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A FLIGHT INVESTIGATION TO DETERMINE THE LATERAL OSCILLATORY DAMPING ACCEPTABLE FOR AN AIRPLANE IN THE LANDING APPROACH

By Walter E. McNeill and Richard F. Vomaske

Ames Research Center
Moffett Field, Calif.

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A FLIGHT INVESTIGATION TO DETERMINE THE LATERAL OSCILLATORY DAMPING ACCEPTABLE FOR AN AIRPLANE IN THE LANDING APPROACH*

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SUMMARY

An F-86E airplane, in which servo actuation of the ailerons and rudder provides artificial variation of the important lateral and directional aerodynamic stability parameters, has been flown by test pilots of the NASA, U. S. Air Force, and one aircraft manufacturer to determine satisfactory and acceptable levels of lateral oscillatory damping in the landing approach. In addition to normal operational use, particular consideration was given to the emergency condition of failure of stability-augmentation equipment.

In this study, the pilots' opinions of the airplane dynamic stability and control characteristics in smooth and simulated rough air have been recorded according to a numerical rating scale. The results are presented in the form of boundaries in terms of cycles to damp to half amplitude, $1/C_{1/2}$, or time to damp to half amplitude, $1/T_{1/2}$, and bank-to-sideslip ratio, and are discussed in relation to existing flying-qualities criteria.

Though the present results, which were obtained at 170 knots indicated airspeed and 10,000-feet altitude, indicated that increased damping is required with increased bank-to-sideslip ratio (as found in previous work), consideration of the dampers-failed condition indicated a great reduction in the minimum acceptable damping. At moderate values of bank-to-sideslip ratio, effects of lateral-oscillation period on pilot-opinion variation with damping appeared to be taken into account by use of the parameter $1/T_{1/2}$.

*Title, Unclassified

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INTRODUCTION

In recent years, several criteria for satisfactory airplane lateral oscillatory behavior (based on pilot opinions) have been proposed (refs. 1, 2, 3, and 4). While different views may exist among these proposals as to how best to express the parameters of airplane motion which are important to the pilot, all agree that poor oscillatory damping and high roll-to-yaw ratios should be avoided.

The current military flying-qualities specification (ref. 5) presents airplane lateral-oscillation requirements, in terms of cycles to damp to half amplitude and rolling parameter (bank-to-sideslip ratio), for normal operational flight and for the emergency condition of failure of stability-augmentation equipment. When the specification appeared, it was the first time that this emergency requirement had to be satisfied in the design of new airplanes. At that time, the locations of the lateral-oscillation boundaries were felt to be in reasonable agreement with existing data (see ref. 6).

Recently, it has been suggested that the normal and emergency boundaries a and b (A and B, ref. 5) are unnecessarily stringent. In particular, questions have arisen as to whether boundary b is a realistic requirement in terms of safe operation; that is, would airplanes having less damping actually be dangerous to fly in the power-approach condition in an emergency? To investigate this point, a flight study was made using the F-86E variable-stability test vehicle to determine, from pilot opinions (based on the numerical rating scale recently introduced in ref. 7), the minimum acceptable lateral oscillatory damping for the landing approach. Ranges of period and bank-to-sideslip ratio were covered which are representative for airplanes of the present and immediate future in this condition.

It is the purpose of this report to present and discuss the results of this investigation in relation to previous work in this field and existing military specifications.

NOTATION

$C_{1/2}$ cycles required for lateral oscillation to damp to half amplitude, $\frac{T_{1/2}}{P}$

C_2 cycles required for lateral oscillation to double amplitude, $\frac{T_2}{P}$

[redacted]

C_l rolling-moment coefficient, $\frac{\text{rolling moment}}{qSb}$

C_{l_β} $\frac{\partial C_l}{\partial \beta}$, per radian

$C_{l_{\delta_{r_p}}}$ $\frac{\partial C_l}{\partial \delta_{r_p}}$, per radian

C_{l_p} $\frac{\partial C_l}{\partial (pb/2V)}$, per radian

C_n yawing-moment coefficient, $\frac{\text{yawing moment}}{qSb}$

C_{n_β} $\frac{\partial C_n}{\partial \beta}$, per radian

$C_{n_{\delta_{a_p}}}$ $\frac{\partial C_n}{\partial \delta_{a_p}}$, per radian

C_{n_p} $\frac{\partial C_n}{\partial (pb/2V)}$, per radian

C_{n_r} $\frac{\partial C_n}{\partial (rb/2V)}$, per radian

P period of lateral oscillation, sec

R_{p_e} empirical pilot rating

R_{p_o} observed pilot rating

S wing area, sq ft

$T_{1/2}$ time required for lateral oscillation to damp to half amplitude, sec

T_2 time required for lateral oscillation to double amplitude, sec

V true airspeed, ft/sec

V_i indicated airspeed, knots

b	wing span, ft
h_p	pressure altitude, ft
p	rolling angular velocity, radians/sec
q	dynamic pressure, lb/sq ft
r	yawing angular velocity, radians/sec
v_e	$V\sqrt{\sigma}\sin\beta \approx V\sqrt{\sigma}\ \beta$
α	angle of attack, radians
β	sideslip angle, radians
δ_{a_p}	pilot-applied total aileron deflection, radians
δ_{r_p}	pilot-applied rudder deflection, radians
σ	ratio of air density at test altitude to that at sea level
φ	bank angle, radians
$\frac{\lvert\varphi\rvert}{\lvert v_e\rvert}$	$\frac{\lvert\varphi\rvert}{\lvert\beta\rvert}\frac{57.3}{V\sqrt{\sigma}}$ ratio of bank-angle amplitude to equivalent-side-velocity amplitude for the oscillatory mode, $\frac{\text{deg}}{\text{ft/sec}}$

EQUIPMENT AND INSTRUMENTATION

A photograph of the variable-stability airplane used in the present investigation is shown in figure 1.

Variable-Stability Equipment

The airplane used in the present tests is capable of artificial variation of the major lateral and directional stability and control parameters through servo actuation of the ailerons and rudder. The estimated ranges of variation of these quantities at the particular flight conditions used are presented in table I. Variation of the longitudinal stability derivatives is possible also with the existing servo installation; however, at present, the stabilizer drive system is used for pilot control and rough-air simulation. Brief descriptions of the rudder and aileron servo systems are given in reference 8. Schematic diagrams of these systems are shown in figure 2 and complete descriptive material is available in the appendix.

Design of the over-all signal system is typical of that used in other variable-stability airplanes. One feature worth noting, however, is that separate servo systems are provided for each aileron. In addition to normal aileron action, this makes possible independent aileron motions, one application of which will be described later.

Three modes of aileron and stabilizer system operation are available to the pilot: (1) normal control, (2) position servo (fly-by-wire), and (3) variable stability. These modes are described in the appendix.

Disturbances, simulating those of rough air, are provided by driving the ailerons, rudder, and stabilizer at adjustable frequencies and amplitudes in a manner similar to that described in reference 6. One refinement which has been added, however, is a provision for superimposing symmetrical aileron motions (both up or both down) on the normal roll-producing deflections. This is made possible by the independent aileron servo systems. In this manner, combinations of stabilizer and symmetrical aileron-deflection amplitudes can be selected which provide a simulation of the vertical rough-air components (i.e., it feels more like rough air to the pilot).

Figure 3 shows the location of the cockpit controls for the variable-stability equipment. The major difference between the servo gearing controls (fig. 3(b)) and those used in previous NASA variable-stability airplanes is that continuous variation of the seven adjustable parameters is provided by means of 10-turn potentiometers instead of discrete step settings.

Recording Instrumentation

An 18-channel photographic oscillograph, with color film, was used to record the following quantities in flight:

Quantity	Range
Left aileron position	$\pm 15^\circ$
Right aileron position	$\pm 15^\circ$
Rudder position	$\pm 20^\circ$
Stabilizer position	$+3^\circ$ to -10°
Pilot-applied aileron position	$\pm 15^\circ$
Pilot-applied rudder position	$\pm 20^\circ$
Rudder servo position	$\pm 8.5^\circ$
Rudder tab position	$\pm 8.5^\circ$

[redacted]

Quantity	Range
Sideslip angle	±12°
Rolling velocity	±120°/sec
Yawing velocity	±0.7 radian/sec
Aileron stick force	±30 lb
Rudder pedal force	±280 lb
Normal acceleration at center of gravity	±4 g
Lateral acceleration at center of gravity	±0.7 g
Lateral acceleration at pilot's seat	±0.7 g

FLIGHT TESTS

Participation

A total of seven pilots took part in the flight investigation reported herein: Four NASA research pilots (A, B, C, D), two from the Air Force Flight Test Center at Edwards AFB, California (E, F), and one aircraft company experimental test pilot (G).

Regions of Characteristics Investigated

Three regions of lateral-oscillation characteristics (pilot controls fixed) were defined and investigated during the present program. These were (1) long period ($3.11 \leq P \leq 4.32$ sec) and moderate roll-yaw coupling ($0.49 \leq |\varphi|/|v_e| \leq 0.70$); (2) long period ($2.75 \leq P \leq 6.90$ sec) and high roll-yaw coupling ($0.93 \leq |\varphi|/|v_e| \leq 1.65$), pilots A, B, C, and D only; and (3) short period ($1.54 \leq P \leq 2.38$ sec) and moderate roll-yaw coupling ($0.45 \leq |\varphi|/|v_e| \leq 0.63$).

Lateral-oscillation damping covered a range from $1/C_{1/2} = 4.65$ (about half critical damping) to $1/C_2 = 1.70$ (rapidly divergent oscillations). The long-period conditions ($P \approx 3$ to 4 sec) were looked upon as representative of those for present-day high-speed airplanes in the landing approach, while the short-period points were included to investigate the effects of period on pilot opinions of the lateral-oscillation characteristics.

Test Conditions

The variable-stability airplane was flown at $V_i = 170$ knots and $h_p = 10{,}000$ feet with gear and flaps retracted during the present tests.

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All pilots assigned numerical ratings to each combination of stability settings on the basis of lateral oscillatory characteristics (pilot controls fixed) and lateral-directional handling qualities in both smooth and simulated rough air. Rough-air settings corresponded to pilot A's impression of moderate to heavy turbulence. Ratings were given for the landing-approach condition only, according to the rating scale presented in table II, taken from reference 7.

In order to minimize the effects of control cross effectiveness (e.g., adverse yaw) on the flight evaluations, $C_{l_{\delta_{r_p}}}$ was set at the normal F-86E value and $C_{n_{\delta_{a_p}}}$ was set at the pilot-selected optimum value (minimum yaw due to aileron deflection) for any given combination of variable-stability settings.

RESULTS AND DISCUSSION

Lateral Oscillatory Characteristics

The lateral oscillatory characteristics (in terms of P, $1/C_{1/2}$, $1/T_{1/2}$, and $|\varphi|/|v_e|$) of the configurations flown and numerical ratings assigned by pilots A through G for over-all suitability in the landing approach are presented in table III. Figure 4 presents the over-all ratings of each pilot on the familiar $1/C_{1/2}$ versus $|\varphi|/|v_e|$ plane, for the long and short periods.

The numerical ratings are grouped in figure 4 to correspond directly to the basic grouping of opinions in the rating scale of table II and are parallel in meaning with the areas defined by boundaries a and b of the current military specification (ref. 5). An additional region ($R_{p_o} \geq 7.5$) is indicated in figure 4 by the flagged symbols, for which an attempted landing would be extremely hazardous or impossible, particularly in gusty air.

It is apparent already that at least one of the pilots would accept, in normal operation, a somewhat lower level of lateral oscillatory damping than specified by boundary a of reference 5 and that practically all the pilots would accept, for emergency operation, much lower damping than required by boundary b.

Two approaches have been used in previous analyses of this type of data: (1) visual fairing of boundaries through the plotted data (refs. 1, 2, and 3) and (2) determination of empirical expressions for pilot rating and statistical correlations with the actual ratings (ref. 4). For the present analysis, a graphical procedure based on the principle of least squares successfully indicated pilot-opinion boundaries applicable to the particular mission and region of characteristics considered. First, the combined long-period and short-period data of figure 4, consisting of 132 data points, were divided into four regions of $|\varphi|/|v_e|$, wherein that parameter was assumed to have no effect on pilot rating (inspection of the basic data showed a small effect of $|\varphi|/|v_e|$ when compared with that of damping). All four groups contained an equal number of points (33). Because of the nonuniform distribution of the data with respect to $|\varphi|/|v_e|$, this method resulted in four regions of unequal area; the values of $|\varphi|/|v_e|$ separating the four groups of data were 0.545, 0.600, and 0.975. Next, within each of these groups, the observed over-all ratings of the individual pilots were plotted as functions of damping $1/C_{1/2}$. These variations (fig. 5) indicated, in each quarter, a nearly linear relationship between pilot rating and damping over the major portion of the plot. In each quarter, a certain number of points with the highest $1/C_{1/2}$ values were classed as showing no further improvement in R_{p_o} with increased damping. In figure 5, these points are shown separated from the main data by vertical dashed lines. The main data in each quarter were fitted, by least squares in terms of R_{p_o}, with a straight line which was assumed to connect with the average R_{p_o} of the high-damping points. Figure 6 presents similar variations in terms of damping time $1/T_{1/2}$ rather than $1/C_{1/2}$.

These modified linear variations of R_{p_o} with damping were considered adequate for the purpose of the present study; that is, they indicate general levels of damping required under the rather restricted condition of the landing approach. It was felt that assumption of variations of higher order would not appreciably increase the significance of the results.

Pilot-opinion boundaries derived from figure 5 are shown in figure 7 in terms of $1/C_{1/2}$ and $|\varphi|/|v_e|$. These boundaries were located by entering the fitted linear variations of figure 5 at pilot ratings of 3.5 and 6.5 (minimum characteristics for normal flying and dampers-failed conditions), as shown by the dashed arrows, and plotting the intercepts on the $1/C_{1/2}$ scale at the average $|\varphi|/|v_e|$ for each quarter. These intercepts are indicated in figure 7 by the plotted points. The final straight-line boundaries were fitted to the plotted points by a second least-squares process performed in terms of $1/C_{1/2}$. Also included in the figure are boundary points for normal flying and the emergency condition, based only on the short-period data of table III(b) with $|\varphi|/|v_e|$ of 0.60 or less. These boundary points were located in a manner identical to that used to find the intercept pairs for the over-all data. Boundaries a and b of the current military lateral-oscillation specification (ref. 5) are included for comparison.

It is noted that in figure 7 fair agreement exists between the upper short-period boundary point (R_{p_e} = 3.5) and boundary a of the military specification and that there is rough quantitative agreement between the upper over-all boundary and boundary a at values of $|\varphi|/|v_e|$ of about 0.6. However, the present lower boundary (dampers failed) is considerably below boundary b of reference 5. Boundaries based on early pilot-opinion work on lateral-oscillation criteria (ref. 1) indicated stringent requirements on damping as bank-to-sideslip ratio became large. The current military specification, though not completely parallel with the early boundaries in meaning, reflected a certain degree of leniency in this regard, which was discussed in reference 6. The leniency shown by the present lower boundary, however, is even greater.[1]

Presented in figure 8 are boundaries similar to those of figure 7, for $R_{p_e} = 3.5$ and 6.5 in terms of $1/T_{1/2}$ and $|\varphi|/|v_e|$. As in figure 7, the military specification boundaries a and b are included, except that a period of 3.5 seconds (about average for all the data) is specified in order that boundaries a and b could be plotted in terms of $1/T_{1/2}$. Again, the boundary points indicated by the short-period data are shown.

The leniency shown by the dampers-failed boundaries ($R_{p_e} = 6.5$) of figures 7 and 8 was surprising at first. Unpublished results of earlier pilot-opinion flights made in the variable-stability F6F-3 airplane showed a similar leniency when the lateral-oscillation damping requirements considered were for the emergency case of stability-augmenter failure. It appears, then, that if the problem is reduced to one of simply flying the airplane home and landing it safely, the amount of natural damping required would be (in relation to that necessary for satisfactory normal behavior) even less than previous studies have indicated. It should be investigated whether this trend prevails at higher speeds and altitudes.

Choice of Damping Parameter

The short-period boundary points and the over-all data boundaries in figure 8 are in better agreement than in figure 7. This suggests that effects of oscillation period can be taken into account more readily if damping is expressed in terms of $1/T_{1/2}$ rather than the cyclic parameter $1/C_{1/2}$. This point is brought out more graphically in figure 9, where linear least-squares fits of pilot rating as functions of $1/C_{1/2}$ and $1/T_{1/2}$ (similar to those of figs. 5 and 6) are presented for the long-period and short-period data at $|\varphi|/|v_e|$ between 0.45 and 0.60. On the left side of figure 9, shortening the period appears to have increased

[1]In the previous work, excessive adverse aileron yaw was frequently noted; in the present study, however, adverse yaw effects on pilot opinions were minimized by means of pilot-selected optimum settings of $C_{n_{\delta_{a_p}}}$.

the rate of change of pilot rating with change of damping $1/C_{1/2}$ and narrowed the intermediate pilot-rating region ($3.5 < R_{p_e} < 6.5$). This has been attributed by some of the pilots to the fact that, for a given $1/C_{1/2}$, the airplane motions simply take less time either to damp or to reach uncontrollable amplitudes. Against $1/T_{1/2}$, however, the variations of pilot rating with damping for the two period groups are shown to be in closer agreement. These results suggest that the simple time basis of expressing damping may, after all, be the proper one in defining satisfactory oscillatory behavior.

A determination, over wider ranges of speed and altitude, of the proper expressions for damping and roll-to-yaw ratio and how best to account for effects of oscillation period should be the subject of further and more detailed study.

Comparison With Operational Types

A comparison between the boundaries of figure 8 (shown for R_{p_e} of 3.5 and 6.5) and pilot opinions of measured lateral-oscillation characteristics of two current operational fighter aircraft (see ref. 9 for F-100A) in the power-approach configuration is made in figure 10. The symbol shade coding is the same as that used in figure 4.

Except for the F4D-1 without external tanks and with yaw damper inoperative, and the higher approach-speed points with tanks on and yaw damper off, good agreement with the boundaries of figure 8 is indicated. One other point of apparent disagreement was the unacceptable rating given the 125-knot approach condition with tanks on and yaw damper inoperative. In this condition, the pilot's comments indicated that poor control-response characteristics, coupled with low directional stability, was the reason for the poor opinion (aileron deflection seemed to produce large sideslip angles before appreciable roll was developed). This was complicated further by a deterioration of the rudder-pedal-force gradient at sideslip angles greater than 6°.

This pilot impression, together with early comments made during flights in the variable-stability F-86E at 170 knots indicated airspeed, suggested that effects such as adverse yaw could influence pilot opinion even more strongly than the lateral oscillatory characteristics themselves. It was mentioned previously that, for the conditions flown during the present study, pilot-selected optimum settings of yaw due to pilot-applied aileron deflection $C_{n_{\delta_{a_p}}}$ were used. Brief tests made during one flight by pilot A indicated a strong adverse effect on pilot opinion of changing $C_{n_{\delta_{a_p}}}$ setting in either direction from optimum. Additional study would be helpful in determining acceptable limits of adverse or favorable $C_{n_{\delta_{a_p}}}$ (and also $C_{l_{\delta_{r_p}}}$) under varying conditions of directional stability and damping.

CONCLUDING REMARKS

A flight study has been made to determine acceptable lateral oscillatory damping in the landing approach, based on pilot opinions obtained in a variable-stability airplane at 170 knots indicated airspeed and 10,000 feet altitude, with emphasis on the emergency condition of damper failure. To minimize effects of adverse aileron yaw on pilot opinions, pilot-selected optimum settings of $C_{n_{\delta_{a_p}}}$ were used throughout the investigation. The study has indicated the following:

As observed in past work, reduced damping and increased bank-to-sideslip ratio resulted in more adverse pilot opinions, though the latter effect was less pronounced in the present study.

Consideration of the emergency (dampers-failed) condition, in which the airplane need only be returned to base and landed, has shown that the damping required for acceptable behavior can be drastically reduced; even slightly divergent oscillations were accepted below $|\varphi|/|v_e|$ of about 1.0. Further investigation should be made of the prevalence of this trend at higher speeds and altitudes.

For a narrow range of moderate $|\varphi|/|v_e|$ where a complete set of data was available, the effects of lateral-oscillation period on the variation of pilot opinion with damping appeared to be correlated by use of the parameter $1/T_{1/2}$ as the damping criterion. To verify this, further study over wide ranges of speed and altitude should be made.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Oct. 10, 1958

APPENDIX

DESCRIPTION OF VARIABLE-STABILITY SERVO EQUIPMENT

The servo equipment installed in the variable-stability F-86E to provide artificial variation of lateral and directional stability parameters is similar in principle to that used in other variable-stability aircraft. Certain design details peculiar to this airplane are included in the following description.

Signal Circuits

Figure 2(a) presents a block diagram relating the important components of the aileron, rudder, and stabilizer servo signal circuits.

Aileron and Stabilizer Systems

The aileron and stabilizer control systems of the F-86E airplane are of the fully powered, irreversible, hydraulic type with constant artificial feel. Three modes of operation of the aileron and stabilizer systems are available to the pilot in the variable-stability F-86E:

1. Normal control: pilot's stick mechanically connected to the hydraulic control valves.

2. Position servo: pilot's stick disconnected from the control valves; valves driven by servomotors in response to electrical signals proportional to stick position (fly-by-wire system).

3. Variable stability: fly-by-wire control with superposition of signals from variable-stability sensing elements (e.g., sideslip vane, roll-rate gyro) according to pilot-adjusted servo-gearing values.

The relationship of mechanical components of one aileron servo system is shown in figure 2(b). The system is basically that of a standard F-86E, except for the addition of the pneumatic disconnect system and the valve servomotor, both of which are energized during position-servo and variable-stability operation. In the disengaged condition, the disconnect assembly is held open by the pressure of compressed nitrogen regulated to 125 psi. In the open position, the disconnect allows ±7.5° of servo-applied aileron travel about the position commanded by the control stick (fly-by-wire control) for variable-stability use. The aileron hydraulic control valve linkage is driven by the electric servomotor, through a slip clutch, in response to the fly-by-wire and variable-stability signals. When the limit of travel allowed by the disconnect is reached, the disconnect bottoms, the control valve closes, and aileron motion ceases until the servomotor drives in the opposite direction or until the stick is moved by the pilot. As a safety measure, the disconnect valve (fig. 2(b)) is arranged so that pressure is removed from all three disconnects in the event of electrical power failure. Should the valve remain in the energized position, however, reconnection can be accomplished by opening the emergency dump valve. This exhausts the entire pneumatic system in about 15 seconds, whereupon reconnection takes place. The dump valve is normally closed unless energized by the pilot, electrical power being furnished by the battery bus system.

Rudder System

The F-86E rudder servo system (including the rudder itself) was, for all practical purposes, removed bodily from the variable-stability F-86A (ref. 6). A schematic diagram of the rudder servo system is shown in figure 2(c). A complete description of the rudder system is given in reference 6; however, there are two main differences which should be noted: (1) the normal airplane hydraulic system is now used to drive the rudder, and (2) the original single-stage servo control valve has been replaced by a two-stage type. The rudder-servo authority is about $\pm 8.5^{\circ}$.

Variable-Stability Cockpit Controls

Figure 3 shows the location of the cockpit controls for the F-86E variable-stability equipment. With the servo master switch on, only hydraulic pressure to the rudder servo remains to be turned on (see ref. 6) to put that system into operation. With position-servo and variable-stability switches on in addition, the aileron servo system is ready for variable-stability use. Aileron system hydraulic pressure is on during all modes of operation.

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TABLE I.- ESTIMATED RANGES OF VARIABLE STABILITY AND CONTROL PARAMETERS AVAILABLE ON AIRPLANE

(V_i = 170 knots; h_p = 10,000 ft)

Parameter	Maximum	Normal	Minimum
C_{n_β}	0.510	0.107	-0.305
C_{n_r}	1.15	-.180	-1.53
C_{n_p}	.121	-.042	-.200
$C_{n_{\delta_{a_p}}}$	.180	.019	-.142
C_{l_β}	.430	-.097	-.625
C_{l_p}	.22	-.35	-1.10
$C_{l_{\delta_{r_p}}}$	.176	.006	-.152

TABLE II.- PILOT-OPINION RATING SCALE OF REFERENCE 7, USED IN PRESENT STUDY

	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Satisfactory	1	Excellent, includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only[1]	Doubtful	Yes
No operation	Unacceptable	7	Unacceptable even for emergency condition[1]	No	Doubtful
		8	Unacceptable - dangerous	No	No
		9	Unacceptable - uncontrollable	No	No
	Catastrophic	10	Motions possibly violent enough to prevent pilot escape	No	No

[1]Failure of a stability augmenter.

TABLE III.- PILOT OPINIONS OF THE LATERAL OSCILLATORY CHARACTERISTICS OF THE VARIABLE-STABILITY AIRPLANE FLOWN IN THE PRESENT INVESTIGATION

(a) Period from 2.75 to 6.90 seconds

Pilot	P	$\frac{1}{C_{1/2}}$	$\frac{1}{T_{1/2}}$	$\frac{\lvert\varphi\rvert}{\lvert v_e\rvert}$	Pilot rating			
					Lateral oscillations	Handling in smooth air	Handling in rough air	Over all
	3.15	1.72	0.546	0.56	2.0	3.0	---	2.5
	3.24	.79	.244	.57	3.0	4.0	---	3.5
	3.47	.18	.052	.62	4.0	4.0	---	4.0
	3.51	-.73	-.208	.59	6.0	6.0	---	6.0
	3.84	-1.39	-.362	.63	8.0	8.0	---	8.0
	3.18	1.52	.478	1.09	---	---	---	3.0
	3.11	.96	.309	1.02	---	---	---	4.0
	3.79	-.51	-.135	1.10	---	---	---	8.0
	2.75	.58	.211	.93	---	---	---	6.0
	3.14	.41	.131	.97	---	---	---	4.0
	2.83	.02	.007	.94	---	---	---	7.0
A	3.33	-.21	-.063	1.00	---	---	---	5.0
	3.00	-.35	-.117	1.00	---	---	---	8.0
	3.67	-.55	-.150	1.01	---	---	---	7.0
	3.14	-.80	-.255	1.02	---	---	---	8.0
	3.24	-1.05	-.324	.98	---	---	---	9.0
	3.55	1.42	.400	1.39	---	---	---	6.0
	3.57	1.54	.431	1.45	---	---	---	6.0
	3.70	.70	.189	1.45	---	---	---	7.0
	4.60	2.68	.583	1.47	---	---	---	3.5
	5.18	2.12	.409	1.47	---	---	---	3.0
	6.45	.75	.116	1.65	---	---	---	3.0
	5.13	1.66	.324	1.56	---	---	---	3.5
	3.15	2.22	.705	.57	---	---	---	3.5
	3.40	.96	.282	.58	---	---	---	3.0
	3.65	.19	.052	.62	---	---	---	4.5
	3.57	-.56	-.157	.59	---	---	---	6.0
	3.84	-1.39	-.362	.63	---	---	---	7.5
	3.34	1.28	.383	.87	---	---	---	3.5
B	4.09	1.76	.430	.84	---	---	---	3.2
	3.36	.80	.238	1.19	---	---	---	4.0
	3.41	.66	.194	1.23	---	---	---	4.5
	3.60	.28	.078	1.32	---	---	---	5.0
	3.93	.04	.010	1.60	---	---	---	7.0
	4.15	-.06	-.014	1.62	---	---	---	8.5
	3.29	2.11	.641	.59	3.0	---	---	3.0
	3.27	.70	.214	.57	5.0	---	---	5.0
	3.51	.23	.066	.60	6.0	---	---	6.0
	3.63	-.39	-.107	.59	7.0	---	---	7.0
	3.84	-1.39	-.362	.63	8.0	---	---	8.0
C	2.98	1.13	.379	1.08	5.0	4.5	5.5	5.0
	2.94	.82	.279	1.10	5.0	5.0	6.0	5.5
	3.41	-.41	-.120	1.22	8.0	8.0	8.5	8.25
	3.07	.29	.094	1.14	6.0	6.0	6.5	6.25
	3.21	-.30	-.093	1.18	7.0	7.5	8.0	7.75
	3.53	-1.20	-.340	1.22	9.0	9.0	9.0	9.0

TABLE III.- PILOT OPINIONS OF THE LATERAL OSCILLATORY CHARACTERISTICS OF THE VARIABLE-STABILITY AIRPLANE FLOWN IN THE PRESENT INVESTIGATION - Continued

(a) Period from 2.75 to 6.90 seconds - Concluded

Pilot	P	$\frac{1}{C_{1/2}}$	$\frac{1}{T_{1/2}}$	$\frac{\lvert\varphi\rvert}{\lvert v_e\rvert}$	Pilot rating: Lateral oscillations	Pilot rating: Handling in smooth air	Pilot rating: Handling in rough air	Pilot rating: Over all
D	3.29	1.69	0.514	0.53	3.0	3.0	3.5	3.0
	3.67	-.90	-.245	.55	6.0	7.0	7.0	7.0
	3.84	-1.55	-.404	.59	7.5	7.5	7.5	7.5
	5.20	4.07	.783	.87	2.5	2.5	3.5	3.0
	4.54	1.17	.258	.74	4.0	4.0	4.5	4.2
	5.38	.05	.009	.77	8.0	8.0	8.0	8.0
	6.90	4.65	.674	1.24	3.0	3.0	3.0	3.0
	6.30	3.69	.586	1.15	3.0	3.0	4.0	3.5
E	3.49	2.07	.593	.57	3.0	3.0	4.0	3.5
	3.39	.45	.133	.52	4.0	4.0	5.0	4.0
	3.76	-.22	-.059	.57	5.5	3.0	4.5	5.0
	3.60	-.65	-.181	.58	7.0	4.0	5.5	6.0
	3.84	-1.70	-.443	.54	8.0	5.5	6.0	6.5
	4.32	2.64	.611	.68	3.0	4.0	4.5	3.5
	4.94	4.24	.858	.75	2.5	2.5	3.5	3.0
	5.20	4.07	.783	.87	2.5	2.0	2.5	2.5
	4.54	1.17	.258	.74	5.0	5.0	5.5	5.0
	5.38	.05	.009	.77	8.5	6.7	6.5	7.0
	6.30	-.19	-.030	.83	9.0	8.5	8.5	8.5
	6.90	4.65	.674	1.24	2.5	3.0	4.0	3.0
	6.30	3.69	.586	1.15	3.0	4.0	4.5	3.5
F	3.29	1.97	.599	.55	3.0	3.0	4.0	3.0
	3.11	.53	.170	.63	4.0	4.5	4.5	4.5
	3.63	.06	.017	.59	8.0	5.0	6.0	6.5
	3.60	-.65	-.181	.58	9.5	7.0	6.0	7.5
	3.84	-1.70	-.443	.54	9.5	7.0	8.0	8.5
	4.32	2.64	.611	.68	6.0	5.0	6.0	5.5
	4.94	4.24	.858	.75	3.5	3.5	4.0	3.5
	5.20	4.07	.783	.87	3.5	3.0	4.0	3.5
	4.54	1.17	.258	.74	7.5	6.5	7.0	7.0
	5.38	.05	.009	.77	8.0	8.0	8.0	8.0
	6.30	-.19	-.030	.83	9.0	8.5	8.5	8.5
	6.90	4.65	.674	1.24	3.0	2.0	3.5	3.0
	6.30	3.69	.586	1.15	3.0	2.0	3.5	3.0
G	3.37	2.03	.603	.49	3.0	2.0	6.0	4.0
	3.51	.63	.180	.51	5.0	4.0	6.5	5.5
	3.74	-.07	-.019	.56	6.5	5.0	6.5	6.0
	3.60	-.65	-.181	.58	6.5	5.0	4.0	6.5
	3.84	-1.70	-.443	.54	8.0	7.0	---	7.0
	4.32	2.64	.611	.68	3.0	2.0	5.0	3.0
	4.94	4.24	.858	.75	2.5	2.5	3.5	3.0
	5.38	.05	.009	.77	5.5	5.75	7.0	6.0
	6.30	-.19	-.030	.83	7.5	7.0	7.0	7.2
	6.30	3.69	.586	1.15	3.0	3.0	4.0	3.5

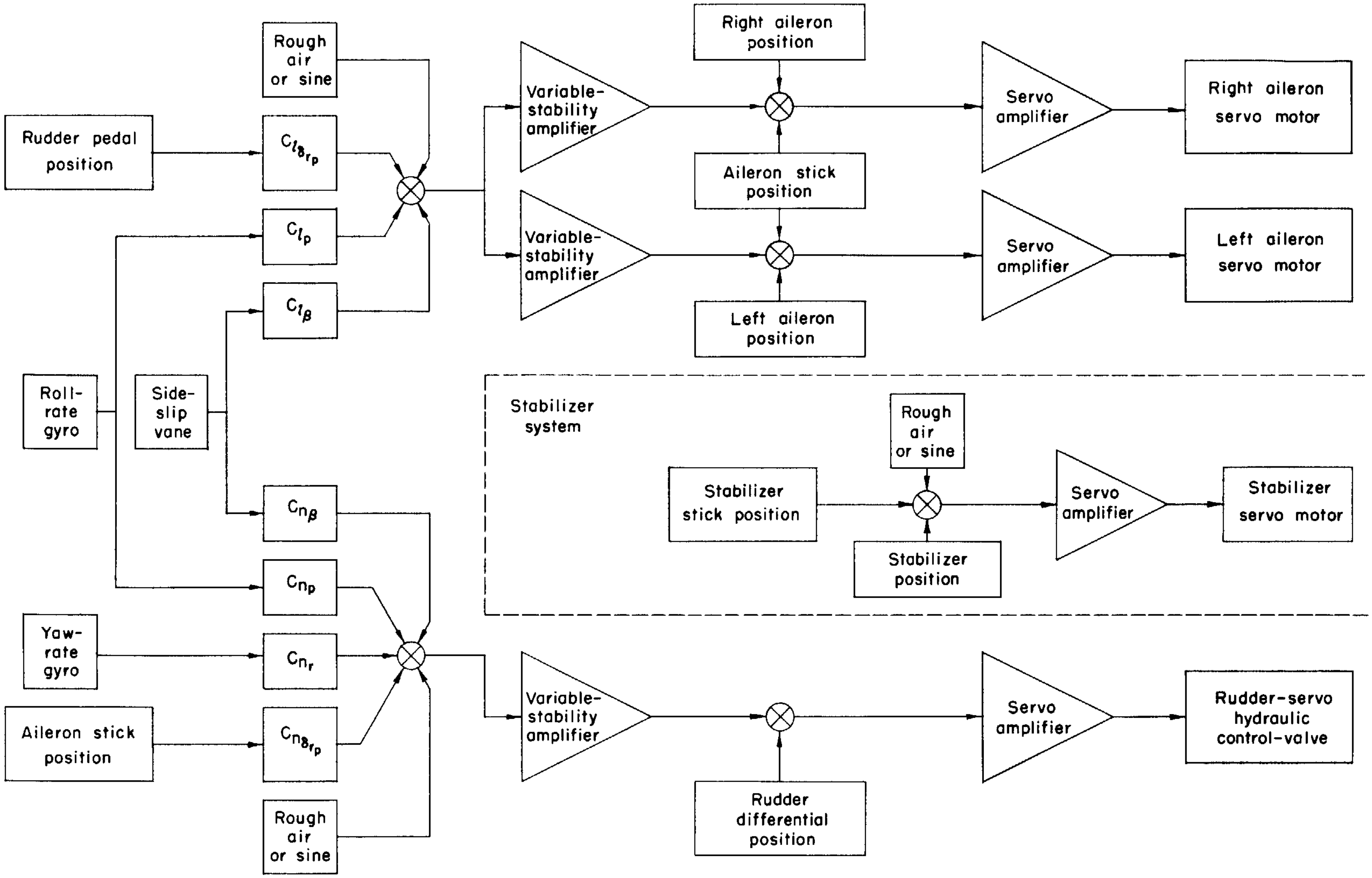
TABLE III.- PILOT OPINIONS OF THE LATERAL OSCILLATORY CHARACTERISTICS OF THE VARIABLE-STABILITY AIRPLANE FLOWN IN THE PRESENT INVESTIGATION - Concluded

(b) Period from 1.54 to 2.38 seconds

Pilot	P	$\frac{1}{C_{1/2}}$	$\frac{1}{T_{1/2}}$	$\frac{\lvert\varphi\rvert}{\lvert v_e\rvert}$	Pilot rating			
					Lateral oscillations	Handling in smooth air	Handling in rough air	Over all
A	1.88	1.30	0.691	0.54	2.0	---	2.0	2.0
	1.94	.73	.376	.59	3.0	---	2.0	2.0
	1.81	.18	.099	.62	5.0	---	6.0	5.0
	2.08	-.31	-.149	.63	6.0	---	7.0	6.0
	2.19	-.89	-.406	.58	8.0	---	9.0	8.0
	2.38	-1.16	-.487	.59	10.0	---	10.0	10.0
B	1.80	1.25	.694	.49	---	---	---	3.0
	1.89	.69	.365	.60	---	---	---	3.5
	1.98	0	0	.59	---	---	---	6.0
	2.08	-.43	-.207	.58	---	---	---	7.0
	2.19	-.78	-.356	.57	---	---	---	8.5
	2.35	-1.32	-.562	.56	---	---	---	10.0
C	1.54	1.31	.851	.55	3.0	2.0	4.0	3.25
	1.95	.64	.328	.57	4.0	3.0	5.0	4.25
	2.06	.01	.005	.58	4.0	4.0	6.0	5.0
	2.06	-.38	-.184	.58	6.0	6.0	7.0	6.5
	2.18	-.85	-.390	.58	7.0	7.0	8.0	7.5
	2.31	-1.48	-.641	.54	9.0	9.0	10.0	9.5
D	2.02	1.80	.891	.53	3.0	4.0	4.0	4.0
	2.15	-.95	-.442	.52	7.0	7.0	7.0	7.0
	2.24	-1.42	-.634	.60	8.0	8.0	8.0	8.0
E	2.08	1.93	.928	.47	2.5	3.0	3.0	3.0
	2.02	1.50	.743	.49	2.8	2.5	2.5	2.5
	1.93	.97	.503	.51	3.5	3.0	3.5	3.5
	1.89	.37	.196	.50	5.0	4.0	4.5	4.5
	2.02	-.28	-.139	.52	7.0	5.5	6.0	6.0
	2.15	-.95	-.442	.52	8.5	7.5	8.0	8.0
	2.35	-1.30	-.553	.53	9.0	9.2	9.0	9.2
F	1.98	2.03	1.025	.50	2.5	2.0	3.5	2.5
	2.00	1.37	.685	.50	2.5	2.5	4.0	3.0
	1.85	.74	.400	.51	3.5	4.0	4.5	4.0
	1.98	.32	.162	.53	4.0	4.5	5.0	4.5
	2.01	-.35	-.174	.52	7.0	6.5	6.5	6.5
	2.15	-.95	-.442	.52	8.0	7.5	7.5	7.5
	2.35	-1.30	-.553	.53	8.5	8.0	8.0	8.0
G	2.10	1.71	.814	.49	1.75	2.0	3.75	[illegible]
	1.98	1.24	.626	.45	2.0	1.5	4.0	[illegible]
	1.97	.89	.452	.50	2.5	3.5	4.5	[illegible]
	1.93	.25	.130	.49	4.5	5.0	5.0	[illegible]
	1.99	-.41	-.206	.52	5.75	6.0	6.0	[illegible]
	2.15	-.95	-.442	.52	---	8.5	---	8.5
	2.35	-1.30	-.553	.53	---	9.0	---	9.0

Figure 1.- Photograph of variable-stability airplane.

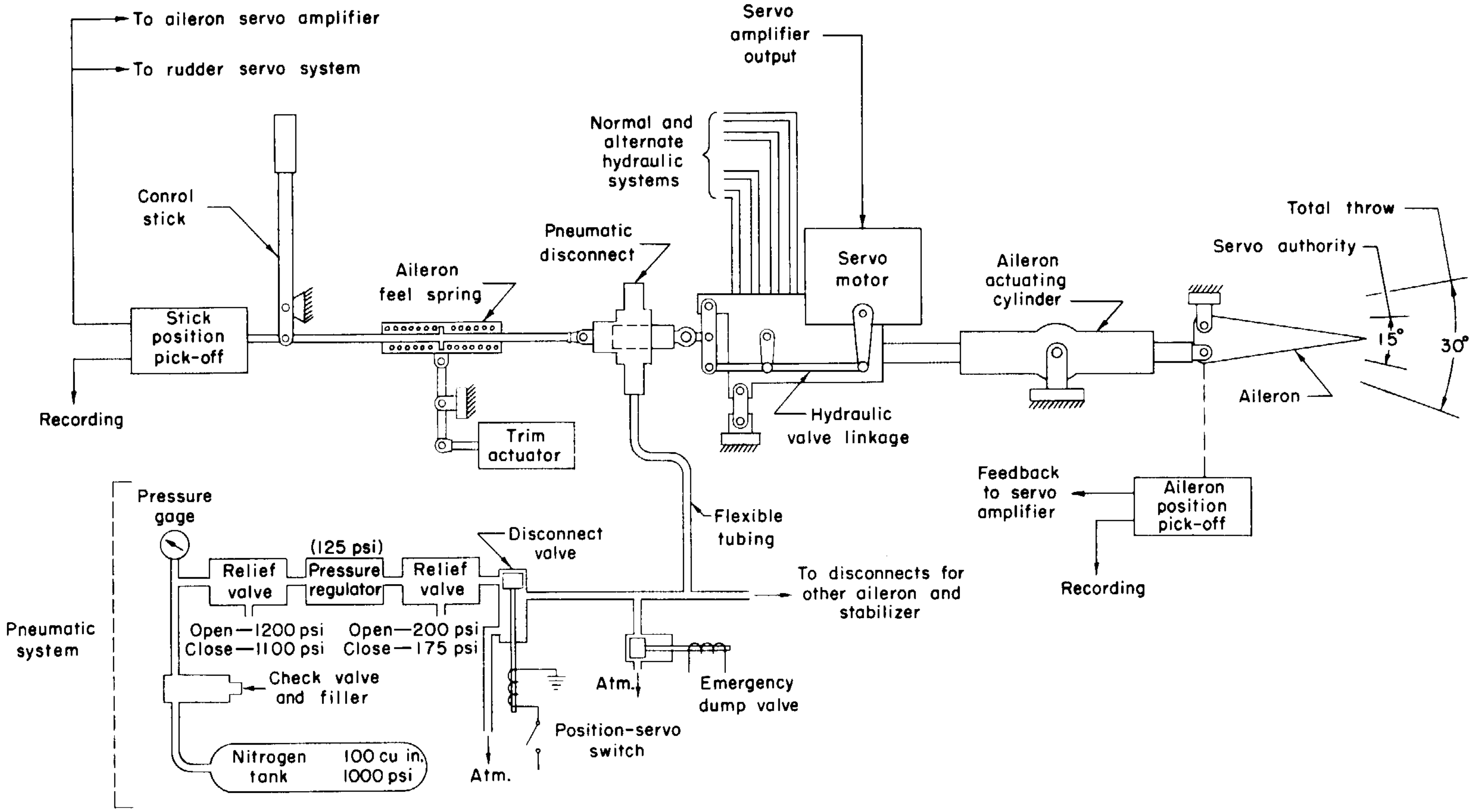
A-23870



(a) Aileron, rudder, and stabilizer signal circuits.

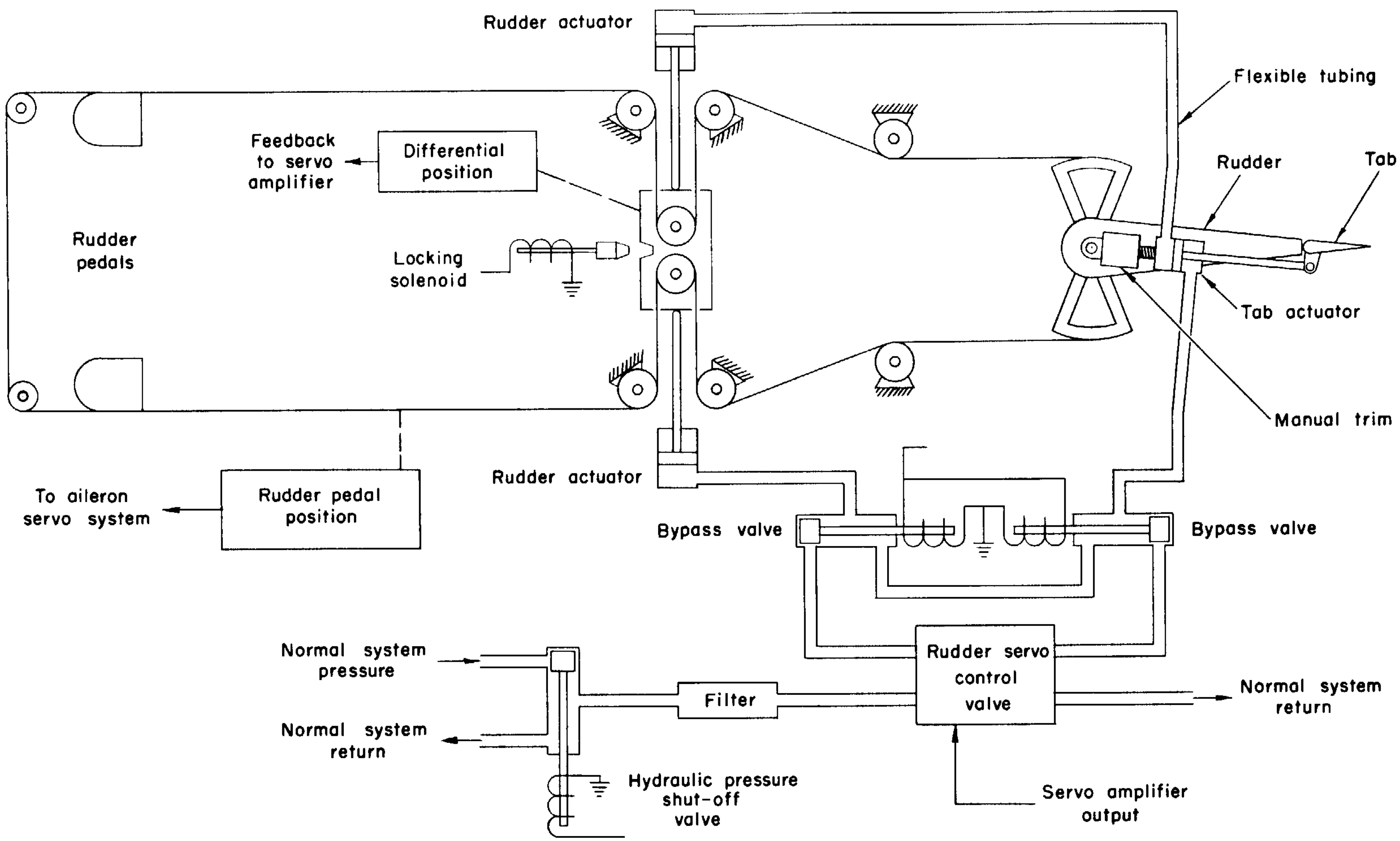
Figure 2.- Schematic diagrams of variable-stability airplane servo systems.

[redacted]



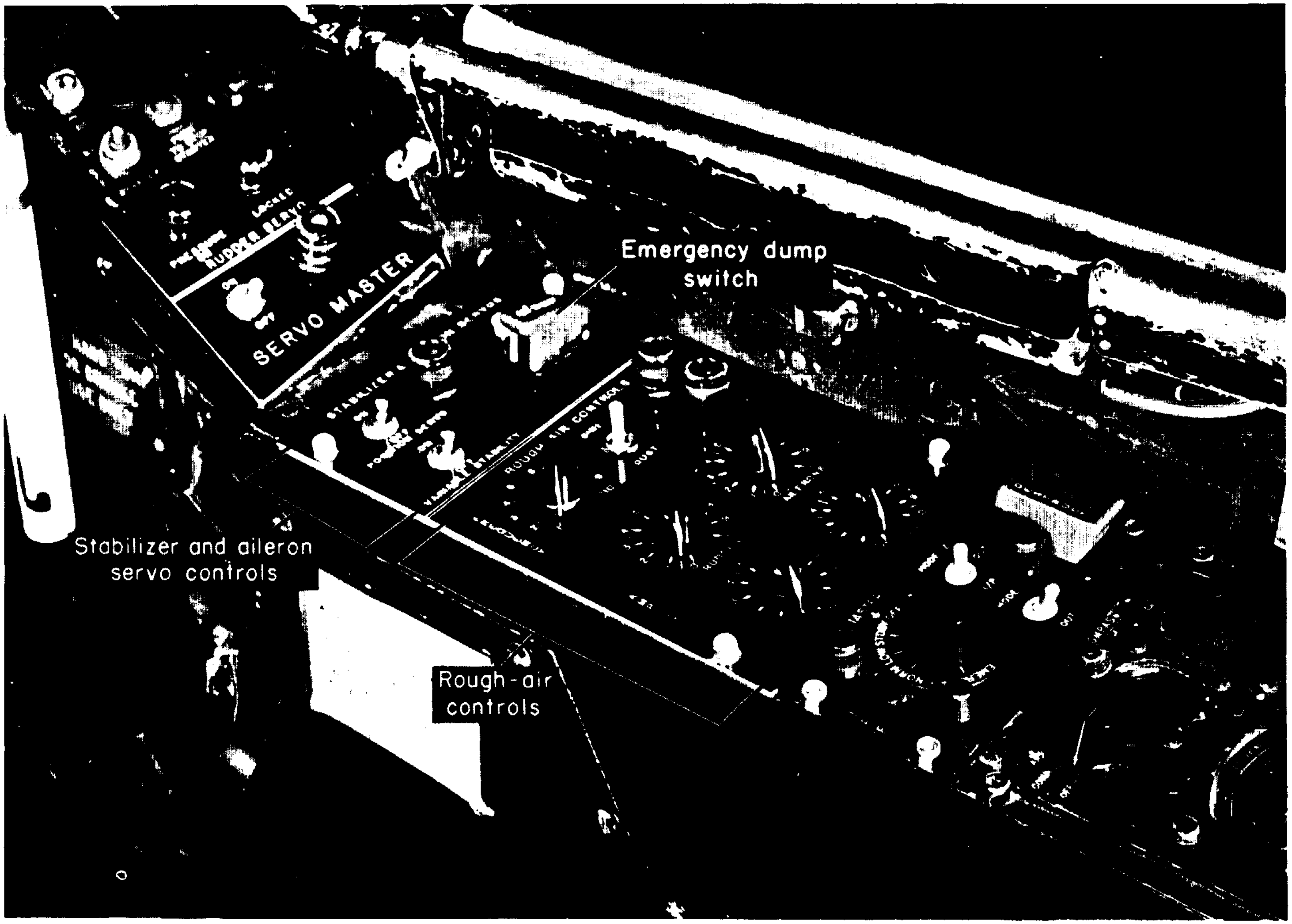
(b) Aileron servo system.

Figure 2.- Continued.



(c) Rudder servo system.

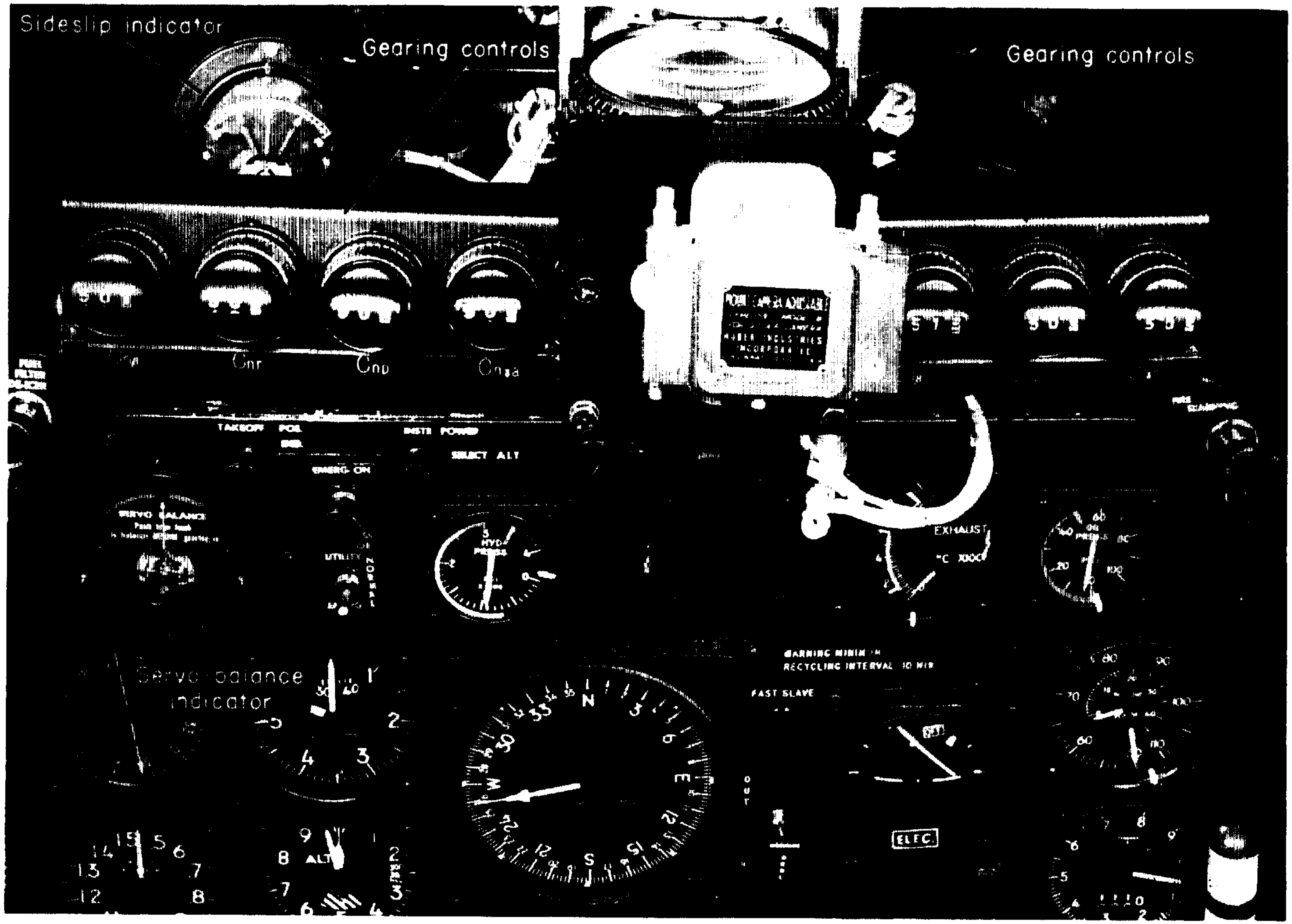
Figure 2.- Concluded.



(a) Main switchgear; right-hand console.

A-21933.1

Figure 3.- Variable-stability airplane cockpit controls.



(b) Servo gearing controls. A-21932.1

Figure 3.- Concluded.

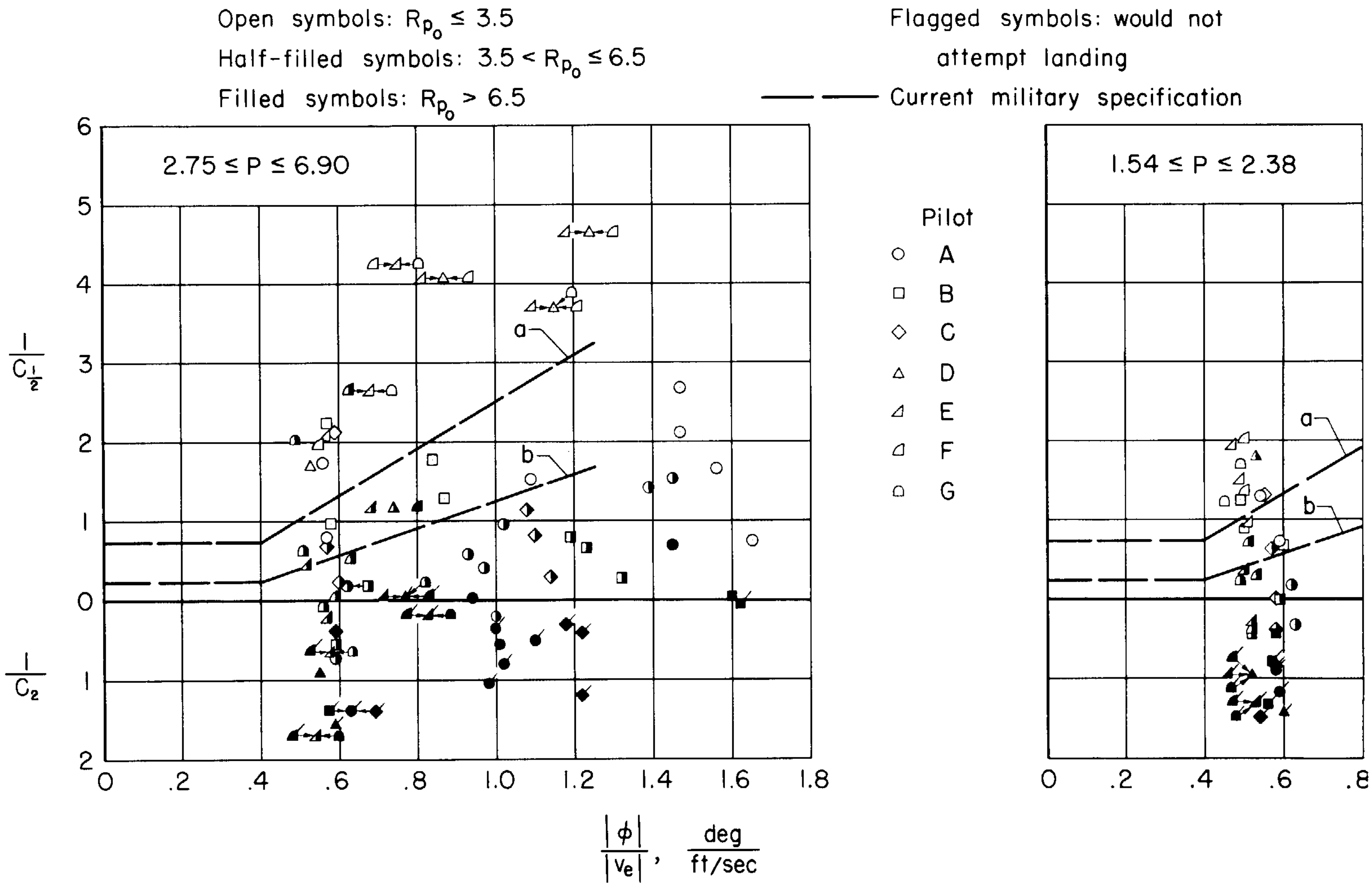


Figure 4.- Lateral oscillatory characteristics and over-all pilot ratings of the configurations flown.

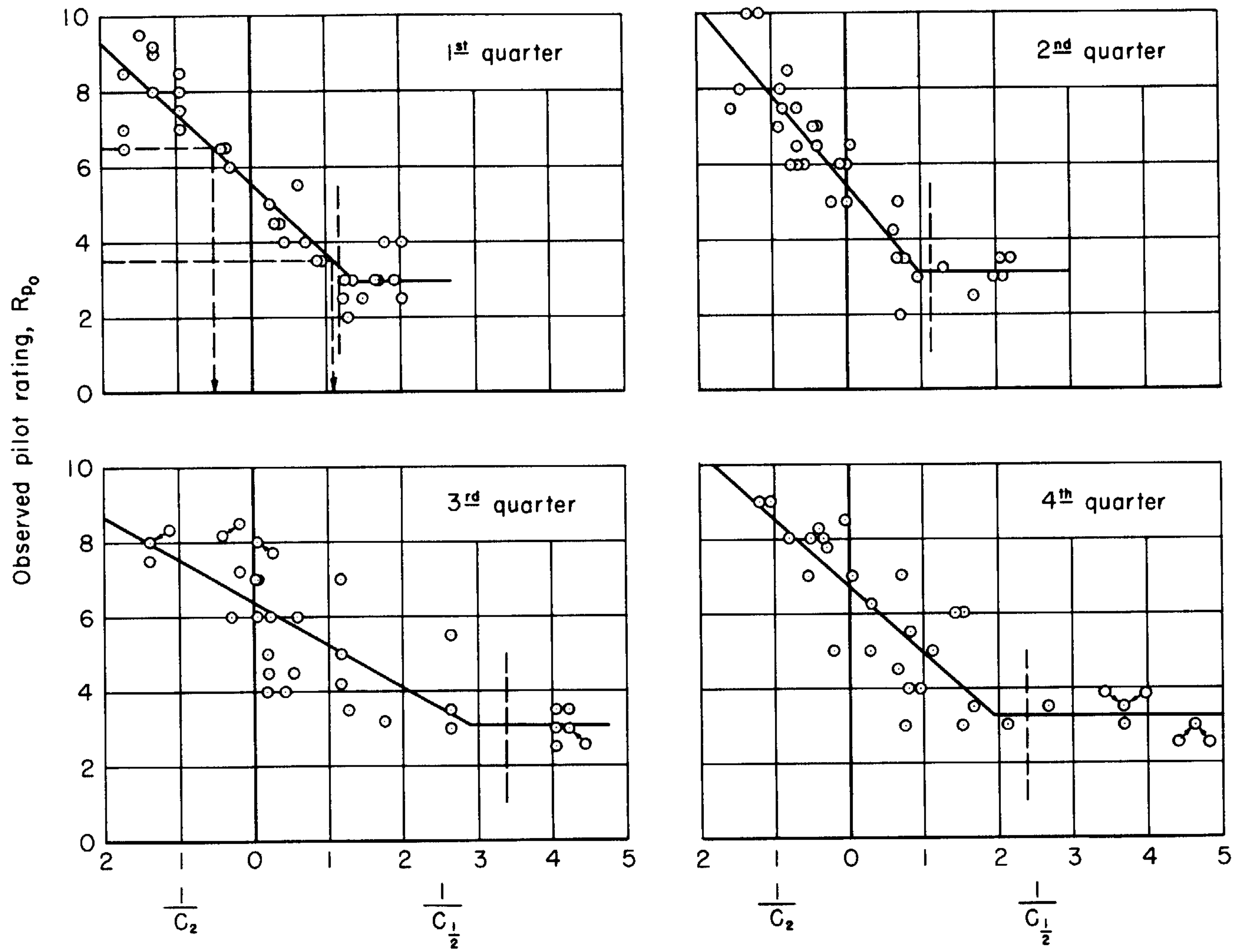


Figure 5.- Modified linear least-squares fits of variations of pilot rating with damping in the four data groups; damping expressed as $1/C_{1/2}$.

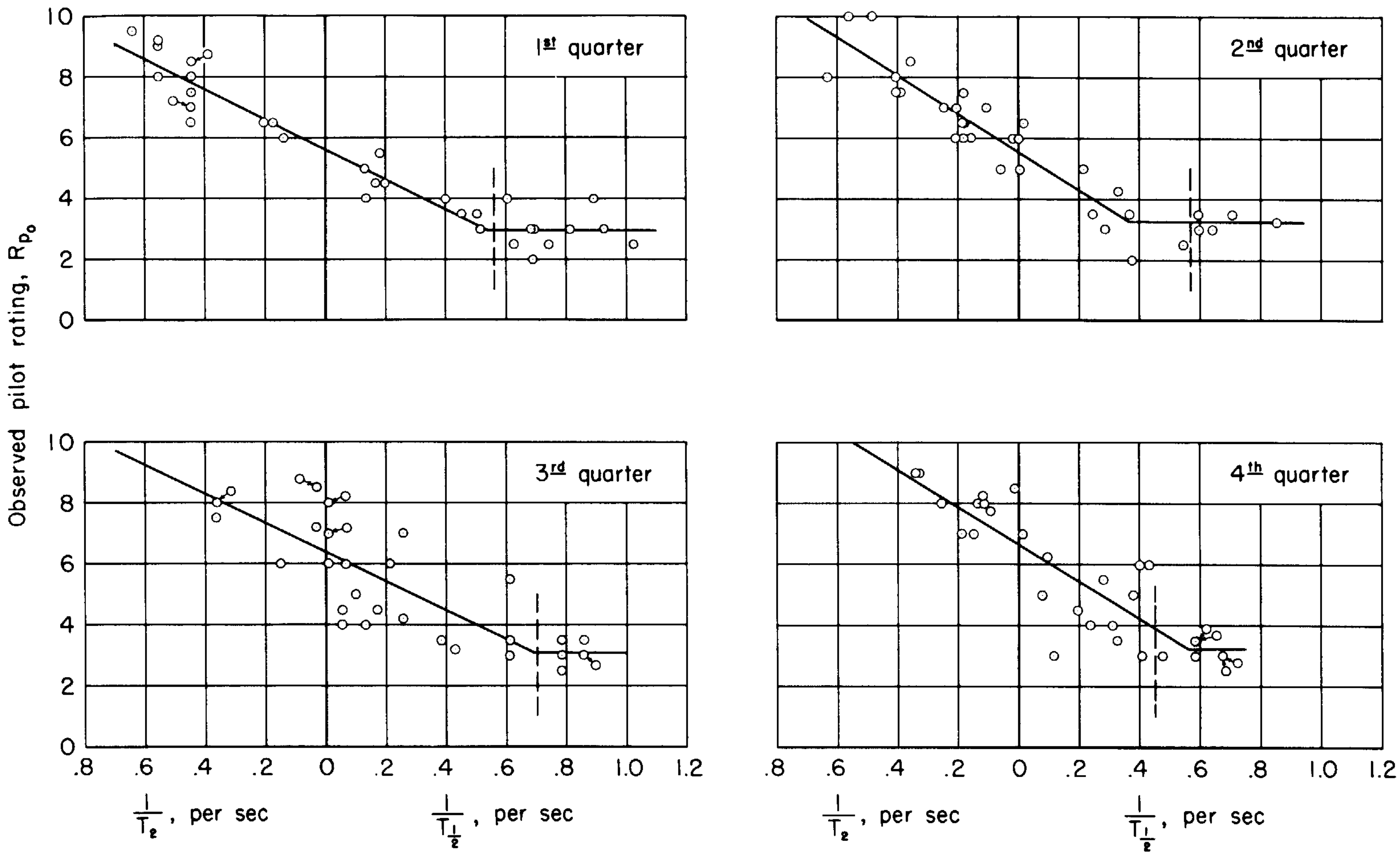


Figure 6.- Modified linear least-squares fits of variations of pilot rating with damping in the four data groups; damping expressed as $1/T_{1/2}$.

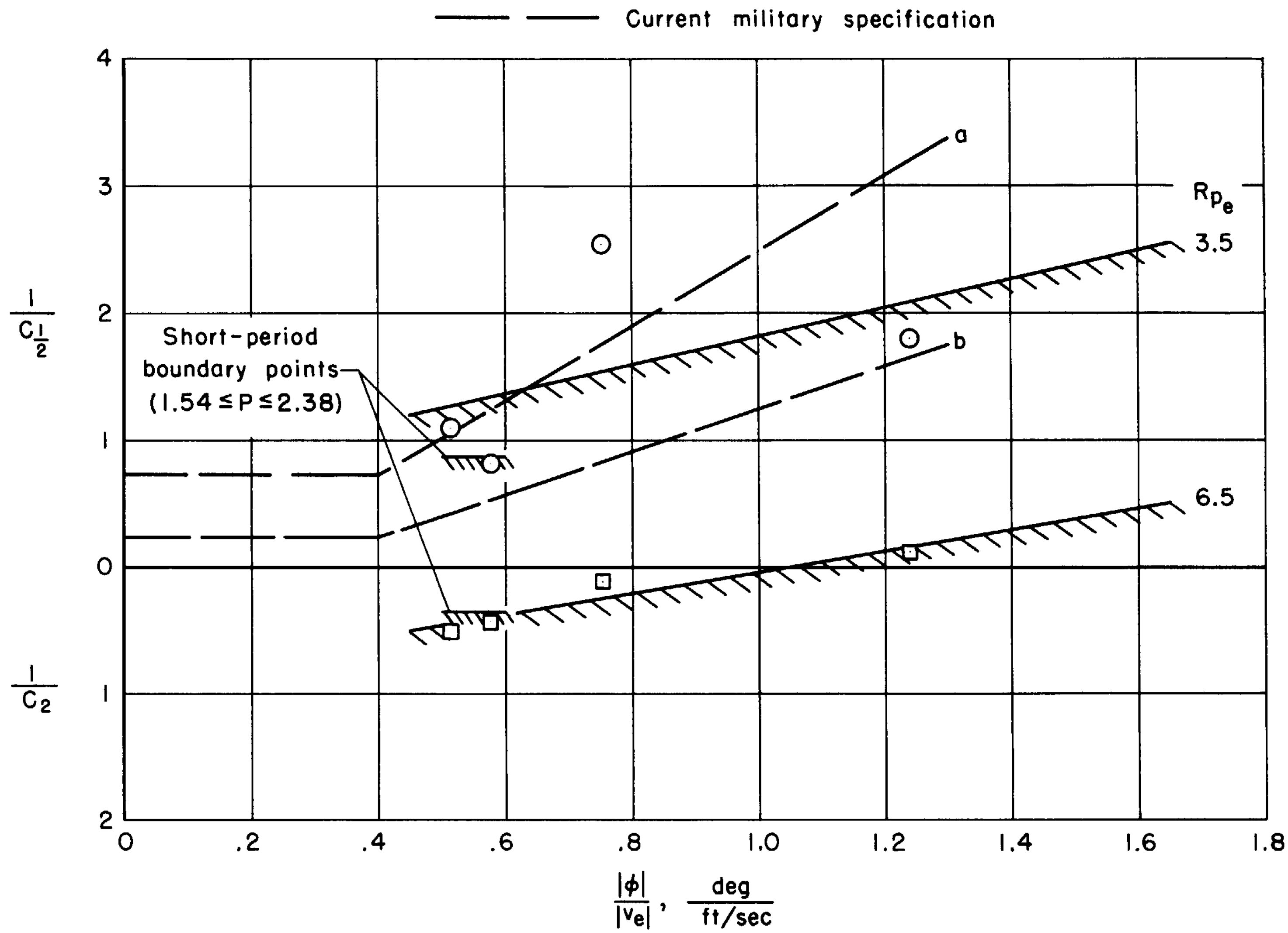


Figure 7.- Comparison of lateral oscillatory damping boundaries (in terms of $1/C_{1/2}$) determined from pilot opinions in the present study with the current military specification (ref. 5).

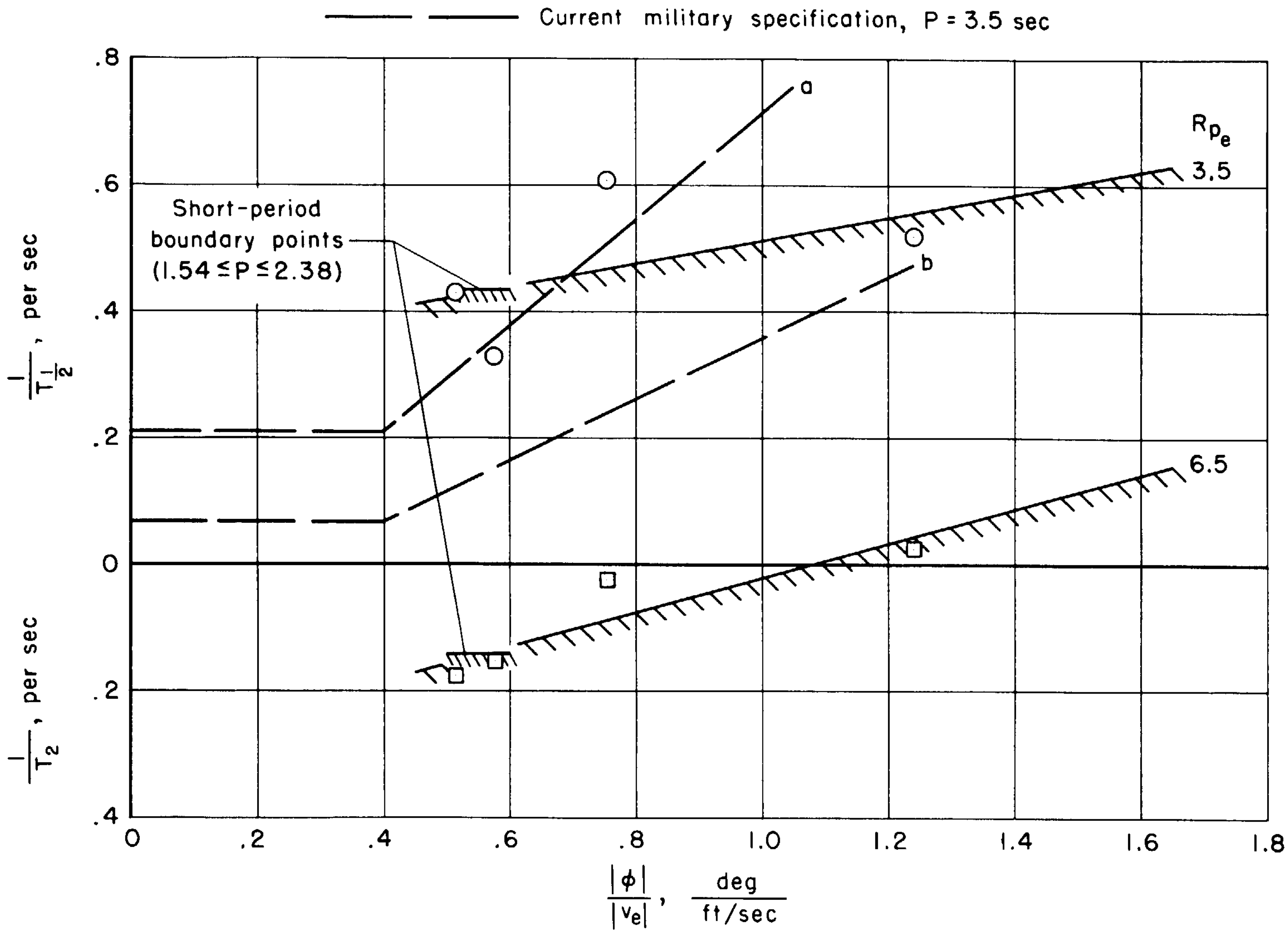


Figure 8.- Comparison of lateral oscillatory damping boundaries (in terms of $1/T_{1/2}$) determined from pilot opinions in the present study with the current military specification (ref. 5).

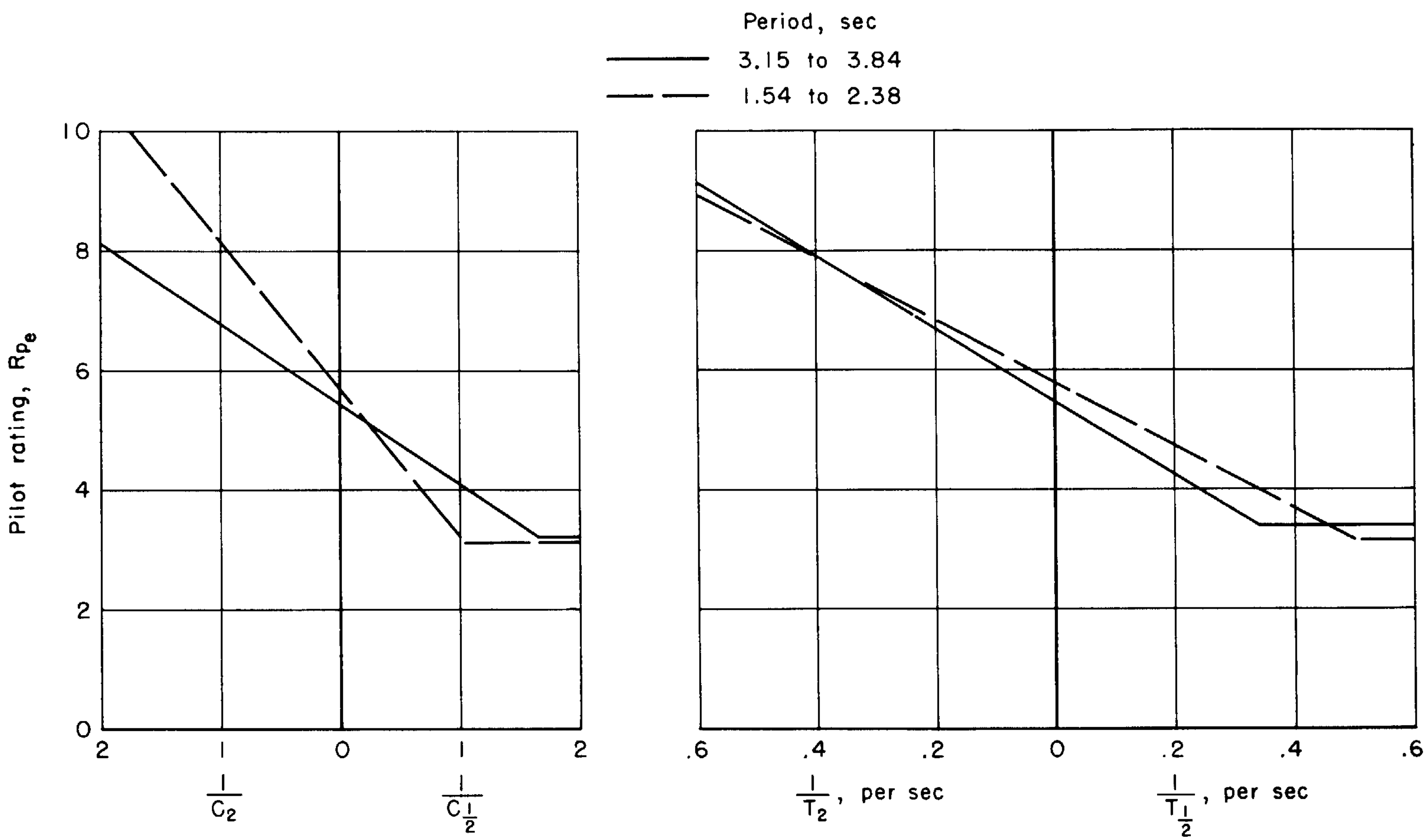


Figure 9.- Modified linear least-squares variations of pilot rating with damping expressed as $1/C_{1/2}$ and $1/T_{1/2}$; $0.45 \leq |\varphi|/|v_e| \leq 0.60 \; \frac{\text{deg}}{\text{ft/sec}}$.

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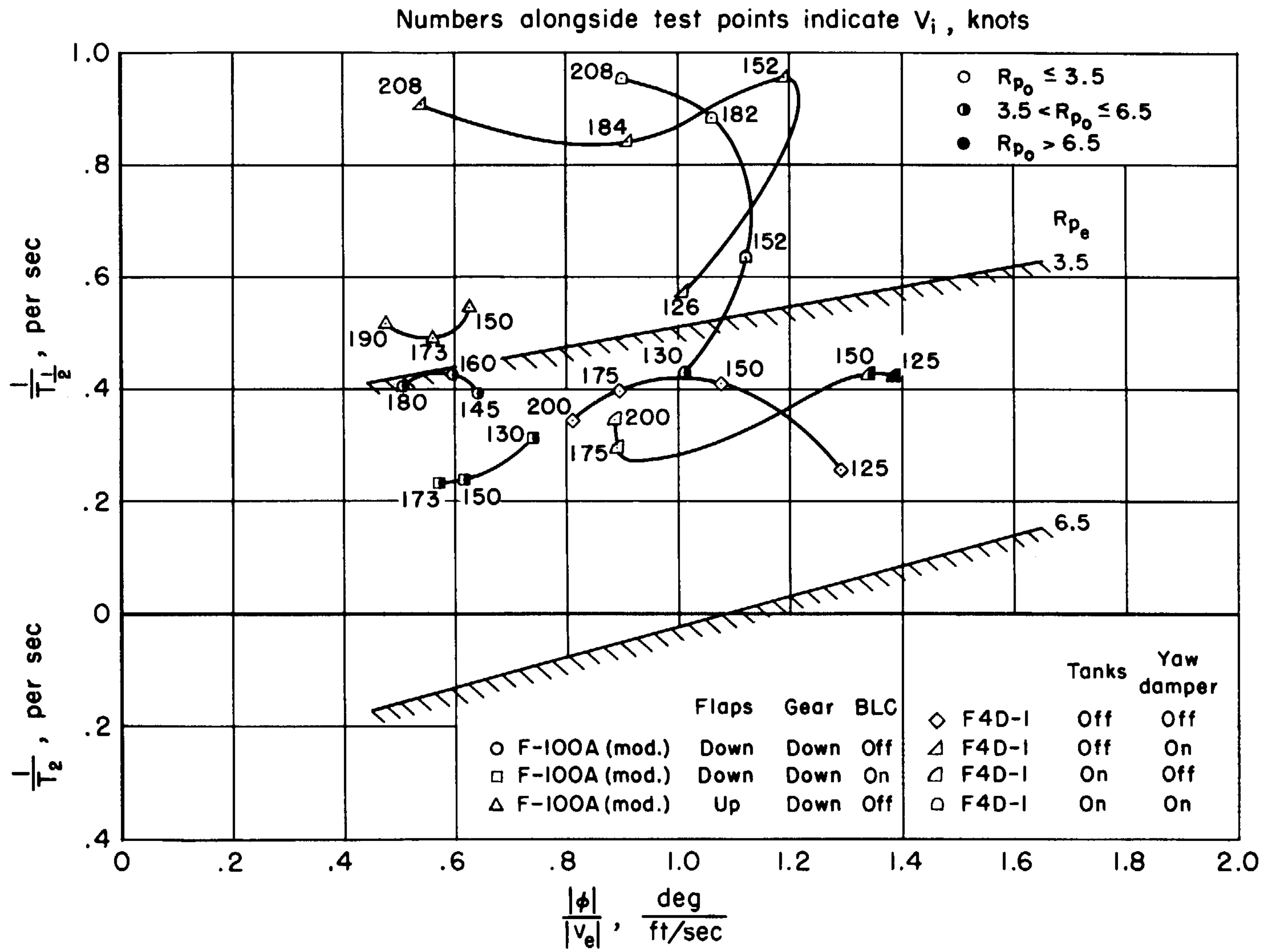

Figure 10.- Pilot opinions of two operational fighter aircraft in the landing configuration, compared with boundaries indicated in the present study; damping expressed as $1/T_{1/2}$.

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NASA MEMO 12-10-58A
National Aeronautics and Space Administration.
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Walter E. McNeill and Richard F. Vomaske.
February 1959. 33p. diagrs., photos., tabs.
(NASA MEMORANDUM 12-10-58A) CONFIDENTIAL
(Title, Unclassified)

A flight study, using an airplane with variable lateral and directional stability, has been conducted to determine the minimum satisfactory and acceptable lateral oscillatory damping of airplanes in the landing approach for normal operation and for failure of stability-augmentation equipment. The effects of oscillatory period and bank-to-sideslip ratio on the opinion ratings of seven pilots are presented and discussed.

Copies obtainable from NASA, Washington

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1. Stability, Lateral and Directional - Dynamic (1.8.1.2.2)
2. Flying Qualities (1.8.5)
3. Stabilization, Automatic (1.8.8)
4. Research Equipment (9.1)

I. McNeill, Walter E.
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