

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
October 1945 as
Memorandum Report L5J09

FLIGHT MEASUREMENTS OF THE EFFECT ON ELEVATOR STICK FORCES

OF STABILIZER INCIDENCE AND ELEVATOR RIB SPACING

ON THE P-63A-1-BE SERIES AIRPLANE

By Harold I. Johnson and Robert G. Mungall

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WASHINGTON

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MRK No. L5J09

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

FLIGHT MEASUREMENTS OF THE EFFECT ON ELEVATOR STICK FORCES
OF STABILIZER INCIDENCE AND ELEVATOR RIB SPACING
ON THE P-63A-1-BE SERIES AIRPLANE

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SUMMARY

Flight tests were made to determine the cause and correction for the unusual stick-free instability of the original production P-63 airplane in high-speed straight flight. When the elevator stick force was trimmed to zero at some level-flight speed, a pull force was required to maintain steady flight at higher speeds. Longitudinal stability tests were made in straight and turning flight with two combinations of stabilizer setting and elevator rib spacing. In addition to usual measurements of longitudinal stability, motion pictures were taken of the elevator in order to determine the fabric distortion characteristics.

Results showed that the longitudinal stick-free instability of original production P-63 airplanes at high speeds in straight flight was caused by the excessive elevator rib spacing and by the high stabilizer incidence. When the elevator rib spacing was changed from $8\frac{1}{2}$ to $4\frac{1}{4}$ inches and the stabilizer incidence was reduced from 2.7° to 1.1° from the thrust axis, the following results were obtained:

- (a) Stick-free stability was improved to a satisfactory degree.
- (b) Maximum fabric deflection was reduced to one-fourth the original amount.

- (c) In turns up to 5g normal acceleration, no measurable change in stick-force characteristics was apparent.

Data obtained by the Bell Aircraft Corporation showed that the use of fabric-covered elevators having narrow rib spacing or of metal-covered elevators with a stabilizer setting 2.7° up from the thrust axis reduced the stick-free instability but did not eliminate it.

INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, an extensive flight investigation was conducted to improve the longitudinal stability characteristics of the P-63 series airplane.

The original production P-63A-1 airplanes possessed undesirable stick-force variations with speed in straight flight. When the elevator stick forces were trimmed to zero at some level-flight speed and the airplane was then dived to a higher speed, a pull force was required to maintain steady flight. To determine the cause of the undesirable variation in stick force with indicated air-speed, flight tests were made and are described herein. These tests consisted of measuring the longitudinal stability and control characteristics of the airplane with two horizontal-tail configurations differing in stabilizer incidence and elevator rib spacing.

AIRPLANE AND TESTS

A three-view drawing of an original production P-63A-1 airplane is shown in figure 1. The main dimensional characteristics of the airplane are listed in the appendix of reference 1. The elevator-to-stick gearing ratio is given in figure 2.

The flight program consisted in determining steady straight and turning flight longitudinal stability and control characteristics with two different airplane configurations. One configuration consisted of the original production stabilizer set 2.7° up from the thrust axis in combination with the original production elevator that had

a rib spacing of $8\frac{1}{2}$ inches. The other configuration consisted of the original horizontal stabilizer set 1.1° up from the thrust axis in combination with elevators of the same contour as the original production elevators, but which had the rib spacing reduced to $4\frac{1}{4}$ inches. In the

straight flight tests, the elevator stick force was trimmed to zero at an indicated airspeed of about 300 miles per hour, and the stick forces and elevator angles required to maintain steady straight flight throughout the speed range were measured. These tests were made with rated power and with engine idling. In turning tests, the elevator stick force was trimmed to zero in straight flight at various chosen indicated airspeeds, using normal rated power, and then the stick forces and elevator angles required to maintain steady normal accelerations between 1 and 5g in turns at the chosen speeds were measured. Motion pictures were taken of the upper and lower surfaces of the elevators by means of cameras mounted in the rear of the fuselage.

Measurements were made first with an original production P-63A-1 airplane (AAF No. 42-68861) which had a stabilizer incidence of 2.7° and was equipped with elevators having an average rib spacing of $8\frac{1}{2}$ inches between rib

center lines. The dimensions of the elevators are given in table I under column A. No measurements of the elevator fabric distortion were obtained in these initial tests. Later, another P-63A-1 airplane (AAF No. 42-68889) having the same stabilizer incidence and type of elevators, except for a minor change in plan form at the inboard end (compare in figs. 1 and 3), was tested briefly to obtain pictures of the elevator fabric distortion characteristics. The dimensions of the horizontal tail of the second airplane tested are given in column B of table I. The elevators of the second airplane tested had an average fabric tension of 3 pounds per inch as measured by an NACA instrument for determining fabric tension. As would be expected, the two airplanes had nearly identical elevator stick-force characteristics. Finally, measurements were repeated with airplane number 42-68889 after the stabilizer incidence had been reduced from 2.7° up from the thrust axis to 1.1° up from the thrust axis and the elevator rib spacing had been cut in half (fig. 4). The fabric tension was not measured on the latter elevator because the only instrument available for measuring fabric tension was too large to be used on panels formed by ribs spaced $4\frac{1}{4}$ inches apart.

The interiors of the elevators tested were vented by openings in the sides of the hinge cut-outs and by drain holes on the lower surfaces near the trailing edge. The openings at the center hinge pocket were $1\frac{1}{2}$ -inch diameter lightening holes in the ribs adjacent to the hinge and the opening at the outer hinge was a half-moon shaped hole of about one-fourth the area, located at the leading edge of the outermost rib. The drain holes were $\frac{3}{8}$ inch in diameter with center lines located 2 inches from the trailing edge and $1\frac{1}{8}$ inches outboard of each rib.

INSTRUMENTATION

Airspeed, elevator internal pressure, elevator angle, stick force, and normal acceleration were all measured with standard NACA recording instruments. The upper and lower surfaces of the right elevator were photographed with electrically driven 16-millimeter gun cameras.

The airspeed pitot-static head was mounted on a boom, one chord length ahead of the right wing, near the wing tip. 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 head free from position error, and may be defined as:

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

where

V_{i_s} corrected service indicated airspeed, miles per hour

f_o standard sea-level compressibility correction factor

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

The elevator angles were measured by an instrument connected directly to the inboard end of the right elevator.

The 16-millimeter gun cameras were mounted inside the vertical fin and in the bottom of the fuselage somewhat to the rear of the elevator hinge axis. Detail views of the camera installations are shown in figures 5 and 6. The locations of the camera ports relative to the right elevator are shown in figure 7. Due to space limitations, a periscope arrangement consisting of an inclined mirror was used with the camera mounted vertically in the fin. The cameras were located close enough to the elevator so that the error in the recorded fabric deflections due to angularity of the camera axis was about 1 percent for the upper surface and about 5 percent for the lower surface. Difficulty was encountered in obtaining clear photographs due to vibration of the airplane. Some sufficiently good pictures were obtained, however, to permit making measurements of the fabric deflection directly from enlargements of the photographs. In order that the deflections at the center of the unsupported fabric panels could be measured easily, strips of white tape were placed chordwise equidistant from the ribs, and spanwise along the leading and trailing edges of the fabric panel boundaries. Representative gun camera pictures obtained in flight are shown in figure 8.

Elevator internal pressure was measured with an NACA airspeed recorder. One side of the pressure cell was vented through an open tube to the center of the elevator fabric panel at midspan of the right elevator. The other side of the pressure cell was vented to the airspeed static pressure head. Elevator internal pressure measurements were corrected for the position error of the pitot-static head.

Symbols used throughout this report are:

P_i	difference between static pressure inside elevator and free-stream static pressure
δ_e	elevator angle, degrees from stabilizer
N.U.	nose up
N.D.	nose down
n	normal acceleration in gravity units

RESULTS AND DISCUSSION

Figure 9 shows a comparison of the static longitudinal stability of the P-63A-1 airplane with normal rated power for comparable center-of-gravity locations with the two different stabilizer incidence and elevator rib spacing combinations tested. Figure 10 is a similar plot for the engine-idling condition. Figures 9 and 10 show that two important effects resulted from decreasing the stabilizer incidence and reducing the elevator rib spacing. First, with the stabilizer set 2.7° up from the thrust axis, the elevator angle for trim in high-speed straight flight was over 3° up from the stabilizer; whereas, with the stabilizer set 1.1° up from the thrust axis, the elevator angle for high-speed trim was about 0.5° down from the stabilizer. Second, increasing pull stick forces with increasing speed were necessary to maintain trim at high speed with the high incidence $8\frac{1}{2}$ -inch rib-spaced elevator combination; whereas, with the low incidence $4\frac{1}{4}$ -inch rib-spaced combination, push stick forces were required to maintain trim throughout the high-speed range tested. Tests made at the Bell Aircraft Corporation showed that increasing the number of elevator ribs decreased the magnitude of the pull stick forces which occurred with the stabilizer set 2.7° up from the thrust axis. The installation of a metal-covered elevator further reduced the magnitude of the pull stick forces which occurred with the original incidence of 2.7° up from the thrust axis but did not cause the force variation with speed to follow a stable trend. Therefore, test data indicate the departure from a stable variation of the stick force versus speed curve was associated with the excessively high stabilizer setting. It is believed that this high stabilizer setting affected the manner of distortion of the elevator covering and possibly resulted in twisting the stabilizer at high speeds.

Further information on the contribution of fabric distortion to the undesirable stick-force variation with speed is provided by the data shown in figure 11 which shows the variation of elevator section shape with speed for the $8\frac{1}{2}$ -inch rib-spaced elevators with the stabilizer incidence 2.7° up from the thrust axis, as determined from gun camera photographs. The fabric distortion characteristics shown by figure 11 may be explained as follows:

1. The fabric on both upper and lower surfaces bowed inward (cusped) under the influence of the negative internal pressure. Since the elevator internal pressure remained at about 14 percent of the free-stream impact pressure below free-stream static pressure, the amount of fabric deflection tended to vary approximately linearly with indicated airspeed. Such a variation is to be expected because although the pressure on the fabric increases as the square of the speed, the resistance of the fabric panel to deflection increases rapidly at large fabric deflections (reference 2). That the variation of fabric deflection (cupping) with indicated airspeed was approximately linear is borne out by the data shown in figure 15, wherein the maximum fabric deflections of the upper and lower surfaces are plotted against indicated airspeed.

2. The elevator mean camber line was bowed downward slightly due to the air load on the elevator. Since up elevator was required to trim the airplane at high speed on account of the high stabilizer incidence, the air load on the elevator was probably downward and the mean camber line was therefore depressed.

Progressive cupping of the elevator might cause the elevator hinge-moment coefficients $C_{H\alpha}$ and $C_{H\delta}$ to become more negative with increasing speed in such a manner as to shift the stick-free neutral point forward. If the stick-free neutral point moved past the center-of-gravity position, an unstable variation of stick force with speed would be expected. Bowing of the elevator mean camber line in a downward direction might cause a change in hinge moment in the direction such that pull stick forces are required as the speed increases.

The quality of the photographs did not permit measurements of sufficient exactness to allow determination of how much either of the two aforementioned effects contributed to the measured stick-force instability.

Figure 12 shows the distortion characteristics through the speed range of the $\frac{1}{4}$ -inch rib-spaced elevators with the low stabilizer incidence of 1.1° up from the thrust axis. The internal pressure for this elevator was about 11 percent of the free-stream impact pressure

below free-stream static pressure at high speeds. Examination of the maximum fabric deflection which occurred with these elevators at high speeds (fig. 15) shows that at the highest speed for which comparable data are available ($V_{is} = 360$ mph) the deflection was only about one-fourth as great as it was for the original $8\frac{1}{2}$ -inch rib-spaced elevators. This large reduction in fabric distortion is to be expected because theory indicates that for constant pressure differential the maximum fabric deflection in a panel should vary approximately as the square of the unsupported gap distance. Warping of the mean camber line of the $4\frac{1}{4}$ -inch rib-spaced elevators at high speed was scarcely discernible so that the elevator mean camber lines are omitted in figure 12. The absence of curvature of the mean camber line would be expected because the elevator air load at high speed should be small when the elevator is approximately aligned with the stabilizer for straight flight trim.

It is of interest to note that the accuracy with which fabric contours can be duplicated from 16-millimeter film is probably indicated by the scatter of the data shown in figure 15. In this connection the large relative scatter in the data for the $8\frac{1}{2}$ -inch rib-spaced elevators as compared to the data for the $4\frac{1}{4}$ -inch rib-spaced elevators is believed to be explained by the quality of the photographs obtained in the two sets of tests. The first tests were made with the $8\frac{1}{2}$ -inch rib-spaced elevators and considerable blurring was encountered in the pictures of the upper surface (see also fig. 8). For the second tests with the $4\frac{1}{4}$ -inch rib-spaced elevators the blurring was largely eliminated by stiffening the upper-surface camera mount.

Figure 13 represents a series of elevator section shapes measured in turns at $V_{is} = 360$ miles per hour with the $8\frac{1}{2}$ -inch elevator rib-spaced, 2.7° up from the thrust axis, stabilizer incidence combination. Figure 14 is a similar plot for the $4\frac{1}{4}$ -inch elevator rib-spaced, 1.1° up from the thrust axis stabilizer incidence combination at $V_{is} = 300$ miles per hour. In both cases the center

of gravity was at 27.5 percent mean aerodynamic chord. These figures indicate the amount of fabric deflection and warping of the elevator mean camber line was independent of normal acceleration or elevator angle at constant indicated airspeed, for the range of elevator angles used in these turns. There was no measurable difference between the variations of stick force with acceleration for the two stabilizer incidence, elevator rib-spacing combinations tested. For this reason the data are not shown. Both combinations tested had normal variations of stick force against acceleration up to 5g acceleration at constant indicated airspeeds below 360 miles per hour.

CONCLUDING REMARKS

On the basis of data presented and discussed in this report, the following conclusions may be drawn:

1. The stick-free longitudinal instability of the original production P-63 airplanes in high-speed straight flight was caused by excessively high stabilizer incidence in combination with fabric-covered elevators having excessively wide rib spacing.
2. Stick-free stability was improved to a satisfactory degree by lowering the stabilizer incidence from 2.7° to 1.1° up from the thrust axis and by changing the elevator rib spacing from $8\frac{1}{2}$ inches to $4\frac{1}{4}$ inches.
3. Maximum deflection of the fabric elevator covering at high speed was reduced to about one-fourth its previous amount by reducing the rib spacing of the original elevators from $8\frac{1}{2}$ inches to $4\frac{1}{4}$ inches, and by reducing the stabilizer incidence from 2.7° up from the thrust axis to 1.1° up from the thrust axis.
4. Stick forces in turns up to 5g normal acceleration at constant indicated airspeeds up to 360 miles per hour were substantially the same within the accuracy of the measurements with the two horizontal-tail configurations tested which consisted of 2.7° stabilizer incidence with an elevator having $8\frac{1}{2}$ -inch rib spacing and 1.1° stabilizer incidence with an elevator having $4\frac{1}{4}$ -inch rib spacing.

5. Data obtained by the Bell Aircraft Corporation indicated that the stick-free instability associated with the stabilizer set 2.7° up from the thrust axis could not be eliminated by resorting to metal-covered elevators; a lowering of the stabilizer incidence was necessary to eliminate the unstable stick-force variation with speed in straight flight.

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REFERENCES

1. Johnson, Harold I.: Résumé of NACA Stability and Control Tests of the Bell P-63 Series Airplane. NACA CMR No. 14J19, 1944.
2. Mathews, Charles W.: An Analytical Investigation of the Effects of Elevator-Fabric Distortion on the Longitudinal Stability and Control of an Airplane. NACA ACR No. 14E30, 1944.

TABLE I.- COMPARISON OF HORIZONTAL-TAIL CONFIGURATIONS
TESTED ON THE P-63A-1 AIRPLANE

	P-63A-1 (AAF No. 42-68861)	P-63A-1 (AAF No. 42-68889)
	A	B
Span, in.	159	159
Total area, sq ft	45.15	44.11
Stabilizer area, sq ft.	31.80	30.44
Elevator area aft of hinge center line, including tab, sq ft.	10.38	10.59
Elevator area forward of hinge line, sq ft	2.97	3.08
Elevator trim tab area, sq ft	0.92	0.92
Distance elevator hinge center line to leading edge of M.A.C., in.	226.28	226.28
Elevator travel from stabilizer, deg down . .	15	15
Elevator travel from stabilizer, deg up . .	35	35

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L-611

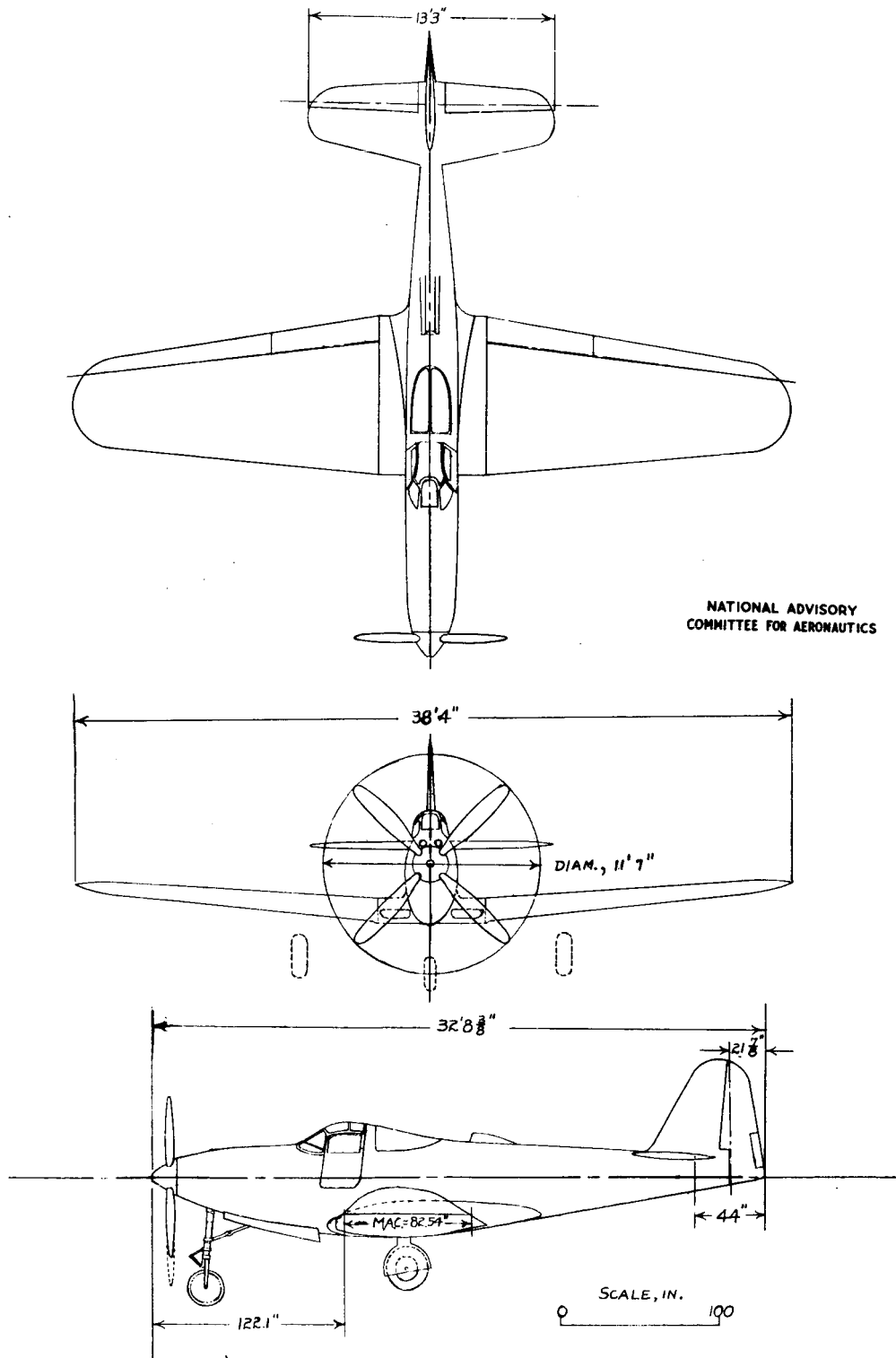


Figure 1.- Three view drawing of the P-63A-1 airplane.

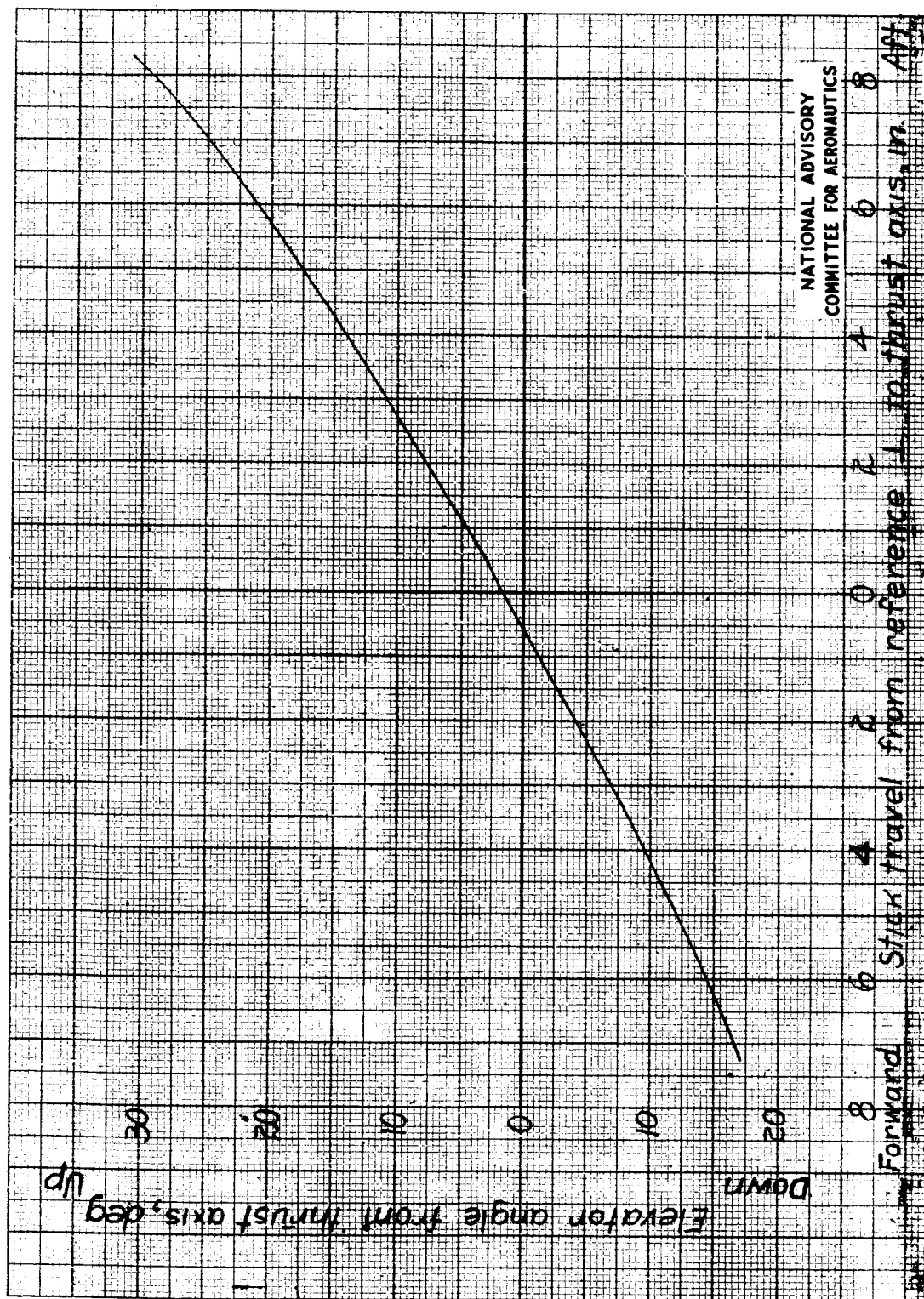


Figure 2.- Elevator-stick gearing relation for the P-63A-1 airplane. Effective stick length = 21 3/8 in. Average $\frac{d\delta e}{ds} = 3.07^\circ$ per inch.

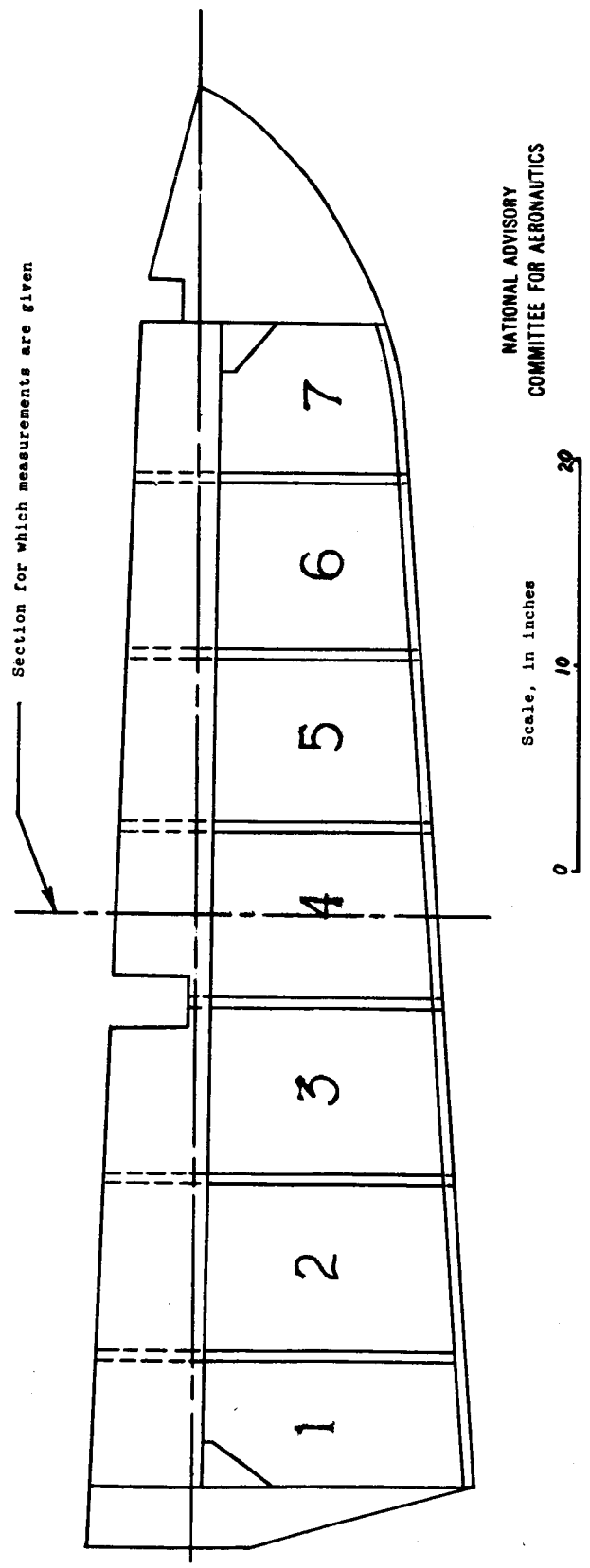


Figure 3.- Planform of P-63A-1 normal short-chord elevator showing rib locations and extent of unsupported fabric panels.

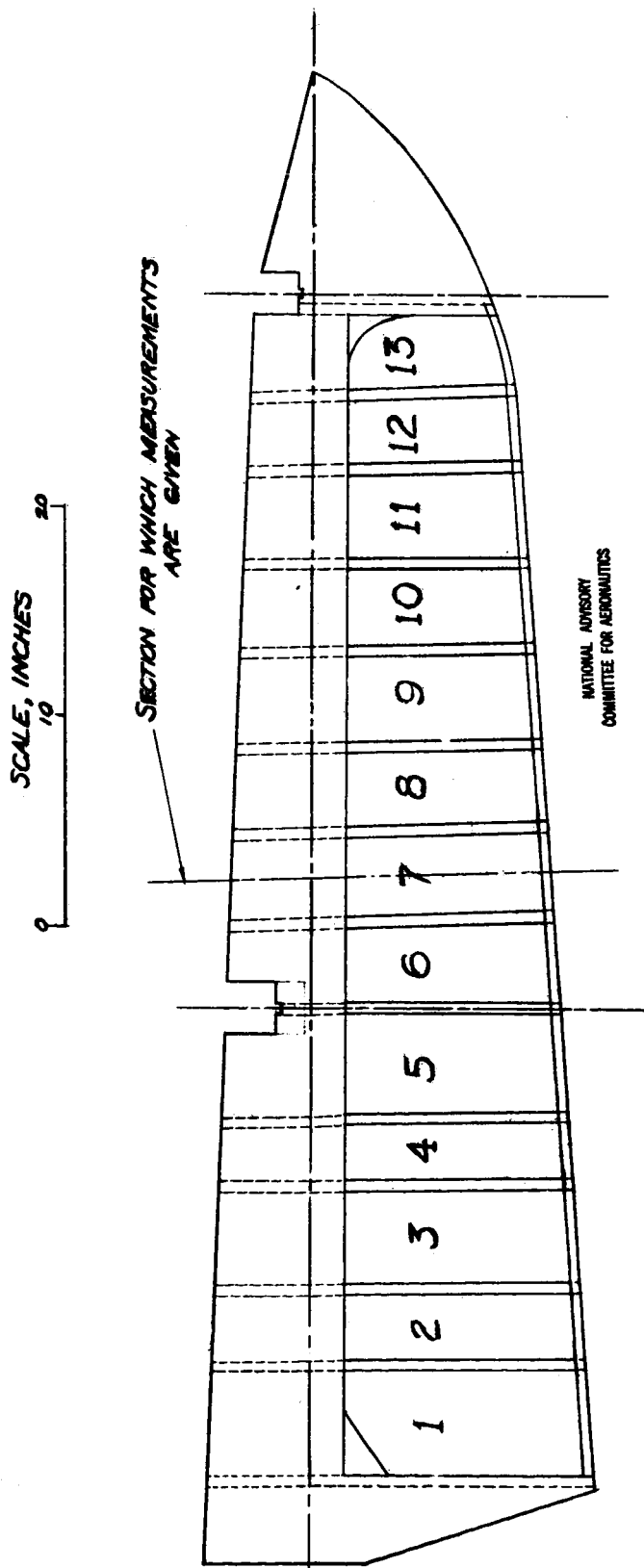
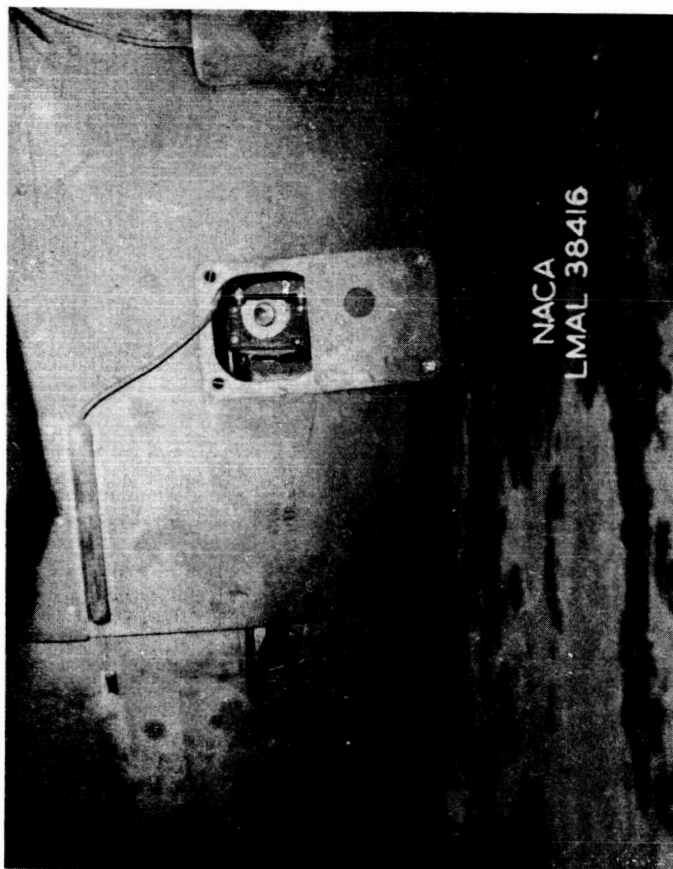


FIGURE 4.-PLANFORM OF P-63A-1
NORMAL SHORT-CHORD HALF-RIB-SPACED
ELEVATOR SHOWING RIB LOCATIONS AND
POSITIONS OF UNSUPPORTED FABRIC
PANELS.

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Figure 5.- Gun camera installation for photographing lower surface of right elevator. View from right side of P-63A-1 airplane.

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Figure 6.- Gun camera installation for photographing upper surface of right elevator. View from left side of P-63A-1 airplane; periscope mirror inside fin not shown.

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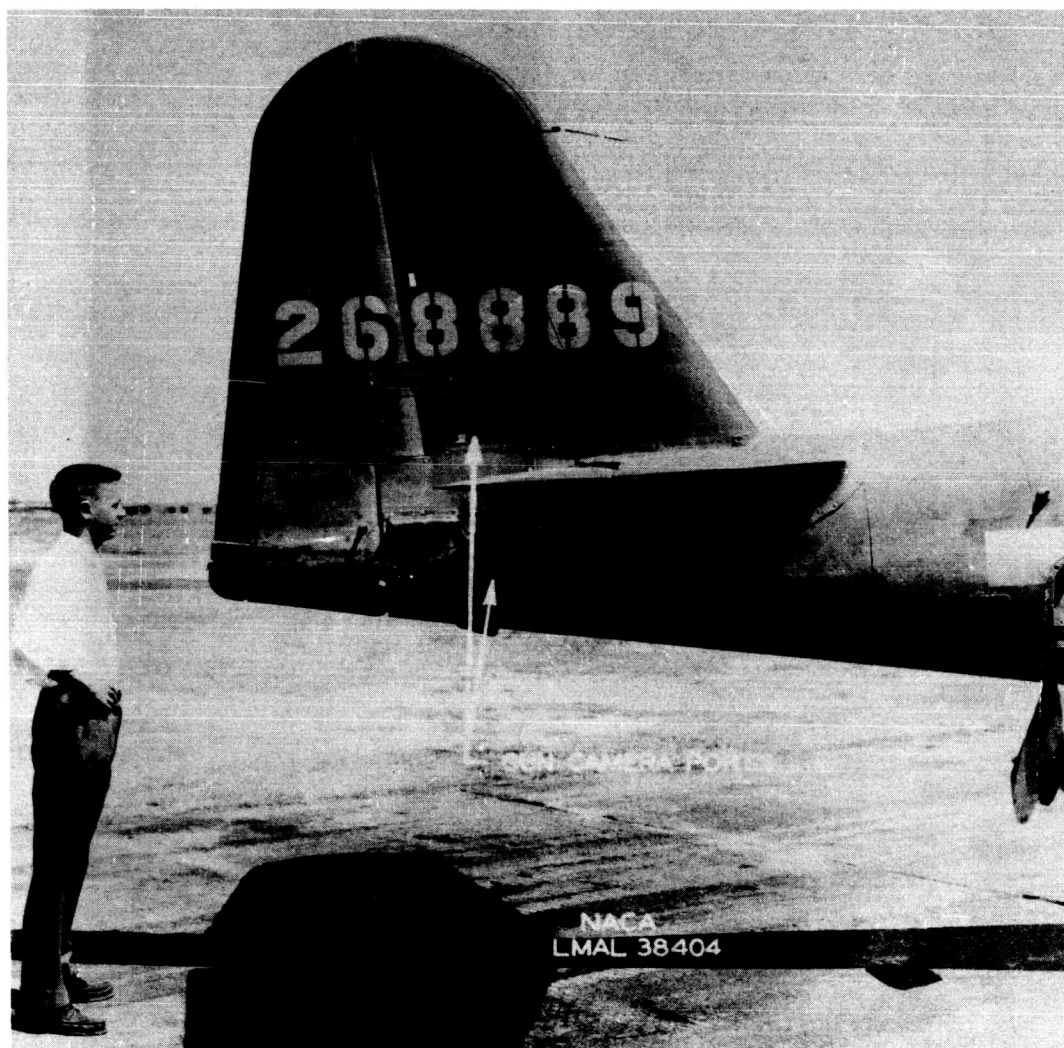


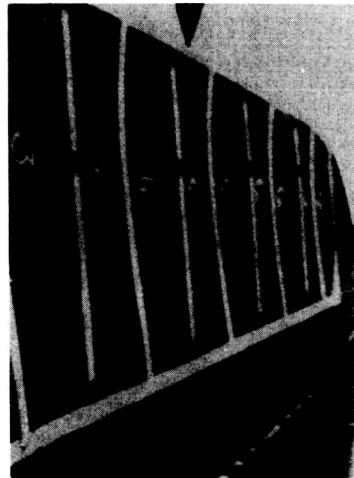
Figure 7.- Locations of gun camera ports relative to right elevator, P-63A-1 airplane.



(a) Upper surface



(b) Upper surface



(a) Lower surface



(b) Lower surface

Figure 8.- Examples of photographs taken to investigate the effects of elevator fabric distortion.

- (a) Original P-63A-1 elevator in straight flight at $V_i = 350$ mph. Elevator rib spacing $8\frac{1}{2}$ inches.
- (b) Stiffened P-63A-1 elevator in straight flight at $V_i = 350$ mph. Elevator rib spacing $4\frac{1}{4}$ inches.

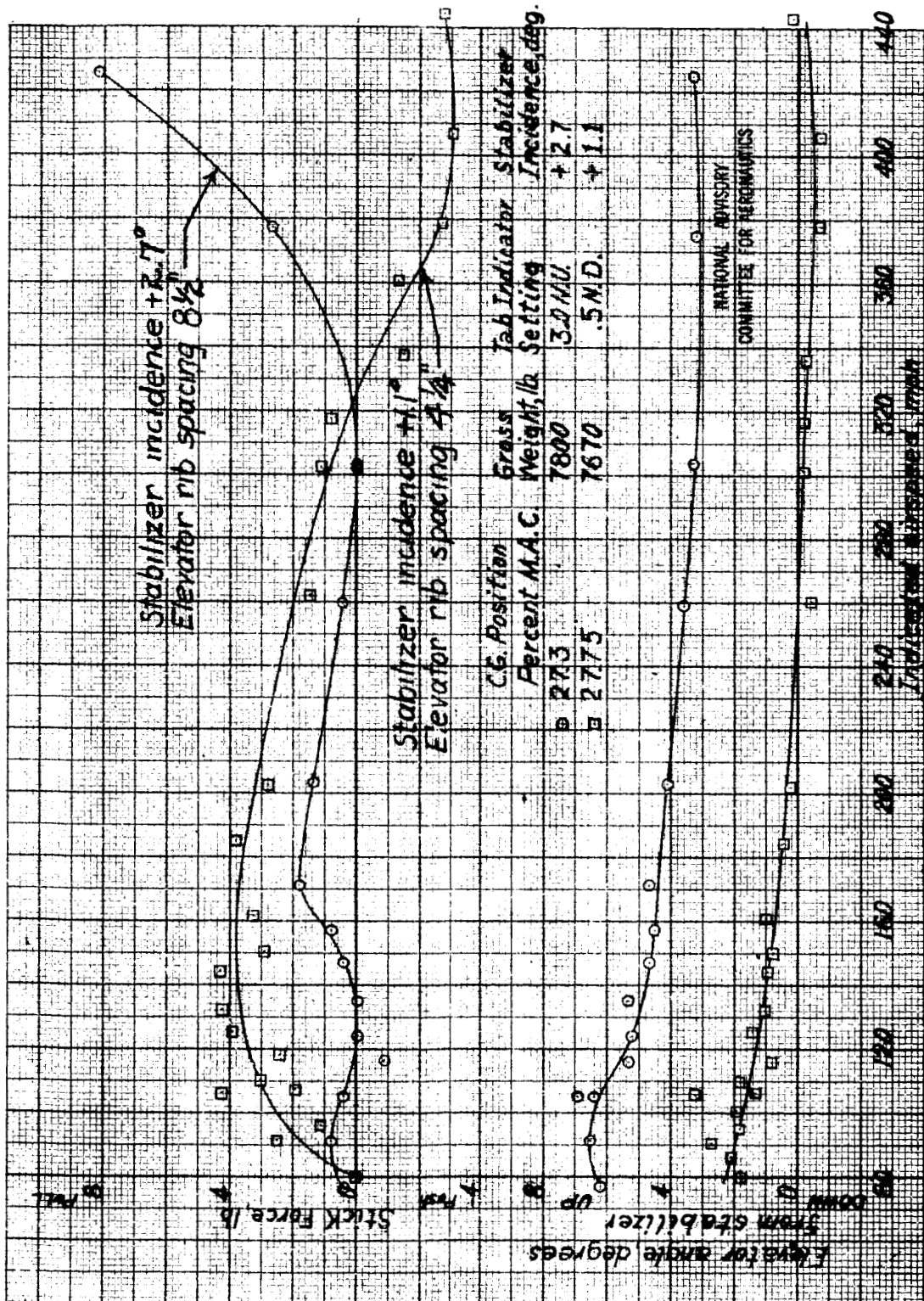


Figure 9. - Data showing the effect of stabilizer incidence setting and elevator rib spacing on the static longitudinal stability characteristics of the P-63A-1 airplane. Clean condition, normal rated power (2600 RPM, 43 in. Hg), altitude range 5-10,000 feet.

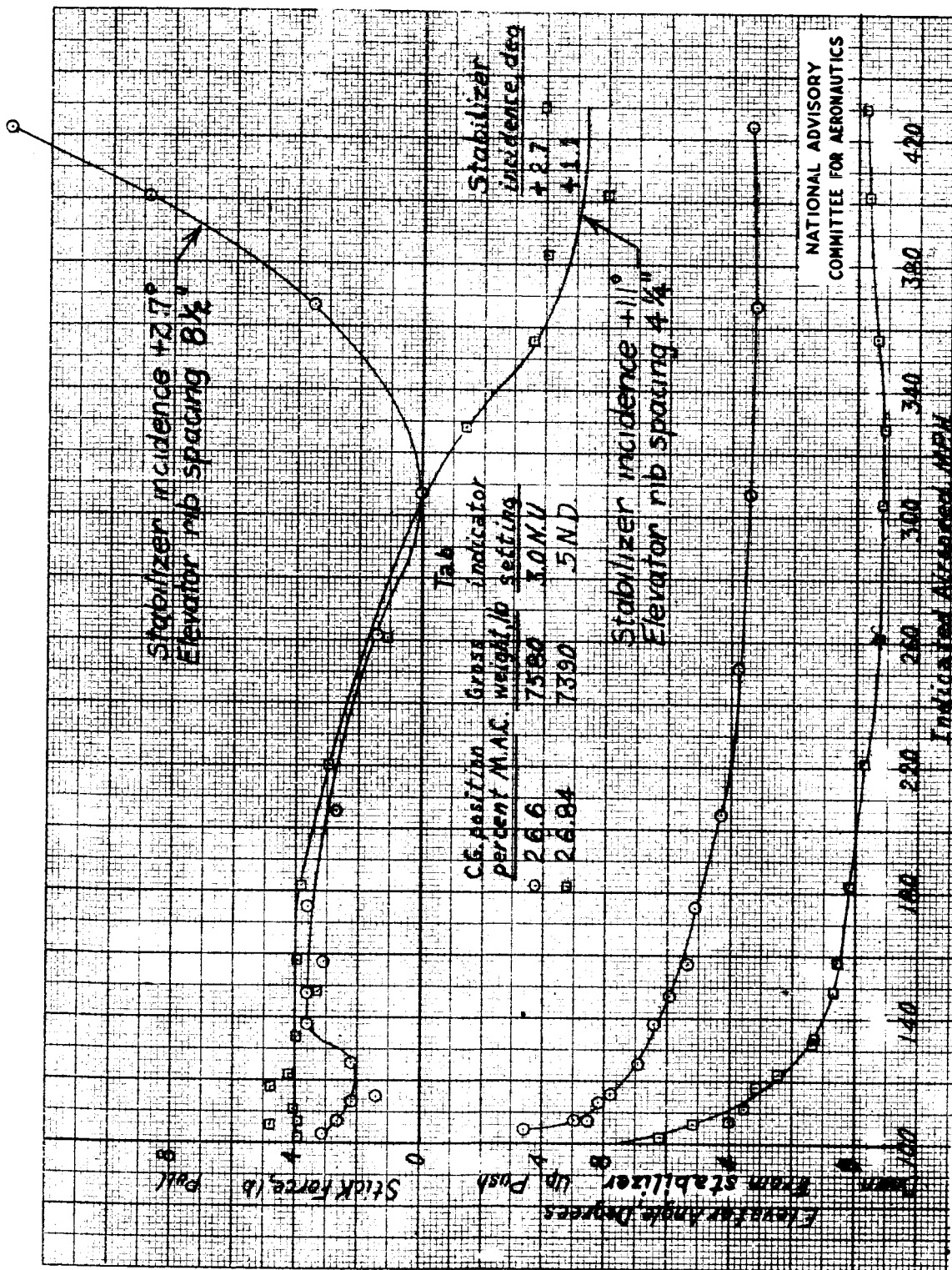


Figure 10. - Data showing the effect of stabilizer incidence setting and elevator rib spacing on the static longitudinal stability characteristics of the P-63A-1 airplane. Clean condition, engine idling, altitude range 5-10,000 feet.

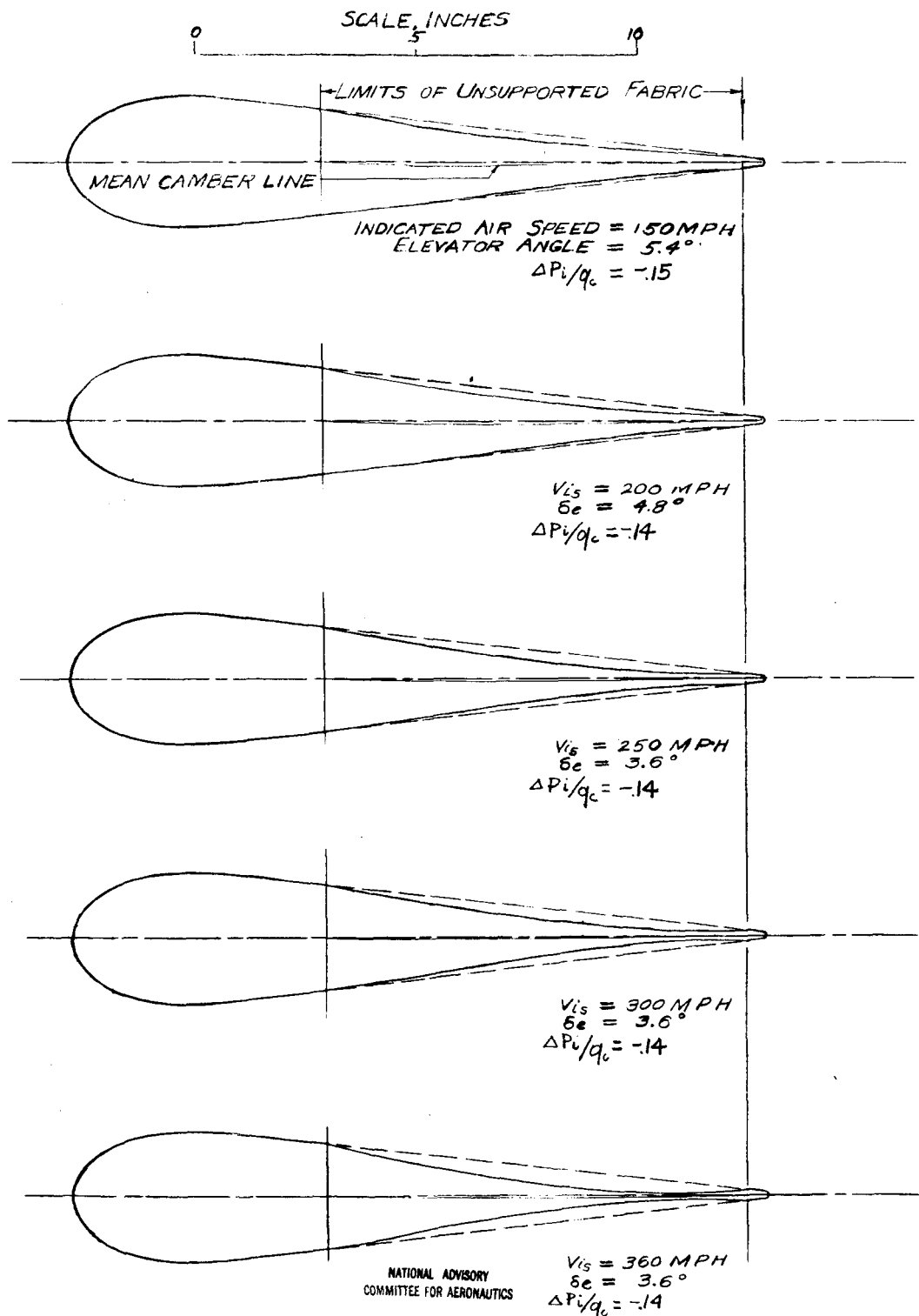


FIGURE 11. - ELEVATOR SECTIONS AT CENTER OF PANEL NUMBER 4 (FIGURE 3) SHOWING THE VARIATION OF FABRIC DEFLECTION WITH INDICATED AIRSPEED AT AN ACCELERATION OF $1g$. ELEVATOR ANGLES ARE GIVEN WITH RESPECT TO STABILIZER. (+ = UP); STABILIZER INCIDENCE 2.7° ELEVATOR RIB SPACING $8\frac{1}{2}$ INCHES. ELEVATOR INTERNAL PRESSURE GIVEN AS FRACTION OF CORRECT IMPACT PRESSURE BELOW CORRECT STATIC PRESSURE.

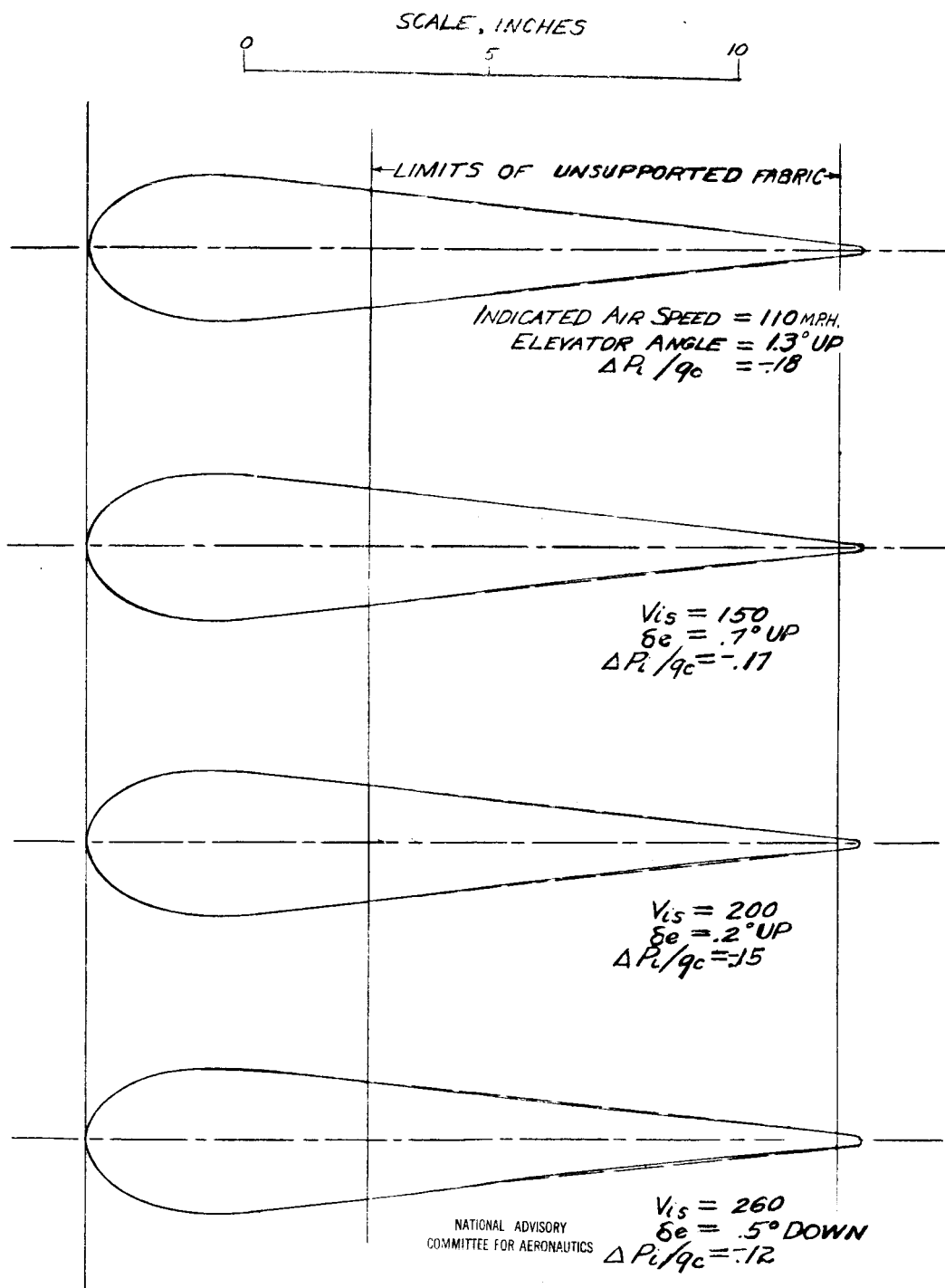


FIGURE 12.- ELEVATOR SECTIONS AT CENTER OF PANEL NUMBER 7 (FIGURE 4) SHOWING THE VARIATION OF FABRIC DEFLECTION WITH INDICATED AIRSPEED IN STRAIGHT FLIGHT. ELEVATOR ANGLES ARE GIVEN WITH RESPECT TO STABILIZER. STABILIZER INCIDENCE $+1.1^\circ$. ELEVATOR INTERNAL PRESSURE MEASURED AT PANEL NUMBER 7 IS GIVEN AS FRACTION OF CORRECT IMPACT PRESSURE BELOW CORRECT STATIC PRESSURE. ELEVATOR RIB SPACING $4\frac{1}{4}$ INCHES.

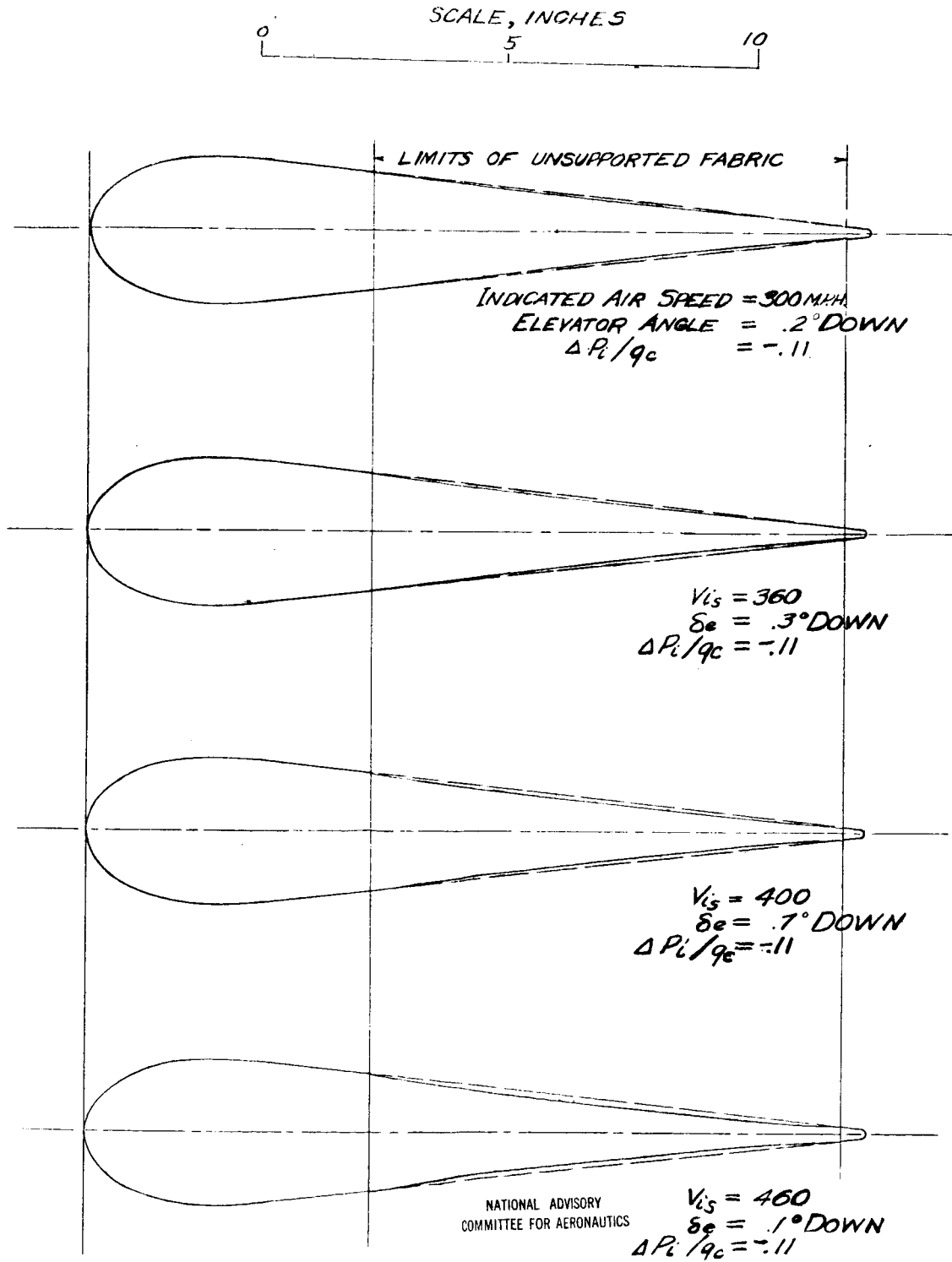


FIGURE 12.- CONCLUDED

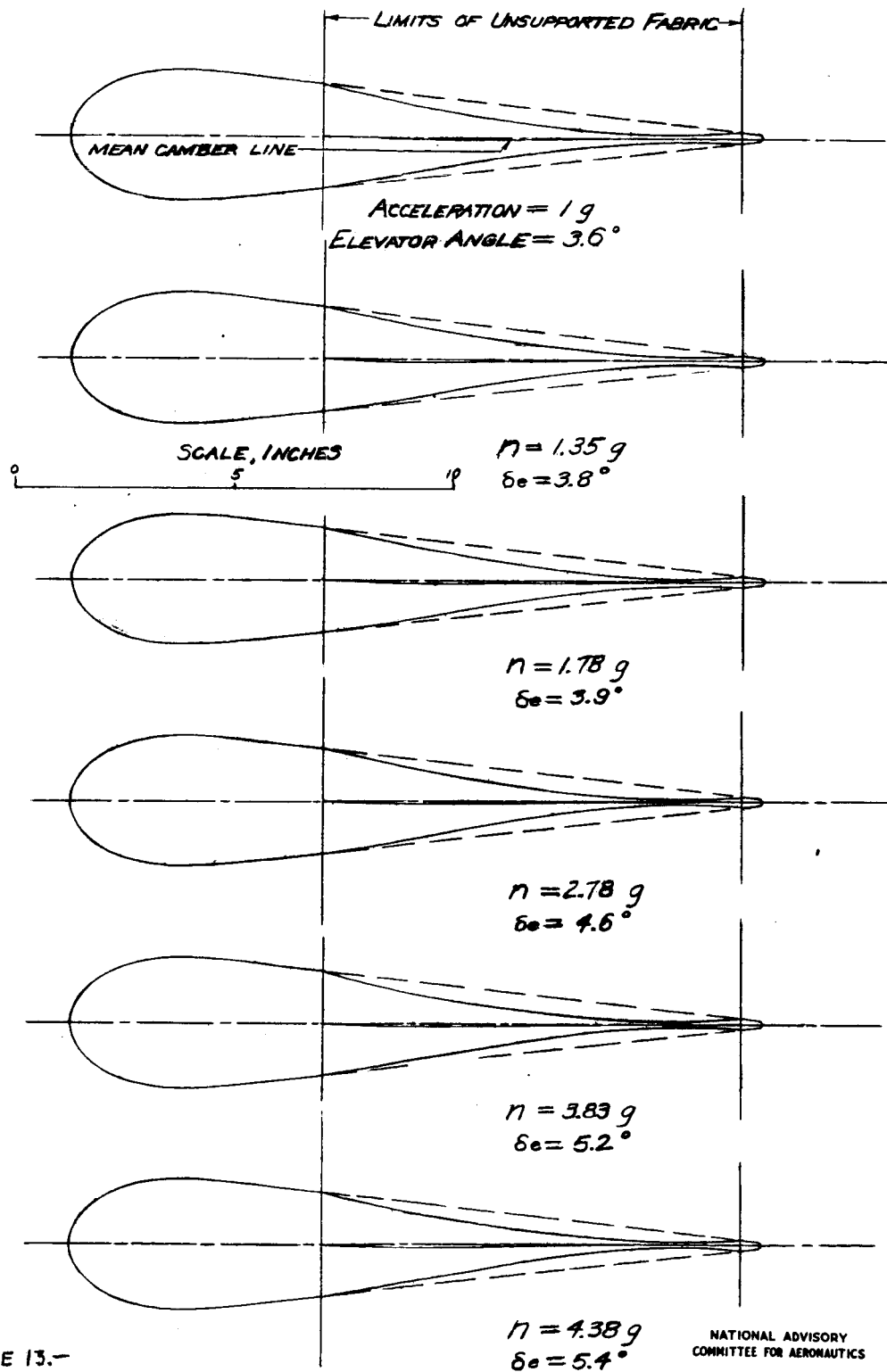


FIGURE 13.-

ELEVATOR SECTIONS AT CENTER OF PANEL NUMBER 4 SHOWING THE VARIATION OF FABRIC DEFLECTION WITH ACCELERATION AT AN INDICATED AIRSPEED OF 360 M.P.H. ELEVATOR ANGLES ARE GIVEN WITH RESPECT TO THE STABILIZER ($\pm$ UP) STABILIZER INCIDENCE 2.7° . ELEVATOR RIB SPACING $8\frac{1}{2}$ INCHES.

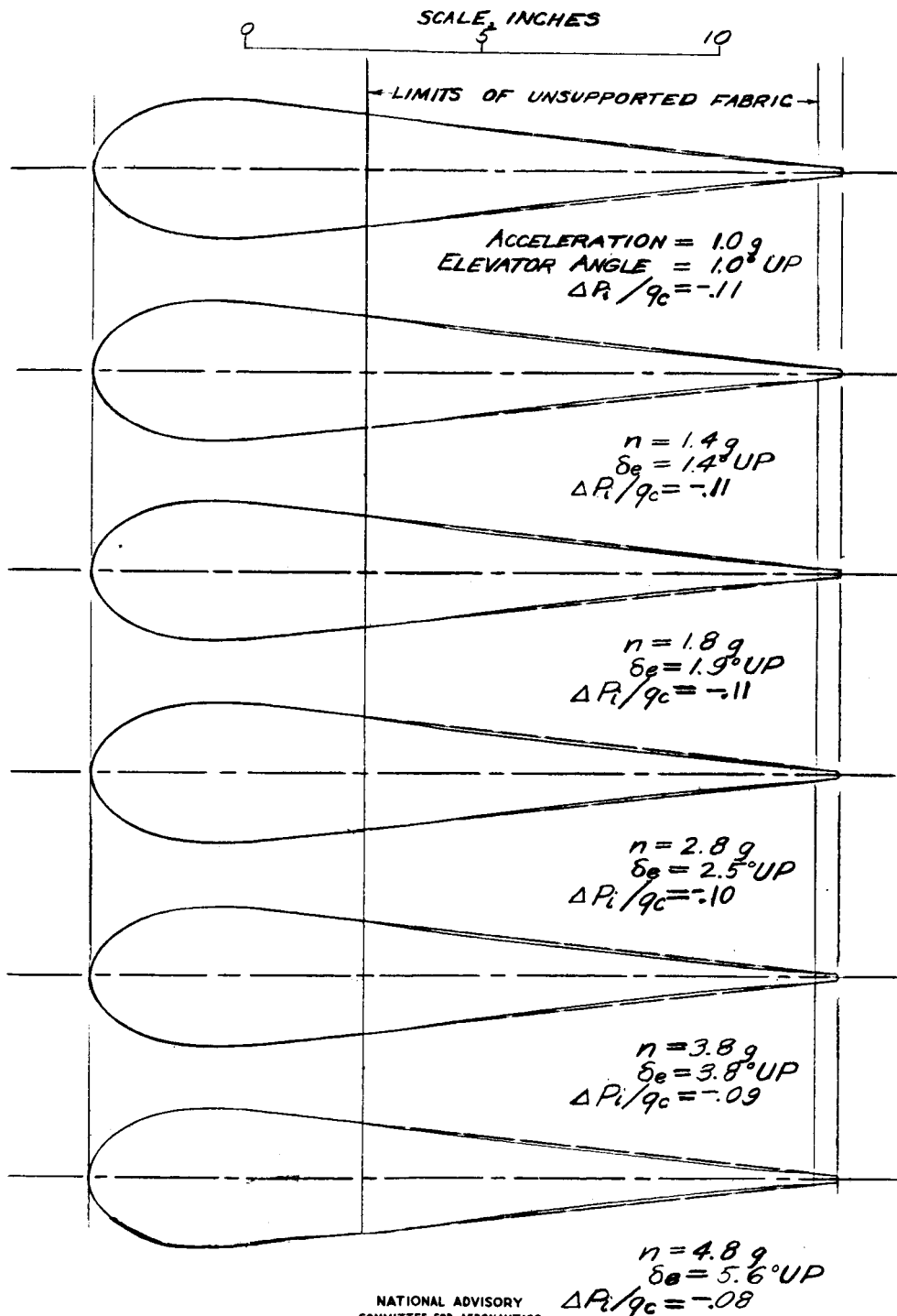


FIGURE 14.—ELEVATOR SECTIONS AT CENTER OF PANEL NUMBER 7 (FIGURE 4) SHOWING THE VARIATION OF FABRIC DEFLECTION WITH ACCELERATION AT AN INDICATED AIRSPEED OF 300 M.P.H. ELEVATOR ANGLES ARE GIVEN WITH RESPECT TO STABILIZER. STABILIZER INCIDENCE +11°. ELEVATOR INTERNAL PRESSURE MEASURED AT PANEL NUMBER 7 IS GIVEN AS FRACTION OF CORRECT IMPACT PRESSURE BELOW CORRECT STATIC PRESSURE.

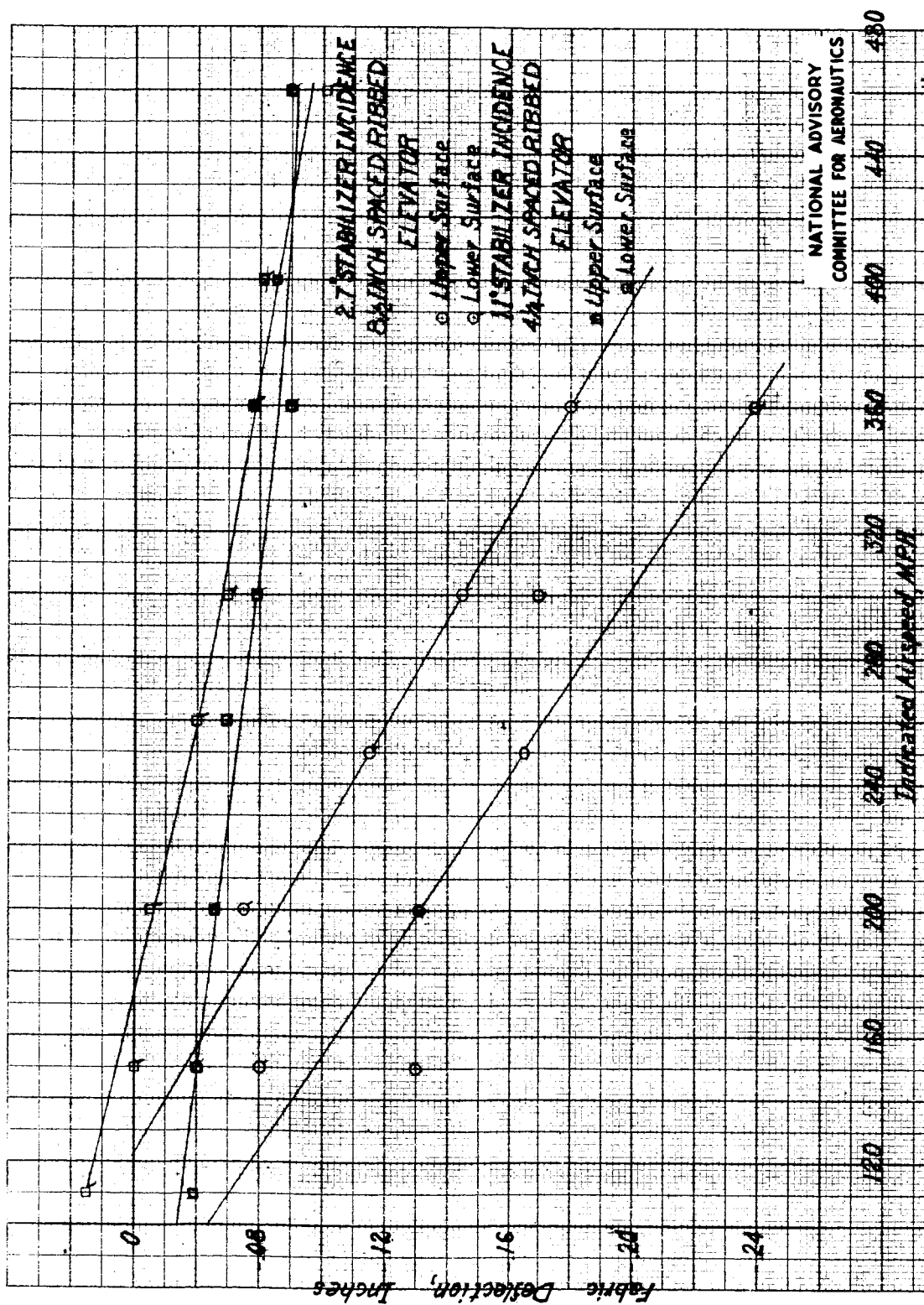


Figure 15.- Maximum fabric depression from figures 11 and 12 plotted against indicated airspeed.

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ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

ATI-10890

REVISION

none

ORIG. AGENCY NO.

MR-L5J09

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Oct'45	Unclass.	U.S.	Eng.	27	photos, tables, graphs, dwgs

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DIVISION: Aerodynamics (2)

SECTION: Stability and Control (1)

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SUBJECT HEADINGS: Airplanes - Stability (08487); Stability, Stick Free (89189); Control, Longitudinal (25489.7); P-63A (89189)

Air Materiel Command
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UNCLASSIFIED PER AUTHORITY: INDEX
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DATED 31 DECEMBER 1947.

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ATI-10890

REVISION

none

ORIG. AGENCY NO.

MR-15109

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