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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

By Harold I. Johnson

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

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

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INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, extensive flight tests are being made at the NACA with a P-63A-1 airplane. One phase of these tests is concerned with the directional characteristics of the airplane because it was found that the original vertical tail did not provide a sufficient degree of directional stability. To improve this characteristic an enlarged vertical tail was designed and built. Identical directional-stability tests were run with both the original and the enlarged vertical tails installed on the airplane. These tests included measurements of the amount of sideslip developed in abrupt rudder-fixed aileron rolls from pull-outs and steady turns at various speeds and normal accelerations.

A recent analysis (reference 1) indicates that very large vertical-tail loads may occur in accelerated rolling maneuvers depending on the aileron power and directional stability of an airplane. For this reason estimates were made of the vertical-tail loads expected to be encountered by P-63 airplanes in such maneuvers. Since data on the yaw characteristics of the airplane were available for two different vertical-tail installations, it was possible to study the effect of directional stability on the vertical-tail loads in rolling maneuvers. The results of this study are presented herein. It is believed these results throw light on the cause for vertical-tail failures and fuselage torsional failures which have been encountered recently with some P-63 airplanes.

AIRPLANE AND INSTRUMENT INSTALLATION

General dimensions of the P-63 airplane are listed in the appendix of reference 2. Side views of the P-63A-1 airplane tested, with both the original and enlarged vertical tails installed, are shown in figures 1 and 2, respectively. Detail pictures of the two vertical tails are given in figure 3 whereas figure 4 is a line drawing which brings out the size and shape relationships of the two vertical tails tested. The following table contains major dimensions of the original and enlarged vertical tail surfaces.

TABLE I.- DIMENSIONAL CHARACTERISTICS OF VERTICAL TAILS TESTED ON P-63A-1 AIRPLANE (AAF NO. 42-68889).

	Over-all height (in.)	Total area (sq ft)	Fixed fin area (sq ft)	Total rudder area (sq ft)	Rudder area forward of hinge ℄ (sq ft)	Rudder area aft of hinge ℄ (sq ft)
Original	78.87	23.73	13.47	10.26	1.96	8.30
Enlarged	94.62	26.58	15.96	10.62	1.97	8.65

Automatically recording NACA flight instruments were used to record airspeed, sideslip angle, the positions of the three flight controls, the three components of acceleration, rolling velocity, yawing velocity, elevator stick force, and rudder pedal force.

The airspeed pitot-static head was mounted on the end of a boom 1 chord length ahead of the right wing, near the wing tip. (See fig. 1.) Service indicated airspeed is used throughout this report. This airspeed is the reading of a standard Army-Navy airspeed meter connected to a pitot-static system that is free from position error, and has the definition

$$V_{i_s} = 45.08\ f_o\sqrt{q_c}$$

where

V_{i_s} service indicated airspeed, miles per hour

f_o standard sea-level compressibility correction factor

q_c difference between total-head and static pressure corrected for pitot-static position error, inches of water

Sideslip angle was measured by means of a vane, free to line up with the relative wind, located on the end of a boom 1 chord length ahead of the left wing, near the wing tip.

Control-position recorders were connected directly to the elevator, rudder, and each aileron.

TESTS AND EVALUATION OF DATA

Abrupt rudder-fixed aileron rolls were made during 3g pull-outs at service indicated airspeeds of approximately 200, 250, and 300 miles per hour at 5000 feet altitude. At V_{i_s} = 250 miles per hour, rolls were also made from level flight and from 2g and 4g pull-outs. In all these tests, the propeller thrust coefficient and blade angle were held constant at the values determined by using normal rated power (2600 rpm, 43 inches Hg, ≈ 1050 horsepower) at the indicated airspeed of 300 miles per hour. Various aileron deflections, set by a chain from the stick grip to the side of the pilot's compartment, were used to produce rolls in each test condition. A time history of a typical roll from a 3g pull-out is shown in figure 5. A limited number of rolls from steady turns was also made, but the data are not used in this report because it was found that, for comparable initial test conditions and within the accuracy of the measurements, the same amount of sideslip was obtained for a given aileron deflection in rolls from either turns or pull-outs.

The data obtained in the rolls from pull-outs were plotted as the ratio of maximum change in sideslip angle divided by the airplane normal-force coefficient against change in total aileron angle producing the roll. The

airplane normal-force coefficient was calculated from the average speed and normal acceleration occurring in each roll. This method of data evaluation was chosen because theory indicates the primary yawing moments in rudder-fixed rolls vary directly with airplane normal-force coefficient; therefore the maximum sideslip angles reached in rudder-fixed aileron rolls would be expected to vary almost directly with airplane normal-force coefficient.

Figure 6 shows the data resulting from the rolls out of 3g pull-outs at V_{i_s} = 200, 250, and 300 miles per hour for both the original and enlarged vertical tails. Figure 7 is a similar collection of data obtained from the rolls with 1, 2, 3, and 4g normal acceleration at V_{i_s} = 250 miles per hour. Examination of the data and comparison of the slopes of the curves of figures 6 and 7 indicate the directional stability of the airplane is essentially constant over the entire range of speeds and accelerations covered; also that the directional stability of the airplane was increased approximately 60 percent by the installation of the enlarged vertical tail.

CALCULATION OF VERTICAL-TAIL LOADS

Estimates of the maximum vertical-tail loads to be expected in rudder-fixed aileron rolls during accelerated flight, using an aileron stick force of 50 pounds, are presented in figure 8. The curve of aileron deflection possible with 50 pounds stick force was taken from previous test data and was extrapolated from V_{i_s} = 315 to V_{i_s} = 450 miles per hour for calculation purposes. The average slopes of the faired curves of change in sideslip angle divided by airplane normal force coefficient against change in total aileron angle (figs. 6 and 7) over a range of total aileron deflection of $\pm 10^{\circ}$ were used to estimate the maximum sideslip angles to be expected. For this purpose the airplane gross weight was taken as 7850 pounds. The maximum vertical-tail loads were calculated by estimating the slopes of the normal-force coefficient versus angle-of-sideslip curves of both vertical tails, then multiplying them by the respective maximum sideslip angles, vertical-tail areas, and free-stream impact pressure. The small effect of yawing velocity during the maneuver was neglected in calculating the tail load. The slopes of the normal-force coefficient

versus angle-of-sideslip curves for the original and enlarged vertical tails were estimated to be 0.0405 and 0.0517 per degree, respectively. These values are based on computed aspect ratios and a collection of wind-tunnel data. Load computations were carried out over the range of conditions where the vertical tails were assumed to be in an unstalled condition. In this connection the stall angle of the enlarged vertical tail was assumed to be 16°. It was further assumed that both vertical tails were capable of producing the same maximum normal-force coefficient. These conditions fixed the stall angle of the original vertical tail at 20.4°.

DISCUSSION

The estimates of vertical-tail loads in accelerated rolling maneuvers shown in figure 8 indicate that vertical-tail loads more critical than that calculated from the gust design condition are likely to occur on P-63 airplanes in fast rolls made with normal accelerations above about 3g. This figure shows that the most critical speeds are not the highest speeds at which the airplane would be flown but, rather, the intermediate speeds at which most flying is probably done. In this connection, it should be possible to cover all the conditions of normal acceleration for which vertical-tail load calculations are shown in figure 8 without stalling the airplane wing, except possibly at extreme altitude. The reason the vertical-tail load decreases with increasing speed at a given normal acceleration and aileron control effort is because the rolling effectiveness in terms of the helix angle $\frac{pb}{2V}$ decreases with increasing speed. The data of figure 8 also indicate that increasing the size and effectiveness of the vertical tail, and consequently the directional stability of the airplane, reduces the maneuvering vertical-tail loads. This trend appears logical for the following reason. Both vertical tails must balance out the same yawing moment due to aileron deflection and rolling, regardless of the sideslip angles involved. However, the fact that the larger tail restricts the sideslip angles to smaller values means that it will not be required to balance out such large unstable fuselage and propeller yawing moments as will the smaller vertical tail.

A comparison between the loads calculated from the gust design condition and those obtained in rolls is shown in figure 8. The horizontal line showing 100 percent of the design load for the original vertical tail was determined by taking 1.5 times the predicted vertical-tail load caused by a sharp-edge gust of 30 feet per second when the airplane is flying at maximum permissible diving speed. If the same procedure were followed for the enlarged vertical tail, 100 percent of the design load for the gust condition would be about 3530 pounds instead of 2470 pounds. With a design strength of 3530 pounds the vertical-tail loads in aileron maneuvers would be relatively much less critical. It appears the gust design condition generally fails to provide enough vertical-tail strength for rolling maneuvers, especially when the directional stability of the airplane is low.

The balancing design condition required about 20 percent greater vertical-tail strength for net load in one direction than the gust condition in the case of the P-63 airplane but the gust condition is used for comparison purposes because of the similarity of the air-load distributions occurring in gusts and in rudder-fixed aileron rolls. Actually, in static tests conducted at Wright Field, the P-63 vertical tail failed at 105 percent of the balancing load, which represents a net load of about 3100 pounds in one direction. It is not known what effect load distribution has on failure load for the P-63 vertical tail; however, figure 8 indicates net loads in excess of 3100 pounds would be encountered in abrupt rolling maneuvers with 4g or more normal acceleration on the airplane in certain speed ranges. The pull-up condition required much less vertical-tail strength than either the gust or balancing conditions. Therefore, a need is indicated for the establishment of a new vertical-tail design load condition which will logically relate vertical-tail strength to the aileron power and directional stability of airplanes.

Emphasis has been placed on rudder-fixed rolling maneuvers in this report as opposed to coordinated use of the rudder and ailerons during violent lateral maneuvering. While it is true that proper use of the rudder will tend to reduce vertical-tail loads in rolling maneuvers to some extent, it appears that if rudder is used against the sideslip after some sideslipping has developed, the vertical-tail load may exceed that which

would have occurred had the rudder been held fixed. It may also be noted that many airplanes have rudder forces which are too heavy to permit correct rudder coordination in rolling maneuvers at any other than low speeds.

CONCLUSIONS

Based on the data and estimates of vertical-tail loads given in this report, the following conclusions may be drawn:

1. Vertical-tail loads more critical than that imposed by any design condition are likely to be encountered with P-63 series airplanes in abrupt rolling maneuvers made with normal accelerations above 4g in the intermediate speed range.

2. For a given normal acceleration and aileron control effort, the likelihood of encountering critical vertical-tail loads in rolls decreases with increasing airspeed so long as the vertical tail remains unstalled.

3. Increasing the size and effectiveness of the vertical tail, and therefore the directional stability of an airplane, decreases the maximum vertical-tail loads in accelerated rolling maneuvers in the usual case where the fuselage-propeller combination is directionally unstable.

4. A new loading condition for vertical-tail design strength appears necessary for highly maneuverable airplanes in order to relate vertical-tail strength to the aileron power and directional stability of the airplane.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 30, 1944

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1. Gilruth, Robert R.: Analysis of Vertical-Tail Loads in Rolling Pull-Out Maneuvers. NACA CB No. L4H14, 1944.

2. Johnson, Harold I.: Résumé of NACA Stability and Control Tests of the Bell P-63 Series Airplane. NACA CMR No. L4J19, 1944.

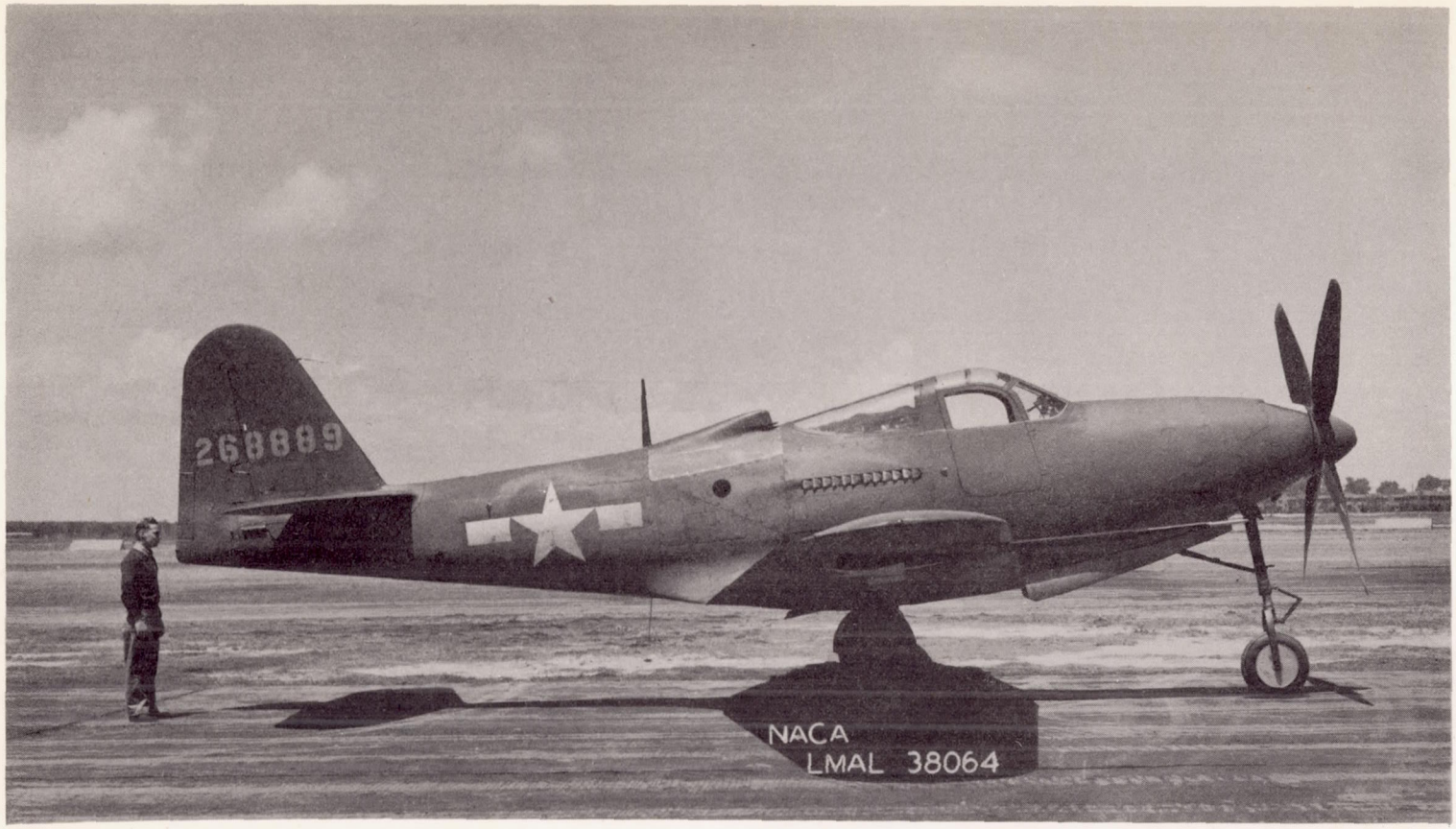


Figure 1.- Side view of P-63A-1 airplane with original vertical tail.

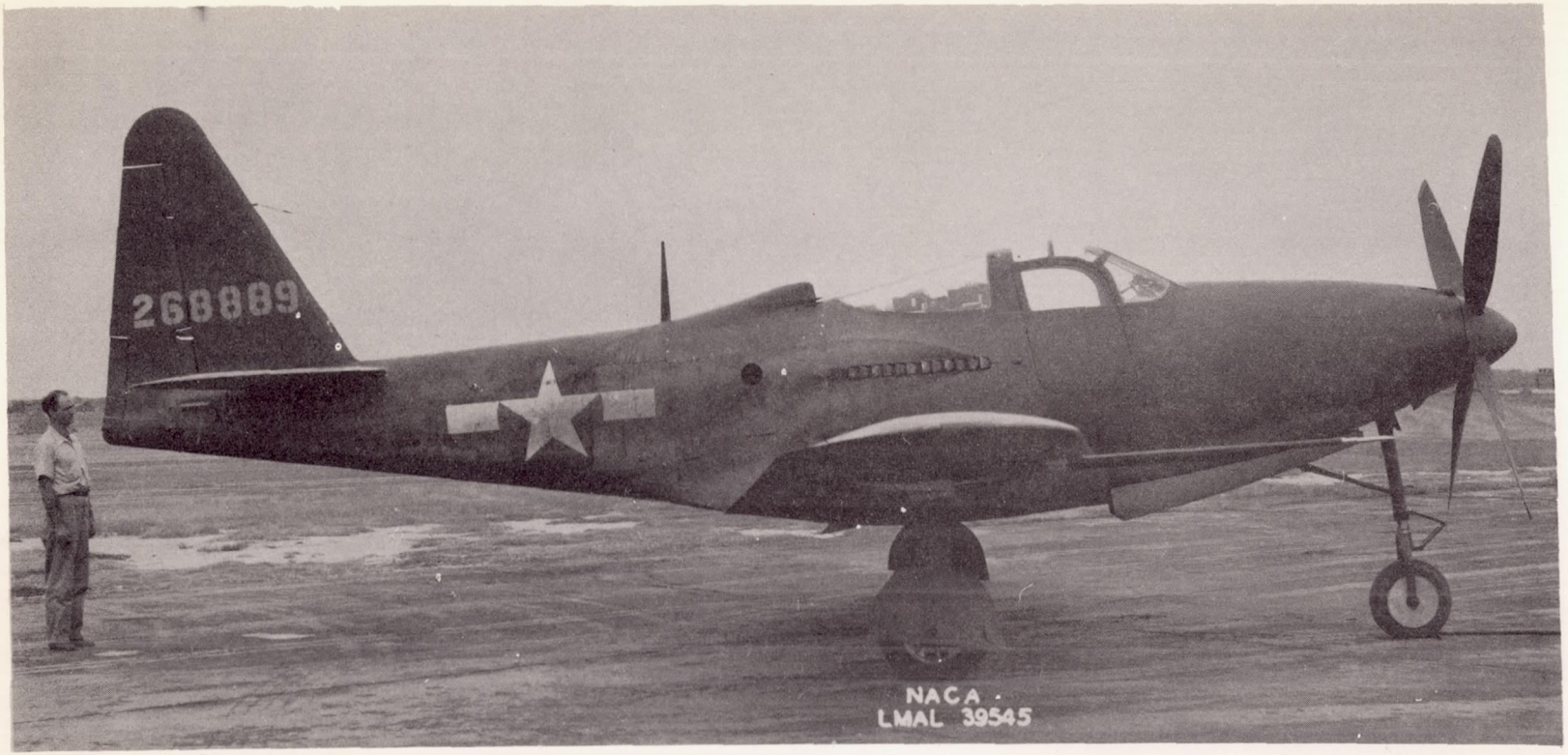
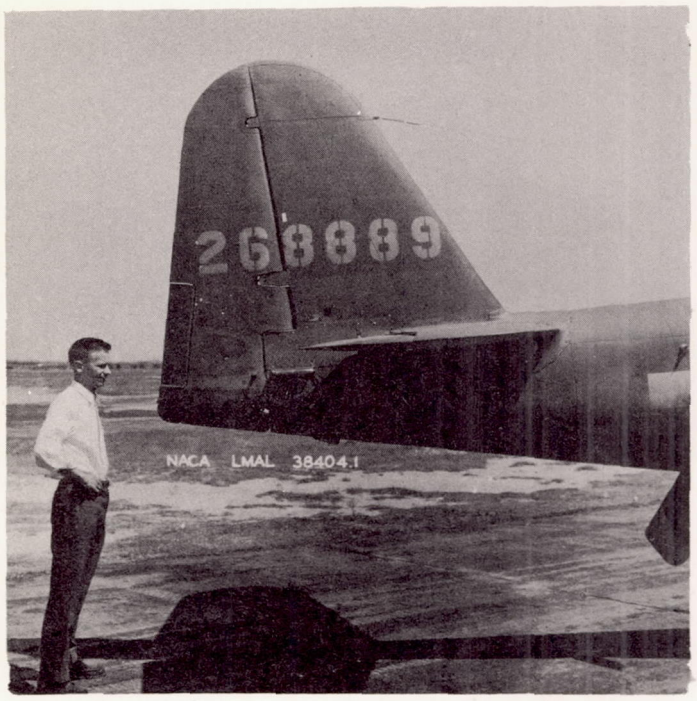


Figure 2.- Side view of P-63A-1 airplane with enlarged vertical tail.



(a) Original vertical tail.

(b) Enlarged vertical tail.

Figure 3.- Close-up views of original and enlarged vertical tails on P-63A-1 airplane.

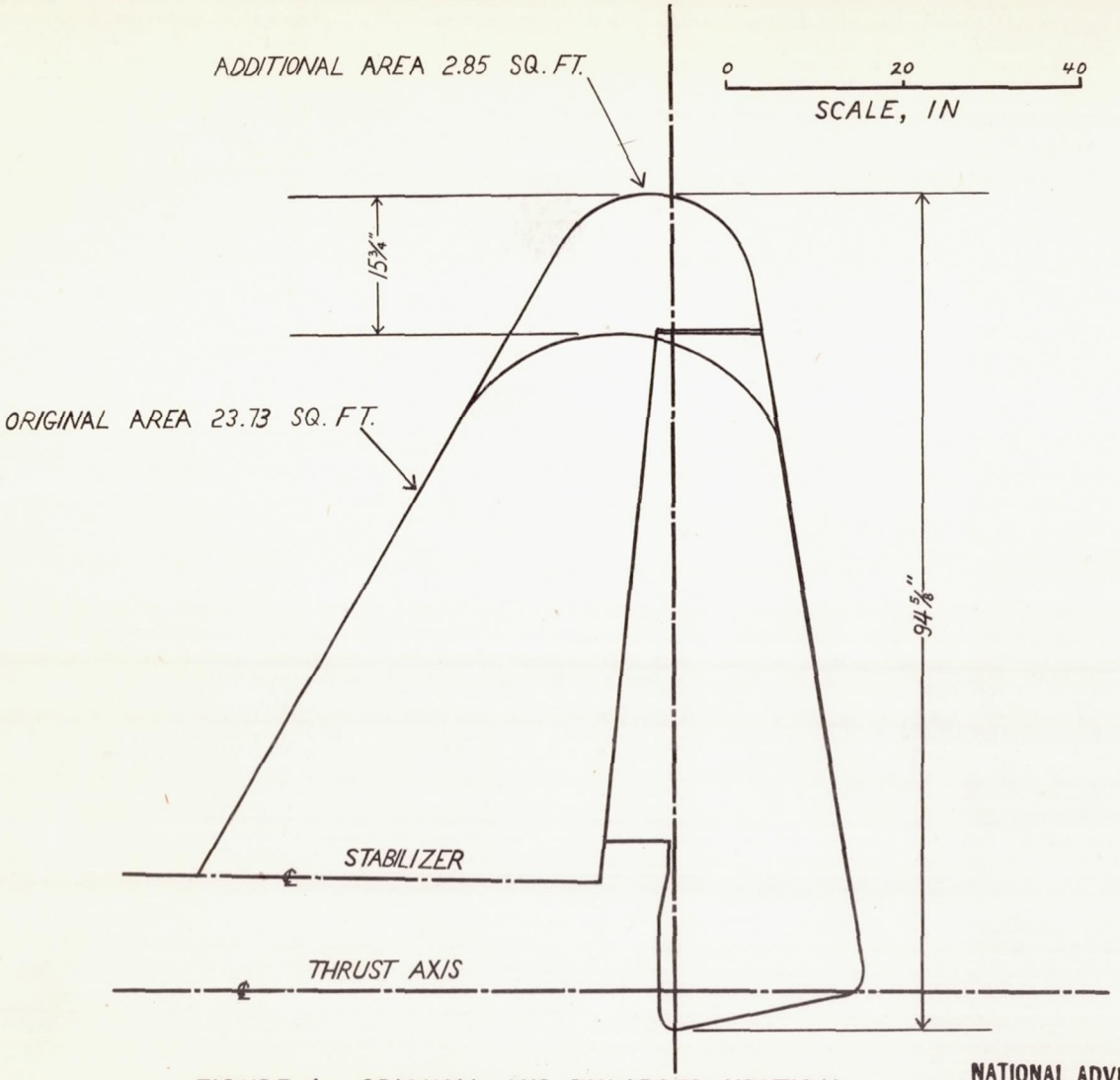


FIGURE 4. - ORIGINAL AND ENLARGED VERTICAL TAIL SURFACES TESTED ON P-63A-1 AIRPLANE

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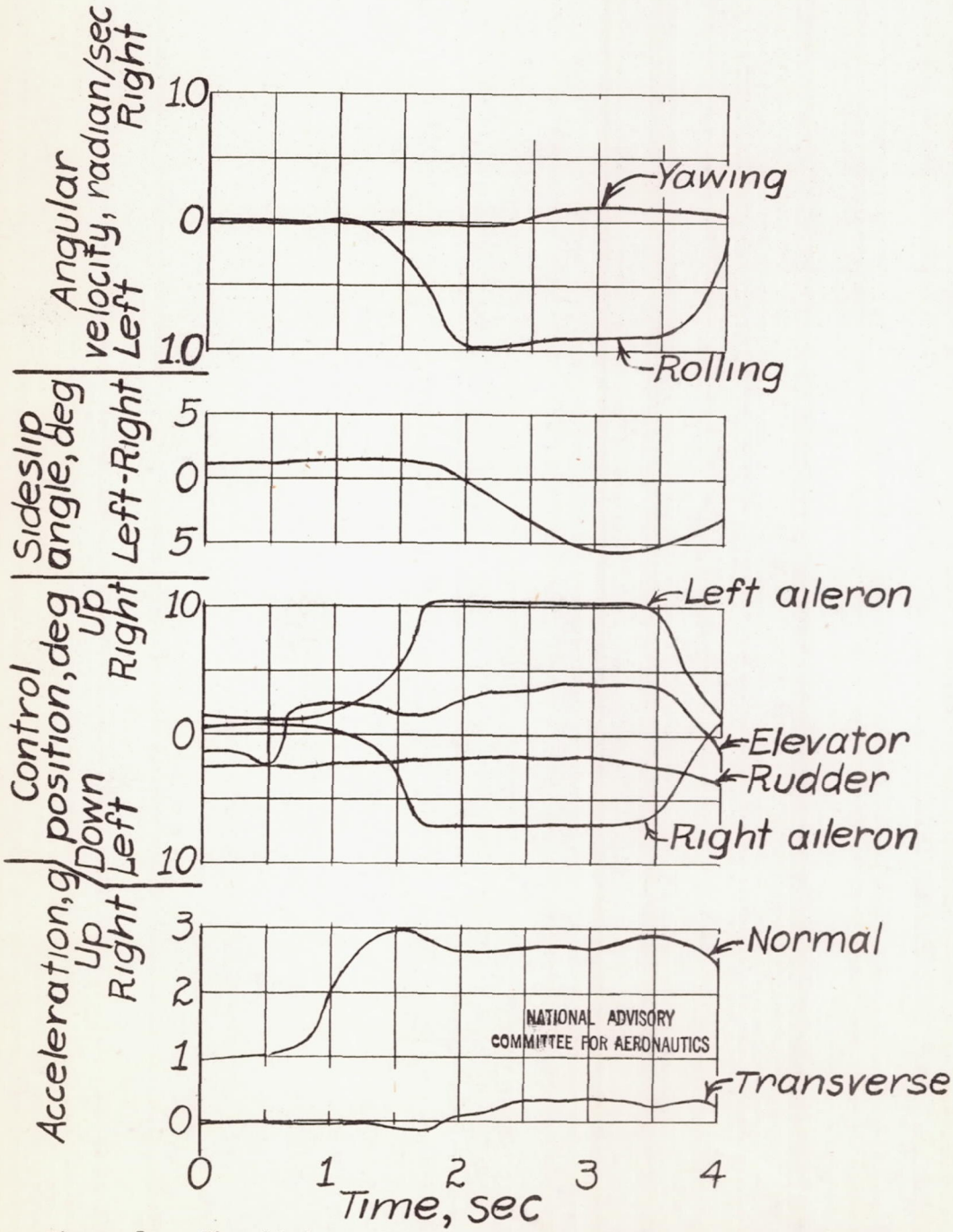


Figure 5. - Time history of typical rudder-fixed aileron roll from 3g pull-out. Bell P-63A-1 airplane, enlarged vertical tail, altitude = 5000 feet, V_{is} = 265 mph.

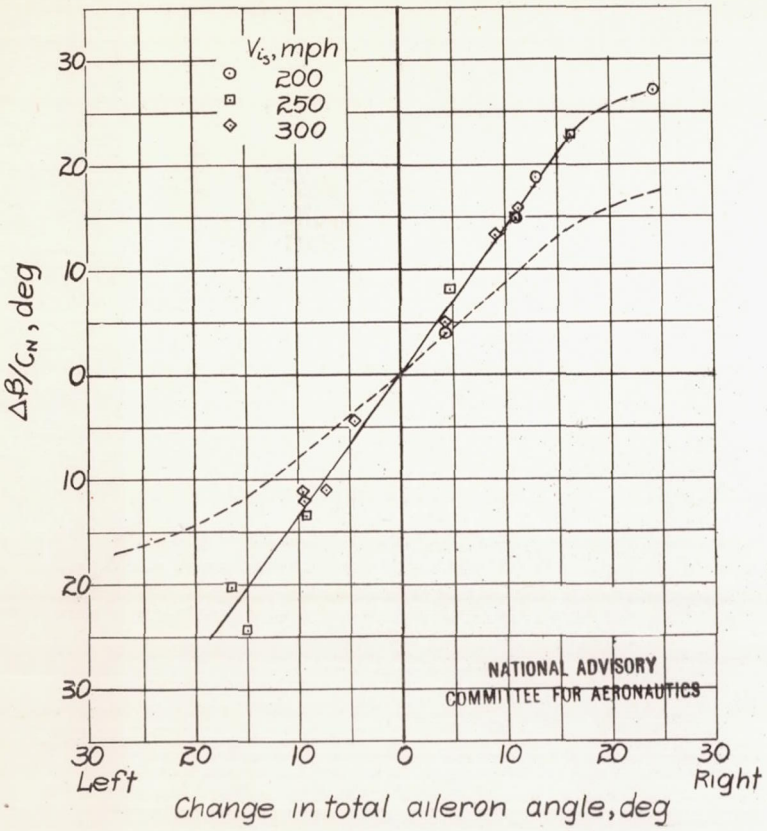
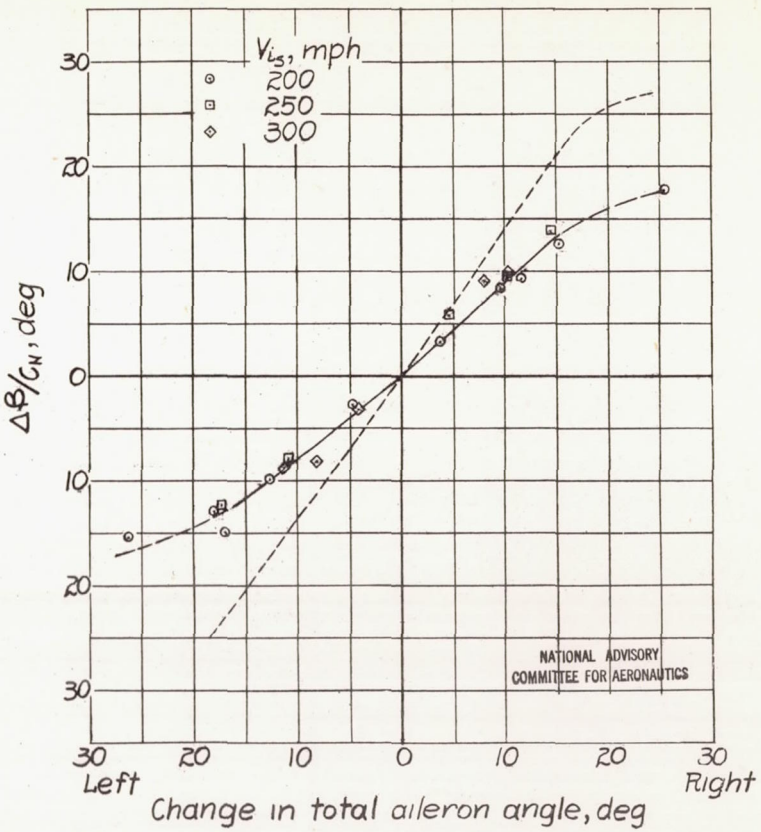


Figure 6 .- Results of rudder-fixed rolls out of 3 g pull-outs at 5000 feet altitude at various speeds using constant propeller blade angle and thrust coefficient. Bell P-63A-1 airplane (AAF No. 42-68889). (a) Original vertical tail. Dash line is faired curve for enlarged vertical tail shown in figure 6b.



(b) Enlarged vertical tail. Dash line is faired curve for original vertical tail shown in figure 6a.

Figure 6 .- Concluded.

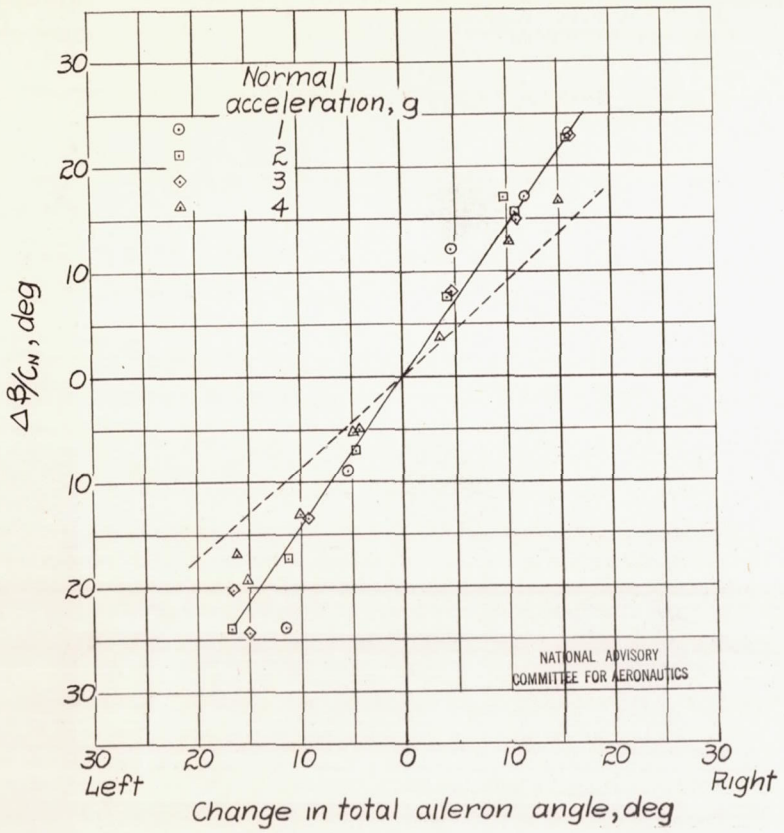
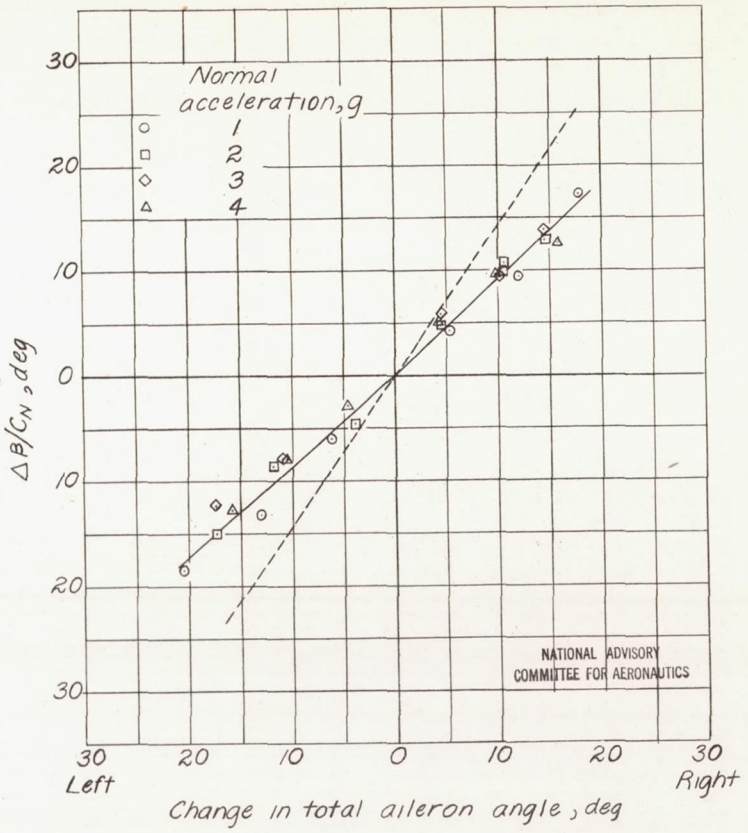


Figure 7 .- Results of rudder-fixed rolls out of pull-outs at various normal accelerations at an indicated speed of 250 MPH at 5000 feet altitude using constant propeller blade angle and thrust coefficient. Bell P-63A-1 airplane (AAF No. 42-68889). (a) Original vertical tail. Dash line is faired curve for enlarged vertical tail shown in figure 7b.



(b) Enlarged vertical tail. Dash line is faired curve for original vertical tail shown in figure 7a.

Figure 7 .- Concluded.

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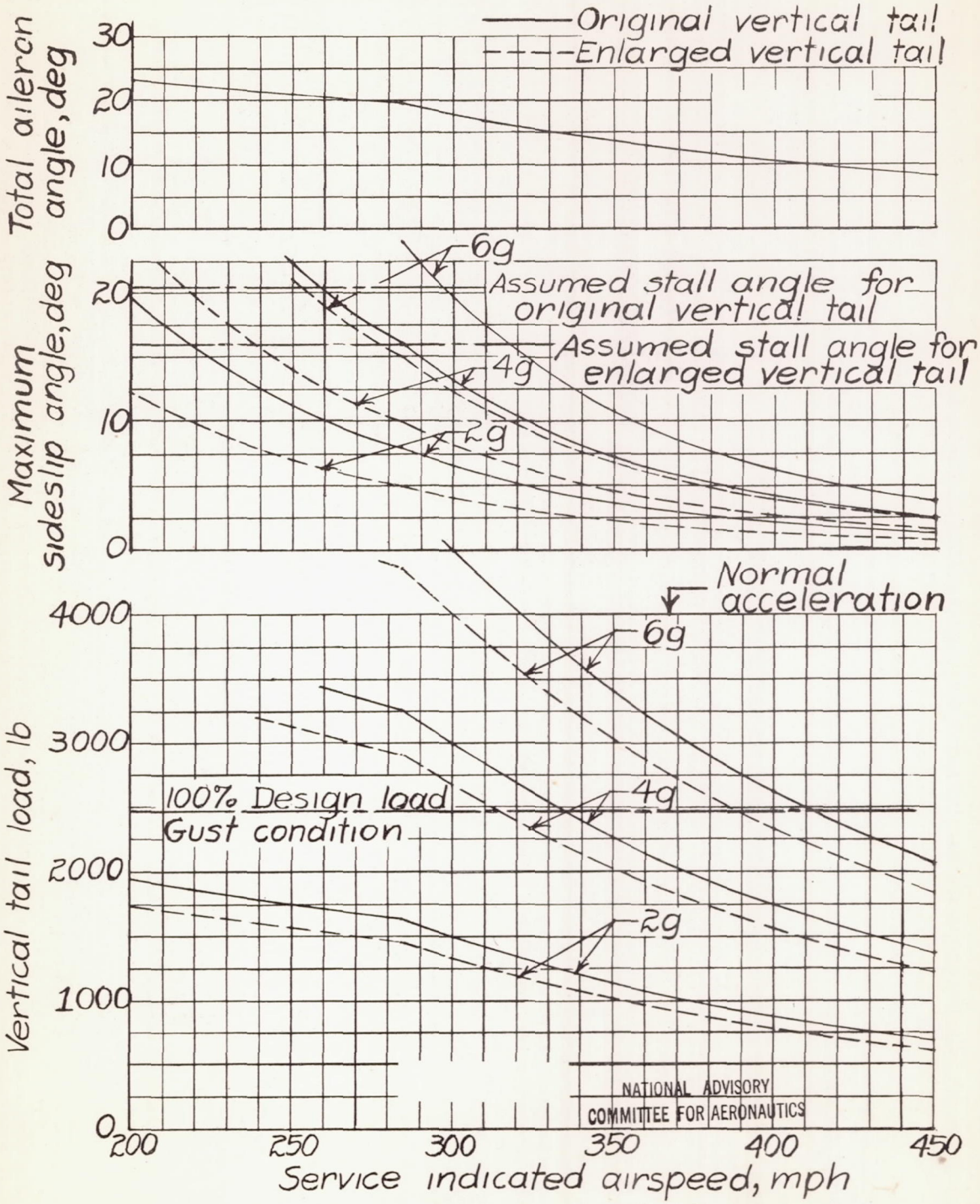

Figure 8.- Estimated maximum vertical tail loads to be expected in rudder-fixed rolls during accelerated flight employing 50 pounds aileron stick force.