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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

FLIGHT INVESTIGATION OF EFFECT OF VARIOUS VERTICAL-TAIL MODIFICATIONS ON THE DIRECTIONAL STABILITY AND CONTROL CHARACTERISTICS OF THE P-63A-1 AIRPLANE (AAF No. 42-68889)

By

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Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
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SUMMARY

Because the results of preliminary flight tests had indicated the P-63A-1 airplane possessed insufficient directional stability, the NACA and the manufacturer (Bell Aircraft Corporation) suggested three vertical-tail modifications to remedy the deficiencies in the directional characteristics. These modifications included an enlarged vertical tail formed by adding a tip extension to the original vertical tail, a large sharp-edge ventral fin, and a small dorsal fin. The enlarged vertical tail involved only a slight increase in total vertical-tail area from 23.73 to 26.58 square feet but a relatively much larger increase in geometric aspect ratio from 1.24 to 1.73 based on height and area above the horizontal tail. At the request of the Air Materiel Command, Army Air Forces, flight tests were made to determine the effect of these modifications and of some combinations of these modifications on the directional stability and control characteristics of the airplane. In all, six different vertical-tail configurations were investigated to determine the lateral and directional oscillation characteristics of the airplane, the sideslip characteristics, the yaw due to ailerons in rudder-fixed rolls from turns and pull-outs, the trim changes due to speed changes, and the trim changes due to power changes.

Results of the tests showed that the enlarged vertical tail approximately doubled the directional stability of the airplane and that the pilots considered the directional stability provided by the enlarged vertical tail to be satisfactory. Calculations based on sideslip data obtained at an indicated airspeed of 300 miles per hour showed that the directional stability of the airplane with the original vertical tail corresponded to a value of C_{n_β} of -0.00056 whereas for the enlarged vertical tail the estimated value of

C_{n_β} was -0.00130. The ventral fin was found to increase by a moderate amount the directional stability of the airplane with the original vertical tail for small sideslip angles at low speeds but little consistent change in directional stability was effected by the ventral fin at higher speeds. The effectiveness of the ventral fin was generally much less when used with the enlarged vertical tail than when used with the original vertical tail. The ventral and dorsal fins were found to be very effective in eliminating rudder-force reversals which occurred in low-speed, high-engine-power, sideslipped conditions of flight. Sideslip tests at two altitudes for approximately the same engine power and indicated airspeed showed that a small decrease in static directional stability occurred with increasing altitude and this decrease in stability was attributed to the increased propeller blade angles required at high altitudes. The variations of rudder pedal force with indicated airspeed using normal rated power and a constant rudder tab setting through the speed range were desirably small for all the configurations tested. The rudder pedal force changed by about 50 pounds for a power change from engine idling power to normal rated power and this pedal force change was largely independent of airspeed or of vertical-tail configuration for the various configurations tested.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, flight tests were made to determine the effect of various vertical-tail modifications on the directional stability and control characteristics of the P-63A-1 airplane. Previous tests had shown that the original vertical tail provided insufficient directional stability to hold the yaw due to full aileron deflection (rudder fixed) below 20° at low speeds; that rudder-force reversals occurred in sideslips at low speeds with high engine power; and that the controls-free lateral and directional oscillations were poorly damped in some flight conditions. Furthermore, it was found to be difficult to maintain constant normal acceleration in steady turns and this was attributed to inability to maintain constant yaw heading because of low directional stability. In order to improve the directional characteristics, the NACA suggested the use of an enlarged vertical tail formed by adding a tip extension to the original vertical tail and also a small dorsal fin. For the same reason, the manufacturer (Bell Aircraft Corporation) suggested a large ventral fin. This report presents data showing the effects of these separate modifications and of a combination of all the modifications on the directional stability and control characteristics of the airplane. The tests reported herein were made at Langley Field, Va. in 1945.

AIRPLANE AND VERTICAL-TAIL MODIFICATIONS

General specifications of the Bell P-63A-1 fighter airplane are given in the appendix. A three-view drawing of the airplane is shown in figure 1. For the tests reported herein the center of gravity varied, primarily because of fuel consumption, from about 26.5 to about 24.5 percent mean aerodynamic chord. Also because of fuel consumption, the gross weight varied between approximately 8350 and 7800 pounds. Calculations and limited test data for widely varying center-of-gravity locations indicated the 2-percent change in center-of-gravity position encountered in the tests would have a negligible effect on the directional characteristics of the airplane. Plan forms of the original vertical tail and the enlarged vertical tail suggested by the NACA are shown in figure 2. Dimensional characteristics of the two vertical tails are given in table I. As is shown by table I and figure 2, the enlarged vertical tail involved an increase in vertical-tail height of $15\frac{3}{4}$ inches and a slight area increase from 23.73 to 26.58 square feet; however, the geometric aspect ratio (based on vertical tail height and area above the horizontal tail) was increased from 1.24 to 1.73. The effect of the increase in aspect ratio was expected to increase the directional stability much more than the effect of the increase in vertical-tail area.

The plan forms and major dimensions of the dorsal and ventral fins are shown in figure 3. The dorsal fin (fig. 4) had a sharp edge extending approximately the first three-quarters of its length along the fuselage; from that point on the edge was gradually rounded to fair into the fin leading edge. The ventral fin (fig. 5) had a sharp edge along its entire length.

Pictures of the various airplane configurations tested, in the order of subsequent data presentation, are reproduced in figure 6. The relation between angular travel of the rudder and linear travel of a rudder pedal along its arc is shown in figure 7.

INSTRUMENTATION

Standard NACA recording instruments were used to measure the following quantities:

(1) Service indicated airspeed

(2) Pressure altitude

(3) Normal acceleration

(4) Aileron angle

(5) Rudder angle

(6) Rudder pedal force

(7) Sideslip angle

Airspeed was measured from a pitot-static head mounted on the end of a special boom extending about 1 chord length ahead of the right wing near the wing tip. Within this report airspeed is defined by

$$Vi_s = 45.08 \, fo\sqrt{q_c}$$

wherein:

Vi_s correct service indicated airspeed, miles per hour

fo standard sea-level compressibility correction factor

q_c difference between total-head pressure and free-stream static pressure (corrected for position error), inches of water

Correct service indicated airspeed corresponds to the reading of a standard Army-Navy airspeed indicator connected to a pitot-static head free from position error. This airspeed is also referred to as calibrated airspeed.

The measurements of aileron and rudder angle were made by instruments connected directly to the respective control surfaces so that no corrections to the measured angles were necessary.

The sideslip angles were measured from a free-floating vane mounted on the end of a special boom extending about 1 chord length ahead of the left wing near the wing tip. No calibration was made of the possible position error of this installation so that the absolute sideslip angles shown herein may be in error by about 1° or 2° due to possible outflow or inflow near the wing tips judging from calibrations of similar installations on other airplanes. In spite of possible error in absolute sideslip angle, however, changes in sideslip angle measured at a given speed and normal acceleration are believed to be correct.

TESTS

The investigation consisted in determining the directional stability and control characteristics of the airplane with the various vertical-tail configurations from the following types of tests:

(1) Lateral oscillations

(2) Sideslips

(3) Rolls out of turns

(4) Rolls from pull-outs

(5) Trim changes due to speed changes

(6) Trim changes due to power changes

The airplane was in the clean condition (landing gear and flaps retracted) for all the tests reported herein.

The lateral oscillations were made by suddenly releasing all the controls after the airplane had been put into a small angle steady sideslip. These runs were made using power for level flight at 5000 feet altitude at indicated airspeeds of 150, 200, 250, and 300 miles per hour.

The sideslips were made by the continuous recording method which is described in detail in reference 1. The steady yawing and rolling velocities in the continuous sideslips were held low enough to consider the resulting data representative of that which would be obtained in steady sideslips. Sideslips were made at 5,000 feet altitude with engine idling at 150 miles per hour and with normal rated power at 150 and 300 miles per hour, and at 25,000 feet altitude with normal rated power at 150 miles per hour.

The rolls out of turns were made with engine idling at 5,000 feet altitude for speeds between 125 and 130 miles per hour (approximately 125 to 130 percent of the stalling speed). For these tests the airplane was first put into a steady banked turn of about 45° bank angle (corresponding to approximately 1.4g normal acceleration) and then the stick was moved abruptly to a predetermined lateral deflection against the direction of bank holding the rudder fixed. The resulting roll was held until after the maximum sideslip angle had been obtained. It was the original intention to make the rolls out of turns at 120 percent of the stalling speed (about 120 miles per hour) but preliminary attempts showed that appreciable aileron deflection at this speed resulted in stalling the wing. In this connection a recent revision to the Army handling qualities specifications raised the test speed for determining yaw due to ailerons at low speed from 1.2 to 1.4 times the power-off stalling speed when the maneuver was changed from a roll from level flight to a roll out of turn.

Rolls from pull-outs were made at about 5000 feet altitude for speeds of 200, 250, and 300 miles per hour. To execute these maneuvers, the pilot rapidly pulled the airplane to 3g normal acceleration with wings laterally level and then abruptly applied a predetermined aileron stick deflection holding the rudder fixed. Until the time maximum sideslip angle was achieved the pilot attempted to hold the initial normal acceleration constant by movements of the elevator in accordance with indications of a visual accelerometer. For this series of tests, the propeller blade angle and thrust coefficient were held constant at the values determined by using normal rated power at 300 miles per hour indicated airspeed. Therefore, at the lower speeds, both the engine speed and manifold pressure were reduced from the values corresponding to normal rated power (2600 rpm, 43 inches of mercury). The propeller blade angle and thrust coefficient were held constant in these tests in an attempt to maintain constant the contribution of the propeller to the directional stability of the airplane.

The directional trim changes due to speed changes were investigated only for the rated power condition at approximately 5000 feet altitude for one rudder trim-tab setting. These tests were made by trimming the rudder force to zero in level flight (roughly 300 miles per hour indicated airspeed) and then taking records in laterally level straight flight at steady speeds ranging from the stalling speed to 450 to 470 miles per hour indicated airspeed.

Directional trim changes due to power changes were determined at 5000 feet altitude at 125, 150, and 300 miles per hour indicated airspeed. In making these tests the airplane was first trimmed for zero rudder force with rated power holding the wings level in straight flight at the chosen speed. The throttle was then retarded to idle the engine and records were taken after the initial flight speed, a laterally level altitude, and a straight flight path had been restored. This procedure was also followed starting from the engine-idling trim condition and then applying normal rated power.

RESULTS AND DISCUSSION

Lateral Oscillation Characteristics

Figure 8 shows a time history of an undamped directional oscillation that was encountered with the original vertical tail during a previous investigation of longitudinal stability characteristics and which was partially responsible for the present investigation. Upon noting a small amplitude periodic motion of the airplane during a routine climb to high altitude, the pilot fixed the controls to the best of his ability and obtained a record of the motion which failed to damp out in spite of the controls being consciously held fixed. The minute control motions that actually did occur during the time history of figure 8 are believed to be the result of the floating tendencies of the control surfaces coupled with control system flexibility and possible play in the control systems rather than the result of stick or rudder pedal movements.

It appears on the surface that the oscillation was a manifestation either of "snaking," a continuous directional oscillation in which movements of the rudder reinforce the motion, or of "dutch roll," a continuous directional oscillation which occurs with rudder fixed. Of these two possibilities, the evidence appears to support the "dutch roll" supposition because the rudder movements which did occur appear much too small to account for the 2° to 3° change in sideslip angle involved. The occurrence of dutch roll would indicate insufficient directional stability in the case of the P-63 because the dihedral effect, though positive, is not strong.

It was interesting to note that the continuous oscillation was not encountered in the present series of tests wherein all the airplane conditions were duplicated with the exception of the longitudinal stability. This suggests the possibility that the continuous oscillation may have been related to coupling of the longitudinal and directional motions through the gyroscopic reactions of the propeller.

A summary of the lateral oscillation characteristics determined in the present tests is given in figure 9. All the results of figure 9 were obtained from time histories of the variation in sideslip angle. The time required to reduce the oscillation to half amplitude was measured directly from envelope curves drawn on the curves of sideslip angle plotted against time. In general, each test point shown in figure 9 is an average of between two to four separate determinations.

The results of figure 9 show that the addition of the ventral fin containing 7.2 square feet area with the original vertical tail caused a sizeable decrease of the period, particularly at higher speeds. This indicates a sizeable increase in directional stability. However, the addition of only 2.85 square feet of area to the tip of the original vertical tail caused a greater decrease in period at all speeds, indicating greater increases in directional stability. It is interesting to note that additions of ventral- and dorsal-fin area to the enlarged vertical tail did not bring about very sizeable changes in period. Therefore it appears that low aspect ratio fins such as the ventral fin tested may be reasonably beneficial to directional stability when the initial directional stability is meager but relatively ineffective when the initial directional stability is good. This view is borne out by the data obtained in the other types of directional stability tests as will be shown later. With regard to the time and number of cycles required to damp to half amplitude, the data indicate the dorsal and ventral fins were, in general, more effective in reducing these damping parameters than was the addition of tip area to the original vertical tail. However, the data on the damping parameters may not be conclusive because considerable scatter of these results was noted during the evaluation of data for comparable test runs. In the case of determining the period, almost perfect agreement was obtained between results from comparable test runs.

Sideslip Characteristics

The results of the sideslip tests are shown in figures 10 through 12. It will be noted that in these and in some subsequent figures, some of the faired curves have been repeated several times to facilitate an evaluation of the effect of the various modifications on the directional characteristics. Hence, the plots at the top of each figure are designed to show the effect of increasing aspect ratio of the vertical tail (and to a lesser extent, increasing vertical tail area), the next set of curves show the effect of adding the ventral fin to the original vertical tail, and similarly, the remaining plots show the effect of adding the ventral and dorsal fins to the enlarged vertical tail.

The data obtained for both the engine idling and the rated power conditions at 150 miles per hour at 5000 feet altitude are shown in figure 10. In the top plot of rudder angle versus sideslip angle in figure 10(a), it is seen that increasing the aspect ratio and vertical tail area caused a definite increase in slope of the curve of rudder angle versus sideslip angle. Measurements of the slopes of these curves at zero sideslip angle result in values of

0.72 and 1.04 for the original and enlarged vertical tails, respectively. On a percentage basis, the slope of the curve for the enlarged vertical tail is about 144 percent of the slope for the original vertical tail. When the relative effectiveness of the two vertical tails and rudders (as estimated from the dimensions of the appendix and the charts of reference 2) is considered, however, it can be shown that these slope values indicate the enlarged vertical tail provided about 194 percent of the rudder fixed directional stability supplied by the original vertical tail. This greater relative increase in directional stability over the increase in slope of rudder angle versus sideslip angle curves is due primarily to the higher lift curve slope of the enlarged vertical tail resulting from the large increase in aspect ratio. The effect of adding the ventral fin (fig. 10(a)) was to increase the directional stability, primarily at high sideslip angles. Here again, the addition of the ventral fin caused a greater increase in directional stability when used with the original vertical tail than when used with the enlarged vertical tail. As regards the rudder-pedal-force characteristics, the dorsal and ventral fins when added to either the original or enlarged vertical tails caused a marked steepening of the curves of pedal force against sideslip angle at large angles of sideslip; this trend is characteristic of the effect of such fins and it results largely from the increase in rudder-fixed directional stability brought about by the fins at high angles of sideslip.

With normal rated power at 150 miles per hour (fig. 10(b)) the airplane exhibited strong tendencies toward rudder force reversal at large angles of sideslip both in left and in right sideslip with either the original or enlarged vertical tails. Actual rudder force reversals were encountered in left sideslip for both configurations but the data are not shown because of unsteadiness in the airplane motion which occurred at very great angles of sideslip. The pilot reported that when a left sideslip angle of approximately 25° was reached, the rate of yawing seemed to increase precipitously without further movement of the rudder pedals. In one particular run with the original vertical tail a left sideslip angle of 35° was attained before recovery was effected. This undesirable characteristic was believed to be caused by the combination of rudder overbalance and great flexibility of the control system. During a slow increase in sideslip angle, as the rudder force was relieved at large sideslip angle, the rudder automatically moved farther without a corresponding movement of the rudder pedals because the deflected control system was returning to an unstressed condition. From the data shown in figures 7 and 10(b), it has been estimated that the rudder would move approximately 6° with the rudder pedals fixed for a rudder hinge-moment change corresponding to 100 pounds rudder pedal force. When the ventral fin was installed with the original vertical tail or when either the ventral or dorsal fins were used with the enlarged vertical tail, the rudder force reversal was eliminated and it was possible to deflect the rudder pedals fully against the stops in the pilots compartment without encountering any precipitous yawing tendency. In the absence of rudder force reversal, the relatively great flexibility of the rudder control system was not objectionable. It is interesting to note in figure 10(b) that the use of both the dorsal and ventral fins together with the enlarged vertical tail caused a marked increase in both rudder fixed and free directional stability in this low speed, high power condition of flight.

Figure 11 presents the data obtained in sideslips at 300 miles per hour indicated airspeed at 5000 feet altitude using normal rated power (2600 rpm, 43 inches of mercury). It should be noted in figure 11 that both the abscissa and ordinate scales for sideslip angle and rudder angle have been expanded by a factor of $2\frac{1}{2}$ over the scales used in figure 10, but the rudder-pedal-force scale has been maintained at the value used for the low speed runs. Therefore, the slopes of the curves of rudder angle versus sideslip angle in figures 10 and 11 may be compared directly to determine the effect of speed on these slope values but the slopes of rudder force versus sideslip angle shown by figure 11 must be multiplied by a factor of $2\frac{1}{2}$ to put these slopes on a comparable basis with those shown by figure 10. From figure 11 it is seen that for the small ranges of sideslip angles over which data were obtained at 300 miles per hour addition of the ventral fin to either the original or enlarged vertical tail had no appreciable effect on the slopes of the curves of rudder angle or rudder force versus sideslip angle whereas addition of the dorsal fin to the enlarged vertical tail had a slightly beneficial effect on the slopes. However, it is seen from the top curves of figure 11 that increasing the aspect ratio and area of the original vertical tail brought about a large increase in the slope of the curve of rudder versus sideslip angle and, as explained previously, this would indicate an even larger increase in the rudder-fixed directional stability.

An attempt has been made to determine the contributions of the various components of the airplane to the directional stability of the complete airplane for both the original and enlarged vertical-tail configurations without ventral or dorsal fins. The results of this effort are shown in table II which is largely self-explanatory. To make these estimations it was assumed that the dynamic pressure at the tail was equal to free-stream dynamic pressure. This assumption is nearly correct for high speed conditions such as that for which data are shown in figure 11.

It is important to point out that because the "unaccounted for" destabilizing increments listed in column 6 of table II are not identical for the two vertical-tail configurations the estimations are not necessarily in error; for, if the unaccounted for loss in directional stability was caused entirely by an unfavorable sidewash effect, the unaccounted for increments would be expected to amount to a constant percentage of the directional stability contributed by the isolated vertical tails (column 1). Actually the unaccounted for losses in directional stability are nearly a constant 15 percent of the estimated directional stability contributed by the isolated vertical tails and this suggests strongly that the losses in directional stability estimated from the flight data as compared with that calculated primarily from the charts were due almost entirely to an unfavorable sidewash ratio $\left(\frac{d\sigma}{d\beta}\right)$ of 0.15. At any rate, if the estimations of table II are only reasonably correct it may be concluded that the airplane with the enlarged vertical tail possessed about twice as much rudder-fixed directional stability as the airplane with the original vertical tail; furthermore, this increase in directional stability was accomplished with only a 12-percent increase in vertical-tail area which was disposed in such a way as to give the greatest practical increase of aspect ratio.

Figure 12 shows the effect of increasing altitude on the directional stability characteristics with rated power at an indicated airspeed of 150 miles per hour for four different airplane configurations. It is believed that the persistent small decrease in directional stability with increasing altitude shown by this figure was attributable to the increased propeller blade angles that were required at the high altitude to produce the higher true airspeed that corresponds to the same indicated airspeed used in tests at the low altitude. In this connection reference 3 shows that increasing the blade angle increases the destabilizing contribution of a tractor propeller.

Characteristics in Rolls Out of Turns

Results of the rudder-fixed rolls out of turns are shown in figure 13. It will be noted that the data are plotted in terms of the maximum change in sideslip angle per unit airplane normal-force coefficient rather than simply the maximum change in sideslip angle against aileron deflection. This procedure was followed in order to take into account small changes in normal acceleration which unavoidably occur between the time the ailerons are abruptly deflected and the maximum sideslip angle is obtained. Theory shows that the yawing moment due to aileron deflection and rolling and hence, the maximum sideslip angle attained depends primarily on the airplane normal-force coefficient. Consequently, in order to put the test results on a sound theoretical basis each test run was analysed to determine the ratio of the maximum change in sideslip angle which occurred to the average airplane normal-force coefficient which existed during the run. For purposes of computing the average airplane normal-force coefficient, the average normal acceleration and speed that existed during each run was used. If it is desired to obtain the actual sideslip angle changes from the data of figure 13, it is only necessary to multiply the ordinate by the airplane normal-force coefficient forwhich the change in sideslip is desired. For instance, at an airplane normal-force coefficient of 1.0, the values of $\frac{\Delta\beta}{C_n}$ given by figure 13 are numerically equal to the maximum changes in sideslip angle that would be expected due to deflection of the ailerons with rudder fixed. When using the data in this way, however, it must be recognized that the data of figure 13 apply only to high angles of attack, low speeds, and the engine idling condition. Also, for very great sideslip changes (greater than about 20°) the data tend to be of academic interest only because in the flight tests it was found that by the time such large sideslip changes were attained the airplane had rolled into a near-inverted attitude in spite of the advantage obtained by starting the rolls from a 45° banked position. When such large changes in attitude occur, the effect of gravity may be important in determining the maximum sideslip angle reached.

The top plot of figure 13 shows that approximately twice as much change of sideslip angle occurred with the original vertical tail as with the enlarged vertical tail for a given aileron deflection. This is probably a good indication that the directional stability of the airplane was roughly doubled by the enlarged vertical tail. In this connection, the complicated dynamic nature of the airplane motion in these roll-out-of-turn maneuvers does not permit easy rigorous conclusions to be made concerning the directional stability simply from a consideration of the maximum sideslip angles attained. However, it is worthwhile remembering, when examining curves of the type shown in figure 13, that a decreased slope corresponds to increased directional stability. Addition of the ventral fin to the original vertical tail (fig. 13) brought about a moderate increase in directional stability for small changes in sideslip angle and large increases for large changes in sideslip angle. The effect of the ventral fin was negligible when used with the enlarged vertical tail. These trends are in general agreement with those obtained from the low-speed sideslip tests already discussed. Addition of the dorsal fin to the enlarged vertical tail apparently reduced the ability of the vertical tail to restrict the yaw due to aileron deflection in left rolls but no detrimental effects of the dorsal fin appeared when the ventral fin also was installed. This peculiar effect of the dorsal fin occurred also in the higher speed rolls from pull-outs (fig. 14). No explanation for the effect is offered.

Characteristics in Rolls from Pull-Outs

Previous work on the P-63A-1 airplane (reference 4) has shown that the roll-from-pull-out maneuver is one in which very large vertical-tail loads may be encountered. It was shown that the magnitude of such vertical-tail loads depend to some extent on the directional stability of the airplane. Increasing the directional stability of the airplane would be expected to reduce the maximum vertical-tail load because, for a given yawing moment due to application of ailerons, the maximum sideslip angle reached is reduced; the vertical-tail load required to offset the unstable yawing moments of the fuselage and propeller is therefore reduced even though the load required to offset the primary yawing moment due to rolling remains essentially constant with varying directional stability.

The results of the rolls from pull-outs at the various speeds tested are shown in figure 14. The faired curves of the top plot indicate that, on the average, the airplane yawed only about 60 percent as much with the enlarged vertical tail as it did with the original vertical tail for a given aileron deflection. The addition of the ventral fin to the original vertical tail increased the yaw due to use of the ailerons for left rolls. This result is contrary to that obtained at low speed with the engine idling (fig. 13) and might possibly be caused by a local increase in unfavorable sidewash in the region of the ventral fin brought about by the use of power. In this connection, however, it should be noted that use of the ventral fin with the enlarged vertical tail was not detrimental to the characteristics in left rolls so that any attempts to explain the effects of the ventral fin on the basis of sidewash must be regarded as conjecture. As would be expected, the data of figure 14 show that the configuration incorporating all the modifications provided the greatest directional stiffness in restricting the yaw caused by the yawing moment due to aileron deflection and rolling.

Direction Trim Characteristics

Typical variations of sideslip angle and rudder angle required for laterally level straight flight throughout the speed range with rated power for the enlarged vertical tail are shown in figure 15. Similar sideslip and rudder angle data for the other five configurations tested were almost identical to those shown in figure 15 and are therefore not presented. It is seen that only about 20° right rudder deflection was required at the stalling speed so that directional control power was adequate. Figure 15 shows that a center-of-gravity movement of 5 percent of the mean aerodynamic chord had a negligible effect on the directional trim characteristics.

Variations of the rudder pedal force with indicated airspeed are shown in figure 16 for the six vertical-tail configurations tested. Here it is seen that the various vertical-tail modifications had a slight but definite effect on the pedal-force variations at high speeds. The shape of the curve for the original vertical tail is characteristic of that which would be expected if the rudder fabric covering or the rudder structure distorted due to high aerodynamic loads, whereas the shape of the curve for the enlarged vertical tail with both dorsal and ventral fins added is approximately that which would be expected without rudder distortion. With regard to the desirability of the various types of force variations with speed shown in figure 16, there appears to be little to choose from; all of the configurations provided desirably small changes in rudder force with changes in speed.

Trim Changes Due to Power Changes

The effect of the various vertical-tail modifications on the trim changes due to power changes is shown in figure 17. The data show that the addition of the dorsal and ventral fins to the two basic vertical-tail configurations had a negligible effect on the rudder angle trim changes due to power changes. On the other hand, considerably more change in rudder angle was required to offset the yawing moment due to power with all of the enlarged vertical-tail configurations than with either of the original vertical-tail configurations, particularly at low speeds. This result is believed to be explained by the difference in height of the two vertical tails as related to the relative twist of the slipstream. At low speeds (high angle of attack) the fixed tip of the enlarged vertical tail probably extended into a region of the slipstream where the cross-flow change due to power change was greatest. Therefore, in order to offset the increased change in yawing moment due to cross flow of the slipstream, greater rudder-angle changes were required with the taller, enlarged vertical tail than with the original vertical tail. It is interesting to note that the rudder-pedal-force change with power change was approximately constant over the speed range tested; also that this trim change was desirably small inasmuch as it amounted to only about 50 pounds for any of the configurations tested.

CONCLUSIONS

From an investigation of the effect of various vertical-tail modifications on the directional stability and control characteristics of the P-63A-1 airplane, the following conclusions were indicated:

1. The directional stability of the airplane was approximately doubled by adding 2.85 square feet of vertical-tail area to the tip of the original vertical tail which contained a total of 23.73 square feet area. Calculations based on data obtained in sideslips at an indicated airspeed of 300 miles per hour showed that the directional stability of the airplane with the original vertical tail corresponded to a value of C_{n_β} of -0.00056 whereas with the enlarged vertical tail the estimated value of C_{n_β} was -0.00130. The pilots considered the directional stability of the airplane inadequate with the original vertical tail but satisfactory with the enlarged vertical tail.

2. The addition of a ventral fin containing 7.2 square feet of area to the airplane with the original vertical tail caused a moderate increase in directional stability for small sideslip angles at low airspeeds but no consistent appreciable change in directional stability at high speeds. The effect of the ventral fin on the directional characteristics of the airplane with the enlarged vertical tail was generally much less than the corresponding effect with the original vertical tail.

3. Rudder force reversals which occurred in sideslips at low speeds for high engine powers with the original vertical tail were eliminated by incorporation of the ventral fin. Similar rudder force reversals which occurred with the enlarged vertical were eliminated by addition of the ventral fin, a small dorsal fin, or a combination of the dorsal and ventral fins.

4. A consistent small decrease in directional stability due to increasing altitude occurred in low speed, high-engine-power sideslips and this effect was attributed to the increased propeller blade angles required to maintain a given indicated airspeed at higher altitudes.

5. The various vertical-tail modifications had a measurable effect on the variation of rudder pedal force with indicated airspeed for fixed rudder tab setting and constant rated power; however, the force variations provided by the various configurations were all desirably small.

6. Greater changes in rudder angle were required to offset a given change in engine power with the enlarged vertical tail than with the original vertical tail, particularly at low speeds; however, the rudder power was entirely adequate to cope with the trim change for any of the configurations tested. A rudder pedal force of approximately 50 pounds was required to offset the directional trim change due to changing the engine power from engine idling to rated power conditions; this change of pedal force was largely independent of either airspeed or vertical-tail configuration.

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APPENDIX

GENERAL SPECIFICATIONS OF AIRPLANE

Name and type . . . . Bell P-63A-1 fighter

Engine . . . . Allison V-1710-93
  Rating:
    Take-off . . . . 1325 hp at 3000 rpm, 54 in. Hg at S. L.
    Normal rated . . . 1050 hp at 2600 rpm, 43 in. Hg at 10,000 ft
    Military rated . 1180 hp at 3000 rpm, 52 in. Hg at 21,500 ft
  Supercharger gear ratio 6.85:1

Propeller (special Aeroproducts type)
  Diameter . . . . 11 ft 1 in.
  Number of blades 4
  Engine-propeller gear ratio 2.23:1

Fuel capacity (without belly tank), gal 136

Weight empty, lb 5910

Normal gross weight, lb 7650

Wing loading (normal gross wt.), lb/sq ft 30.85

Power loading (normal gross wt., 1050 hp), lb/hp 7.29

Over-all height (taxying position) . . . . 11 ft 4 in.

Over-all length . . . . 32 ft $8\frac{3}{8}$ in.

Wing:
  Span, ft 38.33
  Area (including section through fuselage), sq ft 248
  Airfoil section, root . . . . NACA 66,2X-116
  Airfoil section, tip . . . . NACA 66,2X-216
  Mean aerodynamic chord, in. 82.54
    Leading edge M.A C., in. aft L.E. root chord 6.11
  Aspect ratio 5.92:1
  Taper ratio 2:1
  Dihedral (35-percent chord, upper surface), deg 3.67
  Root incidence, deg 1.30
  Tip incidence, deg . . . . -0.45

Wing flaps (plain sealed type):

Total area, sq ft	12.9
Span (along hinge line, each) in.	62.38
Travel, deg. down	45

Ailerons:

Span (along hinge line, each) in.	120.75
Area aft of hinge center line, each, sq ft	8.14
Fixed balance area, each, sq ft	4.83
Location of inboard end of aileron, percent semispan	44.2
Location of outboard end of aileron, percent semispan	96.7
Travel, deg	±15

Horizontal tail:

Span, in.	175
Total area, sq ft	46.92
Stabilizer area, sq ft	34.15
Total elevator area, sq ft	12.77
Elevator area aft hinge center line, including tab, sq ft	9.85
Elevator area forward hinge center line, sq ft	2.92
Elevator trim tab area, sq ft	0.92
Distance elevator hinge center line to L.E. of M.A.C., in.	226.28
Elevator travel from stabilizer, deg down	15
Elevator travel from stabilizer, deg up	35

Vertical tail:

See table I

REFERENCES

1. Johnson, Harold I.: A Comparison of Data Obtained by Two Flight Techniques for Determining the Sideslip Characteristics of a Fighter Airplane. NACA RB No. L5F25a, 1945.

2. Pass, H. R.: Analysis of Wind-Tunnel Data on Directional Stability and Control. NACA TN No. 775, 1940.

3. Ribner, Herbert S : Notes On the Propeller and Slipstream In Relation to Stability. NACA ARR No. L4I12a, 1944.

4. Johnson, Harold I.: Estimates of the Vertical-Tail Loads of a Bell P-63A-1 Airplane (AAF No. 42-68889) in Accelerated Rolling Maneuvers Based on Flight Tests with Two Vertical-Tail Arrangements. NACA MR No. L4K30a, Army Air Forces, 1944.

TABLE I

DIMENSIONS OF ORIGINAL AND ENLARGED VERTICAL TAILS

TESTED ON P-63A-1 AIRPLANE

	Original	Enlarged
Total height along hinge center line, in.	78.87	94.62
Height above horizontal tail center line, in.	62.00	77.75
Total area, sq ft	23.73	26.58
Fin area, sq ft	13.47	15.96
Total rudder area, sq ft	10.26	10.62
Rudder area aft hinge center line, sq ft	8.30	8.65
Rudder area forward hinge center line, sq ft	1.96	1.97
Rudder trim tab area, sq ft	0.84	0.84
Distance rudder hinge center line to L.E. of M.A.C., in.	248.40	248.40
Fin offset from thrust axis, deg.	0	0
Rudder travel, deg	±30	±30

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TABLE II

ESTIMATED CONTRIBUTIONS OF VARIOUS AIRPLANE COMPONENTS

TO DIRECTIONAL STABILITY OF P-63A-1 AIRPLANE

Column	Component	C_{n_β}, per degree: Original vertical tail	C_{n_β}, per degree: Enlarged vertical tail	Source
1	Vertical tail	-0.00185	-0.00266	Calculated from airplane dimensions and charts of reference 2 assuming no sidewash or interference effects.
2	Fuselage and wing	.00040	.00040	Wright Field wind-tunnel data
3	Propeller	.00060	.00060	Estimated from propeller dimensions and charts of reference 3
4	Complete airplane (calculated neglecting sidewash, interference, etc.)	-.00085	-.00166	Sums of columns 1, 2, and 3
5	Complete airplane (estimated from flight data at 300 mph)	-.00056	-.00130	Product of 1, estimated rudder effectiveness from reference 2, and measured $d\delta_r/d_\beta$ from figure 11.
6	Unaccounted for (sidewash, interference, etc.)	.00029	.00036	-(Column 4 - Column 5)

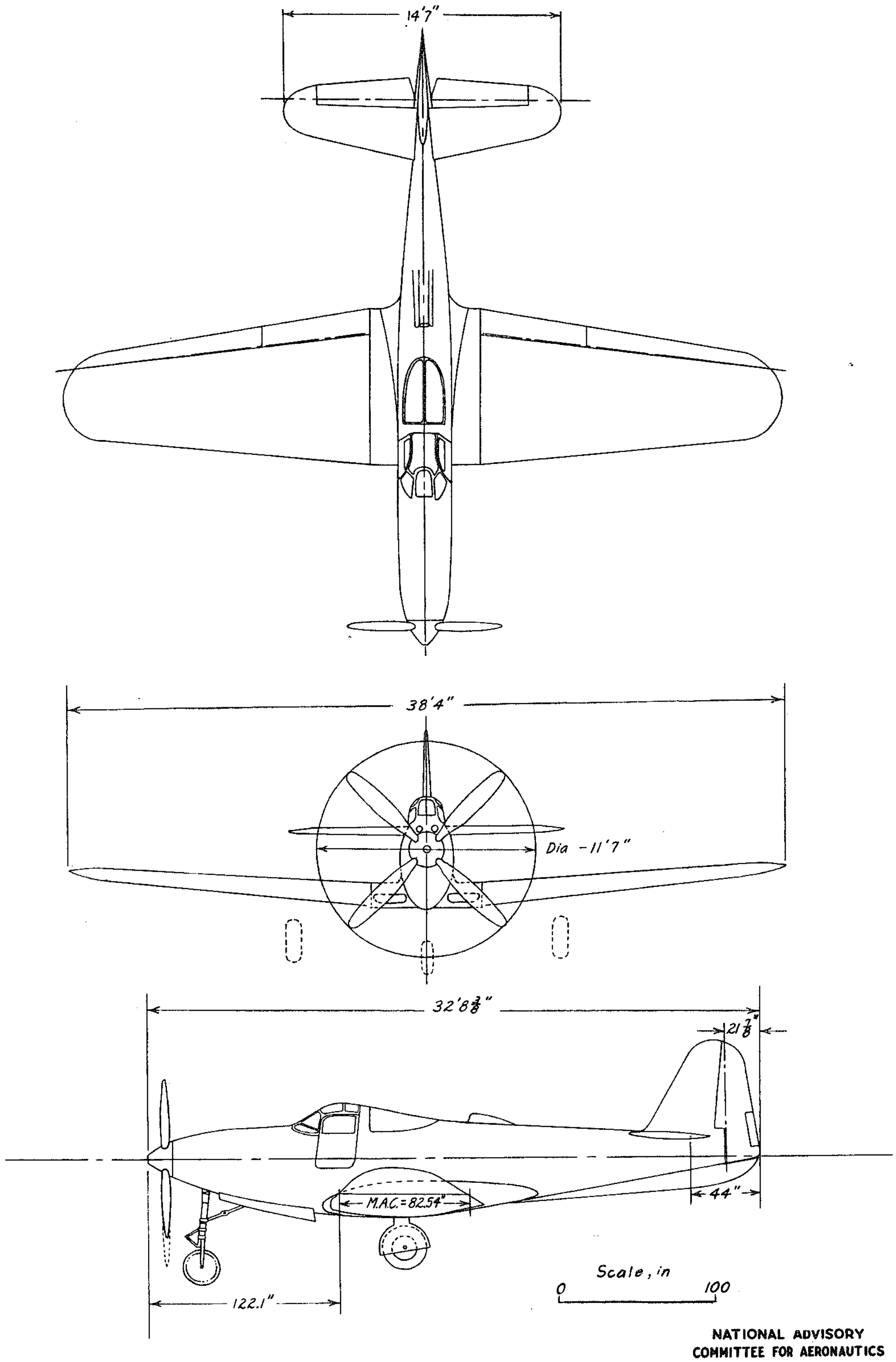

Figure 1. Three-view drawing of the P-63A-1 airplane.

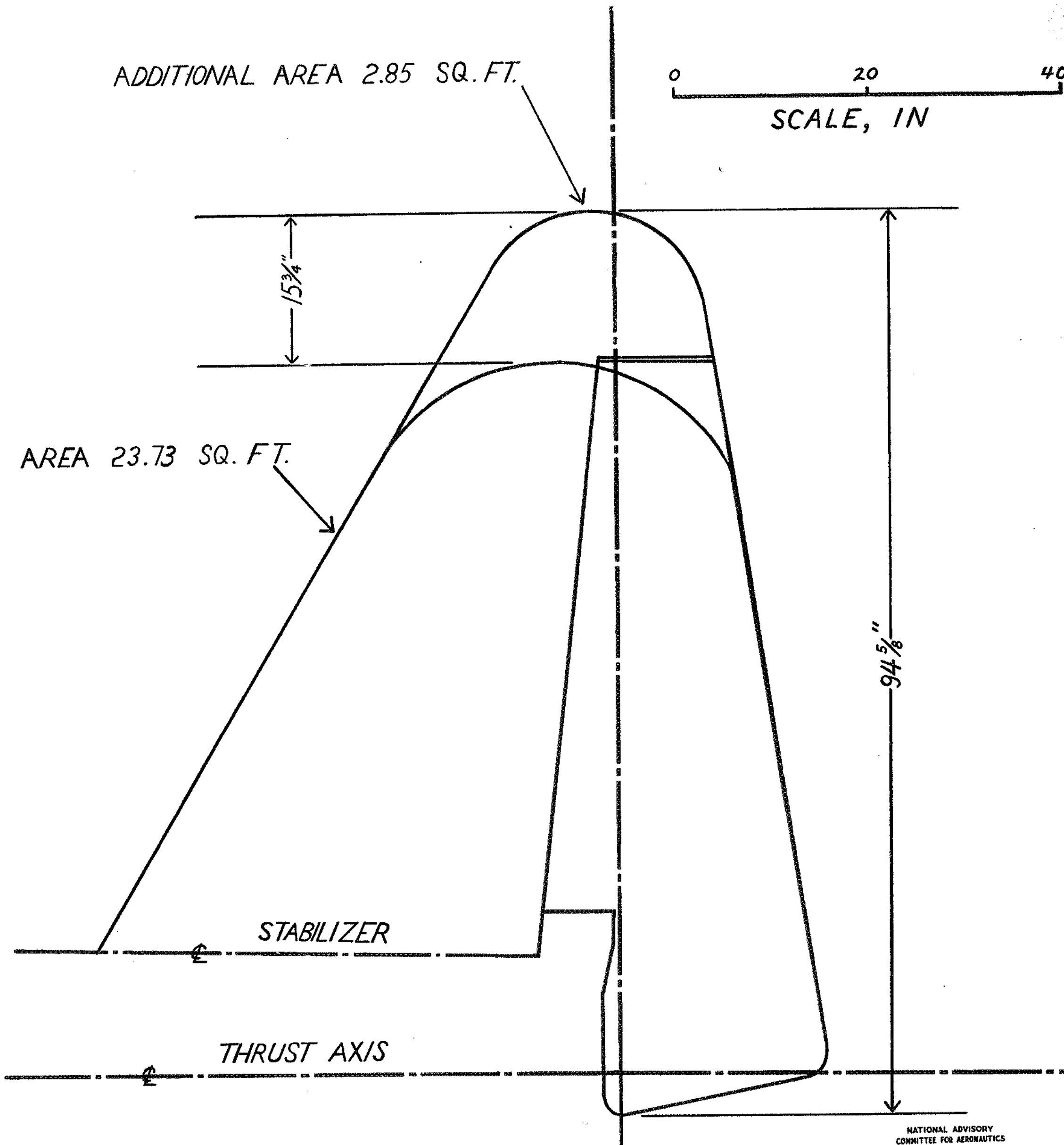

FIGURE 2 - ORIGINAL AND ENLARGED VERTICAL TAIL SURFACES TESTED ON P-63A-1 AIRPLANE

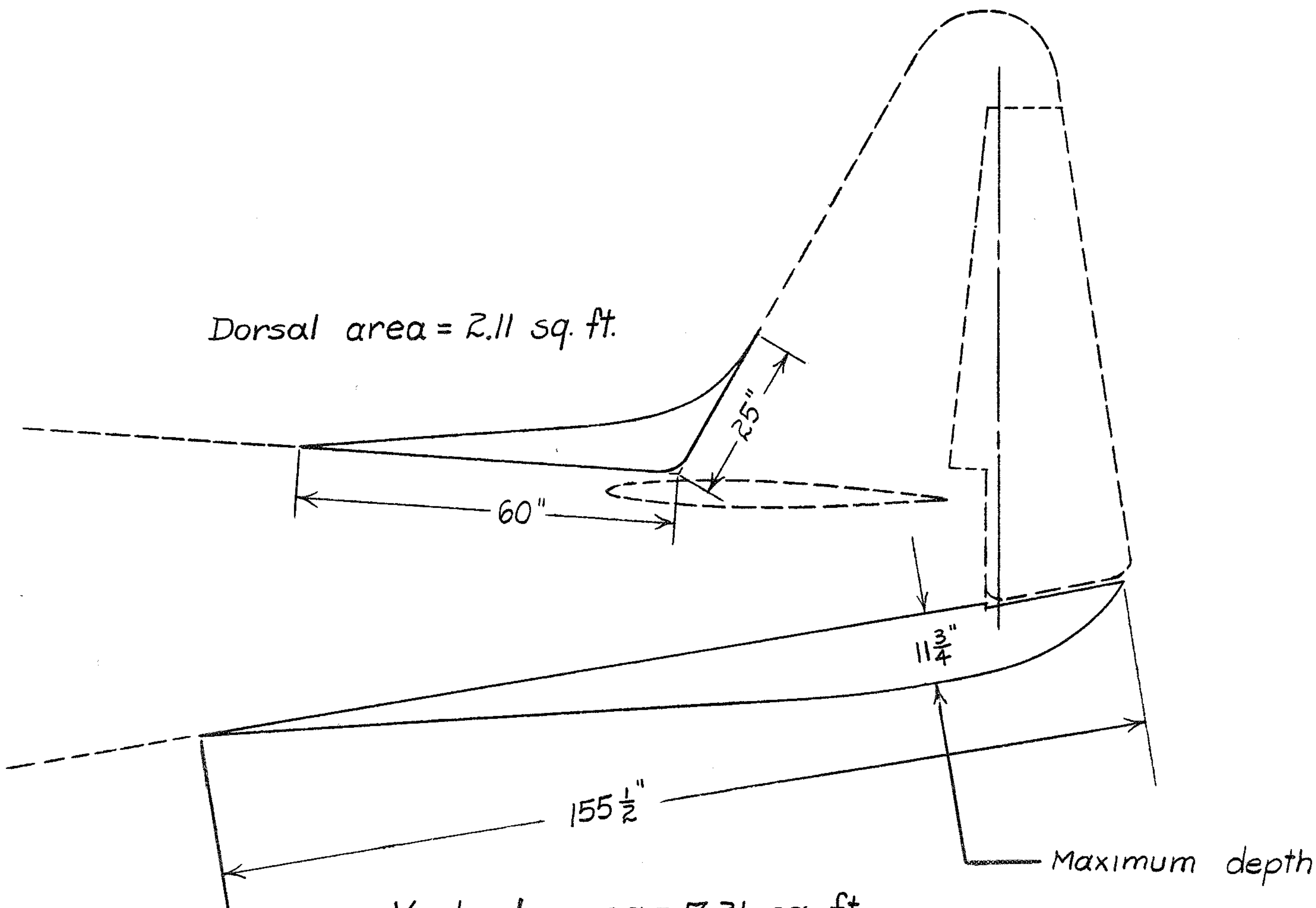

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Figure 3.- Dimensional characteristics of dorsal and ventral fins tested on P-63A-1 airplane.

Figure 4.- Detail view of dorsal fin tested.

Figure 5.- Detail view of ventral fin showing sharp edge and cross-section.

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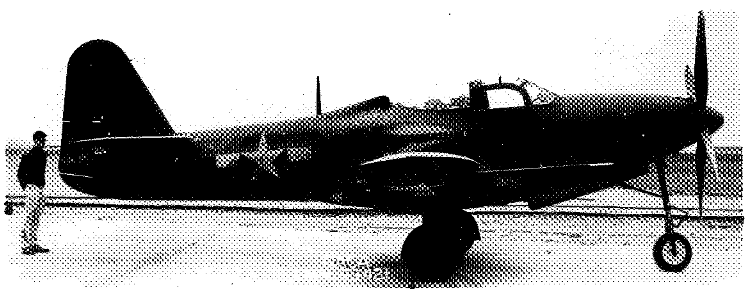
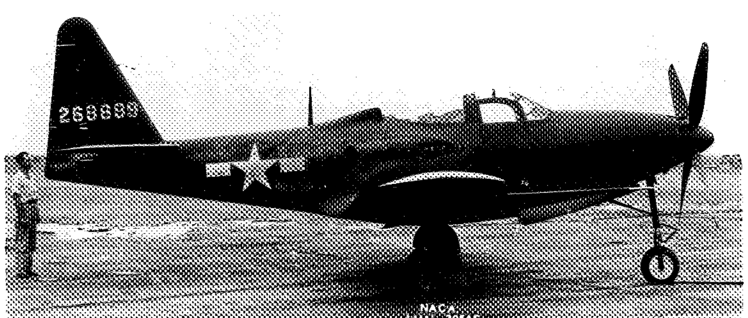
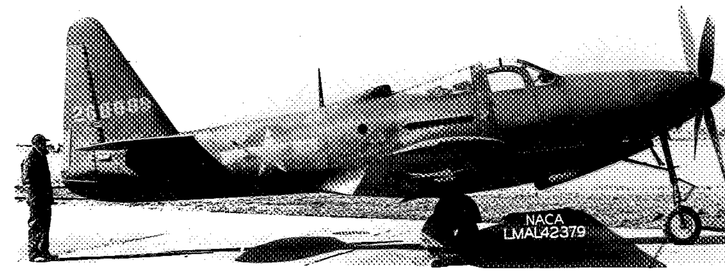
(a) Original vertical tail.



(b) Original vertical tail with ventral fin.

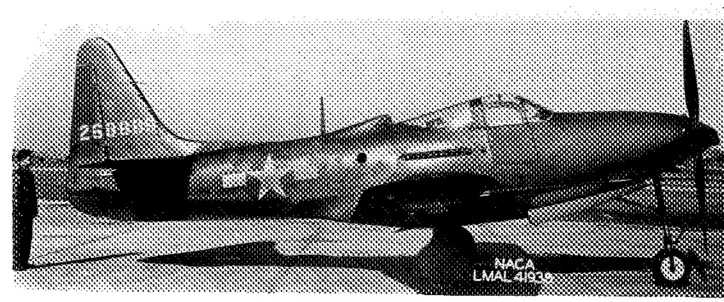


(c) Enlarged vertical tail.



(d) Enlarged vertical tail with ventral fin.

(e) Enlarged vertical tail with dorsal fin.



Enlarged vertical tail with dorsal and ventral fins.

Figure 6.- Vertical tail configurations tested on P-63A-1 airplane.

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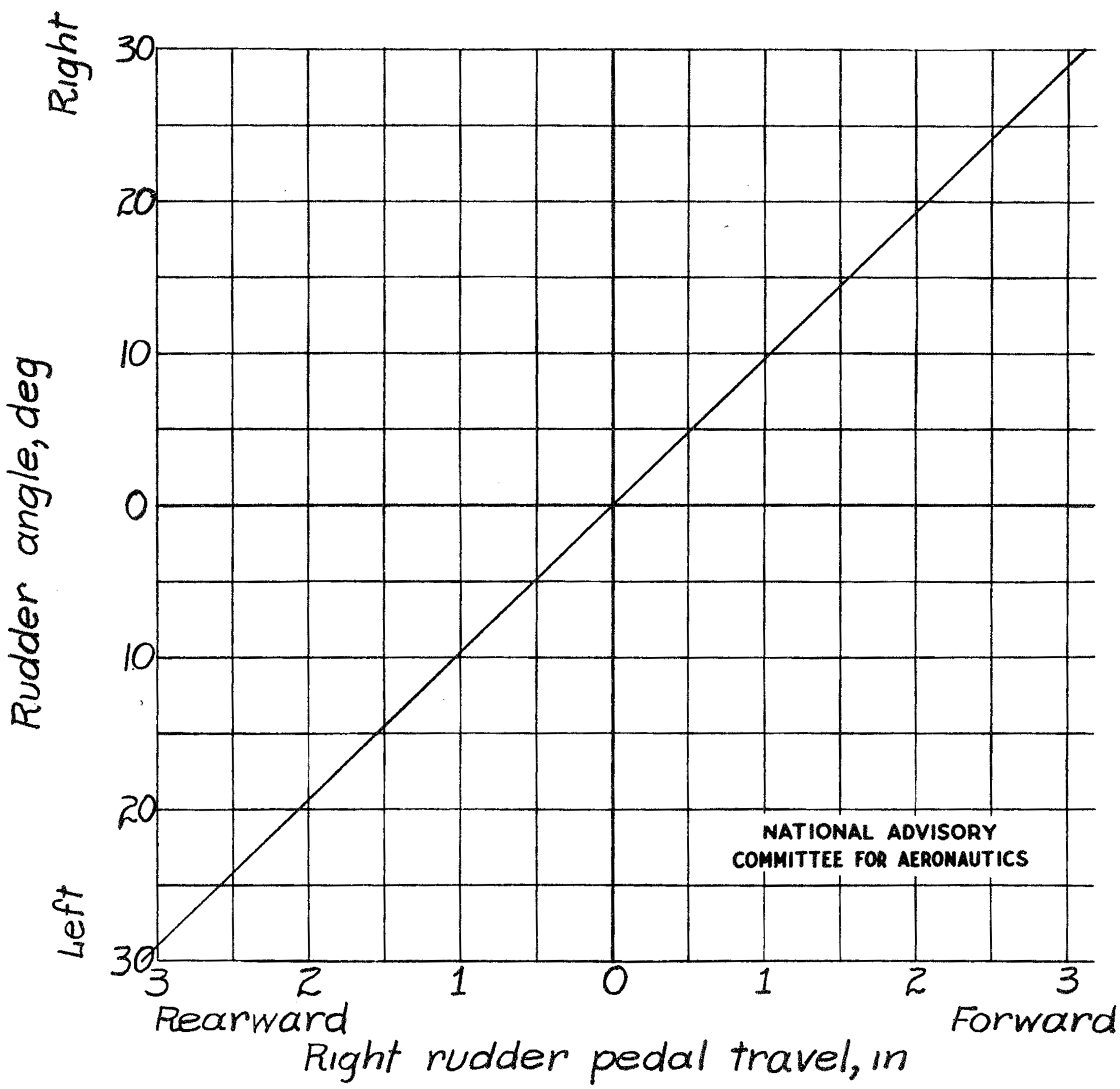


Figure 7.- Variation of rudder angle with position of right rudder pedal. Rudder pedal moment arm $10\frac{3}{4}$ inches. Pedal travel measured along arc.

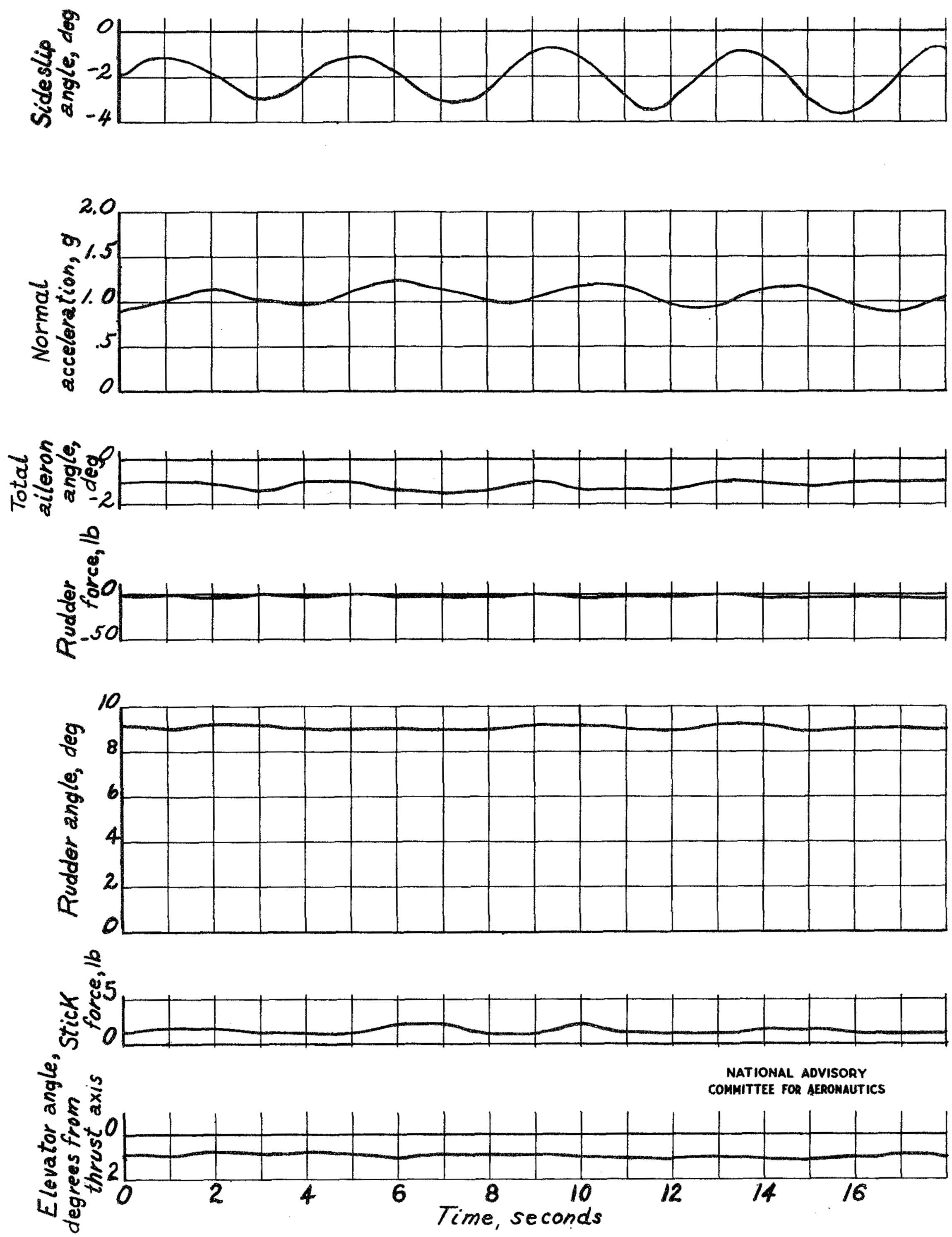


Figure 8.- Time history of undamped directional oscillation which occurred in steady climb at about 150 miles per hour at 22,000 feet altitude using normal rated power. Original vertical tail. Pilot attempted to hold all controls rigidly fixed while obtaining this record.

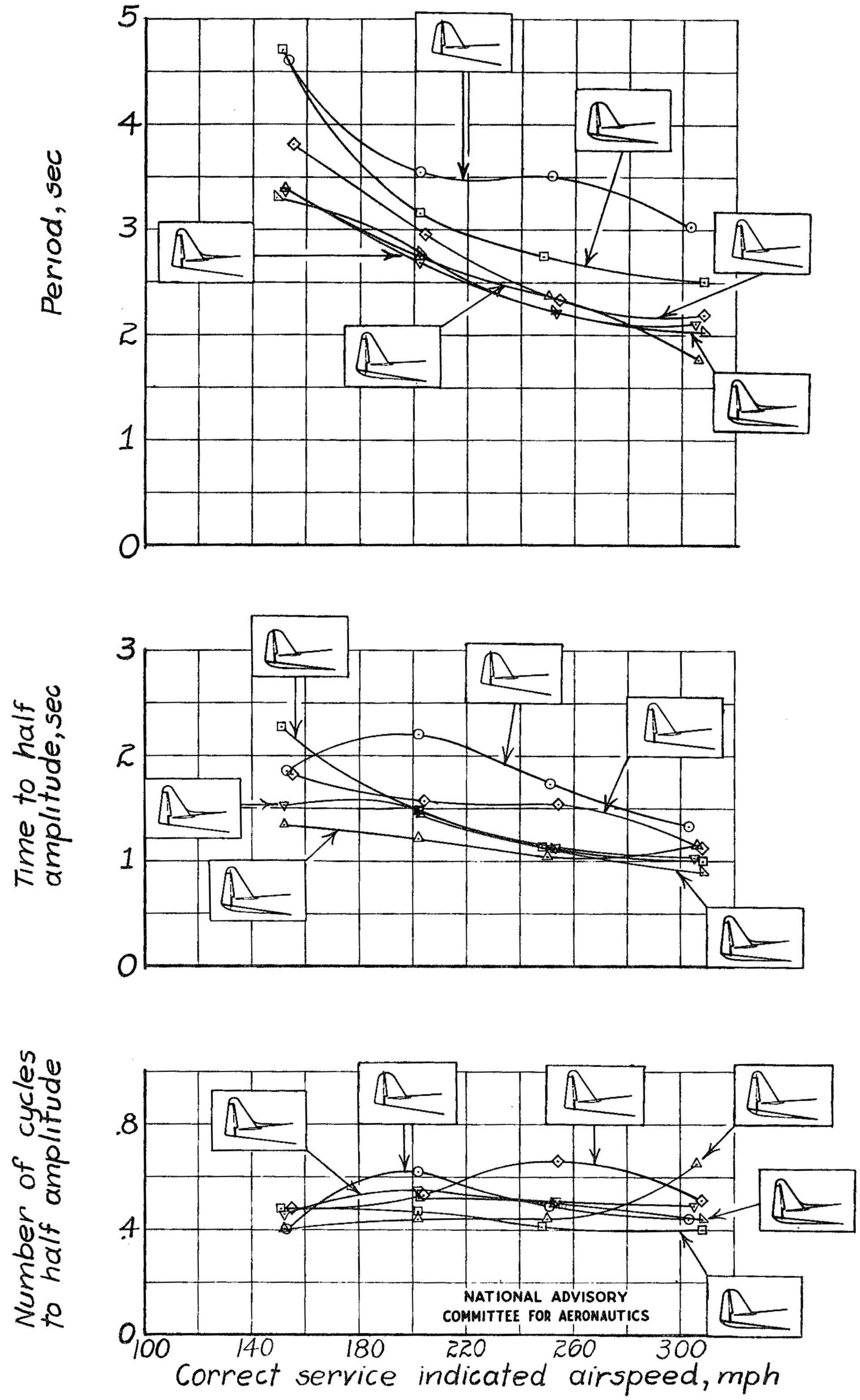
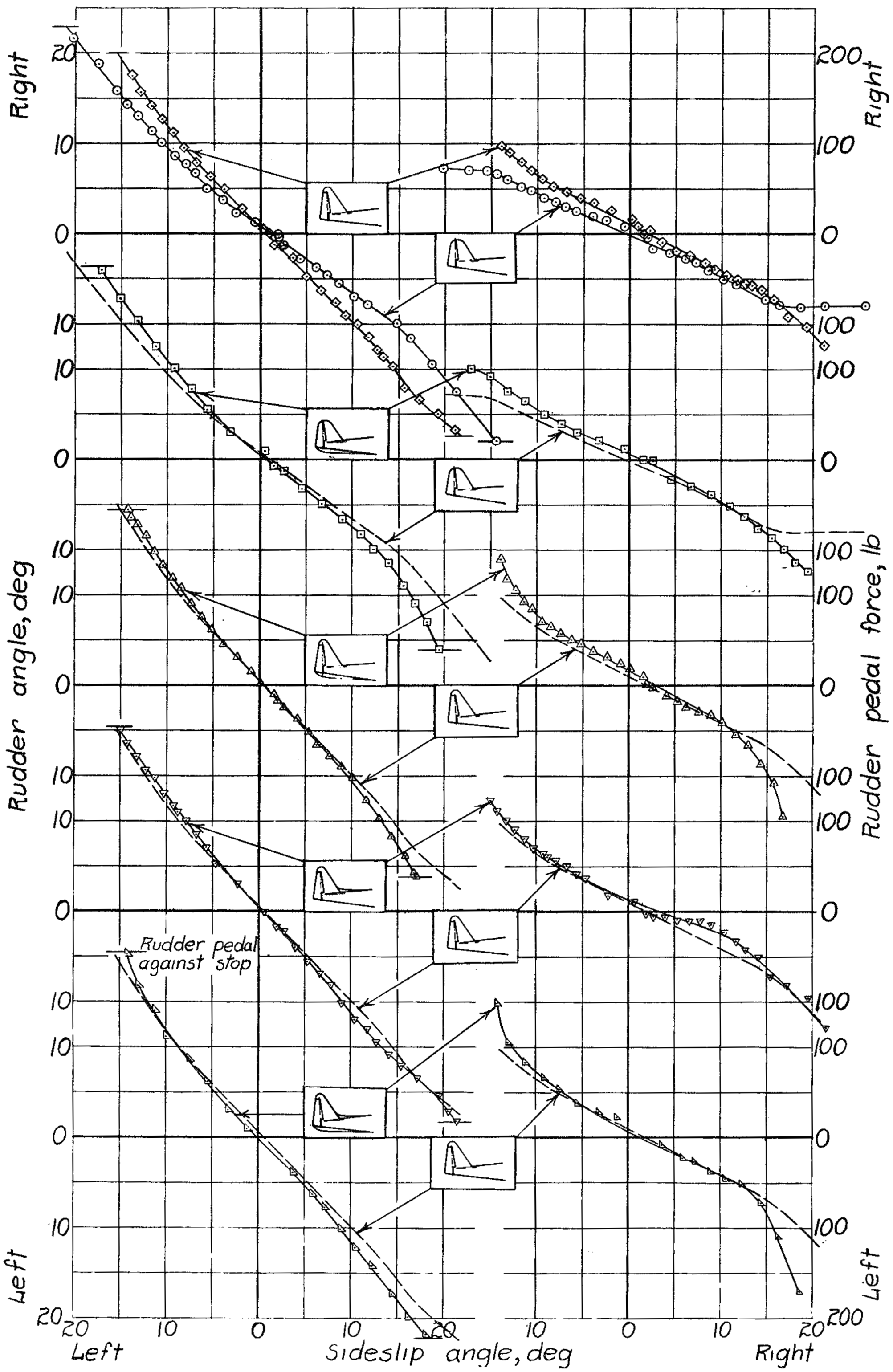


Figure 9.- Effect of vertical tail modifications on the controls-free lateral oscillation characteristics using power for level flight at 5000 feet altitude.



(a) Engine idling.

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Figure 10.- Effect of vertical tail modifications on directional characteristics in sideslips at 150 miles per hour at 5000 feet altitude.

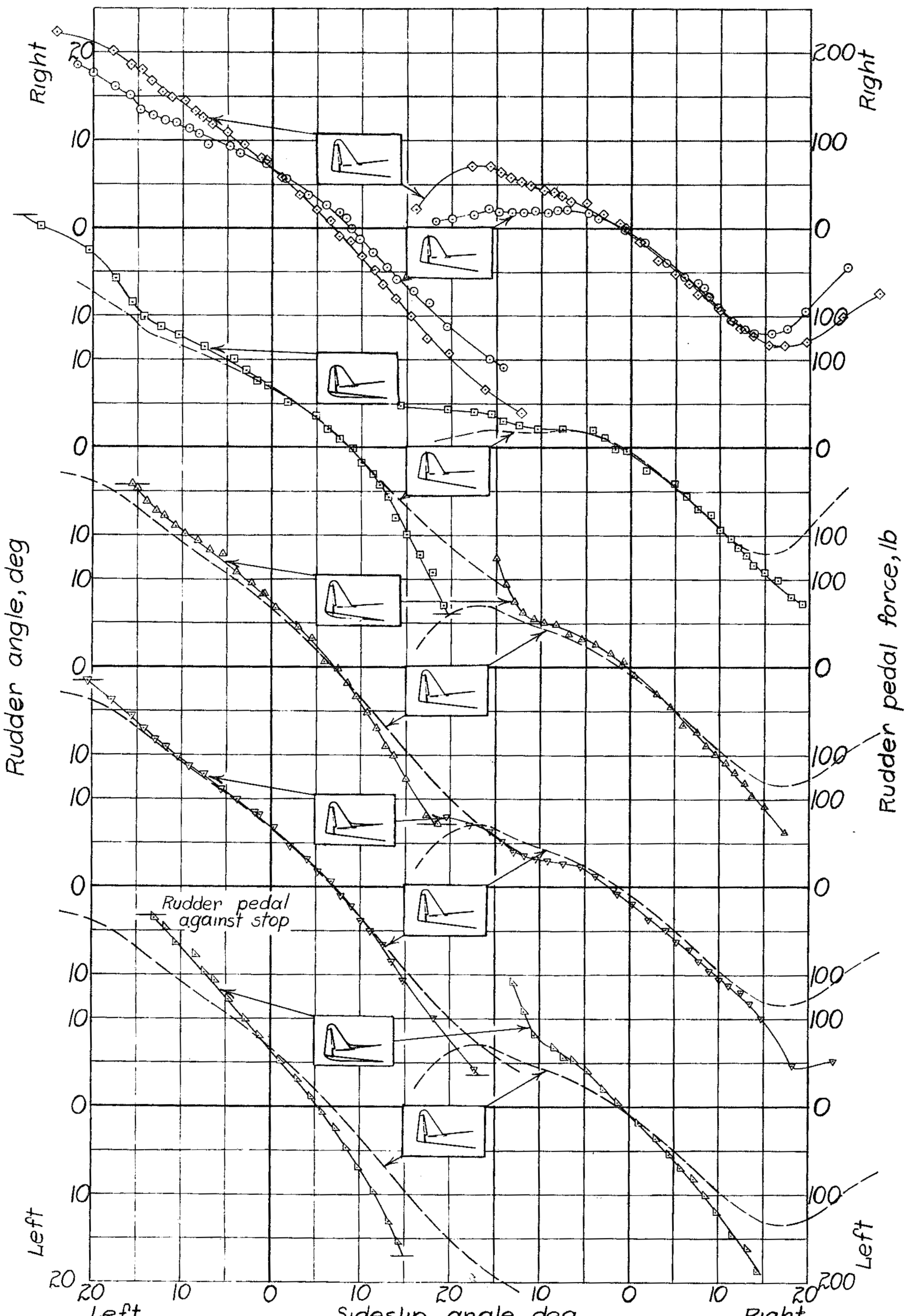

Figure 10.- Concluded.

(b) Normal rated power (2600 rpm, 43 in. Hg ≈ 1050 brake horsepower).

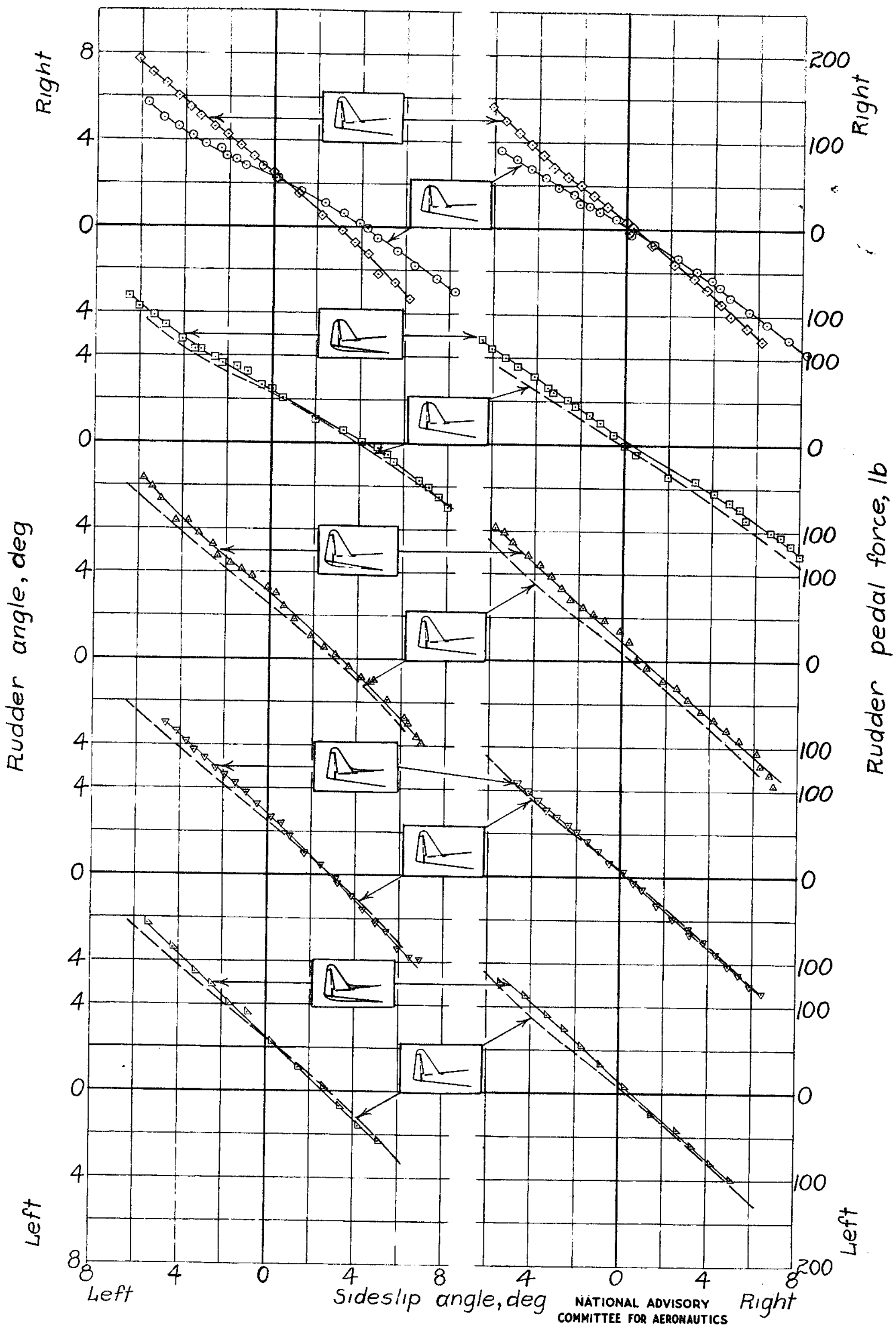

Figure 11.- Effect of vertical tail modifications on directional characteristics in sideslips at 300 miles per hour at 5000 feet altitude. Normal rated power (2600 rpm, 43 in. Hg ≈ 1050 brake horsepower).

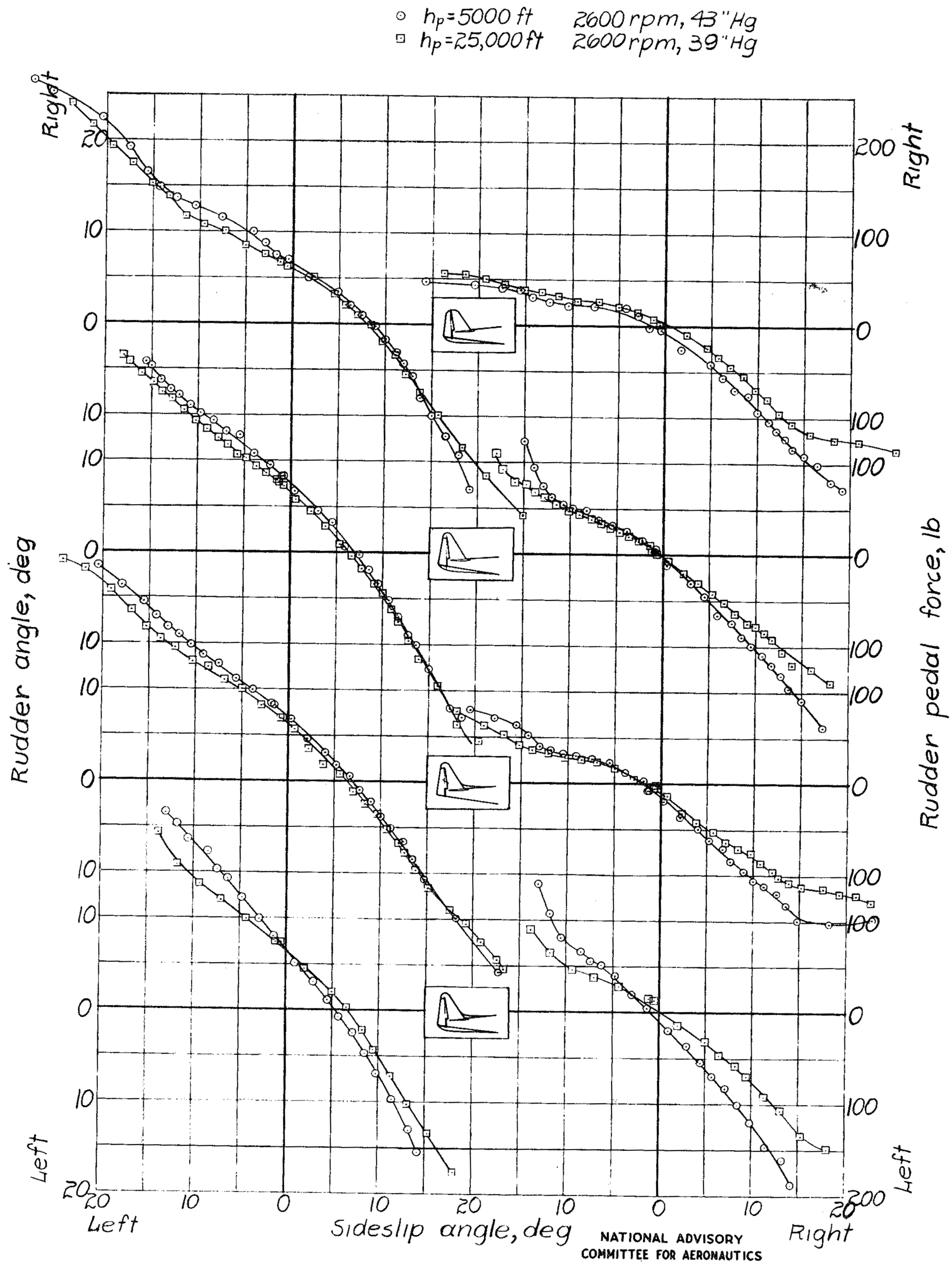

Figure 12.- Effect of altitude on the directional characteristics in sideslips at 150 miles per hour using normal rated power.

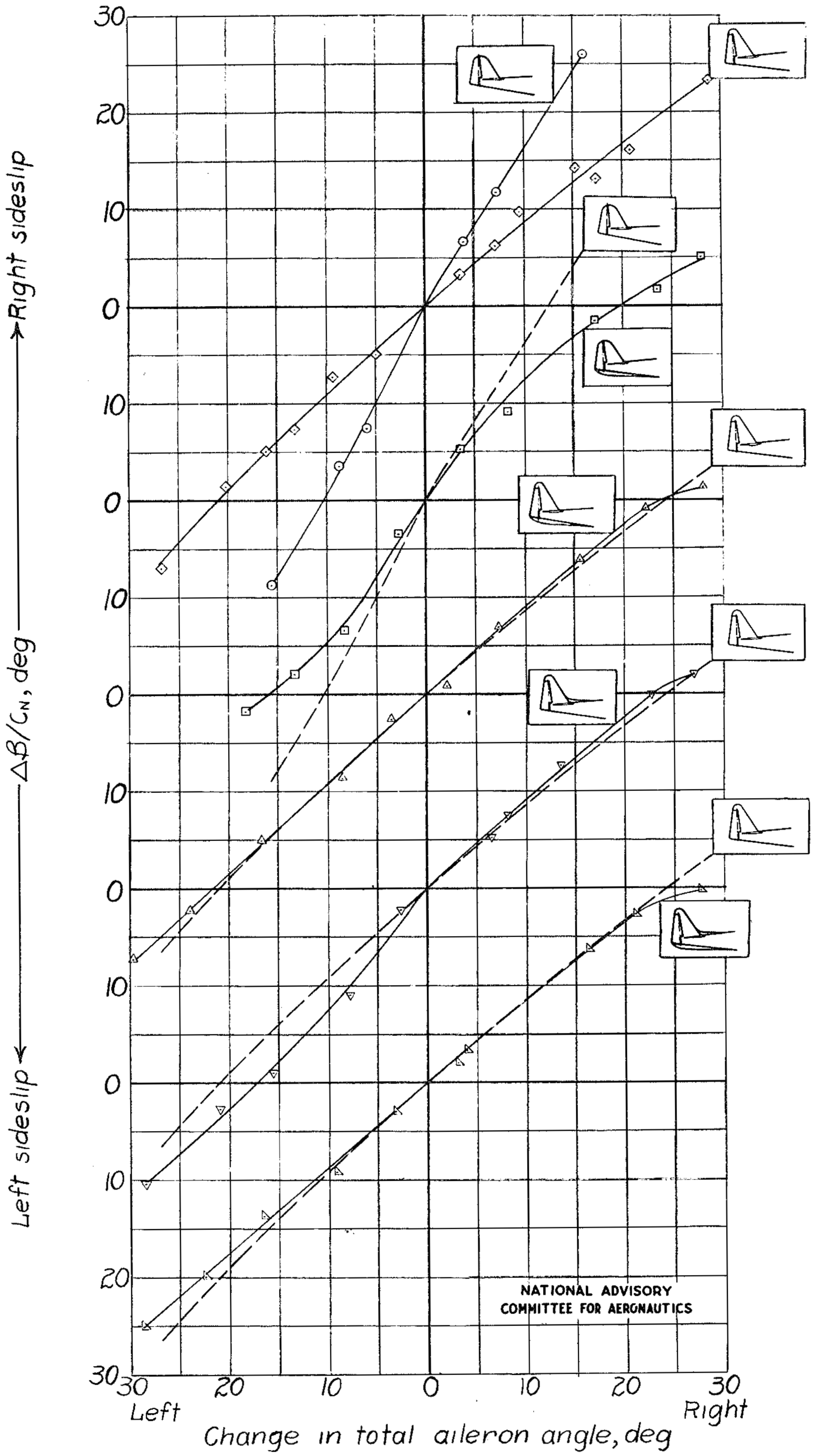

Figure 13.- Effect of various vertical tail modifications on the ability to restrict yaw due to ailerons in rudder-fixed rolls out of turns at 125-130 miles per hour with engine idling. Ratio $\frac{\Delta\beta}{C_n}$ is maximum change in sideslip angle per unit airplane normal force coefficient.

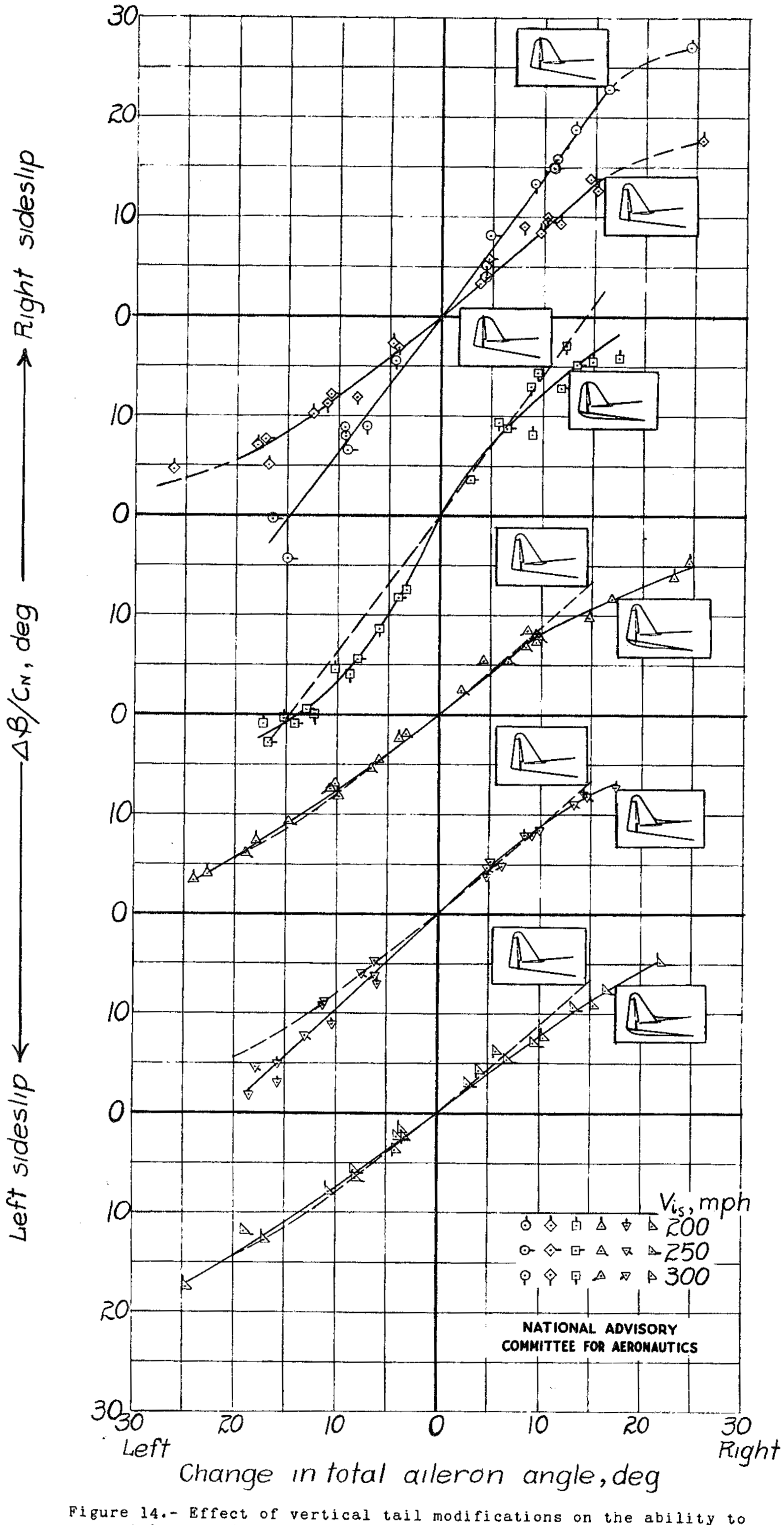

Figure 14.- Effect of vertical tail modifications on the ability to restrict yaw due to ailerons in abrupt rudder-fixed rolls from 3g pull-outs at various speeds. Propeller blade angle and thrust coefficient held constant at values determined by using normal rated power (2600 rpm, 43 in. Hg) at 300 mph. Altitude approximately 5000 feet.

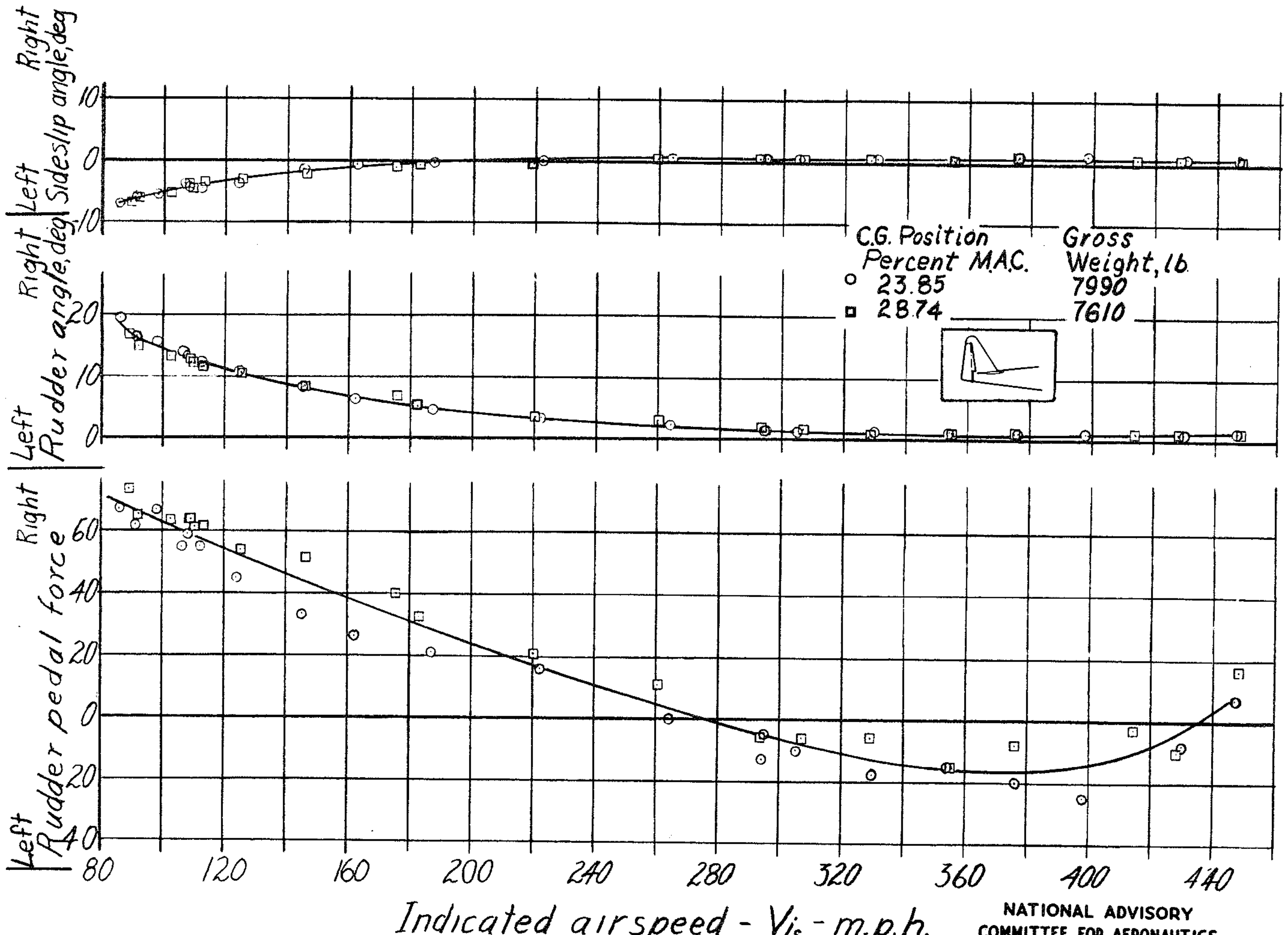

Figure 15.- Data on directional trim characteristics with enlarged vertical tail surface showing typical variations of rudder angle and sideslip angle with airspeed. Clean condition, normal rated power (2600 rpm, 43 in. Hg) altitude 5000 feet.

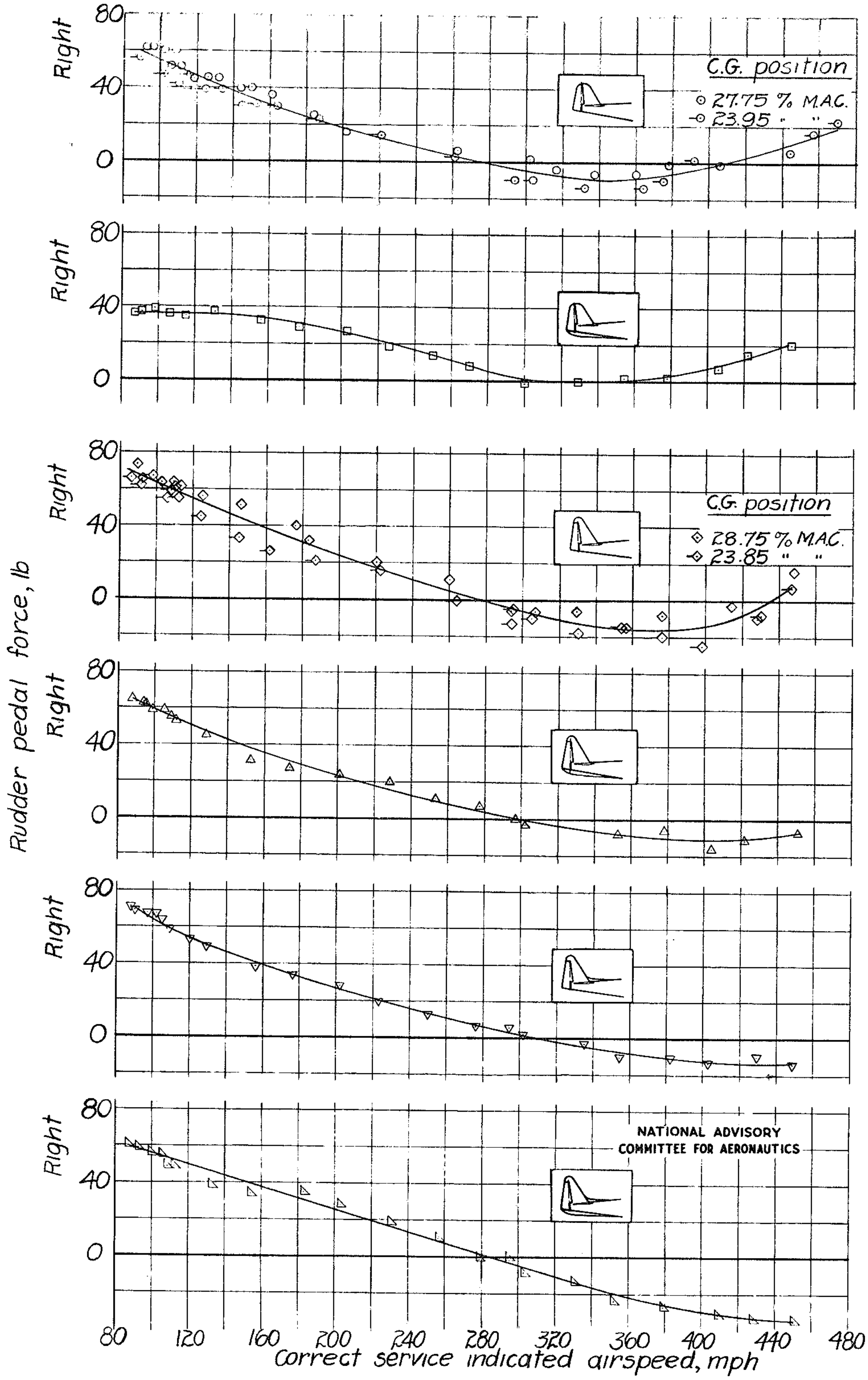

Figure 16.- Effect of vertical-tail modifications on the variation of rudder force with speed for constant trim tab setting. Normal rated power (2600 rpm, 43 in. Hg), 5000 feet altitude.

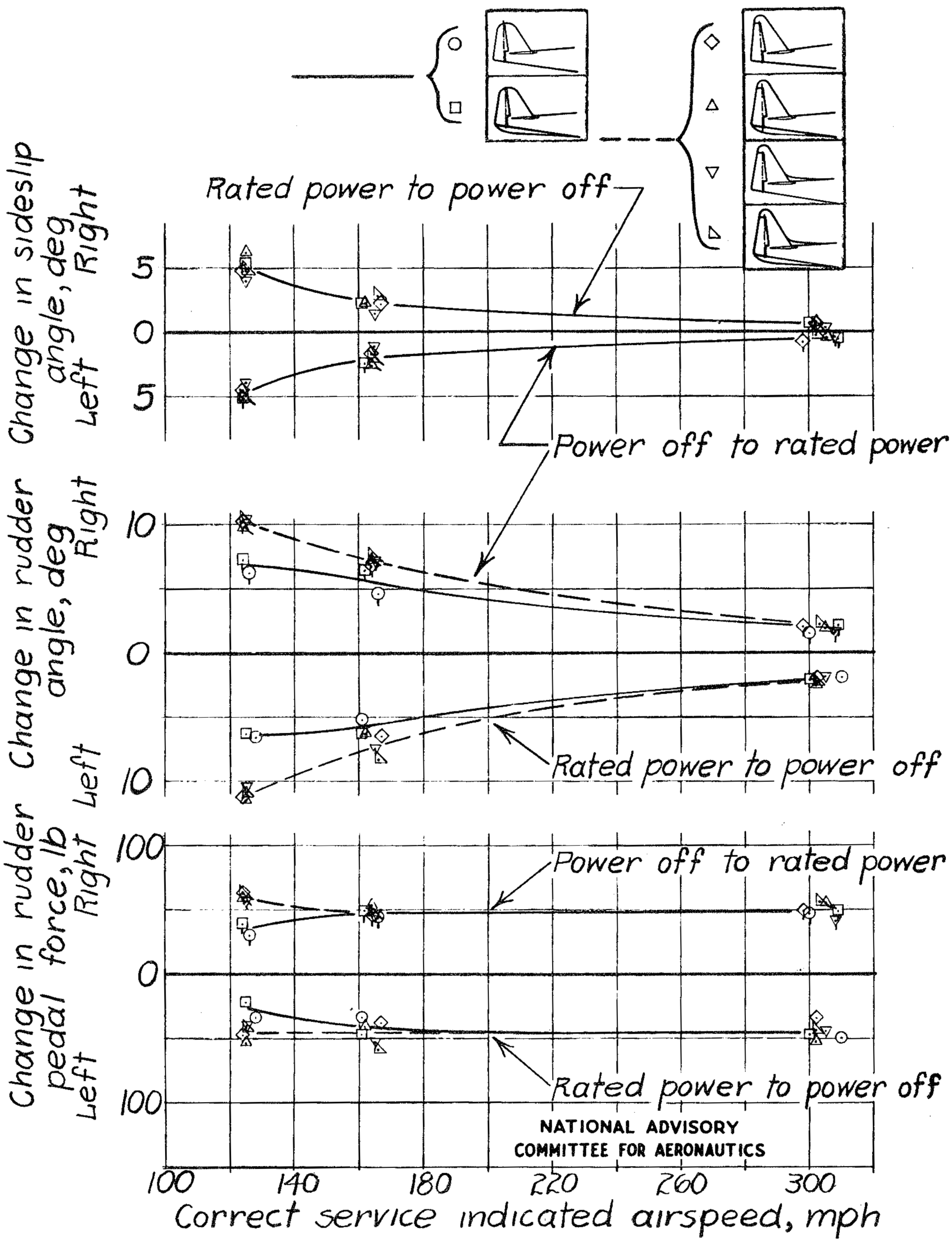

Figure 17.- Effect of vertical tail modifications on the rudder trim changes due to power changes at 5000 feet altitude.