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HELICOPTER INSTRUMENT FLIGHT AND PRECISION MANEUVERS AS AFFECTED BY CHANGES IN DAMPING IN ROLL, PITCH, AND YAW

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SUMMARY

The effects of increased damping in roll, pitch, and yaw on the flying qualities of a single-rotor helicopter for precision flight have been studied by means of visual maneuvers and instrument approaches. Electronic components were used to vary the damping by producing control inputs proportional to rate of roll, pitch, and yaw in a direction to oppose the angular velocities.

The results indicate that, for a representative single-rotor helicopter, increased damping can reduce random deviations from the desired flight path and can decrease the effort required of the pilot, especially at low forward speeds. Increased damping in roll was found to be particularly beneficial; corresponding changes in yaw and pitch, however, were less effective for the combinations of parameters covered.

Some operational aspects of helicopter instrument approaches are also included in the discussion.

INTRODUCTION

Many helicopter operations, such as instrument approaches, Sonar dipping, and the use of the hoist, involve a precision of control that may necessitate better flying qualities than those considered adequate for more general purposes. For example, the helicopter instrument-flying studies reported in references 1 and 2 indicated the need for improved stability and control characteristics, particularly for flights at low forward speeds and for maneuvers requiring a precise control of heading.

Although a number of parameters affect the flying qualities, a review of previous research indicated that helicopter damping would be a worthwhile subject for initial study. Increased damping in pitch, for example, was shown in reference 3 to change the longitudinal characteristics of a small single-rotor helicopter from unsatisfactory to satisfactory for contact flight. In addition, the lateral-directional difficulties encountered during instrument flight suggested that additional damping in roll and yaw might be beneficial. Accordingly, flight tests have been made in which the damping in roll, yaw, and pitch of a single-rotor helicopter was varied by means of electronic components, and these variations were evaluated by performing precision maneuvers that included instrument approaches.

In view of the current interest of military and commercial operators in all-weather helicopter flight, some operational aspects of helicopter instrument approaches are also included in the discussion.

TEST METHODS AND EQUIPMENT

Test Helicopter

The single-rotor helicopter used in the present investigation is shown in figure 1. It had previously been modified for instrument flight by installing in the rear cockpit a set of dual controls, an instrument panel, and a cloth hood. In addition, small biplane tail surfaces were provided which improved the longitudinal characteristics at speeds above about 25 knots.

For the present investigation, further modifications were made which included the addition of an instrument-landing system (ILS) antenna and receivers, an ILS indicator on the instrument panel (fig. 2), and the electronic installation described in the following section.

Variable-Damping Installation

In order to provide a convenient and flexible means for varying the stability and control characteristics, components of an electrical autopilot were installed in the test helicopter. A block diagram of the variable-damping system, which is similar for all three axes, is shown in figure 3. As shown in the diagram, the servomotors were actuated by the rear cyclic stick or rudder pedals, as well as by signals proportional to rate of roll, yaw, or pitch. (Signals proportional to helicopter attitude were also available but were not used in the present tests.)

The instrument pilot in the rear cockpit was provided with a cyclic stick and rudder pedals connected only to potentiometers and centering springs. Control displacements thus produced electrical signals for the appropriate circuits. The electrical servomotors operated the cyclic controls through the existing hydraulic-power control system, and the directional control through the normal cable system. This irreversible arrangement had the advantage of eliminating any feedback of forces from the rotor or control system into the pilot's controls and enabled the use of light springs to provide desirable control-force gradients. Although no effort was made to determine an optimum force gradient, a cyclic-stick gradient of 5 ounces per inch, combined with a preload of 3 ounces, was found satisfactory for the present investigation. Electrical means were also available for trimming and centering the cyclic stick and pedals. The front pilot, acting as safety pilot, had the normal cyclic and rudder controls with which to override the rear instrument pilot's controls in case of emergency.

Rate signals were obtained for the roll and pitch channels by differentiating the output of a vertical gyro and for the yaw channel by a separate rate gyro. A control panel enabled the pilot to vary the gain of these rate circuits from zero to a value which produced an equivalent damping several times greater than that inherent in the basic helicopter.

Selection of Damping Values

In order to arrive at the values of increased damping to be used for the present tests, some compromise was necessary. High values which would be desirable for reducing the response to external disturbances or unstable tendencies might unduly restrict maneuverability unless control power (control moment per unit control deflection) was also increased. Preliminary flights, including both visual and instrument maneuvers over a wide speed range, were therefore made during which the incremental damping was varied from zero to a value several times greater than that inherent in the helicopter, with the control power remaining constant. The values thus selected resulted in an overall damping in pitch about three times the inherent damping of the helicopter, and in an overall damping in yaw approximately four times that of the basic helicopter. However, the damping in roll was found to be limited by instability of the autopilot-helicopter combination to a value about three times that of the basic helicopter, and this was the amount of roll damping used for the present tests.

The rate gains used for the three axes are as follows:

Lateral	Longitudinal	Directional
$0.11 \frac{\text{deg cyclic pitch}}{\text{deg/sec}}$	$0.25 \frac{\text{deg cyclic pitch}}{\text{deg/sec}}$	$0.51 \frac{\text{deg tail-rotor pitch}}{\text{deg/sec}}$

Test Procedure

Several maneuvers were used to evaluate changes in damping of the test helicopter. These included visual take-offs, hovering, and low-speed maneuvering and landings, and instrument take-offs, patterns, ground-controlled approaches (GCA), and instrument-landing-system (ILS) approaches. The visual maneuvers were used by the pilots to evaluate the general effects of added damping and to establish the limits of damping values, whereas the instrument approaches were used to obtain a quantitative measure of the effects of such changes on a precision task.

Previous experience had shown that small changes in stability and control characteristics were most apparent when the pilot's task was neither too easy nor too difficult. The ILS approach provided a practical, repeatable maneuver that fulfilled these requirements, and this was the maneuver used most extensively during the present investigation. A typical procedure was to make consecutive approaches with no additional damping, with damping added about an individual axis, with damping added about all three axes simultaneously, and finally a repeat of the first approach with no additional damping. The results were evaluated by comparing the inadvertent deviations in the flight path, the control motions required of the pilot, and the general ease and accuracy with which the maneuver was performed. Such comparisons were made by means of pilot's opinions, records obtained with standard NACA recording instruments, and, for some cases, motion pictures of low-speed approaches taken with a camera situated in the nose of the helicopter.

RESULTS AND DISCUSSION

Generality of Results

Some consideration of the generality of the results presented herein appears to be warranted in view of differences in the basic physical and aerodynamic characteristics of various helicopters. The inherent damping of different single-rotor systems varies widely, for example, and the ratios of moments of inertia about the three axes differ greatly for other configurations.

Previous research has shown, however, that fairly general conclusions regarding satisfactory longitudinal flying qualities can be applied to a number of different helicopters. (See refs. 4 and 5.) In the present investigation, the tests were conducted on a single-rotor helicopter that is representative of many in current use, and the results are believed to be applicable to helicopters of generally similar characteristics.

Effects of Increased Damping

The results obtained by increasing the damping of the test helicopter were dependent on the axis about which damping was added as well as on the forward speed. Records of ILS approaches at cruising speed (65 knots) showed a slight reduction in pilot control motions and somewhat fewer deviations from the desired flight path when damping was added about the roll axis. Additional damping in yaw, however, was judged to be only slightly helpful, and additional damping in pitch had little effect.

At lower speeds, the results were more pronounced. During ILS approaches at 25 knots, the beneficial effects of increased damping in roll and yaw were readily apparent, both in the improved accuracy of the approach and in the decreased control motions made by the pilot. Figure 4 shows typical records of rolling, yawing, and pitching velocities with and without additional damping about the respective axis. In the case of roll and yaw, the random variations in angular velocity are noticeably less with added damping. Additional damping in pitch, however, again shows little effect.

An example of the reduction in control motions required of the pilot is shown in figure 5, in which are plotted typical records during ILS approaches made with the basic helicopter configuration, with increased damping in roll, and with increased damping in roll, pitch, and yaw. As the records show, the benefits obtained with additional damping in roll alone were almost as great as those obtained with damping added about all three axes.

The preceding results, based on instrument-landing approaches, apply also to such low-speed maneuvers as take-offs, hovering, and landings. For such maneuvers, however, there were indications that increased damping in yaw and pitch might be relatively more important than for the forward-flight cases.

Operational Aspects of Instrument Approaches

<u>Flight instruments</u>.- The helicopter instrument approaches made during the damping evaluation may be of interest from operational considerations. At airspeeds of both 65 and 25 knots, consistently successful ILS approaches were made down to altitudes as low as 5 feet, either with the flight-director type of instrument (fig. 2) or by means of the ILS indicator alone. These approaches were possible either with or without added damping, although, as previously noted, the accuracy was improved and less effort was required of the pilot when damping was added. Although most of the approaches were made with the flight director as the primary instrument, a few were performed, for comparison,

with this instrument turned off. The results indicated that ILS approaches by either method were entirely feasible but required less effort and concentration when performed with the flight director.

Effects of speed.- The choice of 25 knots as an instrument-approach speed was based on preliminary flight tests undertaken to define a flight problem of sufficient difficulty and repeatability to make possible an analysis of the effects of varied damping. Approaches at 65 knots were relatively easy and did not reflect the improvement due to increased damping that was evident at lower speeds. The records of approaches at 25 knots did show an effort consistent with the pilot's opinion of the relative difficulty of the approaches, since a high degree of concentration was required for all approaches at this speed. No attempt was made to establish an optimum approach procedure or airspeed during this program. The optimum procedure will probably vary with the approach systems and landing area available. Some comments and opinions on operational aspects of approaches made during this program, however, are considered appropriate. Approaches at speeds of 65 knots or higher should be relatively easy, if current military flying-qualities requirements are satisfied, and it is probable that only minor modifications to existing airplane patterns will be required. The minimum speed at which consistently successful instrument approaches could be made was 25 knots and these approaches were considerably more difficult than those at higher speed. At 25 knots, the time spent in executing a standard airplane pattern was prohibitively high. The direction and velocity of the wind also had a great effect on the approaches at 25 knots. In some cases, when ground-level winds were 8 to 10 knots, winds at an altitude of 500 to 800 feet appeared to be about 20 to 25 knots and it was impossible to complete the approaches because the drift corrections and the time required for correcting deviations in ground track were extremely high. Operationally, it may be desirable to execute the major part of an approach at cruising speed and to slow down to the minimum feasible speed for the last part of the approach.

Approach accuracy.- The actual deviations from the flight path appeared to be somewhat smaller than would be expected with an airplane, since, at low speed, deviations occur rather slowly. For all the approaches, the maximum lateral deviation from the center line of the runway, when the end of the runway was crossed, was about 150 feet. Most of the approaches, particularly those made in light or no cross wind, were within 75 feet of the center line of the runway. The glide slope appeared to have numerous bends but was usable down to the ground. The approaches were consistently carried below 10 feet before the safety pilot took control and could have been carried to ground contact except for the drift angles present. In other flights, instrument touchdowns were made at comparable rates of descent, with heading information only furnished to the instrument pilot by the safety pilot.

Angle of descent.- In the present investigation, angles of descent above 7° to 10° were not considered feasible at 65 knots, and, at 25 knots, angles of descent above 10° to 12° were not considered desirable. At 65 knots, higher angles of descent were not possible without entering autorotation, after which the rate of descent could be controlled only by varying the airspeed. The limitation at 25 knots was an increasing difficulty in accurate control of the glide path. These limitations will undoubtedly vary with helicopter characteristics. At present, however, it does not appear that high angles of descent into confined landing areas are feasible under instrument conditions. It is the considered opinion of the pilots that a descent angle of about 5° to 6° would have been more desirable for this helicopter for the speed range investigated.

Motion-picture studies.- Motion pictures were made, by means of a camera mounted in the nose of the helicopter, of several of the low-speed approaches both with and without added damping. The differences due to changes in damping during successive approaches were clearly shown as differences in the random motion of the helicopter. The large effect of a moderate cross wind on the heading correction for drift was also evident.

Additional cameras photographed the rear instrument panel and the pilot's eyes during some of these approaches. Motion pictures taken with a camera in the nose of the helicopter indicated large, random heading changes, whereas those of the instrument panel indicated that the actual deviations from the center of the ILS indicator and glide path were not excessive. Also, the sensitive artificial horizon showed only small deviations in pitch and roll. This indicates that larger, more sensitive attitude instruments for the pilot would be helpful.

The motion pictures of the pilot's eyes showed the degree of concentration required during these approaches as contrasted with a similar approach executed visually. The frequency of eye motion during the instrument approaches was somewhat over 2 motions per second, whereas for the visual approach only 1 motion every 2 seconds was required.

A motion-picture film supplement to this paper has been prepared and is available on loan from the NACA Headquarters, Washington, D. C.

CONCLUDING REMARKS

The flying qualities of a single-rotor helicopter have been varied by increasing the damping in roll, yaw, and pitch by means of electronic components, and these variations have been evaluated by performing precision maneuvers including instrument approaches. The results indicate that, for a representative single-rotor helicopter, increased damping can improve the accuracy of maneuvers and reduce the effort required of the pilot, especially at low forward speeds. For the speed range considered, increased damping in roll was found to be particularly effective - much more effective than corresponding changes in yaw and pitch.

Although no attempt was made to establish optimum approach procedures, it was found during the course of the evaluation that consistently successful instrument approaches could be made at airspeeds as low as 25 knots.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 18, 1955.

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5. Amer, Kenneth B.: Some Flying-Qualities Studies of a Tandem Helicopter. NACA RM L51H20a, 1951.

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Figure 1.- Test helicopter.

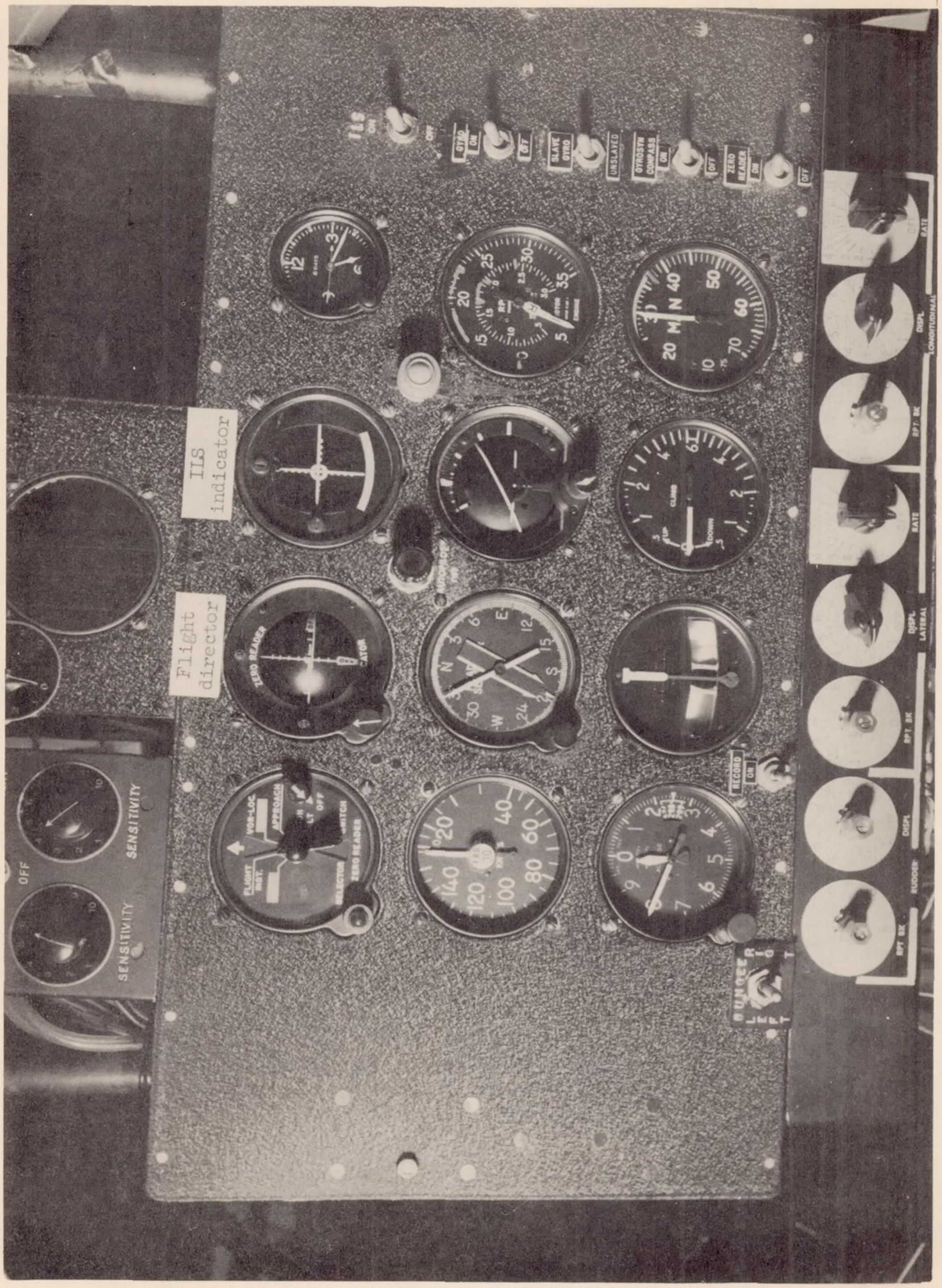

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Figure 2.- Instrument panel.

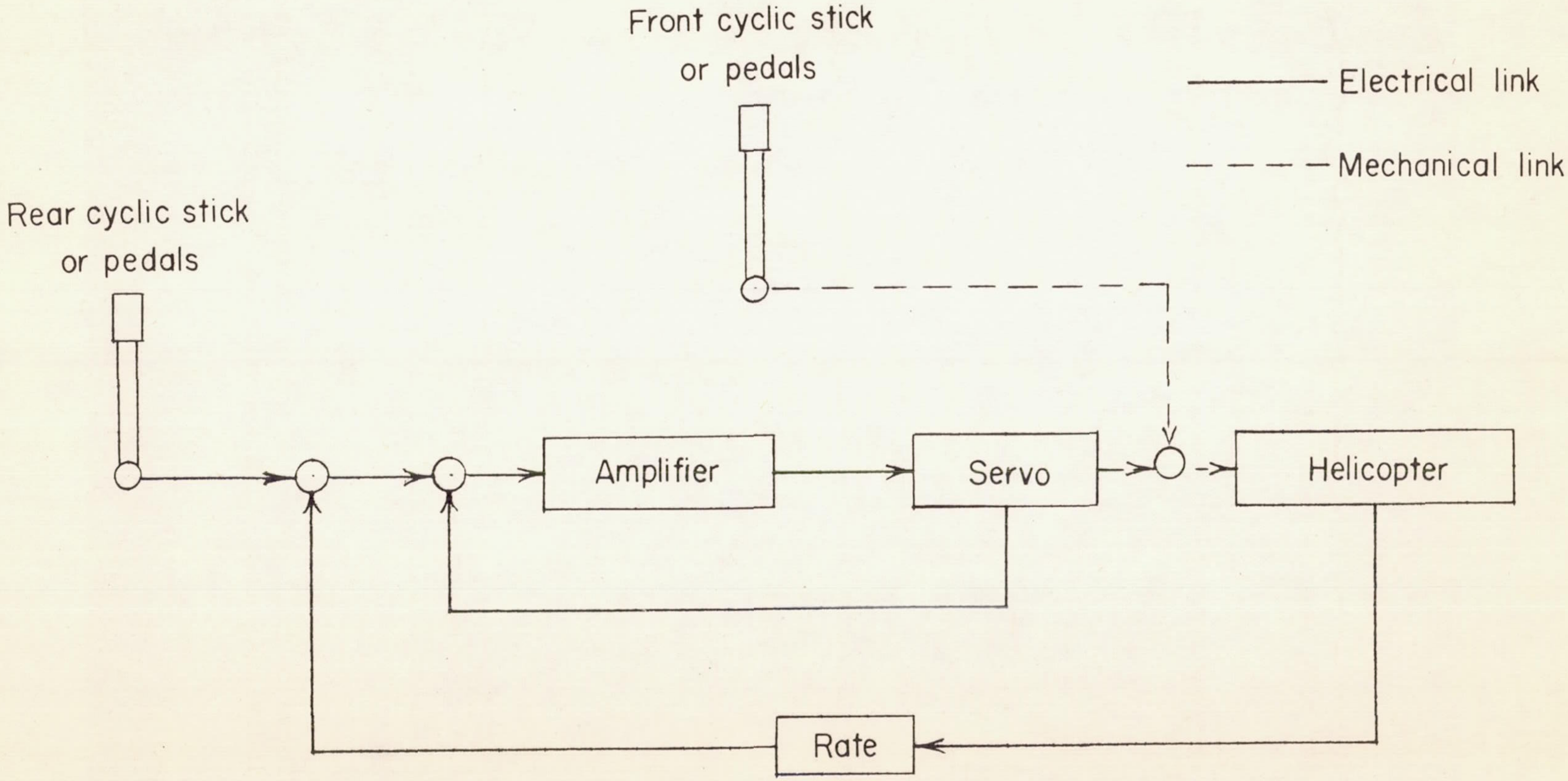


Figure 3.- Block diagram of variable-damping system.

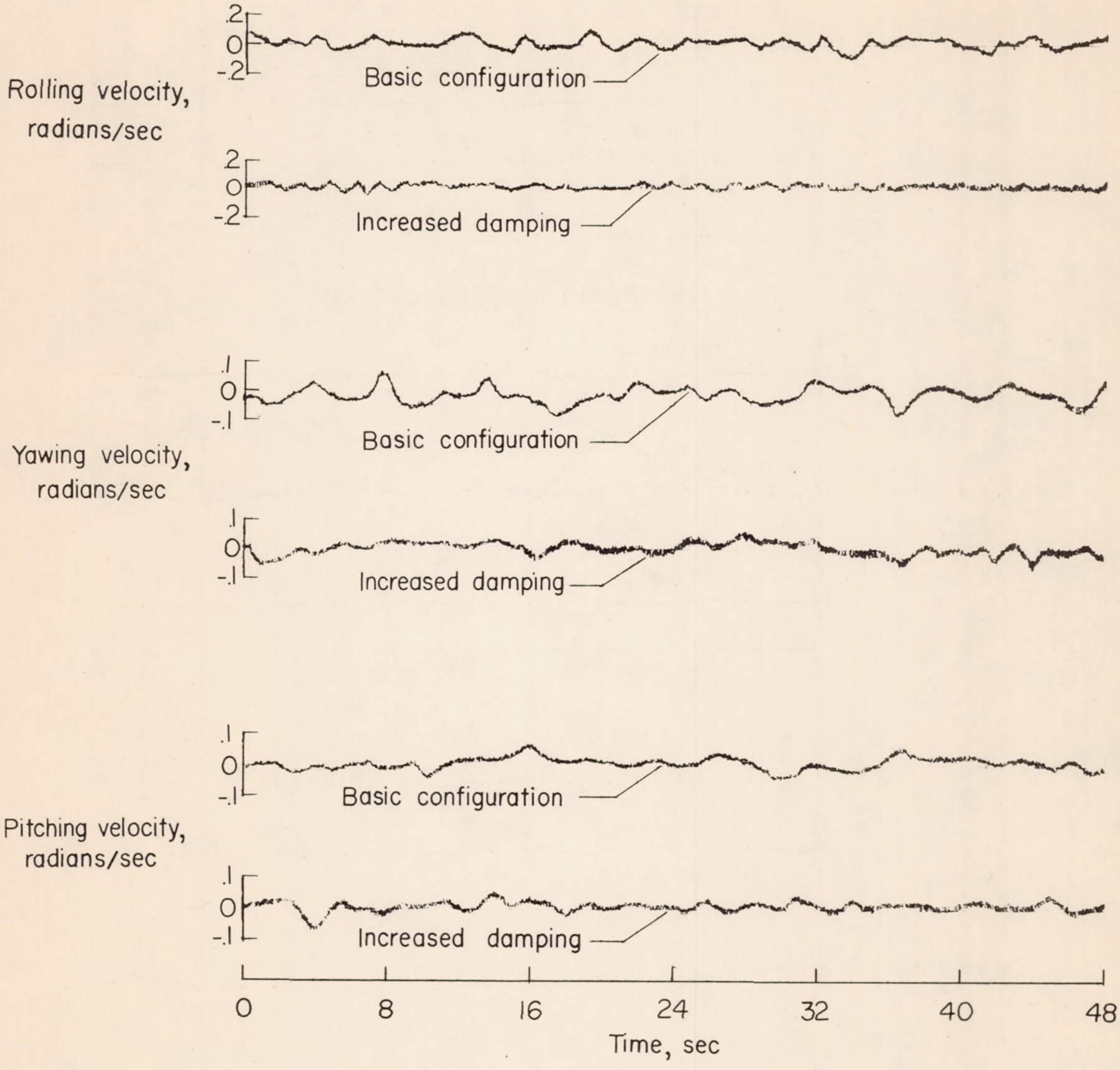
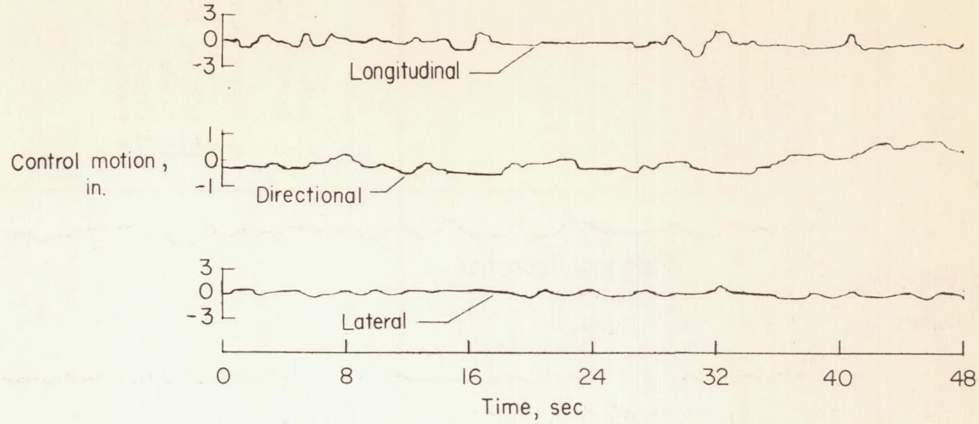
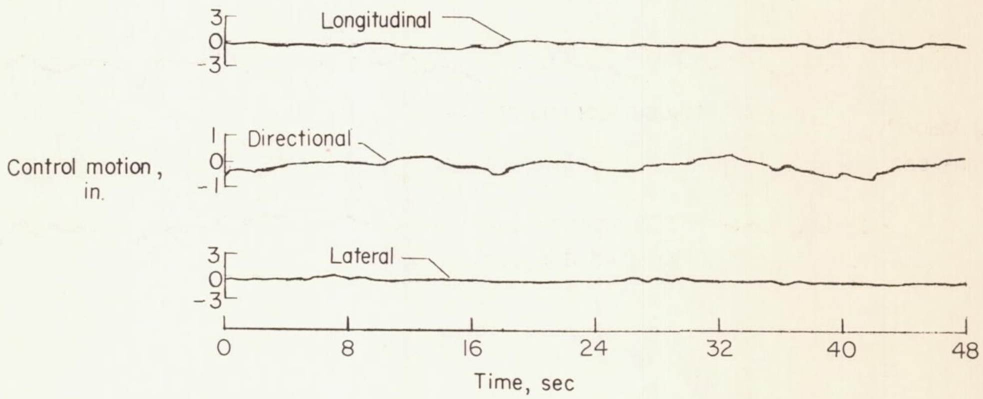


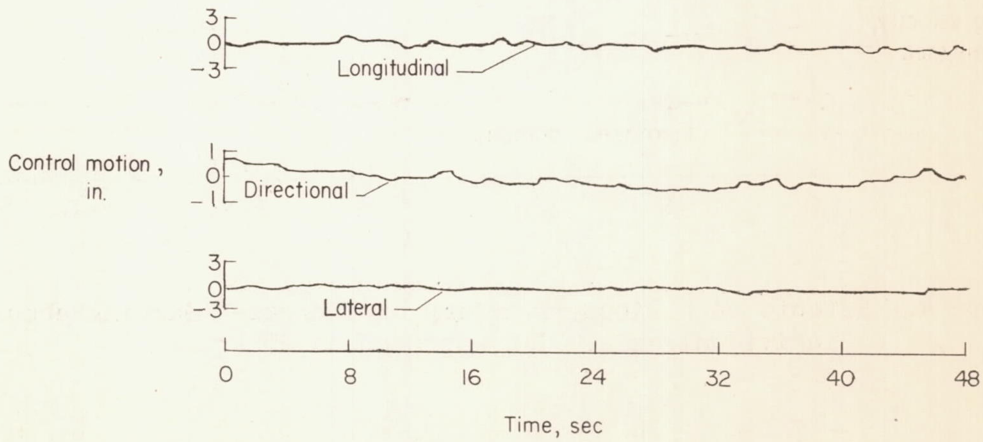
Figure 4.- Effects on helicopter motion of increased damping about an individual axis. ILS approach at 25 knots.



(a) Basic configuration.



(b) Increased damping in roll.



(c) Increased damping in roll, pitch, and yaw.

Figure 5.- Effects of increased damping on pilot's control motions. ILS approach at 25 knots.