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A REVIEW OF TRANSPORT HANDLING-QUALITIES CRITERIA IN TERMS OF PRELIMINARY XB-70 FLIGHT EXPERIENCE

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SUMMARY

A preliminary flight evaluation of handling qualities of the unaugmented XB-70 airplane was made during the initial flight test and envelope-expansion program. The evaluations consisted of pilot ratings and comments on the longitudinal and lateral-directional characteristics. The pilot ratings were compared with several current handling-qualities criteria for transport aircraft to establish the applicability of these criteria to this class of airplane.

The results of the study show that for the longitudinal mode fair correlation was obtained between the XB-70 handling qualities and specific criteria boundaries based on the short-period frequency and damping. In the lateral-directional mode, the use of the Dutch roll and roll-mode parameters, the mode coupling parameter $\frac{\omega_\varphi}{\omega_d}$, and limited combinations of these parameters was not satisfactory for defining the XB-70 handling qualities. It appears that a combination of many handling-qualities factors on the XB-70 airplane obscured the effects of any single handling-qualities parameter. These factors include excessive yaw due to aileron input, restricted sideslip limits, poor pitch and roll control harmony, and poor attitude and heading information.

INTRODUCTION

Present handling-qualities criteria are, in general, based on the characteristics of current aircraft and pilot evaluations of these aircraft characteristics. During the design of new aircraft, established criteria are usually extrapolated to the aircraft of interest in an attempt to predict its handling qualities. The development of a totally new aircraft such as the supersonic transport (SST), with size and speed much greater than previous transport aircraft, requires greater extrapolation and leads to more uncertainty in the application of the handling-qualities prediction methods. It would therefore be highly desirable to examine several of the available handling-qualities criteria for transport aircraft (refs. 1 to 7) in terms of a flight vehicle with size and weight characteristics similar to the SST.

The XB-70 aircraft, although not designed for an SST mission nor refined past the prototype stage to a production aircraft, is a large, supersonic aircraft that operates in the same general speed and altitude envelope as the SST and, thus, can provide

some insight into the validity of available handling-qualities criteria for this class of airplane.

As part of a joint Air Force/NASA XB-70 flight program, pilot evaluations of the XB-70 handling characteristics were obtained during the initial flight tests and envelope-expansion program. The evaluations consisted of pilot ratings and comments on the longitudinal and lateral-directional handling qualities of the basic aircraft without stability augmentation. These evaluations are compared in this paper with several of the available handling-qualities criteria for transport aircraft.

SYMBOLS

$C_{1/2}$	cycles to damp to one-half amplitude
F_e	longitudinal control column force, pounds (newtons)
f_n	natural frequency of short-period longitudinal mode, cycles per second
g	acceleration due to gravity, feet/second^2 (meters/second^2)
h	altitude, feet (meters)
K	Dutch roll criterion constant, seconds
L_α	dimensional lift-curve slope, second^{-1}
L_β	rolling acceleration per unit of sideslip angle, radians/second^2/radian
$L_{\delta_a}\delta_{a_{max}}$	maximum roll acceleration available from aileron deflection, radians/second^2
M	Mach number
n_z	normal acceleration, g units
n_{z_α}	normal-acceleration change per unit change of angle of attack, $\frac{V}{g}L_\alpha$
P	period, seconds
p_{max}	maximum roll rate, degrees/second
$T_{1/2}$	time to damp to one-half amplitude, seconds
V	true airspeed, feet/second (meters/second)

V_e equivalent airspeed, feet/second (meters/second)

β angle of sideslip, degrees

ζ damping ratio of the short-period longitudinal mode

ζ_d damping ratio of the Dutch roll mode

τ_r roll-mode time constant, seconds

φ roll angle, degrees

$\frac{|\varphi|}{|V_e|} = \frac{|\varphi|}{|\beta|} \frac{57.3}{V_e}$, degrees/feet/second (degrees/meters/second)

$\frac{|\varphi|}{|\beta|}$ ratio of amplitudes of bank and sideslip angles in Dutch roll mode

ω_d natural frequency of the Dutch roll mode, radians/second

ω_n natural frequency of the short-period longitudinal mode, radians/second

ω_φ natural frequency of the roll per aileron transfer-function numerator, radians/second

$| \, |$ absolute value

DESCRIPTION OF THE AIRPLANE

The XB-70 is a delta-wing airplane designed for Mach 3 cruise. Two airplanes were built, designated the XB-70-1 and XB-70-2. The two airplanes were similar except that the XB-70-1 had no geometric dihedral of the wing, and the XB-70-2 had 5° of geometric dihedral to improve high-speed handling qualities. A three-view drawing of the XB-70 airplanes is shown in figure 1. Three-position movable wing tips were deflected downward for improved directional stability at high speeds. For the XB-70-1 in the normal sequence, the wing tips were undeflected (tips up) at low speeds, deflected 25° (tips half down) at subsonic and transonic speeds, and deflected 65° (tips full down) at supersonic speeds. The XB-70-2 wing tips were deflected 0°, 30°, and 70° for these same speed regimes. A movable nose ramp was also incorporated to improve high-speed performance and was normally in the raised position for transonic and supersonic flight. Canard flaps were used for takeoff and landing.

Longitudinal control was provided through elevons and a canard, directional control through two vertical stabilizers, and lateral control through differential movement of the elevons. Both longitudinal- and lateral-control effectiveness were reduced with the tips deflected, since the two outboard elevon segments were faired and locked to the

deflected wing tips. Both XB-70 airplanes had a stability augmentation system for the pitch, roll, and yaw axes. The XB-70-1 had, in addition, a lateral bobweight to reduce the negative dihedral effect at high supersonic speeds. However, for the evaluations reported herein the stability augmentation system and lateral bobweight were inoperative.

A more detailed description of the XB-70 aircraft is presented in reference 8.

TEST PROCEDURES AND ANALYSIS

Handling-Qualities Evaluations

Handling-qualities evaluations were obtained from four XB-70 pilots during the initial flight tests and envelope-expansion program. The maneuvers used in the evaluations were stability and control evaluation maneuvers consisting of pulses, windup turns, and steady sideslips, along with mild maneuvering such as altitude changes and level-flight turns. With the aid of a questionnaire (table I) and a pilot rating scale (table II) the pilots evaluated these maneuvers on the basis of such factors as trimmability and maneuverability. Since no special mission tasks such as constant-speed climbs, level off from high rate of climb, or landing approaches were included, the pilot ratings and comments are considered preliminary and representative of an evaluation of the cruise or loiter flight regime.

Handling-Qualities-Criteria Parameters

Stability and control derivative data were obtained at various flight conditions throughout the operating envelope of the unaugmented airplane (ref. 9). The derivative data were used to calculate the various handling-qualities-criteria parameters. When stability and control derivatives were not available at the test condition of the pilot evaluation, the handling-qualities parameters were extrapolated to the test condition.

Handling-Qualities-Criteria Boundaries

In order to compare the XB-70 handling qualities with the various transport-aircraft criteria, the criteria boundaries considered in this paper have been transformed to provide boundaries that correspond to the rating scale shown in table II; that is, the boundary corresponding to a pilot rating (PR) of 3.5 separates "acceptable and satisfactory" and "acceptable but unsatisfactory" regions and a pilot rating of 6.5 separates the "acceptable but unsatisfactory" and the "unacceptable" regions. In the British—French Concord TSS Standards (ref. 3), three conditions are defined: (1) "reasonably probable," (2) "remote," and (3) "extremely remote." These conditions are based on different probabilities of occurrence, and requirements are presented for the "reasonably probable" and "remote" conditions. For comparison with the XB-70 flight ratings, it will be assumed that the boundaries between these regions correspond to a pilot rating of 3.5 between regions (1) and (2) and 6.5 between regions (2) and (3). The Society of Automotive Engineers (SAE) criterion presented in reference 4 is based on three regions: "acceptable augmented," "acceptable unaugmented," and

"unacceptable." For transport aircraft, this criterion recommends that the boundary between the "acceptable unaugmented" and "unacceptable" regions be defined as PR = 4.0. However, for comparison with the flight ratings, these regions are assumed to correspond to the regions of the rating scale in table II and the boundaries between them are assumed to correspond to PR = 3.5 and 6.5. In references 1 and 2, MIL-F-8785 Specification and a proposed revision, there are three regions: acceptable, acceptable for augmentation inoperative, and unacceptable. These regions are assumed to correspond to the three regions of the rating scale in table II.

Method of Analysis

Because of the limited number of XB-70 pilot ratings available and the limited range of the criteria variables covered with the XB-70, it is difficult to establish trends or boundaries for criteria. However, some observations can be made about the validity of existing criteria boundaries by using the following rationale. It is assumed that the factors not included in the criterion parameters are at optimum levels. Thus, any additional factors not accounted for in the criterion would not be expected to improve the handling qualities, although if these factors are not at the assumed optimum level, they could degrade the handling qualities. Therefore, if an unsatisfactory XB-70 rating falls in the satisfactory region of the criterion, either an additional important factor has not been accounted for or the criterion parameters are adequate but the boundary is not stringent enough. For a satisfactory rating in an unsatisfactory region of the criterion, the boundary is too stringent, since additional factors not accounted for in the criterion cannot improve the handling qualities. The following table shows the conclusions that may be drawn when this approach is used:

Condition	Conclusions
Good flight rating in good region of criterion.	Criterion is adequate for this configuration and flight condition.
Good flight rating in bad region of criterion.	Criterion is too stringent and gives pessimistic predictions.
Bad flight rating in good region of criterion.	Criterion does not account for all the important factors, or criterion is not stringent enough.
Bad flight rating in bad region of criterion.	Criterion is correct, or criterion is too stringent and does not account for all the factors.

DISCUSSION

Basic XB-70 Handling Qualities

Before the XB-70 handling-qualities characteristics are compared with specific longitudinal or lateral-directional criteria, the basic XB-70 handling qualities will be considered. The operating envelope and a summary of the test conditions that were evaluated in this study are shown in figure 2. A brief summary of pilot comments with

the associated ratings is presented in table III, and the handling-qualities characteristics corresponding to each rating are presented in table IV.

Longitudinal characteristics. – In the longitudinal mode (fig. 3) the pilot ratings generally indicate that the XB-70 aircraft have satisfactory characteristics at subsonic speeds with the wing tips up (fig. 3(a)). At these speeds, the pilot reported excellent control of speed and rate of climb. The wing tips were normally deflected to the half position at low subsonic speeds, and the associated trim change was small. With the wing tips deflected half down (fig. 3(b)) at M = 0.8, there was a region of relatively low force gradient, especially at aft center-of-gravity conditions, which made the aircraft sensitive in control of normal acceleration, and the ratings were degraded from "satisfactory" to "acceptable but unsatisfactory." For two of these test conditions force gradients were about 33 lb/g (147 N/g), which is not usually considered to be a light or sensitive force gradient. However, this is a lighter force gradient than at most other flight conditions where the gradients ranged up to 92 lb/g (409 N/g). For most of the flight conditions, the longitudinal control forces are generally considered to be higher than desired.

In the high-speed cruise configuration with the nose ramp up and the wing tips full down (fig. 3(c)), the pilot is unable to see the horizon except out of the side windows and the flight is performed primarily under instrument conditions. The attitude-display system has proved to be inaccurate and inadequate and has not been sufficiently sensitive or responsive for precise instrument flying at high Mach numbers. In addition, there has been an apparent lag in the altitude information. These factors, plus the slow pitch response of the aircraft near a Mach number of 3, made accurate altitude control difficult. To achieve acceptable altitude control, increased attention had to be devoted to the longitudinal control task, which was reflected in the "acceptable but unsatisfactory" ratings for this flight regime.

Lateral-directional characteristics. – In the lateral-directional mode (figs. 4(a) to 4(c)), the ratings are generally at the "acceptable but unsatisfactory" level throughout the Mach number range for both airplanes. The effect of the difference in dihedral between the two airplanes is not evident from the ratings because of the small number of points; however, pilot comments generally indicated that the XB-70-1 airplane had better handling qualities at the subsonic speeds, whereas the XB-70-2 airplane had better handling qualities at supersonic speeds. Both aircraft exhibited positive dihedral effect with the wing tips undeflected and half down, and slightly negative dihedral effect with the wing tips full down.

Three undesirable characteristics were noted throughout the flight envelope (table III): sensitive roll control, adverse yaw due to aileron input, and poor attitude and heading information. The first characteristic, sensitive roll control, produced overcontrolling in roll on several occasions, especially in the wing-tip-up configuration where higher roll power is available because of the additional elevon segments operable in this configuration. The problem of overcontrolling has been reduced since the first few flights by doubling the control-wheel force gradient to its current value of 0.8 lb/deg (3.5 N/deg) of wheel travel. This improved the control-force harmony; however, poor pitch and roll control harmony still exists with regard to aircraft response to control displacements. The pilots have described the control harmony as "like a transport in pitch and yaw, but like a fighter in roll."

A second factor, which was reported throughout the flight envelope, was the excessive adverse yaw[1] generated while the ailerons were being used. Because of the rather restricted sideslip limits for structural and engine operation considerations, the pilot was more concerned with sideslip in the XB-70 than in other airplanes. The situation was further aggravated by the low side force per unit sideslip angle sensed by the pilot, which made it necessary to depend on instruments to detect sideslip rather than physically sensing lateral acceleration. In the dynamic situation the pilot was aware of the yaw due to aileron input through the yaw oscillations that appeared whenever the ailerons were used. The pilot had difficulty damping these oscillations, and in the $M = 2.0$ to 2.5 region the adverse yaw in combination with the negative dihedral effect produced a pilot-induced-oscillation tendency that sometimes resulted in neutral to slightly divergent lateral-directional oscillations.

The third factor that may have affected the evaluation of the lateral-directional handling qualities was the inaccurate heading and attitude information which contributed to the pilot workload. Although this problem was experienced throughout the Mach number range, it was especially noticeable at the high speeds. At these conditions, with the windshield ramp up, no natural horizon was available for reference.

Comparison of XB-70 Handling Qualities With Criteria

Pilot ratings for the XB-70 longitudinal and lateral-directional modes are tabulated in table IV with the related flight conditions and handling-qualities parameters. Because of the limited number of evaluations for each condition (usually only one evaluation for each condition), these data should not be compared with the criteria on a point-by-point basis. In the following sections the general level of the flight ratings in different regions will be used to examine the validity of the various criterion boundaries.

Longitudinal handling-qualities criteria. – References 2 to 5 present criteria based on short-period frequency and damping that have been suggested for longitudinal handling qualities of transport aircraft. The criterion of reference 2, shown in figure 5, is a proposed military specification. For the higher damping ratios ($\zeta = 0.5$ to 0.7) it predicts that most of the XB-70 ratings will be "acceptable but unsatisfactory," which does not agree with the "satisfactory" ratings generally given in flight. For the low damping ratios there are several points in the "unacceptable" region that were rated only 3.5 to 5.0. Thus, this criterion appears to be too stringent and gives pessimistic predictions of the XB-70 handling qualities.

The criterion from reference 3, a British—French Concord standard, is shown in figure 6. This criterion also provides a pessimistic prediction of the XB-70 handling qualities. The XB-70 flight ratings indicate that the limits due to damping ratio are generally correct, but satisfactory handling qualities were obtained at much lower frequencies than anticipated by this criterion.

A third criterion, suggested in an SAE document (ref. 4), is shown in figure 7. The acceptability of the lower frequencies is predicted better for the XB-70 with this

[1]Adverse yaw refers to positive sideslip (airplane nose left) for positive aileron input (airplane roll right) with its effect on roll rate dependent on the sign of the dihedral effect.

criterion than with the previous two criteria. However, the lower damping limit ($\zeta = 0.3$) of the "satisfactory" region seems to be too conservative, and it appears that the limit of $\zeta = 0.22$ of figure 6 gives better correlation with the XB-70 flight ratings. Also, the PR = 6.5 boundary at $\zeta = 0.1$ appears to be slightly conservative for the three criteria (figs. 5 to 7), since there are several flight ratings of 4.5 to 5.0 in this region.

Reference 5 proposes a criterion that includes the effect of dimensional lift-curve slope L_α in addition to the frequency and damping parameters. This criterion is shown in figures 8 and 9. In figure 8 the criterion is given in terms of $\frac{L_\alpha}{\omega_n}$ and ζ for $n_{z_\alpha} < 15$ and in figure 9 in terms of $\frac{n_{z_\alpha}}{\omega_n}$ and ζ for $n_{z_\alpha} > 15$. For the XB-70, n_{z_α} is approximately equal to 15; therefore, comparisons are made in both figures. Both criteria show reasonable agreement with the XB-70 pilot ratings in the "satisfactory" region; however, at the lower damping ratios, the criteria are very conservative and give a pessimistic prediction of the XB-70 handling qualities. In neither case is there a sufficient range of $\frac{L_\alpha}{\omega_n}$ or $\frac{n_{z_\alpha}}{\omega_n}$ independent of damping ratio to establish the significance of the L_α effects.

Of the several criteria available for predicting longitudinal handling qualities based on short-period frequency and damping and, in one case, L_α, the best correlation of these criteria with the XB-70 flight ratings was obtained with the criterion of reference 4 (fig. 7). The flight data available at this time provide insufficient information to establish the significance of L_α as a longitudinal handling-qualities parameter.

Lateral-directional handling-qualities criteria. – In discussing lateral-directional handling qualities, the Dutch roll mode and the pure roll mode can often be considered separately. However, with the XB-70 aircraft there was coupling between the modes so that roll maneuvering could not be performed without exciting the Dutch roll mode. Thus, the lateral-directional pilot ratings reflected both the roll and the Dutch roll characteristics. It is still of interest, however, to examine some of the criteria which consider the modes individually to determine if basic trends are predicted by these criteria.

The lateral-directional damping criterion from reference 1 is shown in figure 10 in terms of the damping parameter $\frac{1}{C_{1/2}}$ and the rolling parameter $\frac{|\varphi|}{|v_e|}$. This criterion indicates that the XB-70 damping is good and predicts that the XB-70 ratings would be "satisfactory." However, the XB-70 ratings are generally at the "acceptable but unsatisfactory" level, which indicates that either this criterion is not stringent enough or that additional factors, such as the adverse yaw due to aileron input, are more significant than the Dutch roll parameters of $\frac{1}{C_{1/2}}$ and $\frac{|\varphi|}{|v_e|}$.

Another Dutch roll criterion (ref. 4) is shown in figure 11. This criterion includes the effect of the period of the Dutch roll oscillation by using the parameters $\frac{K}{T_{1/2}}$ and

$\frac{|\varphi|}{|v_e|}$. For periods up to 2.4 seconds, K = P, and for P > 2.4 seconds, K = 2.4 seconds. For P < 2.4 seconds, this criterion is the same as the $\frac{1}{C_{1/2}}$ criterion in figure 10, but for P > 2.4 seconds the damping requirements become more stringent as the period increases, since $\frac{K}{T_{1/2}} = \frac{2.4}{PC_{1/2}}$. For the XB-70, the period is about 5 seconds, so that K = 2.4 seconds. The XB-70 data generally fall in the region that is acceptable for stability augmentation failure, which is in agreement with the XB-70 "acceptable but unsatisfactory" ratings. Thus, either the criterion is correct or it is too stringent and has not accounted for additional factors such as the adverse yaw due to aileron input.

A third criterion (ref. 2) that also uses Dutch roll frequency, damping, and rolling parameters is shown in figure 12. In the high frequency and damping region ($\omega_d \approx 1.3$ rad/sec, $\zeta_d \approx 0.3$), which is assumed to correspond to the "satisfactory" region, there are several "acceptable but unsatisfactory" XB-70 ratings, which indicates that the criterion is not stringent enough in this region or that there are additional factors not accounted for in the criterion. It also appears that the boundary defining the "unacceptable" region is too severe in the region of $\omega_d = 1.0$, $\zeta = 0.1$, since the XB-70 ratings are at the "acceptable but unsatisfactory" level in this region.

Two criteria that specify roll-mode characteristics are shown in figures 13 and 14. A suggested criterion in reference 4 (fig. 13) uses the roll-mode time constant and the maximum roll rate available for an aileron-only input. In addition, reference 4 specifies that aileron inputs will cause no significant sideslip. Since the XB-70 exhibits a significant amount of sideslip due to aileron input, the flight ratings are shown in figure 13(a) for an aileron-only roll where roll rate was calculated from $p_{max} = \left(\frac{\omega_\varphi}{\omega_d}\right)^2 \tau_r L_{\delta_a} \delta a_{max}$ and in figure 13(b) for a coordinated roll ($\beta = 0°$) where roll rate was calculated from $p_{max} = \tau_r L_{\delta_a} \delta a_{max}$. In figure 14, the XB-70 flight ratings are shown in terms of the initial maximum roll acceleration $L_{\delta_a} \delta a_{max}$ and the roll-mode time constant. Both criteria indicate that the maximum roll power of the XB-70 was adequate, and in many cases more roll power was available than is predicted to be desirable. However, the maximum values of roll power shown for the XB-70 were not available within the sideslip limits of the airplane because of the yaw due to aileron input and should be used only as an indication of the roll sensitivity rather than the total roll power. Since the problems of roll sensitivity and yaw due to aileron input are so closely related, it is not possible at this time to establish the relative significance of the roll sensitivity in the XB-70 handling qualities.

A parameter often used for analyzing the interaction of the roll and Dutch roll modes is the $\frac{\omega_\varphi}{\omega_d}$ ratio. In reference 6, the data for several configurations from both flight and simulator evaluations were summarized to indicate the trend of pilot rating

with the $\frac{\omega_\varphi}{\omega_d}$ ratio. A comparison of the XB-70 flight ratings with these data is shown in figure 15. Although the XB-70 ratings fall within the general range of the data of reference 6, no clear trend of the XB-70 ratings with the $\frac{\omega_\varphi}{\omega_d}$ ratio is apparent.

Reference 7 summarizes a simulator survey of lateral-directional handling-qualities parameters in which pilot ratings were established as a function of five parameters, ω_φ, ω_d, ζ_d, $L_{\delta_a}\delta_{a_{max}}$, and L_β. A summary of this survey is shown in figure 16 as a function of $L_{\delta_a}\delta_{a_{max}}$ and $\frac{\omega_\varphi}{\omega_d}$ for the values of the other parameters near those of the XB-70. XB-70 flight ratings are also shown in the figure. As for the data of reference 6, there is no clear trend of pilot rating with the $\frac{\omega_\varphi}{\omega_d}$ ratio. Most of the flight ratings are "acceptable but unsatisfactory" and fall in the "satisfactory" region of the criterion, which indicates that other factors in addition to $\frac{\omega_\varphi}{\omega_d}$ are a strong influence in the lateral-directional handling qualities of the XB-70.

A comparison of available lateral-directional handling-qualities criteria with the XB-70 flight experience shows that the standard criteria based on the individual Dutch roll and roll modes are not sufficient to predict the XB-70 handling qualities. The use of a coupling parameter $\frac{\omega_\varphi}{\omega_d}$ alone or in conjunction with several of the roll and Dutch roll mode parameters did not improve the capability of the handling-qualities criteria to predict the XB-70 handling qualities. This suggests that other factors not accounted for in these criteria played a dominant role. On the basis of the XB-70 pilot comments (table III), the yaw due to aileron input appears to have been a significant factor throughout the flight envelope. Normally, this characteristic is taken into account through the effect of $\frac{\omega_\varphi}{\omega_d}$ on the roll rate and the excitation of the Dutch roll mode during roll maneuvers. However, with the XB-70, in addition to the roll/aileron piloting task for which $\frac{\omega_\varphi}{\omega_d}$ is a prime factor, there was a secondary task of keeping sideslip within rather restricted limits for structural and engine operation considerations. This task was further complicated by the sensitive roll control which made it difficult to accurately restrict aileron inputs. It appears that these factors have exerted a strong influence on the XB-70 handling qualities, which results in the standard parameters having only secondary influences.

CONCLUDING REMARKS

A preliminary flight evaluation of the handling qualities of the unaugmented XB-70 airplane was made during the initial flight test program. The XB-70 flight experience

was compared with available transport handling-qualities criteria with the following results:

For the longitudinal mode, fair correlation was obtained between the XB-70 handling qualities and specific criteria boundaries based on the short-period frequency and damping. Sufficient data are not available from the XB-70 to establish the significance of the dimensional lift-curve slope L_α as a longitudinal handling-qualities parameter.

The use of the Dutch roll and roll-mode parameters, the mode coupling parameter $\frac{\omega_\varphi}{\omega_d}$, and limited combinations of these parameters did not prove satisfactory for defining the XB-70 lateral-directional handling qualities. It appears that a combination of many handling-qualities factors on the XB-70 airplane obscured the effects of any single handling-qualities parameter. These factors included excessive yaw due to aileron input, restricted sideslip limits, poor control harmony, and poor attitude and heading information.

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TABLE I. – HANDLING-QUALITIES-EVALUATION QUESTIONNAIRE

Longitudinal mode	Rating	Comments
Trimmability - Ability to hold airspeed, altitude, and attitude		
Maneuverability - Ability to change airspeed, altitude, and load factor		
Response to turbulence		
Response to configuration changes		
Overall		
Lateral-directional mode		
Trimmability - Ability to hold heading and bank angle		
Maneuverability - Ability to change heading and bank angle		
Response to turbulence		
Overall		
Control harmony		

TABLE II. – PILOT RATING SCALE USED FOR HANDLING-QUALITIES EVALUATION

Category	Adjective description in category	Pilot rating
Acceptable and satisfactory	Excellent	1
	Good	2
	Fair	3
Acceptable but unsatisfactory	Fair	4
	Poor	5
	Bad	6
Unacceptable	Bad[1]	7
	Very bad[2]	8
	Dangerous[3]	9
Unflyable	Unflyable	10

[1]Requires major portion of pilot's attention
[2]Controllable only with a minimum of cockpit duties
[3]Aircraft just controllable with complete attention

TABLE III. – SUMMARY OF XB-70 PILOT COMMENTS

[Stability augmentation off]

Airplane number	Wing tips, deg	M	h,		Longitudinal		Lateral-directional	
			ft	m	Rating	Comments	Rating	Comments
1	25	0.8	20,000	6,100	3.0 to 4.5	Sensitive pitch control; can easily exceed g limits during pullup maneuvers (aft center of gravity).	3.0 to 4.0	Adverse yaw due to aileron.
	65	2.1 to 2.5	50,000 to 60,000	15,300 to 18,300	2.0 to 3.5	High forces required for maneuvering. Attitude indicator inadequate for precise flying.	5.0 to 5.5	Hard to trim because of poor instruments. When trying to damp out oscillations, there is a tendency to feed them, resulting in neutral to slightly divergent oscillations. Very difficult to trim and control airplane in turbulence.
2	0	0.4	5,000	1,500	2.5	Very easy to stabilize and to establish climbs and descents.	4.0	Excessive rudder required for coordinated turns. Difficult to control bank angle precisely.
	30	0.8	20,000	6,100	4.5	Low force gradients.	4.0	Sensitive aileron control causes overcontrol of bank angle. Coordinated turns require a large amount of rudder.
	70	1.6	45,000	13,700	3.5	High control force gradient.	5.0	Excessive yaw due to aileron.
	70	2.8 to 3.0	70,0000	21,400	4.5 to 5.0	Heavy control forces and slow airplane response make accurate control difficult. Speed control difficult. Difficult to stabilize.	4.0 to 4.5	Good roll control; not as sensitive as other conditions. Yaw due to aileron unsatisfactory. Heading changes difficult because of instrument lag.

TABLE IV. – SUMMARY OF PILOT RATINGS AND HANDLING-QUALITIES-CRITERIA PARAMETERS FOR THE XB-70 AIRPLANE

[Longitudinal parameters]

Airplane number	M	h,		Wing tips, deg	Pilot rating	f_n, cps	ζ	$\frac{L_\alpha}{\omega_n}$	$\frac{F_e}{n_z}$,	
		ft	m						lb/g	N/g
1	0.45	10,000	3,050	0	2.0	0.19	0.49	0.49	55	244
1	.45	8,500	2,600	0	2.5	.19	.50	.49	55	244
1	.45	12,000	3,700	0	3.0	.18	.48	.48	55	244
1	.8	20,000	6,100	0	3.5	.22	.51	.47	38	169
1	.8	20,000	6,100	25	4.5	.13	.66	.64	33	147
1	.8	20,000	6,100	25	3.0	.18	.50	.49	49	218
1	2.1	50,000	15,300	65	2.0	.25	.22	.17	92	409
1	2.5	60,000	18,300	65	3.5	.22	.17	.14	75	333
2	.4	5,000	1,500	0	2.5	.17	.50	.51	55	244
2	.6	15,000	4,600	0	1.5	.19	.59	.54	52	251
2	.7	15,000	4,600	0	1.5	.23	.53	.51	60	267
2	.8	20,000	6,100	30	4.5	.13	.66	.64	34	151
2	1.6	45,000	13,700	70	3.5	.25	.27	.24	67	298
2	2.6	62,000	18,900	70	5.0	.23	.14	.16	91	405
2	2.8	67,000	20,400	70	4.5	.22	.11	.12	85	378
2	2.8	68,000	20,700	70	5.0	.22	.11	.12	85	378
2	2.9	70,000	21,400	70	4.5	.20	.10	.11	88	392

[Lateral-directional parameters]

Airplane number	M	h,		Wing tips, deg	Pilot rating	ω_d, rad/sec	ζ_d	$\frac{\lvert\varphi\rvert}{\lvert v_e\rvert}$,		$L_{\delta_a}\delta_{a_{max}}$,	τ_r, sec	$\frac{\omega_\varphi}{\omega_d}$
		ft	m					deg/ft/sec	deg/m/sec	rad/sec^2		
1	0.8	20,000	6,100	0	4.0	1.20	0.21	0.39	1.28	1.20	0.73	0.77
1	.8	20,000	6,100	25	3.0	1.06	.11	.12	.39	5.20	.45	.99
1	.8	20,000	6,100	25	4.0	1.06	.11	.12	.39	5.20	.45	.99
1	2.1	50,000	15,300	65	5.0	1.10	.16	.19	.62	.75	1.37	1.14
1	2.4	60,000	18,300	65	5.5	.90	.15	.17	.56	.55	2.60	1.17
2	.4	5,000	1,500	0	4.0	1.33	.28	.83	2.72	2.60	.50	.69
2	.6	15,000	4,600	0	5.25	1.23	.32	.86	2.82	3.35	.40	.67
2	.7	15,000	4,600	0	5.25	1.23	.33	.80	2.62	3.72	.30	.76
2	.95	30,000	9,200	0	6.0	1.28	.29	.70	2.29	2.55	1.40	.73
2	.95	35,000	10,700	0	5.0	1.44	.24	.70	2.29	2.25	1.85	.60
2	.8	20,000	6,100	30	4.0	1.15	.16	.33	1.08	2.15	.85	.89
2	.95	35,000	10,700	30	4.0	1.15	.15	.36	1.18	1.55	1.35	.80
2	.95	35,000	10,700	30	3.5	1.15	.15	.36	1.18	1.55	1.35	.80
2	1.6	45,000	13,700	70	5.0	1.22	.08	.05	.16	1.00	1.85	1.03
2	2.8	67,000	20,700	70	4.5	.83	.12	.06	.20	.40	3.90	.94
2	2.9	70,000	21,400	70	4.0	.76	.12	.05	.16	.35	4.30	.96

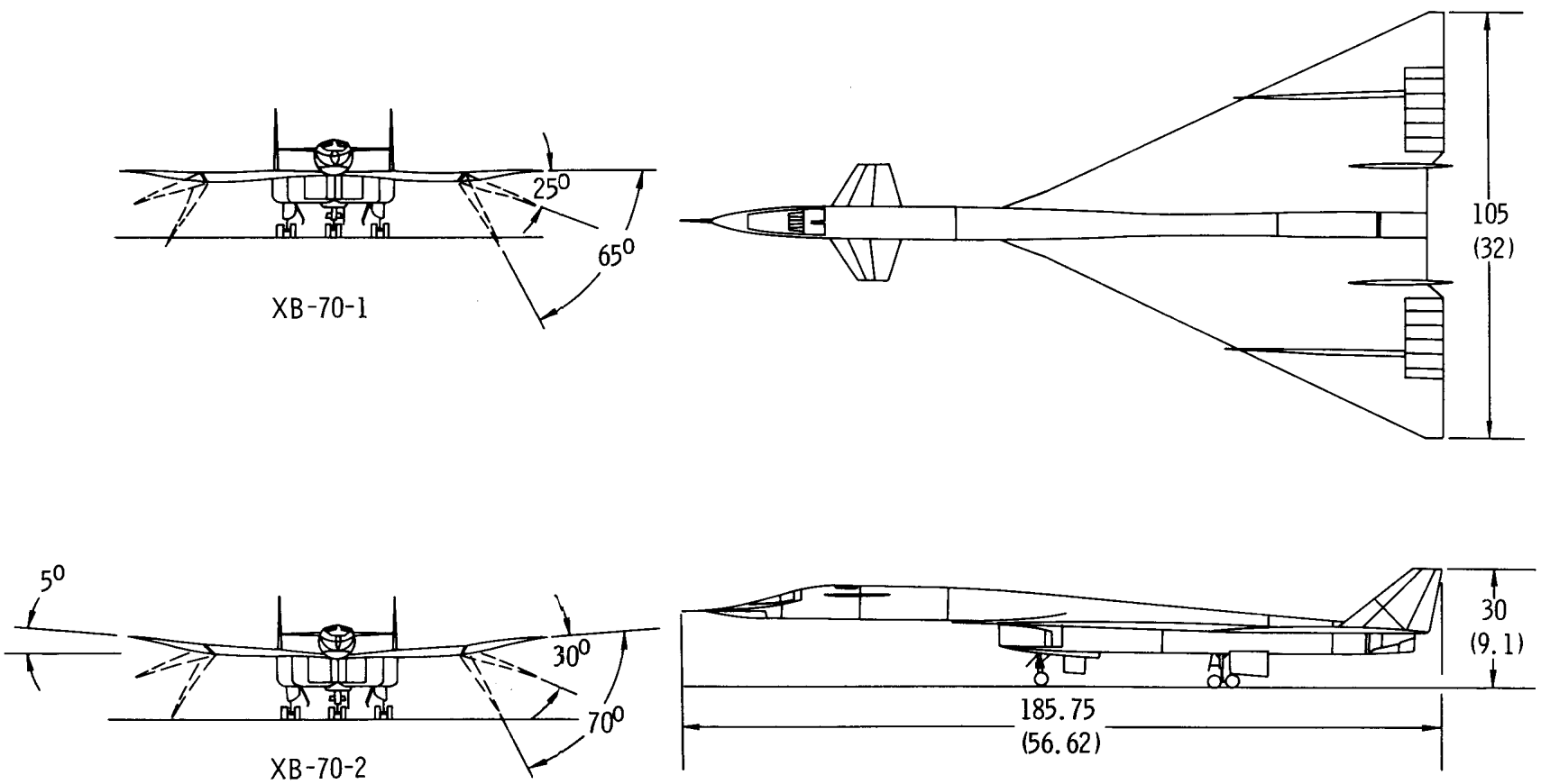


Figure 1. – Three-view drawing of the XB-70 airplane. Dimensions in feet (meters).

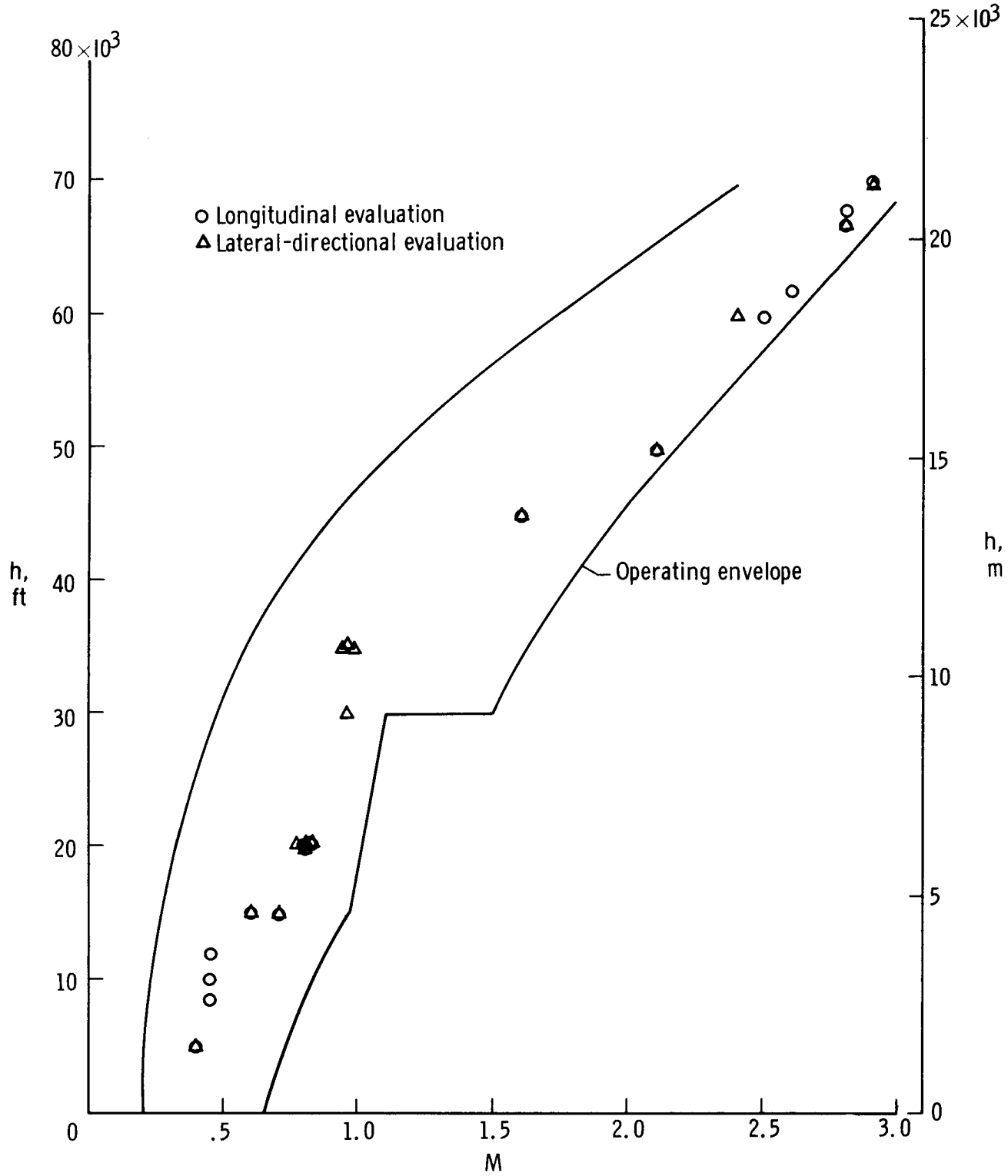
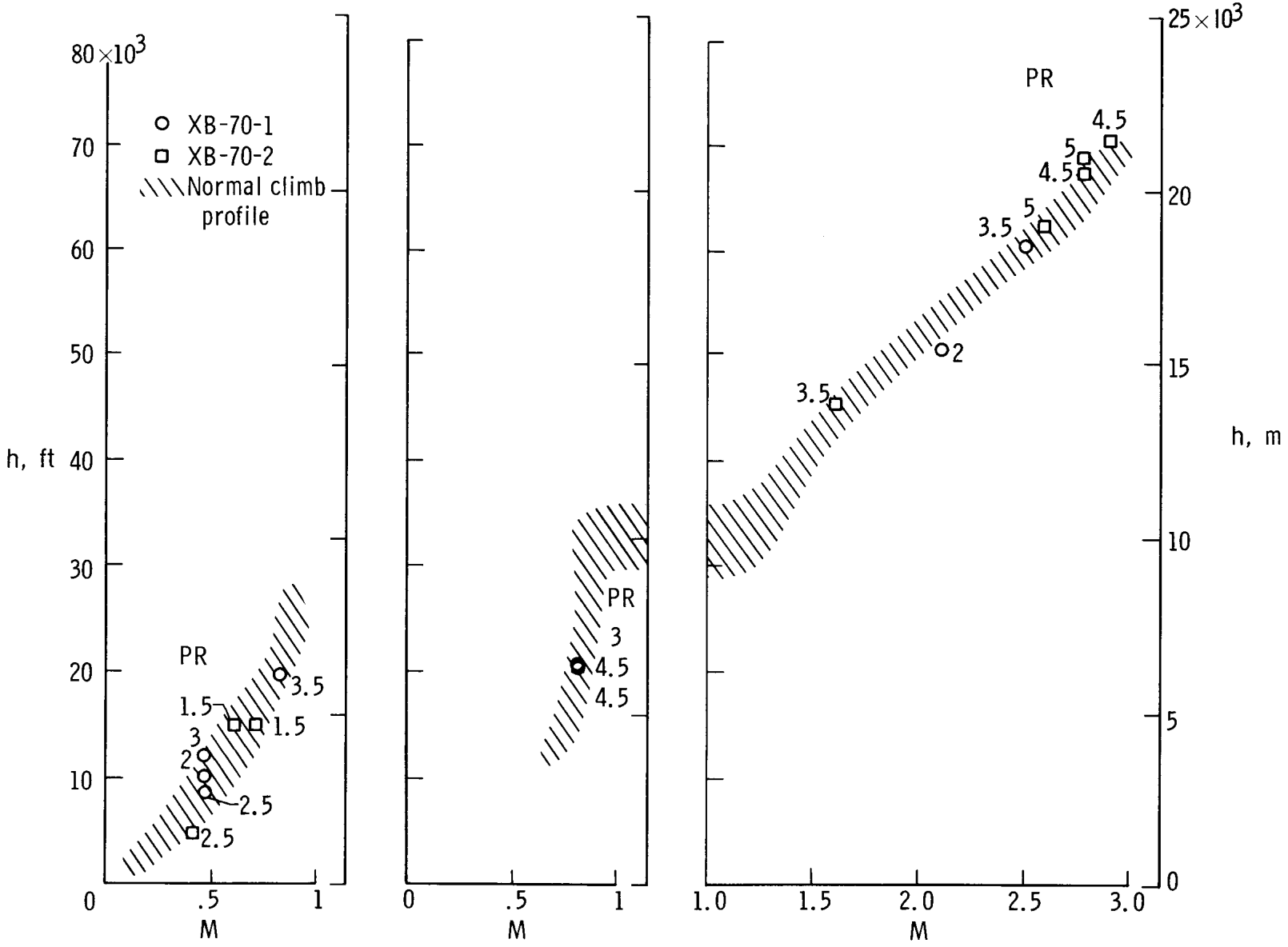
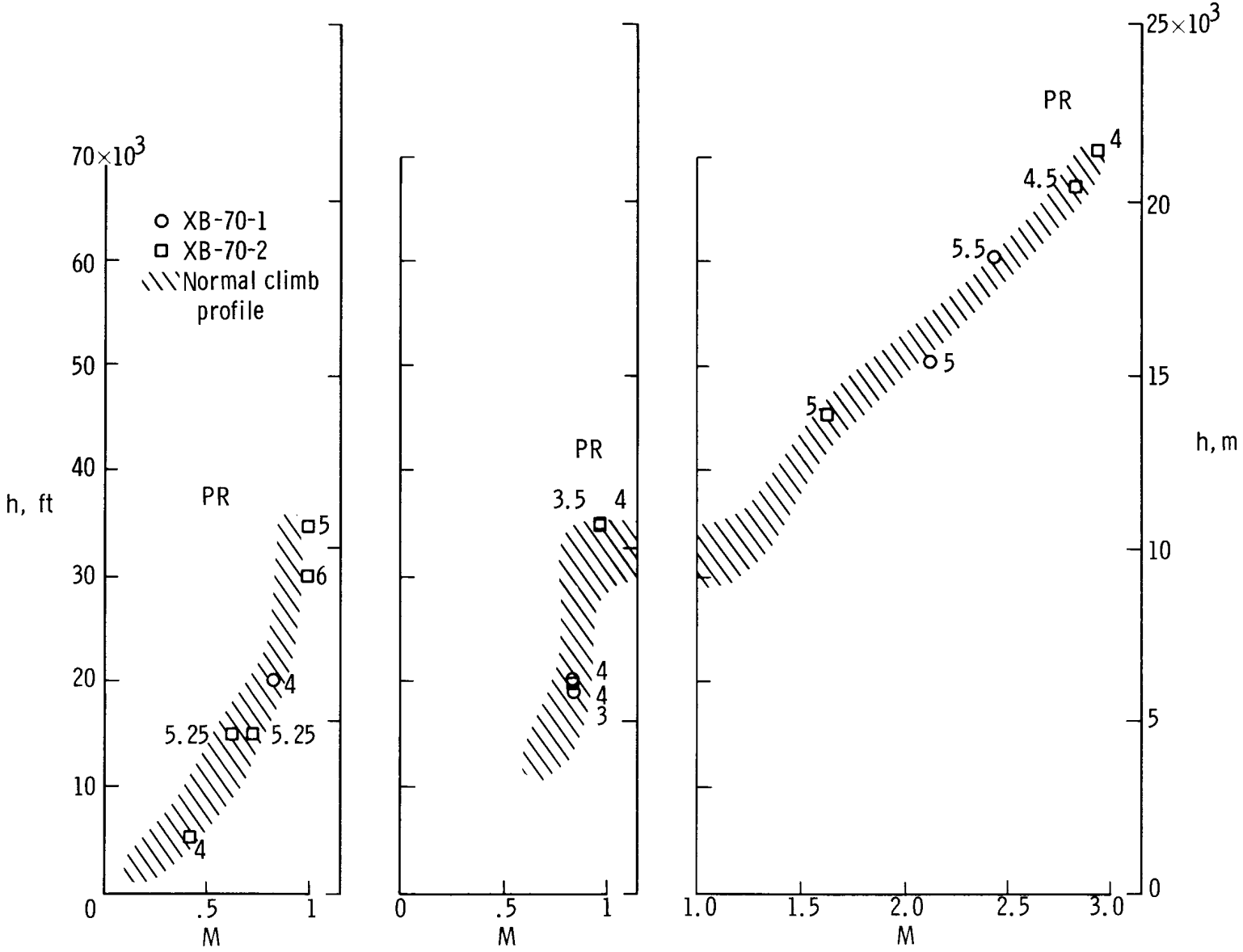


Figure 2. – XB-70 operating envelope and the flight-test conditions for the handling-qualities evaluations.



(a) Tips up. (b) Tips half down. (c) Tips full down.

Figure 3. – Pilot ratings for the XB-70 longitudinal mode. Stability augmentation off.



(a) Tips up. (b) Tips half down. (c) Tips full down.

Figure 4. – Pilot ratings for the XB-70 lateral-directional mode. Stability augmentation off.

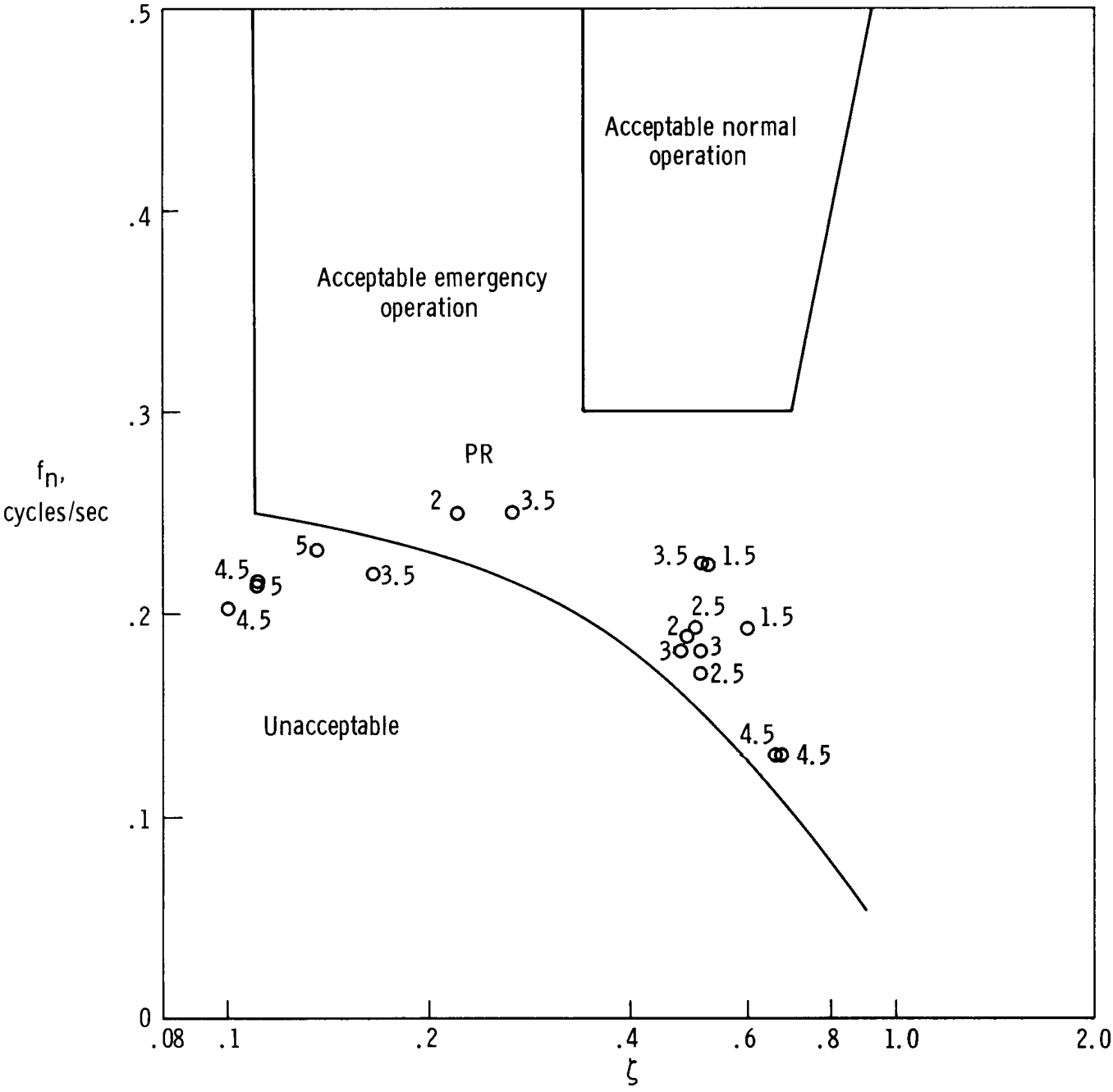


Figure 5. – Comparison of XB-70 flight ratings with the longitudinal short-period criterion of reference 2.

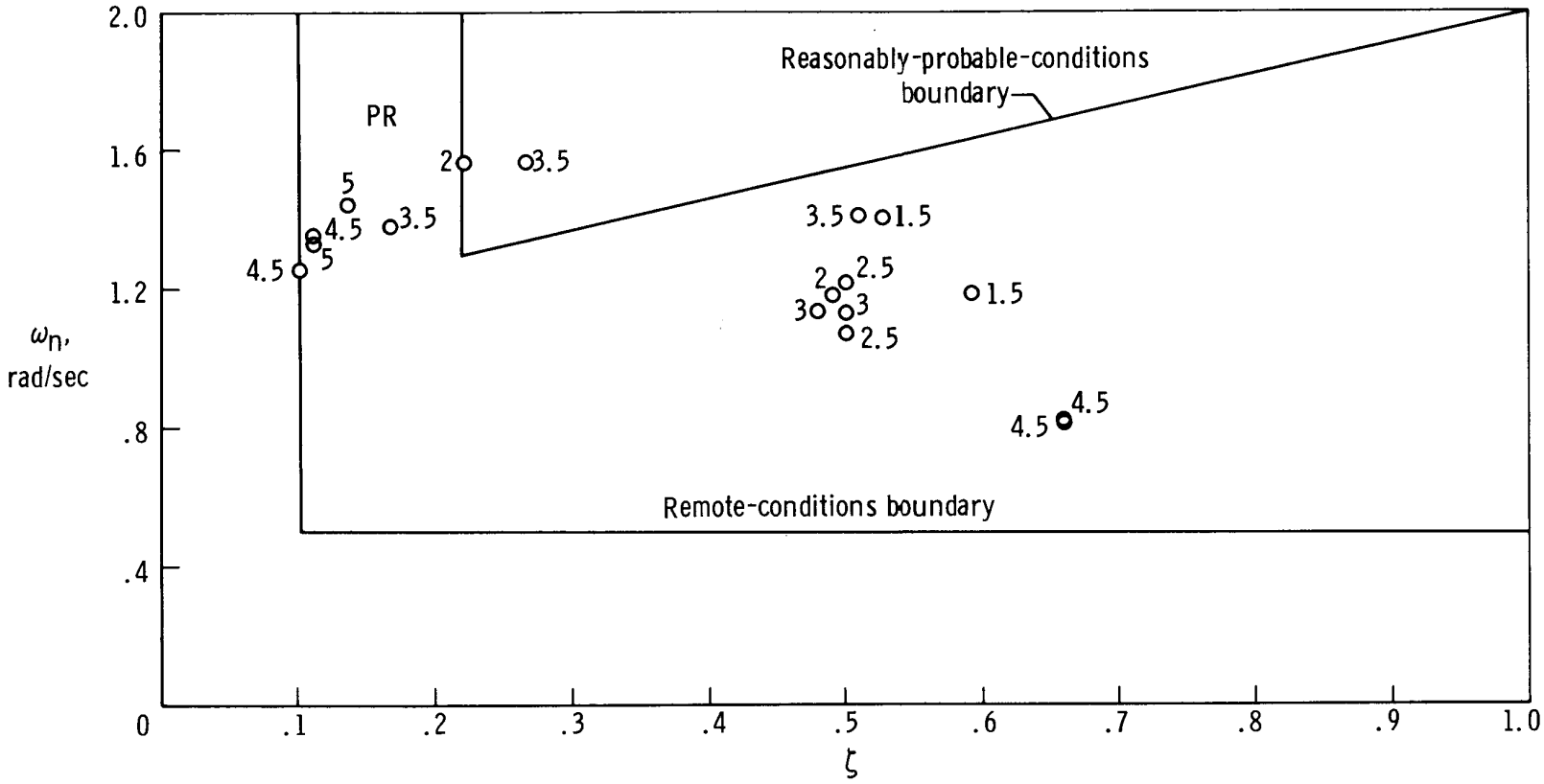


Figure 6.– Comparison of XB-70 longitudinal flight ratings with a tentative criterion presented in reference 3.

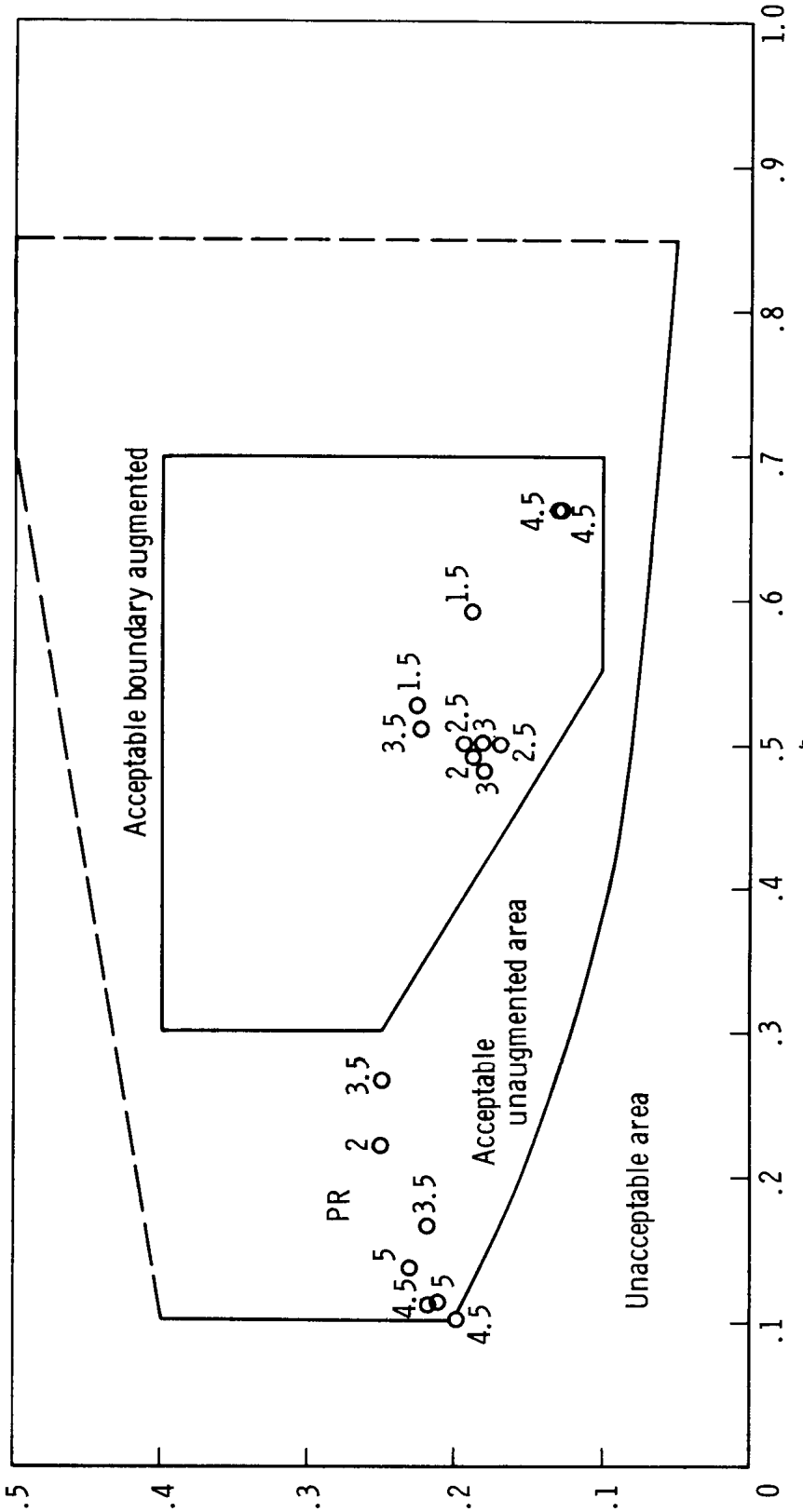


Figure 7. – Comparison of XB-70 longitudinal flight ratings with a tentative criterion presented in reference 4.

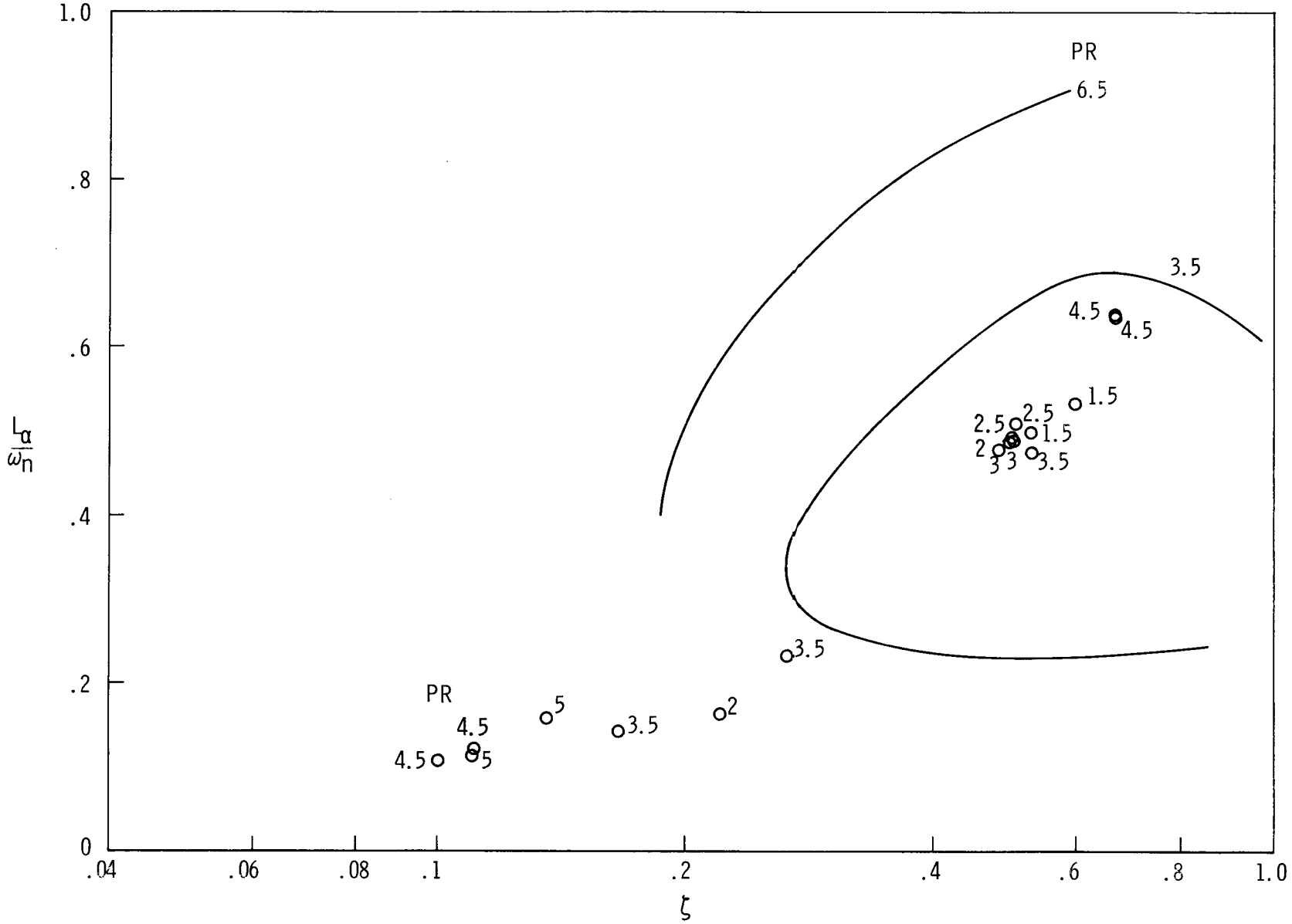


Figure 8. – Comparison of XB-70 longitudinal flight ratings with $\frac{L_\alpha}{\omega_n}$ criterion of reference 5. $n_{z_\alpha} < 15$.

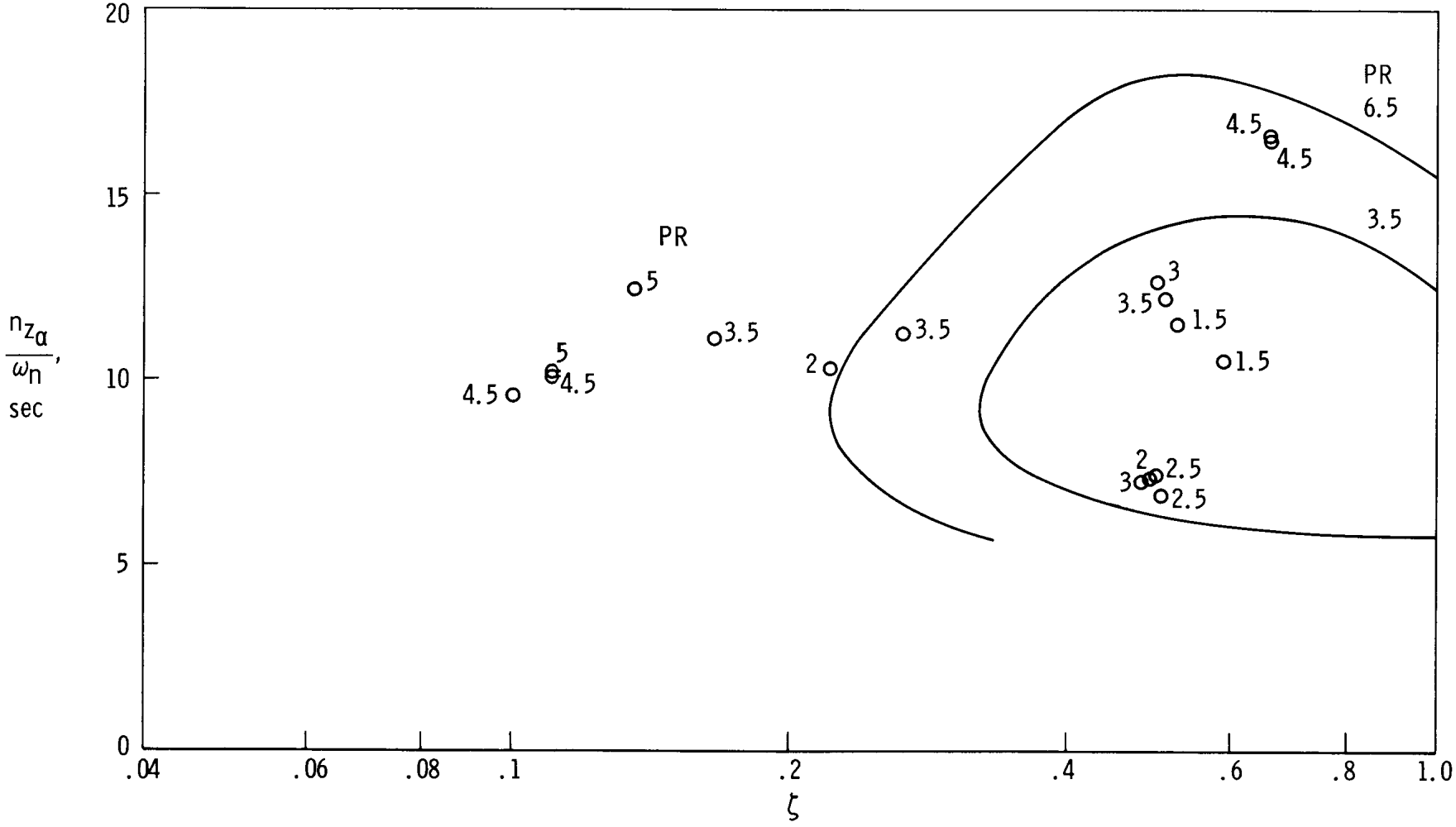


Figure 9. – Comparison of XB-70 longitudinal flight ratings with $\frac{n_{z_\alpha}}{\omega_n}$ criterion of reference 5. $n_{z_\alpha} > 15$.

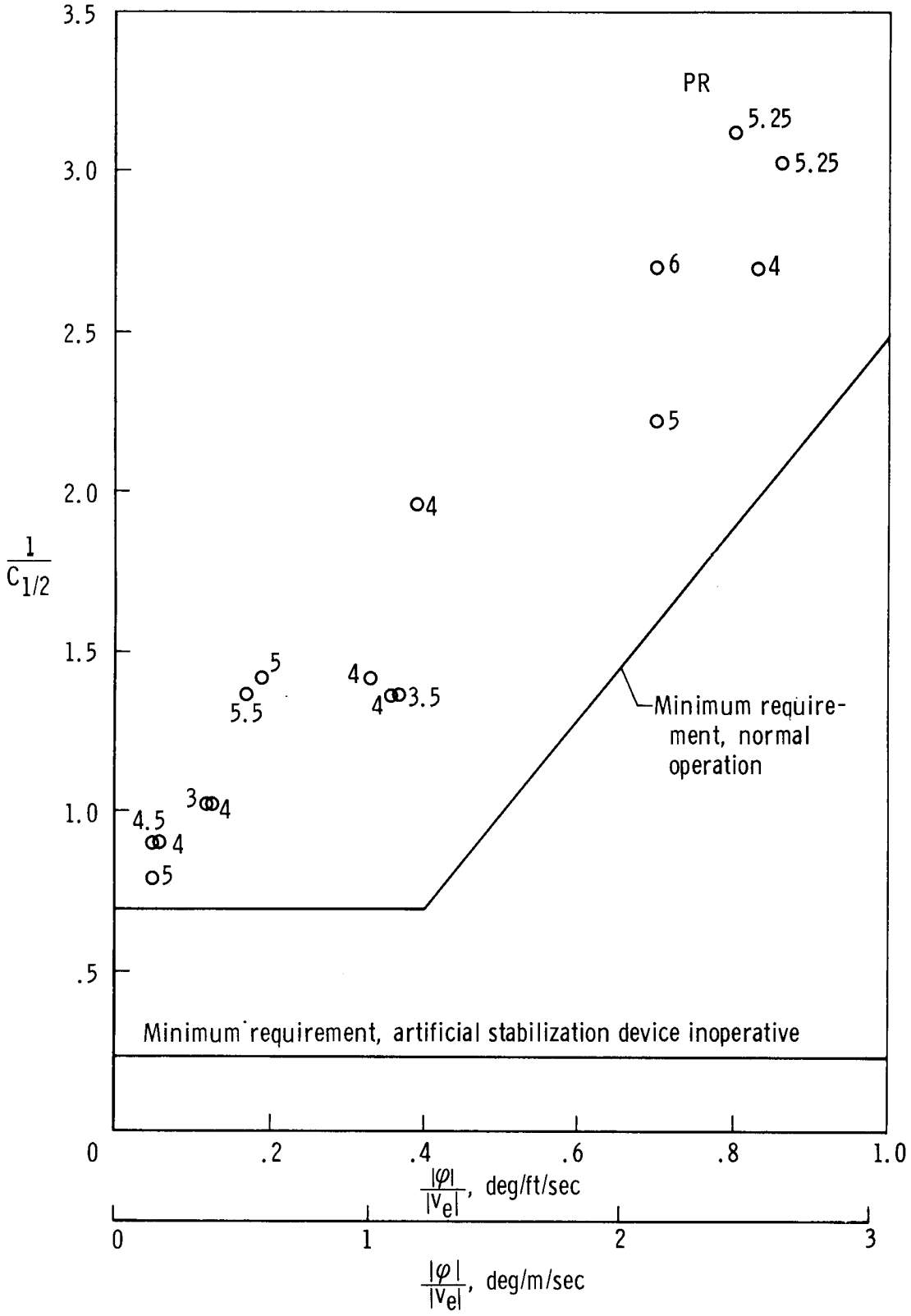


Figure 10. – Comparison of XB-70 lateral-directional flight ratings with Dutch roll criterion of reference 1.

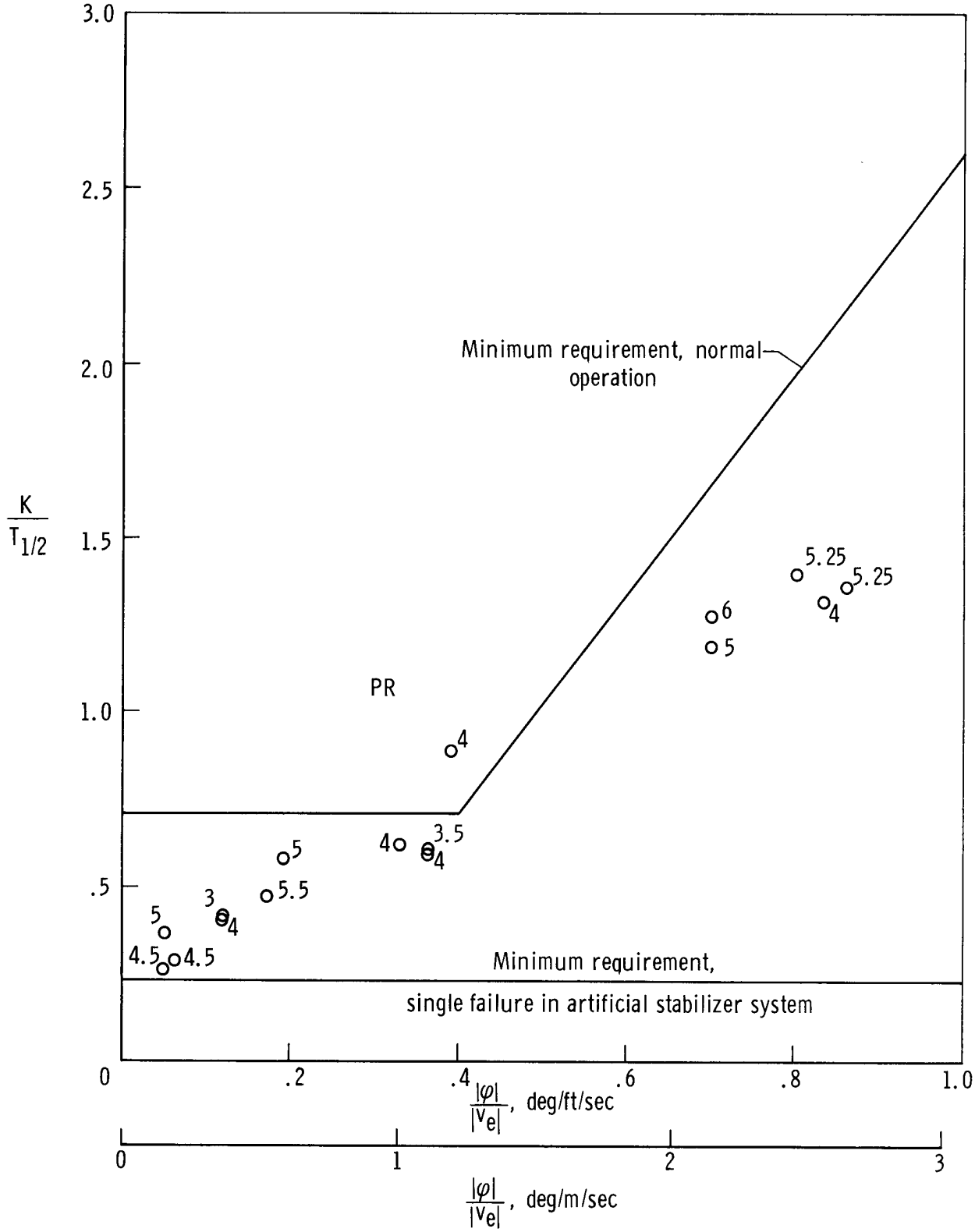


Figure 11. – Comparison of the XB-70 lateral-directional flight ratings with the criterion of reference 4. For $P < 2.4$ sec, $K = P$; $P > 2.4$ sec, $K = 2.4$ sec.

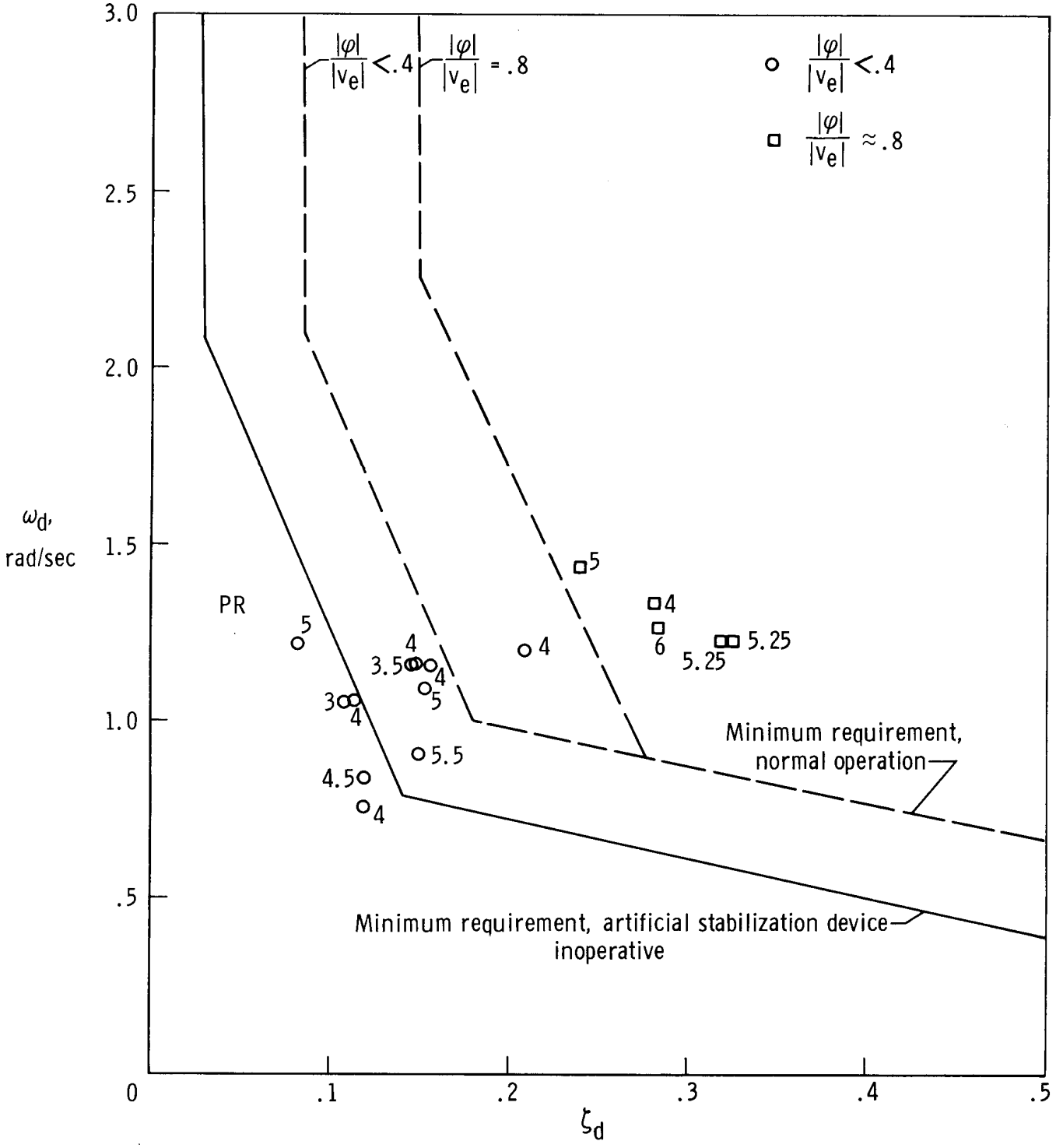
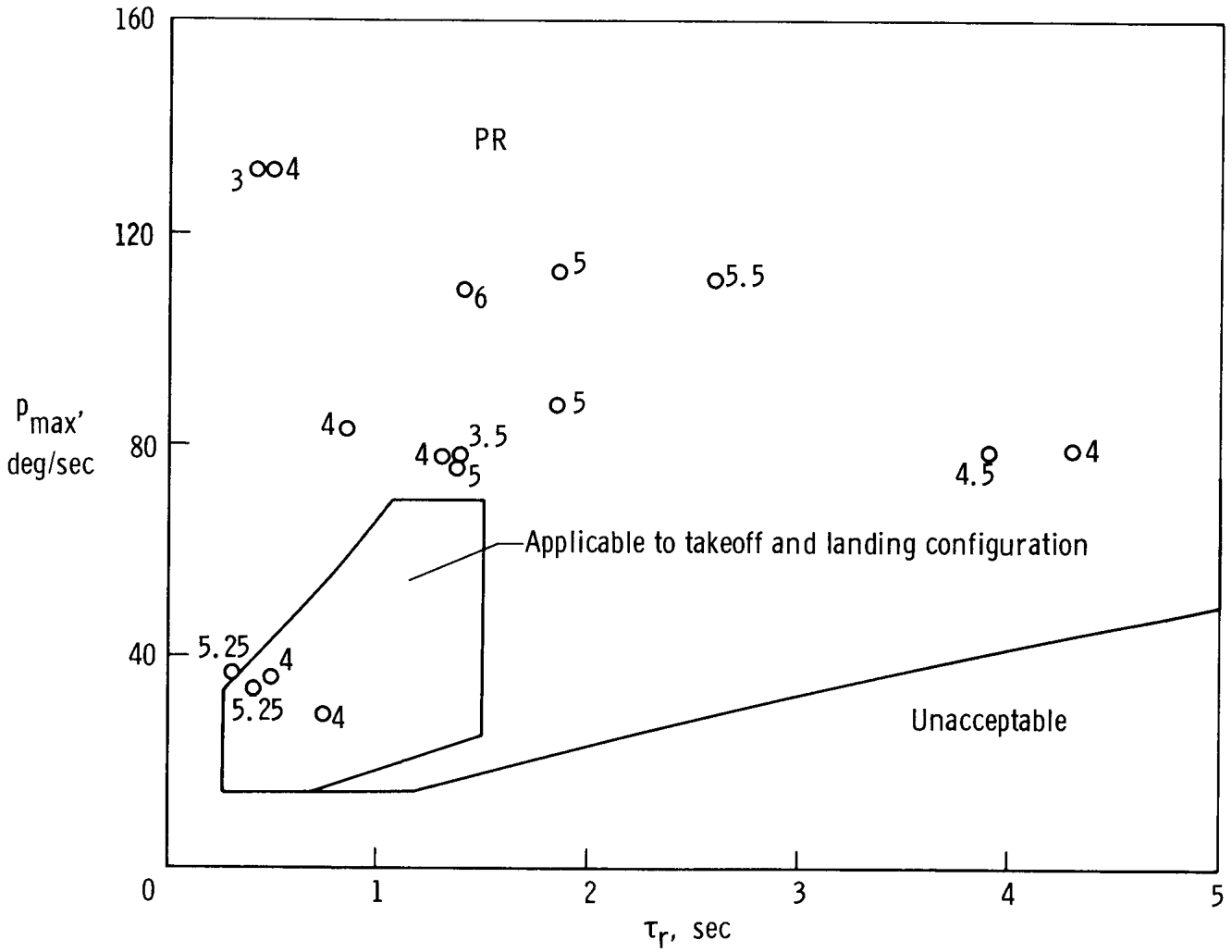
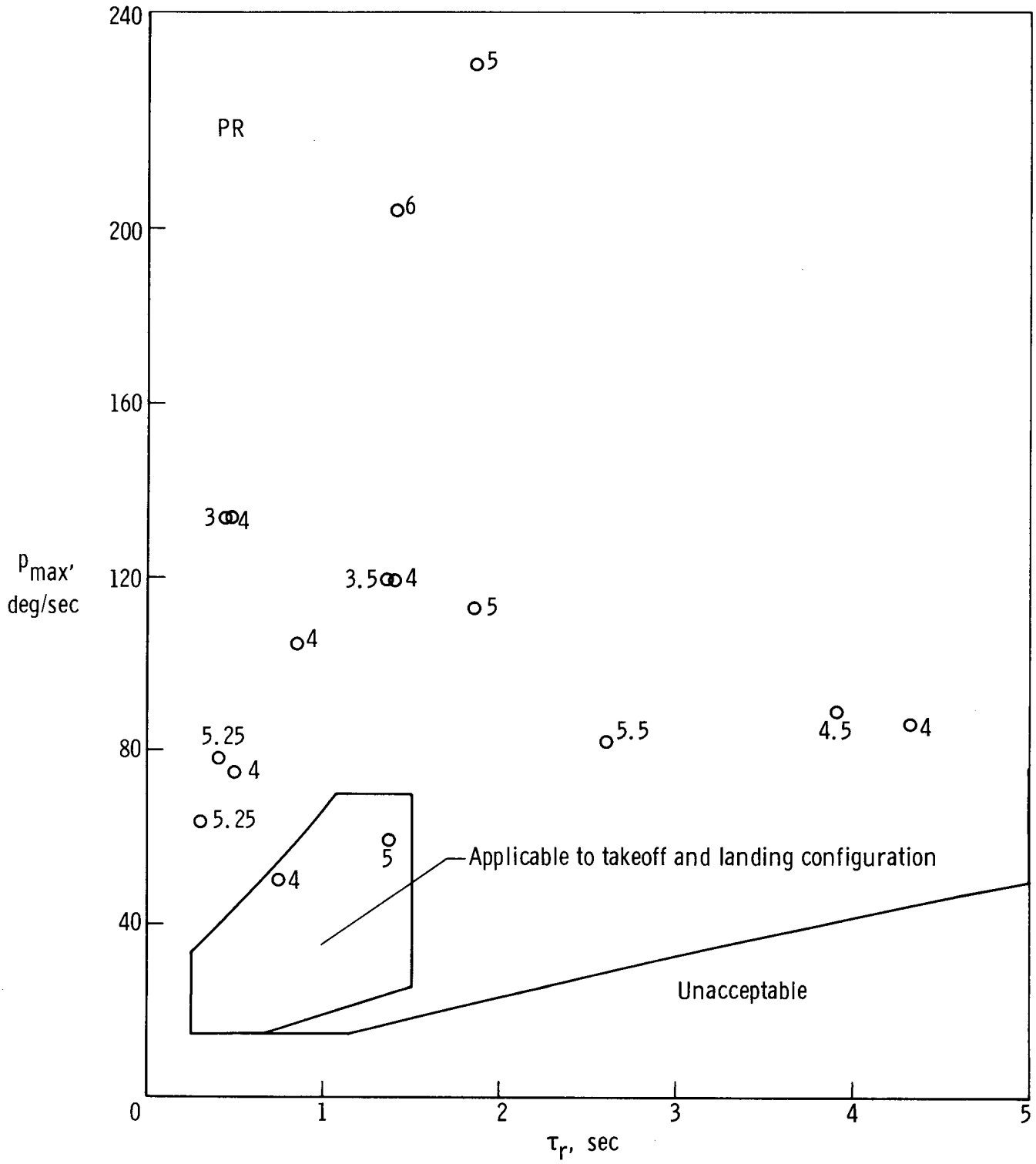


Figure 12. – Comparison of the XB-70 lateral-directional flight ratings with the criterion of reference 2.



(a) Maximum roll rate calculated for an aileron-only roll $\left(p_{max} = \left(\frac{\omega_\varphi}{\omega_d}\right)^2 \tau_r L_{\delta_a} \delta_{a_{max}}\right)$.

Figure 13. – Comparison of XB-70 lateral-directional flight ratings with a tentative roll criterion presented in reference 4.



(b) Maximum roll rate calculated for a coordinated roll ($p_{max} = \tau_r L_{\delta_a} \delta a_{max}$).

Figure 13. – Concluded.

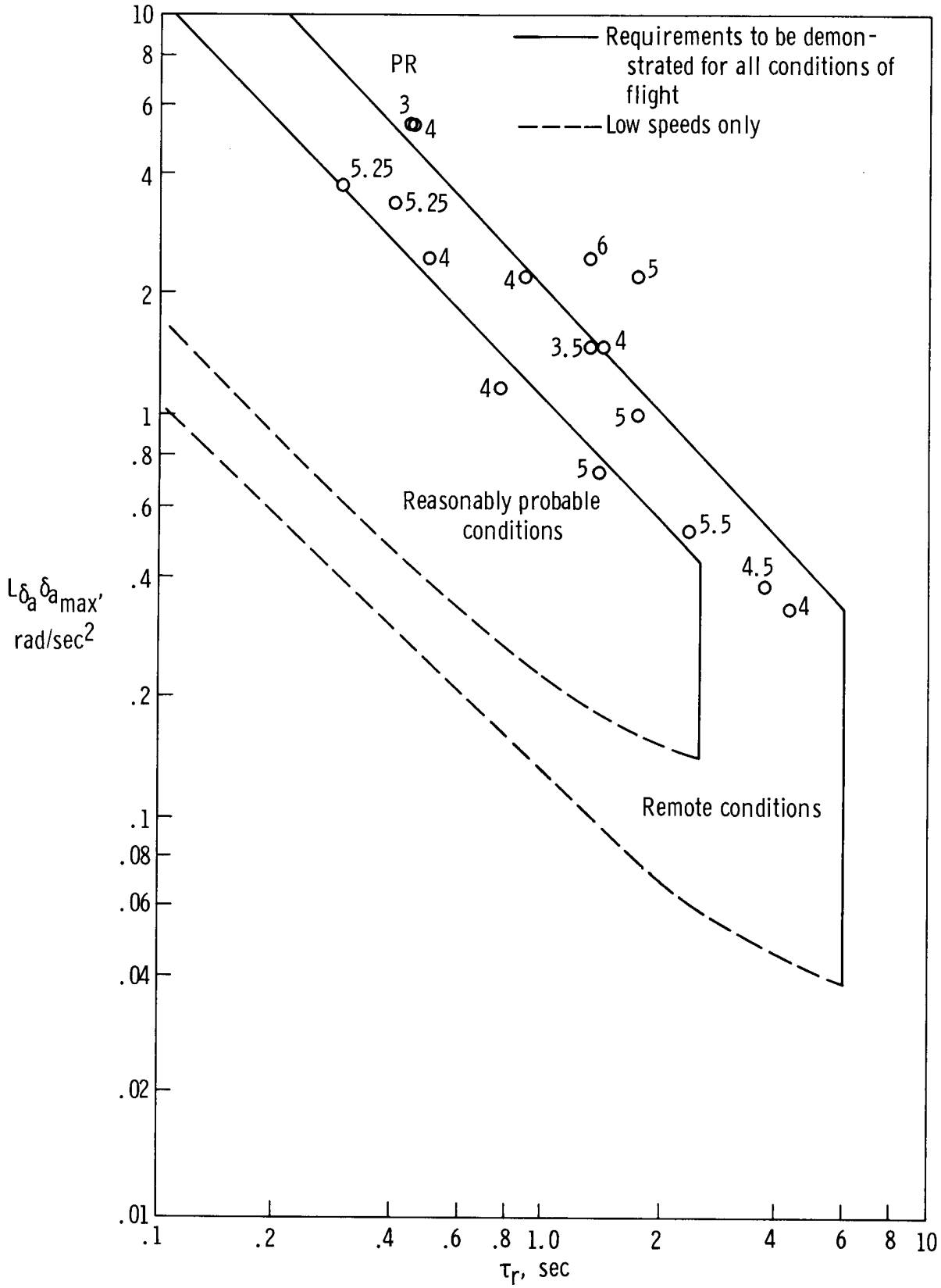


Figure 14. – Comparison of XB-70 lateral-directional flight ratings with the roll criterion of reference 3.

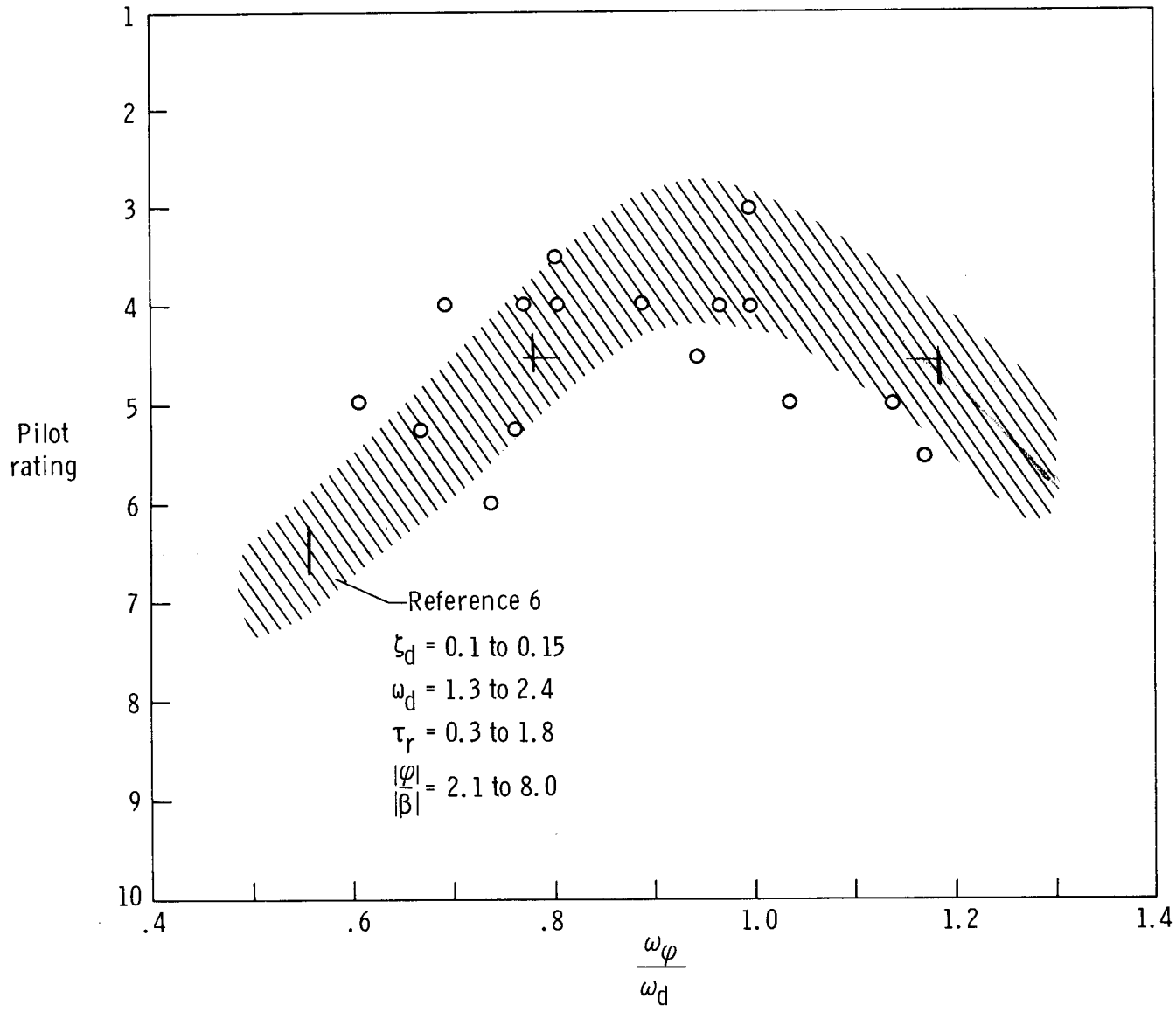


Figure 15. – Comparison of XB-70 lateral-directional flight ratings with $\frac{\omega_\varphi}{\omega_d}$ trends of reference 6.

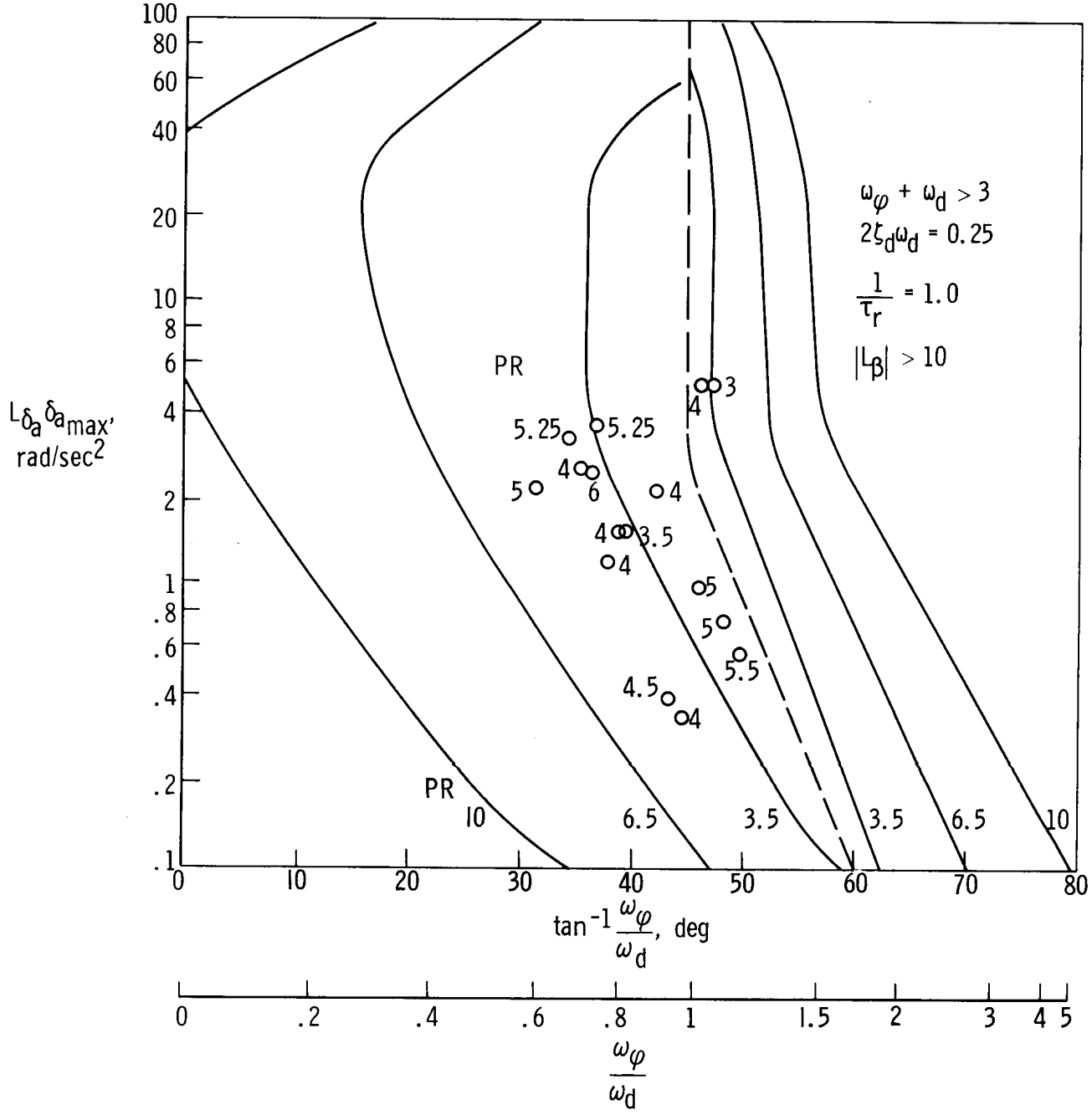


Figure 16. – Comparison of XB-70 flight ratings with the lateral-directional handling-qualities survey of reference 7.

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