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SUMMARY

A limited flight test program has been accomplished with a one-man Hiller YROE-1 "Rotorcycle" (gross wt ≅ 500 lb) to help determine criteria for the handling qualities in hover of VTOL aircraft as affected by gross weight.

The generally high orders of longitudinal and lateral control power and damping inherent were found to be satisfactory. The high directional control sensitivity, combined with high yaw response in one direction, was considered potentially dangerous. The lateral control power for this craft is approximately the same as that found necessary for satisfactory control with similar damping in tests of two other VTOL aircraft with substantially greater gross weight.

INTRODUCTION

The NASA has, in recent years, been studying handling qualities criteria for V/STOL aircraft (ref. 1). A major question is, how do satisfactory and unsatisfactory limits for hovering control power and damping vary with size and gross weight? One form of scaling criteria is presented in reference 2. Only limited flight verification of these criteria is available, chiefly with vehicles in the 3000-4000 pound gross weight category (see, e.g., ref. 3). The Hiller YROE-1 Rotorcycle, with a gross weight of approximately 500 pounds, is at the bottom end of the weight spectrum for manned aircraft and an order of magnitude away from the X-14A (used in ref. 3). It was selected for investigating control power requirements at low gross weights in hope that, thereby, some light would be shed on the influence of size and weight.

DESCRIPTION OF TEST ARTICLE

The Hiller YROE-1 Rotorcycle (fig. 1) was originally designed for the Armed Services as a simple, collapsible, one-man helicopter for observation and liaison purposes. Figure 2[1] shows a three-view sketch of the vehicle. As flown, its gross weight was 515 pounds. The power plant is a 4-cylinder, 2-cycle, Nelson engine of 43 hp. The craft is described in detail in references 4 and 5 and results of previous Navy flight tests are given in references 6 and 7.

[1]Figure 2 was supplied by the Hiller Aircraft Corp., Inc.

For the NASA flight tests a small instrumentation package was hung in a box underneath the pilot as shown in figure 1. The package contained a high-frequency transmitter that telemetered information on three channels, and a single-axis rate-measuring gyro which could be oriented along any one of the three axes. A potentiometer was also included for measuring the position of the control being considered and a button on the control stick allowed the pilot to signal the start of a maneuver.

METHOD OF DATA REDUCTION

The maneuver for obtaining the control power-damping data consisted of a control reversal input to the control affecting the axis being considered ending in a fixed control deflection held for 1-2 seconds. Thus, the first derivative of the resultant angular velocity about the given axis, as this velocity passes through zero after the reversal, represents the angular acceleration corresponding to the control deflection. The maximum excursion of the angular velocity (with the control still held fixed), when compared to the previously determined angular acceleration, indicates the approximate velocity damping, $1/\tau$, about the axis. See reference 8 for an analysis of this method. The angular acceleration corresponding to total control deflection was determined by plotting accelerations measured against percent deflection and fairing a straight line through all the points (assuming a linear variation of initial angular acceleration with control deflection). The pilot ratings were based on tasks described in the Pilot Comments section.

RESULTS AND DISCUSSION

Since total control power required for a given task includes that for correcting disturbing inputs, it will depend on the type of VTOL aircraft because of inherent differences in gust sensitivity, etc. In spite of this it is of interest to examine control power requirements for a wide range of VTOL aircraft to observe any gross trend of the effect of size.

Table I is a summary of the pertinent parameters determined. It shows maximum control power (in terms of initial angular acceleration), angular rate damping (in terms of the reciprocal of the time constant, $1/\tau$), control sensitivity (in terms of initial acceleration per inch of control deflection), and the pilot rating for the visual hovering task (for both maximum control power and sensitivity, where available) on the Cooper Scale (table II and ref. 9) for each of the three axes (two pilot ratings are shown; pilot A being the project pilot and pilot B a visiting NASA pilot who made only one flight). For the directional case values are shown for right yaw only. Also shown are the implied values of the control power, damping, and sensitivity called out in the proposed V/STOL specifications (ref. 2). These have been converted from the response values listed by assuming a "step" input to the control. For comparison similar data are shown, in parallel grouping, for the minimal satisfactory (P.R. = 3.5) rating in the variable stability X-14A (used in ref. 3). Also shown in the "damping" column are the nominal moments of inertia of the two craft in slug-ft^2.

Lateral Characteristics

Figure 3 shows a plot of the initial acceleration in roll for full control deflection (i.e., control power) and for one inch of control travel (i.e., sensitivity) versus gross weight for four vehicles: the YROE-1 helicopter (W = 515 lb), the X-14A deflected jet VTOL (W = 3880 lb, ref. 3), the Hawker P-1127 deflected jet VTOL (W = 12,500 lb), and the XC-142A tilt-wing VTOL transport (W = 37,500 lb, ref. 10). Data for the latter two were supplied by the manufacturer. Pilot ratings for the visual hovering task, where available, are shown in parentheses next to the data points; for the YROE-1, the ratings of the project pilot only are shown. The lack of variation with gross weight of control power required to obtain a satisfactory (P.R. = 3-1/2) rating for this important "X" axis is of interest. For the YROE-1, the pilot rating of unsatisfactory for sensitivity in roll (and also in pitch) was given because of too little sensitivity (too much stick travel, ±7 in. in roll). Pilot ratings for sensitivity in the P-1127 and for the XC-142A are not available. Reference 11 was used to derive a pilot rating for the sensitivity of the X-14A in roll; the sensitivity shown corresponds to the 3-1/2 boundary for control power.

Figure 4 is another plot showing handling qualities information in roll, with some of the same data. The "satisfactory" (P.R. = 3-1/2) and "acceptable" (P.R. = 6-1/2) boundaries for lateral characteristics are shown as determined with the variable stability X-14A (ref. 3). The boundaries are plotted with total control power as the abscissa and rate damping (the reciprocal of the time constant) as the ordinate. Superimposed is a point showing the characteristics of the YROE-1 as determined by the subject tests; it is seen to possess, with a pilot rating of 3, approximately the same control power and damping in roll as was required by the X-14A for a satisfactory pilot rating. The values shown for the P-1127 correspond to the configuration flown by a NASA pilot when the rating of 3-1/2 was assigned. The values for the XC-142A are for the unaugmented configuration and are estimates only.

Longitudinal Characteristics

Figures 5 and 6 show the handling qualities in pitch. It can be seen that the YROE-1 (with a P.R. of 2-3) possesses much higher values of control power and damping about the Y axis than were necessary for satisfactory (P.R. = 3-1/2) characteristics in the X-14A or the P-1127. This combination of control power and damping was too high to be evaluated in the X-14A, but it is significant that the pilot rating indicates little improvement over the ratings obtained at the lower levels of control power and damping along the 3.5 boundary of reference 3. As in the lateral case, the longitudinal control sensitivity was rated at 5 because of the large (±8 in.) stick travel. The values shown for the XC-142A are estimates for the unaugmented configuration.

Directional Characteristics

Because of the unusual circumstances involved, no comparison plots are shown for the directional characteristics. Too much control power (approximately 6 radians/sec^2 in hover near sea level) is available to the right (aiding rotor torque) along with an extremely high sensitivity (approximately 3 radians/sec^2/in. corresponding to 2 in. pedal travel), which were given pilot ratings of 6 and 7, respectively. The pilot must be highly competent to fly the vehicle successfully because of this high sensitivity and control power in yaw. In the opposite direction (to the left, countering rotor torque) no accurate measurements could be taken since control power is marginal and varies considerably with flight condition as a result of the varying power input to the rotor accompanied by the varying tail rotor thrust required and available (in ref. 8, fig. 2, it is shown that, for density altitudes in excess of approximately 3000 ft, insufficient directional control exists to counteract rotor torque).

PILOT COMMENTS

The pilot ratings of control power, sensitivity, and damping provided in this report are based on the vehicle characteristics when hovering and maneuvering at low speeds in a relatively confined area.

Lateral-control power is not the same for left and right inputs, and roll-pitch cross coupling exists for abrupt control displacements. Pitch and roll cyclic control displacements are excessive and the low control sensitivity contributes to a feeling of sluggish pitch and roll response. It also feels as though there is a delay in the control response from the time a step input is applied to the time the response is felt. Full lateral control was often used in roll reversal maneuvers about the hover condition; however, precision hovering over a spot was accomplished with very small lateral-control inputs.

Longitudinal control power was never limiting in any maneuver. Full control was used for the most abrupt quick stops, but, as was noted for the lateral control, there was a lag in the response of the helicopter to abrupt control inputs. These effects, which are similar to those of the larger Hiller 12E, are reportedly due to the characteristics of the servo-paddle-rotor cyclic-control system. The pitch cyclic-control displacement is uncomfortably large, particularly for an overhead cyclic stick. There was no objectionable friction in the cyclic control and the forces were very desirable. Adequate control centering was available, and the rotor feedback through the cyclic stick was only noticed when abrupt control inputs were used.

Pitch and roll damping appeared high and considerable stability in terms of a roll or pitch restoring moment as a function of forward or sideward speed was present.

Yaw control power during hovering was high to the right but just adequate to the left at normal rpm. It was easy to lose all directional control power to the left if the rotor rpm was allowed to decay to the lower rotor speed normal operating limit. Yaw control was too sensitive in normal hover and was considered to be dangerous for general use because of the rocker-plate type of rudder pedals and the very high pedal sensitivity. Yaw rate damping appeared to be high enough and usable yaw rates were not limited by the rate damping or control power at high rotor rpm.

In general, there was a tendency to operate this small helicopter in a much tighter pattern than even the UH-12E (three place, 2800 lb gross wt) helicopter. Transitions to and from a hover were easily done at high rates and the small size of the helicopter minimized the judgment needed to keep a safe distance from obstacles. Operating and observing this small helicopter fly in confined areas indicates that it was being flown differently than a helicopter of even 2800-pound gross weight. Turns and transitions to and from hover were done much quicker than is normally done with the larger helicopters. The cyclic-control power and rate damping did not limit the maneuverability of the YROE-1 in and about the visual hover condition. The high yaw control sensitivity required more than normal pilot attention and considerable familiarization time.

CONCLUDING REMARKS

The most significant data obtained is that representing the lateral characteristics. This indicates that approximately the same lateral control power is required for this vehicle as for those of much higher gross weights to achieve a satisfactory pilot rating. The indication would seem to be that minimum control power requirements should be based primarily on the task to be performed rather than on the gross weight or size, as such.

The data obtained about the other two axes is less conclusive. Apparently, the high control power available longitudinally is ineffective because of the large stick movements necessary with consequent low sensitivity. Directionally, the low control power in the direction opposing rotor torque and high control power in the opposite direction, combined with extremely high control sensitivity, are essentially peculiar to this vehicle and make the results inapplicable in any general sense.

It is to be noted that undue emphasis should not be placed on making comparisons of total control power requirements between dissimilar types of VTOL vehicles (i.e., helicopter, deflected jet, tilt wing, etc.), because of inherent differences in self-disturbing characteristics, ground effects, gust sensitivity, trim requirements, etc. The comparisons made here are presented primarily to provide a convenient cataloging of available data on VTOL aircraft covering a wide range of gross weights and to point out that no gross trend of varying control power requirements with increasing weight is obvious.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., March 16, 1965

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TABLE I.- SUMMARY OF THE PERTINENT PARAMETERS DETERMINED

Mode	A/C	Control power, ~radians/sec^2		Damping, $\sim 1/\tau$ = 1/sec		Sensitivity, ~radians/sec^2/in.		Pilot ratings: Control power		Pilot ratings: Sensitivity	
		Flight test value	AGARD spec. (ref. 2)	Flight test value	AGARD spec. (ref. 2)	Flight test value	AGARD spec. (ref. 2)	A	B	A	B
Lateral (~Roll)	YROE-1	1.7	3.9	2.6 ($\sim I_{xx} \cong 54$)	7.5	0.24	1.3	3	4	5	4 (too low)
	X-14A (minimal satisfactory)	1.8	1.3	2.0 ($\sim I_{xx} \cong 1170$)	2.9	.36	.43	(3-1/2)		4	
Longitudinal (~Pitch)	YROE-1	2.0	2.4	2.6 ($\sim I_{yy} \cong 80$)	4.0	.25	.6	2-1/2	5	5	5 (too low)
	X-14A (minimal satisfactory)	.6	1.0	.8 ($\sim I_{yy} \cong 1990$)	1.5	.11	.25	(3-1/2)		(n.a.)	
Directional (~Yaw)	YROE-1 (Rt. only, aiding torque	6	3.0	≈1 ($\sim I_{zz} \cong 29$)	10	3	1.0	6	(4-1/2)	7	(4-1/2) (too high)
	X-14A (minimal satisfactory)	.5	.7	1.0 ($\sim I_{zz} \cong 2920$)	2.4	.17	.23	(3-1/2)		(n.a.)	

TABLE II.- PILOT OPINION RATING SCHEDULE

	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Unsatisfactory	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*	Doubtful	Yes
No operation	Unsatisfactory	7	Unacceptable even for emergency condition*	No	Doubtful
		8	Unacceptable-dangerous	No	No
		9	Unacceptable-uncontrollable	No	No

*Failure of a stability augmenter

Figure 1.- YROE-1 Rotorcycle in hovering flight.

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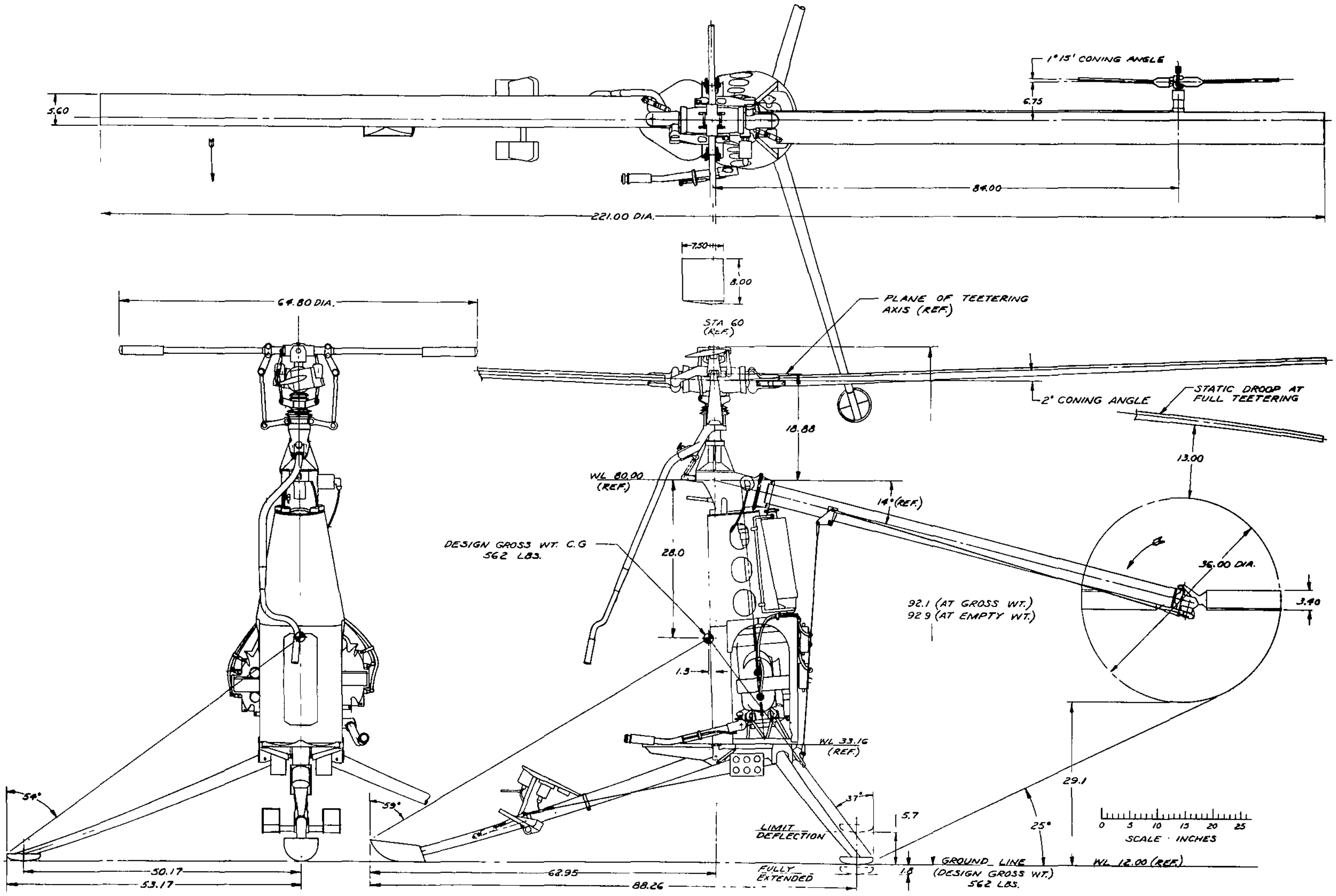

Figure 2.- Three-view drawing of test vehicle.

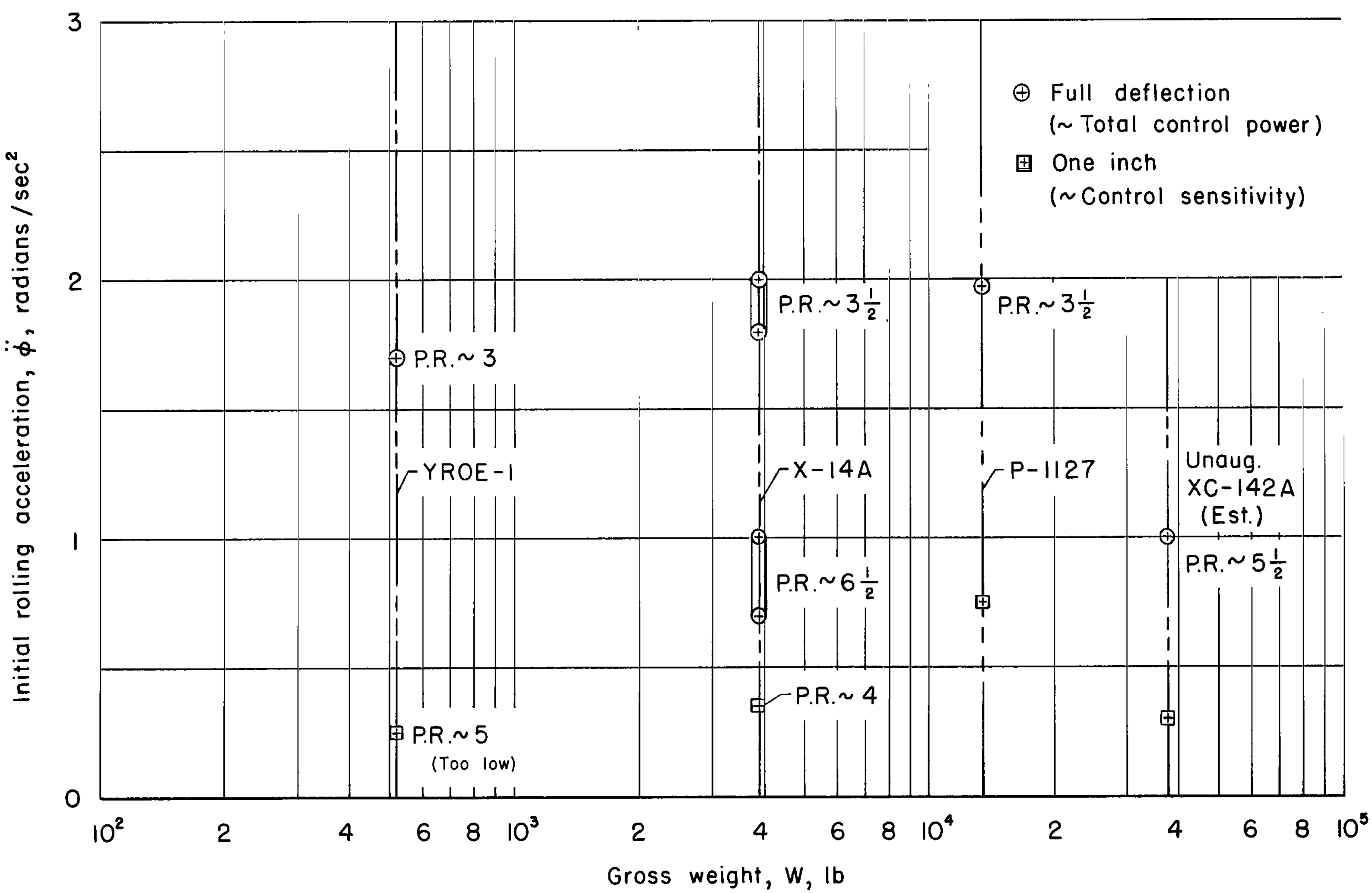

Figure 3.- Lateral control characteristics (~ visual hovering task).

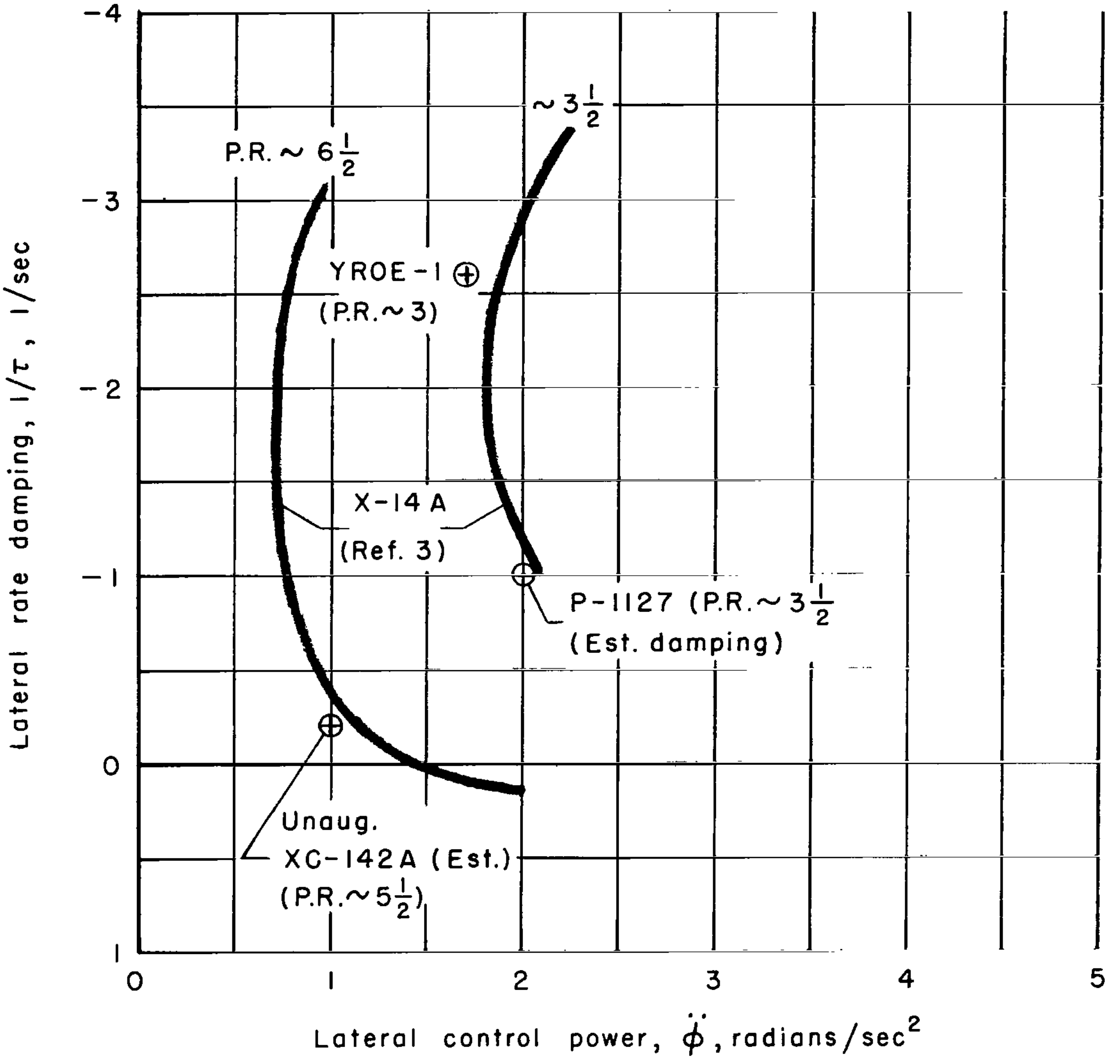

Figure 4.- Lateral handling characteristics.

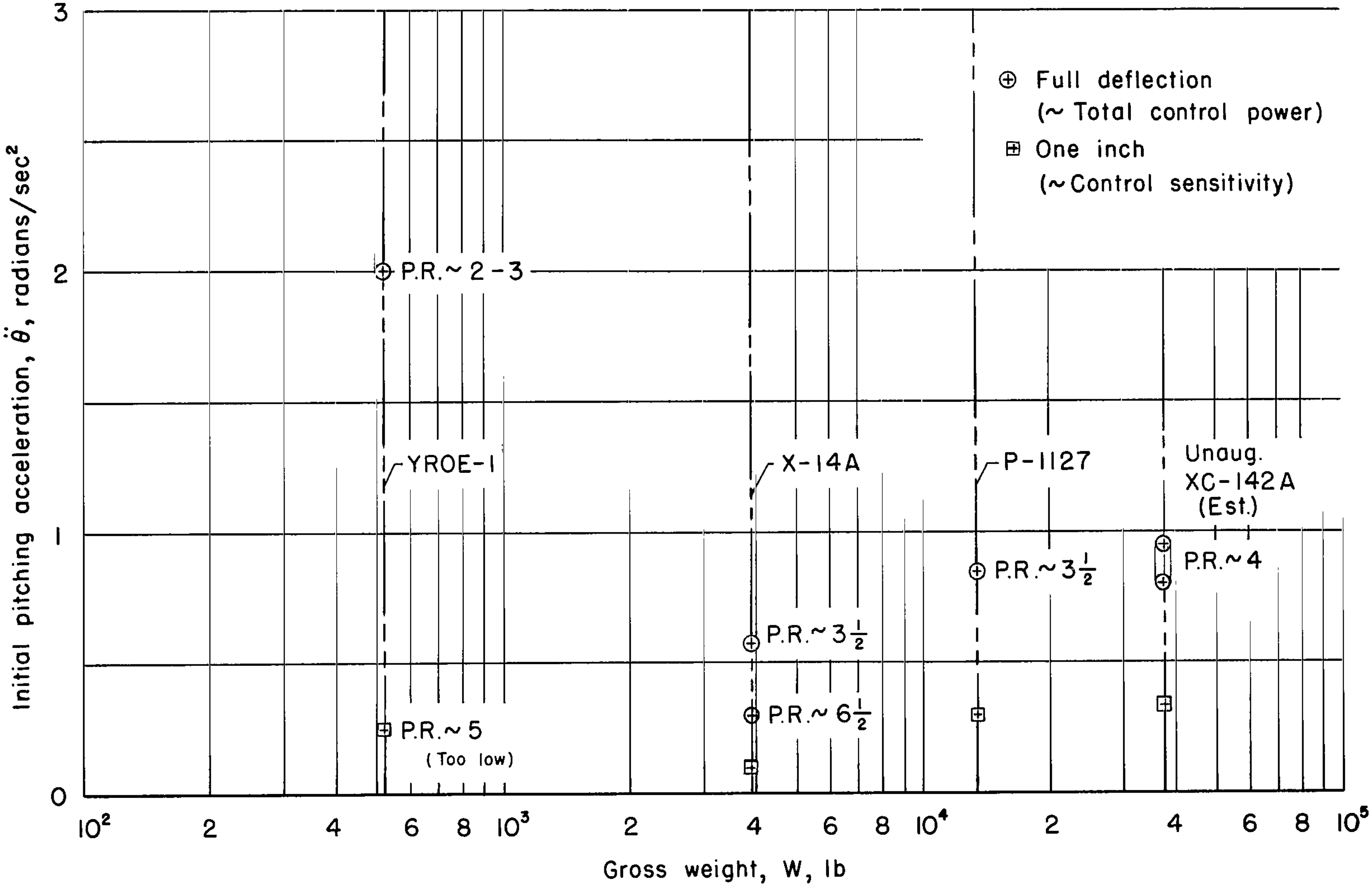

Figure 5.- Longitudinal control characteristics (~ visual hovering task).

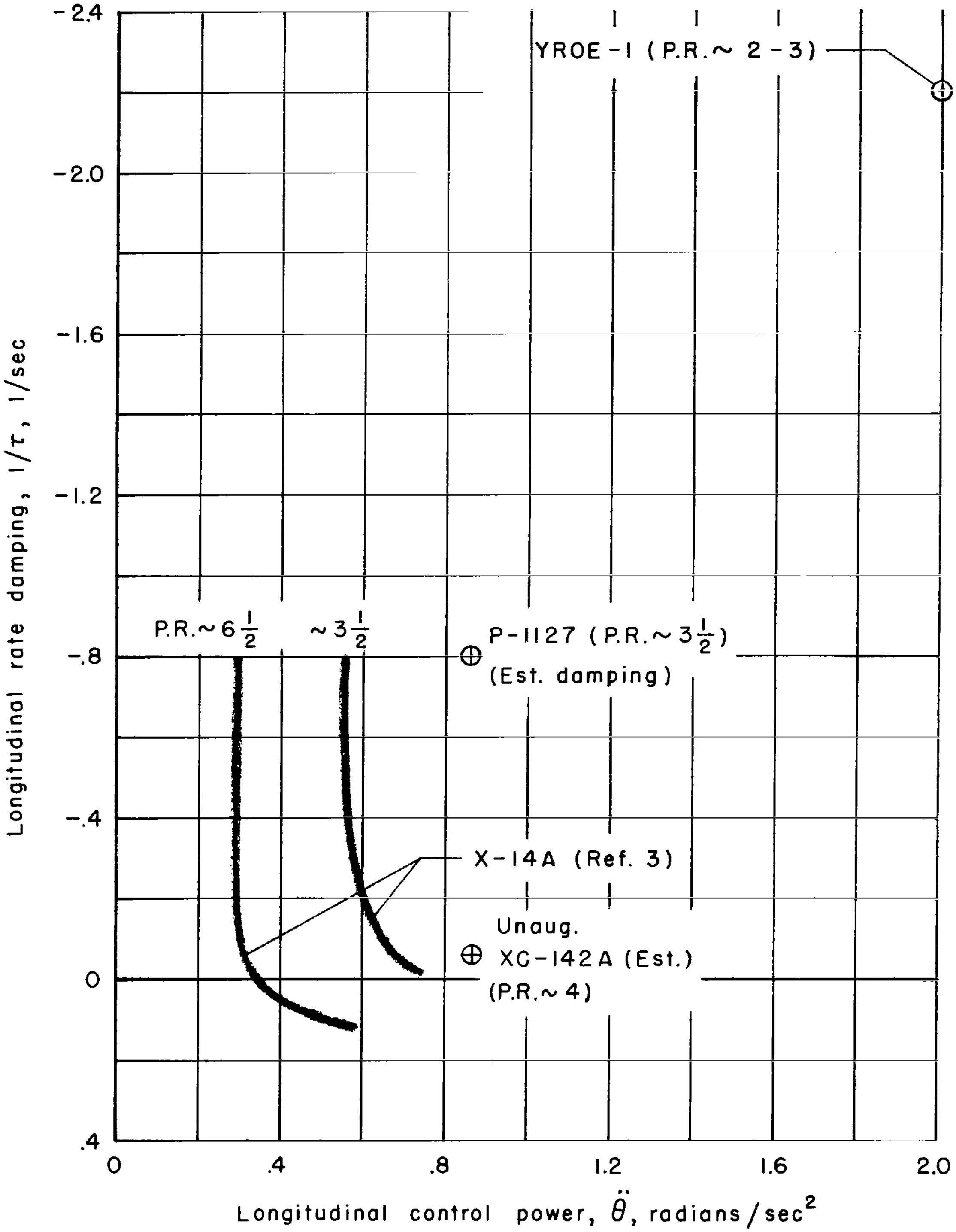

Figure 6.- Longitudinal handling characteristics.

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