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

By ALMER D. CRIM, JOHN P. REEDER,
and JAMES B. WHITTEN

1953
REPORT 1137

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

By ALMER D. CRIM, JOHN P. REEDER,
and JAMES B. WHITTEN

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

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

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President, and serve as such without compensation.

Jerome C. Hunsaker, Sc. D., Massachusetts Institute of Technology, Chairman

Detlev W. Bronk, Ph. D., President, Rockefeller Institute for Medical Research, Vice Chairman

Hon. Joseph P. Adams, member, Civil Aeronautics Board.
Allen V. Astin, Ph. D., Director, National Bureau of Standards.
Leonard Carmichael, Ph. D., Secretary, Smithsonian Institution.
Laurence C. Craigie, Lieutenant General, United States Air Force, Deputy Chief of Staff (Development).
James H. Doolittle, Sc. D., Vice President, Shell Oil Co.
Lloyd Harrison, Rear Admiral, United States Navy, Deputy and Assistant Chief of the Bureau of Aeronautics.
R. M. Hazen, B. S., Director of Engineering, Allison Division, General Motors Corp.
William Littlewood, M. E., Vice President—Engineering, American Airlines, Inc.

Hugh L. Dryden, Ph. D., Director
John W. Crowley, Jr., B. S., Associate Director for Research

Hon. Robert B. Murray, Jr., Under Secretary of Commerce for Transportation.
Ralph A. Oyston, Vice Admiral, United States Navy, Deputy Chief of Naval Operations (Air).
Donald L. Putt, Lieutenant General, United States Air Force, Commander, Air Research and Development Command.
Arthur E. Raymond, Sc. D., Vice President—Engineering, Douglas Aircraft Co., Inc.
Francis W. Reichelderfer, Sc. D., Chief, United States Weather Bureau.
Theodore P. Wright, Sc. D., Vice President for Research, Cornell University.

Edward H. Chamberlin, Executive Officer

Henry J. E. Reid, D. Eng., Director, Langley Aeronautical Laboratory, Langley Field, Va.
Smith J. DeFrance, D. Eng., Director, Ames Aeronautical Laboratory, Moffett Field, Calif.
Edward R. Sharp, Sc. D., Director, Lewis Flight Propulsion Laboratory, Cleveland Airport, Cleveland, Ohio

Hugh L. Dryden, Ph. D., Director
John F. Victory, LL. D., Executive Secretary

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight.
INITIAL RESULTS OF INSTRUMENT-FLYING TRIALS CONDUCTED IN A SINGLE-ROTOR HELICOPTER

By Almer D. Crim, John P. Reeder, and James B. Whitten

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 had 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.

---

1 Supersedes 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.
Figure 1.—Helicopter used in instrument-flying trials.
Figure 2.—Test helicopter with instrument-flying hood.
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 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
maneuvers such as pattern C were accomplished with the
helicopter, and ground-controlled approaches were consist­
tenly made down to altitudes as low as 50 feet. The maneu­
viers were successful with both the tail-off and tail-on con­
figurations, 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 rec­
ords 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
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 pro­
duce 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 instru­
ment 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 con­
figuration. 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 longitudi­
nal 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. How­
ever, 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

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.

**REFERENCES**