NACA TN 1983

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 1983

LONGITUDINAL FLYING QUALITIES OF SEVERAL SINGLE-ROTOR HELICOPTERS IN FORWARD FLIGHT

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Washington
November 1949

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ERRATA NO. 1

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Page 23, figure 5: In the center plot, change the pitching velocity scales to read "Nose up 10" and "Nose down 10" instead of the present "Nose up 20" and "Nose down 20."

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SUMMARY

Flight-test measurements and corresponding pilot's opinions of the forward-flight longitudinal flying-qualities characteristics of several single-rotor helicopters are presented. A comparison which is significant in connection with the defining of satisfactory characteristics is thus provided. On the basis of the comparisons obtained, it is concluded that the most important consideration is the prevention of prolonged stick-fixed divergent tendencies. Additional improvement is concluded to relate to the continuous development of normal acceleration in contrast to a pause in the development of acceleration during the first second following abrupt control deflection. These conclusions are also expressed in the form of tentative flying-qualities requirements.

A maneuver which brings out some of the principal characteristics is theoretically analyzed. It is concluded that the normal-acceleration characteristics appreciated by the pilot can be theoretically predicted.

INTRODUCTION

As was indicated in reference 1, the National Advisory Committee for Aeronautics is currently endeavoring to extend its work on requirements for satisfactory stability and control characteristics for airplanes (references 2 and 3) in order to formulate similar requirements for helicopters. In reference 1, one of the primary flying-qualities problems of current helicopters is shown to be instability with angle of attack in forward flight; that is, the pilot must continually control against a divergent tendency following either longitudinal control motion or a nose-up or nose-down disturbance. The longitudinal stability and control studies are at present far from being sufficient to determine the various combinations of parameters that will give satisfactory characteristics. Flight-test results which have been obtained for three configurations do, however, provide a comparison in connection with the defining of satisfactory longitudinal characteristics. These results, consisting of time histories of forward-flight maneuvers and corresponding pilot's opinions for each of the three configurations, are given herein. There is reason to believe that the criterions for helicopter flying-qualities requirements should remain flexible for some time; however, the indications of the present study together with related results of reference 1 are interpreted in the form of tentative (and incomplete) flying-qualities requirements.

The stability and control characteristics during recovery from a disturbed flight condition have thus far been found to be more critical, in respect to safety, than the immediate effects of a disturbance or uncontrolled-for divergence. (See reference 1.) Accordingly, primary consideration is given in this paper to the longitudinal characteristics as revealed by pull-ups, which are representative of recovery characteristics.

Results of theoretical calculations for pull-up maneuvers of two helicopters are also given as a means of indicating whether the characteristics noted can be theoretically predicted.

Most of the flying represented was done by one NACA test pilot who had had experience in judging the flying qualities of various aircraft. Each of the three configurations, however, was also flown to a more limited extent by another NACA pilot, whose impressions on all principal points proved to be the same as those of the first pilot and, hence, are not enumerated separately.

CONFIGURATIONS TESTED

For convenience, the three configurations are designated helicopter A, helicopter B, and helicopter C. The object of the investigation was to correlate time-history measurements of flight characteristics with pilot's reactions to these flight characteristics. Changes in details such as center of gravity or the addition or removal of external equipment are known to affect the comparisons obtained; however, no attempt is made to discuss the effect of such factors on the comparisons and many details concerning the exact configurations tested are omitted.

Helicopter A is a four-place aircraft of about 5,000 pounds gross weight and has a single lifting rotor 48 feet in diameter. The general arrangement is apparent from figure 1.

Helicopter B is the same helicopter with a small fixed horizontal tail surface added, this change being sufficient to provide a new configuration for the present study. A photograph of the tail-surface installation is given as figure 2, and the location and dimensions are shown in figure 3.

Helicopter C (fig. 4) has the same general arrangement as helicopter A in that a single lifting rotor and torque-counteracting tail rotor are used. It is a two-place helicopter of about 2100 pounds gross weight and has a main-rotor diameter of about 35 feet. This helicopter has a gyroscopic device for improving stability and control characteristics, which for the purposes of this paper may best be viewed as serving to increase the damping moments resulting from angular pitching or rolling velocity of the helicopter. The fuselage configuration of the helicopter was understood to have been found by the manufacturer to result in improved stability characteristics as compared with several alternate fuselage configurations tested.

RESULTS

All of the pull-up time histories presented start with the helicopter in trim in steady level flight at an indicated airspeed of about 80 miles per hour, which is approximately the cruising speed of these helicopters.

Helicopter A

A time history of a "pull-and-hold" maneuver for helicopter A is given in figure 5.

Pitching velocity.- The pitching-velocity record shows that maximum angular acceleration is achieved quickly following control displacement, but that little or no tendency to reach a constant value exists, although (aside from the effects of the initially gradual airspeed change), the attainment of a constant angular velocity is basically what is expected from a fixed control displacement.

Normal acceleration.- The normal-acceleration curve appears even more undesirable in nature than the pitching-velocity curve by showing no tendency to reach a constant or maximum value and exhibiting a pause in the development of acceleration following the initial rapid rise. Because pilots have been found to notice rapid changes in normal acceleration of 0.02g or even less and because the normal acceleration is the primary measure of the change in flight path being achieved, any illogical development of normal acceleration, particularly a divergent tendency, would be expected to cause adverse pilot impressions.

Pilot's comments.- The pilot's report on this maneuver was that considerable apprehension was felt as a result of the tendency for the helicopter to "dig in." Correspondingly, in normal flying at the same speed, any deviations from steady flight had to be checked at an early stage. The reasons for apprehension with helicopters having these divergent tendencies may be further illustrated by means of figure 6 (for a different helicopter at 65 mph), which is taken from reference 1. The figure shows that, although at the time recovery was initiated the normal acceleration differed from that for level flight by only -0.3g, during recovery an increment of 0.8g occurred even though the control stick was full forward by the time this increment was reached. The maneuver was checked at this point only with the aid of other flight controls. Miscellaneous measurements obtained with helicopter A indicate that at 80 miles per hour it would exhibit characteristics generally similar to, though somewhat milder than, those shown in figure 6.

In addition to the divergent tendency, the pilot reported difficulty in anticipating, during the first 1 or 2 seconds, the rapidity with which the divergence would later take place. In pull-ups started at lower speeds, a maximum acceleration value could be reached, but a similar difficulty in anticipating the eventual result was noted.

Stick-fixed oscillations.- Following a nose-up disturbance at 80 miles per hour, it was necessary to effect recovery during the first nose-down motion. In other words, only a part of an oscillation could be tolerated.

Helicopter B

A time history of a pull-and-hold maneuver for helicopter B is given in figure 7.

Pitching velocity.- The maximum angular acceleration is again reached quickly following control displacement and, in this case, a tendency to reach a constant (or at least a maximum) angular velocity is almost immediately evident; that is, the curve of angular velocity is definitely concave downward. Maximum angular velocity is reached in about $1\frac{1}{2}$ seconds, which it is understood would not be objectionable for airplanes.

Normal acceleration.- The normal-acceleration curve again exhibits the pause in development (following the initial rapid rise) as noted for helicopter A, but by the end of about 2 seconds (at which time recovery was applied with helicopter A), a tendency to reach a constant or maximum value was evident and the pilot held the deflection until after peak acceleration was reached. Much less control deflection was needed for recovery from this pull-up than was needed for helicopter A.

Pilot's comments.- The pilot's comments on this maneuver in helicopter B, as compared with the corresponding one in helicopter A, was that as a result of removal of the divergent tendency, the feeling of apprehension was greatly reduced. Although this removal of the divergent tendency was believed to be more important than any further improvements could be, the pull-up characteristics were still considered to be by no means satisfactory because of the difficulty in anticipating, during the early phase of the maneuver, the acceleration (and change in flight path and attitude angle) that would be reached later.

Stick-force gradient.- Consideration of experience with airplane flying qualities suggested that the introduction of a stick-force gradient might provide the pilot with a means for anticipating the final results by providing a continuous indication of the magnitude of the control deflection from trim. Three different values of force gradient were accordingly tried, by use of suitable springs attached to the control stick. The largest gradient (8 lb/in.) only aggravated the pilot's impressions. The smallest gradient (2 lb/in.) had no noticeable effect; control friction, although approximately overcome by control vibration, may have been responsible for this result. The intermediate value ($4\frac{1}{2}$ lb/in.) was reported by the pilot to produce definite improvement but still to leave much to be desired. This intermediate value was sufficient to return the control promptly to trim when the stick was deflected and released, in spite of the friction present.

Stick-fixed oscillations.- With helicopter B, longitudinal disturbances in level flight and moderate climbs at 80 miles per hour, stick fixed, were slowly damped out. Lateral oscillations were noticeable during these trials. In some cases, these lateral motions were checked by use of lateral control. For the climbs, longitudinal stick motions were easily avoided during this process because the stick trimmed against the forward stop.

The fact that the pilot was willing to fly helicopter B with the stick against the forward stop gives a further indication of the difference between helicopters B and A. With helicopter A, a sizeable margin of control had to be maintained in order that the divergent tendencies could be successfully checked. This margin was needed in normal flight as well as in maneuvers.

Helicopter C

A time history of a pull-and-hold maneuver for helicopter C is given in figure 8.

Pitching velocity.- The angular-velocity curve differs from that for helicopter A in a manner similar to the differences discussed in the comparison of helicopter B with helicopter A, except that the changes are more pronounced. That is, a greater downward concavity is shown during the first second after control deflection, and a more definite peak value is evident.

Normal acceleration.- The normal-acceleration curve shows an initial jump, similar to those for helicopters A and B, followed by a comparatively short and much less definite pause (the slope never dropping all the way to zero as before). The time to the peak value is not appreciably different from that for helicopter B.

Pilot's comments.- The pilot's opinion of the pull-up characteristics of helicopter C was that they were satisfactory. The apprehension associated with the divergent tendency for helicopter A was absent and, in addition, the difficulty of anticipating the eventual result, which remained in helicopter B, was also absent. Normal flying was found to be correspondingly simpler. Furthermore, this helicopter could be flown for comparatively long periods in moderately rough air with the cyclic control stick held fixed by the friction clamp provided.

The control friction for this helicopter was moderate. No longitudinal stick-force gradients were apparent. Although the longitudinal characteristics in the pull-and-hold maneuver were considered relatively satisfactory without force gradients, the pilot believed that stable force gradients would be necessary for completely satisfactory pull-up characteristics. Stable force gradients are necessary for readily returning to trim conditions following maneuvers, as well as for assisting the pilot in judging and controlling the maneuvers.

Stick-fixed oscillations.- The longitudinal oscillations, following a disturbance at 80 miles per hour in level flight, were almost deadbeat for this configuration.

DISCUSSION

Characteristics Appreciated

From consideration of the results presented herein and those of reference 1, it is concluded that, for the helicopters represented, the most important factor in the longitudinal characteristics in both pull-ups and steady flight is whether or not a prolonged stick-fixed divergence will occur. Further improvement is concluded to relate to the continuous development of the normal acceleration in contrast with a pause in development of acceleration during the first second following abrupt control deflection.

In order to arrive at these conclusions and to formulate tentative requirements therefrom, it is necessary to show that normal flying is properly represented by pull-ups and also that other characteristics which might be expected to be important can be considered subordinate to acceleration characteristics.

For all cases, the degree of pilot satisfaction with the characteristics in an abrupt pull-and-hold maneuver correlated with his satisfaction with the normal-flying characteristics. The stipulation of satisfactory pull-up characteristics must, of course, be taken as a necessary rather than a sufficient condition; for example, if (at 80 mph) helicopter C had exhibited an unstable variation of stick position with speed, it would not have been considered satisfactory in normal flight regardless of pull-up characteristics. As another example, the stick-force characteristics were actually considered to be in need of improvement.

As was discussed at length in reference 1, improvement in stick forces or provision of stick-free stability does not appear to be the primary need for these helicopters, although the desirability of good stick-force characteristics cannot be too strongly emphasized. Even with complete stick-fixed stability, the forces should be such that the stick will tend to return to the original trim position when deflected. Furthermore, the greater the stick-fixed instability, the greater will be the improvement achieved by incorporating stick-free stability, inasmuch as it can partially mask the difficulties imposed by the stick-fixed instability.

Another alternate possibility requiring discussion is the use of pitching velocity rather than normal-acceleration characteristics as a criterion. For the cases under consideration, improvements in one of these characteristics are accompanied by improvements in the other, but logical pitching-velocity characteristics are reached more readily than logical normal-acceleration characteristics and are not sufficient as a criterion. This situation is analogous to airplane requirements for stick-fixed and stick-free stability in which requirement of stick-free stability has generally been sufficient for the simple reason that, in achieving stick-free stability, stick-fixed stability was automatically obtained. When exceptions occurred and stick-free stability was obtained without achieving stick-fixed stability, the characteristics, in some cases at least, were not considered satisfactory (reference 4).

The time interval between stick deflection and attainment of maximum normal acceleration could be made to provide a criterion for avoidance of prolonged divergence, but not a criterion for completely satisfactory characteristics, inasmuch as the satisfactory configuration (helicopter C) showed a time interval almost identical to that for helicopter B, which had an objectionable delay in development of acceleration. It seems noteworthy that, provided that the manner of development is logical, a time interval of $2\frac{1}{2}$ seconds as shown for helicopter C is not objectionable to the pilot. For operation in close quarters, as in crop dusting, the time interval might have more significance, at least to the extent that the collective pitch control would be used when immediate acceleration is needed. The present study did not include such operations.

The long-period stick-fixed oscillation characteristics for the three helicopters show improvements coincident with those of the pull-up characteristics; however, to require simply that these oscillations damp out would indicate that both helicopters B and C were fully satisfactory, whereas helicopter B was found to cause the pilot undue difficulty in anticipating the final result of a control deflection. Also, although the change from helicopter A to helicopter B resulted in a change of the long-period motion from divergent to convergent, the pause in the development of acceleration appears, if anything, to be somewhat increased rather than diminished. Furthermore, long-period oscillations, even if moderately divergent rather than damped, have generally been found not to influence the pilot's liking for an aircraft. Although the oscillations of the helicopter involve more attitude and acceleration changes than do the long-period (phugoid) oscillation of the airplane, nevertheless from present knowledge (including the toleration of long-period helicopter oscillations in hovering; see reference 1) it does not appear logical to require rapid damping of these oscillations. Furthermore stick-free stability may be found to mask adequately a tendency toward slow divergence of these long-period stick-fixed oscillations (but not a tendency toward rapid divergence). Finally, consideration of the analysis given in the following section, together with consideration of the factors known to affect the oscillations, indicates that no unique relation exists between the details of the early part of the pull-up and the damping of the long-period oscillations. It is concluded, therefore, that a requirement based on long-period oscillations could not be used as a complete substitute for the pull-and-hold requirements.

Theoretical Analysis of Pull-Up Characteristics

A theoretical analysis of helicopters A and B in pull-ups has been made in order to determine whether the pull-up characteristics previously discussed can be theoretically predicted and in what way the tail surface causes the measured change in these characteristics. (No theoretical analysis of helicopter C could be made because some of the necessary parameters were not available.)

Because of the complexity of the phenomenon, several simplifying assumptions were made. The most important of these assumptions are:

(1) Constant rotor speed and collective pitch (the collective pitch on these helicopters varies with lag angle and coning angle)

(2) Small displacements

(3) Representation of the dynamic motion by variations in steady state conditions, for example, the lag in the changes of induced velocity is neglected

For the present purpose at least, these simplifying assumptions should not qualitatively alter the theoretical results and conclusions.

In the analysis, flight-path axes were used and four variables were considered: forward speed, pitching velocity, angle of climb (the time derivative of which is proportional to normal-acceleration increment), and rotor angle of attack (which differs from the fuselage angle of attack by an amount equal to the longitudinal cyclic control). An instantaneous rearward motion of the longitudinal control resulting in a change of 1° in cyclic pitch was assumed, the resulting control position being maintained indefinitely. Four differential equations were set up: three of them expressing the equilibrium of pitching moments and of forces along and perpendicular to the flight path and the fourth expressing the rotor angle of attack as a function of pitching velocity, angle of climb, and control displacement. Most of the rotor terms in these equations were based on the theory of references 5 and 6. The rotor terms which depended on pitching velocity were the only ones not so derived. The values of these latter terms were based on the commonly used parameter $\frac{16}{\gamma\Omega}$, where γ is the blade mass factor and Ω is the rotor speed. This parameter, which is discussed in reference 7, expresses the longitudinal tilt of the thrust vector per unit pitching velocity of the rotor shaft and, while not necessarily precise, is adequate for present purposes. The equation for the time history of the normal-acceleration increment above 1 g was obtained by solving the four differential equations simultaneously by the method of the Laplace transformation. The conventional method could also have been used but with considerable sacrifice in ease of solution. The following two equations were obtained:

Helicopter A:

$$\Delta N = 0.10e^{-2.06t} - 0.088e^{-0.28t} + 0.48e^{0.38t} \sin(14.5t + 5.31)^{\circ}$$

Helicopter B:

$$\Delta N = 0.34e^{-0.028t} \sin(23.15t + 58.1)^{\circ} - 0.45e^{-0.865t} \sin(47.0t + 30.8)^{\circ}$$

where ΔN is the acceleration increment caused by the control displacement which was made at time $t = 0$.

These two equations are plotted in figure 9, which shows that the divergent characteristics of helicopter A and the nondivergent characteristics of helicopter B can be theoretically predicted. Helicopter B, because of its tail surface, has different values from helicopter A for three stability parameters. Moments due to pitching velocity are increased 20 to 30 percent, moments due to speed change are increased 80 to 90 percent, and moments due to angle-of-attack change are changed from unstable to stable with about one-half the magnitude. Further calculations show, however, that the change in pull-up characteristics from helicopter A to helicopter B is primarily due to the change in the value of the moment increment per unit angle-of-attack increment.

Figure 9 also shows that for both helicopters the jump in acceleration at $t = 0$ and the flat spot at the start of the acceleration time history, as well as the general shape of the curve can be theoretically predicted. The cause of this flat spot can be explained as follows: The abrupt rearward control displacement causes an abrupt increase in rotor angle of attack and thus an increase in rotor thrust and normal acceleration. The resulting curvature of the flight path results in a climb, which tends to reduce the rotor angle of attack and normal acceleration from their abruptly increased values back to their trim values. In the meantime, however, the nose-up moment produced by the control displacement tends to cause a nose-up pitching velocity and thus an increase in rotor angle of attack and normal acceleration. These two opposing tendencies result in a flat spot in the normal-acceleration time history. Various means exist whereby the relative proportions of these two tendencies can be altered, for example, by reducing the helicopter pitching inertia while keeping the same gross weight. Another means would be to alter the manner in which the control action is transmitted to the rotor blades so that, when the stick is deflected, a part of the corresponding blade cyclic-pitch change is delayed somewhat.

Inasmuch as the important pull-up characteristics of helicopters A and B could be theoretically predicted, it is concluded that the important longitudinal characteristics of any reasonably similar helicopter for which the necessary parameters are available can also be theoretically predicted.

Practical Requirements

Examination of the time histories presented suggests that a requirement intended to preclude dangerous stick-fixed divergent tendencies, as regards longitudinal stability and control in forward flight, might be worded as follows:

> When the longitudinal control stick is suddenly displaced rearward 1 inch from trim (while in level flight at the maximum placard speed) and held fixed at this displacement, the time history of normal acceleration shall become concave downward within 2 seconds following the start of the maneuver.

Further consideration of the present results suggests that a requirement aimed at reducing the difficulty of anticipating the results of a control deflection and, hence, reducing pilot fatigue and thereby further increasing the safety of operation might be worded as follows:

> When the longitudinal control stick is suddenly displaced rearward 1 inch from trim (while in level flight at the maximum placard speed) and held fixed at this displacement, the time history of normal acceleration should preferably be concave downward throughout the period between the start of the maneuver and the attainment of maximum acceleration, and, in any event, the slope of the normal-acceleration curve must remain positive from the start of the maneuver until the maximum acceleration is approached.

The demonstration of fulfillment of these requirements involves instrumentation which is not always available and, in any case, involves judgment in the fairing of record lines which have a "hash" due to rotor and engine vibrations. As a supplementary requirement, therefore, a requirement based on time histories of oscillations or attempted oscillations such as that of figure 6 and reflecting the results of both reference 1 and of the present paper might be worded as follows:

> When a disturbance is produced by displacing the longitudinal control stick rearward 1/2 inch from trim for 1/2 second and then returning to trim and holding the trim setting, the following qualities shall be demonstrated: (1) The value of normal acceleration g shall not increase by more than 1/4g (total, $1\frac{1}{4}$g) within 10 seconds from the start of the disturbance; and (2) during the subsequent nose-down motion (with controls still fixed at trim), the value of acceleration shall not fall below 3/4g within 10 seconds, the 10 seconds being measured from the time of initial return to 1 g.

This supplementary requirement primarily tends to insure that an oscillation rather than a sudden divergence will occur and, as a rule, comparatively simple instrumentation should suffice. Likewise, on the basis of existing experience, the exact time or amount that the stick is held displaced should seldom be critical.

With any of these checks, a mechanical device providing adjustable stops for limiting the stick travel would be desirable to aid the pilot in obtaining rectangular control-displacement time histories. For reasons of safety, however, such a device must be designed so that the pilot can instantly remove the stops, in event of difficulty, yet will not unintentionally over-ride them.

CONCLUSIONS

The indications of brief studies of forward-flight longitudinal flying qualities of several single-rotor helicopters may be summarized as follows:

1. In relation to the pilot's satisfaction with the flying qualities, the most important consideration is the prevention of prolonged stick-fixed divergence.

2. When prolonged stick-fixed divergence is eliminated, additional improvement is concluded to relate to the continuous development of normal acceleration in contrast to a pause in the development of acceleration during the first second following abrupt control deflection.

3. The normal-acceleration characteristics appreciated by the pilot can be theoretically predicted.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va. September 8, 1949

REFERENCES

1. Reeder, John P., and Gustafson, F. B.: On the Flying Qualities of Helicopters. NACA TN 1799, 1949.

2. Phillips, William H.: Appreciation and Prediction of Flying Qualities. NACA TN 1670, 1948.

3. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. NACA Rep. 755, 1943.

4. Hunter, Paul A., and Reeder, John P.: Flight Measurements to Determine Effect of a Spring-Loaded Tab on Longitudinal Stability of an Airplane. NACA ARR L5I20, 1946.

5. Wheatley, John B.: An Aerodynamic Analysis of the Autogiro Rotor with a Comparison between Calculated and Experimental Results. NACA Rep. 487, 1934.

6. Bailey, F. J., Jr.: A Simplified Theoretical Method of Determining the Characteristics of a Lifting Rotor in Forward Flight. NACA Rep. 716, 1941.

7. Gessow, Alfred, and Amer, Kenneth B.: An Introduction to the Physical Aspects of Helicopter Stability. NACA TN 1982, 1949.

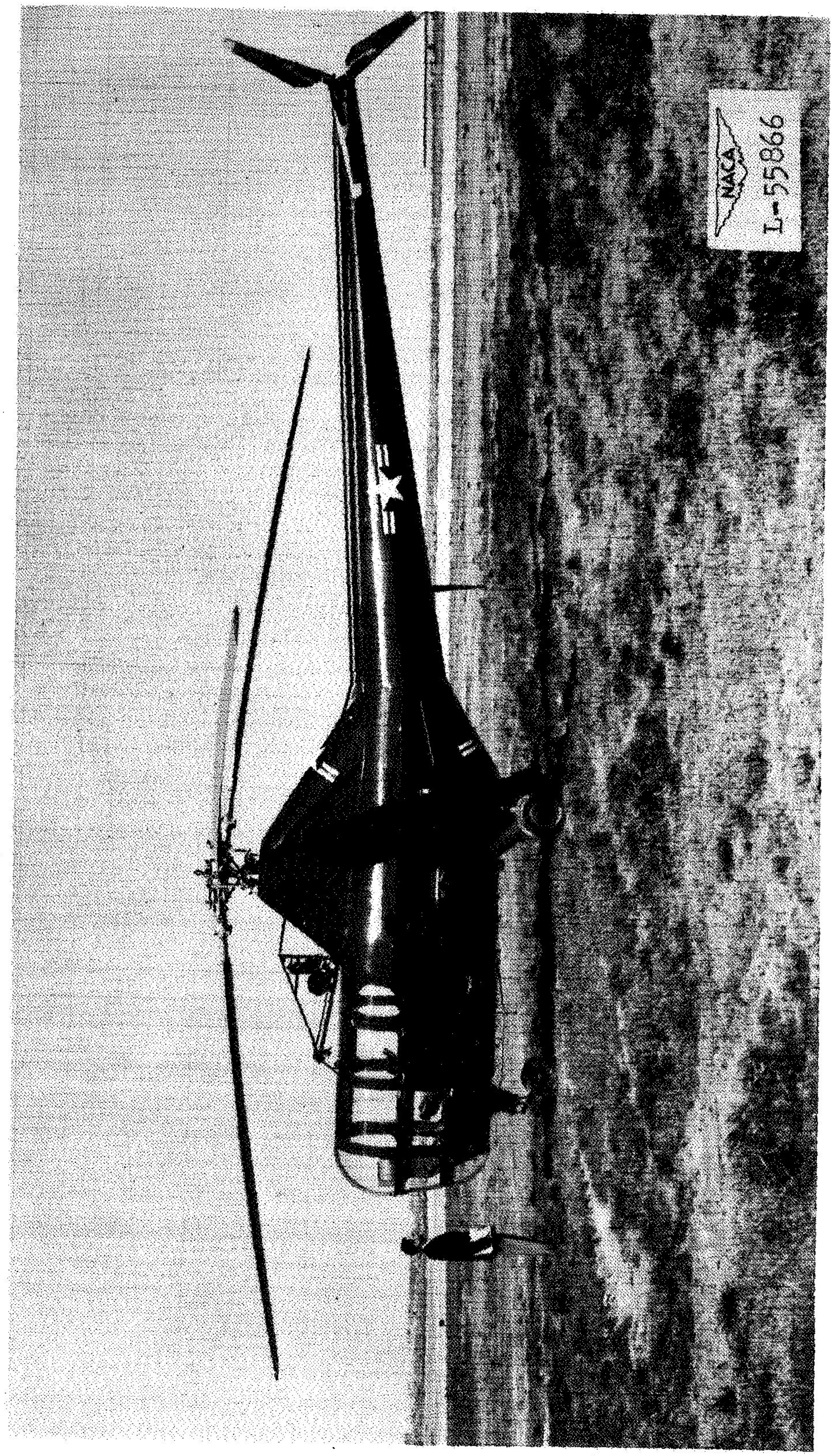


Figure 1.- Helicopter A.

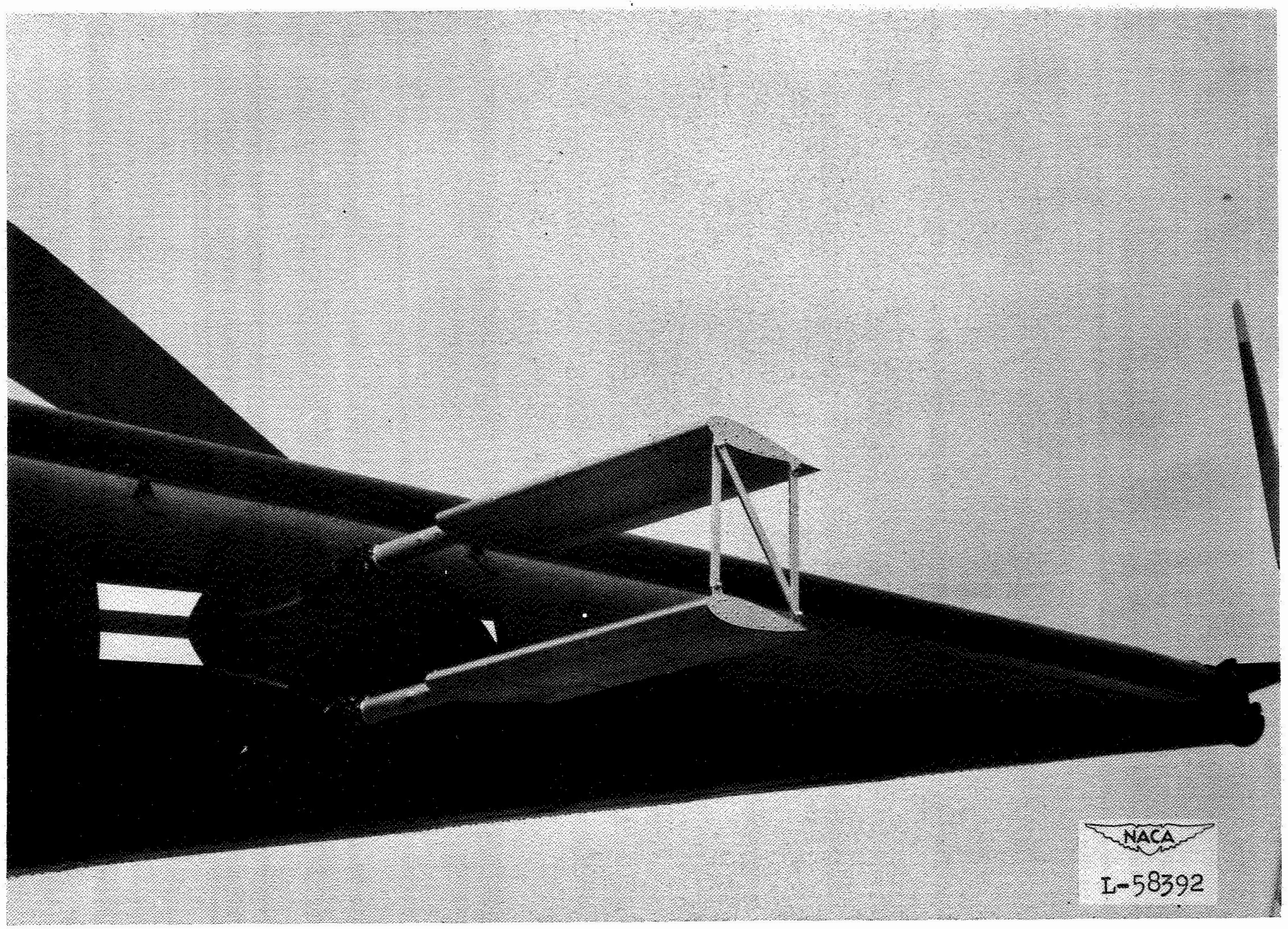


Figure 2.- Tail-surface installation on helicopter B.

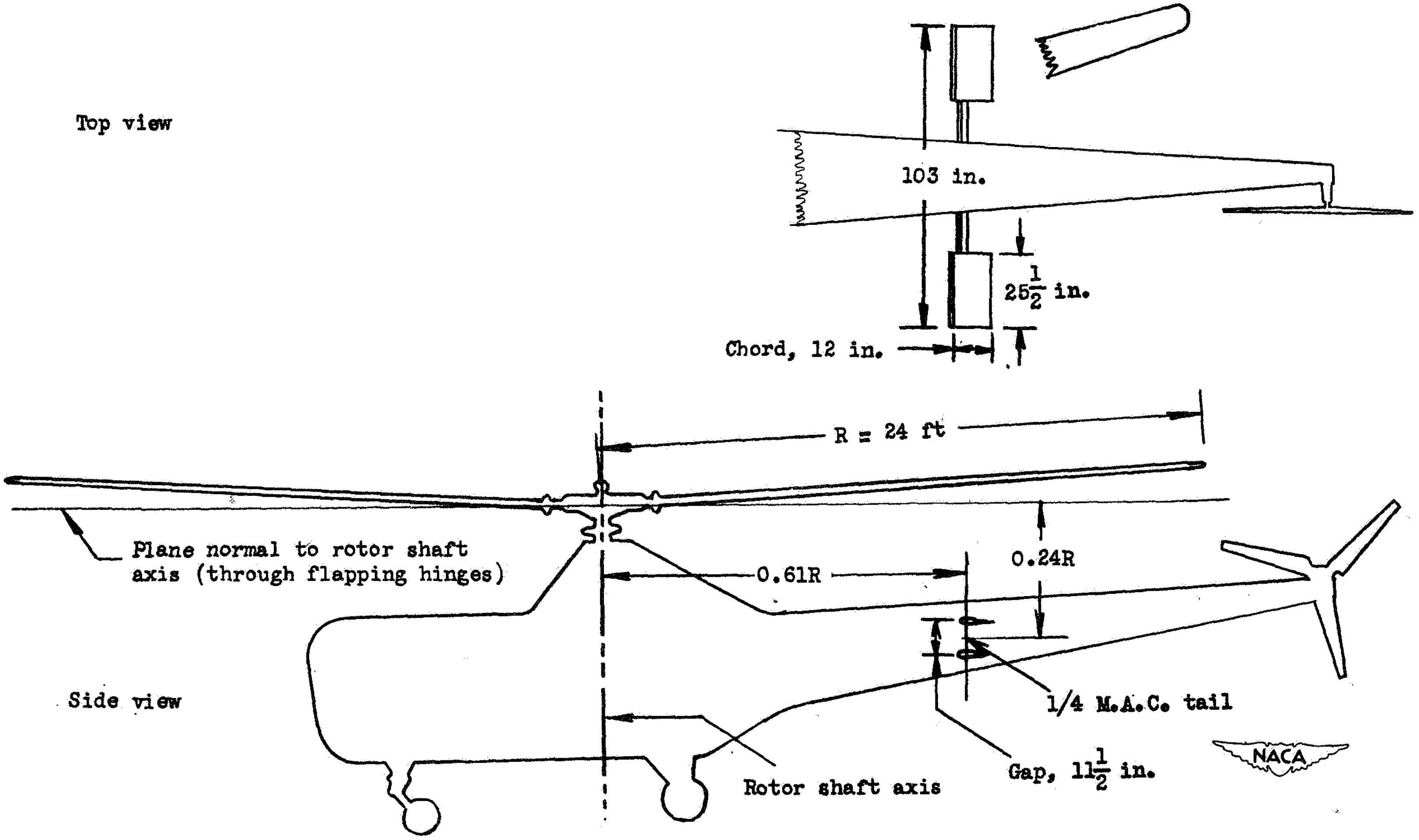


Figure 3.- Location and principal dimensions of biplane tail surface of helicopter B. Angle of incidence of tail surface is 0° relative to plane normal to rotor shaft axis.

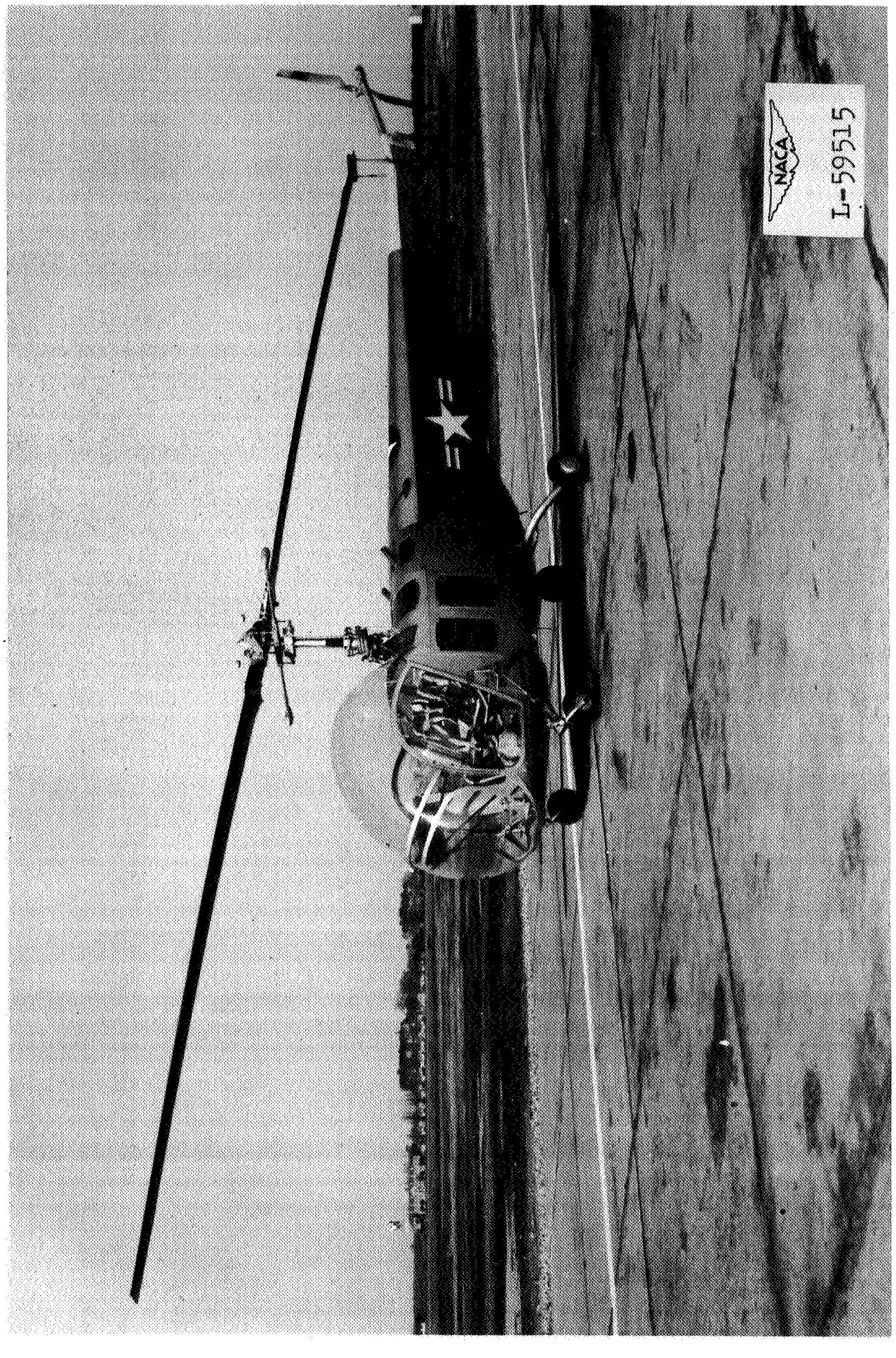


Figure 4.- Helicopter C.

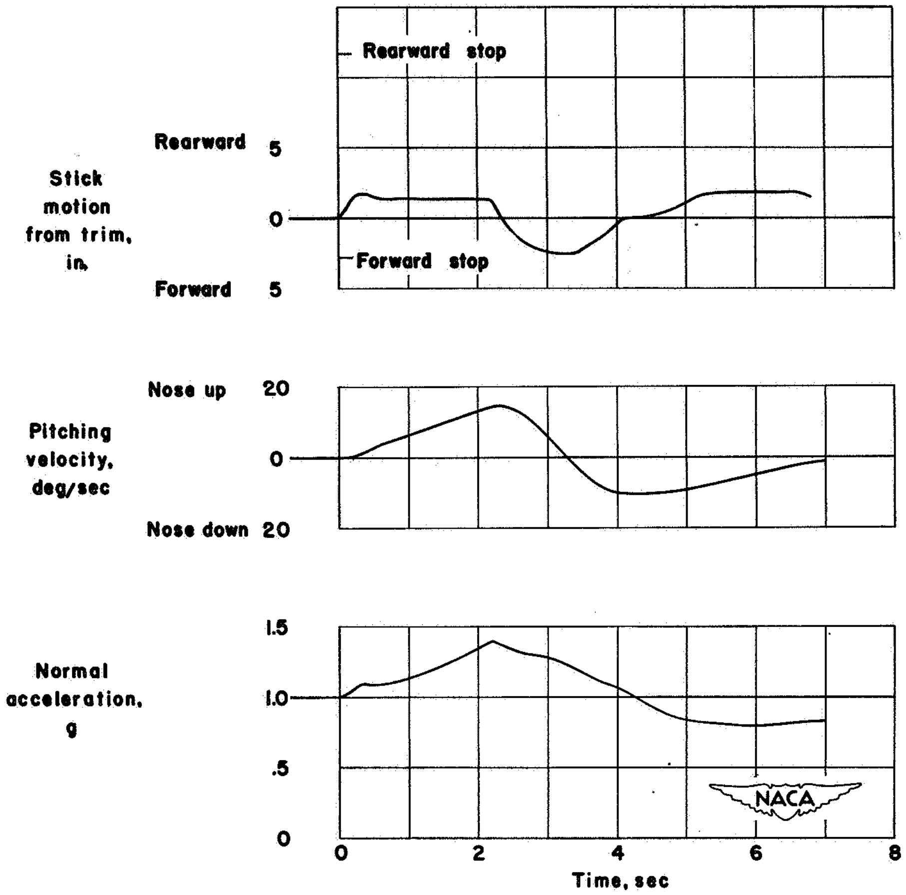


Figure 5.- Time history of a pull-up maneuver for helicopter A at 80 miles per hour.

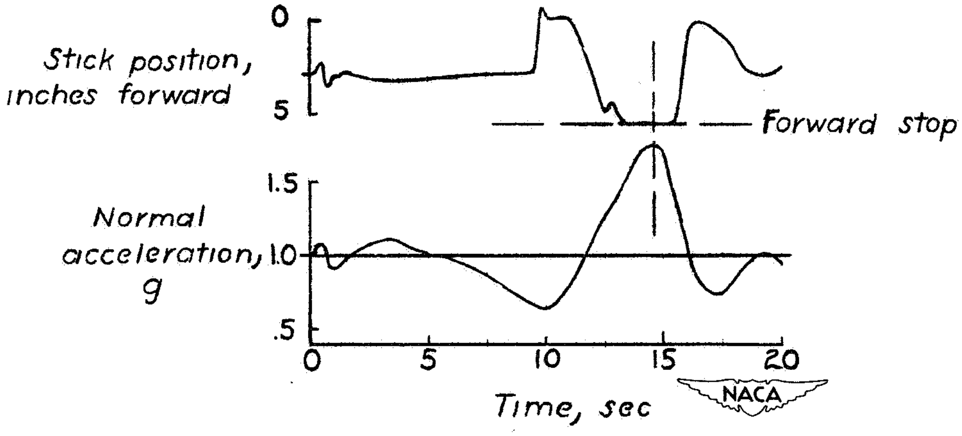


Figure 6.- Time history of an attempted helicopter oscillation which required a pull-up for recovery. (From reference 1.)

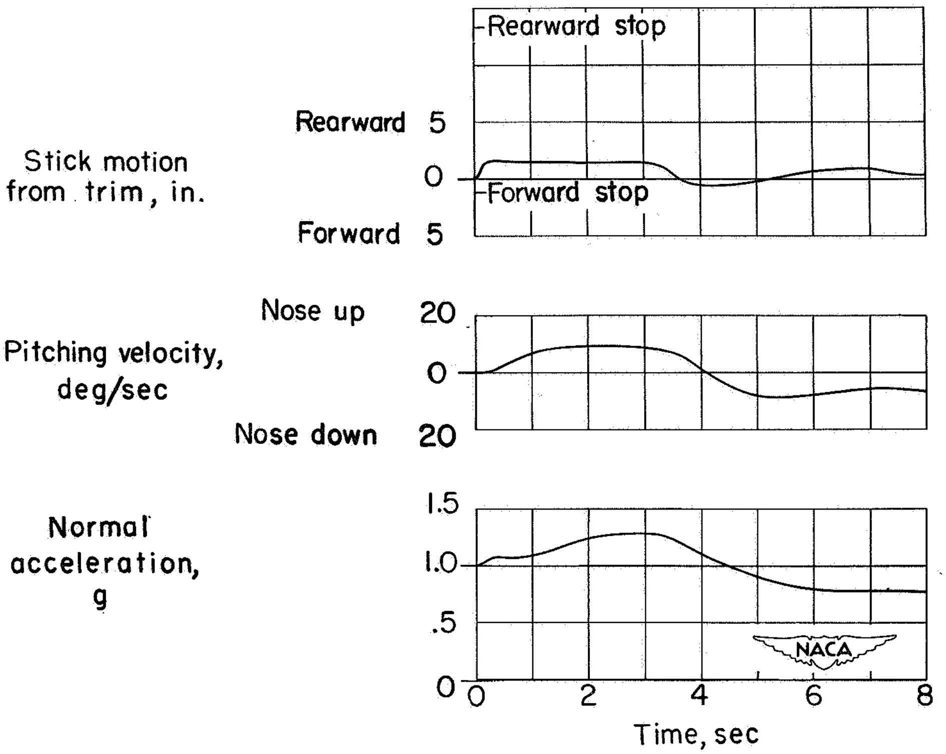


Figure 7.- Time history of a pull-up maneuver for helicopter B at 80 miles per hour.

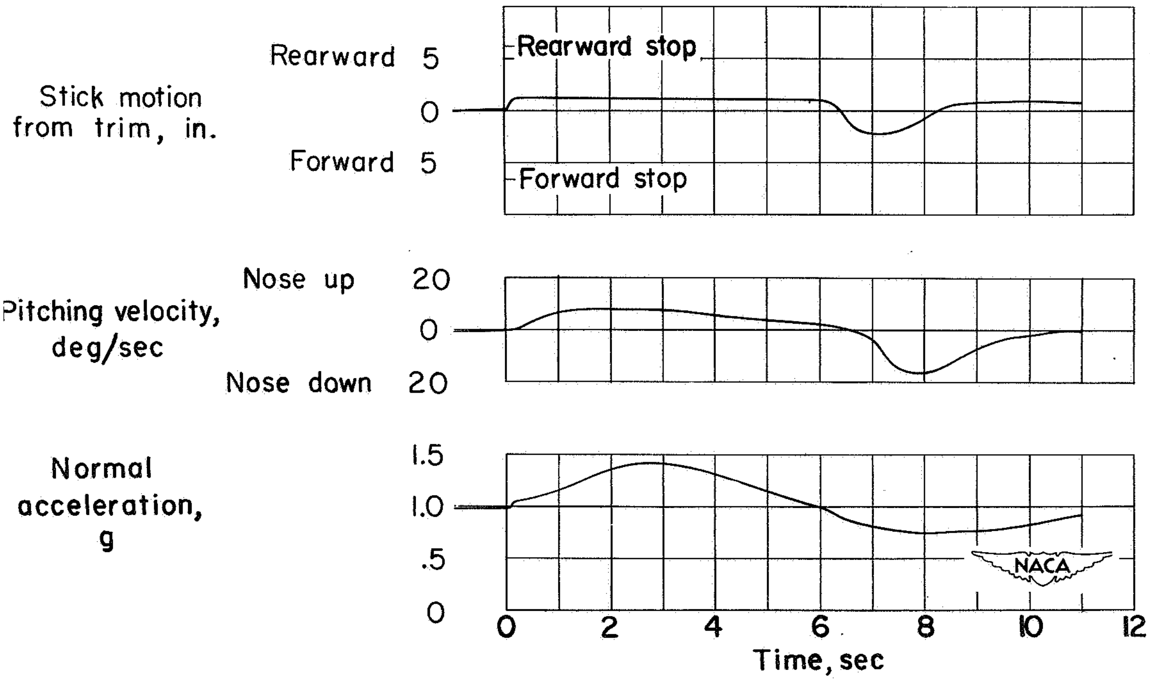
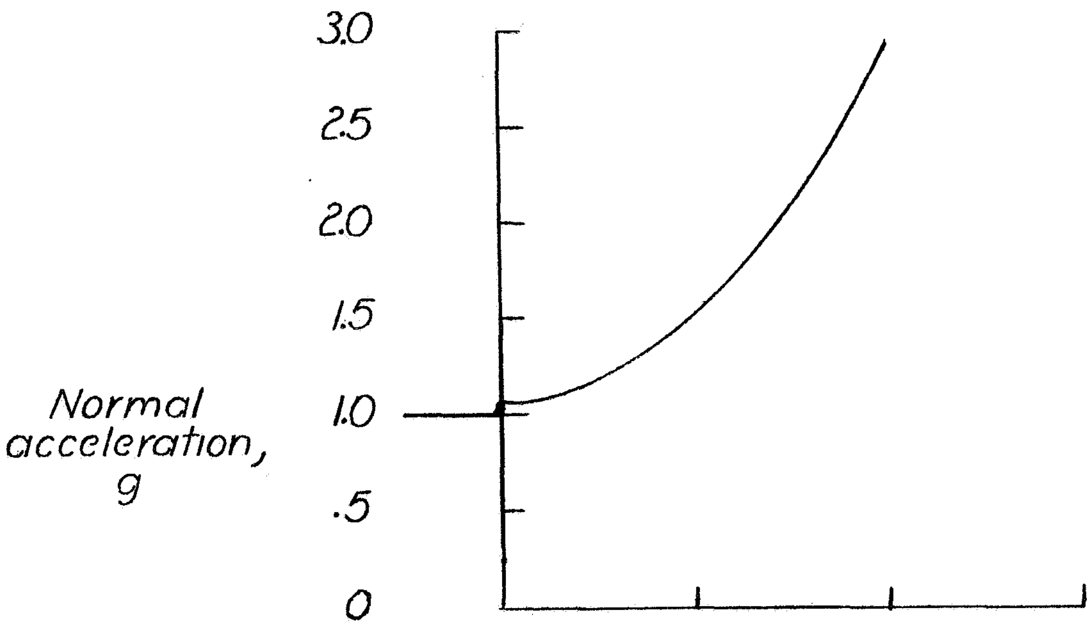
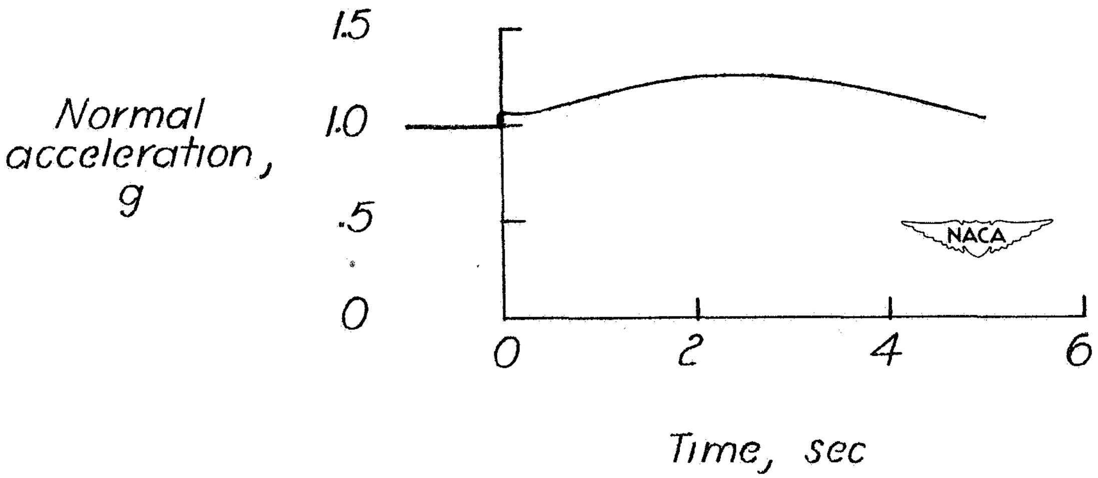


Figure 8.- Time history of a pull-up maneuver for helicopter C at 80 miles per hour.



(a) Helicopter A.



(b) Helicopter B.

Figure 9.- Theoretical time histories of normal acceleration following a sudden rearward displacement of the control stick at 80 miles per hour. A change of 1° in longitudinal cyclic pitch is used.