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A FLIGHT STUDY WITH A LARGE HELICOPTER SHOWING TRENDS OF LATERAL AND LONGITUDINAL CONTROL RESPONSE WITH SIZE

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SUMMARY

A flight study was undertaken with a large single-rotor helicopter in an effort to establish possible effects of vehicle size on minimum acceptable control response. Test results for the pitching and rolling axes indicate that control sensitivity and angular velocity damping characteristics which provided acceptable maneuvering capability, in general, tend to confirm the validity of the reduction of these parameters with increase in vehicle size indicated by the established flying-qualities criteria. The test results show the need for considering the damping in combination with the control sensitivity when control-response criteria are applied for design purposes or when pilot's opinions are used to determine minimum acceptable response characteristics for VTOL vehicles.

INTRODUCTION

Current criteria for control-response characteristics of helicopters and VTOL aircraft (refs. 1 and 2) allow for a decrease in both control sensitivity and the ratio of angular-velocity damping to inertia as the vehicle size increases. The variation with size specified in reference 1 is illustrated by the curves of figure 1. Very little data are

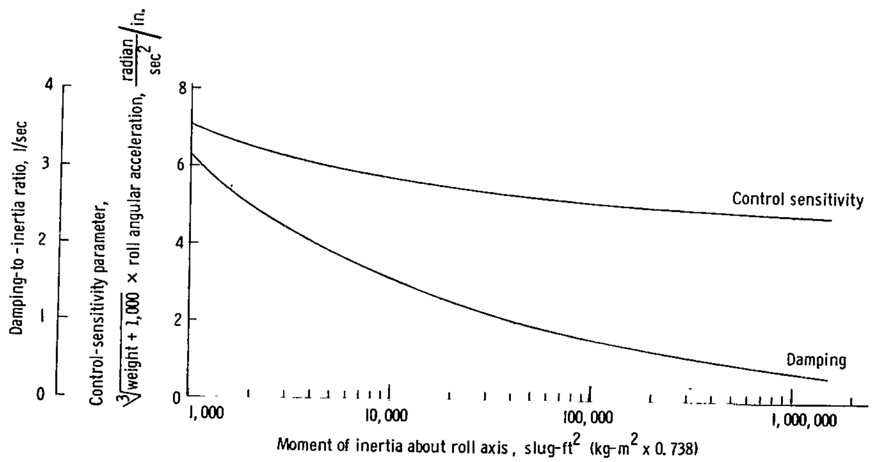

Figure 1.- Illustration of control parameter variation with size (based on criterion of ref. 1 for roll axis, instrument flight).

available, however, from actual tests with the larger vehicles. The flight study reported herein was therefore undertaken by NASA to provide data on control-sensitivity needs with the largest available VTOL vehicle (a nominal 30 000-lb helicopter) and, if possible, to find trends, with increasing size, of the response combinations of control sensitivity and angular-velocity damping that are acceptable for maneuvering during low-speed flight.

The results of this study are presented in terms of pilot ratings obtained during visual hovering and simulated instrument flight tasks for a range of longitudinal and lateral-control-response parameters. The large variations in yaw trim moments of the test vehicle (resulting from changes in main-rotor torque with power) prevented separate study of the maneuvering-only needs for yaw response.

SYMBOLS

Flight measurements were obtained in the U.S. Customary System of Units but are given also, parenthetically, in the International System (SI). Details relating the two systems are discussed in reference 3.

I — moment of inertia, slug-feet^2 (kilogram-meters^2)

M_X, M_Y — moments about rolling and pitching axes, respectively, foot-pounds (meter-newtons)

$M_{X_{\dot{\varphi}}}$ — angular-rate damping moment about rolling axis, $\partial M_X / \partial \dot{\varphi}$, foot-pounds per radian per second (meter-newtons per radian per second)

$M_{Y_{\dot{\theta}}}$ — angular-rate damping moment about pitching axis, $\partial M_Y / \partial \dot{\theta}$, foot-pounds per radian per second (meter-newtons per radian per second)

$M_{X_{\delta_X}}$ — roll-control moment per unit stick deflection, $\partial M_X / \partial \delta_X$, foot-pounds per inch (meter-newtons per centimeter)

$M_{Y_{\delta_Y}}$ — pitch-control moment per unit stick deflection, $\partial M_Y / \partial \delta_Y$, foot-pounds per inch (meter-newtons per centimeter)

W — weight, pounds force (newtons)

δ_X, δ_Y — displacement of control stick from trim position for roll and pitch control motions, respectively, inches (meters)

θ, φ — angular displacements of helicopter from trim attitude about pitch and roll axes, respectively, radians

$\dot{\theta}, \dot{\varphi}$ — angular velocities about pitching and rolling axes, respectively, radians/sec

DEFINITIONS

Control sensitivity: initial angular acceleration per inch for step control displacement.

Control power: initial angular acceleration with full control step displacement.

Angular-velocity damping: angular acceleration proportional to and opposing angular velocity.

METHOD OF TESTING

Description of Test Equipment

The test helicopter is a single-rotor vehicle type with an antitorque tail rotor. A photograph of the helicopter is shown in figure 2 and its principal dimensions are listed in table I.

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Figure 2.- Test helicopter, standard configuration.

TABLE I.- PHYSICAL CHARACTERISTICS OF TEST HELICOPTER

Gross weight	30 000 lbf (133 466 N)
Moments of inertia:	
Pitch	123 000 slug-ft^2 (166 759 kg-m^2)
Roll	73 000 slug-ft^2 (98 971 kg-m^2)
Yaw	117 000 slug-ft^2 (158 625 kg-m^2)
Number of blades in main rotor	5
Rotor rotational speed	19.4 radians/sec
Rotor diameter	72 ft (21.945 m)
Blade mass factor	12
Control travel (basic configuration):	
Longitudinal cyclic	±7 in. (±17.78 cm)
Lateral cyclic	±7 in. (±17.78 cm)
Pedal	±4.25 in. (±10.795 cm)
Control sensitivity:	
Longitudinal	0.13 rad/sec^2/in. (0.051 rad/sec^2/cm)
Lateral	0.19 rad/sec^2/in. (0.074 rad/sec^2/cm)

The helicopter was modified for these tests to provide variable control sensitivity and angular-velocity damping for the pitching and rolling axes. Figure 3 illustrates the variable-response method by which the test parameters were varied. As the diagram shows, control sensitivity was varied by linkage changes, and angular-velocity damping was added to or subtracted from the damping inherent in the helicopter by a rate gyro feedback. The changes made in the control linkages to effect increases in sensitivity over that of the basic vehicle (see table I), resulted in no change in control power. Stops were provided for the stick at the deflection corresponding to full available control power. For the sensitivity values lower than that of the basic vehicle, travel of the stick was limited by the normal stick stops; consequently, the total control power was reduced by the same proportion as the sensitivity.

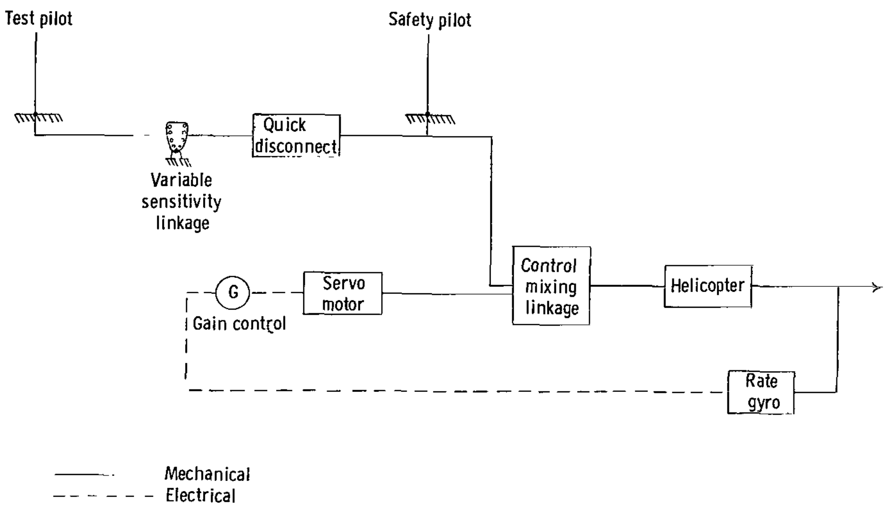

Figure 3.- Typical schematic of variable-response control arrangement.

Panel instruments available to the pilot for instrument flight consisted of an artificial horizon, a gyro compass, and indicators for the following measurements: instantaneous vertical velocity, altitude, airspeed, and instrument-landing-system localizer and glide-path deviation. Standard NASA recording instrumentation with synchronous timing was installed in the test helicopter to measure airspeed, altitude, rotor rotational speed, normal acceleration, control positions, and angular velocities.

Test Procedure

Visual flight maneuvers and simulated instrument flights were conducted for pilot evaluation of the different control characteristics. The visual maneuvers were made at (or near) hovering (less than 15 knots) and included take-offs, landings, turns, square patterns, and point-to-point translations. The simulated instrument flight consisted of hooded ILS (instrument landing system) approaches at airspeeds of about 50 knots. Approaches were started at an altitude of 1000 feet and terminated near the ILS touchdown point. Wind conditions for all flights were generally less than 20 knots; however, no landing approaches were made with tail winds greater than 10 knots. The NASA pilot-rating scale, shown in table II, was used to indicate the relative acceptability of the various combinations of control parameters tried in flight.

In general, except during some calibration flights early in the study, the combinations of damping and control sensitivity were varied proportionately during the tests to maintain response harmony between the pitch and roll axes. This system was used in order to minimize the possibility that the poor characteristics about one axis might influence the pilot's ability to make a proper assessment of the characteristics about the other axis.

TABLE II.- PILOT-OPINION RATING SYSTEM

Operating conditions	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.

PRESENTATION OF RESULTS

Roll Axis

The results obtained for both the visual and instrument flight tasks about the roll axis are shown in figure 4. The ratings shown for the different conditions represent averages of ratings obtained for that condition. The same number of ratings was not

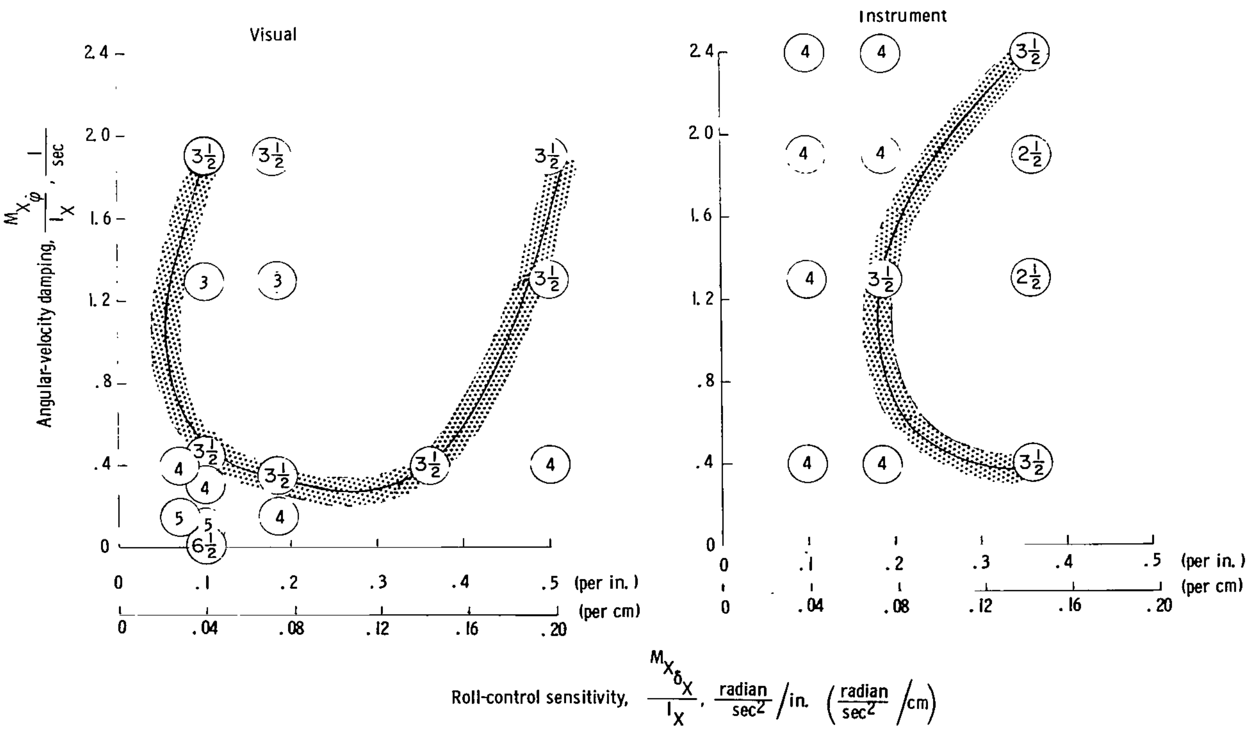

Figure 4.- Roll results for visual and instrument task.

obtained at each condition, nor did each of the three pilots who participated in the tests fly all of the conditions. In general, however, the greatest difference between ratings at any condition, without distinction as to pilot or atmospheric conditions during which the tests were made, was never more than 1 pilot-rating unit with the average deviation for all ratings being 1/2 pilot-rating unit.

The spacing of the test characteristics does not appear optimum as regards firmly establishing pilot rating boundaries; however, it appears that a zone of constant pilot rating of $3\frac{1}{2}$ (boundary between satisfactory and unsatisfactory) can be established reasonably well for the visual and for the instrument task results. Boundaries for the ratings of $3\frac{1}{2}$ are shown by the faired solid lines on the plots of figure 4. In the region of minimum sensitivity and damping (that is, the "knee" of the curve), these boundaries show that satisfactory values of sensitivity are closely related to the level of damping. A comparison of the boundaries shown in figure 4 in the region near the minimum combinations of control sensitivity and damping – that is, nearest the origin of the plot – shows that significantly higher sensitivities, in particular, are indicated for the instrument task.

Pitch Axis

Figure 5 presents the results of the tests about the pitch axis. The average deviation for the pilot ratings at each condition for the pitch axis was about 1/2 pilot-rating unit.

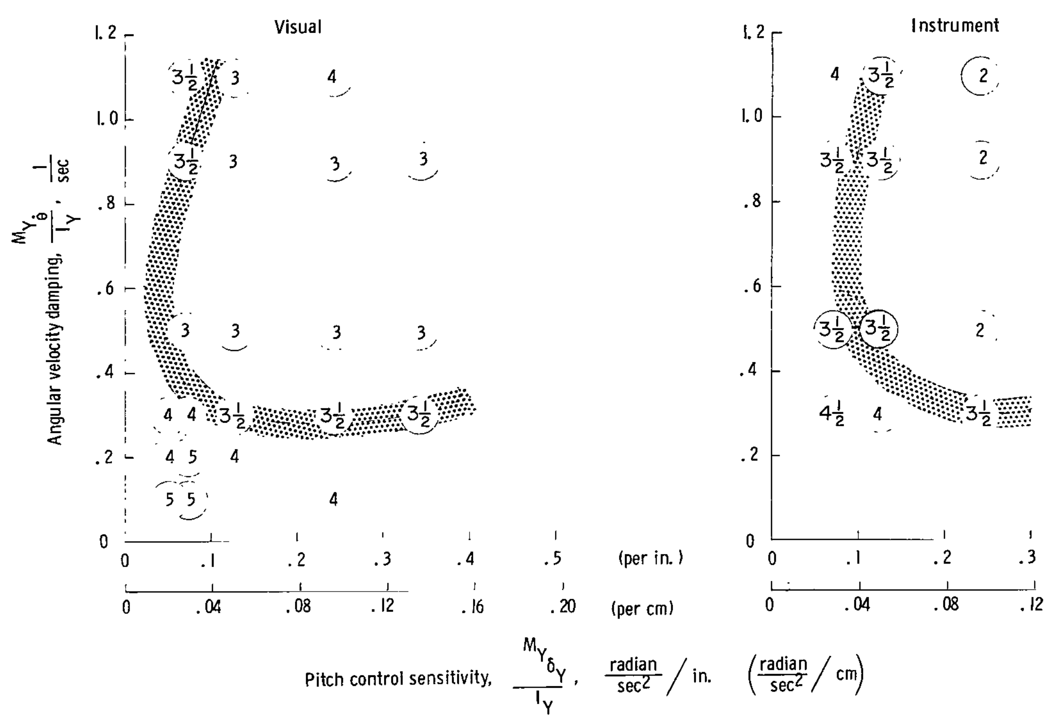

Figure 5.- Pitch results for visual and instrument task.

The maximum spread for pilot ratings at a given condition was somewhat greater for the pitch axis than for the roll axis. It appears that usable boundaries within the results can be established for pilot ratings of $3\frac{1}{2}$ for the visual and for the instrument tasks. Comparisons of the instrument and visual results at given values of damping for the whole range of damping values covered show that a substantially greater variation of pilot rating with sensitivity was obtained for the instrument task.

Pilot Comments

During the course of the early calibration flights made to measure the control-response parameters at different settings of the variable linkages and rate-feedback gains, the pilots commented on the lack of control-response "harmony" in some cases. These comments appeared to be a result primarily of large disparities in angular-velocity damping about the two axes. It would appear from these comments that, in those cases where improvement in characteristics about one axis only would result in relatively large differences between axes, adverse pilot reaction could occur despite the basically improved response. Such considerations point out the need for careful study before attempts are made to establish handling-qualities criteria from pilot opinions based on limited data from a few specific vehicles rather than from controlled experiment, wherein all pertinent factors can be taken into account. Pilots also commented that during reduced-sensitivity trials with the total control power reduced accordingly, the control power was at no time considered a limiting factor for the maneuvers performed.

DISCUSSION OF RESULTS

Figures 6 and 7, respectively, show comparisons of the roll and pitch results presented in the preceding section with the existing criteria (ref. 1) for minimum response characteristics for vehicles in the weight class of 30 000 pounds (133 446 newtons). The lines on the figures are the boundaries for pilot ratings of $3\frac{1}{2}$ from figures 4 and 5 and the cross symbols represent the combination of control sensitivity and angular-velocity damping required to provide the minimum control response called for by the criteria of reference 1. Shown in the plots, also, by the circular symbols are the values of control sensitivity and damping specified by the criteria of reference 1 for a 5000-pound (22 241-newton) vehicle. The criteria for the larger size vehicles were extrapolated from experience with test vehicles in the smaller weight class, primarily that reported in reference 4, by use of the parameters, $\sqrt[3]{W + 1000}$ and $I^{0.7}$. It should be noted that the circular symbols shown on figures 6 and 7 for the 5000-pound vehicle are representative of the minimum control sensitivity and damping combinations for a vehicle of that size; that is, at the knee of the curve as indicated on the dashed line. Comparison of corresponding points on the boundaries for the two vehicles show that satisfactory ratings were obtained with the larger helicopter at considerably lower combinations of control sensitivity and angular-velocity damping than were needed to achieve comparable ratings during the studies with the 5000-pound vehicle. It is of interest to note also that the minimum satisfactory damping, at what might be considered "optimum" sensitivity for an individual axis, is essentially the same (≈0.30 per sec) for all tasks investigated.

Comparisons are shown in figures 6 and 7 for the visual and for the instrument flight tasks. For the instrument flight tasks the pilot opinion boundaries separating satisfactory and unsatisfactory characteristics for both the roll and pitch axes are very close to the respective criterion values. It thus appears that some reduction of these parameters with increased size such as that included in the criteria of reference 1 is needed to provide reasonable estimates of minimum acceptable control sensitivity and angular-velocity damping for the precision instrument tasks with larger vehicles.

For the visual flight tasks, although the present results are in good general agreement with the existing criteria, indications for the roll axis are that satisfactory ratings

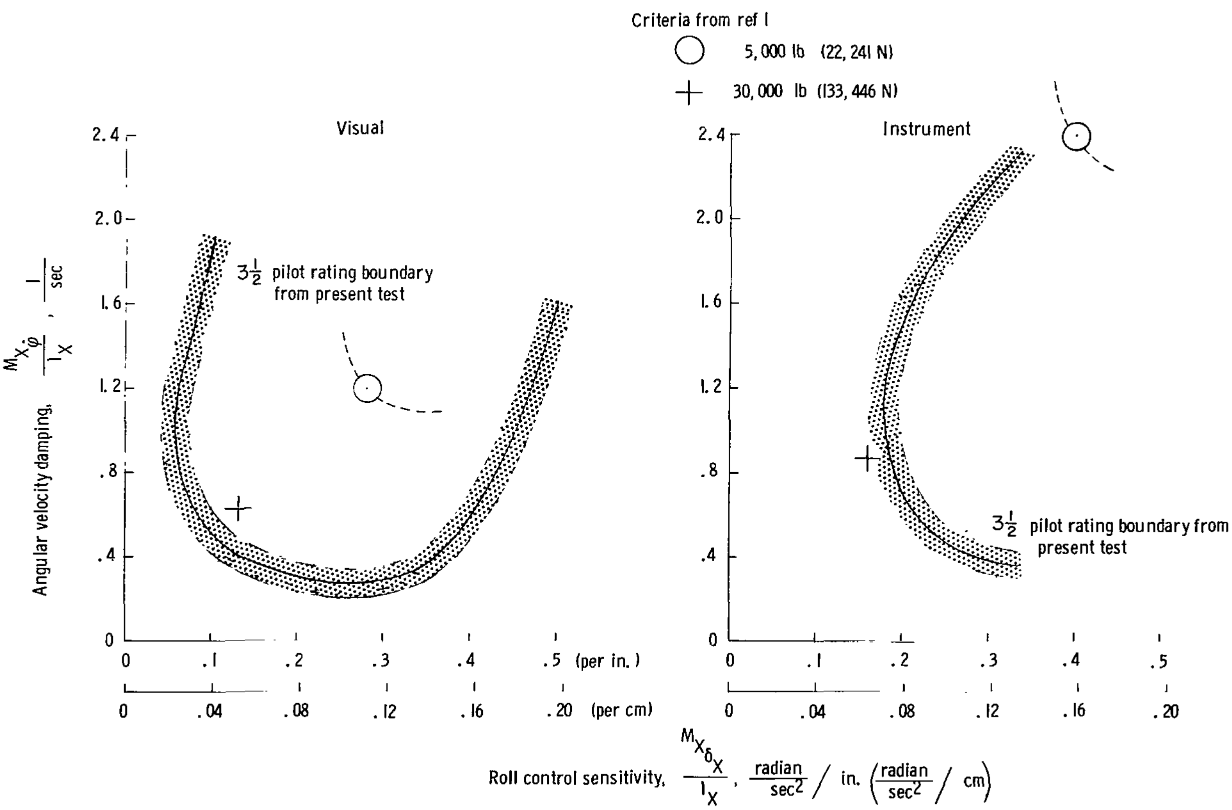

Figure 6.- Comparison of test results for lateral response with existing criteria.

were assigned to somewhat lower values of control sensitivity and damping than are called for by the criteria. For the pitch axis, control sensitivities and damping required to obtain satisfactory pilot ratings were somewhat higher than are called for by the criteria. Insofar as the criteria of reference 1 are intended to provide guidelines for establishing minimum characteristics for vehicles of various size, these differences do not appear critical, particularly when compared with the differences between the test results for the larger vehicles and the characteristics called for by the criteria for smaller (5000-lb) vehicles. This difference, as well as the corresponding ones for instrument trials, tends to support the validity of using scaling factors such as those called for by the criteria when attempting to apply control-response data from one size vehicle to vehicles of significantly different size. The data also show that the acceptable minimum values of control sensitivity are closely related to the damping values. Thus, the need for considering control sensitivity in combination with damping values during design studies or during establishment of criteria is emphasized.

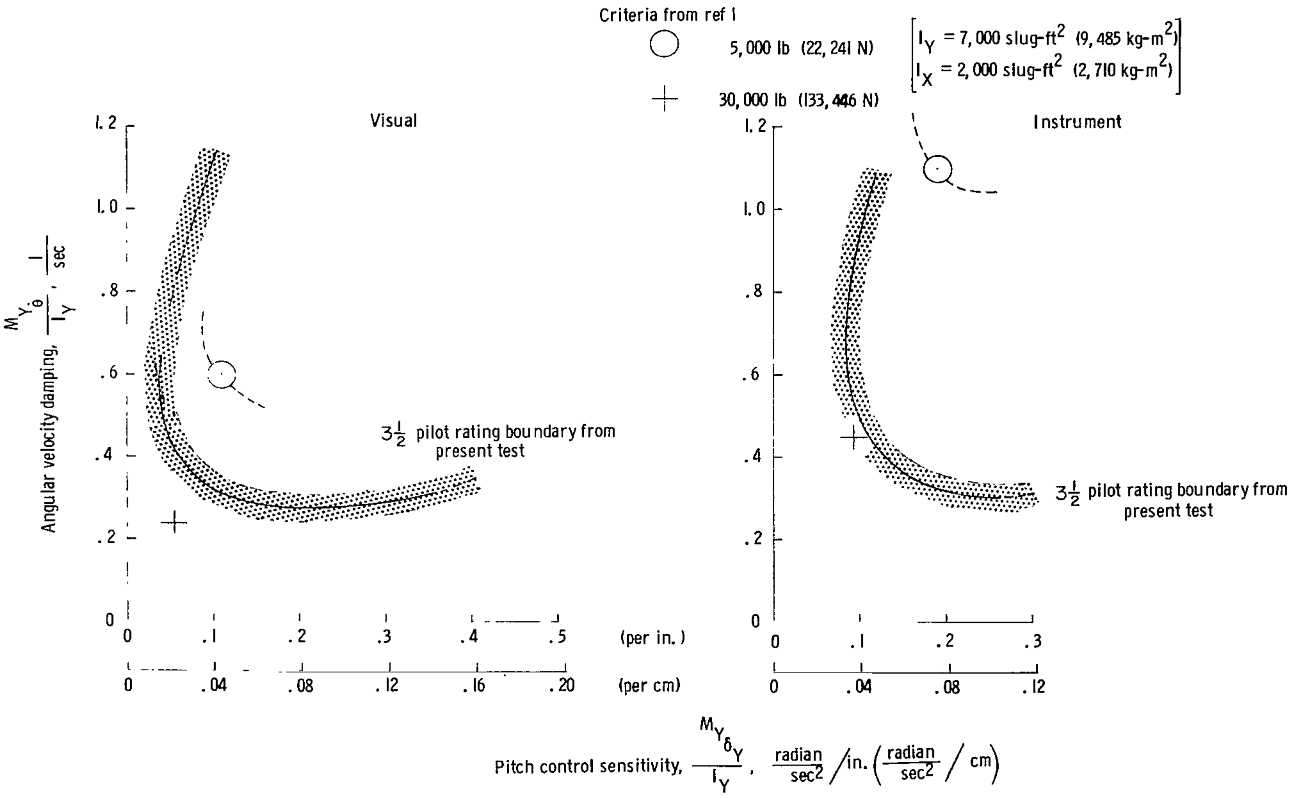

Figure 7.- Comparison of test results for longitudinal response with existing criteria.

CONCLUDING REMARKS

The results of the flight study of control-response characteristics with a large transport helicopter indicate the following conclusions:

1. Values for minimum control sensitivity and angular-velocity damping combinations found to be acceptable for visual and instrument flight tasks for the large transport helicopter generally confirm the downward trend with vehicle size shown by the established flying-qualities criteria.

2. Higher minimum combinations of control sensitivity and angular-velocity damping for both the pitch and roll axes were required to obtain satisfactory pilot ratings for instrument flight tasks than to obtain comparable ratings for visual flight tasks.

3. Satisfactory pilot ratings for minimum control sensitivity values are closely related to the level of angular-velocity damping in a given test configuration.

4. Before acceptable values of angular-velocity damping can be adequately defined for a given axis, consideration must be given to the level of damping reflected by other axes in order to assure that some measure of "damping harmony" exists.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 19, 1966,
721-04-00-02-23.

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