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TECHNICAL NOTE

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ON THE FLYING QUALITIES OF HELICOPTERS

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SUMMARY

The flying-qualities problems of current helicopters as observed during flight are discussed. These problems have been found to be (1) instability with angle of attack in forward flight, (2) control sensitivity in hovering (particularly for the smaller helicopters), and (3) control forces following control movement in maneuvers. Some discussion is also given of tentative remedies for the most outstanding deficiencies.

INTRODUCTION

Experience indicates that, in its present stage of development, the helicopter is different from and more difficult to fly than most airplanes. The difficulty seems to arise from several sources: (1) The helicopter has one additional control (collective pitch) to be operated. (2) The power controls (collective pitch and throttle) must be used almost continuously in conjunction with the flight controls during operations near the ground, chiefly because of the rapid variation of power required with airspeed in the speed range normally used in these operations. (3) The helicopter has undesirable stability characteristics in forward flight which would not be acceptable in an airplane. (4) Undesirable control characteristics exist in both forward flight and hovering. Hovering flight also introduces a new and unique problem of apparent lag in control response which is, however, somewhat analogous to formation flying with airplanes.

The National Advisory Committee for Aeronautics has long been interested in stability and control problems and in setting up requirements for the satisfactory stability and control characteristics for airplanes. This work is now being extended to the helicopter because the helicopter eventually must meet requirements parallel to those for the airplane in order to reach its potential capabilities. Although airplane requirements may not be applicable to helicopters in a specific manner, the underlying reason for setting up the requirements applies to both airplane and helicopter.

During the past several years rotor-performance investigations have been conducted at the Langley Laboratory using the two-place utility aircraft shown in figure 1. The rotors flown during this period differed in solidity, airfoil section, twist, and blade-surface rigidity. During the course of these investigations attention was drawn to certain stability characteristics of the helicopter which have long been considered unacceptable for airplanes, some interesting control characteristics and flight phenomena were revealed, and some very limited measurements of stability and control characteristics were made. Recently, moreover, the status of the performance investigations was such that instrumentation could be installed to get more detailed information on flight characteristics. Some of the data obtained with this instrumentation, experience with other helicopter types, knowledge of British experiments (an example is reference 1), and information from translations of German papers (references 2 and 3) have been used in formulating the ideas presented in this paper. A further valuable source of experience concerning the characteristics of the helicopter in maneuvers has been afforded by pull-up tests for load-factor determination; these tests have been made by the CAA with the assistance of the NACA. With this background, the present paper should help to indicate the most fruitful lines for immediate further study.

OBSERVATIONS OF FLYING QUALITIES

Longitudinal Stability in Forward Flight

During the course of the performance investigations, considerable flying was done at relatively high speeds approaching the limits imposed by blade stalling. Steady conditions were difficult to hold because of a strong tendency of the machine to diverge in pitch, this divergence creating the impression of balancing on a ball. This characteristic seemed far more pronounced with some of the rotors tested than with others but was always troublesome. Upward pitching was most troublesome as it frequently precipitated or intensified stalling, which increased the tendency to pitch up and was accompanied by rather violent periodic stick forces and vibration. The forward displacement of the control from trim necessary to check some of these pitching motions suggested that a short delay in applying corrective control would allow a maneuver severe enough that control would be lost. Although there seemed ample control to stop downward pitching, an excessive amount of forward control was again required in order to check the subsequent upward pitching. These characteristics indicated a pronounced type of longitudinal instability.

The tendency of the helicopter to depart from the trim speed and the necessity of applying appreciable control deflection against a pitching maneuver involving acceleration, initiated either by control or by gusty air, is apparent throughout the speed range normally used in forward flight. This tendency becomes much less pronounced, however, at the lower speeds.

Shortly after a student pilot first experiences forward flight, he is impressed with the necessity for having to control the helicopter constantly. The reasons for this situation are not immediately clear. It is a well-known fact that a flapping rotor tilts to the rear if speed is increased; thus the rotor tilt causes the machine to return to the original speed. This condition constitutes stability of the rotor with respect to speed. Wind-tunnel investigations of the subject fuselage (reference 4) have shown it to be unstable with respect to speed, but this instability is evidently outweighed by the rotor stability just discussed, inasmuch as measurements have shown that the stick-position gradient with respect to speed is stable. Furthermore, observation and measurements have indicated that the static stick-force gradient with respect to speed is small, but it has been either unstable, neutral, or stable, the gradient depending upon the pitching moments of the particular blades and upon the bungee configuration; however, the pilot's over-all impression that the helicopter is unstable is not greatly affected by these force gradients. The source of the difficulty, therefore, cannot be either stick-fixed or stick-free instability with speed.

The somewhat obvious conclusion is that the pilot's impressions are a result of the helicopter's instability with angle of attack. At least two logical sources exist for this instability with angle of attack: (1) When the helicopter rotor is subjected to an angle-of-attack change in forward flight, for constant rotational speed the advancing blades are subjected to a greater upward accelerating force than the retreating blades because the product of angle-of-attack change and velocity squared is greater on the advancing side than on the retreating side. The resulting flapping motion will then tilt the disk in the direction of the initial change and an unstable moment will result. This effect is a function of the tip-speed ratio and becomes more pronounced at higher speeds. (2) Wind-tunnel investigations of the fuselage of the subject helicopter have indicated that it is unstable with respect to angle of attack (reference 4).

Although airplanes can and do exhibit instability with angle of attack at times, this condition is recognized as unsatisfactory and is generally prevented by keeping the center of gravity sufficiently far forward.

The effects of the instability with respect to angle of attack on the flight characteristics of the helicopter were subsequently investigated in more detail, first in the low-speed flight range and then at successively higher speeds. In maneuvers in which the stick was abruptly deflected from trim and held, the normal acceleration was found to build up at an increasing rate for a length of time detectable to the pilot. Furthermore, the acceleration and pitching velocity, at least for small stick deflections when the maneuver could be continued for a reasonable time, did not reach a maximum until 3 or 4 seconds had elapsed. The

acceleration and pitching velocity in this type of maneuver apparently would continue to increase for even greater periods of time were it not for the stabilizing influence of the associated speed change.

The stick forces accompanying these maneuvers are undesirable. The pilot's impressions are that after transient effects have disappeared, the forces become somewhat unstable, that is, a push in pull-ups or a pull in push-downs, the magnitude of the forces depending upon blade characteristics. Of course stable forces are considered necessary for satisfactory handling qualities.

Longitudinal Oscillations

Stick-fixed longitudinal oscillations of the test helicopter were studied to clarify the interaction of the stability with speed and instability with angle of attack. Time histories of two attempted stick-fixed oscillations have been prepared. For these cases the helicopter had a set of experimental blades of low solidity that were not production blades. Low solidity necessitates higher pitch at the same rotational speed and thus stalling was encountered at lower forward speeds for the low-solidity blades than for the production blades.

Figure 2 shows an oscillation initiated from steady level flight at 40 miles per hour by a momentary rearward motion of the stick. The type of motion shown resembles the airplane phugoid motion in that changes in airspeed and altitude occur, but the important difference is that definite changes in angle of attack take place. The period of the motion is about 14 seconds, which is long enough that the pilot does not have trouble controlling the oscillation. The motion about doubles in amplitude in one cycle. During the third cycle the machine reaches 25° nose up from the trim attitude and shows increments in acceleration, from the 1 g condition, of about 0.4g and −0.3g. This maneuver was terminated when the attitude and the rate of change of attitude, acceleration, and speed were such as to cause the pilot to become apprehensive.

Figure 3 shows an oscillation attempted from steady level flight at 65 miles per hour. Again the helicopter was disturbed by an intentional stick motion, after which the stick was held fixed at the trim position. The helicopter nosed up mildly and then nosed down. The helicopter was still nosing down at an increasing rate, as the acceleration curve indicates, at about $9\frac{1}{2}$ seconds after the start of the maneuver, or about 4 seconds after the 1 g axis was crossed, and the recovery had to be made by control application. Immediate response to rearward control was obtained, but as 1 g was reached, the pilot had not only moved the control back to the trim position but was also moving it rapidly forward to check the acceleration which was building up at a high rate. The control reached

the forward stop about 2 seconds before the acceleration reached its peak of 1.7g. The time history does not tell the whole story, however, for during this maneuver, as the stick approached the forward stop, the collective pitch was reduced to about 6° to reduce the acceleration and the associated blade stalling. The rotational speed went above the placard limit. In addition, the horizon disappeared from the pilot's view; thus a very high attitude was indicated, when the field of view from this aircraft is considered. A roll at the top of the maneuver as in a wing-over was necessary for recovery. The maneuver just described could be entered inadvertently should the pilot permit his attention to be briefly diverted. It is obviously extremely hazardous and the consequences should not be underestimated.

Comparison of these two time histories indicates the marked influence that speed has on the instability with angle of attack and therefore on the difficulty of controlling the aircraft. In order to bring out this trend with speed more clearly, additional oscillations, including some made in mildly gusty air, were made to provide more points in the speed range. In order to obtain greater generality, different rotor blades were used on the same helicopter and a later model helicopter of basically similar design was also utilized. In all cases the time required with controls fixed to reach a dangerous flight condition following the first definite nose-down motion was noted. For the cases where relatively complete instrumentation was used, the increment in normal acceleration from the 1 g condition that had been reached, at the flight condition considered dangerous, was usually about $\frac{1}{4}$g, regardless of forward speed. The acceleration increment appears to be a much better criterion for the flight condition at which recovery must be started than is the more commonly discussed attitude angle. The value of $\frac{1}{4}$g mentioned for this increment probably corresponds to the particular helicopter under test and may be expected to vary with size and other characteristics of the helicopter. The results of the measurements that have been made are summarized in figure 4. In this figure the increment in acceleration per unit time is shown plotted against airspeed. The ordinate values were obtained by taking the reciprocal of the values of time to reach a dangerous flight condition, which, as has been pointed out, corresponded to a reasonably fixed acceleration increment of about $\frac{1}{4}$g. Thus, the higher the value shown, the earlier a dangerous condition would be reached and, hence, the more frequently the pilot has to apply control to maintain steady flight. In other words, if corrective control is applied at given intervals, then the higher the value shown, the greater the amount of corrective control required.

From about 40 miles per hour to 50 or 60 miles per hour the values shown are relatively low. In this region the helicopter can actually be made stable by relatively simple means, and in any event it requires relatively little attention from the pilot. At the higher speeds the attentiveness required of the pilot rises rapidly. In like manner, many methods of improving the stability characteristics which could readily be

made to function satisfactorily at low speeds will offer greater difficulty or may even become inadequate at these higher speeds. Note that a peak is shown at about 30 miles per hour. In this range, if the controls are fixed, the helicopter will soon nose up, slow down, and slide backwards with resulting yawing motions and control difficulties.

Observations Particularly Concerning Hovering

Thus far only the forward-flight characteristics have been discussed. Hovering, of course, precedes and follows all forward flight and is the outstanding reason for the existence of helicopters. At the present time, however, the problems associated with hovering are more indefinite than the problems in forward flight; they tend to disappear with a little flight practice; and they do not affect the general utility of the helicopter to the extent that limitations placed on night and instrument flying do.

One of the problems which the trainee must overcome in a helicopter of this type and size is the high control sensitivity in roll or, in other words, the high rate of roll per inch of stick displacement. This sensitivity can lead to overcontrolling which results in a short-period, pilot-induced, lateral oscillation. It is caused, apparently, by the pilot's lag in removing control following response of the machine. The result can be likened to what occurs with an autopilot having improper follow-up. A point to be remembered is that with constant ratio of control-stick displacement to cyclic feathering the steady rolling velocity obtained will vary inversely as the diameter of the rotor, or, the smaller machine will roll faster. Thus, sensitivity becomes less of a problem with larger machines.

The forces the pilot encounters in deflecting the stick can accentuate or minimize his impression of the sensitivity. The pilot should first be able to trim steady forces to zero. He should also have a force gradient, or spring constant, opposing displacement of the stick in order that he can properly judge the control being applied. The control-force gradient centers the stick when it is released; therefore, the lag in the pilot's follow-up process and the effort required are reduced. With one set of blades on the subject machine the lateral gradient was satisfactory, but with other blades peculiar characteristics appeared. In some cases the initial force change with deflection was proper, but the force returned to zero or even reversed as rolling velocity developed. This characteristic is considered very undesirable by the pilot. Figure 5 illustrates the character of the lateral forces immediately following stick displacement for two different rotors. Rotor A illustrates the type of transient force variation considered unsatisfactory, while the force variation for rotor B was considered acceptable.

The longitudinal forces immediately following abrupt stick displacement differ in character from the lateral forces (fig. 6). In this case neither rotor A nor rotor B showed acceptable characteristics, although the pilot reported the characteristics of rotor A noticeably inferior to those of rotor B.

In another case abrupt stick motions were found to cause forces perpendicular to the direction of motion which tended to whirl the stick in the direction of rotor rotation. The stick would go to full deflection in a spiral motion if released. The forces for restraint of the stick became higher as the stick was moved more rapidly. Overcontrol results in this case because the pilot fights the forces.

No less important in promoting overcontrol is high control friction. Friction prevents accurate positioning of the control because of the extremely nonlinear force gradient it provides for small deflections and because the control tends to jump as static friction is broken. Friction also prevents self-centering of the control and consequently causes poor follow-up and an increase in the required pilot effort. The control difficulties imposed by high sensitivity and undesirable forces fortunately can be greatly lessened with relatively little practice. The control difficulties imposed by friction, however, always increase the demands on pilot effort and are hardest for the pilot to overcome in avoiding overcontrol.

The extrapolation of roll measurements to full control deflection indicates that the maximum rate of roll for this aircraft is as great as those of some modern fighter airplanes at the speeds for their maximum rates of roll. The high rate of roll achieved with the helicopter is apparently due to low damping and not to high control power, because the moments developed about the center of gravity are always relatively small. Computations of the damping indicate that it is a fraction of that for airplanes and could be expected to result in large amounts of continued roll following the centering of the controls from high rates of roll. In observations made at 40 miles per hour, however, where experiments with large rates of roll were convenient, no tendency to overshoot could be detected by the pilot. In hovering, both pilot observations and instrument measurements have indicated that the tendency to overshoot, while presumably present, is secondary to the effects of the stability with speed which results from the lateral motion acquired. Apparently, the lateral velocity can, in accordance with the details of the maneuver, either cancel or add to the tendency to overshoot.

Many descriptions of the control response of this and similar helicopters in terms of lag have been made. The control lag, as defined by the time necessary for the rotor to reach a position corresponding to any specified stick position during steady motion of the controls, has been

found to be actually less than 0.1 second for the subject rotors, a time period too short for perception by the pilot. Correspondingly, after the stick reaches its position following an abrupt lateral deflection only about 0.1 second elapses before the fuselage attains maximum angular acceleration in roll. Experience gained from airplane handling-qualities studies indicates that this is a satisfactory response; in fact, airplane requirements allow 0.2 second (reference 5). The helicopter also approaches a steady rate of roll in about the same time as does an airplane. The impression of lag when hovering, therefore, seems to arise from the fact that velocity changes or displacement of the helicopter in space do not follow the inclination of the thrust vector immediately, because of the mass of the machine. A similar apparent lag effect occurs in airplane formation flying where the problem is to control the rate of closure. The pilot overcomes his first impressions of lag during training by learning to control the helicopter's accelerations.

In hovering the helicopter also drifts back and forth as a result of the motions of the air. Some drift has to be expected of any aircraft since it is supported by the air. The stability of the machine with respect to speed and the directional stability in connection with yawing motions, both of which are desirable in other respects, increase the tendency to move or yaw with changes in wind velocity or direction. In this respect, reduction of stability can be beneficial.

In hovering, control-fixed lateral and longitudinal oscillations have been found to build up rapidly in amplitude per cycle. Since the machine performs an oscillation, a restoring tendency following a disturbance exists due to stability with speed. The restoring tendency itself is beneficial, provided the period of the motion is long enough to allow for the pilot's reaction time in perceiving and correcting the motion. The longitudinal period for the helicopter was found to be about 14 seconds, while the lateral period was about 6 seconds, a considerably shorter time. From experience gained from airplane handling-qualities studies and from personal experience with this and some other helicopters the period of the lateral motion is considered great enough to eliminate it as a control problem.

Isolated Flight Phenomena

Early in the rotor performance investigations a phenomenon in connection with vertical flight was encountered. In determining the power required at zero airspeed with varying rates of descent, a region was encountered in which control of the machine could not be maintained. The descents were entered from forward flight with fixed power, and when zero airspeed was reached the rate of descent was low. If the power was insufficient to maintain descent at less than 500 feet per minute (as indicated by a standard rate-of-climb indicator) the machine would slowly increase its vertical velocity. At an indicated rate of descent of about 500 feet per minute, shaking of the machine became quite pronounced. Rather

violent, random yawing motions would then occur with some roll, the rate of descent would apparently increase rapidly, the rotational speed of the rotor would vary noticeably, and more often than not the machine would eventually pitch nose down and recover by gaining speed, despite application of considerable rearward control. This behavior had many variations which apparently depended on small horizontal velocities and on power conditions. In some cases similar shaking of the machine was encountered at indicated rates of descent of only 300 feet per minute. The loss of control appeared most severe when the power was as high as possible at the required rate of descent. As power was progressively reduced during successive trials the difficulties were reduced to the point at which no trouble was encountered for the power settings permitting steady descents of about 1500 feet per minute and higher. These descents were always performed with a margin of altitude and no difficulty was ever encountered in recovering at any stage desired.

The yawing motions and inadvertent recovery mentioned previously are possibly affected by rearward velocity. Nevertheless, the fundamental cause of the phenomenon appears to be an irregular flow of air through the rotor. In hovering, a definite downward flow of air through the rotor occurs, and in descent with the power completely off an upward flow of air through the rotor takes place; but in this intermediate condition the air tends to move with the rotor. A logical assumption is that when the air attempts to stay with the rotor, it might actually mix in turbulent and erratic fashion with the air outside the rotor disk. Motion-picture studies of tufted blades during some of these cases have thus far shown no stalling but have shown pronounced, but irregular, blade bending. The presence of this irregular bending tends to support the irregular-flow explanation, but much remains to be learned about this region of operation.

Another phenomenon has been encountered following take-off. The machine was being accelerated rapidly horizontally from hovering and, at 20 to 30 miles per hour, it pitched up abruptly. In several cases it was necessary to have the control against the forward stop for a short interval of time to check the motion. This same tendency has been noticed in other helicopters. The horizontal acceleration is normally low enough that full control deflection is not required. This characteristic may be due to the dynamic stability characteristics in pitch and to the rapid entry into the higher speed range. This condition should be investigated, however, as a possible critical one in determining the required control range.

The preceding sections have pointed out some of the stability and control characteristics found for a particular helicopter type. They appear to be applicable to other types, however, in whole or in part.

DISCUSSION AND POSSIBLE SOLUTIONS

The basic purposes for making flying-qualities studies are to isolate the characteristics most in need of improvement and to find means for achieving these improvements. A discussion of a few examples of the lines of development which are suggested by the evaluation of flying qualities which have been given therefore seems in order.

In the authors' opinion the problem which seems to need investigation most urgently is the instability with angle of attack. One proposed solution to this problem is to provide stick forces in the proper direction, or stick-free stability. This proposal means that in maneuvers at constant speed pull forces are required to hold constant positive acceleration and push forces to hold negative acceleration. This solution does not alter the fact that the control moves in the wrong direction as the maneuver develops. Stick-free stability is considered to be essential for a completely satisfactory solution but is not, in itself, sufficient. First, the stick is never actually free because of friction; also, the pilot imposes some restraint on the stick, either consciously or unconsciously, because the stick will tend to move noticeable amounts in counteracting the stick-fixed instability. Second, and most important, the stick-free stability does not alter the fact that maneuvers (either intentional or due to gusts) can be severe enough that insufficient control for prompt recovery exists.

If the machine could be provided with stick-fixed stability with respect to angle of attack, the danger of loss of control would be virtually eliminated, and friction or pilot restraint of the stick would not affect the machine's tendency to maintain steady flight. Maneuvers could be executed without reversing the stick motion, and recovery could be made by simply returning the stick to the trim position. Stick-free stability could be provided in this case by mechanical means such as simple springs.

Since the instability with angle of attack arises as a result of forward speed and is greatest at the highest speeds, to attempt to obtain the desired stabilizing forces by using some form of horizontal tail surface mounted on the fuselage seems logical. This use of a horizontal tail surface is particularly valid, of course, for overcoming the instability of the fuselage itself. Rotor instability could more logically be eliminated by self-contained means, but the more practical immediate solution may nevertheless lie in the use of some form of horizontal tail surface. Preliminary calculations indicate that a rather small tail area should suffice; for example, calculations for a sample two-place helicopter indicated that about 4 square feet would be needed to stabilize the fuselage and that an additional area of about 4 square feet should serve to stabilize the rotor.

One obvious disadvantage resulting from the use of the tail surface lies in the undesired vertical loads and pitching moments developed in hovering and vertical flight. For the areas mentioned these forces are actually quite small but may be further reduced, if desired, by using a biplane tail surface which would present less projected area in vertical flow or by using a free-floating tail surface arranged to be effective only in forward flight. More serious problems may arise from the fact that, in forward flight, a change from level flight to climb or to autorotation results in a sizable change in the angle of attack of the tail surface. This change occurs because the attitude angle of the helicopter remains roughly constant while the flight-path angle changes. This situation suggests that for at least the faster and more highly powered helicopters the tail surface should be made to move in conjunction with the pitch controls or should be made free-floating.

These problems and a number of details concerning the rotor downwash need further clarification before the helicopter designer can be expected to make full use of the tail surface as a cure for the angle-of-attack instability.

An improvement in the hovering characteristics should also be possible. Control sensitivity could be reduced by changing the control-system gearing, but this change is undesirable because it would limit the control available for trim unless a nonlinear system were used. A more logical solution would be to provide the pilot with a stick-force gradient which is suitably proportioned to the control sensitivity. In this regard the effects of size tend to be contradictory. In other words, the smaller the helicopter the greater its control sensitivity but the smaller the probable force gradient, and vice versa; whereas the greater sensitivity should be accompanied by a larger force gradient.

Control sensitivity could also be reduced by increasing the damping and thus reducing the rate of roll. One way of making this reduction involves increasing the control lag by changing the rotor characteristics. Control lag, however, should not be increased to more than perhaps three or four times that of the subject helicopter, or more than perhaps 0.2 to 0.3 second, as it may lead to overcontrol of a different type than that mentioned previously and one which is more dangerous because of larger amplitude. A better solution would be to increase damping without changing lag.

Friction in the control system should be kept to a minimum or to a value which will permit good self-centering characteristics. Undesirable transient control forces in maneuvers, as well as excessive vibratory stick forces, should be prevented from reaching the pilot by means of irreversible mechanisms rather than by introduction of large amounts of friction. The desired control feel can then be introduced on the pilot's side of the irreversible mechanism.

In order to reduce the tendency of the machine to react to horizontal gusts in hovering, the stability with speed could be reduced as by the use of a linkage such that flapping causes corrective feathering.

CONCLUDING REMARKS

Flight investigations of a helicopter have been made to help in clarifying the outstanding flying-qualities problems and have lead to the following observations:

The forward-flight instability with angle of attack of the rotor and the fuselage is of greatest concern. The rotor instability is considered to arise as a result of flapping and increases in severity with increasing speed. This instability may result in the loss of control in rough air, in maneuvers, or during instrument flight. The possibility of alleviating this difficulty by means of a tail surface is briefly discussed.

In hovering, neither the period of the stick-fixed oscillations nor the lag in the response of the rotor to control application - both of which have at times been suspected of making hovering difficult for the beginner - was found objectionable. The smaller helicopters, however, have been found to develop high rates of roll per unit stick displacement, and this sensitivity results in a tendency for an inexperienced pilot to overcontrol, particularly during hovering. Reduction in sensitivity by changing the control-system gearing is not feasible because of requirements for trim in forward flight. The situation can be alleviated, however, by increasing the rotor damping, although caution must be used to prevent introducing excessive control lag as a result. A further means for reduction of the control difficulties caused by high sensitivity lies in the providing of an appropriate stick-force gradient.

It is difficult with any whirling rotor system, and particularly with the larger and faster machines, to prevent the occurrence of undesirable control-system forces. In several cases movement of the control stick was found to result in transient forces of an unstable nature or in forces out of phase with the direction of stick motion. These phenomena were noted in hovering as well as in forward flight. Such forces were found to increase the difficulty of control greatly and therefore indicate the desirability of irreversible control systems with the desired feel introduced on the pilot's side of the irreversible mechanism. Friction has been used as a cure but in itself has been found very undesirable.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
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Figure 1.- General view of test helicopter.

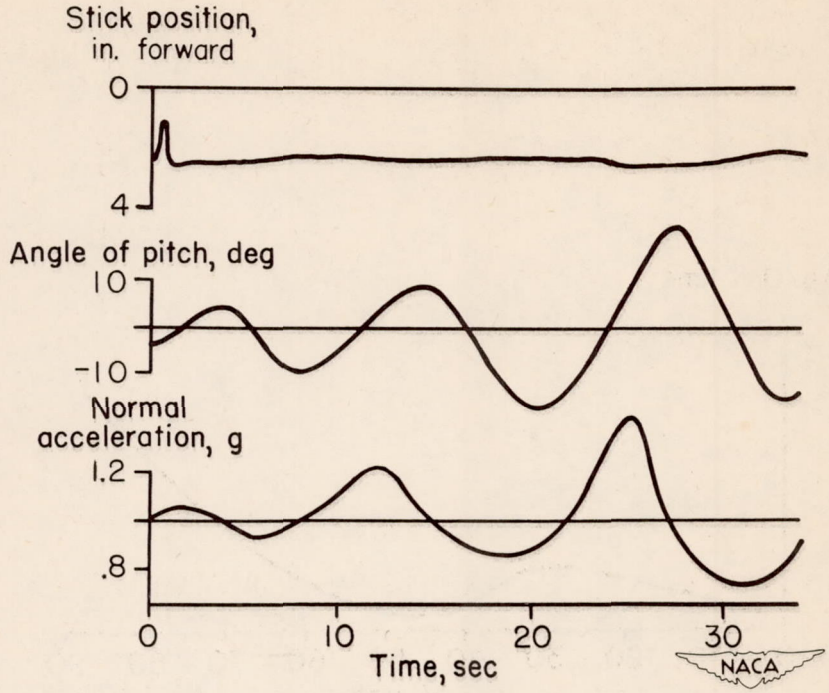

Figure 2.– Longitudinal oscillation at 40 miles per hour.

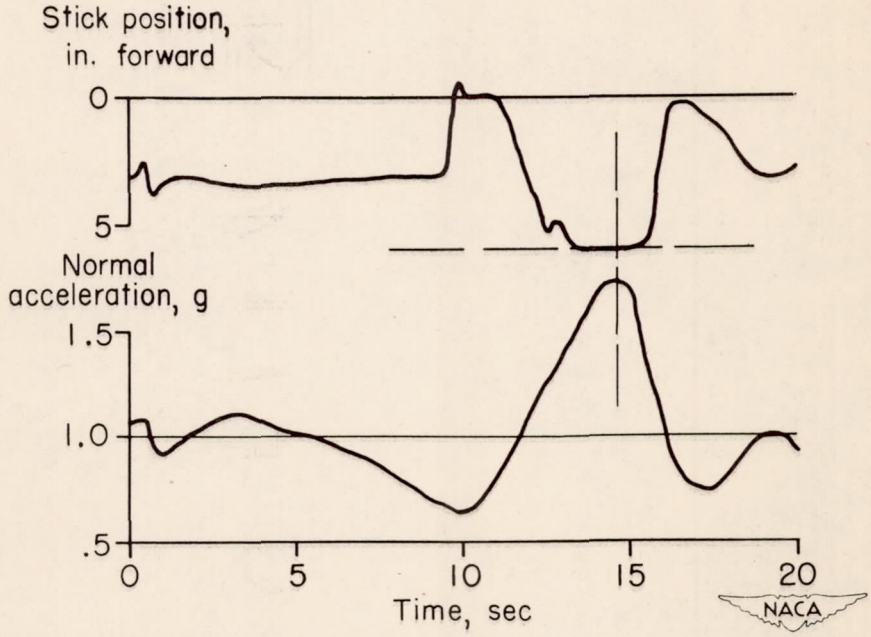

Figure 3.– Longitudinal oscillation at 65 miles per hour.

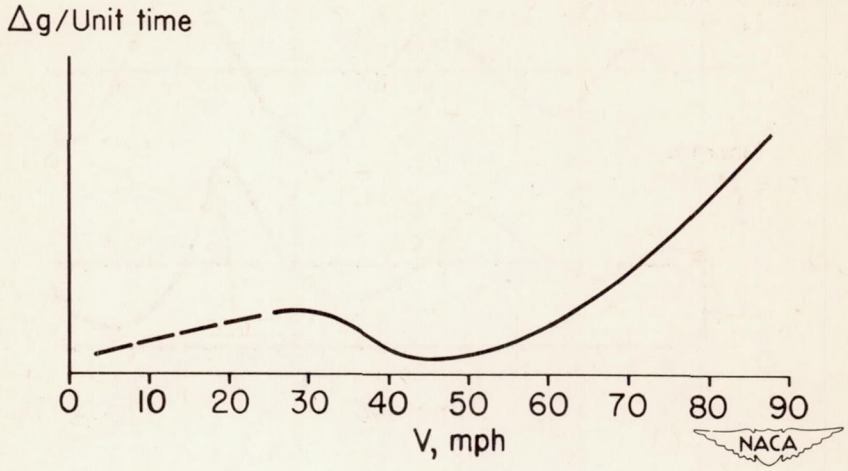

Figure 4.– Rate of deviation from steady trimmed flight.

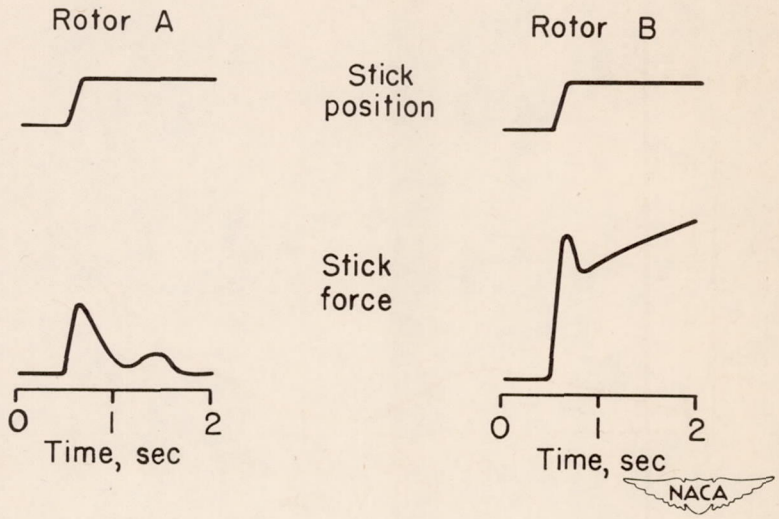

Figure 5.– Stick forces following abrupt lateral stick deflection.

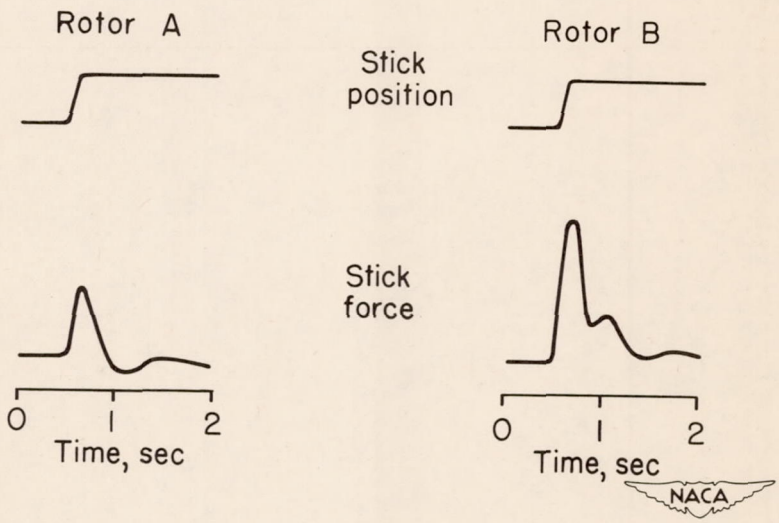

Figure 6.– Stick forces following abrupt longitudinal stick deflection.