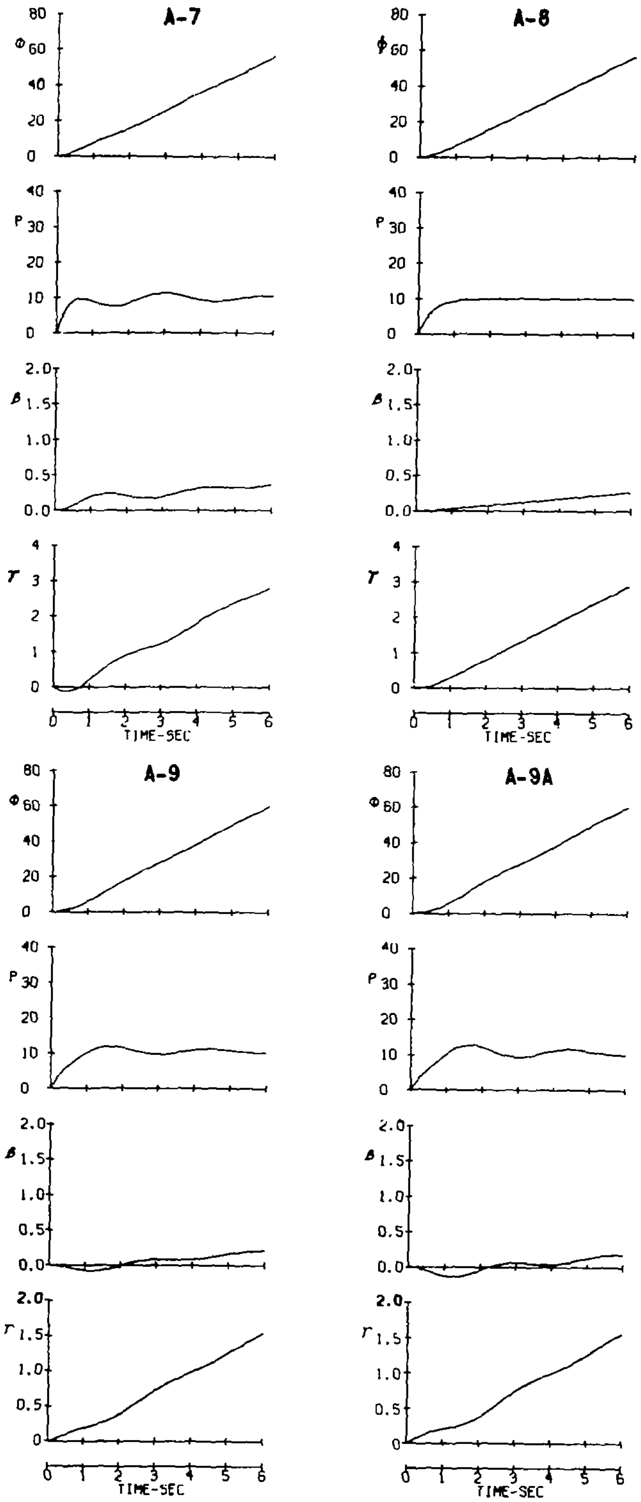


Figure I- 9 Transient Responses To Aileron Stick Step Calculated For Fixed-Base Configurations From Pseudoderivatives



ϕ and $\beta \sim$ degrees
p and $r \sim$ deg/sec
δ_{AS} Step = .5 inch

Figure I-10 Transient Responses To Aileron Stick Step Calculated For Fixed-Base Configurations From Pseudoderivatives



ϕ and β ~ degrees
p and r ~ deg/sec
δ_{AS} Step = .5 inch

Figure I-11 Transient Responses To Aileron Stick Step Calculated For Fixed-Base Configurations From Pseudoderivatives

ϕ and β ~ degrees
p and r ~ deg/sec
δ_{AS} Step = .5 inch

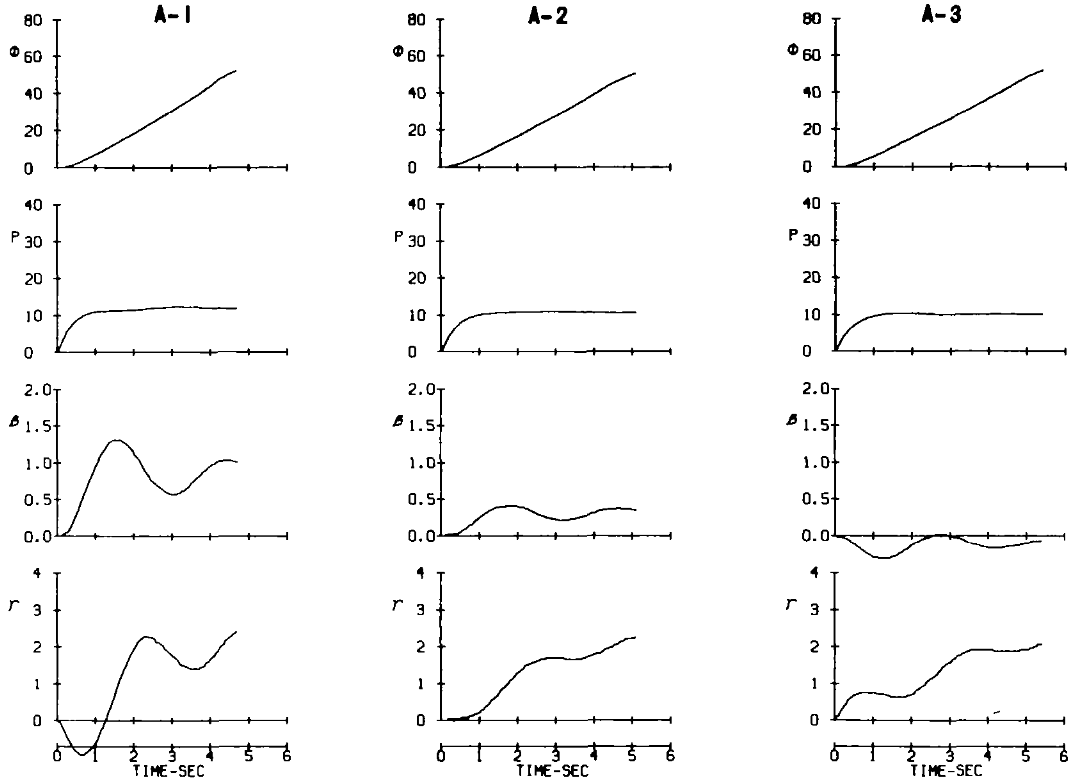
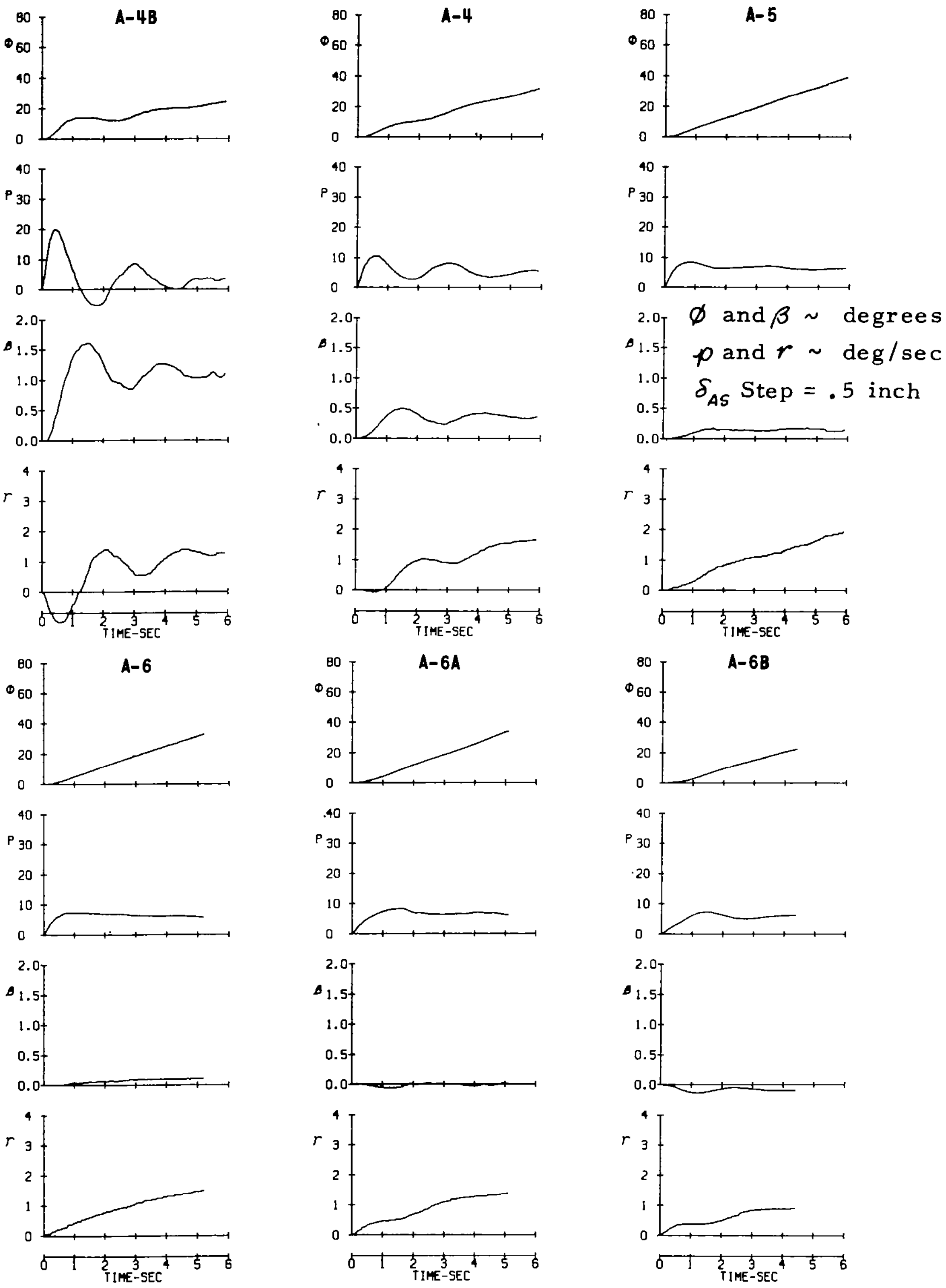


Figure I-12 Transient Responses to Aileron Stick Step From Flight Records Normalized to .5-inch δ_{AS} Step

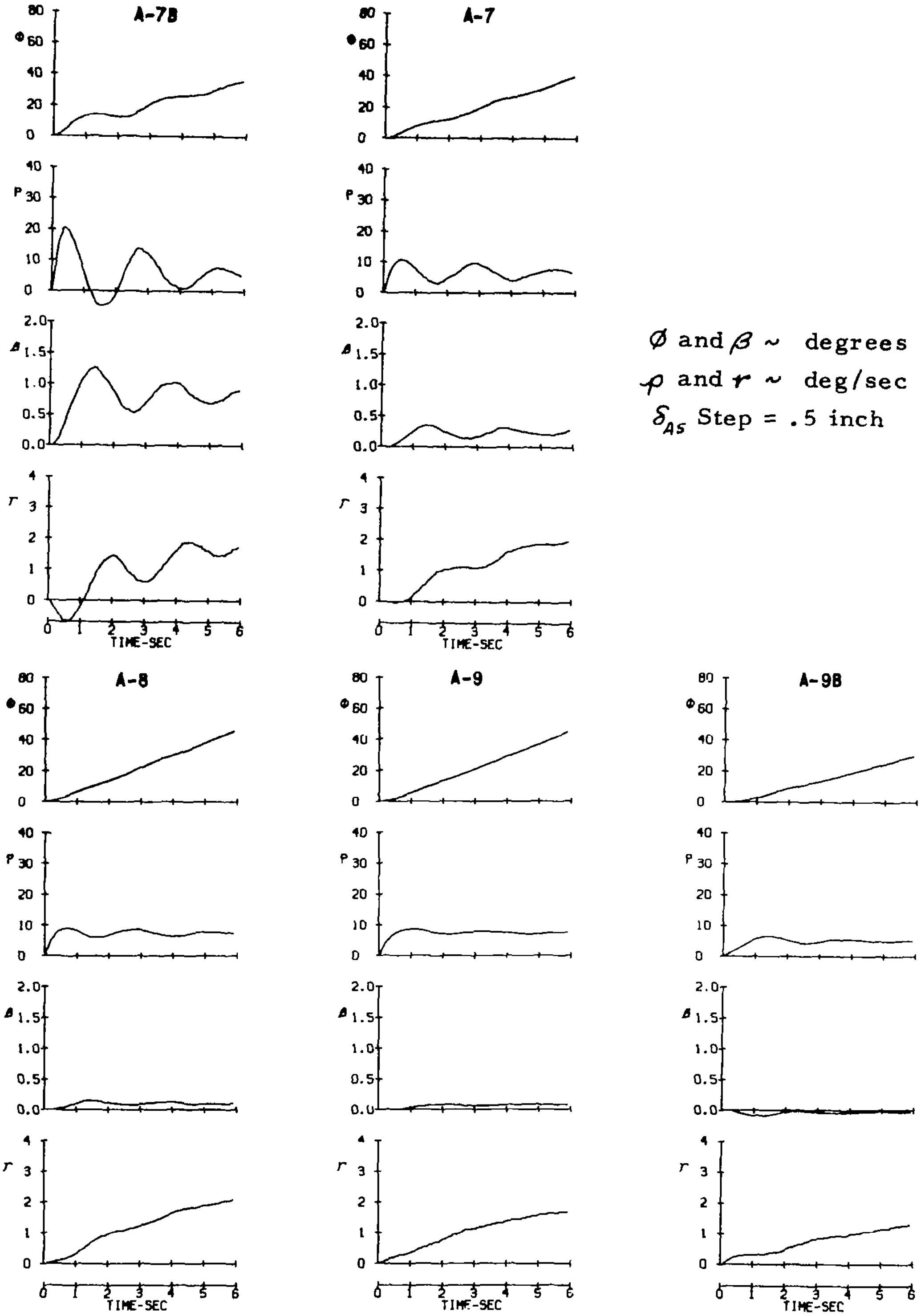


A-4B A-4 A-5

A-6 A-6A A-6B

ϕ and β ~ degrees
p and r ~ deg/sec
δ_{AS} Step = .5 inch

Figure I-13 Transient Responses to Aileron Stick Step From Flight Records Normalized to .5-Inch δ_{AS} Step

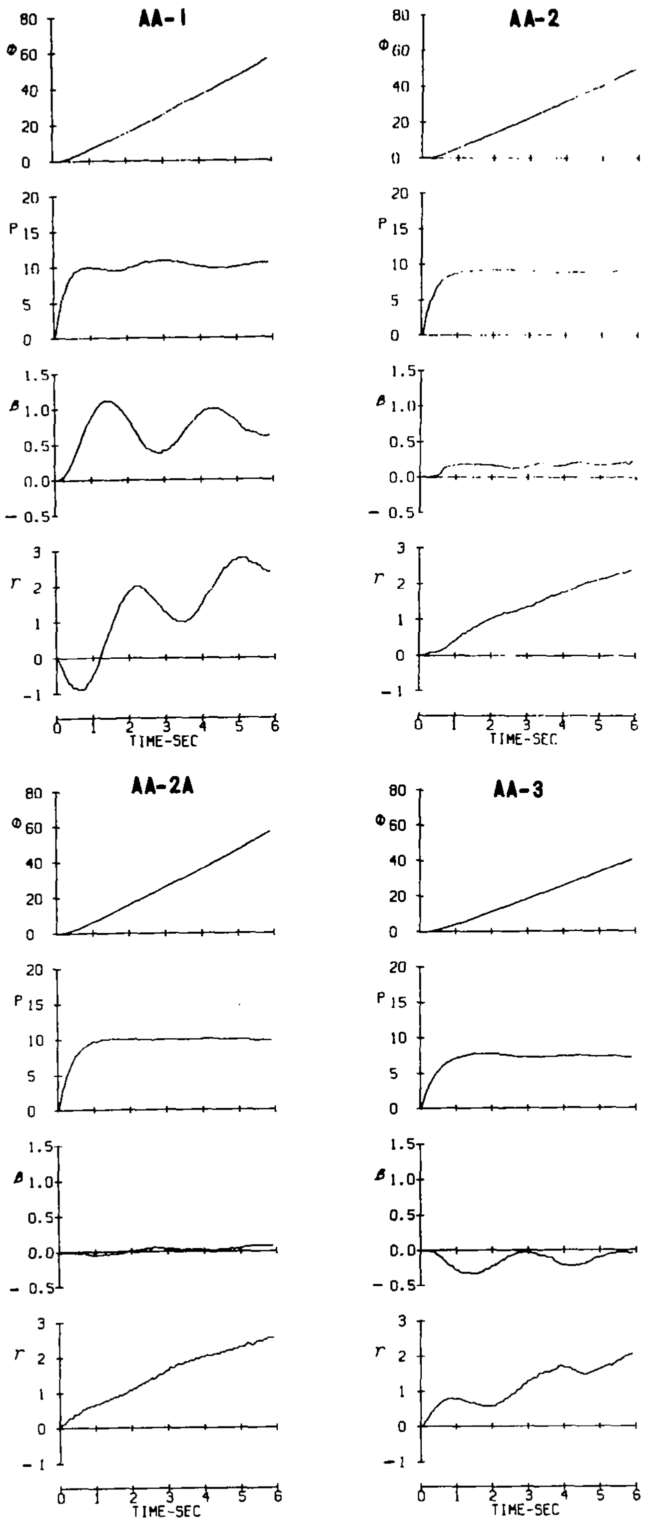


ϕ and β ~ degrees

p and r ~ deg/sec

δ_{AS} Step = .5 inch

Figure I-14 Transient Responses to Aileron Stick Step From Flight Records Normalized to .5-Inch δ_{AS} Step



ϕ and β ~ degrees

p and r ~ deg/sec

δ_{AS} Step = .5 inch

Figure I-15 Transient Responses to Aileron Stick Step From Flight Records Normalized to .5-Inch δ_{AS} Step

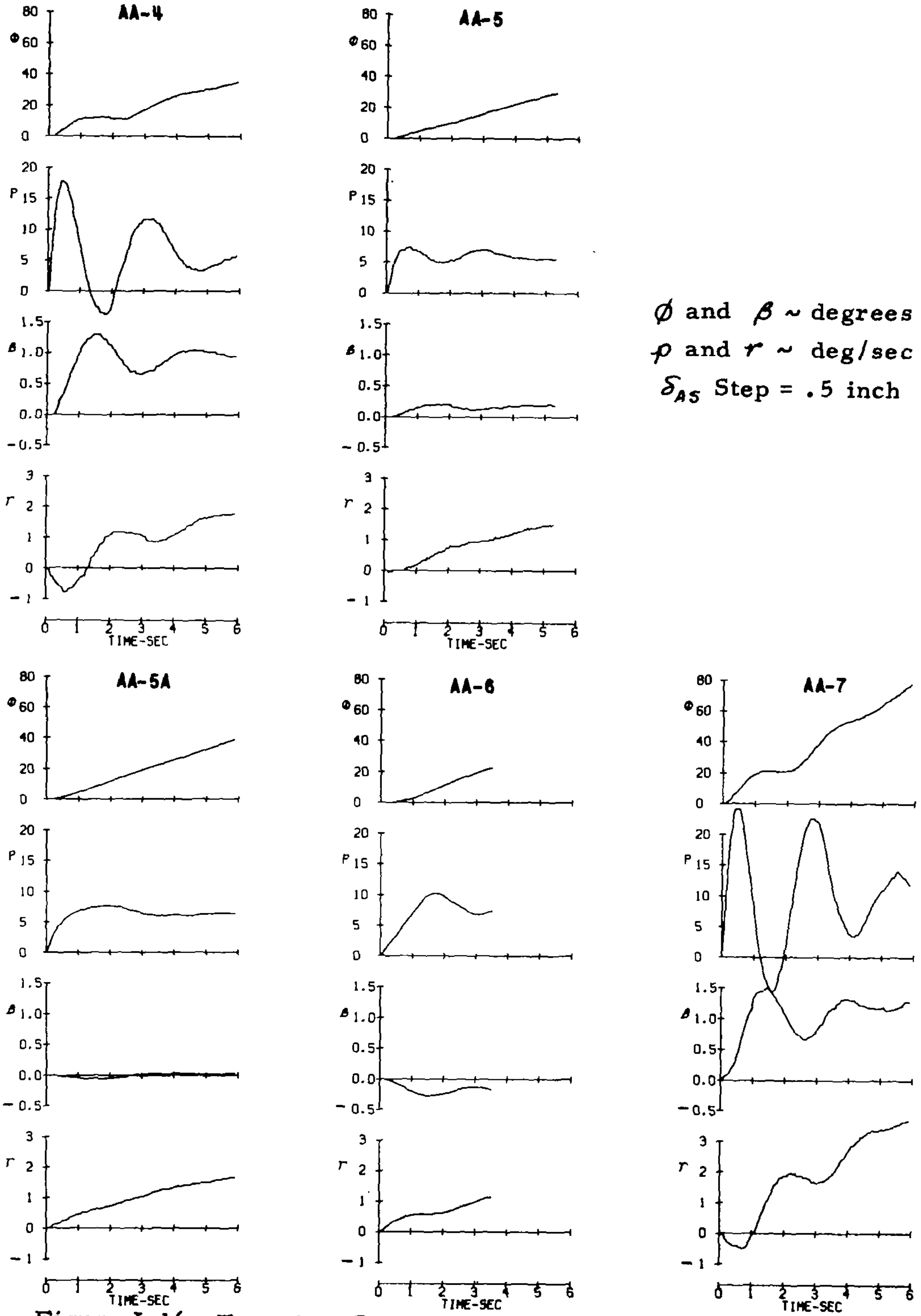
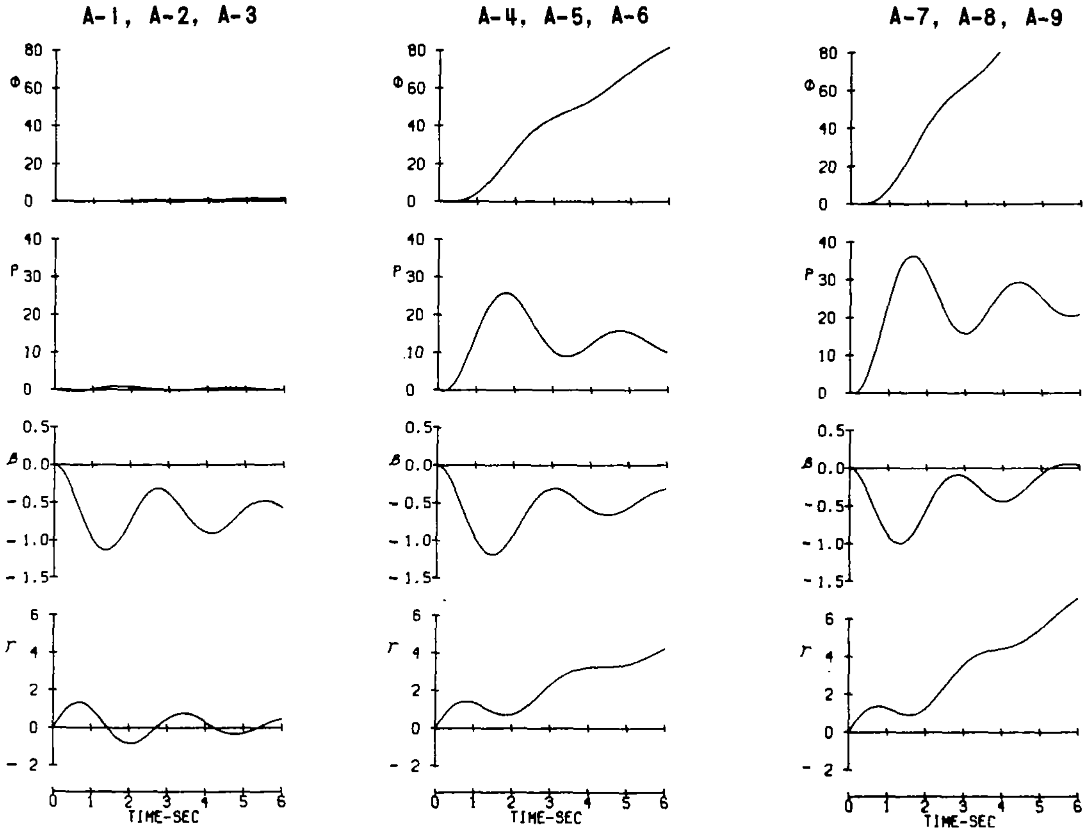
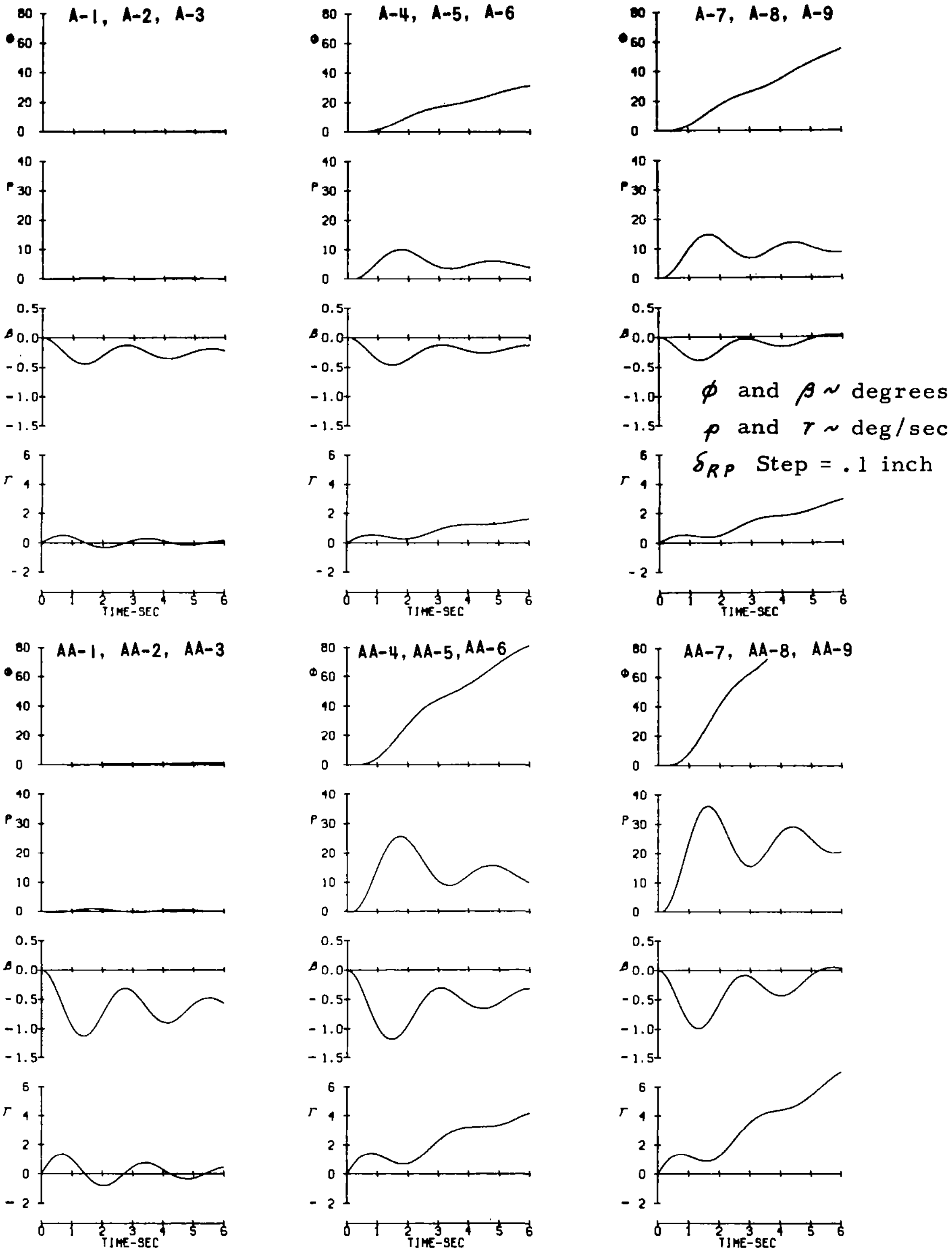


Figure I-16 Transient Responses to Aileron Stick Step From Flight Records Normalized to .5-Inch δ_{AS} Step



ϕ and β ~ degrees
p and r ~ deg/sec
δ_{RP} Step = .1 inch

Figure I-17 Transient Responses To Rudder Pedal Step Calculated For Fixed-Base Configurations From Pseudoderivatives


A-1, A-2, A-3

A-4, A-5, A-6

A-7, A-8, A-9

AA-1, AA-2, AA-3

AA-4, AA-5, AA-6

AA-7, AA-8, AA-9

ϕ and β ~ degrees

p and r ~ deg/sec

δ_{RP} Step = .1 inch

Figure I-18 Transient Responses To Rudder Pedal Step Calculated For In-Flight Configurations From Pseudoderivatives

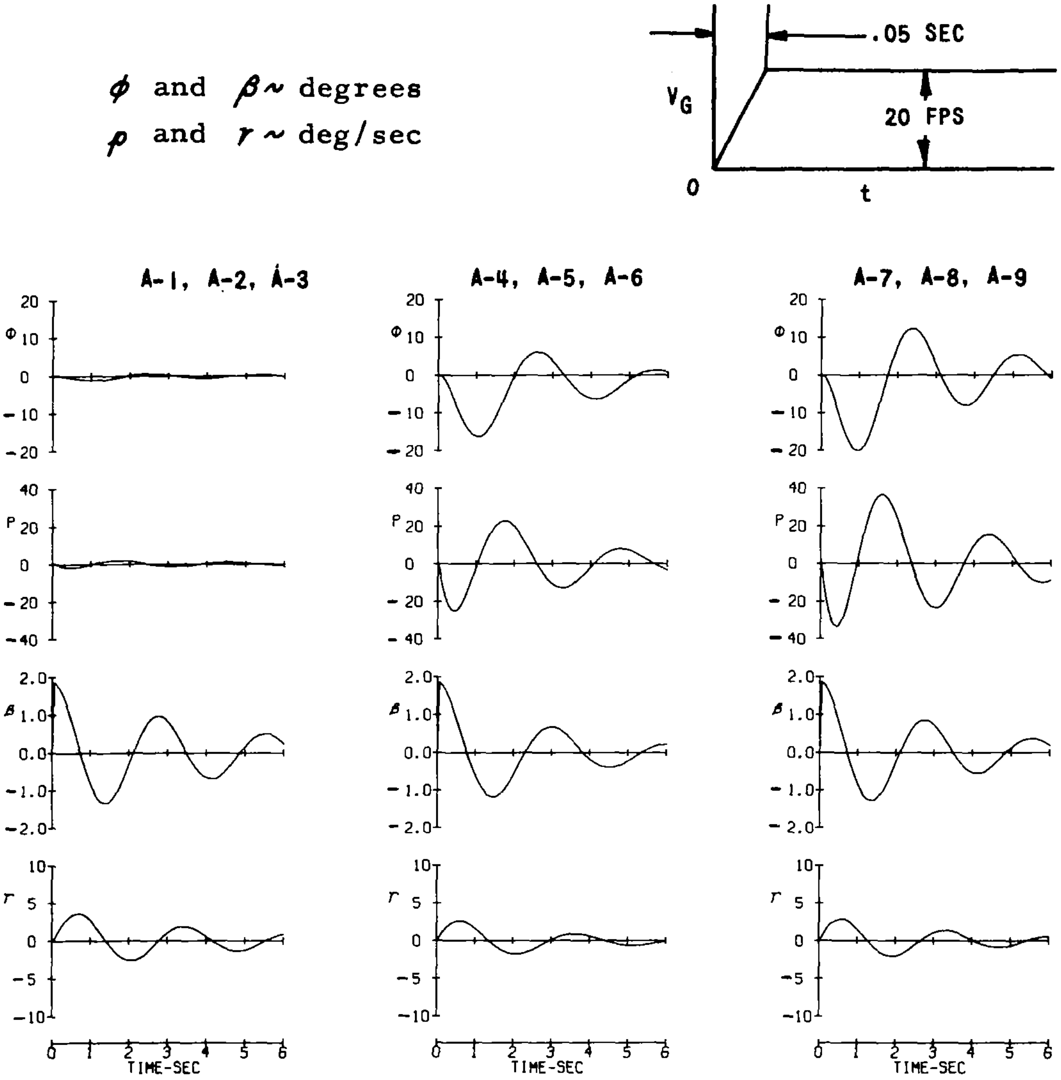


Figure I-19 Transient Responses To Side Gust Calculated From Pseudoderivatives

GROUND SIMULATOR CONFIGURATIONS

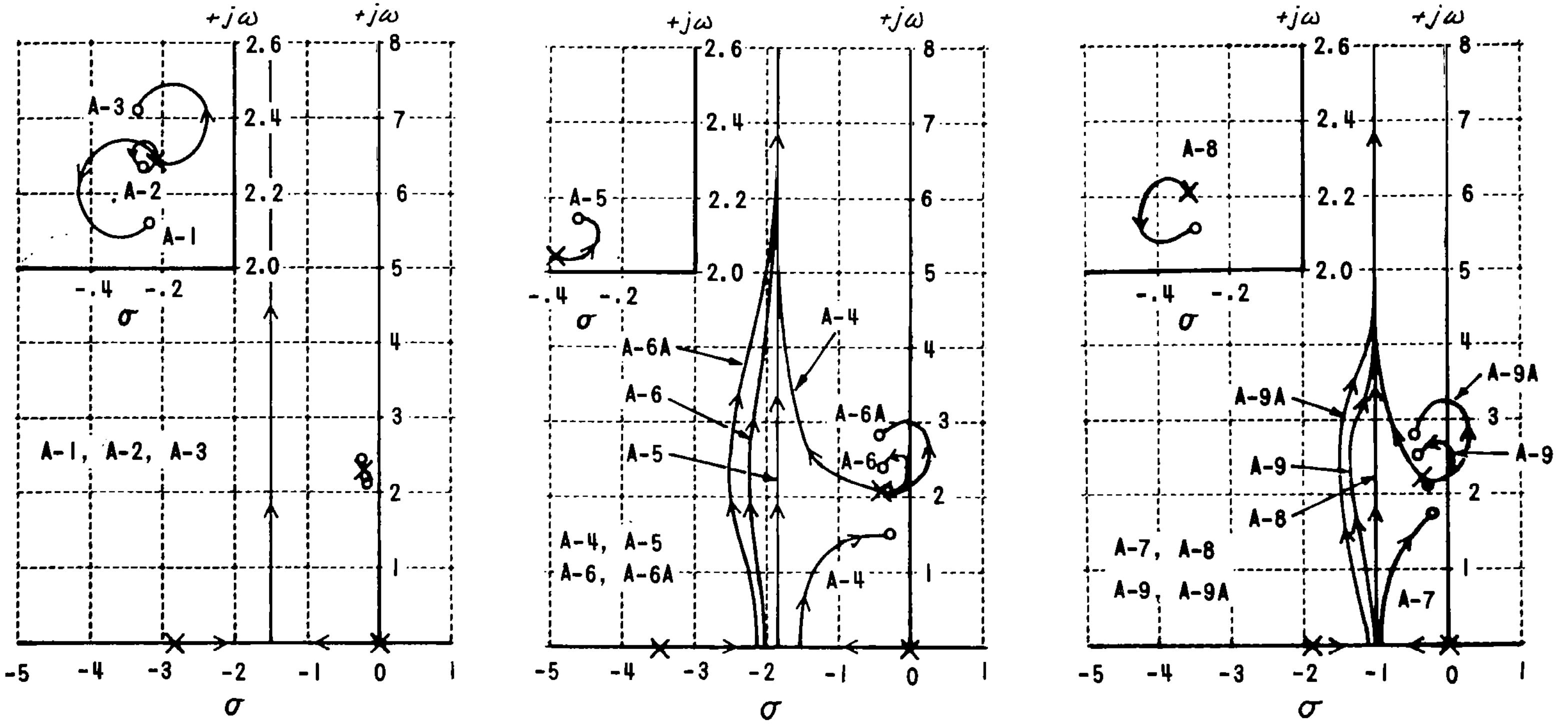


Figure I-20 Root Locus Diagrams of Fixed-Base Configurations Varying Pilot Gain Closure of Aileron to Bank Angle Loop

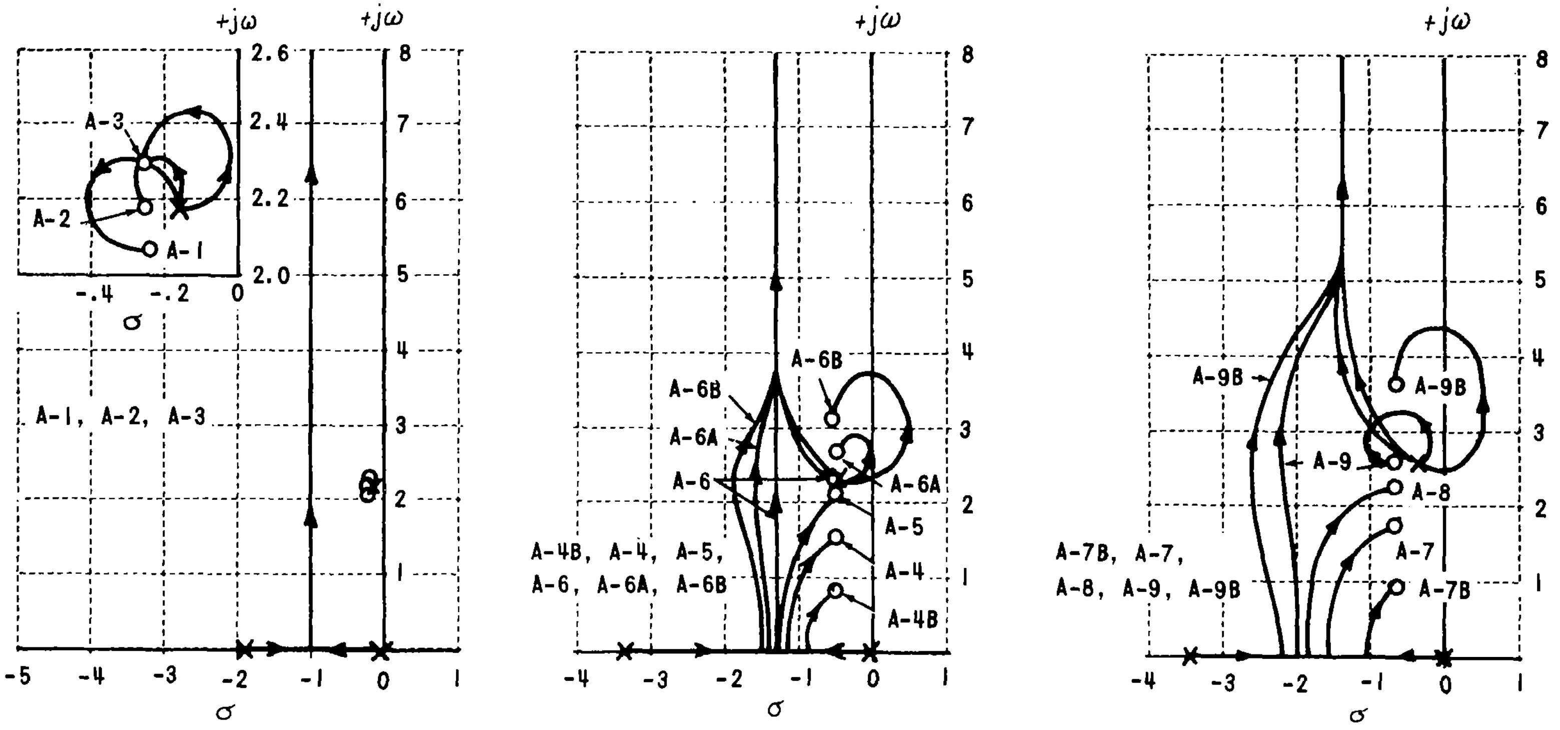


Figure I-21 Root Locus Diagrams of In-Flight Configurations
Varying Pilot Gain Closure of Aileron to Bank Angle Loop

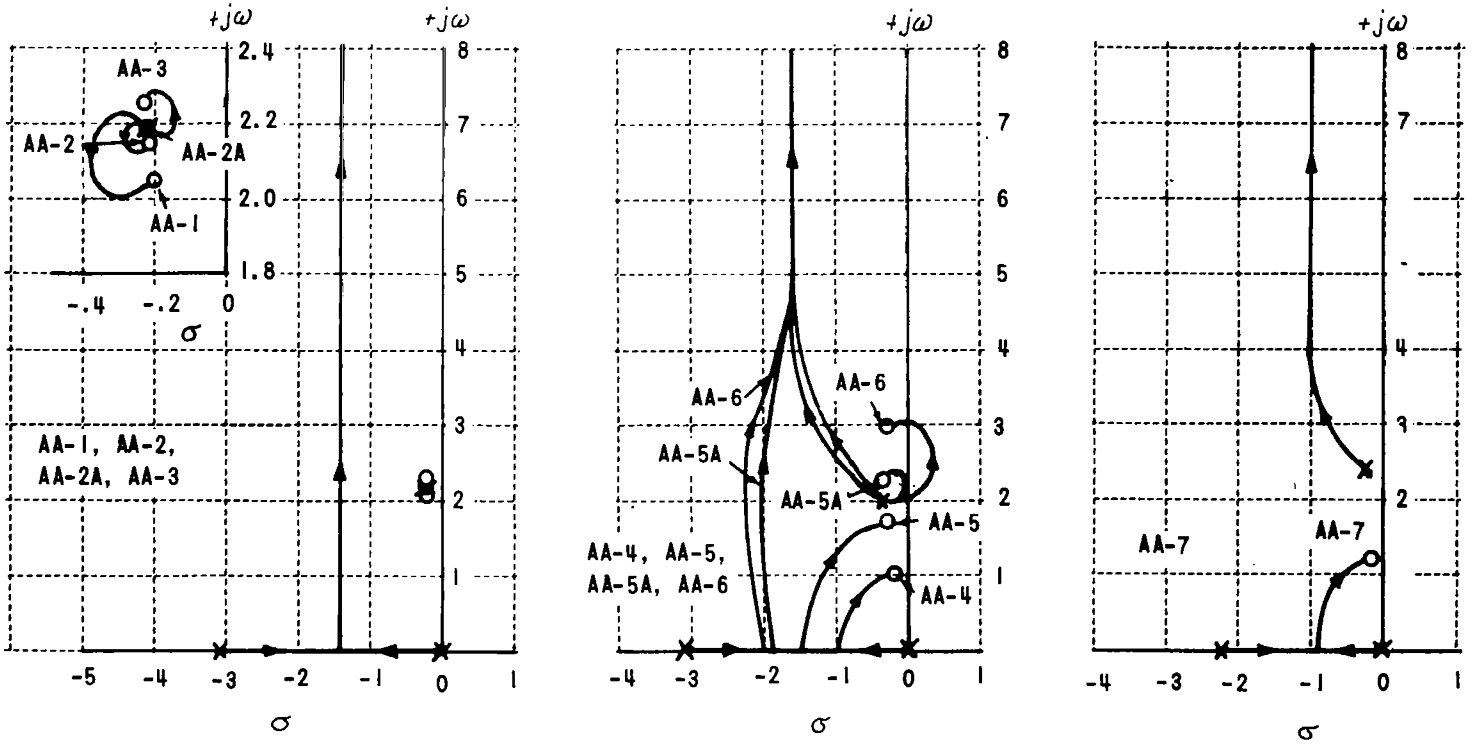


Figure I-22 Root Locus Diagrams of In-Flight Configurations Varying Pilot Gain Closure of Aileron to Bank Angle Loop

3.4 PART II EXPERIMENT

In Reference 2, a criterion for assessing the lateral-directional handling qualities of an airplane is proposed which considers five primary handling qualities parameters. The criterion was developed at NASA Flight Research Center and was based primarily on experimental results obtained from a fixed-base simulator which was equipped with a color contact analog display. In Part II of this experiment it was planned to evaluate certain configurations in the T-33 (both as a fixed-base simulator and as an in-flight simulator) to verify the results obtained in the NASA contact analog simulations which were used as the basis for the criterion proposed in Reference 2.

The configurations evaluated in this part of the experiments were defined by NASA FRC as indicated in Tables II-1 and II-2. The five configurations defined by NASA consisted of variations of ω_ϕ and ω_d achieved by variations of the stability derivatives N'_β and $N'_{\delta_{AS}}$. The spiral mode root, $-1/\tau_s$, was zero and g/V was zero. Since the design of the NASA experiment precluded the use of rudder pedals, they were not used in this simulation.

Because g/V was assumed zero and Y_β for the NASA configurations was different from that of the T-33, it was not possible for the T-33 variable stability airplane to simulate both the mode characteristics and the stability derivatives obtained from NASA. However, by employing the method described in Appendix C, a set of pseudoderivatives was determined that matched the specified mode characteristics and could be set up on the T-33 variable stability airplane in flight. The NASA derivatives, the pseudoderivatives and the associated mode characteristics are listed in Tables II-1 and II-2.

The evaluation results are presented in the form of pilot comment summaries and pilot ratings.

The similarities and differences for the Part II configurations can be summarized as follows: the values of $\zeta_d \omega_d$ and $\zeta_\phi \omega_\phi$ were held constant while ζ_d, ω_d, ζ_ϕ and ω_ϕ varied; $L'_{\delta_{AS}}$ was held constant while p_{ss}/δ_{AS} varied; and L'_β was held constant while $|\phi/\beta|$ varied. Several handling qualities parameters (some of which are often used to correlate pilot ratings) were varied in a prescribed manner from one configuration to the next. The results are summarized in Figure II-1 where composite pilot ratings are plotted for both the fixed-base and in-flight evaluations. The variation of parameters is shown on the multiple abscissas of the plots. Pilot rating points were taken from the summary pilot rating prediction chart in Figure 14(b) of Reference 2 and are shown in Figure II-1 for comparison. Figure II-2 presents all of the pilot ratings on similar plots.

3.4.1 Configuration B-1

The pilots objected primarily to the large generation of sideslip with aileron inputs and the extremely sensitive aileron control. They objected to the slowing down and, in some cases, reversal of the roll rate because of the sideslip resulting from aileron inputs for the in-flight simulation. In the fixed-base simulation, they objected to the lightly damped roll oscillations excited by aileron inputs. In-flight transient response records for aileron stick steps were not obtained for this configuration because it was not possible to keep the airplane in a stable lateral trim condition long enough to take a record. The transient responses generated from the pseudoderivatives, Figures II-4 and II-5, verify the pilot objections that there is large sideslip excitation with aileron control.

3.4.2 Configuration B-2

The major pilot objections are still the large adverse aileron yaw and the lightly damped Dutch roll oscillation with high $|\phi/\beta|$ that is easily excited by the aileron control. They also object to the high aileron sensitivity. Configuration B-2A, which was the same as B-2 except that the aileron sensitivity was 63% as large, was evaluated in flight to check the effects of aileron sensitivity on the evaluations. This resulted in a significant improvement in pilot rating as shown on Figure II-1. The pilot comments were essentially the same except that they no longer objected to high sensitivity. The transient responses show good agreement between the in-flight recordings and the calculated responses. They also verify the high aileron sensitivity and large Dutch roll excitation. Note the change in scales when comparing in-flight recorded responses with calculated responses.

3.4.3 Configuration B-3

High aileron sensitivity was still the major pilot complaint for this configuration. In addition, they objected to the Dutch roll mode which was lightly damped and had a high $|\phi/\beta|$. These objections were common for both the fixed-base and the in-flight simulations. An additional objection, which was stronger for the in-flight configuration, was the sideslip induced by aileron control. The responses for B-3 in Figures II-4, -5 and -6 show the large roll response and the large sideslip that was objectionable to the pilots. The in-flight recorded transient response of yaw rate shows that the aileron yaw was essentially zero. The sideslip response, however, shows considerable sideslip excitation with the aileron input which confirms the pilot comments. Since the aileron yaw was near zero, ω_ϕ/ω_d was close to the desired value of 1.0 and the sideslip disturbance must have been caused by $(N'_p - \frac{g}{V})$. This would also cause a difference between ζ_ϕ and ζ_d. The values of ζ_ϕ listed in Table II-2 were calculated as indicated in Appendix B and are largely dependent upon the values of the pseudoderivatives. Discrepancies between the pseudoderivatives and the derivatives actually simulated, especially N'_p and N'_β, on the variable stability T-33 could have a large effect on ζ_ϕ . Refer also to the Part I discussion, paragraph 3.3. The actual value of ζ_ϕ could not be accurately determined from measurements of response records.

In-flight evaluation of configuration B-3A, which is the same as B-3 except that the aileron sensitivity is only 31% as large, showed a considerable improvement in pilot rating by merely reducing the aileron sensitivity. The pilot comments were essentially the same except that they no longer objected to the aileron sensitivity.

There were frequent complaints during the Part II evaluations about the lack of rudder pedals. Rudder pedals were provided for one fixed-base evaluation of B-3. The rudder characteristics set up, however, were quite poor with an essentially zero force gradient and a $N'_{\delta_{RP}}$ value of .533 $1/\text{sec}^2$-in. The resulting rudder pedal forces were so light and the sensitivity so high that they actually made the pilot's task more difficult. It can only be concluded that bad rudder control characteristics can make the pilot's opinion of a bad configuration even worse. Time did not permit a meaningful examination of the control improvements that could be realized with good rudder characteristics.

The pilot rating numbers obtained during the fixed-base evaluations were considerably lower than expected based on previous simulation results at the NASA Flight Research Center. Configuration B-3 was simulated by two additional methods to investigate this situation. This was accomplished by setting up the NASA B-3 and Pseudo B-3 configurations directly on the analog computer without using the T-33 variable stability system. The cockpit displays, control feel system and longitudinal control characteristics were the same as those used in the other fixed-base simulations of B-3. The only difference was the manner in which the lateral-directional characteristics were simulated. The pilot comments for both of these configurations were essentially the same with respect to lateral-directional handling. They objected to the high aileron sensitivity and noted that there was only very little Dutch roll excitation with aileron inputs. They commented that the nose tended to rise in steep turns with the NASA B-3 configurations, but this is expected with the $\frac{g}{V}$ term in the side force equation set equal to zero.

A comparison of the pilot rating for the two configurations set up directly on the analog computer with the composite pilot ratings would seem to indicate that these two configurations exhibited more desirable handling qualities. At this point, it should be noted from Table II-4 that both pilots evaluated these two configurations and the standard B-3 in three successive runs. These were all performed on one day at the end of the Part II fixed-base evaluations. The results of these runs are as follows.

Pilot	Run	Configuration	Pilot Rating Smooth Air/Random Noise
A	39	NASA B-3 on Analog	5/5
A	40	Pseudo B-3 on Analog	5/6
A	41	B-3 on V/S T-33	4.5/4.5
B	31	B-3 on V/S T-33	6.5/8
B	32	Pseudo B-3 on Analog	4.5/5
B	33	NASA B-3 on Analog	4/5

It would be difficult to conclude from these successive runs by each pilot that any one of the configurations is significantly better than the others. From the trend of the ratings, it would probably be more appropriate to conclude that the longer a pilot flies configurations that are essentially the same, the less he tends to downrate them because of their objectionable features.

3.4.4 Configuration B-4

Pilot comments verify the low frequency, high $|\phi/\beta|$, lightly damped Dutch roll mode and the high aileron sensitivity. The fixed-base comments noted slightly proverse aileron yaw. The configuration was given a pilot rating number of 10 with the major objection being a divergent closed-loop oscillation and very high lateral control sensitivity. The in-flight comments indicate that the yaw acceleration for aileron inputs was essentially zero and the sideslip excited was quite small and adverse. The configuration was given a pilot rating of 5 to 6. The in-flight transient response records in Figure II-6 verify the small sideslip excitation for an aileron step. A comparison of the in-flight transient responses of yaw rate, r , shows that $N'_{\delta_{AS}}$ was negative for B-2, essentially zero for B-3 and positive for B-4. This was the planned variation of $N'_{\delta_{AS}}$. The sideslip excitation however is minimum for B-4. This is verified by the pilot comments and B-4 is rated the best configuration of the three for the in-flight evaluations. The pilot rating appears to be much more closely tied to the sideslip excitation than to $N'_{\delta_{AS}}$. As was discussed in Section 3.2 and when discussing B-3, the sideslip excitation is related to $(N'_p - \frac{g}{V})$. The Dutch roll excitation in roll rate for aileron inputs is related to ζ_ϕ and ζ_d as well as ω_ϕ / ω_d . It was pointed out in Section 3.2 that ζ_ϕ and ζ_d can be different if $(N'_p - \frac{g}{V})$ is not zero.

The closed-loop oscillation which was a major objection with the fixed-base evaluations of B-4, was not noted during the in-flight evaluations. A difference in ζ_ϕ could account for the closed loop oscillations for the fixed-base configurations while they were not experienced in flight.

The in-flight evaluations of configuration B-4A, with 15.4% of the aileron sensitivity of B-4, showed a significant improvement in pilot rating. This eliminated the major objection to B-4, i.e., high aileron sensitivity, and there were no major pilot objections to B-4A.

3.4.5 Configuration B-5

The major objections for the configuration were the high aileron sensitivity, generation of sideslip with aileron inputs, and a divergent rolling oscillation. The possibility of a divergent oscillation is indicated in the root locus diagrams, Figures II-9 and II-10, and was experienced by the pilots in both the fixed-base and in-flight simulations.

The in-flight evaluation of configuration B-5X was the result of an error in setting the aileron control gains, but it closely approximates B-5 in-flight characteristics, pilot comments, and pilot rating.

This configuration was extremely difficult to set up in flight. The Dutch roll damping and roll mode time constant were very dependent on the value of ($N'_p - \frac{g}{V}$).

3.4.6 Summary of Part II Results

The longitudinal control characteristics were kept constant for the Part II configurations with characteristics as shown in Table II-3. The pilots objected to the large elevator stick motions in relation to the extremely sensitive aileron control.

Transient responses to a side gust in Figure II-7 show that the roll response to a given side gust increases as the Dutch roll frequency decreases. See Appendix E for a discussion of the roll response to sideslip disturbances.

Pilot rating points were taken from the comparable pilot rating chart, Figure 14(b) in Reference 2, for an $L'_{\delta_a} \; \delta_{a_{MAX}}$ of 17.15 sec^{-2} (the value of $L'_{\delta_{AS}} \; \delta_{AS_{MAX}}$ used for the Part II configurations) and plotted on Figure II-1 for comparison with the results of Part II. The comparison is not very good. The pilot ratings obtained in this program were largely downgraded because of the extreme roll sensitivity and significantly improved ratings resulted when the sensitivity was reduced by less than a factor of two. This is not consistent with the referenced chart which indicates that the pilot ratings are relatively insensitive to a factor of two change in $L'_{\delta_{AS}}$ for the values under consideration. Based on these observations, and the pilot comments, the roll sensitivity appears to be a major factor in the discrepancy between the results of this experiment and the reference chart.

TABLE II-2 CONTROL DERIVATIVES AND NUMERATOR ZEROS

	Configuration	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$\frac{p_{ss}}{\delta_{AS}} \sim \frac{deg/sec}{in}$
NASA config-uration	B-1	-.4	2.86	0	-.140	.1325	.364	.80	.156	21.71
	B-2	-.114		0	-.040	.584	.764	1.30	.0960	95.66
	B-3	0		0	0	1.00	1.0	1.50	.0833	163.88
	B-4	.0571		0	.020	1.30	1.14	1.60	.0781	212.98
	B-5	.286	↓	0	.100	4.00	2.0	2.00	.0625	655.51
Pseudo config-uration	B-1	-.398	2.86	0	-.139	.1325	.364	.80	.145	21.71
	B-2	-.143		0	-.040	.584	.764	1.30	.112	95.66
	B-3	-.00857		0	-.003	1.00	1.0	1.50	.0860	163.88
	B-4	.0440		0	.0154	1.30	1.14	1.60	.0852	212.98
	B-5	.211	↓	0	.074	4.0	2.0	2.00	.0648	655.51
Fixed base config-uration	B-1	-.441	2.88	.00447	-.153	.103	.321	.706	.115	13.2
	B-2	-.157	2.84	.00165	-.0554	.468	.684	1.18	.105	74.5
	B-3	-.00942	2.83	.000165	-.00333	.960	.979	1.55	.0826	163.3
	NASA B-3*	0	2.86	0	0	1	1	1.50	.0833	156.0
	Pseudo B-3*	-.00857	2.86	0	-.003	.9590	.977	1.42	.091	137.5
	B-4	.0472	2.825	-.000396	.0167	1.22	1.101	1.63	.0862	188.5
	B-5	.232	2.85	-.00223	.0814	2.98	1.721	2.04	.0772	699.1
In-flight config-uration	B-1	-.386	2.88	.00556	-.134	.165	.406	.905	.103	27.2
	B-2	-.138	2.88	.00233	-.048	.536	.732	1.29	.101	106.0
	B-2A	-.0874	1.82	.00147	-.048	.536	.732	1.29	.101	67.0
	B-3	-.0144	2.87	.00069	-.005	.941	.970	1.64	.0768	151.8
	B-3A	-.00445	.889	.000214	-.005	.941	.970	1.64	.0768	47.0
	B-4	.0524	2.91	0	.018	1.26	1.12	1.75	.0814	171.9
	B-4A	.00806	.448	0	.018	1.26	1.12	1.75	.0814	26.4
	B-5	.219	2.85	-.00212	.077	2.82	1.678	1.90	.0792	460.7
	B-5X	.128	2.32	-.00112	.055	2.30	1.513	1.71	.0681	306.0

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* These configurations were set up directly on the analog computer without using the T-33 variable stability system

TABLE II-3 CONTROL FEEL AND PITCH DYNAMICS

	Fixed Base	In-Flight
Aileron stick spring rate, lb/in	2.8	2.8
Aileron breakout force, lb	±.7	±.71
Rudder pedal spring rate, lb/in	250**	250**
Elevator stick spring rate, ~ lb/in	4.2	4.2
Short period frequency, ω_n ~ rad/sec	2.95*	3.4*
Short period damping ratio, ζ	.48*	.4*
Stick force per "g", ~ lb/g	5.2	5.2
$\delta_{ES\ MAX}$ ~ in.	+7.75, -3.5	+7.75, -3.5
$\delta_{AS\ MAX}$ ~ in.	±6	±6
$\delta_{RP\ MAX}$ ~ in.	±4	±4

* nominal values from flight and ground simulator records

** rudder pedals did not drive control surfaces

TABLE II-4 FIXED-BASE PILOT RATINGS

	Configuration	Run	Pilot Rating Smooth Air/Random Noise	ω_ϕ	ω_d	$\frac{P_{SS}}{\delta_{AS}} \sim \frac{deg/sec}{in}$
Pilot "A"	B-1	19	8/9	.706	2.20	13.2
	B-2	22	8/9.5	1.18	1.72	74.5
	B-3	2	10/--	1.55	1.58	163.3
	B-3	4	9/--	1.55	1.58	163.3
	B-3	24	6/7	1.55	1.58	163.3
	B-3	41	4.5/4.5	1.55	1.58	163.3
	B-3(1)	5	10/--	1.55	1.58	163.3
	B-3(2)	39	5/5	1.50	1.50	156.0
	B-3(3)	40	5/6	1.42	1.45	137.5
	B-4	23	10/10	1.63	1.48	188.5
	B-5	25	10/--	2.04	1.18	699.1
Pilot "B"	B-1	15	10/10	.706	2.20	13.2
	B-2	17	9/9	1.18	1.72	74.5
	B-3	20	5/7	1.55	1.58	163.3
	B-3	31	6.5/8	1.55	1.58	163.3
	B-3(2)	33	4/5	1.50	1.50	156.0
	B-3(3)	32	4.5/5	1.42	1.45	137.5
	B-4	21	10/10	1.63	1.48	188.5
	B-4	23	9/10	1.63	1.48	188.5
	B-5	19	10/10	2.04	1.18	699.1

(1) with rudder pedals
but poor rudder control

(2) NASA B-3 on analog

(3) Pseudo B-3 on analog

TABLE II-5 IN-FLIGHT PILOT RATINGS

	Configuration	Flight	Pilot Rating Smooth Air/Random Noise	ω_ϕ	ω_d	$\frac{P_{SS}}{\delta_{AS}} \sim \frac{deg/sec}{in}$
Pilot "A"	B-1	500-1	10/--	.905	2.23	27.2
	B-2	499-2	10/10	1.29	1.76	106.0
	B-3	499-1	8.5/9	1.64	1.69	151.8
	B-3A	514-1	5/5	1.64	1.69	47.0
	B-4	500-2	6/5.5	1.75	1.56	171.9
	B-5X	503-1	9/9	1.71	1.13	306.0
Pilot "B"	B-1	501-2	9/10	.905	2.23	27.2
	B-2	498-2	8/9	1.29	1.76	106.0
	B-2A	512-2	7/8	1.29	1.76	67.0
	B-3	498-1	4.5/5	1.64	1.69	151.8
	B-3	501-1	7.5/8	1.64	1.69	151.8
	B-3	506-1	7/7.5	1.64	1.69	151.8
	B-3A	512-1	4.5/5	1.64	1.69	47.0
	B-4	498-3	5/5.5	1.75	1.56	171.9
	B-4A	512-3	2.5/--	1.75	1.56	26.4
	B-5	506-2	8.5/8.5	1.90	1.13	460.7

TABLE II-6 SUMMARY OF PILOT COMM
FOR FIXED-BASE CONFIGU

CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABLE FEATURES
	GENERAL	AILERON YAW	COORDINATION	FEEL		
B-1	YAWING MOMENT IS SO LARGE THAT ANY MODERATE INPUT GENERATES SIDESLIP AND ROLL OSCILLATIONS THAT ARE INTOLERABLE. CONTROL SENSITIVITY IS INTOLERABLE.	QUITE STRONGLY ADVERSE	WOULD NOT BE ABLE TO COORDINATE EVEN WITH RUDDERS.	LOW BREAKOUT FORCE, LOW GRADIENT, ADEQUATE.	NONE.	EXTREMELY SENSITIVE AILERON CONTROL. LARGE ADVERSE YAW GENERATED WITH AILERON INPUT AND THE ENSUING LIGHTLY DAMPED, LARGE AMPLITUDE ROLL-YAW OSCILLATIONS. LARGE YAW DUE TO ROLL CONTROL AND LARGE ROLL DUE TO SIDESLIP
B-2	A TENDENCY FOR GROSS OVERCONTROL WITH EVEN MODERATE INPUTS RESULTING IN SIZABLE SIDESLIP AND ROLLING OSCILLATIONS. CLOSED -LOOP DAMPING BETTER THAN OPEN-LOOP BUT REQUIRES CAREFUL PILOT ATTENTION.	GREAT MAGNITUDE OF ADVERSE YAW.	NO COMMENT.	LOW BREAKOUT FORCE, LOW FORCE GRADIENT, VERY SENSITIVE.	HEADING CONTROL NOT DIFFICULT. ABLE TO DO STEEP TURNS PRETTY WELL.	GREAT SENSITIVITY OF LATERAL CONTROL. LARGE ADVERSE YAW DUE TO AILERON GENERATES LARGE SIDESLIP ANGLES RESULTIN IN EXCITATION OF THE LIGHTLY DAMPED DUTCH ROLL MODE GIVING VERY OSCILLATORY ROLL RESPONSE. PITCH CONTROL IS LOUSY.
B-3	SPEED OF RESPONSE IS ADEQUATE BUT PRECISION IS TERRIBLE. CONTROL SENSITIVITY POSES A PROBLEM. IT FOSTERS OVERCONTROL AND GENERATES DUTCH ROLL OSCILLATIONS WHICH ARE SLOW TO DAMP OUT. EXCESSIVE ROLL RATE ACCELERATIONS.	SOME ADVERSE YAW. OBJECTIONABLE, BUT NOT TOO GREAT.	WOULD BE BETTER WITH RUDDER PEDALS.	TOO SENSITIVE, LOW BREAKOUT FORCE, EXTREMELY LIGHT FORCE GRADIENT, POOR STICK CENTERING.	HEADING CONTROL IS GOOD. RESPONSE TO AILERON IS GOOD.	CONFIGURATION TOO ROLLY. LATERAL CONTROL TOO SENSITIVE WITH A TENDENCY TO BUILD UP HIGH ROLL RATES INADVERTENTLY. THE YAW AND RESULTING SIDESLIP GENERATED FROM AILERON INPUTS EXCITES THE HIGHLY OSCILLATORY LOW DAMPED DUTCH ROLL MODE. EXTREMELY HIGH ROLL DUE TO SIDESLIP CAUSES UNACCEPTABLE OSCILLATIONS WHILE TRYING TO MAINTAIN BANK ANGLE.
B-3 WITH RUDDER PEDALS	CONFIGURATION B-3 WAS SET UP WITH RUDDER PEDALS TO SEE IF THEY WOULD AID THE PILOT IN CONTROLLING THE CONFIGURATION. BOTH THE LATERAL-DIRECTIONAL AND THE LONGITUDINAL CHARACTERISTICS WERE THE SAME AS IN THE PREVIOUS B-3 CONFIGURATIONS. THE RUDDER PEDAL SPRING RATE WAS ESSENTIALLY ZERO, I.E., VERY LIGHT PEDAL FORCES AND $R_{\delta_{RP}}$ WAS .533 sec^{-2} PER INCH. THIS RESULTED IN VERY POOR RUDDER CONTROL WHICH THE PILOT DID NOT LIKE. THE PILOT COMMENTS WERE: RUDDER PEDAL FORCES ARE SO LOW YOU DON'T HAVE MUCH FORCE FEEL. CAN'T RESOLVE SMALL ENOUGH INPUTS REQUIRED TO CONTROL THE SIDESLIP. MAJOR OBJECTION IS THE TERRIBLE RUDDER PEDAL CHARACTERISTICS - MUCH TOO LIGHT A FORCE GRADIENT, MUCH TOO SENSITIVE WITH TOO MUCH FRICTION. USE OF THESE RUDDER PEDALS DEGRADES CONFIGURATION.					
NASA B-3 ON ANALOG	HIGH ROLL RATES GENERATED WITH SMALL INPUTS. VERY SENSITIVE. HOWEVER, NO MORE THAN A COUPLE OF DEGREES OF SIDESLIP ARE GENERATED WITH ONLY MINOR DUTCH ROLL OSCILLATIONS.	VERY LITTLE PROVERSE.	NOT REQUIRED, WOULD NOT USE RUDDER IF AVAILABLE.	HIGH SENSITIVITY, HIGH CONTROL POWER, LOW BREAKOUT FORCE, LOW FORCE GRADIENT. POOR CENTERING.	DO NOT HAVE TO WORRY ABOUT SIDESLIP GENERATION OR DUTCH ROLL OSCILLATIONS EVEN FOR ABRUPT INPUTS. HEADING CONTROL PRECISE.	TOO SENSITIVE LATERAL CONTROL. TOO MUCH AILERON RESPONSE FOR A SMALL INPUT CAUSES OSCILLATORY BANK ANGLE CONTROL. SIMULATION POOR, I.E., NOSE RISES IN STEEP TURNS.
PSEUDO B-3 ON ANALOG	VERY ROLLY. REALLY SENSITIVE WITH MORE THAN ADEQUATE ROLL RATE ACCELERATION, FOSTERING OVERCONTROL AND OSCILLATIONS IN BANK ANGLE. ONLY A SMALL MAGNITUDE OF SIDESLIP IS GENERATED WITH A SLIGHT DUTCH ROLL EXCITATION.	ESSENTIALLY ZERO.	NOT REQUIRED.	OVERLY SENSITIVE, POOR CENTERING, LIGHT BREAKOUT FORCE AND LIGHT FORCE GRADIENT.	NO APPRECIABLE AMOUNTS OF SIDESLIP GENERATED AND NO DUTCH ROLL OSCILLATIONS INCURRED. HEADING CONTROL PRECISE.	GREAT SENSITIVITY OF LATERAL CONTROL RESULTING IN A ROLLY CONFIGURATION. POOR LONGITUDINAL FORCE FEEL.
B-4	CONTROL NEARLY IMPOSSIBLE. TOO SENSITIVE. MODERATE TO LARGE INPUTS RESULT IN COMPLETE LOSS OF CONTROL THROUGH A DIVERGENT SIDESLIP ROLL OSCILLATION.	SLIGHTLY PROVERSE.	NO COMMENT.	LOW BREAKOUT FORCE, EXTREMELY LOW FORCE GRADIENT, POOR STICK CENTERING. TOO SENSITIVE.	NONE.	EXTREMELY SENSITIVE LATERAL CONTROL. SMALL AMOUNT OF YAW EXCITES A HIGHLY OSCILLATORY DUTCH ROLL MODE WHICH, CLOSED-LOOP, APPEARS TO GROW DIVERGENT, BOTH IN SIDESLIP AND BANK ANGLE.
B-5	IMPOSSIBLE TO PERFORM THE SIMPLEST TASK.	STRONG AND PROVERSE.	NONE	QUITE SENSITIVE, VERY LOW FORCE GRADIENT, NEGLIGIBLE BREAKOUT FORCE.	NONE.	THE SMALLEST AMOUNT OF AILERON INPUT RESULTS IN INTOLERABLE YAW GENERATION AND ENSUING LARGE ROLL YAW OSCILLATIO THAT RESULTS IN COMPLETE DIVERGENCE BOTH IN ROLL AND PITCH.

MARY OF PILOT COMMENTS
FIXED-BASE CONFIGURATIONS

ABLE FEATURES	OBJECTIONABLE FEATURES	SPECIAL PILOTING *TECHNIQUES*	CONTROL IN PRESENCE *OF DISTURBANCES*	OVERALL OPINION	LATERAL-DIRECTIONAL *FREE RESPONSE*	LONGITUDINAL *HANDLING*
	EXTREMELY SENSITIVE AILERON CONTROL. LARGE ADVERSE YAW GENERATED WITH AILERON INPUT AND *THE ENSUING LIGHTLY* DAMPED, LARGE AMPLITUDE ROLL-YAW OSCILLATIONS. LARGE YAW DUE TO ROLL CONTROL AND LARGE ROLL DUE TO SIDESLIP	FLY BANK ANGLE.	IMPOSSIBLE TO MAINTAIN STRAIGHT AND LEVEL WITHIN TOLERABLE VALUES OF SIDE-*SLIP AND ROLL OSCILLATIONS. PILOT* ATTEMPTS TO STOP THE ROLL GENERATED, USUALLY MAGNIFIED THE SIDESLIP RESULTING IN A DIVERGENT ROLL-YAW OSCILLATION.	QUITE LARGE SIDESLIP GENERATED WITH VERY MODEST CONTROL INPUTS. INTOLERANT *OF PILOT MISTAKES. UNSATISFACTORY* FOR RECOVERY FROM UNUSUAL ATTITUDES.	MODERATELY HIGH $\|\phi/\beta\|$, LIGHTLY DAMPED DUTCH ROLL MODE.	HEAVILY DAMPED SHORT PERIOD MODE. LIGHT BREAKOUT FORCE, LIGHT FORCE GRADIENT. LARGE AMOUNT OF STICK MOTION REQUIRED IS OBJECTIONABLE.
OL NOT DIFFICULT. ABLE TURNS PRETTY WELL.	GREAT SENSITIVITY OF LATERAL CONTROL. LARGE ADVERSE YAW DUE TO AILERON GENERATES LARGE SIDESLIP ANGLES RESULTING IN EXCITATION OF THE LIGHTLY DAMPED DUTCH ROLL MODE *GIVING VERY OSCILLA*TORY ROLL RESPONSE. PITCH CONTROL IS LOUSY.	USE MINIMUM BANK ANGLE EXCURSIONS.	FLYABLE IF PILOT KEEPS HIS GAIN DOWN. HEADING CONTROL IS TERRIBLE. CAN'T CONTROL PITCH ATTITUDE IN STEEP TURNS.	ROLL CONTROL TOO SENSITIVE AND INDUCES EXCESSIVE SIDESLIP THAT EXCITES THE DUTCH ROLL OSCILLATION. WOULD BE IMPOSSIBLE TO RECOVER FROM UNUSUAL ATTITUDES. SIMULATION IS GROSSLY INADEQUATE DUE TO THE LARGE ROLLING VELOCITIES AND ACCELERATIONS WHICH IF THEY WERE BEING FELT MIGHT CHANGE PILOT OPINION.	HIGH $\|\phi/\beta\|$. LIGHT DUTCH ROLL DAMPING.	
OL IS GOOD. RESPONSE GOOD.	CONFIGURATION TOO ROLLY. LATERAL CONTROL TOO SENSITIVE WITH A TENDENCY TO BUILD UP HIGH ROLL RATES INADVERTENTLY. THE YAW AND RESULTING SIDESLIP GENERATED FROM AILERON INPUTS EXCITES THE HIGHLY OSCILLATORY LOW DAMPED DUTCH ROLL MODE. EXTREMELY HIGH ROLL DUE TO SIDESLIP CAUSES UNACCEPTABLE OSCILLATIONS WHILE TRYING TO MAINTAIN BANK ANGLE.	FLY BANK ANGLE TIGHTLY. MODIFIED $\dot{\beta}$ TECHNIQUE HELPS DAMP OUT DUTCH ROLL OSCILLATIONS.	INCREASED OSCILLATORY RESPONSE TO AILERON CONTINUALLY EXCITES DUTCH ROLL MODE REQUIRING CONSTANT PILOT ATTENTION.	SENSITIVITY OF AILERONS OFTEN GENERATES MORE ROLL RATE THAN DESIRED CAUSING OVERCONTROL AND OSCILLATIONS IN BANK ANGLE. POOR PITCH CONTROL COMPLICATES THE PILOT TASK. DUTCH ROLL EASILY EXCITED CREATING LARGE SIDESLIP ANGLES. CONFIGURATION REQUIRES CONSTANT ATTENTION. SIMULATION SEEMED REALISTIC IN THE ABSENCE OF MOTION.	HIGH $\|\phi/\beta\|$, LIGHTLY DAMPED DUTCH ROLL MODE.	
HARACTERISTICS WERE THE SULTED IN VERY POOR S REQUIRED TO CONTROL *UDDER PEDALS DEGRADES CONFIGURATION.*						
TO WORRY ABOUT SIDESLIP R DUTCH ROLL OSCILLATIONS UPT INPUTS. HEADING ISE.	TOO SENSITIVE LATERAL CONTROL. TOO MUCH AILERON RESPONSE FOR A SMALL INPUT CAUSES OSCILLATORY BANK ANGLE CONTROL. SIMULATION POOR, I.E., NOSE RISES IN STEEP TURNS.	NONE REQUIRED.	SIMPLY AN INCREASE IN PILOT WORK LOAD.	HIGH ROLL RATES AND CONTROL SENSITIVITY LEADS TO CONTROL PROBLEMS. NO SIDESLIP OR DUTCH ROLL OSCILLATIONS GENERATED. SIMULATION SEEMS POOR. THE NOSE TENDS TO CLIMB IN STEEP TURNS.	HIGH $\|\phi/\beta\|$, LOW DAMPED LOW FREQUENCY DUTCH ROLL MODE.	
LE AMOUNTS OF SIDESLIP D NO DUTCH ROLL OSCILLAED. HEADING CONTROL	GREAT SENSITIVITY OF LATERAL CONTROL RESULTING IN A ROLLY CONFIGURATION. POOR LONGITUDINAL FORCE FEEL.	NONE REQUIRED.	DRASTIC INCREASE IN WORK LOAD BUT CONTROL SENSITIVITY ALLOWS CONTROL OF NOISE WITH SMALL STICK DEFLECTIONS.	NOT A WELL HARMONIZED CONFIGURATION, TOO MUCH ROLL DUE TO AILERON AND NOT ENOUGH PITCH DUE TO ELEVATOR DEFLECTION. BANK ANGLE CONTROL TENDS TO BE OSCILLATORY. SIMULATION MUCH IMPROVED.	HIGHLY OSCILLATORY, LOW FREQUENCY DUTCH ROLL MODE, HIGH $\|\phi/\beta\|$.	
	EXTREMELY SENSITIVE LATERAL CONTROL. SMALL AMOUNT OF YAW EXCITES A HIGHLY OSCILLATORY DUTCH ROLL MODE WHICH, CLOSED-LOOP, APPEARS TO GROW DIVERGENT, BOTH IN SIDESLIP AND BANK ANGLE.	$\dot{\beta}$ TECHNIQUE SOMEWHAT HELPFUL IN DAMPING DUTCH ROLL SIDESLIP OSCILLATIONS.	CONTROL IS VIRTUALLY IMPOSSIBLE. SIDESLIP ANGLES GET VERY LARGE RESULTING IN THE NOSE RISING IN STEEP TURNS. VERY DIFFICULT TO DAMP SIDESLIP OSCILLATIONS.	LATERAL CONTROL TOO SENSITIVE. SOME CONTROL POSSIBLE WITH TIGHT BANK ANGLE CONTROL. HIGHLY OSCILLATORY DUTCH ROLL MODE EASILY EXCITED.	HIGH $\|\phi/\beta\|$, LIGHTLY DAMPED LOW FREQUENCY DUTCH ROLL MODE.	
	THE SMALLEST AMOUNT OF AILERON INPUT RESULTS IN INTOLERABLE YAW GENERATION AND ENSUING LARGE ROLL YAW OSCILLATION THAT RESULTS IN COMPLETE DIVERGENCE BOTH IN ROLL AND PITCH.	NONE.	IMPOSSIBLE.	FOR THE SMALLEST INPUT THE MAGNITUDE OF SIDESLIP AND YAW GROW TO UNCONTROLLABLE MAGNITUDES.	HIGH $\|\phi/\beta\|$, LOW DUTCH ROLL DAMPING.	

SUMMARY OF PILOT COMMENTS FOR INFLIGHT CONFIGURATIONS

FAVORABLE FEATURES	OBJECTIONABLE FEATURES	SPECIAL PILOTING TECHNIQUES	CONTROL IN PRESENCE OF DISTURBANCES	OVERALL OPINION	LATERAL-DIRECTIONAL FREE RESPONSE	LONGITUDINAL HANDLING
	HIGH ADVERSE YAW RESULTING IN SIDESLIP DISTURBANCES THAT CULMINATE IN SIDESLIP DIVERGENCE WITH OVER 30° OF BANK. LATERAL CONTROL RESTRICTED TO SLOW SMALL INPUTS.	MAKE ONLY VERY SMALL SLOW INPUTS.	DISTURBANCES WOULD SET OFF SIDESLIP, UNFLYABLE.	UNFLYABLE FOR THE MISSION DUE TO THE COMPLETE RESTRICTION ON LATERAL CONTROL.	LIGHTLY DAMPED DUTCH ROLL, ZERO DAMPED SIDESLIP OSCILLATION, MEDIUM $\|\phi/\beta\|$.	HIGHLY DAMPED SHORT PERIOD MODE. LOW BREAKOUT FORCE, LOW FORCE GRADIENT, LOW SENSITIVITY. MEDIUM CONTROL POWER WITH GOOD STICK CENTERING.
ED HEADING CONTROL IS QUITE	SENSITIVE LATERAL CONTROL, LOW ROLL DAMPING, STRONG ADVERSE YAW AND RESULTING *HIGHLY OSCILLATORY DUTCH ROLL* MODE. LACK OF DIRECTIONAL STABILITY.	SLOW SMALL LATERAL CONTROL INPUTS.	CONTINUOUS DUTCH ROLL OSCILLATIONS. CLOSED-LOOP ATTEMPTS TO CONTROL HEADING *OR BANK ANGLE GREATLY INCREASES THE* PROBLEM.	AIRCRAFT EXHIBITS CLOSED-LOOP DIVERGENT DIRECTIONAL OSCILLATIONS.	LOW DAMPED DUTCH ROLL MODE, HIGH $\|\phi/\beta\|$.	
CONTROL GOOD.	THE INTOLERABLE MAGNITUDE OF SIDESLIP. VERY HIGH ADVERSE YAW WITH LATERAL CONTROL INPUT AND LARGE $\|\phi/\beta\|$ DUTCH ROLL OSCILLATION. HIGH ROLL DUE TO SIDESLIP.	$\dot{\beta}$ TECHNIQUE HELPS STOP OSCILLATIONS.	QUITE A BIT OF ACTIVATION THROUGH THE RUDDER CHANNEL. CONTINUOUS LATERAL INPUTS REQUIRED TO MAINTAIN ±10° STRAIGHT AND LEVEL OR GIVEN BANK ANGLE. AT TIMES INPUTS TENDED TO MAGNIFY SIDESLIP MAGNITUDE.	VERY HIGH ADVERSE YAW AND INTOLERABLE SIDESLIP CAUSES CONTINUOUS DUTCH ROLL OSCILLATIONS.		
	HIGH SENSITIVITY. ABRUPT INITIAL ROLL ACCELERATION AND UNDEFINABLE ROLL RATES. OBJECTIONABLE ADVERSE YAW. ALMOST COMPLETE LACK OF ROLL DAMPING. LARGE ROLL DUE TO SIDESLIP AND LOW DAMPED DUTCH ROLL MODE.	USE SMALL SMOOTH INPUTS. $\dot{\beta}$ TECHNIQUE HELPS DAMP SIDESLIP.	RANDOM OSCILLATIONS MAKE IT DIFFICULT TO HOLD A BANK ANGLE OR STRAIGHT AND LEVEL.	ROLL *RESPONSE* IS ABRUPT AND UNPREDICTABLE. DIFFICULT TO FIND THE AILERON INPUT THAT WILL GIVE ZERO ROLL RATE.	LOW DIRECTIONAL STIFFNESS. LOW DAMPED DUTCH ROLL MODE. MEDIUM TO HIGH ROLL DAMPING. HIGH $\|\phi/\beta\|$.	
CONTROL NOT TOO BAD. DESIR- NTROL POWER AND SENSITIVITY.	LARGE STRONG SIDESLIP INDUCED BY ROLLING MOMENTS THAT TRIGGERS OBJECTIONABLE DUTCH ROLL OSCILLATIONS. STRONG ROLL DUE TO SIDESLIP. GENERATION OF ADVERSE YAW RESTRICTS USE OF LATERAL CONTROL WITH RESPECT TO PRECISE MANEUVERING. LOW DIRECTIONAL STIFFNESS.	NONE REQUIRED.	CARRIES OVER IN HIGH $\|\phi/\beta\|$ CHARACTERISTIC AND CAUSES BANK ANGLE CONTROL PROBLEMS.	DIFFICULT TO ESTABLISH A GIVEN BANK ANGLE.		
NTAIN HEADING REASONABLY WELL.	LATERAL CONTROL SENSITIVITY TOO HIGH. TOO MUCH ROLL ACCELERATION AND ROLL RATE FOR A GIVEN STICK DEFLECTION. LARGE ROLL DUE TO SIDESLIP. UNCERTAIN ROLLING VELOCITY. NOT STIFF ENOUGH DIRECTIONALLY.	KEEP THE GAIN DOWN ON PILOT INPUTS.	RATING NOT NOTICEABLY AFFECTED.	ROLL ACCELERATION IS QUITE ABRUPT. ROLL RATE TOO HIGH. ROLL CONTROL OVERLY SENSITIVE. CONFIGURATION IS MARGINAL FOR THE MISSION.	LOW DAMPED DUTCH ROLL MODE. HIGH $\|\phi/\beta\|$, LOW DIRECTIONAL STIFFNESS.	
BANK ANGLE CONTROL IS QUITE *HEADING CONTROL* IS QUITE GOOD. CONTROL SUFFICES QUITE WELL NORMAL MANEUVERING TASKS. ROLL EXCITATION IS VERY SLIGHT.	NO MAJOR OBJECTIONS. WOULD LIKE A LITTLE GREATER LATERAL CONTROL SENSITIVITY.	NONE REQUIRED.	RANDOM NOISE EVALUATION NOT MADE. HOWEVER *IN LIGHT TO MODERATE TURBULENCE* THERE WERE NO MAJOR OBJECTIONS.	BANK ANGLE AND HEADING CONTROL QUITE GOOD. *LOW ROLL DAMPING FORCES ME TO* MAKE AN OPPOSITE CONTROL INPUT IN STOPPING. QUITE HIGH ROLL DUE TO YAW. ACCEPTABLE SATISFACTORY, FAIR TO GOOD.		
	PROVERSE YAW THAT TRIGGERS HIGHLY OSCILLATORY DUTCH ROLL MODE. MUCH TOO SENSITIVE LATERAL CONTROL. HIGH ROLL DUE TO SIDESLIP.	*EVERYTHING MUST BE DONE QUITE SLOWLY* WITH SMALL INPUTS. INVERSE β TECHNIQUE WAS USEFUL IN DECREASING AMPLITUDE OF RANDOM OSCILLATIONS.	*PROBLEM NOT ALTERED SIGNIFICANTLY BY* RANDOM NOISE.	*CONSTANT ATTENTION REQUIRED TO KEEP* WINGS LEVEL. CAN DO PRETTY GOOD JOB IN A STEEP TURN. HEADING CONTROL FAIR. HIGH ROLL DUE TO SIDESLIP. SENSITIVE LATERAL CONTROL WITH PROVERSE YAW TRIGGERS HIGHLY OSCILLATORY DUTCH ROLL MODE.	HIGH $\|\phi/\beta\|$. QUITE LOW DUTCH ROLL DAMPING, PARTICULARLY AT LOW FREQUENCIES.	
	UNABLE TO FLY IT OPEN LOOP IN BANK ANGLE BECAUSE OF UNSTABLE DIVERGENT SIDESLIP OSCILLATIONS. CONTROLLABLE ONLY WITH COMPLETE ATTENTION. LARGE INITIAL ROLL ACCELERATION. ROLL CONTROL TOO SENSITIVE. HEADING CONTROL DIFFICULT.	NO COMMENT.	NOT BAD IF PILOT GAIN IS KEPT LOW.	DIFFICULT TO FLY IN ROLL. AIRCRAFT WENT DIVERGENT CLOSED LOOP IN SIDESLIP DUE TO AILERON INPUTS. MORE FLYABLE IN STEEP TURNS. ROLL CONTROL TOO SENSITIVE. ROLL DUE TO SIDESLIP PRETTY LARGE. UNABLE TO MAINTAIN BANK ANGLE IN STRAIGHT AND LEVEL FLIGHT. CONTROLLABLE WITH COMPLETE ATTENTION.		

TABLE II-7 SUMMARY OF PILO
FOR INFLIGHT CON

CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABLE FEATU
	GENERAL	AILERON YAW	COORDINATION	FEEL		
B-1	AILERON RESPONSE INITIALLY ABRUPT, THEN SIDESLIP COMES IN AND ROLL RATE SLOWS DOWN. ENCOUNTERED ROLL REVERSAL DUE TO THE QUANTITY OF ADVERSE YAW GENERATED REQUIRING EXCESSIVE LATERAL CONTROL. THIS CAUSED THE SIDESLIP TO BE INTOLERABLE. LIMITED TO SMALL STEP TYPE INPUTS.	TREMENDOUS AMOUNT OF ADVERSE YAW.	NO COMMENT.	HIGH SENSITIVITY, LOW FRICTION BAND, LOW FORCE GRADIENT, LOW BREAKOUT FORCE. STICK CENTERING OK.	NONE.	HIGH ADVERSE YAW RESULTING SLIP DISTURBANCES THAT CULM SIDESLIP DIVERGENCE WITH OVE BANK. LATERAL CONTROL RESTR SLOW SMALL INPUTS.
B-2	ROLL CONTROL TOO SENSITIVE. TOO MUCH ROLL RATE ACCELERATION FOR A GIVEN STICK DEFLECTION. EVEN SMALL INPUTS INDUCE ZERO DAMPED SIDESLIP OSCILLATIONS. CONTINUOUS DUTCH ROLL OSCILLATIONS. COULD NOT MAINTAIN BANK ANGLE.	STRONG ADVERSE YAW	PILOT A - REFUSE TO FLY IT ON THE MISSION WITHOUT RUDDER PEDALS. PILOT B - NO RUDDERS WOULD BE REQUIRED IF THEY WERE AVAILABLE TO COORDINATE SMALL BANK ANGLE CHANGES.	HIGH SENSITIVITY, HIGH CONTROL POWER, INSIGNIFICANT BREAKOUT FORCE, SMALL FRICTION BAND, POOR STICK CENTERING.	STABILIZED HEADING CONTROL IS QUITE GOOD.	SENSITIVE LATERAL CONTROL. LO DAMPING, STRONG ADVERSE YAW A SULTING HIGHLY OSCILLATORY DU MODE. LACK OF DIRECTIONAL ST
B-2A	SLIGHTEST DEFLECTION CAUSES DUTCH ROLL OSCILLATION.	VERY HIGH ADVERSE YAW.	I THINK THAT RUDDERS WOULD NOT HELP.	LOW BREAKOUT FORCE, LIGHT FORCE GRADIENT, POOR STICK CENTERING, MEDIUM TO HIGH LATERAL CONTROL POWER,	HEADING CONTROL GOOD.	THE INTOLERABLE MAGNITUDE OF VERY HIGH ADVERSE YAW WITH LA CONTROL INPUT AND LARGE $\lvert\phi/\beta$ ROLL OSCILLATION. HIGH ROLL SIDESLIP.
B-3	UNPREDICTABLE ROLL RESPONSE DUE TO SIDESLIP INDUCED. CONTROL TOO SENSITIVE, ABRUPT, TEND TO OVERSHOOT IN SMALL BANK ANGLE CHANGES. ROLL ACCELERATION CAPABILITY TOO GREAT. YOU GET A SUSTAINED SIDESLIP OSCILLATION THAT IS NEITHER CONVERGENT NOR DIVERGENT.	OBJECTIONABLE ADVERSE YAW.	PILOT A - RUDDER PEDAL DESIRABLE AND WOULD IMPROVE RATING. PILOT B - NO COORDINATION WITH RUDDER REQUIRED.	ROLL SENSITIVITY IS SO HIGH YOU TEND TO OPERATE IN THE BREAKOUT REGION ALL THE TIME. LIGHT FORCE GRADIENT, POOR STICK CENTERING.	NONE.	HIGH SENSITIVITY. ABRUPT INI ROLL ACCELERATION AND UNDEF'L ROLL RATES. OBJECTIONABLE AD YAW, ALMOST COMPLETE LACK OF DAMPING. LARGE ROLL DUE TO S AND LOW DAMPED DUTCH ROLL MOD
B-3A	GOOD LATERAL CONTROL POWER IN CONJUNCTION WITH THE LATERAL SENSITIVITY. OK FOR SMALL BANK ANGLE CHANGES BUT OBJECTIONABLE FOR LARGE CHANGES. FOR SMOOTH CHANGES IN BANK ANGLE YOU ARE RESTRICTED TO ±½ INCH DEFLECTION.	GENERALLY PRETTY SMALL AND ADVERSE. IF I LOOK AT THE YAW RATE INDICATOR, THE YAWING ACCELERATION DUE TO ROLL CONTROL IS ZERO BUT IT DOES INDUCE ADVERSE SIDESLIP.	PILOT A - LACK OF RUDDER CONTROL DEGRADES CONFIGURATION. NOT NECESSARY FOR SLOW CAUTIOUS MANEUVER. PILOT B - RUDDERS NOT REQUIRED OR DESIRED.	LOW BREAKOUT FORCE, LOW FRICTION BAND, VERY LIGHT GRADIENT, MEDIUM POWER CONTROL, POOR STICK CENTERING.	HEADING CONTROL NOT TOO BAD. DESIRABLE CONTROL POWER AND SENSITIVITY.	LARGE STRONG SIDESLIP INDUCED ING MOMENTS THAT TRIGGERS OBJ ABLE DUTCH ROLL OSCILLATIONS. ROLL DUE TO SIDESLIP. GENERA ADVERSE YAW RESTRICTS USE OF CONTROL WITH RESPECT TO PREC NEUVERING. LOW DIRECTIONAL
B-4	TOO SENSITIVE AND ABRUPT WITH TOO MUCH ROLL ACCELERATION AND ROLL RATE FOR A GIVEN DEFLECTION.	QUITE SMALL ADVERSE YAW. IF YOU LOOK AT YAW RATE INDICATOR IT'S ABOUT ZERO. RELATIVELY INSIGNIFICANT SIDESLIP INDUCED BY AILERON.	NO COMMENT.	HIGH SENSITIVITY, HIGH CONTROL POWER, LOW BREAKOUT FORCE, LOW FORCE GRADIENT	CAN MAINTAIN HEADING REASONABLY WELL.	LATERAL CONTROL SENSITIVITY TOO MUCH ROLL ACCELERATION A RATE FOR A GIVEN STICK DEFLE LARGE ROLL DUE TO SIDESLIP. TAIN ROLLING VELOCITY. NOT ENOUGH DIRECTIONALLY.
B-4A	COULD ESTABLISH AND MAINTAIN BANK ANGLE OR HEADING EASILY. COULD USE FULL DEFLECTION. COULD BE A LITTLE MORE SENSITIVE.	VERY SLIGHT ADVERSE YAW. JUST A LITTLE SIDESLIP EXCITATION.	NOT REQUIRED.	LOW BREAKOUT FORCE, LOW FRICTION BAND, LOW TO MEDIUM FORCE GRADIENT. LOW TO MEDIUM SENSITIVITY, LOW TO MEDIUM CONTROL POWER.	OVERALL BANK ANGLE CONTROL IS QUITE GOOD. HEADING CONTROL IS QUITE GOOD. LATERAL CONTROL SUFFICES QUITE WELL FOR THE NORMAL MANEUVERING TASKS. DUTCH ROLL EXCITATION IS VERY SLIGHT.	NO MAJOR OBJECTIONS. WOULD LITTLE GREATER LATERAL CONT SENSITIVITY.
B-5	MUCH TOO SENSITIVE. CAN USE ONLY SMALL INPUTS.	BAD PROVERSE YAW.	NO COMMENT.	LOW BREAKOUT FORCE, SMALL FRICTION BAND, LIGHT FORCE GRADIENT, HIGH SENSITIVITY, MEDIUM TO HIGH CONTROL POWER, POOR STICK CENTERING.	NONE.	PROVERSE YAW THAT TRIGGERS OSCILLATORY DUTCH ROLL MODE. TOO SENSITIVE LATERAL CONTRO ROLL DUE TO SIDESLIP.
B-5X	COULDN'T ACHIEVE A TRIMMED FLIGHT CONDITION. USE OF AILERONS CAUSED THE AIRPLANE TO BE DIVERGENT CLOSED LOOP IN SIDESLIP (OSCILLATORY DIVERGENCE). DID NOT INDUCE SIDESLIP IN STEEP TURNS LIKE THEY DID IN STRAIGHT AND LEVEL FLIGHT. OVERLY SENSITIVE. INITIALLY ABRUPT.	SMALL AND PROVERSE	WOULD LIKE TO HAVE RUDDER PEDALS.	OVERLY SENSITIVE.	NONE.	UNABLE TO FLY IT OPEN LOOP I ANGLE BECAUSE OF UNSTABLE DI SIDESLIP OSCILLATIONS. CONT ONLY WITH COMPLETE ATTENTION. INITIAL ROLL ACCELERATION. TROL TOO SENSITIVE. HEADING TROL DIFFICULT.

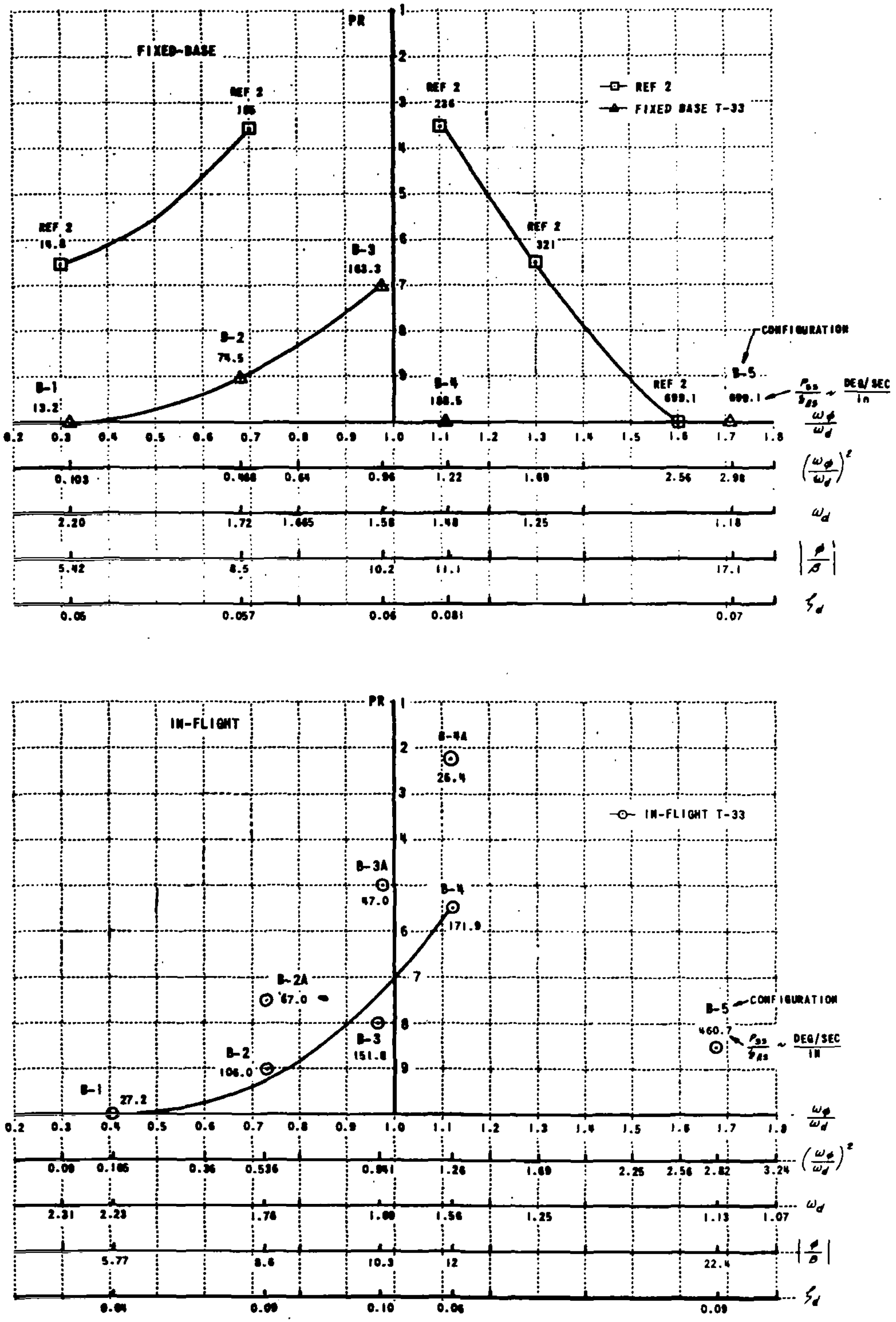


Figure II-1 Composite Pilot Ratings

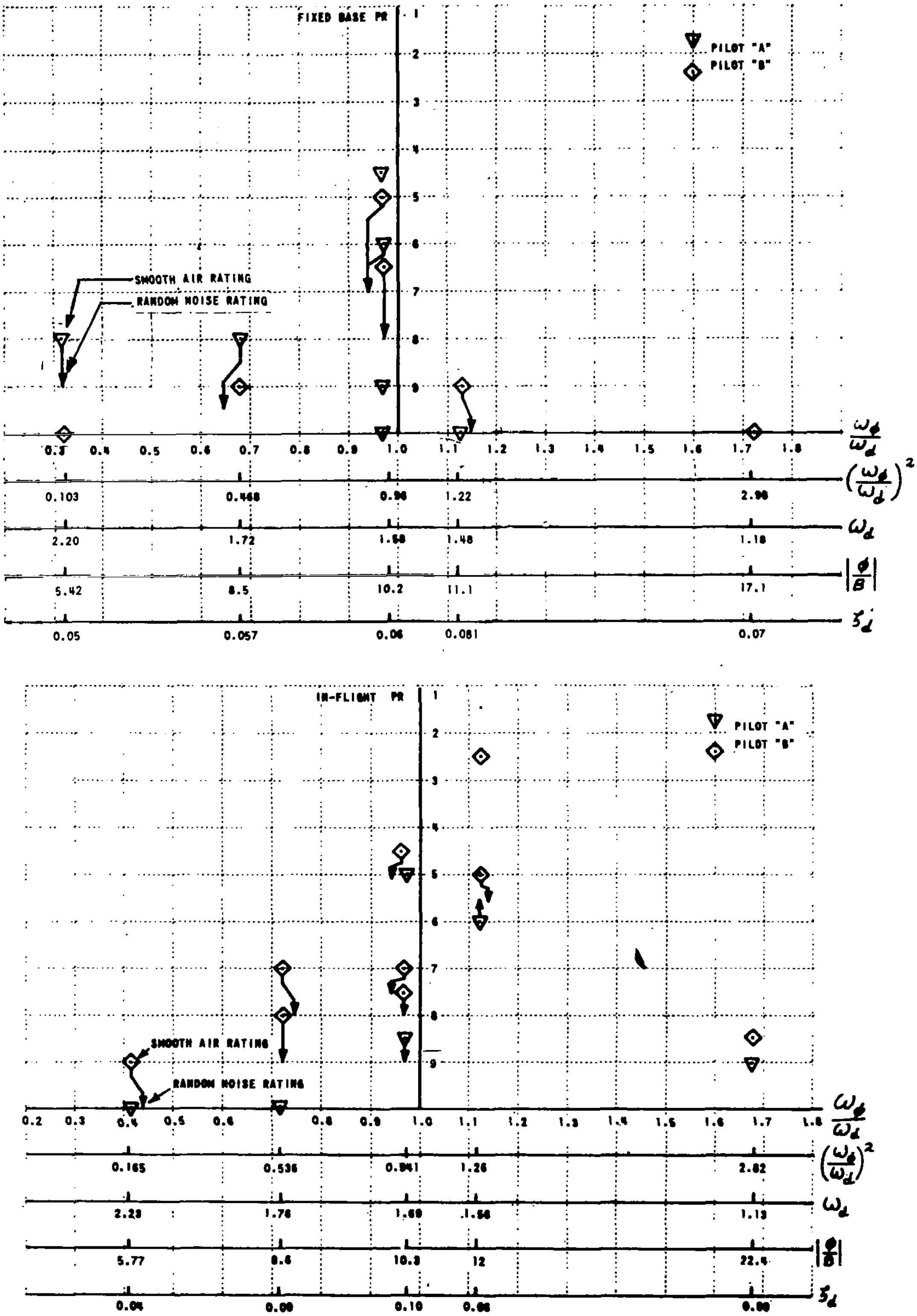


Figure II-2 Pilot Ratings

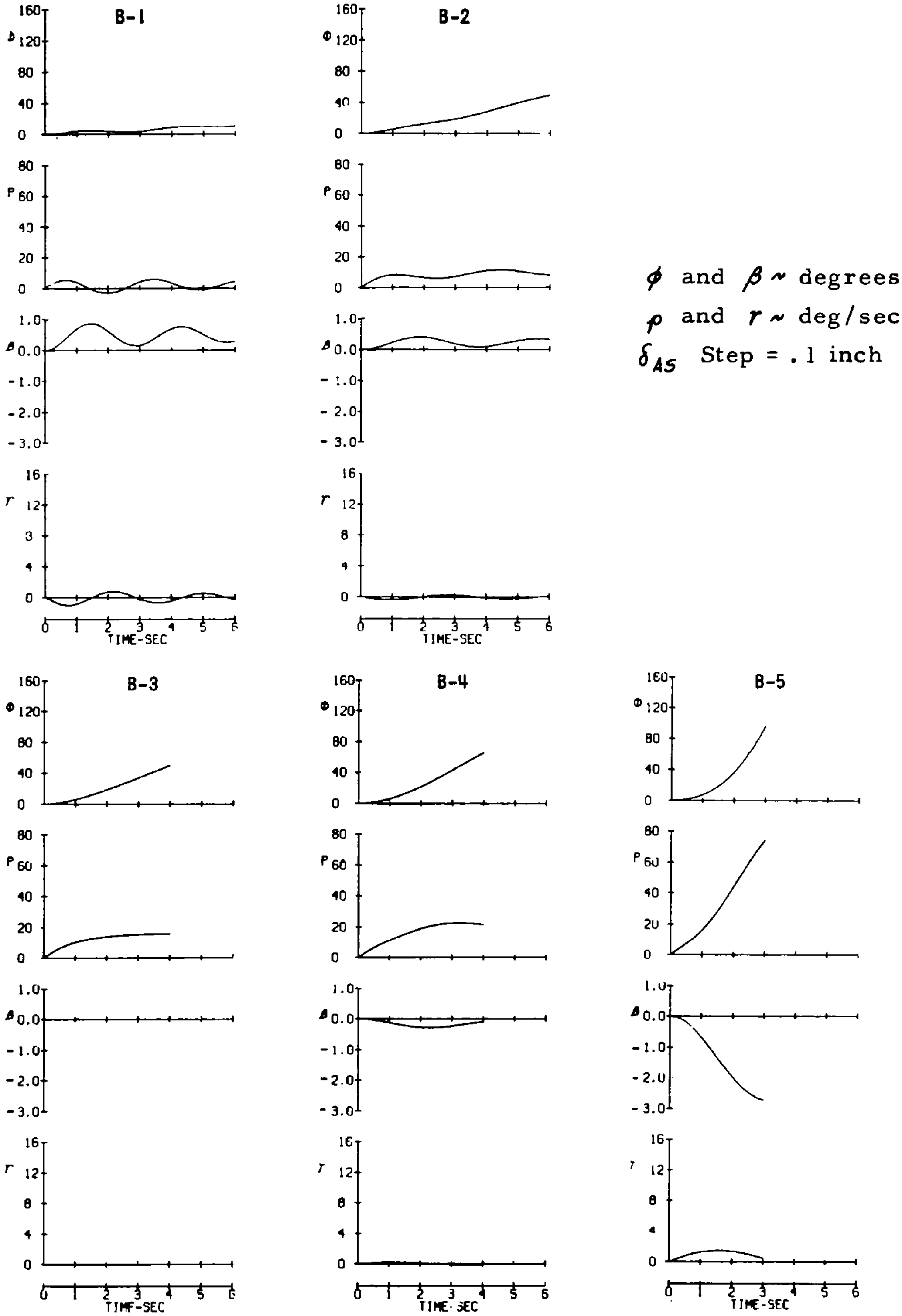
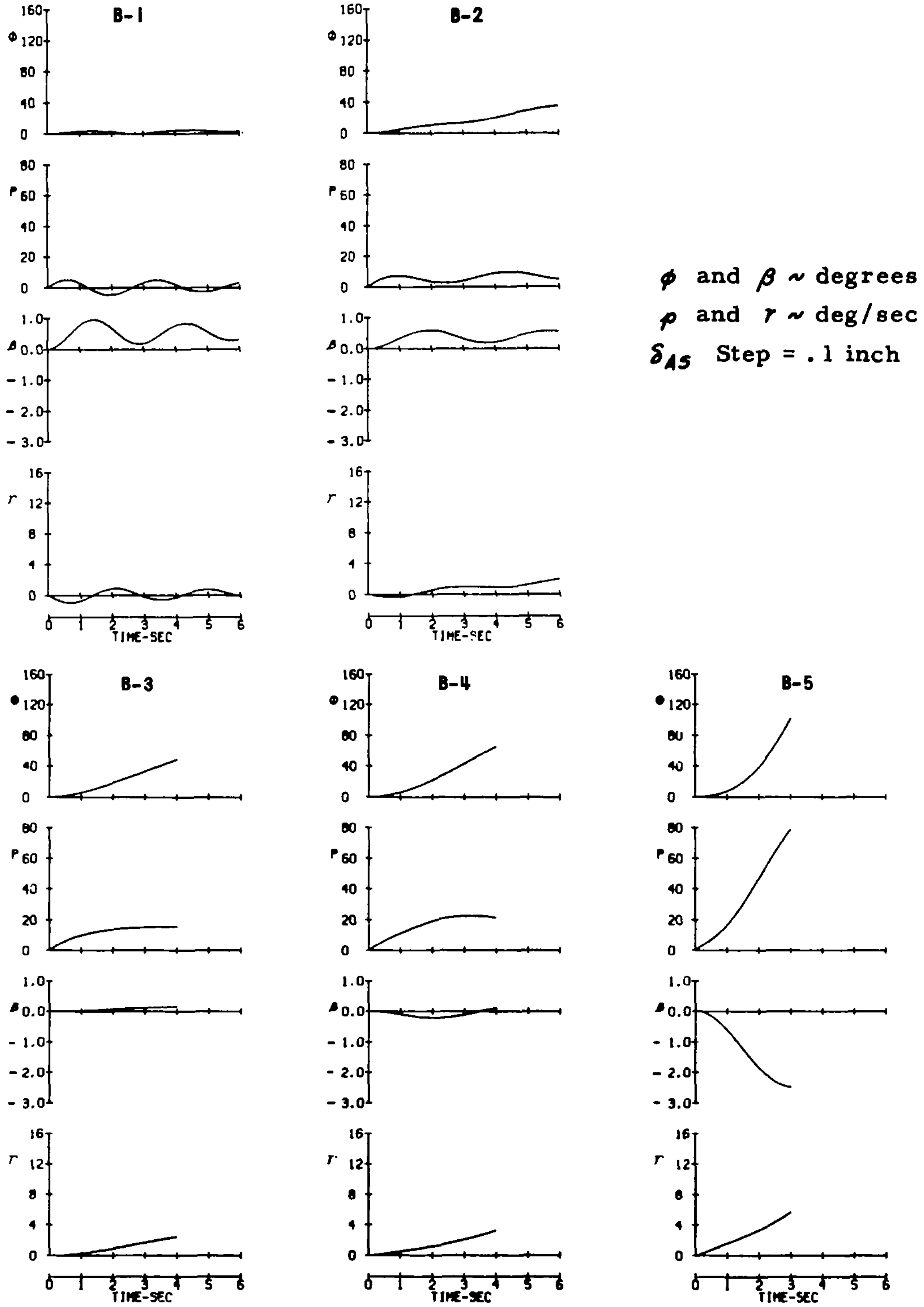
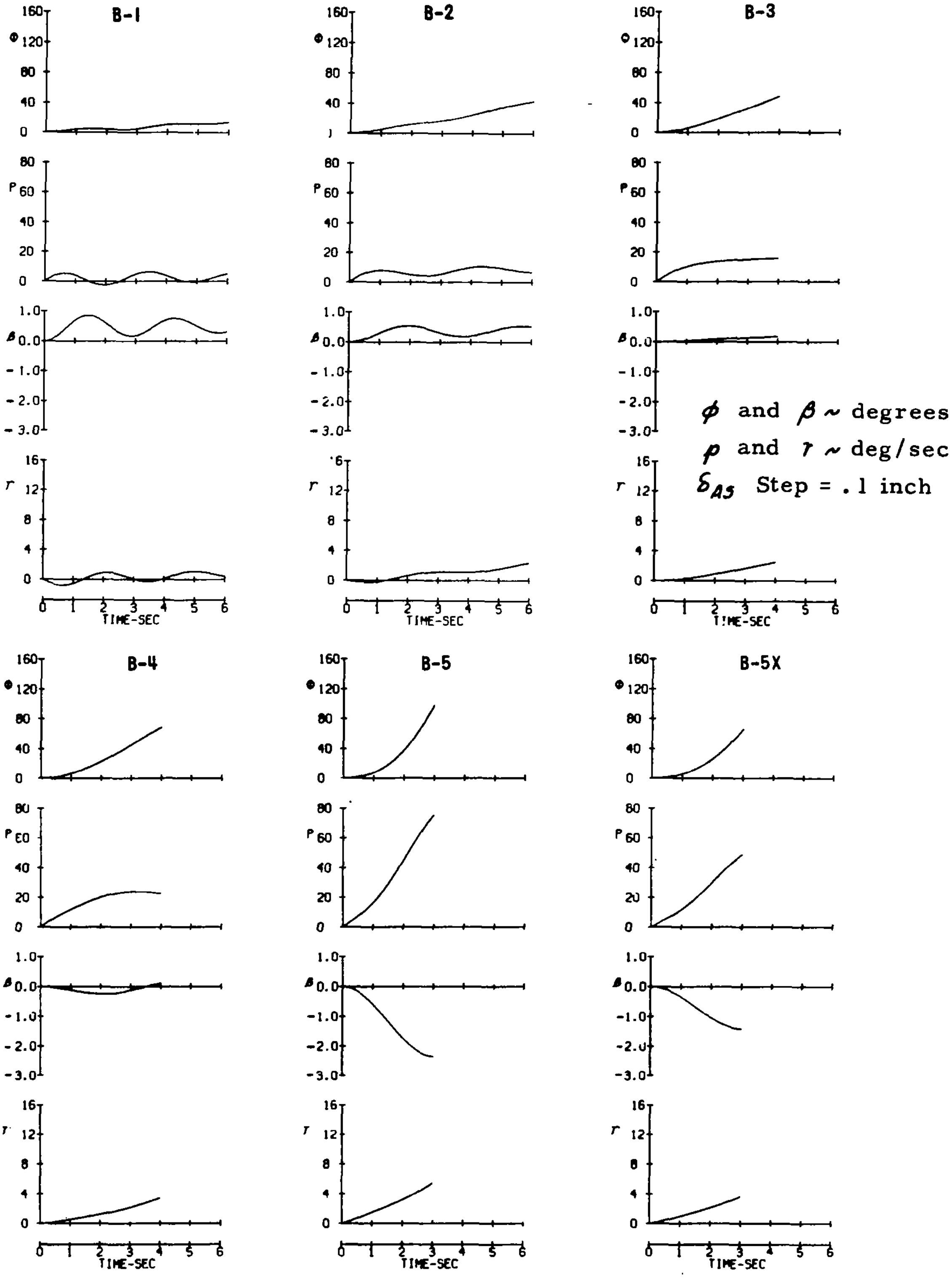


Figure II-3 Transient Responses To Aileron Stick Step Calculated From NASA Derivatives



ϕ and β ~ degrees
p and r ~ deg/sec
δ_{AS} Step = .1 inch

Figure II-4 Transient Responses To Aileron Stick Step Calculated For Fixed-Base Configurations From Pseudoderivatives

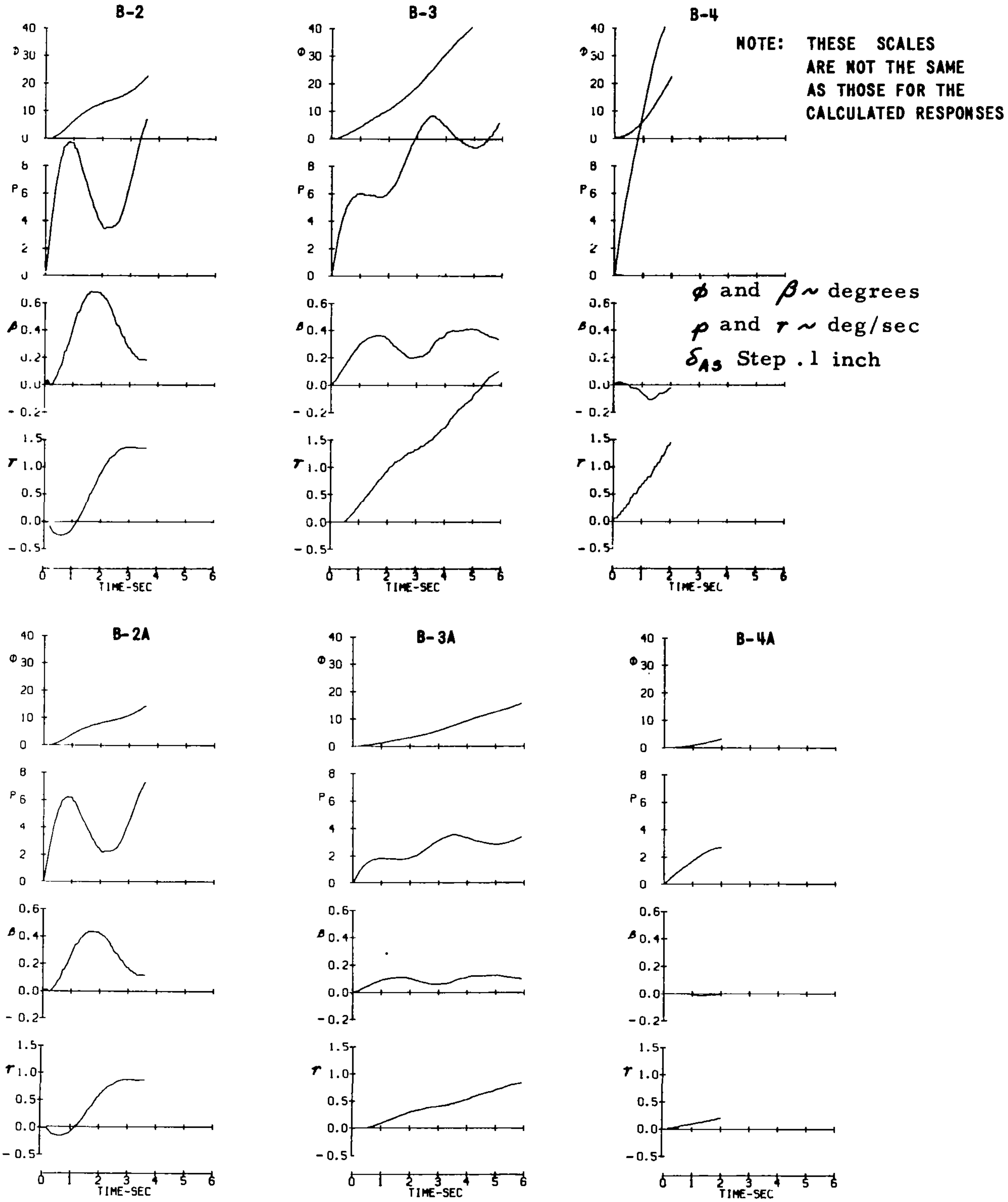


ϕ and β ~ degrees

p and r ~ deg/sec

δ_{AS} Step = .1 inch

Figure II-5 Transient Responses To Aileron Stick Step Calculated For In-Flight Configurations From Pseudoderivatives



NOTE: THESE SCALES ARE NOT THE SAME AS THOSE FOR THE CALCULATED RESPONSES

ϕ and β ~ degrees
p and r ~ deg/sec
δ_{AS} Step .1 inch

Figure II-6 Transient Responses To Aileron Stick Step From Flight Records Normalized To .1 Inch δ_{AS} Step

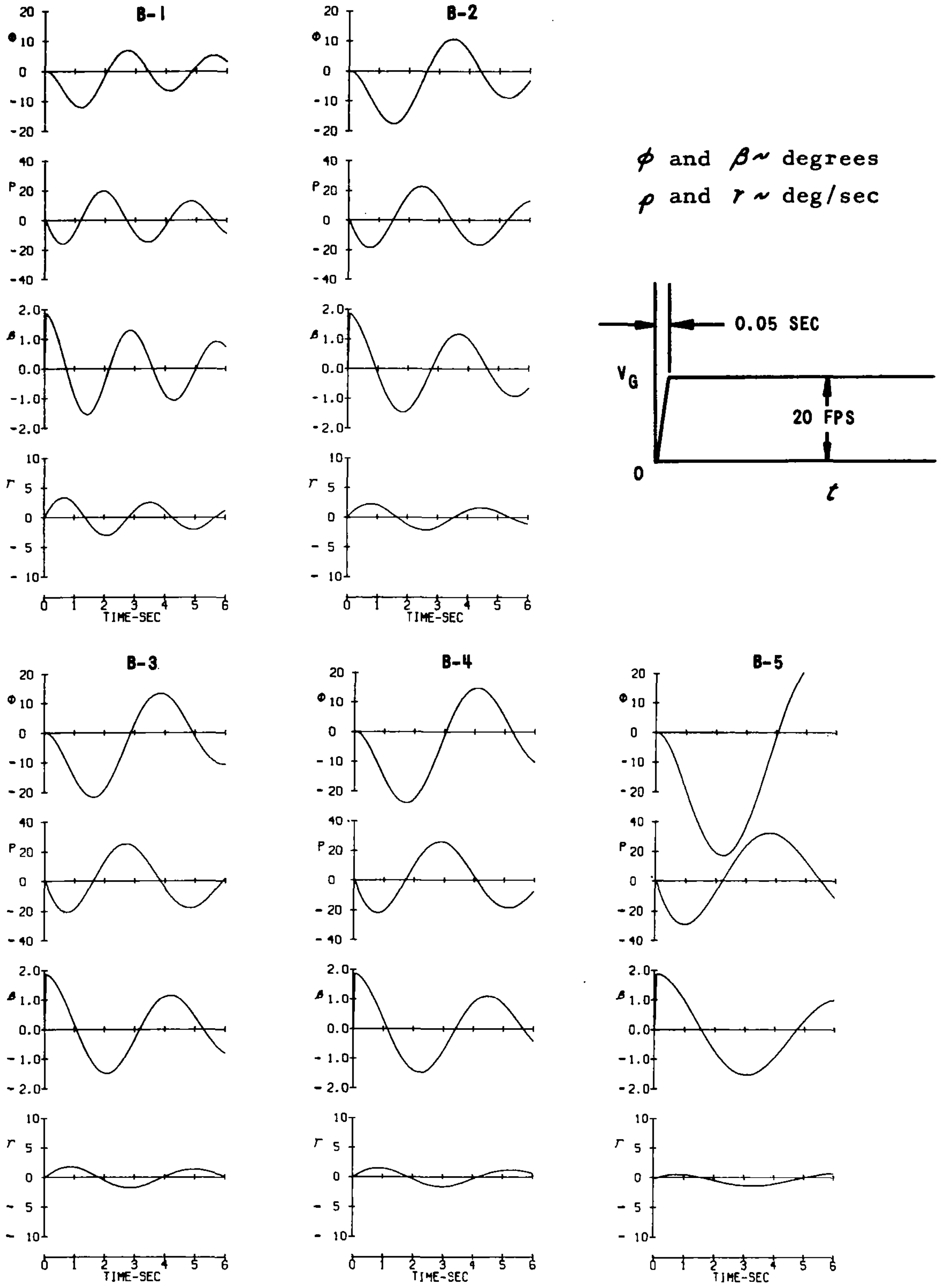


Figure II-7 Transient Responses To Side Gust Calculated From Pseudoderivatives

GROUND SIMULATOR CONFIGURATIONS

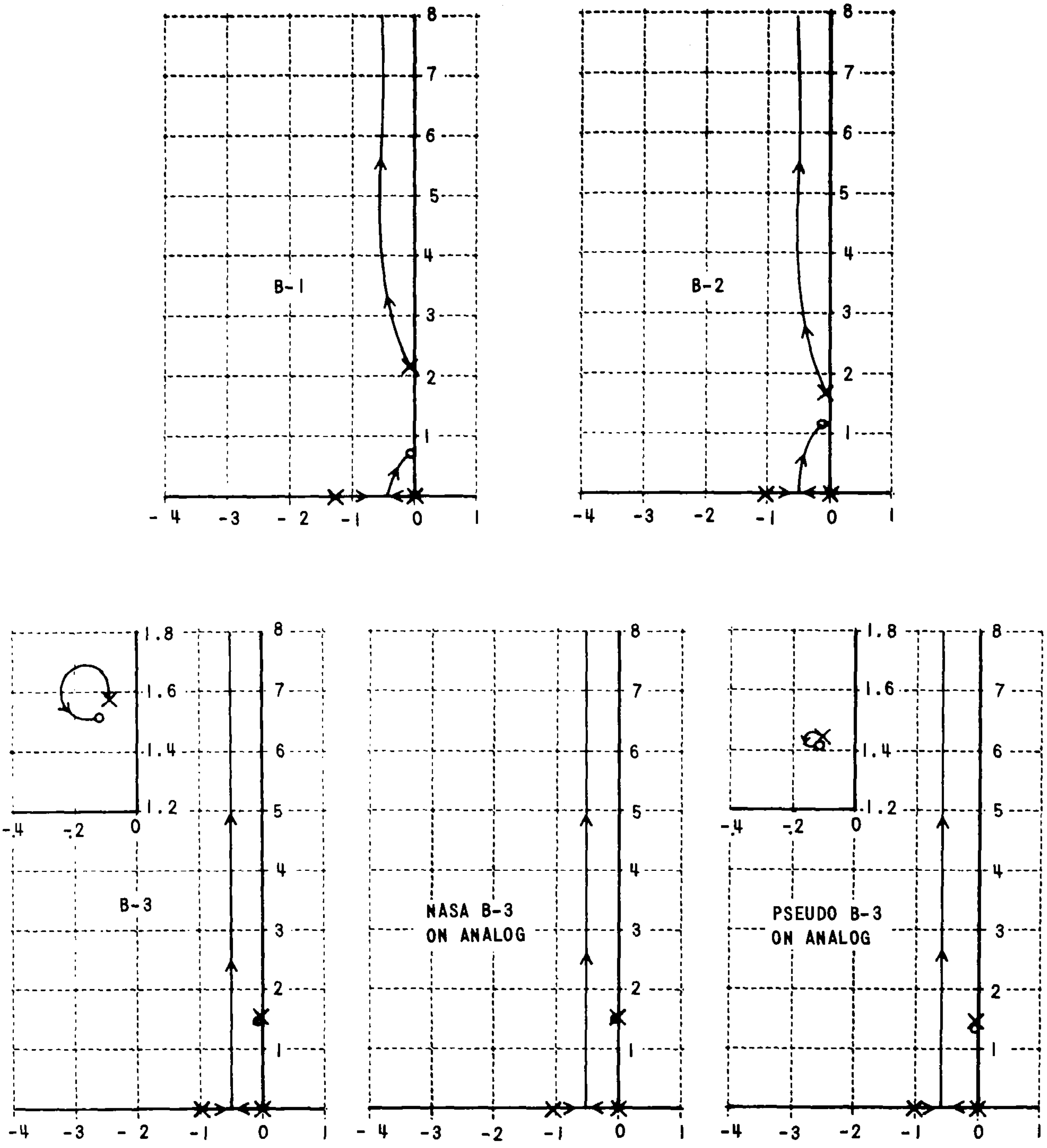


Figure II-8 Root Locus Diagrams of Fixed-Base Configurations Varying Pilot Gain Closure of Aileron to Bank Angle Loop

3.5 PART III EXPERIMENT

In Part III, specific configurations were evaluated to supplement handling qualities investigations of lifting body designs being conducted by the NASA Flight Research Center. The flight program consisted of four groups of three configurations each. The three configurations in each group had the same characteristic equation and the same rudder control but different aileron control derivatives. The four groups represented different phases of the re-entry mission. One group was evaluated during a steep spiral descent to a landing approach but the others were evaluated in up-and-away flight under the same conditions as Parts I and II. All four evaluation pilots evaluated the descent configurations and three evaluated the other groups.

The fixed-base evaluation program was quite limited with only four configurations being evaluated once by each of two pilots. The same configurations were not evaluated in flight because there was more interest in other configurations when the Part III flight program was conducted approximately two months later.

The results of Part III of the experiment are presented in the Part III Data section, where individual pilot ratings and composite ratings are plotted and the pilot comments are summarized. In addition the response of these configurations to side gusts is discussed.

3.5.1 Configurations 1-D, 1-E, 1-F' (Spiral Descent - In-Flight)

These configurations were evaluated in flight while flying the profile shown in Figure 7 (Section 2). This consisted of a 270° turn during a steep descent from 23,000 ft. to 2,800 ft. The lift/drag ratio was maintained at $\frac{L}{D} \approx 2.5$ during the descent by using idle power and full extension of the T-33 drag petals. The random noise disturbance was not used during the descent because of the limited evaluation time (less than two minutes). The level of turbulence, however, was noted and recorded by the pilots for each evaluation. The pilot rating numbers and comments control." Adverse aileron yaw and the associated Dutch roll excitation was the major objection to configuration 2-D. Configuration 2-F was objectionable because of its proverse aileron yaw and the resulting tendency toward a lateral PIO and the large roll response to aileron control. Possibility of a closed-loop oscillation for 2-F is indicated by the root locus diagram in Figure III-15.

Reference to the transient responses to aileron stick steps in Figure III-8 and 9 shows increasing roll response to aileron on the calculated responses as the aileron yaw becomes more proverse. This is in agreement with the pilot comments. The roll acceleration due to aileron, $L'_{\delta_{AS}}$, for 2-D and 2-E was within the optimum range previously noted from reference 8. Configuration 2-F, with the large proverse aileron yaw, had objectionably large rolling motions for aileron inputs even though the $L'_{\delta_{AS}}$ was lower than the optimum.

The pilots objected to the sensitive rudder control which, with the large dihedral effect, resulted in large rolling motions. It should be noted that the wrong rudder set-up was used for some of these evaluations. Transient responses for a rudder step input are shown in Figure III-12. Large rolling responses to sideslip disturbances was a common objection to all three configurations. Reference to the pilot ratings in Figure III-5 shows a trend for all configurations to be downrated to approximately the same level after being evaluated with the random noise disturbance. This indicates that the other objections to the configurations were masked by the greater objections to their response to disturbances. The transient responses to side gusts shown in Figure III-13 show that the pseudoderivative configuration has a much larger response than the NASA configuration for the same velocity side gust. This is because the same gust velocity produces a smaller β disturbance with the higher velocity NASA configuration. Whether the objectionable response to disturbances would be valid for an actual re-entry vehicle depends upon the disturbances that would be encountered and this has not been well defined. See Appendix E for a discussion of roll response to sideslip disturbances.

The pilots did not object to the longitudinal characteristics, and these characteristics did not influence the lateral-directional evaluations. The longitudinal characteristics are listed in Table III-4.

3.5.3 Configurations 3-D, 3-E, 3-F (In-Flight)

The composite pilot ratings derived from the up-and-away flight evaluations of these configurations are plotted on Figure III-2. The pilot comments were in agreement with the specified lateral-directional modes. Aileron yaw was correctly noted for the configurations but was not a major objection except for 3-F where the proverse aileron yaw caused oscillations when precise control of bank angle with aileron was attempted. The $|\phi/\beta|$ of 2.5, which is low compared to the other Part III configurations, tends to make the aileron yaw less objectionable. Although the lightly damped Dutch roll was almost continuously excited, it did not present a major problem in control of the airplane. The major objection was the acceleration ordering feature of aileron control with low sensitivity.

The low aileron sensitivity was especially objectionable during the evaluations with random noise disturbances because of the large stick deflections required to control the airplane. The $L'_{\delta_{AS}}$ values were lower than the optimum values for acceleration control taken from Reference 8.

The rudders were used to help establish the desired roll rates but the pilot comments indicate that they did not play an important part in the lateral-directional evaluations. Again pilots A and B evaluated part of these configurations with the wrong rudder pedal forces. The rudder set up of Part I was used for several of the initial evaluations.

3.5.4 Configurations 4-D, 4-E, 4-F' (In-Flight)

The composite pilot ratings derived from the up-and-away flight evaluation of these configurations are plotted on Figure III-2. They are basically acceleration-ordering in roll control with a lightly damped, high $|\phi/\beta|$ Dutch roll mode. These characteristics were verified by the pilot comments. A major objection to these configurations was the acceleration-ordering aileron control with very low control power. $L'_{\delta_{AS}}$ decreased

f
v
m
4
l
f

F
a

r
a
t
h
p
d

s
c
f

3

a
f

TABLE III-1 IN-FLIGHT SIMULATION CONFIGURATIONS

		1-D, E, F'		2-D, E, F,		3-D, E, F,		4-D, E, F'	
	Config.	NASA	Pseudo	NASA	Pseudo	NASA	Pseudo	NASA	Pseudo
Derivatives	g/V	.0644	.0659	.03024	.0525	.03024	.0525	.01636	.0525
	L'_β	-132.6	-132.2	-59.95	-59.97	-64.19	-64.12	-42.89	-42.91
	$L'_{\dot\beta}$	0	.003726	0	-.002026	0	-.2616	0	-.07987
	L'_p	-.7874	-.9791	-.2494	-.2779	-.09885	-.06856	-.1051	-.1106
	L'_r	1.936	1.892	.4495	.2589	.4340	.2500	.1801	.05612
	N'_β	24.54	24.36	9.787	9.788	25.07	25.03	5.326	5.328
	$N'_{\dot\beta}$	0	-.3510	0	-.09269**	0	-.1938	0	-.08285
	N'_p	.1387	.1761	.02929	.05620	.01383	.02426	.01527	.05209
	N'_r	-.9826	-.9602	-.1461	-.08415	-.2972	-.1712	-.07092	-.02210
	Y_β	-.368	-.55	-.1038	-.23	-.1049	-.43	-.0438	-.18
	Y_p	0	0	0	0	0	0	0	0
	Y_r	0	0	0	0	0	0	0	0
Calculated modes	ω_d	4.982	4.982	3.127	3.127	5.007	5.007	2.307	2.307
	ζ_d	.1771	.1771	.03900	.03900	.03596	.03596	.02296	.02296
	$\left\|\frac{\phi}{\beta}\right\|$	5.373	5.373	6.125	6.125	2.560	2.560	8.058	8.058
	$\measuredangle \frac{\phi}{\beta}$	-7.12°	-5°	1.4°	1.40°	-1.05°	-1.05°	.535°	.535°
	τ_R or $\zeta_{RS}{}^*$	.4032*	.4032*	5.528	5.528	.7081*	.7081*	.7118*	.7118*
	τ_s or $\omega_{RS}{}^*$	.4634*	.4634*	13.41	13.41	.09943*	.09943*	.08003*	.08003*
In-flight nominal measured modes	ω_d		5.1		3.39		5.23		2.28
	ζ_d		.18		.0612		.0424		.0322
	$\left\|\frac{\phi}{\beta}\right\|$		5.2		5.39		2.47		8.58
	τ_R or $\zeta_{RS}{}^*$		.4*		--		--		--
	τ_s or $\omega_{RS}{}^*$		.45*		--		--		--

** Average

TABLE III-2 IN-FLIGHT SIMULATION CONTROL DERIVATIVES AND NUMERATOR ZEROS

	Config.	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$N'_{\delta_{RP}}$	$L'_{\delta_{RP}}$	$Y_{\delta_{RP}}$
NASA config.	1-D	-.0825	.5975	0	-.1381	.258	.508	2.528	.1810	.2577	.4443	-.002093
	1-E	.02570	.3931	↓	.06538	1.350	1.161	5.784	.1056	↓	↓	↓
	1-F[1]	.1232	.2092		.590	4.16	2.04	10.17	.1117			
Pseudo config.	1-D	-.0830	.5975	0	-.1389	.258	.508	2.528	.178	.2580	.4440	---
	1-E	.02525	.3931	↓	.06424	1.35	1.161	5.784	.1107	↓	↓	---
	1-F[1]	.1232	.2092		.590	4.16	2.04	10.17	.1225			
In-flight config.	1-D	-.0865	.601	.00112	-.144	.238	.488	2.488	.129	.259	.446	-.00321
	1-E	.025	.385	-.000267	.065	1.344	1.160	5.913	.118	↓	↓	↓
	1-F[1]	.1245	.215	-.00153	.580	4.071	2.019	10.29	.157			
NASA config.	2-D	-.03166	.3311	0	-.09562	.415	.644	2.016	.04597	.1042	-.2503	-.0003457
	2-E	.006772	.2376	↓	.02850	1.178	1.085	3.393	.03428	↓	↓	↓
	2-F	.04551	.1450		.3139	2.92	1.71	5.351	.03193			
Pseudo config.	2-D	-.0316	.3311	0	-.0954	.415	.644	2.016	.0486	.1042	-.2503	---
	2-E	.00675	.2376	↓	.02841	1.178	1.085	3.393	.03373	↓	↓	↓
	2-F	.0454	.1450		.3131	2.92	1.71	5.351	.0282			
In-flight config.	2-D	-.0289	.328	.000436	-.088	.524	.724	2.454	.0266	.102	-.250	-.00134
	2-E	.0075	.234	-.0000319	.032	1.173	1.081	3.672	.0347	↓	↓	↓
	2-F	.0437	.142	-.00052	.310	2.676	1.635	5.545	.0487			

TABLE III-3 IN-FLIGHT SIMULATION CONTROL DERIVATIVES AND NUMERATOR ZEROS

	Config.	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$N'_{\delta_{RP}}$	$L'_{\delta_{RP}}$	$Y_{\delta_{RP}}$
NASA config.	3-D	-.07783	.2411	0	-.3228	.174	.417	2.088	.05512	.06926	.1936	-.0003268
	3-E	-.02331	.1770	↓	-.1317	.663	.814	4.079	.03698	↓	↓	↓
	3-F	.03099	.1139	↓	.2721	1.70	1.303	6.525	.03471	↓	↓	↓
Pseudo config.	3-D	-.0776	.2411	0	-.3219	.174	.417	2.088	.0639	.06926	.1936	---
	3-E	-.0234	.1770	↓	-.1322	.663	.814	4.079	.0327	↓	↓	---
	3-F	.03099	.1139	↓	.2721	1.70	1.303	6.525	.04380	↓	↓	---
In-flight config.	3-D	-.0792	.246	.00102	-.322	.204	.452	2.362	-.00445	.0699	.194	-.000823
	3-E	-.0225	.176	.000312	-.128	.684	.827	4.326	.0667	↓	↓	↓
	3-F	.0308	.107	-.000359	.288	1.712	1.309	6.843	.0576	↓	↓	↓
NASA config.	4-D	-.004297	.09688	0	-.04435	.644	.803	1.851	.02606	.04342	-.09486	-.0000729
	4-E	.01180	.06170	↓	.1912	2.55	1.598	3.679	.01809	↓	↓	↓
	4-F[1]	.02154	.04059	↓	.531	5.32	2.306	5.302	.01805	↓	↓	↓
Pseudo config.	4-D	-.00429	.09688	0	-.04428	.644	.803	1.851	.0278	.04342	-.09486	---
	4-E	.01179	.06170	↓	.1911	2.55	1.598	3.679	.01838	↓	↓	---
	4-F[1]	.02154	.04059	↓	.531	5.29	2.30	5.300	.01984	↓	↓	---
In-flight config.	4-D	-.0045	.100	.0000748	-.045	.613	.796	1.785	.0247	.0436	-.0955	-.000554
	4-E	.0126	.063	-.000129	.200	2.718	1.65	3.759	.0340	↓	↓	↓
	4-F[1]	.0218	.042	-.000258	.520	5.467	2.338	5.331	.0443	↓	↓	↓

TABLE III-4 CONTROL FEEL AND PITCH DYNAMICS FOR IN-FLIGHT CONFIGURATIONS

Aileron stick spring rate, ~ lb/in	2.8*
Aileron stick breakout force, ~ lb	±.71
Rudder pedal spring rate, ~ lb/in	19*
Rudder pedal breakout force, ~ lb	±7.9
Elevator stick spring rate, ~ lb/in	4.2
Short period frequency, ω_n ~ rad/sec	3.35*
Short period damping ratio, ζ	.38*
Short period frequency for descents, ω_n rad/sec	2.4*
Short period damping ratio for descents, ζ	.25*
Stick force per "g" ~ lb/g	5.2
δ_{ES} ~ in.	+7.75, -3.5
δ_{AS} ~ in.	±6
δ_{RP} ~ in.	±4

*nominal values from flight records

Table III-5

TURBULENCE EXPERIENCED DURING IN-FLIGHT DESCENT EVALUATIONS

CONFIGURATION	EVALUATION PILOT	FLIGHT NUMBER	PILOT RATING	PILOT COMMENTS ON TURBULENCE
I-D	A	528-2	9	FAIR AMOUNT, SOME PRETTY STRONG GUSTS.
	A	529-2	5-1/2	SOME
	B	532-2	3-1/2	LITTLE, DID NOT AFFECT RATING.
	B	537-3	3-1/2	SOME GUSTING, CAUSED $\Delta\phi$ OF 20°.
	B	545-4	2-1/2	LIGHT, CAUSED $\Delta\phi$ OF 10°.
	C	530-3	2	FAIR AMOUNT, LIGHT TO MEDIUM
	C	538-4	3	LIGHT
	D	541-2	4-1/2	LIGHT
	D	541-2	5-1/2	MODERATE
	D	542-2	4	LIGHT
	D	544-4	4	LIGHT
I-E	A	526-2	9	STRONG NEAR GROUND
	A	227-2	7	LITTLE BIT, SOME
	A	529-3	6	LIGHT
	B	533-4	4	LITTLE ON LOW PORTION OF APPROACH
	B	539-4	3	LIGHT, CAUSED $\Delta\phi$ OF 10°
	C	531-3	6	QUITE A BIT
	C	536-4	4	FEW GUSTS
	C	546-3	3	VERY LIGHT
	D	541-4	4-1/2	LIGHT TO MODERATE
	D	542-4	3-1/2	LIGHT ONLY
	D	544-2	4	LIGHT
I-F'	A	528-3	10	HIT TURBULENCE JUST PRIOR TO FLARE
	A	529-4	10	SOME
	B	535-4	5	LIGHT
	B	540-4	4-1/2	LIGHT
	B	545-3	4-1/2	LIGHT, CAUSED $\Delta\phi$ OF 10°-15°
	C	534-4	5	LIGHTER THAN USUAL
	C	543-4	8	MODERATE NEAR GROUND
	C	546-4	9	MODERATE NEAR GROUND
	D	542-3	4-3/4	LIGHT ONLY
	D	544-3	5	LIGHT

TABLE III-7 FIXED-BASE PILOT RATINGS

Config.	Pilot/Run	Pilot Rating Smooth Air / Random Noise	ω_ϕ	ζ_ϕ	ω_d	ζ_d	τ_R or ζ_{RS}*	τ_S or ω_{RS}*	$L'_{\delta_{AS}}$
1-A	B/26	3/3.5	2.17	.9832	4.042	.8435	.4710*	1.303*	.56
1-A	A/33	4.5/5	2.17	.9832	4.042	.8435	.4710*	1.303*	.56
1-B	B/27	2.5/4	3.242	.7207	2.838	.6292	.318	.915	.536
1-B	A/34	4/4	3.242	.7207	2.838	.6292	.318	.915	.536
1-C	B/29	3/4	4.190	.6142	3.352	.4043	.232	1.75	.489
1-C	A/32	4/4	4.190	.6142	3.352	.4043	.232	1.75	.489
1-F	B/28	4/6.5	3.981	.1476	3.101	.1789	.5093*	.7235*	.473
1-F	A/35	5.5/7	3.981	.1476	3.101	.1789	.5093*	.7235*	.473

TABLE III-8 FIXED-BASE SIMULATION CONFIGURATIONS

		1-A		1-B		1-C		1-F	
	Config.	NASA	Pseudo	NASA	Pseudo	NASA	Pseudo	NASA	Pseudo
Derivatives	g/V	.0644	.0543	.0644	.0543	.0644	.0543	.0644	.0543
	L'_β	-119.5	-121.3	-119.5	-120.9	-119.5	-120.1	-119.5	-119.5
	$L'_{\dot\beta}$	0	1.003	0	-.9917	0	-.0767	0	.5
	L'_p	-3.425	-3.328	-3.201	-3.037	-2.972	-2.866	-.7136	-.7136
	L'_r	6.861	8.497	6.853	8.476	6.845	8.455	1.312	1.59
	N'_β	10.85	11.19	10.85	11.20	10.85	11.12	10.85	10.85
	$N'_{\dot\beta}$	0	-.5121	0	-.4633	0	-.5356	0	0
	N'_p	.1348	.1134	-.007326	-.03025	-.1519	-.1741	.06105	.0509
	N'_r	-4.231	-4.999	-4.227	-5.011	-4.221	-5.023	-.7759	-.920
	Y_β	-.368	-.21	-.368	-.21	-.368	-.21	-.368	-.21
	Y_p	.000515	-.0013	.001794	.000072	.003103	.0015	-.00002075	-.0061
	Y_r	.0305	.041	.0304	.041	.0304	.042	-.001	.0077
Calculated modes	ω_d	4.032	4.042	2.960	2.838	3.408	3.352	3.252	3.101
	ζ_d	.8279	.8435	.6132	.6292	.3961	.4043	.1725	.1789
	$\left\lvert\frac{\phi}{\beta}\right\rvert$	10.61	10.83	13.04	14.0	9.228	9.503	11.35	12.47
	$\measuredangle\left\lvert\frac{\phi}{\beta}\right\rvert$	-42.3°	-44.0°	1.6°	2.2°	16.7°	16.0°	-5.1°	-5.466°
	τ_R or ζ_{RS}*	.5159*	.4710*	.316	.318	.232	.232	.532*	.5093*
	τ_R or ω_{RS}*	1.307*	1.303*	1.00	.915	1.81	1.75	.6913*	.7235*
Fixed-base nominal measured modes	ω_d	↓	--	↓	2.62	↓	3.29	↓	3.09
	ζ_d		--		.446		.385		.18
	$\left\lvert\frac{\phi}{\beta}\right\rvert$		--		--		--		--
	τ_R or ζ_{RS}*		.396*		--		--		.54*
	τ_R or ω_{RS}*		1.55*		--		--		.66*

TABLE III-9 FIXED-BASE SIMULATION CONTROL DERIVATIVES AND NUMERATOR ZEROS

	Config.	$N'_{\delta_{AS}}$	$L'_{\delta_{AS}}$	$Y_{\delta_{AS}}$	$\frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}$	$\left(\frac{\omega_\phi}{\omega_d}\right)^2$	$\left(\frac{\omega_\phi}{\omega_d}\right)$	ω_ϕ	ζ_ϕ	$N'_{\delta_{RP}}$	$L'_{\delta_{RP}}$	$Y_{\delta_{RP}}$
NASA config.	1-A	-.0384	.5798	-.000647	-.0662	.2804	.539	2.169	.9859	.2321	-.3664	-.00209
	1-B	-.0104	.5349	-.000905	-.01946	1.195	1.093	3.241	.7195	↓	↓	↓
	1-C	.0185	.4892	-.00116	.0378	1.512	1.23	4.191	.6122	↓	↓	↓
	1-F	.0185	.4892	-.00116	.0378	1.50	1.225	3.981	.1855	↓	↓	↓
Pseudo config.	1-A	-.03472	.5798	0	-.05989	.288	.5369	2.170	.9832	.2321	-.3664	---
	1-B	-.005821	.5349	↓	-.01088	1.305	1.142	3.242	.7207	↓	↓	---
	1-C	.0245	.4892	↓	.05010	1.56	1.25	4.190	.6142	↓	↓	---
	1-F	.02011	.4892	↓	.04111	1.65	1.2838	3.981	.1476	↓	↓	---
Fixed-base config.	1-A	-.0394	.560	.000408	-.0704	--	--	--	--	.232	-.363	-.00232
	1-B	-.00552	.536	.0000689	-.0103	--	--	--	--	↓	↓	↓
	1-C	.0282	.489	-.000269	.0577	--	--	--	--	↓	↓	↓
	1-F	.0191	.473	-.000178	.0404	--	--	--	--	↓	↓	↓

TABLE III-10 CONTROL FEEL AND PITCH DYNAMICS FOR FIXED-BASE CONFIGURATIONS

Aileron stick spring rate, ~ lb/in	2.2
Aileron stick breakout force, ~ lb	±.7
Rudder pedal spring rate, ~ lb/in	18.8*
Rudder pedal breakout force, ~ lb	±9.4
Elevator stick spring rate, ~ lb/in	4.2
Short period frequency, ω_n ~ rad/sec	2.4*
Short period damping ratio, ζ	.23*
Stick force per "g" ~ lb/g	5.2
$\delta_{ES\ MAX}$ ~ in.	+7.75, -3.5
$\delta_{AS\ MAX}$ ~ in.	±6
$\delta_{RP\ MAX}$ ~ in.	±4

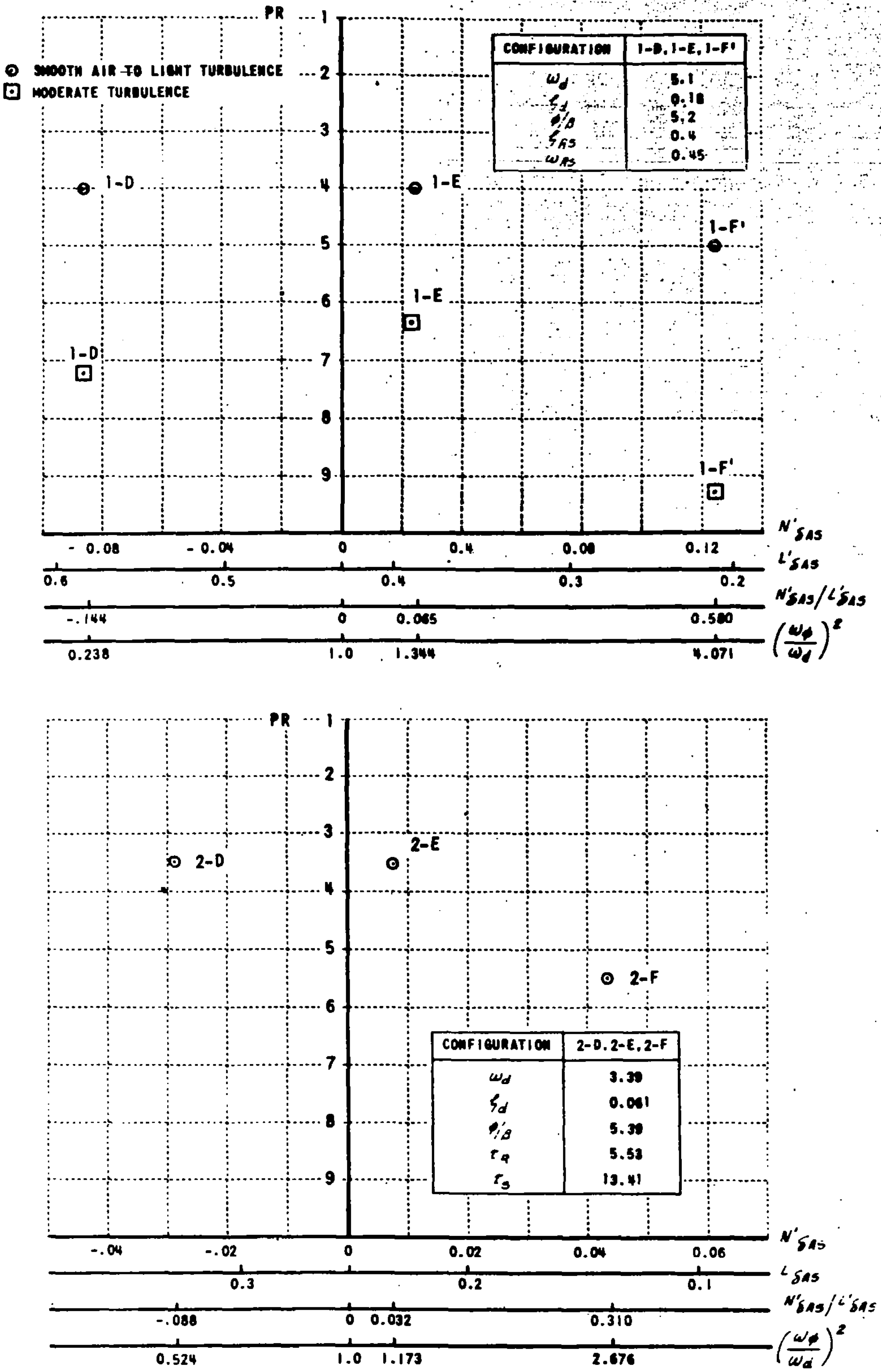
*nominal values from ground simulator records

SUMMARY OF PILOT COMMENTS FOR FIXED-BASE CONFIGURATIONS

OBJECTIONABLE FEATURES	SPECIAL PILOTING TECHNIQUES	CONTROL IN PRESENCE OF DISTURBANCES	OVERALL OPINION	RUDDER CONTROL	SPIRAL DESCENT	LATERAL-DIRECTIONAL FREE RESPONSE	LONGITUDINAL HANDLING
E OF MANEUVERABILITY. POOR PITCH TROL. LARGE CONTROL FORCES REQUIRED HOLD STEADY BANK ANGLES. TOO MUCH DER REQUIRED. DEFICIENCY IN LATERAL TROL POWER. LIGHT RUDDER PEDAL FORCE IENT.	COORDINATION REQUIRED FOR ALL MANEUVERS. MUST HOLD CONTROL FORCES IN TURNS	TOO MUCH RUDDER AILERON REQUIRED TO COUNTER DISTURBANCES. CONTROL HARMONY REDUCED. NOT MUCH DETERIORATION IN PERFORMANCE.	CAN ROLL AIRCRAFT WITH RUDDER OR AILERON. CONTROL FORCES MUST BE HELD IN A TURN. WHEN FORCES ARE RELEASED, VEHICLE ROLLS BACK TO STRAIGHT AND LEVEL. LATERAL CONTROL POWER IS LIMITED. MANEUVERABILITY IS LIMITED.	LOW BREAK OUT FORCE. LIGHT FORCE GRADIENT, YOU HAVE TO PHYSICALLY REPOSITION THE RUDDER AFTER USAGE. RUDDER CONTROL IS FAIRLY POWERFUL IN GENERATION OF ROLL. CAN USE RUDDER FOR BANK ANGLE IF YOU WANT TO ACCEPT THE SIDESLIP. ROLL DUE TO RUDDER INITIALLY GOES IN THE OPPOSITE DIRECTION AND THEN REVERSES.	BANK ANGLE AND AIRSPEED CONTROL IS QUITE GOOD. HOWEVER, A GOOD DEAL OF ATTENTION IS REQUIRED WITH RESPECT TO ALTITUDE. ANGLE OF ATTACK AND FOR SPEED CONTROL. POOR LONGITUDINAL CONTROL DEGRADES THE CONFIGURATION. MAJOR OBJECTION IS STILL THE LIMIT ON LATERAL CONTROL. COORDINATION DEFINITELY REQUIRED FOR ALL MANEUVERING.	LOW ϕ/β. NICELY DAMPED DUTCH ROLL MODE. LOW DAMPING RATIO IN THE ROLL SPIRAL.	LOW BREAKOUT FORCE. VERY LIGHT FORCE GRADIENT. THE BASIC DISHARMONY THAT EXISTS BETWEEN THE ROLL AND PITCH FEEL IS OBJECTIONABLE. LIGHTLY DAMPED SHORT PERIOD MODE. RESPONSE TO ELEVATOR IS TOO OSCILLATORY. A DEFINITE TENDENCY TO BOBBLE IN PITCH.
REQUIREMENT FOR COORDINATION TO EITHER ERATE REASONABLE ROLL RATES OR TO IEVE BANK ANGLES GREATER THAN 45°. NOT LIKE TO HOLD THE LATERAL FORCES ORDER TO SUSTAIN A GIVEN BANK ANGLE. DISHARMONY BETWEEN THE PITCH AND L CONTROLS. ROLL CONTROL CHARACTER- ICS ARE HEAVY ENOUGH THAT THEY TEND INADVERTENTLY INDUCE PITCHING INPUTS ROLLING MANEUVERS.	RUDDERS REQUIRED FOR BANK ANGLES OVER 20° TO ZERO SIDE-SLIP AND TO ACHIEVE BANK ANGLES GREATER THAN 45°	LATERAL DIRECTIONAL CHARACTERISTICS RELATIVELY UNRESPONSIVE TO TURBULENCE. GREATEST TOTAL EFFECT SEEN IN THE PITCH CONTROL AND ADDED PILOT EFFORT FOR BANK ANGLE CONTROL. HARMONY BETWEEN PITCH AND ROLL CONTROL A MUCH GREATER PROBLEM.	MAY NOT BE OPTIMUM LATERAL DIRECTIONAL CHARACTERISTICS, BUT CERTAINLY GOOD FOR THE MISSION AND THE LANDING APPROACH. NOT QUITE ENOUGH MANEUVERABILITY.	LOW BREAK OUT FORCE, QUITE LIGHT DIRECTIONAL CONTROL. FRICTION BAND POSES SOME PROBLEMS IN RECENTERING. RUDDER POWER IS GOOD. SENSITIVITY IS JUST ABOUT RIGHT. CAN FLY BANK ANGLE WITH RUDDER PEDALS. I LIKE THE DIRECTIONAL CONTROL.	BANK ANGLE CONTROL IS GOOD. SPEED CONTROL IS GOOD. GENEROUS USE OF RUDDER AND COORDINATION OF TURN REQUIRED TO KEEP DOWN THE LATERAL FORCE REQUIRED AND TO ACHIEVE STEEPER BANK ANGLES. PITCH CONTROL FORCE FEEL IS POOR. DESIRE GREATER LATERAL CONTROL POWER.	WELL DAMPED DUTCH ROLL MODE	
K OF LATERAL CONTROL POWER. LIMITED EUVERABILITY. LIGHTLY DAMPED PITCH RACTERISTICS. HAVING TO HOLD EITHER RON OR RUDDER FORCE IN A TURN.	RUDDER COORDINATION REQUIRED FOR LARGE AILERON INPUTS.	NOT MUCH DETERIORATION IN BANK ANGLE CONTROL BUT PITCH CONTROL COMPLICATES PILOT TASK.	LIMITED MANEUVERABILITY BUT EXCELLENT STABILITY. HIGH AILERON FORCES REQUIRED UNLESS SOME COMPENSATING SIDESLIP IS INTRODUCED BY HOLDING STEADY RUDDER PEDAL DEFLECTION. ACCEPTABLE FOR THE LANDING APPROACH.	RUDDER FEEL IS VERY LIGHT. ACCEPTABLE AND AT A DESIREABLE LEVEL. LOW BREAK OUT FORCE. GOOD RUDDER CONTROL POWER.	STABILITY IN BANK ANGLE WAS BEAUTIFUL. WOULD LIKE BETTER PITCH DAMPING. COORDINATION DEFINITELY REQUIRED. THE LOW RUDDER PEDAL FORCE GRADIENT IS DESIREABLE.	ROLL DAMPING APPEARS GOOD MODERATE ROLL DUE TO SIDE-SLIP. DUTCH ROLL NICELY DAMPED AND PRETTY STIFF.	
TLY DAMPED DUTCH ROLL OSCILLATION. VARIABLE ROLL RATE ENCOUNTERED N LARGE AILERON INPUTS DUE TO THE ESLIP OSCILLATION INCURRED THROUGH DUTCH ROLL EXCITATION. SPONGEY GITUDINAL CONTROL. THE LOW ROLL ING.	DO NOT FORCE PITCH/BANK OSCILLATIONS AND THEY WILL DIE OUT.	GENERALLY CONTROL IS QUITE POOR. AILERON RESPONSE IS NOT IMMEDIATE ENOUGH. DUTCH ROLL CONTINUOUSLY EXCITED. PILOT TASK GREATLY INCREASED.	LARGE ROLL DUE TO SIDESLIP MAKES RUDDERS VERY DIFFICULT TO USE. AILERON RESPONSE UNPREDICTABLE. WHILE MAINTAINING BANK ANGLE THERE IS A TENDENCY TO OSCILLATE AT A COUPLE OF FREQUENCIES. ONCE AT THE DUTCH ROLL FREQUENCY AND AGAIN AT A LOWER FREQUENCY.	TOO SENSITIVE. FORCE FEEL ISN'T ADEQUATE. TOO MUCH ROLLING MOMENT FOR A SMALL AMOUNT OF PEDAL FORCE. NOT ENOUGH RESOLUTION.	VEHICLE OSCILLATED IN KIND OF A COUPLED PITCH/BANK OSCILLATION. ROLL MANEUVERABILITY WAS GOOD. CONTROLLING THE INDUCED OSCILLATIONS REQUIRED A MAJOR PORTION OF THE PILOT'S ATTENTION.	CLEARLY A COUPLED ROLL SPIRAL, LIGHTLY DAMPED DUTCH ROLL MODE, MODERATELY STIFF. FAIRLY HIGH ϕ/β	

TABLE III-11 SUMMARY OF P
FOR FIXED-BAS

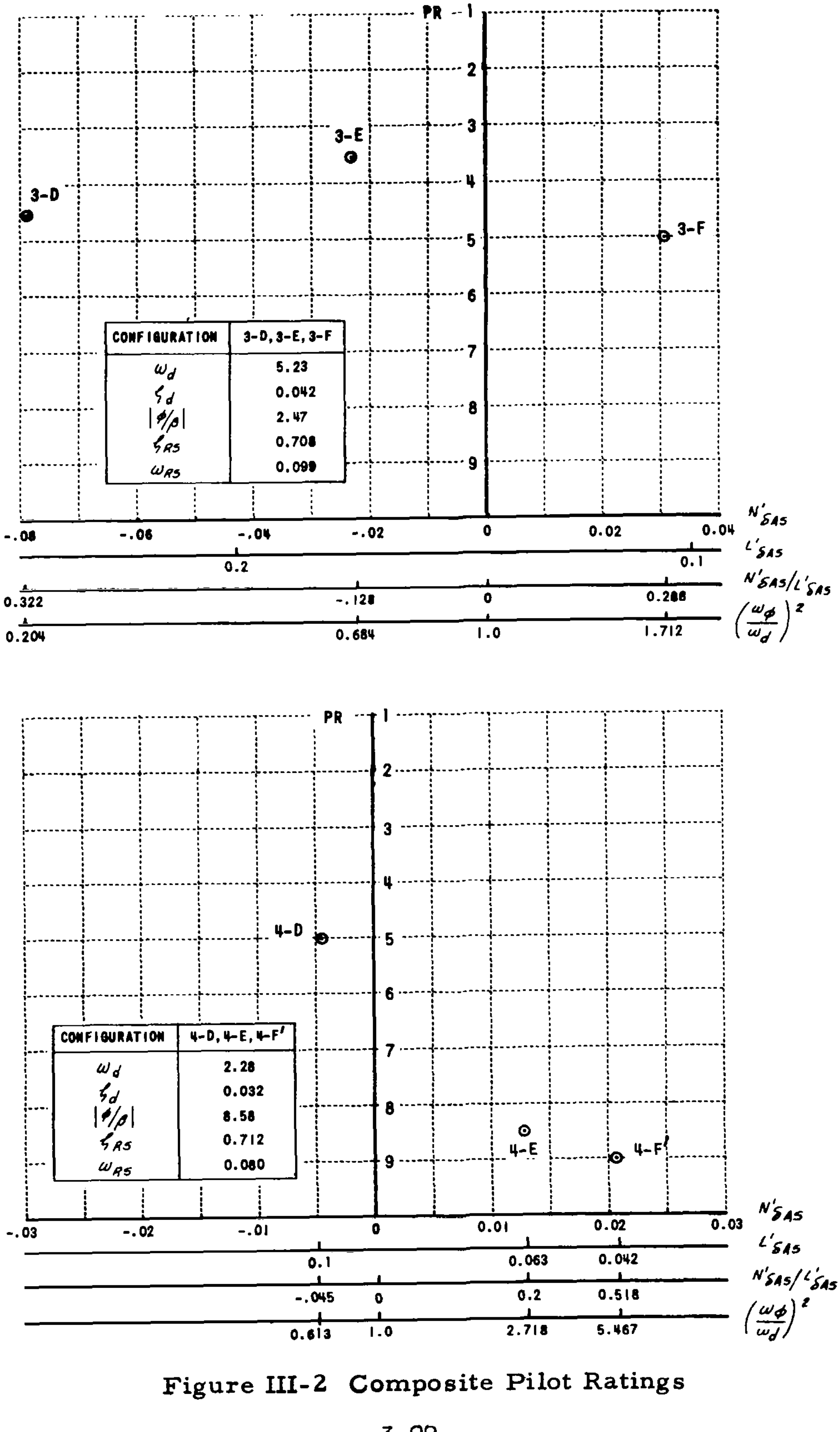
CONFIG.	AILERON CONTROL				FAVORABLE FEATURES	OBJECTIONABLE FEATURES	
	GENERAL	AILERON YAW	COORDINATION	FEEL			
1-A	FULL DEFLECTION RESULTS IN A RELATIVELY SLOW ROLL RATE BEING GENERATED. WITHOUT RUDDER COORDINATION, FULL AILERON DEFLECTION GIVES ONLY 40° OF BANK. WITH RUDDER COORDINATION FULL AILERON GIVES ABOUT 60° OF BANK. TO GET GREATER THAN 60° OF BANK ONE MUST GENERATE PROVERSE YAW TO TAKE ADVANTAGE OF C_{L_β}. AILERONS ARE BANK ANGLE ORDERING. REQUIRES CONSTANT FORCE TO HOLD A BANK ANGLE	ADVERSE YAW	DIFFICULT TO COORDINATE STEEPER TURNS. ALMOST FULL RUDDER DEFLECTION IS REQUIRED IN A STEEP STEADY TURN TO KEEP AILERON FORCES DOWN TO AN ACCEPTABLY LOW LEVEL. REQUIRED FOR ALL MANEUVERS.	LOW BREAKOUT FORCES, RELATIVELY HEAVY FORCE GRADIENT.	NO BOTHERSOME DUTCH ROLL OSCILLATIONS INCURRED WITH EVEN RAPID STICK INPUTS. BANK ANGLE AND HEADING CONTROL IS QUITE PRECISE.	LACK OF MANEUVERABILITY. GOOD PITCH CONTROL. LARGE CONTROL FORCES REQUIRED TO HOLD STEADY BANK ANGLES. TOO MUCH RUDDER REQUIRED. DEFICIENCY IN LATERAL CONTROL POWER. LIGHT RUDDER PEDAL FORCE GRADIENT.	COORDINATI MANEUVERS, FORCES IN
1-B	LATERAL CONTROL ACTS AS A BANK ANGLE POSITION CONTROLLER. CONTROL APPEARS VERY HEAVY AND SLUGGISH. MUST HOLD CONTROL FORCES TO MAINTAIN BANK ANGLE. WHEN CONTROLS ARE RELEASED THE CRAFT ROLLS OUT STRAIGHT AND LEVEL. FULL DEFLECTION WITH COORDINATED RUDDER GIVES 60° OF BANK.	SLIGHTLY ADVERSE	REQUIRED FOR BANK ANGLES OVER 30°	LIGHT BREAKOUT FORCE, FEEL IS GENERALLY HEAVY.	GOOD PRECISION CAPABILITY FOR HOLDING EITHER BANK ANGLE OR HEADING. LACK OF ANY NOTICEABLE DUTCH ROLL OSCILLATIONS INCURRED WITH ANY DEGREE OF MANEUVERING. OVER ALL GOOD DAMPING RATIO FOR BOTH THE DUTCH ROLL AND SHORT PERIOD MODE.	THE REQUIREMENT FOR COORDINATION TO EITHER GENERATE REASONABLE ROLL RATES OR TO ACHIEVE BANK ANGLES GREATER THAN 45°. DO NOT LIKE TO HOLD THE LATERAL FORCES IN ORDER TO SUSTAIN A GIVEN BANK ANGLE. THE DISHARMONY BETWEEN THE PITCH AND ROLL CONTROLS. ROLL CONTROL CHARACTERISTICS ARE HEAVY ENOUGH THAT THEY TEND TO INADVERTENTLY INDUCE PITCHING INPUTS IN ROLLING MANEUVERS.	RUDDERS OVER 30° ACHIEVE
1-C	EXTREMELY LARGE AILERON STICK FORCE REQUIRED TO MAINTAIN BANK ANGLE. IF YOU DON'T COORDINATE YOU GET A STEADY STATE BANK ANGLE FOR A STEADY STATE AILERON INPUT. LARGE DEFLECTIONS REQUIRED TO GENERATE EVEN MODEST ROLL RESPONSE. WITHOUT COORDINATION FULL DEFLECTION GIVES ONLY 60° OF BANK.	PROBABLY PROVERSE	NOT REQUIRED FOR SMALL AILERON INPUTS BUT FOR LARGE BANK ANGLES RUDDER COORDINATION IS DESIRABLE	QUITE LOW BREAKOUT FORCE. FORCE GRADIENT LIGHT TO MEDIUM BUT APPEARS HEAVIER DUE TO THE VERY SLUGGISH ROLL RESPONSE NOTED.	ABILITY OF THE PILOT TO MAINTAIN HEADING AND BANK ANGLE IS EXCELLENT. LACK OF ANY APPRECIABLE SIDESLIP GENERATION WITH AILERON INPUT WITH NO YAW ROLL OSCILLATIONS INCURRED AT ANY TIME. WELL DAMPED DUTCH ROLL MODE.	LACK OF LATERAL CONTROL POWER. LIMITED MANEUVERABILITY. LIGHTLY DAMPED PITCH CHARACTERISTICS. HAVING TO HOLD EITHER AILERON OR RUDDER FORCE IN A TURN.	RUDDER LARGE AIL
1-F	AILERON RESPONSE IS A LITTLE UNPREDICTABLE. YOU TEND TO OVERSHOOT AND OSCILLATE BACK AND FORTH ABOUT THE DESIRED BANK ANGLE AT A LOW FREQUENCY. STEEP TURNS ARE BETTER THAN SHALLOW TURNS IN TERMS OF BANK ANGLE OSCILLATIONS. A SMALL AMOUNT OF STEADY AILERON FORCE IS REQUIRED FOR A STEADY TURN.	SMALL AMOUNT OF PROVERSE YAW	NO USE OF RUDDERS FOR COORDINATION WOULD BE REQUIRED. COULD NOT USE RUDDERS BECAUSE THEY ARE TOO SENSITIVE AND PRODUCE TOO MUCH ROLLING MOMENT FOR A SMALL DEFLECTION.	LIGHT BREAKOUT FORCE, QUITE LOW FORCE GRADIENT, GOOD STICK CENTERING	BETTER CONTROL HARMONY BETWEEN PITCH AND ROLL. GOOD MANEUVERABILITY.	LIGHTLY DAMPED DUTCH ROLL OSCILLATION. THE VARIABLE ROLL RATE ENCOUNTERED WITH LARGE AILERON INPUTS DUE TO THE SIDESLIP OSCILLATION INCURRED THROUGH THE DUTCH ROLL EXCITATION. SPONGY LONGITUDINAL CONTROL. THE LOW ROLL DAMPING.	DO NOT AND THEY



CONFIGURATION	1-D, 1-E, 1-F'
ω_d	5.1
ζ_d	0.18
ϕ/β	5.2
ζ_{RS}	0.4
ω_{RS}	0.45

CONFIGURATION	2-D, 2-E, 2-F
ω_d	3.39
ζ_d	0.061
ϕ/β	5.39
τ_R	5.53
τ_S	13.41

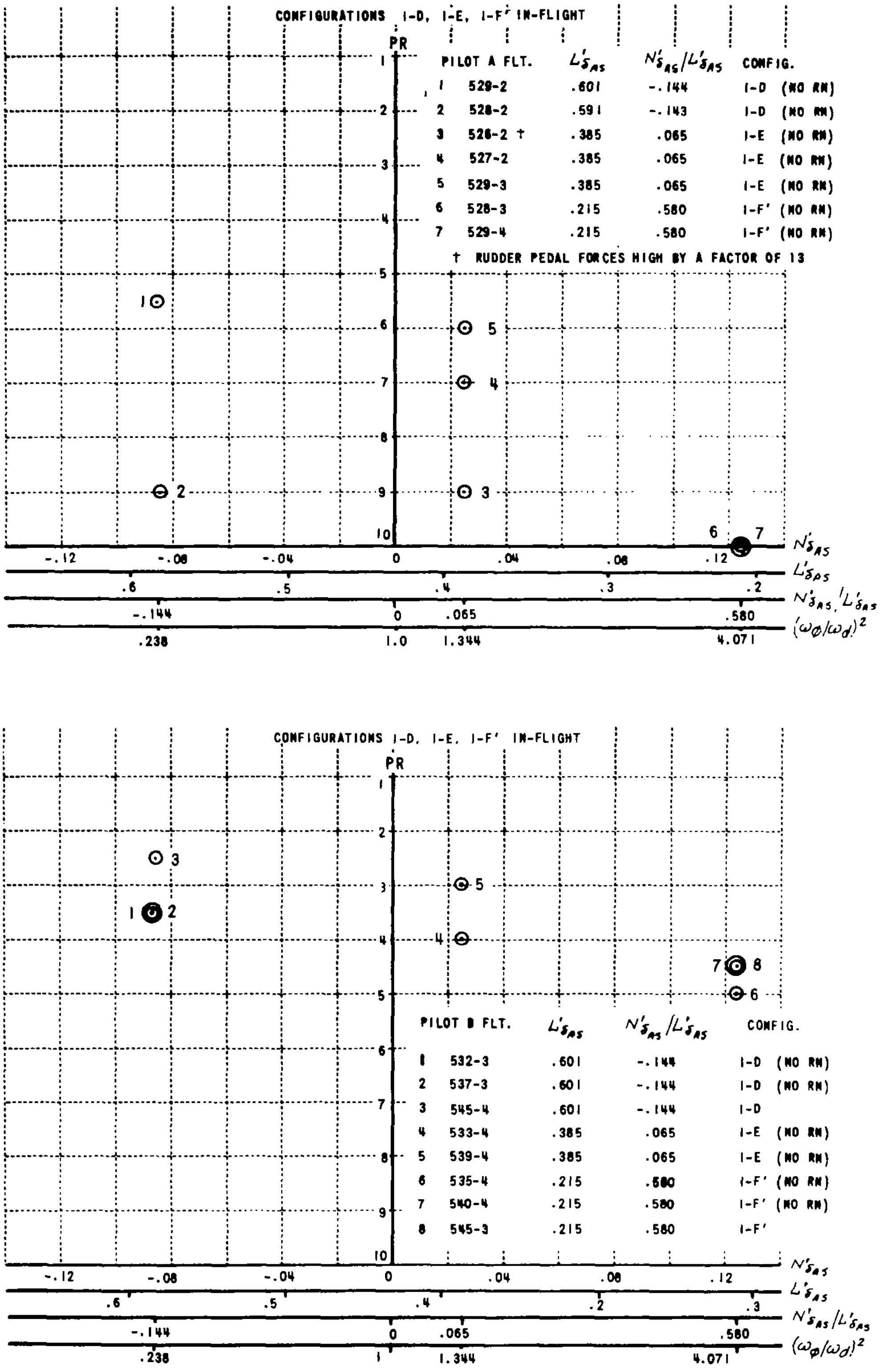
Figure III-1 Composite Pilot Ratings



CONFIGURATION	3-D, 3-E, 3-F
ω_d	5.23
ζ_d	0.042
$\lvert\phi/\beta\rvert$	2.47
ζ_{RS}	0.708
ω_{RS}	0.099

CONFIGURATION	4-D, 4-E, 4-F'
ω_d	2.28
ζ_d	0.032
$\lvert\phi/\beta\rvert$	8.58
ζ_{RS}	0.712
ω_{RS}	0.080

Figure III-2 Composite Pilot Ratings

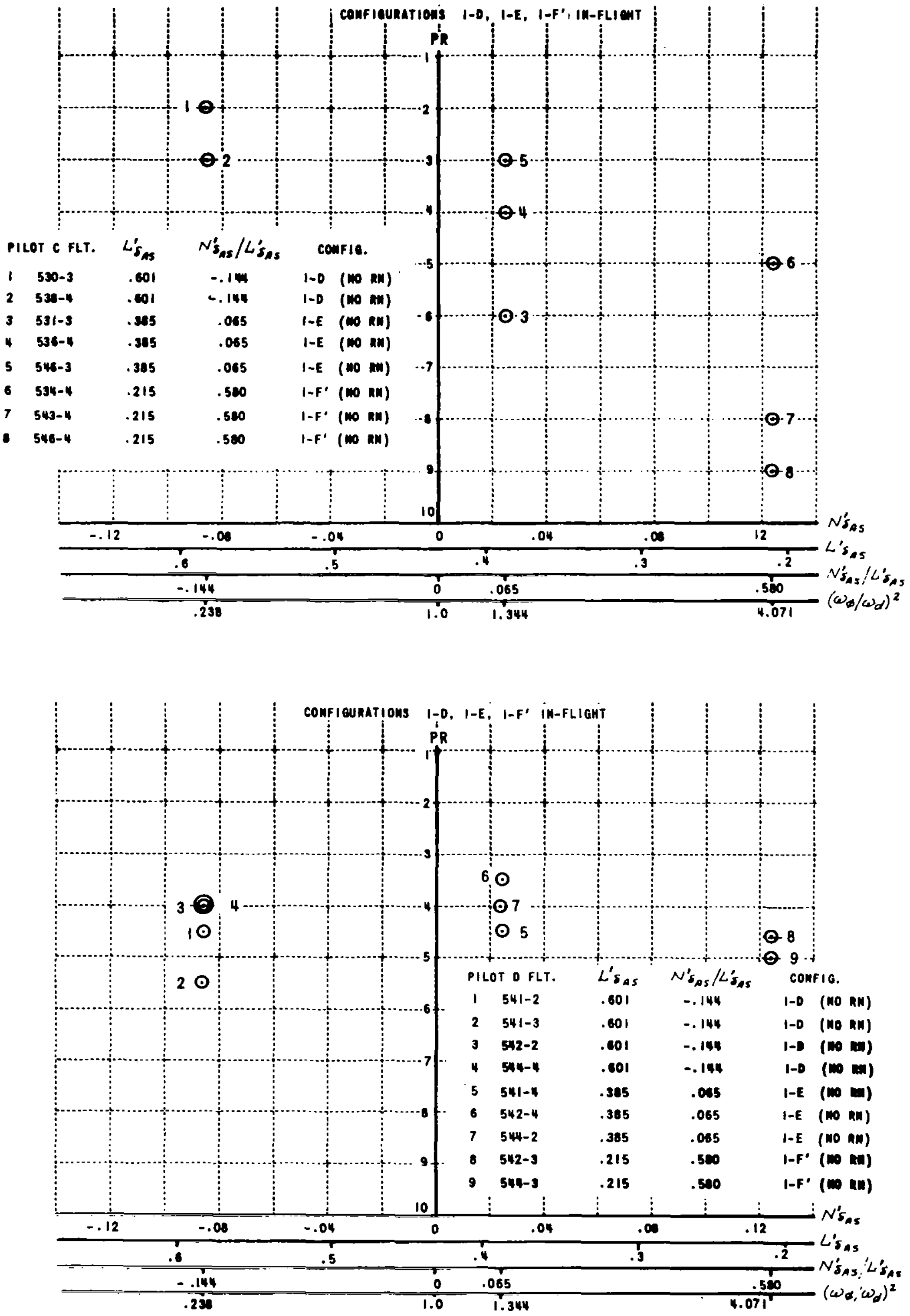


PILOT A FLT.		$L'_{\delta_{AS}}$	$N'_{\delta_{AS}}/L'_{\delta_{AS}}$	CONFIG.
1	529-2	.601	-.144	I-D (NO RM)
2	528-2	.591	-.143	I-D (NO RM)
3	526-2 †	.385	.065	I-E (NO RM)
4	527-2	.385	.065	I-E (NO RM)
5	529-3	.385	.065	I-E (NO RM)
6	528-3	.215	.580	I-F' (NO RM)
7	529-4	.215	.580	I-F' (NO RM)

† RUDDER PEDAL FORCES HIGH BY A FACTOR OF 13

PILOT B FLT.		$L'_{\delta_{AS}}$	$N'_{\delta_{AS}}/L'_{\delta_{AS}}$	CONFIG.
1	532-3	.601	-.144	I-D (NO RM)
2	537-3	.601	-.144	I-D (NO RM)
3	545-4	.601	-.144	I-D
4	533-4	.385	.065	I-E (NO RM)
5	539-4	.385	.065	I-E (NO RM)
6	535-4	.215	.580	I-F' (NO RM)
7	540-4	.215	.580	I-F' (NO RM)
8	545-3	.215	.580	I-F'

Figure III-3 In-Flight Pilot Ratings



PILOT C FLT.		$L'_{\delta_{AS}}$	$N'_{\delta_{AS}}/L'_{\delta_{AS}}$	CONFIG.
1	530-3	.601	-.144	I-D (NO RN)
2	538-4	.601	-.144	I-D (NO RN)
3	531-3	.385	.065	I-E (NO RN)
4	536-4	.385	.065	I-E (NO RN)
5	546-3	.385	.065	I-E (NO RN)
6	534-4	.215	.580	I-F' (NO RN)
7	543-4	.215	.580	I-F' (NO RN)
8	546-4	.215	.580	I-F' (NO RN)

PILOT D FLT.		$L'_{\delta_{AS}}$	$N'_{\delta_{AS}}/L'_{\delta_{AS}}$	CONFIG.
1	541-2	.601	-.144	I-D (NO RN)
2	541-3	.601	-.144	I-D (NO RN)
3	542-2	.601	-.144	I-D (NO RN)
4	544-4	.601	-.144	I-D (NO RN)
5	541-4	.385	.065	I-E (NO RN)
6	542-4	.385	.065	I-E (NO RN)
7	544-2	.385	.065	I-E (NO RN)
8	542-3	.215	.580	I-F' (NO RN)
9	544-3	.215	.580	I-F' (NO RN)

Figure III-4 In-Flight Pilot Ratings

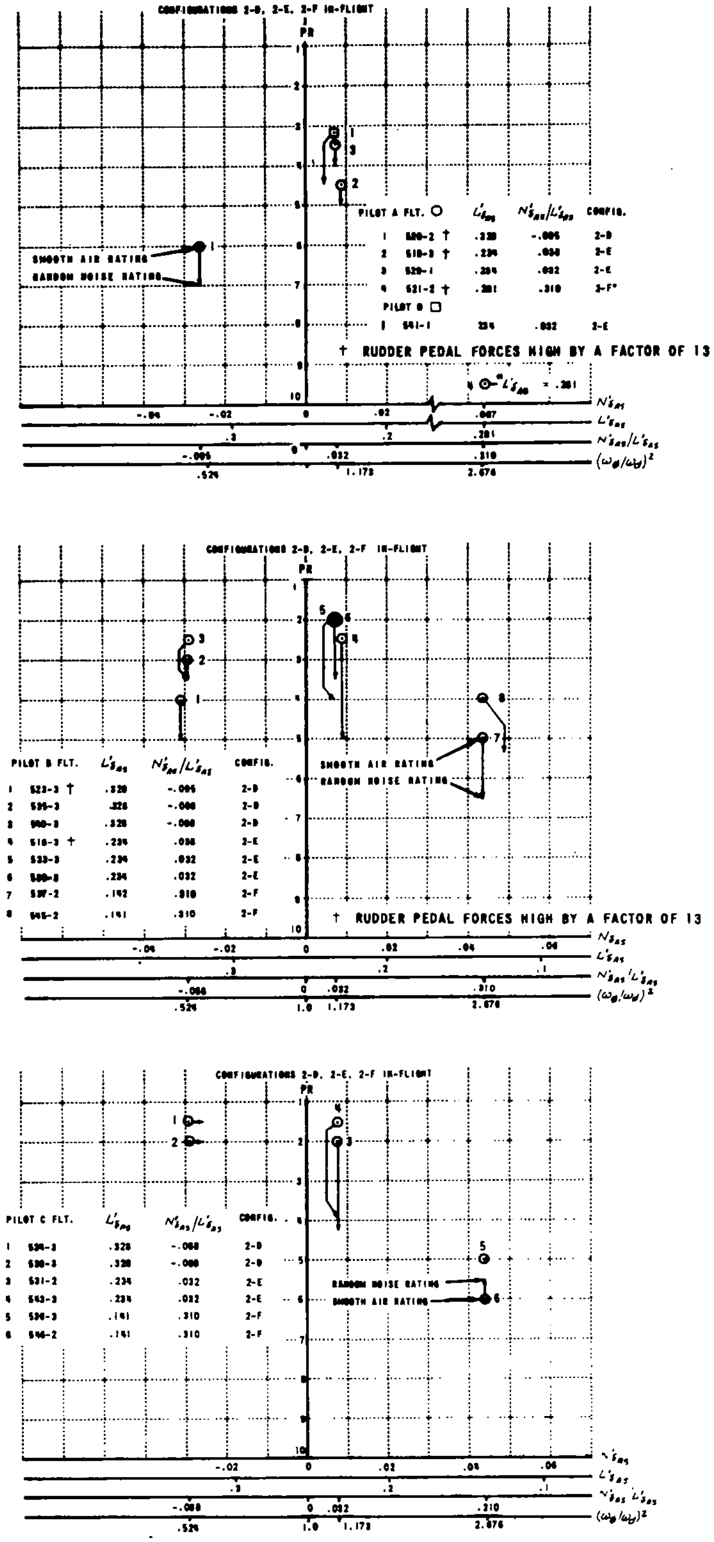
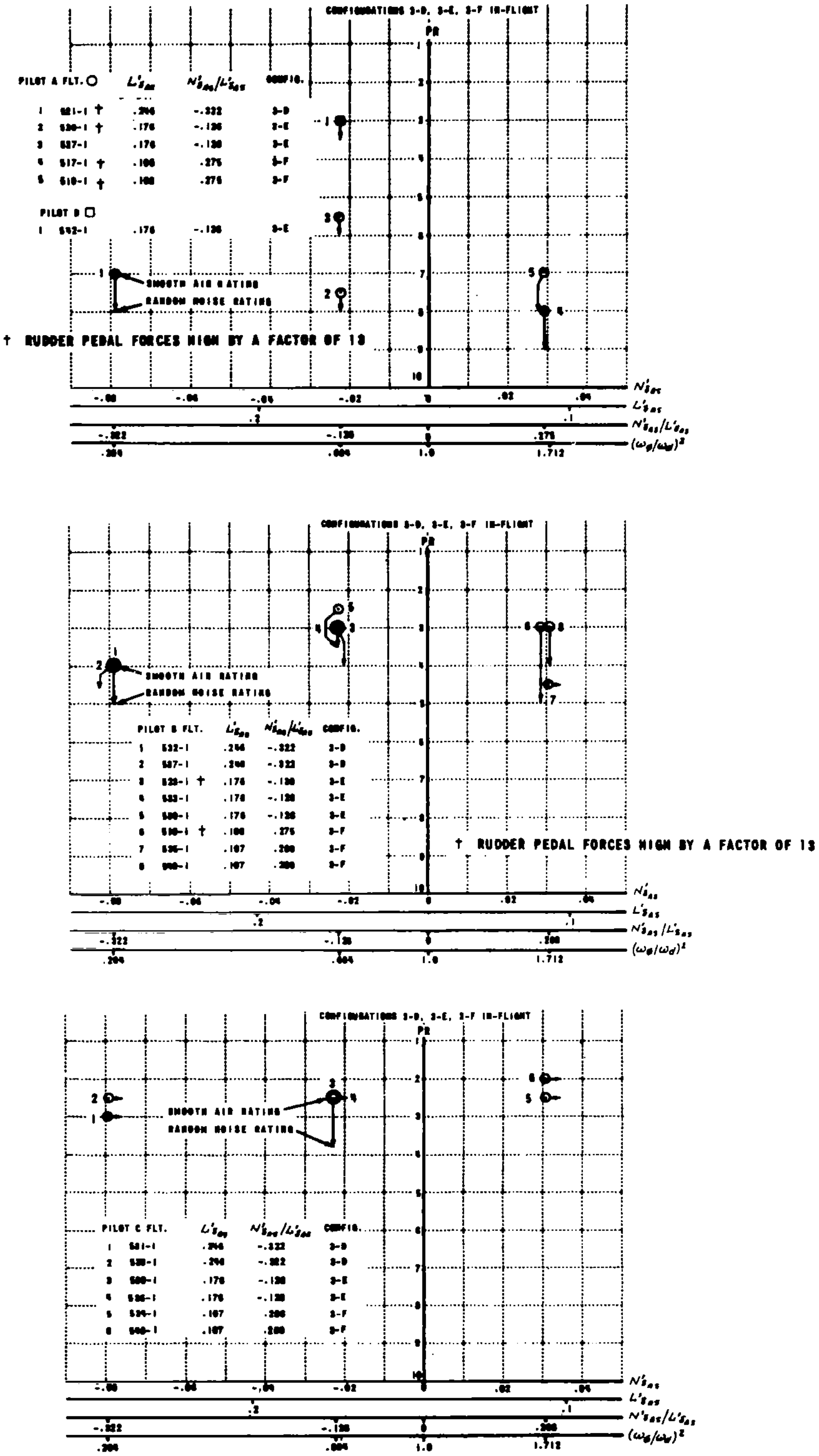


Figure III-5 In-Flight Pilot Ratings



† RUDDER PEDAL FORCES HIGH BY A FACTOR OF 13

PILOT A FLT. ○		$L'_{\delta_{as}}$	$N'_{\delta_{as}}/L'_{\delta_{as}}$	CONFIG.
1	521-1 †	.246	-.322	3-D
2	520-1 †	.176	-.128	3-E
3	537-1	.176	-.128	3-E
4	517-1 †	.108	.275	3-F
5	510-1 †	.108	.275	3-F
PILOT B □				
1	542-1	.176	-.128	3-E

PILOT B FLT.		$L'_{\delta_{as}}$	$N'_{\delta_{as}}/L'_{\delta_{as}}$	CONFIG.
1	532-1	.246	-.322	3-D
2	537-1	.246	-.322	3-D
3	528-1 †	.176	-.128	3-E
4	533-1	.176	-.128	3-E
5	500-1	.176	-.128	3-E
6	510-1 †	.108	.275	3-F
7	535-1	.107	.200	3-F
8	560-1	.107	.200	3-F

† RUDDER PEDAL FORCES HIGH BY A FACTOR OF 13

PILOT C FLT.		$L'_{\delta_{as}}$	$N'_{\delta_{as}}/L'_{\delta_{as}}$	CONFIG.
1	531-1	.246	-.322	3-D
2	530-1	.246	-.322	3-D
3	500-1	.176	-.128	3-E
4	536-1	.176	-.128	3-E
5	534-1	.107	.200	3-F
6	540-1	.107	.200	3-F

Figure III-6 In-Flight Pilot Ratings

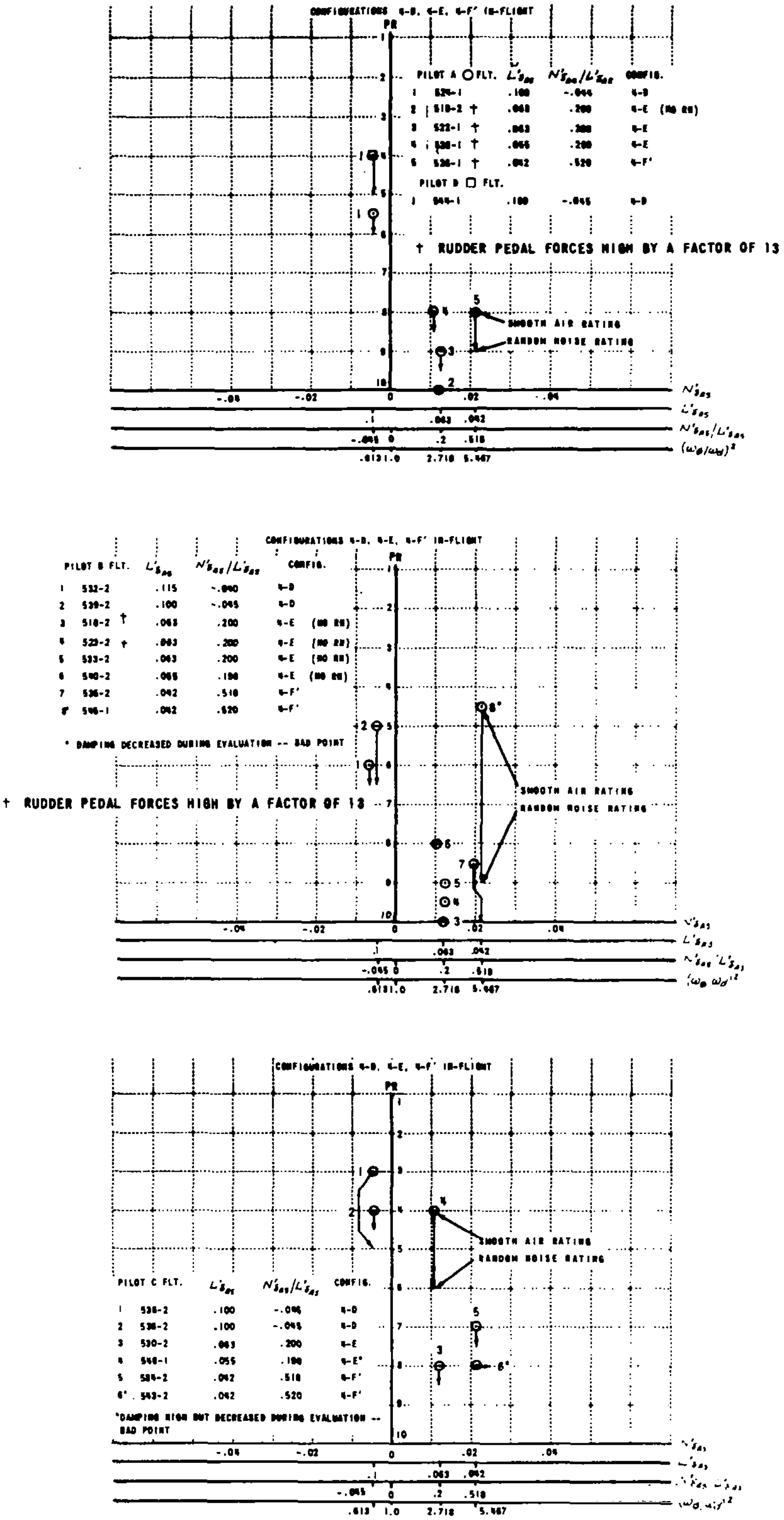
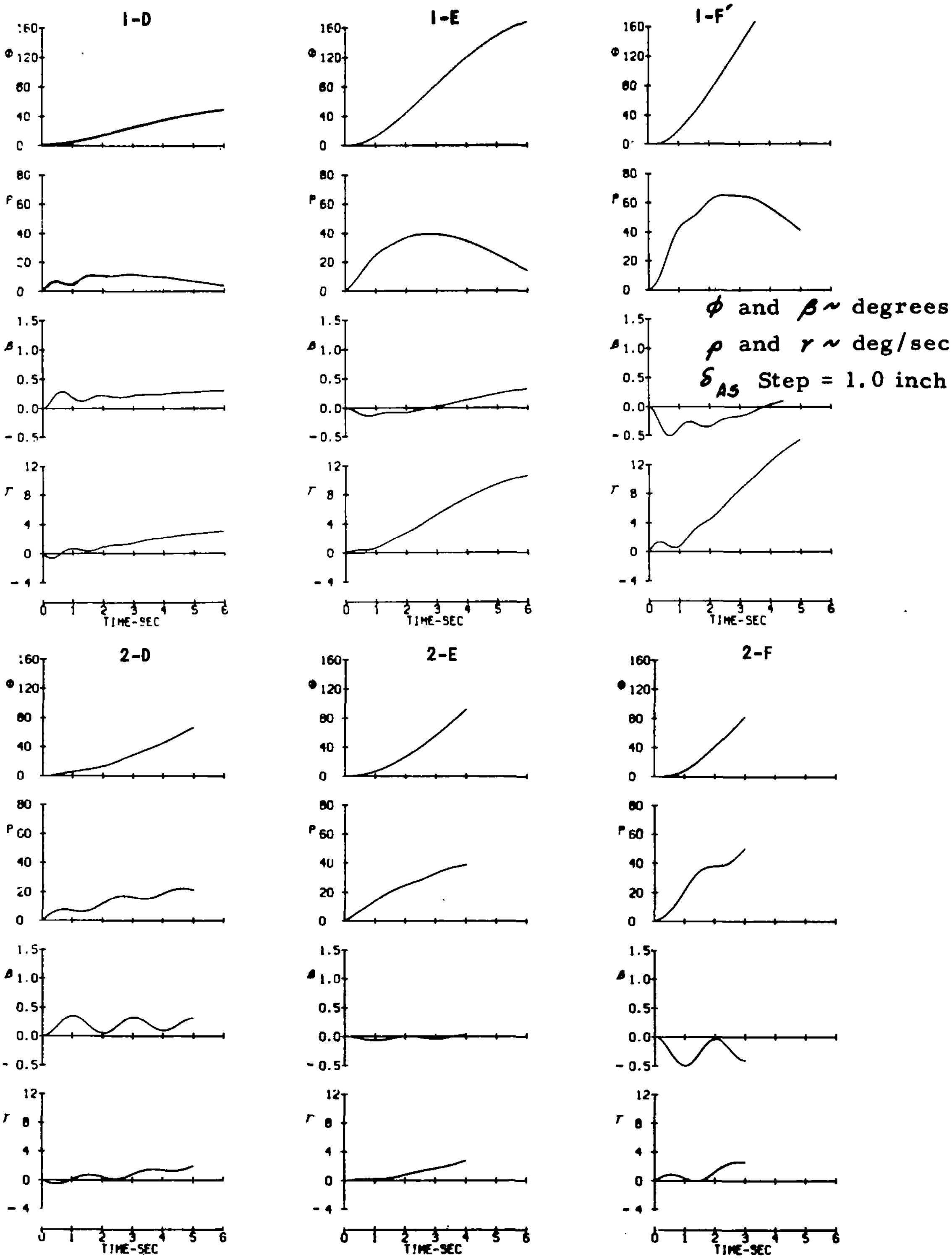


Figure III-7 In-Flight Pilot Ratings

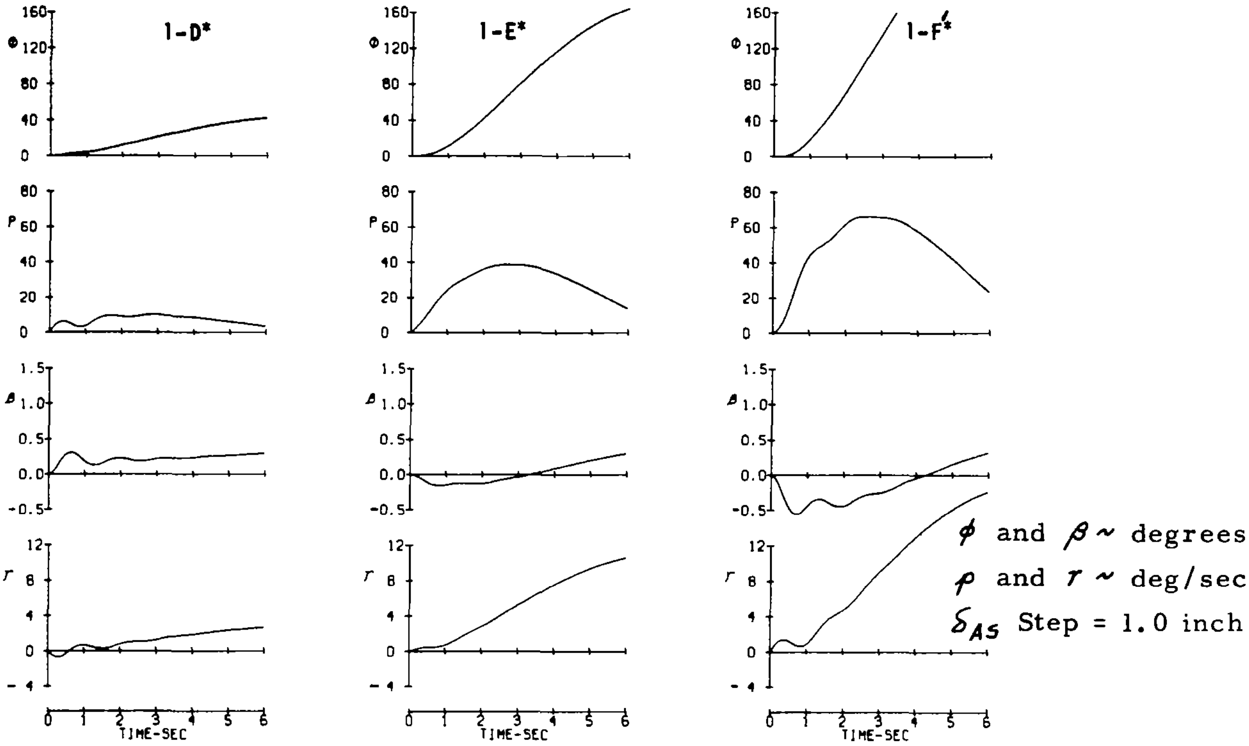


ϕ and β ~ degrees

p and r ~ deg/sec

δ_{AS} Step = 1.0 inch

Figure III-8 Transient Responses To Aileron Stick Step Calculated From NASA Derivatives



*Calculated From Pseudoderivatives (In-Flight Records Not Obtained)

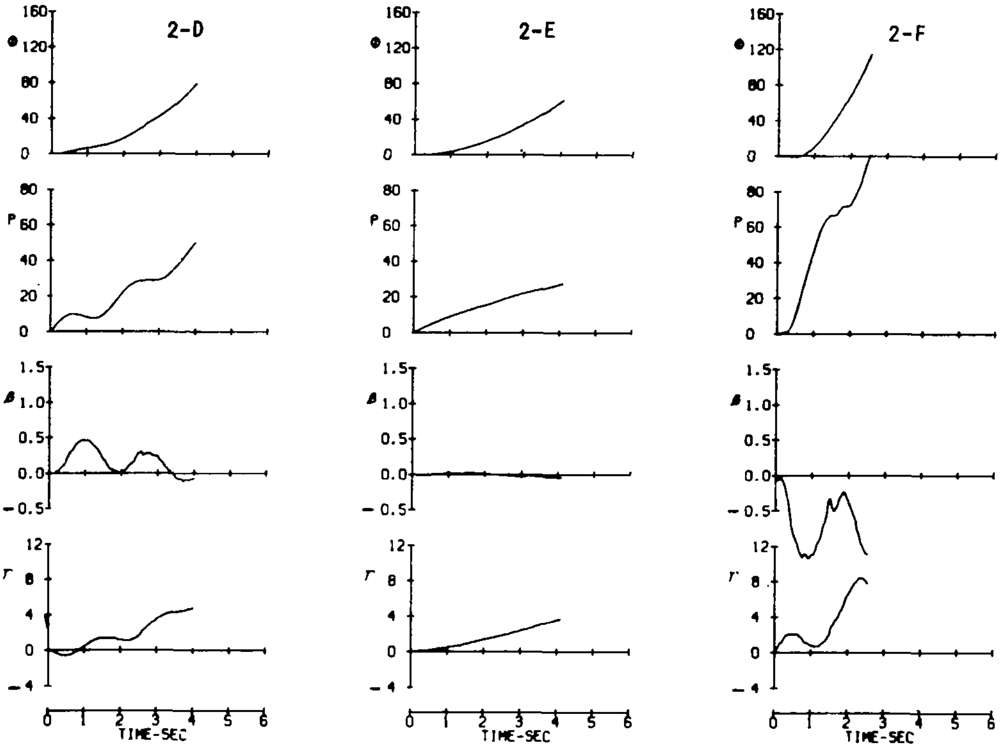
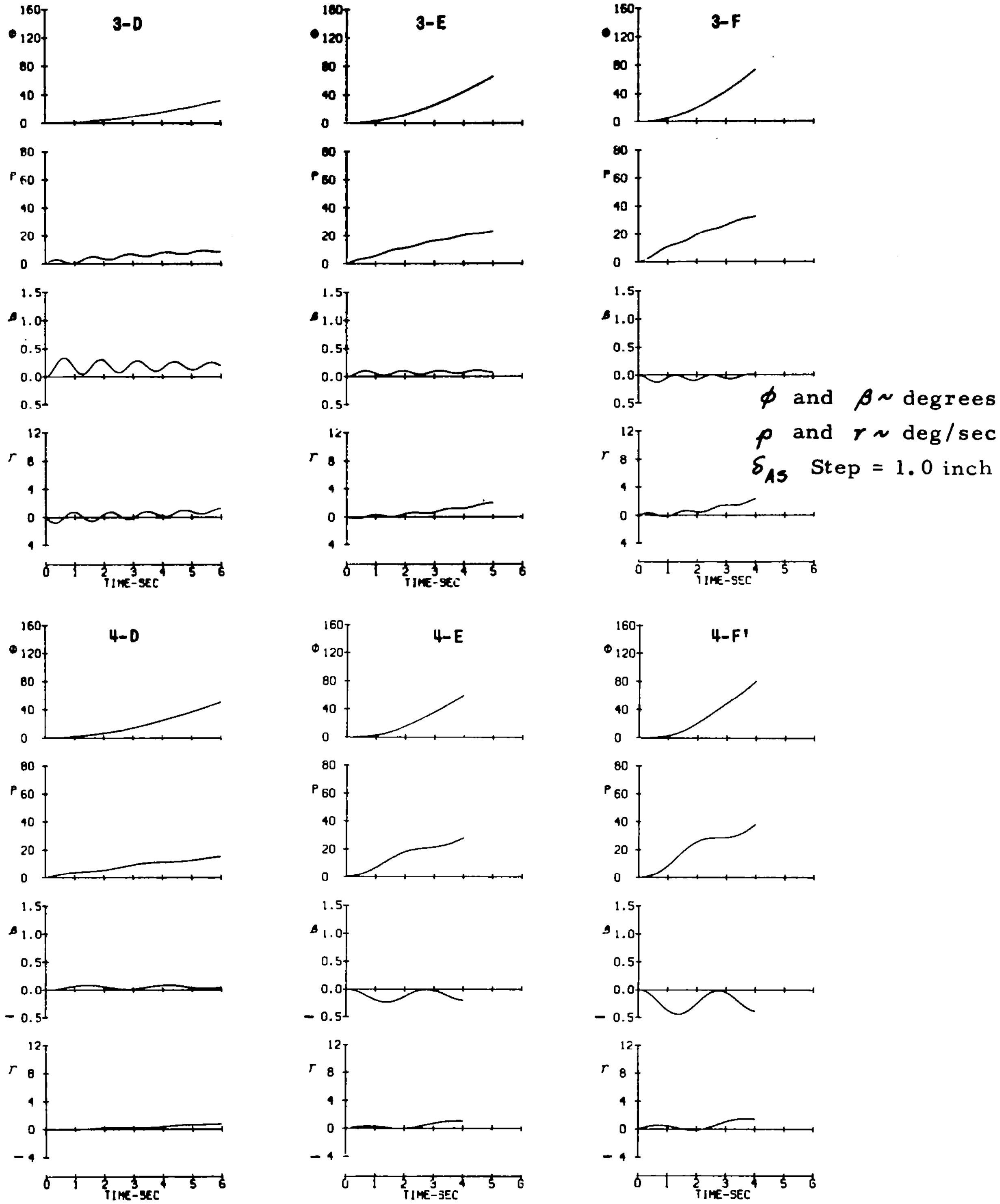
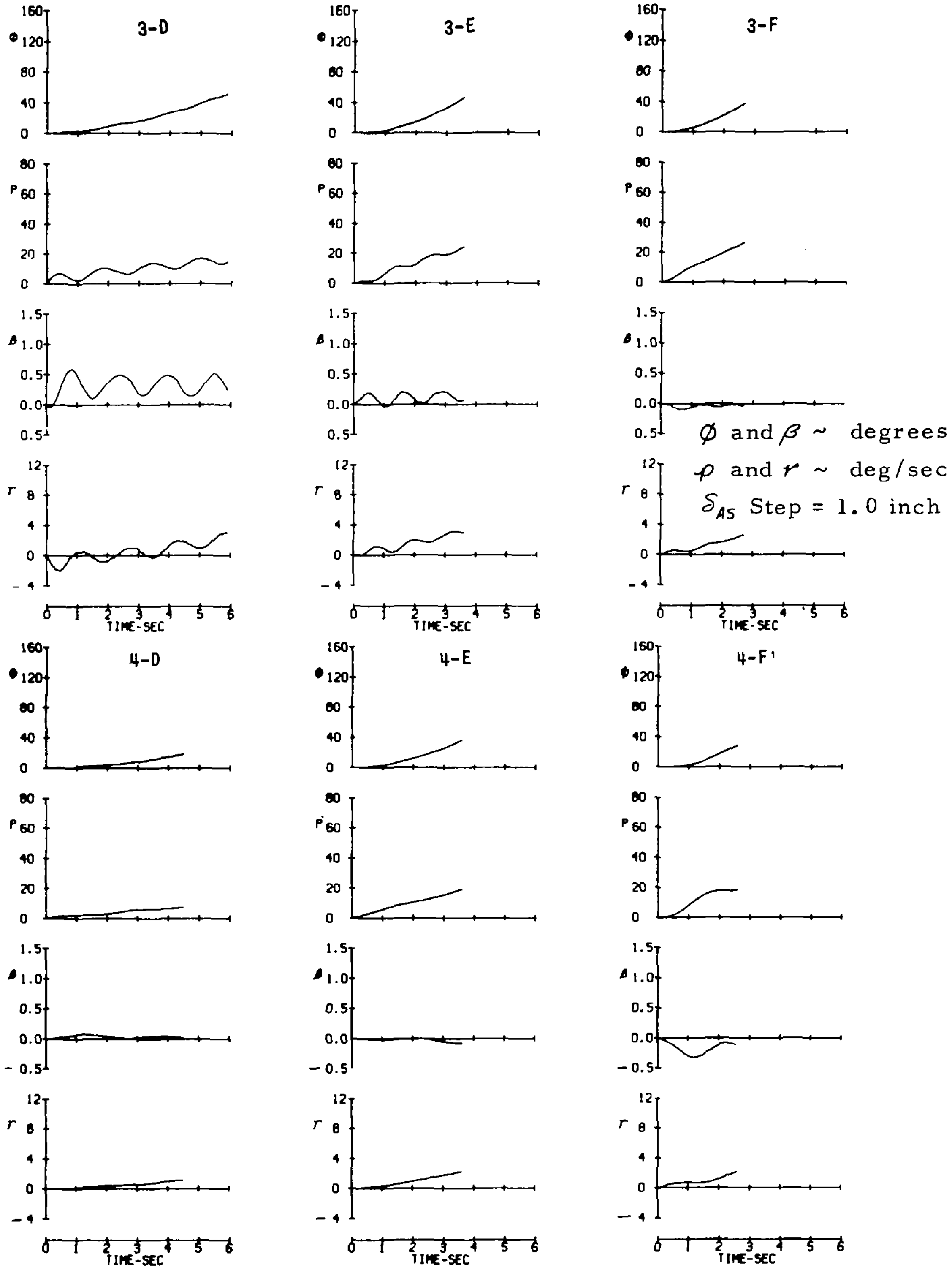


Figure III-9 Transient Responses To Aileron Stick Step From Flight Records Normalized To 1.0 Inch δ_{AS} Step



ϕ and $\beta \sim$ degrees
p and $r \sim$ deg/sec
δ_{AS} Step = 1.0 inch

Figure III-10 Transient Responses To Aileron Stick Step Calculated From NASA Derivatives



ϕ and β ~ degrees
p and r ~ deg/sec
δ_{AS} Step = 1.0 inch

Figure III-11 Transient Responses To Aileron Stick Step From Flight Records Normalized To 1.0 Inch δ_{AS} Step

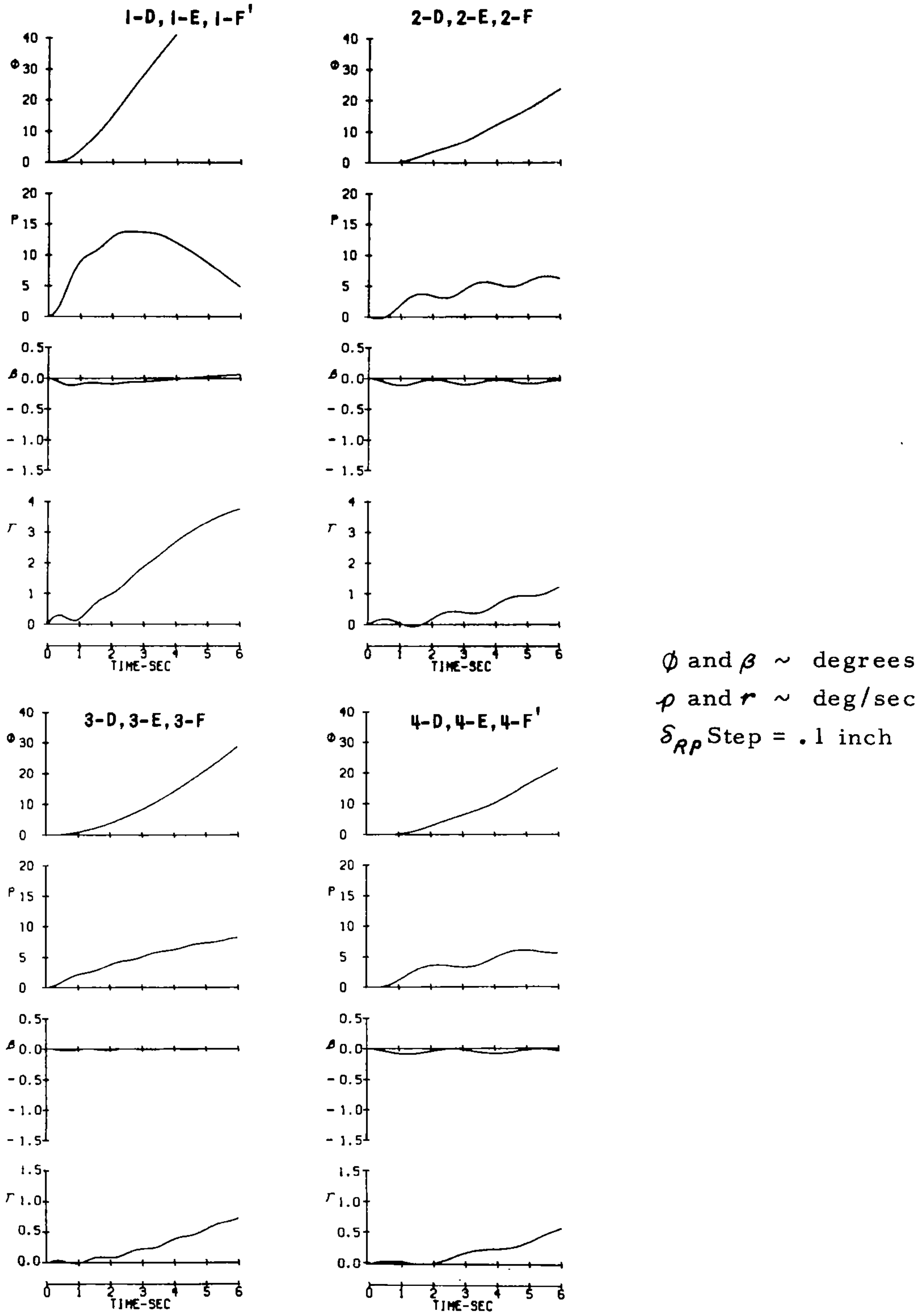
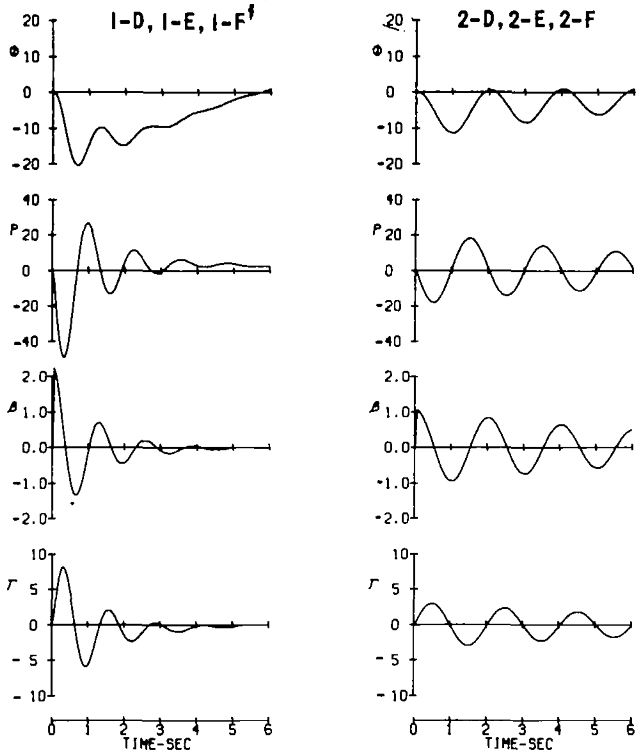
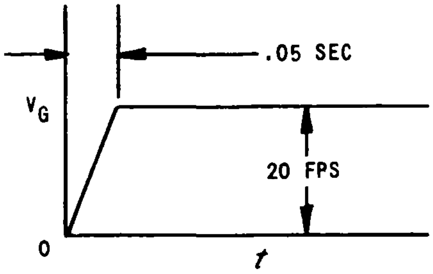
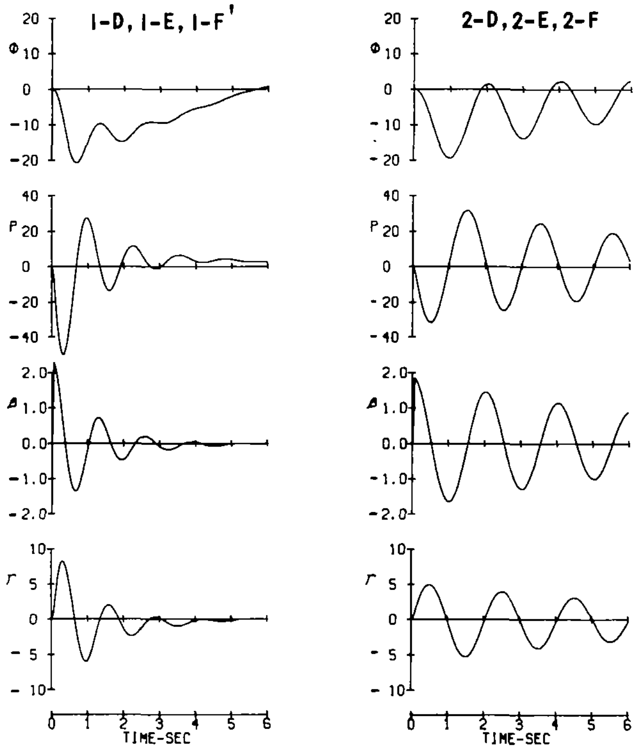


Figure III-12 Transient Responses To Rudder Pedal Step Calculated For In-Flight Configurations From Pseudoderivatives





Calculated From NASA Derivatives

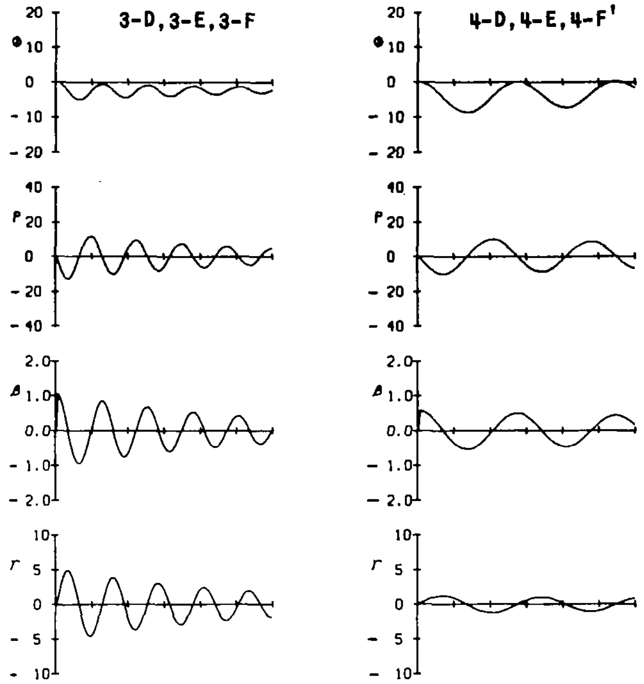


Calculated From Pseudoderivatives

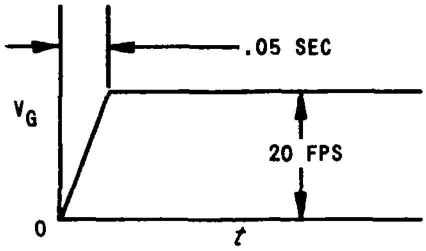
ϕ and β ~ degrees

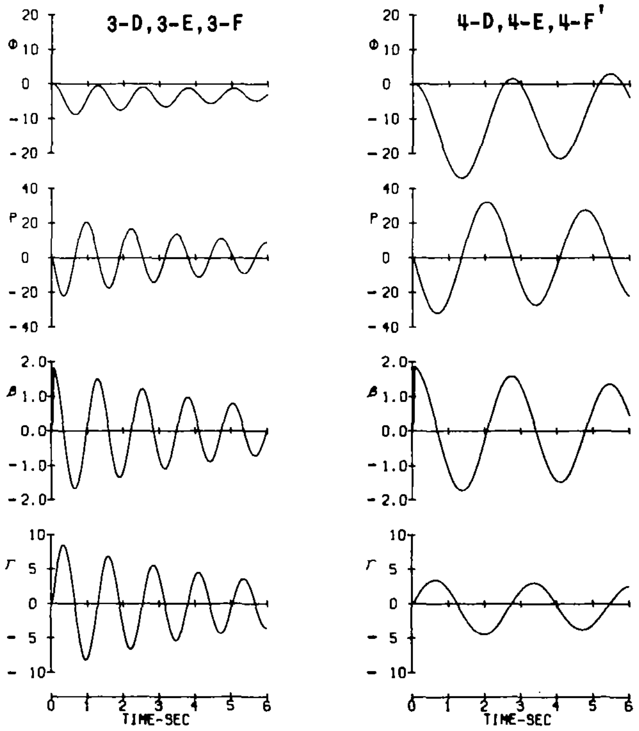
p and r ~ deg/sec

Figure III-13 Transient Responses To Side Gust



Calculated From NASA Derivatives





Calculated From Pseudoderivatives

ϕ and β ~ degrees

p and r ~ deg/sec

Figure III-14 Transient Responses To Side Gust

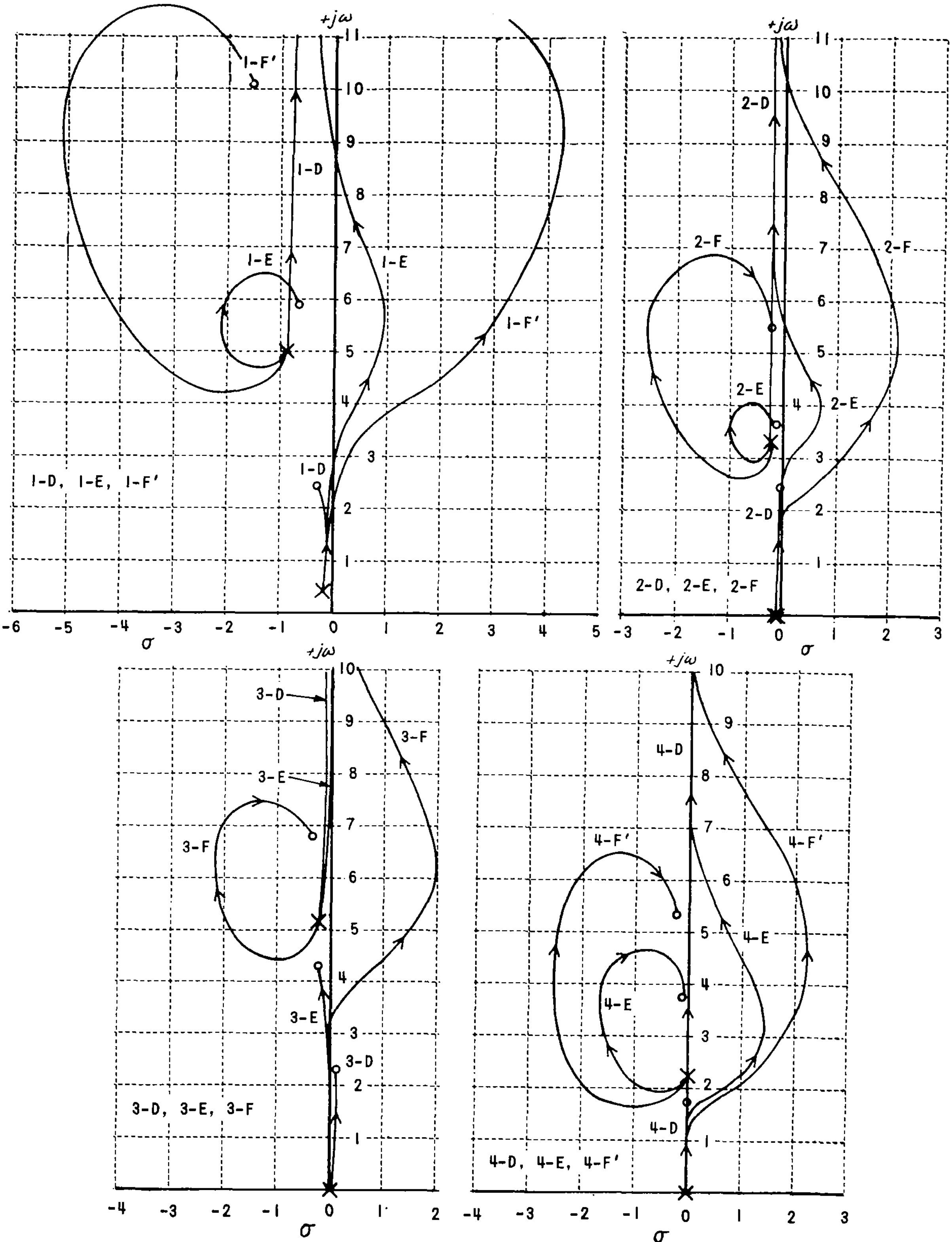
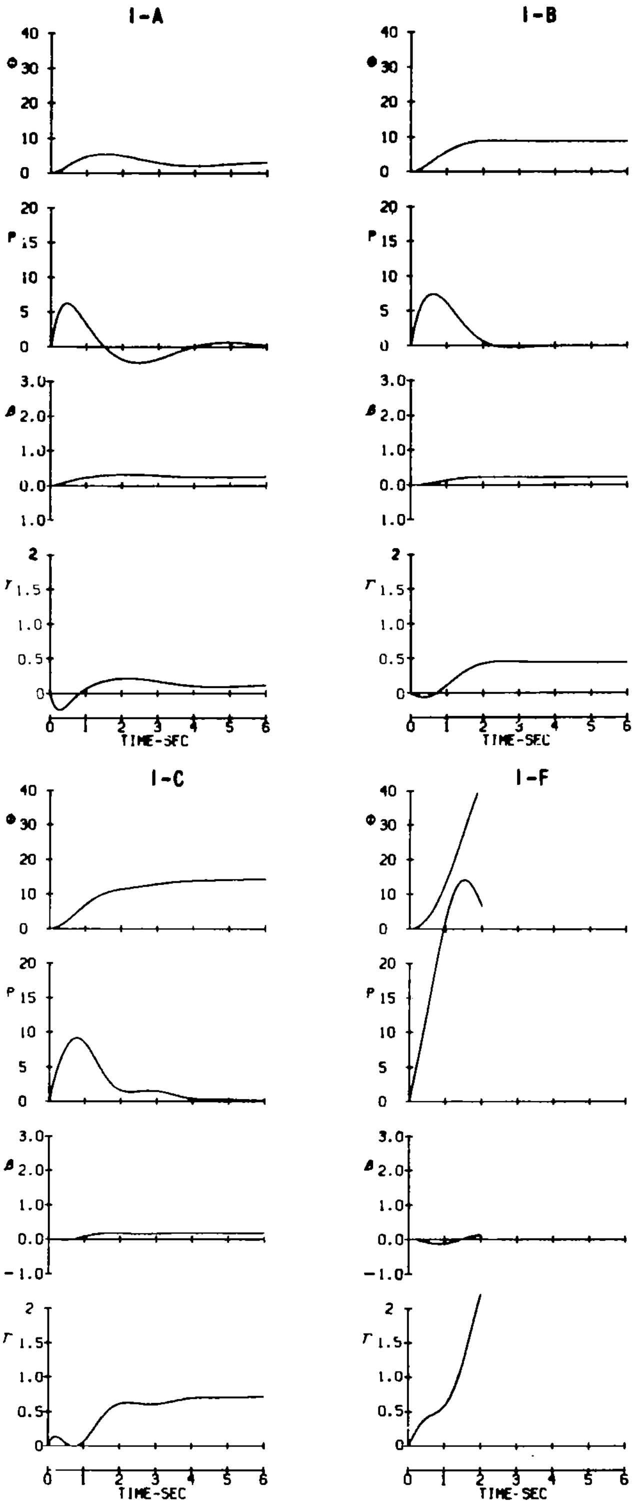
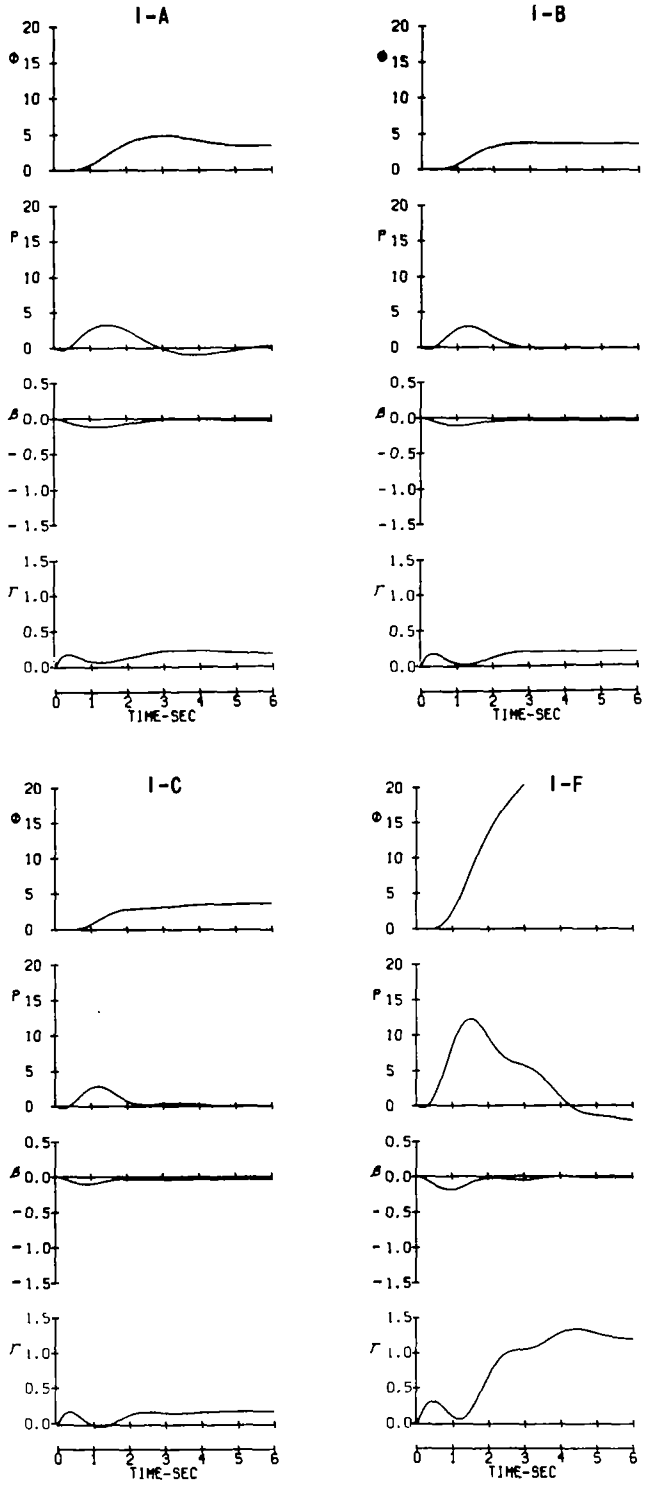


Figure III-15 Root Locus Diagrams of In-Flight Configurations Varying Pilot Gain Closure of Aileron to Bank Angle Loop



ϕ and $\beta \sim$ degrees
p and $r \sim$ deg/sec
δ_{AS} Step 1.0 inch

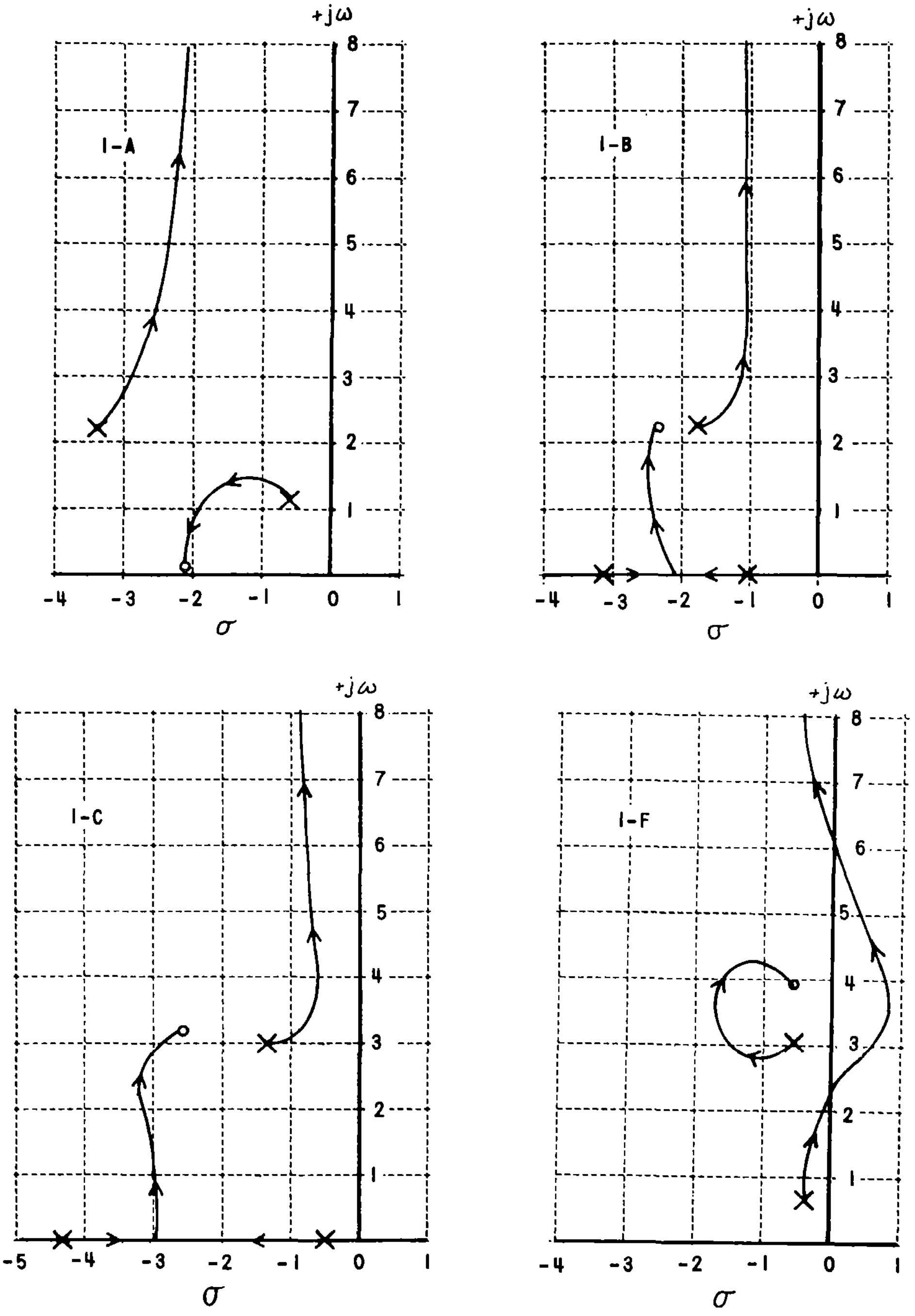
Figure III-16 Transient Responses To Aileron Stick Step Calculated For Fixed-Base Configurations From Pseudoderivatives



ϕ and β ~ degrees
p and r ~ deg/sec
δ_{RP} Step .1 inch

Figure III-17 Transient Responses To Rudder Pedal Step Calculated For Fixed-Base Configurations From Pseudoderivatives

GROUND SIMULATOR CONFIGURATIONS



NOTE: POLES AND ZEROS CALCULATED FROM PSEUDODERIVATIVES

Figure III-18 Root Locus Diagrams of Fixed-Base Configurations Varying Pilot Gain Closure of Aileron to Bank Angle Loop

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

The preferred configurations in this experiment were those for which aileron control was; roll rate-ordering, had adequate sensitivity, and did not generate sideslip or excite the Dutch roll mode. If these conditions were not met, then "good" rudder control was helpful to damp out the Dutch roll oscillations, keep sideslip zero or to augment the roll response to aileron.

For configurations where the aileron stick was roll rate-ordering and the control sensitivity was adequate, the pilot ratings and comments were found to be related to the amount and the sign of the sideslip that was caused by aileron stick control together with the magnitude and phase of the Dutch roll excitation appearing in the bank angle response. The Dutch roll excitation parameter, ω_ϕ/ω_d, by itself, was not adequate to correlate the pilot rating and comment data. Rather it appears necessary to consider the residue of the Dutch roll mode in the bank angle response to aileron stick inputs, together with the magnitude and sign of sideslip excited by aileron stick inputs.

The results of the fixed-base and in-flight simulations were in general quite similar; however, the time histories of responses to aileron stick step inputs indicate that there were differences in numerator factors between the fixed-base and in-flight simulations which frustrate detail comparison of the results.

The configurations evaluated in the program demonstrate the effect of rolling moment due to sideslip, L'_β , the Dutch roll mode, ω_d , ζ_d and the roll mode time control, τ_R , on the roll response to sideslip disturbances. The response at all frequencies is proportional to L'_β while the response at low frequency is inversely proportional to ω_d and λ_R . When the Dutch roll damping ratio is low, the response at the Dutch roll frequency is dominant and the roll response to sideslip disturbances is indicated by the magnitude of the roll-to-sideslip ratio in the Dutch roll mode.

Evaluation of the configurations in the presence of random noise disturbances proved to be a valuable part of the investigation. It often emphasized objectionable handling qualities that were not obvious in the smooth air environment. Although the random noise disturbance, as employed in this investigation, showed the effects of an external disturbance on the handling qualities, simulation of actual turbulence would be more desirable. It is recommended that techniques be developed to (1) determine characteristics of the turbulence that is representative of the mission environment, (2) determine the responses of the actual vehicle to this representative turbulence and (3) simulate the significant responses to turbulence for the evaluation.

The results of this program indicate that pilot rating of the lateral-directional handling qualities is noticeably influenced by aileron control sensitivity. It is recommended that further investigations be performed to establish the range of values and the relationships of the aileron sensitivity, maximum deflection and force gradient desirable for the re-entry mission. Investigations are especially needed for acceleration ordering aileron control.

SECTION 5

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APPENDIX A

LATERAL-DIRECTIONAL EQUATIONS OF MOTION

The lateral-directional equations of motion may be written in stability axes as follows (from References 4, 1, and 9).

$$\begin{bmatrix} Y_\beta - s & -1 & \frac{g}{V_0} \\ N'_\beta + N'_{\dot\beta} s & N'_r - s & N'_p s \\ L'_\beta + L'_{\dot\beta} s & L'_r & (L'_p - s)s \end{bmatrix} \begin{bmatrix} \beta \\ r \\ \phi \end{bmatrix} = \begin{bmatrix} -Y_{\delta_{AS}} & -Y_{\delta_{RP}} \\ -N'_{\delta_{AS}} & -N'_{\delta_{RP}} \\ -L'_{\delta_{AS}} & -L'_{\delta_{RP}} \end{bmatrix} \begin{bmatrix} \delta_{AS} \\ \delta_{RP} \end{bmatrix} \quad \text{(A-1)}$$

The aerodynamic side force derivatives $Y_{\dot\beta}$, Y_p and Y_r were neglected because they had only a small effect on the side force equations for the configurations evaluated in this program. They were present only because the rudder was driven by $\dot\beta$, p and r signals to match the yawing moment pseudoderivatives. The bank angle per aileron stick transfer function can be written as follows:

$$\frac{\phi}{\delta_{AS}} = \frac{1}{\Delta}\Big\{\big[L'_{\delta_{AS}} + Y_{\delta_{AS}} L'_{\dot\beta}\big] s^2 + \big[N'_{\delta_{AS}}(L'_r - L'_{\dot\beta}) - L'_{\delta_{AS}}(N'_r - N'_{\dot\beta} + Y_\beta) + Y_{\delta_{AS}}(N'_{\dot\beta} L'_r + L'_\beta - N'_r L'_{\dot\beta})\big] s$$
$$+ \big[L_{\delta_{AS}}(N'_\beta + Y_\beta N'_r) - N_{\delta_{AS}}(L'_\beta + Y_\beta L'_r) + Y_{\delta_{AS}}(N'_\beta L'_r - N'_r L'_\beta)\big]\Big\} \quad \text{(A-2)}$$

$$\Delta = s^4 + \big[N'_{\dot\beta} - L'_p - N'_r - Y_\beta\big] s^3 + \big[N'_\beta + N'_r L'_p - N'_p L'_r - N'_{\dot\beta} L'_p + N'_p L'_{\dot\beta} + Y_\beta(L'_p + N'_r) - \tfrac{g}{V_0} L'_{\dot\beta}\big] s^2$$
$$+ \big[N'_p L'_\beta - N'_\beta L'_p + Y_\beta(N'_p L'_r - N'_r L'_p) + \tfrac{g}{V_0}(N'_r L'_{\dot\beta} - N'_{\dot\beta} L'_r - L'_\beta)\big] s + \big[\tfrac{g}{V_0}(N'_r L'_\beta - N'_\beta L'_r)\big] \quad \text{(A-3)}$$

This transfer function could be written in one of the three following forms for the configuration in this program:

$$\frac{\phi}{\delta_{AS}} = \frac{K_{\phi_{\delta_{AS}}}\left(\frac{s^2}{\omega_\phi^2} + \frac{2\zeta_\phi}{\omega_\phi} s + 1\right)}{s(\tau_R s + 1)\left(\frac{s^2}{\omega_d^2} + \frac{2\zeta_d}{\omega_d} s + 1\right)} \quad \text{(A-4)}$$

This form was valid for Parts I and II of this program where the spiral mode was essentially at the origin (i.e., τ_5 was large) which is true for $\frac{g}{V_0}(N'_r L'_\beta - N'_\beta L'_r) \approx 0$.

$$K_{\phi_{\delta_{AS}}} = \frac{L'_{\delta_{AS}}(N'_\beta + Y_\beta N'_r) - N'_{\delta_{AS}}(L'_\beta + Y_\beta L'_r) + Y_{\delta_{AS}}(N'_\beta L'_r - N'_r L'_\beta)}{N'_p L'_\beta - N'_\beta L'_p + Y_\beta(N'_p L'_r - N'_r L'_p) + \frac{g}{V_0}(N'_r L'_{\dot\beta} - N'_{\dot\beta} L'_r - L'_\beta)} \qquad \text{(A-5)}$$

The spiral mode was not at the origin for the Part III configurations and the transfer function could be expressed by one of the following forms depending upon the characteristic modes.

$$\frac{\phi}{\delta_{AS}} = \frac{K_{\phi_{\delta_{AS}}}\left(\frac{s^2}{\omega_\phi^2} + \frac{2\zeta_\phi}{\omega_\phi}s + 1\right)}{(\tau_s s + 1)(\tau_R s + 1)\left(\frac{s^2}{\omega_d^2} + \frac{2\zeta_d}{\omega_d}s + 1\right)} \qquad \text{(A-6)}$$

$$\frac{\phi}{\delta_{AS}} = \frac{K_{\phi_{\delta_{AS}}}\left(\frac{s^2}{\omega_\phi^2} + \frac{2\zeta_\phi}{\omega_\phi}s + 1\right)}{\left(\frac{s^2}{\omega_{RS}^2} + \frac{2\zeta_{RS}}{\omega_{RS}}s + 1\right)\left(\frac{s^2}{\omega_d^2} + \frac{2\zeta_d}{\omega_d}s + 1\right)} \qquad \text{(A-7)}$$

where:

$$K_{\phi_{\delta_{AS}}} = \frac{L'_{\delta_{AS}}(N'_\beta + Y_\beta N'_r) - N'_{\delta_{AS}}(L'_\beta + Y_\beta L'_r) + Y_{\delta_{AS}}(N'_\beta L'_r - N'_r L'_\beta)}{\frac{g}{V_0}(N'_r L'_\beta - N'_\beta L'_r)} \qquad \text{(A-8)}$$

APPENDIX B

CALCULATIONS

B.1 STEADY STATE ROLL RATE PER AILERON STICK STEP

Equation A-2 of Appendix A can be rewritten in the following form:

$$\frac{\phi}{\delta_{AS}} = \frac{A_\phi \left(s^2 + 2\zeta_\phi \omega_\phi s + \omega_\phi^2\right)}{\left(s + \frac{1}{\tau_s}\right)\left(s + \frac{1}{\tau_R}\right)\left(s^2 + 2\zeta_d \omega_d s + \omega_d^2\right)} \tag{B-1}$$

$$A_\phi = \left[L'_{\delta_{AS}} + Y_{\delta_{AS}} L'_{\dot{\beta}}\right] \tag{B-2}$$

For Parts I and II, the spiral mode is essentially at the origin, i.e., τ_s is large, and B-1 becomes

$$\frac{\phi}{\delta_{AS}} = \frac{A_\phi \left(s^2 + 2\zeta_\phi \omega_\phi s + \omega_\phi^2\right)}{s\left(s + \frac{1}{\tau_R}\right)\left(s^2 + 2\zeta_d \omega_d s + \omega_d^2\right)} \tag{B-3}$$

or

$$\frac{\dot{\phi}}{\delta_{AS}} = \frac{p}{\delta_{AS}} = \frac{A_\phi \left(s^2 + 2\zeta_\phi \omega_\phi s + \omega_\phi^2\right)}{\left(s + \frac{1}{\tau_R}\right)\left(s^2 + 2\zeta_d \omega_d s + \omega_d^2\right)} = \left(\frac{A_\phi \omega_\phi^2}{\frac{\omega_d^2}{\tau_R}}\right) \frac{\left(\frac{s^2}{\omega_\phi^2} + \frac{2\zeta_\phi}{\omega_\phi} s + 1\right)}{\left(\tau_R s + 1\right)\left(\frac{s^2}{\omega_d^2} + \frac{2\zeta_d}{\omega_d} s + 1\right)} \tag{B-4}$$

Thus the steady-state roll rate per step aileron stick input becomes:

$$\frac{p_{ss}}{\delta_{AS}} = \frac{A_\phi}{\frac{1}{\tau_R}} \left(\frac{\omega_\phi}{\omega_d}\right)^2 = \left[L'_{\delta_{AS}} + Y_{\delta_{AS}} L'_{\dot{\beta}}\right] \tau_R \left(\frac{\omega_\phi}{\omega_d}\right)^2 \tag{B-5}$$

$Y_{\delta_{AS}} L'_{\dot{\beta}}$ was small compared to $L'_{\delta_{AS}}$ for the configurations in Parts I and II, and the following computing equation was used for the fixed-base and in-flight evaluation configurations:

$$\frac{p_{ss}}{\delta_{AS}} = L'_{\delta_{AS}} \tau_R \left(\frac{\omega_\phi}{\omega_d}\right)^2 \tag{B-6}$$

$L'_{\delta_{AS}}$ values were obtained from system gain calibrations and basic T-33 control derivatives. τ_R values were obtained from nominal measured values of ground simulator and in-flight data. $(\omega_\phi / \omega_d)^2$ values were calculated as shown in paragraphs 2 and 4 below.

B.2 CALCULATION OF ω_ϕ

The following expression for $\omega_\phi{}^2$ comes from Equation A-2 in Appendix A.

$$\omega_\phi{}^2 = \frac{L'_{\delta_{AS}}(N'_\beta + Y_\beta N'_r) - N'_{\delta_{AS}}(L'_\beta + Y_\beta L'_r) + Y_{\delta_{AS}}(N'_\beta L'_r - N'_r L'_\beta)}{L'_{\delta_{AS}} + Y_{\delta_{AS}} L'_{\dot\beta}} \qquad \text{(B-7)}$$

The two $Y_{\delta_{AS}}$ terms, $Y_{\delta_{AS}}(N'_\beta L'_r - N'_r L'_\beta)$ and $Y_{\delta_{AS}} L'_{\dot\beta}$ were always small compared to the terms they were added to in this program and could be neglected. $Y_\beta L'_r$ was also small compared to L'_β and could be neglected. ω_ϕ^2 now becomes

$$\omega_\phi{}^2 \approx (N'_\beta + Y_\beta N'_r) - \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_\beta \qquad \text{(B-8)}$$

The following approximation from Reference 10 was checked and determined to be valid for the pseudoderivatives simulated in this program:

$$\omega_d{}^2 \approx N'_\beta + Y_\beta N'_r \approx N'_\beta \qquad \text{(B-9)}$$

$$\left|\frac{\phi}{\beta}\right| \approx \left|\frac{L'_\beta}{N'_\beta}\right| \left(\frac{1 + \dfrac{N'_\beta L'_r}{L'_\beta{}^2}}{1 + \dfrac{L'_p{}^2}{N'_\beta}}\right)^{1/2} \qquad \text{(B-10)}$$

The $N'_\beta L'_r / L'_\beta{}^2$ term in Equation B-10 is small compared to unity and the equation can be simplified to:

$$\left|\frac{L'_\beta}{N'_\beta}\right| \approx \left|\frac{\phi}{\beta}\right| \left(1 + \frac{L'_p{}^2}{N'_\beta}\right)^{\frac{1}{2}} \qquad \text{(B-11)}$$

or, since N'_β was always positive and L'_β negative

$$\frac{L'_\beta}{N'_\beta} \approx -\left|\frac{\phi}{\beta}\right| \left(1 + \frac{L'_p{}^2}{N'_\beta}\right)^{\frac{1}{2}} \qquad \text{(B-12)}$$

Substituting Equation B-9 into B-8 and B-12 and rearranging yields:

$$\frac{\omega_\phi^2}{\omega_d^2} \approx 1 - \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} \frac{L'_\beta}{N'_\beta} \tag{B-13}$$

$$\frac{L'_\beta}{N'_\beta} \approx -\left|\frac{\phi}{\beta}\right| \left[1 + \left(\frac{L'_p}{\omega_d}\right)^2\right]^{\frac{1}{2}} \tag{B-14}$$

Substituting B-14 into B-13 yields:

$$\left(\frac{\omega_\phi}{\omega_d}\right)^2 \approx 1 + \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}} \left|\frac{\phi}{\beta}\right| \left[1 + \left(\frac{L'_p}{\omega_d}\right)^2\right]^{\frac{1}{2}} \tag{B-15}$$

$N'_{\delta_{AS}}/L'_{\delta_{AS}}$ values were obtained from system gain calibrations and basic T-33 control derivatives. $|\phi/\beta|$ and ω_d values were obtained from nominal measured values of ground simulator and in-flight data. L'_p values were obtained from the pseudoderivatives. Equation B-15 was used to compute ω_ϕ for the fixed-base and the Part II and III in-flight evaluations. Equation B-13 was found to be inaccurate for the Part I in-flight configurations because of the ω_d^2 approximation and ω_ϕ was determined as described in paragraph 4 below for these configurations.

B.3 CALCULATION OF ζ_ϕ

The following expression for $2\zeta_\phi\omega_\phi$ comes from Equation A-2 in Appendix A.

$$2\zeta_\phi\omega_\phi = \frac{N'_{\delta_{AS}}(L'_r - L'_{\dot\beta}) - L'_{\delta_{AS}}(N'_r - N'_{\dot\beta} + Y_\beta) + Y_{\delta_{AS}}(N'_{\dot\beta}L'_r + L'_\beta - N'_r L'_{\dot\beta})}{L'_{\delta_{AS}} + Y_{\delta_{AS}} L'_{\dot\beta}} \tag{B-16}$$

Since $N'_{\dot\beta}L'_r$ and $N'_r L'_{\dot\beta}$ are small compared to L'_β and $Y_{\delta_{AS}} L'_{\dot\beta}$ was small compared to $L'_{\delta_{AS}}$, they can be neglected and Equation B-16 reduces to

$$2\zeta_\phi\omega_\phi \approx \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}(L'_r - L'_{\dot\beta}) - (N'_r - N'_{\dot\beta} + Y_\beta) + \frac{Y_{\delta_{AS}}}{L'_{\delta_{AS}}} L'_\beta \tag{B-17}$$

The rudder was driven by the aileron stick to obtain the desired $N'_{\delta_{AS}}$ for the evaluation configurations which introduced the $Y_{\delta_{AS}}$.

$$N'_{\delta_{AS}} \approx N'_{\delta_r}\left(\frac{\delta_r}{\delta_{AS}}\right) \tag{B-18}$$

and

$$Y_{\delta_{AS}} \approx Y_{\delta_r}\left(\frac{\delta_r}{\delta_{AS}}\right) \tag{B-19}$$

$Y_{\delta_r} \approx -.0128\ N'_{\delta_r}$ for the T-33 and therefore $Y_{\delta_{AS}}/N'_{\delta_{AS}} \approx -.0128$. When this substitution is made, Equation B-17 is reduced to:

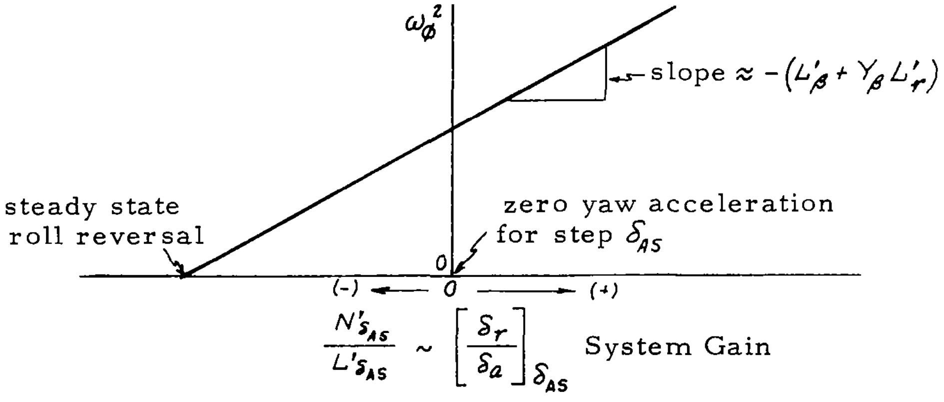
$$2\zeta_\phi\omega_\phi \approx \frac{N'_{\delta_{AS}}}{L'_{\delta_{AS}}}\left(L'_r - L'_{\dot\beta} - .0128\,L'_\beta\right) - \left(N'_r - N'_{\dot\beta} + Y_\beta\right) \tag{B-20}$$

This equation was used to calculate $2\zeta_\phi\omega_\phi$. Values of L'_r , L'_β , $L'_{\dot\beta}$, N'_r , $N'_{\dot\beta}$, and Y_β were obtained from the pseudoderivatives. It was not used for the Part I in-flight configurations where ζ_ϕ was determined as described in paragraph 4 below.

B.4 ADDITIONAL DETERMINATION OF ω_ϕ AND ζ_ϕ

The values of ω_ϕ and ζ_ϕ calculated for the Part I in-flight configurations, using the equations in paragraphs 2 and 3 above, did not show good agreement with the recorded transient responses. Values of ω_ϕ and ζ_ϕ were therefore determined by matching the recorded transient responses with responses generated using an analog computer.

The following sketch can be drawn using Equation B-7, assuming $Y_{\delta_{AS}} = 0$.



The intersection of the line in the above plot with the abscissa defines the $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ ratio required to make ω_ϕ^2 equal to zero, and therefore, from Equation B-6, p_{ss}/δ_{AS} equal to zero. The T-33 variable stability system has a gain control which sets the ratio of rudder deflection relative to aileron stick inputs, $\left[\frac{\delta_r}{\delta_a}\right]_{\delta_{AS}}$, which sets $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ for the configuration. The system also has the capability of putting simultaneous step inputs into the aileron and rudder channels. The magnitude and sign of these inputs can be varied independently for each channel. This is equivalent to changing $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ for a δ_{AS} step input. For each group of configurations (such as A-4, A-5, A-6 where only the control derivatives were varied from one configuration to the next), a series of transient responses was recorded for simultaneous aileron and rudder step inputs where only the rudder input was varied from one record to the next. The magnitude and sign of the rudder input was adjusted to provide the equivalent $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ for each configuration. For the higher $|\phi/\beta|$ groups of configurations, $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ was made increasingly negative until steady state roll reversal was encountered. This fixed the intercept of the straight line with the abscissa.

In addition to the step input transient responses, records were made for rudder doublet inputs for each group of configurations. Values of ω_d and ζ_d were obtained from these records.

Values for τ_R and τ_S were determined by selecting the step response record with minimum Dutch roll response from each group of configurations and matching the roll rate response with the roll rate response generated by an analog computer. The ϕ/δ_{AS} transfer function (Equation B-1) was set up on the analog computer and the only restraint in matching the record to determine τ_S and τ_R was that ω_d and ζ_d were set to the values determined from the rudder doublet records. With τ_R, τ_S, ω_d and ζ_d now fixed, ω_ϕ and ζ_ϕ were determined for the configurations by varying ω_ϕ and ζ_ϕ on the analog responses to obtain the best match with the recorded in-flight response. In matching the responses, the best set of matching responses were selected with the constraints that: (1) ω_ϕ^2 values should fall on a straight line plot of ω_ϕ^2 vs. $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ and (2) the location of the transfer function zeros defined by ζ_ϕ and ω_ϕ should follow a regular path on an s-plane plot as $N'_{\delta_{AS}}/L'_{\delta_{AS}}$ was

For the purpose of calculating the variable stability system gains, it was convenient to express the stability derivatives in primed, dimensional form, referenced to T-33 body axes. It was, therefore, necessary to compute the stability derivatives in the same form for the airplane to be simulated. Since the data supplied were in the form of nondimensional derivatives referenced to body axes, it was necessary to transform them to stability axes, convert to the desired dimensional form and prime. (The T-33 body axes and stability axes were coincident for the nominal flight conditions.)

C.2 REPRESENTATION OF THE SIMULATED VEHICLE

Except for the Part I configurations, it was not generally possible to select a flight condition where the speed of the T-33 could match the speed of the vehicle being simulated. It is also beyond the capability of the T-33 to independently vary the side force derivatives. It was, therefore, necessary to select which parameters were to be matched and which were not. In this case, it was decided to match the important mode characteristics of the simulated vehicle. This required that a set of stability derivatives different from the actual set be used to calculate the variable stability system gains. These derivatives are termed pseudoderivatives in the sense that they result in flying qualities that are closely similar to those of the vehicle being simulated.

When the true speed could not be matched, it was not possible to match both bank angle and steady yaw rate in a steady coordinated turn. These quantities are approximately related by:

$$r = \frac{g}{V} \phi$$

It was decided to attempt to match the bank angle response to aileron control and to scale the yaw rate response proportional to g/V .

The equations of motion for a coordinated ($\beta = \dot{\beta} = 0$) turn are:

$$(1 - Y_r) r = \frac{g}{V} \phi + Y_{\delta_{AS}} \delta_{AS} + Y_{\delta_{RP}} \delta_{RP}$$

$$N'_r r = -N'_{\delta_{AS}} \delta_{AS} - N'_{\delta_{RP}} \delta_{RP}$$

$$L'_r r = -L'_{\delta_{AS}} \delta_{AS} - L'_{\delta_{RP}} \delta_{RP}$$

If the side force terms $Y_r r$, $Y_{\delta_{AS}} \delta_{AS}$, $Y_{\delta_{RP}} \delta_{RP}$ are neglected, the side force equations become:

$$r = \frac{g}{V} \phi$$

Substituting this expression for the yaw rate, r, in the two moment equations, an expression for rudder pedal deflection as a function of bank angle can be written:

$$\frac{\delta_{RP}}{\phi} = \frac{g}{V} \left[\frac{L'_{\delta_{AS}} N'_r - N'_{\delta_{AS}} L'_r}{N'_{\delta_{AS}} L'_{\delta_{RP}} - L'_{\delta_{AS}} N'_{\delta_{RP}}} \right]$$

From this expression it can be seen that by matching $\frac{g}{V} N'_r$ and $\frac{g}{V} L'_r$ rather than N'_r and L'_r it is possible to match the steady rudder deflection required as a function of bank angle in coordinated turns when the control derivatives are matched.

Since the roots of the characteristic equation were to be matched, the following equation was obtained by equating the last coefficient of the quartic with the product of the roots:

$$\frac{\omega_d^2}{\tau_R \tau_S} = \frac{g}{V} \left[L'_\beta N'_r - N'_\beta L'_r \right]$$

From this expression it can be seen that matching $\frac{g}{V} N'_r$ and $\frac{g}{V} L'_r$ permits satisfying this equation by matching the sideslip derivatives L'_β and N'_β .

At this point it is in order to look at how many parameters are required to describe the dynamics of an airplane and to see how many are controllable using the T-33 variable stability airplane.

An airplane, when considered as a rigid body with conventional rudder and aileron controls, is adequately described as a three-degree-of-freedom, fourth-order system for fixed elevator controls.

The total number of independent coefficients in the uncontrolled or homogeneous set of equations is:

C.3 CALCULATION OF THE GAINS REQUIRED

The variable stability system gains required to match the pseudo-derivatives were calculated from the following matrix equations using the information obtained in steps 1 and 2.

$$\begin{bmatrix} \frac{\delta_a}{\beta} & \frac{\delta_a}{\dot\beta} & \frac{\delta_a}{p} & \frac{\delta_a}{r} \\ \frac{\delta_r}{\beta} & \frac{\delta_r}{\dot\beta} & \frac{\delta_r}{p} & \frac{\delta_r}{r} \end{bmatrix} = \begin{bmatrix} L'_{\delta_a} & L'_{\delta_r} \\ N'_{\delta_a} & N'_{\delta_r} \end{bmatrix}^{-1} \begin{bmatrix} \Delta L'_\beta & \Delta L'_{\dot\beta} & \Delta L'_p & \Delta'_r \\ \Delta N'_\beta & \Delta N'_{\dot\beta} & \Delta N'_p & \Delta N'_r \end{bmatrix}$$

where for example $L'_{\beta_{PSEUDO}} = L'_{\beta_{T-33}} + \Delta L'_\beta = L'_{\beta_{T-33}} + L'_{\delta_{r_{T-33}}} \frac{\delta_r}{\beta} + L'_{\delta_{a_{-33}}} \frac{\delta_a}{\beta}$

$$\begin{bmatrix} \frac{\delta_a}{\delta_{AS}} & \frac{\delta_a}{\delta_{RP}} \\ \frac{\delta_r}{\delta_{AS}} & \frac{\delta_r}{\delta_{RP}} \end{bmatrix} = \begin{bmatrix} L'_{\delta_a} & L'_{\delta_r} \\ N'_{\delta_a} & L'_{\delta_r} \end{bmatrix}^{-1} \begin{bmatrix} L'_{\delta_{AS}} & L'_{\delta_{RP}} \\ N'_{\delta_{AS}} & N'_{\delta_{RP}} \end{bmatrix}$$

where

$$L'_{\delta_{AS}} = L'_{\delta_{AS}} \Big|_{PSEUDO}$$

C.4 DEFINITION OF VARIABLE STABILITY SYSTEM CHARACTERISTICS

The following variable stability system characteristics had to be considered before the gain calculated in step 3 could be converted to knob settings.

A. Sensor Characteristics

B. Channel Lags

C. Control System Compliance

C.4.1 Sensor Characteristics

The equations of motion used for the simulation are written in terms of β , $\dot{\beta}$, p , and r measured with respect to an axis system fixed to the airplane with the origin at the c.g. Since the airframe is a reasonably rigid body, the rate gyros measure p and r without correction. However, the sideslip probe is mounted on the nose of the airplane and therefore, senses components of the angular rates proportional to the probe distance from the c.g. In addition, the angle sensed by the probe is influenced by the local flow of air around the fuselage. The following equation was used to represent the output of the sideslip probe:

$$\beta_{\underset{MEAS}{PROBE}} = \left[\frac{\beta_{PROBE}}{\beta_{TRUE}}\right]_{c.g.} \left(\beta_{\underset{@\,c.g.}{TRUE}} + \frac{rx}{V_0}\right) - \frac{pz}{V_0}$$

where x and z are coordinates of the probe in the reference axis system and $\left[\frac{\beta_{PROBE}}{\beta_{TRUE}}\right]_{c.g.}$ is a gain factor due to the local air flow around the fuselage. For the flight condition used in the simulation program, the following numerical values were used in this equation:

$$\beta_{\underset{MEAS}{PROBE}} = 2.10 \left[\beta_{\underset{@\,c.g.}{TRUE}} + .024\,r\right] - .00318\,p$$

C.4.2 Channel Lags

The sensors, the electronic components, such as filters, and the servos all contribute lags between the airplane response being sensed and the control surface deflection that is supposed to be proportional to the response. These lags must be considered in the calculation of the variable stability system gains. The technique used is to treat each channel as having an equivalent first order time constant and to compute a new set of gains that are compensated for the effects of sensor characteristics and channel time lags. The equivalent time constants measured or estimated for the variable stability channels are tabulated below in seconds.

en matched. Measurements can be made for the records of ω_d, ζ_d, τ_R, $_{RS}$, ζ_{RS}, $\left|\frac{\phi}{\beta}\right|$, $\frac{p_{ss}}{\delta_{AS}}$, etc. If satisfactory agreement between the sired and the measured responses is not obtained, it is necessary to examine the calculations and make required revisions. It may, for example, necessary to check system calibrations, revise estimates of the T-33 bility derivatives, or revise the time constants used to represent the stem dynamics.

It is often informative to take a series of response records for variations a single channel gain and to examine the effect this has on the measured sponse parameters of a configuration. These in-flight checks are a very essary step in the simulation procedure and cannot be by-passed if one is have confidence in the results of the experiment. There are a large number calculations involved, many system components to calibrate and maintain, l many operations by the test crew which are subject to error. For these sons, the in-flight check of system response to specific inputs is an ispensable step in conducting the experiment.

The T-33 has been equipped with a device for injecting sharp step or nmetrical doublet signals directly into the control surface servos for this pose. Calibration records were taken for each in-flight evaluation to ify that the desired configuration was set up.

) SETUP OF FEEL SYSTEM AND COMMAND GAINS

Although the T-33 feel system has provision for using response ameters such as n_z and dynamic pressure as inputs, this simulation uired only the simulation of a spring feel system. This allowed the feel tem to be set up on the ground. The spring rate or force gradient for h control in terms of pounds per inch of stick or rudder pedal deflection simulated.

The friction characteristics existent in the T-33 feel system are roximately the same as those estimated for realistic re-entry vehicle rol systems. Special effort was therefore not required to simulate tion characteristics.

The signals used to command the control surfaces were proportional to both the stick and rudder pedal positions. The following four gain controls were available to set up the control derivatives:

$$\frac{\delta_a}{\delta_{AS}}, \quad \frac{\delta_r}{\delta_{RP}}, \quad \left(\frac{\delta_r}{\delta_a}\right)_{\delta_{AS}\ \text{INPUTS}}, \quad \left(\frac{\delta_a}{\delta_r}\right)_{\delta_{RP}\ \text{INPUTS}}$$

The aileron control derivatives were simulated using the following relationships:

$$L'_{\delta_{AS}}\Big|_{\substack{\text{SIMULATED}\\ \text{AIRCRAFT}}} = \left[L'_{\delta_a\ T-33} + L'_{\delta_r\ T-33}\left(\frac{\delta_r}{\delta_a}\right)_{\delta_{AS}\ \text{INPUTS}} \right]\frac{\delta_a}{\delta_{AS}}$$

$$N'_{\delta_{AS}}\Big|_{\substack{\text{SIMULATED}\\ \text{AIRCRAFT}}} = \left[N'_{\delta_a\ T-33} + N'_{\delta_r\ T-33}\left(\frac{\delta_r}{\delta_a}\right)_{\delta_{AS}\ \text{INPUTS}} \right]\frac{\delta_a}{\delta_{AS}}$$

Rudder pedal control derivatives were simulated in a similar manner.

C.10 GROUND SIMULATOR MECHANIZATION

The ground simulation program was accomplished by mechanizing TR-10 analog computers to represent the basic T-33 plus the characteristics of the sideslip probe. The T-33 feel system and variable stability system was then used to simulate the desired configurations. The feel system setup was identical to that used for flight.

The command signals to the analog were taken from the surface servo feedback potentiometers rather than from the actual surface position pickoffs. This was done because the control system has slop and compliance which causes different surface motion to result on the ground without air loads than occurs in flight with air loads. Since the analog computer is a d-c machine and the variable stability system is an a-c system, it was necessary to have demodulators for the control signals from the airplane into the analog and to have modulators for the response signals generated in the analog and used as inputs to the variable stability system.

The 50 channel oscillograph was used to record responses to control inputs. In addition, a direct writing recorder was used to record β , p , r , ϕ and the command input. These records were used to check the configuration dynamics before each evaluation.

C.11 GROUND SIMULATOR CALIBRATIONS

The T-33 variable stability system was used in conjunction with the analog computer in the same manner that it was used in flight. There were, however, enough differences, such as the airplane/computer interface equipment, to require calibration of the variable stability channels for the fixed-base simulation in much the same manner as was done for the in-flight simulation.

The time lags were also measured for each channel and used for calculating the compensated gains.

The dynamic and static characteristics of the simulated configurations were checked for the analog setup in much the same manner described in paragraph C.8 for the in-flight simulation.

APPENDIX D

FIXED-BASE SIMULATION OF THE T-33

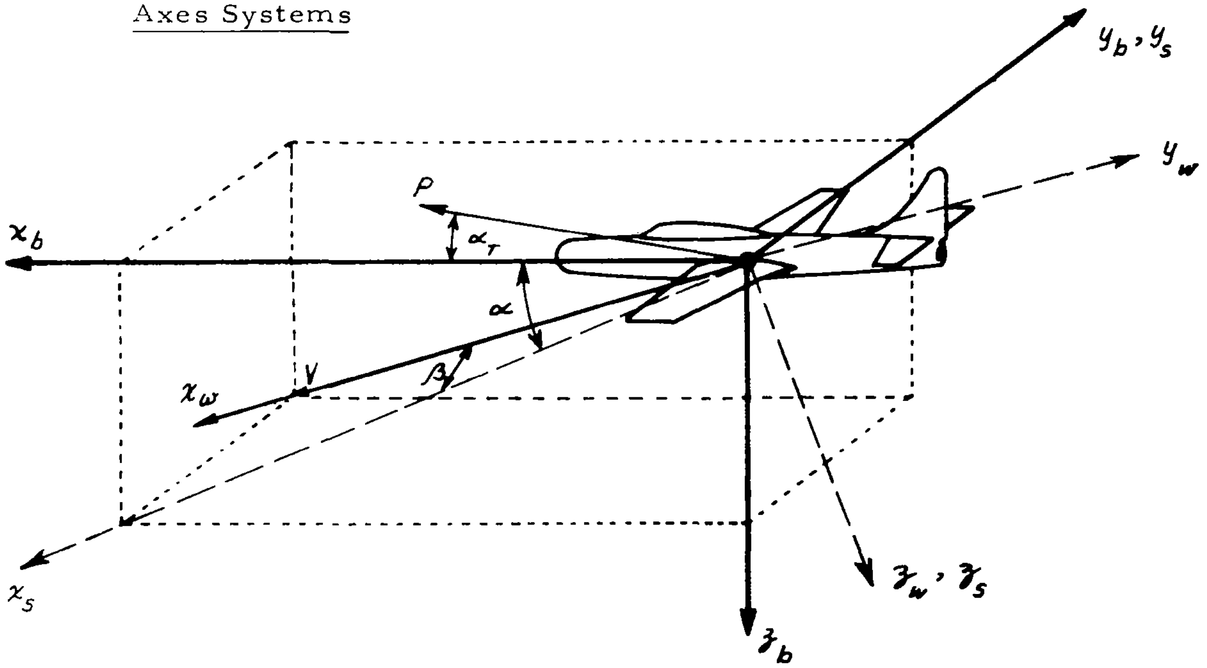
This Appendix defines the equations of motion and aerodynamic data used to represent the T-33 airplane for the ground simulation.

Full six-degree-of-freedom equations are quoted from Reference 13. These are in terms of body axes for the moment equations, stability axes for the force equations and body axes-referenced Euler angles. This choice of axes systems is the most economical in the amount of analog equipment required for simulations incorporating the small perturbation approximations and not requiring all three earth-referenced velocity components. For more sophisticated simulations it may be advantageous to use wind axes for the force equations instead of stability axes, see Reference 13.

The simplifications assumed for the simulations are listed and the resulting approximate equations are given.

Because of the confusion which exists regarding the various types of axes systems these are defined as follows:

Axes Systems



Body Axes x_b, y_b, z_b

These are a right-handed orthogonal triad with origin at c.g. They are fixed relative to the airplane with the x_b and z_b axes in the plane of symmetry of the aircraft.

The alignment of the x_b axis within the plane of symmetry is arbitrarily fixed in relation to the fuselage reference line. In this study the x_b axis is taken to be parallel with the x_s stability axis in the steady state flight condition.

Wind Axes x_w, y_w, z_w

A right-handed orthogonal triad with origin at the c.g.

The x_w axis is coincident with the relative wind and the z_w axis is in the plane of symmetry of the aircraft.

Stability Axes x_s, y_s, z_s

A right-handed orthogonal triad with origin fixed at the center of gravity.

The x_s stability axis is coincident with the projection of the x_w wind axis onto the plane of symmetry and rotates with the wind axis in relation to the airplane.

The z_s stability axis lies in the plane of symmetry and is coincident with the z_w wind axis. The y_s stability axis is coincident with the y body axis.

Note that the x_s and z_s axes rotate relative to the aircraft but remain in the plane of symmetry.

Moment Equations -- in Body Axes

$$L_b = I_x \dot{p}_b + (I_z - I_y) q_b r_b - I_{xz}(p_b q_b + \dot{r}_b)$$

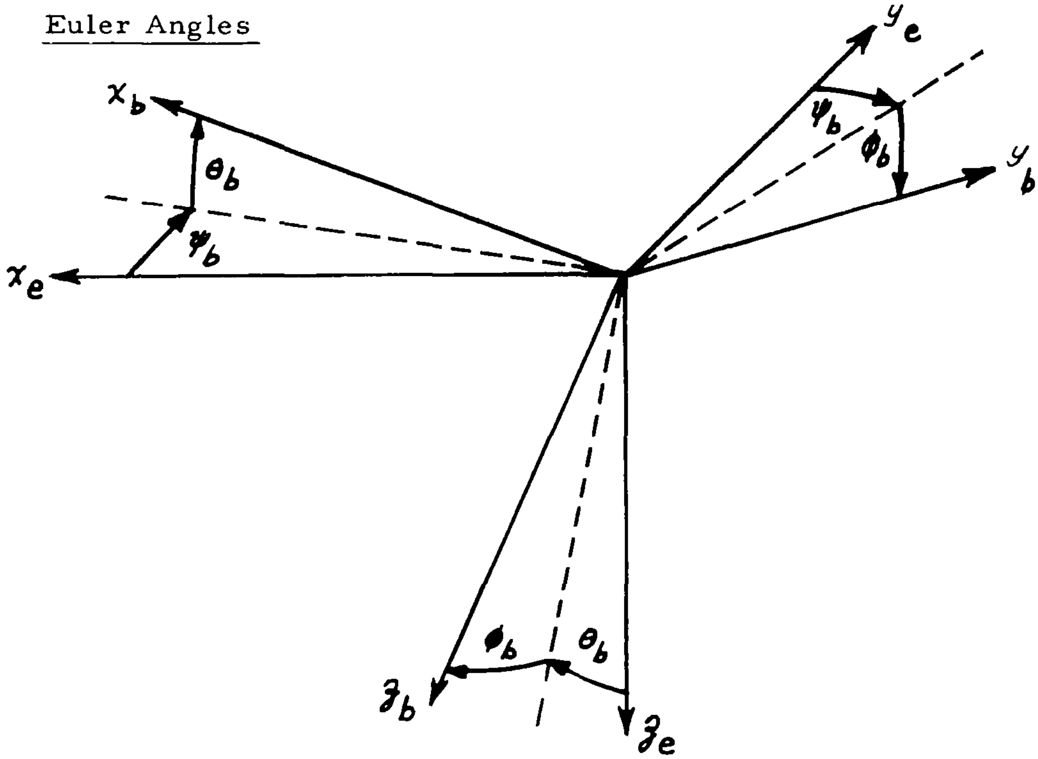
$$M_b = I_y \dot{q}_b + (I_x - I_z) p_b r_b - I_{xz}(r_b^2 - p_b^2)$$

$$N_b = I_z \dot{r}_b + (I_y - I_x) p_b q_b - I_{xz}(\dot{p}_b - r_b q_b)$$

Where L_b, M_b, N_b are the aerodynamic rolling, pitching and yawing moments about the x_b, y_b, z_b body axes respectively.

These are the complete equations. It is assumed that there are no gyroscopic effects or moments from thrust misalignments.

Euler Angles



Euler angles describing the orientation of body axes relative to the earth axes are shown above.

Displacements are in the order: yaw ψ_b, pitch θ_b, roll ϕ_b.

In terms of the body axes angular rates we get:

$$\dot{\phi}_b = p_b + \tan\theta_b \, (q_b \sin\phi_b + r_b \cos\phi_b)$$

$$\dot{\theta}_b = q_b \cos\phi_b - r_b \sin\phi_b$$

$$\dot{\psi}_b = \frac{q_b \sin\phi_b + r_b \cos\phi_b}{\cos\theta_b}$$

Earth Referenced Velocities

For this simulation, only the height above the earth is of interest. This is given by:

$$-\dot{h} = w_e = -u_s \cos\alpha \sin\theta_b + v_s \sin\phi \cos\theta + u_s \sin\alpha \cos\phi \cos\theta$$

However, for completeness, the two translational components of velocity are given by:

$$u_e = u_s \cos\alpha \cos\theta_b \cos\psi_b + v_s \left(\sin\phi_b \sin\theta_b \cos\psi_b - \cos\phi_b \sin\psi_b\right) + u_s \sin\alpha \left(\sin\phi_b \sin\psi_b + \cos\phi_b \cos\psi_b \sin\theta_b\right)$$

$$v_e = u_s \cos\alpha \cos\theta_b \sin\psi_b + v_s \left(\cos\phi_b \cos\psi_b + \sin\phi_b \sin\theta_b \sin\psi_b\right) + u_s \sin\alpha \left(\cos\phi_b \sin\theta_b \sin\psi_b - \sin\phi_b \cos\psi_b\right)$$

Force Equations in Stability Axes

$$X_s = m\left[\dot{u}_s - v_s\left(r_b \cos\alpha - p_b \sin\alpha\right) + g\left(\sin\theta_b \cos\alpha - \cos\theta_b \cos\phi_b \sin\alpha\right)\right] - P \cos\left(\alpha + \alpha_T\right)$$

$$Y_s = m\left[\dot{v}_s + u_s\left(r_b \cos\alpha - p_b \sin\alpha\right) - g \cos\theta_b \sin\phi_b\right]$$

$$Z_s = m\left[v_s\left(p_b \cos\alpha + r_b \sin\alpha\right) - u_s\left(q_b - \dot{\alpha}\right) - g\left(\cos\theta_b \cos\phi_b \cos\alpha + \sin\theta_b \sin\alpha\right)\right] + P \sin\left(\alpha + \alpha_T\right)$$

Where X_s, Y_s and Z_s are the aerodynamic forces along the x_s, y_s and z_s stability axes respectively and P is the engine thrust.

These equations are complete, (i.e., they have no approximations) and include gravitational and thrust components.

Simplifications Assumed for Simulation

(1) Assume α, β, θ are small so that

$$\sin\alpha \approx \alpha, \quad \sin\beta \approx \beta, \quad \sin\theta \approx \theta$$

$$\cos\alpha \approx \cos\beta \approx \cos\theta \approx 1$$

(2) Products and squares among α, β, p, q, r are negligible.

(3) Assume $u_s \approx V$ and $\tan\beta \approx \beta$

so that $\dfrac{v_s}{u_s} \approx \beta$

(4) Thrust component $P \sin\left(\alpha + \alpha_T\right)$ is negligible.

Collection of Simplified Equations Used in the Simulation

Moments:

$$\frac{L_b}{I_x} = \dot{p}_b - \frac{I_{xz}}{I_x}\dot{r}_b$$

$$\frac{M_b}{I_y} = \dot{q}_b$$

$$\frac{N_b}{I_z} = \dot{r}_b - \frac{I_{xz}}{I_z}\dot{p}$$

Forces:

$$\dot{V} = \frac{X_s}{m} - g(\theta_b - \alpha\cos\phi_b) + \frac{P}{m}$$

$$V(\dot{\beta} + r_b - p_b\alpha) = \frac{Y_s}{m} - g\sin\phi_b$$

$$V(\dot{\alpha} - q_b) = \frac{Z_s}{m} + g\cos\phi_b$$

Euler Angle Rates:

$$\dot{\phi}_b = p_b + \theta_b\dot{\psi}_b$$

$$\dot{\theta}_b = q_b\cos\phi_b - r\sin\phi_b$$

$$\dot{\psi}_b = q_b\sin\phi_b + r\cos\phi_b$$

Height:

$$\dot{h} = V(\theta_b - \alpha\cos\phi_b - \beta\sin\phi_b)$$

$$\Delta V = \int \dot{V}\,dt$$

For the T-33 airplane an adequate representation of the aerodynamic forces and moments is given by the following expressions:

Aerodynamic Moment Equations -- Body Axes

$$\frac{L_b}{I_x} = L_\beta\beta + \frac{\partial L_\beta}{\partial\alpha}\alpha\beta + L_p p + L_r r + \frac{\partial L_r}{\partial\alpha}\alpha r + L_{\delta_a}\delta_a + L_{\delta_r}\delta_r$$

$$\frac{N_b}{I_z} = N_\beta\beta + N_p p + \frac{\partial N_p}{\partial\alpha}\alpha p + N_r r + N_{\delta_a}\delta_a + N_{\delta_r}\delta_r + \frac{\partial N_{\delta_a}}{\partial\alpha}\alpha\delta_a$$

$$\frac{M_b}{I_y} = M_\alpha\alpha + M_{\dot{\alpha}}\dot{\alpha} + M_q q + M_{\delta_e}\delta_e$$

APPENDIX E

RESPONSE TO SIDE GUSTS

There were frequent references in the pilot comment data to the aircraft response to turbulence or disturbances. The major complaint voiced was the large roll response for sideslip disturbances experienced for some configurations. Transient responses to disturbances were generated as indicated below to obtain a measure of the susceptibility of a configuration to turbulence.

The input disturbance used was equivalent to a gust along the aircraft y axis.

Equation A-1 from Appendix A is shown below for the control fixed, i.e., no pilot inputs case:

$$\begin{bmatrix} Y_\beta - s & -1 & \frac{g}{V_0} \\ N'_\beta + N'_{\dot\beta} s & N'_r - s & N'_p s \\ L'_\beta + L'_{\dot\beta} s & L'_r & (L'_p - s) s \end{bmatrix} \begin{bmatrix} \beta \\ r \\ \phi \end{bmatrix} = 0 \qquad \text{(E-1)}$$

The assumption that the air mass is nonaccelerating, i.e., the air mass is a satisfactory inertial reference, is implicit in the equation. When the air mass is allowed to have motion along the aircraft y axis, this must be accounted for and the equation can be written as the following set:

$$\begin{aligned} &Y_\beta \beta_A - s(\beta_A - \beta_G) && - r && + \left(\frac{g}{V_0}\right)\phi && = 0 \\ &\left(N'_\beta + N'_{\dot\beta} s\right)\beta_A && + \left(N'_r - s\right) r && + \left(N'_p s\right)\phi && = 0 \\ &\left(L'_\beta + L'_{\dot\beta} s\right)\beta_A && + L'_r r && + s\left(L'_p - s\right)\phi && = 0 \end{aligned} \qquad \text{(E-2)}$$

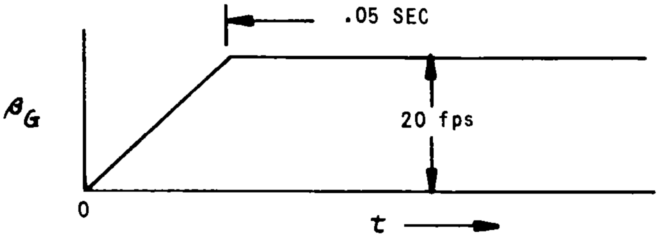
β_A - the aerodynamic sideslip angle or $\frac{1}{V_0}$ times the velocity of the aircraft with respect to the air mass along the y axis. (This is the sideslip angle displayed to the pilot.)

β_G - the sideslip gust or $\frac{1}{V_o}$ times the velocity of the air mass with respect to the earth along the negative y axis. (A positive β_G disturbance gives a positive β_A indication to the pilot.)

The set of equations can be replaced by the following equation where β_G appears as an input.

$$\begin{bmatrix} Y_\beta - s & -1 & \frac{g}{V_o} \\ N'_\beta + N'_{\dot\beta} s & N'_r - s & N'_p s \\ L'_\beta + L'_{\dot\beta} s & L'_r & (L'_p - s)s \end{bmatrix} \begin{bmatrix} \beta_A \\ r \\ \phi \end{bmatrix} = \begin{bmatrix} -s \\ 0 \\ 0 \end{bmatrix} \beta_G \qquad \text{(E-3)}$$

This equation was solved on a digital computer for the side gust input shown below to generate the gust responses presented in this report. It should be noted that the sideslip angle β_G is the same angle that would be sensed by a sideslip vane for display to the pilot.



The transfer function for bank angle response to a β_G input determined from equation E-3 is shown below.

$$\frac{\phi}{\beta_G} = \frac{1}{\Delta}(-s)\left[L'_{\dot\beta} s^2 + (L'_r N'_{\dot\beta} - L'_{\dot\beta} N'_r + L'_\beta)s + (L'_r N'_\beta - L'_\beta N'_r)\right] \qquad \text{(E-4)}$$

$\Delta = \left(s + \frac{1}{\tau_s}\right)\left(s + \frac{1}{\tau_R}\right)\left(s^2 + 2\zeta_d \omega_d s + \omega_d^2\right)$ and is further defined by equation A-3 in Appendix A.

The spiral mode root was essentially zero for Parts I and II configurations which means that the term ($L'_r N'_\beta - L'_\beta N'_r$) was also near zero. $L'_{\dot\beta}$ was also zero and L'_β was large compared to $L'_R N'_\beta$ for these configurations. For these conditions, the transfer function becomes:

The following sketch illustrates the bank angle response to sideslip disturbances for the configurations in Part III: