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A FLIGHT INVESTIGATION OF LATERAL-DIRECTIONAL HANDLING QUALITIES FOR V/STOL AIRCRAFT IN LOW SPEED MANEUVERING FLIGHT

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FOREWORD

This report was prepared for the United States Air Force by the Flight Research Section, National Aeronautical Establishment, National Research Council, Ottawa, Canada under the sponsorship of the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The research was conducted under Subcontract S-68-48 to the Cornell Aeronautical Laboratory, Inc. The CAL project engineer was Mr. C. Chalk and Mr. W. Klotzback was the project officer for the Flight Dynamics Laboratory.

Mr. K-H. Doetsch, Dr. D.G. Gould and Mr. D.M. McGregor of the Flight Research Section collaborated in the preparation of the simulation, the programming of the tests, and the analysis of the results. The evaluation pilots were Mr. N. Infanti of CAL; Mr. A.D. Wood, Mr. D.M. McGregor, Mr. F. Augusta of the Flight Research Section; and Mr. D. Morrison of Canadair Ltd.

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ABSTRACT

An investigation to determine the ranges of various lateral-directional characteristics required to provide adequate flying qualities for turning manoeuvres at low speed was undertaken using an airborne V/STOL aircraft simulator. Five parameters were varied in a systematic manner: the damping ratio, the frequency, and the ratio of the roll-angle to the side slip angle in the Dutch roll mode, together with the damping ratio and the frequency of the numerator of the roll-angle to aileron-control-input transfer function. The pilots performed a low speed, visual manoeuvring task and documented their assessment of the characteristics through extensive comments and a numerical rating. This report presents all the data categorized with respect to the test parameters as comprehensively as possible to allow others to examine them thoroughly from various points of view. No attempt has been made here to analyse the findings in detail. This is the subject of continuing work.

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SYMBOLS

CW	Cross-wind speed, ft/sec
DB	Decibels
F_y	Lateral aerodynamic force, lb
F_B	Lateral aerodynamic force excluding those components at the top of the mast and at the tail rotor, lb
g	Acceleration due to gravity, ft/sec^2
h_r	Height of main rotor above the centre of gravity, ft
I_{xx}	Rolling moment of inertia of the simulator, slug-ft^2
I_{zz}	Yawing moment of inertia of the simulator, slug-ft^2
I_{xz}	Cross product of inertia of the simulator, slug-ft^2
k_1, k_2	Constants relating the stability derivatives in roll and yaw to the side force derivatives, ft
k_1', k_2'	Modified values of k_1 and k_2 to account for misalignment of axes, ft
ℓ_t	Tail rotor distance aft of the centre of gravity, ft
L	Rolling angular acceleration per unit subscript, rad/sec^2/unit subscript OR Scale length of turbulence, ft
M	Pitching angular acceleration per unit subscript, rad/sec^2/unit subscript
m	Mass of the simulator, slug
N	Yawing acceleration per unit subscript rad/sec^2/unit subscript OR Numerator expression of transfer functions

SYMBOLS (Cont'd)

p	Angular rate of roll, rad/sec
q	Angular rate of pitch, rad/sec
r	Angular rate of yaw, rad/sec
S	Laplace operator
U	Flight speed, ft/sec
v	Lateral component of velocity, ft/sec
w	Vertical component of velocity, ft/sec
Y	Side acceleration per unit subscript, $ft/sec^2/unit$ subscript
Z	Normal acceleration per unit subscript, $ft/sec^2/unit$ subscript
α	Angle of attack, rad
β	Angle of sideslip, rad
δ_a	Pilot's roll control deflection, in
δ_e	Pilot's elevator control deflection, in
δ_r	Pilot's yaw control deflection, in
δ_t	Pilot's heave control deflection, in
ζ	Damping ratio
θ	Pitch angle, rad
λ_R	Roll subsidence root of the lateral-directional characteristic equation, rad/sec
λ_S	Spiral root of the lateral-directional characteristic equation
σ	Root mean square value

SYMBOLS (Cont'd)

ϕ	Roll angle, rad OR Power spectral density of turbulence, rad^2/rad/sec
ψ	Change in heading from approach direction (in cross-wind expression), deg
ω	Frequency, rad/sec
∂	Partial derivative
Δ	Indicates "change in"

SUBSCRIPTS

c	Calculated (see Fig. 6)
d	Dutch roll
f	Fuselage
g	Gust
H	Helicopter
M	Model
o	Initial condition
p	Roll rate
q	Pitch rate
r	Yaw rate
S	Spiral
R	Roll subsidence
y	In direction of lateral axis

SIGN CONVENTION

The axes of this simulator are determined by the orientation of the angular rate gyro package and the accelerometers used in the "model-controlled" system. The x-axis is considered positive forward, the y-axis positive to the right and the z-axis positive downward. Nose-up pitching, right rolling, and right yawing motions and the moments and control movements producing these motions are positive. Motions of the aircraft nose-up and nose-left cause positive changes in the angles of attack and sideslip respectively.

CONFIGURATION IDENTIFIER

Refer to the first sheet of Table 3 for an explanation of the configuration identifier.

FIG. 1 AIRBORNE V/STOL SIMULATOR

1.0 INTRODUCTION

To enable pilots to take the fullest advantage of the unique capabilities of V/STOL aircraft, it may be necessary for aircraft designers to provide flying characteristics quite different from those of helicopters and conventional fixed-wing aircraft. It was the object of this research to provide some of the information necessary to assess these differences and to assist Cornell Aeronautical Laboratory, Inc. in drawing up preliminary handling qualities specifications under a United States Air Force Contract. Specifically, these flight tests using a variable stability helicopter shown in Figure 1 and described briefly in the following section, attempted to determine the ranges of various lateral-directional characteristics required to provide adequate flying qualities for turning manoeuvres at low speed.

The results are presented, in general, in the form of pilot opinion contours with respect to the parameters varied, but it is appreciated that there probably are other characteristics which could be used more advantageously to categorize the handling qualities. A comprehensive description of the experimental conditions as well as the pilots' comments and ratings have been included to allow others to analyze the data from different points of view.

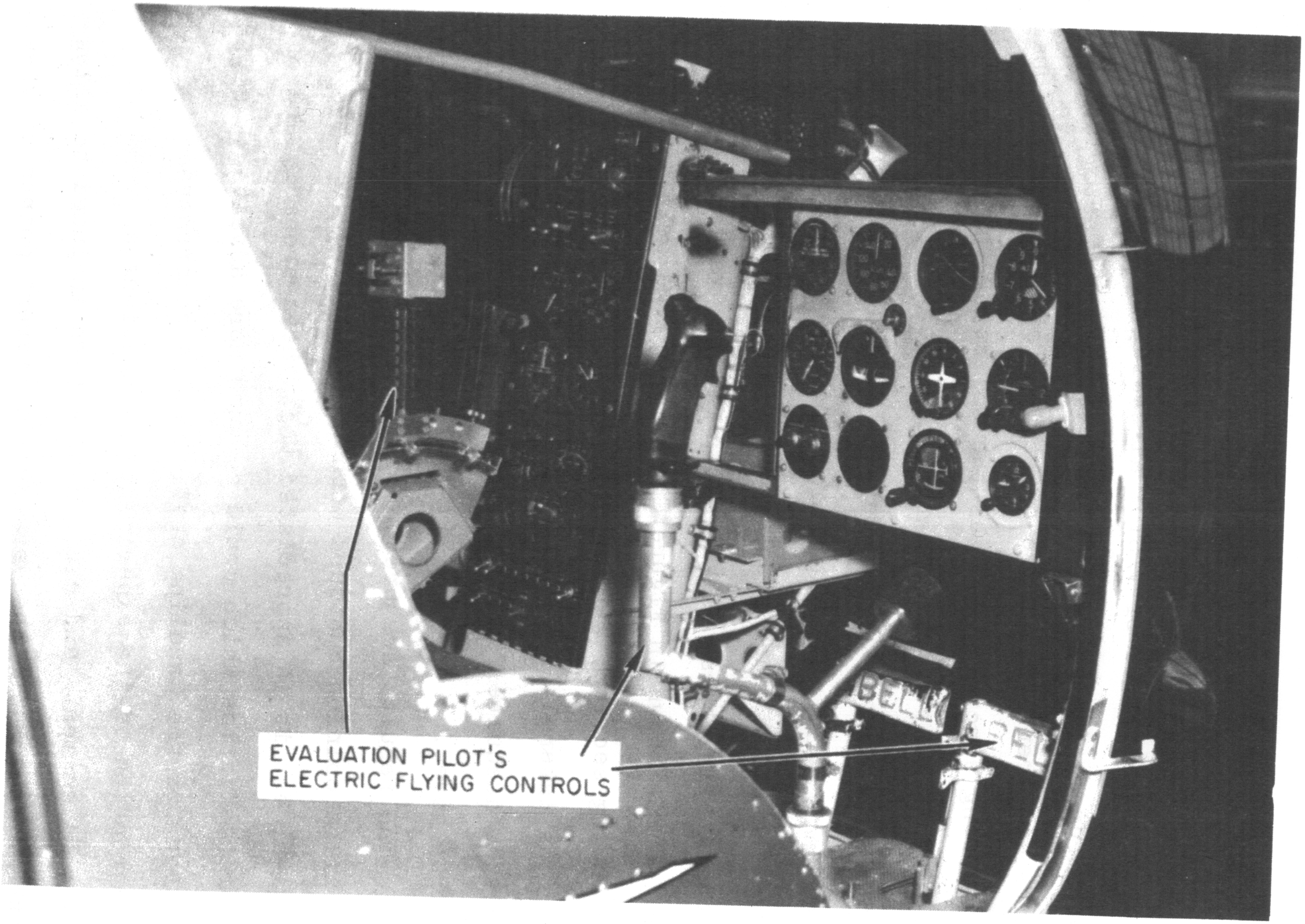


FIG 2 VIEW OF THE SIMULATOR COCKPIT FROM THE RIGHT SIDE

The Dutch roll damping ratio, ζ_d, and frequency, ω_d; the damping ratio, ζ_ϕ, and the frequency, ω_ϕ, of the numerator of the roll angle to aileron-control-input transfer function, $\frac{\phi}{\delta_a}$; and the ratio of roll angle to sideslip angle in the Dutch roll mode, $\left|\frac{\phi}{\beta}\right|_d$, were varied in a systematic fashion while the spiral root, λ_S, and the roll subsidence root, λ_R, of the lateral-directional characteristic equation were held constant at zero and -4 respectively. To effect the desired changes in the five variable parameters and to hold the other two constant, the electrical analogue which comprises the "model" in the method used in the simulator was "patched" to allow variations in seven lateral-directional stability derivatives through seven gain-setting potentiometers and seven switches (for sign changes) mounted in the cockpit and selected by the safety pilot. The derivatives varied were: L_β, the dihedral effect; L_p, the damping in roll; L_r, the rolling acceleration per unit yaw rate; N_β, the weathercock stability; N_r, the damping in yaw; N_p, the yawing acceleration per unit roll rate; and N_{δ_a}, the yawing acceleration per unit aileron deflection - a control cross-coupling term.

The only other lateral-directional stability derivatives included in the analogue model were the control sensitivity in roll, L_{δ_a}, and that in yaw, N_{δ_r}. Their magnitudes were preset to fixed values which, it was anticipated, would lead to comfortable control characteristics. All the other derivatives in the rolling and yawing equations of motion such as L_{δ_r}, $N_{\dot{\beta}}$, $L_{\dot{\beta}}$, etc. were held at zero. The pitching characteristics were set to comfortable levels and remained invariant throughout the programme.

The bulk of the research investigated two main themes; the influence on pilot opinion of: (1) changes in the positions of the lateral-directional oscillatory poles, as described by ζ_d and ω_d, with the zeros of the $\frac{\phi}{\delta_a}$ transfer function on top of the poles (i.e. $\zeta_\phi = \zeta_d$ and $\omega_\phi = \omega_d$), for three values of $\left|\frac{\phi}{\beta}\right|_d$ (0.2, 0.75 and 1.5), and (2) altering the positions of the zeros of the $\frac{\phi}{\delta_a}$ transfer function with respect to the poles at $\left|\frac{\phi}{\beta}\right|_d = 0.2$ with the majority of the investigation centring around $\omega_d = 0.25, 0.5, 1.0$ and $\zeta_d = -0.1, 0, +0.2$ respectively. The number of data points flown was 161 with the majority being evaluated by at least two pilots.

To create realistic flight conditions, synthetic vertical and lateral turbulence was introduced continuously and a 10 knot crosswind was switched into the simulation as the evaluation pilot started his approach.

A visual constant speed manoeuvring task, including an approach almost to the point of touchdown, was performed by the five pilots who participated in the programme. As they flew the pattern, their comments were recorded on

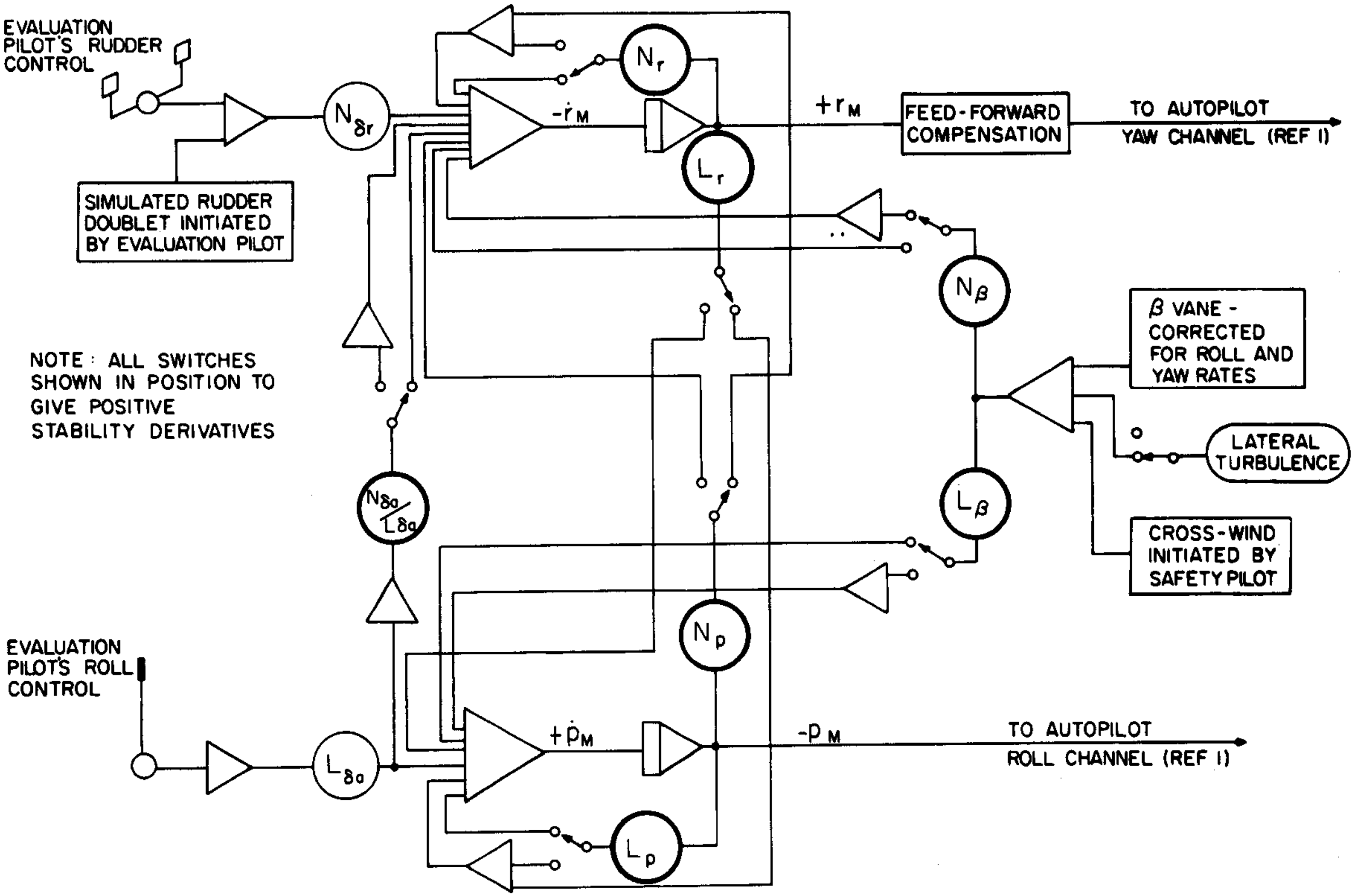


FIG 3 SCHEMATIC OF LATERAL-DIRECTIONAL "MODEL" ANALOGUE CIRCUIT

magnetic tape along with thirteen parameters defining the motion of the simulator and after landing specific items were written up on a flight card and a rating assigned using the scale of Table 1 (Ref. 2). A brief summary of pilot experience is contained in Table 2(a).

This report presents the results of the experiments as required by CAL contract S-68-48, but due to insufficient time, a thorough analysis of the data could not be completed. It is anticipated that a more comprehensive report ultimately will be published.

2.0 TEST EQUIPMENT

2.1 The Simulator

These flight tests were performed utilizing a "model-controlled" variable stability helicopter, described in detail in Reference 1, which is capable of altering its characteristics in four degrees of freedom - pitch, roll, yaw and heave. (Although the lateral and longitudinal force characteristics are affected by the model parameters and had to be taken into account in this programme, no independent means of directly altering the forces along these axes exist.) In this simulation method, movements of the evaluation pilot's flying controls (Fig. 2) supply electric signals proportional to control deflections to the analogue computer. The computer, which is mounted in the pod on the left side of the aircraft, is "patched" for the characteristics of the

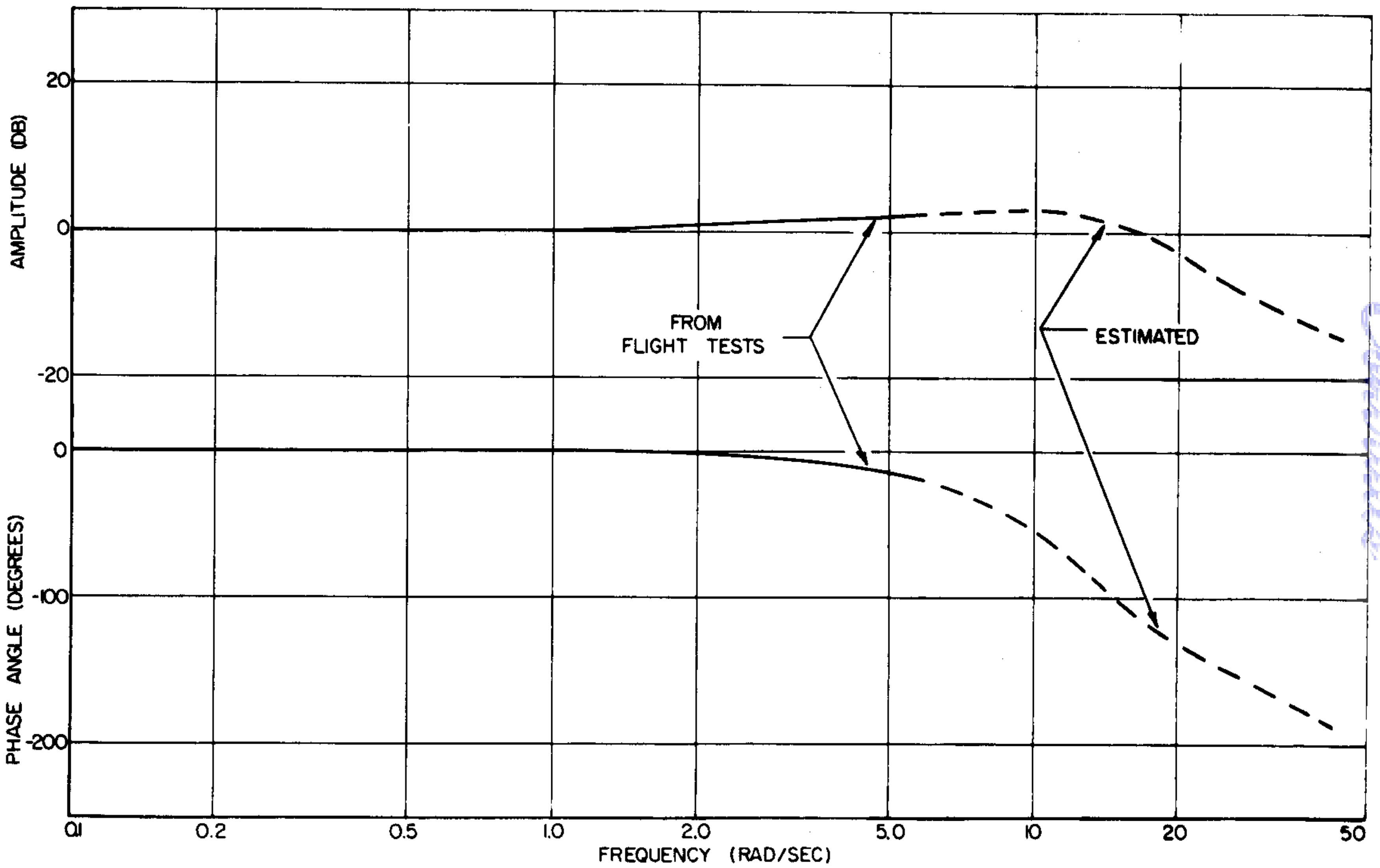
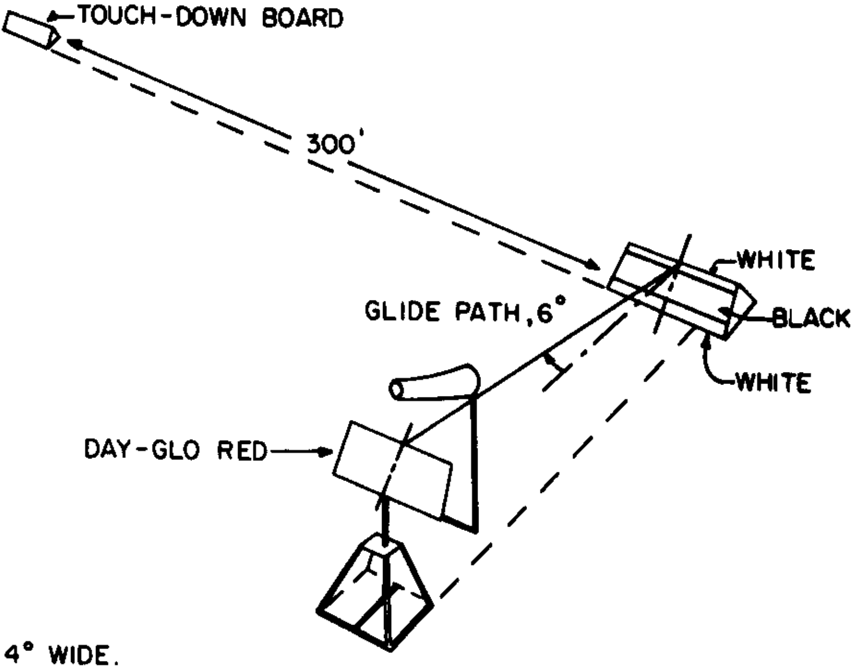


FIG 4 FREQUENCY RESPONSE FOR YAW CONTROL LOOP WITH FEED-FORWARD COMPENSATION

equations of motion to be simulated and yields signals that are properly scaled to represent the pitch, roll and yaw angular rates, and the normal acceleration of the simulated vehicle. These calculated motions are compared with those of the helicopter, as sensed by angular rate gyros and normal accelerometers, and the autopilot, operating in a closed-loop fashion, forces the helicopter to follow the motions prescribed by the computer. The model-following autopilot was essentially as described in Reference 1 with the addition of a so-called "feed-forward" compensation circuit in yaw (Fig. 3). This circuit was inserted to overcome the slight droop (approximately 2 DB at 1 rad/sec) in the directional control loop at low frequencies which resulted in the actual helicopter rate being somewhat less than the commanded model rate. Figure 4 shows the frequency response characteristics of this channel. The low frequency portion was established from flight test data, but due to excitation of structural modes, the simulator could not be driven with higher frequency sine waves and the data above 6 rad/sec are thus estimated. (During this work the normal acceleration loop was not closed, but the evaluation pilot's "power lever", actuated in the manner of a throttle control, operated the helicopter collective control directly.) Other inputs to the equations of motion such as synthetic turbulence, simulated steady winds, and angles of attack and sideslip as



VISUAL APPROACH TASK

1. APPROACH INTO WIND.
2. GLIDE PATH ANGLE, 6°, ±4° WIDE.
3. APPROACH SPEED, 50 KTS.
4. CIRCUIT HEIGHT, 1000' ABOVE GROUND LEVEL.
5. CO-ORDINATED "S" TURN AT 200'.

FIG 5 VISUAL APPROACH AID

measured by vanes corrected for their mounting positions by the helicopter rates of pitch, roll, and yaw were utilized to produce realistic flight conditions. Calibration of the sideslip vane around the trimmed flight condition indicated that the flow effect was less than ±5 per cent of the indicated sideslip angle; hence, no correction was made for this factor.

By comparing the motions calculated in a laboratory simulation of the equations of motion using the pilot inputs occurring during flight with the actual helicopter motions recorded during the flight it was concluded that the programmed characteristics were attained with very acceptable accuracy. This comparison is described in detail in Section 3.1.1.

The simulator is always occupied by two pilots during flight tests: the safety pilot who can take control whenever a dangerous situation is developing and who looks after setting the model characteristics on the computer and the evaluation pilot who can perform any manoeuvre in all degrees of freedom within the flight envelope of the helicopter used as the simulator. The evaluation pilot's control levers (Fig. 2) consisted of a conventional centre stick, rudder pedals and a "power lever", operated with the left hand (like a conventional throttle control lever) and moved forward to increase the normal force. The control force gradients, supplied by springs with viscous damping, are shown in Table 2(b) along with the break-out forces and the maximum control throws selected for the stick and rudder pedals. Adjustable friction only was available on the power lever. Both press-to-release and "beep" type trimmers were provided on the control column. The lateral trimmer was used seldom and since the pitch trim changes experienced were very small, the longitudinal trim was employed very infrequently.

The conventional flight instrument panel, shown in Figure 2, supplied the information necessary for the pilot to accomplish the visual flying task with the desired precision.

To duplicate the ease of engine management present in modern V/STOL aircraft, the engine speed of the simulator is governed and requires no attention from the evaluation pilot other than an occasional trimming (seldom more than once per flight) through a switch on his power lever.

Along with power supplies for the various computing elements, instruments, etc., the pod on the right side of the aircraft contains a fourteen channel magnetic tape recorder used to document various pilot inputs, aircraft responses, and pilot's comments for analysis on the ground, as indicated in subsequent sections. The parameters recorded during these trials were: (i) lateral acceleration, (ii) evaluation pilot's aileron input, (iii) evaluation pilot's rudder input, (iv) calculated roll rate, (v) actual roll rate, (vi) actual roll angle, (vii) calculated yaw rate, (viii) actual yaw rate, (ix) actual yaw acceleration, (x) sideslip angle, (xi) sideslip angle due to synthetic gusts, (xii) helicopter tail rotor angle and (xiii) helicopter lateral cyclic inputs. These latter two parameters were found useful occasionally for trouble-shooting the system.

2.2 The Visual Approach Aid

The only piece of equipment outside the simulator involved in the flight tests was a visual approach aid which was composed of three boards, two of which indicated "localizer" (or approach direction) and glide path to the pilot by their displacements relative to one another, and a third board to mark the desired touchdown point following the sidestep manoeuvre attempted at the end of each approach (Fig. 5). For these tests the "flight path" boards were spaced to indicate a 6 deg approach path and were aligned with the surface wind at the beginning of each flight while the touchdown board was placed at right angles to the approach path and 300 feet to the left of the lower flight path board.

3.0 THE "MODEL" EQUATIONS OF MOTION

3.1 Lateral-Directional Equations

The majority of the work conducted with this simulator heretofore (e.g. Ref. 3) has concentrated on determining the influence of individual stability derivatives on pilot opinion and has not utilized a detailed knowledge of the side force derivatives of the basic helicopter or how they are altered by the analogue model. This procedure could not be followed while attempting to simulate overall lateral-directional modal characteristics as was done in this programme when all three equations, the rolling moment, the yawing moment, and the side force equations had to be taken into account to achieve orderly variations in the $\left|\frac{\phi}{\beta}\right|_d$ ratio and in four factors of the roll angle to aileron-control-input transfer function which was of the following form:

$$\frac{\phi}{\delta_a}(S) = \frac{K(S^2+2\zeta_\phi\omega_\phi S+\omega_\phi^2)}{S(S+4)(S^2+2\zeta_d\omega_d S+\omega_d^2)}$$

Since seven modal parameters, ζ_d, ω_d, ζ_ϕ, ω_ϕ, $\left|\frac{\phi}{\beta}\right|_d$, $\lambda_S = 0$, $\lambda_R = -4$, were to be set to specific values, adjustment of seven lateral-directional stability derivatives through gain-setting potentiometers in the analogue computer representation of the rolling and yawing moment equations was required. L_β, L_p, L_r, N_β, N_p, N_r, and N_{δ_a} were selected to effect these changes.

The lateral-directional equations of motion, in Laplace operator notation, that were "patched" into the airborne analogue computer, as shown schematically in Figure 3, then took the form:

Rolling Moment:

$$-L_\beta \cdot \beta + S(S-L_p)\phi - L_r \cdot r = L_\beta \cdot \beta_g + L_\beta \cdot \beta_{CW} + L_{\delta_a} \cdot \delta_a$$

Yawing Moment:

$$-N_\beta \cdot \beta_g - N_p S\phi + (S-N_r)r = N_\beta \cdot \beta + N_\beta \cdot \beta_{CW} + N_{\delta_a} \cdot \delta_a + N_{\delta_r} \cdot \delta_r$$

Assuming that all the significant stability derivatives could be related to the control inputs, δ_a and δ_r, and the responses, β, p and r as outlined in Appendix A, the side force equation was of the form:

Side Force:

$$(US-Y_\beta)\beta-(g+Y_pS)\phi+(U-Y_r)r = Y_{\beta_g} \cdot \beta_g + Y_{\beta_{CW}} \cdot \beta_{CW} + Y_{\delta_a} \cdot \delta_a + Y_{\delta_r} \cdot \delta_r$$

since $\cos\theta_o \doteqdot 1$ and $\alpha_o \doteqdot o$

(See Appendix A for an explanation of how the side force derivatives are related to the model rolling and yawing moment derivatives and the basic helicopter characteristics.)

The methods used to obtain electrical signals proportional to the cross-wind effect, β_{CW}, and the desired gust input, β_g, are outlined in Sections 3.3.2 and 3.3.3 respectively.

The three equations of motion plus the expressions for the side force stability derivatives contained in Appendix A provided a digital computer programme at Cornell Aeronautical

Laboratory, Inc. with enough information to calculate the stability derivatives necessary to yield the desired modal characteristics. Table 3 lists the stability derivatives set on the model for each of the 161 configurations tested and should be referred to for an explanation of the rather complicated configuration designation system used throughout the report. The levels of the modal parameters indicated in Table 3 are those obtained by recalculating the transfer function characteristics using the "rounded-off" stability derivatives actually set on the airborne analogue computer. The control sensitivities in roll and yaw, L_{δ_a} and N_{δ_r}, were held constant throughout at 0.4 and 0.75 $\frac{\text{rad/sec}^2}{\text{in}}$ respectively. Due to the combinations of stability derivatives required to achieve the desired modal characteristics (N_r was always relatively small while L_p was approximately -4) poor lateral-directional control harmonization resulted throughout the entire programme. This facet of the work was not appreciated until a significant number of tests had been conducted and it was then impractical to alter the control sensitivities.

Solving the three equations yields the quartic lateral-directional characteristic equation:

$$\begin{aligned}
& U\,S^4 - \left[U(N_r + L_p) + Y_\beta\right] S^3 \\
& + \left[(N_r + L_p)Y_\beta - L_\beta Y_p - N_\beta Y_r + U(N_r L_p - N_p L_r) + U\,N_\beta\right] S^2 \\
& + \left[(N_p L_r - N_r L_p)Y_\beta + (N_r L_\beta - N_\beta L_r)Y_p + (N_\beta L_p - N_p L_\beta)Y_r + U(N_p L_\beta - N_\beta L_p) - g L_\beta\right] S \\
& + g(L_\beta N_r - N_\beta L_r) = 0
\end{aligned}$$

Similarly the numerator of the roll angle to aileron input transfer function, $\frac{\phi}{\delta_a}(S)$, is

$$N^{\phi}_{\delta_a} = U\,L_{\delta_a}S^2 + \left[U(N_{\delta_a}L_r - N_rL_{\delta_a}) + L_\beta Y_{\delta_a} - L_{\delta_a}Y_\beta\right] S$$

$$+ \left[(N_rL_{\delta_a} - N_{\delta_a}L_r)Y_\beta + (N_{\delta_a}L_\beta - N_\beta L_{\delta_a})Y_r + \right.$$

$$\left. + (N_\beta L_r - N_r L_\beta)Y_{\delta_a} + U(N_\beta L_{\delta_a} - N_{\delta_a}L_\beta)\right]$$

Appendix B, containing the numerator expressions for all nine lateral-directional transfer functions relating ϕ, ψ, and β to δ_a, δ_r, and β_g, has been included for the convenience of the reader.

3.1.1 Verification of the Lateral-Directional Characteristics

Since the modal parameters varied during this research were dynamic in nature and interdependent in producing the final motions, it can be appreciated that it would have been a formidable task to verify the characteristics of each configuration from flight test data. In fact, such a procedure would have been tantamount to measuring the transfer function characteristics (the numerator terms as well as the "normal" modes of motion) of 161 different aircraft. Clearly, this could not be accomplished in the time available and other, less comprehensive, tests were carried out, as outlined below, to check the validity of the results.

Possible sources of error that could have influenced the aircraft motion were:

(i) Incorrect lateral-directional stability derivatives from the digital computer programme,

(ii) Inaccurate estimation of the side force characteristics used to determine the rolling and yawing stability derivatives,

(iii) Malfunctioning of the airborne analogue computer or the autopilot,

(iv) Improper values on the gain-setting potentiometers, and

(v) Inadequate model following.

To check the extent of the first of these possible errors, namely that the desired transfer function characteristics would result from the calculated stability derivatives, an inverse procedure of calculating the modal parameters from the derivatives, which were rounded off to the setting accuracies attainable on the airborne analogue computer, was carried out. Any large discrepancies that arose were corrected at this stage and the in-flight characteristics to be expected from the derivatives are given in Table 3.

It was indicated in the previous section that a knowledge of the side force derivatives of the simulator was required to obtain the lateral-directional stability derivatives that would give the desired overall dynamics. These side force derivatives were estimated from the geometrical, inertial, aerodynamic and test configuration characteristics as outlined in Appendix A. To assess the influence of errors in these estimates, the side force derivatives were varied over significant ranges for a representative selection of configurations. Only minor variations in the modal parameters, the primary variables of this programme, were evident. Appendix A illustrates these results with a representative example.

It was virtually impossible to ensure that the analogue computer and the autopilot functioned properly at all times. However, a qualitative assessment of the entire system was carried out at the beginning of each flight by setting the model to a so-called "Standard Configuration" (see the last configuration of Table 3 for the stability derivatives of this model), which had a lightly damped Dutch roll mode, $\zeta_d = 0.1$, and an easily monitored Dutch roll frequency, $\omega_d = 1 \frac{\text{rad}}{\text{sec}}$. The pilots soon became familiar with the dynamic responses of this configuration to the "documentation rudder doublet" described in Section 3.3.4 and were able to detect any gross inadequacies that very occasionally occurred. The subsequent ground simulation, described later, of nine models chosen to cover a representative range of stability derivatives, also indicated that problems of inadequate simulation had not arisen during the corresponding flight periods.

To minimise the possibility of incorrect potentiometer settings remaining undetected, their sign and magnitude was monitored by the safety pilot after each configuration had been flown, prior to their values being reset for the next model.

The adequacy of the following of the model was assessed qualitatively by comparing the flight records of the calculated yawing and rolling angular rates with the actual angular rates and was found to be very good.

The preceding checks indicated that the individual contributions to the error between the actual and the desired results were well within acceptable limits. To illustrate the magnitude of the total error arising during the flights, all three lateral-directional equations of motion were synthesized on an analogue computer in the laboratory using the verified moment stability derivatives and the estimated side-force characteristics. The flight recorded pilot inputs and synthetic turbulence disturbances were introduced and the calculated responses (p_c, r_c, β_c) were compared with the actual helicopter responses (p_H, r_H, β_H) resulting from the same inputs. This procedure was followed for nine configurations covering a wide range of modal parameters and almost the complete range of stability derivatives employed in the programme. The results are shown in Figs. 6(a) to 6(i).

The main control input in the comparisons was the "documentation rudder doublet" described in Section 3.3.4 (not always set to the same amplitude), but for the high $\left|\frac{\phi}{\beta}\right|_d$ configuration (HH 100+30+30) of Figure 6h, the divergent configuration (LH 100-20-20) of Figure 6f and the illustration of long term following in Figure 6i (LH 129+20+50 - for which N_{δ_a} was the highest in the entire programme), significant aileron inputs also were used by the pilots.

The reader should be cautioned at this point to interpret Figures 6a to 6i carefully since: (i) the calculated responses shown were obtained in the manner described above and are <u>not</u> those of the model in flight which utilized the sideslip vane in its calculations, (ii) the motion following the rudder doublets is not necessarily due to the "normal" modes only, as in some instances the pilot control inputs were not zero. (The desired response may be seen from the values given by the calculated model which, in all cases, possessed the required modal characteristics), (iii) the natural atmospheric turbulence affected the flight responses but not the calculated responses. (All the flight results shown were recorded on moderately smooth days, but absolutely calm air was not always available), and (iv) the time scale of Figure 6i is 2-1/2 times that of the other figures.

The first five configurations illustrated in Figures 6a to 6e have the same frequency $\omega_\phi = \omega_d = 1$ rad/sec, the same

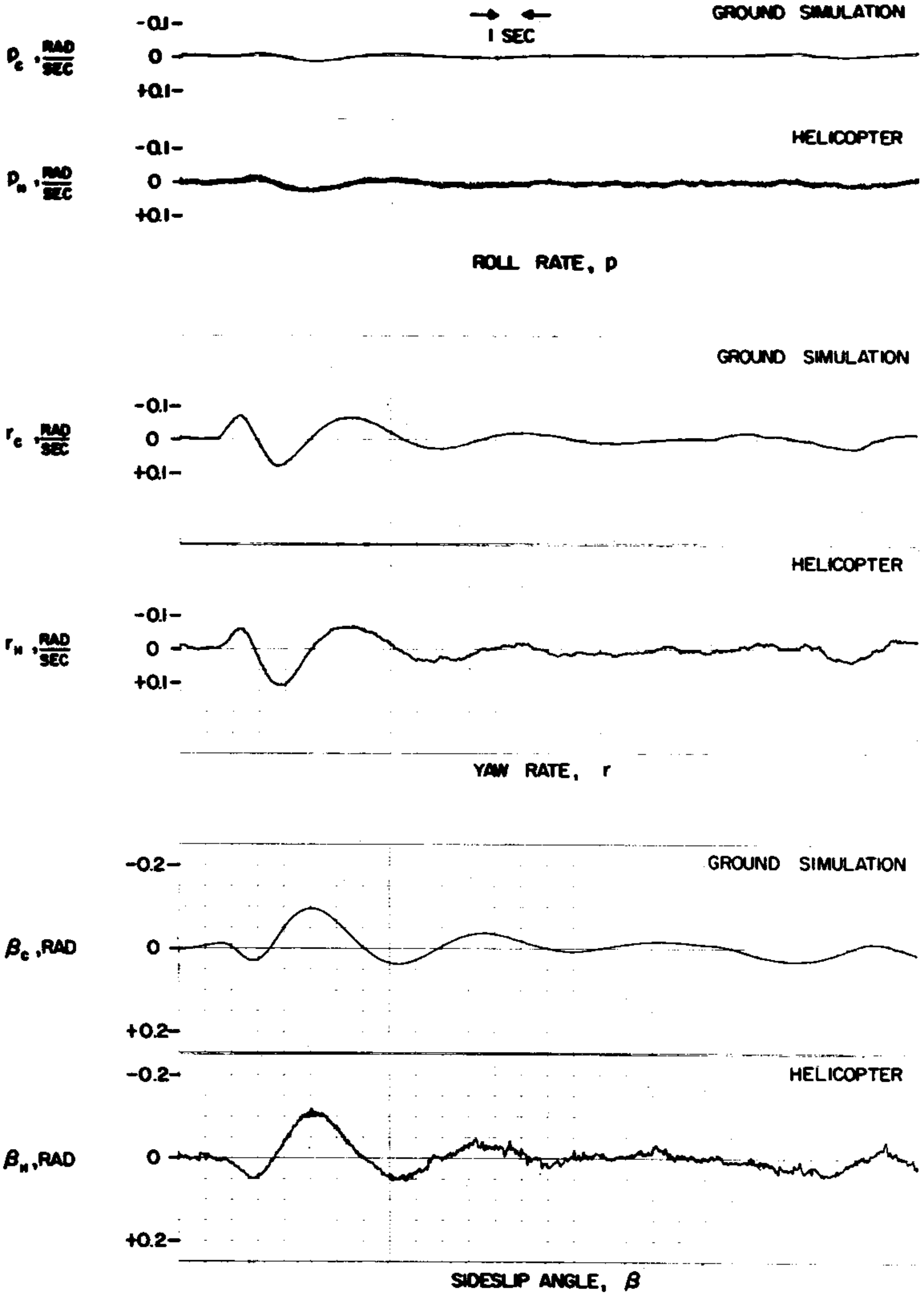


FIG 6a COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 100 + 20 + 10

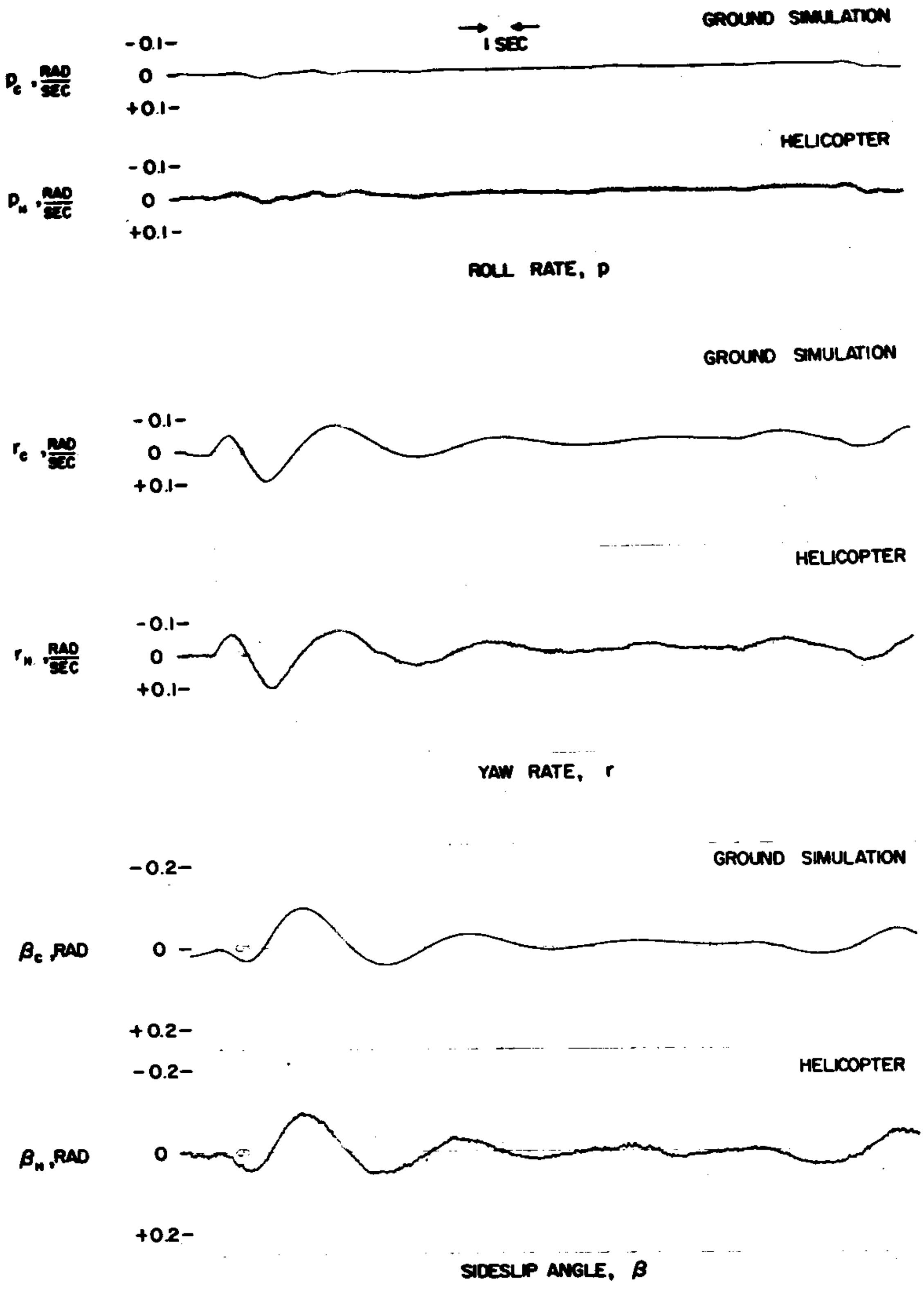
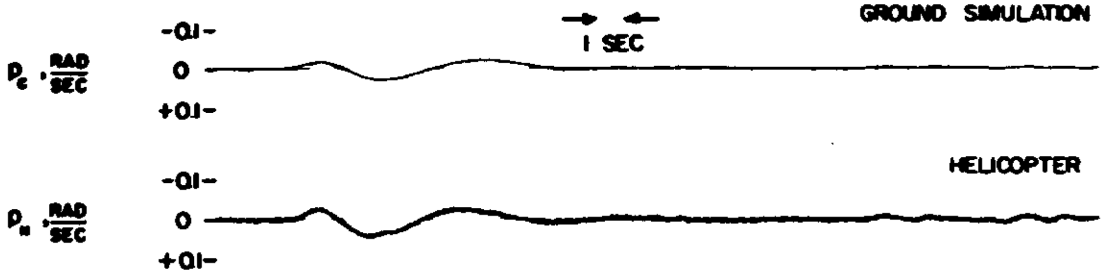
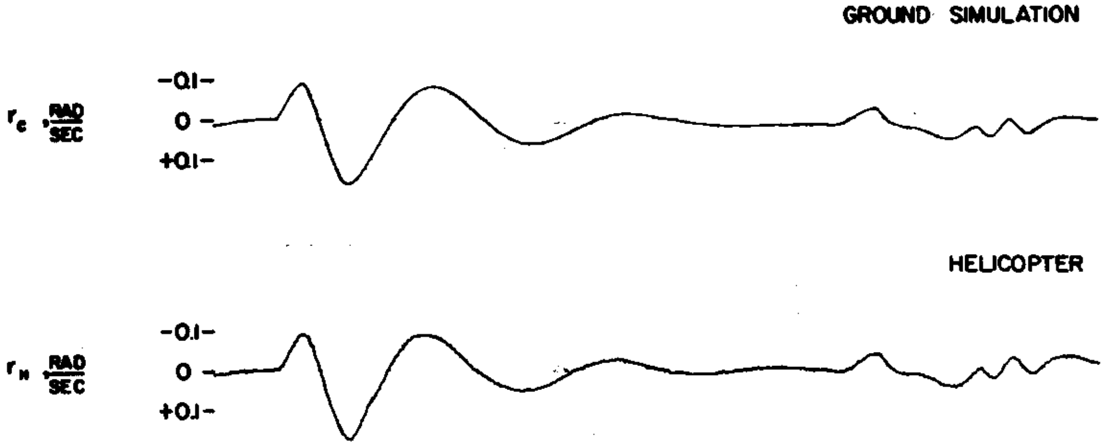


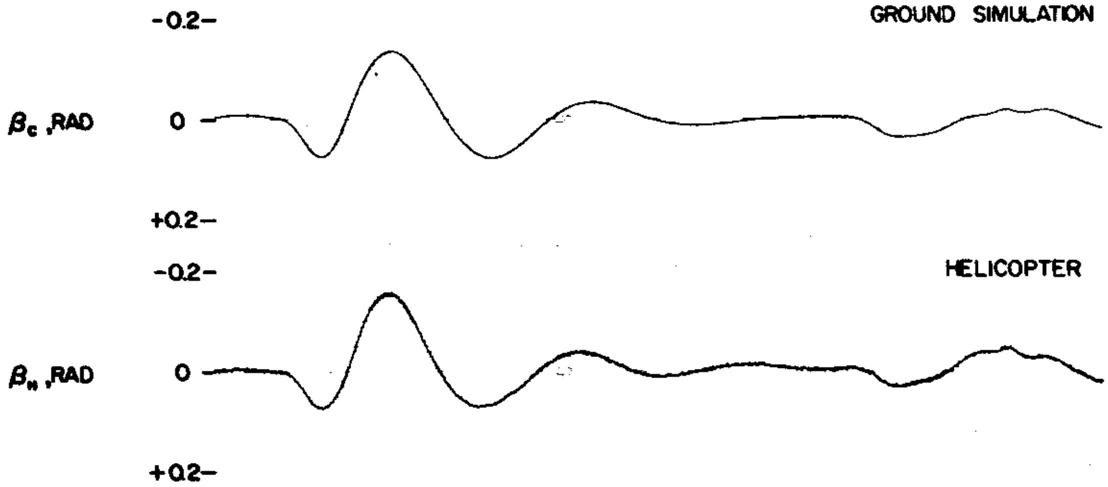
FIG 6b COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 100 + 20 + 20



ROLL RATE, p



YAW RATE, r



SIDESLIP ANGLE, β

FIG 6c COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 100 + 20 + 30

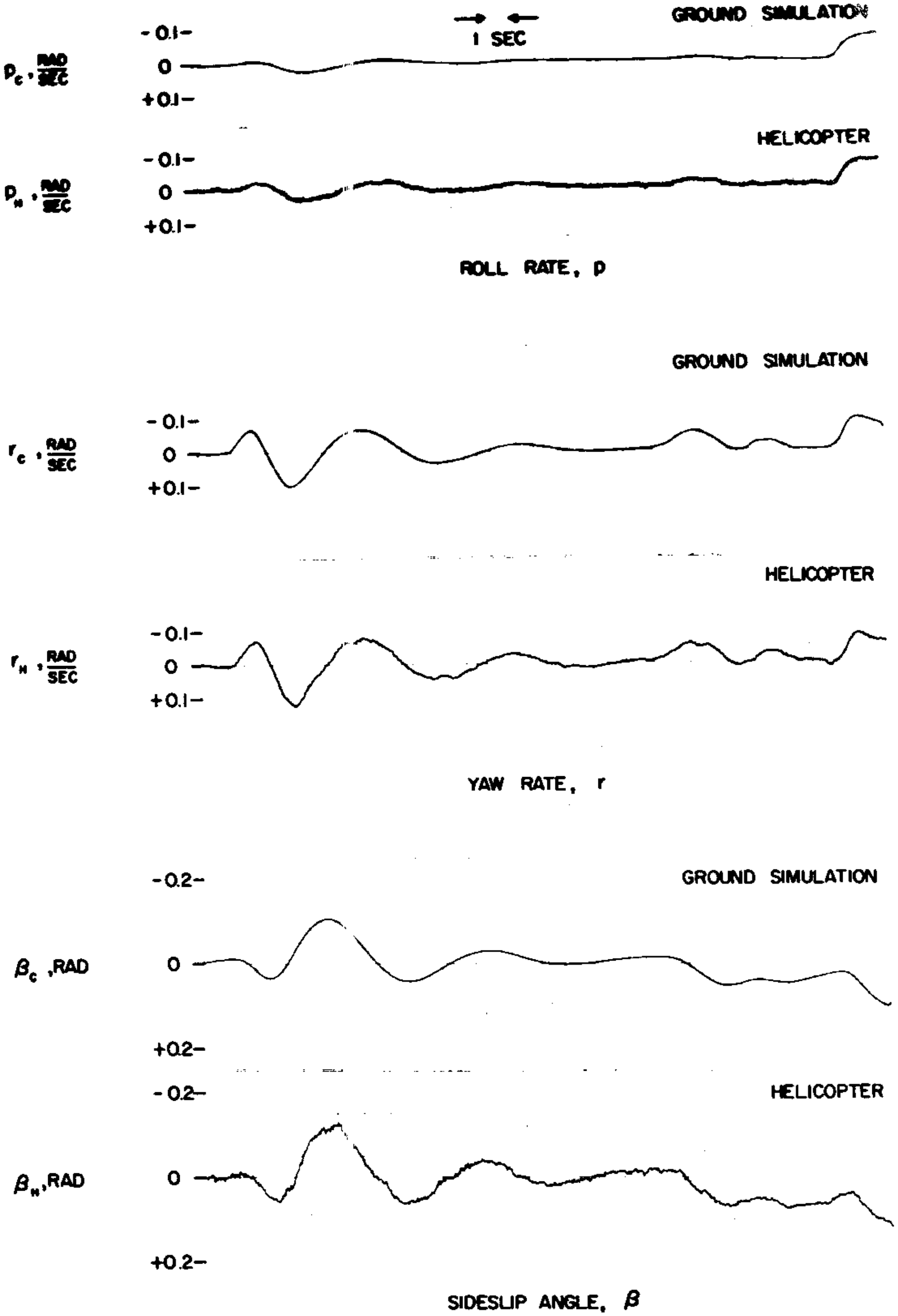


FIG 6d COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 100 + 20 + 40

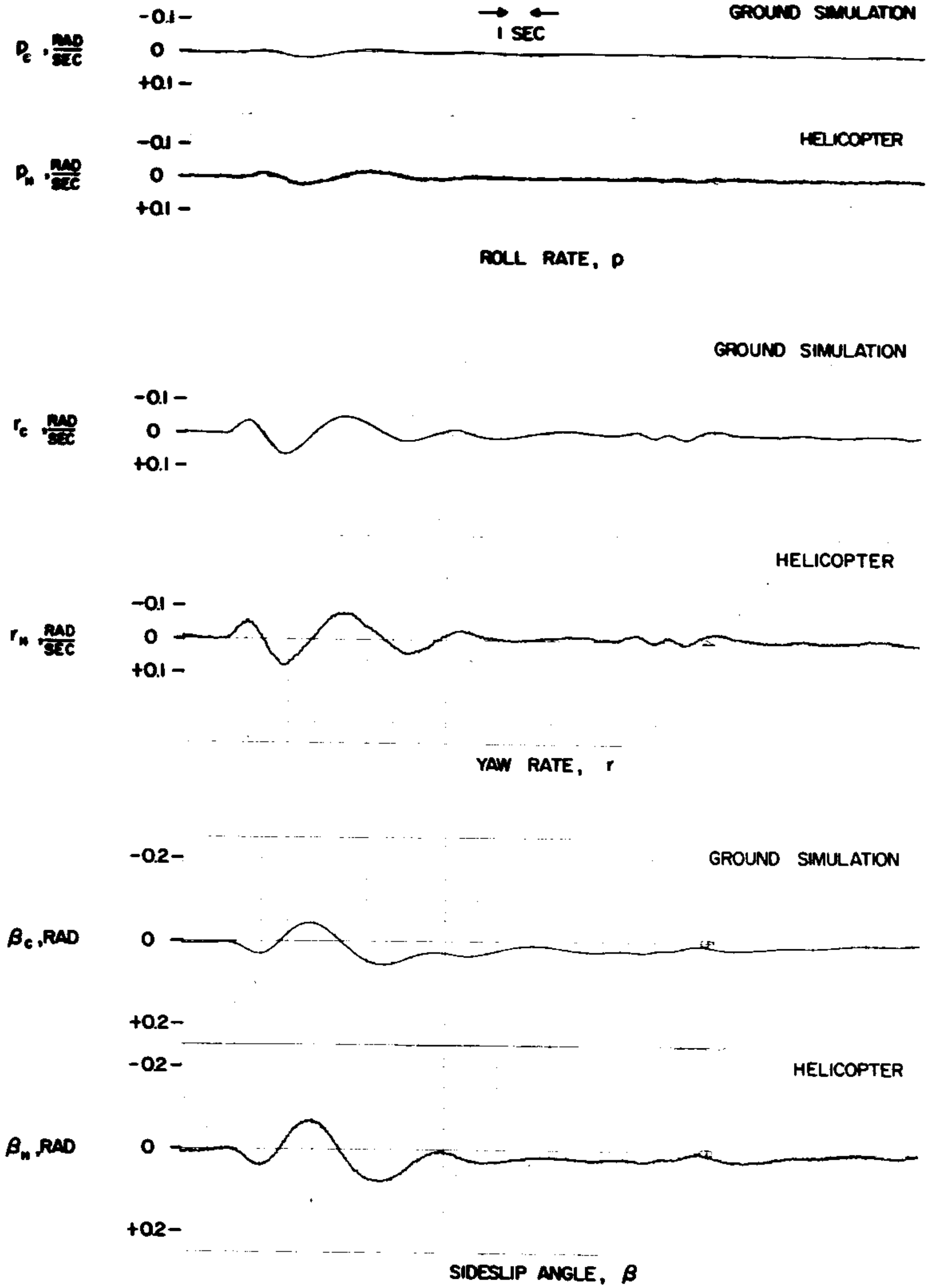


FIG 6e COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 100 + 20 + 50

Dutch roll damping ratio, $\zeta_d = 0.2$, and the same $\left|\frac{\phi}{\beta}\right|_d = 0.2$, but differ in their ζ_ϕ values which start at 0.10 and proceed in equal steps to 0.50. (These configurations and the one of Figure 6i are identified in Figure 9 by the solid symbols.) The normal modes of motion for all five configurations should have been the same even though the stability derivatives changed enormously. (For example N_p changed from +4.64 in Figure 6a to -11.4 in Figure 6e.) It can be seen, qualitatively, that this was achieved and the comparison of the calculated and the flight results, even for the sideslip angle which the variable stability helicopter is not forced to follow, is excellent throughout.

The comparisons presented in Figure 6f, 6g and 6h are for low, intermediate, and high $\left|\frac{\phi}{\beta}\right|_d$ configurations with negative, zero, and positive values of ζ_d respectively. The pilot ratings for these three configurations are presented in Figures 18c, b and a. Even for the strongly divergent configuration of Figure 6f, it can be seen that the results compare well.

The final figure of this group is included to illustrate the system performance over a longer time period (140 seconds of calculated versus actual motions are presented) with significant aileron inputs in the presence of a large N_{δ_a} which was at its maximum value of 1.0. Once again, the comparison indicates that the overall system was functioning very well.

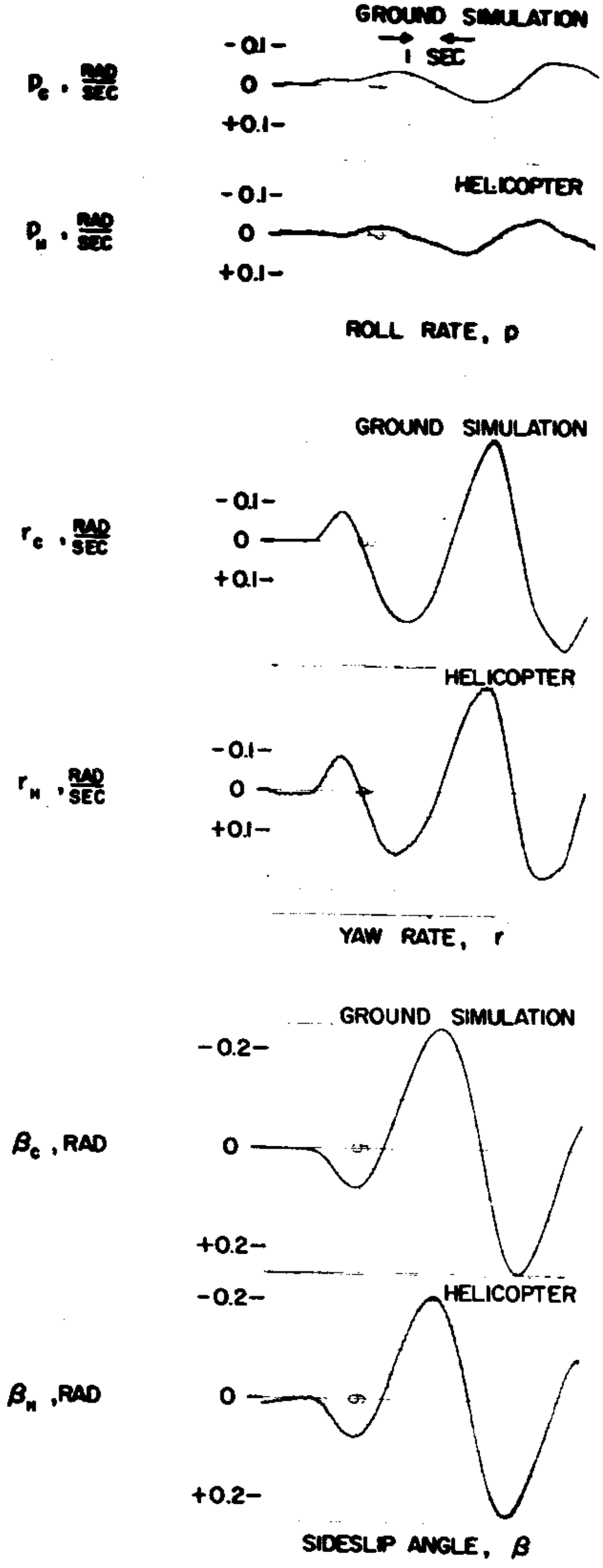
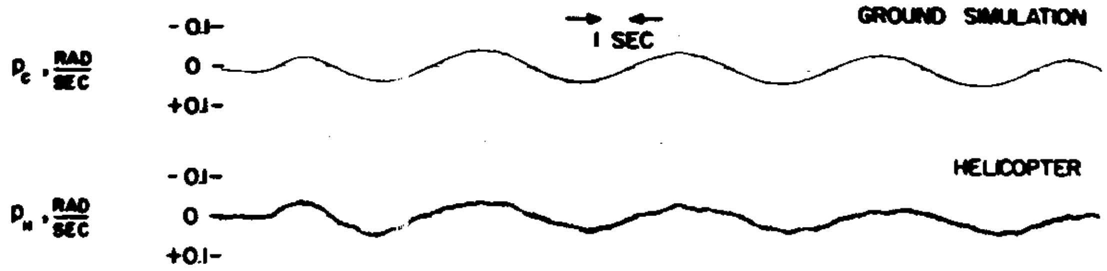
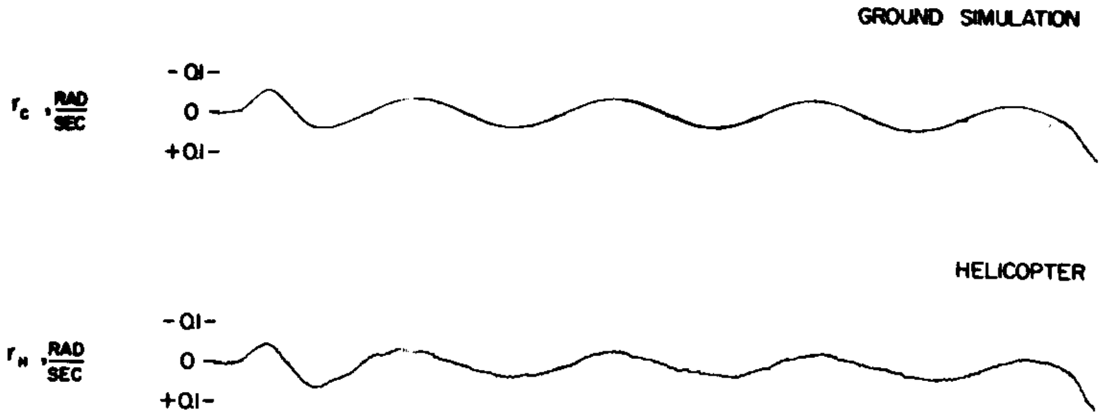


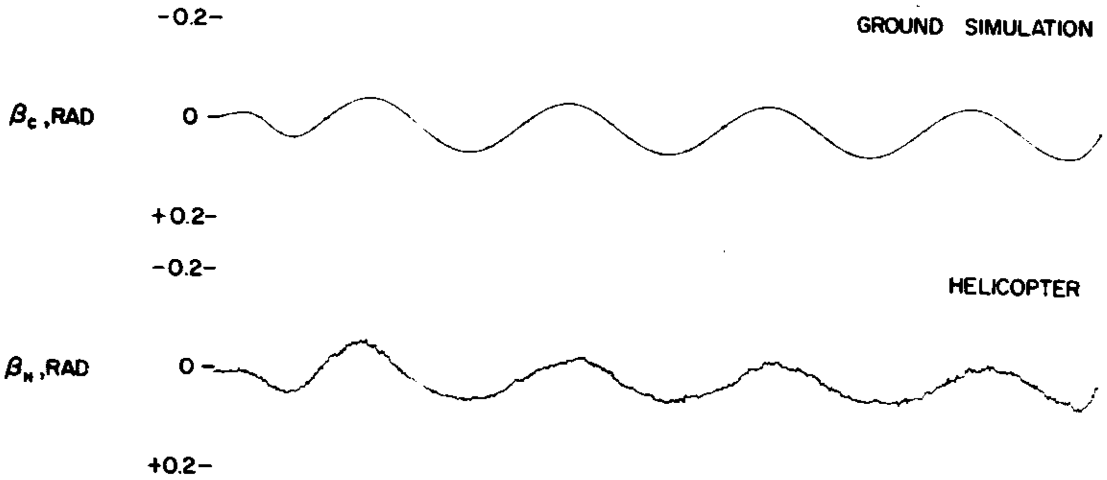
FIG 6f COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 100-20-20



ROLL RATE, p

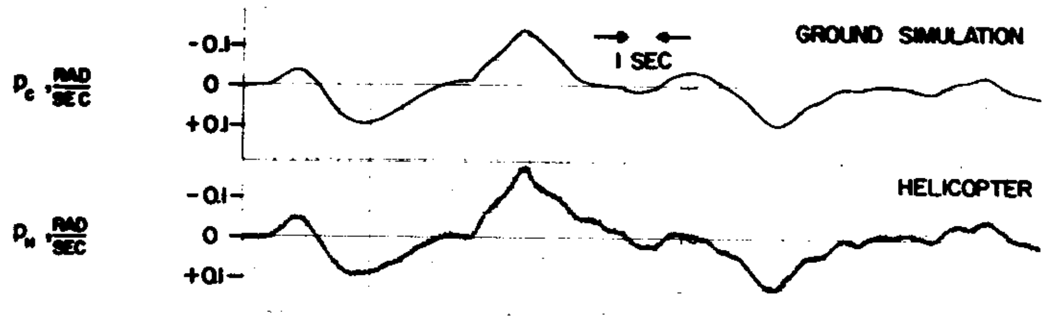


YAW RATE, r

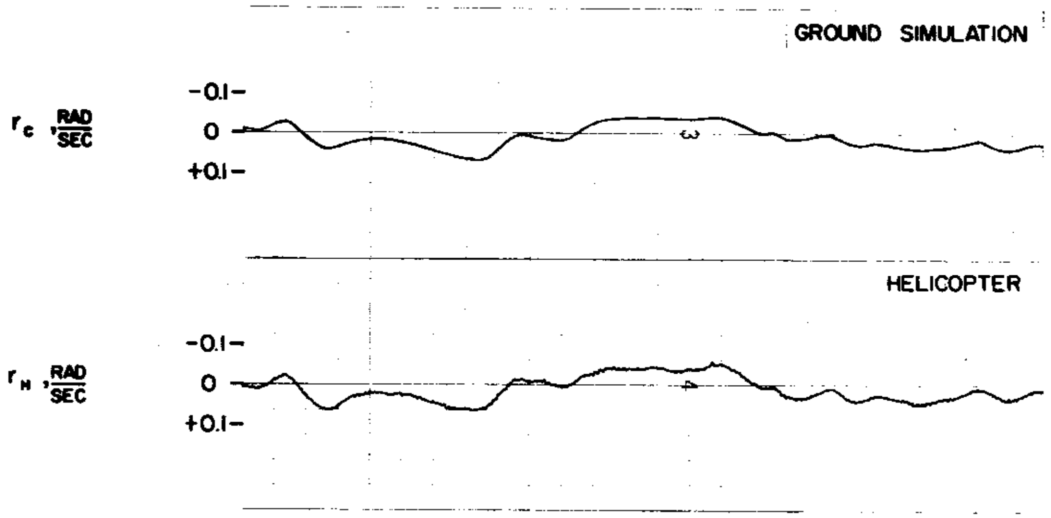


SIDESLIP ANGLE, β

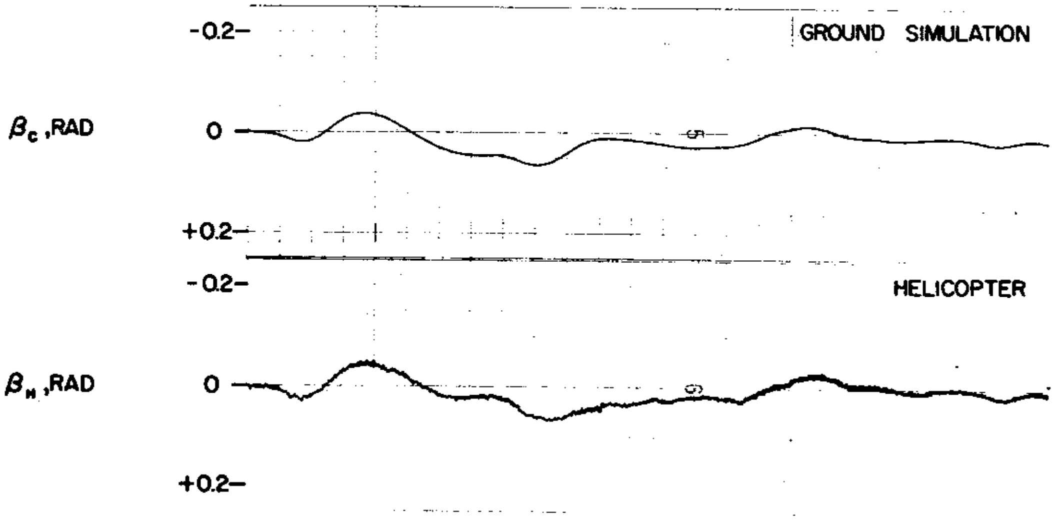
FIG 6g COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No MH 100 + 0 + 0



ROLL RATE, p



YAW RATE, r



SIDESLIP ANGLE, β

FIG 6h COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No HH 100 + 30 + 30

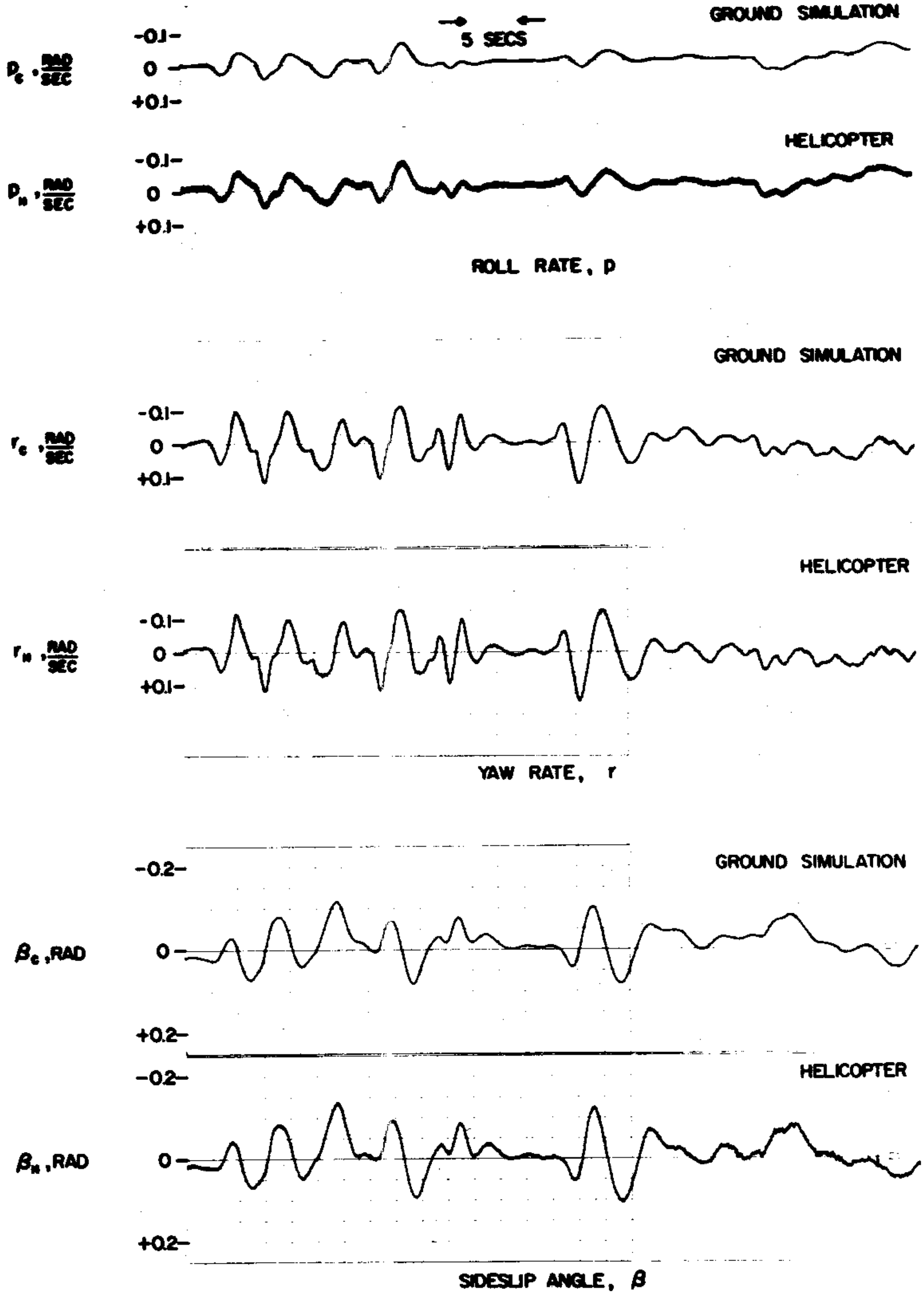


FIG 6i COMPARISON OF HELICOPTER RESPONSE TO CONTROL INPUTS WITH THAT EXPECTED FROM GROUND SIMULATION - MODEL No LH 129 + 20 + 50

Although all these checks have not been carried out for all 161 configurations flown during the programme, a representative sample has been investigated in a variety of ways and indications are that the programmed test parameters were achieved with acceptable accuracy.

3.2 Longitudinal Equations

3.2.1 Pitching

Since this programme concentrated on the effects of variations in lateral-directional parameters the longitudinal characteristics were held at pleasant levels.

A previous programme conducted at this Establishment, research at N.A.S.A. Langley (Ref. 4), and these tests indicate that satisfactory pitch control is achieved if the following values of the stability derivatives are used:

$$M_{\delta_e} = 0.3 \ \frac{\text{rad/sec}^2}{\text{in}}$$

$$M_q = -4.0 \ \frac{\text{rad/sec}^2}{\text{rad/sec}}$$

$$M_\alpha = -0.5 \ \frac{\text{rad/sec}^2}{\text{rad}}$$

The form of the pitching moment equation then was:

$$\dot{q} = M_{\delta_e} \cdot \delta_e + M_q \cdot q + M_\alpha \cdot \alpha$$

3.2.2 Heave

As was mentioned in Section 2.1, the normal-acceleration closed-loop control of the autopilot system was not employed during this programme. Rather, the evaluation pilot controlled the normal force on the simulator by moving a "power lever" with his left hand like a conventional throttle actuating the safety pilot's helicopter collective control lever through a position control system. The "gearing" between the two levers was adjusted to give a heave sensitivity, Z_{δ_t}, of 8 $\frac{\text{ft/sec}^2}{\text{in}}$ which in the presence of the other vertical characteristics of the basic helicopter provided very pleasant handling qualities in this control mode.

3.3 Simulation of Special Effects

3.3.1 Tilting of Simulator Axis System

The side force equation of Section 3.1 assumes that the X-axis of the reference system is aligned with the initial direction of flight; that is, stability or wind axes are used. If this is not the case, a term proportional to the product of (i) the initial angle between the X-axis and the direction of flight, α_o, and (ii) the roll rate, p, must be included.

The reference system of this simulator is determined by the alignment of the three rate gyros which are mounted orthogonally in a machined metal block. The X-axis (the roll axis) is normally coincident with the horizontal reference line of the helicopter and, since the helicopter flies in virtually a level attitude when in straight and level flight at 50 knots, this reference system was valid for the major portion of the flight task. However, when the pilot began to descend on the 6 deg glide path, the attitude of the simulator remained invariant causing the angle of attack to increase by the glide path angle. It can be shown that such an angle between the relative wind and the reference axis significantly alters the response in sideslip to aileron inputs, in particular, and influences other reponses to a lesser degree. Consequently, a mechanism was installed to tilt the rate gyro package down by 6 deg as the glide path was intercepted. This transition was effected through a switch (see also the following section) mounted on the safety pilot's collective lever and took 6 seconds to complete. (Since the autopilot system sensed the pitching motion of the rate gyro package it attempted to correct for the apparent disturbance resulting in a nose up motion of the simulator which was extremely mild and usually passed unnoticed by the pilot.)

3.3.2 Cross-wind

To provide the pilot with an indication of the influence on the handling qualities of a cross-wind during the approach to landing, the effects of the sideslip due to a 10 knot cross-wind from the left was simulated during the descending portion of each approach. The variation of sideslip due to a cross-wind at right angles to the approach direction with changes of heading from the approach direction is described by

$$\beta_{CW} = \tan^{-1}\left(\frac{U \sin\psi + CW}{U \cos\psi}\right) - \psi$$

Through non-linear function generation a very good approximation to this equation (plotted in Figure 7) was obtained. As the descent on the glide path was initiated, the safety pilot operated the switch mentioned in the previous section, phasing in this cross-wind effect over a 5 second period.

The pilots were instructed to carry out a sideslipping rather than a "crabbing" approach. Since the side force characteristics of this simulator cannot be altered independently and since all approaches were made into the real surface wind, a properly executed approach resulted in the ball of the turn-and-slip indicator remaining central and the wings level, but with the evaluation pilot's roll and directional controls appropriately displaced. This is equivalent to simulating the cross-wind effects on an aircraft with the programmed weathercock stability and dihedral effect, but with zero side force due to sideslip, Y_β.

3.3.3 Turbulence

To prevent external turbulence from disturbing the simulator unduly, flight tests were not attempted when the

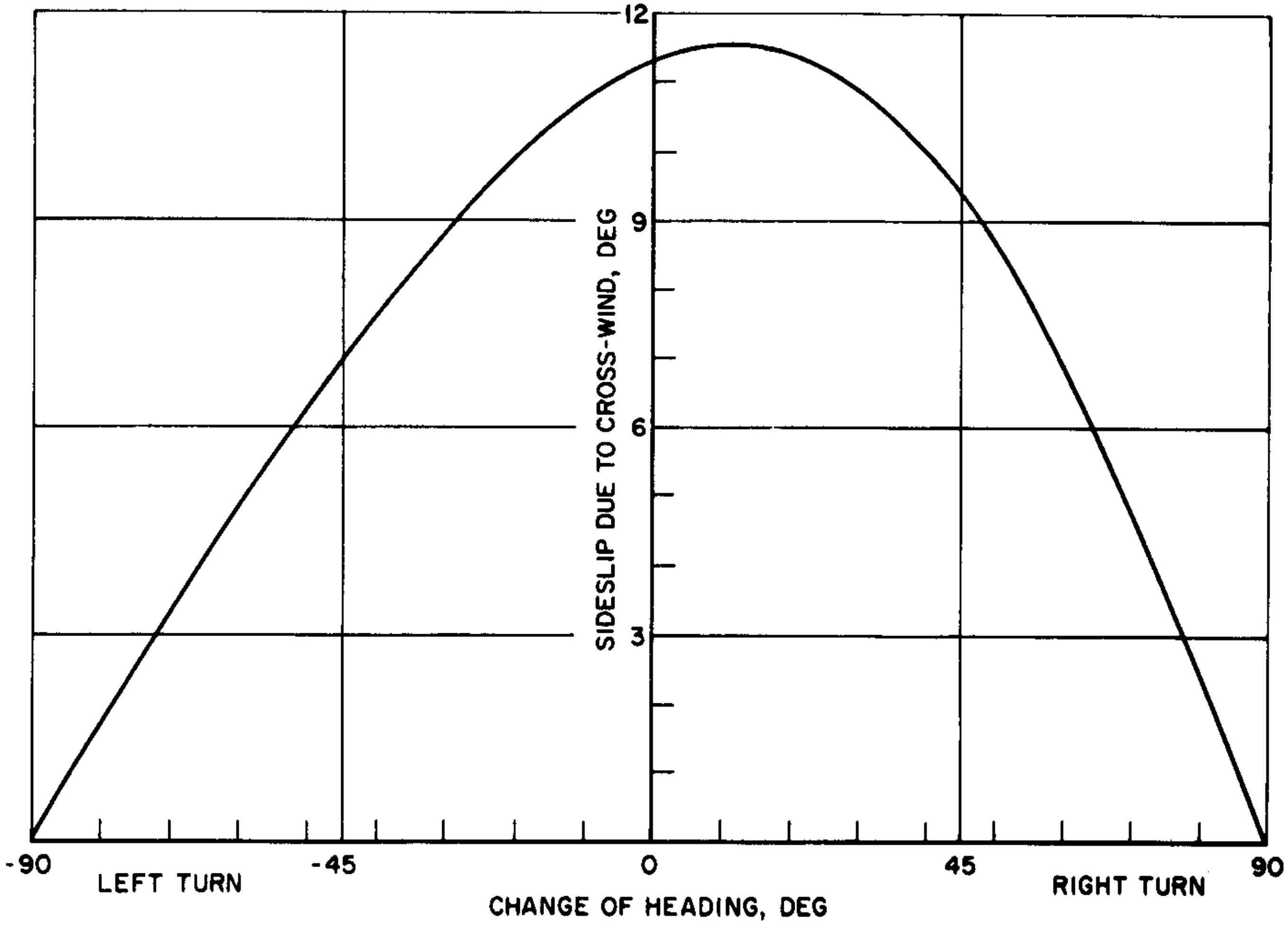


FIG 7 VARIATION OF CROSS-WIND EFFECTS WITH CHANGE OF HEADING

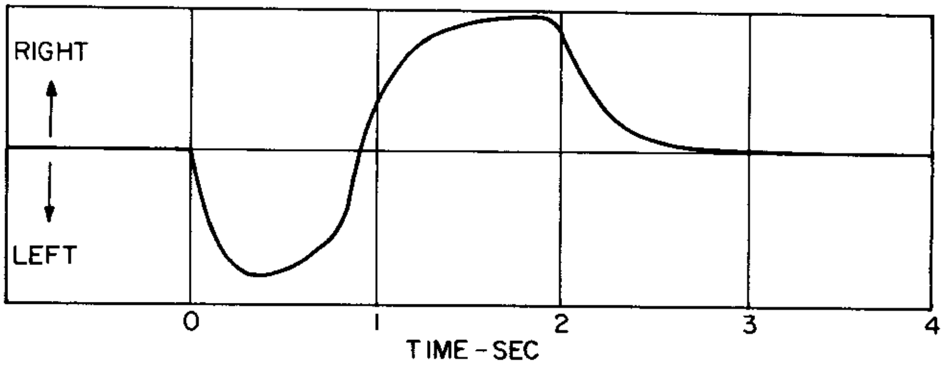
surface wind exceeded 10 knots, but to simulate realistic and repeatable flight conditions both lateral and vertical components of synthetic turbulence, β_g and α_g, were introduced as shown in Figure 3 with the spectral shapes shown in Figure 8. These spectral shapes approximate the Von Karman equation (Ref. 5)

$$\phi(\omega) = K \frac{1 + 8/3\,(1.339\,\frac{L}{U}\,\omega)^2}{\left[1 + (1.339\,\frac{L}{U}\,\omega)^2\right]^{11/6}}$$

where the scale length, L, was chosen as 1000 feet for the lateral component and 200 feet for the vertical component (Ref. 6). A root mean square value, σ_{β_g} = 3.4 deg, (σ_{v_g} = 5 ft/sec) was used laterally, since similar turbulence was introduced in other subcontracts of this overall programme, while σ_{α_g} = 2 deg (σ_{w_g} = 3 ft/sec) disturbed the pitching motion. Since the value of M_α was so low, the vertical turbulence was never a factor in the evaluation and was never commented on by the pilots. Many of the values of weathercock stability and dihedral effect, however, were exceedingly high - especially when the $\left|\frac{\phi}{\beta}\right|_d$ ratio became large - and the configurations were de-rated due to the lateral turbulence.

3.3.4 Documentation Rudder Doublet

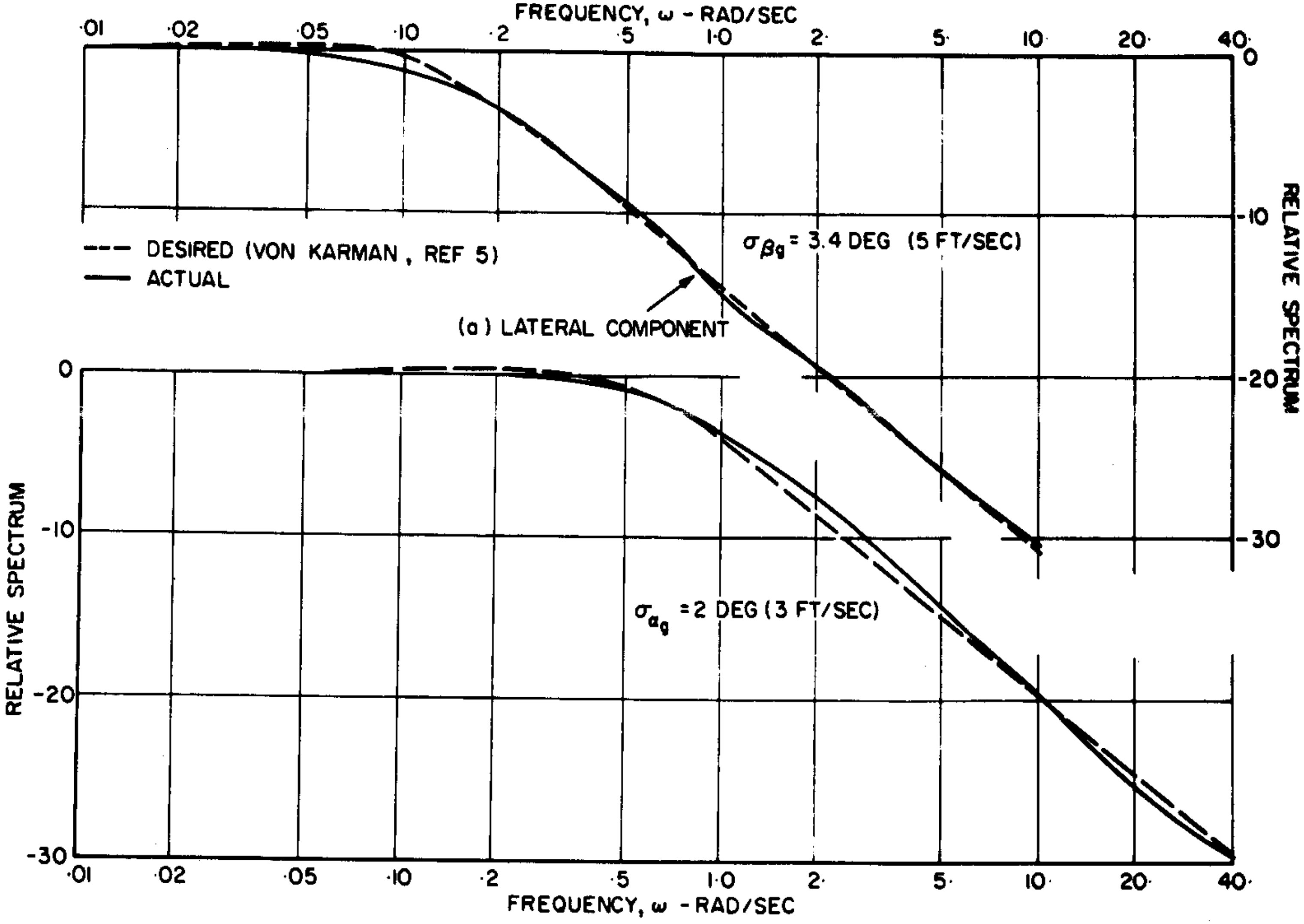
At the beginning of the evaluation of each configuration a repeatable rudder doublet was used to disturb the model and allow documentation of its characteristics with a known input that could be reproduced in the laboratory. Repeatability of the input was ensured by artificially producing an electrical doublet of the shape shown below by a computer circuit which was energized through a switch mounted on the evaluation pilot's power lever. The amplitude of the doublet was readily controlled through a potentiometer in the cockpit and was set to give a reasonable response. Figure 6 illustrates the responses of a variety of configurations to this simulated rudder excitation.



DOCUMENTATION RUDDER DOUBLET

4.0 FLIGHT EVALUATION PROCEDURE

Since the purpose of this work was to investigate lateral-directional handling qualities during turning manoeuvres at low airspeed, and since V/STOL aircraft find themselves in this flight regime most often during the circuit flying and approach sequence, the following order of events was employed to assess the characteristics of



(b) VERTICAL COMPONENT

FIG 8 SPECTRA OF SIMULATED ATMOSPHERIC TURBULENCE the various configurations:

(1) After adjusting the seven potentiometers and selecting the seven switches (to determine the magnitude and sign of each variable stability derivative), switching out the two turbulence components, and raising the rate gyro package, the safety pilot flew the simulator to 1000 feet above ground level and stabilized at 50 knots IAS on the downwind leg of the circuit.

(2) The tape recorder was started and the previous model of the flight was identified by stating its configuration number. This served the dual purpose of identifying it on the magnetic tape record and informing the evaluation pilot of the model he had just completed to allow him to insert its number on his comment sheet. Until this point the evaluation pilot had been provided with no information on the characteristics other than the fact that lateral-directional parameters were being tested.

(3) The engine speed governor and the autopilot were engaged and the analogue computer switched to its "operate" mode at which time the evaluation pilot assumed full control of the simulator.

(4) After stabilizing at 50 knots the synthetic rudder documentation doublet (see Section 3.3.4) was switched in and the electric flying controls were held steady as long as required to obtain a reasonable record of the response or

until recovery had to be made from an unusual attitude such as occurred in roll with the higher values of $\left|\frac{\phi}{\beta}\right|_d$.

(5) The doublet was switched out, the turbulence switched in and the controlled evaluation manoeuvres were begun.

(6) During these manoeuvres the pilot was instructed to fly at 50 knots and to:

(a) maintain straight and level flight in the presence of the turbulence for several seconds,

(b) turn through at least 45 deg of heading change with 20 deg of bank using aileron only, if possible, making sure that the turn was held long enough to assess if a steady bank angle could be held adequately before rolling out and stabilizing on a selected heading or distinct geographical point,

(c) repeat step (b) in the opposite direction turning through at least 90 deg of heading change,

(d) repeat steps (b) and (c) using rudder as required to keep the turn well coordinated (the ball in the centre) finally rolling out tracking along the downwind leg of the circuit once again,

(e) execute several turn reversals changing bank from 20 deg one way to 20 deg the other, keeping the turns coordinated,

(f) turn on to the cross-wind leg of the circuit pattern and fly until the "localizer" as indicated by the approach boards (Sec. 2.2) was intercepted and then turn on to the approach heading,

(g) proceed until the two boards were superimposed indicating glide path interception and then start down the glide path [At this point the safety pilot actuated the switch on his collective lever which tilted the rate gyro box down to change the simulator reference axes (Sec. 3.3.1) and phased in the cross-wind (Sec. 3.3.2)],

(h) continue the descent holding the approach boards coincident until reaching 200 feet above ground level, and

(i) execute a sidestep manoeuvre to move to the left by 300 feet aiming to hit a point adjacent to the "touch-down" board heading in the original approach direction at 50 knots.

If the evaluation pilot desired a further look at any particular manoeuvre he was quite free to repeat any or all of them as many times as required.

(7) At approximately 10 feet the safety pilot assumed control and landed the simulator.

(8) While the characteristics were being reset on the analogue computer for the next configuration, the evaluation pilot wrote his comments and rating (using the scale of Table 1) on a flight card. Throughout the entire programme

comments could be made on any aspect of the model and after flight number 60 (flight number 29 was the first evaluation flight) the pilots were asked, in addition, to comment specifically on the following features.

(i) Roll control
(ii) Yaw due to roll
(iii) Coordination (rudder control)
(iv) Oscillatory characteristics (not due to doublet)
(v) Effects of turbulence
(vi) Cross-wind
(vii) Sidestep manoeuvre.

(9) The procedure was repeated starting at (1) above for each of the four models tested on each flight and, with a total of one hour and fifteen minutes available per flight, each configuration was actually flown for approximately 10 minutes.

4.1 Standard Configuration

To ensure that the system was operating correctly, a so-called "standard configuration" was set on the model for the first flight of each day, and on most occasions, for the first model of each flight. This configuration was selected to have a low Dutch roll damping ratio ($\zeta_d = 0.1$) and a relatively high Dutch roll frequency ($\omega_d = 1$ rad/sec) which could be monitored qualitatively by the pilots by exciting the normal modes of motion through the documentation rudder doublet as the simulator was flown from the base to the test area. The other modal parameters for this configuration were $\omega_\phi = 1.0 \frac{\text{rad}}{\text{sec}}$, $\zeta_\phi = .01$ and $\left|\frac{\phi}{\beta}\right|_d = 0.2$. The last row of Table 3 indicates the stability derivatives required to achieve the desired characteristics.

5.0 DISCUSSION OF RESULTS

The ratings and comments of all pilots obtained during the flight-testing programme are presented in Table 4. These data which were used to reach the conclusions contained herein, are published in as much detail as was available to the authors in order to allow others to examine the results as thoroughly as possible. A detailed analytical appraisal of these results is currently under way and will be presented in a subsequent report.

The pilots evaluated four configurations selected from the complete programme during each flight. The results are shown in the various figures either as contours of constant pilot opinion for individual pilots, or as the individual ratings shown in relation to the maximum, minimum and averaged ratings of all pilots.

The roll subsidence root and the spiral root of the characteristic equation were held constant throughout the programme at $\lambda_R = -4.0 \frac{1}{\text{sec}}$ and $\lambda_S = 0$ respectively.

For the purposes of evaluating the effects of different parameters the results are grouped under the following headings:

(1) The effects of varying the zeros of the $\frac{\phi}{\delta_a}$ transfer function at $\left|\frac{\phi}{\beta}\right|_d = 0.2$ about the following Dutch roll roots:

(a) $\omega_d = 1.0$ rad/sec, $\zeta_d = 0.2$

(b) $\omega_d = 0.5$ rad/sec, $\zeta_d = 0.0$

(c) $\omega_d = 0.25$ rad/sec, $\zeta_d = -0.1$

(2) The effects of varying $\left|\frac{\phi}{\beta}\right|_d$ with

$\omega_d = \omega_\phi = 1.0, 0.5, 0.25$ rad/sec, and

$\zeta_d = \zeta_\phi = 0.3, 0.0, -0.2$ for each frequency.

(3) (a) The effects of varying the Dutch roll characteristics at $\left|\frac{\phi}{\beta}\right|_d = 0.2$ whilst the locations of the zeros of the $\frac{\phi}{\delta_a}$ transfer function were held in the following relationship to those of the Dutch roll roots:

$\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d$, $\zeta_d + 0.1$, $\zeta_d - 0.1$

with $\omega_d = 1.0, 0.5, 0.25$ rad/sec and

$\zeta_d = 0.3, 0.2, 0.1, 0, -0.1, -0.2, -0.3, -0.4$, in general, for each frequency.

(b) A similar investigation to that of (a), but with $\left|\frac{\phi}{\beta}\right|_d = 0.75$,

$\omega_d = \omega_\phi = 1.0,\ 0.5,\ 0.25$ rad/sec and

$\zeta_d = \zeta_\phi = 0.3,\ 0.0,\ -0.2$ for each frequency.

(c) A similar investigation to (a), but with $\left|\frac{\phi}{\beta}\right|_d = 1.5$,

$\omega_d = \omega_\phi = 1.0,\ 0.5,\ 0.25$ rad/sec and

$\zeta_d = \zeta_\phi = 0.3,\ 0.2,\ 0.1,\ 0,\ -0.1,\ -0.2$ for each frequency.

The stability derivatives required to obtain these modal characteristics were derived as outlined in Section 3.1 and are presented in Table 3.

5.1 Flights with the Zeros of the $\frac{\phi}{\delta_a}$ Transfer Function Varying about the Dutch Roll Roots of the Characteristic Equation - Low $\left|\frac{\phi}{\beta}\right|_d$

5.1.1 Dutch Roll at Highest Frequency and Moderate Damping

The characteristics of the lateral-directional normal modes of motion were:

$\omega_d = 1.0$ rad/sec $\qquad \lambda_R = -4.0\ \frac{1}{\text{sec}}$

$\zeta_d = 0.2 \qquad \lambda_S = 0$

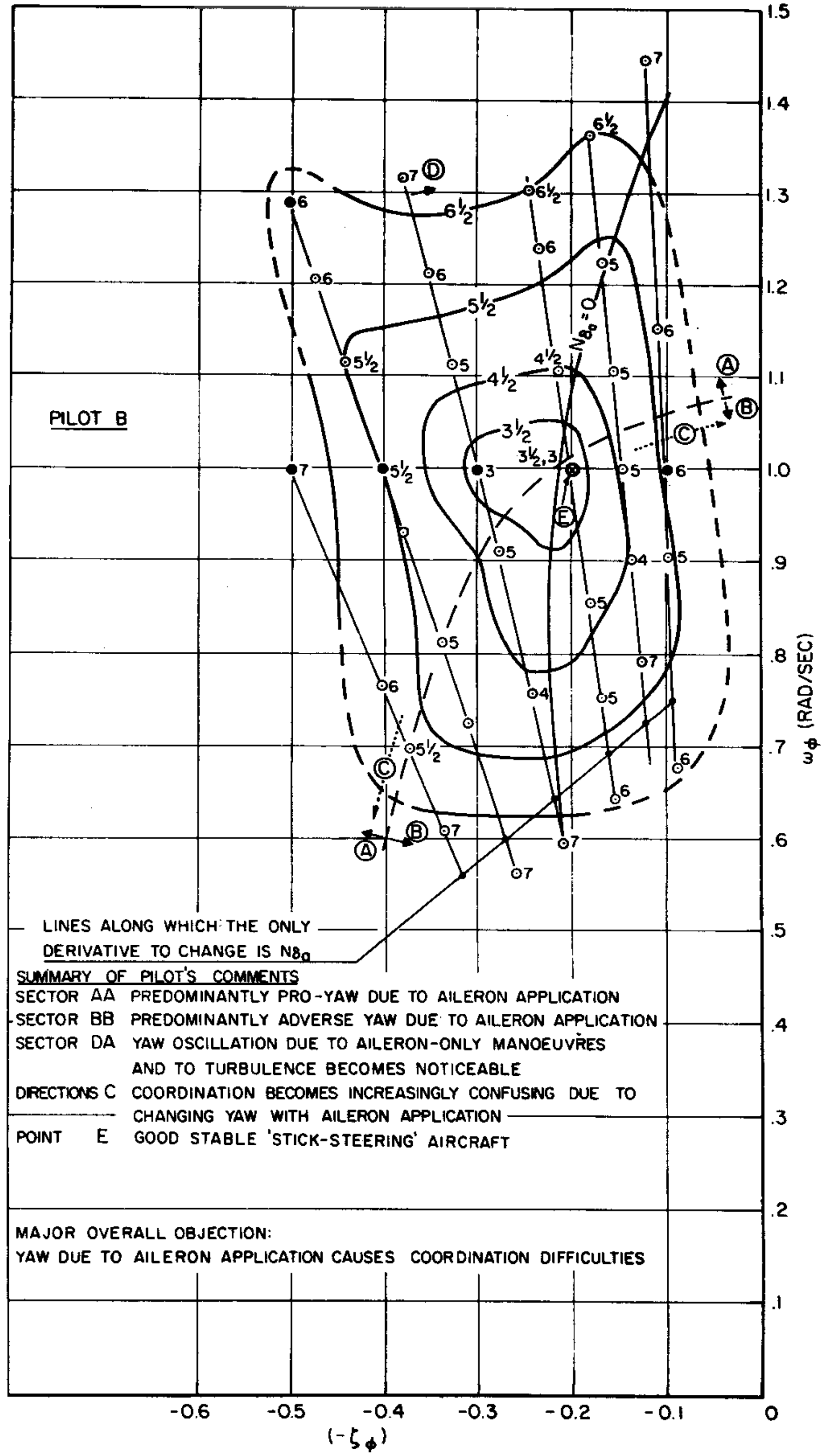
$\left|\frac{\phi}{\beta}\right|_d = 0.2$

ω_ϕ and ζ_ϕ varying.

The pilots' comments for these evaluations are summarized in Table 4a. Since the ratings assigned by the two pilots who flew the majority of the configurations in this phase of the evaluations differed consistently in certain regions, it was felt that separate plots of pilot's ratings were warranted. These are presented in Figures 9 and 10 in terms of frequency, ω_ϕ, and damping ratio, ζ_ϕ, and in Figures 11 and 12 in terms of damped frequency, $\omega_\phi\sqrt{1-\zeta_\phi^2}$, and total damping, $\omega_\phi\zeta_\phi$.

A comparison of Figures 9 and 10 shows that Pilot B, in general, did not have as steep a gradient in his ratings away from the characteristic Dutch roll root as did Pilot C. The pilots' comments, however, agree as to which parameters caused the down-grading of the various configurations and the difference in ratings reflects a difference in the degree to which each pilot felt that these parameters affected his performance of the task in relation to the effort required of him.

The major difficulty experienced by all pilots, as the zeros of the $\frac{\phi}{\delta_a}$ transfer function were moved away from the Dutch roll pole, was due to the rudder coordination required to counteract the yawing that occurred when aileron was applied. Even as the line of minimum net yaw (line AA, Figs. 9, 10, 11, and 12, obtained from the pilots' comments) was followed away from the pole, pilots found that the phase difference in the effect of N_{δ_a} and N_p caused considerable coordination confusion. The reason for this was that, although the two derivatives counteracted each other along this line,



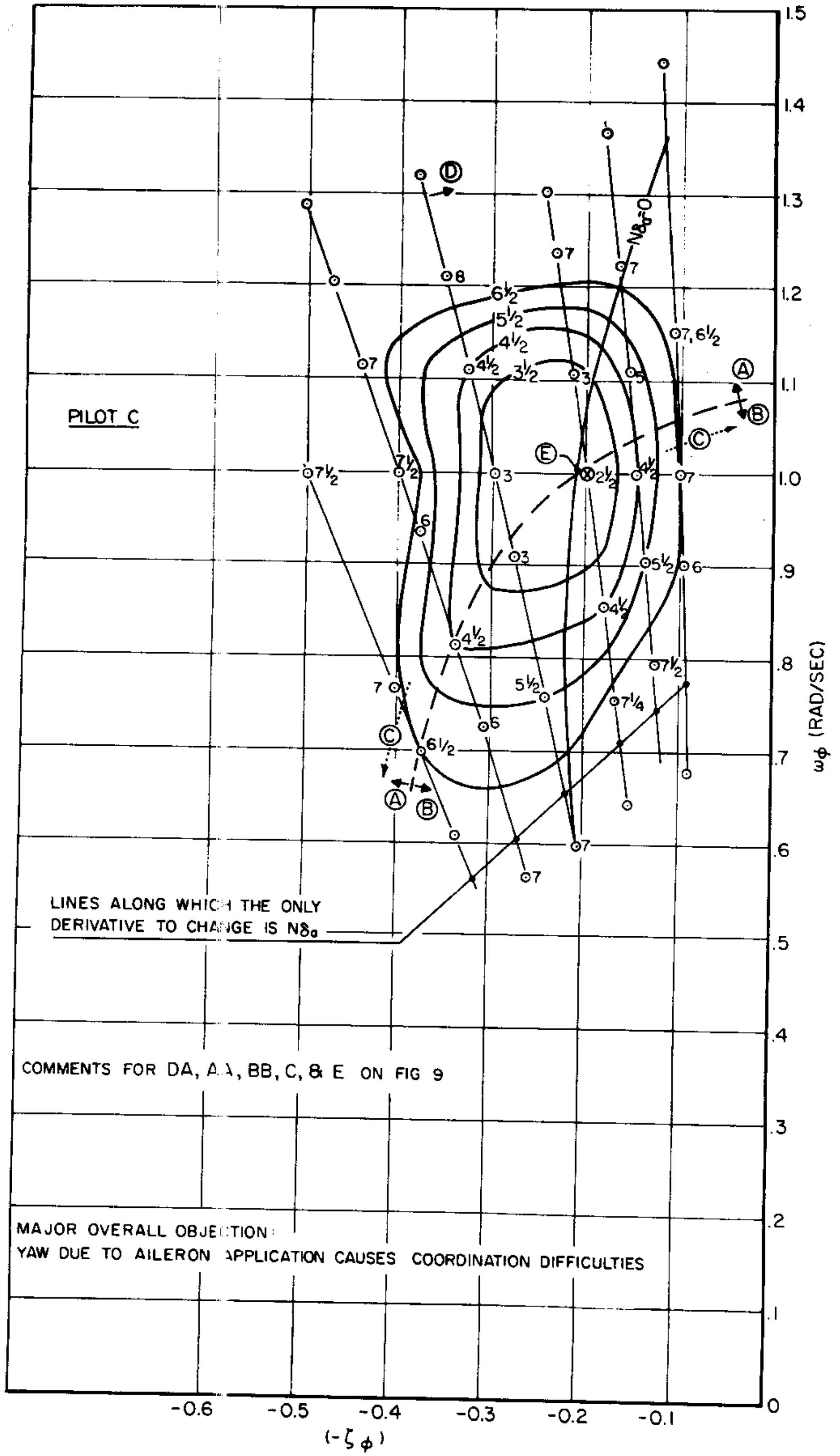
LINES ALONG WHICH THE ONLY DERIVATIVE TO CHANGE IS N_{δ_a}

SUMMARY OF PILOT'S COMMENTS

SECTOR	AA	PREDOMINANTLY PRO-YAW DUE TO AILERON APPLICATION
SECTOR	BB	PREDOMINANTLY ADVERSE YAW DUE TO AILERON APPLICATION
SECTOR	DA	YAW OSCILLATION DUE TO AILERON-ONLY MANOEUVRES AND TO TURBULENCE BECOMES NOTICEABLE
DIRECTIONS	C	COORDINATION BECOMES INCREASINGLY CONFUSING DUE TO CHANGING YAW WITH AILERON APPLICATION
POINT	E	GOOD STABLE 'STICK-STEERING' AIRCRAFT

MAJOR OVERALL OBJECTION:
YAW DUE TO AILERON APPLICATION CAUSES COORDINATION DIFFICULTIES

FIG 9 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT $\omega_d = 1.0$, $\zeta_d = 0.2$ ON PILOT B'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d = 0.2$

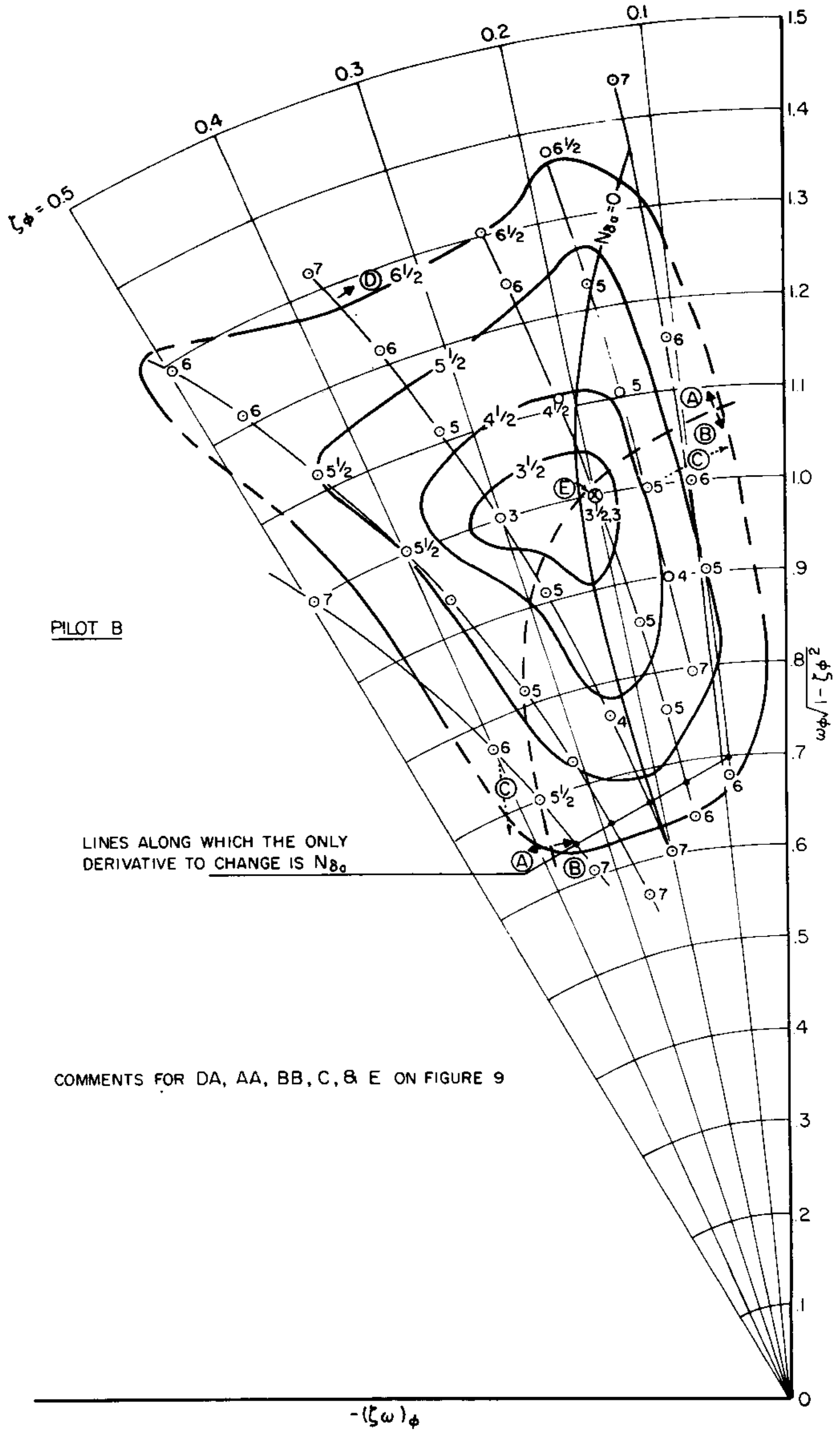


LINES ALONG WHICH THE ONLY DERIVATIVE TO CHANGE IS N_{δ_a}

COMMENTS FOR DA, AA, BB, C, & E ON FIG 9

MAJOR OVERALL OBJECTION:
YAW DUE TO AILERON APPLICATION CAUSES COORDINATION DIFFICULTIES

FIG 10 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT $\omega_d = 1.0$, $\zeta_d = 0.2$ ON PILOT C'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d = 0.2$



PILOT B

LINES ALONG WHICH THE ONLY DERIVATIVE TO CHANGE IS N_{δ_a}

COMMENTS FOR DA, AA, BB, C, & E ON FIGURE 9

FIG 11 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT ω_d = 1.0, ζ_d = 0.2 ON PILOT B'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d$ = 0.2

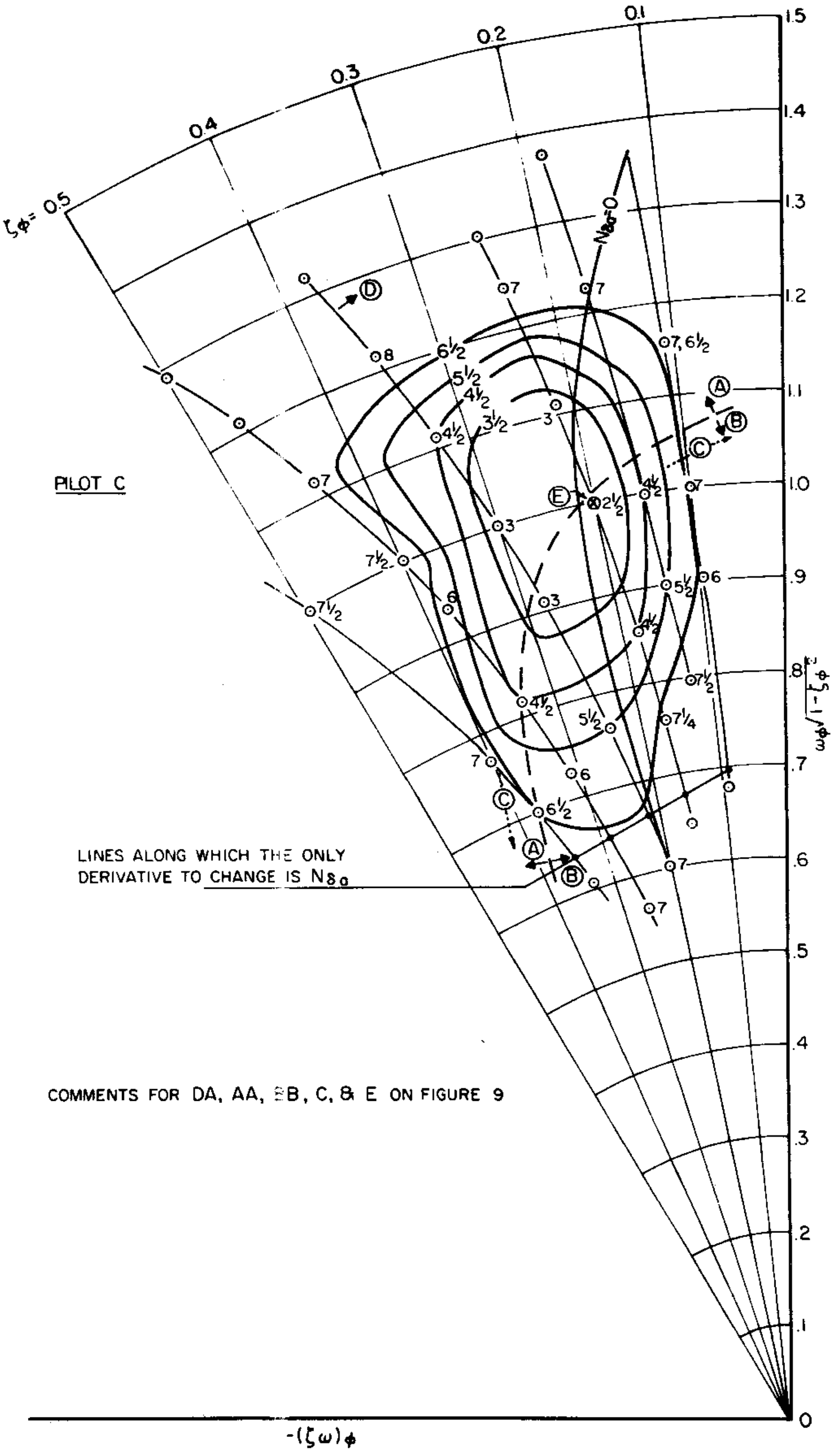


FIG 12

EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\beta_a}$ TRANSFER FUNCTION ABOUT $\omega_d = 1.0$, $\zeta_d = 0.2$ ON PILOT C'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d = 0.2$

both were of sufficient magnitude for the timing of their individual effects to become apparent to the pilot in the form of yaw, generated first in one direction by N_{δ_a}, closely followed by yaw generated in the other by N_p as the roll rate built up. Since the damping of the Dutch roll mode was moderately high, the open-loop oscillation that was excited mainly in yaw by this effect was not sustained for long enough to be the major objection to the pilot. The predominant complaint was concerned with the initial yaw excursions, rather than with the control of the subsequent oscillatory behaviour. However, control of the oscillatory characteristics did demand increasing attention from the pilots as the zero was moved from the pole because of the increasing magnitude of the yaw excursions caused by both aileron application and by turbulence. The oscillatory characteristics became most noticeable to the pilot when the zero was moved to higher frequencies and lower damping ratios. When it was moved to lower frequencies and higher damping ratios, Pilot C found an increasing tendency for large sideslips to build quickly from any small out-of-trim on the rudder pedals.

Analysis of the $\frac{r}{\beta_g}$ transfer function for these configurations showed that the minimum open-loop response to turbulence occurred on the line through LH 100+20+35 along which only the derivative N_{δ_a} was varied and that the response increased as paths perpendicular to this family of lines were followed in either direction. (The open-loop $\frac{\phi}{\beta_g}$ response is virtually independent of the location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function.) The pilots' comments confirmed that the effects of turbulence became most noticeable as the zeros of the $\frac{\phi}{\delta_a}$ transfer function were moved from the Dutch roll characteristic roots in the direction of lower values of damping ratio and indicated a pronounced gradient in the response to turbulence.

5.1.2 Dutch Roll at Intermediate Frequency and Zero Damping

The characteristics of the lateral-directional normal modes of motion were:

$$\omega_d = 0.5 \text{ rad/sec} \qquad \lambda_R = -4.0 \frac{1}{\text{sec}}$$

$$\zeta_d = 0 \qquad \lambda_S = 0$$

$$\left|\frac{\phi}{\beta}\right|_d = 0.2$$

ω_ϕ and ζ_ϕ varying.

The pilots' comments are summarized in Table 4b and the ratings by the two pilots, who again did the majority of the flying with this group of configurations, are plotted in Figures 13, 14, 15, and 16. Figures 13 and 14 are plotted in terms of frequency, ω_ϕ, and damping ratio, ζ_ϕ, whereas Figures 15 and 16 are plotted in terms of damped frequency, $\omega_\phi\sqrt{1-\zeta_\phi^2}$, and total damping, $\omega_\phi\zeta_\phi$.

As would be expected from the zero damping of the Dutch roll mode, the oscillatory characteristics of these configurations became much more apparent to the pilots than those of

MAJOR OVERALL OBJECTION:

YAW DUE TO AILERON INPUTS, OSCILLATORY CHARACTERISTICS, AND LOW OR NEGATIVE STATIC STABILITY IN YAW, REQUIRE CONTINUOUS ATTENTION TO RUDDER

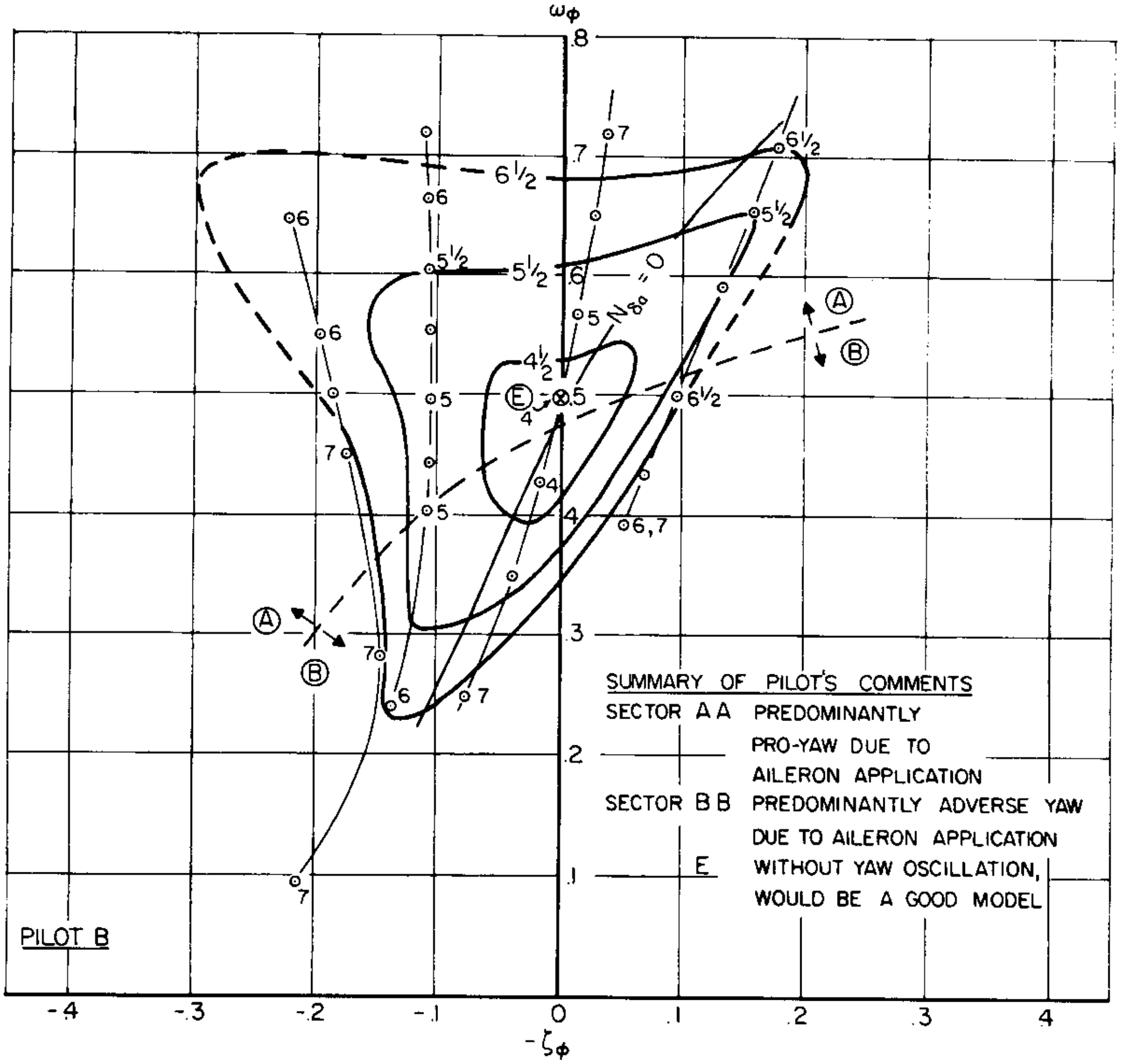


FIG 13 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT ω_d=0.5, ζ_d =0.0 ON PILOT B'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d$=0.2

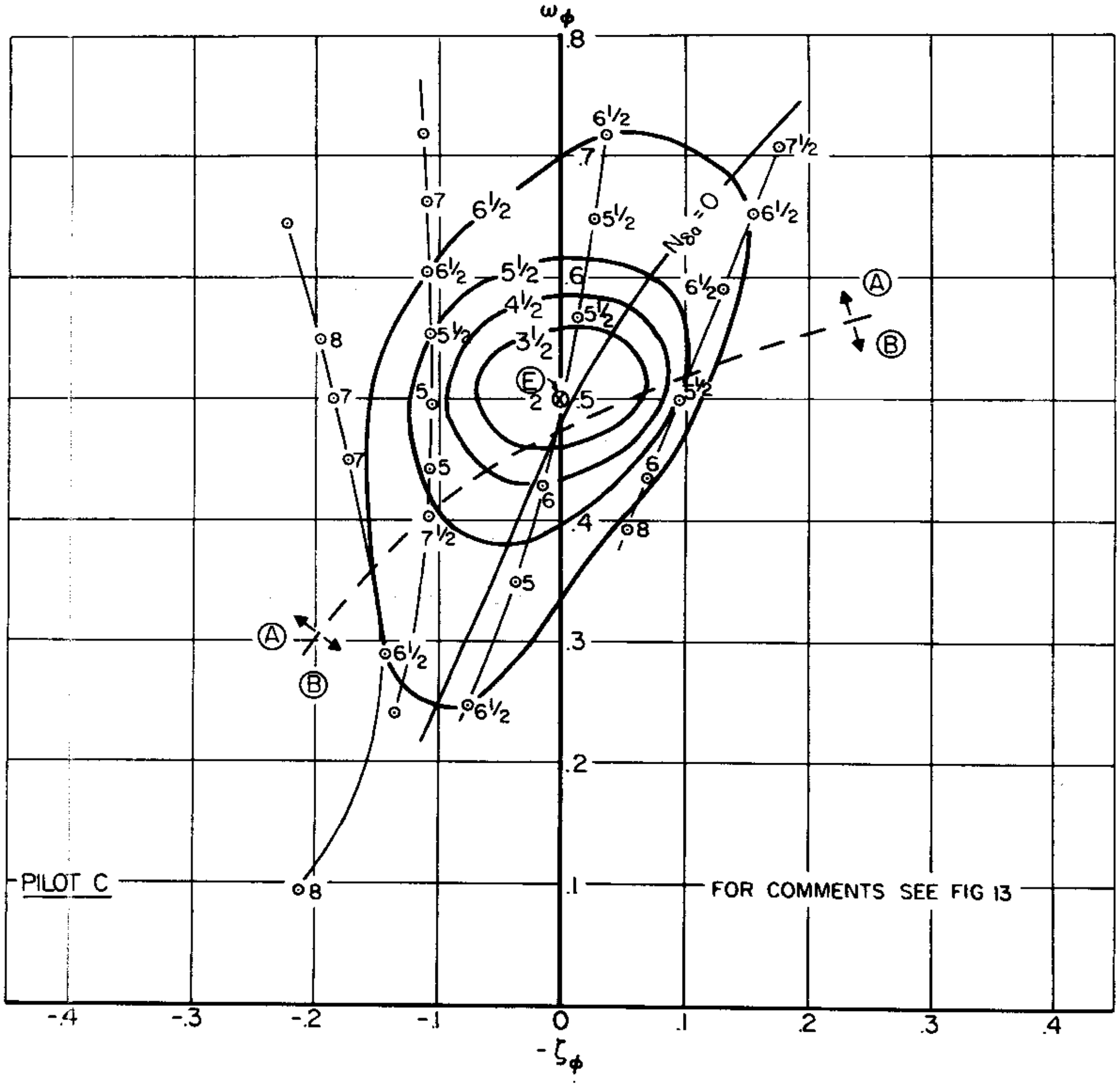
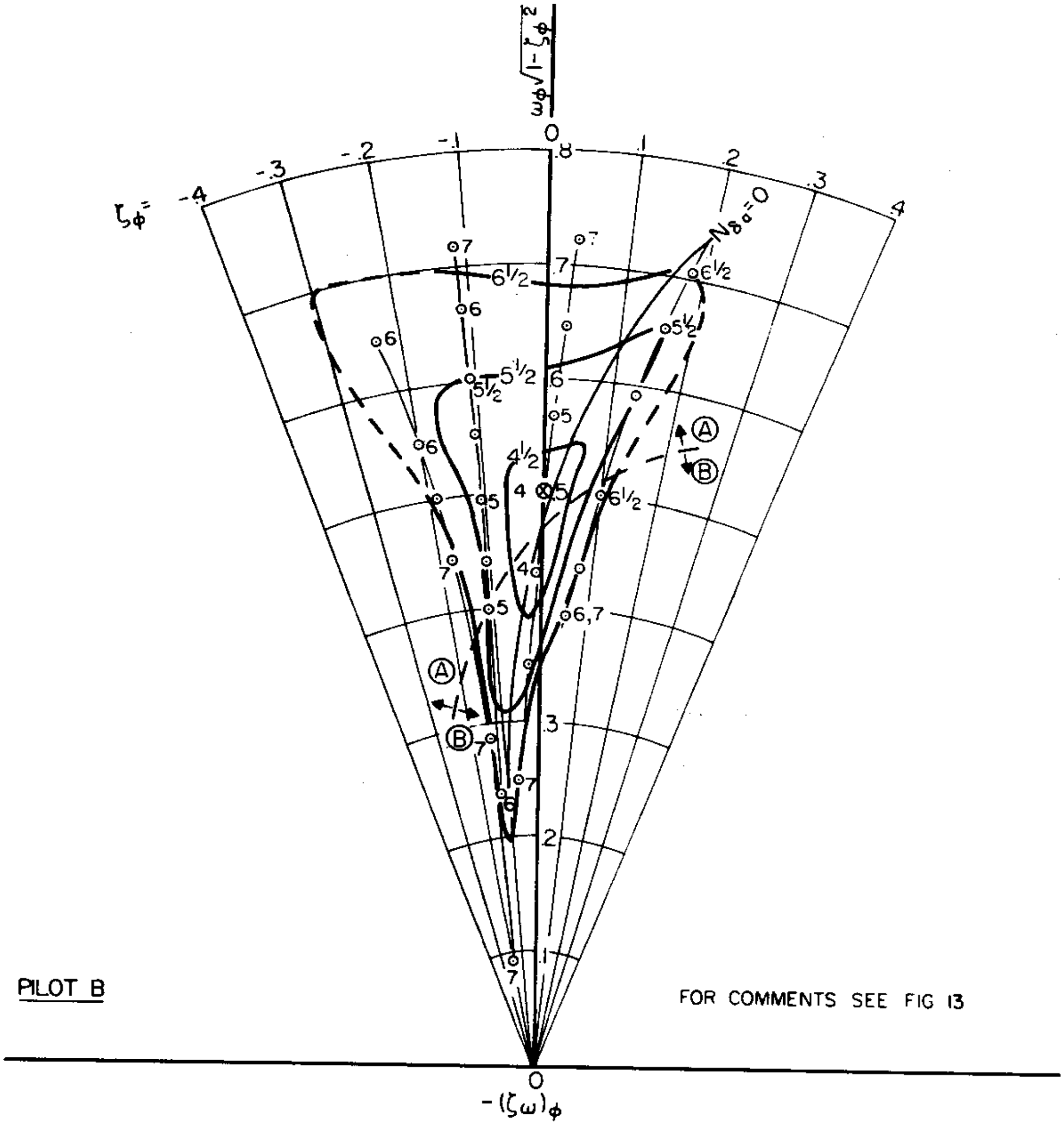


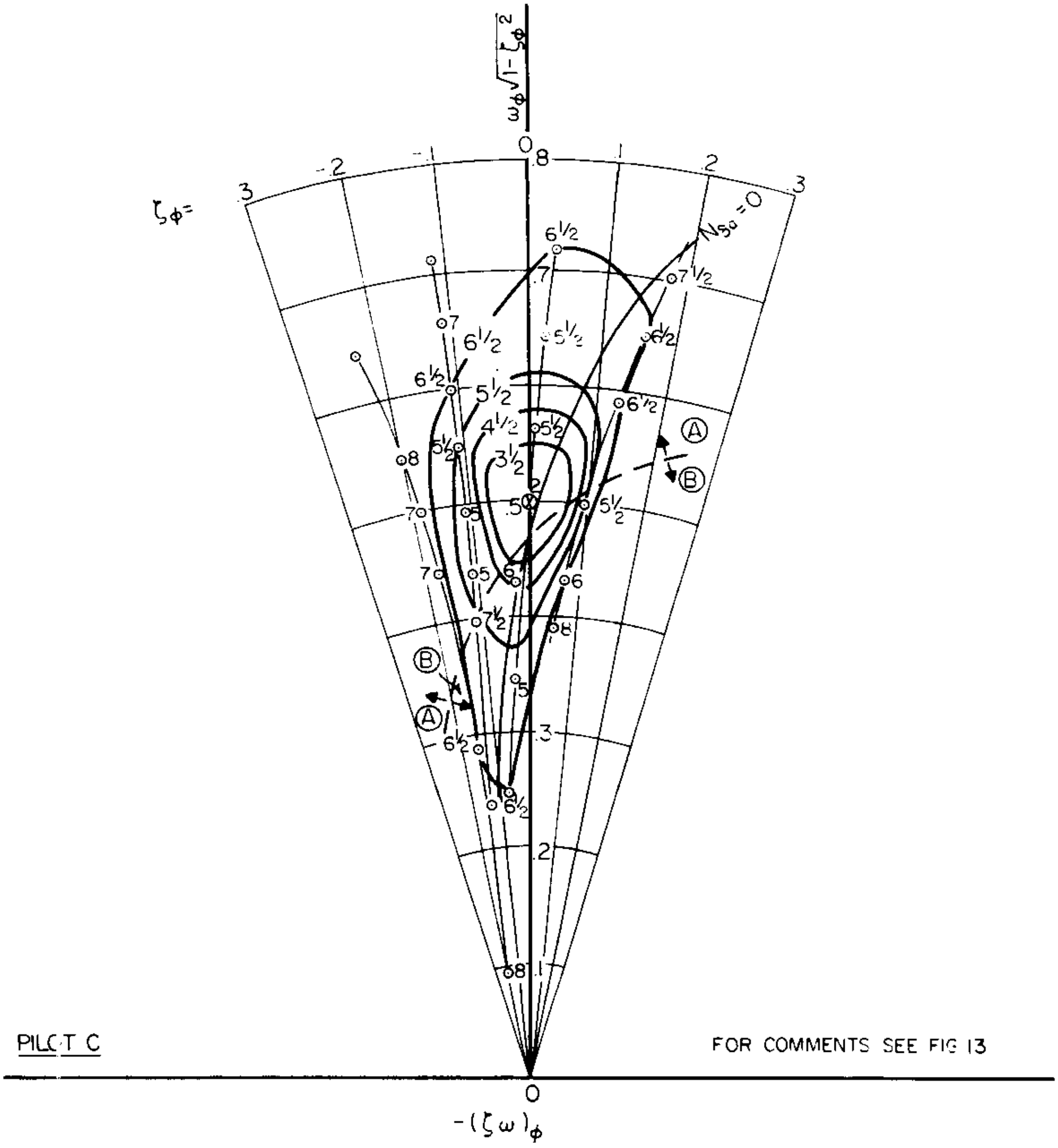
FIG 14 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT $\omega_d = 0.5$, $\zeta_d = 0.0$ ON PILOT C'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d = 0.2$



PILOT B

FOR COMMENTS SEE FIG 13

FIG 15 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT $\omega_d = 0.5, \zeta_d = 0.0$ ON PILOT B'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d = 0.2$



PILOT C

FOR COMMENTS SEE FIG 13

FIG 16 EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT $\omega_d = 0.5, \zeta_d = 0.0$ ON PILOT C'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d = 0.2$

the previous group. Both pilots still found the yaw generated by the application of aileron to be one of the dominant, objectionable features, but the yaw oscillation initiated by these excursions also demanded a considerable amount of their attention. There was a tendency for both pilots to find that the frequency of the oscillation increased when the zero of the $\frac{\phi}{\delta_a}$ transfer function was moved in the direction of increasing ω_ϕ along lines for which the only derivative to be changed was N_{δ_a} (see Fig. 13). Indeed, for low values of ω_ϕ, Pilot C consistently commented on a static instability in yaw, rather than on the oscillatory characteristics. Both pilots found that it was generally possible to suppress the oscillation and the apparent instability in yaw without undue difficulty with the powerful rudder control available. However, if attention was not given to this aspect, large yaw oscillations or apparent static divergences would quickly develop.

A small out-of-trim on the rudder pedals caused either the rapid build-up of sideslip angle or high amplitude oscillations in yaw, resulting in a need for continuous attention to the trim position of the rudder pedals.

Turbulence effects were, on the whole, minor in this group, but any oscillations that were excited tended to grow unless checked with rudder.

5.1.3 Dutch Roll at Lowest Frequency and Negative Damping

The characteristics of the lateral-directional normal modes of motion were:

$\omega_d = 0.25$ rad/sec $\qquad \lambda_R = -4.0 \frac{1}{\text{sec}}$

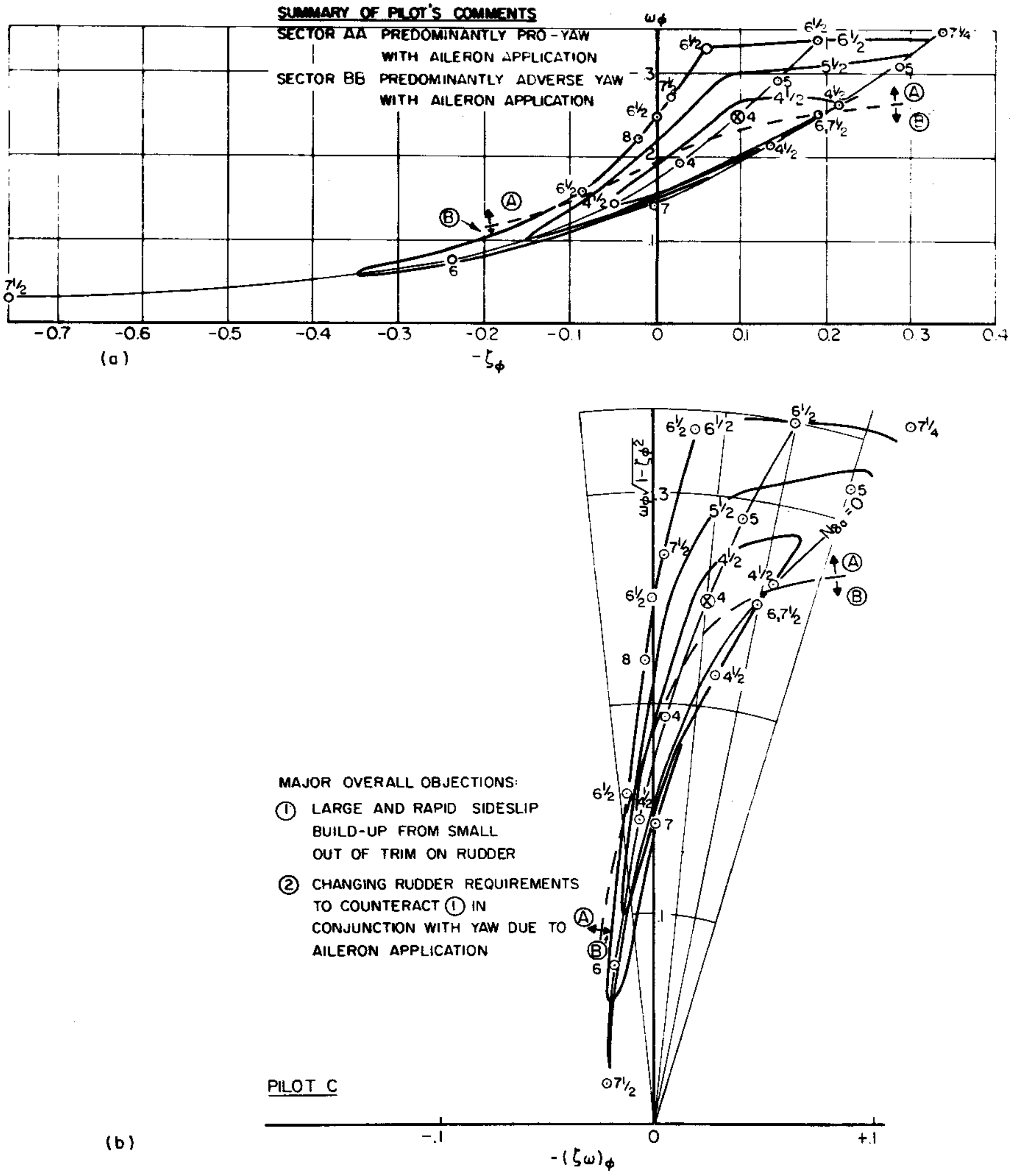
$\zeta_d = -0.1 \qquad \lambda_S = 0$

$\left|\frac{\phi}{\beta}\right|_d = 0.2$

ω_ϕ and ζ_ϕ varying.

The pilots' comments for these configurations are summarized in Table 4c. Owing to the lack of time, only one pilot (Pilot C) flew the majority of these configurations and his ratings are plotted in terms of frequency, ω_ϕ, and damping ratio, ζ_ϕ, in Figure 17a, and in terms of damped frequency, $\omega_\phi\sqrt{1-\zeta_\phi^2}$, and total damping, $\omega_\phi\zeta_\phi$, in Figure 17b. Configurations based on low levels of the damping ratio, ζ_ϕ, with $\omega_\phi = 0.25$ rad/sec could not be evaluated as no convergent solutions were obtained from the computer programme in that region.

The predominant difficulty occurring in this group arose from the apparent static instability in yaw. A small out-of-trim on the rudder pedals caused a rapid build-up of sideslip angle. The rudder necessary to coordinate aileron turns was generally not as objectionable as in the previous two groups, but the poor weathercock stability resulted in a requirement for much closer monitoring of rudder pedal position



SUMMARY OF PILOT'S COMMENTS

SECTOR AA PREDOMINANTLY PRO-YAW WITH AILERON APPLICATION

SECTOR BB PREDOMINANTLY ADVERSE YAW WITH AILERON APPLICATION

MAJOR OVERALL OBJECTIONS:

① LARGE AND RAPID SIDESLIP BUILD-UP FROM SMALL OUT OF TRIM ON RUDDER

② CHANGING RUDDER REQUIREMENTS TO COUNTERACT ① IN CONJUNCTION WITH YAW DUE TO AILERON APPLICATION

FIG 17(a)&(b) EFFECT OF CHANGING ZEROS OF $\frac{\phi}{\delta_a}$ TRANSFER FUNCTION ABOUT ω_d =0.25, ζ_d =-0.1 ON PILOT C'S RATINGS; $\left|\frac{\phi}{\beta}\right|_d$=0.2

in both steady-state turns and in straight and level flight. On isolated occasions the pilot commented on a low frequency divergent oscillation, rather than on the apparent static instability in yaw.

The effects of turbulence, in general, caused no problems for the pilot.

5.1.4 Summary of Configurations Evaluated with Zeros of $\frac{\phi}{\delta_a}$ Transfer Function Varied around Different Oscillatory Characteristic Roots with Low $\left|\frac{\phi}{\beta}\right|_d$

(1) Configurations based on $\omega_d = 1.0$ rad/sec, $\zeta_d = 0.2$

With the high prevailing damping ratio of the characteristic equation, the Dutch roll oscillatory mode was generally not the dominant feature in the assessments of the configurations by different pilots. The oscillations that did occur were mainly in yaw, and thus it does not seem that the $\frac{\phi}{\delta_a}$ transfer function is the most relevant parametric notation with which to classify the configurations. It is felt that a categorisation of the configurations with parameters that are more directly related to those physical aspects of immediate concern to the pilots, such as for example, the $\frac{\beta}{\delta_a}$ or $\frac{r}{\delta_a}$ transfer functions, may prove to be more appropriate.

(2) Configurations based on $\omega_d = 0.5$ rad/sec, $\zeta_d = 0$

The use of the location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function to describe the flight characteristics of the different configurations has even less physical justification than in the previous cases, since directional characteristics dominated pilot attention throughout the range.

(3) Configurations based on $\omega_d = 0.25$ rad/sec, $\zeta_d = -0.1$

The location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function become irrelevant in describing the flight characteristics of the different configurations. Such steep gradients in pilot opinion existed for very small changes in the location of the zeros of this transfer function, that its use as a means of classification could lead to completely erroneous predictions as to the handling qualities of aircraft with these open-loop characteristics.

5.2 Effect of changing $\left|\frac{\phi}{\beta}\right|_d$

The effects of changing $\left|\frac{\phi}{\beta}\right|_d$ from 0.2 to 0.75 and 1.5 were investigated with all other lateral-directional modal characteristics remaining constant. In these configurations the zeros of the $\frac{\phi}{\delta_a}$ transfer function coincided with roots of the oscillatory mode of the characteristic equation. The pilots' comments are summarized in Table 4d.

5.2.1 Dutch Roll at Highest Frequency and Various Damping Ratios

The characteristics of the lateral-directional normal modes of motion were:

$$\omega_d = \omega_\phi = 1.0 \text{ rad/sec} \qquad \lambda_R = -4.0 \frac{1}{\text{sec}}$$

$$\zeta_d = \zeta_\phi = 0.3,\ 0,\ -0.2 \qquad \lambda_S = 0$$

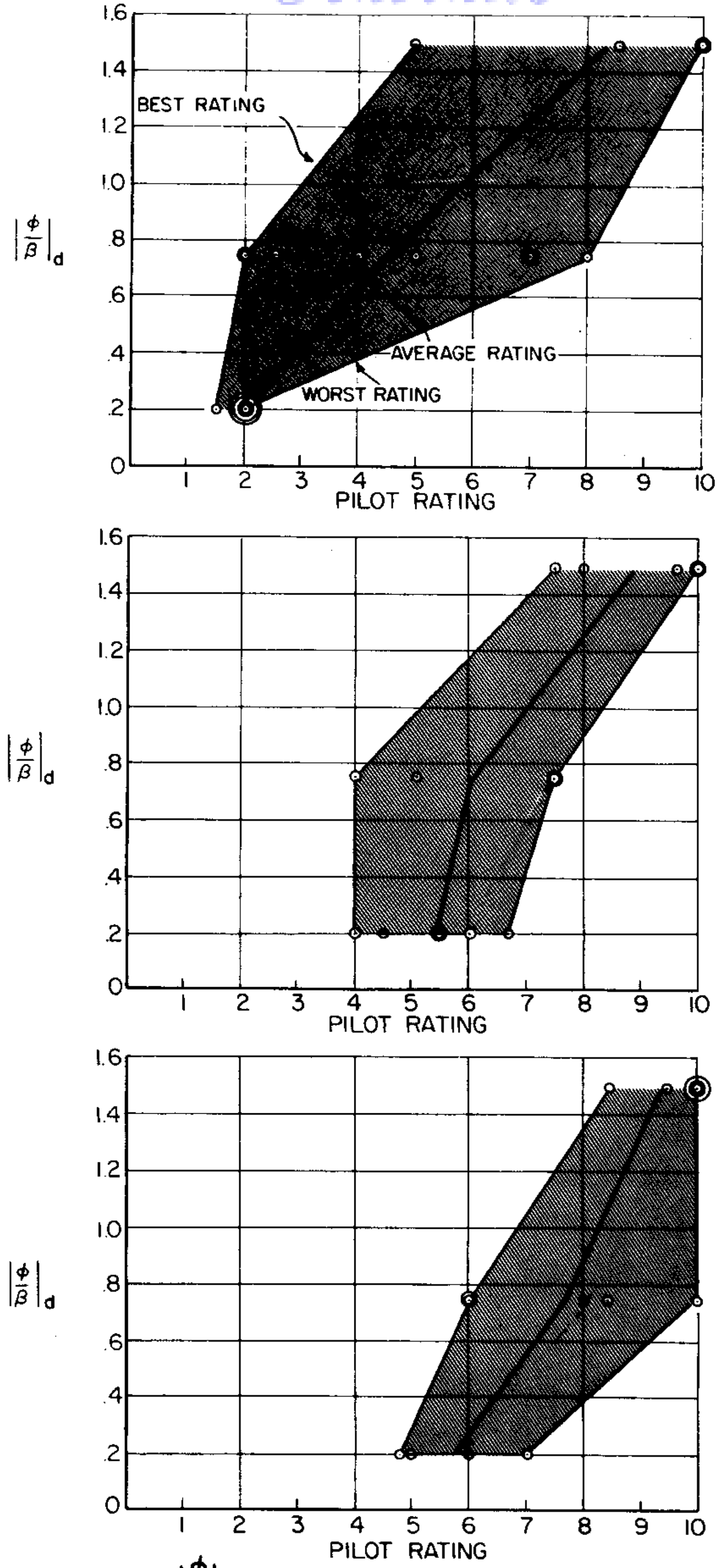
and $$\left|\frac{\phi}{\beta}\right|_d = 0.2,\ 0.75,\ 1.5.$$

(i) $\zeta_d = 0.3$

It may be seen immediately from their ratings, plotted in Fig. 18a, that the pilots experienced varying degrees of difficulty in flying these configurations, the difference becoming more apparent with increasing $\left|\frac{\phi}{\beta}\right|_d$. However, the line of averaged pilots' ratings indicates a general deterioration of handling qualities as $\left|\frac{\phi}{\beta}\right|_d$ is increased.

At the lowest $\left|\frac{\phi}{\beta}\right|_d$, 0.2, all pilots agreed that the configuration was one of the best behaved of the programme with virtually no necessity to coordinate turns with rudder, little noticeable effect of turbulence or cross-wind, no difficulty with the sidestep manoeuvre and with aileron sensitivity being adequate, although a little low.

The greatest differences in ratings in the programme occurred for the intermediate $\left|\frac{\phi}{\beta}\right|_d$, 0.75. All pilots found that the aileron control power of this configuration was low, and that too much of that available was required on the approach to counteract the cross-wind. However, similarities in comments ended here. Pilot A found the configuration was generally good, stable and easily controllable. In contrast, Pilot C was affected to a much greater extent by the aircraft's response to turbulence, in that it caused an uncomfortable, coupled rolling-yawing motion. He also found that he was unable to roll-out of the sidestep manoeuvre without rudder assistance, because of the limited roll control remaining



(a) $\zeta_\phi = \zeta_d = 0.3$

(b) $\zeta_\phi = \zeta_d = 0$

(c) $\zeta_\phi = \zeta_d = -0.2$

FIG 18 EFFECT OF $\left|\frac{\phi}{\beta}\right|_d$ ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES AT DIFFERENT DAMPING RATIOS; $\omega_d = \omega_\phi = 1.0$ RAD/SEC

after the cross-wind had been counteracted. The other pilots were affected to varying degrees by the aircraft's response to turbulence and generally had some difficulty in recovering from the sidestep manoeuvre because of the small aileron control travel remaining.

It should be noted that the low frequency portion of the turbulence input could have a pronounced effect on the amount of aileron available on approach, as it could, in some instances, add to the cross-wind effect and, in others, counteract it. The execution of the sidestep manoeuvre takes approximately 20 seconds and a gust (amounting to a variation in the wind direction) with a period of this order, could have considerable influence on the performance of the manoeuvre.

In order to discover if poor control harmony affected Pilot C's rating of the configuration, the rudder sensitivity, N_{δ_r}, was reduced to such a level that the gain of the low frequency, open-loop yaw rate, r, to rudder, δ_r, response was the same as in the configuration with the lower $\left|\frac{\phi}{\beta}\right|_d$. There was an improvement in his rating, but the comments were generally similar to those in his previous evaluations, the major difference being that he was able to recover from the sidestep manoeuvre. This latter factor, which doubtless influenced the pilot's rating, cannot, of course, be attributed to the decrease in rudder sensitivity. The aileron sensitivity, L_{δ_a}, was then increased by 50%, whilst that of the rudder, N_{δ_r}, was returned to its normal value. The result was a greater improvement in rating, with no difficulty being experienced due to a lack of aileron control power.

The difference in ratings can be attributed only in part to these changes in control sensitivities, as the different time history of the turbulence to which the aircraft was subjected may have caused varying degrees of difficulty at crucial points during the evaluation.

The high $\left|\frac{\phi}{\beta}\right|_d$, 1.5, caused all but Pilot D considerable difficulty at this damping level. The major problem was that of the large roll angles generated by small sideslips. The roll control power available proved inadequate for the task and, on approach, full aileron control deflection was required for much of the time because of the cross-wind and turbulence. This resulted in insufficient aileron being available to recover from the sidestep manoeuvre without rudder assistance during the roll-out. Turbulence proved to be bothersome in that it caused continual and large disturbances in roll. Improvements in control harmony and aileron control sensitivity, made on the same basis as that used for the intermediate $\left|\frac{\phi}{\beta}\right|_d$ ratio, did not this time prove to be of sufficient benefit to overcome the difficulties experienced with the roll excursions.

(ii) $\zeta_d = 0$

From the pilots' ratings for this group, plotted in Figure 18b, it can be seen that the ratings deteriorated with increasing $\left|\frac{\phi}{\beta}\right|_d$, and that their general level was worse than that of the previous group.

The main objection at low $\left|\frac{\phi}{\beta}\right|_d$ was to the yaw oscillation that was continually being excited by the turbulence. The aileron sensitivity was generally considered as quite good, whereas the rudder was a little over-sensitive.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ pilots again showed an increased difference in their ratings. The general complaint was of the oscillatory response in both roll and yaw to turbulence and to rudder inputs. The aileron control power was considered to be low, especially in comparison with the sensitive rudder control. Pilot C also flew the configuration with the aileron control sensitivity increased by 50% and, although commenting on the improved response in roll, did not change his rating of the configuration.

All pilots agreed that the task could not be performed adequately at the high $\left|\frac{\phi}{\beta}\right|_d$. The major complaint was of the severe effect of turbulence in disturbing the aircraft in roll. Even small sideslips caused such large roll disturbances that full aileron was frequently required to hold off bank. The cross-wind required full aileron for most of the approach and the sidestep manoeuvre could not be accomplished satisfactorily. Increasing aileron sensitivity by 50% did not improve matters.

(iii) $\zeta_d = -0.2$

The pilot ratings for this group are plotted in Figure 18c. In this case the ratings consistently deteriorated with increasing $\left|\frac{\phi}{\beta}\right|_d$ and the general level of ratings was worse than in the previous groups of higher damping.

At low $\left|\frac{\phi}{\beta}\right|_d$ the dominant feature was the divergent yaw oscillation that was excited by turbulence. The oscillation could be readily controlled with the powerful rudder, but constant attention to this aspect was required.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ the oscillation again dominated the assessments, the difference being that it now became much more apparent in roll. Consequently, the low roll control power was noticeable, with ensuing difficulties from the cross-wind occurring on the approach. Small sideslips used up all the roll control available, resulting in the necessity to maintain continuous rudder coordination.

At high $\left|\frac{\phi}{\beta}\right|_d$ this configuration proved to be virtually unflyable. Large roll excursions were continually initiated by turbulence and sideslip, and control of the ensuing oscillatory motion in roll dominated pilots' attention. The aileron control power available was inadequate to cope with the situation.

5.2.2 Dutch Roll at Intermediate Frequency and Various Damping Ratios

The characteristics of the lateral-directional normal modes of motion were:

$$\omega_d = \omega_\phi = 0.5 \text{ rad/sec} \qquad \lambda_R = -4.0 \frac{1}{\text{sec}}$$

$$\zeta_d = \zeta_\phi = 0.3,\ 0,\ -0.2 \qquad \lambda_S = 0$$

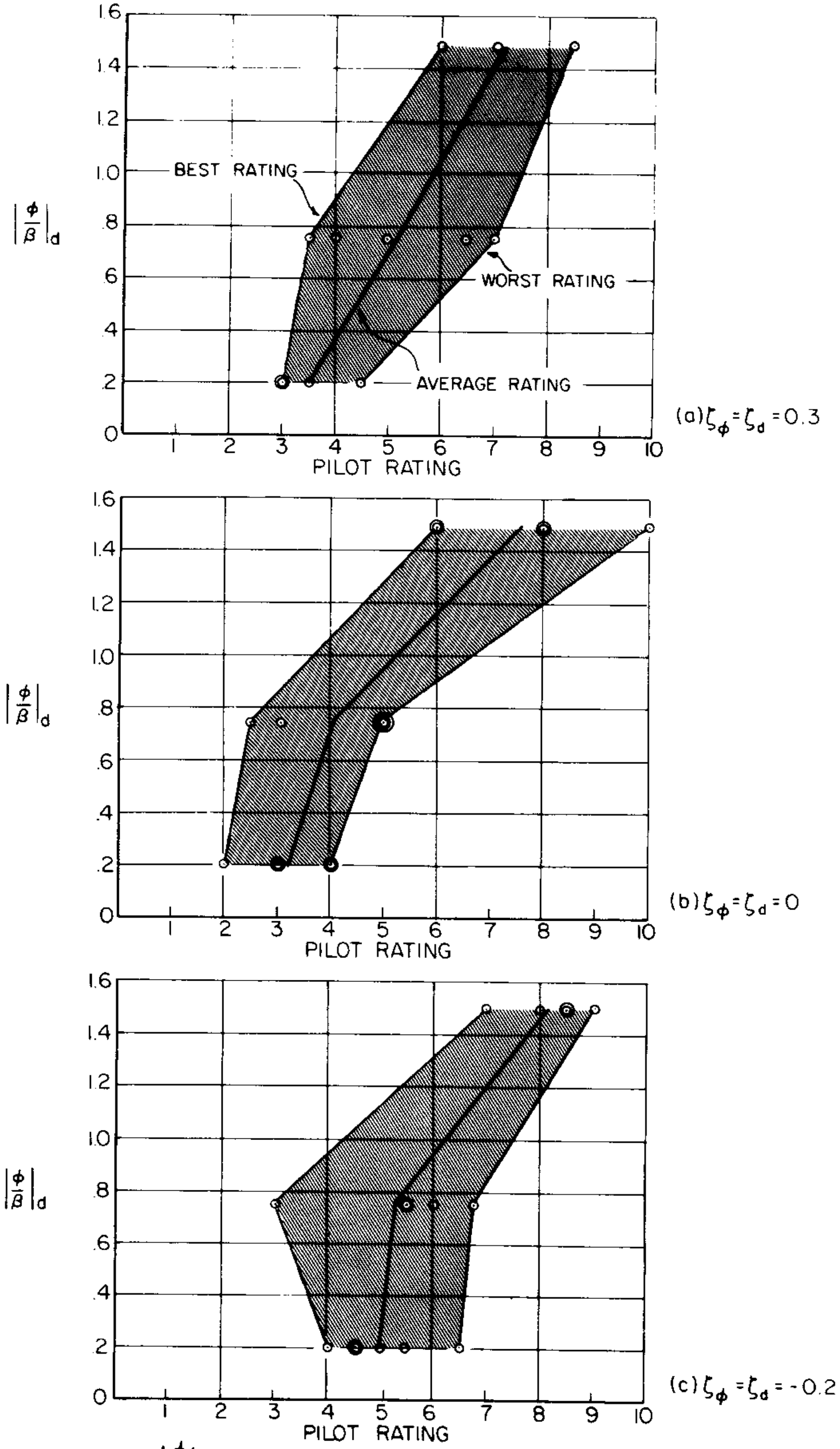
and $\left|\frac{\phi}{\beta}\right|_d = 0.2,\ 0.75,\ 1.5$

(i) $\zeta_d = 0.3$

The pilots' ratings are plotted in Figure 19a. The comments at low $\left|\frac{\phi}{\beta}\right|_d$ indicated slight oscillatory tendencies in yaw, a slight effect of turbulence and a need for small rudder inputs for coordination.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ a spread in pilots' ratings occurred. In general, a long period oscillation in both roll and yaw, which could be checked relatively easily but led to the impression that the aircraft was rather 'loose' about the lateral-directional axes, was evident. Pilots C and E commented on the lack of roll control power, especially in the presence of sideslip, and the sidestep manoeuvre required much attention from these pilots because of this factor. The other pilots found the roll control power adequate. The effect of turbulence was minor, although it did set off the oscillation.

At high $\left|\frac{\phi}{\beta}\right|_d$ oscillations in roll that were set off



(a) $\zeta_\phi = \zeta_d = 0.3$

(b) $\zeta_\phi = \zeta_d = 0$

(c) $\zeta_\phi = \zeta_d = -0.2$

FIG 19 EFFECT OF $\left|\frac{\phi}{\beta}\right|_d$ ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES AT DIFFERENT DAMPING RATIOS; $\omega_d = \omega_\phi = 0.5$ RAD/SEC

continually by both turbulence and rudder inputs dominated the assessments. Aileron control power was generally inadequate for controlling the cross-wind and for manoeuvring.

(ii) $\underline{\zeta_d = 0}$

The pilots' ratings are plotted in Figure 19b, and the deterioration in handling qualities with increasing $\left|\frac{\phi}{\beta}\right|_d$ may again be observed.

At low $\left|\frac{\phi}{\beta}\right|_d$ the only objectionable characteristic was the yaw oscillation of long period that was occasionally set off by rudder inputs. The oscillation was easily controlled, but required attention.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ the oscillation in yaw became more pronounced and made constant use of rudder necessary. The cross-wind and sidestep manoeuvre caused no undue concern to the pilot.

At high $\left|\frac{\phi}{\beta}\right|_d$ control of the oscillation, which was apparent in both roll and yaw, required continual attention. Turbulence had considerable influence on the lateral stability of the configuration and all pilots had difficulty with the sidestep manoeuvre because of the inadequate roll control power.

(iii) $\underline{\zeta_d = -0.2}$

The pilots' ratings are plotted in Figure 19c. From the mean line it can be seen that the deterioration in pilots' opinions of the configurations became more rapid with increasing $\left|\frac{\phi}{\beta}\right|_d$.

At low $\left|\frac{\phi}{\beta}\right|_d$ the complaint was of the oscillatory characteristics in yaw which required much use of rudder to restrain the directional response to the desired level. The effect of turbulence was small.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ the oscillation, again mainly in yaw, was more pronounced and was set off more noticeably by the turbulence. Neither the sidestep manoeuvre nor the cross-wind caused difficulty.

At high $\left|\frac{\phi}{\beta}\right|_d$ the oscillation in roll and yaw dominated the attention of the pilot, with large roll angles being generated by yaw. The effects of turbulence were severe, requiring full aileron deflection occasionally on approach.

5.2.3 Dutch Roll at Lowest Frequency and Various Damping Ratios

The characteristics of the lateral-directional normal modes of motion were:

$$\omega_d = \omega_\phi = 0.25 \text{ rad/sec} \qquad \lambda_R = -4.0 \ \frac{1}{\text{sec}}$$

$$\zeta_d = \zeta_\phi = 0.3,\ 0 \qquad \lambda_S = 0$$

and $$\left|\frac{\phi}{\beta}\right|_d = 0.2,\ 0.75,\ 1.5.$$

(i) $\underline{\zeta_d = 0.3}$

The pilots' ratings are plotted in Figure 20a. It will be noted that no evaluation was conducted at the highest $\left|\frac{\phi}{\beta}\right|_d$ since no converged solution was obtained from the computer programme for this case.

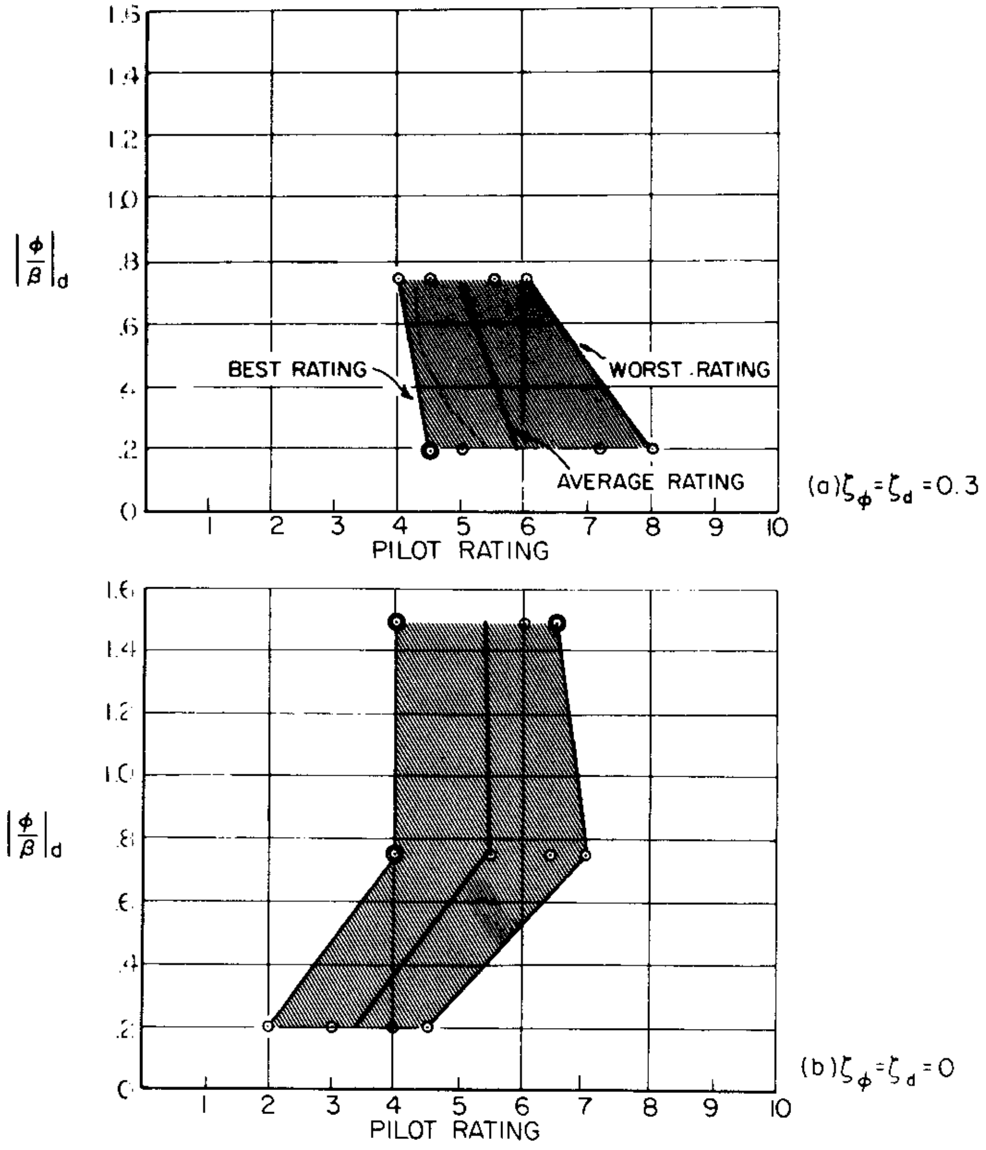


FIG 20 EFFECT OF $\left|\frac{\phi}{\beta}\right|_d$ ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES AT DIFFERENT DAMPING RATIOS; $\omega_d = \omega_\phi = 0.25$ RAD/SEC

At low $\left|\frac{\phi}{\beta}\right|_d$ one of the dominant features was the adverse yaw due to aileron application which set off yaw oscillations of long period. These oscillations sometimes appeared to the pilot to behave more as a static divergence in yaw and required continual attention to rudder. Rudder coordination was required in rolling manoeuvres.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ adverse yaw due to aileron movement again occurred and the aircraft had the same poor weathercock stability that characterised the low $\left|\frac{\phi}{\beta}\right|_d$ configuration; consequently, constant attention to rudder coordination was required.

(ii) $\underline{\zeta_d = 0}$

The pilots' ratings of this group of configurations are plotted in Figure 20b, from which it may be seen that the rate of deterioration of pilot opinion decreased with increasing $\left|\frac{\phi}{\beta}\right|_d$.

At low $\left|\frac{\phi}{\beta}\right|_d$ oscillations of long period in yaw that were easily, but necessarily, controlled with rudder, were apparent.

At intermediate $\left|\frac{\phi}{\beta}\right|_d$ the major complaint was of the poor directional stability that required constant attention to rudder coordination. Turbulence, cross-wind and the sidestep manoeuvre caused no difficulties.

At high $\left|\frac{\phi}{\beta}\right|_d$ the general complaint was again of poor directional stability, but the disturbances were initiated to a greater extent by turbulence. The cross-wind and sidestep manoeuvre could be handled easily by the pilots.

5.2.4 Summary of the Effect of $\left|\frac{\phi}{\beta}\right|_d$

At the highest frequency the major effects of increasing $\left|\frac{\phi}{\beta}\right|_d$ were:

(1) A marked increase in the effect of turbulence in disturbing the aircraft, particularly in roll.

(2) An apparent decrease in the roll control power available, probably resulting from (3) below.

(3) An increasing proportion of the available roll control power being required to counteract the rolling moment due to sideslip angle.

Decreasing damping levels caused a general deterioration of pilots' ratings at all levels of $\left|\frac{\phi}{\beta}\right|_d$ because of the increased pilot-workload required to control the oscillations. The effects of turbulence also became more pronounced at all levels of $\left|\frac{\phi}{\beta}\right|_d$ with decreased damping.

At the intermediate frequency the major effects of increasing $\left|\frac{\phi}{\beta}\right|_d$ were similar to those at the highest frequency, although the degree of their influence was smaller. The oscillation in roll did not become dominant as quickly and hence relatively more attention was available to counteract the oscillation in yaw.

Unfortunately, the lowest frequency could not be investigated fully because of the inability of the computer

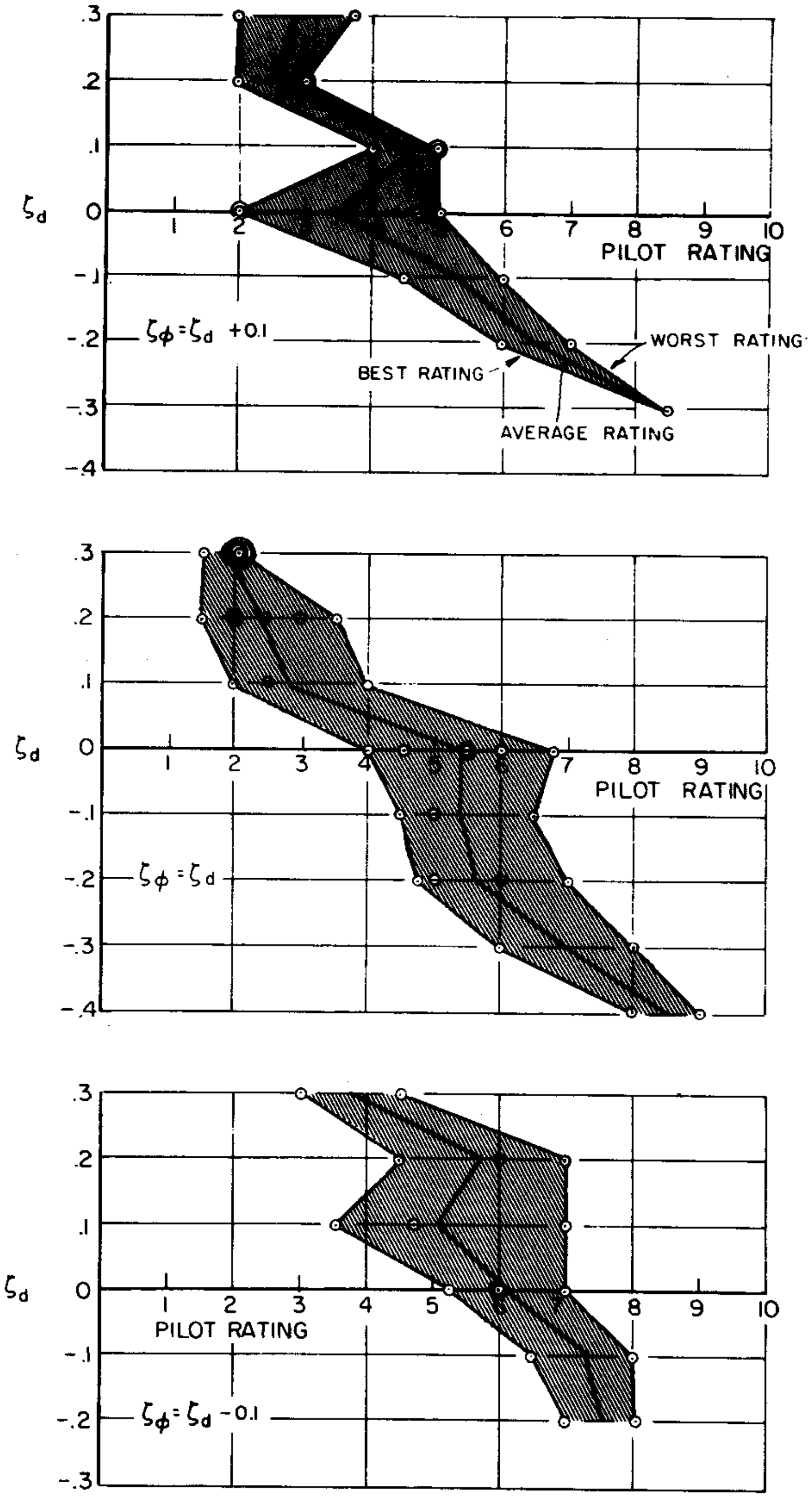


FIG 21 EFFECT OF ζ_d AND ζ_ϕ ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES; $\left|\frac{\phi}{\beta}\right|_d = 0.2$, $\omega_d = \omega_\phi = 1.0$ RAD/SEC

programme to produce converged solutions in all regions of interest. From the limited data available, however, $\left|\frac{\phi}{\beta}\right|_d$ did not appear to have a marked effect on pilots' opinions since the objection at all levels was to the low directional stability. The increasing effect of turbulence with increasing $\left|\frac{\phi}{\beta}\right|_d$, noted at the higher frequencies, was much less pronounced at this frequency.

5.3 The Effects of Varying the Dutch Roll Characteristics and the Zeros of the $\frac{\phi}{\delta_a}$ Transfer Function

5.3.1 Low $\left|\frac{\phi}{\beta}\right|_d$

5.3.1.1 Dutch Roll at Highest Frequency

The characteristics of the lateral-directional normal modes of motion were:

$\omega_d = \omega_\phi = 1.0$ rad/sec $\qquad \lambda_R = -4.0 \ \frac{1}{\text{sec}}$

ζ_d and ζ_ϕ varying $\qquad \lambda_S = 0$

$\left|\frac{\phi}{\beta}\right|_d = 0.2.$

The changes in pilots' ratings with decreasing Dutch roll damping ratio may be seen from Figure 21. The pilots' ratings, their envelopes and their average values are presented in this figure, whereas the pilots' comments on the configurations are summarized in Table 4e.

(i) $\zeta_\phi = \zeta_d$

The major effect of decreasing the damping of the characteristic oscillatory mode was, not unexpectedly, the increasingly dominant requirement on the part of the pilot to control the oscillatory characteristics of the aircraft. As the damping was decreased turbulence, as well as the small initial yaw response resulting from aileron application, played an ever increasing role in setting off the oscillation, which was predominantly in yaw.

(ii) $\underline{\zeta_\phi = \zeta_d + 0.1}$

The difference between this group and the previous group lay in the change in the relative influence of the yaw generated by aileron application and of the turbulence in setting off the oscillations, which were again mainly in yaw. The effects of turbulence were less severe and those of the generated yaw more severe than in the previous group with $\zeta_\phi = \zeta_d$.

(iii) $\underline{\zeta_\phi = \zeta_d - 0.1}$

In this group, the effect of turbulence was more severe in setting off the yaw oscillation than for the configurations of (i) and the effect of yaw, generated by aileron in the opposite sense to that for the configurations of (ii), was of comparable severity to that in the second group. For a given ζ_d, the cumulative result of these effects was to degrade the handling qualities in comparison to those of the configurations with $\zeta_\phi = \zeta_d$ and $\zeta_\phi = \zeta_d + 0.1$. The magnitude of the deterioration, in terms of averaged pilots' rating points, may be seen from Figure 24.

5.3.1.2 Dutch Roll at Intermediate Frequency

The characteristics of the lateral-directional normal modes of motion were:

$\omega_d = \omega_\phi = 0.5$ rad/sec $\qquad \lambda_R = -4.0 \frac{1}{\text{sec}}$

ζ_d and ζ_ϕ varying $\qquad \lambda_S = 0$

$\left|\frac{\phi}{\beta}\right|_d = 0.2$

The changes in pilots' ratings with decreasing damping ratio are presented in Figure 22, and the pilots' comments are summarized in Table 4f.

(i) $\underline{\zeta_\phi = \zeta_d}$

The effect of decreasing the damping of the oscillatory mode of the characteristic equation was not pronounced until a damping ratio of $\zeta_d = -0.1$ was reached. The oscillatory mode was not excited readily by either turbulence or control inputs at damping levels in excess of this value. Thereafter the decreasing directional stiffness allowed the rapid build-up of sideslip from small out-of-trim on rudder, causing an oscillation, predominantly in yaw, to build to levels that required continual rudder attention for its suppression. The effect of turbulence was small until the lowest damping ratios were reached, when some pilots felt that it excited the oscillation moderately.

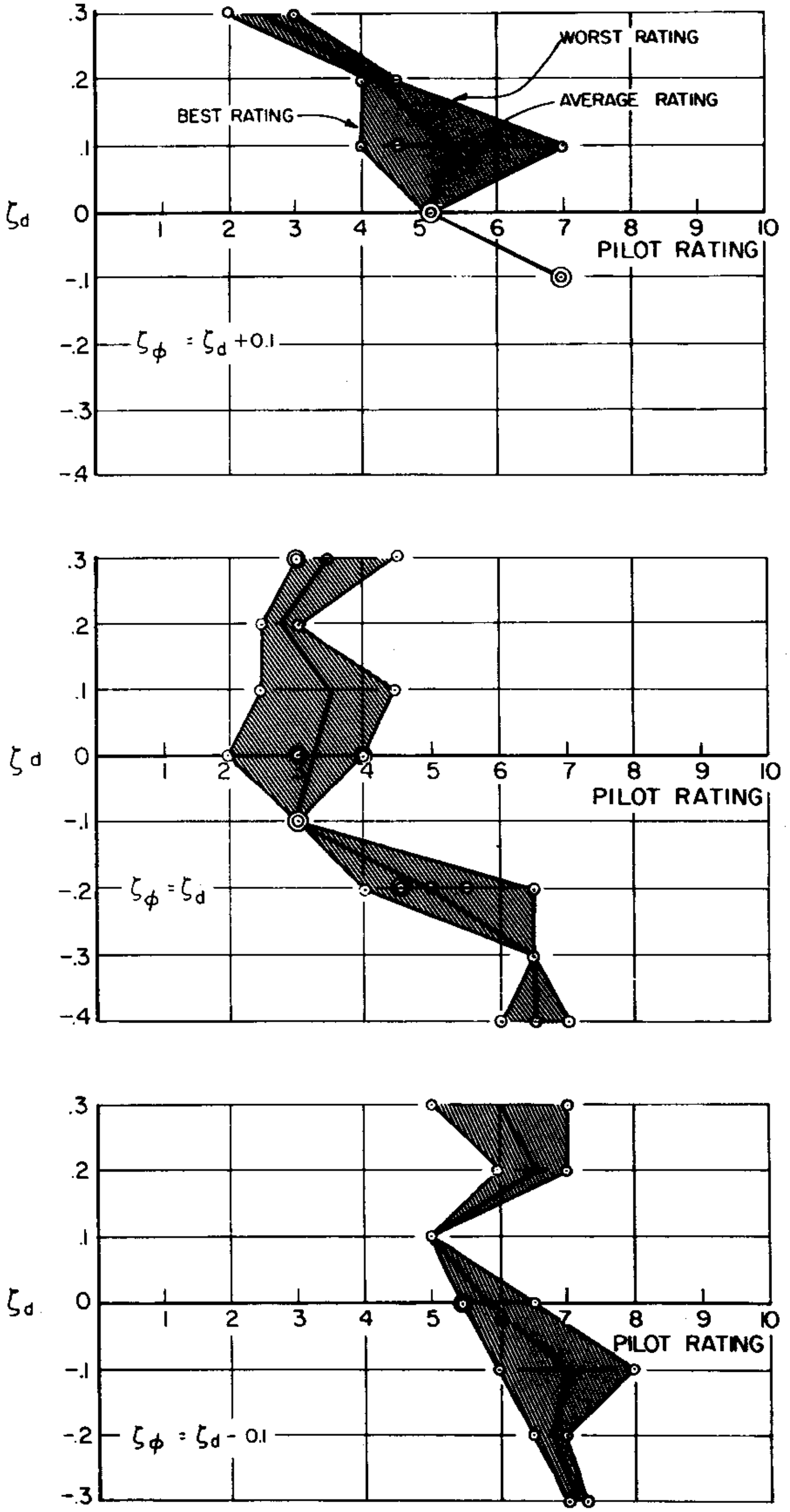


FIG 22 EFFECT OF ζ_d AND ζ_ϕ ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES; $\left|\frac{\phi}{\beta}\right|_d = 0.2, \omega_d = \omega_\phi = 0.5$ RAD/SEC

(ii) $\zeta_\phi = \zeta_d + 0.1$

The deteriorating in handling qualities with decreasing ζ_d was due to the increasing coordination difficulties caused by the initial adverse yaw followed by pro-yaw which was generated by the application of aileron. Although this effect was not too severe in itself, it did excite the oscillation at low values of ζ_d. The diminishing directional stiffness coupled with the sensitive rudder was also a factor in the deterioration of ratings assigned to the configurations as ζ_d was decreased.

(iii) $\zeta_\phi = \zeta_d - 0.1$

The effects of changing the damping ratio in these configurations were not pronounced. The recurring complaint at high damping ratios was of the yaw generated by aileron application. This changed from adverse yaw, followed by pro-yaw at the highest damping ratio, to pro-yaw at the negative damping ratios. The yaw following aileron application became less severe as the damping ratio decreased, but, because the oscillatory characteristics became more pronounced, the overall result was a requirement for considerable rudder coordination to suppress either the yaw due to aileron or the oscillation excited by it. The effects of turbulence did not appear to have a consistent pattern as the damping ratio was decreased, but seemed to have varying influence throughout the range. Because of its long period, the oscillation often had the appearance of a static divergence. Constant monitoring of the sideslip was required to suppress this divergence, particularly as the damping ratio was decreased.

5.3.1.3 Dutch Roll at Lowest Frequency

The characteristics of the lateral-directional normal modes of motion were:

$$\omega_d = \omega_\phi = 0.25 \text{ rad/sec} \qquad \lambda_R = -4.0 \ \frac{1}{\text{sec}}$$

$$\zeta_d \text{ and } \zeta_\phi \text{ varying} \qquad \lambda_S = 0$$

$$\left|\frac{\phi}{\beta}\right|_d = 0.2$$

The changes in pilots' ratings with decreasing damping ratio are presented in Figure 23, and the pilots' comments are summarized in Table 4g.

(i) $\underline{\zeta_\phi = \zeta_d}$

Low directional stiffness dominated pilot attention at all levels of ζ_d. As the damping ratio was decreased, yaw with aileron application reached a minimum at about $\zeta_d = 0.1$, resulting in the minimum disturbance of either the long period oscillation or of the apparent static divergence in this region. However, it was still necessary for the pilot to provide good rudder coordination at this damping ratio, mainly because of the poor directional stiffness.

(ii) $\underline{\zeta_\phi = \zeta_d + 0.1}$

The low directional stiffness was again the dominant

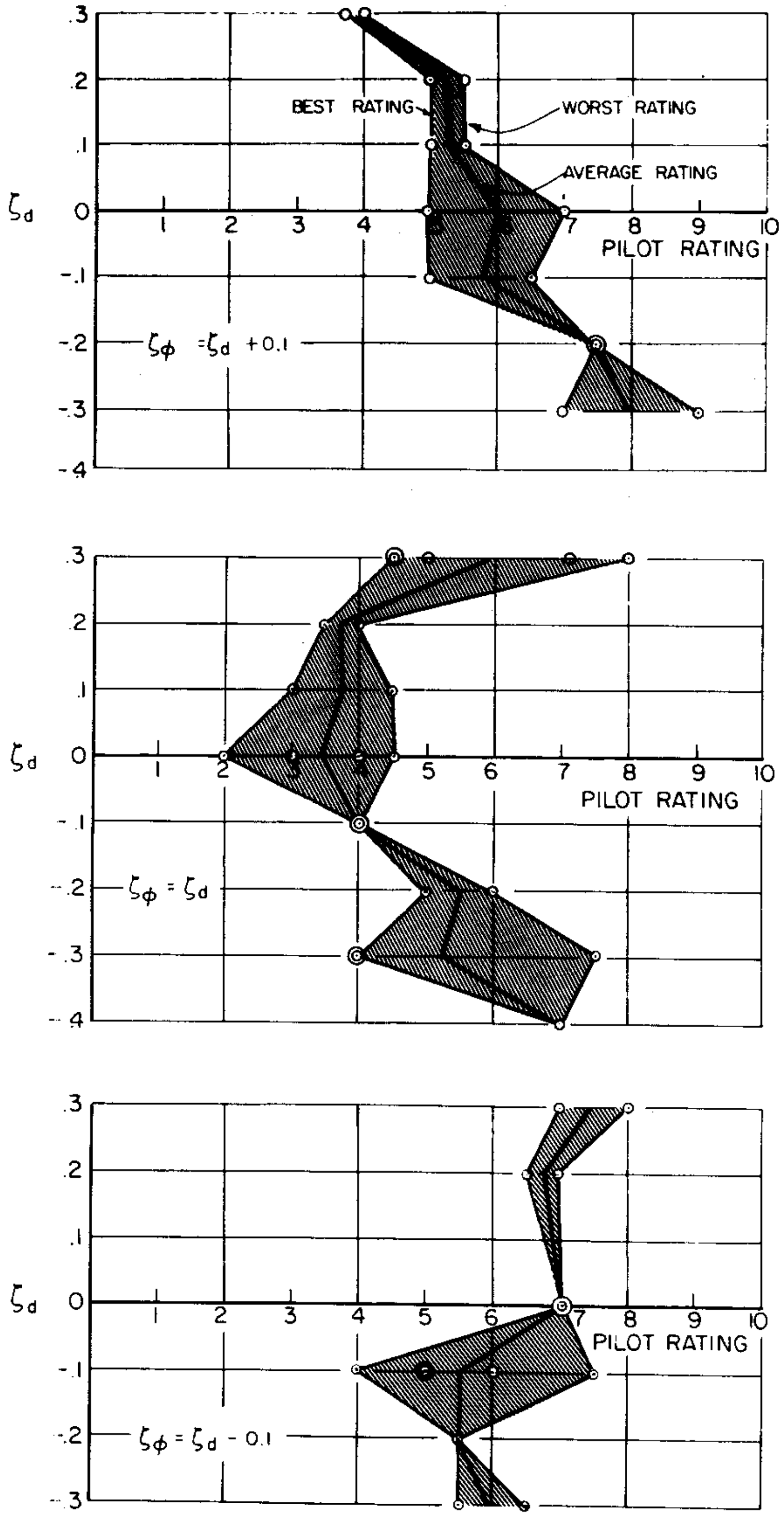


FIG 23 EFFECT OF ζ_d AND ζ_ϕ ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES; $\left|\frac{\phi}{\beta}\right|_d = 0.2$, $\omega_d = \omega_\phi = 0.25$ RAD/SEC

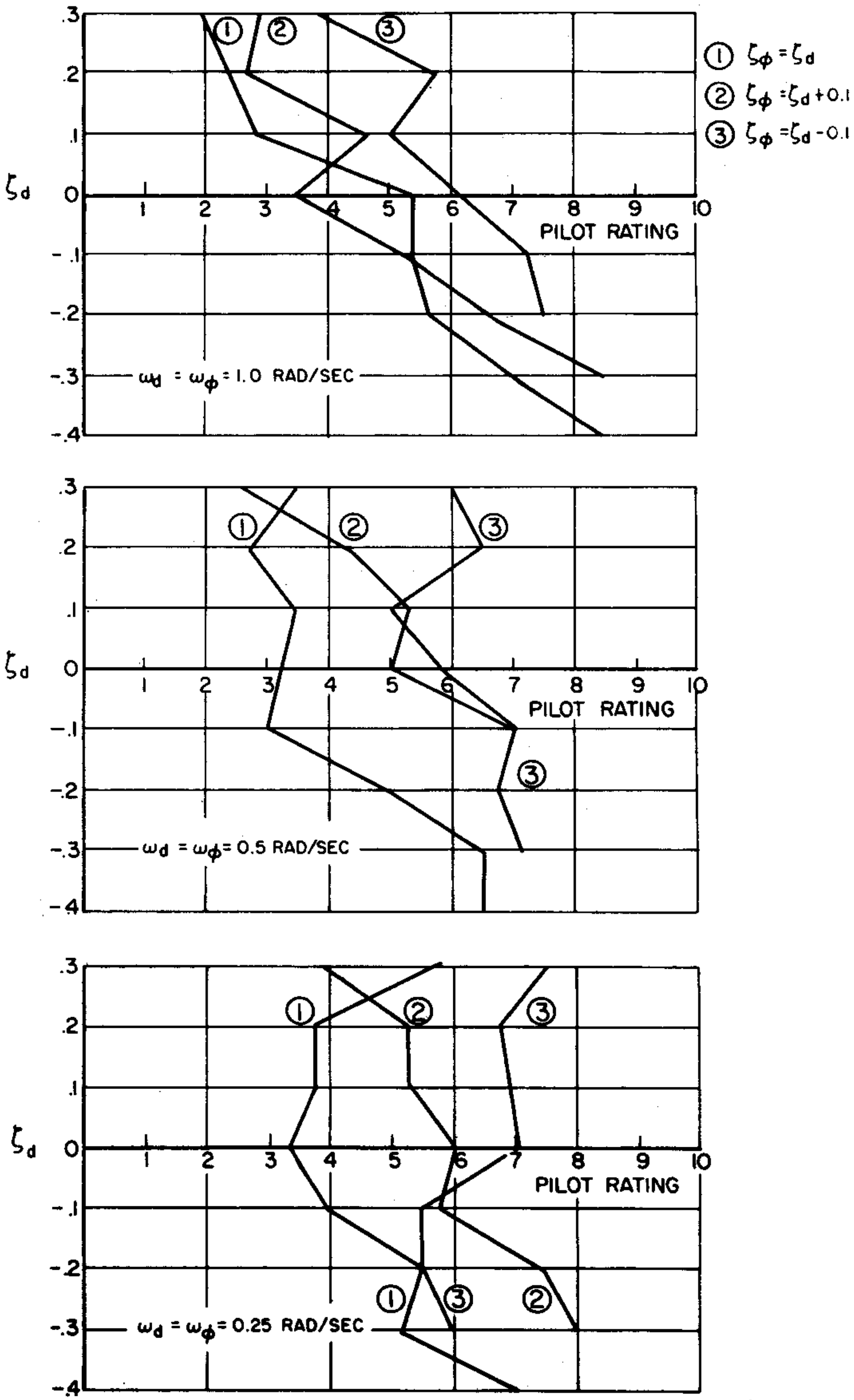


FIG 24 EFFECT OF $\omega_d, \zeta_d, \& \zeta_\phi$ ON AVERAGED PILOTS' RATINGS, $\left|\frac{\phi}{\beta}\right|_d = 0.2$

feature for these models. Heading wander was initiated by the yaw due to aileron application and the pilots generally had difficulty in coordinating the entries to and exits from turns because of the changing rudder requirements. The effects of turbulence were not a factor until ζ_d had been reduced to -0.3.

(iii) $\zeta_\phi = \zeta_d - 0.1$

At high damping levels, the major difficulty was due to the changing rudder requirements for the correct rudder coordination of aileron inputs. The oscillatory characteristics, again mainly in yaw, were more pronounced than in the previous two groups, and the oscillation was readily excited by aileron application and by turbulence. The directional stiffness, although not as low as in the previous two groups, did require that attention be given to rudder trim position to prevent the rapid build-up of large sideslips. As the damping ratio was reduced, the effects of turbulence became less pronounced. The rudder coordination required was smallest at damping ratios of about $\zeta_d = -0.1$, which coincided with the lowest absolute values of N_β and N_{δ_a}.

5.3.1.4 Summary of the Effects of Damping on Pilots' Ratings at Low $\left|\frac{\phi}{\beta}\right|_d$

(1) Highest frequency, $\omega_d = \omega_\phi = 1.0$ rad/sec

At this frequency, the oscillatory characteristics in yaw dominated the assessment of the configurations by the pilots. The oscillation was initiated by the effects of turbulence and by the yaw generated following aileron application. For this frequency, the locations of the zeros of the $\frac{\phi}{\delta_a}$ transfer function in relation to the oscillatory characteristic roots appear to be reasonable parameters with which to represent the lateral-directional characteristics of the configurations, because of the lateral and directional coupling in the open-loop oscillatory mode. It should be noted, however, that the influence of the location of the zero of the $\frac{\beta}{\delta_a}$ transfer function on the above characteristics must also be considered before the limitations of this generalization can be formulated.

(2) Intermediate frequency, $\omega_d = \omega_\phi = 0.5$ rad/sec

This frequency led to transitional results among the different parameters that dominated the lateral-directional characteristics of the configurations. The factors which caused pilots difficulty were: low directional stiffness, oscillatory characteristics in yaw, yaw response to aileron application and the effects of turbulence. No one parameter dominated throughout the range of damping ratios investigated and it was the net sum of the detrimental characteristics that finally led to the pilot's rating. In view of the changing nature of the predominant parameter causing difficulty, the use of the location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function as the main parametric reference for configurations of this frequency, is no longer justified, and can give a misleading emphasis to the wrong parameters throughout much of the range.

(3) Lowest frequency, $\omega_d = \omega_\phi = 0.25$ rad/sec

The dominant feature in the ratings given by the pilots to configurations with this frequency arose from the yaw due to aileron application. The directional stiffness generally appeared to be low if not negative and the yaw following aileron application caused large sideslip angles to build rapidly, often with an oscillatory content. Turbulence caused concern in some regions. As at the intermediate frequency, the location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function no longer provides a useful parametric form for categorizing the configurations.

5.3.2 Intermediate $\left|\frac{\phi}{\beta}\right|_d$

The lateral-directional modal characteristics were:

$\omega_d = \omega_\phi = 1.0, 0.5, 0.25$ rad/sec $\qquad \lambda_R = -4.0 \frac{1}{\text{sec}}$

$\zeta_d = \zeta_\phi = 0.3, 0.0, -0.2 \qquad \lambda_S = 0$

$\left|\frac{\phi}{\beta}\right|_d = 0.75$

The various configurations with this $\left|\frac{\phi}{\beta}\right|_d$ have already been considered in Section 5.2. Figure 35 presents these data in the form of pilots' ratings versus damping ratio for the three different frequencies.

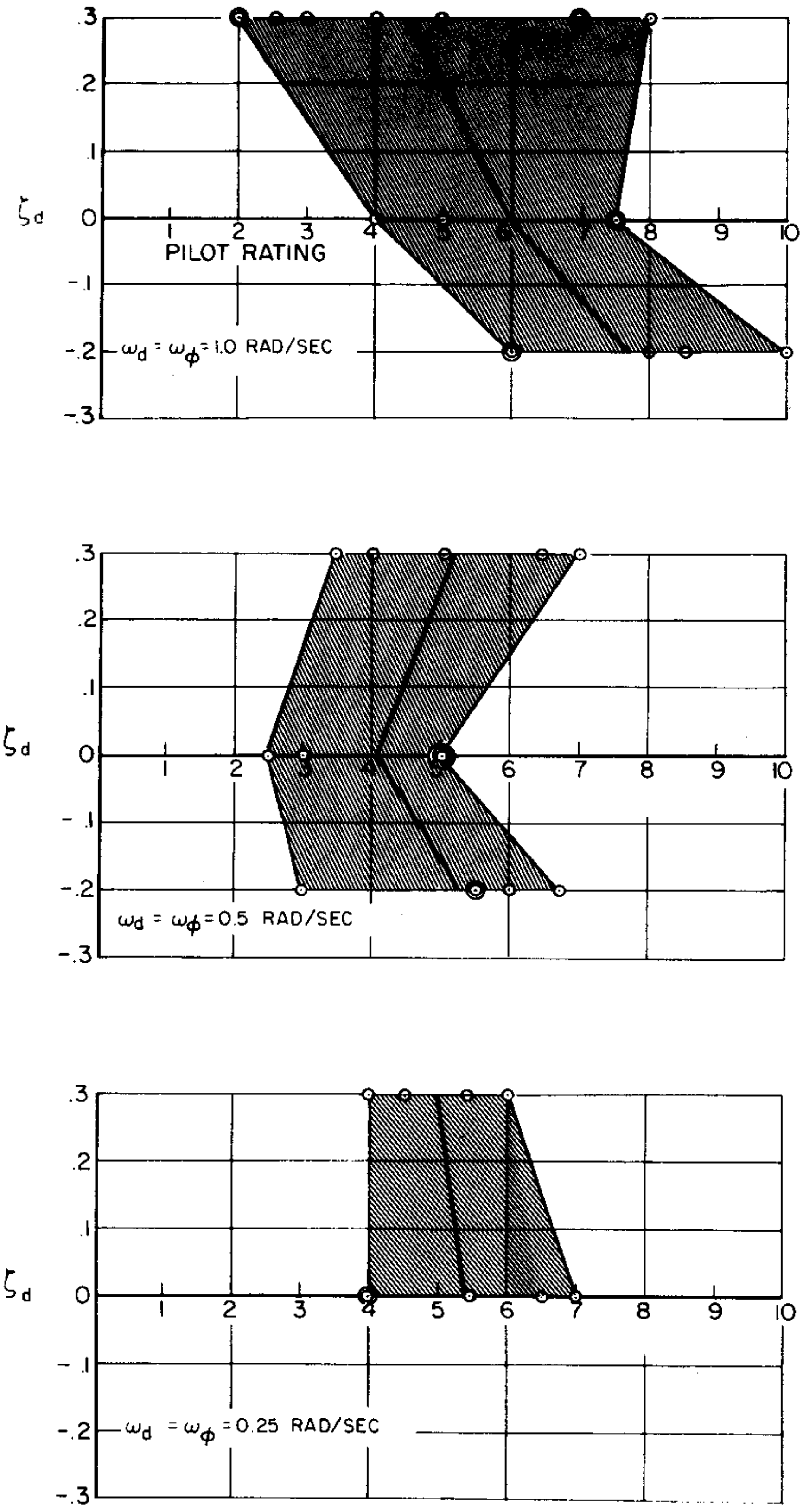


FIG 25 EFFECT OF ζ_d AND ω_d ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES; $\left|\frac{\phi}{\beta}\right|_d = 0.75$, $\zeta_d = \zeta_\phi$

5.3.2.1 Summary of the Effects of Damping on Pilots' Ratings at Intermediate $\left|\frac{\phi}{\beta}\right|_d$

(1) Highest frequency, $\omega_d = \omega_\phi = 1.0$ rad/sec

For these characteristics, the pilots found that the oscillation in roll became more pronounced as ζ_d was decreased. Both turbulence and rudder inputs initiated predominantly roll oscillations and the available roll control power caused the pilots varying degrees of difficulty, as full aileron control deflection was often required to overcome the large rolling excursions. The deteriorating in the oscillatory characteristics with decreasing damping was, in general, found to be objectionable, but on occasion, the lack of sufficient roll control power was the overriding, undesirable feature. Indeed, during several evaluations two of the pilots considered that they would have been unable to roll out of the sidestep manoeuvre before ground contact, since the synthetic cross-wind and a small amount of sideslip had diminished the roll control power available in the recovery direction to an extremely low level.

(2) Intermediate frequency, $\omega_d = \omega_\phi = 0.5$ rad/sec

The oscillatory characteristics in both roll and yaw became more pronounced for these configurations, as the damping ratio was decreased. At the highest damping ratio, the low roll control power again caused concern, but this effect became less dominant with decreasing damping ratios.

At the lowest damping ratio, $_{d} = -0.2$, the effect of turbulence was quite pronounced in setting off the oscillation, particularly in yaw, and there was also a tendency for the oscillation to be excited by the yaw following aileron application.

(3) Lowest frequency, $\omega_d = \omega_\phi = 0.25$ rad/sec

The dominant feature at this frequency was the need for continual rudder coordination, because the low directional stiffness allowed oscillations, mainly in yaw, to be easily excited. Pilots did not complain of low roll control power and did not experience the difficulties that ensued from it at the higher frequencies.

5.3.3 High $\left|\frac{\phi}{\beta}\right|_d$

The lateral-directional modal characteristics were:

$\omega_d = \omega_\phi = 1.0, 0.5, 0.25$ $\lambda_R = -4.0 \frac{1}{\text{sec}}$

$\zeta_d = \zeta_\phi$, varying $\lambda_S = 0$

$\left|\frac{\phi}{\beta}\right|_d = 1.5$

The changes in pilots' opinions as the damping ratio of the oscillatory root of the characteristic equation was decreased, are shown in the three parts of Figure 26. The pilots' ratings, their envelopes and their averaged values are presented in this figure, whilst the pilots' comments on the configurations are summarized in Table 4h.

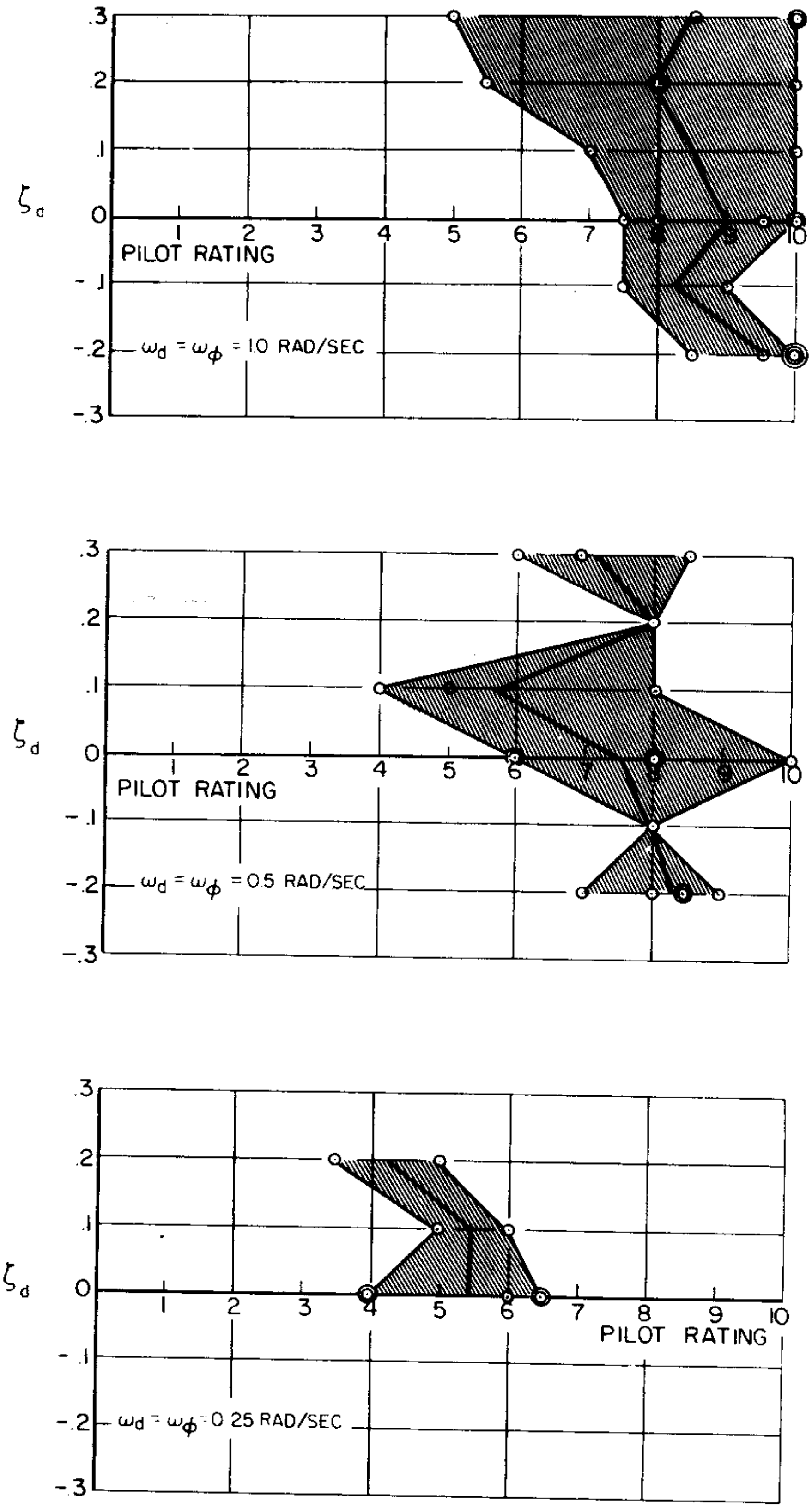


FIG 26 EFFECT OF ζ_d AND ω_d ON AVERAGED PILOTS' RATINGS AND ON PILOT RATING ENVELOPES; $\left|\frac{\phi}{\beta}\right|_d = 1.5$, $\zeta_d = \zeta_\phi$

(i) $\underline{\omega_d = \omega_\phi = 1.0,\ \zeta_d = \zeta_\phi}$

The major complaint at all levels of damping was of the large roll excursions caused by small sideslip angles. The aileron control power available to counteract the roll was inadequate to cope simultaneously with the cross-wind, the turbulence and the need to manoeuvre. As the oscillatory characteristics became more pronounced with decreasing damping, an ever greater proportion of the task became impossible.

(ii) $\underline{\omega_d = \omega_\phi = 0.5,\ \zeta_d = \zeta_\phi}$

The characteristics of this group of configurations were similar to those at the higher frequency, except that their effects were generally less pronounced. In relation to the rolling characteristics, the inadequacies of the directional characteristics became more obvious to the pilot than in the previous group.

(iii) $\underline{\omega_d = \omega_\phi = 0.25,\ \zeta_d = \zeta_\phi}$

The major characteristic of the low frequency configurations tested was the decreasing directional stiffness that occurred with decreasing ζ_d. This demanded strict attention to rudder coordination. The effects of turbulence also became more pronounced with decreasing ζ_d, but low roll control power was no longer a significant factor.

6.0 CONCLUDING REMARKS

From an investigation into the effects of the lateral-directional characteristics on handling qualities of STOL aircraft at low speeds (50 knots), the following tentative conclusions have been reached:

(1) When the zeros of the $\frac{\phi}{\delta_a}$ transfer function coincide with the oscillatory characteristic roots, increasing $\left|\frac{\phi}{\beta}\right|_d$ generally causes a deterioration in handling qualities. The deterioration is very marked at the highest frequency, but is hardly noticeable at the lowest frequency.

(2) At the highest frequency, as $\left|\frac{\phi}{\beta}\right|_d$ is increased, the effects of turbulence, particularly in roll, become very pronounced, and small sideslip angles cause large rolling moments. The rolling moments generated in the present investigation were of such magnitude at higher $\left|\frac{\phi}{\beta}\right|_d$ that the pilot often required considerably more roll control power to overcome them than that available. This became especially noticeable after the roll due to the synthetic cross-wind, introduced during the approach phase of the task, had been counteracted.

(3) At the lowest frequency, the low directional stability of the aircraft becomes the major concern of pilots of all levels of $\left|\frac{\phi}{\beta}\right|_d$.

(4) As the location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function is moved round the oscillatory characteristic roots

at low $\left|\frac{\phi}{\beta}\right|_d$, the recurring complaints originate from the handling characteristics in the directional plane. For this reason, it would seem to be expedient to categorize the handling qualities by some means which has a more direct bearing on those physical aspects of concern to the pilots than does the $\frac{\phi}{\delta_a}$ transfer function. The reasonable contours of pilots' ratings obtained on the basis of the location of the zeros of the $\frac{\phi}{\delta_a}$ transfer function at the highest frequency, appear to be due to a coupling between the lateral and directional modal characteristics. At the lower frequencies, however, the $\frac{\phi}{\delta_a}$ transfer function is no longer sensitive to the major causes of deterioration in handling qualities, which are associated with stability in the directional plane. As $\left|\frac{\phi}{\beta}\right|_d$ is increased, the use of the $\frac{\phi}{\delta_a}$ transfer function is still not considered as being particularly suitable because the rolling excursions caused by the effects of turbulence and sideslip angle increase to such an extent that the additional excitation of the characteristic modes, which occurs with the movement of the zeros away from the roots, is of little more than academic interest.

(5) An analysis, as to which parameters may better be used to categorize the lateral-directional characteristics tested herein, should be undertaken.

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APPENDIX A

Derivation and Influence of the Side Force Stability Derivatives

In any variable stability system, the responses in the six degrees of freedom can be varied at will only if six means of achieving moments and forces are available. It is desirable also that the three controls providing moments are such that the dominant effect of each is about only one axis and that the unbalanced forces arising from their use are small. Similarly the devices producing the three forces should be aligned approximately with the coordinate axes and cause only small moments about these axes. In the variable stability helicopter used in this investigation, lateral cyclic control, longitudinal cyclic control and tail rotor collective control provide approximately independent moments respectively about the x, y and z axes, while main rotor collective control results in a force approximately in the z direction. The lateral and longitudinal cyclic and the tail rotor collective controls, moving in a manner to produce the desired aerodynamic derivatives about the x, y and z axes, give unbalanced forces approximately along the x and y axes. Since there are no independent force producing devices along these axes, apparent longitudinal force and lateral force aerodynamic derivatives result that are related to the programmed values of the pitching moment, rolling moment and yawing moment aerodynamic derivatives.

A.1 Estimation of the Values of the Side Force Derivatives

If it is assumed that the only significant external moments on the helicopter about the rolling and yawing axes result from lateral forces at the top of the main rotor mast and at the tail rotor and that these two axes are principal axes, then at any instant, the total lateral aerodynamic force is

$$F_y = \frac{I_{xx}}{h_r}\left[L_p\cdot p+L_r\cdot r+L_\beta\cdot\beta+L_{\delta_a}\cdot\delta_a+L_{\delta_r}\cdot\delta_r+L_\beta\cdot\beta_g\right]$$

$$-\frac{I_{zz}}{\ell_t}\left[N_p\cdot p+N_r\cdot r+N_\beta\cdot\beta+N_{\delta_a}\cdot\delta_a+N_{\delta_r}\cdot\delta_r+N_\beta\cdot\beta_g\right]$$

$$+F_B \qquad \text{A.1}$$

It must be remembered that β_g is a synthetic turbulence that is felt on the helicopter only through forces produced at the main rotor and tail rotor. F_B is the resulting lateral aerodynamic force acting on the helicopter excluding the contribution of those components at the top of the mast and at the tail rotor. Because of the initial assumption, it acts through the centre of gravity.

If F_y is expressed in terms of aerodynamic side force derivatives, namely,

$$F_y = m\left[Y_p\cdot p+Y_r\cdot r+Y_\beta\cdot\beta+Y_{\delta_a}\cdot\delta_a+Y_{\delta_r}\cdot\delta_r+Y_{\beta_g}\cdot\beta_g\right] \qquad \text{A.2}$$

then it follows that these apparent side force derivatives are:

$$Y_p = k_1 L_p - k_2 N_p + \frac{1}{m}\frac{\partial F_B}{\partial_p}$$

$$Y_r = k_1 L_r - k_2 N_r + \frac{1}{m}\frac{\partial F_B}{\partial_r}$$

$$Y_\beta = k_1 L_\beta - k_2 N_\beta + \frac{1}{m}\frac{\partial F_B}{\partial_\beta} \qquad \text{A.3}$$

$$Y_{\delta_a} = k_1 L_{\delta_a} - k_2 N_{\delta_a} + \frac{1}{m}\frac{\partial F_B}{\partial_{\delta_a}}$$

$$Y_{\delta_r} = k_1 L_{\delta_r} - k_2 N_{\delta_r} + \frac{1}{m}\frac{\partial F_B}{\partial_{\delta_r}}$$

$$Y_{\beta_g} = k_1 L_\beta - k_2 N_\beta$$

where $k_1 = \frac{I_{xx}}{m \cdot h_r}$

A.4

and $k_2 = \frac{I_{zz}}{m \cdot \ell_t}$

It would be expected that to a good approximation, the aerodynamic side force of the helicopter body, F_B, is a function of only the sideslip angle. In this case, the above expressions reduce to

$$Y_p = k_1 L_p - k_2 N_p$$

$$Y_r = k_1 L_r - k_2 N_r$$

$$Y_\beta = k_1 L_\beta - k_2 N_\beta + Y_{\beta_f} = Y_{\beta_g} + Y_{\beta_f} \qquad \text{A.5}$$

$$Y_{\delta_a} = k_1 L_{\delta_a} - k_2 N_{\delta_a}$$

$$Y_{\delta_r} = k_1 L_{\delta_r} - k_2 N_{\delta_r}$$

Under the conditions of the present tests, the values of $Y_{\beta_f} = \frac{1}{m} \frac{\partial F_B}{\partial_\beta}$, k_1 and k_2 have been estimated to be

$$Y_{\beta_f} = -3.74 \ \frac{\text{ft/sec}^2}{\text{rad}}$$

$$k_1 = 1.16 \text{ ft}$$

$$k_2 = 0.76 \text{ ft}$$

From estimates of the magnitude of aerodynamic forces and moments arising from terms that have been neglected, the above expressions would appear to give reasonably accurate values for the side force coefficients when the reference axes are aligned with the helicopter's principal axes (in the present case, the reference axes directions are those of the rate gyros). Misalignment of the rolling and yawing axes from the helicopter principal axes requires that additional moments be provided to overcome the coupling moments produced by the cross product of inertia I_{xz}. These additional moments are:

$$\Delta L = -I_{xz}\,\dot{r}$$

$$\Delta N = -I_{xz}\,\dot{p}$$

Then, the side force becomes

$$F_y = \left[\frac{I_{xx}}{h_r} + \frac{I_{xz}}{\ell_t}\right]\left[L_p \cdot p + L_r \cdot r + L_\beta \cdot \beta + L_{\delta_a} \cdot \delta_a + L_{\delta_r} \cdot \delta_r + L_\beta \cdot \beta_g\right]$$
$$- \left[\frac{I_{zz}}{\ell_t} + \frac{I_{xz}}{h_r}\right]\left[N_p \cdot p + N_r \cdot r + N_\beta \cdot \beta + N_{\delta_a} \cdot \delta_a + N_{\delta_r} \cdot \delta_r + N_\beta \cdot \beta_g\right]$$
$$+ F_B \qquad \text{A.6}$$

and

$$k_1' = \frac{I_{xx}}{mh_r} + \frac{I_{xz}}{m \cdot \ell_t} = k_1 + \frac{I_{xz}}{m\ell_t}$$
$$\text{A.7}$$
$$k_2' = \frac{I_{zz}}{m\ell_t} + \frac{I_{xz}}{mh_r} = k_2 + \frac{I_{xz}}{mh_r}$$

If the rolling reference axis is misaligned 6° from the helicopter principal axis, corresponding to the change in angle of the gyro package for the glide slope portion of the task in these tests, $I_{xz} = -75$ slug ft^2 approximately and

$$k_1' = 1.16 - .04 = 1.12$$

$$k_2' = 0.76 - .16 = 0.60$$

A.2 Experimental Substantiation of Estimates

Some flight experiments were conducted to show that the above procedures gave good estimates for the apparent side force derivatives. In flight, measured lateral acceleration is proportional to the total lateral aerodynamic force acting on the helicopter. The parameters p, r, β, δ_a, δ_r and β_g in equation A.2 were measured, the expressions for the side force derivatives from A.5 were assumed and the values of k_1, k_2 and Y_{β_f} adjusted to give the best fit between the computed value of the right hand side of equation A.2 and the measured left hand side given by the recorded lateral acceleration. The dominant response during these tests was in yaw so that the lateral side force was insensitive to the value of k_1, but the required values of k_2 and Y_{β_f} to give the best fit agreed closely with the estimated values. These tests were conducted with the rate gyro package in the position for level flight so that it was not possible to check the influence of I_{xz} on the value of k_2.

In addition to the above tests, an indirect verification that the previous procedures give adequate estimates of the side force derivatives is given in Section 3.1.1. The equations of motion, including the effect of the estimated side force derivatives, were programmed for certain configurations on an analog computer in the laboratory.

The control movements of the evaluation pilot and the synthetic turbulence recorded on magnetic tape during the flight tests, were used as inputs to this analog and the resulting computed responses were compared with the in-flight measured responses of the simulator. The comparisons are shown in Figures 6a to 6i. The sideslip angle, β, in particular is sensitive to the side force derivatives and it may be seen from these Figures that the previous assumptions provide an adequate estimate.

The effect of the predicted reduction in k_1 and k_2 caused by the 6° tilt in the rate gyro package on the modes of motion and the numerator roots of the nine transfer functions relating bank angle, yaw rate and sideslip angle response to aileron, rudder and synthetic lateral turbulence was checked for a number of models used during the investigation. The influence was small in all cases with the values given in Table A.1 for model LH 100+10+1 being typical. It can be seen that the only significant changes occurred in the real factors of the numerators of the β/δ_a, ϕ/δ_r, β/δ_r, and β/β_g transfer functions, and these changes were offset by reciprocal changes in the constant multipliers. Hence, the response is different only at very high frequencies.

TABLE A.1

INFLUENCE OF VARIATIONS IN k_1 and k_2 ON FACTORS OF RESPONSE TRANSFER FUNCTIONS

DENOMINATOR FACTORS

k_1	k_2	Spiral Mode	Roll Subs. Mode	Dutch Roll Mode	
				Damp. Ratio	Nat. Freq.
1.16	.76	.0010	3.9951	.1010	.9946
1.12	.76	.0010	3.9973	.1011	.9943
1.16	.60	.0010	3.9962	.1002	.9945

NUMERATOR ϕ TO δ_a FACTORS

k_1	k_2	Constant Multiplier	Damp. Ratio	Nat. Freq.
1.16	.76	.4	.0113	1.0028
1.12	.76	.4	.0113	1.0028
1.16	.60	.4	.0104	1.0028

NUMERATOR r TO δ_a FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Damp. Ratio	Nat. Freq.
1.16	.76	-.3300	-1.1380	.1947	.6090
1.12	.76	-.3300	-1.1399	.1940	.6086
1.16	.60	-.3300	-1.1403	.1939	.6085

NUMERATOR β TO δ_a FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Real Factor	Real Factor
1.16	.76	.00724	-.3569	.0392	45.6329
1.12	.76	.00828	-.3565	.0392	39.9222
1.16	.60	.00784	-.3562	.0392	42.1849

TABLE A.1 (Cont'd)

NUMERATOR ϕ TO δ_r FACTORS

k_1	k_2	Constant Multiplier	Real Factor
1.16	.76	-.0213	-29.4750
1.12	.76	-.0213	-29.4750
1.16	.60	-.0225	-27.9142

NUMERATOR r TO δ_r FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Damp. Ratio	Nat. Freq.
1.16	.76	.75	4.2172	.0467	.2755
1.12	.76	.75	4.2194	.0467	.2754
1.16	.60	.75	4.2198	.0467	.2754

NUMERATOR β TO δ_r FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Real Factor	Real Factor
1.16	.76	-.0675	.0033	4.1849	111.2286
1.12	.76	-.0675	.0033	4.1845	111.2395
1.16	.60	-.0532	.0033	4.1845	140.9052

NUMERATOR ϕ TO β_g FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Real Factor
1.16	.76	-.840	.0129	.0440
1.12	.76	-.840	.0129	.0440
1.16	.60	-.840	.0129	.0440

NUMERATOR r TO β_g FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Real Factor
1.16	.76	1.700	.0440	2.1641
1.12	.76	1.700	.0440	2.1641
1.16	.60	1.700	.0440	2.1641

TABLE A.1 (Cont'd)

NUMERATOR β TO β_g FACTORS

k_1	k_2	Constant Multiplier	Real Factor	Real Factor	Real Factor
1.16	.76	-.0242	.0010	2.3860	69.1246
1.12	.76	-.0264	.0010	2.3937	63.1992
1.16	.60	-.0236	.0010	2.3940	70.7448

APPENDIX B

Summary of Lateral-Directional Transfer Functions

The factors of the nine lateral-directional transfer functions relating responses ϕ, r, and β to inputs δ_a, δ_r and β_g are itemized below.

Denominator Factors

S^4: U

S^3: $-[U(N_r+L_p) + Y_\beta]$

S^2: $[(N_r+L_p)Y_\beta - L_\beta Y_p - N_\beta Y_r + U(N_r L_p - N_p L_r) + UN_\beta]$

S : $[(N_p L_r - N_r L_p)Y_\beta + (N_r L_\beta - N_\beta L_r)Y_p + (N_\beta L_p - N_p L_\beta)Y_r + U(N_p L_\beta - N_\beta L_p) - gL_\beta]$

constant: $(N_r L_\beta - N_\beta L_r)g$

Numerator Factors

Aileron Input

(a) $N^{\phi}_{\delta_a}$

S^2: $U L_{\delta_a}$

S : $[-L_{\delta_a} Y_\beta + L_\beta Y_{\delta_a} + U(N_{\delta_a} L_r - N_r L_{\delta_a})]$

constant: $[(N_r L_{\delta_a} - N_{\delta_a} L_r)Y_\beta + (N_{\delta_a} L_\beta - N_\beta L_{\delta_a})Y_r + (N_\beta L_r - N_r L_\beta)Y_{\delta_a} + U(N_\beta L_{\delta_a} - N_{\delta_a} L_\beta)]$

(b) $N^{r}_{\delta_a}$

s^3: $U N_{\delta_a}$

s^2: $[U(N_p L_{\delta_a} - N_{\delta_a} L_p) - N_{\delta_a} Y_\beta + N_\beta Y_{\delta_a}]$

S : $[(N_{\delta_a} L_p - N_p L_{\delta_a}) Y_\beta + (N_\beta L_{\delta_a} - N_{\delta_a} L_\beta) Y_p + (N_p L_\beta - N_\beta L_p) Y_{\delta_a}]$

constant: $(N_\beta L_{\delta_a} - N_{\delta_a} L_\beta) g$

(c) $N^{\beta}_{\delta_a}$

s^3: Y_{δ_a}

s^2: $[L_{\delta_a} Y_p + N_{\delta_a} Y_r - (N_r + L_p) Y_{\delta_a} - U N_{\delta_a}]$

S : $[(N_{\delta_a} L_r - N_r L_{\delta_a}) Y_p + (N_p L_{\delta_a} - N_{\delta_a} L_p) Y_r + (N_r L_p - N_p L_r) Y_{\delta_a}$

$+ U(N_{\delta_a} L_p - N_p L_{\delta_a}) + g L_{\delta_a}]$

constant: $(N_{\delta_a} L_r - N_r L_{\delta_a}) g$

Rudder Inputs

(a) $N^{\phi}_{\delta_r}$

S : $(L_\beta Y_{\delta_r} + U N_{\delta_r} L_r)$

constant: $[-N_{\delta_r} L_r Y_\beta + N_{\delta_r} L_\beta Y_r + (N_\beta L_r - N_r L_\beta) Y_{\delta_r} - U N_{\delta_r} L_\beta]$

(b) $N^{r}_{\delta_r}$

s^3: $U N_{\delta_r}$

s^2: $(-N_{\delta_r} Y_\beta + N_\beta Y_{\delta_r} - U L_p N_{\delta_r})$

s : $[N_{\delta_r} L_p Y_\beta - N_{\delta_r} L_\beta Y_p + (N_p L_\beta - N_\beta L_p) Y_{\delta_r}]$

constant: $-N_{\delta_r} L_\beta g$

(c) $N^{\beta}_{\delta_r}$

s^3: Y_{δ_r}

s^2: $[N_{\delta_r} Y_r - (N_r + L_p) Y_{\delta_r} - U N_{\delta_r}]$

s : $[N_{\delta_r} L_r Y_p - N_{\delta_r} L_p Y_r + (N_r L_p - N_p L_r) Y_{\delta_r} + U N_{\delta_r} L_p]$

constant: $N_{\delta_r} L_r g$

Synthetic Turbulence Inputs

(a) $N^{\phi}_{\beta_g}$

s^2: $U L_\beta$

s : $[-L_\beta (Y_\beta - Y_{\beta_g}) + U(N_\beta L_r - N_r L_\beta)]$

constant: $(N_r L_\beta - N_\beta L_r)(Y_\beta - Y_{\beta_g})$

(b) $N^{r}_{\beta_g}$

s^3: $U\ N_\beta$

s^2: $[-N_\beta(Y_\beta - Y_{\beta_g}) + U(N_p L_\beta - N_\beta L_p)]$

s : $(N_\beta L_p - N_p L_\beta)(Y_\beta - Y_{\beta_g})$

(c) $N^{\beta}_{\beta_g}$

s^3: Y_{β_g}

s^2: $[-(N_r + L_p)Y_{\beta_g} + L_\beta Y_p + N_\beta Y_r - UN_\beta]$

s : $[(N_r L_p - N_p L_r)Y_{\beta_g} + (N_\beta L_r - N_r L_\beta)Y_p + (N_p L_\beta - N_\beta L_p)Y_r$

$+ U(N_\beta L_p - N_p L_\beta) + L_\beta g]$

constant: $(N_\beta L_r - N_r L_\beta)g$

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

TABLE I REVISED PILOT RATING SCALE

PILOT	FIXED-WING PROPELLER	FIXED-WING JET	ROTARY-WING	OTHERS	TOTAL
A	2,700	1,750	200	–	4,650
B	2,350	50	700	10	3,110
C	450	1,025	1,550	5	3,030
D	5,000	2,450	225	–	7,675
E	4,620	740	1,200	40	6,600

TABLE 2(a) SUMMARY OF PILOTS' FLYING EXPERIENCE

CONTROL	FORCE GRADIENT LB/IN	BREAK-OUT FORCE LB	MAXIMUM THROW IN
LONGITUDINAL (PITCH)	1.9	1	± 4
LATERAL (ROLL)	1.3	1	± 3
DIRECTIONAL (RUDDER PEDALS)	10	1.5	± 3
HEAVE	ADJUSTABLE FRICTION ONLY		+ 1.5 − 4.

TABLE 2 (b) EVALUATION PILOT'S CONTROL CHARACTERISTICS

TABLE 3

TEST CONFIGURATION CHARACTERISTICS

LL 112+20+44

- Sign and Magnitude of ζ_ϕ x 100
- Sign and Magnitude of ζ_d x 100
- Magnitude of ω_ϕ $\left(\frac{\text{rad.}}{\text{sec.}}\right)$ x 100
- Level of ω_d: L = 0.25, M = 0.50, H = 1.0 $\frac{\text{rad.}}{\text{sec.}}$
- Level of $\left|\frac{\phi}{\beta}\right|_{DR}$: L = 0.2, M = 0.75, H = 1.5

IN ABOVE EXAMPLE:

$\left|\frac{\phi}{\beta}\right|_{DR}$ = 0.2

ω_d = 0.25 $\frac{\text{rad.}}{\text{sec.}}$

ω_ϕ = 1.12 $\frac{\text{rad.}}{\text{sec.}}$

ζ_d = +0.20

ζ_ϕ = +0.44

	CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
		N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
1(a)	FLIGHTS AROUND ω_d = 1.0 ζ_d = 0.2							
	LH 100+20+50	.98	1.09	-11.4	-1.13	.83	-5.45	-.85
	77+20+40	.80						
	70+20+37	.75						
	61+20+34	.69						
	LH 129+20+50	1.0	.28	- 6.74	- .39	.61	-4.64	-.80
	121+20+47	.90						
	112+20+44	.80						
	100+20+40	.68						
	94+20+38	.62						
	81+20+34	.52						
	73+20+31	.45						
	56+20+26	.35						

TABLE 3 (ii)

	CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
		N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
	LH 132+20+38	.70	-.203	-2.81	.347	.425	-4.14	-.776
	121+20+35	.563						
	111+20+33	.445						
	100+20+30	.324						
	91+20+28	.238						
	76+20+24	.111						
	60+20+21	0						
	LH 130+20+25	.30	-.383	.84	1.09	.265	-3.95	-.78
	124+20+24	.219						
	111+20+22	.061						
	100+20+20	-.053						
	86+20+18	-.189						
	76+20+17	-.27						
	64+20+15	-.35						
	LH 137+20+18	.20	-.35	2.80	1.46	.187	-3.99	-.789
	123+20+17	.014						
	111+20+16	-.127						
	100+20+15	-.233						
	90+20+14	-.329						
	LH 144+20+12	.12	-.263	4.64	1.83	.111	-4.07	-.811
	115+20+11	-.252						
	100+20+10	-.412						
	90+20+10	-.504						
	68+20+ 9	-.68						
1(b)	FLIGHTS AROUND $\omega_d = 0.5$, $\zeta_d = 0$							
	LM 65+ 1+22	.87	.28	-6.88	-.455	.24	-4.23	-.40
	55+ 1+20	.748						
	50+ 1+19	.70						
	45+ 1+17	.649						
	29+ 1+15	.533						
	9+ 1+21	.460						

TABLE 3 (iii)

	CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
		N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
	LM 72+ 0+11	.640	.015	-3.30	-.12	.080	-3.98	- .395
	66+ 0+11	.563						
	60+ 0+11	.486						
	55+ 0+11	.428						
	50+ 0+11	.368						
	44+ 0+11	.318						
	40+ 0+11	.283						
	24+ 0+14	.180						
	LM 72+ 0- 4	.292	.040	.099	.224	-.084	-3.99	- .403
	65+ 0- 3	.197						
	56+ 0- 1	.100						
	50+ 0+ 0	.028						
	43+ 0+ 2	-.038						
	35+ 0+ 4	-.101						
	25+ 0+ 8	-.160						
	LM 71+ 0-18	-.039	.321	3.58	.555	-.249	-4.27	- .421
	65+ 0-16	-.113						
	59+ 0-13	-.185						
	50+ 0-10	-.283						
	43+ 0- 7	-.343						
	39+ 0- 5	-.375						
1(c)	FLIGHTS AROUND $\omega_d = 0.25$, $\zeta_d = -0.1$							
	LL 33-10- 6	.597	-.142	-4.38	-.181	-.151	-3.76	-1.97
	27-10- 2	.521						
	25-10+ 0	.499						
	22-10+ 2	.470						
	16-10+ 9	.420						
	LL 34-10-19	.349	-.079	-1.92	-.053	-.291	-3.83	- .201
	29-10-14	.284						
	25-10-10	.237						
	19-10- 3	.185						
	14-10+ 5	.150						

TABLE 3 (iv)

	CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
		N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
	LL 08-10+23	.118	- .079	-1.92	- .053	- .291	-3.83	- .201
	03-10+76	.107						
	LL 35-10-34	.121	.152	.538	.074	- .437	-4.06	- .208
	31-10-29	.067						
	26-10-21	.003						
	25-10-19	-.010						
	21-10-14	-.045						
	14-10+ 0	-.099						
2.	EFFECTS OF $\lvert\frac{\phi}{\beta}\rvert_{DR}$							
	LH 100+30+30	-.08	- .63	1.06	1.14	.41	-3.9	- .75
	MH 100+30+30	-.084	- .882	1.0	1.57	1.58	-3.62	-2.83
	HH 103+29+29	-.08	-1.2	.92	2.2	3.26	-3.22	-5.79
	LH 100+ 0+ 0	.009	.051	.279	.984	- .053	-3.99	- .822
	MH 100+ 0+ 0	.008	.046	.29	.94	- .161	-3.95	-3.05
	HH 100+ 0+ 0	.006	.047	.304	.904	- .324	-3.91	-6.03
	LH 100-20-20	.071	.383	- .397	.869	- .389	-3.92	- .855
	MH 98-20-19	.064	.213	- .35	.488	-1.37	-3.72	-3.05
	HH 100-20-20	.068	.009	- .289	.024	-2.62	-3.49	-5.90
	LM 50+29+29	-.16	- .40	1.76	.39	.39	-3.84	- .38
	MM 49+30+30	-.156	- .849	1.58	.797	1.53	-3.38	-1.45
	HM 47+30+28	-.16	-1.57	1.29	1.49	3.38	-2.63	-3.2
	LM 50+ 0+ 0	.028	.040	.099	.224	- .084	-3.99	- .403
	MM 50+ 0+ 0	.027	.026	.108	.15	- .275	-3.96	-1.5
	HM 51+ 0+ 0	.026	.009	.118	.057	- .534	-3.93	-2.96
	LM 50-20-20	.150	- .097	-1.14	.107	- .396	-3.85	- .409
	MM 50-20-20	.149	- .27	- .99	- .285	-1.38	-3.47	-1.46
	HM 50-20-20	.149	- .773	- .792	- .818	-2.74	-2.95	-2.91

TABLE 3 (v)

	CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
		N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
	LL 24+31+32	-.25	- .32	2.61	.17	.34	-3.79	- .19
	ML 25+30+32	-.26	-1.07	2.25	.565	1.47	-3.02	- .78
	LL 25+ 0+ 0	.116	.001	- .766	.006	- .144	-3.96	- .201
	ML 25+ 0+ 0	.107	- .098	- .65	- .134	- .534	-3.85	- .74
	HL 25+ 0+ 0	.107	- .237	- .612	- .338	-1.05	-3.70	-1.50
3(a)	EFFECTS OF ω_d, ζ_d, AND ω_ϕ, ζ_ϕ AT $\left\vert\frac{\phi}{\beta}\right\vert_{DR} = 0.2$, HIGHEST ω_d							
	(i) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d$							
	LH 100+30+30	-.08	- .63	1.06	1.14	.41	-3.9	- .75
	+20+20	-.053	- .383	.84	1.09	.265	-3.95	- .78
	+10+10	-.022	- .15	.58	1.04	.11	-4.0	- .8
	+ 0+ 0	.009	.051	.279	.984	- .053	-3.99	- .822
	-10-10	.04	.23	- .048	.928	- .219	-3.97	- .84
	-20-20	.071	.383	- .397	.869	- .389	-3.92	- .855
	-30-30	.101	.51	- .76	.809	- .560	-3.85	- .868
	-40-40	.132	.609	-1.14	.747	- .731	-3.75	- .879
	(ii) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d + 0.1$							
	LH 100+30+40	.301	- .311	-2.52	.392	.58	-4.23	- .765
	+20+30	.324	- .203	-2.81	.347	.425	-4.14	- .776
	+10+20	.35	- .11	-3.1	.30	.27	-4.03	- .79
	+ 0+10	.375	- .047	-3.4	.25	.107	-3.90	- .794
	-10+ 0	.402	0	-3.7	.199	- .052	-3.74	- .80
	-20-10	.430	.026	-3.99	.148	- .211	-3.57	- .804
	-30-20	.459	.030	-4.27	.095	- .368	-3.38	- .806
	(iii) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d - 0.1$							
	LH 100+30+20	-.462	- .652	4.69	1.88	.263	-3.88	- .773
	+20+10	-.412	- .263	4.64	1.83	.111	-4.07	- .811
	+10+ 0	-.364	.099	4.50	1.77	- .053	-4.23	- .844
	+ 0-10	-.319	.432	4.28	1.71	- .227	-4.36	- .874
	-10-20	-.277	.734	4.01	1.64	- .408	-4.46	- .900
	-20-30	-.237	1.0	3.67	1.58	- .595	-4.53	- .924

TABLE 3 (vi)

CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
	N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
MEDIUM ω_d							
(i) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d$							
LM 50+29+29	-.16	- .40	1.76	.39	.39	-3.84	- .38
+20+20	-.095	- .21	1.26	.335	.236	-3.94	- .389
+10+10	-.03	- .06	.70	.28	.076	-3.99	- .40
+ 0+ 0	.028	.040	.099	.224	- .084	-3.99	- .403
-10-10	.096	.086	- .597	.158	- .238	-3.94	- .407
-20-20	.15	.097	-1.14	.107	- .396	-3.85	- .409
-30-30	.212	.058	-1.75	.048	- .544	-3.71	- .410
-40-39	.286	- .043	-2.42	- .022	- .676	-3.51	- .407
(ii) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d + 0.1$							
LM 50+30+40	.207	- .058	-1.70	.034	.578	-4.19	- .386
+20+30	.257	.006	-2.22	- .013	.408	-4.16	- .391
+10+20	.31	.032	-2.76	- .06	.24	-4.08	- .39
+ 0+11	.368	.015	-3.30	- .12	.080	-3.98	- .395
-10+ 0	.433	- .042	-3.86	- .175	- .080	-3.81	- .395
-20-10	.497	- .142	-4.35	- .231	- .231	-3.61	- .392
(iii) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d - 0.1$							
LM 50+30+20	-.508	- .45	5.06	.729	.232	-3.80	- .383
+20+10	-.430	- .137	4.69	.675	.077	-4.01	- .398
+10+ 0	-.354	.12	4.14	.607	- .080	-4.15	- .415
+ 0-10	-.283	.321	3.58	.555	- .249	-4.27	- .421
-10-20	-.215	.467	2.91	.491	- .413	-4.31	- .429
-20-30	-.148	.558	2.18	.426	- .575	-4.31	- .434
-30-40	-.084	.600	1.46	.362	- .733	-4.25	- .438

TABLE 3 (vii)

CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
	N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
LOW ω_d							
(i) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d$							
LL 25+31+32	-.25	- .32	2.61	.17	.34	-3.79	- .19
+20+20	-.126	- .113	1.59	.122	.176	-3.94	- .195
+10+10	-.005	- .008	.431	.065	.013	-4.0	- .199
+ 0+ 0	.116	.001	- .766	.006	- .144	-3.96	- .201
-10-10	.237	- .079	-1.92	- .053	- .291	-3.83	- .201
-20-20	.341	- .224	-2.8	- .102	- .435	-3.63	- .201
-30-30	.474	- .457	-3.77	- .163	- .55	-3.35	- .198
-40-40	.604	- .750	-4.48	- .219	- .650	-3.02	- .193
(ii) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d + 0.1$							
LL 25+30+40	.041	- .103	- .074	.036	.522	-4.0	- .19
+20+30	.148	.021	-1.13	- .014	.342	-4.08	- .194
+10+20	.26	.055	-2.26	- .068	.168	-4.06	- .197
+ 0+10	.395	.005	-3.54	- .133	.013	-3.96	- .198
-10+ 0	.499	- .142	-4.38	- .181	- .151	-3.76	- .197
-20-10	.625	- .358	-5.23	- .238	- .290	-3.50	- .195
-30-20	.76	- .637	-5.9	- .294	- .412	-3.17	- .191
(iii) $\omega_\phi = \omega_d$; $\zeta_\phi = \zeta_d - 0.1$							
LL 25+30+20	-.522	- .299	5.26	.311	.183	-3.8	- .193
+20+11	-.387	- .031	4.27	.255	.022	-4.02	- .199
+ 0- 9	-.138	.194	1.88	.138	- .296	-4.15	- .207
-10-19	-.01	.152	.538	.074	- .437	-4.06	- .208
-20-29	.116	.026	- .733	.011	- .567	-3.88	- .208
-30-39	.234	- .16	-1.80	- .047	- .687	-3.64	- .206

TABLE 3 (viii)

	CONFIGURATION IDENTIFIER	STABILITY DERIVATIVES						
		N_{δ_a}	N_r	N_p	N_β	L_r	L_p	L_β
3(c)	EFFECTS OF ω_d, ζ_d AT $\left\|\frac{\phi}{\beta}\right\|_{DR} = 1.5$ ($\omega_\phi = \omega_d$, $\zeta_\phi = \zeta_d$ THROUGHOUT)							
	(i) Highest ω_d							
	HH 103+29+29	-.08	-1.2	.92	2.2	3.26	-3.22	-5.79
	100+20+20	-.054	- .632	.807	1.79	2.09	-3.63	-5.94
	103+10+10	-.02	- .20	.59	1.35	.88	-3.86	-6.0
	100+ 0+ 0	.006	.047	.304	.904	- .324	-3.91	-6.03
	100-10-10	.037	.113	- .002	.457	-1.50	-3.78	-5.99
	100-20-20	.068	.009	- .289	.024	-2.62	-3.49	-5.90
	(ii) Medium ω_d							
	HM 47+30+28	-.16	-1.57	1.29	1.49	3.38	-2.63	-3.2
	51+20+20	-.095	- .61	1.16	.977	1.92	-3.5	-3.08
	53+10+ 9	-.03	- .10	.71	.51	.63	-3.9	-3.0
	51+ 0+ 0	.026	.009	.118	.057	- .534	-3.93	-2.96
	50-10-10	.088	- .225	- .433	- .385	-1.70	-3.60	-2.93
	50-20-20	.149	- .773	- .792	- .818	-2.74	-2.95	-2.91
	(iii) Lowest ω_d							
	HL 25+20+20	-.138	- .598	1.53	.649	1.58	-3.43	-1.71
	25+10+10	-.016	- .012	.537	.122	.138	-3.97	-1.5
	25+ 0+ 0	.107	- .237	- .612	- .338	-1.05	-3.7	-1.5
	"STANDARD" CONFIGURATION LH 100+10+ 1	-.33	+ .06	4.1	1.70	- .036	-4.19	- .84

TABLE 4 SUMMARY OF PILOTS' COMMENTS

4a FLIGHTS AT $|\phi/\beta|_{DR} = 0.2$ WITH THE LOCATION OF THE ϕ-δ_a TRANSFER FUNCTION MOVED AROUND $\omega_d = 1.0$ RAD/SEC, $\zeta_d = 0.2$

4a(i)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100+20+50	134	B	7	Strong, immediate pro-yaw is the overriding feature.			Pro-yaw requires rapid, compensating opposite rudder to prevent skid when initiating turns.			Noticeable on approach but small aileron movements cause larger heading changes.	No problem.	Required use of rudder to coordinate.	
LH100+20+50	133	C	7½	Pro-yaw makes steady state turning without rudder impossible since small roll angle corrections give large yawing.			Rudder requirements changing rapidly and directional control was difficult right down to touch down.	Noticeable but damped. (Documentation seemed undamped at first).		Noticeable in yaw but not bothersome.	No problem.	Very uncomfortable due to very large pro-yaw which was difficult to coordinate.	
LH 77+20+40	134	B	6	Strong pro-yaw with aileron, but as roll develops adverse yaw occurs. Sharp initial yaw response to small quick aileron movements is very objectionable.			Rudder coordination required at all stages of manoeuvres. The sharper the manoeuvre, the more difficult to properly coordinate.	No problem.		Response small.	No problem.	Awkward.	
LH 77+20+40	133	C	7	Enormous pro-yaw with aileron which takes hold immediately (especially on rapid control inputs) but is followed by nose swinging out of turn.	Adequate, but hit stop either way on S-turn.		Coordination on turn exit especially difficult.	Second swing induced out of turn by aileron only, feels like oscillation starting, which appears lightly damped.	Slight out of trim on rudder resulted in a moderate β, but nose oscillated about.	No problem	No problem.	Constant touches of rudder required in sidestep turning. Sidestep quite sloppy with much rudder and aileron required.	
LH 70+20+37	134	B	5½	Pro-yaw with aileron but adverse yaw with roll. Yaw response to aileron possibly compensated for as roll starts to develop. Sharp use of aileron gives immediate yaw response which is objectionable.			Difficult to keep coordinated in sharp manoeuvres. Different yaw effects are somewhat confusing, so that it becomes difficult to anticipate which way to apply rudder. Instead rudder is used after response is noticed.			Large slow heading variations on approach - up to ± 8 deg.	No problem.	Manageable but difficult to execute smoothly.	
LH 70+20+37	133	C	6½	Pro-yaw quite strong, but followed shortly by a swing out of turn.	In general adequate, but in S turn, (which was very rapid because wind picked up from rear right side), hit stops.		Best to let pro-yaw develop and then to come in with aileron as the swing out of turn occurs.		Slight out of trim on rudder results in large but manageable β with a slight oscillation about the mean β.	No problem.	No problem.	Very little attention to coordination required.	
LH 61+20+34	139	B	7	Slight pro-yaw with aileron and strong adverse yaw with roll.	Rather sluggish roll response.	Fast response to rudder.	Difficult to perform smooth coordinated turn because of poor control harmony - jerky.	No pronounced oscillatory characteristics.		Marked effects in yaw (± 4 to 5 deg.)	No problem.	Difficult to perform quickly and without jerkiness.	Poor control harmony.
LH129+20+50	139	B	6	Sharp pro-yaw with aileron. Yaw with roll not discernible. Excessive yaw develops with all but gentle manoeuvres.	Sluggish	Rudder effectiveness much greater than that of aileron.	Considerable opposite rudder required to coordinate turn entries and exits.	No pronounced oscillatory tendencies		Noticeable on approach (heading variations ± 4 deg.)	No problem.	Awkward - requires excessive manipulation of rudder.	Poor control harmony.
LH121+20+47	134	B	6	Strong pro-yaw with aileron. Very sharp yaw response to small aileron input. Seems to require opposite rudder to coordinate as long as aircraft is rolling.			Sharp manoeuvres difficult to coordinate. Strong pro-yaw with initial aileron input, but opposite rudder is required to coordinate as long as aircraft is rolling. Hence a lot of aileron is required to keep turn going.	Noticeable on approach.		Yaw disturbances of several degrees on approach - possibly a result mainly of oscillatory characteristics in yaw following small turbulence input.	No problem	Difficult to execute smoothly.	
LH112+20+44	97	B	5½	Too much pro-yaw with aileron. If aileron only manoeuvres are made, they must be very gentle otherwise they become jerky, (yaw overshoots).	Adequate		Considerable rudder coordination required in rapid manoeuvres, e.g., opposite rudder in reversing roll direction.	Rudder inputs produce oscillation which dies away in a few cycles.		Minor. Approach heading steady <±2 deg. if aileron inputs avoided; otherwise ±5 deg.	No problem	O.K., but jerky because of yaw response to aileron.	

4a(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH112+20+44	98	C	7	Enormous pro-yaw.	Full roll power could not be used due to yawing effect - roll rates had to be kept low.		Not natural but could probably be learned fairly quickly.	Not evident.		No problem.	No problem.	Jerky due to yawing with aileron and probably some external turbulence at low altitude	
LH100+20+40	61	A	5	Initial roll response generates pro-yaw and creates coordination problem. Aileron causes pro-yaw.			This is the major problem. For moderate rate and amplitude manoeuvres it is not too bad, but for large amplitude manoeuvres such as sidestep, it is quite poor. Fair ability to coordinate.	Not very oscillatory because Dutch roll frequency and damping are moderate.				Quite poor coordination.	Good model on heading control, quite poor for large transients.
LH100+20+40	137	B	$5\frac{1}{2}$	Sharp aileron input gives initial pro-yaw response. There appears to be some yaw in opposite sense as roll develops.			In continuous linked manoeuvres, major characteristic is the need to apply opposite rudder as turns are reversed. Needs rudder coordination in all but very slow manoeuvres.			Minor.	No problem.	S-turn O.K., but requires excessive opposite rudder during reversal.	
LH100+20+40	70	C	$7\frac{1}{2}$	Pro-yaw very powerful.			The pro-yaw sets off a well damped directional oscillation which ends up in a moderately well coordinated turn. On turn exit yawing stops as soon as the aileron is applied to roll out, and, after the wings become level, the nose yaws in the original turn direction.	Well damped directional oscillation set off by pro-yaw.		No problem.	No problem.	Yawing during exit is very uncomfortable.	
LH 94+20+38	65	A	6	Initial roll O.K., but may possibly be too abrupt due to pro-yaw with aileron.			Coordination very difficult, and I believe that this is aggravated quite a bit by turbulence. Large amplitude manoeuvres difficult because large β can be generated. Very poor overall coordination, (precision very poor).	Quite a bit of pilot induced oscillation and yaw oscillation due to overcontrol and turbulence.		Aggravates coordination difficulties. Causes yaw oscillation.		Very poor and much oscillation on final approach.	
LH 94+20+38	86	C	6	Very large pro-yaw causes large sideslips on turn entry which result in one swing in opposite direction before things settle down into a fairly well coordinated turn.	The aileron is as effective as yaw control as roll control. Roll control adequate - never hit stop.		Confusing. Opposite rudder on initiation of roll, followed by rudder into turn.			No problem.	No problem.	Uncomfortable β build up during S-turn, which could not be prevented with amount of practice on model.	
LH 81+20+34	136	B	5	Initial response to aileron is slight pro-yaw, followed by adverse yaw as roll develops.	A little sluggish.		Sharper turns require coordination with rudder, but still a bit sluggish, even though rudder in same direction as aileron.	No oscillation tendency.		Noticeable in yaw ± 3-4 deg.	No problem.	O.K., but a bit sluggish and too much rudder into turn required.	
LH 81+20+34	125	C	$4\frac{1}{2}$	Some pro-yaw with aileron which changes to adverse yaw after first few seconds. Nose yaws into turn and then out before settling into a relatively well coordinated turn.	Adequate.		Too many changes in rudder required to coordinate: 1) cross control, 2) into turn, 3) none.	Not a factor.		No problem.	No problem.	Required changing rudder throughout.	

4a(iii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRES	MISCELLANEOUS
LH 81+20+34	128	E	5	Adverse yaw.			Adverse yaw coupled with yaw oscillation makes roll reversal difficult. Flight path changes on localizer uncoordinated. After a while you get adjusted to reversing rudder in order to coordinate.	Yaw oscillation.				Roll reversal difficult.	
LH 73+20+31	131	C	6	First instant of aileron turn feels fairly good,although a slight pro-yaw with aileron can be detected. This is followed quite shortly by an adverse yaw which is quite pronounced and precludes aileron only turns.	Adequate.		Turn coordination could be learned for entry and exit by leading with rudder. Coordination in the steady turns very good, and requires little attention.	Moderately damped oscillation does seem to be excited by turbulence on occasion.		Excites damped oscillation on occasion.	No problem.	S-turn required a fair amount of rudder application due to adverse yaw.	
LH 56+20+26	134	B	7	Strong, immediate adverse yaw with aileron. This is the overriding factor.			Very quick use of pro-roll rudder required on entry and exit from any but slow turns. Once into the turn no rudder required for coordination.	No particular oscillatory tendency.		Mild effects in yaw.	No problem.	Difficult - hit aileron stops at times.	
LH 56+20+26	133	C	7	Initial instant of aileron turn causes nose to swing slightly into the turn, but this is short lived since it swings violently out shortly thereafter. Aileron turns are absolutely hopeless.		Extremely large sideslips develop from touches of rudder.	Rudder into turn must be taken off smartly after achieving the desired conditions, or a large swing into the turn develops. Constant touches of rudder are required during the steady state turn.	Oscillation not evident.		No problem.	No problem.	S-turn sloppy due to yawing, but also hit aileron stop on turn entry and during final roll-out.	
LH132+20+38	139	B	7	Sharp pro-yaw with aileron. Possibly also pro-yaw with roll.			Sharp manoeuvres unpleasant and require much opposite rudder. Gentle manoeuvres possible using aileron.	No pronounced oscillatory tendencies.		Minor.	No problem.	Possible but difficult to prevent excessive skid.	Major objection is yaw due to aileron.
LH121+20+35	122	B	6	Strong pro-yaw response to aileron.			Gentle turns only unless considerable rudder is used for coordination. Opposite rudder required for starting and stopping turns - makes continuous manoeuvring difficult.	Some tendency to oscillate slowly unless checked by rudder.			No problem.	Moderately difficult due to need for excessive use of rudder to coordinate.	
LH121+20+35	87	C	8	Pro-yaw with aileron.	Adequate.		Coordination is a difficult problem since cross-control is required during all lateral directional manoeuvres.	Oscillation was damped.		Noticeable,especially on approach,but not bothersome.	No problem.	Quite imprecise - could not keep the aircraft from sideslipping to uncomfortable angles.	Would have rated as '7' without S-turn. - repeated S-turn to get a second impression.
LH111+20+33	123	B	5	Aileron produces pro-yaw.	Adequate.	Sloppy rudder characteristics.	Mild manoeuvres require practically no coordination. Sharp manoeuvres and turn reversals require strong opposite rudder as aileron is applied, and some rudder to check swing at the end of the manoeuvre.	Some yaw oscillation develops in any sharp use of aileron or rudder.			No problem.	O.K. - see coordination comments.	Heading wander occurred on approach due to yaw oscillation and sloppy rudder characteristics.

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH111+20+33	84	C	4½	Pro-yaw with aileron is uncomfortably high.	Adequate.		Aileron only turns no great problem, but opposite rudder is required to keep things smooth if rapid turn entries and exits are executed. Some rudder into the turn is required to keep the ball central.	β oscillation which is very well damped, is induced on turn entry and exit by pro-yaw due to aileron.		No problem.	A touch of rudder required on approach - no problem.	Sidestep caused the changing rudder requirements described under coordination but it could have been accomplished without rudder.	
LH111+20+33	126	E	7		Much too sensitive.		On roll out of turn, all is well until roll control is returned to neutral, then a rapid, sharp yaw excursion (pro) takes place.					Expected difficulty, but it did not occur.	
LH100+20+30	135	B	3	Response to aileron is roll and some pro-yaw.			In sharp manoeuvres, some opposite rudder is required to coordinate entry and exit; a little too much in fact. Mild manoeuvres are possible with aileron only.	No problems.		Fairly small, ± 3 deg. on approach, rudder fixed.	No problem.	O.K. except a bit too much opposite rudder is required, and hence aileron is just on stops.	
LH100 +20+30	45	C	3	Slight tendency for pro-yaw to occur with aileron application, followed by adverse yaw, and then no yaw. This effect is the mildly unpleasant part.						No Problem.	No problem.		
LH 91+20+28	122	B	5		Rather sluggish. Can put aileron to stops without any concern about response.	Yaw control lacks crispness - tends to overshoot.	Relatively mild manoeuvres require practically no coordination. In sharp manoeuvres there appears to be slight adverse yaw requiring some use of rudder.			Noticeable on approach but can be suppressed.	No problem.	Used full aileron control.	
LH 91+20+28	98	C	3	Some adverse yaw.	Not as powerful as desired.		Touch of rudder required, especially on turn exit, to smooth out the motion. Aileron only turns can be done with an acceptable performance.	Not evident.		Not bothersome.	Not bothersome.	Hit aileron stop on exit from sidestep manoeuvre, but was able to get a respectable roll rate.	
LH 91+20+28	127	E	4½	Some pro-yaw noticeable.			Minor sharp yaw inputs which make turns objectionable.					Pro-yaw seemed to make sidestep manoeuvre easier to execute.	Jittery model in yaw.
LH 76+20+24	97	B	4	Pronounced adverse yaw.	Fair.	Quite good, very little tendency to overshoot and oscillate.	Rudder required to coordinate turn entry and exit.			Effects on heading minor.	No problem.	No problem.	Would rate better than 4 if adverse yaw not present.
LH 76+20+24	142	C	5½	Predominantly adverse yaw, although on rapid aileron application the initial response is pro-yaw. Effect not dangerous on turn entry and after establishing steady state no rudder is required.			Rudder absolutely essential on turn entry to limit the sideslip. Coordination relatively easy by leading with a fair amount of rudder.	Oscillation excited when rolling into and out of turns; but damps out quickly.		Noticeable on approach but not bothersome.	No problem.	Went well with use of rudder.	
LH 76+20+24	128	E	5	Adverse.			Adverse yaw requires too much effort to coordinate, cannot coordinate roll reversal.						Most objectionable manoeuvre is roll reversal. Could rate better if only very gentle control inputs are used.

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRES	MISCELLANEOUS
LH 60+20+21	136	B	7	Sharp adverse yaw response to aileron. Most objectionable if stick moved quickly.			Sharper turn entries and exits require considerable co-ordination.	No oscillation problem.		Response is ±2½ deg. in heading changes with rudder fixed.	No problem.	Manageable but too much rudder required to maintain coordination.	
LH 60+20+21	131	C	7	Very powerful adverse yaw.	Adequate.		Could probably learn to live with powerful adverse yaw by always leading with rudder, but this requires too much attention. Can get into a strange condition of steady sideslip (particularly on roll out of turn) with a small aileron displacement and no rudder.	Well damped.	A small rudder out of trim results in an unacceptably high sideslip.	Noticeable in yaw, but not bothersome.	No problem.	Very unsteady due to adverse yaw.	
LH130+20+25	141	B	4½	Pro-yaw with aileron. Sharp turns without rudder produce overswing in the direction of turn.	A little sluggish in consequence of opposite rudder requirements.		Opposite rudder required on initiating rolling manoeuvres. Coordinated manoeuvres possible, but require conscious effort with opposite rudder.	Oscillation, subsiding in one cycle, caused by sharp aileron turns.		Noticeable yaw response to turbulence.	No problem.	Manageable.	
LH130+20+25	143	B	6½	Sharp pro-yaw with aileron. Appears to have some adverse yaw due to roll.			Aileron only turns must be very gentle to avoid excessive yaw overshoot and oscillation. Can approximately coordinate with rudder, but this requires considerable use of rudder.	Aircraft tends to oscillate in a convergent manner if disturbed.		Noticeable, but heading variations on approach with rudder fixed < ± 3 deg.	No problem.	Manageable but difficult to perform without slip or skid.	
LH124+20+24	121	B	6	Strong pro-yaw response to aileron.			Requires considerable rudder to coordinate turns.	Caused heading to wander considerably on approach, with rudder fixed.		Heading, with rudder fixed, wandered considerably – apparently due to turbulence and oscillatory characteristics.	No problem.	Moderately difficult to keep coordinated.	Not a good model.
LH124+20+24	58	C	7	Pro-yaw with aileron made the roll-in and roll-out of aileron-only turns very uncomfortable.			Had to use opposite rudder on roll-in and roll-out of turns to coordinate – this was unnatural and very unpleasant.	After the bank was established, the yaw excursions settled down quickly.		No problem.	Requires a little of both aileron and rudder.	Required top rudder.	
LH111+20+22	64	A	4½	We seem to have pro-yaw due to aileron, and this causes coordination problem.	Initial roll response O.K.			Pilot induced oscillation in yaw can be generated. Dutch roll seems well damped, and this helps. Also frequency is moderate, giving reasonable lateral response.		Noticeable and creates a feeling that the pilot lacks precision of control.		Requires quite a bit of cross control and was only fair.	Coordination requirements the most objectionable feature. Fair configuration.
LH111+20+22	65	A	5	Have pro-yaw due to aileron. Yaw due to roll rate? – I don't know, may be adverse.	Initial roll response O.K.	Rudder response too sensitive – easy to overcontrol.	Not possible to coordinate with precision. Must cross-control quite a bit for large amplitude manoeuvres.			Turbulence and crosswind to some extent affect β control.		O.K. only because I consciously cross-controlled.	Not very bad configuration, but also not very easy to fly.
LH111+20+22	138	B	4½	Initial response to aileron appears to be roll accompanied by some pro-yaw. Without rudder the yaw tends to overshoot in the direction of the roll and then swings back to become adverse before settling down.			In linked turns it is necessary to use predominantly opposite rudder to maintain coordination.	No very pronounced oscillatory effects.		Minor: ± 3 deg.	No problem.	Manageable.	

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH111+20+22	71	C	3	Pro-yaw with roll annoying on turn exit.	Good.		Pro-yaw with roll required a touch of opposite rudder on roll out. Coordination poor only on turn exit, not on turn reversals.	Some heading wander in straight and level made it feel as though the aircraft was somewhat loose directionally - no doubt due to turbulence.		Caused heading wander in straight and level flight.	Noticeable on rudder, but no problem.	Easily done.	Quite good. Coordination and heading wander difficulties minor.
LH111+20+22	128	E	3½	Some adverse yaw present.	Seemed a little sluggish in roll.	Too responsive in yaw.	Most difficulty was experienced with stopping roll reversal and coordinating ball - coordination during actual reversal was O.K.						A jittery model in yaw.
LH100+20+20	63	A	1½	No yaw due to ailerons.	Good roll control - maybe slightly sluggish - ailerons felt a little stiff.		Flew entire pattern with aileron and elevator only. This was a two control airplane. No coordination required.	No oscillatory tendency except when I used a little rudder. I had a slight tendency to over-control.		Not affected by turbulence.	Not noticed.	O.K.	Special pilot technique is to stay off rudder except possibly for very close heading control. No objectionable features.
LH100+20+20	119	B	3½	Very slight adverse yaw.	Roll control good.		Only slight rudder coordination required in turns.			Tends to wander in yaw and this seems most likely due to turbulence.	No problem.	No problem.	Generally quite pleasant. Main complaint: not as precise in yaw as desirable and turbulence quite noticeable.
LH100+20+20	140	B	3	Very slight adverse yaw with aileron.	A bit sluggish in roll - can readily apply full aileron.		Requires little use of rudder to coordinate.	A slight oscillation is to be suppressed at the end of a manoeuvre.		Turbulence - a little more heading change than I would like (±3 deg). Can reduce a little with rudder (±2 deg).	No problem.	No problem, but used full aileron.	Generally quite a good model.
LH100+20+20	54	C	2½			Only factor I would change is the rudder sensitivity which causes a bit of jostling if the ball is kept as close as possible to the centre.	Good stick steering A/C.			No problem.	Slight X-wind effect on rudder.		
LH100+20+20	48	D	2		Controls responsive.		Without rudder A/C turns either way with minimum slip.	Aircraft very stable.					Very good model. Pleasant to fly. No bad characteristics.
LH100+20+20	108	E	2										Very pleasant model. Feels very much like normal Bell.
LH 86+20+18	119	B	5	Sharp adverse yaw with aileron, which is a bit sluggish by comparison. Turns poor without use of rudder.	A bit sluggish.		Turns can be coordinated with rudder if not made too quickly.	Does not tend to develop any yaw oscillation, rudder fixed.		Small response to turbulence in yaw.	No problem.	Manageable but not easy to maintain good coordination.	
LH 86+20+18	102	C	4½	Adverse yaw not quite powerful enough to prevent aileron only turns but swings on exit especially are so large that rudder would always be used.	Adequate.		Relatively easy, but adverse yaw is somewhat more than just minor.	Oscillation not evident.		Noticeable but not bothersome.	No problem.	Manoeuvre went well, but rudder absolutely essential.	
LH 76+20+17	124	B	5	Adverse yaw with aileron. Sharp yaw response to aileron unpleasant if stick moved either side.			Requires considerable rudder coordination in turns and manoeuvres. Difficult to be fast enough with rudder to be smoothly coordinated.	No tendency to oscillate.		Some response to turbulence on approach (±3 deg. heading).	No problem.	O.K., but not smooth.	

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRES	MISCELLANEOUS
LH 76+20+17	59	C	7¼	Enormous adverse yaw.			A lot of rudder is required to keep turn entry and exit manageable. After the bank was established conditions were almost stable with no roll control inputs, but the ball slowly slipped into the inside of the turn. Only a very small rudder deflection was required, however, to keep the ball in the centre.			No problem.	No problem.	Very uncomfortable and we would have been fortunate to get rid of all the β before touch down. The adverse yaw was too severe to overcome with the amount of rudder applied.	
LH 64+20+15	139	B	6	Sharp adverse yaw with aileron. No noticeable yaw effect from roll.	Harmony poor. Roll control sluggish compared to rudder.		Aileron only manoeuvres must be gentle - otherwise excessive yaw occurs. Difficult to coordinate without jerky effects.	No pronounced oscillatory effects.		Noticeable on approach (± 3-4 deg.).		Managed, but jerky and unpleasant.	
LH137+20+18	141	B	6½	Pro-yaw due to roll and due to aileron. Rolling manoeuvres without rudder result in excessive yaw motions.			Can coordinate moderate turns, but require considerable opposite rudder.	Some tendency to oscillate to large angles on approach - rudder fixed.		Noticeable response to turbulence (but natural turbulence rather high).	No problem.	Manageable but requires considerable use of rudder.	
LH123+20+17	135	B	5	Response to aileron is first roll followed by pro-yaw, with minor tendency to overshoot in mild yaw oscillation.	Roll control rather sluggish.		Excessive opposite rudder required in rolling manoeuvres.			Some noticeable effect of turbulence on approach, ± 3-4 deg. heading variation.	No problem.	Manageable but requires too much use of opposite rudder.	
LH123+20+17	104	C	7	Pro-yaw with aileron too high.			Much rudder concentration is required to keep the nose pointing where it should during manoeuvres. Opposite rudder is required as the aileron is moved and this had to be removed smartly or a lightly damped oscillation would start to build up.	Damped but would become noticeable even in straight and level flight.		Excites oscillation.	Required some rudder, but not a problem.	Uncomfortable and I would have touched down with some right aileron and some left rudder.	
LH111+20+16	136	B	5	Aileron gives roll followed by pro-yaw as roll develops. Possibly just a shade of adverse yaw with initial aileron			Sharper manoeuvres require opposite rudder to coordinate	No oscillation problems, but moderately sensitive in yaw to turbulence.		Moderately sensitive in yaw to turbulence, ± 5 deg. on approach, rudder fixed.	No problem.	O.K., but too much opposite rudder required and a bit sluggish.	
LH111+20+16	102	C	5	Bothersome. Aileron-only turns possible but cause large swings to develop.	Adequate.		Uncomfortable. Initial portion goes well but after bank is established or after roll out, the rudder adjustments necessary are unnatural and cause a jostling motion.	No problem.		Noticeable but not bothersome.	No problem.	Went well, but rudder was played carefully.	
LH100+20+15	123	B	5		A bit sluggish. Using full aileron at times. Sharp aileron input causes initial adverse yaw and is rather unpleasant.		Moderate turn entries and exits are possible without rudder coordination.	On approach tended to oscillate in yaw ± 7 deg.		Seemed to cause oscillation in yaw on approach.	No problem.	O.K.	Would rate better but for a) yaw response to sharp aileron inputs, b) sloppy yaw behaviour, overshoots heading.
LH100+20+15	100	C	4½	Slight adverse yaw with aileron. Not particularly bothersome on turn entry but starts oscillation going for a couple of cycles on turn exit.	Could be more powerful. Hit stop on S.S. manoeuvre once.	Powerful.	Not a great problem, except, when turbulence disturbs heading in steady turn, it is difficult to select right amount of rudder.	Aileron-only turns cause oscillation for couple of cycles on turn exit.		Bothersome. Causes heading change of ±4° on approach.	Touch of rudder.	Not smooth, yawing quite a bit at end.	

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH 90+20+14	124	B	4	Some adverse yaw with initial aileron. Yaw response to sharp aileron input unpleasant.			Rudder coordination required for sharper turn entries and exits. Steady part of turn requires no coordination.	Minor tendency to oscillate in yaw.		Appeared to respond to turbulence ± 6 deg.	No problem.	O.K., but required rapid use of rudder.	
LH 90+20+14	101	C	5½	Strong adverse yaw with aileron. Aileron-only turns impossible due to yawing on turn exit which cannot be stopped on desired heading.	Adequate.		Fairly natural, but requires a lot of rudder initially and this has to be taken off in the turn to prevent yawing from starting - this requires too much concentration.	Not noticeable.		No problem.	No problem.	Went well with rudder being adjusted judiciously.	
LH 79+20+13	137	B	7	Sharp adverse yaw response even to small aileron movements very objectionable. Apart from this, characteristics would be quite good.			Requires quick use of rudder in same sense as aileron during turn entries and exits.	No strong oscillatory characteristics.		Noticeable on heading on approach (± 4 deg.).	No problem.	Manageable but difficult to coordinate.	
LH 79+20+13	115	C	7½	Enormous adverse yaw overshadows everything else.	Seemed adequate but could not use all available due to yaw response.		Coordination difficult due to the changing demands whilst aileron is manipulated.	Oscillation not evident.	Aircraft seems to be loose in yaw.	Aircraft is disturbed to a moderate degree by turbulence.	No problem.	Very jerky, and too much attention required to stop yawing.	
LH 79+20+13	126	E	8	Aileron causes adverse yaw.					A jittery model - reaction of aircraft cannot be anticipated by the pilot.			Full concentration required to fly aircraft accurately in sidestep. Rapid control movements and changes required.	Worst feature is accurate control on localizer. Corrections cause rapid adverse yaw inputs.
LH144+20+12	60	A	8	Very large pro-yaw due to aileron.	Controlling roll is very difficult.		Coordination is not possible unless pilot thinks about cross controlling and uses aileron very slowly.		Bank angle control in steady state is also difficult.	Turbulence is a problem.		Not really possible.	Very poor configuration. Main problem is coordination.
LH144+20+12	121	B	7	Aileron produces greater response in yaw than in roll. Consequently any attempt at sharp manoeuvres results in considerable skid.			Necessary to use a great deal of rudder to coordinate.			Noticeable on approach. Rudder often required to minimize heading changes.	No problem.	Difficult - must be gentle to avoid sharp yaw response due to aileron.	Unpleasant model to fly.
LH115+20+11	137	B	6	Aileron results in first a slight adverse yaw followed by roll and pro-yaw. This pro-yaw tends to overshoot and consequently there is a yaw oscillation.			If rudder is used to attempt coordination, only partial success results unless the manoeuvre is very gentle.	Heading variation was ± 5 deg. during approach. Not reduced by using rudder.			No problem.	Can be accomplished but difficult to coordinate.	
LH115+20+11	84	C	6½	Pro-yaw with roll much too high - does not feel like positive N_{δ_a} but rather positive N_p, since it seemed to take a moment to start yawing after aileron application.	Aileron adequate for roll requirements.		Coordination difficult since a fair amount of opposite rudder was required on initial roll and then rudder into turn and then nothing. Turn exits were especially uncomfortable without rudder.	Oscillation was fairly well damped but noticeable when aileron applied.		Turbulence was noticeable, and on approach had heading changing by approximately ± 5 deg. -not too bad though, since the mean heading was maintained.	No problem.	Uncomfortable due to turning reasons.	

4a(ix)

NO.	NO.		RATING	AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY	STATIC	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100+20+10	64	A	4½	Initial roll acceleration is sluggish due to adverse yaw with aileron, but then improves as roll rate becomes moderate. Can be flown with aileron only. However, when β increases beyond a certain point, and the aircraft is rolled rapidly into a 30° bank, the yaw rate increases rapidly and gives the feeling it is getting away from the pilot.			Manoeuvring is not restricted except for the high yaw rate and yaw acceleration response.	Good Dutch roll damping with rather high frequency.				Poor sidestep manoeuvre. Yaw rate became excessive in sidestep which was flown without rudder to avoid a tendency to overcontrol when rudder used.	
LH100+20+20	89	B	6	Strong aileron yaw very objectionable, and dominates assessment.	Satisfactory.		All manoeuvres completed satisfactorily, the main consideration being the constant necessary use of rudder.			Yaw response in turbulence quite pronounced.			
LH100+20+10	55	C	7	Adverse yaw makes turn entry and especially exit very sloppy.				On turn exit, if one attempts to hold heading with aileron only, a very large directional oscillation, which is quite well damped, results.		It is fortunate the directional oscillation is quite well damped since the turbulence disturbance is bothersome.	No problem.		
LH 90+20+10	138	B	5	Marked adverse yaw with aileron. This is the dominant objectionable characteristic.	Rather sluggish in roll.		Can accomplish all manoeuvres, but it is difficult to preserve full coordination in sharper turn entries and exits.	No oscillation problems.		Response to turbulence ± 3°.	No crosswind problem	S-turn O.K., but difficult to execute in a completely coordinated manner.	
LH 90+20+10	87	C	6	Very large adverse yaw with aileron application which causes enormous swinging on turn exit. Entry not good but can be accepted.	Adequate			Oscillation damps out very quickly. No problems.		No problem.	No problem.	End of sidestep manoeuvre was very unsteady due to difficulties in accurately overcoming yaw with aileron.	
LH 68+20+9	140	B	6	Sharp adverse yaw with aileron - very unpleasant.	Roll control less effective in roll than in yaw. Hence harmony poor in terms of effectiveness.		Difficult to perform smooth coordinated manoeuvres.	No oscillatory tendencies.		Noticeably responsive to turbulence in yaw (±3 to 4 deg). Too fast to readily suppress with rudder.	No problem.	Manageable but requires deft use of rudder to counter adverse yaw.	

4b FLIGHTS AT $|\phi/\beta|_{DR}=0.2$ WITH THE LOCATION OF THE ϕ-δ_a TRANSFER FUNCTION MOVED AROUND $\omega_d=0.5$ RAD/SEC, $\zeta_d=0.0$

4b(i)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 65+1+22	143	B	6	Sharp pro-yaw with aileron. Aileron-only turns must be very gentle to avoid excessive yaw followed by oscillation	Full aileron used in S turn.		Approximate coordination with rudder possible but the results are jerky in sharp manoeuvres.	Divergent yaw oscillation of moderate period if rudder held fixed.		Negligible effects.	No problem.	Full aileron used. Difficult to completely coordinate.	Heading variations on approach can be suppressed, but this would be tiring for continuous flying.
LM 55+1+20	140	B	6	Excessive pro-yaw with aileron.	Aileron effectiveness much lower than that of rudder. Harmony not very good in this respect		Gentle aileron manoeuvres possible but sharp manoeuvres difficult to coordinate as a result of fast and large rudder inputs required.	Tendency to oscillate if disturbed in yaw.		Effects minor, but once disturbed will oscillate.	No problem.	Difficult to perform smoothly.	
LM 55+1+20	125	C	8	Enormous pro-yaw with aileron.			Powerful rudder capable of controlling the yaw oscillation, but too much attention required particularly on turn entry and exit. Coordination requires cross controlling and much rudder kicking.	On aileron only turns the nose yaws in and then swings out, beginning an undamped yaw oscillation which must be controlled by rudder. Oscillation can be readily suppressed by rudder.		No problem.	No problem.	Very sloppy, requiring much use of rudder.	
LM 50+1+19	61	A	6	Yaw due to aileron effects difficult to evaluate. Yaw in rolling manoeuvres may be generated by aileron or roll rate. Apparent pro-yaw due to aileron and adverse yaw due to roll.		Rudder forces are light. Easy to overcontrol with rudder.	Coordination is a problem. Overall poor precision of lateral control and coordination.			Holding heading is difficult, especially in turbulence.		Pilot performance fair to poor in the sidestep manoeuvre.	
LM 50+1+19	71	C	7	Pro-yaw excessive.	Aileron control satisfactory in roll but is too effective in yaw.		Excessive pro-yaw requires uncomfortable amounts of opposite rudder. Aileron only turns cannot be done since the heading oscillation becomes very large. Opposite rudder required on turn entry and exit.	The oscillation starts with a small pro-yaw swing and then a large swing out of turn. Cannot do aileron only turns as the heading oscillation gets very large indeed. (one ball width either way before rudder necessary to suppress).		No problem.		S-turn went well but I had to be right on top of the rudder.	
LM 45+1+17	123	B	7	Pro-yaw with aileron	Rather sluggish		Considerable opposite rudder required in fast turn entries and exits.	Yaw oscillation develops in turns if rudder not used. This can result in a bad swing particularly on exit.		Not noticeable but heading did oscillate on approach.	No problem.	Manageable. Rudder coordination necessary. Rudder control was sloppy.	
LM 45+1+17	104	C	7		Adequate, although I did hit the stop on exit from the S-turn.		Yaw due to aileron and the rather high frequency yaw swing back on turn entry make turn coordination most difficult. Leading with opposite rudder must be almost immediately reversed as the swing reverses.	Oscillation somewhat confusing since it appeared of moderately high frequency on turning manoeuvres, but following rudder impulses in straight and level flight, it was of quite low frequency and damping.	Small rudder out of trim results in large β.	No problem.		Required intense rudder concentration. Hit aileron stop.	
LM 29+1+15	135	B	7	Initially pro-yaw with aileron, then adverse yaw as the roll develops.			Considerable coordination required in all sharp manoeuvres.	Slow, divergent oscillation in yaw tends to develop if rudder held fixed.		Turbulence effects minimal but developing yaw oscillation causes large heading variations (±15°) if not controlled.	No problem.	Manageable but difficult to coordinate.	
LM 29+1+15	132	C	6½	Initial swing with aileron is distinctly pro, but before the final bank angle is achieved, a much more distinctly adverse swing occurs.	Adequate		Coordination in turns seems natural, following aileron inputs by rudder to counteract the adverse swing. In steady state turns, coordination is quite easy but it is absolutely necessary to keep giving touches of rudder.		If incorrect rudder is used for coordination, the nose will drift off as if the directional characteristics were statically unstable.	No problem.		S-turn went relatively well, with rudder into turn absolutely necessary.	

4b(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 9+1+21	143	B	7	Sharp adverse yaw as roll develops. Aileron only turns must be very gentle in presence of adverse yaw and slow oscillation.			Can coordinate with rudder but sharp manceuvres become jerky.	Long period apparently diverging oscillation develops if rudder is held fixed.		Effect almost negligible.	No problem.	Jerky and difficult to perform without slip or skid.	
LM 9+1+21	142	C	8	Initial response to aileron is pro-yaw, which is immediately followed by a violent yaw out of turn.	Adequate but was unable to use all available due to yaw response.		Yaw response to aileron plus static instability require continuous use of rudder. Coordination very difficult.	Not evident as such.	Seemed like a static instability.	Turbulence bounced nose around severely on approach.	No problem.	Extremely uncontrollable due to yaw.	
LM 72+0+11	141	B	7	Pro-yaw due to aileron.			Difficult to perform other than very gentle manoeuvres with ailerons only. Possible to perform sharper manoeuvres - but requires excessive use of rudder.	With rudder fixed the aircraft tends to develop yaw oscillations which increase in amplitude. Period moderate and can be suppressed with rudder.		Minor - but large heading oscillations increasing in magnitude may develop, rudder fixed.	No problem	Can be performed, but difficult to avoid some slip or skid.	
LM 66+0+11	135	B	6	Moderately strong pro-yaw with aileron.			Only very gentle turns possible without rudder coordination and this must still be used to check oscillation. When fully coordinated, roll rate becomes rather sluggish.	Also tends to develop a slow divergent oscillation in yaw if rudder fixed.		Not noticeable.	No problem.	Manageable, but difficult to perform without skid or slip.	
LM 66+0+11	130	C	7	A wild amount of positive yaw with aileron requires constant cross controlling. The aileron is a better yaw control than the rudder.	Roll control adequate, but could not use it all due to yawing.		Coordination on turn exit and entry difficult due to cross controlling, but very little required in steady turns.	The moderate frequency, undamped yaw oscillation is easily excited with aileron but relatively easily eliminated with rudder - nevertheless seems extremely loose in yaw.		No problem.	No problem.	Very sloppy.	
LM 60+0+11	122	B	5½	Pro-yaw with aileron	Again sluggish.	Lacks crispness - overshoots headings too easily.	Opposite rudder required in all sharper manoeuvres. Very gentle manoeuvres can be made with ailerons only.	Some tendency to oscillate (due to turbulence) if rudder left alone.			No problem.	Used full aileron and required opposite rudder to coordinate.	
LM 60+0+11	131	C	6½	Enormous pro-yaw with aileron which requires much attention to cross control of rudder.				Extremely loose in yaw, and a small rudder out of trim results in a very large β oscillation of long period, which appears divergent but can be suppressed with rudder fairly well.		No problem.	No problem.	Quite uncomfortable, but, by paying strict attention to rudder, came off surprisingly well.	
LM 60+0+11	127	E	6½				Constant cross-control required to coordinate any turns Ratio of aileron to rudder in preceding is about one to one.					If you do not concentrate and apply correct rudder, it is a bit hairy. This happened on the sidestep manoeuvre.	Interesting model to fly. Could get used to it if I were Orville Wright.
LM 55+0+11	106	C	5½	Pro-yaw.	Seemed adequate.		Pro-yaw with aileron prevents aileron-only turns since on roll out it is absolutely impossible to stop on heading as desired and make small changes around it without rudder. The rudder coordination required is opposite to the aileron applied and, to me, is uncomfortable.	Oscillation not evident.	Continuous small rudder applications required to hold the heading since, if the rudder position is not correct, enormous sideslips build up rather rapidly.	No problem.	No problem.	No problem, although opposite rudder was required.	

4b(iii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50+0+11	122	B	5	Pro-yaw with aileron but also tends to oscillate in yaw.	A bit sluggish.		Rudder coordination required to control yaw oscillation even for very gentle manoeuvres. Rudder needed to suppress heading variation on approach.	Yawing oscillation excited by aileron inputs. Oscillation possibly excited by turbulence on approach.			No problem.	Satisfactory but required much rudder work to keep coordinated.	
LM 50+0+11	104	C	5	Moderate pro-yaw with aileron exciting yawing oscillation, rendering aileron only turns impossible.	Adequate.		Opposite rudder required to coordinate in presence of yawing oscillation - not too difficult.	Moderate pro-yaw with aileron excites yaw oscillation which takes too long to damp out so that rudder is required to keep β reasonable. If rudder not trimmed, unexpectedly high oscillatory β results.		No problem.	No problem.	Somewhat jerky but quite good. Required opposite rudder.	
LM 44+0+11	103	C	5	Slight pro-yaw.	Adequate.		Requires opposite rudder on turn exit and entry, but this is easily accomplished.	A slight amount of pro-yaw with aileron starts the neutrally damped directional oscillation going - particularly on turn exit - and the amplitude builds to such an extent that it appears divergent, requiring rudder to save the day.	The powerful rudder is more than adequate, but if proper trim position is not found enormous sideslips build.	Tended to set off oscillation on approach, but easily stopped.	No problem.	Went well.	
LM 40+0+11	138	B	5	As roll develops adverse yaw occurs.			Requires considerable use of rudder to coordinate. No tendency to oscillate but can get some overshoot due to swing in yaw during aileron only turns.			Minor (± 2 deg.)	No problem.	Manageable, but required much attention to rudder.	
LM 40+0+11	120	C	7½	No difficulties with yaw due to roll.	Adequate.		Very difficult especially on turn exit when nose swings further in turn direction.	Divergent oscillation that takes off quickly on entering or rolling out of aileron turns. Initial turn entry seems reasonable, but within a few seconds the nose yaws violently out of turn and rudder is required to save the day.		Starts oscillation going in straight and level flight, but seemed light on approach.	No problem.	Much attention required to coordinate S-turn, which went surprisingly well.	
LM 24+0+14	141	B	6	Adverse.			With rudder fixed, results in yaw angles of about 15 deg. if moderately sharp turns attempted. Can be mostly suppressed with rudder, but difficult to eliminate entirely.	Relatively large heading changes on approach with rudder fixed - possibly partly due to oscillations in yaw as small roll control actions applied.			No problem.	Manageable, but difficult to avoid yaw.	
LM 72+0-4	119	B	7	Aileron produces strong pro-yaw response (greater than roll response).			Excessive rudder coordination required in all manoeuvres to control both pro-yaw and the strongly divergent, slow yaw oscillation.			Not particularly noticeable since aircraft oscillates in yaw anyway.	Can be handled without much difficulty.	Very difficult to perform without much slipping and skidding.	

4b(iv)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRES	MISCELLANEOUS
LM 72+0-4	134	C	6½	Much too much pro-yaw with aileron.	Adequate but could not be used rapidly or else the yawing got out of hand.		Much too much pro-yaw with aileron together with the neutrally damped oscillation. Enormous β results if rudder not used. Aileron only turns absolutely impossible. Coordination awkward in that first opposite rudder required on turn entry and then small inputs to suppress the oscillation.			No problem.	No problem.	S-turn was jerky and I felt uncomfortable about a touchdown since small yaw jostles still existed.	
LM 65+0-3	88	C	5½	Pro-yaw is fairly powerful, exciting the undamped yaw oscillation to such an extent that rudder must be used in turns.	Adequate.		Turn exit especially uncomfortable since it is difficult to find the correct amount of rudder and hunting takes place. Turn entry also requires opposite rudder initially, followed by small amount of rudder into turns.	Pro-yaw is fairly powerful, exciting the undamped yaw oscillation to such an extent that rudder must be used in turns.		No problem.	No problem.	S-turn acceptable but rudder absolutely necessary.	
LM 56+0-1	136	B	5	Response to aileron is roll followed by pro-yaw.			Pro-yaw in turns requires some opposite rudder to coordinate, and more as turns made sharper.	The moderately long period yaw oscillation is not difficult to control, but fairly large yaw excursions (±20° on approach) can occur if rudder held fixed.		Not noticeable.	No problem.	Satisfactory, but too much opposite rudder required.	Major objection is yaw buildup when rudder held fixed. Rating otherwise would be one point better.
LM 56+0-1	103	C	5½	Pro-yaw with aileron.	Adequate.		Aileron only turns impossible due to swinging. Coordination requires opposite rudder, but is accomplished fairly easily.	Neutrally damped directional oscillation.	Very low weathercock stability. Slight rudder out of trim results in enormous β.	No problems.		Satisfactory, but did require squeezing opposite rudder.	Uncomfortable model.
LM 50+0+0	75	A	3	Yaw due to aileron seems about zero - if anything may be slightly pro-yaw. Yaw due to roll may also be slightly pro.		Some tendency to overcontrol with rudder.	Can fly this airplane with aileron only most of the time. However for rapid roll reversals and in turbulence it is necessary to use rudder. Coordination not easy, but not much happens if pilot miscoordinates. Rudder requirements small and, in fact, better to stay off rudder until β of sufficient magnitude is generated.			Turbulence effects small.		Good approach, fair sidestep.	Overall can do reasonable job with precision in heading and bank control.
LM 50+0+0	95	B	4	No yaw due to aileron.	Roll control good (response could be a shade faster).			Yaw oscillation of a long period develops with rudder input. Rudder required to minor extent throughout flight to suppress yaw oscillation.		Turbulence effects minor.	No problem.	No problem.	Without yaw oscillation would be a good model.
LM 50+0+0	42	C	2				Only deficiency is that after the steady turn is established a slight slip (ball to inside of bank) occurs which rectifies itself if left alone. Easily coordinated.						Very nice.

4b(v)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50+0+0	44	D	3			Rudder input in either direction does not produce any roll.	Turns without rudder produce some sideslip initially, but aircraft soon recovers to a coordinated turn.						Good model. Responsive, and can be flown accurately and comfortably.
LM 50+0+0	108	E	4	Adverse yaw due to roll noticeable.			Aileron turns were coordinated (reasonably), however attempts at using rudder on entering turn resulted in uncoordinated turns.					Had to cross control in sidestep.	
LM 43+0+2	119	B	4	No appreciable yaw response to aileron; slightly adverse if any.	Quite good.		Some use of rudder required on occasion to check oscillation, but practically none to assist aileron.	Very slow oscillation in yaw develops if rudder held fixed.		Hardly noticeable.	No problem.	Fairly good manoeuvre. Some tendency to overshoot in yaw in such sharp manoeuvres.	
LM 43+0+2	115	C	6	Yaw due to roll not discernible. Initial roll entry feels fine but the nose soon digs into turn feeling like it will continue to yaw until it hits the tail.	Adequate.	Rudder quite powerful and readily stops yawing caused by turns. A slight rudder out of trim results in ever increasing β.	Rather low frequency rudder inputs required to coordinate.	Oscillation seemed undamped and of long period when excited in straight and level flight, but was not a problem.		No problem.		Sloppy due to nose tucking in.	
LM 35+0+4	87	C	5		Adequate.	A very small rudder out of trim results in a very large β in a very short time due to the high yaw sensitivity and apparently low weathercock stability.		Oscillatory characteristics seem evident only on turn entry when the initial swing is out of turn followed by a seemingly divergent swing into turn.	There appears to be a small static instability making aileron only turns impossible, although the powerful rudder can readily overcome the sideslip tendency.	No problem.	No problem.	No problem (surprisingly).	
LM 25+0+8	140	B	7	Pronounced adverse yaw apparently due to aileron but could be due to roll (or both).	Roll control a bit sluggish, at least compared with yaw due to rudder.		Considerable use of rudder required to coordinate manoeuvres. Good coordination difficult due to adverse yaw and oscillatory effects.	Tends to oscillate if distrubed and rudder held fixed.		Effects small, but oscillation will grow once started.	No problem.	Manageable, but difficult to perform smoothly.	
LM 25+0+8	101	C	6½	Adverse yaw plus static divergence preclude aileron only turns.	Adequate. Not fully utilized due to yawing.		Adverse yaw plus static divergence preclude aileron only turns. The difficulties can be overcome with rather natural use of rudder, but constant inputs are required or else the static divergence takes over.		Adverse yaw plus static divergence preclude aileron only turns. On roll in the nose just continues to yaw out. If rudder trim position not correct, large β increase results.	No problem.		This manoeuvre went well but much rudder required to keep things going straight.	
LM 71+0-18	138	B	6½	No appreciable initial yaw response to aileron, but strong pro-yaw as roll develops.			Aileron only turns must be kept gentle - large swing occurs otherwise. Considerable opposite rudder required in reversing turns and on turn entry and exit.	Aircraft tends to oscillate one or two cycles if disturbed in yaw.		Minor.	No problems.	Manageable with considerable use of rudder.	
LM 71+0-18	131	C	7½	Initial response to aileron feels fairly good, but this is immediately followed by an enormous pro - yaw probably due to a large positive N_p which requires cross controlling of large amplitude.	Adequate.			If the turn is left alone after achieving fairly steady conditions, a seemingly divergent oscillation starts which is easily stopped with rudder.		No problem.	No problem.	Very uncomfortable due to yaw with roll and opposite rudder requirements.	

4b(vi)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 65+0-16	124	B	5½	Pro-yaw.	Response to sharp aileron upset unpleasant.		Pro-yaw with aileron requires opposite rudder in starting and stopping all turns.	Tends to oscillate (divergent osc.) in yaw unless checked with rudder. Long period so can hold quite steady heading on approach.		No noticeable effect.	No problem.	Requires careful use of rudders.	
LM 65+0-16	125	C	6½	Adverse yaw does not take hold sharply as in many models, but comes in a [illegible]ally. Hence probably due to roll rate rather than aileron input.	Adequate.		Cross controls required on turn entry and exit which could probably be learned fairly quickly but is not comfortable.	The undamped directional oscillation is fully excited by the adverse yaw precluding aileron only turns.		No problem.	No problem.	Uncomfortable due to large sideslips that built up on turn reversal.	
LM 59+0-13	87	C	6½	Delayed pro-yaw is uncomfortable and starts the nose swinging into a turn. The yaw is "delayed" since there is no initial yaw response to aileron, but very soon after the input the yaw begins.	O.K.		Pro-yaw requires opposite rudder during manoeuvres, to which I object.		The static instability keeps the nose going in turns, precluding aileron only turns.	No problem.	No problem.	Not too uncomfortable, but fairly sloppy.	
LM 50+0-10	64	A	5½	Moderate adverse yaw due to aileron. Roll control not bad but did seem to generate pro-yaw due to roll rate.		Easy to overcontrol with rudder and yaw rate difficult to control. Heading control poor.	Difficult. Yaw rate characteristics give pilot a feeling of insecurity and restricts amplitude and rate of manoeuvres.	Feels very loose directionally.			Not noticeable.	Sidestep done slowly because pilot felt uncertain of sidestep control.	
LM 50+0-10	137	B	6½		Rather sluggish.		Manoeuvres can be coordinated by continuous attention to rudder.	Oscillatory characteristics in yaw dominate. Slow oscillation occurs intermittently if rudder held fixed. Not always present.	Very large heading variations can occur if small rudder input is applied and not checked.	Effects not particularly noticeable.	No problem.	Manageable if close attention given to rudder.	
LM 50+0-10	57	C	5½	Low frequency instability set off by adverse yaw causing large β in steady aileron turns.		No real problem holding heading quite well using rudder.	Turn coordination quite easily accomplished with the powerful rudder. Very little rudder required on turn entry and during turn, but it is virtually impossible to prevent an uncomfortable swing from developing on turn exit. If rudder not used the swing is enormous.	Low frequency instability is set off by adverse yaw causing large β in steady aileron turns.		Causes nose to swing ± 15° and more if rudder not squeezed on.	No problem.	Swing on roll reversal somewhat uncomfortable, but rudder more than adequate to cope with β resulting.	
LM 43+0-7	101	C	6	Adverse yaw.	Adequate.		Fairly natural, but the constant changes necessary make for too much work.	Undamped oscillation, which actually feels like a static divergence since the period is so long that one cannot wait for the return of the motion, prevents aileron only turns.		No problem.	No problem.	Very jerky in yaw and somewhat uncomfortable although we ended up heading in the right direction over the right spot.	
LM 39+0-5	123	B	7	Adverse yaw with aileron.	Adequate.		Requires considerable use of rudder to coordinate. Sharp manoeuvres very unpleasant.	Oscillatory yaw characteristics which make heading inaccurate on approach (± 5 deg.), and leads to overshooting in turns.		Not noticeable.	No problem.	Difficult to make smoothly.	
LM 39+0-5	124	B	6	Adverse yaw to aileron followed by pro-yaw as turn develops. Unpleasant yaw effect if rudder moved quickly either side.			Rudder required in all manoeuvres, particularly if sharp.	Oscillatory in yaw. Tends to oscillate, unless rudder used to suppress, during approach.		Not noticeable.	No problem.	Managed O.K., but required much rudder coordination.	

4b(vii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 39+0-5	100	C	8	Adverse yaw is enormous.	The roll control did not hit its stops, but I did not dare use it all due to the enormous adverse yaw.		(See next column)	Lightly or neutrally damped oscillation makes coordination and smooth manoeuvres impossible. Oscillation was ever on the verge of starting due to control inputs or turbulence.	Slight out of trim on the rudder results in very uncomfortable sideslip angles.	Not causing rapid motions, but does excite the oscillation.	No problem.	I think it requires "substantial pilot skill and attention" to get the a/c around the S-turn and going in the right direction.	

4c FLIGHTS AT $|\phi/\beta|_{DR} = 0.2$ WITH THE LOCATION OF THE $\phi - \delta_a$ TRANSFER FUNCTION MOVED AROUND $\omega_d = 0.25$ RAD/SEC, $\zeta_d = -0.1$

4c(i)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 33-10-6	132	C	6½	Very strong pro-yaw with aileron.	Adequate.		Very strong pro-yaw with aileron can be counteracted with rudder, but too much attention required. Cross control required on turn entry and exit. Touches of rudder required during steady state turns to keep nose from wandering badly.		Slight rudder out of trim sets off enormous β which appears to be unbounded.	No problem.	No problem.	Worked out surprisingly well, but lots of rudder required.	
LL 27-10-2	98	C	7½	Powerful pro-yaw with aileron together with apparent static instability in yaw precludes aileron only turns.	Quite brisk.		Requires opposite rudder which is uncomfortable.		Constant small rudder inputs required to prevent the build up of enormous β in very short times. Inattention could be dangerous.	No problem.	No problem.	S-turn went quite well but with constantly varying rudder and with a lot of attention to rudder required.	
LL 25-10+0	61	A	5			Rudder forces light.	Moderate difficulty in coordinating. Too much effort required to coordinate, and pilot induces oscillations.	Directional stiffness seems slight. Feels as if aircraft can get away from pilot directionally.		Turbulence generated large β.			Only a fair to poor configuration.
LL 25-10+0	57	C	6½	Pro-yaw with aileron excites the low frequency divergent oscillation.			The divergent oscillation excited in turns can be overcome with rudder, but too much attention is required to accomplish this. Roll reversals could be accomplished with rudder assistance but were uncomfortable.	Pro-yaw during aileron turns excites the low frequency divergent oscillation so that the first swing is into the turn, the second out etc.		No real problem.	No problem.	Uncomfortable due to yaw with roll.	
LL 22-10+2	102	C	8	Immediate and powerful pro-yaw with aileron.	Full aileron was used in S-turn but was generally adequate.		Not natural and once established in the bank, small rudder applications are necessary.		Immediate and powerful pro-yaw with aileron together with the static divergence in yaw require too much concentration on rudder applications. Enormous β builds moderately quickly from small out-of-trim rudder.	No problem.	No problem.	Not very comfortable and with these characteristics I would not like to do such a turn without a safety pilot.	
LL 16-10+9	142	C	6½	Slight pro-yaw starts nose into turn and when aileron is backed off to hold the bank angle, the nose yaws violently out of the turn and feels as if it will not come back.			Coordination with the very powerful rudder control is accomplished fairly easily, but too much attention required.		Small rudder out of trim results in ever increasing β.	No problem.	No problem.	Went quite well.	
LL 34-10-19	101	C	6½	Aileron only turns impossible.	Moderately weak.		Aileron only turns absolutely impossible. The rudder coordination necessary is fairly easy to learn but as it is opposite rudder, some thought is required.	Not evident as such but a static divergence is present.	Static divergence in yaw required constant rudder applications.	Turbulence not bothersome but the static divergence is always being excited.	No problem.	This manoeuvre went surprisingly well but did require rudder concentration.	
LL 29-10-14	97	B	4	Pro-yaw with aileron.	Roll control good but a bit slow. (Roll rate with full aileron quite moderate.)	Rudder control lacks precision.	Pro-yaw with aileron inputs required rudder coordination to prevent slow yaw oscillation, particularly on turn recovery.	Long period oscillation builds to at least ± 25°.		Turbulence effects barely noticeable.	No problem.	No problem.	Suppression of yaw oscillation the major reason for the rating given.

4c(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 29-10-14	88	C	5	Moderate pro-yaw with aileron starts the nose digging into the turn.	Adequate.	The powerful rudder was adequate to stop the statically divergent β build up, but too much attention required even in straight and level flight. For example, time for sideslip to build to one ball width was 3 to 4 seconds.		No oscillatory characteristics, only a static divergence.	Moderate pro-yaw with aileron started the nose digging into the turn, and the static instability in yaw kept it going.	No problem.	No problem.	The opposite rudder coordination necessary in turns made the sidestep manoeuvre a little sloppy.	
LL 25-10-10	57	C	4	Yawing was not started during turn entry or exit but developed during steady turns.				Aileron only turns were good on roll in and roll out, but a low frequency, apparently divergent, oscillation occurs sometimes during steady turns.		No problem.	No problem.	S-turn done almost exclusively with ailerons, with just a hint of rudder to touch it up.	
LL 25-10-10	56	D	4				Tendency for slip in turns not using rudder - recovery produced yaw in direction of roll. Using all controls, no problem, a/c could be flown quite accurately with moderate concentration.	During straight and level the aircraft yawed through approximately 30 deg. with no tendency to dampen.					Good model.
LL 19-10-3	88	C	4	No yaw due to roll. The static instability in yaw precludes aileron only turns.	Adequate.		Well coordinated turns are easily accomplished with the powerful and positive rudder. Coordination is natural.	Oscillation is not evident at most times but on two occasions when the nose started swinging out of a turn on turn entry, it slowly came back and tucked into the turn.	Static instability in yaw is the only real problem. A few seconds of inattention to β allows very large values to build within seconds.	No problem.	No problem.	S-turn required coordination as the nose started to swing out.	
LL 14-10+5	103	C	4½	No perceptible yaw with aileron but shortly after roll starts the nose seems to hang up out of turn slightly, and then yaws into the turn in a divergent manner.		Enormous β will build rather slowly from very small rudder out of trim and consequently I had to be squeezing rudder almost constantly. This was not a great bother however.	Coordination required very little attention but did need squeezes of rudder.		A slow directional static divergence prevents aileron only turns.	No problems.			
LL 08-10+23	121	B	5½	Aileron produces marked adverse yaw.	Good.		All manoeuvres require considerable coordination. Pro roll rudder required when initiating turn, but a little opposite rudder often necessary after turn started.	Yaw oscillation period quite long. The oscillations die after a few cycles.		Turbulence effects on heading during approach quite marked.	No problem.	Required fair amount of rudder coordination.	
LL 08-10+23	106	C	6		Adequate.		The divergent rather low frequency oscillation together with the adverse yaw makes aileron only turns impossible.			No problem.	No problem.	No problem.	Turning response together with lack of weathercock stability make for "very objectionable deficiencies" requiring "major improvements" although I do not think that best available pilot compensation is required to achieve acceptable performance.
LL 03-10+76	129	C	7½	Enormous adverse yaw.		Enormous adverse yaw coupled with an apparently divergent oscillation makes for a very difficult directional control task.	Coordination extremely uncomfortable since rudder requirements change quite quickly from rudder into turn initially, to overcoming heading wander.			No problem.	No problem.	S-turn very uncomfortable. Fortunate to get direction straightened out before touchdown.	

4c(III)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 35-10-34	120	C	7½	Enormous pro-yaw with aileron requiring cross control on turn entry and exit. If turn not coordinated, the initial swing into the turn is followed very quickly by a seemingly divergent swing out which must be stopped by rudder.	Adequate.		Coordination not difficult with the very powerful rudder but requires a light touch since a small out of trim results in an enormous β build up.	Oscillatory characteristics not a problem as such, but yaw divergence is.		Noticeable but not bothersome in yaw.	No problem.	S-turn required lots of cross control on entry, reversal and exit.	
LL 31-10-29	106	C	5	Moderate pro-yaw with aileron excites the very low frequency, slightly divergent oscillation, preventing aileron only turns.	Adequate.		Rudder required in [illegible] to aileron input.	Moderate pro-yaw with aileron excites the very low frequency, slightly divergent oscillation preventing aileron only turns. The oscillation will start even in straight and level flight, particularly if slight out of trim rudder exists.		No problem.	No problem.	No problem except that opposite rudder required.	
LL 26-10-21	103	C	4½	No perceptible yaw with aileron but shortly after roll starts, the nose yaws into the turn in a divergent manner.	Felt quite pleasant.	Enormous β will build rather slowly from small rudder out of trim and consequently I had to be squeezing rudder almost constantly. This was not a great bother however.	Required very little attention but did need squeezes of rudder.		A slow directional static divergence prevents aileron only turns.	No problem.	No problem.	No problem.	
LL 25-10-19	64	A	5	Initial roll response was fair but I could not determine if yaw due to aileron was pro or adverse. It seemed slightly pro.			Difficult because little rudder was required and rudder forces were so light that it was easy to overcontrol.	Directional stiffness seemed slight.		No noticeable effect.	No noticeable effect.		Manoeuvring is inhibited because of yaw generated. It is probably better to fly this configuration with aileron, keeping rudder inputs to a minimum.
LL 25-10-19	121	B	4		Good.		Small amount of opposite rudder required when initiating sharp turns.	Tends to develop slow yaw oscillation unless checked by rudder, but effort required very minor.	Not difficult to maintain steady heading on approach.	Negligible effects.	No problem.	Satisfactory, but required opposite rudder to coordinate.	
LL 25-10-19	120	C	6	Apparently a static yaw divergence on aileron turns. The initial yaw is into the turn but quite quickly the nose yaws out of the turn and must be recovered with rudder. Slightly pro yaw with roll but not in itself bothersome.	Adequate.		Turns can be coordinated but this requires a light touch on the rudder since a small amount of rudder out of trim results in an ever increasing β.			No problem.	No problem.	Required close rudder monitoring, but went well.	
LL 25-10-19	58	C	7½	Aileron turns impossible although in general the roll in and out are fairly smooth. On other occasions the nose swung into the turn starting a fairly low frequency yawing which was uncomfortable.	Approximately 30% of maximum aileron used on approach and although the S-turn went quite well, I did hit the aileron stop during reversal.			On occasion the nose swung into the turn starting a fairly low frequency yawing which was uncomfortable.				Approximately 30% of the maximum aileron used on approach, and although the S turn went quite well, I did hit the aileron stop during the reversal.	The steady state portion of the turn was most uncomfortable mainly from the large and varied wandering aileron inputs required. Straight and level flight even required quite a bit of aileron movement.

4c(iv)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRES	MISCELLANEOUS
LL 25-10-19	127	E	5					Long period yaw oscillation which caused considerable grief on roll reversal, but during gentle turns is hardly noticeable. Yaw oscillation is pronounced but slow and subtle in effect.					
LL 21-10-14	99	C	4½	There may have been a touch of adverse yaw with aileron but this presented no problem.			Turn entry and steady turn performance require very little rudder and are fairly pleasant. Coordination easy and natural.	No oscillatory characteristics.	Rudder required to stop slow apparently static divergence on turn exit. If the trim rudder position is not correct the β builds.	No problem.	No problem.	No problem.	
LL 14-10+0	130	C	7	Large but manageable adverse yaw.	Adequate.		Rudder necessary to counteract adverse yaw could be learned, but I had a definite tendency to overcontrol. Coordination fairly easy, but if attention was not given to this aspect, the aircraft seemed to want to wind up into the turn.	The divergent oscillation could be set off at any time by attempting an aileron only turn.	Extremely loose in yaw, and a small rudder out of trim results in what appears to be a static divergence.	No problem.	No problem.	S-turn went well but required rudder attention.	

4d EFFECT OF CHANGING $|\phi/\beta|_{DR}$; $|\phi/\beta|_{DR}=0.2,\ 0.75,\ 1.5$ CONFIGURATIONS WITH $\omega_\phi=\omega_d=1.0,\ 0.5, 0.25$ RAD/SEC FOR EACH $|\phi/\beta|_{DR}$ AND WITH $\zeta_\phi=\zeta_d=0.3,\ 0, -0.2$ FOR EACH FREQUENCY

4d(i)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100+30+30	72	A	1½	Yaw due to aileron about zero. Cannot generate very much β no matter what I do.	Roll control a little stiff but O.K.		Very little rudder (if any) needed for coordination. Can fly with aileron only if desired.	No oscillatory tendencies. Damping seems good and frequency moderate.		Turbulence has little effect.	X-wind not very noticeable.	Sidestep: can do easily and well.	φ/β low. All around all good features! Nothing objectionable that is obvious. Good performance by pilot. Good precision.
LH100+30+30	90	B	2	No apparent adverse yaw.	A shade sluggish in roll.		Easy to coordinate and manoeuvre.			About ± 3 deg. heading variation due to turbulence.	No problem.	No problem.	Pleasant model.
LH100+30+30	54	C	2				Aileron-turns like a kiddy-car.			Turbulence noticeable but not bothersome.			Very nice!
LH100+30+30	70	C	2	No unwanted yawing on turn entry.	Would like a touch more roll sensitivity to go with very powerful rudder.		The A/C has a tendency to fall into turns slightly, but this is no bother.	Just a hint of an oscillation in steady banks, but this dies out rapidly.		No turbulence effect.	No X-wind effect.	Sidestep smooth.	No problems.
LH100+30+30	105	C	2	No yaw due to roll.	Roll control adequate.		Coordination easy with ball about ¼ width into turn.	No detectable oscillation.		Turbulence noticeable but not bothersome.	X-wind required a touch of rudder.	Sidestep went well.	No problems. One of the best behaved models flown on the programme.
MH100+30+30	60	A	2	No yaw due to roll or aileron.	Roll control a little heavy.		Coordination seemed easy and no oscillatory tendencies.			Some turbulence and structural feedback bothered me a little.		The sidestep was O.K., but seemed to require effort to apply left aileron on initiation of the manoeuvre.	No special piloting techniques. Overall good, stable and easily controlled configuration.
MH100+30+30	72	A	2		Aileron forces a little stiff. I would prefer slightly more initial acceleration with lighter forces.		This is again a two control airplane. Rudder required is minor - may give better heading precision but it also is easy to overcontrol thereby possibly generating small amplitude oscillations.				Did notice X-wind to right. May be actual X-wind effect.	Hit stop with aileron on sidestep, but O.K.	No problems.
MH100+30+30	79	B	4		Roll response rather sluggish.		Easy to coordinate turns.			Very small response to turbulence.	In X-wind approach, found it necessary to use full left aileron in a coming out of "S" turn. For this reason rated as 4.		Generally quite pleasant to fly.
MH100+30+30	68	C	8	Yawing with aileron not noticeable.	Roll control power low - hit stops in normal manoeuvres without getting desired roll rate.		Aileron only turns no problem.			An uncomfortable roll-yaw motion occurred continuously during level flight and, during steady turns, the bank angle varied a small amount, but randomly - probably the influence of turbulence.	X-wind required approx. ½ aileron.	Hit stop on S-turn entry and at roll out the wings could not be levelled except by sideslipping to the right. If this condition had not been present I probably would have given it about 5, but we would have crashed in a +10 deg. bank if negative rudder had not been applied.	
MH100+30+30	70	C	7	No problem.	Roll control weak during manoeuvres; started with the ball to the same side as roll initiated.		Coordination helps on turn exit.			Continuous aileron changes required to keep desired bank angle, even when cruising straight and level. Directional disturbances quite low.	X-wind requires about ¼ aileron and was against the stop in turn entry.	Kept β small to make sure we could recover at end of "S" turn and things worked out well.	Special technique - be ready with rudder on turn exit.
MH100+30+30	82	D	7	At minimum.	Roll control responsive.		Coordination good - lots of rudder control.	Very good. No yawing encountered.		Turbulence effect minimum.	X-wind about ¼ ball skid to right and some left aileron heaviness.	Full aileron required to recover at bottom of "S" turn. Generally - appeared to be an excellent model until final "S" turn where full control deflection required. Otherwise O.K.	Good model to fly. Please discuss this with me as to rating.

4d(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
MH100+30+30	109	E	2½	Adverse yaw on entering and recovering from turns, but not very noticeable.				Thought I noticed a little roll oscillation during one turn.			No trouble on approach or doing sidestep.		Generally nice model.
MH100+30+30	109	E	5		A/C very sensitive to roll and yaw control and rather a jittery model. A/C sensitivity could be due to turbulence.					(See comments under roll and yaw control)	Only had about ¼ inch left stick remaining on approach.		A/C responses I like, however, approach was jerky and controls had to be handled lightly.
MH100+30+30	110	E	3	Some yaw due to roll is noticeable.			Pleasant to coordinate in turns.				Lots of roll control on this approach, but still had to hold on some aileron.		(I knew the model number before we started.)
MH100+30+30 NB: For this evaluation N_{δ_r} was reduced from 0.75 to 0.195 $\frac{rad/sec^2}{in.}$	105	C	5½	Not perceptible.	Could be more powerful, but adequate.		Continuous attention required to keep the wings at the desired bank angle - even when straight and level.	Not evident.		Felt very unsteady in roll as the aileron required changed in an unpredictable fashion. Bouncing us around quite severely below 500 ft. AGL due to external gusts. (Flight terminated after this model.)	About ¼ full aileron and 1 inch of rudder required to hold the X-wind which was not objectionable.	Hit the stop on "S" turn entry, the right stop momentarily when reversing and then left stop again on roll out. I was getting the desired roll rate, in general, but it did feel that we got everything sorted out just before touchdown more by good fortune than by good handling qualities.	
MH100+30+30 NB: For this evaluation L_{δ_a} was increased from 0.4 to 0.6 $\frac{rad/sec^2}{in.}$	116	C	3	No problem.	Adequate.		No coordination necessary.	No oscillatory characteristics.		A slightly too high turbulence response in roll and yaw with a somewhat uncomfortable phasing is the only objectionable part of the model.	X-wind required approx. ¼ of full aileron, but left plenty for the S-turn.	I did the S-turn rather vigorously and things turned out well.	
HH103+29+29	79	B	8½		Inadequate roll control.		Very gentle manoeuvring only, <5 deg, otherwise up against roll stops holding off bank. The use of rudder to coordinate turns makes little difference under these circumstances.			Turbulence response noticeable in roll.		Very difficult to complete gentle sidestep manoeuvre.	Yaw doublet gave roll response.
HH103+29+29	54	C	10				Aileron only turns possible and quite surprisingly the ball stays in the centre without rudder assistance.		A touch of rudder, which results in very low β, required full aileron to stop roll.	Constantly varying, random aileron required.		Full aileron required on approach and during S-turn, when we would have hit in approx. 10 deg. of bank if wing had not been picked up with rudder.	
HH103+29+29	82	D	5	No yaw produced by roll.	Roll control marginal. Requires large stick movements for effective control.	Rudder control good.				Very unstable laterally. Turbulence appeared to increase instability. Model would not correct for wing drop occasioned by turbulence.	No special problem - ½ ball skid and some left aileron heaviness.	Sidestep O.K., but required some rudder and some aileron to recover.	Generally, problem of general stability - objectionable. Requires constant attention.
HH103+29+29	109	E	10		Fast stick movements required and then overcontrolling.			Very oscillatory in roll.			Out of control in roll on approach.		Bad roll control overshadows all other characteristics.

4 d(iii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HH103+29+29 **NB**: For this evaluation N_{δ_r} was reduced from 0.75 to 0.095 $\frac{\text{rad/sec}^2}{\text{in.}}$	106	C	10	No yaw due to roll.	Roll control was obviously inadequate for the dihedral present, but adequate for manoeuvring.		No coordination necessary but if rudder used to get the ball smack in the centre, opposite aileron required in the turns.	No oscillatory problems.		After the approach and "S" turn, where control was extremely marginal, only a 10 would suffice. Full left aileron required for about 95% of approach along with approx. 80% rudder and on occasion even this amount of aileron was not sufficient. During circuit flight the turbulence disturbances in roll were very bothersome and were causing excursions of ±10 deg. of bank. This was requiring ±30% of aileron to hold the desired bank angle.		S-turn required left rudder to pick up the wing before touchdown - extremely uncomfortable.	I was prepared to give it something around 6-6½ in the circuit.
HH103+29+29 **NB**: For this evaluation, L_{δ_a} was increased from 0.4 to 0.6 $\frac{\text{rad/sec}^2}{\text{in.}}$	116	C	9				Enormous roll with sideslip. About ¼ ball of sideslip took up full aileron. No rudder required in turns to coordinate, but did need it to overcome disturbances.	Not evident.		Constant large amplitude disturbances which require as much as ¼ aileron to control.	Stick was about 80% to full left stop but never actually hit stop until in S-turn.	Felt as though I could lose it any time during S-turn.	
LH100+0+0	31	A	5½	Low N_{δ_a}.			Coordination is required and moderate to heavy pilot effort required to do a good job.	About zero ζ_d. Most difficulty in controlling heading, strong tendency to maintain yaw oscillation. Probably improve situation by increasing ζ and decreasing Dutch roll period. Period of this configuration seems to be about 6 to 8 sec.					L_β about zero. Relatively low N_β. I believe I can do the mission, but must work too hard.
LH100+0+0	92	B	4	No yaw response to aileron.	Roll control good (a bit sluggish)	Requires light use of rudder in all manoeuvres to suppress oscillation but easy to accomplish all tasks.		Slow oscillation in yaw if rudder left alone.		No problem. Heading variation due to turbulence ±4 deg.	No problem.		
LH100+0+0	50	C	6½				Aileron turns possible - ball did not stay in centre but the oscillatory movement was small enough to ignore.	On roll out, after everything seems sorted out, a neutrally damped oscillation of around 6 sec. period and bothersome amplitude started. This happened several times on turn exit.		The turbulence itself is not bothersome, but it does set off the yawing oscillation which is uncomfortable.	No problem.		
LH100+0+0	77	C	5½	No yaw due to roll.	Quite pleasant.	The rudders are so powerful that a very light touch on the controls is required to prevent overcontrolling.		Directional oscillation starts almost any time, but never reaches an alarming sideslip - in fact, it damps out.		Turbulence seems to start the oscillation off.	No problem.	No particular problem but could not stop a slight heading jostle before ground contact.	
LH100+0+0	78	C	6	Yaw due to roll positive but relatively small and not really a problem except that it starts the sideslip which excites the oscillation.	O.K.	The powerful rudder can hold the ball in the centre, but too much attention required.		Undamped directional oscillation is continuously being excited by control inputs and by turbulence.		Turbulence starts the oscillation.	No problem.	No problem.	
LH100+0+0	111	E	4½	Had to use opposite rudder on entering some of the turns.				Yaw oscillation of ±7 to 8 deg. when straight and level with feet off rudders. During turns this is annoying but period and frequency are such that it is very controllable.					

4d(iv)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
MH100+0+0	62	A	4	Seems to have adverse yaw due to N_{δ_a} but only moderate.	Roll control O.K.	Rudder forces light. Precision of rudder control not very good, but is reasonable. Heading control a little sloppy.	Coordination is somewhat of a problem due to tendency to overcontrol.	Dutch roll oscillation easily disturbed due to low damping.		Responds to turbulence moderately.		O.K. with careful coordination.	Overall fairly good pilot performance.
MH100+0+0	91	B	5		Sluggish roll control.	Poor harmony between roll and yaw.	Little rudder coordination required in manoeuvres. No peculiar yaw response.	Yaw oscillation following rudder input persists. Manoeuvres can be carried out if oscillation suppressed.		Heading variation ± 5 deg.	O.K.	O.K.	
MH100+0+0	69	C	7½		If ball out to same side as turn at turn entry, the roll response is extremely weak.		Seemed to constantly creep on positive aileron due to ball being out to the right, but when the ball brought back to the centre no aileron required. Can get more roll with rudder than with aileron.	Ball must be kept in the centre or the oscillation in roll gets out of bounds and we run out of aileron. Oscillation quite bothersome especially in roll.		Turbulence excites oscillation but controllable.		About ½ aileron on approach.	
MH100+0+0	107	E	7½		Roll control weak. On occasion stick is on left stop - especially on final approach. Full stick gives 10 deg. of bank in 2 sec.		Tendency for turn to tighten up when bank applied.				(See roll control comments)	Able to perform sidestep.	Worst feature is roll control although yaw excursions are a close second.
MH100+0+0 NB: For this evaluation L_{δ_a} was increased from 0.4 to 0.6 $\frac{\text{rad/sec}^2}{\text{in.}}$	116	C	7½	No problem.	Quite adequate.			An undamped oscillation would start any time in both roll and yaw, which was readily suppressed with rudder.		Large roll disturbances present at all times requiring much too much work on the aileron. Very severe.	Took approx. ½ aileron.	Very unsteady due to roll disturbances.	
HH100+0+0	31	A	8	N_{δ_a} - not possible to determine magnitude or sense.			Difficult to coordinate. Not able to make precise roll out and control bank angle and yaw rate.	Dutch roll damping seems low. Almost constant roll oscillation.		Very responsive to turbulence.		Not able to complete terminal manoeuvre due to lack of aileron control.	L_β high. Very poor configuration for the mission. Probably can be corrected by decreasing L_β and increasing Dutch roll damping.
HH100+0+0	89	B	7½	No appreciable yaw due to roll	Roll control inadequate. Low aileron effectiveness and turbulence response dominate assessment.					Turbulence effects in roll and yaw quite sharp. Frequently against aileron stops when correcting for gusts.	Just able to cope - but erratic.		Very unpleasant to fly and necessary to keep manoeuvres gentle.
HH100+0+0	84	C	10		Enormous aileron workload.		In steady banked turns consistently holding off 50% to 100% of aileron and even then the bank does not stay constant. Roll control completely inadequate if any β allowed but it is impossible to keep β small enough to stop aileron demands.	The oscillation is of moderate frequency and appears to build slowly in yaw and roll.		Turbulence continually disturbs the roll especially, requiring constant attention.			Would have been a 9 without the approach. Full ailerm required for at least ½ of approach and could not get into sidestep without sideslipping.
HH100+0+0	112	E	10		Roll control weak.					Full aileron control required to stop roll upsets.			Did not do approach since control lost in circuit.
HH100+0+0 NB: For this evaluation L_{δ_a} was increased from 0.4 to 0.6 $\frac{\text{rad/sec}^2}{\text{in.}}$	116	C	9½	Not detectable.			Enormous roll with sideslip. No rudder required in turns to coordinate but did need it to overcome disturbances.	Not evident.		Constant large amplitude roll disturbances which require as much as ½ full aileron to control.	Aileron hard against left stop for approx. 80% of approach. Felt as though a large gust could cause loss of control any time on approach.	Aileron hard against stop while levelling at end of "S" turn.	

4d(v)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100-20-20	47	B	5		Aileron response sluggish.	Rudder response sharp, poor harmony.	Difficult to maintain steady turn rate.	Tends to oscillate in yaw unless controlled.		Responsive in yaw to turbulence. Very steady laterally.			
LH100-20-20	41	C	4¼			The rudder is powerful enough to allow ready control of ball position.	Quite pleasant on turn entry and requires no rudder until oscillation begins.	Aileron only turns impossible due to directional oscillation that builds up after bank is established.		The turbulence was a factor in that it set off the directional divergence, but it was not too severe.			
LH100-20-20	114	C	7	No problem.	Adequate.		Turn exit and entry with aileron extremely pleasant but once established in steady conditions (even straight and level) the moderate frequency oscillation starts and rapidly grows to unmanageable amplitude in two swings. Can be stopped readily with rudder but requires constant attention.	Divergent directional oscillation overshadows all other characteristics.		Turbulence causing moderate disturbances in yaw - particularly on approach - which starts oscillation going.	No problem.	No problem.	
LH100-20-20	76	D	6		O.K.		Coordination can be achieved but requires lots of attention.	Lots of yaw develops when aileron applied and, unless stopped with rudder, continues to increase. Oscillation tends to increase unless stopped with rudder.		Quite susceptible to turbulence.	No problem.		Not a good model due to yaw oscillation and requires constant attention.
MH 98-20-19	65	A	6	Slight, overall appears to have pro-yaw due to aileron and roll.	O.K.			Main problem is that Dutch roll damping is negative and ϕ/β is high - probably over one. Very oscillatory, but pilot can do a reasonable job in damping out. Dutch roll was disturbed throughout approach and terminal manoeuvre. Must spend much time - constant - using rudder to damp. Aileron alone not able to damp out oscillation.		Turbulence does affect very much.		Reasonable.	Overall poor, but can be flown with reasonable precision on heading etc.
MH 98-20-19	94	B	6	No yaw resulting from aileron.	Very sluggish.		Rudder input produces yaw but is followed perhaps 2 sec. later by roll in same direction.	Oscillations are of fairly long period, but roll tends to diverge unless corrected.		Effects minor	Required ½ aileron and any small corrections to track put aileron against stop.	"S" turn required full aileron to recover.	All manoeuvres lack precision.
MH 98-20-19	69	C	8½	No great problem with yaw due to roll.	Roll control used up completely by small amount of β leaving nothing for manoeuvring.		Coordination absolutely necessary since the aileron required to hold the bank is not available unless β kept very small.	The oscillation was apparently divergent and mostly in roll.	Wild amount of roll with β.	The turbulence apparently set off the oscillation and I found myself on several occasions with full aileron quite unnecessarily (i.e. could prevent by centring ball).	About ¾ aileron for X-wind.	"S" turn went amazingly well.	
MH 98-20-19	76	D	8	Yaw due to roll is high with lateral instability developing.	Roll control requires large stick movement.		Can be coordinated, but requires full concentration.			A/C tends to oscillate a lot but in no specific pattern, probably due to turbulence.	X-wind has considerable effect on force required for wings level, but controllable.	Sidestep manoeuvre required full aileron deflection to recover.	Generally unsatisfactory, requires a lot of attention. Don't buy an airplane that flies like this!
MH 98-20-19	113	E	10					During aileron turns roll oscillation tends to take off bank.			Ran out of aileron control on approach and during sidestep manoeuvre.		

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HH100-20-20	75	A	9½	Pro-yaw due to aileron.			The big problem is inability to coordinate due mainly to negative dihedral. When using rudder to reduce β we generate rolling moments opposite to rudder; that is, left rudder - right roll.	Very strong rolling and yawing oscillation all the time and PIO tendency very strong.		Turbulence affects configuration strongly.		To make the step manoeuvre I had to use bottom rudder to roll to right.	This configuration probably could be rated a 10 if flown sufficiently because would possibly lose control.
HH100-20-20	90	B	8½		Roll characteristics dominant and very poor. Extremely sluggish in roll.			Tends to develop a slow roll oscillation.		Sensitive to gusts in roll, particularly, but also in yaw. Consequently all manoeuvres have to be quite gentle.	X-wind on approach - just managed to cope.	Difficulty in completing "S" turn. Loss of control in trying to line up with marker (ran out of aileron).	
HH100-20-20	77	C	10	Not significant on turn entry.	Enormous rolling with yawing which results in aileron requirements larger than that available.	The immediate effect of rudder appeared to be a positive L_β but it really is a large negative L_r. There was a negative L_β as shown in a steady sideslip.		Shortly after the bank came on an enormous roll-yaw oscillation of alarming magnitude started. Whether it was set off by turbulence or not is difficult to say but the problem was always there.		(See "oscillatory characteristics")	Full aileron required for latter part of approach.	Could not start "S" turn and could not get it in.	Special flying technique - eject.
HH100-20-20	76	D	10		Roll control not adequate but can be flown if no more than 10 deg. of bank used.		Requires constant application of rudder and aileron.	Oscillation in yaw not pronounced, tends to keep going without any sign of recovery.		Immense.	X-wind requires large aileron movements - hardly controllable.		Generally beyond control capability. Could not be flown with any degree of accuracy.
HH100-20-20	108	E	10		In turns and straight and level, full stick required to stop roll inputs.			Roll oscillations completely overshadow other characteristics.			Could not complete glide path as full aileron being used and a/c still rolling right.		
LM 50+29+29	74	A	3½	Initially pro-yaw with roll. Roll generates or maintains pro-yaw, but is not very large.	Roll response O.K.		Small rudder inputs only required to coordinate. Some tendency to miscoordinate due to cross control requirements, but still do not generate very large β	No real oscillatory tendency so we have good damping and good rudder gradient.		Little effect.	Little effect.	Sidestep fair - generated initially large β due to miscontrol with rudder. Recovered O.K., however.	Configuration can be improved but is probably acceptable.
LM 50+29+29	47	B	4½		Harmony poor. Aileron response sluggish.	Rudder response sharp.	Difficult to maintain a steady turn rate.	Tends to oscillate somewhat in yaw unless controlled.		Responsive in yaw to turbulence. Very steady laterally.			
LM 50+29+29	41	C	3	Some yaw away from turn on entry, but this vanished quickly and the turn appeared coordinated until a long period wander, which was convergent, showed up.			Small application of rudder sufficient to hold ball in centre.			No problem.	No problem.		
LM 50+29+29	111	E	3	Adverse yaw when rolling is quite noticeable.								Adverse yaw most noticeable during sidestep manoeuvre.	
MM 49+30+30	60	A	3½	At times I felt that the aileron was generating pro-yaw, but it did not seem consistent.	Roll control seemed reasonable.	Rudder forces did seem a little light and I overcontrolled. Some pilot induced yaw oscillation.	Coordination was fair, but I did have some difficulty.	Good Dutch roll damping so not much roll oscillation.				Rather poor, maybe fair, coordination in the step manoeuvre.	Good feature was feeling that I could manoeuvre without fear of getting into trouble.
MM 49+30+30	89	B	4		Roll control satisfactory.		Coordination by rudder required in turns only to check slow yaw oscillation.	Have to correct for slow oscillatory tendency in roll and yaw. Period in yaw and roll long enough to be corrected easily, but a nuisance.		Turbulence effects minor.	X-wind easily corrected.	Sidestep managed without problems.	

4d(vii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
MM 49+30+30	69	C	7	Adverse yaw due to roll not too bothersome but does contribute to sloppy turn exit (especially).	Roll control is very weak and becomes nonexistent if β of wrong sign when entering turn.			Oscillation of a very long period makes the a/c feel extremely loose in both roll and yaw.	Extremely loose model.	Turbulence sets off the "loose" oscillation.	X-wind required about ½ aileron, but did not hit the stop on entry or exit since much attention was devoted to keeping the ball central.		
MM 49+30+30	81	D	5		Roll control is sensitive. When roll initiated, a/c tends to increase bank; however, only minor yaw is initiated.		In a sustained turn, slip does develop, but can be easily corrected. Yaw produces wing drop. Good coordination can be achieved.			No problem.	X-wind no problem except that a greater load is felt on aileron (left) and a/c wants to roll right.		Moderately satisfactory with no special techniques required. Roll sensitivity and instability the problem.
MM 49+30+30	112	E	6½		Noticed lack of roll power in circuit but it was quite adequate for 20 deg. bank.			Some lateral oscillation noticed in straight and level flight.			On approach, I was carrying about ½ left stick (maybe less).	On sidestep had to use full aileron therefore derated to a 6½.	Would rate it 2½ in circuit.
HM 47+30+28	74	A	7		Initial roll is fair, but becomes poor unless rudder is used.	Rudder is very effective in controlling roll - ϕ/β seems high. PIO tendencies due to rudder overcontrol.	Coordination is difficult because of high rudder effectiveness relative to aileron. But must use rudder, otherwise aileron forces get high and roll performance poor when β in opposition to aileron is generated.	Much roll oscillation.		Turbulence disturbs aircraft quite a bit.			Poor precision in all manoeuvres. Not good overall.
HM 47+30+28	91	B	6	No noticeable yaw with aileron.	Roll control sluggish and tends to overshoot.	Rudder control seems good.		Increasing roll oscillation if stick left alone. Some slow oscillation in roll during approach.			No problem.	Required full aileron to recover.	
HM 47+30+28	43	C	8½		Constant attention required in roll.		Aileron turns possible but it swung back at least 5 deg. on turn exit when no rudder applied.			Turbulence requires constant aileron of a bothersome amplitude.	Requires approx. 80% of aileron for X-wind.	Hit stops on aileron going into and out of "S" turn.	
LM 50+0+0	75	A	3	For comments see TABLE 4b.									
LM 50+0+0	95	B	4										
LM 50+0+0	42	C	2										
LM 50+0+0	44	D	3										
LM 50+0+0	108	E	4										
MM 50+0+0	63	A	2½	Very little if any N_{δ_a}.	Roll control felt a little stiff. Aileron forces felt slightly high, but reasonable.		Coordination was easy and not really required for initiation of roll nor in roll, but some bottom rudder was required. Can manoeuvre as desired without worrying about coordination or losing control.			Turbulence did not bother me.	X-wind caused overshoot in sidestep but no trouble.		Precision in manoeuvres was reasonable. Nothing very objectionable except possibly initial roll response slightly sluggish due to stiff aileron.
MM 50+0+0	95	B	5	No yaw, (possibly slight pro-yaw), with aileron.	Roll control rather sluggish.	Rudder control sloppy.		Without use of rudder, yaw oscillation develops with some accompanying roll. Requires attention to rudder in all manoeuvres to suppress oscillation.		Turbulence effects, ± 6 deg. heading variation on approach.	O.K. - requires ½ aileron.	O.K. - but required full aileron to recover.	

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CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HM 50+0+0	69	C	5	Roll control somewhat no yawing.	weak but induces		Turn entry quite pleasant, but looseness in yaw starts a directional swing which gets into fairly large sideslips. Turn exit impossible on a given heading using aileron alone as the swing continues for quite a while. Turn coordination relatively easy but absolutely necessary.			No problem.	No problem (approx. ½ aileron required).	"S" turn went well.	
HM 50+0+0	76	D	3	Yaw due to roll is minimal, but there is some. Aircraft first skids out away from turn, then develops a sideslip into turn.	Roll control acceptable, but requires fair amount of stick displacement for desired control - adequate.			None.		Small - no difficulties.	About ½ ball skid to right. With ball in centre about 10 deg. to line of flight.	Sidestep easily controllable.	Reasonably good model. Requires no special compensation Fairly stable.
HM 50+0+0	126	E	5				Entry and recovery from turns easily coordinated.	Aileron turns cause long period yaw excursions which diverge - controllable but annoying.				On entering sidestep, touched aileron stop, but did not touch it on exit.	
HM 51+0+0	74	A	8			Constant rudder inputs required. There was much yaw oscillation, probably mostly PIO. Rudder forces initially seem reasonable, but then seem to lighten as β is generated.	Initially roll acceleration seems O.K., but immediately after starting a roll with aileron only, the sideslip builds up and seems to accelerate so that recovery is required. Seems pro-yaw and then seems to diverge directionally. Coordination very difficult.			Turbulence affects configuration very much.	X-wind caused the ailerons to hit the stop.	Sidestep was restricted due to aileron hitting stops.	Very poor configuration, must not take attention off controls any time.
HM 51+0+0	95	B	6	No yaw with aileron.	Roll control very sluggish.		Can be manoeuvred.	Rudder produces a yaw oscillation of a long period. Roll in same direction occurs after 1 to 2 sec. Requires careful use of rudder and continuous aileron control to suppress oscillation.		Turbulence effects minor.	Requires ½ aileron.	"S" turn completed, but full aileron used on recovery.	
HM 51+0+0	43	C	8		If β becomes large, as it did on turn to localizer, the required aileron was enormous.		Aileron only turns impossible - β builds and oscillates.	Turbulence set off a directional oscillation (while leaving rudder alone and controlling bank to zero) of approx. ± 15 deg.		Continuous almost random aileron required to hold bank.	Approx. ½ aileron required on approach.	Hit stop on S-turn.	
HM 51+0+0	81	D	6	Roll produces only minor yaw.	Roll control good for 20 deg. banked turns. Aileron control deflection and control objectionable. Would require modification before being considered satisfactory.	Rudder control sensitive and positive.				Turbulence produces lateral instability requiring constant attention to aileron.	X-wind produced only some right wing heaviness.	On "S"-turn we ran out of aileron displacement and took some time to recover.	Generally fair. Longitudinal stability good.
HM 51+0+0	113	E	10		Weak roll control.			Long period roll oscillation.			Out of aileron control on the approach	During sidestep, I could just barely maintain control by rapid use of rudder to help pick up wing.	This was not entirely unpleasant to fly in the circuit.

4d(ix)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50-20-20	35	A	6½			Rudder activity is excessive and it is quite easy to overcontrol.	Most of the problem is to maintain heading and zero sideslip. Coordination is difficult. Too difficult to establish a coordinated turn.		Seems that N_β is low and may be negative.				Poor pilot performance on all mission tasks.
LM 50-20-20	94	B	5	No yaw due to aileron.	Roll characteristics good (shade slower [illegible] would like).			A/c oscillates in yaw - moderately long period, slowly diverging if left unchecked. All manoeuvres possible if oscillation prevented with rudder. Becomes annoying in straight and level. Would be a good model if yaw oscillation not present.		Turbulence effect hardly noticeable.	No problem.	No problem.	
LM 50-20-20	45	C	4½				Aileron only turns impossible through any large heading change as the a/c winds up into the turn badly and appears divergent. Very small rudder displacements required to overcome and coordinates turn quite easily.			No effect.	No effect.		Turn reversals quite pleasant.
LM 50-20-20	81	D	4	Very little yaw produced by roll.	Roll control good - a/c stable in roll.		Easily coordinated by rudder which was sensitive and positive.	Some sideslip encountered after prolonged bank.		Turbulence produced some yaw but, compensated easily.	No effect.	O.K.	A/c handled well. Generally fair.
LM 50-20-20	107	E	4½	Adverse yaw.	Roll control good.		20 deg. bank through 360 deg. easily coordinated. Roll reversals required effort on rudder to coordinate.	You get pro and adverse yaw while turning but it is easily controllable since the rudder power is good.		Not bothersome.	Not bothersome.		
LM 50-20-20	113	E	5½	Some adverse yaw.				Rudder-free divergent excursion completely overshadows all other characteristics. Rather long period so not too difficult to coordinate.			Not noticeable.		
MM 50-20-20	63	A	5½	Pro-yaw - moderate making it difficult to use aileron only without generating large β into the turn.		Rudder forces light-easy to overcontrol in yaw and PIO at low rate.	Need bottom rudder either due to N_r or L_β - coordination is difficult. With care, can coordinate low amplitude manoeuvre but manoeuvring must be restricted.			Yaw response to turbulence excessive.	Did not notice X-wind since had other problems.	Sidestep done rather gently to inhibit overcontrol in yaw.	
MM 50-20-20	90	B	5½	Some pro-yaw produced with roll.	Roll control O.K.		Can execute all manoeuvres quite well as long as rudder used throughout to coordinate.	Slow oscillation in yaw. Yaw oscillation would prevent aileron only manoeuvres.		Turbulence affects heading by ± 5 deg.	No problem.	No problem.	
MM 50-20-20	70	C	6¾	No problem, with yaw on turn entry.	Weak but adequate.		The turns could be coordinated, but much too much attention required.	Shortly after settling into the bank, the aircraft would start to oscillate around the heading and I felt that the oscillation was diverging. Turn exit without rudder was especially uncomfortable as the yaw oscillation became quite large. During these oscillations aileron applications, resulting in somewhat objectionable forces, were required.		Noticeable in that in straight and level flight the oscillation was excited.	No problem.	No problem, but did hit the stop on sidestep entry.	

4d(x)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
MM 50-20-20	82	D	3	Roll produces little yaw.	Aileron control good.		Commencing turn initiates ¼ ball skid. Stabilized in turn with ¼ ball slip.	No particular yaw oscillation noticed.		Effects minor.	No problems.	Beautiful.	General- adequate. Lateral stability and longitudinal stability both very good.
MM 50-20-20	111	E	6				In turns yaw oscillation results in very noticeable cross controlling on occasion. Roll reversals are reasonably well coordinated.	Yaw excursions of ± 25 deg. with rudder not used.				No trouble.	Difficult model to assess - suggest playback of comments.
HM 50-20-20	36	A	8		At times aileron forces felt very high and rudder forces low and it was thus easy to overcontrol with the rudder. Initially when rolling into a turn, coordination was O.K. and bank angle and roll rate were controllable, but after reaching desired ϕ, β was generated and the bank angle tended to decrease; and aileron forces increased and coordination became a problem.		Very difficult to maintain zero β. Coordination felt peculiar.					Not able to make S-turn at 200 feet because of lack of aileron control.	In any case controlling heading and β very difficult.
HM 50-20-20	75	A	9	Yaw due to aileron pro-yaw.	Initial roll O.K.		To coordinate,must use combination of aileron and rudder because we have negative dihedral. When using rudder to reduce β we generate quite strong rolling moments opposite to rudder- i.e. left rudder gives right roll. Pilot cannot coordinate.	Very strong rolling and yawing oscillation almost all the time and PIO tendency very strong.		Affects strongly.		To make the step manoeuvre I had to use bottom rudder to roll to right.	Cannot do anything with any real precision. Just all around poor configuration and can be dangerous.
HM 50-20-20	94	B	7	No yaw with aileron.	Very sluggish roll.	Strong adverse roll with rudder inputs.		Tends to oscillate predominantly in roll with long period. Difficult to prevent slow oscillation in roll and some in yaw.		Effects of turbulence not particularly noticeable.	Required use of full aileron at times during X-wind approach.		All manoeuvres manageable but lack precision and smoothness.
HM 50-20-20	46	C	8½	In steady (?) turns the aileron had to be manipulated continuously and almost always moved into the turn.	Enormous ϕ with yaw but phasing is different in that as the a/c was yawed right the roll was left and vice versa.					The turbulence was severe and would start the divergence going readily.	Required approx. ¼ aileron but on occasion hit full deflection due to turbulence.		Wild.
HM 50-20-20	126	E	8½	Some yaw with roll but not sure which way.	Lack of roll power in conjunction with roll upset is worst feature. In turns roll upset tends to take off bank and about ½ aileron required to maintain bank.								Very uncomfortable model. Do not like sloppiness and lack of feel of aircraft.
LL 25+31+32	74	A	4½	On initial roll slight adverse yaw followed by pro-yaw as roll rate builds.		Some PIO tendencies - rudder overcontrol.	Rudder required initially is small, then must cross control substantially and then in steady state it is difficult to determine exactly the amount and sense of rudder required. Coordination is fair.			Small effect of turbulence.	Slight effect.	Sidestep sort of skidding manoeuvre, and undershot.	Fair configuration. Special technique is to cross control in roll.
LL 25+31+32	91	B	4½	Has adverse yaw - quite pronounced.	Roll response satisfactory; a shade sluggish.		Requires coordination in turns, but not difficult to perform all manoeuvres.	Slow oscillation in yaw if left alone.		Very steady in roll. Heading variation on approach ± 2 to 3 deg.	No problem.	No problem.	

4d(xi)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25+31+32	54	C	7½	Aileron produces adverse yaw which sets the divergence off, precluding aileron only turns.			Rolling out of turns is especially difficult to do smoothly.	The divergence appears to be a static divergence, but is quite slow - can be controlled with very small rudder inputs but requires constant attention.		Not a factor.	Not a factor.		
LL 25+31+32	82	D	8	It is difficult to find what is producing yaw - turbulence or roll because model wants to change ends in a very erratic pattern.	Roll stability seems poor at times then fairly good at others.					Turbulence was not too noticeable because of requirement to concentrate on keeping the a/c flying.	No problem except aileron heaviness.	Sidestep was O.K. but required some rudder to assist in getting aircraft level. Required full aileron.	Generally very unsatisfactory. Required constant attention to control in flight. Favourable features, nil. Most things were objectionable, in fact, all.
LL 25+31+32	110	E	5	Yaw excursions during turns and active rudder make it rather miserable to fly.		Model extremely sensitive to rudder inputs. Very active rudder.	Full attention required to try to coordinate roll.				Not noticeable.		
ML 25+30+32	60	A	4½	Seemed to have adverse yaw due to aileron, but possibly pro-yaw due to roll rate.	Roll control only fair.		In any event coordination was a problem and I had tendency to induce oscillation.	A/c open loop had no oscillatory tendency. At first I thought it had a divergent spiral.				Performance of sidestep only fair and coordination seemed somewhat peculiar.	Only fair to poor configuration.
ML 25+30+32	92	B	4	Mild adverse yaw.	Roll control good (a shade sluggish).		Hence continuous light rudder coordination required. Would be annoying in prolonged flights.	A/c will build up slowly divergent yaw oscillation if rudder left alone.		Turbulence - minor effects in yaw only (heading variation ± 2-3 deg.).	No problem.	No problem.	All manoeuvres easily performed.
ML 25+30+32	71	C	6	Some adverse yaw on turn entry.			Adverse yaw coupled with loose directional stiffness makes aileron turns impossible since the ball slides into the inside of the turn an alarming amount. Very little rudder required to overcome, but this means a small rudder error results in a large β. Constant attention required of rudder.			Not significant.	Not significant.	S-turn uncomfortable due to adverse yaw - did not get lined up precisely.	
ML 25+30+32	108	E	5½	Pro-yaw comes in about 1 sec. after fairly fast roll input.								Yaw is excessive and rapid causing rather wild control movements during sidestep. Not dangerous but controls must be used gingerly.	
LL 25+0+0	91	B	4½	Some pro-yaw with aileron.	Rather sluggish roll control but very steady in roll.			Left alone will develop slow diverging yaw oscillation - so slow that easily controlled. Consequently, all manoeuvres O.K. but would be a nuisance in prolonged flight.		Turbulence response quite small - zero in roll, ± 2-3 deg. heading variation on approach.	No problem.	No problem.	
LL 25+0+0	53	C	4				Easily coordinated with the very powerful rudder that seems present on all models.	Aileron turns are possible, but long period lightly damped oscillation makes small rudder movements absolutely necessary.		No effect.	No effect.		
LL 25+0+0	80	D	2	Very little yaw due to roll, however, model initially skids when aileron applied and this develops into slip of about ½ ball's width. This is noticeable on all turns.	Aileron control good.			Oscillatory qualities good.		Very little turbulence effect.	Negligible.	O.K.	Good model. No difficulties, well behaved. Stability in roll and yaw O.K. Only skid and slip on turns caused any concern.

4d(xii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25+0+0	112	E	3	Adverse yaw (I think).			Can do better turns not using rudder.					Sidestep was well coordinated.	
ML 25+0+0	65	A	5½	Pro-yaw due to aileron and roll rate.		Very easy to over-control with rudder.	In steady state turn, required bottom rudder. Initial roll response reasonable, but coordination required looking at sidestep indicator. Not too bad if low rate manoeuvres are made with concentration on coordination.	Almost constant tendency for heading to wander at low rate. Almost constant yaw oscillation on final approach of a low frequency. Seemed contradictory response – open loop Dutch roll seemed moderate frequency to good damping. Closed loop N_β seemed very low.					
ML 25+0+0	94	B	4	No adverse yaw noticeable.	Good roll characteristics.	Rudder input produces rather sloppy response. Would rate higher if yaw control more crisp.	Turns require some coordination from rudder.	Tends to overshoot during rudder control and produce slow oscillation.		Turbulence effects very minor.	No problem.	No problem.	
ML 25+0+0	68	C	7			Main difficulties are in turns and in level cruise when continuous yaw attention required.	Roll entry fairly brisk and pleasant, but divergence, which yawed the nose badly out of the turn, soon set in. Coordination quite easy, but absolutely essential.	No oscillatory characteristic but a straight divergence.		No problem.	No problem.	No problem.	
ML 25+0+0	81	D	4	Roll produces little yaw in either direction.	Roll control very good.	Rudder extremely sensitive, but positive.	Can be flown feet off, but after applying bank, sideslip does develop. Recovery can be made to level flight without rudder. Coordinated turns good.	A/c has no tendency to oscillate due to turbulence.			Not noticeable.	Good.	All controls normal. Generally a good model, no special problems. Stability in roll favourable. Sensitivity of rudders is problem.
ML 25+0+0	111	E	6½	Yaw excursions appear as pro-yaw in turns. Any roll applied in direction of turn results in wind up of turn.			Have to hold off bank in turns while applying rudder.	Yaw excursions to 30 deg. straight and level and rudder free.					
HL 25+0+0	32	A	6				Very difficult to coordinate and trim. Bank angle control O.K. if both aileron and rudder used, and can maintain heading, but have to work to roll out on desired heading.		N_β either zero or possibly negative with very little or no dihedral effect.			Cannot make S-turn too rapidly or β becomes excessive.	Can do the job, but workload is too high.
HL 25+0+0	92	B	4	Slight pro-yaw with aileron.	Roll control good (a shade sluggish).		Coordination required in turns to suppress the oscillation. Relatively easy to manoeuvre (with this reservation).	Will develop a slow yaw oscillation if left alone.		Turbulence effect on heading ± 2 to 3 deg.	No problem.	No problem.	
HL 25+0+0	78	C	6½	Pro-yaw which started the nose swinging into the turn causing a β build up which was, then reversed at low frequency and felt as though it was becoming uncontrollably large.	Adequate.		Rudder coordination fairly easy, but absolutely necessary.	(See first and seventh comment columns)	Directional divergence appears to be a static divergence.	The turbulence was blamed for the directional divergence starting in straight and level flight, requiring constant small rudder inputs.	No problem.	No problem.	
HL 25+0+0	44	D	4			Pleasant to fly in all respects with the exception of yaw. A/c will not return to straight and level flight, but tends to continue yawing in increasing amounts.						No difficulty on approach – reasonable.	Good model.

4d(xiii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HL 25+0+0	112	E	6½				Difficult to harmonize the rudder and roll control.	In straight and level flight, rudder-free 25 deg. excursions in yaw occur.		Yaw excursions noticeable on approach.	About ½ left stick on approach.	Full opposite roll control on sidestep roll out.	

4e EFFECT OF CHANGING DUTCH ROLL DAMPING RATIO AT THE HIGHEST FREQUENCY WITH $|\phi/\beta|_{DR} = 0.2$; $\omega_\phi = \omega_d = 1.0$ RAD/SEC, $\zeta_\phi = \zeta_d$, $\zeta_d + 0.1$, $\zeta_d - 0.1$

4e(i)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100+30+30	72	A	$1\frac{1}{2}$	See TABLE 4d for comments.									
LH100+30+30	90	B	2										
LH100+30+30	54	C	2										
LH100+30+30	70	C	2										
LH100+30+30	105	C	2										
LH100+20+20	63	A	$1\frac{1}{2}$	See TABLE 4a for comments.									
LH100+20+20	119	B	$3\frac{1}{2}$										
LH100+20+20	140	B	3										
LH100+20+20	54	C	$2\frac{1}{2}$										
LH100+20+20	48	D	2										
LH100+20+20	108	E	2										
LH100+10+10	96	B	4	No adverse yaw.	Roll control good.			Yaw oscillation of moderate period develops unless checked continuously with rudder. Oscillation tends to die away but is restarted by gusts or slight control inputs.		No problem- heading variation ± 4 deg.	No problem	No problem	
LH100+10+10	42	C	$2\frac{1}{2}$		Could use more roll sensitivity on all models.		No problems with turns.			Turbulence noticeable but not bothersome.			
LH100+10+10	44	D	2		Controls precise and positive throughout.								Very good model. Requires minimum concentration by pilot.
LH100+0+0	31	A	$5\frac{1}{2}$	See TABLE 4d for comments.									
LH100+0+0	50	C	$6\frac{3}{4}$										
LH100+0+0	77	C	$5\frac{1}{2}$										
LH100+0+0	78	C	6										
LH100+0+0	111	E	$4\frac{1}{2}$										
LH100-10-10	34	A	$4\frac{1}{2}$				Need moderate effort to coordinate without overcontrol and rapidity of entry into manoeuvres somewhat restricted due to β generated at higher rates.	Period of Dutch roll seems reasonable – about 5 to 6 seconds. Damping zero or slightly negative. Only difficulty is in heading hold and constant yaw oscillation which must be corrected (damped) with rudder.				Pilot performance of approach and terminal manoeuvres was fair.	φ/β seems low. To fix add Dutch roll damping.
LH100-10-10	96	B	5	No adverse yaw.	Good response in roll.	Some use of rudder always necessary to suppress the oscillation.		Divergent oscillation in yaw of moderate period.		Heading variation ± 4 deg. on approach. Difficult to distinguish turbulence effect in yaw from tendency to oscillate rudder fixed.	No problem.	No problem except for need to prevent yaw on manoeuvres.	
LH100-10-10	29	C	$6\frac{1}{2}$	Aileron only turns virtually impossible but turn reversals with aileron very easily managed without rudder; i.e., as long as steady state not attempted then the rudder is not required.				Continuous oscillation in yaw during steady turns.		Directional turbulence disturbing.		"S" turn easily managed.	
LH100-20-20	47	B	5	See TABLE 4d for comments.									
LH100-20-20	41	C	$4\frac{3}{4}$										
LH100-20-20	114	C	7										
LH100-20-20	76	D	6										

4e(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100-30-30	58	C	8	The initial swing on turn entry is not large but things start to build quickly from there.		The rudder is quite powerful (as always) hence the motion can be stopped short of a catastrophe.		Unstable directional oscillation precludes aileron only turns. The sideslip gets out of hand within two swings requiring rudder.		The turbulence sets the divergence off requiring constant attention to rudder.	No problem.	S-turn went fairly well but lots of activity was required on rudder.	
LH100-30-30	56	D	6					Yaw oscillation continues throughout flight, tending to increase unless damped with rudder constantly. Otherwise fairly good on roll and stick control.					Bad model. Consider this model just borderline for handling.
LH100-40-40	73	A	8	Seems to have some pro-yaw due to aileron.	Initial roll response fair.	Rudder forces light and extremely easy to overcontrol and set up PIO.		In initiating a turn, oscillation starts which makes a steady state turn not possible. Yaw rate is oscillatory and ϕ can be held reasonably well. Dutch roll damping must be negative.		Airplane very responsive to turbulence - especially on approach.			Not acceptable performance in any task, but can be controlled.
LH100-40-40	55	C	9			If the rudder were not so powerful we would have been out of control.		Directional divergence appears statically unstable. Impossible to even come close to doing aileron only turns.		Very severe.	Not a factor.		Mission can be accomplished but only with unrelenting rudder attention.
LH100+30+40	50	C	3½	Aileron turns quite pleasant and turn reversals easily done.			Pro-yaw due to roll presents confusing coordination problem especially on bank exit.			No problem.	No problem.	Unexpectedly large yaw at entry.	Quite pleasant.
LH100+30+40	49	D	2	Uncoordinated turns were no problem with only some very slight sideslip in left turns.	Normal control deflections required to produce turn (compared to standard model).		Some yaw when returning to level flight most probably the result of natural turbulence. Coordinated turns good.	No tendency towards lateral instability in any respect.					Good model, easy to fly with some degree of accuracy.
LH100+20+30	35	A	2	See TABLE 4a for comments.									
LH100+20+30	135	B	3										
LH100+20+30	45	C	3										
LH100+10+20	72	A	5	Pro-yaw initially, changing to adverse in steady state turns.			Difficult to coordinate during transients especially during initial input. Bottom rudder required in steady state turns.	Oscillations due to pilot inputs and turbulence prominent.		Generated oscillations.		Fair but had to think about cross-control on initiation of turns.	Too much pilot effort needed. Cross controlling is a special pilot technique.
LH100+10+20	96	B	4	No adverse yaw.	Good though a little slow.		Some use of rudder always necessary to suppress oscillations.	Aircraft oscillates slowly in yaw to moderate amplitude, if rudder fixed.		Moderate effect (± 2 to 3°).	No problem.	No problem, easy to manoeuvre.	Very pleasant except for oscillatory tendency.
LH100+10+20	59	C	5	Turn entry quite pleasant with aileron only but after arriving at desired bank angle, nose yaws back out of turn. It oscillates about 1½ cycles and dies away.			Undesired motion can be overcome fairly readily with the powerful rudder available, but work load is moderate.	Oscillation on turn entry with aileron. Much more uncomfortable swinging at turn exit with the pro-yaw due to aileron.		Gives some fair heading excursions but damps out quickly.	No problem.		Moderate workload to overcome undesired motions.
LH100+0+10	39	A	2	Not much yaw due to aileron.	Aileron forces and displacements normal.	Rudder forces and displacements normal.	I think it would be easy to coordinate in smooth air.	Acceptable, not requiring attention.					No outstanding deficiencies. Pilot performance quite good considering a high natural wind and turbulence.

4e(iii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100+0+10	95	B	5	None, or if any, slightly pro-yaw with aileron, but followed by developing oscillation in yaw of long period.	Roll response rather sluggish.		Rudder coordination required in turns to suppress yawing oscillation.	Long period yawing oscillation following aileron input. Rudder input causes oscillation in yaw only.		Noticeable effect on yaw during approach.	No problem.	Acceptable but required full aileron on recovery.	
LH100+0+10	40	C	$4\frac{3}{4}$	Turn entry quite pleasant.			Rolling out of turns presented some problems as the nose yawed in the direction of original turn and then oscillated about. This was easily corrected with rudder.	Yaw oscillation on rollout from turns and in turbulence was easily corrected with rudder.	Easy to hold steady bank.	Heading excursions ± 15° were easily stopped with rudder.			
LH100+0+10	80	D	2	Aileron produces very little yaw.	Very good.		Coordinated turns good.	Small oscillation due to turbulence has good damping qualities.		Excites small oscillation.	Not noticeable.	Easily controllable.	Pleasant model, only small yaw oscillations objectionable.
LH100-10+0	36	A	$4\frac{1}{2}$				Coordination for moderate amplitude manoeuvres was fairly easy but both aileron and rudder coordination was definitely needed for this aircraft.	Appeared to have a divergent oscillatory response, mainly in β, and rudder was always required to damp it.					Pilot could never relax, but performed reasonably well with moderate effort. Manoeuvrability restricted due to increased coordination problems at higher rate inputs.
LH100-10+0	33	C	6	Turn entry fairly pleasant.				Slightly divergent yaw oscillation requires continuous small rudder applications.	Seems as if a steady turn has been settled into when the β builds and rudder is required.	Noticeable but not objectionable.	No problem.	S-turn rollout presented a "jostle" which had to be kicked off with rudder.	
LH100-20-10	71	C	7	Pro-yaw combined with divergent directional oscillation require constant rudder applications. The first large swing after turn initiation is away from the turn, and occurs just before steady state bank angle is achieved.	Satisfactory			Divergent directional oscillation requires constant rudder applications.		Turbulence set off directional divergence in straight and level flight, which required constant rudder applications.	No problem.	Sidestep went fairly well but rudder was used as learned during earlier portion of task.	
LH100-20-10	80	D	6	Initial skid due to roll with tendency for it to become slip when turn held. Not too serious but oscillates through approx. 20 deg. and does not tend to damp out.	Good characteristics in roll. Aileron deflections normal and response positive.		Yaw oscillation becomes dangerous if not coordinated in turns.	Yaw oscillation of approx. 20 deg. which does not tend to damp out, caused by aileron only turns.		Tends to make yaw oscillation more pronounced.	Not noticeable.	Generally not good - requires lots of rudder.	Yaw oscillation very unsatisfactory.
LH100-30-20	125	C	$8\frac{1}{2}$	Nose yaws into turn on aileron application and then very quickly out at which time rudder is required to prevent extremely uncomfortable sideslips. Pro-yaw due to roll but not too powerful.	Adequate.		Coordination necessary to prevent uncomfortable sideslips on turn entry. Coordination possible but requires a great deal of attention.	Rapidly divergent oscillation shows up especially in turns.		Will excite divergence but is very mild in itself.	None.	Sloppy due to yawing excursions but I did not feel that I would lose control.	
LH100+30+20	47	B	$4\frac{1}{2}$	Adverse yaw due to aileron objectionable.									Fairly good characteristics.
LH100+30+20	41	C	3	The only disconcerting characteristic was the adverse yaw due to aileron which became bothersome during fairly rapid aileron inputs. Not of serious concern for normal manoeuvres			Steady turns require some coordination.						

4e(iv)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100+20+10 LH100+20+10 LH100+20+10 LH100+20+10	64 89 55 127	A B C E	4½ 6 7 6	See TABLE 4a for comments.									
LH100+10+0	34	A	4½				Rudder must be used to coordinate for precise heading control and there is a tendency to over-control.	Damping and directional stiffness seemed moderate. Experienced tendency for PIO in yaw especially during approach.		Apparent natural turbulence may have caused some of the difficulty with PIO on approach.		Very sloppy with quite large β generated.	Pilot performance only fair but never felt aircraft would get away. Fair configuration.
LH100+10+0	92	B	3½	Slight adverse yaw with aileron (I think!).	Roll response good but a bit sluggish. Full control used in test inputs.		Requires some use of rudder in manoeuvres, mainly to check tendency to oscillate.	Response to rudder input oscillatory - not divergent.		Steady in roll. Heading variation ± 3 to 4 deg. if controlled with rudder, otherwise ± 7 to 8 deg.	No problem.	No problem.	All manoeuvres easily accomplished.
LH100+10+0	51	C	7	Adverse yaw sets off the lightly damped directional oscillation which does not entirely prevent aileron only turns since β never gets entirely out of hand.			Turn exits extremely uncomfortable and difficult to do smoothly even with rudder since the yaw is so pronounced.			Turbulence light, and a touch of rudder required on approach.		Adverse yaw on S-turn not acceptable.	
LH100+0-10	67	A	6	Seems to have little yaw due to aileron or roll rate.				Initial response to aileron acceptable but if I attempt to make a rapid input, Dutch roll oscillation is generated. It is then not possible to control roll rate or bank angle. Aircraft was quite oscillatory on approach.		Very responsive to turbulence.		Done at moderate rate and was oscillatory. Fair.	Pilot tends to restrict manoeuvres in amplitude and rate. Pilot can perform fairly well.
LH100+0-10	96	B	6	Pronounced adverse yaw followed by tendency to oscillate in yaw during turns.	Rather sluggish.			Oscillation period moderately short and hence motion seems jerky. Yaw oscillation reaches ± 10 to 15 deg. but does not appear to diverge.		Effect of turbulence on yaw is noticeable. Heading variations ± 5 deg.	Manageable but lack precision due to yaw behaviour.		
LH100+0-10	40	C	5¼	Yaws as bank is applied.			Turn entry a little sloppy due to yawing as bank is applied, but once established in the turn, no rudder is required. Turn exit the worst part and definitely requires rudder to stop yawing.			Effects quite large but manageable.	Not perceptible.		
LH100+0-10	114	C	7	Adverse yaw causes the nose to dart out of the turn initially but it rapidly swings back into the turn and starts an undamped oscillation which appears to be divergent if aileron only used. Aileron only turns are not possible due to swinging which develops during steady state turns as well as on entry and exit.	Seemed adequate until stop hit on final roll out from S-turn.		Coordination required was difficult to determine since the yawing with aileron changes so rapidly.	If oscillation is allowed to persist, it appears to be undamped.		Turbulence excites the oscillation in straight and level flight.	Noticeable on rudder but not bothersome.	S-turn not comfortable since the left stop was hit on roll out and because of too much yawing with aileron.	

4e(v)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LH100-10-20	38	A	6½			Very sensitive directionally.	Manoeuvring restricted to low rates if coordination to be reasonable. Very easy to generate PIO.	The most objectionable characteristic is an apparently negative Dutch roll damping, restricting the pilot from manoeuvring without inducing large amplitude oscillations.				S-turn generated very undesirable large amplitude oscillations.	
LH100-10-20	46	C	8	Aileron turns not possible because of oscillation. Turn reversals surprising in that during aileron application the lateral-directional characteristics appear good but as soon as we became settled in the bank, the yaw wanders badly.			Requires too much attention.	For the first cycle it feels as if the directional oscillation is going to get away, but divergence is slow.		Severe.	No problem.		
LH100-20-30	66	A	7	Seems to have pro-yaw with aileron.	Initial response is snappy.	Easy to overcontrol with rudder. Forces light.	Very poor.	Dutch roll damping seems negative or at least zero with a moderate to high frequency so that aircraft oscillates almost continuously.		Aircraft responds to turbulence quite a bit.		Approach and sidestep very oscillatory. Unable to maintain β near zero.	
LH100-20-30	59	C	8	Initial roll with aileron does not feel bad. Rapid aileron inputs indicate a severe adverse yaw.			Much too much attention required to the rudders.	Initial roll in with aileron feels not bad but this is immediately followed by a rapid swing into the turn which is the beginning of a moderate frequency unstable oscillation.		Extremely bothersome, continually exciting the dynamic instability.	No problem.		

4f(i)

4f EFFECT OF CHANGING DUTCH ROLL DAMPING RATIO AT THE INTERMEDIATE FREQUENCY

WITH $|\phi/\beta|_{DR} = 0.2$; $\omega_\phi = \omega_d = 0.5$ RAD/SEC, $\zeta_\phi = \zeta_d$, $\zeta_d + 0.1$, $\zeta_d - 0.1$

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50+29+29	74	A	$3\frac{1}{2}$	See TABLE 4d for comments.									
LM 50+29+29	47	B	$4\frac{1}{2}$										
LM 50+29+29	41	C	3										
LM 50+29+29	111	E	3										
LM 50+20+20	51	C	$2\frac{1}{2}$			Only problem is the rudder which is somewhat too sensitive, and when one attempts to keep the ball in the centre, too much yawing occurs.				No problem.	No problem.		
LM 50+20+20	49	D	2				Uncoordinated turns were no problem with only some slight sideslip in left turns. Some yaw when returning to level flight - most probably the result of natural turbulence. Coordination turns good.	No tendency toward lateral instability in any respect.					Good model. Easy to fly with some degree of accuracy.
LM 50+10+10	32	A	$4\frac{1}{2}$	N_{δ_a} seems to be almost zero and so does L_β.			I just can't explain why I should have trouble coordinating with rudder and my tendency to over-control with rudder. Otherwise configuration was O.K. - can do all manoeuvres fairly well with just aileron.	Moderate Dutch roll frequency - maybe good D.R. damping, but can't explain apparent non-linearity of response as described on tape.	I'm also mystified concerning my initial reaction that N_β was low - it was easy to move the nose directionally. Maybe its the high frequency giving impression of low stiffness.				
LM 50+10+10	50	C	$2\frac{1}{2}$				Requires a little rudder concentration in steady bank to keep ball from falling in, but no real problem.						Very pleasant.
LM 50+0+0	75	A	3	See TABLE 4b for comments.									
LM 50+0+0	95	B	4										
LM 50+0+0	42	C	2										
LM 50+0+0	44	D	3										
LM 50+0+0	108	E	4										
LM 50-10-10	40	C	3				Turning with aileron-only quite pleasant requiring a minimum of rudder.	No problem with oscillation, however if rudder is used in a heavy-footed manner, a directional oscillation starts which appears to be divergent. Looks as though the rudder excites the mode but the aileron does not. This may be a deficiency in the task when we do not show up this sort of characteristic.					
LM 50-10-10	48	D	3				Easy to fly using all controls. On turns not using rudder, a/c tended to slip in direction of turn, but not to a degree that was uncomfortable.			Not affected to any degree.			Quite good model.
LM 50-20-20	35	A	$6\frac{1}{2}$	See TABLE 4d for comments.									
LM 50-20-20	94	B	5										
LM 50-20-20	45	C	$4\frac{1}{2}$										
LM 50-20-20	81	D	4										
LM 50-20-20	107	E	$4\frac{1}{2}$										
LM 50-20-20	113	E	$5\frac{1}{2}$										

4f(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50-30-30	51	C	6½	If roll-in rapid the pro-yaw causes the first swing to be into turn.			The divergence is always pecking away requiring constant rudder attention.	Aileron only turns impossible. If roll-in slow, the directional divergence starts by yawing out of turn.		No problem.	No problem.		
LM 50-40-39	67	A	6½	Roll response due to aileron alone was difficult to assess due to difficulty in establishing zero β.			Had to use rudder constantly. Coordination was difficult, but reasonable results except for almost constant small amplitude yaw oscillation.			Turbulence does definitely affect aircraft.		Sidestep turned out fairly well, however, and approach was not too bad. Had to be careful with rudder during sidestep.	Overall pilot effort too high for acceptability but performance is passible.
LM 50-40-39	117	C	7	No yaw due to roll.	Adequate.		Coordination difficult and constant jostle in heading present.	Divergent directional oscillation must be suppressed with rudder by the second peak or the sideslip gets out of hand. This oscillation is continuously excited, even during straight and level flight, requiring constant use of rudder.	Very small rudder out of trim results in alarming β very quickly.	Turbulence not severe but probably the cause of oscillation.	No effect.	"S" turn went surprisingly well although some unsteadiness.	
LM 50-40-39	56	D	6					Yaw oscillations continual throughout flight, tending to increase unless damped with rudder constantly. In turns without rudder, yaw was so large that a recovery with rudder was required in all instances. Yaw and skid tended to increase rather than settle into a pattern.					Poor model. Barely acceptable, but could be flown if required.
LM 50+30+40	89	B	3	No appreciable tendency to yaw.	Satisfactory.		Some rudder required to coordinate oscillatory characteristics, but acceptable.	Yaw oscillation period long but a bit slow to die away.		Noticeable in yaw but effects mild.	No problem.	No problem.	Quite pleasant.
LM 50+30+40	83	C	2	A slight bit of pro-yaw with aileron.	No problem.		No problems. A slight bit of pro-yaw was easily compensated for with a touch of opposite rudder on turn entry and then a touch of rudder into the turn.			No problem.	No problem.	No problem.	Good model.
LM 50+20+30	66	A	4½	Initial response to aileron satisfactory. Appears to have pro-yaw due to aileron but adverse due to roll rate.			Coordination is a problem but can incorrectly coordinate without creating very large β. Requires bottom rudder to maintain turn rate.	Not oscillatory. Dutch roll seems of moderate to high frequency with adequate damping.	Bottom rudder required in steady turns.	Little effect.	Little effect.		Just a fair ability to fly with precision. Poor visibility may have affected performance.
LM 50+20+30	71	C	4	Pro-yaw is bothersome on turn exit.	Roll control brisk.		Pro-yaw is bothersome on turn exit requiring rudder into turn. Coordination relatively easy, however.		Inside rudder required during all steady turns or ball falls in about ¼ to ½ ball width, oscillating slightly as it goes.	No problem.	No problem.	A little sloppy because of poor rudder coordination on reversal, although turn reversals at altitude were quite smooth without rudder. Possibly due in part to better heading reference near the ground.	
LM 50+10+20	62	A	4½	Appears to have pro-yaw with aileron.			Coordination phasing peculiar but can coordinate incorrectly without generating very large β. Very difficult to coordinate with precision.	Frequency and damping moderately high.	Large amount of bottom rudder required in steady state turn.			Satisfactory but only fair β control.	

4f(iii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50+10+20	79	B	5½		Sluggish.		Difficult to execute accurate manoeuvres since constant rudder attention required.	Slowly oscillatory in yaw.		Not particularly noticeable.	Manageable.	Manageable.	
LM 50+10+20	54	C	7	Pro-yaw on turn entry produces a reasonable aileron turn but turn exits appear as a straight divergence.		Very powerful rudder makes it difficult to find correct trim position.	Powerful rudder allows difficulties of turn exit to be overcome with a squeeze of the pedals, but if the trim position not found, β builds.		Very loose directional characteristics. Enormous β can be generated from very small out of trim rudder.	None.	None.		
LM 50+10+20	114	C	4	Initially pro-yaw, followed by swing in opposite direction.	Adequate		No rudder required in steady state turn.	Yaw occurring with aileron input excites the well damped directional oscillation which disappears after one swing in the opposite direction.		No problem.	No problem.	Had to kick rudder around more than desired during S-turn.	
LM 50+0+11	122	B	5	See TABLE 4b for comments.									
LM 50+0+11	104	C	5										
LM 50-10+0	31	A	7	Yaw due to aileron difficult to determine.					Difficult to maintain zero β and to control heading precisely.				Too much pilot effort needed to fly the mission. Confusing configuration. Open loop responses seemed contradictory. I do not feel that I was able to pick out the variables.
LM 50-10+0	53	C	7	Pro-yaw due to aileron not severe in itself, but feeds oscillation, especially on turn exit.				The long period (12-13 sec.) neutrally damped oscillation is quite bothersome and precludes aileron turns. Although the pro-yaw effect is not too severe in itself, it does feed the oscillation. The oscillation will start seemingly of its own accord in straight and level flight but it reaches an amplitude and stays there.		No problem.	No problem.		
LM 50+30+20	63	A	5	Adverse yaw rather large.		Occasionally yaw rate seems to build up very rapidly causing some pilot concern.	When turn is established, much less rudder is required and in fact almost seems reversed. Coordination is poor for very rapid manoeuvres and yaw rate control is very poor.	Good damping.		Not bothersome.	Effect noticed in sidestep.	Overshot in sidestep manoeuvre. Turbulence noticeable in this manoeuvre.	Main objection is coordination and yaw rate control.
LM 50+30+20	93	C	7	Adverse yaw much too high to be acceptable. Swinging of nose on turn exit precludes aileron only turns.	Roll control seemed adequate but could not use all that was available because yawing was excessive.		Rudder coordination necessary to stop undesired yawing on turn exit is too difficult to produce a smooth manoeuvre.	Oscillatory characteristics per se were not bothersome.		Turbulence bounced the aircraft around quite a bit, and the external disturbances were found, on the next climb out, too high to continue.	No problem.	Rolling out of S-turn was uncomfortable due to yawing.	Subsequent flights terminated due to gusty conditions and apparent wind shear.
LM 50+20+10	73	A	6	Poor initial roll acceleration due to adverse yaw with aileron, but immediately β changes and roll and yaw rate increase rapidly in aileron only turns. Apparent pro-yaw with roll rate and large adverse yaw with aileron.	Bank angle can be kept reasonably constant in turns.		A real problem. Must fly carefully with aileron or coordination becomes very poor.	Steady state turns not possible due to yaw oscillation. Tendency to PIO with rudder.		Moderate response to turbulence.		Poor.	

4f(iv)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LM 50+20+10	58	C	7	Adverse yaw extremely uncomfortable and makes turn entry and exit quite a challenge. Absolutely impossible to roll out on a desired heading with aileron only (± 5 deg. accuracy only).			Amount of rudder required to prevent the swing was difficult to predict.	After established in the steady turn the motions settle down rapidly and there is no problem with the oscillation.		No problem.	No problem.	Not enough rudder used in roll reversal.	
LM 49+10+0	86	C	5	Adverse yaw starts the nose swinging in an apparently undamped manner unless rudder used. Hence aileron only turns are not possible.	Adequate.		Relatively easy since the rudder required is in the normal sense.	Oscillation bothersome on aileron only turns, especially on roll out.	Large β can result from very small rudder out of trim. This requires more rudder monitoring than desired.	No problem.	No problem.	S-turn went surprisingly well considering the amount of adverse yaw.	
LM 50+0-10	64	A	5½	See TABLE 4b for comments.									
LM 50+0-10	137	B	6½										
LM 50+0-10	57	C	5½										
LM 50-10-20	55	C	8	Enormous swing into turn occurs when aileron alone used, but does not occur immediately. Rather it lags the input by a couple of seconds and then comes in sharply.			Divergent directional characteristics require constant attention even when flying straight and level.			Quite bothersome.	No problem.		
LM 50-10-20	115	C	6	No problem with yaw due to roll.	Roll control not as powerful as desired during "S" turn.		Coordination not terribly difficult, but absolutely necessary.	A slow divergent oscillation appears almost like a static divergence particularly during turns, the entry being very pleasant but the nose yawing quickly into the turn shortly after establishing the bank angle. A similar effect was noted on turn exit.		No problem.	No problem.	Roll control not as powerful as desired during "S" turn.	
LM 50-20-30	31	A	7	Yaw due to aileron about zero.	When applying aileron, responses seemed to depend on initial conditions, i.e. aileron responce affected by initial β.			During the first open loop calibration input there seemed to be a directional instability or at least spiral divergence but the next input seemed less unstable.				Very poor terminal manoeuvre. Large β generated, and heading changes difficult to make, although eventually managed to line up.	
LM 50-20-30	50	C	6½	Turns without rudder are impossible. On turn entry the nose overswings and the oscillation is set off.				The directional divergence appears at first like a static instability and unless it is allowed to proceed, one would not know that it is a slightly unstable oscillation.		Light but seems enough to start the divergence while in straight and level flight.	No effect.	Fine.	
LM 50-30-40	66	A	7	Large amount of pro-yaw generated as roll develops.	Aileron stiff initially.	Difficult to control heading and yaw rate. Easy to overcontrol with rudder - forces light.	Coordination difficult (not really possible) in sidestep. Difficult to control heading and yaw rate.	Dutch roll seemed of moderate frequency since it responded snappily initially. On second overshoot it tended to continue, giving impression of negative damping. Much yaw oscillation in sidestep (probably PIO).	Aircraft very loose directionally.			Poor pilot performance in sidestep. Coordination difficult (not really possible) with much yaw oscillation (probably PIO).	
LM 50-30-40	59	C	7¼	Turn entry initially felt fine but after rolling through 5 to 10° the nose yawed badly into the turn and it felt statically unstable requiring rudder to stop.		Always more than enough rudder to allow positive control.	Too much attention required to control the yaw divergence with rudder.	Yaw divergence always present, required too much attention.	The yaw divergence following turn entry felt like a static instability.	Turbulence excited dynamically unstable oscillation in straight and level flight.	No problem.		

4g EFFECT OF CHANGING DUTCH ROLL DAMPING RATIO AT THE LOWEST FREQUENCY WITH $|\phi/\beta|_{DR} = 0.2$; $\omega_\phi = \omega_d = 0.25$ RAD/SEC, $\zeta_\phi = \zeta_d$, $\zeta_d + 0.1$, $\zeta_d - 0.1$

4g(1)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25+31+32 LL 25+31+32 LL 25+31+32 LL 25+31+32 LL 25+31+32	74 91 54 82 110	A B C D E	4½ 4½ 7½ 8 5	See TABLE 4d for comments.									
LL 25+20+20	86	C	3½	No yaw due to roll.	Roll adequate (hit stop on a couple of turn reversals, but roll rate O.K.).	Very little rudder required to overcome the slow directional divergence and not much concentration required.			Directional static divergence is very slow but prevents aileron only turns since the nose slowly yaws out of the turn (in general).	No turbulence.	No X-wind.	No problem.	
LL 25+20+20	56	D	4		Aileron control good.	Rudder responsive.	A/c tends to slip into turns in both directions.		On recovery from turns not using rudder, recovery initially quite steady with a gradual yaw, developing following levelling of the wings.				Reasonable model that can be easily compensated for in flight.
LL 25+10+10	43	C	4½		Hit stop on S-turn even though no X-wind effect was noticed.				Static instability in yaw is slow enough to be no particular problem during banked turns, but attention wander and turbulence can result in large heading changes.				
LL 25+10+10	52	D	3	In uncoordinated turns, the aircraft initially slipped into the direction of the turn.	Control response good, and minimum stick deflection required to produce desired results.		Not hard to keep a/c in line with use of all controls.		In uncoordinated turns a/c initially slipped into direction of turn, but when bank stabilized at 20 deg. a/c tended to skid out and continue yaw.				Reasonably acceptable model. Lateral stability very good.
LL 25+0+0 LL 25+0+0 LL 25+0+0 LL 25+0+0 LL 25+0+0	91 53 80 107 112	B C D E E	4½ 4 2 5 3	See TABLE 4d for comments.									
LL 25-10-10 LL 25-10-10	57 56	C D	4 4	See TABLE 4c for comments.									
LL 25-20-20	143	B	5	No significant yaw with aileron. In aileron only turns, once turn develops, nose yaws in adverse sense. This could be due to roll, but possibly a result of oscillatory characteristics.			Can suppress slip and skid quite readily with rudder coordination. Aircraft manoeuvres quite well as long as rudder used to prevent slow yaw motions.	Aircraft develops long period diverging yaw oscillation if rudder fixed.		Negligible.	No problem.	No problem.	Would be tiring to fly for long periods due to oscillation.
LL 25-20-20	77	C	6	Pro-yaw with aileron.	O.K.		A small amount of rudder required to keep the ball in the centre, but if the wrong "small amount" selected the β builds rapidly. The coordination on turn exit is difficult to do smoothly and heading jostle results in most cases. Crossed controls required on turn reversals followed by a touch of rudder into the turn.		Pro-yaw and very loose directional stiffness precludes aileron only turns.	No problem.	No problem.	No problem.	

4g(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25-30-30	34	A	4	May have pro-yaw (+ve N_{δ_a})			Coordination is not easy. Some coordination difficulty, and β moderate but overall not too bad.	Seems to have good Dutch roll damping and reasonable directional stiffness.				Fair.	I was confused by the asymmetric response when releasing controls from steady sideslips ϕ/β small.
LL 25-30-30	29	C	7½	Initial swing with aileron was into the turn, but was closely followed by swing in opposite direction.			Could be manoeuvred as long as rudder was "tickled" in the turns.	Third swing felt as though it would be lost in yaw and recovery had to be made; that is, the oscillation feels and acts divergent. If rudder used to hold ball, oscillation frequency goes up - probably PIO.		Turbulence not bad.			
LL 25-30-30	48	D	4				Reasonable model that requires good rudder and stick coordination to fly accurately. Aircraft tends to slip into direction of turn in both directions, although more pronounced in left turns.						Induced yaw does not produce bank.
LL 25-40-40	67	A	7	Yaw due to aileron seems pro, and then, to establish steady state turn, bottom rudder is required.	Roll response is initially poor, and then aileron feels almost like a yaw control, i.e. it generates large β.		Coordination very poor and much yaw oscillation - mostly pilot induced.		Very loose directionally and easy to overcontrol with rudder.	Response to turbulence excessive.			Poor heading control - wanders constantly and rudder is required constantly. Large amplitude, high rate manoeuvres not possible without generating large β.
LL 25+30+40	51	C	3½			Rudder control very positive.	Could easily overcome deficiences with the very positive rudder.	Only problem is the long period swing occurring especially during roll out from turn which damps but leaves a steady state sideslip. Quite loose directionally.	Steady state sideslip (one time ½ ball width) left on exit from turns. Aircraft was quite loose directionally.	No effects.	No effects.		
LL 25+30+40	52	D	4	In uncoordinated turns, rather large sideslip into direction of turn results.	Model handles very well laterally.		Sideslip which develops in steady state turns is rather easily compensated for by pilot, but does require some degree of concentration.		Sideslip induced in uncoordinated turns continues with no sign of returning to zero.				Could be flown adequately.
LL 25+20+30	79	B	5		Rather slow, resembling a heavy aircraft.		Tendency to oscillate slowly in yaw dominates all manoeuvres, requiring constant rudder attention.	Doublet causes oscillatory yaw response, possibly slightly divergent. Tendency to oscillate slowly in yaw dominates all manoeuvres, requiring constant rudder attention.		Not particularly noticeable, but heading tends to wander on approach.	Manageable.	Manageable.	
LL 25+20+30	117	C	5½	No yaw due to roll evident. On aileron turns aircraft tends to dig into turn and then on roll out, swing further in the direction of the turn.	Adequate.		Coordination in turns possible but requires too much concentration.	Very loose directionally.	A very small rudder out of trim gives enormous sideslip.	No problem.	No problem.	"S" turn went well but not comfortable since rudder was required to keep β acceptable.	
LL 25+10+20	73	A	5½	Pro-yaw is generated which then tends towards adverse yaw, makes bank angle control difficult.	Initial roll response O.K.	Rudder forces quite light and pilot tends to overcontrol.	Coordination is a problem especially for rapid manoeuvres and reversals. This, and need to cross control is the major deficiency. Steady state turn requires bottom rudder - not too bad.	Some oscillatory tendencies in yaw, probably pilot induced.		Gust response moderate.		Sidestep done at moderate rate and turned out fair.	

4g(iii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25+10+20	83	C	5	Aileron only turns impossible since β builds up. Yaw due to roll noticeably pro, but not at all bothersome except that it starts the β build up on turn entry.	Adequate.		Only a small amount of rudder required to control β in turns.	The oscillation, when it could be allowed to proceed, was of very low frequency and divergent, but could be stopped easily.	Very loose directionally. If the pilot's attention were diverted for several seconds, β could increase unnoticed to large values. Feels like a static divergence even when straight and level.	No problem.	No problem.	No problem.	
LL 25+0+10	53	C	7	Pro-yaw is quite severe, exciting lightly damped directional oscillation which does not entirely prevent aileron only turns but makes them very uncomfortable.			Stopping the yaw on turn exit was the most difficult part of the model.	Aileron inputs excite lightly damped directional oscillation. Without the experience of the doublet, the first cycle of the oscillation would have been interpreted as divergent.		No problems.	No problems.		
LL 25+0+10	52	D	5	Any slight aileron input gives considerable yaw away from the direction of turn initially. Then it oscillates so that the aircraft is slipping into turn.			Yawing oscillation and slip in turns can be compensated for by rudder, but requires constant attention by the pilot.	Any slight aileron input gives considerable yaw away from direction of turn initially and then it oscillates so that the aircraft is slipping into the turn.					
LL 25-10+0	61	A	5	See TABLE 4c for comments.									
LL 25-10+0	57	C	6½										
LL 25-20-10	34	A	7½ + 8-9	I think there is pro-yaw with aileron followed by adverse yaw with roll.			Coordination is a problem. Yaw with aileron causes difficulty in determining the rudder required during a manoeuvre.		N_β is either zero or negative and I think negative. The reason I say I think it is, is that it is difficult to trim the aircraft and initial conditions can and do mask the responses.			Coordination problems caused very large β to be generated during terminal manoeuvre.	L_β is zero or very small. This is definitely a very poor configuration. For the terminal manoeuvre, the aircraft is approaching a dangerous condition.
LL 25-20-10	29	C	7½	Pro followed by adverse yaw with aileron.				Initial swing with aileron input was into turn but was closely followed by a swing in the opposite direction. The next swing felt as if it would be lost in yaw and recovery had to be made, i.e. oscillation feels and acts divergent. If rudder used to hold ball central, oscillation frequency goes up - probably a PIO.		Not bad.		Required lots of rudder. .	
LL 25-30-20	73	A	7	Large pro-yaw with aileron.		Rudder very sensitive with light forces.	Yaw changes to adverse during turn and it is very difficult to keep β within acceptable limits. Bank angle and yaw rate control in turns very poor.	Much PIO in yaw.	Heading control seemed acceptable in straight and level flight.	Turbulence gave much trouble on final approach.		Poor but can be done if you think to cross-control initially.	Coordination and large β excursions most objectionable. Performance in turns unacceptable.
LL 25-30-20	55	C	9	Enormous pro-yaw.				Enormous pro-yaw excites the slightly unstable dynamic oscillation, preventing aileron turns.	The directional divergence felt like a static divergence (except when straight and level) and had to be immediately controlled.	Very bothersome.	No problem.	Fortunate to eliminate β after S-turn.	

4g(iv)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25+30+20	67	A	7	Difficult to determine if yaw due to aileron is pro or adverse. Initial response to aileron seems satisfactory but must use rudder once β is generated.		Very poor control of yaw rate. I occasionally felt that aircraft was flying me.	Initial response to aileron seems satisfactory but must use rudder once β is generated. Very poor coordination in presence of almost constant yaw oscillation on approach. Cross control often needed.	Very poor coordination in the presence of almost constant yaw oscillation on approach. Moderate frequency and good damping but became increasingly bothersome.	Poor heading control.	Large effect.	Large effect.	Very poor.	The more I flew the configuration the less I liked it.
LL 25+30+20	68	C	8	Adverse yaw with aileron causes very uncomfortable swings. Turn reversals especially uncomfortable due to adverse yaw.	Roll control fairly brisk.		Coordination absolutely essential due to directional divergent oscillation occurring in steady turns.	Coordination absolutely essential due to directional divergent oscillation occurring in steady turns. Oscillation is of very low frequency and hence controllable, but requires much attention.	Yaw in level cruise appears to be a static divergence.	No great problem.	No great problem.	Went rather well, but required much rudder attention.	
LL 25+20+11	72	A	6½	Initial roll response is satisfactory but almost immediately pro-yaw is generated. Bank angle can be established after some oscillation yaw but soon large β is generated and rudder must be used.			Coordination is very difficult and rudder forces very light, giving tendency to produce PIO.	This configuration is oscillatory in turbulence and precision of heading control very poor. Tendency to produce PIO.		Excites oscillations.		Very poor.	Pilot effort too high for task. Can or must fly with slow inputs for reasonable results.
LL 25+20+11	115	C	7	Moderate amount of adverse yaw excites the yaw oscillation.	Roll control could be more powerful since the stop was contacted on one turn.		Coordination required to find proper rudder position.	Yaw oscillation excited by aileron appears to be divergent, requiring rudder after second peak.	Very small out-of-trim rudder results in enormous, in fact divergent, sideslips.	Turbulence excites yawing oscillation at a rate requiring attention during approach.	No problem.		
LL 25+0-9	35	A	7	Apparent pro-yaw due to aileron complicates the coordination.		Rudder effectiveness makes it easy to overcontrol in yaw.	Coordination is the major problem. Pro-yaw complicates coordination. Very poor performance in heading and in maintaining zero β in attempting coordinated turns.	Well behaved open loop Dutch roll with good damping and moderate stiffness.					
LL 25+0-9	46	C	7	Directional divergent oscillation precludes aileron turns.			Inattention to rudder allows large β to build rapidly. No great problem with roll entry but too much concentration required during banked turns.			No problem.	No problem.		
LL 25-10-19	64	A	5	See TABLE 4c for comments.									
LL 25-10-19	121	B	4										
LL 25-10-19	58	C	7½										
LL 25-10-19	120	C	6										
LL 25-10-19	127	E	5										

4g(v)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
LL 25-20-29	117	C	$5\frac{1}{2}$	No yaw due to roll. Aileron only turns impossible if aircraft held in steady state for a moderate length of time because of oscillatory characteristics.	Adequate.		Aileron only turns impossible if aircraft held in steady state for moderate length of time since the nose first overturns and then swings around to underturn causing alarming β to build. Coordination is quite easy, however. A very slight amount of rudder out of trim (i.e. $\approx \frac{1}{4}$ inch) causes enormous β to build very quickly and consequently too much attention required to rudder.	See column 4 of comments.		No problem.	No problem.	No problem.	
LL 25-39-39	36	A	$5\frac{1}{2}$	Predominant characteristic seems to be pro-yaw requiring coordination.		Light rudder forces caused tendency to overcontrol with rudder.	Pro-yaw requires cross control when initiating roll manoeuvres, and normal rudder coordination for steady state roll. This is not desirable and may cause very poor β control.	Model seemed loose directionally and with no or little dihedral effect.				Very large β generated.	Pilot can learn to do a good job but must be thinking about coordination all the time. Overall performance fair.
LL 25-30-39	33	C	$6\frac{1}{2}$	Pro-yaw with aileron starts the problem in turns which is compounded by a long period divergent oscillation:			Pro-yaw with aileron starts the problem in turns which is compounded by a long period divergent oscillation. Can be, controlled with rudder but amount of attention required is too high.	Pro-yaw with aileron starts the problem in turns which is compounded by a long period divergent oscillation.		No real problem.	No real problem.	Anticipating rudder in S-turn produced a surprisingly smooth manoeuvre.	

4h EFFECT OF CHANGING THE DUTCH ROLL DAMPING RATIO AT
$|\phi/\beta|_{DR} = 1.5$; $\omega_\phi = \omega_d = 1.0, 0.5, 0.25$ RAD/SEC, $\zeta_\phi = \zeta_d$

4h(i)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HH103+29+29 HH103+29+29 HH103+29+29 HH103+29+29	79 54 82 109	B C D E	8½ 10 5 10	See TABLE 4d for comments.									
HH100+20+20	32	A	5½	N_{δ_a} doesn't seem to be very large - possibly zero.			Must learn to use little rudder to coordinate turns - on the other hand, if good initial roll response is desired then rudder is necessary.	Difficult to maintain steady flight or bank angle - constant small amplitude roll oscillation.			Ran out of aileron on final due to crosswind so could not make S-turn.		Very large L_β and possibly poor roll damping but I believe the major effect is L_β. It is not a comfortable configuration but I can perform the mission.
HH100+20+20	78	C	10	No problem.			Bank angle tended to overshoot badly requiring opposite aileron in turns.	The oscillation was not evident as a very periodic phenomenon, but the turbulence would excite the roll especially which would give a couple of large bank angle excursions.		Very bothersome even in straight and level flight.	Could not hold on the approach track with the ball in the centre - slipped off to the right while holding full left aileron. The only way to stay on was to let the ball go to the right.	Could not initiate the "S" turn with the ball in the centre - would have hit the ground either sideslipping or banking or both.	
HH100+20+20	44	D	8		Yaw induces roll effect that cannot be overcome by full travel of aileron. Aircraft can only be levelled by using opposite rudder.			Very unstable in flight, in yaw and roll.		In severe turbulence there would be lots of roll experienced.	Crosswind compensation on approach required full left aileron - unacceptable.		
HH100+20+20	48	D	8		Application of yaw produces large roll in either direction.		Large stick displacements required for turns.	A/c laterally unstable requiring considerable attention.			Crosswind required full stick intermittently.	Rudder had to be used to level aircraft for simulated landing.	Unsatisfactory.
HH103+10+10	83	C	10	No problem.	Enormous $\|\frac{\phi}{\beta}\|$. Roll control completely inadequate for all but minute β. Just a touch of rudder requires full aileron.		Absolutely necessary to keep the bank angle constant.	Oscillation evident and continually excited by turbulence.		(See "oscillatory" column)	Holding full aileron on for about 50% of approach and could not initiate the S-turn without assistance of rudder.	Would have landed on right wing tip in about 20 deg. of sideslip.	
HH103+10+10	49	D	7		Pronounced lateral instability requires full aileron deflection with rudder assistance to remain upright. Absolute control was marginal in all the manoeuvres, however, by using rudder a/c could be levelled O.K.		Model has no tendency to stabilize in turns - requires constant monitoring.						
HH100+0+0 HH100+0+0 HH100+0+0 HH100+0+0 HH100+0+0	31 89 84 112 116	A B C E C	8 7½ 10 10 9½	L_{δ_a} increased from 0.4 to 0.6 $\frac{\text{rad/sec}^2}{\text{in.}}$		See TABLE 4d for comments.							
HH100-10-10	35	A	7½	Aileron inputs induced yaw, and rudder was essential to stop oscillation.	Aileron forces and displacements at times felt excessive. Bank angle control very poor.	Heading control fair to poor.	Very difficult to coordinate due to high $\|\frac{\phi}{\beta}\|$ and probably high frequency Dutch roll.	Almost constant roll oscillation no matter how carefully I tried to coordinate. Aileron inputs induced yaw and rudder was essential to stop oscillation.	Trim not possible.				
HH100-10-10	46	C	9				Enormous roll with β unless the ball is watched continuously.	There is a hint of an oscillation but it appears more like a static divergence in roll.		Very severe.	Requires about 75% aileron and hit stops on approach often, due to turbulence.	"S" turn would have ended in crash with about 15 deg. of bank if wing had not been picked up with rudder.	Wild!
HH100-20-20 HH100-20-20 HH100-20-20 HH100-20-20 HH100-20-20	75 90 77 76 108	A B C D E	9½ 8½ 10 10 10	See TABLE 4d for comments.									

4h(ii)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HM 47+30+28 HM 47+30+28 HM 47+30+28	74 91 43	A B C	7 6 8½	See TABLE 4d for comments.									
HM 51+20+20	120	C	8	Aileron only turns impossible because in general aircraft wants to yaw out of turn. No problem with yaw due to roll.	Adequate if started with ball in centre but if ball out, it is very inadequate.	Very sensitive.	Unless a lot of attention paid to ball during turns the full aileron can be required either into or out of turn. Coordination very touchy with the very sensitive rudders.	Oscillation not showing up as such, but rather as a static divergence in yaw following aileron inputs.		Moderate in roll.	Requires approx. ½ full aileron (not objectionable).	Full aileron required on entry and exit.	
HM 53+10+9	32	A	4	Either the spiral was negative or the N_{δ_a} was affecting the response in some peculiar way.			I was able to fly reasonably well with just aileron except that during steady state turns the sideslip would come in and require more aileron to maintain bank angle. This would indicate (normally) that the spiral is convergent but in open loop response it seems divergent. I just don't know what is going on. Coordination was fair during large amplitude manoeuvres and terminal S-turn except that aileron hit the stop.	Seems to have moderate $\left\|\frac{\phi}{\beta}\right\|$ with moderate Dutch roll frequency and good damping.				(See "coordination")	
HM 53+10+9	29	C	8				Every turn overbanked to begin with. In steady turns the bank angle was continually wandering around.			Lots of turbulence.	Full left aileron required to hold X-wind and turbulence.	Would have hit the ground with 20 deg. of bank if I had not gone into a positive β to pick up wing - hence could not get to landing spot.	
HM 53+10+9	48	D	5				Yaw characteristics seem reasonable but A/c will not stabilize in a turn. Requires considerable pilot monitoring at all times. Can be flown but requires more concentration than normal.		A/c tends to return to wings level attitude.				Rather unpleasant to fly.
HM 51+0+0 HM 51+0+0 HM 51+0+0 HM 51+0+0 HM 51+0+0	74 135 43 81 113	A B C D E	8 6 8 6 10	See TABLE 4d for comments									
HM 50-10-10	55	C	8	Aileron only turns impossible due to large β build up.	The roll acceleration does not seem to come in immediately when rudder moved, but seems to lag and then comes in with a rush (maybe negative L_r and negative L_β?)		Aileron only turns impossible due to large β build up. Continuous movement of aileron required at all times due to rather erratic roll disturbances.			Quite strong.	Quite strong.	Hit left stop on S-turn entry and exit and had to sideslip to pick up the wing for touchdown.	
HM 50-20-20 HM 50-20-20 HM 50-20-20 HM 50-20-20 HM 50-20-20	36 75 94 46 126	A A B C E	8 9 7 8½ 8½	See TABLE 4d for comments.									

4h(III)

CONFIGURATION NO.	FLIGHT NO.	PILOT	PILOT RATING	YAW DUE TO AILERON APPLICATION	ROLL CONTROL	YAW CONTROL	COORDINATION	OSCILLATORY CHARACTERISTICS	STATIC CHARACTERISTICS	TURBULENCE	CROSSWIND	SIDESTEP MANOEUVRE	MISCELLANEOUS
HL 25+20+20	47	B	5		Aileron rather sluggish and difficult to establish precise bank angle.			Tends to oscillate with a long period in yaw and roll if left alone.					Pro-roll with rudder quite noticeable.
HL 25+20+20	41	C	3½				Aileron only turns impossible due to β build up, but it takes a while to get large enough to be a bother and can be easily prevented with the very positive rudder available.			No problem.	Small amount of aileron, but O.K.		
HL 25+10+10	83	C	6	No detectable yaw due to roll.	Effective enough but could be more brisk.		Turn coordination surprisingly easy and, on some aileron-only turns, only moderate β occurred. On a couple of others, rudder was absolutely necessary.		Surprising model in that in straight and level flight with no input the heading diverges and a very large β builds – appears like a static divergence – but all this happens slowly enough to be controlled with rudder.	No problem.	Required approx. ¼ aileron but no problem.	No problem.	Constant attention required to prevent sideslip from building.
HL 25+10+10	80	D	5				Laterally unstable – requires constant attention to aileron – wants to continue to roll in direction of turn with large degree of slip – no tendency to stabilize. Has to be flown constantly.			Keeps pilot busy.	O.K.	Had full aileron deflection to recover from 25 deg. of bank.	Generally not good. Requires concentration and constant attention.
HL 25+0+0	32	A	6	For comments see TABLE 4d.									
HL 25+0+0	92	B	4										
HL 25+0+0	78	C	6½										
HL 25+0+0	112	E	6½										

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13. ABSTRACT

An investigation to determine the ranges of various lateral directional characteristics required to provide adequate flying qualities for turning maneuvers at low speed was undertaken using an airborne V/STOL aircraft simulator. Five parameters were varied in a systematic manner: the damping ratio, the frequency, and the ratio and the frequency of the numerator of the roll-angle to aileron-control-input transfer function. The pilots performed a low speed, visual maneuvering task and documented their assessment of the characteristics through extensive comments and a numerical rating. This report presents all the data categorized with respect to the test parameters as comprehensively as possible to allow others to examine them thoroughly from various points of view. No attempt has been made here to analyze the findings in detail. This is the subject of continuing work.

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