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TECHNICAL NOTE

No. 1224

FLIGHT TESTS OF A DOUBLE-HINGED HORIZONTAL TAIL SURFACE WITH REFERENCE TO LONGITUDINAL-STABILITY AND -CONTROL CHARACTERISTICS

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FLIGHT TESTS OF A DOUBLE-HINGED HORIZONTAL TAIL SURFACE WITH REFERENCE TO LONGITUDINAL-STABILITY AND -CONTROL CHARACTERISTICS

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SUMMARY

A double-hinged horizontal tail was tested in flight on a small low-speed airplane to determine the longitudinal-stability and -control characteristics. The center portion of the horizontal surface served as an adjustable trimmer and the rear portion as an elevator. Test data were obtained for various airplane flight conditions, both with and without an elevator seal installed.

The flying characteristics of the airplane equipped with the double-hinged horizontal tail surface were generally satisfactory. Optimum floating characteristics for the elevator are dependent on the conflicting requirements imposed by the conditions of wave-off, recovery from a stall, trimming to low speeds and landing.

The primary effect of removal of the elevator seal was a decrease in the elevator effectiveness.

INTRODUCTION

The problem of attaining adequate longitudinal control has become more complex with the use of heavily flapped aircraft and the necessity of providing for a large center-of-gravity travel. A possible solution of this problem is the use of a double-hinged horizontal tail.

It can be shown that with the double-hinged horizontal tail it is possible, without increasing the horizontal-tail area, to obtain improved stick-free stability characteristics, greater tail loads for landing and maneuvering, the ability to trim to lower airspeeds, and lower stick-force gradients.

This investigation was formulated to obtain from flight tests results that would indicate some of the advantages and disadvantages of this type of control which were not appreciated in the design stage. The conclusions drawn from the test data have been verified and amplified by pilot opinion whenever possible.

While this type of tail surface is more applicable to heavy aircraft requiring a large center-of-gravity range, it is felt that the results presented herein will be of value for future test work and will indicate the critical features of the design.

DESCRIPTION OF TEST EQUIPMENT

The airplane used to investigate the characteristics of the double-hinged tail was a two-place, single-engine, midwing, cantilever monoplane equipped with a conventional fixed-type landing gear. A description of those features of the airplane pertinent to the investigation is as follows:

Wing	
Area (including section projected through fuselage), sq ft	261.9
Span, ft	35.89
Taper ratio	1.5:1
Aspect ratio	5.1:1
Section	
Root	NACA 23015
Tip	NACA 23009
Incidence, deg	3.0
M.A.C., in	89.5
Dihedral (outer panel chord line), deg	7.0
Modified horizontal tail (including stabilizer, trimmer, and elevator)	
Area (including 3.8 sq ft covered by fuselage), sq ft	59.4
Span, in	187.75
Aspect ratio	4.05
Incidence, deg	2.0
Airfoil section	(Approx. NACA 0013)
Chord	
Root, in	51.5
Tip, in	37.4
Average, in	44.4
Trimmer (sealed, movable center section, zero aerodynamic balance and radius nose)	
Area aft of hinge line (including 0.5 sq ft covered by fuselage and excluding elevator area), sq ft	12.3

Percent total tail area	20.7
Average chord aft of hinge line, in	9.6
Percent average tail chord	21.5
Travel (max.)	21.0° up 19.0° down

Elevator

Area aft of hinge line (excluding area covered by fuselage) sq ft	12.0
Percent total tail area	20.2
Elevator balance area, sq ft	2.6
Percent aerodynamic balance	21.6
Type of balance	Sealed, blunt overhang
Chord aft of hinge line (constant), in	9.5
Percent average tail chord	21.3
Travel (max.)	27.5° up 21.7° down

Engine

Type	R-985-50
Rating, take-off	450 bhp at 2300 rpm and 35.5 in. Hg at S. L.
Rating, normal	400 bhp at 2200 rpm from S. L. to 5500 ft

A three-view drawing of the airplane is shown in figure 1. A photograph of the airplane instrumented for flight tests is given in figure 2, and figure 3 is a photograph showing various positions of the horizontal control surface. To eliminate any tendency of the separate halves of the elevator to assume different angles (because of play inherent in the actuating mechanism), the two portions of the elevator were connected rigidly together by a strip at the elevator trailing edge. The mechanics of the elevator system were such that the range of elevator deflection (relative to the trimmer) was independent of the trimmer setting. Friction in the elevator control system was less than one-half pound, as measured when the control was moved slowly through the neutral position with no load on the surfaces. The variation of elevator angle with stick position as measured on the ground with no load applied to the surfaces is shown in figure 4. The trimmer drive mechanism was hand-operated from the cockpit through a cable-chain system. The mechanical advantage was such that 1.0 turn of the control handle (on a 5-inch arm) was required to change the trimmer angle 1°. Plan and section views of the horizontal tail are shown in figures 5 and 6, respectively.

The selection of the chords for the trimmer and elevator was based upon the results of wind-tunnel tests of current designs. The area of the double-hinged horizontal tail was chosen approximately equal to the area of the original horizontal surface of the test airplane. This was accomplished by the addition of the trimmer section, a redesign of the horizontal-tail tips, a reduction in span of the original tail, and a modification of the elevator incorporating a constant-chord design.

INSTRUMENT INSTALLATION

Data presented herein were obtained by the use of standard NACA photographically recording instruments synchronized by a standard NACA timer. The elevator-position recorder was connected to the push-pull tube system near the tail. It is believed that no appreciable deflection in the push-pull-tube system occurred between the elevator and the point of attachment of the control-position recorder. The trimmer-position recorder was connected directly to the control surface.

Indicated airspeed was determined from the readings of a standard NACA free-swiveling airspeed head mounted approximately one chord length ahead of the wing leading edge and located near the left wing tip. Indicated airspeeds given in this report have been corrected for position error.

SYMBOLS

The following list of symbols is included for reference:

A_Z normal acceleration factor, ratio of the net aerodynamic force along the airplane Z-axis (positive when directed upward) to the weight of the airplane

A_X longitudinal acceleration factor, ratio of the net aerodynamic force along the airplane X-axis (positive when directed forward) to the weight of the airplane

δ_t trimmer angle, measured with respect to the stabilizer chord line, degrees

δ_e elevator angle, measured with respect to the trimmer chord line, degrees

F_e elevator control force, measured at grip of stick, pounds

C_{h_δ} variation of elevator hinge-moment coefficient with elevator deflection

C_{h_α} variation of elevator hinge-moment coefficient with angle of attack

V_{S_A} stalling speed in the landing condition, miles per hour

V_{S_B} stalling speed in the landing-approach condition, miles per hour

$\frac{\partial \delta_e}{\partial \delta_t}$ rate of change of elevator angle with trimmer angle required for balance in steady straight flight, indicated airspeed constant $\left(\frac{\partial C_m/\partial \delta_t}{\partial C_m/\partial \delta_e}\right)$

TESTS

Tests were made in flight to determine the longitudinal-stability and -control characteristics of the test airplane equipped with the double-hinged horizontal tail surface. The various airplane configurations are defined as follows:

Airplane configuration	Flaps	Power (bhp)
Climb	Up	390
Glide	Up	Engine throttled
Wave-off	Down	390
Landing	Down	Engine throttled
Landing-approach	Down	180

The airplane was flown with an average gross weight of 4740 pounds at take-off and a center-of-gravity range from 22.7 to 30.5 percent mean aerodynamic chord.

RESULTS AND DISCUSSION

The results of the tests to determine the dynamic and static longitudinal-stability characteristics are presented in table I and in figures 7 and 8, respectively. The elevator control characteristics are presented in figure 9 for landings and in figure 10 for maneuvering flight. Trim changes due to variation of flaps and power are shown in table II. Figures 11 and 12 present data showing the trimming characteristics of the

double-hinged tail. The effect of removing the elevator seal is shown in figures 13, 14, and 15, and table II for various test conditions.

Examination of the data presented in figures 7 to 12 and in tables I and II shows that the longitudinal handling characteristics of the airplane were satisfactory except for the dynamic longitudinal-stability characteristics (initiated by abruptly deflecting and releasing the elevator control) and a large forward movement of the stick (stick walking) when trimming to low speeds (flaps down, forward center of gravity).

The reason for the existence of the elevator oscillation is not clearly understood. It is believed, however, that this oscillation is not peculiar to the double-hinged tail and, therefore, further testing to isolate the actual cause of this oscillation was not carried out.

The problem of adjusting the elevator floating characteristics as the airplane is trimmed to decreasing airspeeds in the landing and landing-approach conditions of flight (figs. 11 and 12) is basic for this type of longitudinal control.[1] Not only did the pilots object to the forward movement of the stick because of the possibility of loss of control in a wave-off or inability to recover from a stall, but the minimum trim speed in the landing condition was limited by the elevator travel.

To more fully investigate the wave-off condition several wave-offs were performed at altitude. The results of these tests for the forward center-of-gravity position, not presented herein, indicate that only a small amount of additional down-elevator (order of 1° to 2°) was needed, providing sufficient margin within the available down-elevator deflection for adequate control. The adequacy of the elevator is attributed, in part, to the moderate trimmer setting and elevator deflection required to trim at $1.2V_{S_A}$ in the approach.

To increase the trim range to lower values of airspeed would require a change in the floating characteristics of the elevator as the trimmer is moved. The choice of the floating characteristics of the elevator as the trimmer is moved is dependent upon the opposing requirements from several conditions of flight: namely, the control in a wave-off, control in stall recovery, the ability to trim to low speeds and control in landing. A discussion of the foregoing flight conditions is presented in paragraphs 1 and 2.

1. If the elevator floats in the opposite direction to the trimmer as the trimmer is moved (elevator floats down as the trimmer moves up as is the case with the tail tested herein) the ability to trim the airplane to low speeds and the recovery characteristics in a wave-off or a

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[1]This problem applies also to the adjustable stabilizer.

stall maneuver are affected adversely while the landing characteristics are improved. The wave-off and the stall conditions may be critical due to insufficient down-elevator available, while the landing characteristics should improve because of the up-trimmer deflection present and consequently the increased range of up-elevator angle yet available.

2. If the elevator does not change its angular relationship with the trimmer as the trimmer is moved ($C_{h_\alpha} = 0$), the ability to trim the airplane to lower speeds is increased and the wave-off and stall conditions become less critical; however, the control in landings is affected adversely. In the design of a double-hinged-tail surface a compromise must, therefore, be made between the preceding items by adjusting the aerodynamic balance of the elevator to give the desired floating characteristics.

The effect of the removal of the elevator seal on the elevator control power, the trimmer effectiveness, and the elevator deflection required to offset a given trimmer deflection is presented in figures 13 to 15. These data indicate a marked reduction in the ability of the elevator to balance the airplane in the presence of the ground (fig. 15) when the elevator seal is removed. In addition, the effectiveness of the elevator in offsetting movement of the trimmer was reduced by 18 percent (fig. 13). However, this change had practically no effect on the ability of the trimmer to trim the airplane throughout the speed range and on the desirably low trim force changes due to power and flaps (table II). The number of cycles required to damp the short-period elevator oscillation was reduced slightly by the removal of the elevator seal (table I).

CONCLUSIONS

The results of the flight tests and the data obtained from pilot's opinion of a double-hinged horizontal surface indicate the following:

1. The flying characteristics of the test airplane equipped with the double-hinged tail were generally satisfactory.

2. Undesirable flying characteristics of the test airplane were unsatisfactory damping of dynamic longitudinal oscillations (this was not considered characteristic of this type of control) and large forward movement of the stick when trimming to low speeds (flaps down, forward center-of-gravity position).

3. The choice of the elevator floating characteristics as the trimmer is moved is dependent upon the conflicting requirements for the control in wave-off, control in stall recovery, and the ability to trim to low speeds as opposed to the requirement for sufficient elevator-control power in landing.

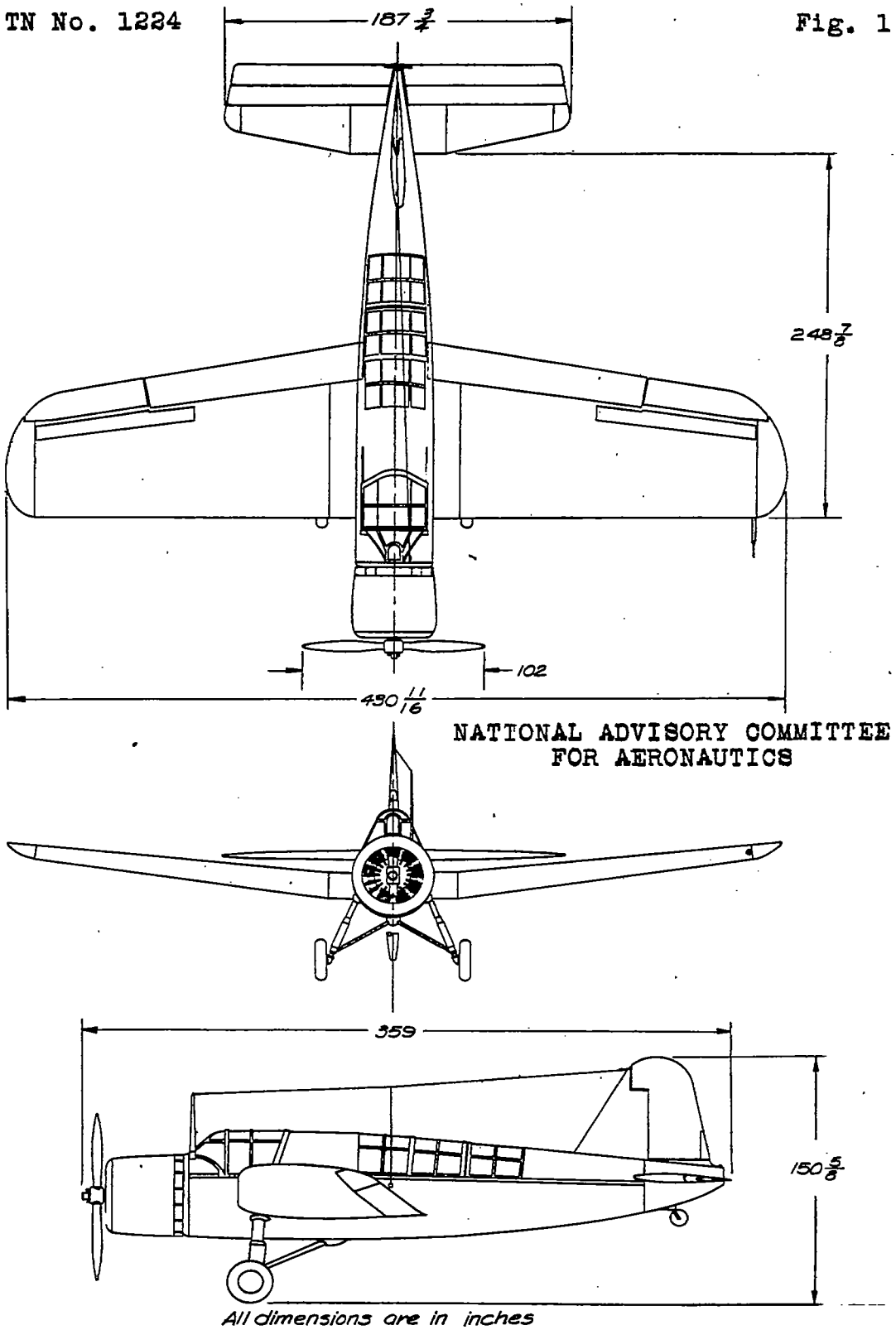

Figure 1.- Three-view drawing of the test airplane equipped with a double-hinged horizontal tail.

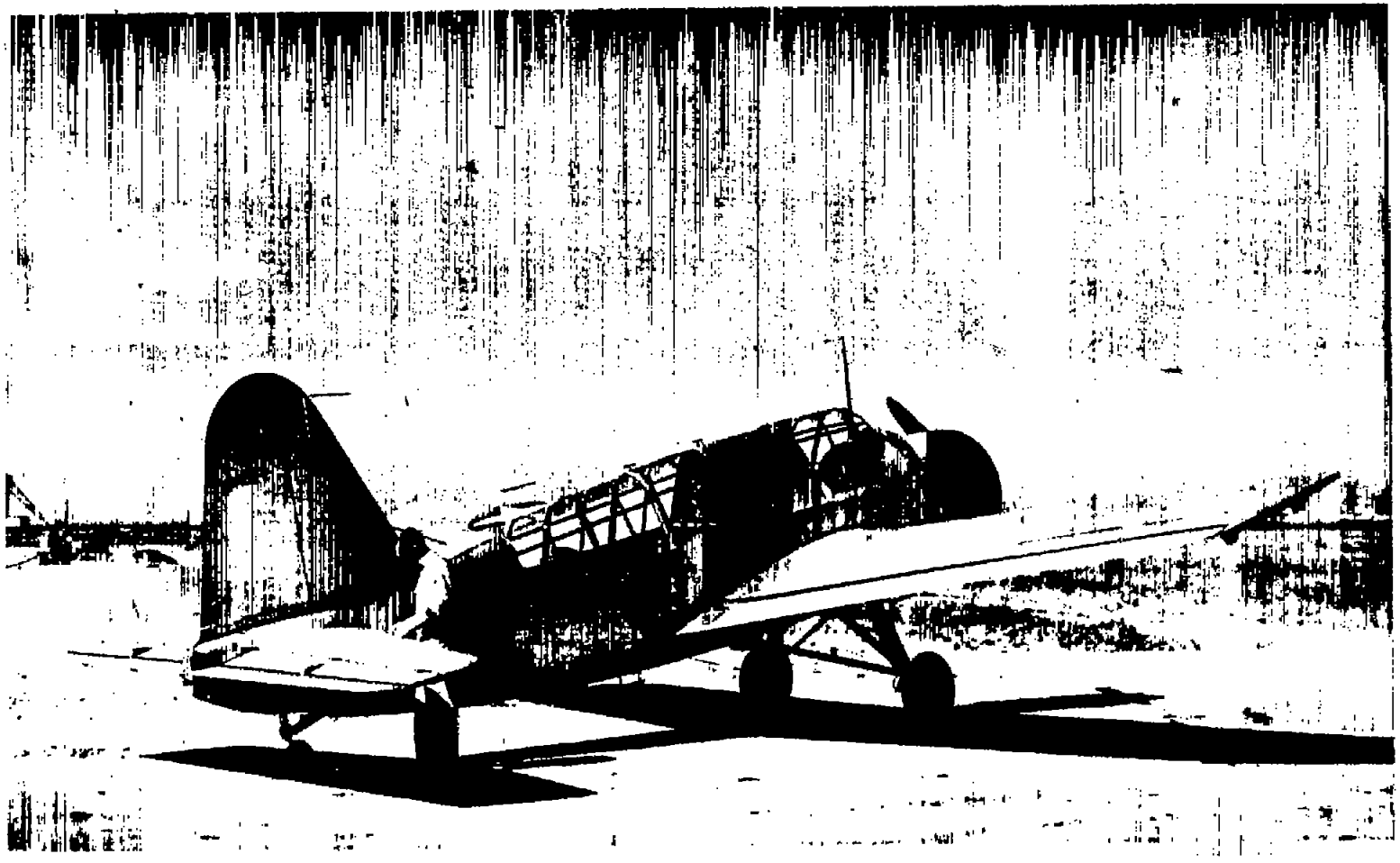

Figure 2.- The double-hinged horizontal-tail surface installed on the test airplane.

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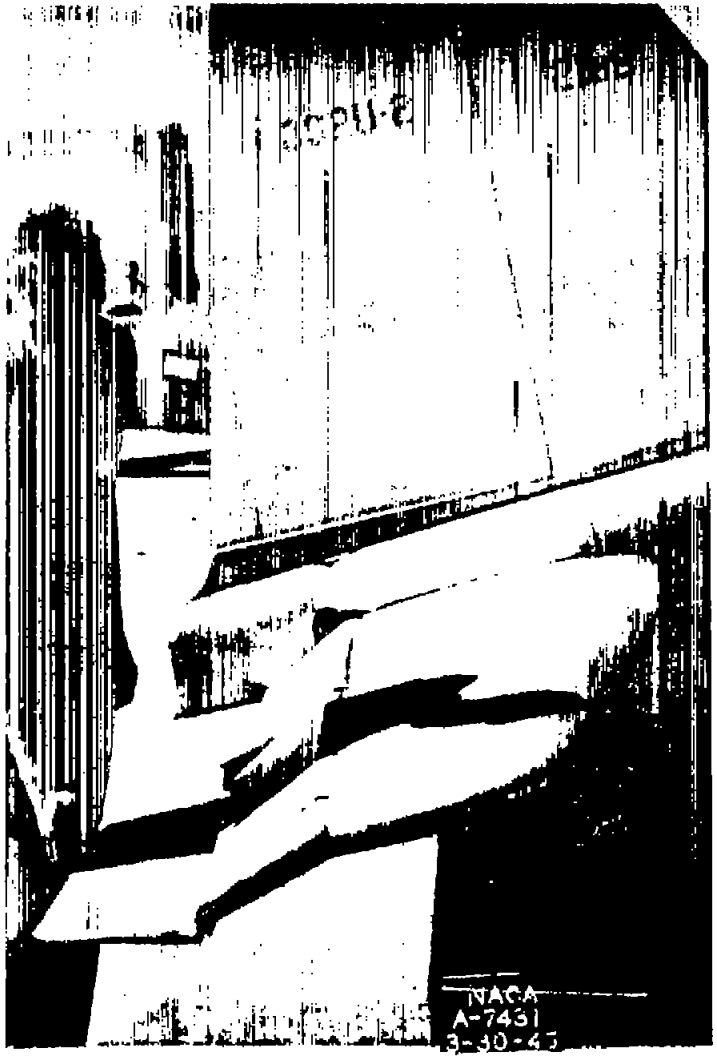
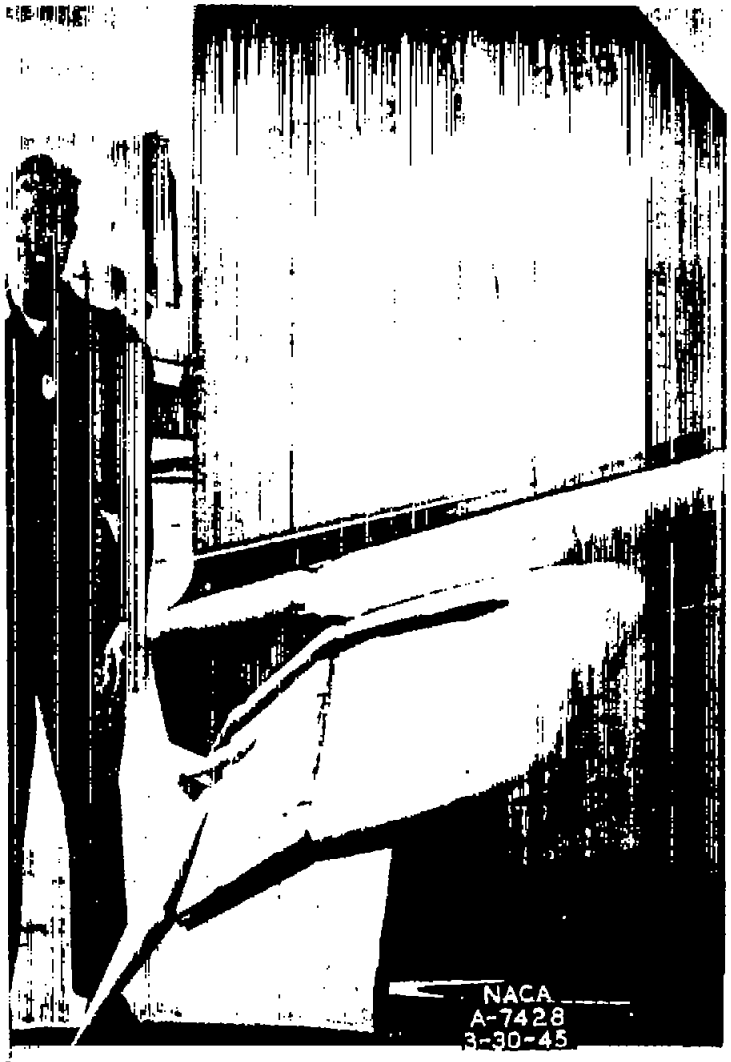


(a) Trimmer full down, elevator full up.



(b) Trimmer full down, elevator full down.

Figure 3.- Side view of the double-hinged horizontal-tail surface, trimmer and elevator deflected.

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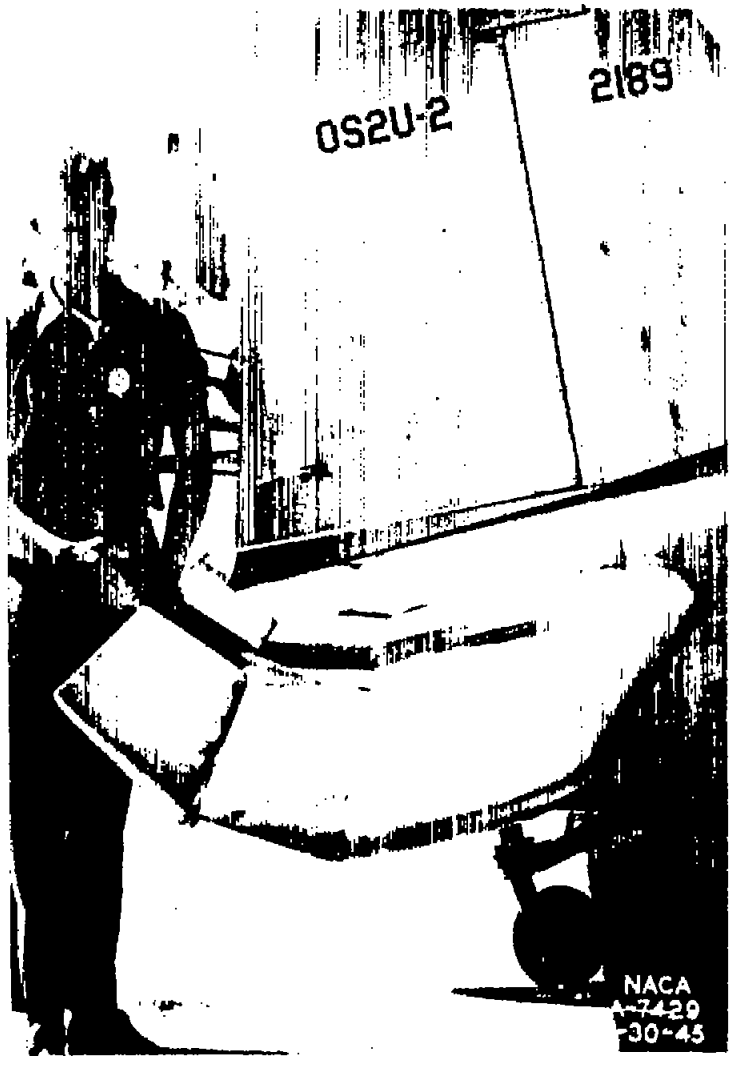
(c) Trimmer full up, elevator full down.



(d) Trimmer full up, elevator full up.

Figure 3.- Concluded.

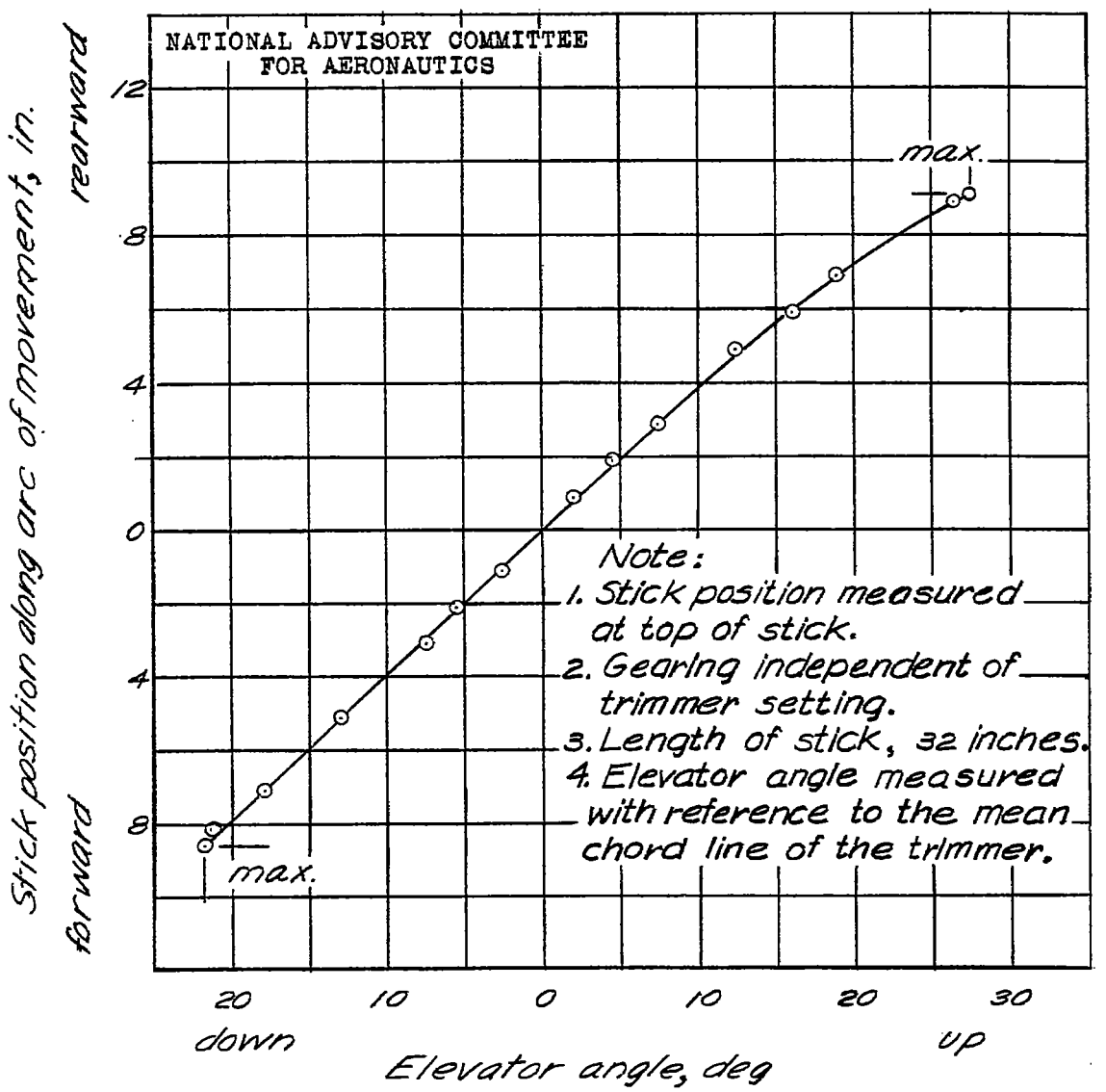


Figure 4 - Variation of stick position with elevator angle as measured on the ground with no load on the surfaces.

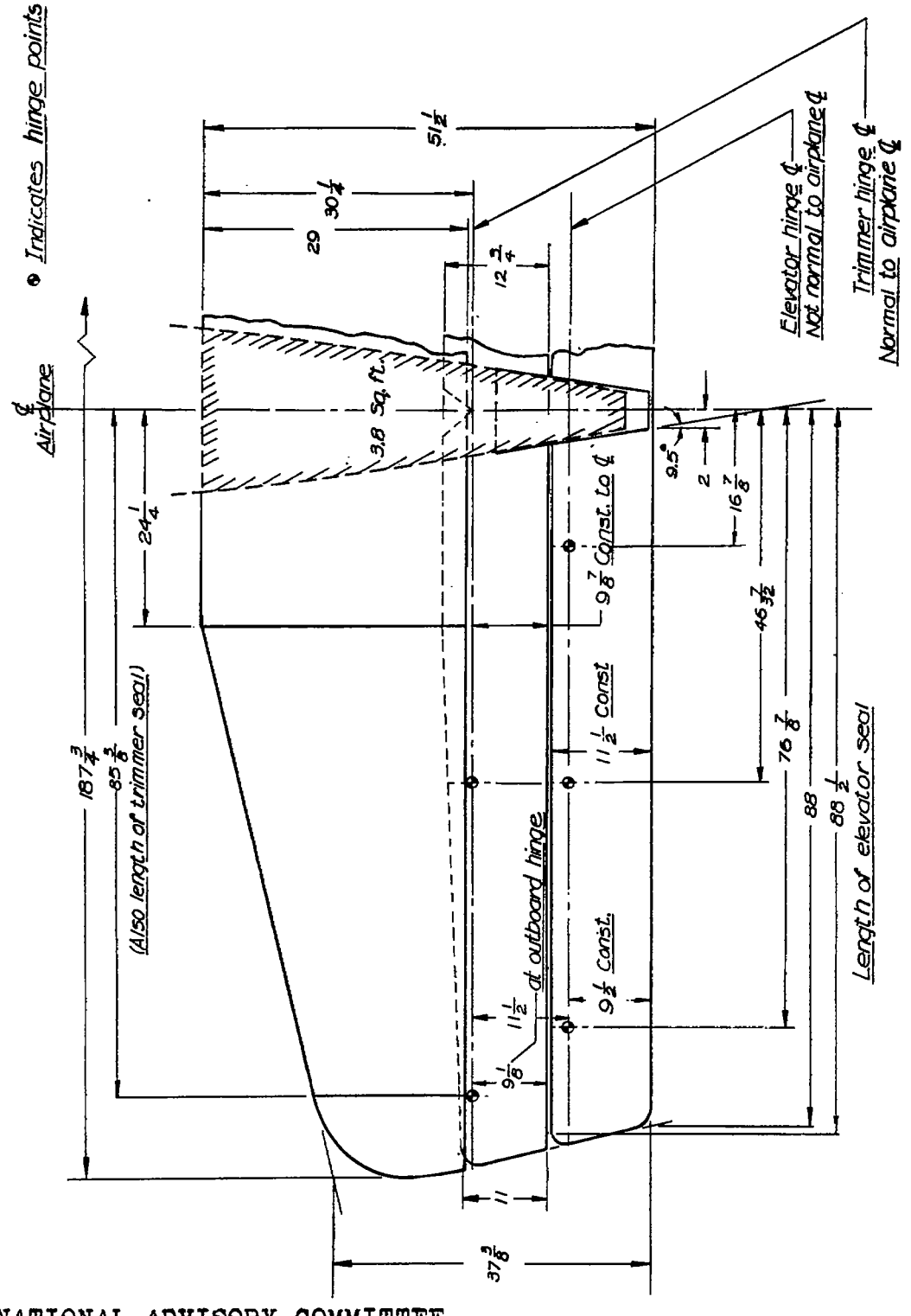


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Figure 5.-Plan form of double-hinged horizontal tail.

General notes:
1. The Vought Special airfoil used approximates an NACA 0013 airfoil.
2. Full-span seals were employed except for trimmer hinge cut-outs.
3. Approximately true to scale.

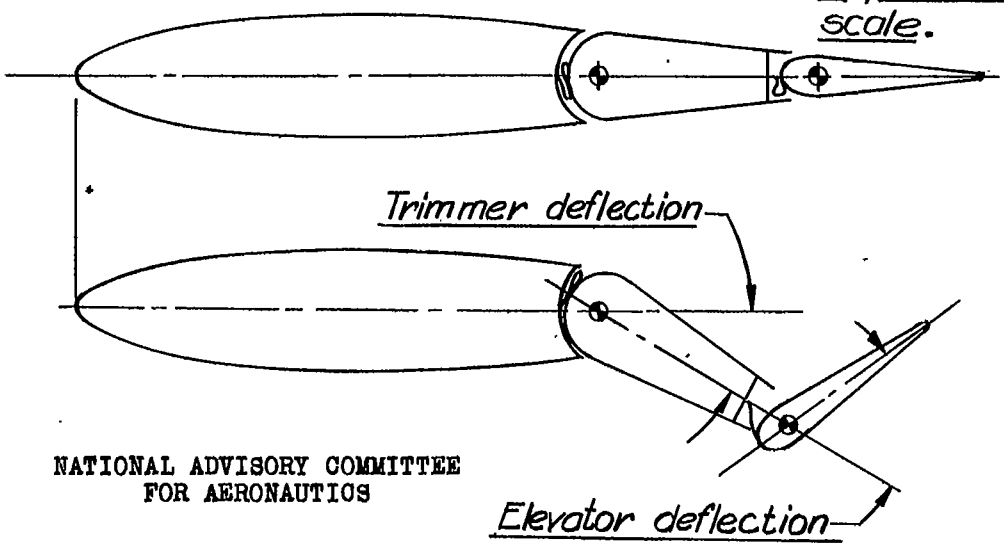

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Figure 6.- Cross section of the double-hinged horizontal tail.

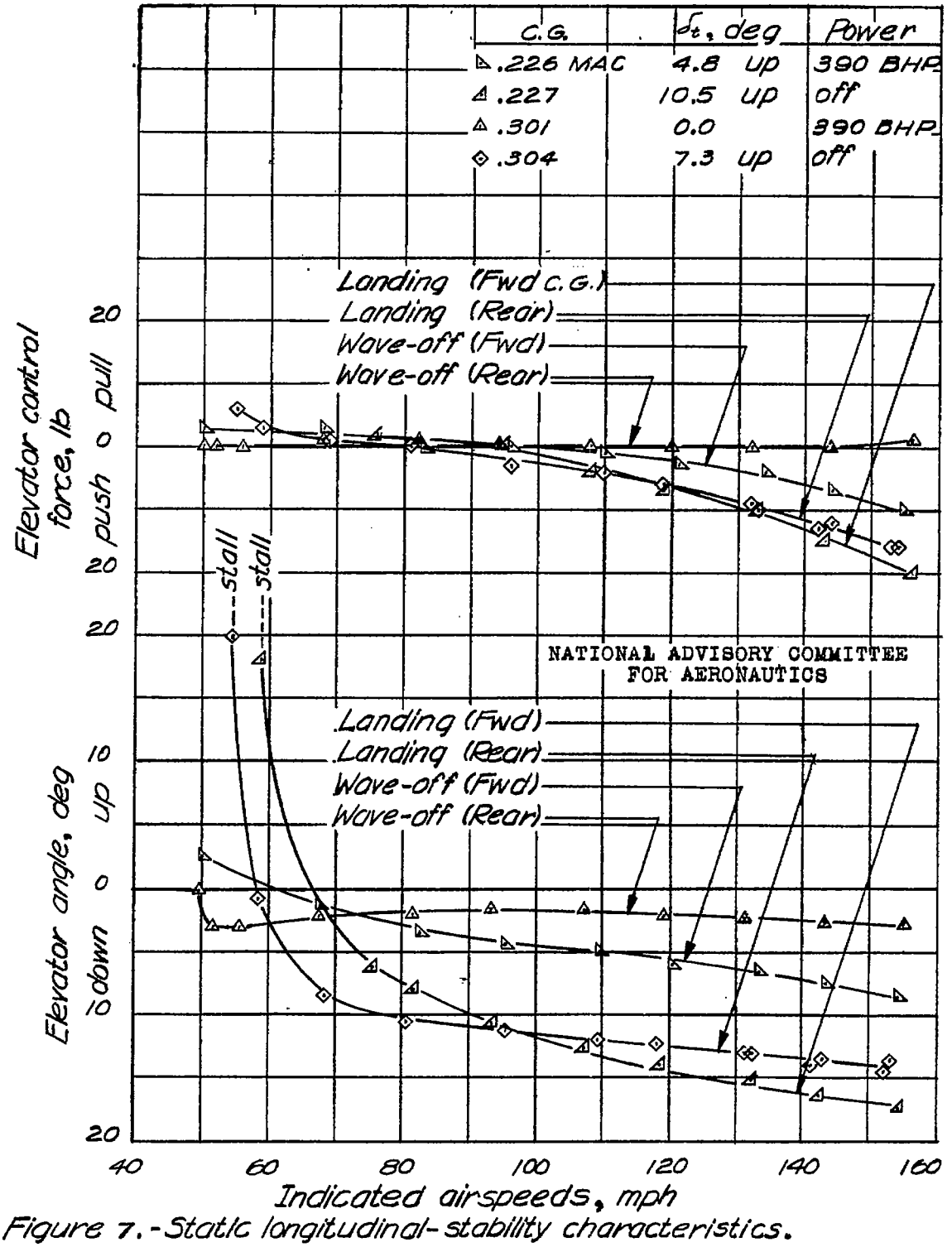


Figure 7.-Static longitudinal-stability characteristics. Flaps down.

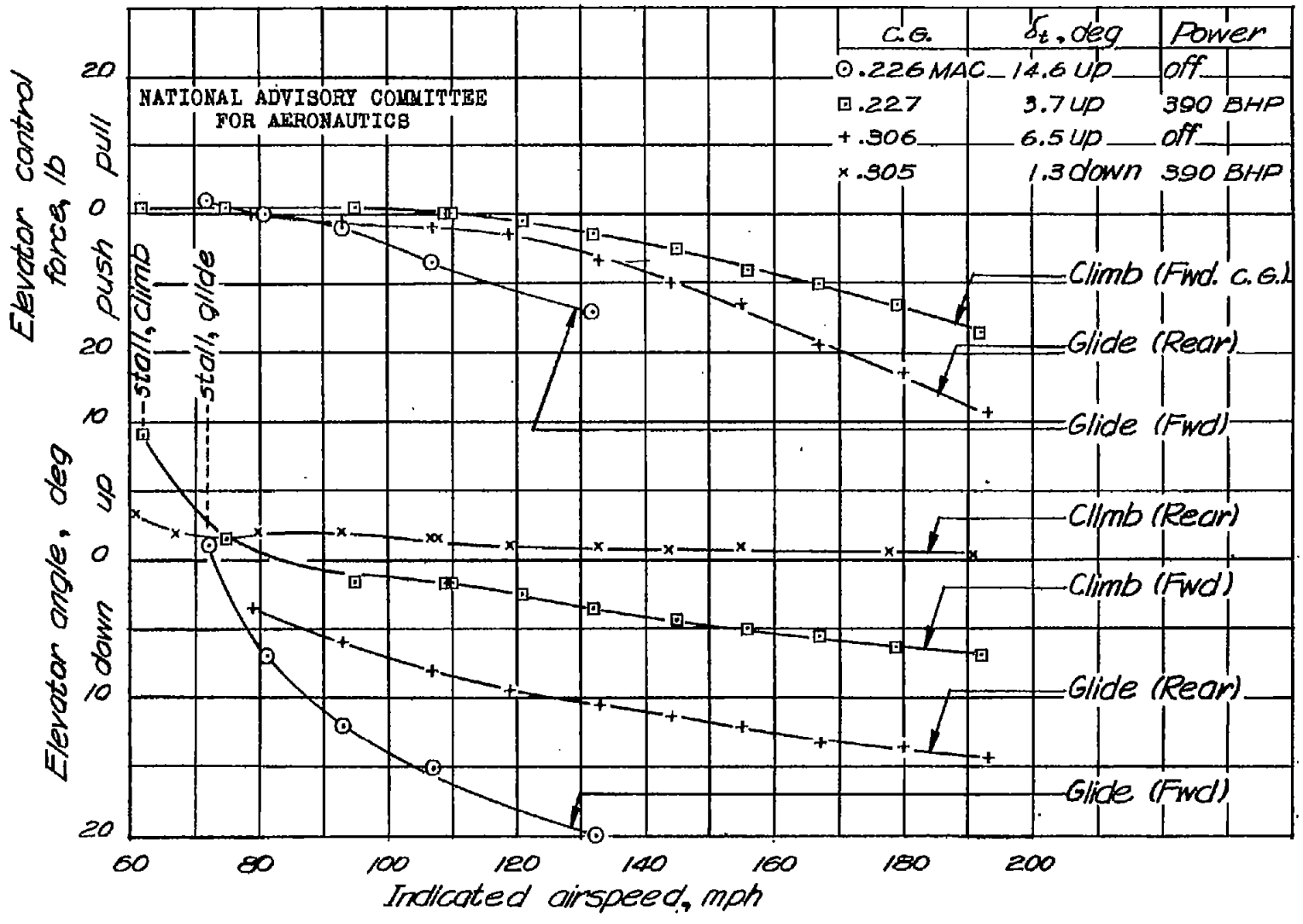


Figure 8.-Static longitudinal-stability characteristics. Flaps up.

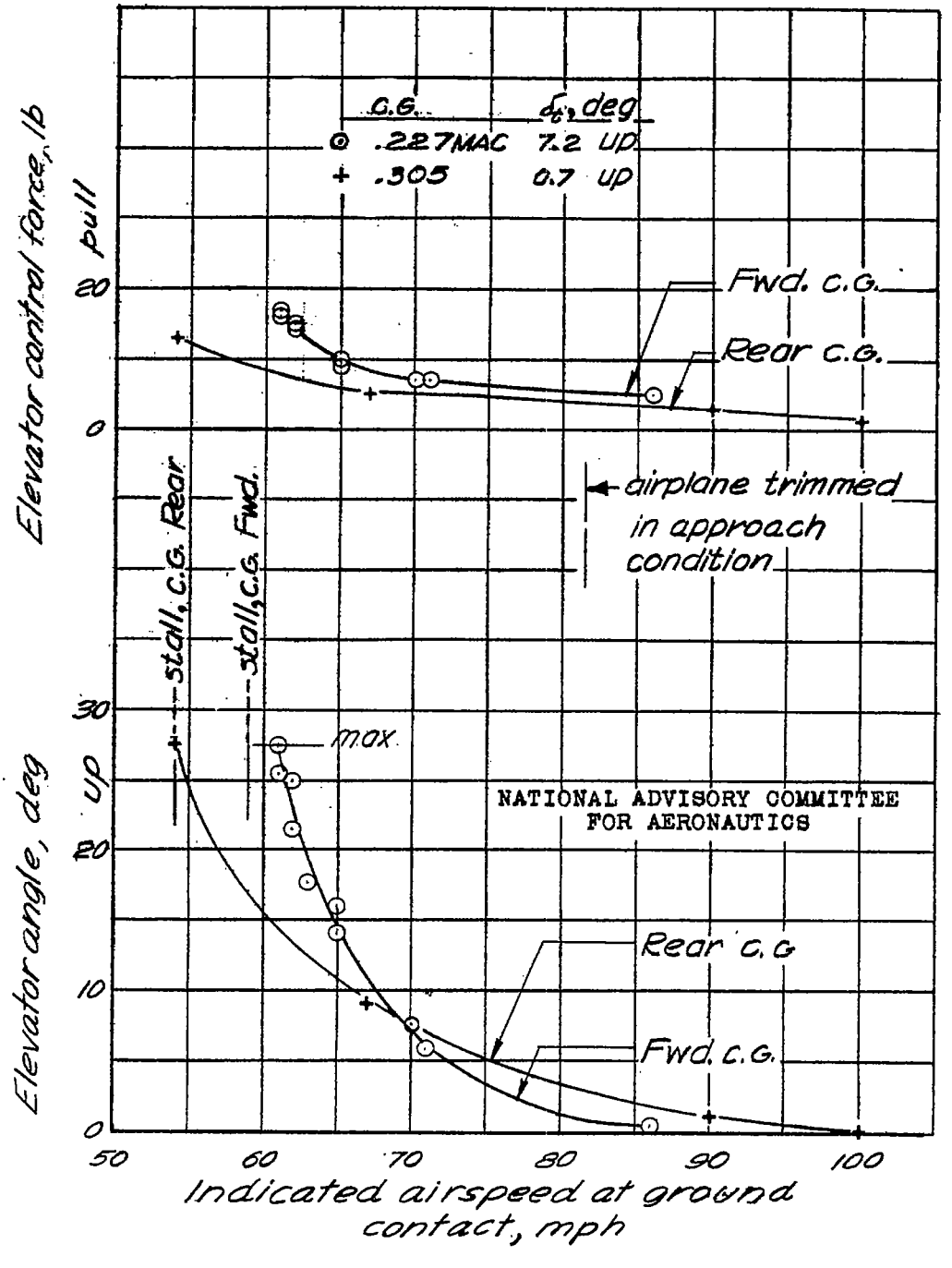
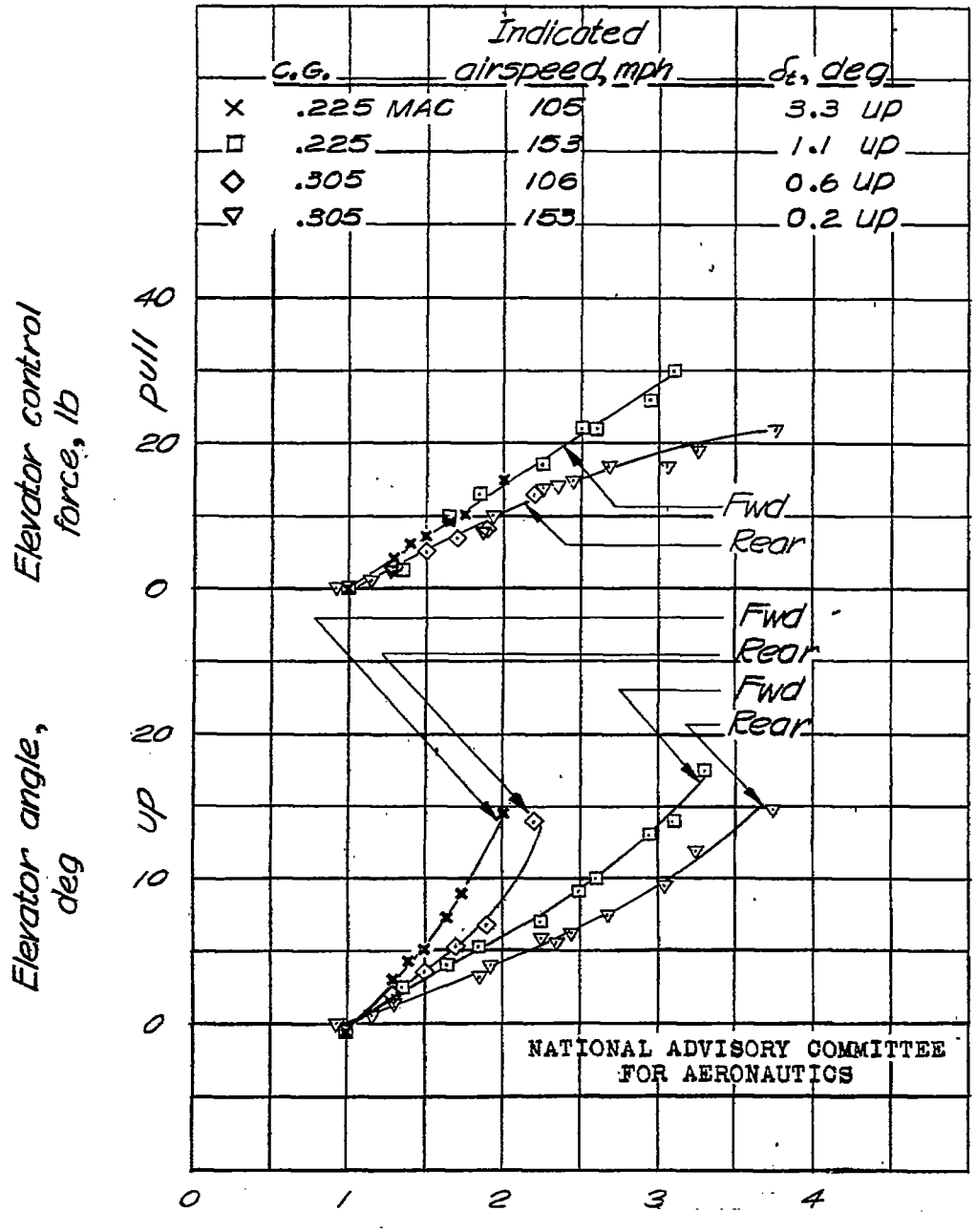
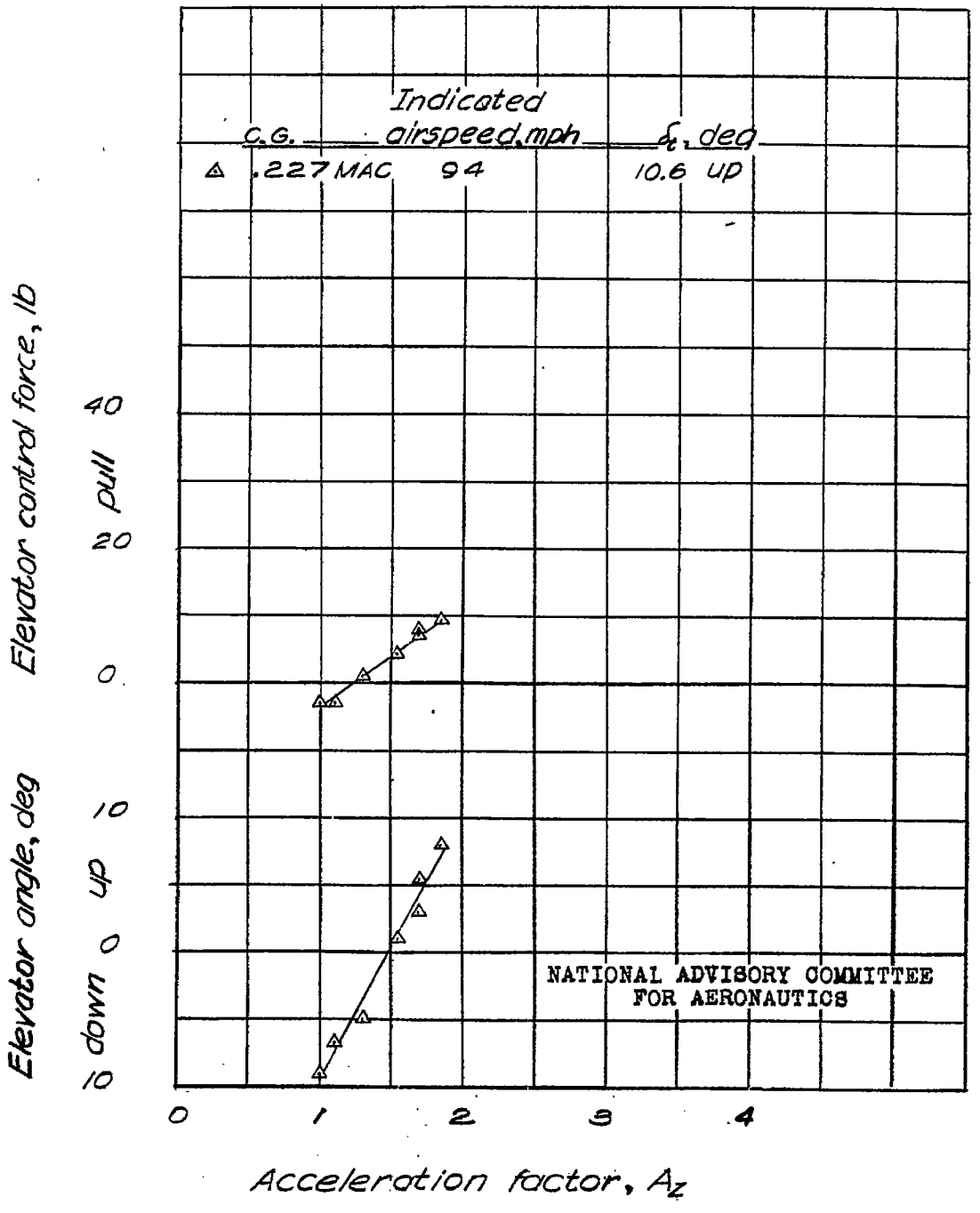


Figure 9.-Elevator angle and force required for various ground contact speeds. Flaps down, power off.



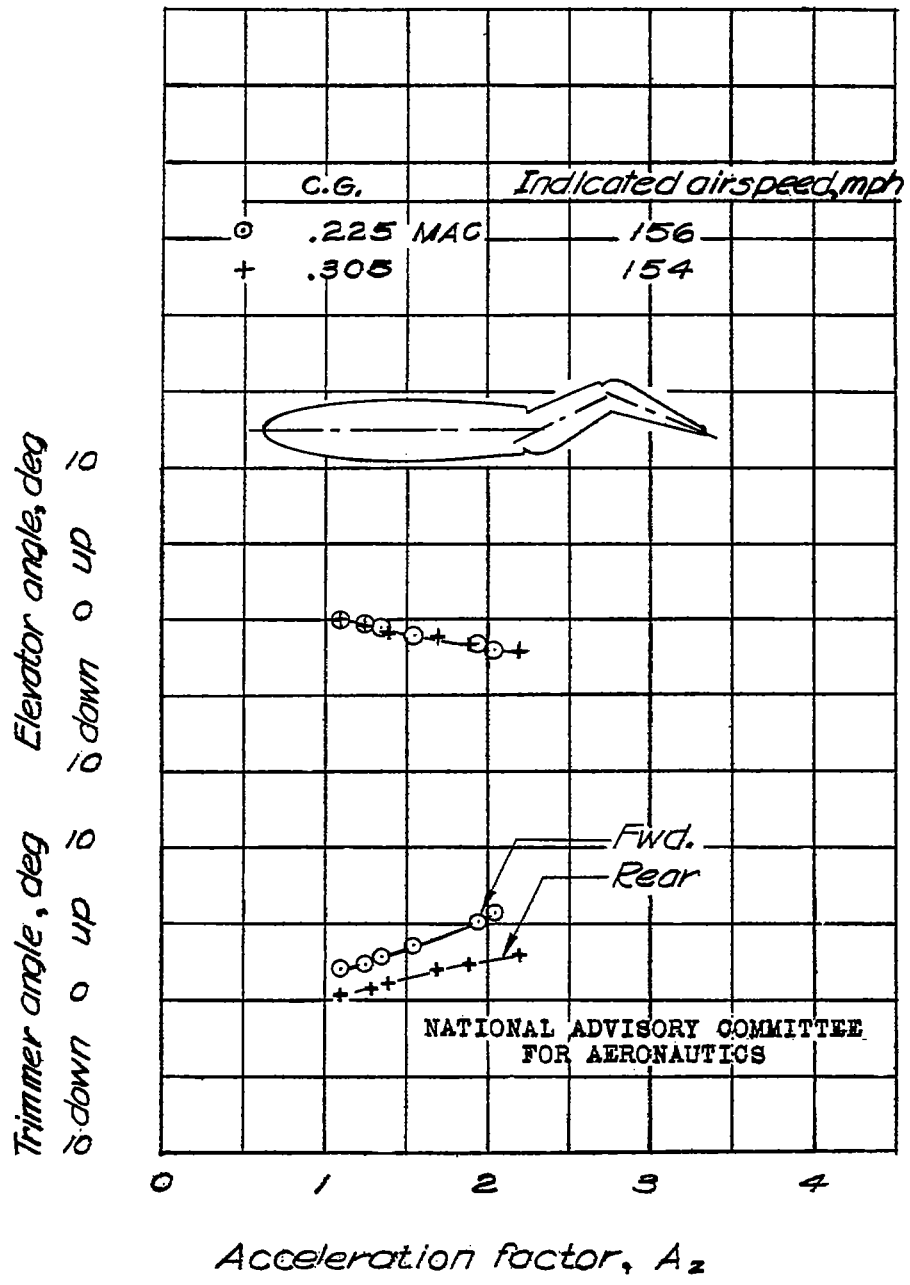
(a) Flaps up, normal rated power

Figure 10.-Longitudinal control in steady turning flight.



(b) Flaps down, power off

Figure 10.- continued.



(c) Flaps up, normal rated power, using trimmer for control (stick force equal to zero)

Figure 10.- Concluded.

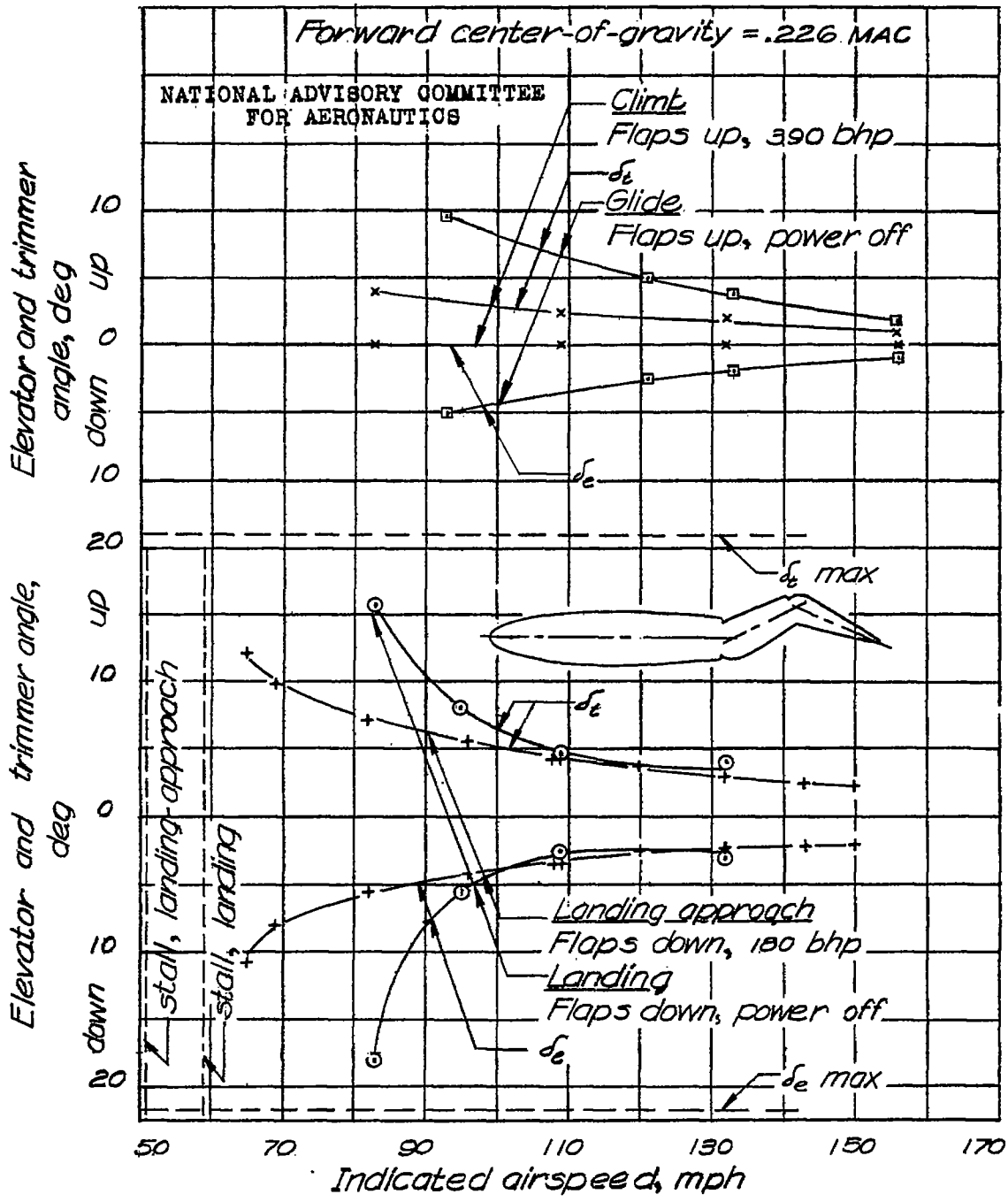


Figure 11.- Elevator and trimmer angles required to trim for various airspeeds. Center of gravity forward. Control force equal to zero.

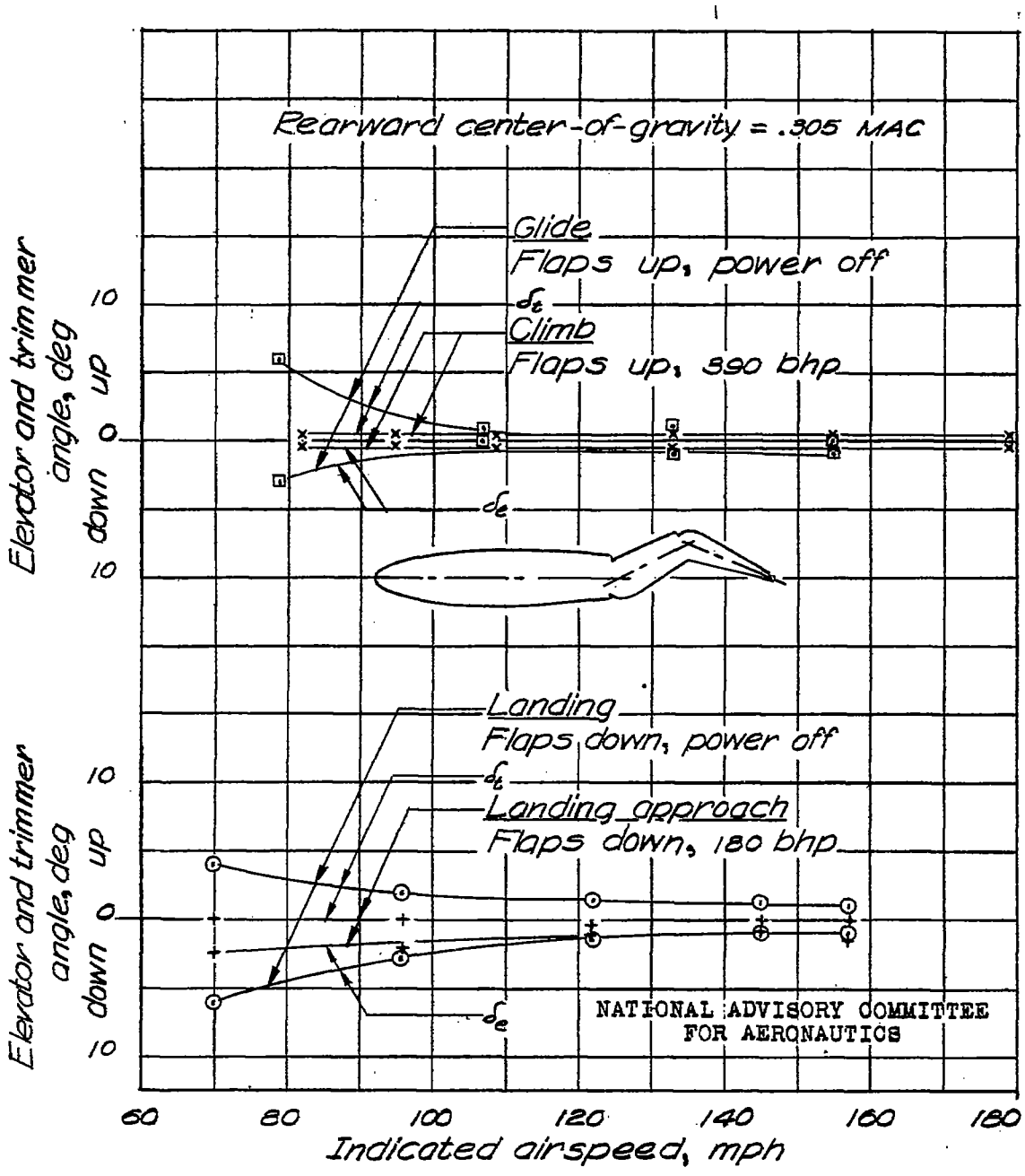


Figure 12.-Elevator and trimmer angles required to trim for various airspeeds. Center of gravity rearward. Control force equal to zero.

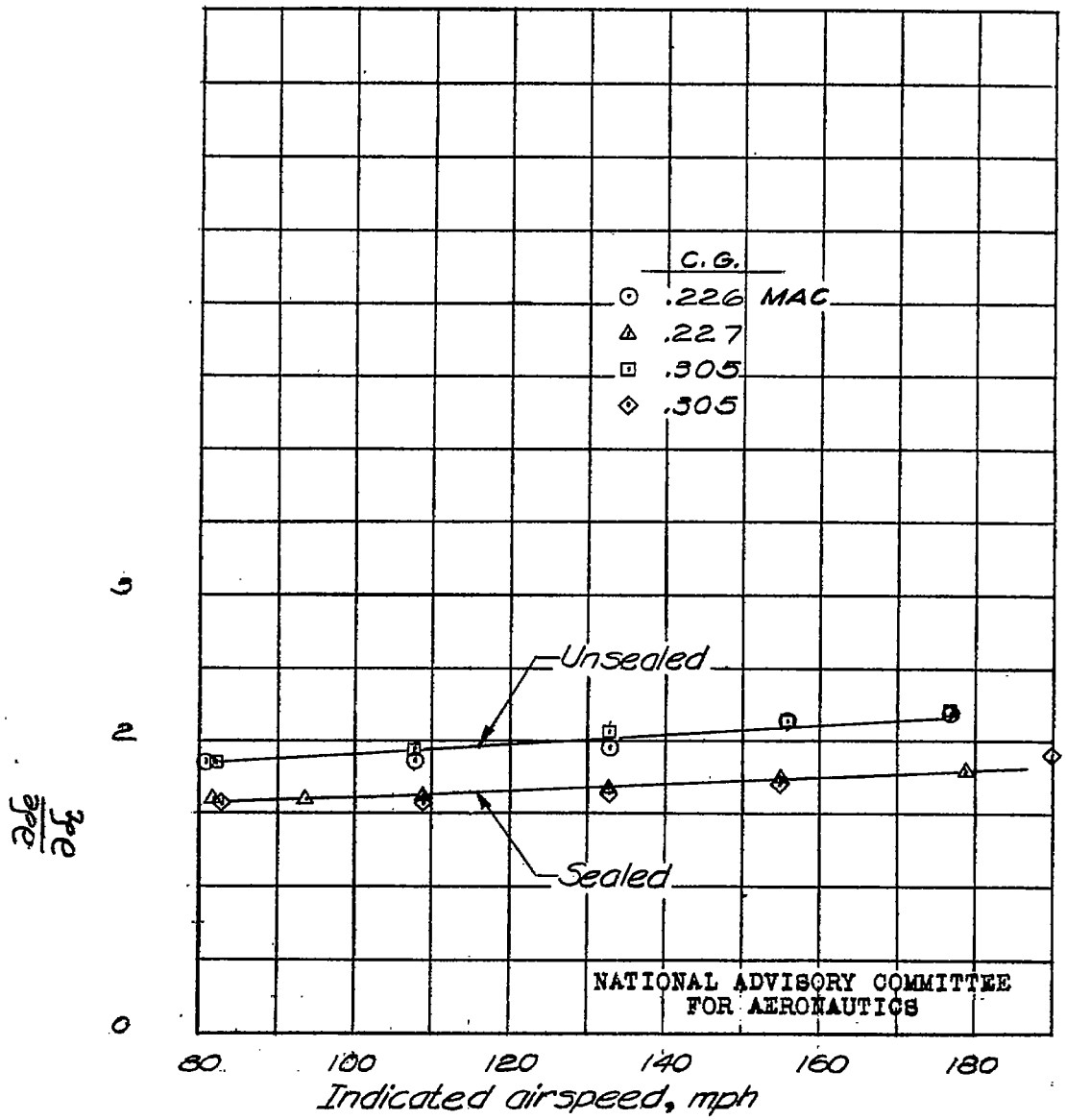


Figure 13.-Variation with airspeed of the ratio $\partial\delta_e/\partial\delta_t$ for steady straight flight. Flaps up, normal rated power.

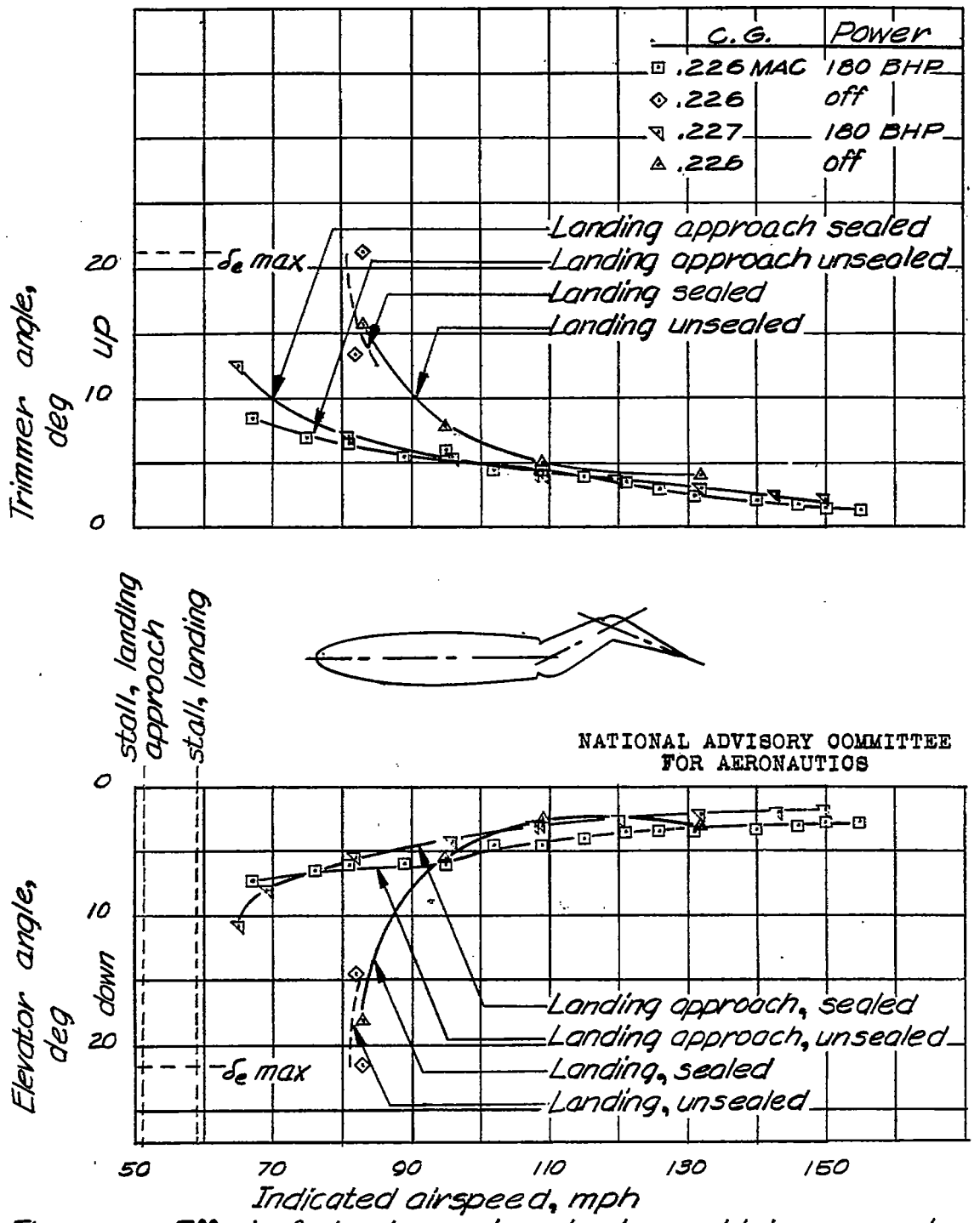


Figure 14 - Effect of elevator seal on elevator and trimmer angles required to trim for various airspeeds. Flaps down. Control force equal to zero.

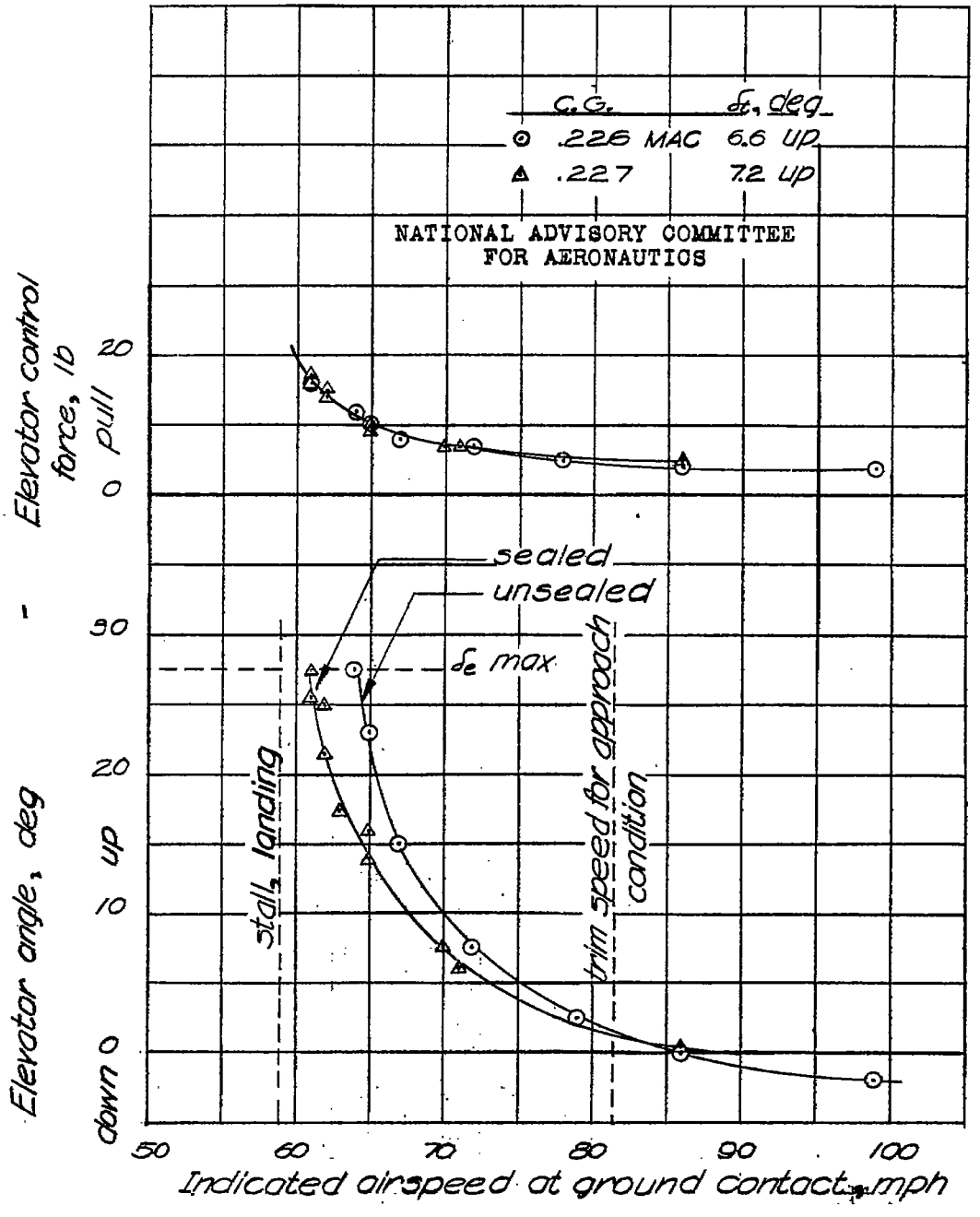


Figure 15.- Effect of elevator seal on elevator angles and elevator control force required for various contact speeds. Flaps down, power off.