NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1060

AN INVESTIGATION OF ADDITIONAL REQUIREMENTS FOR SATISFACTORY ELEVATOR CONTROL CHARACTERISTICS

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SUMMARY

Tests of three airplanes have been conducted in an effort to develop elevators that would provide stick forces in steady turns within the limits required by the Army and Navy handling-qualities specifications over a large range of center-of-gravity positions (about 10 percent of the mean aerodynamic chord). In order to obtain the desired stick forces in steady turns, closely balanced elevators were used in conjunction with bobweights or with types of balance that gave the elevators a tendency to float against the relative wind. Although the desired stick forces in steady turns were obtained, the control characteristics were considered unsatisfactory by the pilots because of the lightness of the forces required in rapid pull-ups and because of the uncertainty of the control in rough air. These tests indicate that the desire to provide stick forces in steady turns within specified limits over a large center-of-gravity range tends to conflict with the need for sufficiently heavy stick forces in maneuvers involving rapid stick movements. Several factors that may limit the degree of elevator balance permissible (and hence set a limit on the allowable reduction in variation of force per g with center-of-gravity position) are discussed.

As a result of the tests, requirements have been added to the Army and Navy stability and control requirements for airplanes that the gradient of elevator control force per g in quick pull-ups shall never be less than in steady

turning flight under the same conditions. Further research is needed to determine whether a more severe restriction is desirable and to investigate flight test procedures for studying control characteristics in quick maneuvers.

INTRODUCTION

Requirements for the elevator-control characteristics in maneuvers were first established on the basis of the stick force required per g normal acceleration in steady turns (reference 1). Tests at the Langley Laboratory of the NACA have shown that an airplane designed to have stick-force gradients within the required limits over the allowable center-of-gravity range may still be considered unsatisfactory because of undue lightness of the control force required for rapid movements of the stick. Limitations on the degree of elevator balance that may be required to provide satisfactory characteristics in this respect are therefore discussed.

TESTS, RESULTS, AND DISCUSSION

Tests of three airplanes have recently been conducted to develop elevators that would provide light stick forces over a large center-of-gravity range. Two of these airplanes, a small fighter and a scout-bomber, were of conventional design; the third was an airplane equipped with an experimental all-movable horizontal tail. In the case of the fighter and scout-bomber types, it was desired to meet the requirements for satisfactory stick forces (3 to 8 pounds per g) specified in references 2 and 3 over a center-of-gravity range of approximately 10 percent of the mean aerodynamic chord and over a considerable range of altitudes. The desired characteristics in steady maneuvers were obtained by providing closely balanced elevators to reduce the variation of force per g with center-of-gravity position and small bobweights to adjust the stick forces to the desired level. A similar arrangement was used in the airplane with the all-movable tail. Although the specified characteristics in steady turns were obtained, the control characteristics of all three airplanes were considered unsatisfactory by the pilots. The objectionable characteristics consisted in a feeling of uncertainty in normal flight, because of the ease with which rapid inadvertent movements of the stick could be made. This condition was aggravated in flight in rough air, where continual attention to the control was required to avoid introducing unsteadiness in the airplane motion due to movements of the control stick.

The undesirable control characteristics appeared to be related to the control forces required in rapid rather than in steady maneuvers. For this reason records of stick forces, control movements, and airplane motion were obtained in various types of rapid maneuvers in airplanes equipped with experimental closely balanced elevators and also in some conventional airplanes for comparison.

One maneuver tried was a rapid pull-up in which the pilot moved the control stick quickly to some deflection and then immediately returned it to its trim position. Typical time histories of this type of maneuver are shown in figure 1. This maneuver is of interest because it simulates the small-amplitude control movements that a pilot may make in correcting for disturbances caused by rough air or the stick movements used in rapidly entering accelerated maneuvers. It also affords a comparison with the theoretical analysis of the control forces associated with this control movement presented in reference 4. An analysis of some of the records of pull-ups made at varying rates is presented in figure 2. In this figure the ratio of the maximum stick force to the maximum acceleration obtained in each pull-up has been plotted against the duration of the maneuver, which is defined in figure 1.

Results are given for the fighter airplane equipped with a closely balanced elevator that had a tendency to float against the relative wind, in conjunction with a bobweight that required a 3.5-pound pull force on the stick. Similar data are presented for another airplane of about the same size with a less closely balanced elevator that was considered satisfactory by the pilots. The results indicate that the ratio of maximum force to maximum acceleration for an airplane considered satisfactory by the pilots increased greatly as the maneuver was made more rapidly. On the other hand, the ratio of maximum force to maximum acceleration for the airplane with experimental elevators decreased slightly as the maneuver was made more rapidly, until the maneuvers became very fast (about 0.7 sec). For still faster maneuvers, the ratio of force to acceleration rose sharply. This increase is attributed to the effect of inertia of the control system rather than to aerodynamic forces.

It has been shown in reference 4 that the stick-force characteristics presented in figure 2 for the conventional airplane are associated with an arrangement in which the stick force comes mainly from the variation of elevator hinge-moment coefficient with elevator deflection $\frac{\partial C_{h_e}}{\partial \delta_e}$. The stick force for a given acceleration in a rapid maneuver is greater than that for a steady turn, mainly because of the larger elevator deflection required for a given acceleration. The type of variation shown in figure 2 for the experimental elevator is attributed to the fact that the value of $\frac{\partial C_{h_e}}{\partial \delta_e}$ is small and the stick force comes largely from the bobweight or from the variation of elevator hinge-moment coefficient with angle of attack of the tail $\frac{\partial C_{h_e}}{\partial \alpha_t}$. The stick-force increment from these sources does not change with the rapidity of the maneuver. The ratio of maximum stick force to maximum acceleration may even decrease as the maneuver is made faster, as shown in figure 2, because the maximum stick-force increment from the bobweight occurs simultaneously with the maximum stick-force increment due to elevator deflection in slow maneuvers but lags behind the increment due to elevator deflection in rapid maneuvers.

In reference 4 it is pointed out that arrangements in which the ratio of force to acceleration decreases for rapid maneuvers would probably prove unsatisfactory. The present tests indicate that some increase in the force with rapidity of the maneuver is required for good control feel.

Another type of maneuver used to investigate the undesirable characteristics of the closely balanced elevators was a forced longitudinal oscillation in which the pilot moved the control stick back and forth with varying frequencies and amplitudes. Typical records of these oscillations are shown in figure 3 for the fighter airplane mentioned previously and for an airplane of the scout-bomber class that was considered satisfactory by the pilots. Though the records were not obtained with the same type of airplane, they are comparable in that the force per g in steady turns was about 4 pounds per g for both airplanes in the test condition shown. The force required for rapid movements of the elevator, however, was about one-tenth as great for the fighter airplane. This large difference in the force required for rapid stick movements is believed to be the reason for the difference in the pilots' impression of the handling characteristics of the two airplanes.

Present NACA flying requirements for the damping of the short-period control-free longitudinal oscillations state that when the elevator is abruptly deflected and released any oscillation of the elevator or the normal acceleration should disappear in less than one cycle. (See reference 1.) Measurements were made of the short-period-oscillation characteristics of the airplanes by abruptly deflecting and releasing the control stick. As would be expected from theoretical considerations, poorly damped short-period longitudinal oscillations, which were considered unsatisfactory, were obtained with the airplanes tested under conditions that included a combination of a low value of $\frac{\partial C_{h_e}}{\partial \delta_e}$, a bobweight in the control system, and flight at high altitude. In some cases, however, the airplanes were still considered unsatisfactory under conditions in which they met the requirements for damping of the short-period oscillations and stick forces in steady maneuvers. For example, records are shown in figure 4 of a short-period oscillation obtained with the fighter airplane with closely balanced elevators taken under the same conditions as the data shown in figure 2. Similar records are also shown for the airplane with the all-movable tail, equipped with a bobweight that provided a stick-force gradient of 6 pounds per g in steady turns. In both of these cases, the oscillation of the elevator disappeared within one cycle after the stick was released; yet the airplanes were considered unsatisfactory. Satisfactory control characteristics, therefore, do not appear to be assured if the present requirements for damping of the control-free oscillation are met.

No definite recommendations can be made at present for the limits to which the negative value of $\frac{\partial C_{h_e}}{\partial \delta_e}$, and hence variation of force per g with center-of-gravity position, can be reduced without causing control difficulties of the type described. One factor of importance in determining the limits appears to be the force required for a sudden deflection of the elevator. Because the force required for a sudden deflection is proportional to the product of $\frac{\partial C_{h_e}}{\partial \delta_e}$ and the span times the square of the chord of the elevator, a smaller negative value of $\frac{\partial C_{h_e}}{\partial \delta_e}$ would appear to be permissible on a larger airplane.

The use of a bobweight to increase the force per g in steady turns to a desirable value when the center of gravity is close to the stick-fixed neutral point appears to contribute to the undesirable sensitivity of the controls of the airplanes that were equipped with closely balanced elevators. One disadvantage of the use of a bobweight, or a positive value of $\frac{\partial C_{h_e}}{\partial \alpha_t}$, is that the forces are transmitted to the pilot through the stick when the airplane flies through bumpy air. From the standpoint of rough-air control-force characteristics, a value of $\frac{\partial C_{h_e}}{\partial \alpha_t}$ of zero appears to be most desirable. Bobweights have proved successful, however, on some airplanes that had small values of stick-fixed stability but less closely balanced elevators. Some airplanes with small values of the product of $\frac{\partial C_{h_e}}{\partial \delta_e}$ and elevator span times the square of the elevator chord have been considered satisfactory if the force per g were obtained by having the center of gravity well ahead of the stick-fixed neutral point rather than by using a bobweight. This arrangement results in increased values of the ratio of maximum force to maximum acceleration in rapid maneuvers, even though the force required for a sudden elevator deflection is small.

Some device embodying springs, inertia weights, or damping devices might possibly be used to increase the force required for rapid stick movements and to avoid the undesirable feel associated with a closely balanced elevator. No such devices have yet been tried in flight.

As a result of the tests reported herein of the airplanes with closely balanced elevators, a requirement has been added to the Army and Navy stability and control requirements for airplanes (references 2 and 3) which states that the gradient of elevator control force per g in quick pull-ups shall never be less than in steady turning flight under the same conditions. Because of lack of complete knowledge of the subject, any more rigid requirement at the time the Army and Navy requirements were revised was considered inadvisable.

RECOMMENDATIONS FOR FUTURE RESEARCH

A simple and conclusive flight test to determine whether or not an airplane is satisfactory from the standpoint of control characteristics in quick maneuvers would be very desirable. Neither the rapid pull-ups made at varying rates nor the forced sinusoidal stick oscillations appear to be completely suitable for this purpose, because they require a large number of runs and because they are not readily reproducible by different pilots. Another maneuver that has been suggested to test for this condition consists in trimming the airplane to zero stick force in a turn at a reasonable value of acceleration and then returning to straight flight at the same speed and abruptly releasing the stick. If the airplane pulls up and overshoots the steady acceleration, the stick force per g at the point of maximum acceleration is shown to be lighter than the stick force per g in steady accelerated flight. This motion in this maneuver is, of course, directly related to the damping of the control-free oscillation and, as noted previously, the specified damping of the control-free oscillation does not appear to insure satisfactory characteristics in quick maneuvers. It is possible, however, that a more rapid damping of the oscillation than that specified in the present requirements would be necessary to prevent overshooting the steady acceleration in this type of maneuver. Insufficient flight experience has been accumulated on any of these maneuvers to set up a suitable test for the longitudinal-control characteristics. It would, therefore, be desirable to investigate this problem more completely to arrive at a satisfactory test procedure.

CONCLUSIONS

Tests of three airplanes have shown that undesirable control characteristics, consisting of undue lightness of the stick forces for rapid stick movements and sensitivity of the control in rough air, may be encountered if the elevator is too closely balanced, even though the stick forces in steady turns are sufficiently large. Conditions defining the limiting degree of balance allowable are not completely understood at present. The following conclusions may, however, be stated:

1. The requirements for stick forces in steady turns and damping of the control-free longitudinal oscillation are not adequate to assure that the elevator control characteristics will be satisfactory in all cases. An airplane may meet these requirements and still be unsatisfactory because the stick forces for rapid stick movements are too light. As a result of these tests, a requirement has been added to the Army and Navy stability and control requirements for airplanes, namely, that the gradient of elevator control force per g in quick pull-ups shall never be less than in steady turning flight under the same conditions.

2. The requirement for providing stick forces in steady turns within certain specified limits over a large center-of-gravity range tends to conflict with the need for sufficiently heavy stick forces in maneuvers involving rapid stick movements.

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National Advisory Committee for Aeronautics
Langley Field, Va., July 19, 1945

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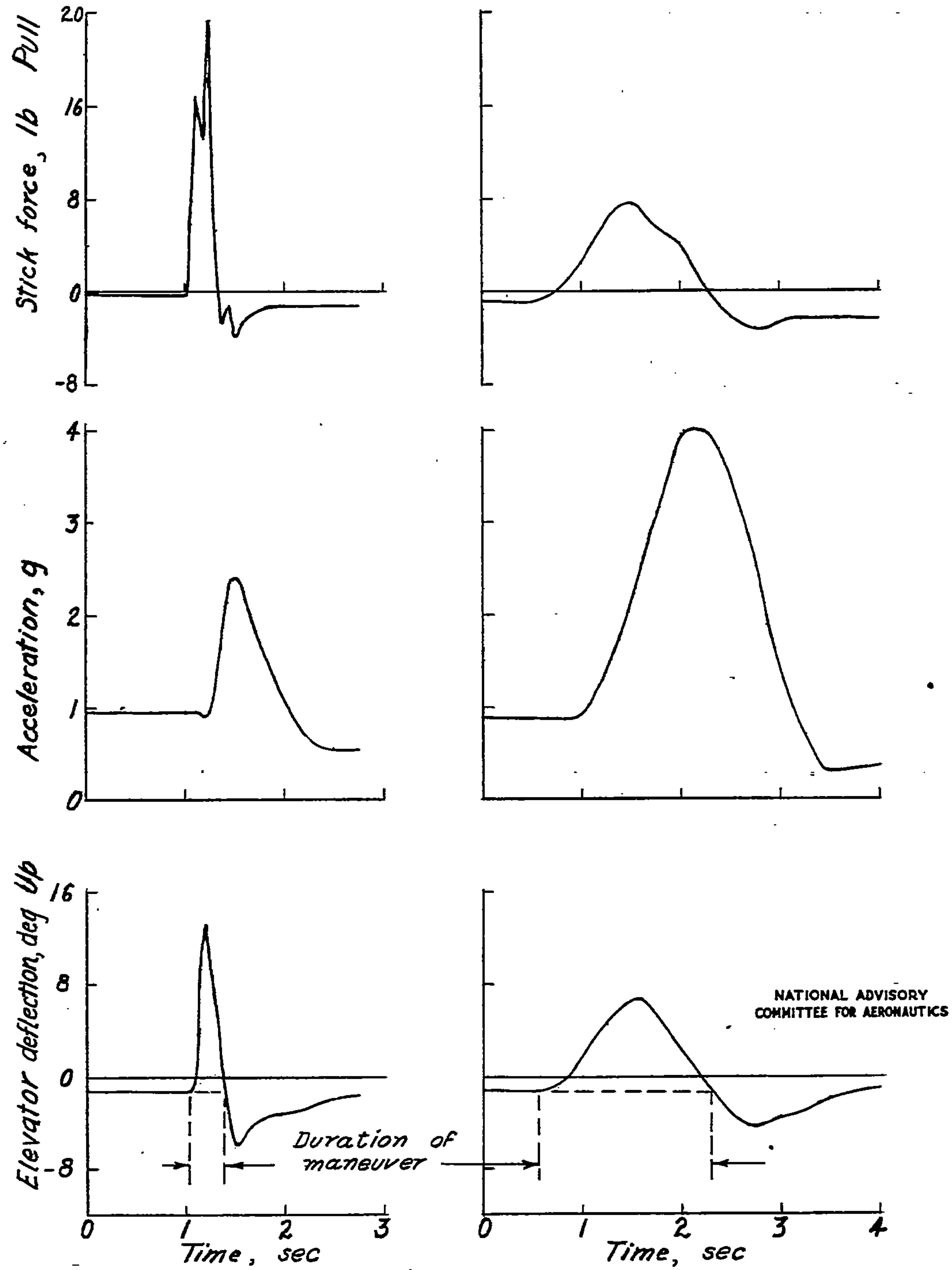


Figure 1.- Typical time histories of rapid pull-ups of fighter airplane with closely balanced elevators, no bobweight. Indicated airspeed, 200 miles per hour.

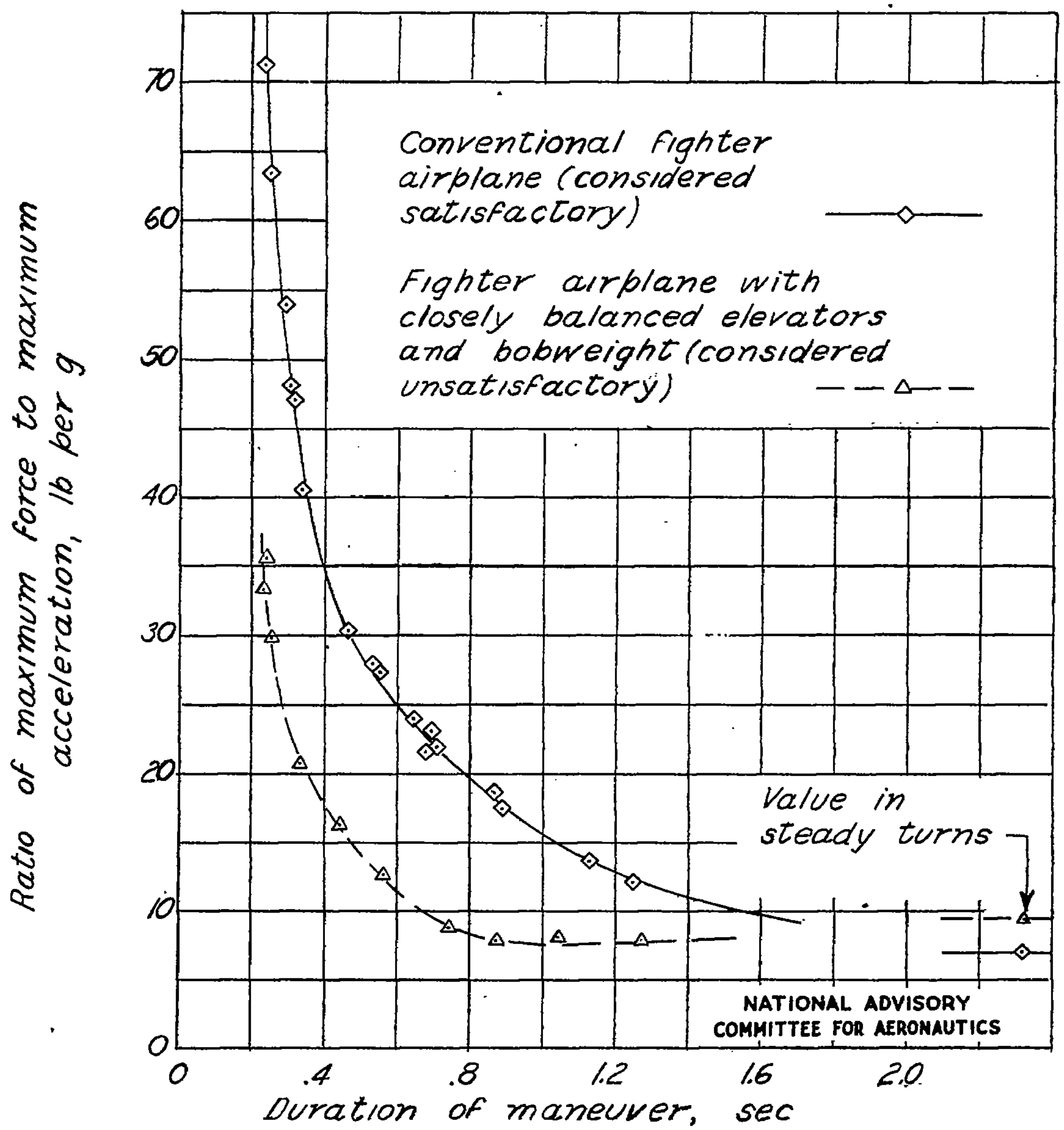
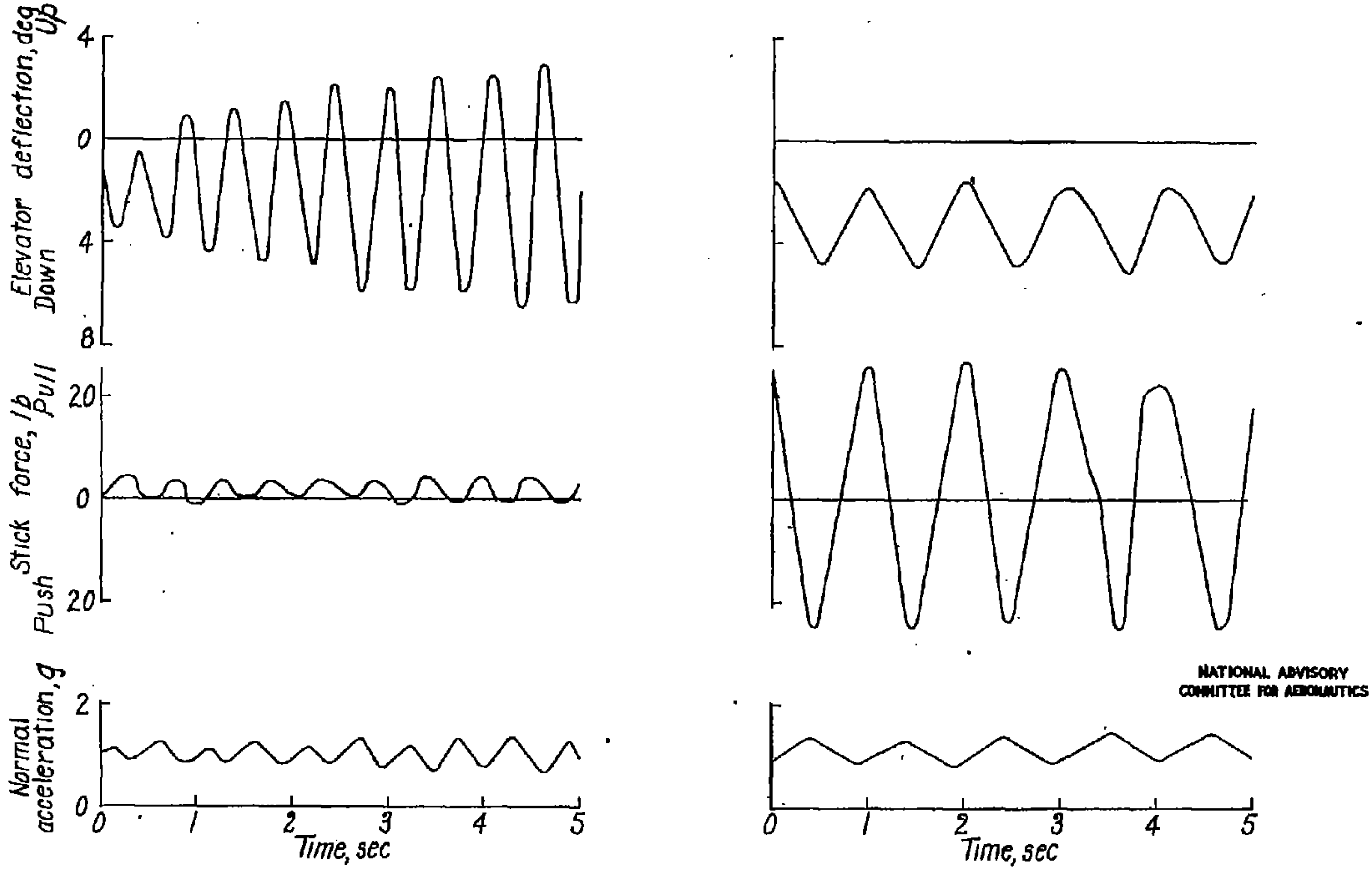


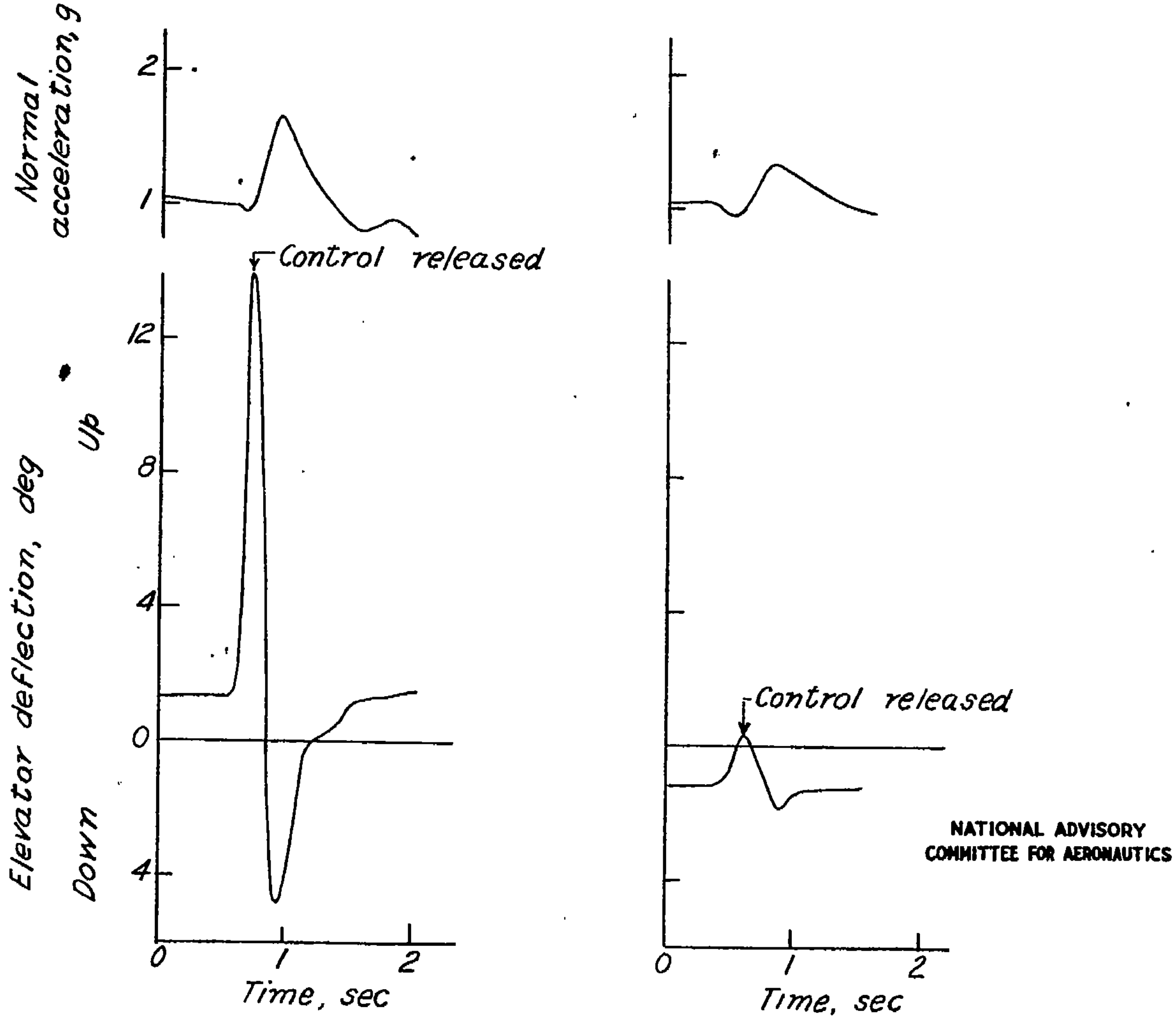
Figure 2.- Ratio of maximum stick force to maximum acceleration in rapid pull-ups as a function of duration of maneuver. Indicated airspeed, 200 miles per hour. Typical pull-ups are shown in figure 1.



(a) Fighter airplane with closely balanced elevators (considered unsatisfactory). Indicated airspeed, 284 miles per hour.

(b) Airplane of scout-bomber class (considered satisfactory). Indicated airspeed, 315 miles per hour.

Figure 3.- Variation of elevator deflection, stick force, and normal acceleration with time in forced control-stick oscillation. Force per g in steady turns was 4 pounds per g in each case.



(a) Fighter airplane with closely balanced elevators and bobweight. Indicated airspeed, 200 miles per hour.

(b) Airplane with all-movable horizontal tail. Indicated airspeed, 157 miles per hour.

Figure 4. - Time histories of control-free short-period longitudinal oscillations.