NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FLIGHT TESTS OF AN ALL-MOVABLE HORIZONTAL TAIL WITH GEARED UNBALANCING TABS ON THE CURTISS XP-42 AIRPLANE

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SUMMARY

Results are presented of flight tests of an all-movable tail with geared unbalancing tabs installed on the Curtiss XP-42 airplane. Previous tests of the all-movable tail showed that a servotab control and bobweight provided a stable variation of stick force with speed and acceleration; however, the stick forces were unsatisfactorily light for rapid maneuvers. After these tests the pilot's stick was connected directly to the tail and the tabs were changed from servotabs to geared unbalancing tabs. The present paper covers tests made with this control arrangement.

The unsatisfactory lightness that had been obtained with the servotab control was eliminated with the tabs connected as geared unbalancing tabs. In the final configuration, which included stick-centering springs to increase the stick forces in landing, the all-movable tail was considered a satisfactory control, indistinguishable from a good conventional elevator. The longitudinal stability and control characteristics of the airplane were not materially changed with the all-movable tail, and no unconventional control characteristics were encountered in sideslips or in stalls. A cockpit control over the tab gear ratio was found satisfactory for adjusting the stick force per g in turns according to the pilot's preference.

Extrapolation of the flight data obtained showed that satisfactory landings and desirable stick forces in turns would be obtainable with an installation similar to that

on the XP-42 airplane for a center-of-gravity range from 10 to 30 percent mean aerodynamic chord as compared with a range from 22 to 30 percent of the mean aerodynamic chord for the original conventional tail. Calculations showed that the same total range of permissible center-of-gravity locations provided by the conventional tail of the XP-42 airplane could be obtained with an all-movable tail of 35 percent less area; however, the permissible center-of-gravity range for the all-movable tail would be located 7 percent of the mean aerodynamic chord forward of the range permitted by the conventional tail. At Mach numbers near unity the all-movable tail will require a power boost control that could be adapted as well to a movable stabilizer. The reduction in tail size that can be obtained with an all-movable tail, however, would be expected to improve elevator control characteristics for this high-speed range.

INTRODUCTION

The initial flight tests of the all-movable horizontal tail on the Curtiss XP-42 airplane were reported in reference 1. These tests were made with a servotab control arrangement that gave near-zero variations of stick force with elevator angle and tail angle of attack. With this control arrangement the all-movable tail appeared to offer a means of eliminating difficulties that were being reported by pilots in recovering from dives at high Mach numbers, namely excessive stick forces and elevator ineffectiveness. In the initial flight tests the elevator control with the servotab arrangement was found to be unsatisfactory. Although the bobweight in the control system gave a stable variation of stick force with speed and acceleration, the near-zero variation of stick force with stick deflection made the control so light in rapid movements that the pilot felt uneasy and uncertain in handling the airplane.

After the initial tests of reference 1 the control system was changed in order to obtain more conventional variations of stick force with elevator angle and tail angle of attack. The pilot's stick was connected directly to the tail, and the tabs were changed from servotabs to geared unbalancing tabs that were similar to those used on the vertical tail surfaces of references 2 and 3. A program of flight tests was then carried out to evaluate this configuration of the all-movable tail. The present paper describes the results of these flight tests and presents some additional analyses that are pertinent to the use of an all-movable tail.

SYMBOLS

C_L	airplane lift coefficient $\left(\frac{\text{lift}}{qS}\right)$
C_{L_T}	tail lift coefficient
S	wing area
S_T	horizontal-tail area; includes area of section through fuselage
g	acceleration due to gravity
l_T	tail length; distance from airplane center-of-gravity position to elevator hinge line
q	free-stream dynamic pressure
q_T	dynamic pressure at tail
δ_t/δ_e	tab gear ratio
V_i	indicated airspeed $\left(\sqrt{\frac{2q}{\rho_0}}\right)$
α_T	tail angle of attack
δ_e	elevator deflection, measured from thrust axis
δ_t	tab deflection
τ_{et}	relative effectiveness of equivalent full-span tab $\left(\frac{\partial C_{L_T}/\partial \delta_{et}}{\partial C_{L_T}/\partial \alpha_T}\right)$

C_{h_e}	elevator hinge-moment coefficient $\left(\frac{\text{Hinge moment}}{q_T b_e \bar{c}_e^2}\right)$
b_e	elevator span
$\bar{c}_e$	elevator root-mean-square chord
$C_{h_{\alpha_T}}$	variation of elevator hinge-moment coefficient with angle of attack of tail $\left(\partial C_{h_e}/\partial \alpha_T\right)$
$C_{h_{\delta_e}}$	variation of elevator hinge-moment coefficient with elevator deflection $\left(\partial C_{h_e}/\partial \delta_e\right)$
$\left(C_{L_\alpha}\right)_T$	variation of tail lift coefficient with tail angle of attack $\left(\partial C_{L_T}/\partial \alpha_T\right)$
ρ_0	mass density of air at sea level

AIRPLANE AND TAIL CHARACTERISTICS

The Curtiss XP-42 airplane as tested with the all-movable horizontal tail is shown in figure 1, and general specifications for this airplane are given in the appendix. In order to determine the effect of the all-movable tail on stability and control characteristics, the XP-42 airplane with the all-movable tail was compared with an equivalent airplane, the Curtiss P-36A, with conventional tail. Comparable photographs of the two airplanes are shown in figures 1 to 4. The long-nose engine and cowling that constituted the primary difference between the original XP-42 airplane and the P-36A airplane were replaced with a conventional short-nose engine and cowling prior to the tests with the all-movable tail. Figures 1, 2, 3, and 4 indicate that the P-42 airplane tested is sufficiently similar to the P-36A airplane to justify the assumption that the two airplanes are equivalent.

Characteristics of the all-movable tail are given in the appendix and are shown in figures 5 to 9. A three-view drawing of the XP-42 airplane with the all-movable tail is shown in figure 7. For comparative purposes, the dimensions of the original fixed-stabilizer horizontal tail are also included in the appendix. The area of the all-movable tail was made about equal to the area of the original tail; the aspect ratio was increased in comparison with that of the original tail in order to compensate in part for a shorter tail length that was required for installation purposes. (See fig. 8.) The tail effectiveness parameter $l_T S_T \left(C_{L_\alpha}\right)_T$ of the all-movable tail is equal to 0.9 that of the original fixed-stabilizer tail.

Each side of the all-movable tail was mass-balanced about the hinge line so that the product of inertia about the tail hinge line and the airplane center line was zero. The tabs were mass-overbalanced about the tab hinge lines to give dynamic balance for rotation of the elevators (main surface). The weight required to mass-balance the all-movable tail tested was about 60 pounds, which is, in general, greater than the weight required for a conventional elevator. In a production all-movable tail, however, this weight could probably be considerably reduced by decreasing the weight of the structure of the tail behind the hinge line. The moment of inertia of the all-movable tail was about 10 times that of the original elevators, but because the elevator deflection for a given stick travel was much less for the all-movable tail, the inertia at the pilot's stick was about the same for the two elevators.

The control system used for the present tests is shown in figure 10. The unit to change the tab gear ratio was connected to a control in the cockpit so that the tab gear ratio was adjustable by the pilot in flight. A tab gear ratio of 1.0 was used in obtaining all the data reported herein, and the control with the variable gear ratio was tested only in the final flights. The relations between tab angle and elevator angle and between stick position and elevator angle are shown in figure 11. The elevator angles were measured from the thrust axis, and the tab angles were measured from the elevator mean chord line. Because the tab-actuating bell crank restricted the total tab deflection, the tab gear ratio and the tab deflection available for trimming were limited.

Several other details of the tail installation are worth noting. During the tests of reference 1, strips were attached to the elevator trailing edge (fig. 9) to move the aerodynamic center back to the elevator hinge line. These strips were kept on the elevator for the present tests. The bobweight in the control system for the tests of reference 1 was removed, but unbalance of the control system gave an effective bobweight of 0.5 pound stick force for the present tests. The gap between the tail and the fuselage was partly sealed with sponge-rubber strips; the gap around the "carry-through" structure was not sealed. This gap consisted of transverse openings through the fuselage above and below the carry-through structure, which was located between about 7 and 23 percent of the tail chord at the tail-fuselage juncture. These openings were necessary to permit unobstructed deflection of the entire horizontal tail about the 24-percent-chord hinge location. An idea of the shape and size of the gap around the carry-through structure may be obtained from figure 6.

Some changes were made during the present tests, and these changes are listed as follows:

(1) A spring was added between the tabs and the elevator to take up the backlash in the linkage and thereby to eliminate play in the tab system. The location of the spring is shown in figure 10.

(2) Friction was added in the control system for some flights to increase the frictional stick force from about ±0.2 pound to ±2 pounds. The added friction was useful in improving coordination for rapid maneuvers of the elevator control with the aileron control, which was heavy and had large friction.

(3) Stick-centering springs were added for the last flights. These springs gave a linear variation of stick force with stick deflection and required a 16-pound stick force to deflect the stick full forward or full back.

SCOPE AND GENERAL RESULTS OF TESTS

The flight tests reported herein are those made to evaluate the all-movable tail with geared unbalancing tabs. The test program is given in the following paragraphs in chronological order together with some of the principal results so that the sequence of modifications can be traced. Photographic records were taken with NACA recording instruments during each flight. Measurements were made of indicated airspeed, normal acceleration, elevator position, tab position, and elevator stick force. In addition, measurements were made of angle of sideslip, rudder angle, and rudder force for the sideslip tests. Airspeed was measured by a swiveling static head and shielded total head 1 chord length ahead of the wing tip, and no correction was made for position error.

In the first flight with the geared tab control system (fig. 10) the elevator was found to be unsatisfactorily light and sensitive. The records showed the fault to be inexact following of the elevator motion by the tabs because of play in the tab control linkage. As a result, there was effectively zero unbalancing tab action for elevator movements of 0.5° or less. The play in the tab system was eliminated by use of the spring between the tabs and the elevator, and with added friction in the system, the control was fairly satisfactory. The stick forces were still considered light, particularly in landing, and the tab gear ratio would have been increased at this time if more tab deflection had been available.

The test program was continued with this arrangement, and seven flights were made to obtain data on the longitudinal stability and control characteristics. No changes were made during these tests except that the added friction was removed for several flights when accurate stick forces were desired. For this series of flights the airplane weight was about 5800 pounds and the center of gravity was at 23.8 percent of the mean aerodynamic chord with wheels down and at 25.7 percent with wheels up.

When the foregoing flights were completed, stick-centering springs were added to the control system to increase the stick forces in landing and, to a lesser degree, the stick forces in the normal flying range. The springs were not added for the early tests because their addition would have complicated the measurement of the elevator hinge moments. With the springs installed the control was considered satisfactory in all respects. The present tests were then concluded with flights by different NACA pilots. All the pilots agreed that with this control arrangement the all-movable tail was a satisfactory longitudinal control, indistinguishable from a good conventional elevator.

DETAILED RESULTS AND DISCUSSION

Dynamic Longitudinal Stability and Control

In the first flight of the present tests a short-period control-free longitudinal oscillation was obtained which did not damp out in one cycle as required by reference 4. The oscillation was the result of play in the tab-actuating system, which resulted in effectively zero unbalancing tab action for elevator movements of 0.5° or less. After the play was eliminated, the oscillations damped satisfactorily (fig. 12).

The problem of dynamic longitudinal control, or control feel, was encountered in the initial tests of reference 1 for which the all-movable tail was controlled by a servotab. In these tests it was found that, because of the use of a bobweight, the control forces were satisfactory in steady maneuvers. For rapid or abrupt maneuvers, however, the control forces were found to be too light to satisfy the pilots. This lightness of the control resulted from the fact that the stick-force variation with stick deflection was near zero. The difficulty was eliminated for the present tests when the servotab control was changed to a direct control between the pilot's stick and the elevator, with the tabs connected as geared unbalancing tabs. This arrangement provided sufficient variation of stick force with elevator deflection to indicate to the pilot the amount of control that he was using. The experience with the closely-balanced all-movable tail and other experiences with experimental conventional elevators have shown the need for additional control requirements in rapid maneuvers (reference 5).

Static Longitudinal Stability

Representative data on the static longitudinal stability of the Curtiss XP-42 airplane with the all-movable tail are presented in figure 13. The data show that the airplane is generally stable but is characterized by a tendency toward stick-free instability at low speeds for all power conditions and by a large loss in the stick-fixed stability in changing the engine power from power off to rated power.

A comparison is made in figure 14 of available stick-fixed static stability data for the XP-42 airplane with the all-movable tail with the data for the P-36A airplane with the conventional fixed-stabilizer tail. In figure 14 the P-36A elevator angles are shown on a scale twice that of the XP-42 elevator angles because the P-36A elevator effectiveness is approximately one-half the effectiveness of the all-movable tail as estimated from the charts of reference 6. With this arrangement equal slopes of δ_e with C_L represent approximately the same degree of stick-fixed stability. Because the product $l_T S_T (C_{L_\alpha})_T$ is smaller for the all-movable tail, the XP-42 airplane would be expected to have somewhat less stability than the P-36A airplane, but figure 14 shows that the reverse of this expectation is true. The relatively higher stability of the all-movable tail might be attributed in part to the fact that the fuselage gap was partly sealed, whereas the fixed-stabilizer tail had an elevator with an unsealed gap at the hinge line and with a large cut-out for the rudder. This difference in the gap conditions may have led to a relatively higher estimated value of the tail lift-curve slope for the fixed-stabilizer tail.

Elevator Control

Elevator control in turning flight.- Representative data obtained in turning flight are presented in figure 15. The data indicate that the stick force per g in steady turns was within the limits prescribed in reference 4 for the center-of-gravity position tested. Data in turning flight were not obtained for comparative conditions after the stick-centering springs were added. The springs would be expected to increase the force per g in turns, the increase being proportionately greater at lower speeds. This effect with speed is favorable because it increases the force required to stall the airplane at low values of normal acceleration.

With the stick-centering springs installed and with a tab gear ratio of 1.0, the stick force per g at 200 miles per hour with power for level flight was measured to be about 10 pounds. From these initial conditions the pilots experimented with the cockpit control over the tab gear ratio and found this type of control a satisfactory method for reducing stick forces in turning flight. The pilots' favorable reaction to the control prompted the suggested use (reference 7) of this type of control for extending the center-of-gravity range for satisfactory stick forces in turning flight.

Elevator control in sideslips.- The elevator control characteristics were investigated in sideslips to determine whether the distorted flow conditions at the tail in yawed flight caused unusual elevator force characteristics with the all-movable tail. Data are presented in figure 16 to show the variation of rudder and elevator force and deflection with sideslip and the effect thereon of power, flaps, and airspeed. The results show that no unconventional elevator control characteristics were encountered with the all-movable tail.

Elevator control in stalls.- The elevator control characteristics were investigated in stalls to determine whether the all-movable tail caused unusual control characteristics. Stalls were made with power on (manifold pressure, 25 in. Hg and engine speed, 2200 rpm) and power off, both with flaps up and with flaps down. The duration of stalled flight was short in each case because the XP-42 airplane stalls with an abrupt and violent divergence in roll and yaw. As a consequence, the pilot was unable to fly beyond the stall and immediately applied forward elevator to check the instability. No unconventional elevator control characteristics were encountered with the all-movable tail in the stalls.

Elevator control in take-off.- Elevator control characteristics in take-off, including a take-off with a 15 mile-per-hour 90° cross wind, were normal in all respects. In the tests of reference 1, when full-down elevator (10°) was used to get the tail up, the pilot noticed a sudden and powerful nose-down pitching of the airplane as the tail of the airplane started to come up. This effect occurred because the elevator initially was stalled (10° down elevator combined with 13° ground angle) and then became unstalled as the tail came up. This difficulty was eliminated when the maximum down-elevator deflection was reduced to 6°.

The all-movable tail did not provide sufficient elevator control on take-off to satisfy requirements. The tail would rise at 45 miles per hour with the center of gravity at 26.8 percent mean aerodynamic chord. If the take-off criterion of reference 4 is applied, the speed should be 35 miles per hour with the center of gravity at 28.5 percent mean aerodynamic chord (maximum rearward). In order to meet control requirements on take-off, the all-movable tail provides less control than a conventional elevator for airplanes with conventional landing gear and provides more control for airplanes with tricycle landing gear. This result is to be expected because, with conventional landing gear where the object is to raise the tail from the ground quickly, the use of down elevator with a fixed stabilizer results in greater upward tail loads than can be obtained from the essentially unflapped surface of an all-movable tail. In the case of tricycle landing gear where the object is to raise the nose wheel from the ground quickly, less downward load can be obtained from the fixed-stabilizer conventional tail than from the all-movable unflapped surface because the elevator of the conventional tail must overcome the upward load on the stabilizer.

Elevator control in landing.- Elevator control characteristics in landing were satisfactory after the stick-centering springs were added to the control system. Time histories of typical landings made without and with the springs installed are given in figure 17. The stick forces at ground contact were 10 and 25 pounds, respectively. The effect of the increase in stick force in improving the feel of the control is not evident in figure 17, but is evident when the records are shown to a larger scale in figure 18. These records show that with the springs added a more definite stick force is associated with each movement of the elevator (the force leads the elevator motion slightly).

The small variation of stick force with elevator deflection in landing with the all-movable tail as compared with the variation of stick force obtained with the fixed-stabilizer tail is due principally to the linear hinge-moment characteristics on the all-movable tail over the entire range of deflections and angles of attack. Most conventional elevators have nonlinear hinge-moment characteristics for large angles of attack and elevator deflections so that an increase in the variation of stick force with elevator deflection accompanies the large up-elevator deflections used in landing.

The pilots commented favorably on the relatively greater response of the all-movable tail in landing and in other low-speed maneuvers as compared with that of some conventional elevators. The pilots were impressed by the great response of the all-movable tail on the XP-42 airplane because some recent fighter airplanes having narrow-chord conventional elevators have given sluggish control in landing and at low speeds.

Elevator trimming characteristics.- The airspeed range for which the elevator control force could be trimmed to zero, together with the control effectiveness of the tabs, is shown in figure 19. The limited tab movement available restricted the speed range for some flight conditions. The requirements of reference 4, pertaining to adequacy of the elevator trim tab, would be met if the downward tab deflection were increased about 2°.

A small loss in tab effectiveness is shown in figure 19 for the condition of flaps down and power off. This loss amounts to a change in stick force of about 0.3 pound per degree elevator deflection at 80 miles per hour and contributes to the light stick forces encountered in landing.

Elevator Hinge-Moment Characteristics

A value of the elevator hinge-moment parameter $C_{h_{\alpha_T}}$ was obtained by use of data from stick-release pull-ups. A time history of a typical maneuver of this type is given in figure 20. A value of $C_{h_{\alpha_T}}$ is obtained from a consideration of the movement of the free elevator as the angle of attack at the tail changes because of the change in the normal acceleration of the airplane. The change in tail angle of attack consists of one increment due to the change in angle of attack of the airplane and a second increment due to the curvature of the flight path. In addition to the change in tail angle of attack, the 0.5-pound bobweight and the hinge moment on the tail surface due to the camber effect of the curved flight path also affect the movement of the free elevator. The value of the hinge-moment parameter $C_{h_{\alpha_T}}$ was computed to be -0.0002 per degree when an allowance was made for the bobweight and the camber effects.

The value of the elevator hinge-moment parameter Ch_{δ_e} was determined from the increments of stick force and elevator angle used in pull-up maneuvers from trimmed level flight, such as those for which time histories are shown in figure 12. For these calculations the ratio of dynamic pressure at the tail to free-stream dynamic pressure q_T/q was estimated from the data of figure 19 to be 1.05 at 150 miles per hour and 1.00 at 200 miles per hour. From these data the value of Ch_{δ_e} was computed to be -0.0031 and -0.0028 per degree at 150 and 200 miles per hour, respectively. These values include the effect of the geared unbalancing tabs. The difference at the two speeds is due to a flexible tab system that permits the tabs to deflect under load; the result is about a 17 percent reduction in tab deflection at 200 miles per hour as compared with the no-load deflection. With a rigid tab system the value of Ch_{δ_e} would be about -0.0033 per degree. A value of Ch_{δ_e} was calculated from the tail characteristics by the method of reference 3. In order to apply this method $\left(C_{L_\alpha}\right)_T$ and τ_{et} were estimated from the curves of reference 6 to be 0.067 and 0.39, respectively. The value of the hinge-moment parameter Ch_{δ_e} was then calculated to be -0.00325 per degree. This value is in good agreement with the value computed from the flight test data for a rigid tab-control system.

The position of the aerodynamic center has a large effect on the values of Ch_{α_T} and Ch_{δ_e} for the all-movable tail. The effect for the tail with partial-span tabs used in the present tests is shown in figure 21. The computed value of Ch_{α_T} of -0.0002 per degree establishes the aerodynamic center at about 24.3 percent mean aerodynamic chord. This position is in close agreement with the value of 24 percent mean aerodynamic chord shown by data obtained at 45 miles per hour in reference 1. Before the trailing-edge strips were attached, the aerodynamic center was between 20 and 21 percent mean aerodynamic chord. This forward position is attributed to a relatively large trailing-edge angle (12° to 15°). A cusped trailing edge could be used to give a more rearward aerodynamic-center position without the extra drag of trailing-edge strips. A more rearward aerodynamic-center position would permit a more rearward hinge location, and consequently less mass-balance weight would be required.

The all-movable tail was somewhat more highly balanced than the P-36A elevators. In order to give the same stick-force characteristics as the P-36A elevators, the all-movable tail would have had to have values of Ch_{α_T} and Ch_{δ_e} of about -0.0015 and -0.0040 per degree, respectively.

The stick-centering springs used in the final flights of this program gave an increment of stick force of 2 pounds per degree deflection. The relative magnitude of the spring force through the speed range is shown in figure 22, which also shows the magnitude of the loss in stick force from the flexible tab system. Figure 22 shows that the centering springs doubled the stick force per degree elevator deflection at 90 miles per hour and just balanced the loss from the flexible tab system at 230 miles per hour.

EXTRAPOLATED RESULTS AND SUPPLEMENTARY ANALYSES

Elevator Control in Landing

The all-movable tail is capable of developing a greater downward tail load in landing than a conventional elevator and fixed stabilizer. Three-point landings, therefore, can be made with more forward center-of-gravity positions. With the present experimental tail installation, no appreciable movement of the center of gravity could be obtained conveniently because of the excessive amount of weight that would have been required on the nose of the airplane. Calculations were made, however, which show the magnitude of the increase in permissible center-of-gravity range for three-point landings resulting from use of the all-movable tail on the XP-42 airplane, and the results are shown in figure 23. Figure 23 was constructed by use of the method of reference 8 to obtain the slopes of elevator angle against center-of-gravity position and then by fairing the curves through the test points obtained for power-off three-point landings. The 7° elevator angle (all-movable tail) for zero tail angle of attack that is indicated in figure 23 results from the difference between a 13° airplane ground angle and a 6° downwash angle obtained by use of reference 9. The assumed 14° tail angle of attack for tail stalling indicated in figure 23 was obtained from the taxi runs of reference 1 in which the tail stalled with 4° down elevator, 13° airplane ground angle, and an estimated 3° downwash angle. The maximum up deflection of the all-movable tail was limited to 3° below the tail stalling angle to avoid any possibility of tail stalling. Figure 23 shows that, through use of the all-movable horizontal tail, the permissible center-of-gravity range of the XP-42 airplane is increased to 20 percent mean aerodynamic chord from an original range of 8 percent where the permissible range is defined by a rearward limit for acceptable stability in maneuvers and a forward limit for power-off three-point landings.

A reduction in tail area is possible with an all-movable tail (reference 10) if more forward center-of-gravity positions are used or if the tail-off neutral point is shifted rearward. Figure 23 shows that with the present airplane a reduction in tail area of 35 percent could be effected and the 8 percent permissible center-of-gravity range of the original airplane could still be retained. With the tail area reduced, the allowable center-of-gravity range would extend from 15 to 23 percent mean aerodynamic chord instead of from 22 to 30 percent, which is the range of the original airplane. The forward shift of the most rearward center-of-gravity position for acceptable stability with the reduction in tail area was obtained by assuming the aerodynamic center of the airplane with tail off to be at 10 percent mean aerodynamic chord.

If an airplane is designed with a small horizontal tail and a forward center-of-gravity position, particular attention should be given, in the design stage, to the effects of power. If the application of power with flaps down causes a large nose-down pitching movement, the wave-off condition may become critical as the tail area is reduced because of the possibility of tail stalling.

Elevator Control in Turning Flight

The all-movable tail with the servotab control (reference 1) offered the possibility of obtaining stick forces in turning flight that would be dependent only on the bobweight effect and would be independent, therefore, of airplane center-of-gravity position and altitude. This advantage is not obtainable, of course, with the present control arrangement. With the present tail the stick force per g in turns varies with airplane center-of-gravity position and altitude in the same way as with a conventional elevator.

Calculations were made of the variation of stick force per g with center-of-gravity position with the present tail for different tab gear ratios, and the results are shown in figure 24. The region of desirable stick forces is shown in figure 24 in accordance with the requirements of reference 4. For any given tab gear ratio the center-of-gravity range is seen to be small, as is the case for airplanes having conventional elevators. For the P-36A airplane the center-of-gravity range extended approximately from 26 to 30 percent mean aerodynamic chord.

If use is made of a cockpit control over the tab gear ratio (reference 7), desirable stick forces in turning flight could be provided over any reasonable center-of-gravity range. From figure 24, it is evident that, with such a control and with tab gear ratios from 0.5 to 2.0, desirable stick forces in turns would be obtainable for a range of center-of-gravity positions from 10 percent mean aerodynamic chord, which is the calculated forward limit for elevator control in landing, to 30 percent, which is the rearward limit for satisfactory stick forces in turns for the P-36A airplane and the approximate rearward limit for acceptable stability in straight flight.

Elevator Control in Spins

No spins were made in the XP-42 airplane with the all-movable tail; however, the general spinning characteristics can be predicted from available spin-tunnel tests. In 1938 tests were made in the NACA 15-foot free-spinning tunnel of a model of the Curtiss P-36A airplane. The results indicated that good spin recovery was obtained by complete rudder reversal with the elevator held full up. The angle of attack in the spin varied from 30° to 50° and the corresponding airspeeds (full scale) varied from 170 to 110 miles per hour, respectively. Tests were made recently in the NACA 20-foot free-spinning tunnel of a Curtiss XP-60A model (the Curtiss P-36A model was not available) with both a conventional and an all-movable horizontal tail. The results of these tests showed that good spin recovery was obtained by rudder reversal alone and that substituting the all-movable tail gave no significant difference in spin recovery.

The all-movable tail will normally be stalled in a spin and therefore will have a large hinge moment tending to hold it in the up position. On most airplanes this moment is expected to be too large for the pilot to overcome. It appears necessary with an all-movable tail, therefore, to require that spin recovery be effected by movement of the rudder and aileron controls alone. If spin recovery is provided in this way, the excessive elevator stick force would not be dangerous because the downward pitching of the airplane when the spin stops would unstall the elevator and permit the pilot to resume normal control.

Elevator Control at High Mach Numbers

The present tail installation was designed for tests in the low-speed range and no flights were made at high Mach numbers. Recent experience has indicated that a conventional sealed elevator will maintain its effectiveness at least to Mach numbers for which severe compressibility effects are encountered on the tail itself. Tests of the all-movable tail also show that the stick forces with the all-movable tail should be equivalent to those of a conventional elevator in order to give satisfactory elevator control at low speeds. On this basis, for comparable tail sizes the all-movable tail would appear to offer no advantage over a conventional tail in regard to control characteristics at speeds approaching that for which severe compressibility effects occur on the tail. As noted previously in the present paper and in reference 10, however, the all-movable tail offers the possibility of a reduction in tail size as compared with a fixed-stabilizer tail. In this connection, reference 10 has shown that a reduction in tail size would be expected to improve elevator control characteristics at speeds below that for which severe compressibility effects occur on the tail.

At speeds above that for which severe compressibility effects occur on the tail itself, however, recent tests by the NACA wing-flow method have shown that the effectiveness of a conventional elevator drops nearly to zero for a small Mach number region slightly below a Mach number of 1, whereas a sufficiently thin airfoil maintains its effectiveness. It appears, therefore, that either an all-movable tail or a movable stabilizer may be required for control. For either of these tails some type of power boost appears mandatory in order to handle the large compressibility hinge-moment changes that are expected to occur. For the all-movable tail figure 25 shows a schematic drawing of a control-system arrangement that is considered to satisfy the requirements of a longitudinal control for Mach numbers approaching unity. The servocontrol would be locked in only for flight at high Mach numbers and could be designed specifically for this purpose without compromises to obtain the rapid rates of control movement required in take-off, landing, and at low speed. Because the servocontrol would be used in only one speed range, stick-force variation with speed would be relatively unimportant, and the servocontrol could be made irreversible in order to dissociate the stick forces from hinge-moment changes due to compressibility effects. Stick force from a spring on the servocontrol stick together with large servocontrol stick movement would provide essential control feel. It is apparent that the suggested control system is equally adaptable to a movable stabilizer. It can be concluded then that at Mach numbers at which severe compressibility effects are encountered on the tail itself, the all-movable tail will have no aerodynamic advantage over a movable stabilizer. If an all-movable tail is employed, however, to obtain increased control in landing or a greater center-of-gravity range, the control for high Mach numbers will be equal to the control from any stabilizer-elevator combination.

CONCLUSIONS

From the results of the present flight tests of an all-movable horizontal tail with geared unbalancing tabs on the Curtiss XP-42 airplane the following observations can be made:

1. The unsatisfactory control feel in rapid maneuvers that had been obtained in preliminary tests of the all-movable tail with servotab control was eliminated with the pilot's stick connected directly to the elevator and the tabs connected as geared unbalancing tabs. This control arrangement provided sufficient variation of stick force with elevator deflection to indicate to the pilot the amount of control he was using.

2. Play in the tab-actuating system caused the occurrence of a continuous control-free longitudinal oscillation of short period and small amplitude. The oscillation damped satisfactorily when the play in the system was removed by means of a spring between the tabs and the elevator.

3. The stick-free and stick-fixed longitudinal stability characteristics of the airplane were not materially changed with the all-movable tail.

4. No unconventional elevator control characteristics were encountered in sideslips or when the airplane was stalled.

5. A cockpit control over the tab gear ratio was found satisfactory for adjusting the stick force per g in turns according to the pilot's preference.

6. It was found necessary to restrict the maximum down-elevator deflection to 6° in order to eliminate powerful nose-down pitching moments in take-off due to unstalling of the elevator when the tail started up.

7. Stick-centering springs were required to increase stick forces for landing. Because the all-movable tail has linear hinge-moment characteristics, the usual increase in stick force with large up-elevator deflection is not obtained.

8. In the final configuration the all-movable tail with geared unbalancing tabs was considered a satisfactory control. The pilots considered the all-movable tail indistinguishable from a good conventional elevator.

From an extrapolation of the flight test data and from analyses of control characteristics not covered by the flight tests, the following additional observations can be made:

1. If a cockpit control were used to vary the tab gear ratio of the all-movable tail from 0.5 to 2.0, satisfactory control forces in turns would be obtainable for a range of center-of-gravity positions from 10 to 30 percent mean aerodynamic chord.

2. If an up-elevator deflection of the present all-movable tail of 17° were used, power-off three-point landings could be made with the center of gravity at 10 percent mean aerodynamic chord. For a nearly identical airplane, the P-36A, having a conventional fixed-stabilizer horizontal tail, the corresponding forward permissible center-of-gravity position was 22 percent mean aerodynamic chord.

3. With an all-movable tail reduced in area 35 percent below that of the conventional fixed-stabilizer tail, the airplane would have satisfactory characteristics over the same total center-of-gravity range, but the range would extend from 15 to 23 percent instead of from 22 to 30 percent mean aerodynamic chord for the conventional fixed-stabilizer tail.

4. Spin recovery would probably have to be provided by rudder and aileron action alone for an airplane with an all-movable tail because the tail would be stalled, and the resulting aerodynamic moment would probably prevent the pilot from reversing the elevator until after the spin had been stopped.

5. There is no inherent aerodynamic advantage or disadvantage of the all-movable tail over a conventional elevator and fixed stabilizer of comparable size at Mach numbers below those for which severe compressibility effects are encountered on the tail itself. The reduction in tail size obtainable with the all-movable tail, however, would be expected to improve elevator control characteristics for this high-speed range. At Mach numbers near unity the all-movable tail will require a

power boost control that could be adapted as well to a movable stabilizer.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., May 17, 1946

APPENDIX

GENERAL SPECIFICATIONS OF THE CURTISS XP-42 AIRPLANE

Name	Curtiss XP-42
Number	Air Corps No. 38-4
Engine	Pratt & Whitney R-1830-31
Rating (with 92-octane gasoline used for the present tests):	
Take-off	
Horsepower	1050
Manifold pressure, in. Hg	42.8
Engine speed, rpm	2700
Climb	
At sea level	
Horsepower	810
Manifold pressure, in. Hg	34
Engine speed, rpm	2550
At 10,000 ft	
Horsepower	900
Manifold pressure, in. Hg	34
Engine speed, rpm	2550
Cruise	
At 10,000 ft	
Horsepower	570
Manifold pressure, in. Hg	26
Engine speed, rpm	2230
Supercharger (single-stage) gear ratio	8.47:1
Propeller	Curtiss electric
Diameter, ft	10
Number of blades	3
Gear ratio	16:9
Fuel capacity, gal	
Fuselage tank (removed for present tests)	60
Rear wing tanks	61
Front wing tanks	41
Oil capacity, gal	13.5
Weight for present tests, lb	5800
Center-of-gravity position for present tests (wheels up), percent M.A.C.	25.7
Length (over-all), ft	29
Height (over-all), ft	
Three-point attitude	10.5
Flying attitude	9

Wing:	
Span, ft	37.3
Area, sq ft	236
Airfoil section, root	NACA 2215
Airfoil section, tip	NACA 2209
Mean aerodynamic chord, ft	6.8
Aspect ratio	5.9
Taper ratio	0.43
Dihedral (leading edge of wing), deg	6
Incidence, deg	1
Sweepback (leading edge of wing)	1°25'
Wing flaps (split type):	
Area, sq ft	34.8
Travel (maximum), deg	45
Chord, ft	1.76
Ailerons (Frise type):	
Length, ft	6.94
Chord (maximum), ft	1.54
Area (including 4.24 sq ft balance area and 0.11 sq ft trim-tab area), sq ft	18.41
Deflection, deg	
Up	24
Down	11
Vertical tail:	
Fin area, sq ft	7.0
Rudder area (including balance area of 1.94 sq ft and tab area of 0.55 sq ft), sq ft	13.74
Chord (maximum), ft	2.54
Offset from thrust axis, nose left, deg	1.5
Deflection (right and left), deg	30
Horizontal tail:	
Original tail, identical with P-36A tail, conventional fixed-stabilizer type	
Span, ft	12.8
Area (including 3.56 sq ft fuselage), sq ft	48.0
Elevator area (including balance area of 3.8 sq ft and tab area of 1.68 sq ft), sq ft	19.2
Chord (maximum), ft	1.69
Incidence (stabilizer nose up), deg	2
Aspect ratio	3.42
Distance from elevator hinge line to 25 percent M.A.C. of wing, ft	18.1
Deflection, deg	
Up	28
Down	25

All-movable horizontal tail:

Span, ft	14.77
Area (including 6.1 sq ft fuselage), sq ft	47.0
Tab area, sq ft	3.6
Aspect ratio	4.64
Taper ratio	0.42
Mean aerodynamic chord, ft	3.25
Distance from elevator hinge line to 25 percent M.A.C. of wing, ft	14.58
Deflection, deg	
Up	10
Down	6

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1. Kleckner, Harold F.: Preliminary Flight Research on an All-Movable Horizontal Tail as a Longitudinal Control for Flight at High Mach Numbers. NACA ARR No. L5C08, 1945.

2. Jones, Robert T., and Kleckner, Harold F.: Theory and Preliminary Flight Tests of an All-Movable Vertical Tail Surface. NACA ARR, Jan. 1943.

3. Kleckner, Harold F.: Flight Tests of an All-Movable Vertical Tail on the Fairchild XR2K-1 Airplane. NACA ACR No. 3F26, 1943.

4. Anon.: Stability and Control Characteristics of Airplanes. AAF Specification No. R-1815-A, April 7, 1945.

5. Phillips, William H.: An Investigation of Additional Requirements for Satisfactory Elevator Control Characteristics. NACA TN No. 1060, 1946.

6. Gilruth, R. R., and White, M. D.: Analysis and Prediction of Longitudinal Stability of Airplanes. NACA Rep. No. 711, 1941.

7. Kleckner, Harold F.: Use of Variable-Ratio Geared Tabs to Improve Stick-Force Characteristics in Turning Flight. NACA RB No. L5I05, 1945.

8. Goranson, R. Fabian: A Method for Predicting the Elevator Deflection Required to Land. NACA ARR No. L4I16, 1944.

9. Katzoff, S., and Sweberg, Harold H.: Ground Effect on Downwash Angles and Wake Location. NACA Rep. No. 738, 1943.

10. Harmon, Sidney M.: Comparison of Fixed-Stabilizer, Adjustable-Stabilizer, and All-Movable Horizontal Tails. NACA ACR No. L5H04, 1945.

Figure 1.- Three-quarter front view of Curtiss XP-42 airplane as tested with all-movable horizontal tail.

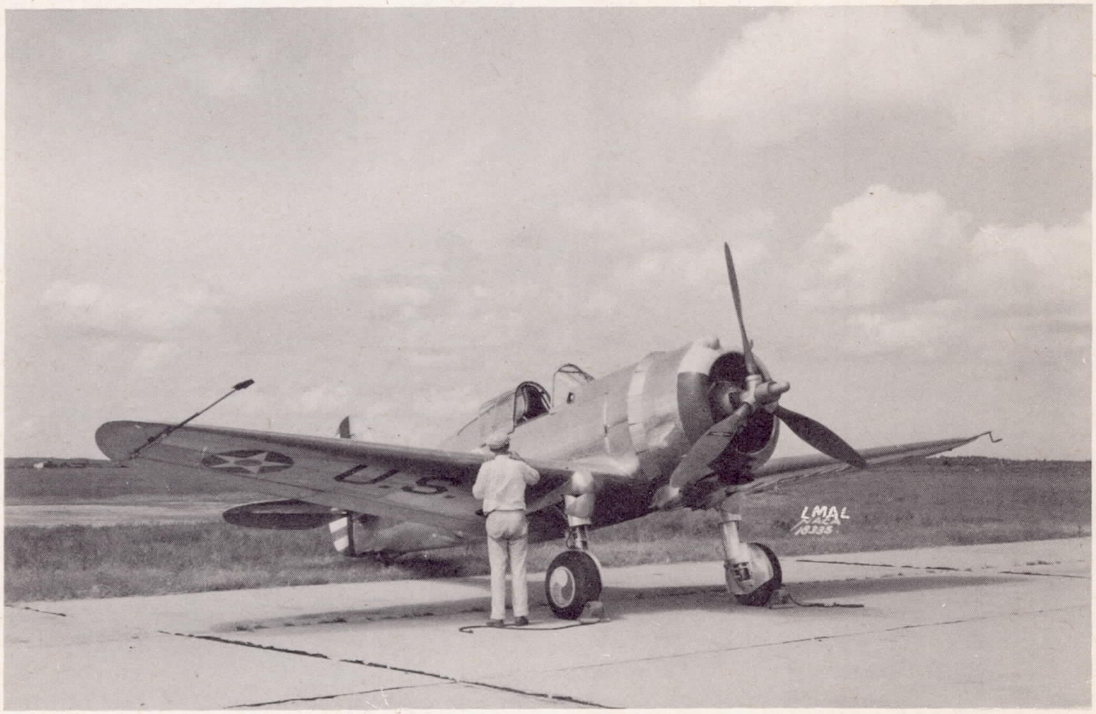

Figure 2.- Three-quarter front view of Curtiss P-36A airplane (used for purposes of comparison) as tested at the Langley laboratory.

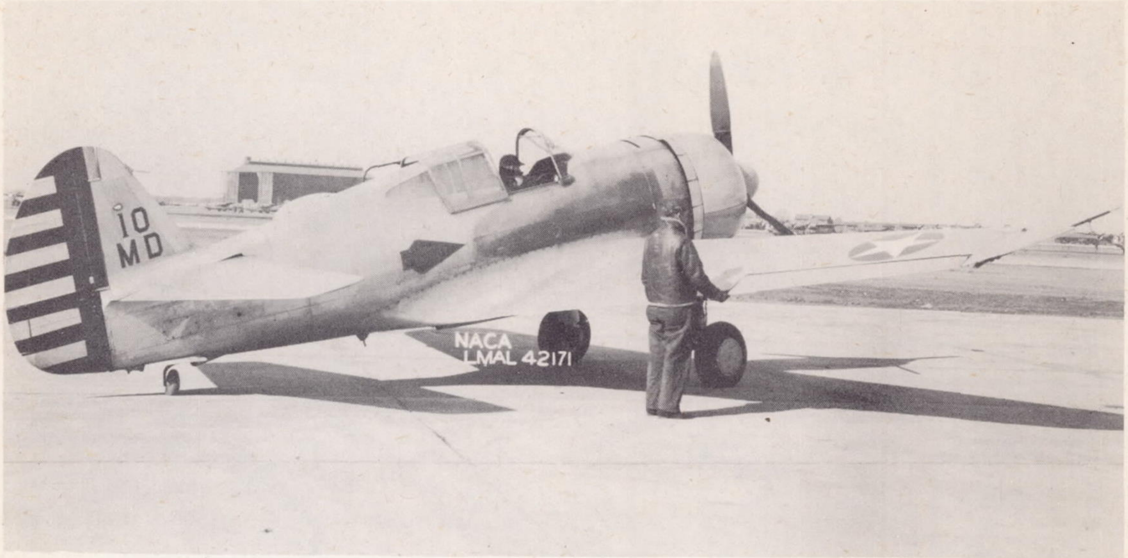

Figure 3.- Three-quarter rear view of Curtiss XP-42 airplane with all-movable horizontal tail.

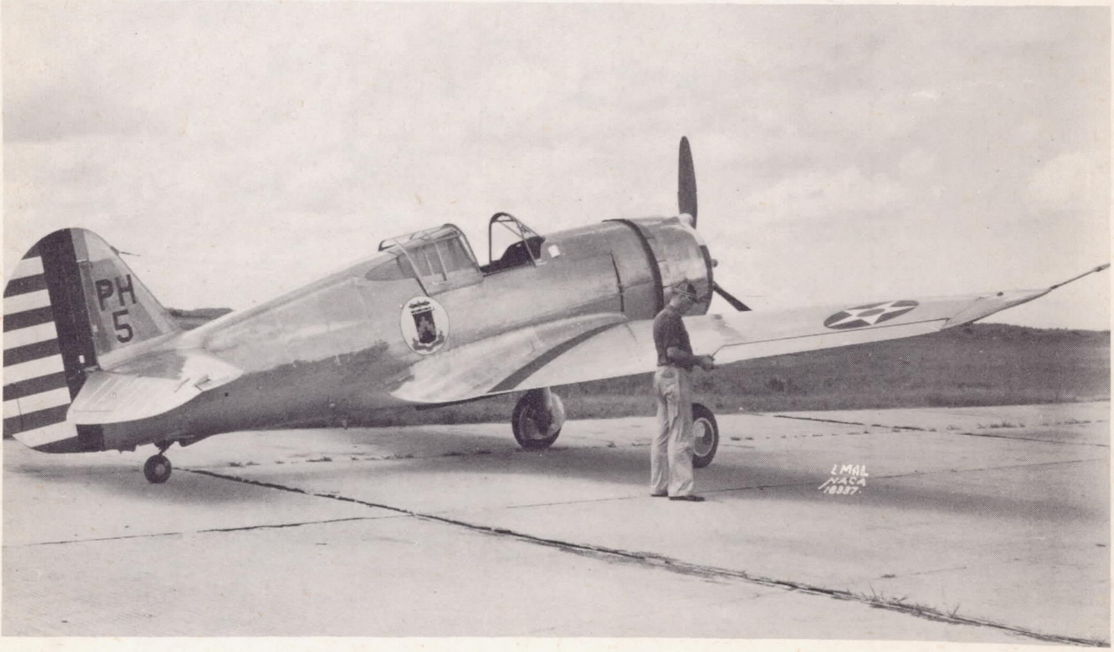

Figure 4.- Three-quarter rear view of Curtiss P-36A airplane.

Figure 5.- All-movable horizontal tail deflected full down.

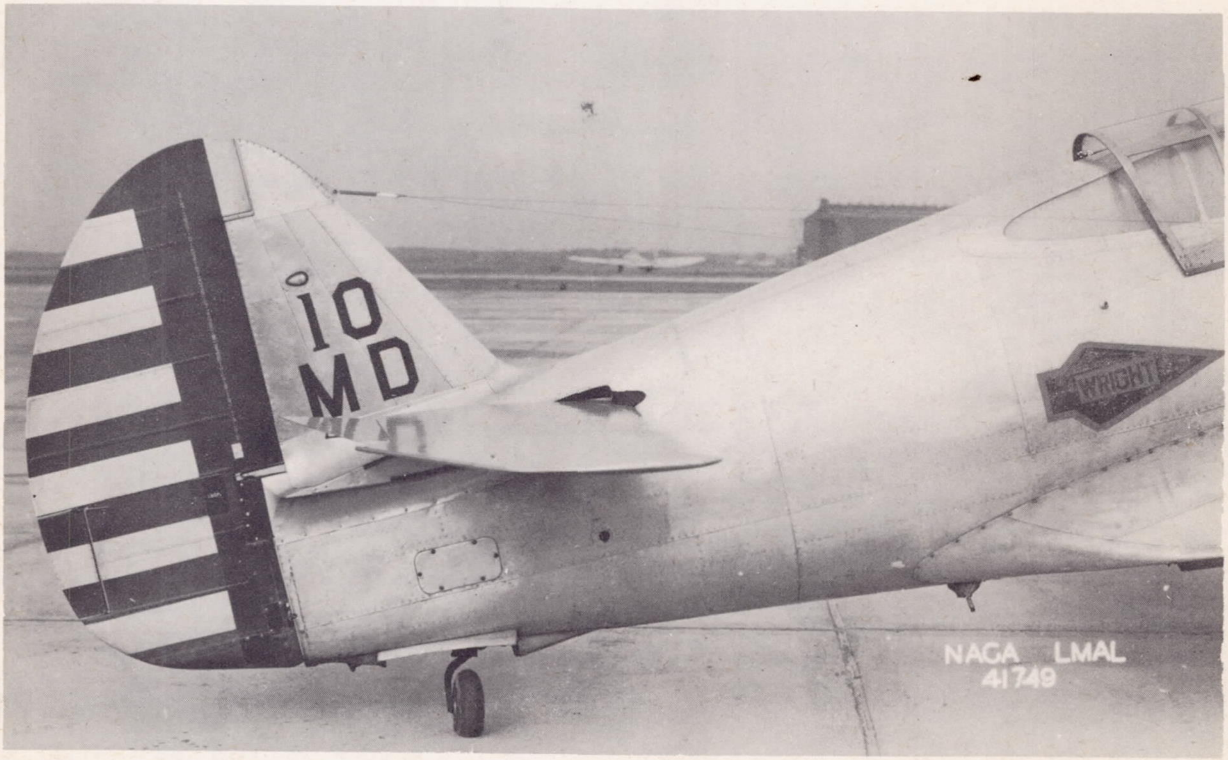

Figure 6.- All-movable horizontal tail deflected full up.

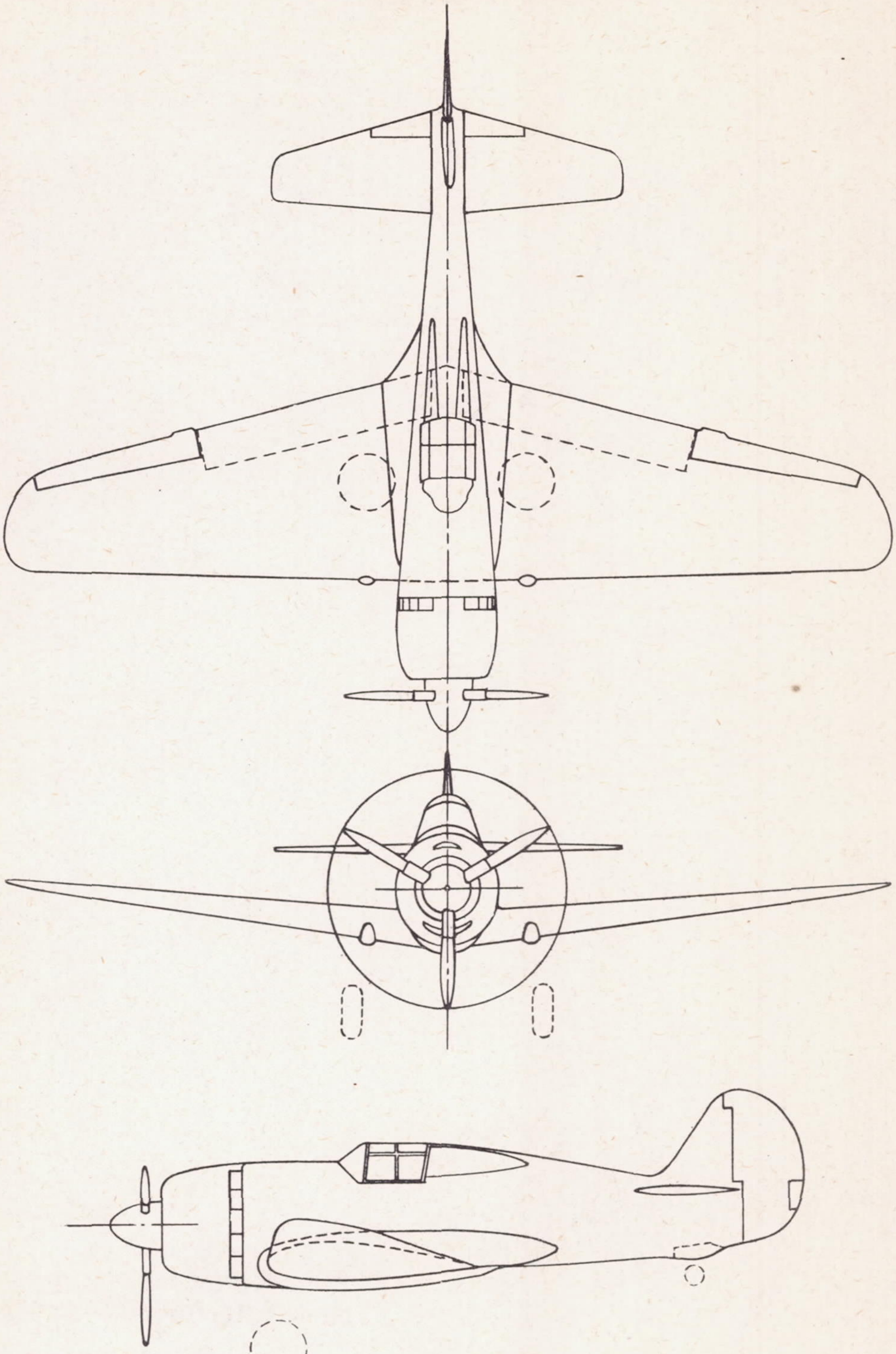

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Figure 7.- Three-view drawing of Curtiss XP-42 airplane with all-movable horizontal tail.

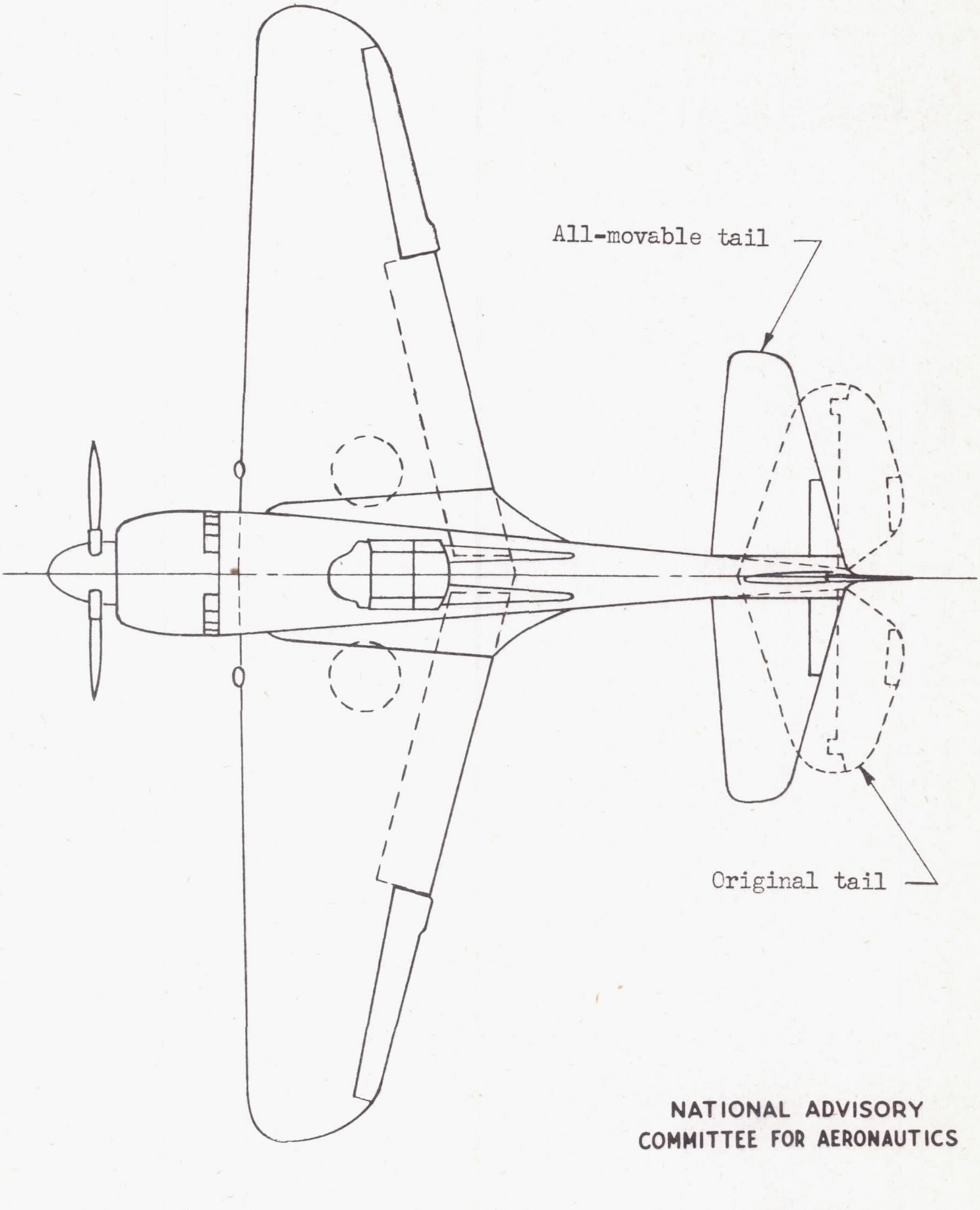

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Figure 8.- Plan view of Curtiss XP-42 airplane showing location of original and all-movable horizontal tails.

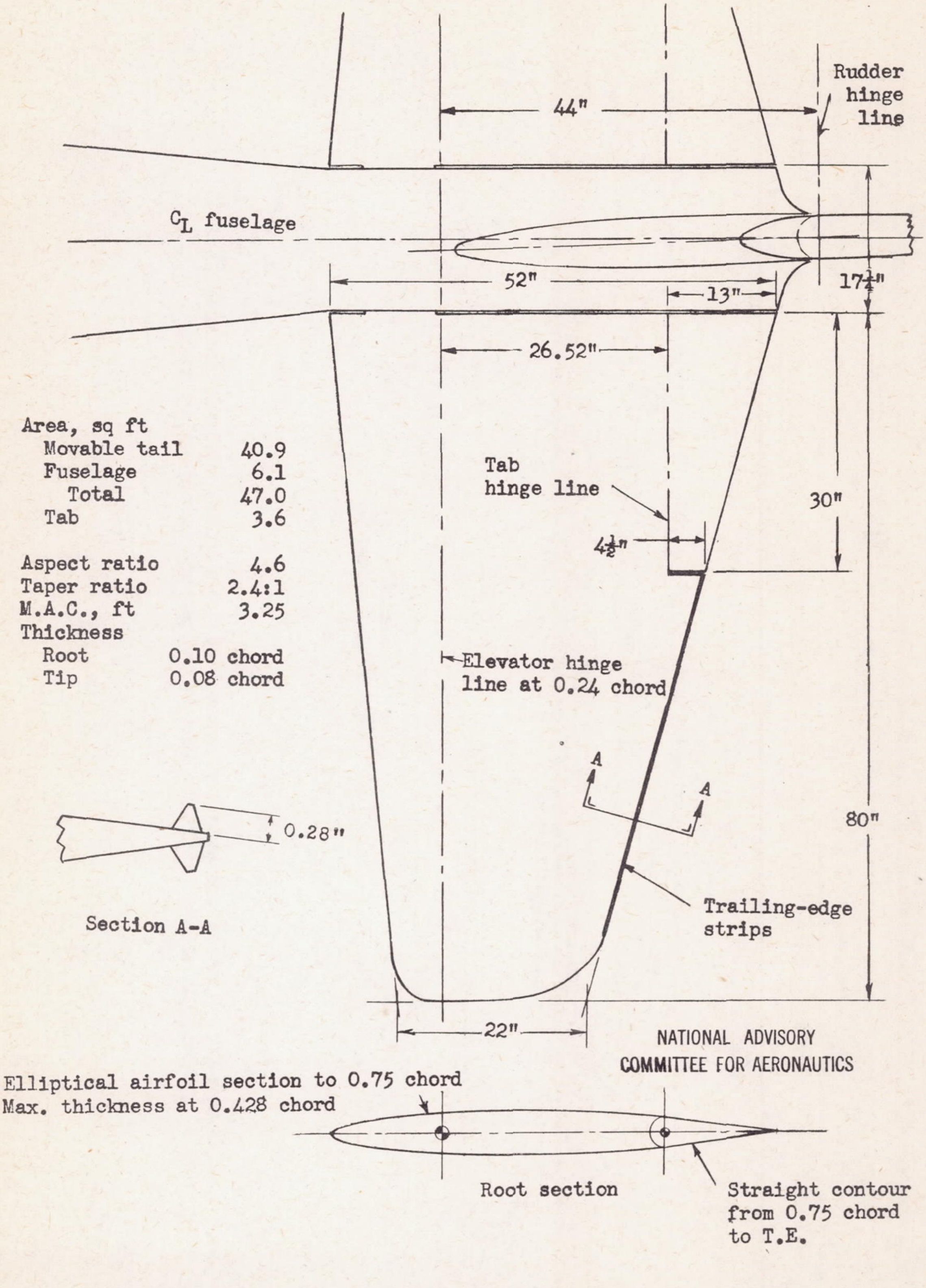

Figure 9.- Dimensions of all-movable horizontal tail for Curtiss XP-42 airplane.

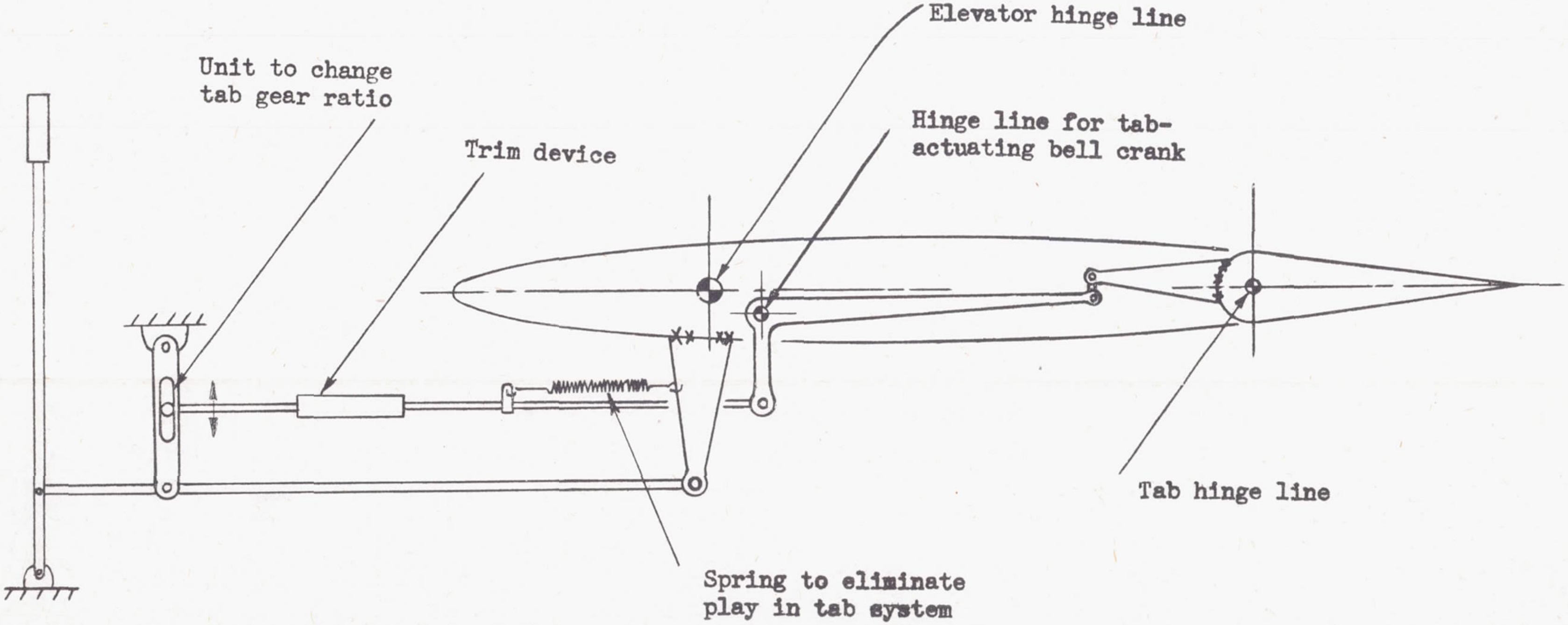

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Figure 10.- Schematic drawing of control system for the present tests. The elements of the control system are shown approximately as used.

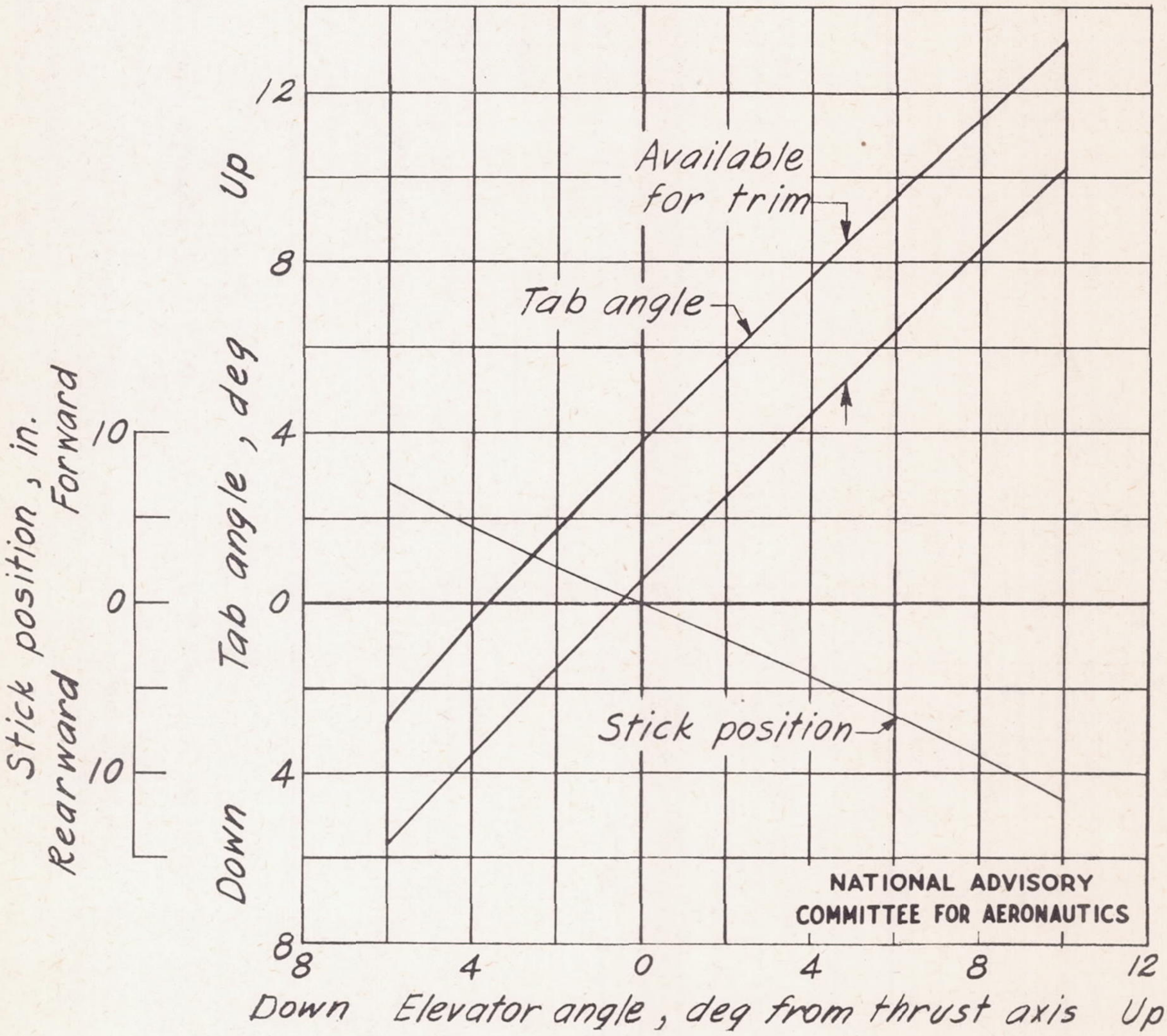
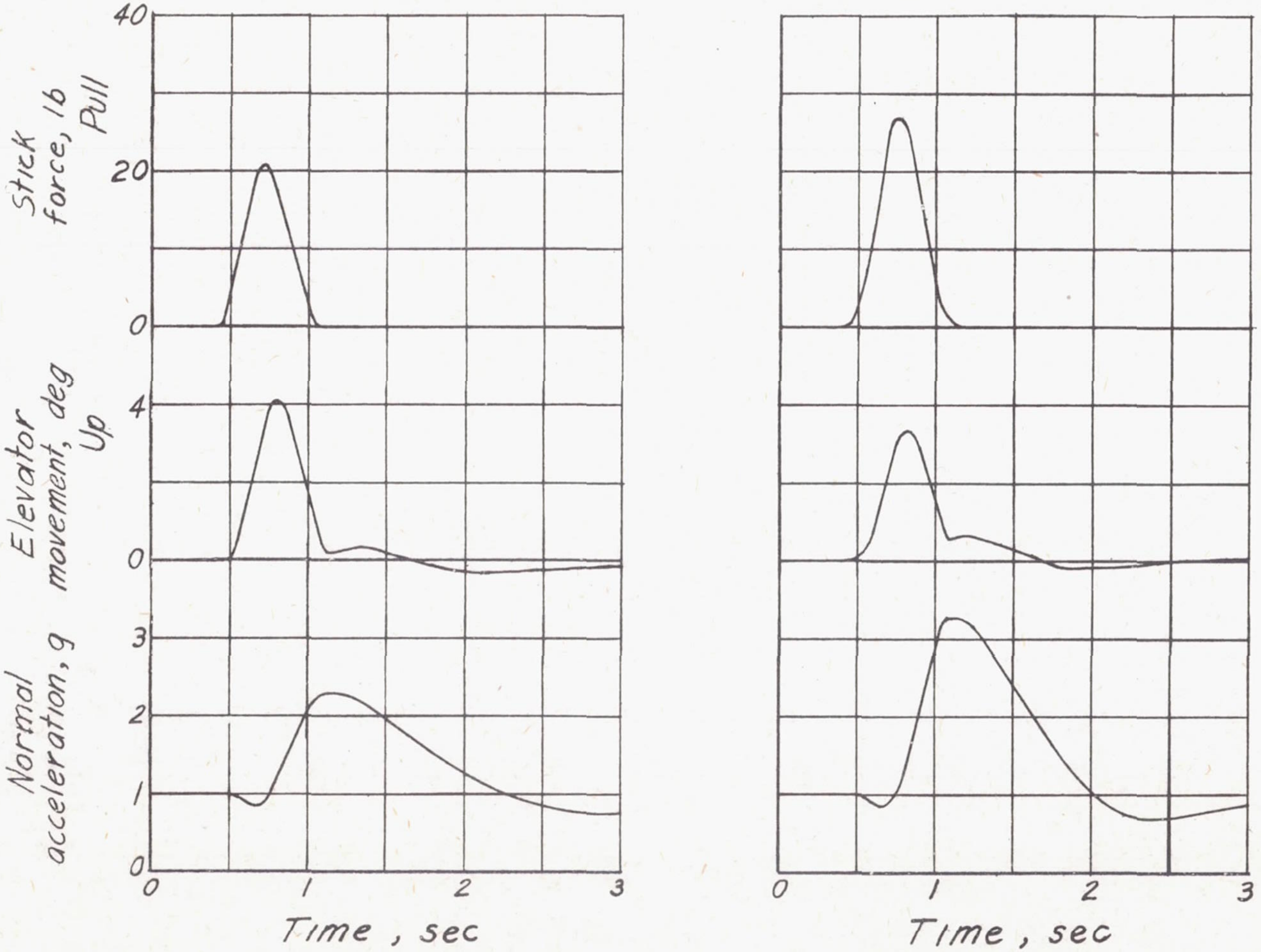


Figure 11.- Relation between tab angle and elevator angle and between stick position and elevator angle for all-movable horizontal tail.



(a) V_i, 150 miles per hour.

(b) V_i, 205 miles per hour.

Figure 12.- Time histories of longitudinal oscillations made by abruptly moving and then releasing the stick.

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	Condition	Landing flaps and gear	Manifold pressure (in. Hg)	Engine speed (rpm)	Tab angle at $\delta_e = 0$ (deg)
□	Gliding	Up	Power off		0.5
◇	Climbing	Up	34	2550	2.0
△	Landing	Down	Power off		.5
▽	Wave-off	Down	34	2550	.5

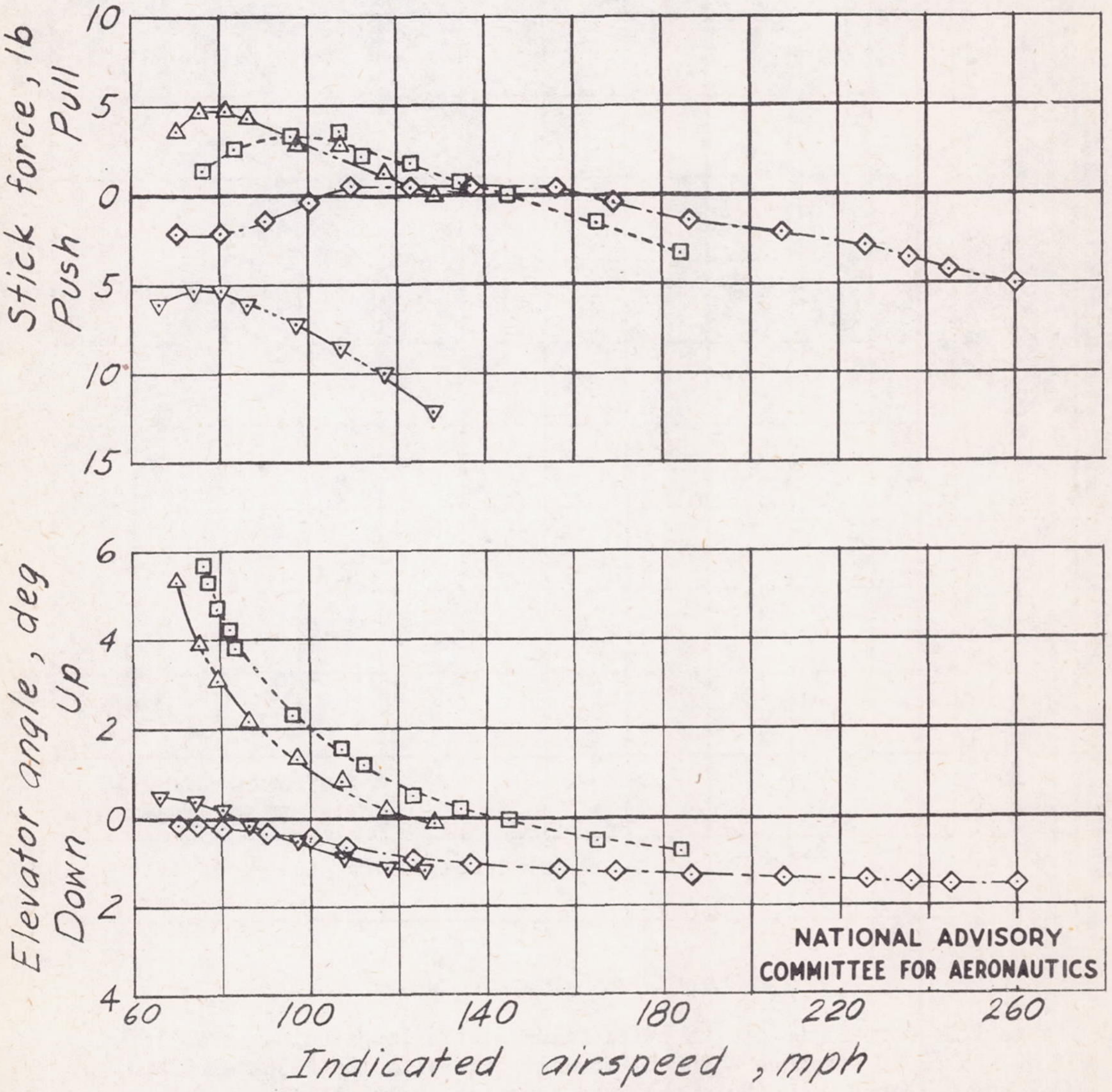


Figure 13.- Representative static longitudinal-stability data for XP-42 airplane with all-movable horizontal tail.

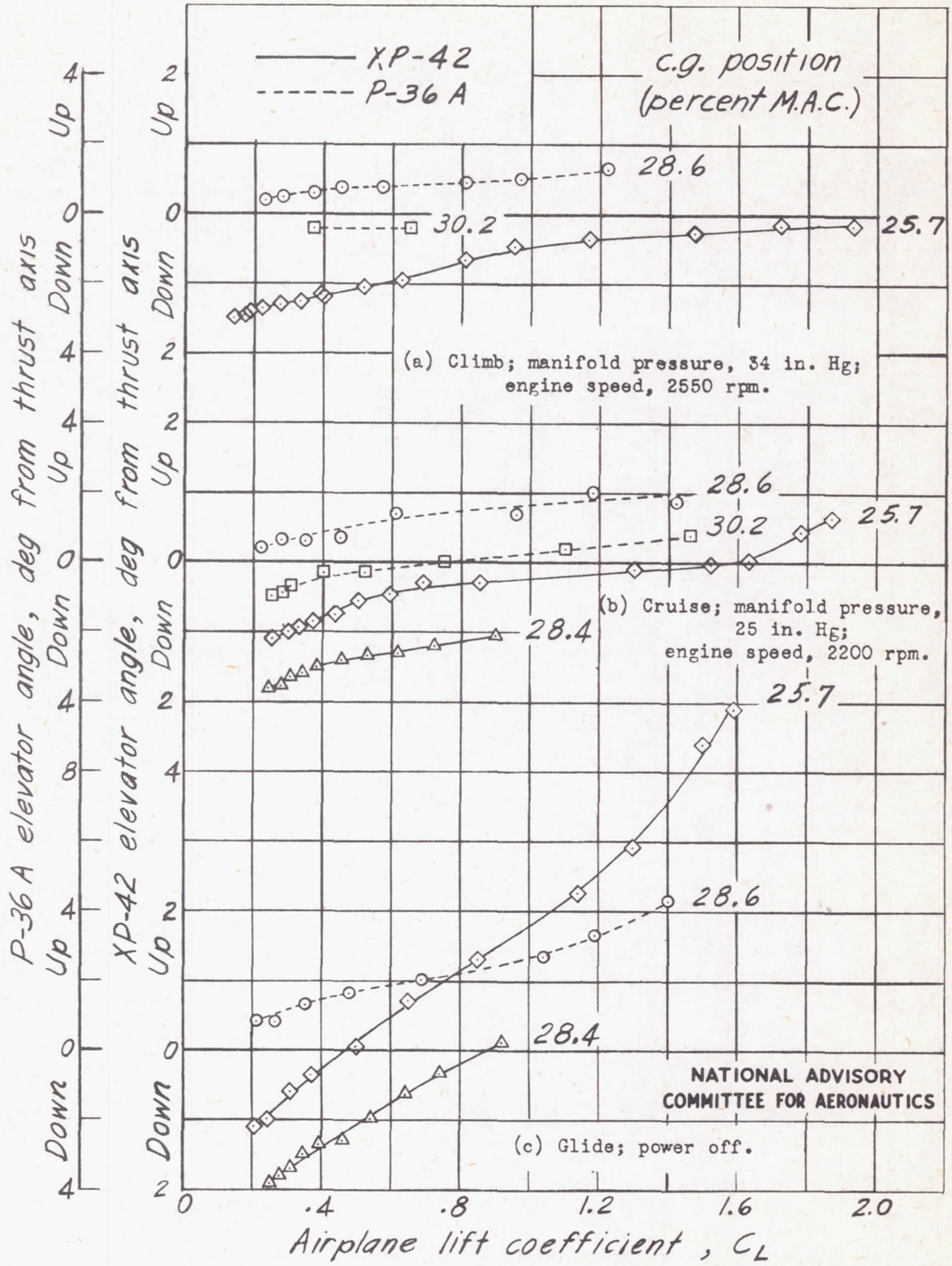
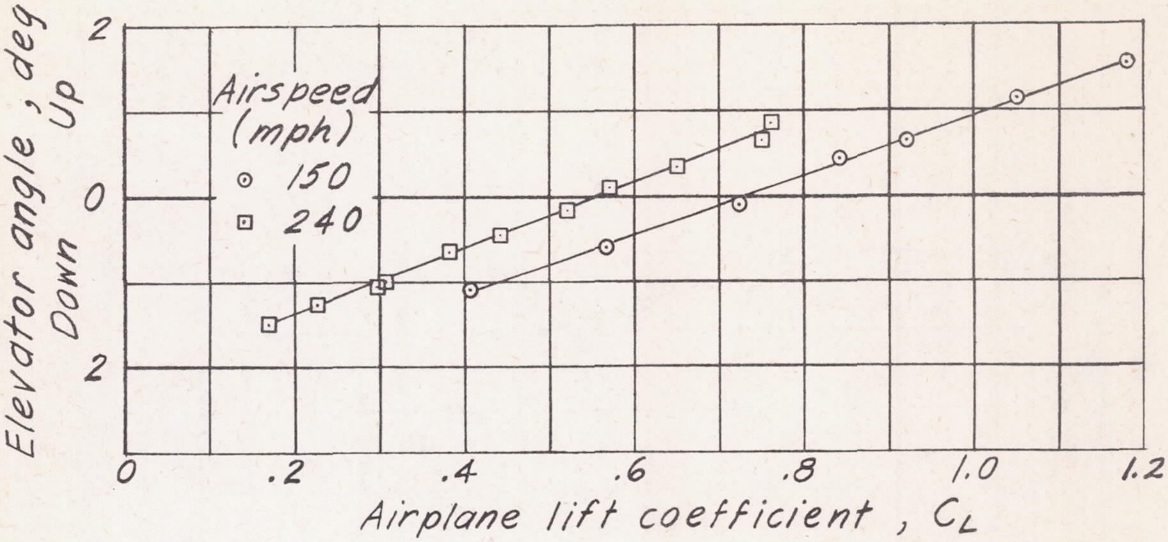


Figure 14.- Comparison of the stick-fixed static longitudinal stability of the XP-42 airplane with all-movable tail with the P-36A airplane. Flaps and gear up. (Note that the elevator-angle scales are inversely proportional to elevator effectiveness; therefore equal slopes represent approximately equal stability.)



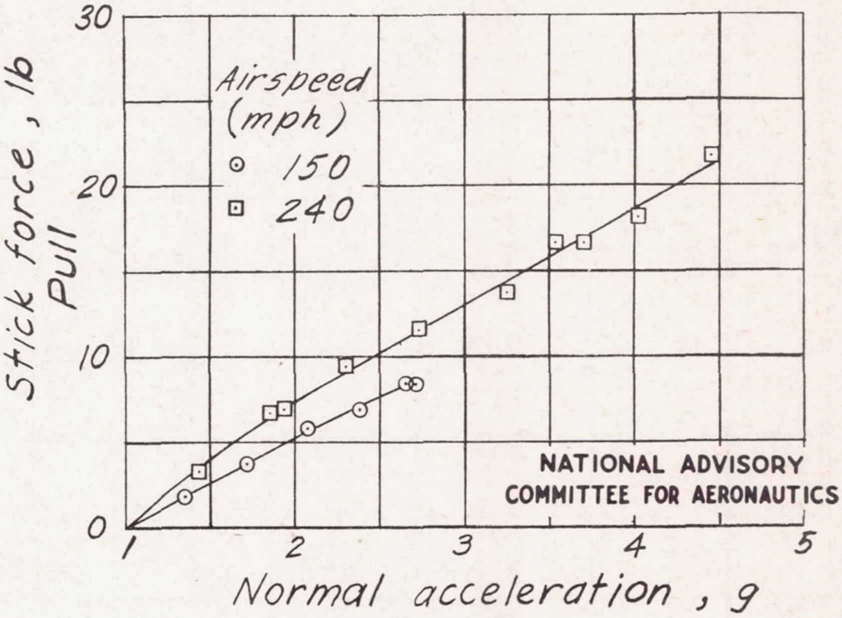


Figure 15.- Representative data obtained in steady turns with XP-42 airplane and all-movable tail. Altitude, 8500 feet; power on; manifold pressure, 34 in. Hg; engine speed, 2550 rpm; center of gravity at 25.7 percent mean aerodynamic chord.

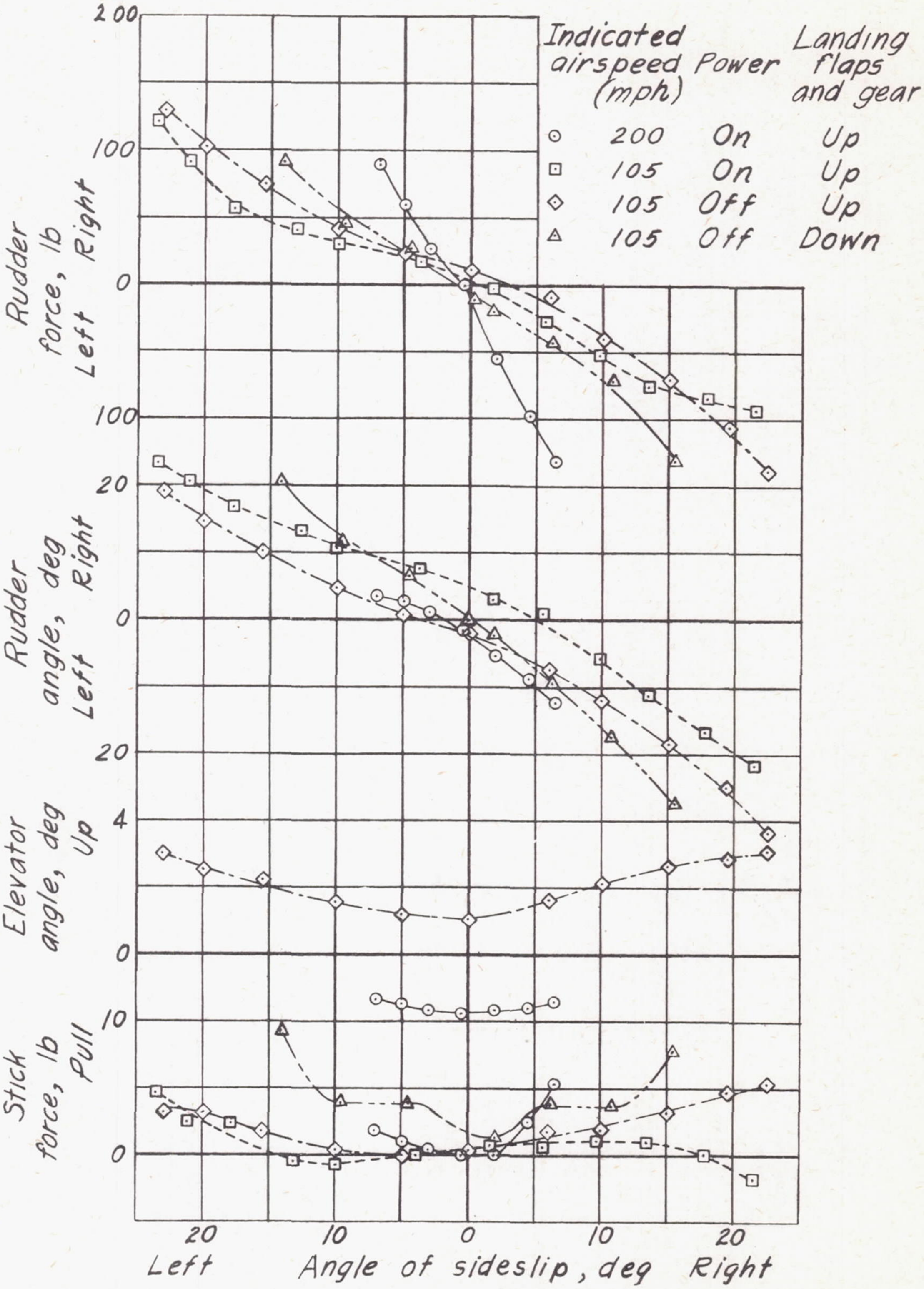


Figure 16.- Sideslip characteristics of XP-42 airplane with all-movable horizontal tail.

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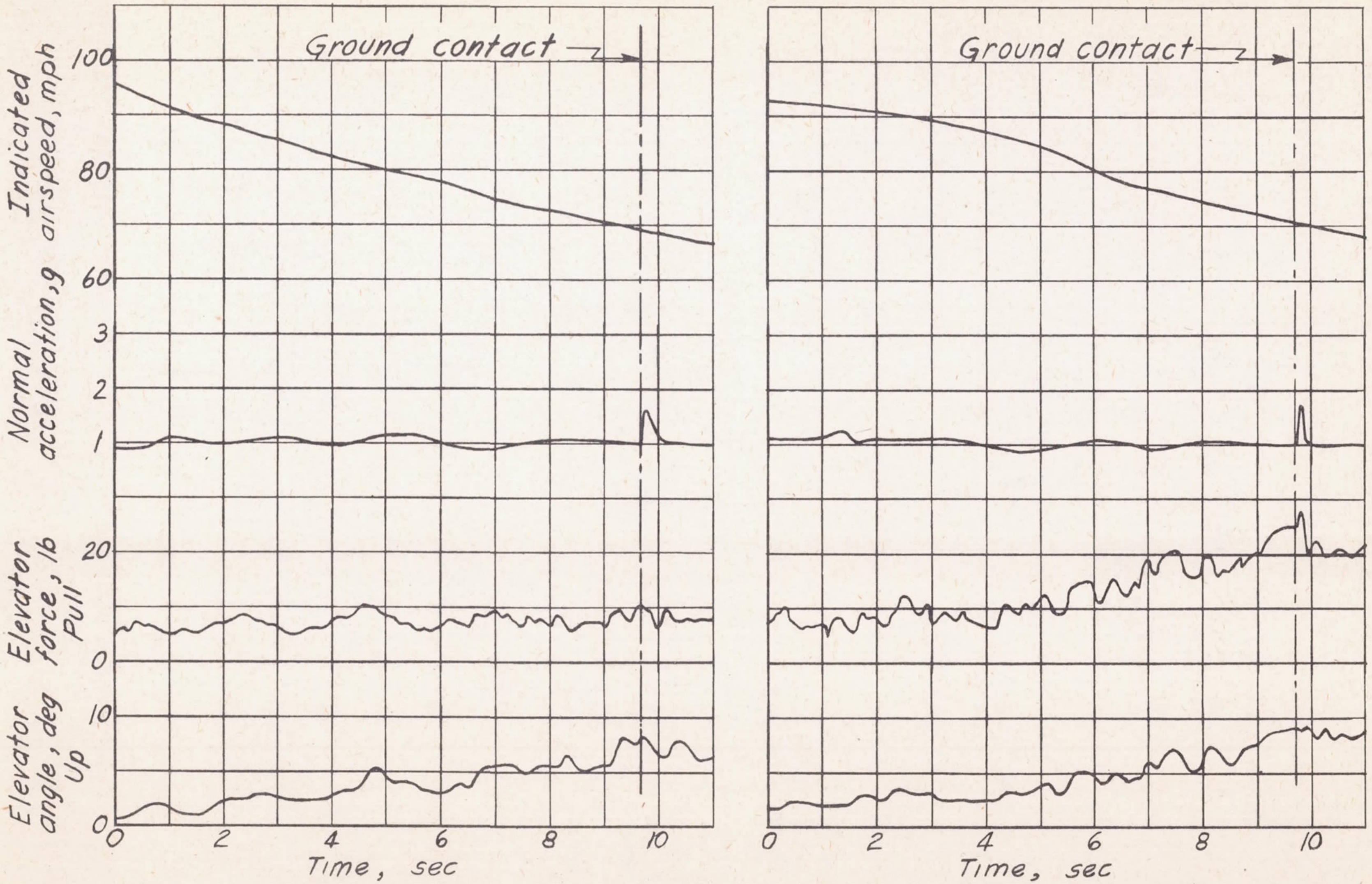

(a) Without centering springs.

(b) With centering springs.

Figure 17.- Time histories of typical power-off three-point landings.

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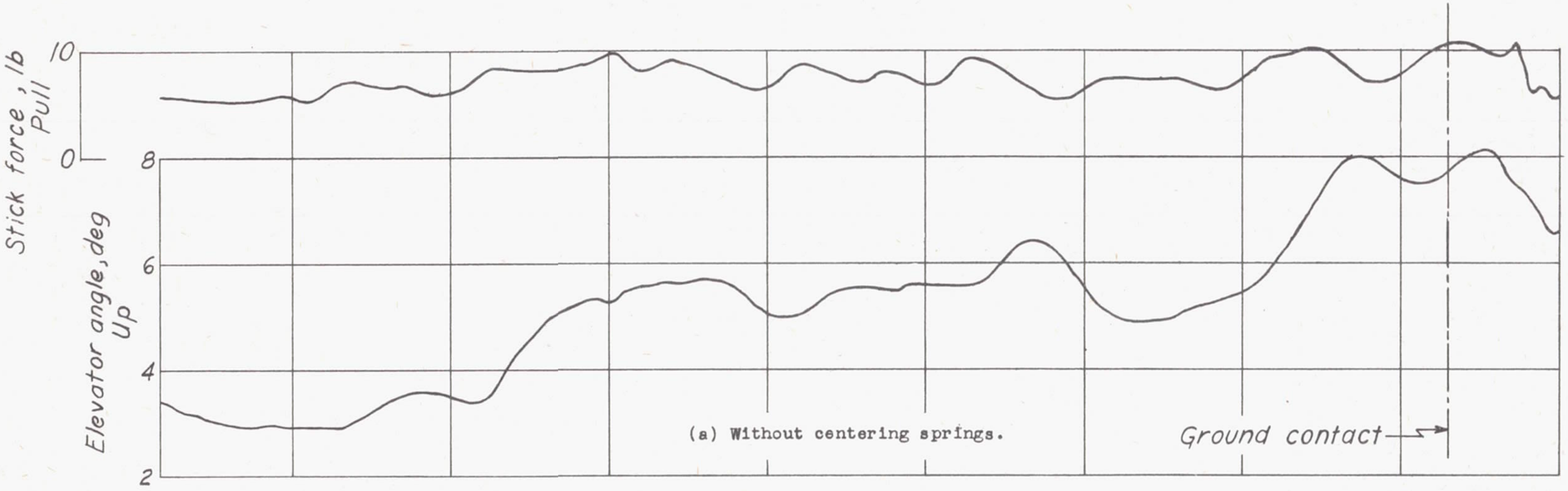
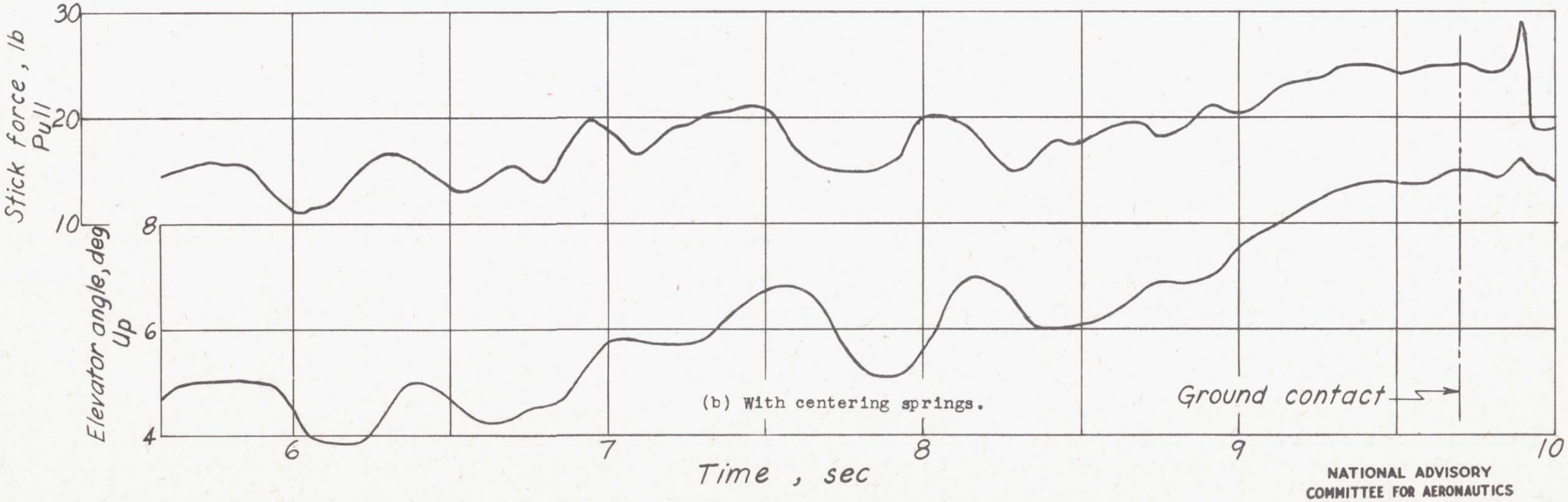


(a) Without centering springs.



(b) With centering springs.

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Figure 18.- Enlarged-scale time histories of elevator angle and stick force for the landings of figure 17.

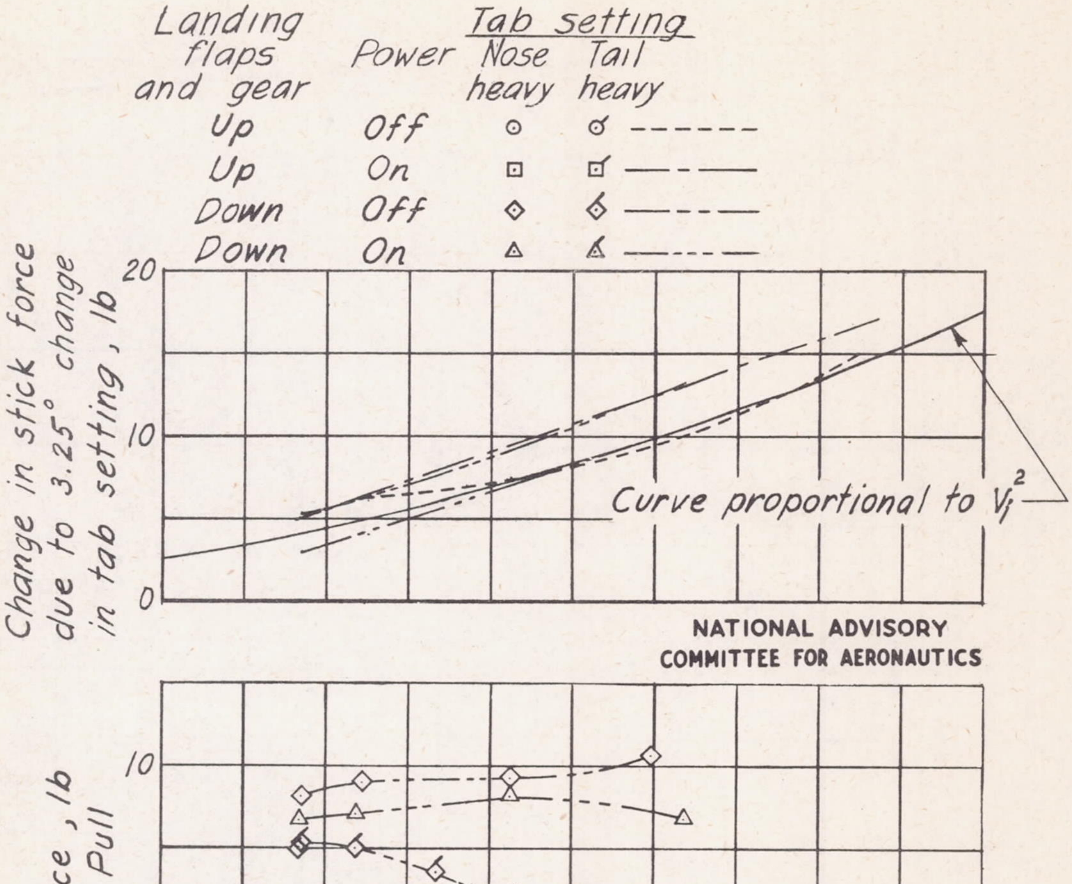

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Figure 19.- Variation of stick force with indicated airspeed for airplane trimmed full nose heavy and full tail heavy. Difference in tab settings, 3.25°. Power for power-on condition; manifold pressure, 23 in. Hg; engine speed, 2350 rpm.

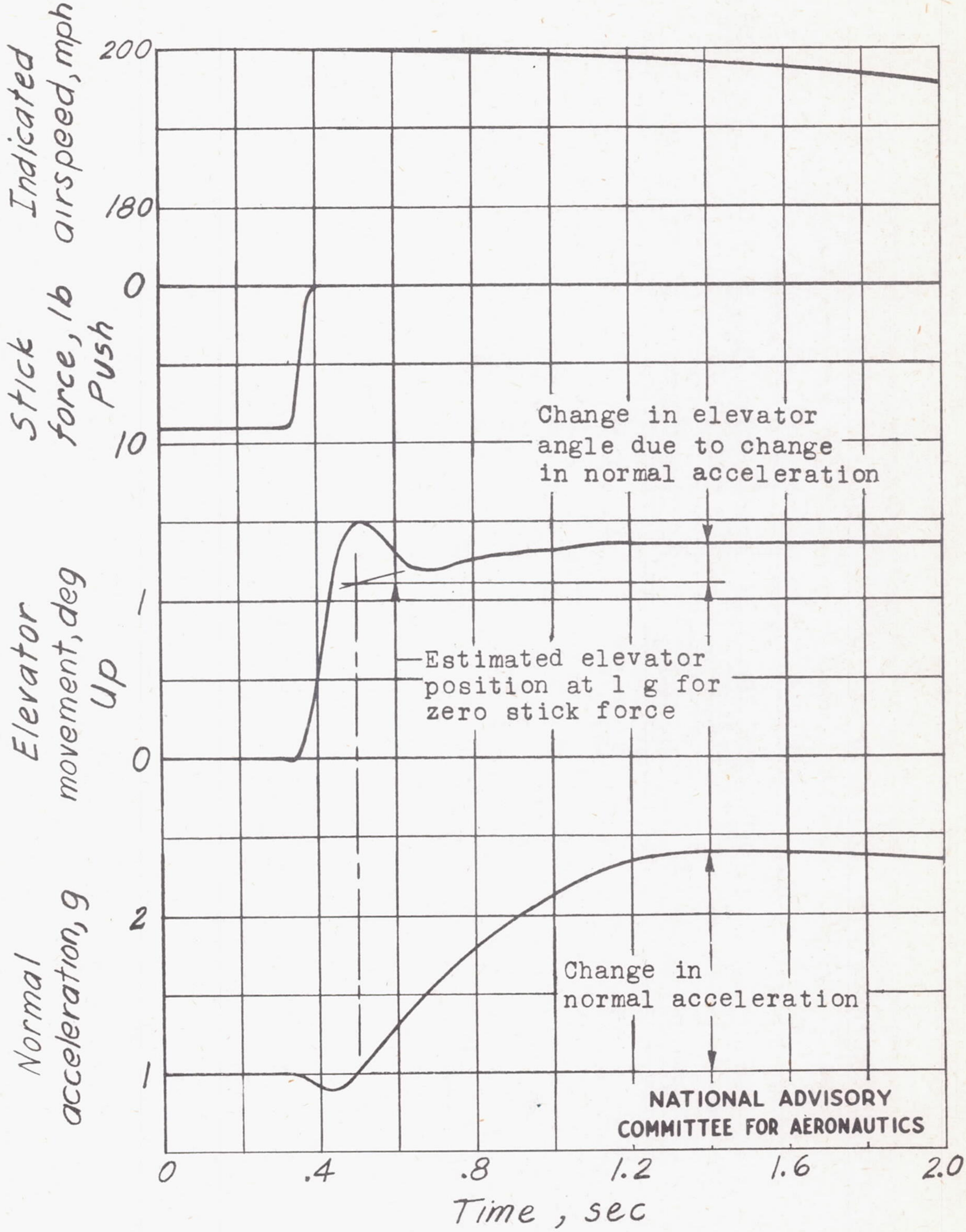

Figure 20.- Time history of a pull-up made by trimming the airplane tail heavy and then releasing the stick.

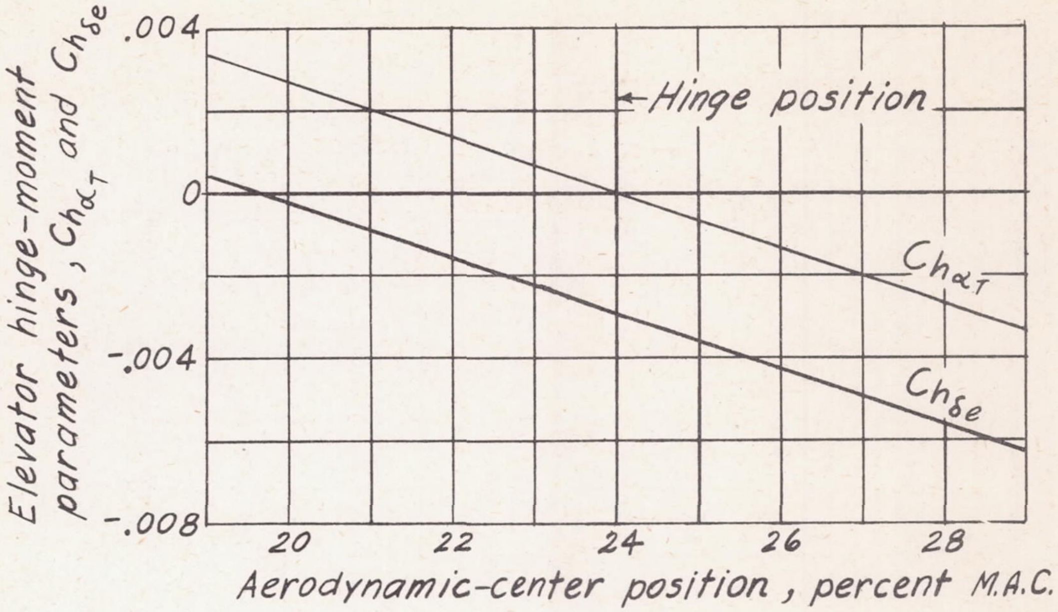

Figure 21.- Effect of aerodynamic-center position on the elevator hinge-moment parameters $C_{h_{\alpha_T}}$ and $C_{h_{\delta_e}}$.

$\frac{\delta_t}{\delta_e} = 1.0$

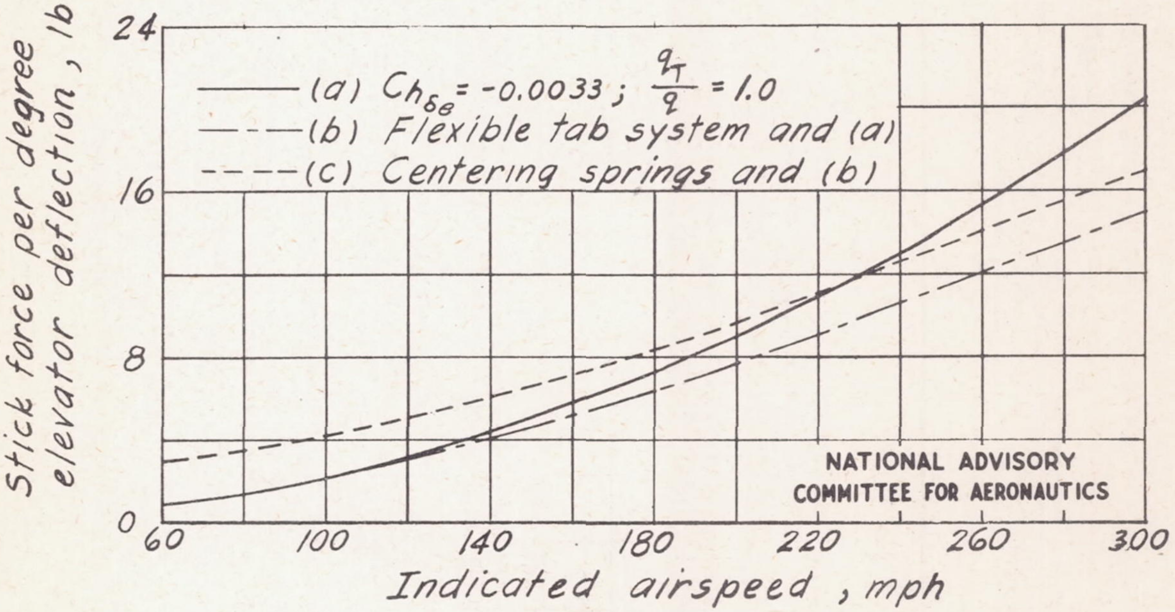

Figure 22.- Effect of flexible tab system and stick-centering springs on the stick force per degree elevator deflection.

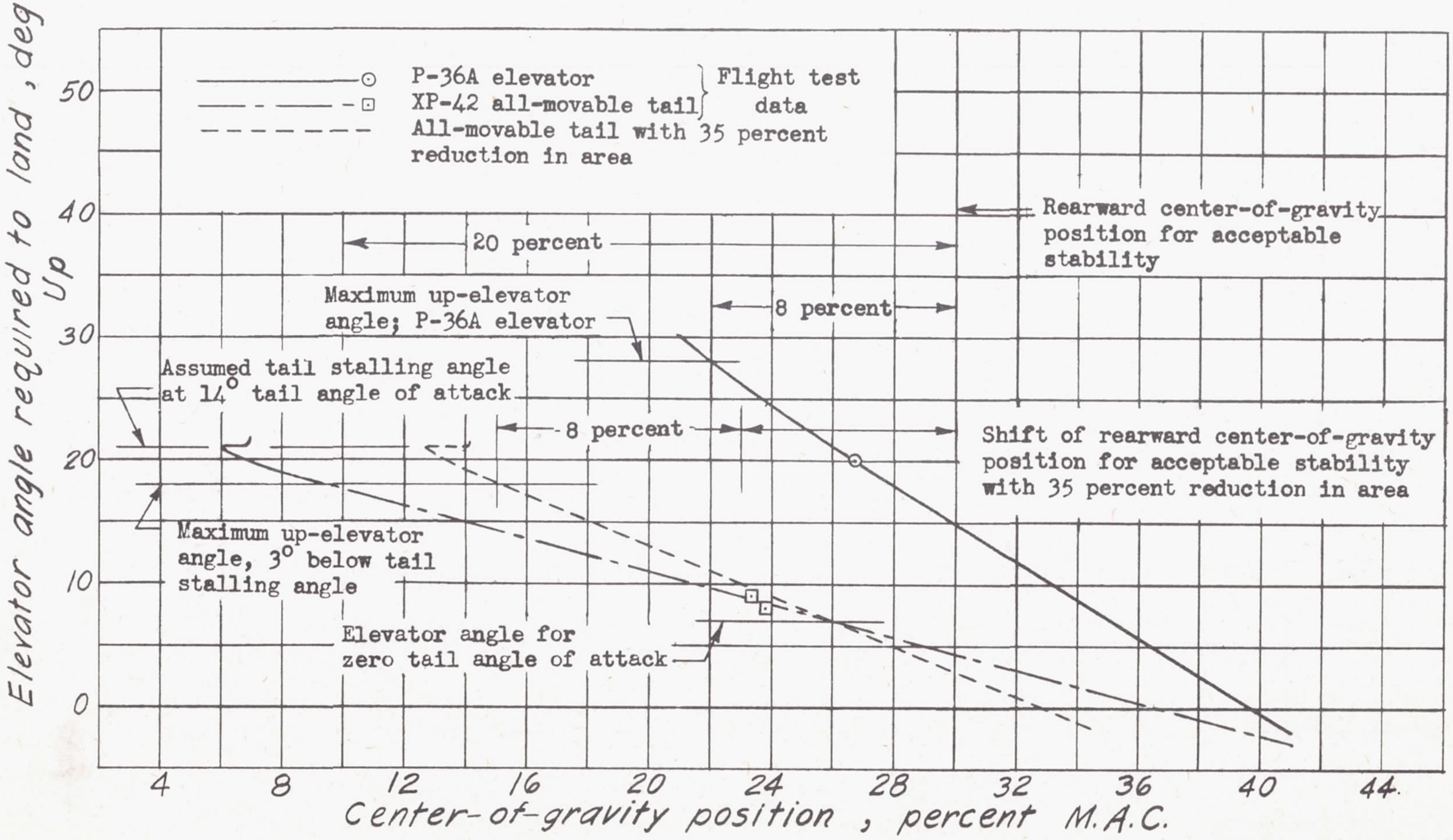

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Figure 23.- Variation of elevator angle required to land with airplane center-of-gravity position.

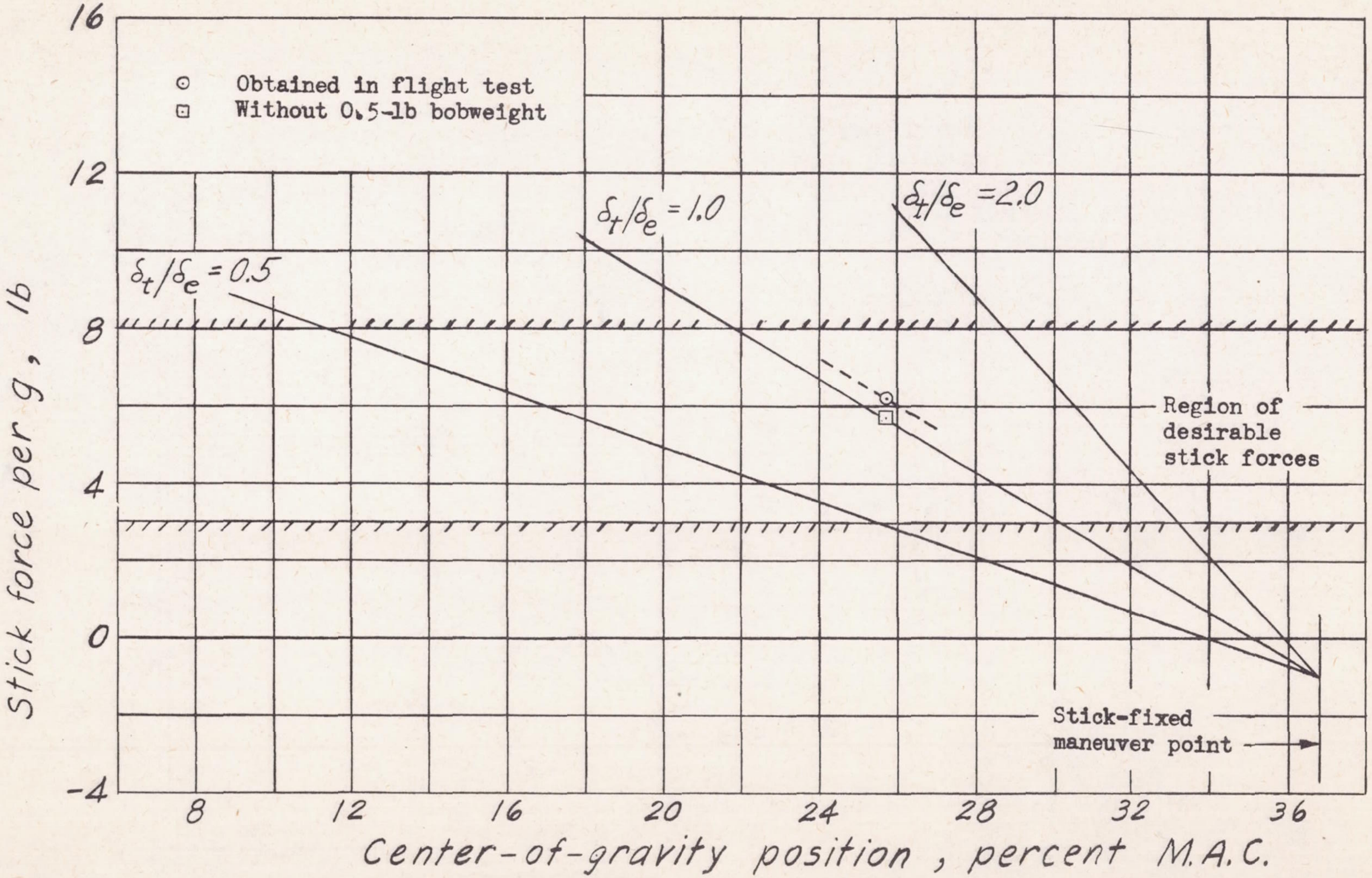

Figure 24.- Calculated variation of stick force per g with center-of-gravity position for several tab gear ratios.

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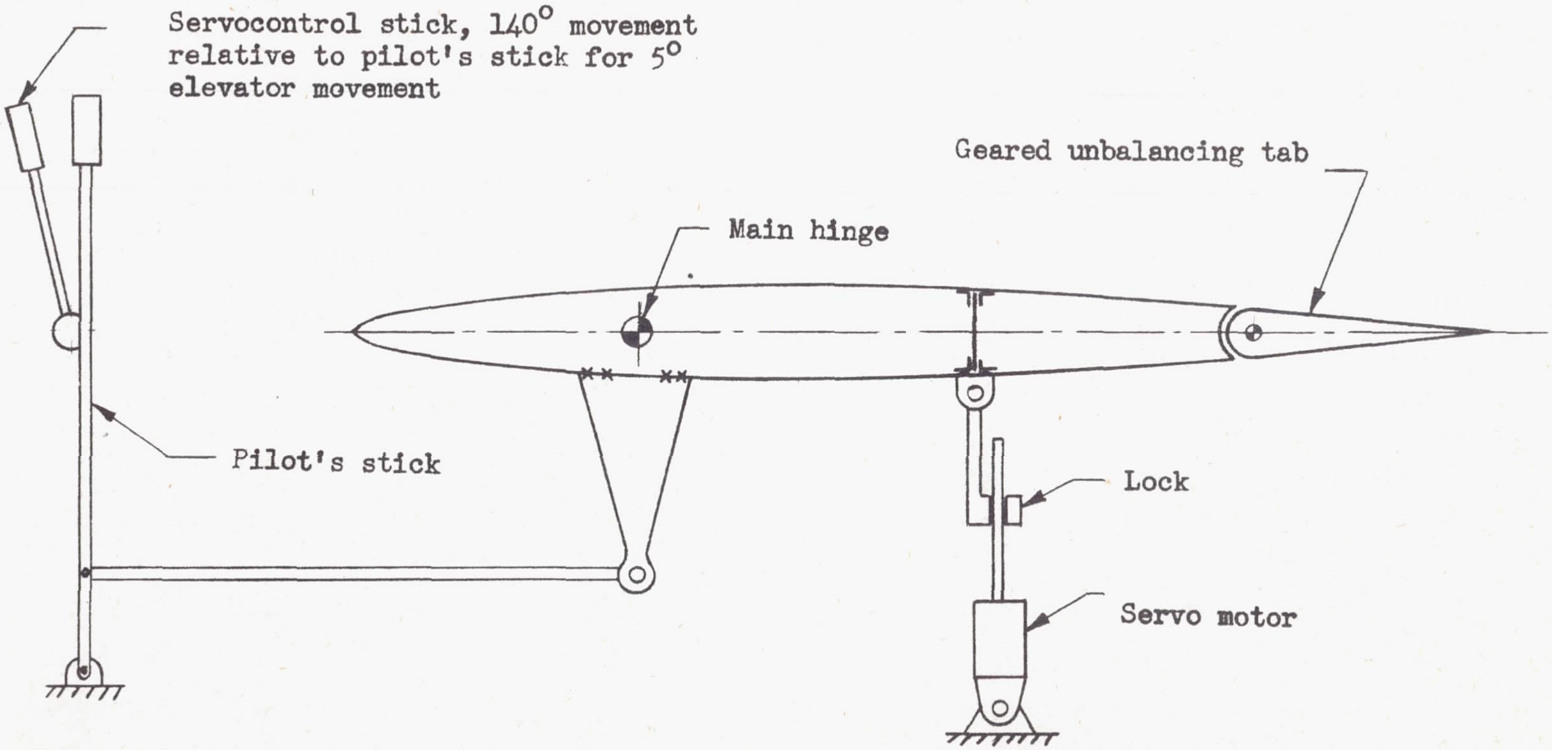

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Figure 25.- Schematic drawing of all-movable horizontal tail and irreversible servocontrol for high Mach numbers.