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FLIGHT INVESTIGATION OF MODIFICATIONS TO IMPROVE THE ELEVATOR CONTROL-FORCE CHARACTERISTICS OF THE CURTISS SB2C-1C AIRPLANE IN MANEUVERS

By Maurice D. White and John P. Reeder

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

FLIGHT INVESTIGATION OF MODIFICATIONS TO IMPROVE THE ELEVATOR CONTROL-FORCE CHARACTERISTICS OF THE CURTISS SB2C-1C AIRPLANE IN MANEUVERS

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SUMMARY

Three sets of elevators with various combinations of section contour, balancing tabs, bobweights, and control-system mechanical advantage were tested on an SB2C-1C airplane in an attempt to improve the elevator control-force characteristics in maneuvers. An arrangement was developed which with a 3-pound bobweight gave a variation of maneuvering stick forces of 6 to 18 pounds per g acceleration over the operating center-of-gravity range of 33.2 to 23.8 percent mean aerodynamic chord; this arrangement consisted of elevators having a nose contour less blunt than that of the production elevators, beveled trailing edges, a geared balancing tab with a linkage ratio $d\delta_t/d\delta_e$ of -0.33, and a control-system mechanical advantage that gave stick forces 22 percent less than that of the production arrangement for a given hinge moment. For the production elevators with the standard control system and a 5-pound bobweight the variation in maneuvering stick forces over the operating center-of-gravity range was 5 to 24 pounds per g.

A set of elevators was tested that provided further reduction in the value of $C_{h_{\delta_e}}$, the variation of elevator hinge-moment coefficient with elevator deflection, in an effort to obtain stick forces within the desired limits of 3 to 8 pounds per g over the operating center-of-gravity range. These elevators in conjunction with an 8-pound

bobweight were found to provide a stick-force variation with center-of-gravity position in steady turns of about this magnitude, but the control was considered very objectionable by the pilot because it resulted in involuntary overcontrol during take-offs and rapid elevator movements. Because of this consideration no reduction in the variation of maneuvering forces with center-of-gravity position below that given by the improved arrangement mentioned previously was possible.

INTRODUCTION

The operating center-of-gravity range of the Curtiss SB2C-1 airplane is being extended to the limits 23.8 to 33.2 percent mean aerodynamic chord. Results of previous tests by the National Advisory Committee for Aeronautics on an SB2C-1 airplane indicate that with the production elevator arrangement the maneuvering forces would be excessive at the forward center-of-gravity limit and negative at the rearward center-of-gravity limit specified. At the request of the Bureau of Aeronautics, Navy Department, therefore, flight tests were made on an SB2C-1C airplane to determine modifications to reduce the variation of maneuvering forces with center-of-gravity position to the limits of approximately 3 to 8 pounds per g that are specified in the Navy handling-qualities requirements for this class of airplane.

Previous tests conducted by the NACA on other SB2C-1 airplanes showed an unaccountable difference in elevator hinge-moment characteristics between various production airplanes, so it was considered advisable to repeat these tests on the present airplane in order to provide a standard for evaluating the improvements effected by the modifications tested. These production elevators were not used as a foundation for modifications, however, because in high-speed dive recoveries during the earlier NACA tests, they had evidenced undesirable tendencies for the stick forces to lighten, which were attributed to changing pressure distributions over the blunt nose of these elevators. Instead the modifications were made on two sets of elevators provided by the Curtiss company which differed from the production elevators in that the nose contours were less blunt and the rib spacings were halved; the latter change was made in order to reduce the effects

of fabric distortion. The modifications made to these test elevators included changes in elevator trailing-edge angle, balancing tab linkage ratio, bobweight size, and control-system mechanical advantage.

The results of tests of the production elevators and of the various modifications on the test elevators are presented in the following report.

THE AIRPLANE

The Curtiss SB2C-1C airplane (No. 18294) shown in figure 1 is a two-place single-engine monoplane, dimensions of which are given in reference 1. As flown during the present tests the gross weight varied from approximately 12,000 to 14,000 pounds. The flight conditions used during the test program are as defined in reference 1, with the exception that in the present tests the cowl flaps were closed in the climbing condition.

ELEVATORS AND MODIFICATIONS

Three sets of elevators were tested during the flight program, the plan form and airfoil sections of which are shown, respectively, in figures 2 and 3. The plan form of all the elevators was the same. The production elevators had a rib spacing of 8 inches to 9 inches; the test elevators designated in figure 2 as "normal contour" and "beveled trailing-edge contour" differed from the production elevators in that the nose contours of the former were less blunt and they had a rib spacing of 4 inches to $4\frac{1}{2}$ inches.

The elevators designated as beveled trailing-edge contour were constructed to the contour shown in figure 3 by modifying the trailing-edge shape of the normal contour elevators with balsa blocks and covering with fabric. The trailing-edge contour was modified to a uniform included angle of $15\frac{1}{2}^{\circ}$ only over the portions of the elevators outboard of the tabs. The original elevators had a trailing-edge angle that varied from 11.5° at the outboard end of the tab to 9° near the tip.

The designations 3-, 5-, and 8-pound bobweights, indicate the static stick forces and the number of pounds per g added by the bobweights which were installed for the tests.

For some of the tests the mechanical advantage of the elevator control system was increased by reducing the elevator travel with respect to the stabilizer center line from 22° down and $33\frac{1}{2}$° up to 16° down and 27° up, without changing the stick travel. This change resulted in a 22-percent reduction in stick forces for a given hinge moment. The mechanical advantage change was accomplished by fitting to the bell crank to which the control cables are attached at the aft end of the fuselage an extension which lengthened the arms of the bell crank.

In tests to determine the internal pressure in one of the elevators, a line was run from a pressure recorder to a point in the interior of the left elevator at about the midspan, midchord location.

A list of the elevator configurations tested is given in table I. It should be noted that, for convenience, the production elevator was tested with the increased mechanical advantage in the present test program; the actual production airplane has the original mechanical advantage.

INSTRUMENTATION

Standard NACA recording instruments were used to determine airspeed, elevator-control force, elevator angle, acceleration, air pressure, and time.

Correct service indicated airspeed as used in the report represents the reading that would be given by a standard AN airspeed meter if it were connected to a pitot-static head that was free from position error, and is defined by the relation:

$$V_i = 45.08\ f_o\sqrt{q_c}$$

where

V_i correct service indicated airspeed

f_o sea-level compressibility factor

q_c dynamic pressure, obtained from the difference between total pressure and static pressure corrected for position error on the airplane, inches of water

TESTS, RESULTS, AND DISCUSSION

Most of the results presented in this report were obtained in steady turns performed in the climbing condition, [flaps neutral, landing gear retracted, and engine operating at about rated power (38 inches of mercury - 2400 rpm)]. In addition, tests were made investigating the static longitudinal stability of the airplane in the gliding (flaps neutral, gear retracted, power off) and climbing (flaps neutral, gear retracted, rated power) conditions of flight. During some of the latter tests the internal pressures in one of the elevators was recorded.

In order to establish the adequacy of the reduced elevator travel, several landings, take-offs, and stall recoveries were made with the center of gravity at the most critical position for each maneuver.

Maneuvering Stability

Production elevators.- The results obtained in steady turns with the production elevators on airplane No. 18294 are shown in figures 4 and 5. Figure 4(a) shows the variation of stick force with normal acceleration and figure 4(b), the variation of elevator deflection with airplane normal-force coefficient. In figure 5 the variation with center-of-gravity position of the parameters, stick force per unit normal acceleration, F_e/n, and elevator angle per unit airplane normal-force coefficient, $d\delta_e/dC_N$, are shown. The values of F_e/n and $d\delta_e/dC_N$ shown are determined, respectively, for an acceleration of 4g and for the value of C_N corresponding to straight flight.

The data shown in figures 4 and 5 were obtained with a mechanical advantage of the elevator control system greater than that of the production airplane. In order to permit comparison with the stick-force data obtained from reference 1 for SB2C-1 airplane No. 00014, stick-force data obtained with both airplanes have been corrected to correspond to the production mechanical advantage and 5-pound bobweight. The results given in figure 5 show that the variation in maneuvering stick forces over the operating center-of-gravity range was 5 to 24 pounds per g.

The following values of $C_{h_{\delta_e}}$ and C_{h_α}, the variations of elevator hinge-moment coefficient with deflection and with angle of attack of the horizontal tail, respectively, were obtained from a comparison of the data in figure 5:

Airplane	$C_{h_{\delta_e}}$	C_{h_α}
SB2C-1 No. 00014 (reference 1)	-0.0033	-0.0012
SB2C-1C No. 18294	-0.0024	-0.0005

These differences in the values of $C_{h_{\delta_e}}$ and C_{h_α} which result in a shift in maneuver point of about $2\frac{1}{2}$ percent mean aerodynamic chord are of the same order as differences that have been found between other SB2C-1 airplanes tested at the NACA.

Normal contour elevators.- For the normal contour elevators the variations of stick force with normal acceleration for several balancing tab linkages are shown in figure 6. The corresponding variations with center-of-gravity location of stick force per unit normal acceleration are shown in figure 8(a).

With the balancing tab locked, the maneuvering forces varied from about 1 to 28 pounds per g acceleration over the center-of-gravity range from 33.2 to 23.8 percent mean aerodynamic chord. This variation is greater than was obtained with the blunt nose elevators, which is to be expected.

With increasing balancing-tab linkage ratio the variation of maneuvering forces with center-of-gravity position was progressively reduced (fig. 8(a)), and for a tab linkage ratio $d\delta_t/d\delta_e$ equal to -1.26, the

variation at high speeds was reduced to a magnitude which would be considered acceptable for an airplane of this size. However, as indicated in figure 6, at the lower speeds a tendency for the stick forces to lighten at high accelerations became increasingly evident as the force gradients were reduced by the increased tab linkage ratios; this tendency would have resulted in overbalance of the control at more rearward center-of-gravity positions. The control feel was considered by the pilot to be somewhat undesirable with the largest tab linkage ratio, because of the lightness of the stick forces required in rapid elevator movements.

Beveled trailing-edge elevators.- The results of tests with the elevators having beveled trailing edges are shown in figures 7 and 8(b). A comparison of the data in figures 8(a) and 8(b) indicates that, as expected, the beveled trailing edges made both $C_{h_{\delta_e}}$ and C_{h_α} for the elevator less negative, as evidenced, respectively, by the reduced variation of maneuvering forces with center-of-gravity locations and by the higher maneuvering forces experienced at rearward center-of-gravity locations.

With the balancing tab connected the maneuvering forces were reduced and the tendency for the stick forces to lighten in turns at low speeds which was experienced with the elevators having the normal contour was less pronounced. However, with this control arrangement it was found that when the balancing tab linkage ratio was increased to a magnitude that yielded a desirably small variation of maneuvering force with center-of-gravity location (fig. 8(b), $d\delta_t/d\delta_e = -1.29$), the elevator characteristics became very undesirable for abrupt control movements. It appeared to the pilot that there was a lag in response of the airplane to elevator movement. This sensation of lag in response is attributed to the fact that, owing to the small value of $C_{h_{\delta_e}}$, the pilot was able to move the control abruptly and with little force to a considerable deflection before the airplane responded and the stick force due to the bobweight was felt. For the balancing tab linkage ratio of -1.29, also, the lack of the usual variation of control force with deflection caused the stick forces due to the bobweight and due to inertia effects to predominate. When the pilot attempted to control the airplane longitudinally, these forces were in an unfamiliar phase relation to the elevator movement,

and as a result the pilot tended to overcontrol. This difficulty led to dangerous pitching oscillations of large amplitude during the first take-off with this arrangement, and as a result no further flights were attempted. With the balancing-tab ratio reduced to -0.7, and with a 5-pound bobweight, the airplane was not considered dangerous to fly, but the elevator forces were still considered somewhat too light in rapid maneuvers.

In order to obtain reduced stick forces without the undesirable control characteristics due to very small values of $C_{h_{\delta_e}}$, the mechanical advantage of the control system was increased so that for a given hinge moment the stick forces were reduced by 22 percent; this change was recommended in reference 1. The results of tests of the elevators having beveled trailing edges with a 3-pound bobweight, the balancing tab geared at $d\delta_t/d\delta_e = -0.33$, and the increased mechanical advantage are shown in figures 9 and 10. As indicated in figure 9 the variation of stick force with acceleration was approximately linear for all the speeds investigated, and the pilot reported no abnormal control feel for the arrangement. It, therefore, appears that this balancing-tab linkage ratio is about the largest that could be used without introducing undesirable control feel. The maneuvering forces varied from 6 to 18 pounds per g acceleration over the operating center-of-gravity range of 33.2 to 23.8 percent mean aerodynamic chord (fig. 10). A force gradient of 18 pounds per g is larger than is usually specified as desirable, but was not considered an unreasonable value for this airplane. By reducing or eliminating the bobweight it would be possible to reduce the force gradients at all center-of-gravity locations somewhat, but this change is not recommended because the pilots considered a force gradient of about 3 pounds per g too low for this airplane.

Comparison of Production Elevators and Recommended Arrangement

The recommended elevator control system consisting of the beveled-trailing elevator with balancing tab geared at $\frac{d\delta_t}{d\delta_e} = -0.33$, the increased mechanical advantage, and 3-pound bobweight, which was found to be the most satisfactory arrangement on the basis of maneuvering

characteristics, was tested to determine its effect on static stability and its adequacy for control in stalls, landings, and take-offs.

Comparative static longitudinal stability data for the modified elevators and the production elevators are presented in figures 11 and 12 for the climbing and gliding conditions of flight, respectively. The variations of elevator angle and stick force with airspeed indicate no important differences in either the stick-fixed or stick-free stability.

The adequacy of the reduced down-elevator travel of the modified elevator arrangement was determined by making take-offs and stall recoveries with the center of gravity at the rearmost position. The increased stick motion due to the increased mechanical advantage was particularly apparent to the pilot in stall approaches with power on and the center of gravity at the rearward limit where extreme forward movements of the stick were required. This condition was not considered objectionable, however, because the elevator travel available was adequate for recovery from the stalls. The adequacy of the up-elevator travel was determined by making landings with the center of gravity at the most forward position. The elevator travel was found to be sufficient for this condition.

If the increased mechanical advantage were used in conjunction with the production elevators, the variation of force per g with center-of-gravity position would be only slightly greater than that obtained with the recommended arrangement. The recommended arrangement has a slight advantage, however, in that a 3-pound bobweight rather than a 5-pound bobweight is required in order to obtain sufficiently heavy maneuvering forces with the rear center-of-gravity position. Furthermore, the modified elevators incorporate a less blunt nose shape and closer rib spacing than the production elevators, which would be expected to make them more satisfactory in high-speed dives.

Internal Elevator Pressures

The results of measurements of the internal pressures in the modified elevators are presented in figure 13 as a function of indicated airspeed. The data indicate that at high speeds the internal pressures are approximately

4 percent of q_c above free-stream static. These data are presented as an aid to estimating possible effects of fabric deflection if it is desired to test these elevators in high-speed dives. The elevators were sealed at the hinge gaps and vented with $\frac{1}{4}$-inch holes located near each rib on the lower surface near the trailing edge. Each vent hole was covered by a small scoop-shaped shield, opening rearward. A change in venting to give lower internal elevator pressures seems desirable. No tests were made of the modified elevators in high-speed dives to evaluate the effects of the changed nose shape, the beveled trailing edge, and the closer rib spacing on the control characteristics at high speeds.

CONCLUSIONS

Flight tests on a Curtiss SB2C-1C airplane indicate the following conclusions:

1. Improved maneuvering stick forces may be obtained with elevators having a nose radius smaller than that of the production elevators, trailing edges beveled to an included angle of $15\frac{1}{2}^{\circ}$, a balancing tab geared at a linkage ratio $d\delta_t/d\delta_e = -0.33$, a 3-pound bobweight, and an increase in mechanical advantage that reduced the stick forces by 22 percent. With this arrangement the maneuvering forces varied from 6 pounds per g acceleration at 33.2 percent mean aerodynamic chord to 18 pounds per g at 23.8 percent mean aerodynamic chord.

2. Further reduction in the value of $C_{h_{\delta_e}}$, the variation of elevator hinge-moment coefficient with elevator deflection, which decreased the variation of maneuvering forces with center-of-gravity position, also resulted in a control feel during abrupt elevator movements that was considered objectionable by the pilot. This consideration may establish a lower limit to the value of $C_{h_{\delta_e}}$ that may be used, and, hence, a lower limit to the variation of maneuvering forces with center-of-gravity position.

3. Stick-free static instability noted at low speeds in the climbing condition of flight was not affected

appreciably by the modified elevator arrangement. The increased stick movements required with the modified elevator arrangement, while apparent to the pilot, were not objectionable since adequate elevator travel was provided for critical flight conditions.

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

REFERENCE

1. Phillips, W. H., Williams, W. C., and Hoover, H. H.: Measurements of Flying Qualities of a Curtiss SB2C-1 Airplane (No. 00014). NACA MR, March 14, 1944.

TABLE I

TEST CONFIGURATIONS

Elevator contour (See fig. 3)	Balancing tab linkage ratio $d\delta_t/d\delta_e$	Bobweight pounds at stick	Elevator travel (deg)	
			Down	Up
Production	0	5	16	27
Normal	0	5	22	$33\frac{1}{2}$
Do--------	-0.7	5	22	$33\frac{1}{2}$
Do--------	-1.26	8	22	$33\frac{1}{2}$
Beveled trailing edge	0	8	22	$33\frac{1}{2}$
Do--------	-0.7	5	22	$33\frac{1}{2}$
Do--------	-1.29	8	22	$33\frac{1}{2}$
Do--------	-0.33	3	16	27

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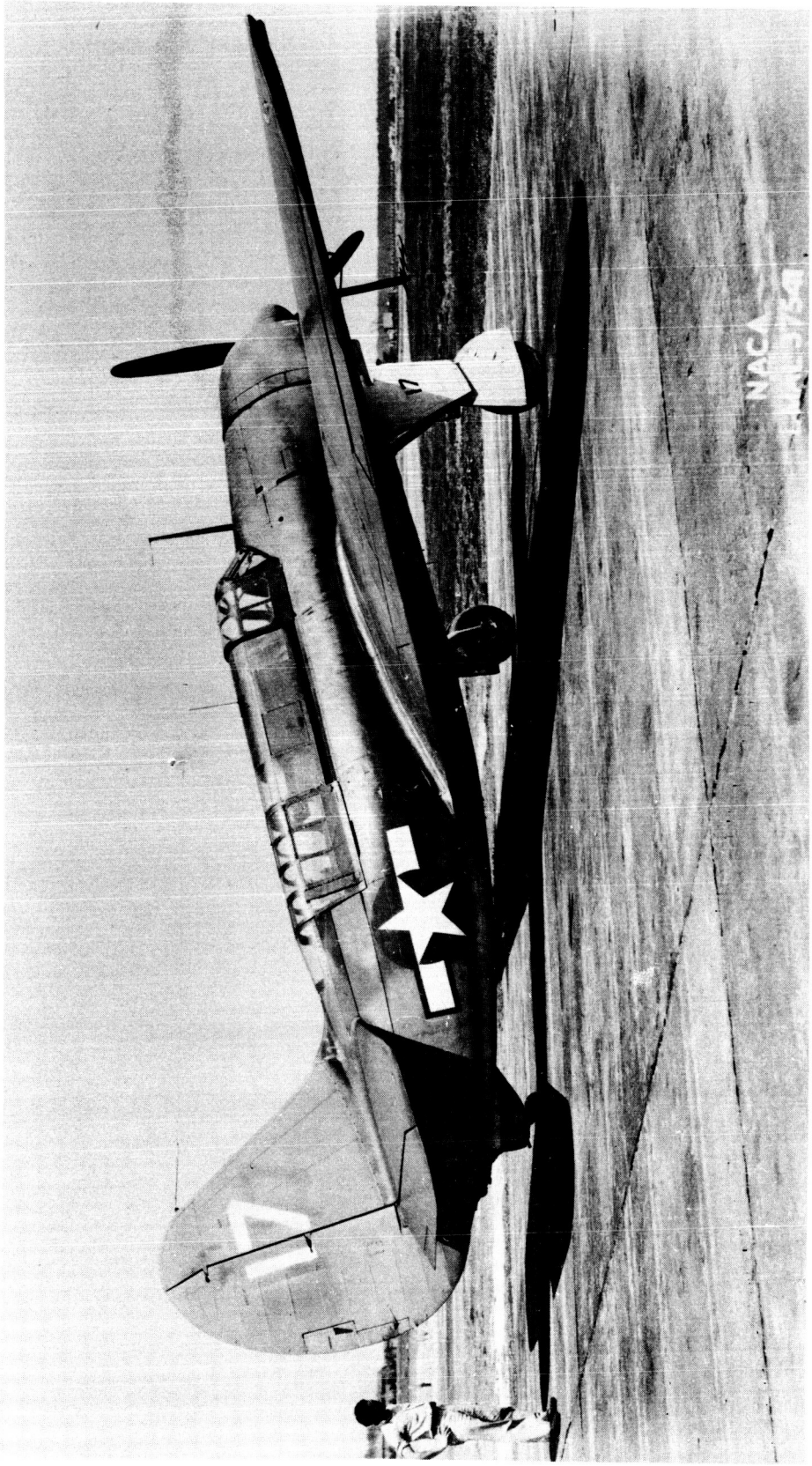

Figure 1.- Three-quarter rear view of Curtiss SB2C-1C airplane, No. 18294.

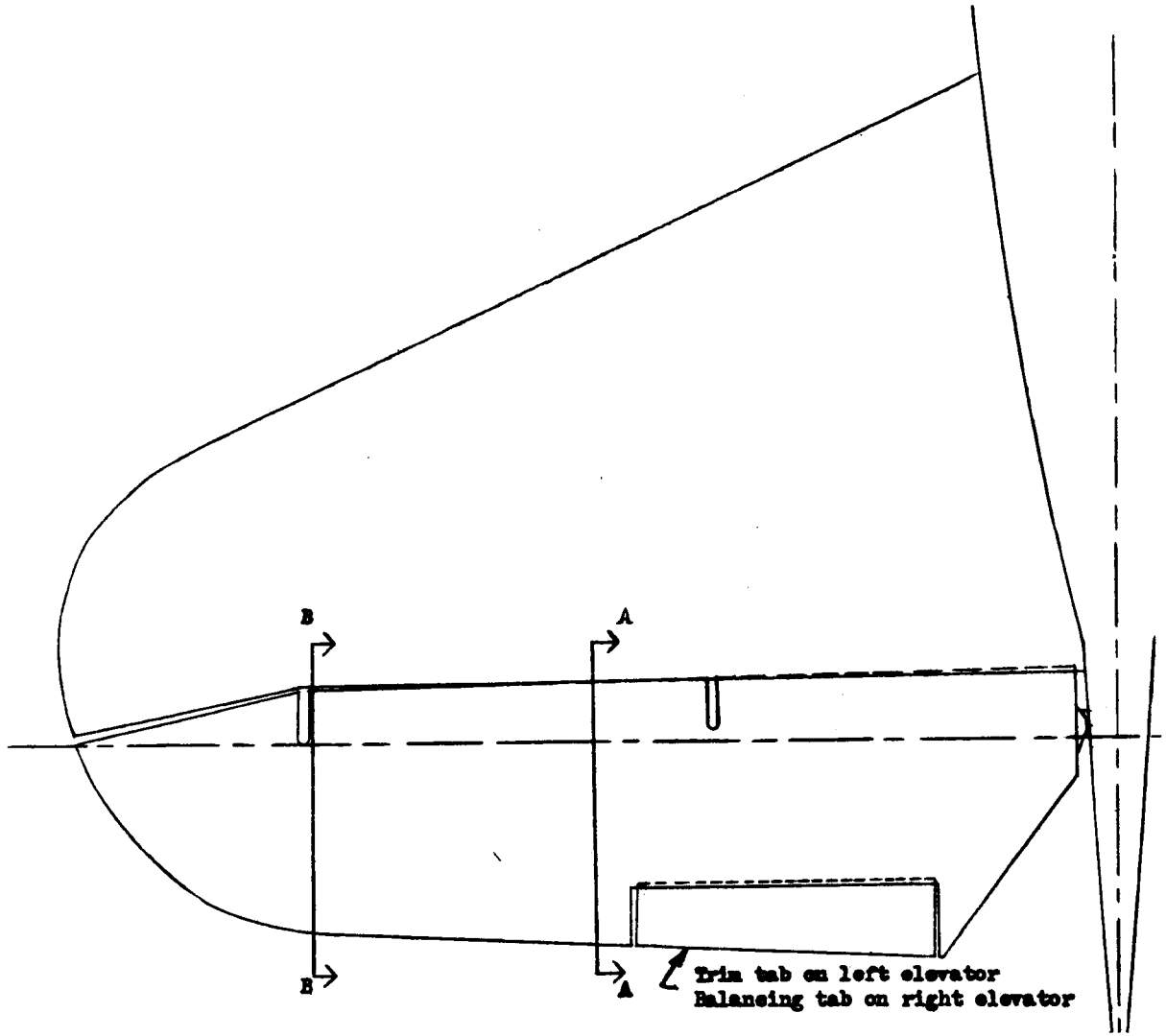

Figure 2. - Plan form of SB2C-1C horizontal tail.

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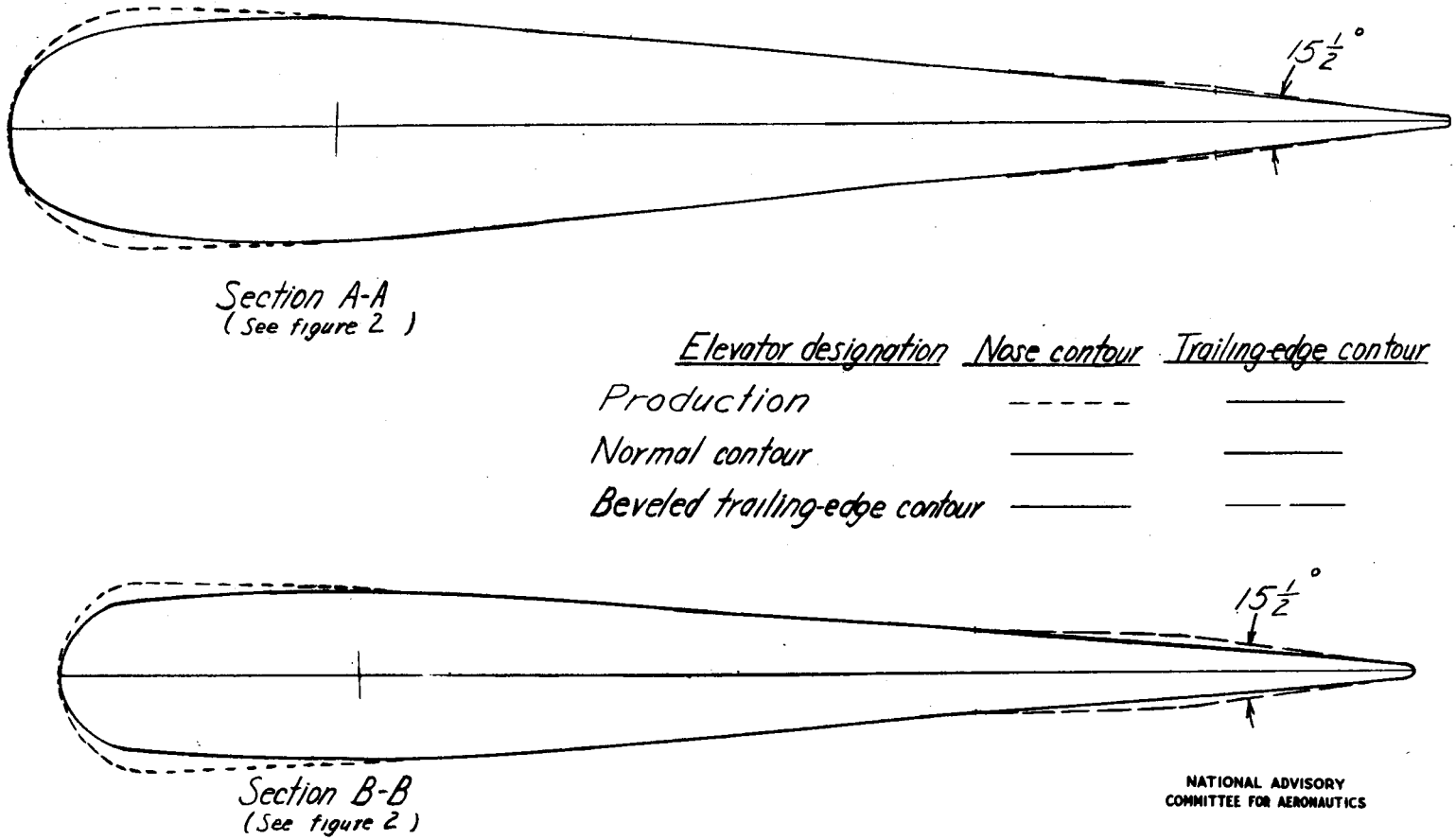

Figure 3.- Contours of elevators tested on SB2C-1C airplane

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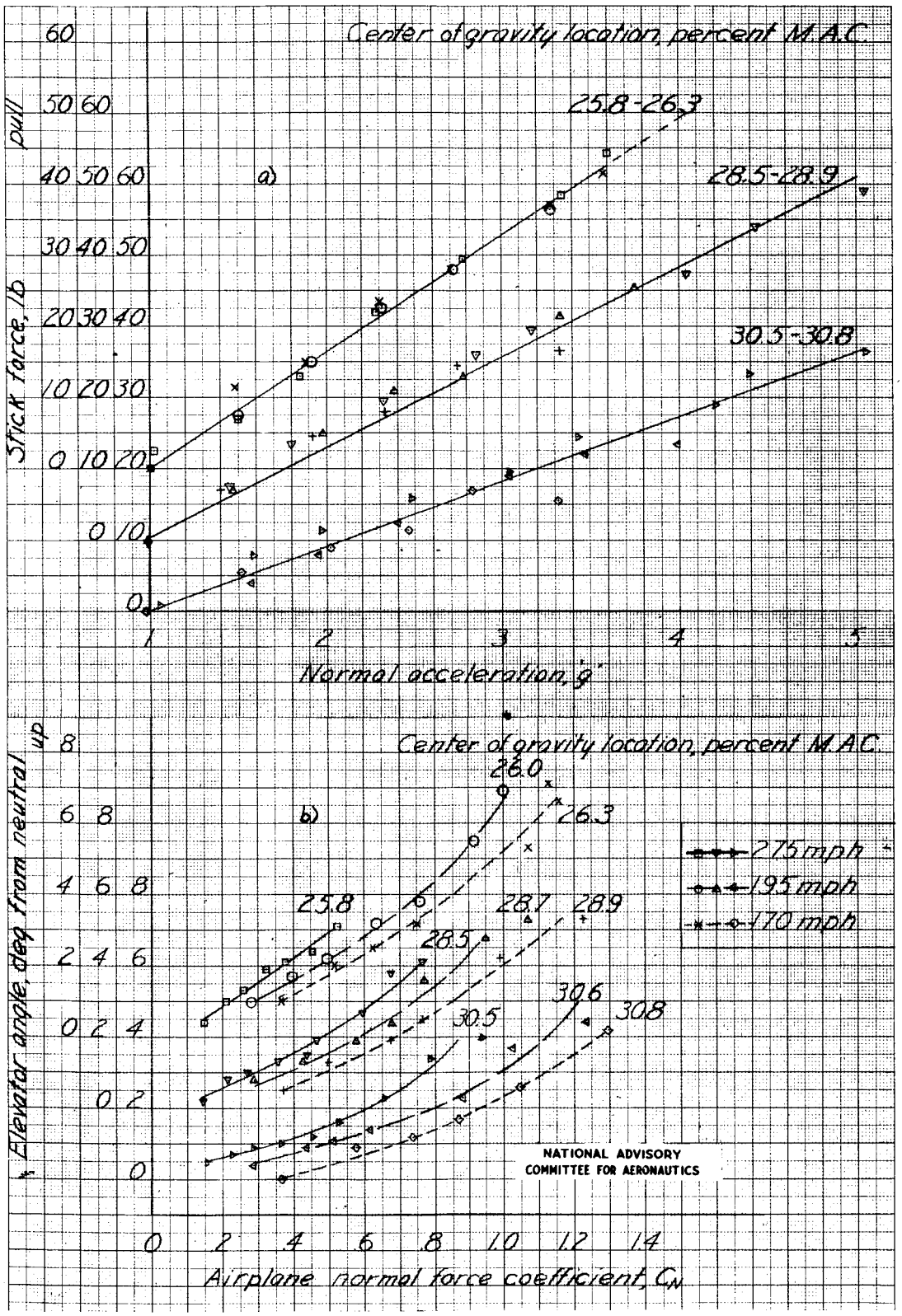

Figure 4. - Elevator characteristics in maneuvers of SB2C-1 airplane with production elevators, increased mechanical advantage, and 5-pound bobweight.

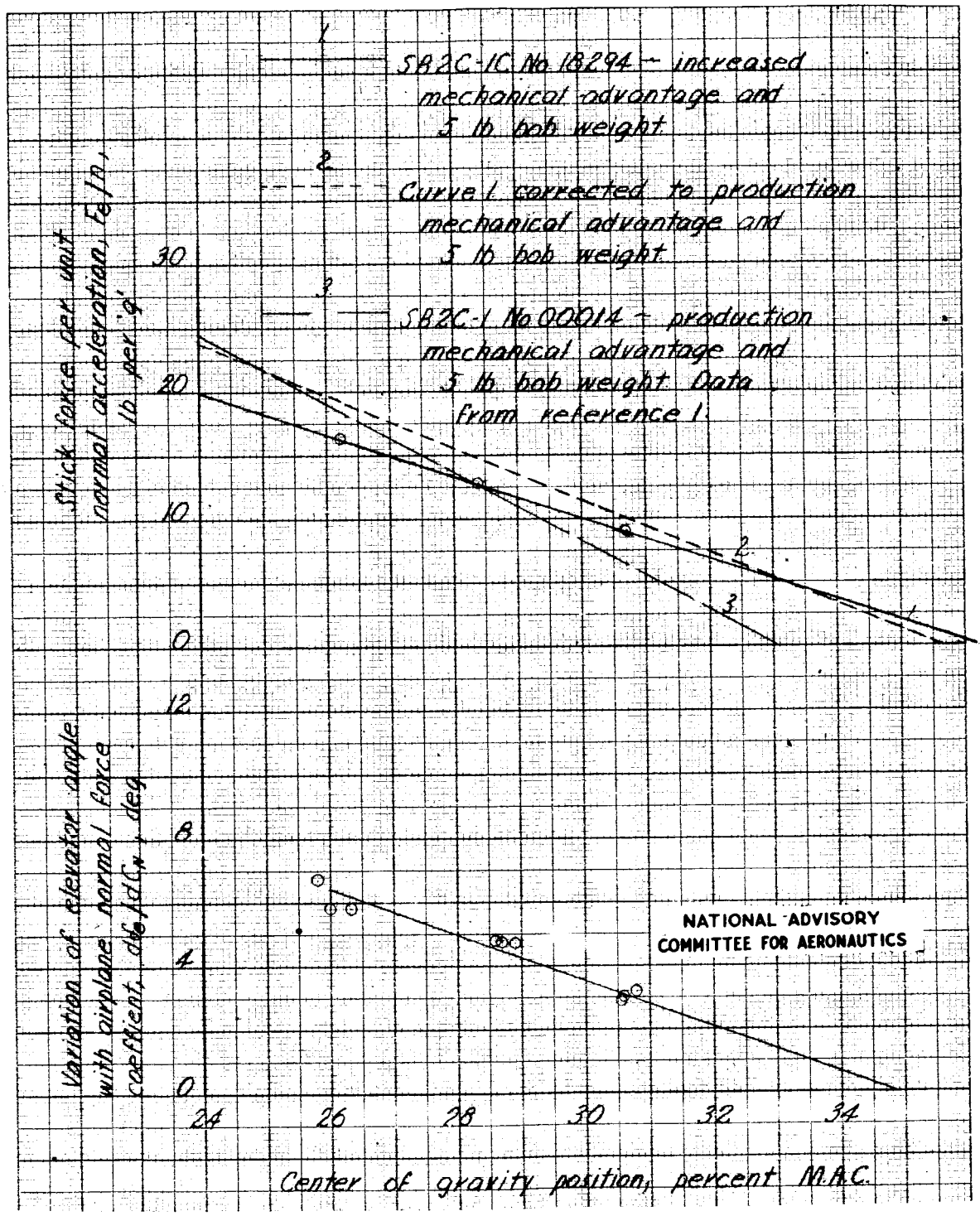

Figure 5. - Comparison of maneuvering characteristics of two SB2C-1 airplanes with production elevators.

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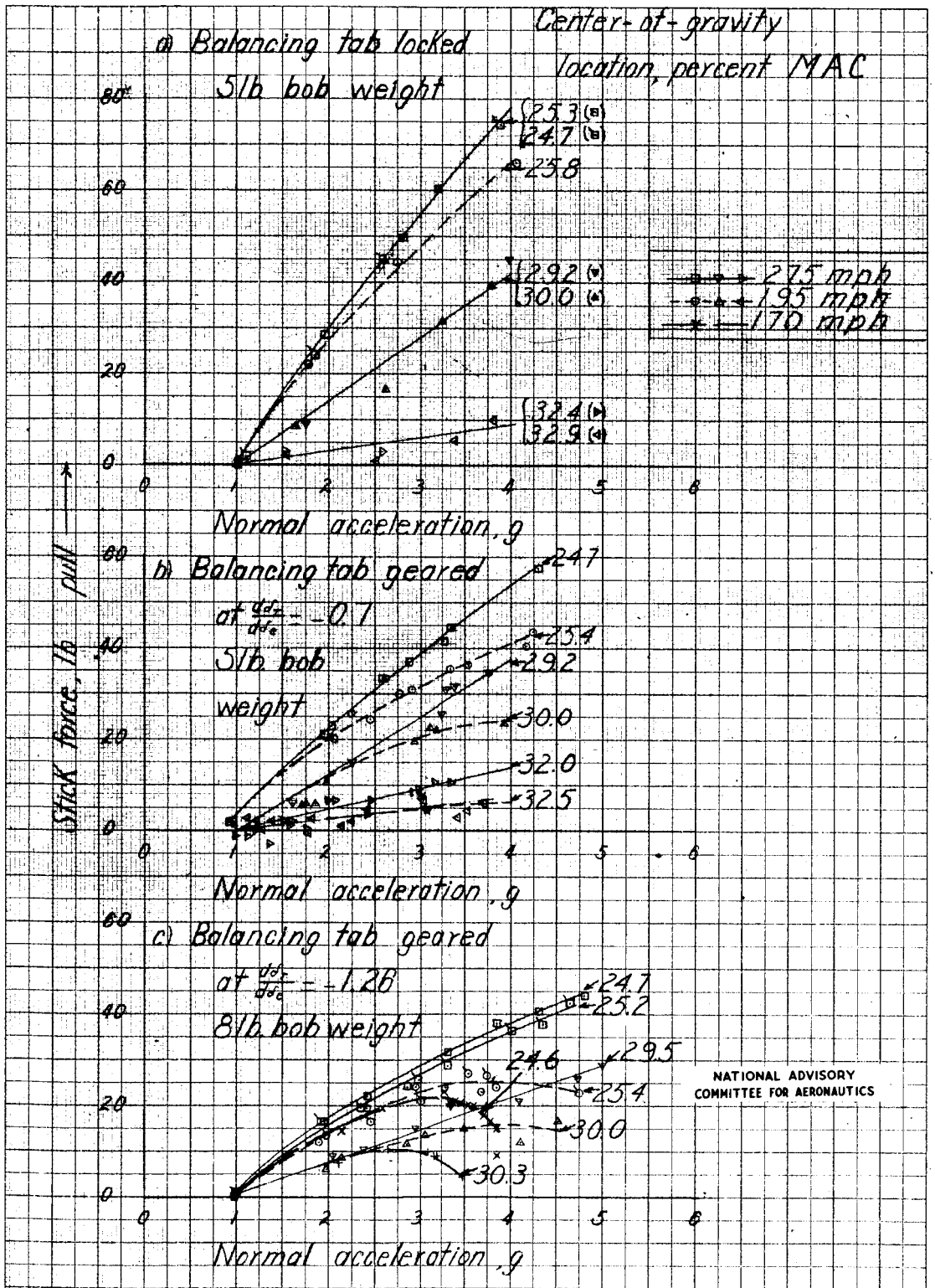

Figure 6.- Variation of stick force with normal acceleration as measured in steady turns. Elevators with halved rib-spacing and normal contour. Curtiss SB2C-1C airplane.

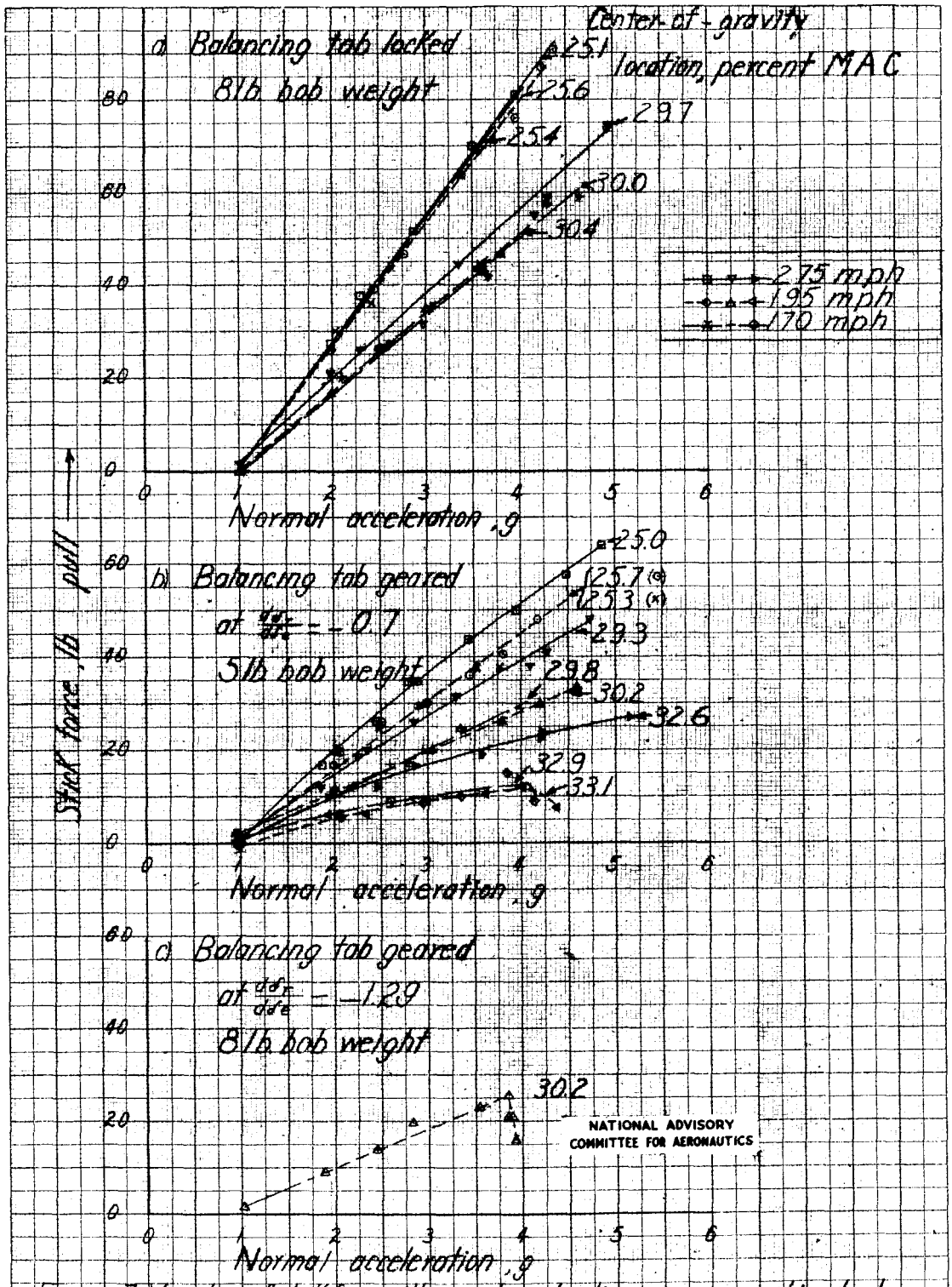

Figure 7.- Variation of stick force with normal acceleration as measured in steady turns. Elevators with halved rib-spacing and beveled trailing-edge contour having 15½° included angle at trailing edge. Curtiss SB2C-1C airplane.

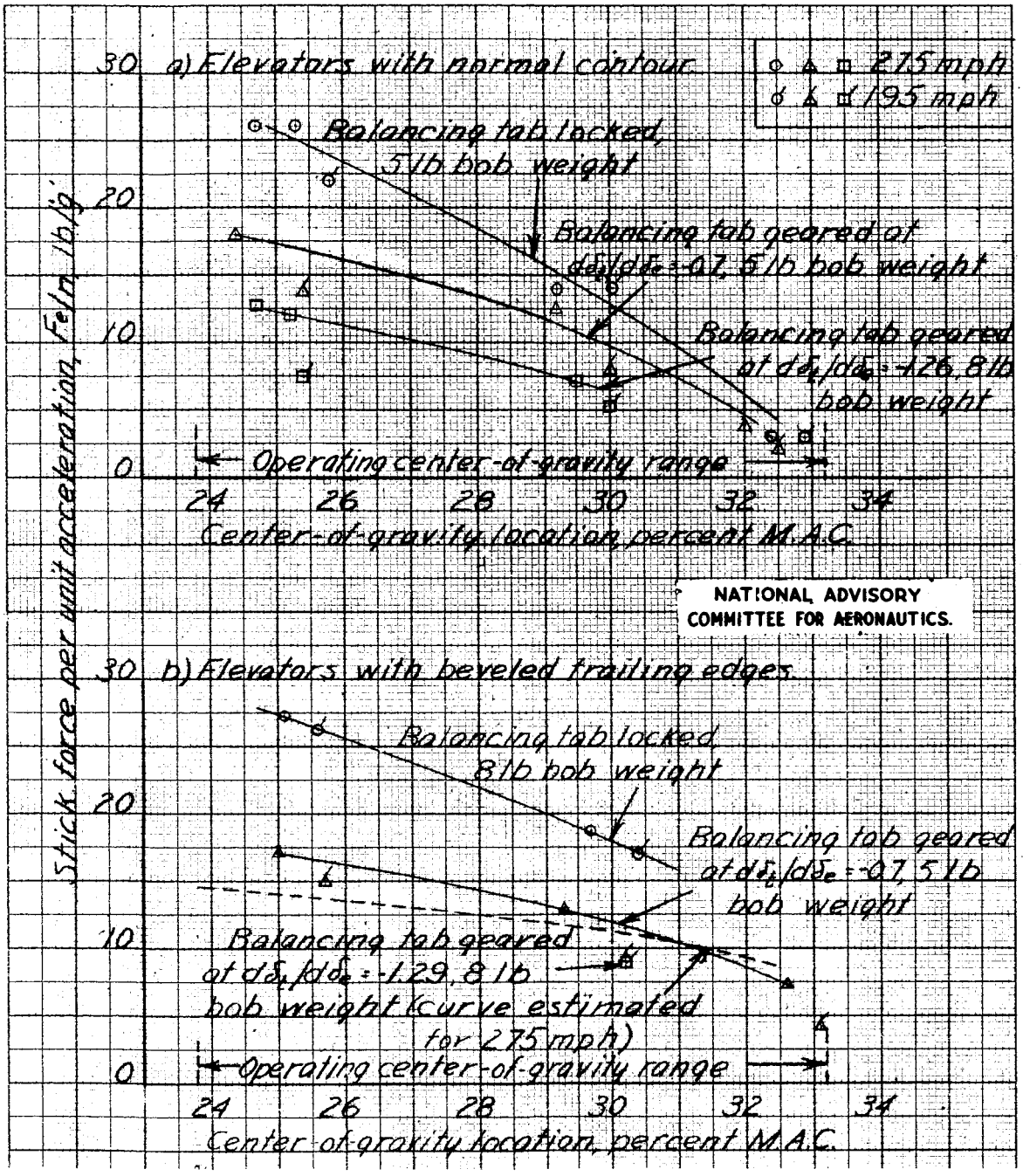

Figure 8. - Variation with center-of-gravity location of stick force per unit normal acceleration, F_e/n. Data taken for acceleration of 4 g in figures 6 and 7. Curves drawn through data for 275 miles per hour. SB2C-1C airplane.

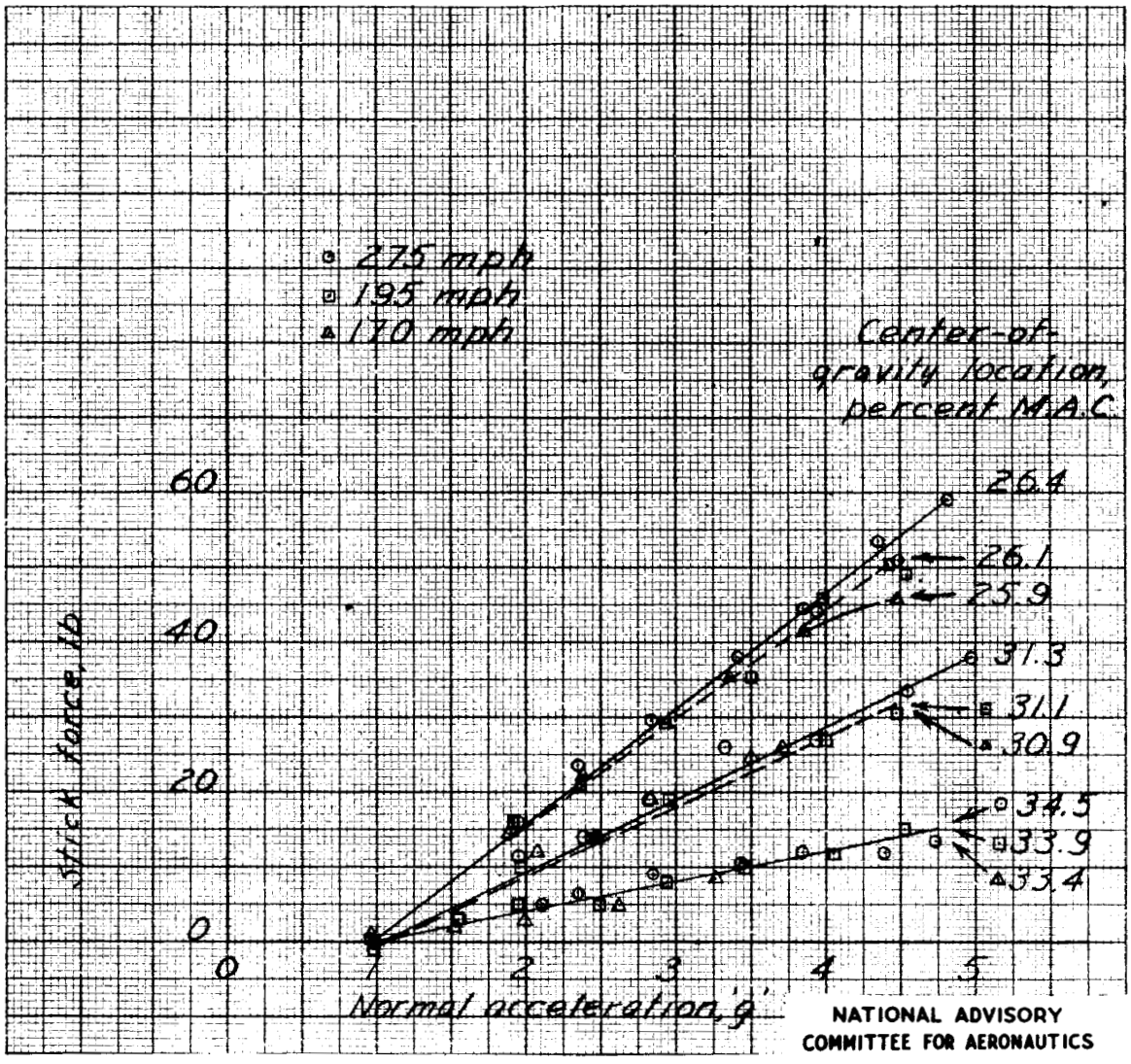

Figure 9. - Variation of stick force with normal acceleration as measured in steady turns. Elevator with beveled trailing edge, balancing tab geared at $\frac{d\delta_t}{d\delta_e} = -0.33$, increased mechanical advantage, and 3-pound bobweight. SB2C-1C airplane.

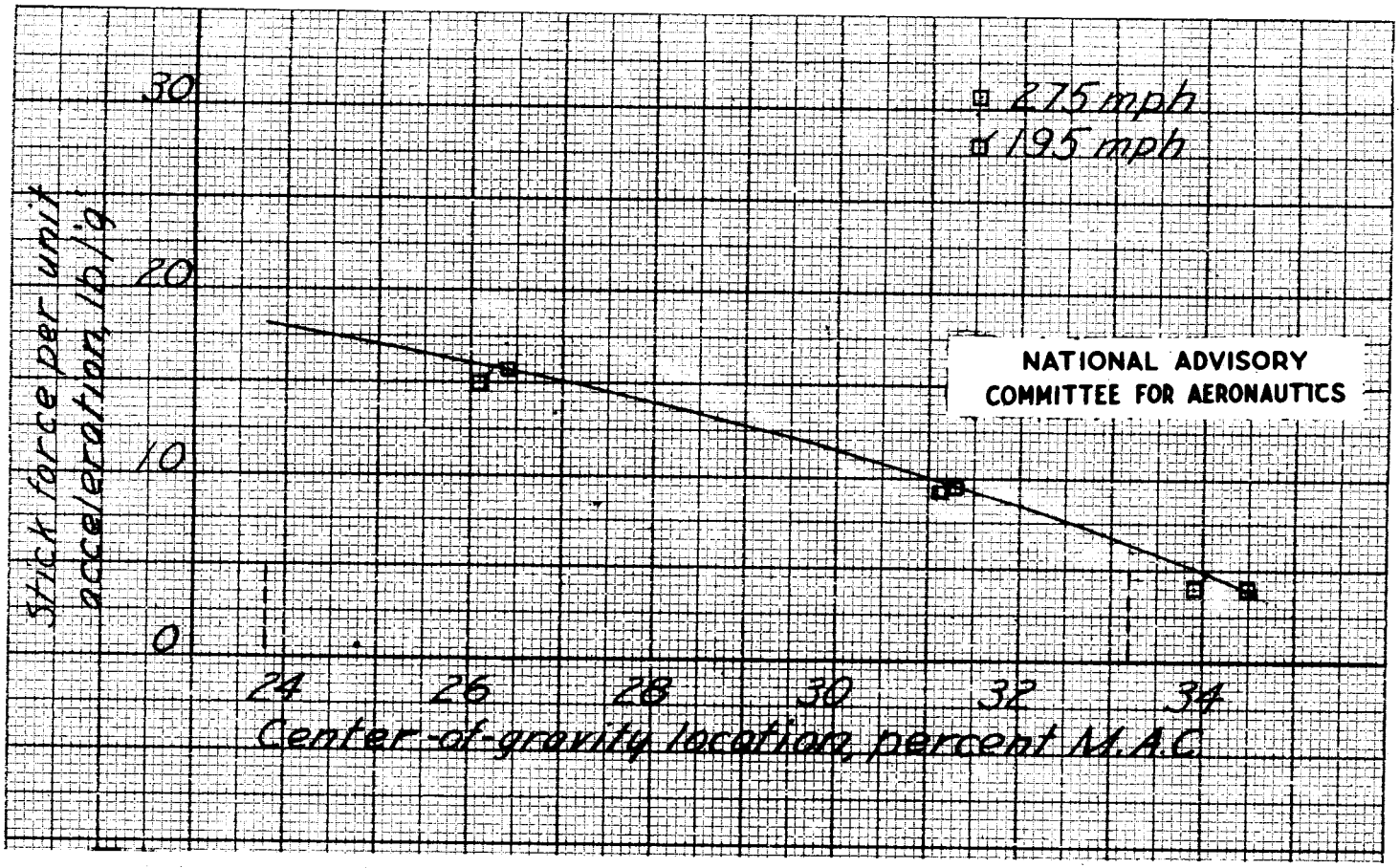

Figure 10. - Variation with center-of-gravity location of stick force per unit normal acceleration. Elevators with beveled trailing edges; balancing tab geared at linkage ratio, $d\delta_t/d\delta_e$, of -0.33; 3-pound bobweight, increased mechanical advantage. Data for acceleration of 4 g.

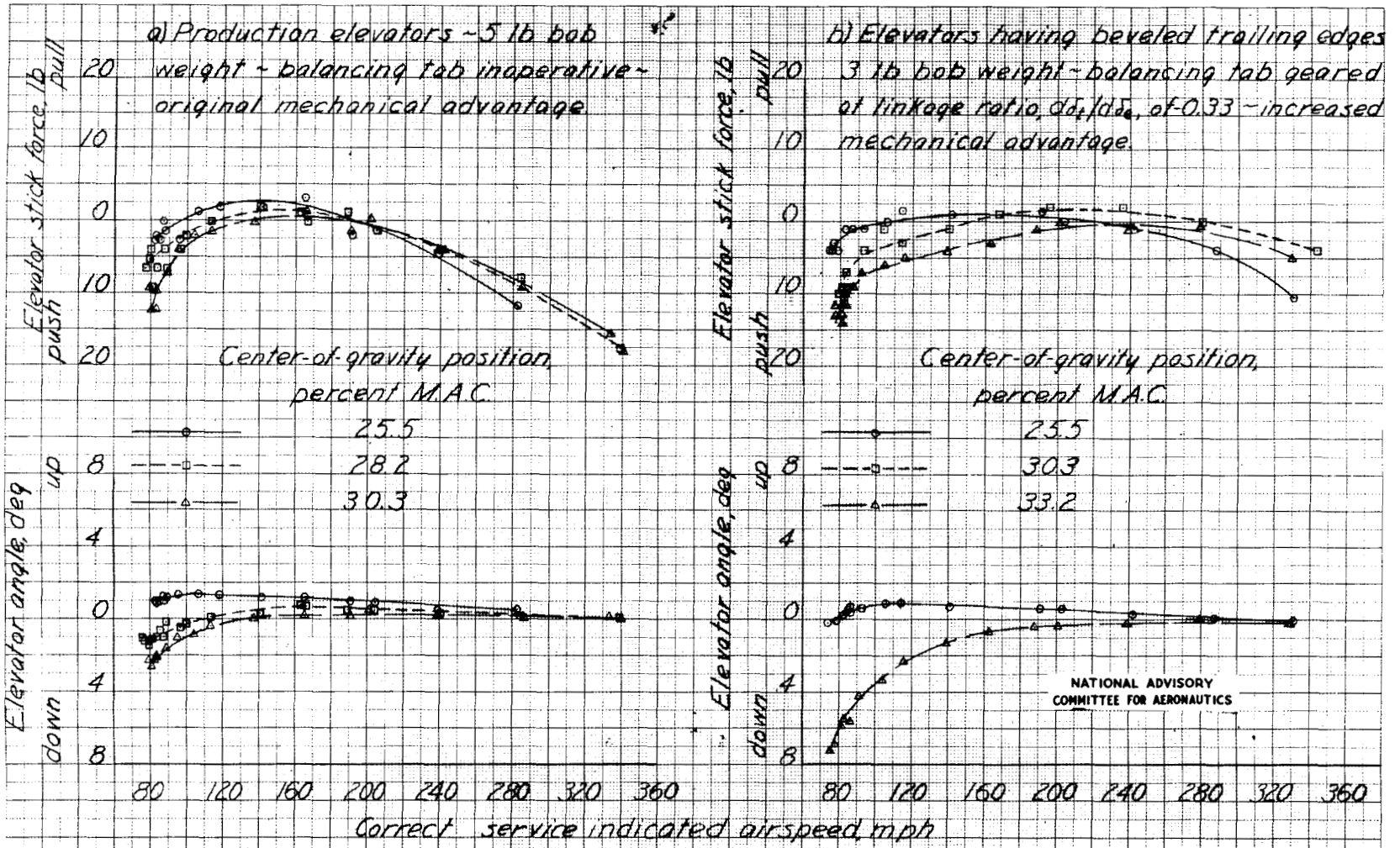

Figure 11 - Comparison of static longitudinal stability of SB2C-1C airplane with production elevators and with modified elevator arrangement. Climbing condition.

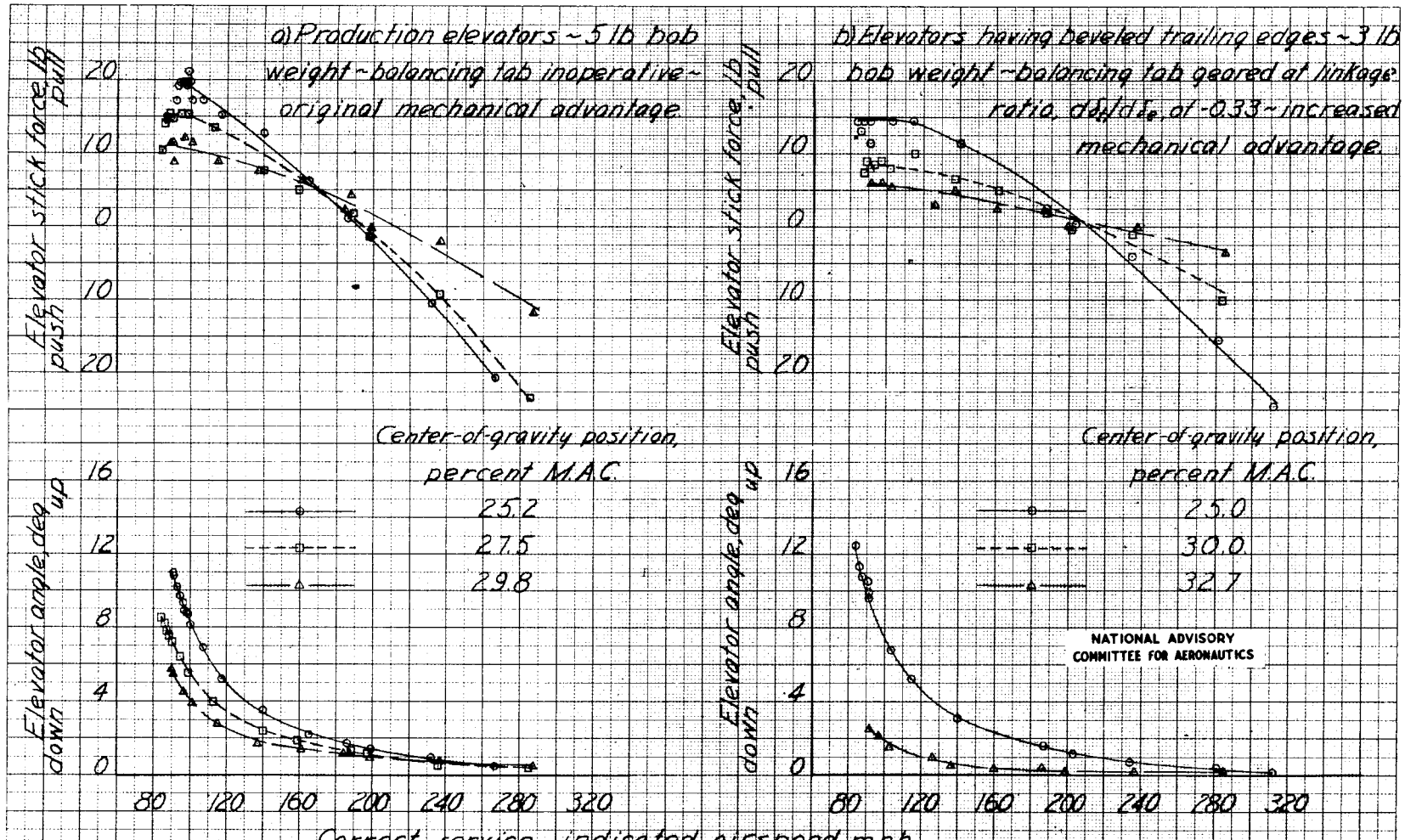

Figure 12: Comparison of static longitudinal stability of SB2C-1C airplane with production elevators and with modified elevator arrangement. Gliding condition.

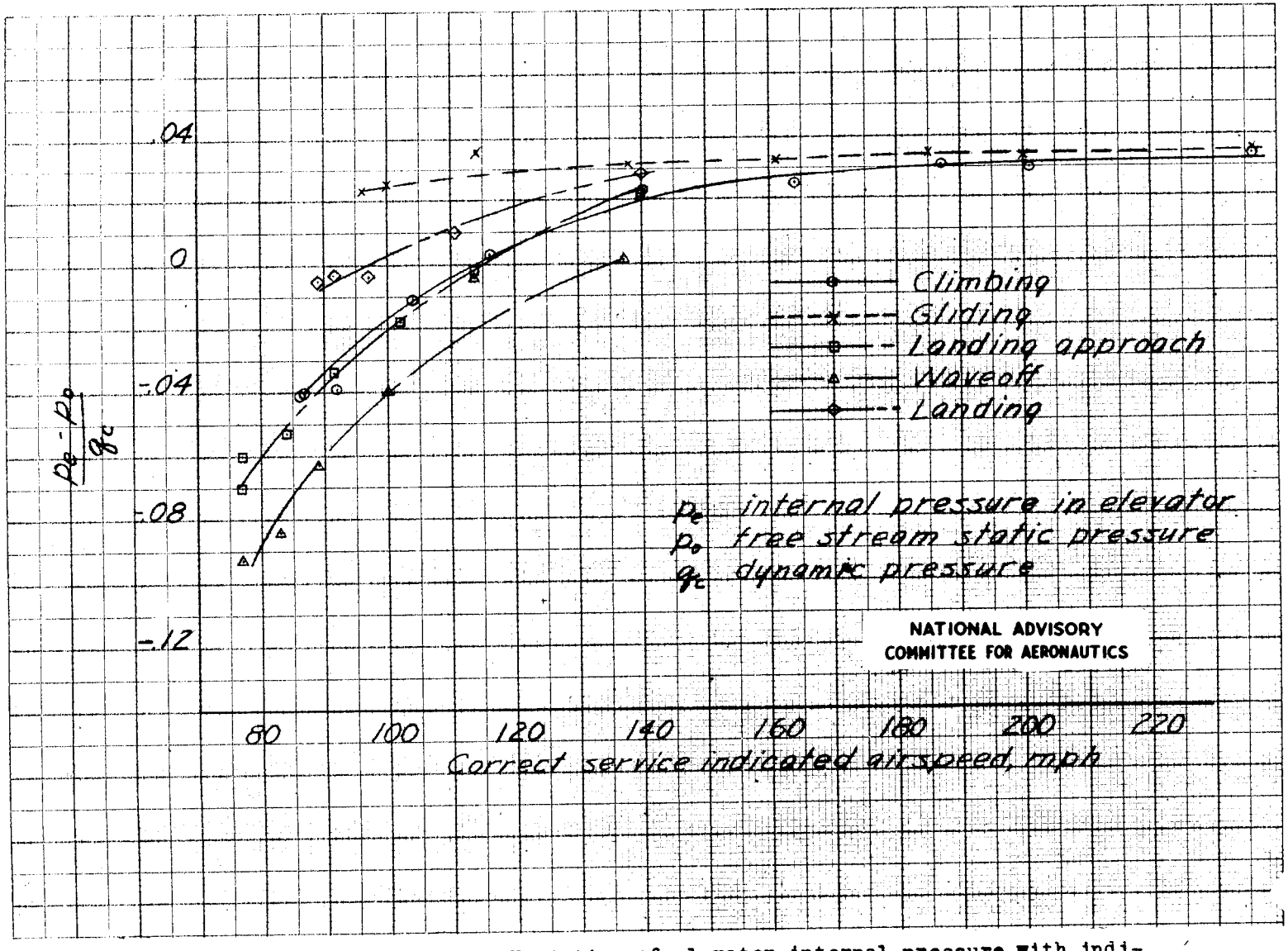

Figure 13. - Variation of elevator internal pressure with indicated airspeed in steady flight. Modified elevators. SB2C-1C airplane.

TITLE: Flight Investigation of Modifications to Improve the Elevator Control-Force Characteristics of the Curtiss SB2C-1C Airplane in Maneuvers

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ABSTRACT:

Three sets of elevators, designated as production, normal-contour, and beveled trailing-edge elevators, were tested on the SB2C-1C Curtiss Hell diver in an attempt to improve elevator control-force characteristics. Results indicate that improved maneuvering stick forces may be obtained with an arrangement including a nose contour smaller than that of the production elevators, trailing edges beveled to an angle of 15-1/2°, and an increase in mechanical advantage that reduced the stick forces 22%.

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