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ELEVATOR STICK FORCES IN SPINS AS COMPUTED

FROM WIND—TUNNEL MEASUREMENTS

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NACA

WASHINGTON

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ELEVATOR STICK FORCES IN SPINS AS COMPUTED

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SUMMARY

Data from wind-tunnel measurements of elevator hinge-moment coefficients at high angles of attack are utilized in estimating elevator stick forces in spins.

The analysis indicates that elevator forces on several current airplanes will be so high that the pilot will be unable to push the stick to the neutral position. Large nose balances involve danger of the elevator locking in the full-up position. Trimming tabs can be used to reduce the elevator stick farce. Stick forces will be greater in steep spins than in flat spins.

INTRODUCTION

Considerable difficulty has recently been experienced in the recovery of airplanes from spins because the pilot has been unable to apply a sufficient force to move the control surfaces. This problem is growing more acute with the present trend in airplane design toward increased weights with accompanying higher velocities. The manipulation of rudder, ailerons, and elevator, singly or in combination, is necessary to effect a recovery from a spin; therefore, information on the required forces for all three control surfaces is essential. Because most control-force investigations have been carried out in the normal flight range, very little information is available for airplanes in spinning attitudes.

Measurements of elevator hinge-moment coefficients on a model at high angles of attack were recently made in the LMAL 7- by 10-foot tunnel (referenca 1). In the present paper, these results are applied in estimating the elevator hinge moments and the corresponding stick forces in spins. For an airplane in a typical spinning attitude, the

effects of various blunt- and sharp-nose balances are compared and the effectiveness of a trailing-edge tab is shown. In addition, the stick forces for four specific current airplanes have been computed.

For most of the current airplanes likely to be spun, the rudder is the predominant control in the recovery from spins. In many cases, however, the elevator must be neutralized or reversed in order to effect satisfactory recovery. Frequently the position of the ailerons is of considerable importance. It must be realized, therefore, that the present study, in which only elevator forces are considered, covers only one phase of the problem of control forces in spins. Because the original measurements were made on one specific tail unit, the results obtained when the data are applied directly to other tail arrangements without corrections for aerodynamic variables must be considered only rough estimates and should bo interpreted qualitatively. In the present paper, only the hinge moments at a given elevator deflection are considered; the effectiveness of the elevator in producing lift is discussed in reference 1.

METHOD OF COMPUTATION

The elevator hinge-moment coefficients used in the present study were taken directly from the data of reference 1. These data were obtained from measurements for a horizontal tail surface mounted on the fuselage of' a typical pursuit airplane. The rotation of the spin mas not simulated in the tests of reference 1. The fuselage was tested to a range of angles of attack from about -10° to 47° and to a range-of-yaw angles from -10° to 45°. The coefficients presented show the effect of different amounts of alevator nose balance and of a trailing-edge tab for a range of elevator deflection.

The conditions at the tail for representative spins were obtained from unpublished data from the NACA 15-foot free-spinning tunnel.

For the application of the test data, the angles of attack and yam and the velocity at the horizontal *tail* were obtained from the spin-tunnel data. The angle of attack at the tail plane for zero tail setting with respect to the wing was taken to be the same as the angle of attack

on the **wing** at the plane of symmetry. **The** angle of **yaw** at the tail **was** computed as

$$\psi = \frac{\Omega R_T}{V} - \phi$$

where

Ω angular velocity in spin

V rate of descent

R_T distance from axis of rotation to elevator hinge axis

ϕ angle between span axis and horizontal

The efevator hinge-moment coefficients corresponding to these angles were taken frari the data of reference 1 and were assumed to apply directly to the specific tails under consideration. **The** full-scale hinge moments were then calculated for the density at the spin-task altitude. The stick forces **were** determined from the hinge moments on the assumption of uniform gearing between the elevator and stick, far which an 18-inch movement of the stick corresponded to a 50° movement of the alevator.

This procedure gives the effects due to the aerodynamic forces and involves the **assumption** that the correction for any elevator mass unbalance, control-system **mass** forces, and friction will be **small.** The effects of rotation are **also** neglected. It is appreciated that, as a result of the rotation of the spinning airplane, there is a variation in **angle** of attack along the tail span which amounts to a difference of 5° between the value at the center and the tip of the tail plane. As the tail plane is well above the stall in the **spin,** it *is* believed **that this** variation of angle *of* attack **will** not have a significant effect on **the** hinge moments. The corresponding variation in the magnitude of air velocity across the tail span is **less** than 1 percent.

In using the test data from reference 1 to compute the stick forces of the various airplanes, no correction was **made** for the ratio of elevator area to tail-plana **area** nor **for** the tail-plane airfoil thickness, aspect ratio, and plan form. Although it **was realized** that these **factors would** affect the hinge moments, it was felt that the information available was insufficient to form the basis for

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accurate corrections. The dimensional characteristics of
the tail plane used in the tests of reference 1 are pre-
sented for comparison with the dimensional characteristics
of the tail planes to which the data are currently applied.
(See tabla I and figs. 1 to 5.)

RESULTS AND DISCUSSION

Results are presented that show the effects of various
pose balances and of a trailing-edge tab on the stick for-
ces for tho P-36A airplane (referred to as airplane B
later in the text;) spinning under the following conditions:

Angle of attack, a, deg . . . . . , ... 45
Angle between span axis and horizontal, $\emptyset$, deg . . . 0
Rate of desoent, V, ft/sec . . . . . . , ... 161
Yaw angle at tail, deg 0
Altitude, ft 12,000

The yaw et the tu21 was taken as zero because the data
of reference 1 cover the effect of yaw for only two eleva-
tor deflections and it was desired to plot stick force
against elevator angle. The available data indicate the
effect of moderate yaw tc be negligible.

The stick forces for various elevator angles arc com-
puted for the same basic spin condition to evaluate the
force required to push the stick forward rapidly in such
a way that the motion is completed before the spin can be
altered by the changed elevator position. Figure 6, which
is based on information from reference 2 and shows the
maximum elevator stick forces that a pilot can apply with
one hand, is presented for comparison.

Effect of Nose Balances

The stick-force variation for various nose balances
is shown in figure 7. Little difference is shown between
the trends for sealed and unsealed, controls. Data for
the balanced surfaces were not available for elevator-up
deflections larger than 20° because the balance nose un-
ported at larger deflections.

The plain elevator shows a larger force variation
than any of the balanced surfaces throughsut the deflection

range investigated. The high pull force for the **Pull-up**
elevator deflection is a very desirable feature because
the pilot has to exert a pull to hold the stick back in
the steady spin. When the elevator approaches neutral,
however, the aerodynamic force acts in the opposite direc-
tion, and the pilot must exert considerable effort to neu-
tralize the elevator. It is probable that the elevator
can be neutralized even though the force required to **hold**
it at neutral is high.

The 35-percent blunt-nose balance requires a fairly
large push to move the stick when it is back but has an
advantage over the plain elevator in that a smaller force
is required to hold the stick neutral. Inasmuch as the
push that a pilot is capable of exerting on the stick is
least when the stick is back (see fig. 6), there is some
danger of the elevator locking **with** the 55-percent blunt-
nose balance.

The 35-percent sharp-nose balance is similar in affect
to the 35-percent blunt-nose balance at low elevator de-
flections but, when the elevator has a large upward deflec-
tion, the force required to **begin** moving the stick **forward**
is very **small.** There is no danger of the elevator locking
at the 20° up position when this belanco is installed.

The elevator **with** sealed 50-percent blunt-nose balance
is overbalanced in that the required push on the stick be-
comes smaller as the elevator is moved **down.** This decrease
in stick force gives the wrong stick "feel" and may give
the pilot the erroneous impression that the elevator is fa-
effective. With **this** balance unsealed, the stick-force
curve is irregular but again shows overbalance in part of
the range.

The 50-percent sharp-nose **design** shows overbalance
for up deflections exceeding 15°. **For** both 50-percent bal-
ance types **there** is serious danger of the elevator locking
in the spin. It should be appreciated that the 50-percent
blunt-nose balance, according to reference 1, **also shows**
overbalance in the normal flight range. A desirable fea-
ture of the 50-percent balance **is** the low force required
to hold **ths elevators in** neutral.

It should be realized that, for both the 35-percent
and **the** 511-percent balances, elevator-up deflections ex-
ceeding 20° mill probably give definite elevator locking
as a result of unporting.

Effect of Tab

The effect of a 20-percent-chord tab on the plain sealed elevator is shown in figure 8. The spin conditions and tail-plane plan form were the same as for the preceding computations which were made to show the effects of nose balance. It is seen that a 10^0 up deflection of the trimming tab reduces by about 50 percent the force required to neutralize the elevator. A balascing tab would increase the forces until the stick was forward of neutral.

Effect of Angle of Paw

Owing to the Limitations of the data, the effect of yaw angle on stick forces could be determined for only two elevator deflections (fig. 9). The spin and tail-plane plan form were the same as for the previous case. The curves show that for the plain elevator the stick forces remain constant up to an angle of yaw of 10^0. Between yam angles of 10^0 and 25^0 there is a small change in force in a direction which **would** tend to move the stick back. Other balance types are **also** sbonn (reference **1**) to be insensitive to yam up to 10^0.

Applications to Specific Airplanes

The experimental results obtained from the investigation of reference **1** were **also** utilized in estimating the stick forces in the **normal** spin for four modern pursuit airplanes. The dimensional Characteristics of the tail planes .are given in table I, the plan forms are shown in figures 2 to 5, and the normal spin characteristics of **these** airplanes (**basad** on spin-tunnel tests) are shown in table, II. Results for airplane A and airplane B, which have approximately 21-percent and 25-percent blunt-nose balances, respectively, were obtained by interpolation 'between the values for the 35-percent blunt-nose balance and **for** the plain elevator (taken to have 9-percent balance). Airplane C, which bad a shielded horn balance, was considered to have two elements ‒ one with a plain balance and the other with an unsealed 50-percent blunt-nose balance.

Tbe computed stick forces were compared with. the curve of figure 6 showing the maximum push an average pilot could exert mitb one hand (average of the attitudes for the cockpit level and the cockpit nosed 90^0 down). This push **2s**

called the "allowable force" on figure 10. The effect of
yaw angle on hinge moments is not included and the eleva-
tor is assumed to have tab neutral. The yaw angles at the
tail did not exceed 15°; as a result, their effects would
be slight.

The forces required to move the stick forward on air-
planes A and B remain smaller than the allowable force
for practically the whole elevator range studied, and it
is prabable that the elevator can be safely neutralized on
the two airplanes. On the other hand, airplanes C and D
have much higher stick forces, and it is doubtful that the
elevator can be pushed more than three-fourths of the dis-
tance to neutral from its full-up position. It appears
unlikely that the pilot can abruptly push the stick forward
of neutral for any af these airplanes. It should be remem-
bered, however, that the reversal of the rudder and partial
forward movement of the stick., as normally used for recov-
ery, may altar the spin and the magnitude of the stick force.

In figure 11, the stick force required to neutralize
the elevator is plotted as a function of angle of attack in
the spin. It can be seen that the stick force increased as
the spins steepened, This increase is a result of the in-
creased airspeeds associated with. the steeper spins.

For airplanes C and D the percentage of change in
stick force over the angle-of-attack range from 35° to 45°
was small because the percentage of change in velocity mas
small for these models. The decrease, in absolute value of
the hinge-mornant coefficient with decreasing angle of at-
tack tended to compensate for the effect of the increased
airspeed.

Pilots have frequently reported high stick forces for
spins of current airplanes, In this connection it should
be noted that, although an average pilot can push 110 pounds,
flight-test reports indicate that pilots consider 50 pounds
a heavy force and prefer to use two hands for forces exceed-
ing this value. The high stick forces shown for airplane
C were substantiated in flight in that the test pilot found
that in a spin he mas unable to push the stick forward using
two hands.

In order to extend the study of control forces in spins,
it would be desirable to obtain considerable additional data
on rudder and elevator hinge moments at high angles of attack.
Information is required for a greater range of angles of

attack, for other balance types, and for other fuselage-tail combinations. These data mould also furnish information on the problem of rudder locking in normal flight conditions.

CONCLUSIONS

The present analysis, which is based on the direct 'application of data obtained for one specific tail plane, leads to the fallowing conclusions regarding elevator stick forces in spins:

1. Although nose balance will reduce the force required to neutralize the elevator, there is danger of elevator locking in the full-up position for large balances.

2. The stick farce to neutralize the elevator can be materially reduce0 by use of the trimming tab.

3. Elevator forces on several current airplanes may be so high that the pilot will be unable to push the stick to the neutral position. Thin tendency will be detrimen—tal for cases in which elevator-down movement is essential for recovery.

4. Stick forces will be greater for steeper spins.

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    National Advisory Committee for Aeronautics,
        Langley Field, Va.

REFERENCES

1. Sears, Richard I., and Hoggard, H. Page, Jr.: Characteristics of Plain and Balanced Elevators on a Typical Pursuit Fuselage at Attitudes Simulating Normal-Plight and Spin Conditions. NACA A.R.R., March 1942.

2. Gough, M. N., and Beard, A. P.: Limitations of the Pilot in Applying Forces to Airplane Controls. T.N. No. 550, NACA, 1936.

TABLE I. - DIMENSIONAL CHARACTERISTICS OF THE

TAIL PLANES OF THE TEST AIRPLANES

[Nose balance unsealed]

Airplane	Elevator dimensions			Approximate nose balance (percent)
	Area (sq ft)	Root-mean-square chord (ft)	Mean chord (ft)	
Tail plane of reference 1	0.48	0.20	0.19	—————————————
A	18.20	1.28	1.14	21-percent blunt nose
B	15.40	1.37	1.20	25-percent blunt nose
C	20.82 / 2.84	1.97 / .97	1.43	Plain elevator / 50-percent blunt nose
D	18.70	1.40	1.37	Plain elevator

TABLE II.- SPIN CHARACTERISTICS OF THE TEST AIRPLANES

Airplane	α (deg)	$\emptyset^1$ (deg)	Ω (radians/sec)	Vertical velocity V (ft/sec)	Radius of spin at tail, R_T (ft)	Yaw angle at tail, ψ (deg)
A	38	2D	2.67	226	19.59	11.0
B	30	9D	2.S8	244	15.60	1.0
C	50	1D	2.68	189	19.55	16.0
D	37	3D	2.58	238	17.82	8.0

[1]D   indicates that the inner wing is down.

2.66"

216.72"

Plain elevator

Maximum thickness of the horizontal tail is 9 percent of the chord
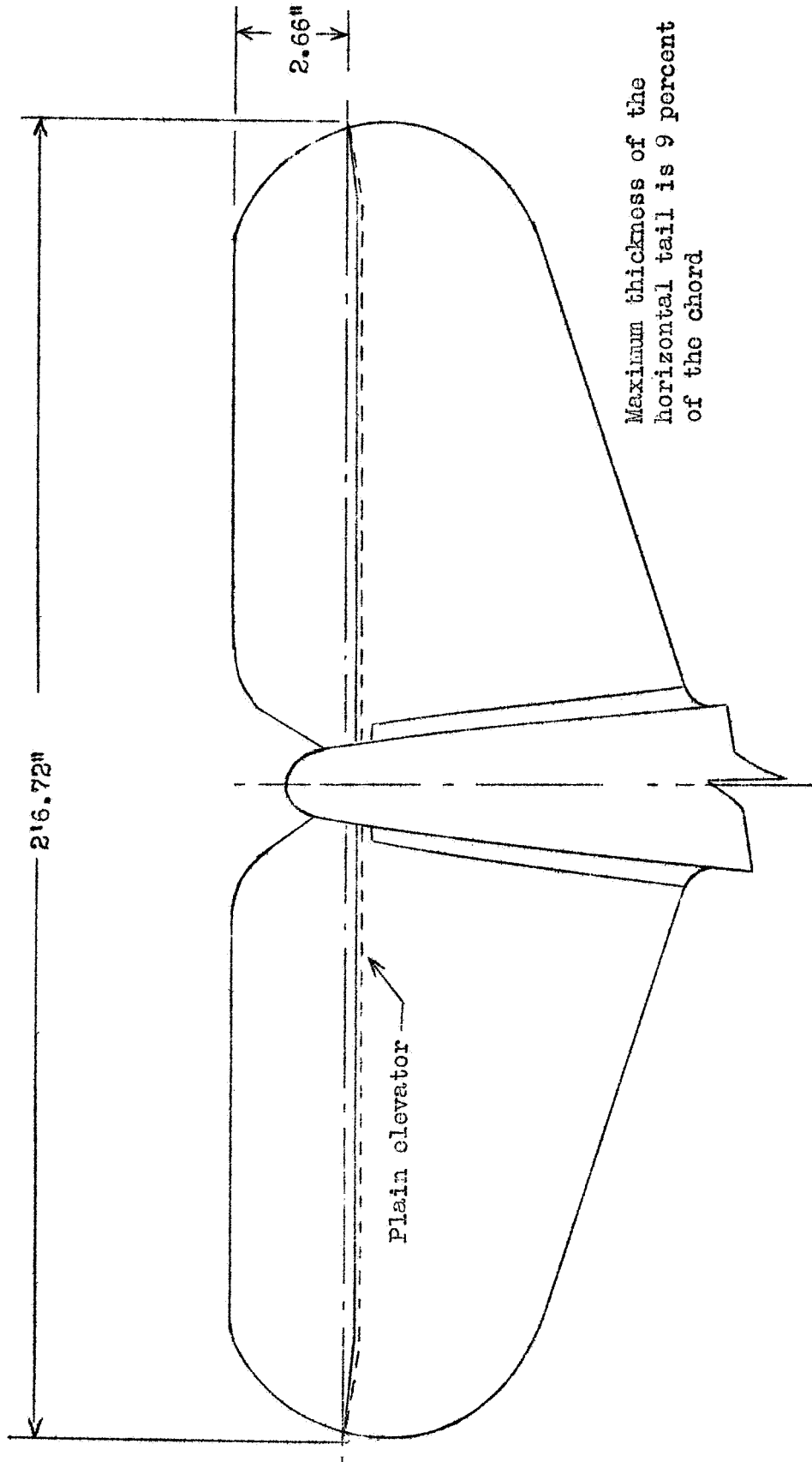
Figure 1.- Tail plane used in tests of reference 1.

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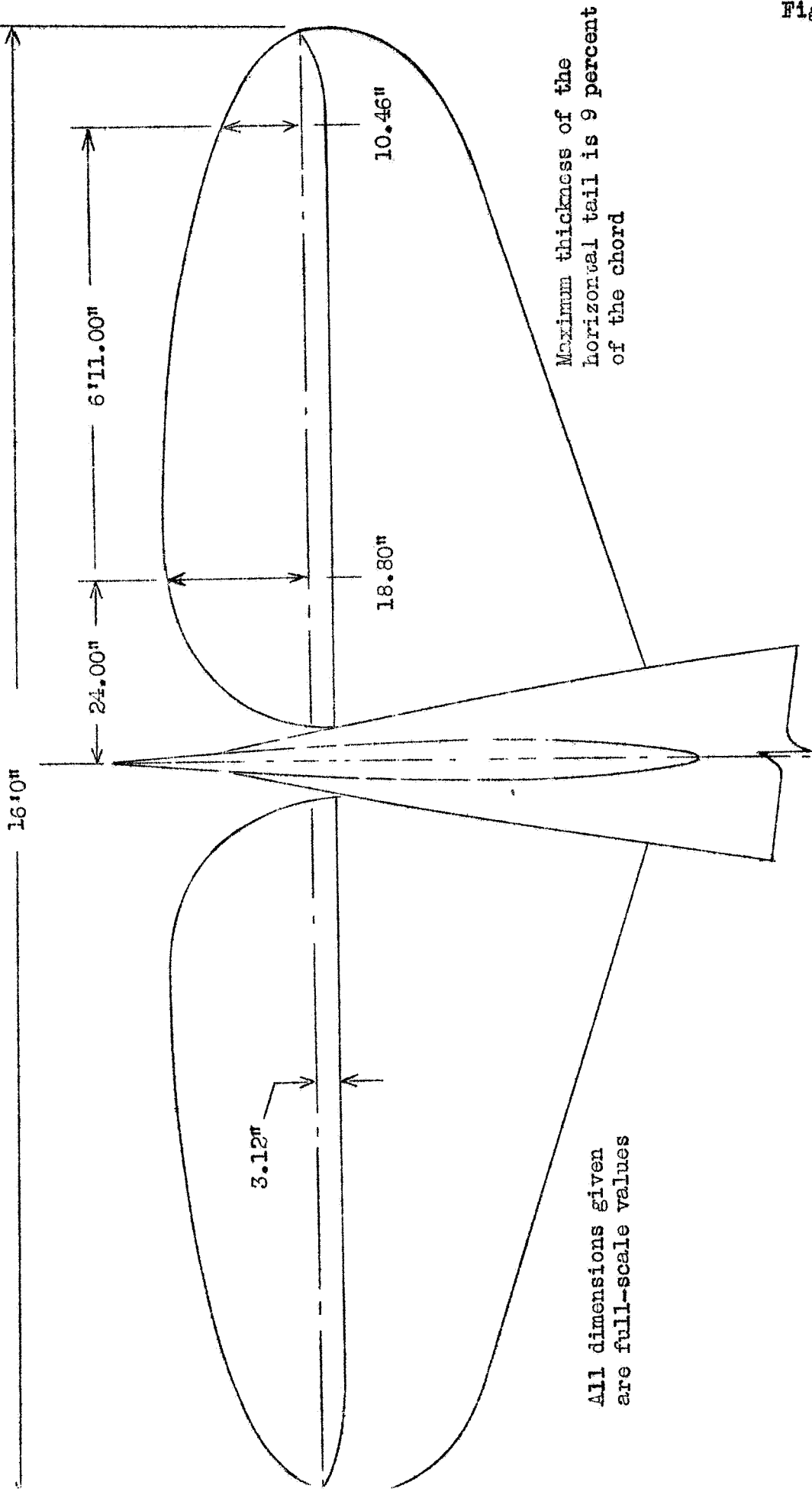
Fig. 2

10.46"

6'11.00"

18.80"

24.00"

16'0"

3.12"

Maximum thickness of the horizontal tail is 9 percent of the chord

All dimensions given are full-scale values

Figure 2.- Horizontal tail of airplane A, 1/20 scale.
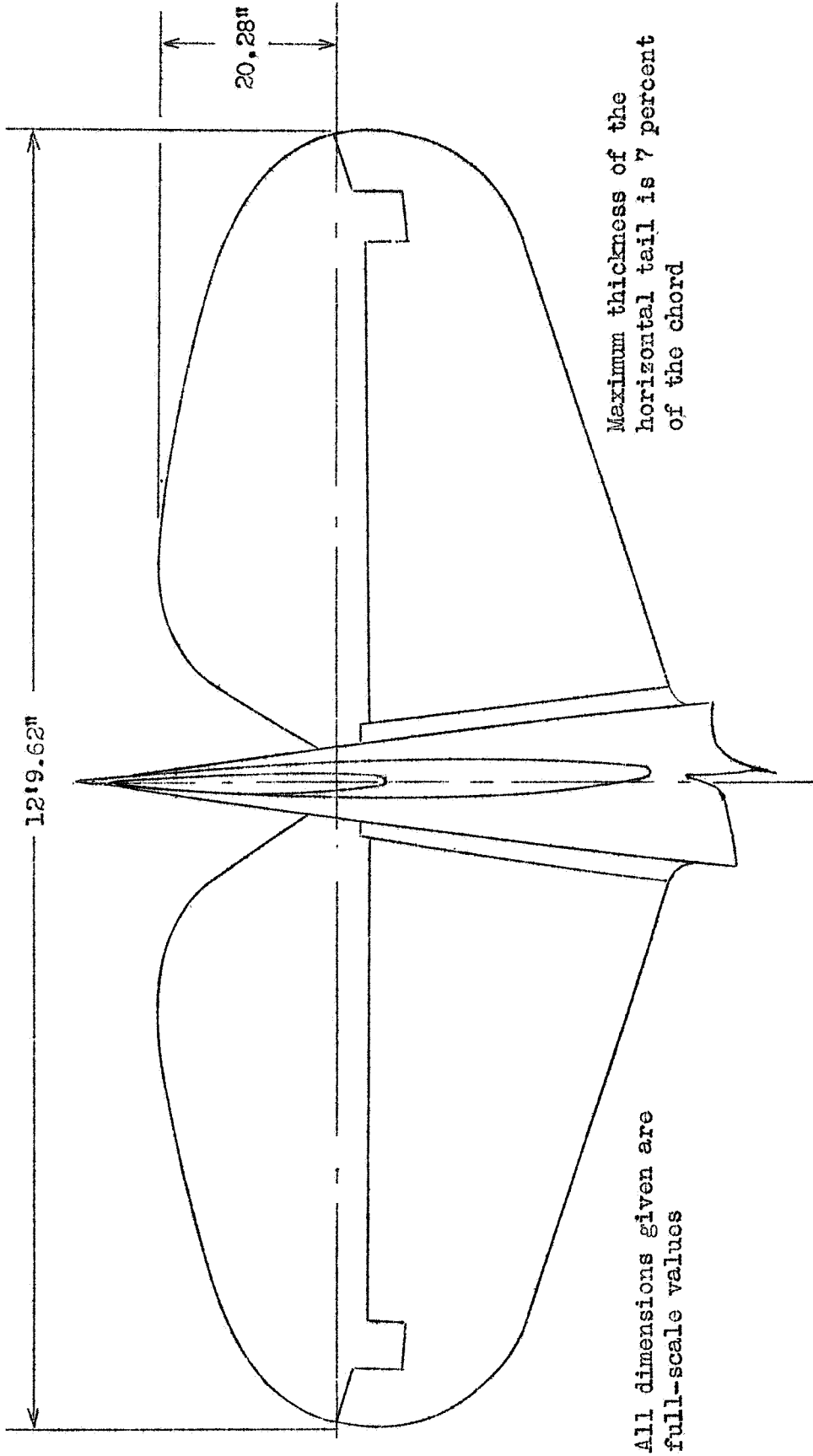
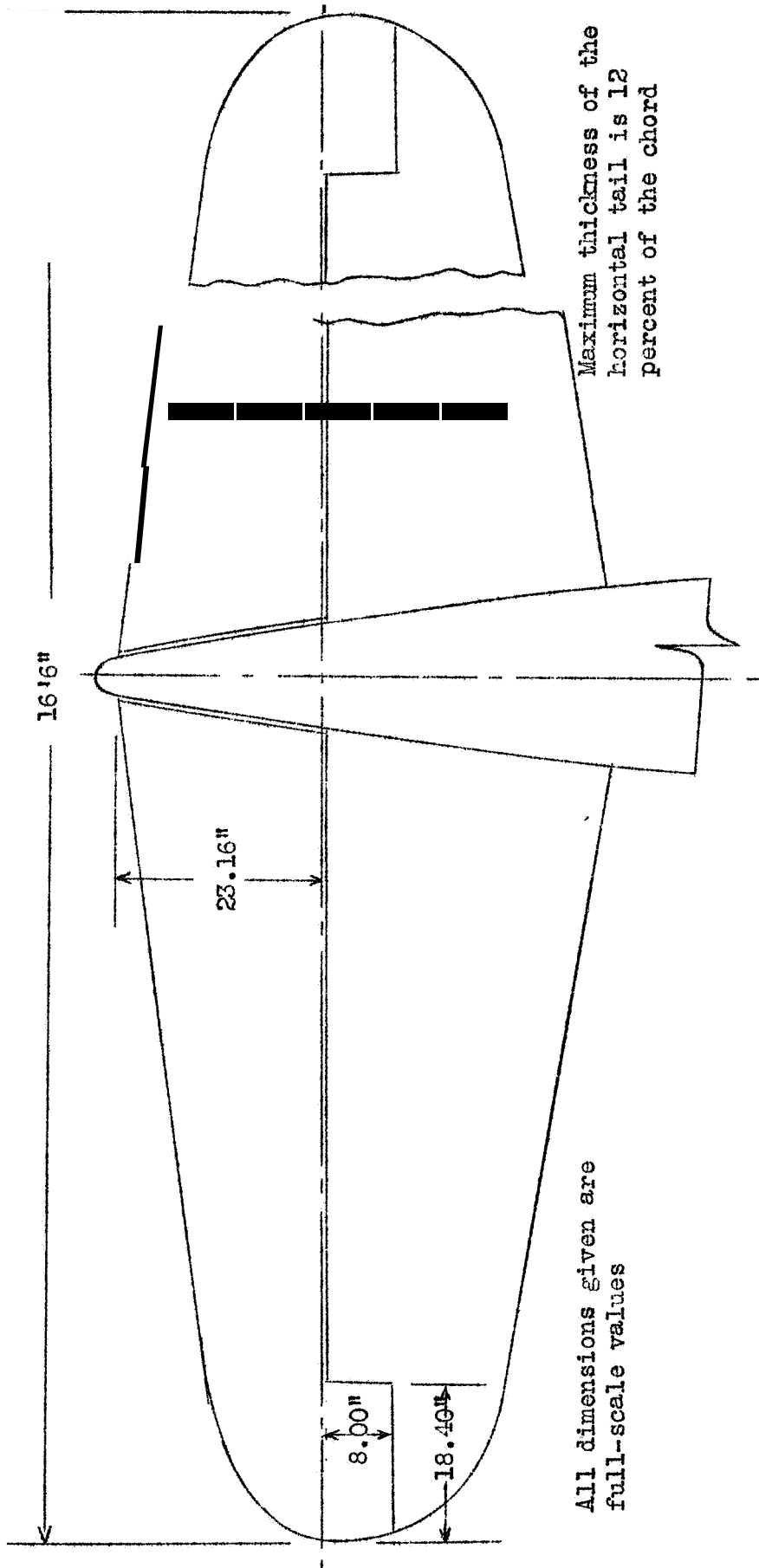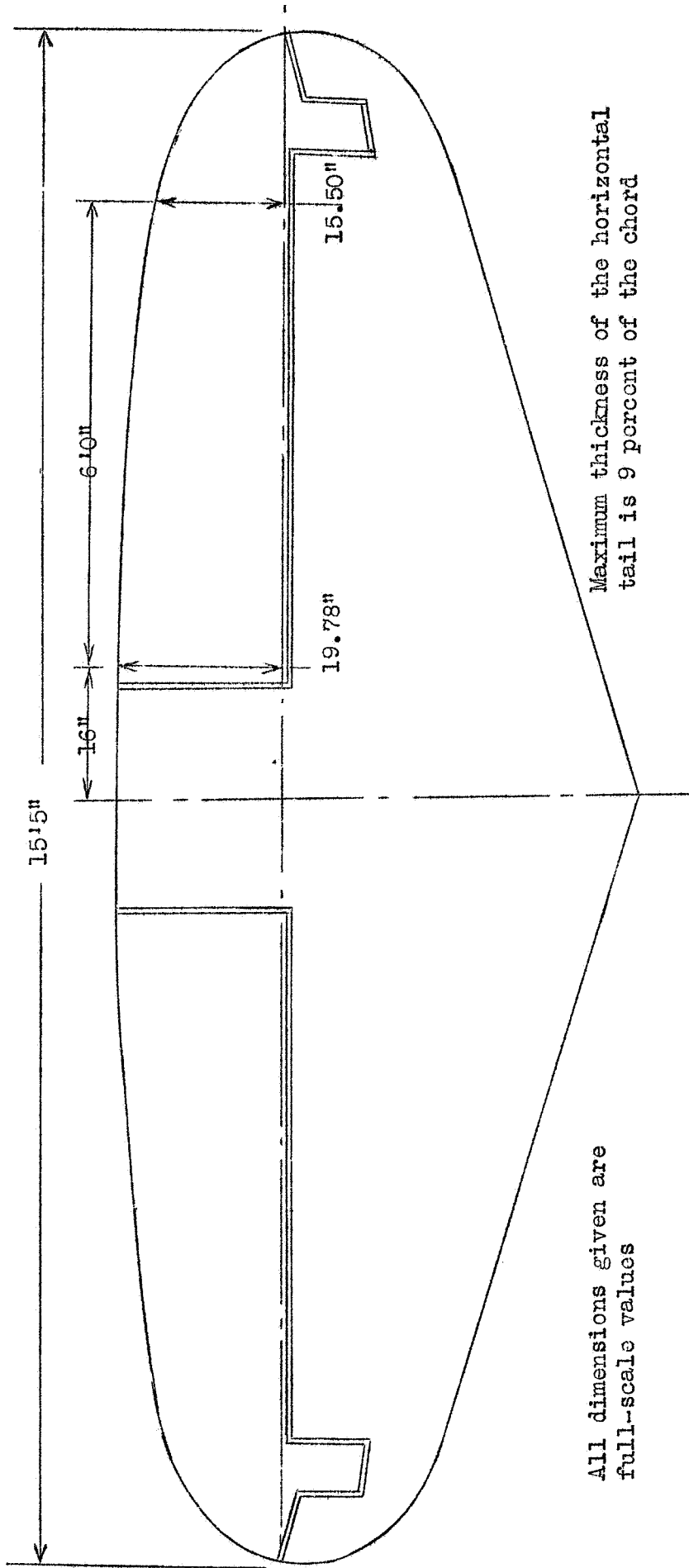Figure 3.— Horizontal tail of airplane B, 1/20 scale.

Fig. 4

Maximum thickness of the
horizontal tail is 12
percent of the chord

16'6"

23.16"

8.00"

18.40"

All dimensions given are
full-scale values

Figure d.- Horizontal tail of airplane t, 1/20 scale.

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Fig. 5

15.50"

6.10"

19.78"

16"

15.15"

Maximum thickness of the horizontal
tail is 9 percent of the chord

All dimensions given are
full-scale values

Figure 5.- Horizontal tail of airplane D, 1/20 scale.

Fig. 6
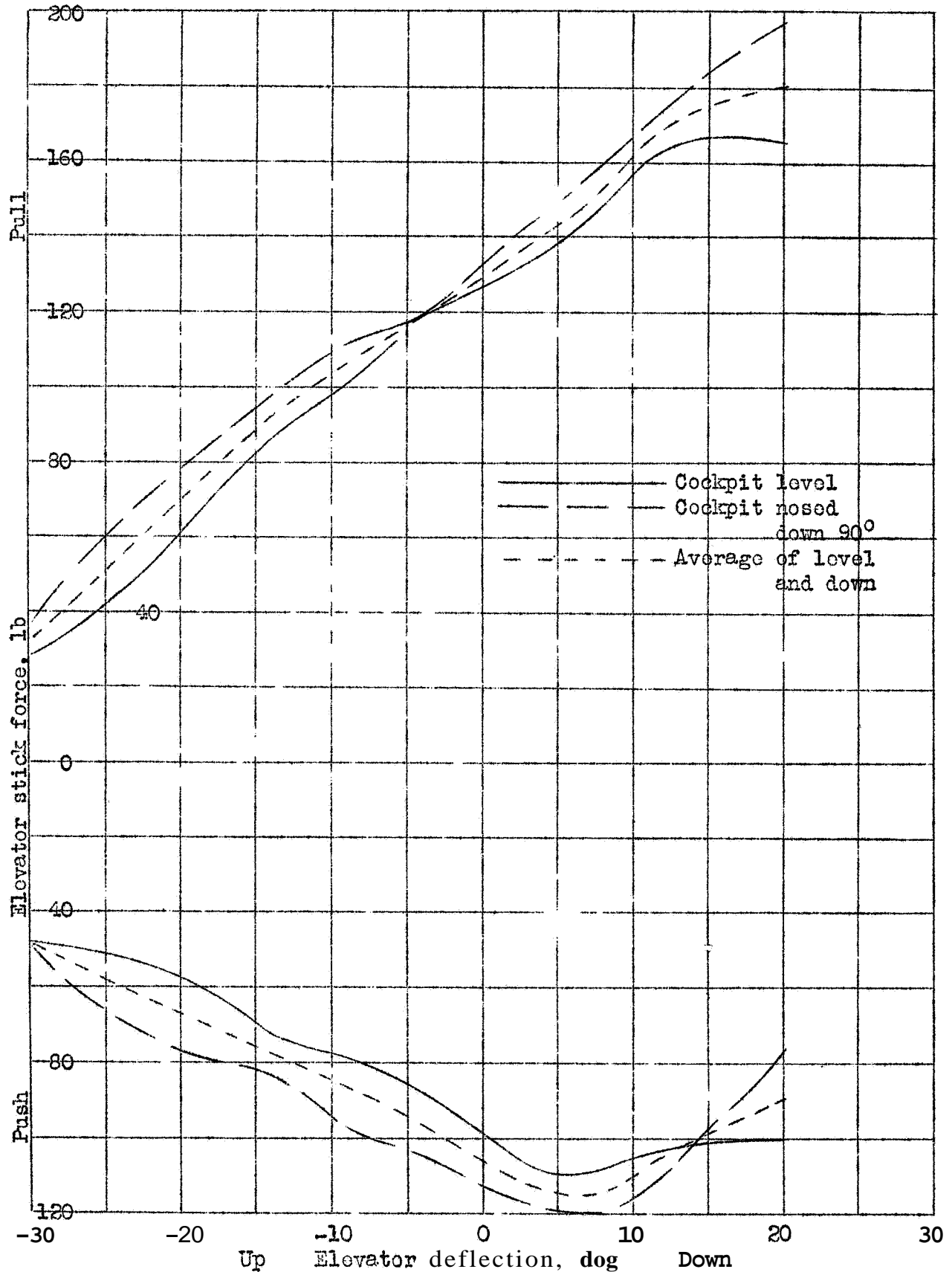
Figure 6.- Limitations of the forces a pilot can exert (average for two pilots from results of reference 2).

L-422
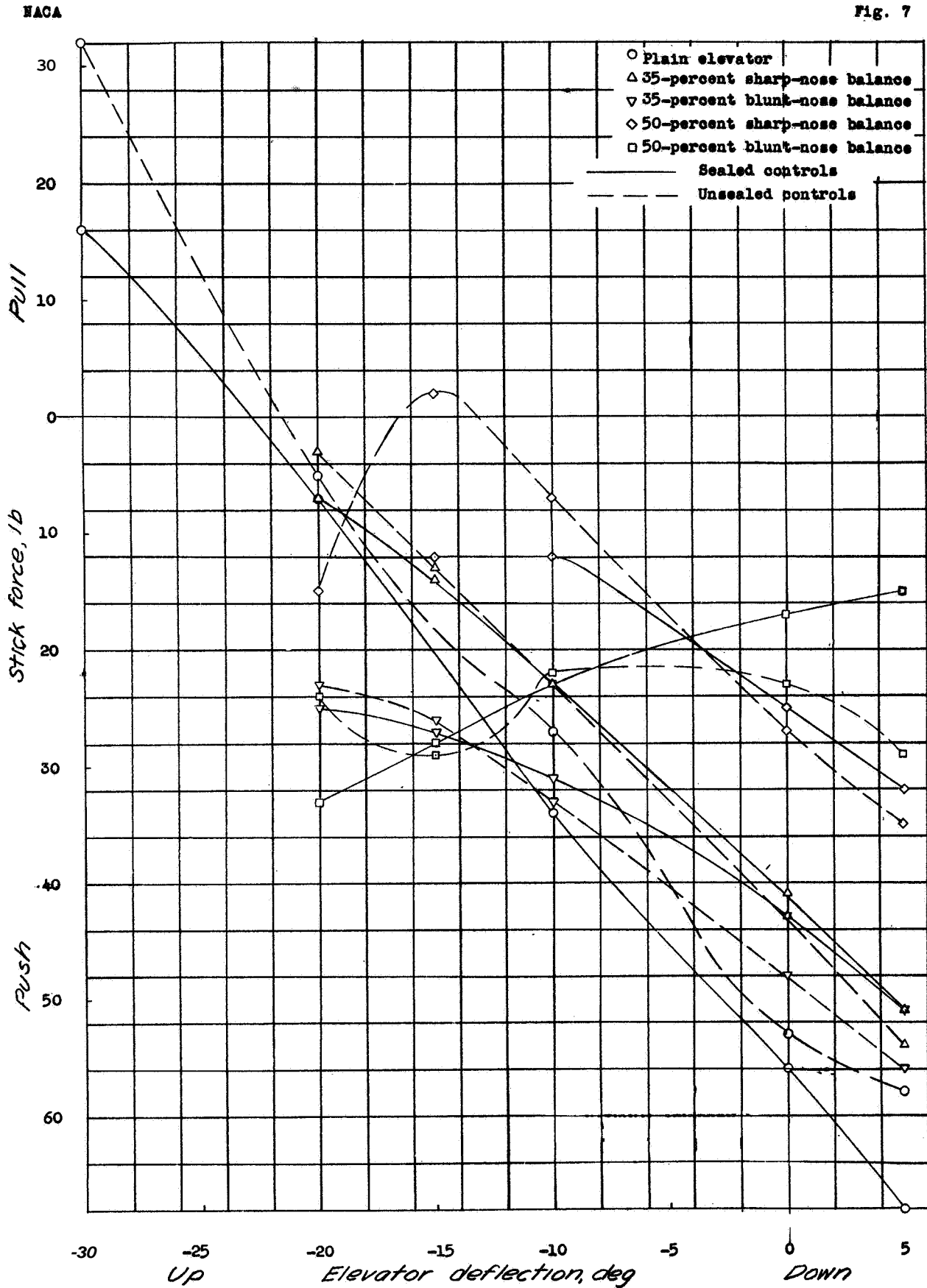
Figure 7.- Variation of etick force with elevator deflection for several nose balancee on the P-36A
airplane in a typical epin. Tab neutral; a, 45°; V, 161 feet per second; altitude, 12,000 feet.

L-427

Figure 8.– Variation of stick force with elevator deflection showing the effect of a 20-percent-chord tab for the P-36A airplane in a typical spin. Plain sealed elevator; a, 45°; V, 161 feet per second; altitude, 12,000 feet.

L-742
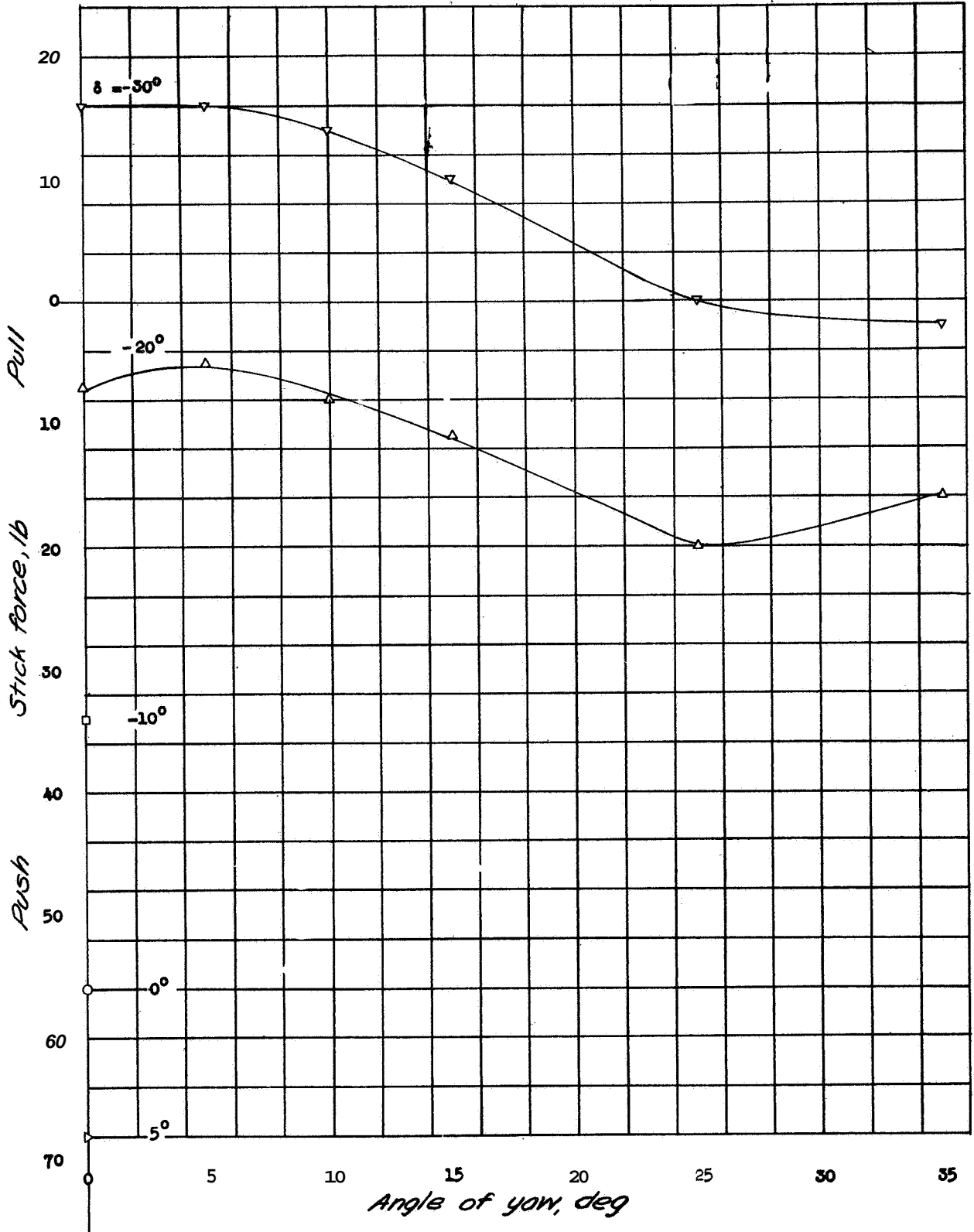
Figure 9.- Variation of stick force with angle of yaw for the P-36A airplane in a typical spin.
Plain sealed elevator; tab neutral; a, 45°; V, 161 feet per second; altitude, 12,000 feet.
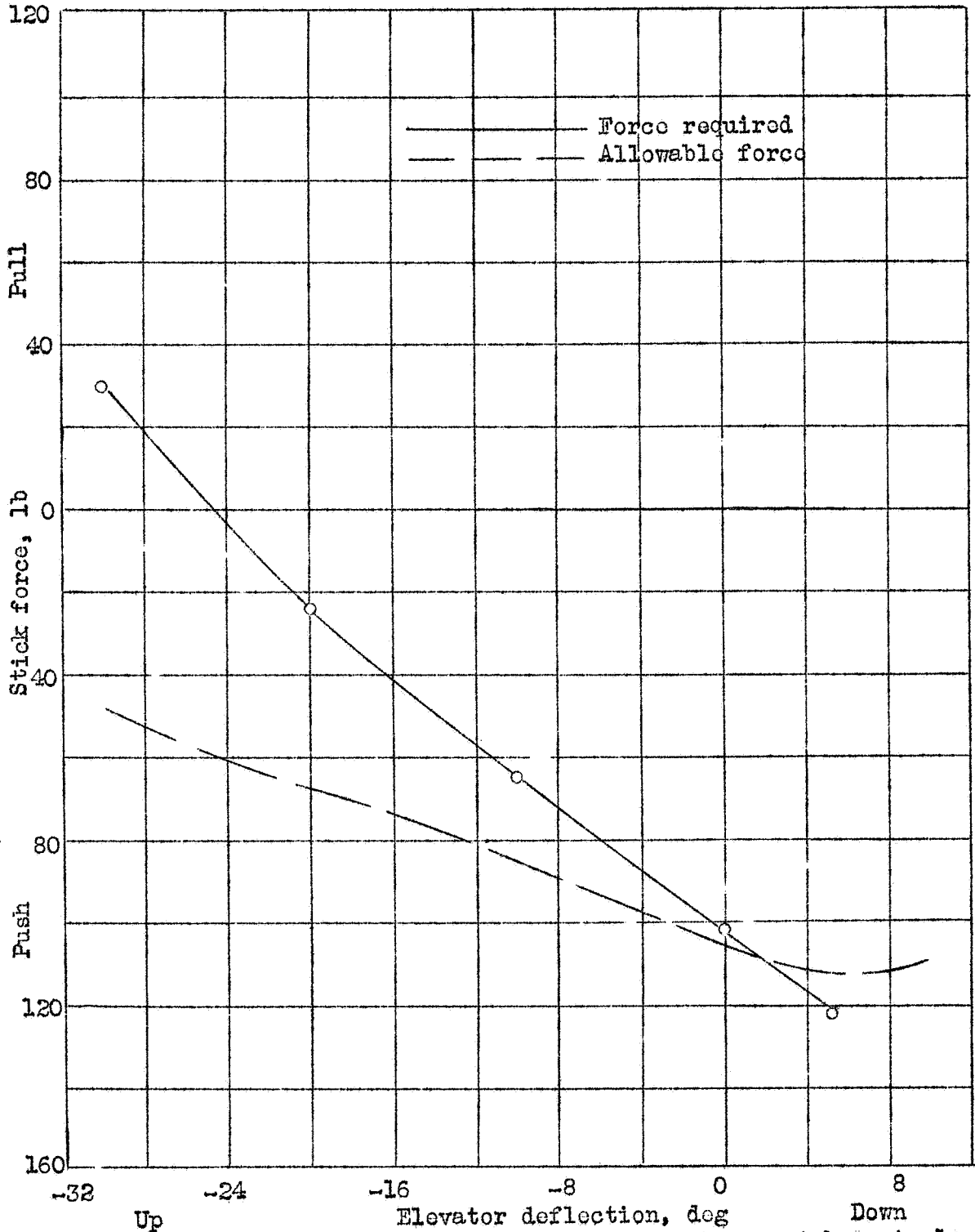
(a) Airplane A. Unsealed 21-percent blunt-nose balance; tab neutral;
α, 38°; V, 232 feet per second; altitude, 10,000 feet.

Figure 10(a to d).- Variation of stick force with elevator deflection
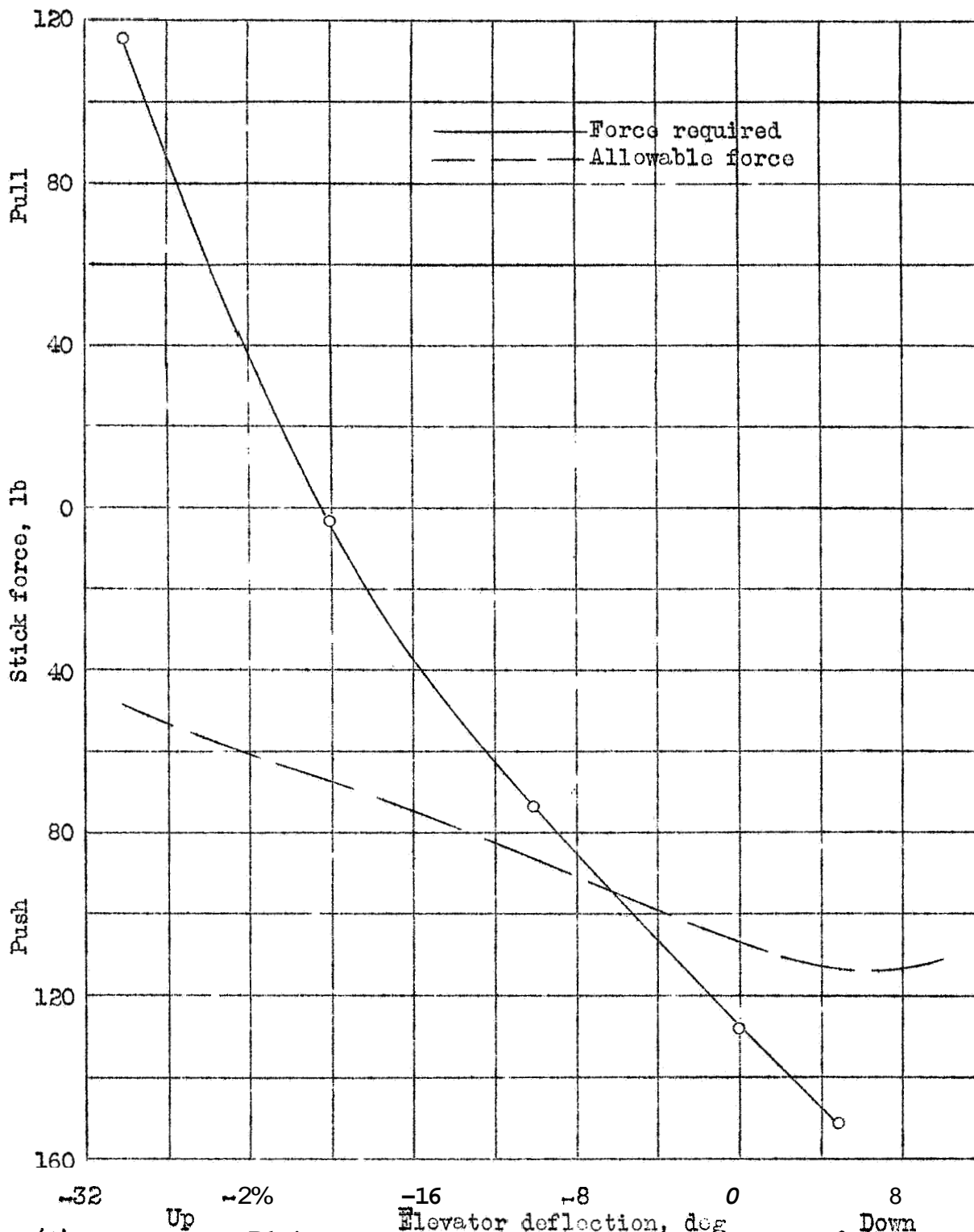for airplanes in normal spinning attitudes.
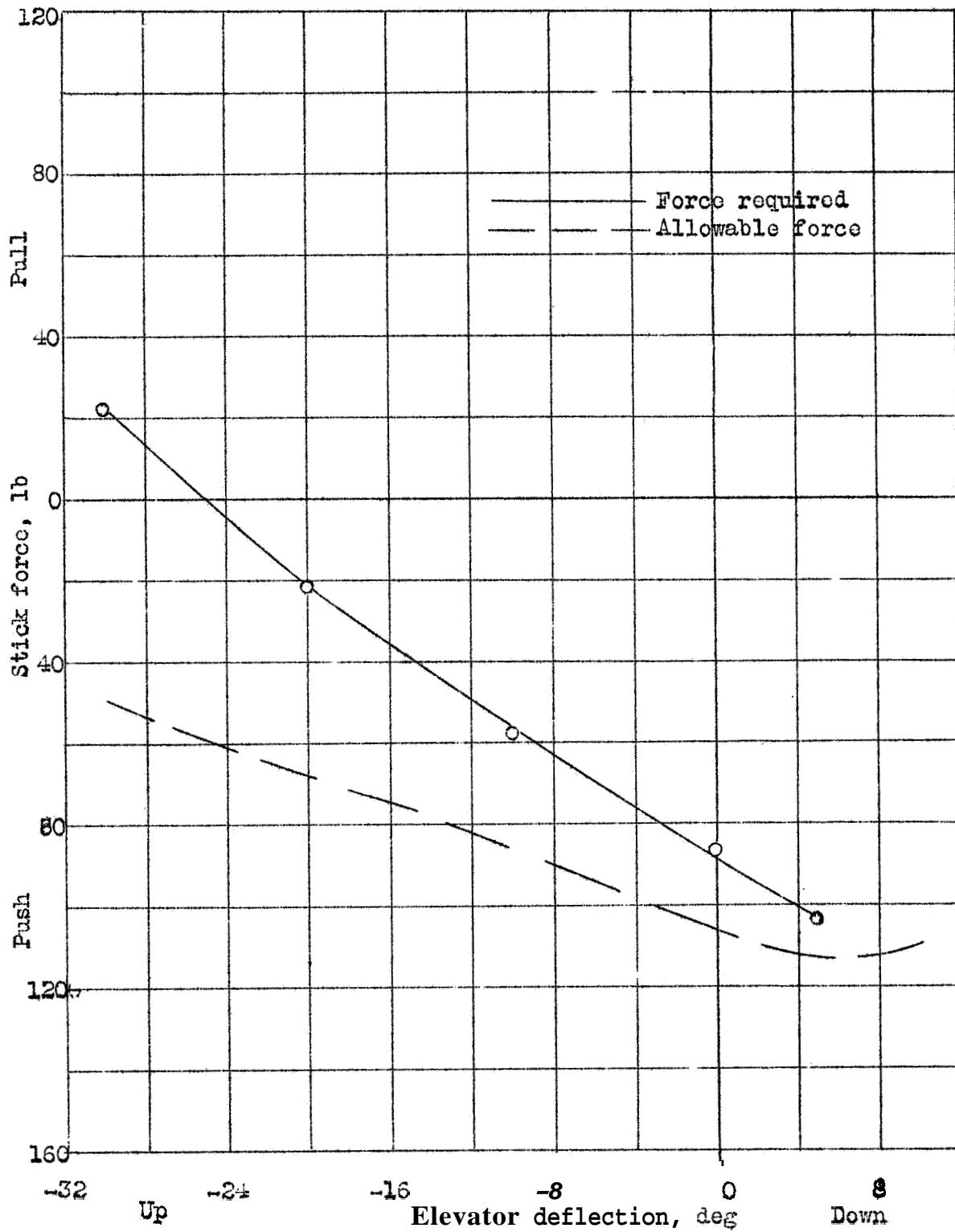
(b) Airplane B. Unsealed 25-percent blunt-nose balance; tab neutral:
    a, 30°; V, 248 feet per second; altitude, 12,000 feet.
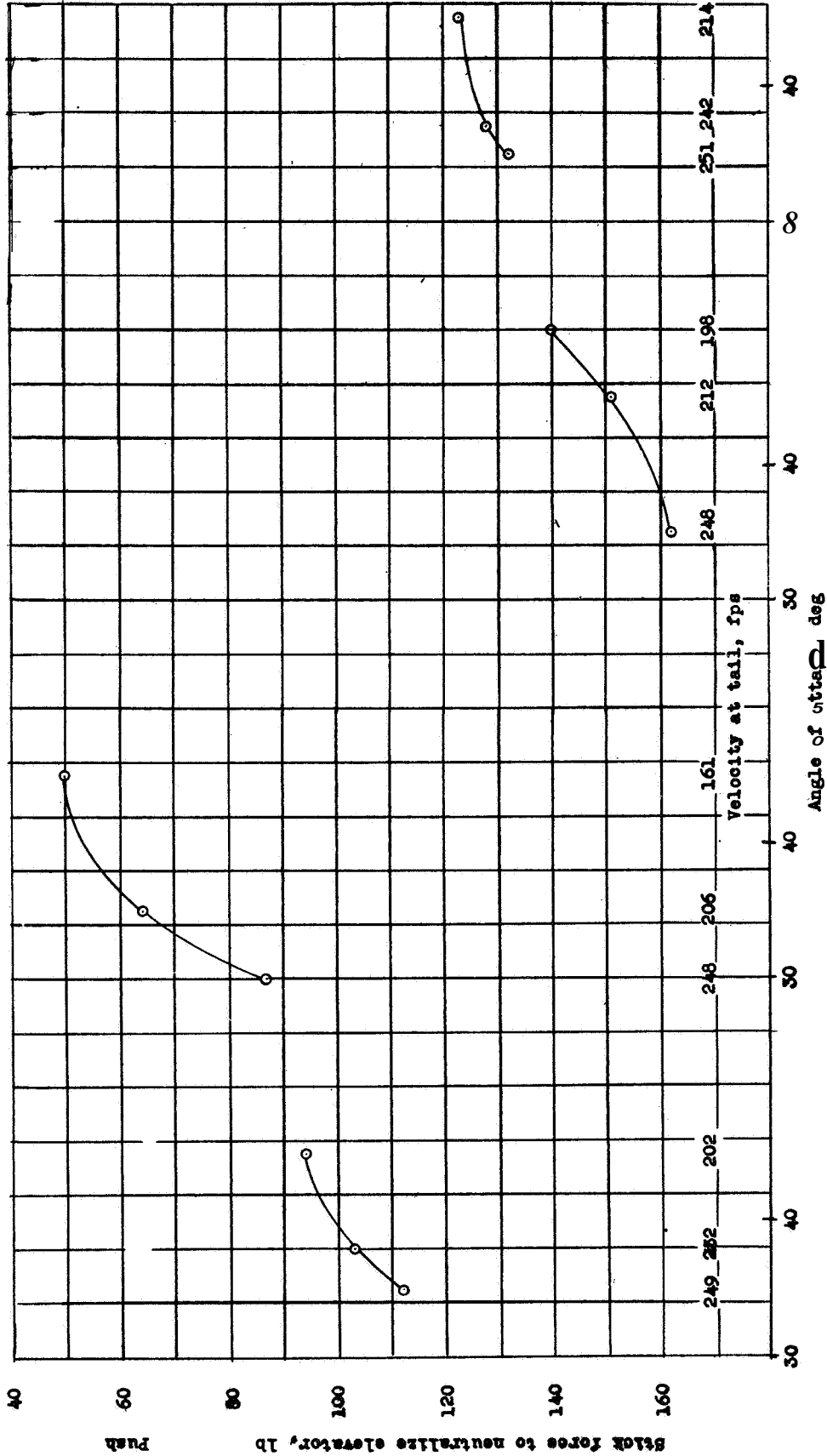
Figure 10.- Continued.
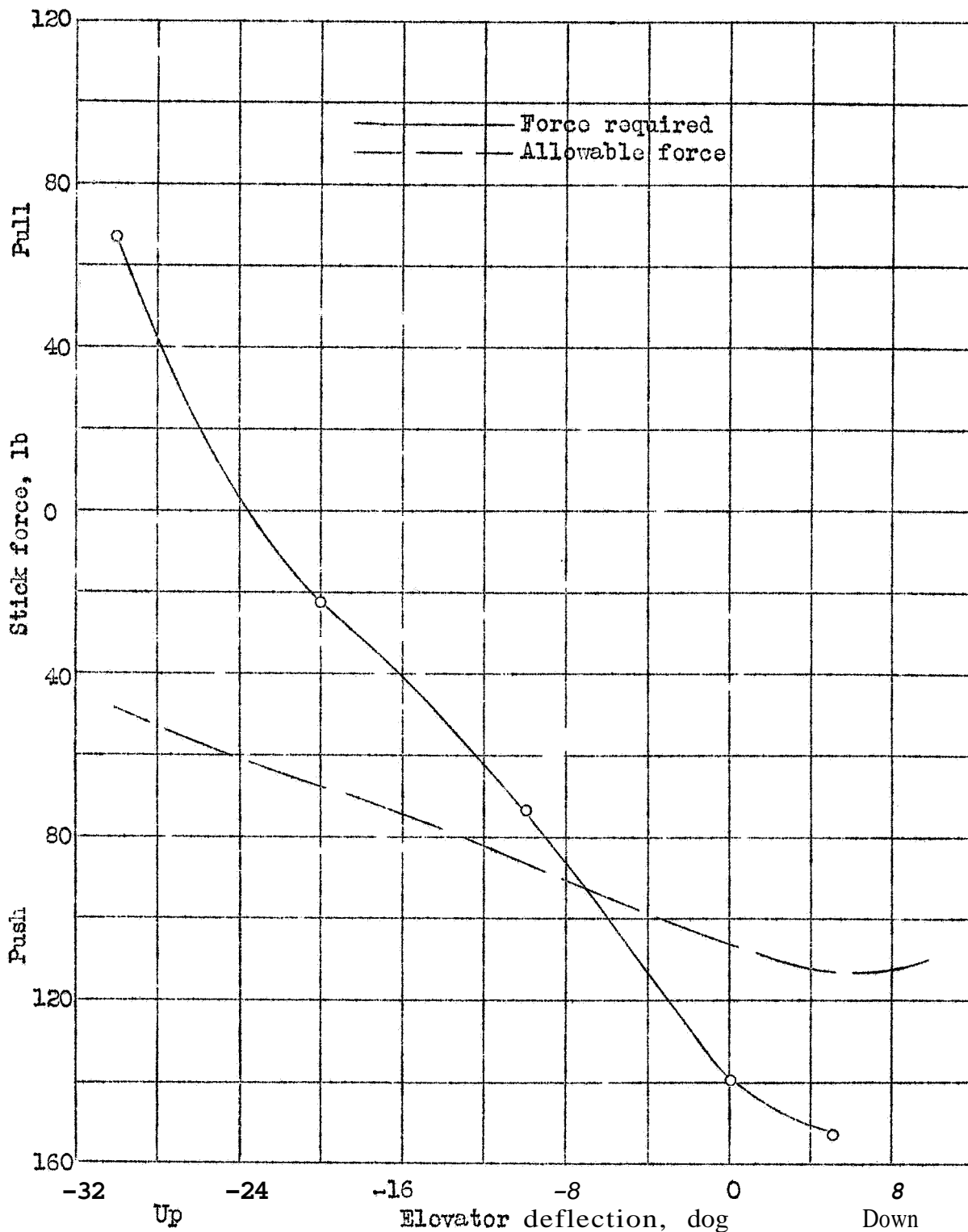
(c) Airplane C. Combination *of* 50-percent blunt-noso balance **and plain**
   elevator; tab neutral; α, 50°; V, **198** foot per second; altitude,
   12,000 foot.

Figure 10.- Continued.

(d) Airplane D. Plain unsealed elevator; tab neutral; α, 37°; V, 242 feet per second; altitude, 10,000 feet.

Figure 10.- Concluded.

Fig. 11

Figure 11.- Stick force to neutralize elevator at various angles of attack.