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REPORT 1137

INITIAL RESULTS OF INSTRUMENT-FLYING TRIALS CONDUCTED IN A SINGLE-ROTOR HELICOPTER

**By ALMER D. CRIM, JOHN P. REEDER,
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National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW, Washington 25, D. C.

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Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

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SUMMARY

Instrument-flying trials have been conducted in a single-rotor helicopter, the maneuver stability of which could be changed from satisfactory to unsatisfactory. The results indicated that existing longitudinal flying-qualities requirements based on contact flight were adequate for instrument flight at speeds above that for minimum power. However, lateral-directional problems were encountered at low speeds and during precision maneuvers.

The adequacy, for helicopter use, of standard airplane instruments was also investigated, and the conclusion was reached that special instruments would be desirable under all conditions and necessary for sustained low-speed instrument flight.

INTRODUCTION

If the capabilities of the helicopter are to be fully realized, instrument and night flight must be readily accomplished. Since comparatively little instrument flying has been attempted with helicopters, the Langley Aeronautical Laboratory has undertaken a flight investigation to determine whether the flying-qualities requirements for helicopters suggested in reference 1 are adequate for instrument flight and whether any unknown or unusual problems exist. In addition, information was sought as to whether special flight instruments are necessary for successful instrument flying in rotary-wing aircraft. The initial results of this program are given in the present report.

TEST HELICOPTER AND METHODS

CONFIGURATION AND MODIFICATIONS

The single-rotor helicopter used in this investigation is shown in figure 1. An additional set of controls, a flight-instrument panel, and a cloth hood (fig. 2) were installed in the rear cockpit to enable the pilot to fly solely by instruments.

The flight instruments provided (fig. 3) were those that are normally considered adequate for an airplane and included a directional gyro, an artificial horizon, and a turn-and-bank indicator, all of which were electrically driven. The artificial horizon was somewhat more sensitive in pitch

than a standard instrument, 27° providing full-scale deflection. The trim range of this instrument was kept within desirable limits by tilting the entire instrument panel approximately 6° to compensate for the nose-down flight attitude of the helicopter.

For test purposes the maneuver stability, or the presence or absence of a tendency to diverge in pitch (see ref. 2), was changed by means of horizontal tail surfaces linked to the longitudinal cyclic control. Two configurations were used: tail-off, wherein the helicopter did not meet the longitudinal requirements of reference 1, and tail-on, wherein it satisfied these criteria.

Inasmuch as the test helicopter was equipped with irreversible servocontrols, which give no stick-force gradient, it was possible to introduce artificial "feel" by means of spring-loaded centering devices installed in the lateral and longitudinal cyclic control systems.

MANEUVERS

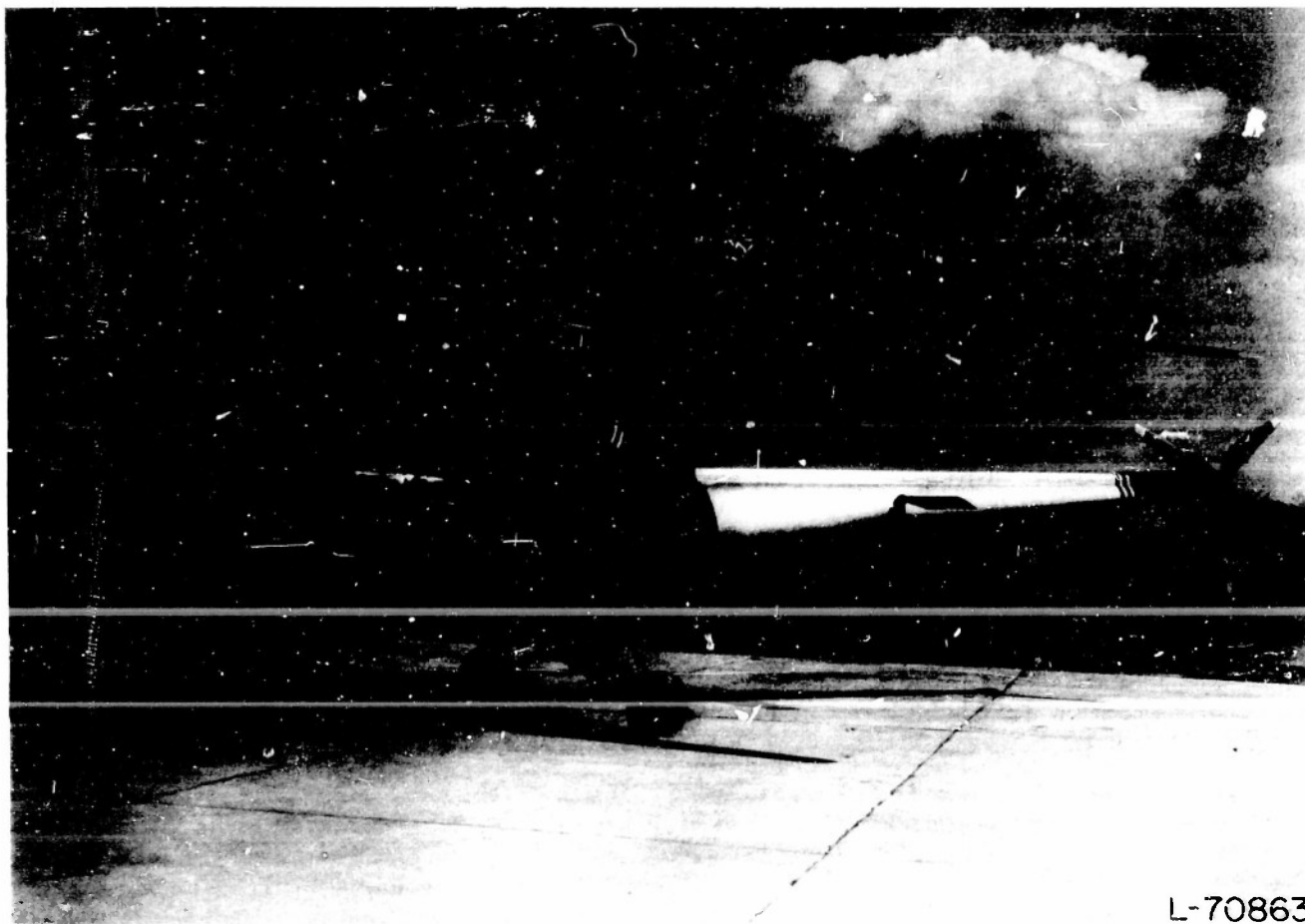
Three different flight maneuvers were used for purposes of this investigation: (1) straight and level flight for 1 minute followed by left and right 90° turns, (2) pattern C (shown in fig. 4), and (3) ground-controlled approach (GCA).

Precision GCA was flown at 65 to 70 knots (lower speeds were not permitted because of traffic conditions) with both the tail-on and tail-off configurations. Pattern C was also flown with both configurations. The level-flight-plus-turn pattern was performed not only with the tail on and off but also with the artificial horizon covered and uncovered, at various airspeeds ranging from 15 to 75 knots. No effort was made to find smooth air, and all flights were made in light to moderate turbulence.

In general, each maneuver was performed by two pilots who were experienced in helicopters and held airplane instrument ratings but who had not previously flown helicopters under instrument conditions.

Standard NACA recording instruments were used to obtain records of control position, altitude, airspeed, manifold pressure, stick force, and yawing velocity.

¹Supersedes NACA TN 2721, "Initial Results of Instrument-Flying Trials Conducted in a Single-Rotor Helicopter" by Almer D. Crim, John P. Reeder, and James B. Whitten, 1952.



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FIGURE 1.—Helicopter used in instrument-flying trials.

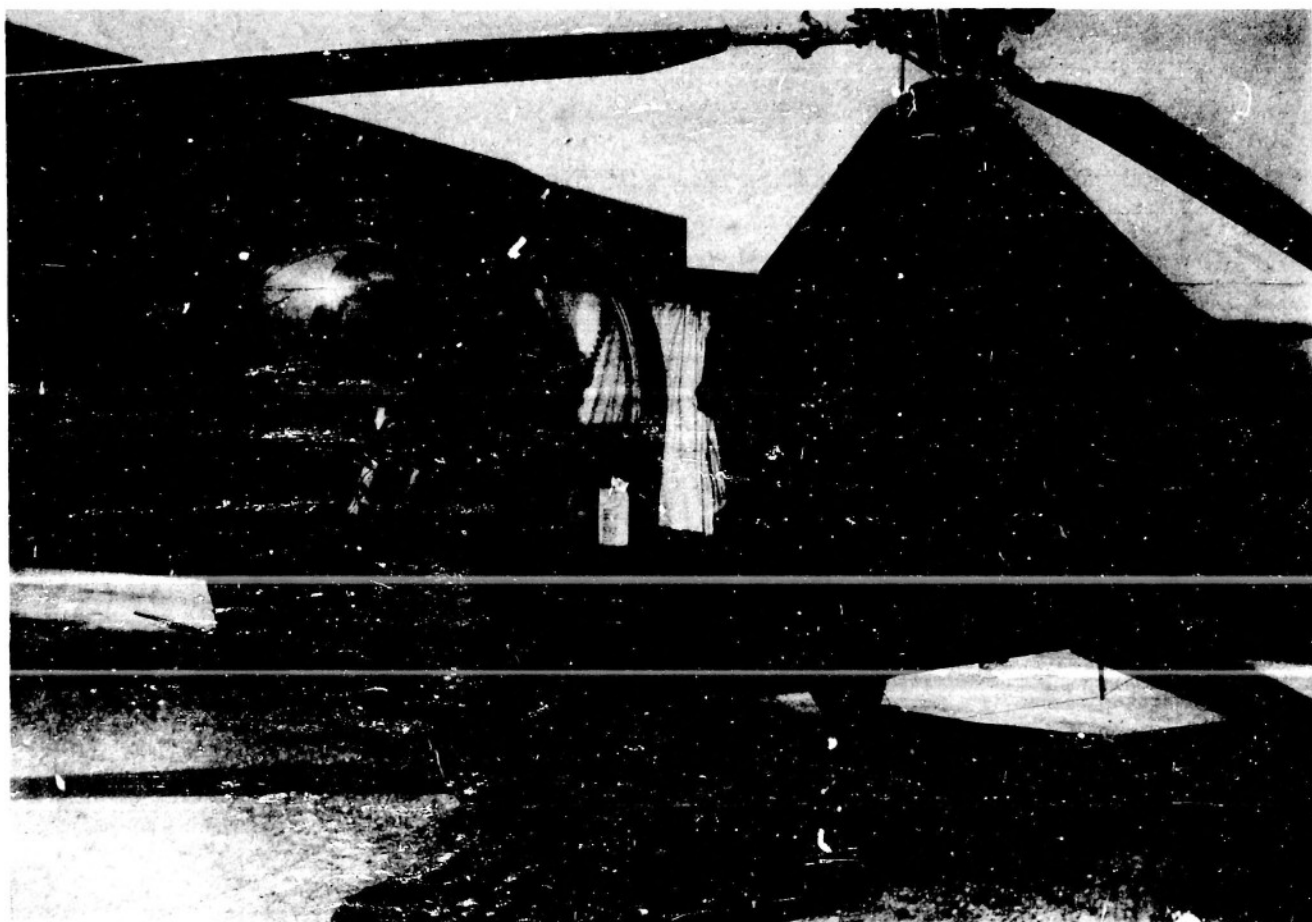


FIGURE 2.—Test helicopter with instrument-flying hood.



FIGURE 3.—Flight-instrument panel installed in rear cockpit.

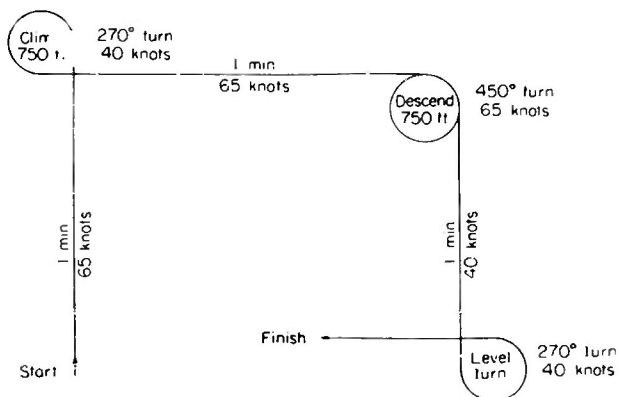


FIGURE 4.—Instrument-flying pattern C.

RESULTS AND DISCUSSION

MANEUVER STABILITY

Maneuver stability is an important flying-qualities requirement for contact flight of helicopters (see ref. 2). As pointed out in reference 3, a helicopter which lacks such stability can exhibit a rapid and dangerous divergence in pitch if the pilot allows his attention to be diverted. The applicability

of this requirement to instrument flying was investigated by means of hooded flights in which the maneuver stability was changed from unsatisfactory to satisfactory by the addition of the previously mentioned tail surfaces. The results indicate that although the accuracy with which any given maneuver could be flown was about the same with the tail on or off, the effort lessened for the stable configuration as the speed increased above about 45 knots, whereas a reverse trend in this respect was shown with tail off, the effort and concentration required increasing with speed. At 25 knots little difference was noted between the two configurations. Although the records provide no measure of the mental effort and concentration required, the greater physical effort at 75 knots for the unstable as compared with the stable configuration is shown in the flight records of figure 5 in the form of greater frequency and amplitude of control motion.

DIRECTIONAL CONTROL

Under certain instrument-flying conditions, holding a given heading appears to be a greater problem than maintaining airspeed or altitude. Although the pilots had no particular difficulty in flying a given course under cruising conditions, they reported that at low airspeeds large deviations in heading occurred. Also, during ground-controlled

approaches, where precise headings and small corrections are necessary, a disproportionate amount of attention was required to maintain headings within reasonable limits. A major reason for the difficulty in heading control is that the rate of turn for a given bank angle goes up as speed is reduced, becoming rather high at the lower helicopter speeds. Inadvertent deviations in bank resulted in relatively large heading changes while the pilot was scanning the instrument panel, particularly when other corrections to flight attitude had to be made. Flight records show larger and more frequent control motions and an increase in yawing-velocity variation for the low-speed and GCA maneuvers.

The yawing-velocity records are of particular interest. At almost all speeds and under most flight conditions the yawing velocity varied in a characteristic oscillatory manner; the amplitude changed with flight condition but the period did not vary materially (fig. 6). Harmonic analysis of several such records revealed the predominant motion to have a period of between 3 and 5 seconds. This period was such that it might have been related to the time required for the pilot to scan the instrument panel. However, when the helicopter was intentionally disturbed by rudder kicks, the resulting oscillation, although usually damped, had approximately the same frequency as that for controlled flight; therefore, the

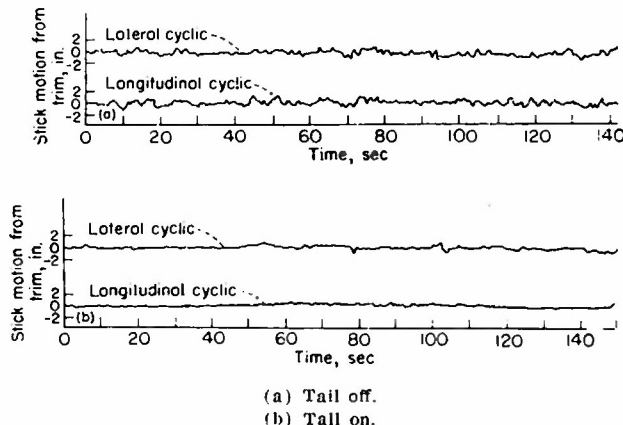


FIGURE 5.—Comparison of cyclic control motion, tail on and tail off, during level-flight-plus-turn maneuver at 75 knots.

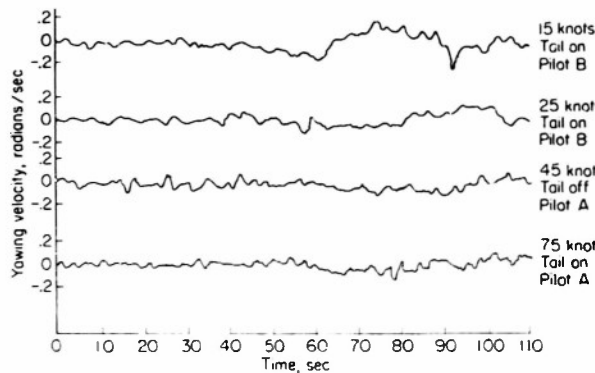


FIGURE 6.—Yawing-velocity variations during level-flight-plus-turn maneuvers.

motion was probably not induced by the pilot. Typical oscillations following an intentional disturbance are shown in figure 7. The significance of this lateral-directional oscillation in relation to the pilots' difficulties is not clear at the present time. However, since the helicopter was almost continually being disturbed, either by small control motions or by atmospheric turbulence, and since under instrument-flying conditions the pilot can devote only a part of his attention to heading indication, oscillations having a relatively short period would probably add to the problem of maintaining directional control.

SIMULATED INSTRUMENT FAILURE

In order that the feasibility of helicopter instrument flying in event of failure of the artificial horizon might be determined, several of the level-flight-plus-turn maneuvers were made with the face of this instrument covered. In the unstable configuration (tail-off), the uncertainty felt by the pilots at the higher speeds with the horizon covered was indicated by continuous manipulation of the controls in contrast to the relatively little motion employed when the horizon was available. Also, larger deviations in flight path occurred when the horizon was not available.

For the stable configuration (tail-on), the flight records show little difference between maneuvers made with the horizon covered and uncovered. At cruising speeds, heading, altitude, and airspeed were maintained with about the same accuracy and with little or no more control movement than when all instruments were available. Even in the stable configuration, however, the pilots stated that prolonged flight without the artificial horizon was undesirable except as an emergency measure because of the high degree of concentration and mental effort required when flying without this instrument.

EFFECTS OF FORWARD SPEED

The degree of difficulty encountered in these helicopter instrument-flying trials depended to a large extent upon the forward speed at which they were attempted. At speeds in the vicinity of cruising, all the maneuvers previously listed were successfully accomplished. By means of close and constant attention to flight instruments, altitude, airspeed, and heading were maintained within reasonable limits. Although more difficult than in an airplane, relatively complex

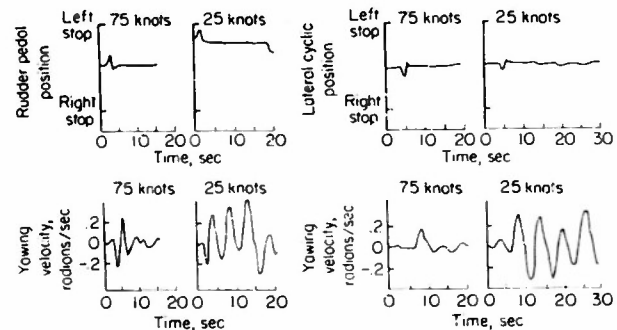


FIGURE 7.—Oscillations resulting from control displacements at two different airspeeds.

maneuvers such as pattern C were accomplished with the helicopter, and ground-controlled approaches were consistently made down to altitudes as low as 50 feet. The maneuvers were successful with both the tail-off and tail-on configurations, although, as previously mentioned, the stable condition required less effort on the part of the pilot.

As forward speed was decreased below that for minimum power, the helicopter became increasingly difficult to fly on instruments. Larger and more frequent control motions were necessary, and greater deviations from the desired flight path occurred. The increased control motions at low speed can be seen in figure 8, which is a comparison of flight records at various airspeeds. Although no sharp dividing line seems to exist between practical and impractical forward speeds, the pilots' opinion was that steady flight below 25 knots would be possible only for short periods of time.

Some of the difficulties encountered below 25 knots are

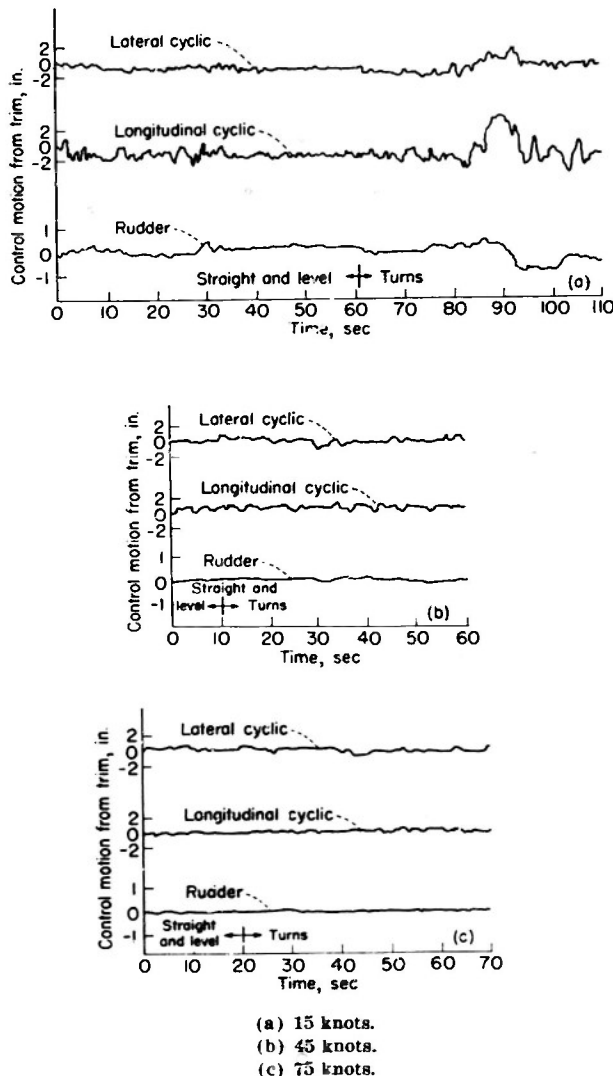


FIGURE 8.—Comparison of control motion at various airspeeds during level-flight-plus-turn maneuvers, tail-on configuration.

apparently due to errors in the present airspeed indicating system. Steady indications are difficult to maintain, even during visual flight, and fluctuations due to yaw and pitch have been observed. Also, the pilots reported that at these lower speeds unsteady conditions were often encountered, similar to those found in the vortex-ring state of operation during descents at low forward velocity with partial power.

There are other problems peculiar to the low-speed region. For example, at low speeds very small angles of bank produce high rates of turn, so that precise lateral-directional control is difficult. In addition, the pilot experiences little or no normal acceleration during maneuvers at low speeds, whereas at higher speeds such accelerations are believed to be an aid in detecting changes in the flight path. There is also the fact that at speeds below that for minimum power the relationship between power required and speed is just opposite to that normally expected, and an additional burden is thus placed upon the pilot.

CONTROL FORCES

The data of reference 3 indicate that the pilot should be able to trim steady forces to zero and that he should also have a force gradient opposing displacement of the controls. These requirements seem particularly desirable for instrument flight, since in the present trials the pilots objected to small out-of-trim forces that had not been apparent to them in contact flight.

Various force gradients were tried in the longitudinal and lateral control systems of the helicopter in the stable configuration. For this helicopter, the pilots found that stick-force gradients of about 2 pounds per inch longitudinally and 1 pound per inch laterally were satisfactory. This longitudinal gradient was too light, however, to provide satisfactory maneuvering forces. The preload necessary to overcome friction (about 1 lb laterally and 4 lb longitudinally) and provide positive stick centering was found to be objectionable since it had to be overcome each time the stick was moved from trim. A trimming device is considered to be necessary since the pilots objected to out-of-trim forces as low as 1 pound.

POSSIBLE MEANS FOR IMPROVEMENT

STABILITY AND CONTROL CHARACTERISTICS

The results of the present investigation have shown that improving the maneuver stability in accordance with the requirements of reference 1 decreases the effort required of the pilot in maintaining a given flight path. For the test helicopter, this improvement was accomplished by means of tail surfaces linked to the longitudinal cyclic control. However, depending upon the basic configuration, there are other methods, such as those suggested in reference 2, which might work equally well for helicopters lacking in maneuver stability.

The lateral-directional problem seems less likely to have a simple solution. One possibility for improvement would be to increase the damping in roll and thus reduce the sensitivity to gusts. Another suggestion has been to reduce both the directional-control sensitivity and the weathercock stability

in order to avoid overcontrolling and to decrease the sensitivity to lateral gusts, although this procedure may conflict with practical requirements. A third solution is to use an autopilot, either to control the helicopter directly or, in effect, to modify its stability derivatives. This approach is feasible but involves a substantial weight penalty and does not alter the fact that, in event of autopilot failure, inherent stability of the helicopter would be highly desirable.

The previously mentioned directional oscillation requires further investigation to determine the extent to which it contributes to the pilot's difficulties. An increase in either period or damping of this motion might reduce directional-control difficulties. However no basis for evaluating the importance of this item has as yet been obtained.

FLIGHT INSTRUMENTS

Since the fuselage attitude of a helicopter is independent of the lifting-rotor position, the conventional artificial horizon does not always provide a reliable indication of flight-path change and does not supply the pilot with information that will allow him to anticipate displacement of the helicopter from trim conditions. Instruments which indicate the attitude of the rotor with respect to the horizon would appear to offer solutions to problems of this type. Another approach is to provide the pilot both attitude and rate indication. Flight data obtained with an instrument which combines fuselage pitch attitude and rate of change of attitude have indicated that a combination of rate and attitude information, possibly about all three axes of the helicopter, might be desirable. There are also strong indications that an instrument which combines information usually obtained from several sources might reduce considerably the difficulty of helicopter instrument flying.

Another possibility for improvement exists in regard to airspeed indication, since at very low speeds reliable airspeed information is difficult to obtain in the helicopter. In addition to usual problems, the variation of inflow through the rotor makes the avoidance of installation errors difficult, and gusts, even of small magnitude, can produce a large percentage of the indicated reading. A satisfactory instrument would probably have to average or damp the gust velocities and be relatively insensitive to variations in yaw and pitch.

CONCLUSIONS

As a result of instrument-flying trials conducted with a single-rotor helicopter, the following conclusions were drawn:

1. Existing longitudinal flying-qualities requirements for helicopter appeared to be adequate for instrument flying; at speeds above that for minimum power.
2. Changing the maneuver stability from unsatisfactory to satisfactory markedly reduced the effort required of the pilot to maintain a given flight path under instrument conditions. In addition, the danger due to divergent tendencies was removed.
3. During precision maneuvers, such as ground-controlled approaches, and for low-speed flight in general, control of heading appeared to be a greater problem than maintaining altitude or airspeed. Much of this difficulty was due to the fact that, at usual helicopter speeds, small angles of bank result in high rates of turn. The lightly damped lateral-directional oscillation, which is not always apparent to the pilot, requires further investigation to determine the extent to which it contributes to the pilot's difficulties.
4. With standard airplane instruments, normal instrument-flying maneuvers were possible in the helicopter at speeds from about 45 to 75 knots. However, close and constant attention to flight instruments was necessary. Increasing difficulty was encountered at lower speeds, and flight below 25 knots was possible only for very short periods.
5. All unbalanced control forces, even those of small magnitude, were objectionable during instrument flight and means must be provided for trimming such forces to zero about all axes.

LANGLEY AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., March 11, 1952.

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