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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1260

FLIGHT INVESTIGATION OF THE EFFECTS ON AIRPLANE
STATIC LONGITUDINAL STABILITY OF A BUNGEE
AND ENGINE-TILT MODIFICATIONS

By George A. Rathert, Jr.

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SUMMARY

Flight tests have been conducted to evaluate an elevator stick-force bungee and engine tilt as methods of improving the longitudinal-control characteristics of an existing airplane. Particular emphasis was placed on measuring the effect on the stick-free stability in the power-approach condition. The stick-force bungee was the simplest and most effective modification. It is indicated, however, that when large changes in elevator trim-tab angle are required objectionable stick-force changes with speed and power will be induced.

The use of engine tilt reduced the stick-force changes with power, but the stability characteristics were not improved sufficiently to justify the modification.

The effects of both the bungee and the engine tilt could be calculated with sufficient accuracy for a preliminary evaluation of a proposed installation.

A simple flight-test method of selecting the bungee installation required to correct given unsatisfactory stick-free-stability characteristics is presented in an appendix to the report.

INTRODUCTION

It is frequently necessary to modify the longitudinal-stability and -control characteristics of an existing airplane in order to correct critical deficiencies. These deficiencies are most commonly induced by changes in the airplane configuration to meet increased performance requirements, changes in the magnitude and disposition of the useful load, or lack of sufficient information for the preliminary

design or weight and balance estimates. The modifications to be employed should be simple as well as effective and should not change existing satisfactory characteristics. The most effective modifications that can easily be made are the elevator stick-force bungee, engine tilt, and the springy tab, or spring-loaded elevator trim tab.

This report summarizes the results of flight tests of the bungee and engine-tilt modifications installed on a late model carrier-based fighter aircraft which had proved during the service acceptance trials to be unstable stick free in the power-approach condition (carrier-approach). The springy tab was not installed on the test airplane; however, a detailed discussion of this additional type of modification may be found in reference 1.

DESCRIPTION OF AIRPLANE AND MODIFICATIONS

The Basic Airplane

The test airplane was an experimental model of a low-wing, single-place, carrier-based (VF) type monoplane equipped with a tricycle landing gear. The airplane is powered by both a reciprocating engine driving a three-blade tractor propeller, and a jet-propulsion unit mounted behind the pilot's compartment and exhausting through a tail pipe terminating at the extreme aft end of the fuselage. A three-view drawing and the general specifications of the airplane are presented in figure 1 and tables I and II, respectively.

The activity factor of the propeller (per blade) is 120. The propeller side-force factor (per blade) is 112. The force and motion characteristics of the elevator control system are presented in figures 2 and 3. Figure 2 is a plot of the variation of elevator angle with stick position. Figure 3 shows the amount of force required to move the control stick slowly back and forth over its complete range when there are no air loads acting on the tail surfaces. Although figure 3 indicates an acceptably low friction of ± 2 pounds it should be noted that in a case like the present one, where the stick-free stability was such that very low pull forces were required at speeds below the trim speed, the reduction of friction to the minimum possible value is very desirable.

The Modifications

Figure 4 is a schematic diagram of the elevator stick-force-bungee installation. The force characteristics of the

long coil springs connected to the elevator control quadrants were determined from figure 3 by comparing the data with and without the bungee. The springs supplied a force equivalent to a 9.5-pound push on the stick. In addition to the effect of the bungee, the NACA stick-force recorder acted as a bob-weight, adding two more pounds push force for each unit of normal acceleration. This effect was caused by the configuration of the control stick, which is illustrated in figure 4.

The engine-tilt modification was accomplished by the airplane manufacturer by changing a spare front engine and mount so that the thrust axis was tilted 40° nose down with respect to the fuselage reference line. The geometry of this change is given in figure 5. The 40° tilt increased the moment arm of the thrust forces about the center of gravity from 3.6 percent M.A.C. to 9.9 percent M.A.C. in the flap and gear-down configuration.

INSTRUMENTATION

The elevator angle and stick force were recorded photographically by standard NACA instruments synchronized by an electric chronometer. In the range of stick-force data presented the error in elevator angle due to stretch in the control cables between the elevator and the recorder did not exceed $\pm 0.5^\circ$.

The elevator trim-tab data were obtained by applying a calibration made with no load acting on the surface to the values noted by the pilot from the standard cockpit position indicator. The accuracy of the tab-angle data presented is $\pm 0.5^\circ$.

The values of indicated airspeed were determined from a standard NACA recording system connected to a swivelling airspeed head boom. This system was considered to be accurate within ± 2 miles per hour, and no correction for position error was applied.

The normal acceleration factor A_z and engine operating conditions were noted by the pilot from calibrated standard indicating instruments.

TESTS AND RESULTS

The static longitudinal-stability characteristics were measured in each of the four flight conditions specified in

the following table:

Condition	Weight (lb)	Manifold pressure (in. Hg)	Engine speed set- ting (rpm)	Brake- horse- power	Flap and gear posi- tion	Trim speed (mph)
Power-on clean	9300	38	2600	1030	Up	170
Glide	9200	Throttled	Idle	----	Up	Same tab setting as power-on clean
Power- approach	9300	28	2500	730	Down	^a 103
Landing	9200	Throttled	Idle	----	Down	Same tab setting as power- approach

^a1.15V_{SL}

The static longitudinal-stability characteristics of the airplane for each modification configuration are presented in figures 6 through 10 and summarized in table III. The evaluations of table III were made by comparing the characteristics of the modified airplane to the characteristics of the original airplane at two center-of-gravity positions; the normal (27 percent M.A.C.), figure 6, and the forward (22 percent M.A.C.) figure 7.

In each airplane configuration the data for the power-approach and landing conditions were taken at the same elevator trim-tab setting so that the data would show directly the stick-force changes with power as well as those with speed. The same is true of the power-on clean and glide conditions. These stick-force changes have been summarized in table IV.

Tests were also conducted to determine the effect of the modifications on the elevator stick-force gradients in maneuvering flight. These data have been grouped directly into a summary plot in figure 11. The flight conditions are specified on the figure.

DISCUSSION

Bungee

The bungee modification is used to obtain stick-free static longitudinal stability without affecting the stick-fixed characteristics or the elevator stick-force gradients in maneuvering flight. Although it is usually defined and referred to by the characteristics of the spring alone the complete modification actually consists of two related changes in the control system: an increment in nose-up elevator trim tab (down-tab deflection), and a constant tension spring. Since most of the difficulty encountered in the selection of a satisfactory bungee installation is due to the magnitude of the tab deflections required, it is useful to regard this quantity rather than the force of the spring as the primary variable. A more complete discussion of the use of spring moments, from a different point of view, is presented in reference 2. In actual practice, of course, once the size of the spring has been determined the trim tab is used in the normal manner with no definite increment being set by the pilot.

The effect of these two changes is best illustrated by considering the variation of elevator stick force required for level flight with the dynamic pressure q . The increment in tab deflection changes the slope dF_e/dq by rotating the curve about the intercept on the zero q axis. The force of the bungee spring does not affect the slope but shifts the curve parallel to the force axis a constant amount equal to the force required to hold the stick in neutral with no load acting on the control surfaces. In terms of the flight-test data used to demonstrate stick-free stability, the increment in trim-tab angle changes the stick-force gradient dF_e/dV_1 to the desired value and the bungee spring displaces the curve sufficiently to restore trim ($F_0 = 0$) at the desired speed. A flight-test method of selecting the bungee installation required to correct given unsatisfactory stick-free-stability characteristics is presented in appendix B.

A summary is presented in figure 12 of the effect of 140 more nose-up tab and bungee spring of 9.5 pounds on the stick-free characteristics of the airplane in the power-approach condition. The characteristics calculated from the tab-effectiveness data of figure 13 and the equations used in appendix B agree quite well with the flight-test data.

Although the desired degree of stick-free stability was readily obtained by use of the bungee modification, the large increment in trim tab necessary induced objectionable

stick-force changes with speed in the high-speed range and with power. As noted in table IV, the additional pull force required when the power is reduced from the power-approach condition to the landing condition was increased from 4 to 11 pounds. Increasing the speed from 170 to 350 miles per hour without retrimming resulted in a push force of 20 pounds when the bungee was installed as compared to 11 pounds without the bungee. Although these stick-force changes are not excessive they were regarded as objectionable and might become excessive on some designs. The stick-force changes with speed inherent in the bungee design might be eliminated by changing to the springy tab modification discussed in reference 1.

The magnitude of the stick-force changes with power induced by the bungee installation depends on the amount of additional tab deflection used and the effect of the slipstream on the trim-tab effectiveness $dF_e/d\delta_t$. If the trim-tab deflection which requires the entire bungee force for trim in the power-approach condition is much less effective when the power is cut, the major portion of the constant bungee spring force remains as an increment to the stick-force changes. For this change of power in the test installation the tab effectiveness was reduced 50 percent as the data in figure 13 indicate.

These stick-force changes can be lowered by reducing the effect of the slipstream on the tab. A set of elevators having trim tabs located approximately 30 inches outboard of the position indicated in figure 1 were proposed and tested by the staff of the Ames 40- by 80-foot wind tunnel. The test data, showing the variation in $dC_{he}/d\delta_t$ (which results from the variation in q_{tab}/q_0), are reproduced in figure 14. The effect of slipstream, although still large, is definitely reduced on the outboard tabs. The effect of change of power on the stick forces required for trim would be proportionally reduced.¹

¹Similar considerations apply to the use of a springy tab, since its effectiveness depends primarily upon the variation of q_{tab} with flight speed. Tests in the Ames 40- by 80-foot wind tunnel indicated that for the test airplane in the power-approach configuration the action of the slipstream was such that, with decreasing speed, q_{tab}/q_0 increased as q_0 decreased, thereby reducing the variation of q_{tab} with flight speed and the potential effectiveness of a springy tab installation.

Although the tab effectiveness in the power-on clean condition was not measured in flight it should be noted that large trim-tab deflections used to obtain stability at low speeds will be much more effective at high speeds and induce large stick-force changes with speed.

The data of figure 11 show that, as expected, the bungee modification did not affect the stick-force gradients in maneuvering flight.

Engine Tilt

The use of an inclined thrust axis to reduce the destabilizing effects of power results in greater negative pitching-moment slopes, $\partial C_m / \partial C_L$ at T_0 for constant power, in effect moving both the stick-fixed and stick-free neutral points aft. The method of reference 3 has been used to compute the effect of 4° tilt on the pitching moment of the test airplane equipped with double-slotted flaps in the power-approach condition. The increments of pitching moment are presented in figure 15 as a function of airplane lift coefficient. At a lift coefficient of 1.24 corresponding to the trim speed of 1.15 V_{S_L} or 103 miles per hour, the total change in $\partial C_m / \partial C_L$ is -0.012, corresponding to an approximate rearward movement of the stick-fixed neutral point of only 1.2 percent M.A.C.

The effects of tilt as measured in flight in the power-approach condition are summarized in figure 16. The data of figure 15 and unpublished elevator-effectiveness data were used to compute the stick-fixed characteristics of the airplane with tilt. The calculated effect agrees very well with that measured, indicating that the method of reference 3 is satisfactory for use in the preliminary evaluation of a proposed modification.

No unsatisfactory effects induced by tilt were noted during the flight tests. The stick-force changes with power were generally reduced as indicated by the data in table IV. This effect is explained by the fact that the tilt reduces the normal nose-up pitching moment due to power, consequently reducing the δ_0 change, and therefore the force change, required. The trim-tab effectiveness in the power-approach condition was not changed.

The stick-force gradients in maneuvering flight were also unaffected, as shown in figure 11. This would be expected, since the tilt affects only the $\partial C_m / \partial C_L$ at T_0 for constant power and not $\partial C_m / \partial C_L$ at constant T_0 .

The data of figure 15 indicate that most of the effect of tilt on the pitching-moment slope is due to the direct propeller-thrust forces. The effectiveness of any proposed tilt installation therefore depends mainly on the amount of increase of the moment arm of the thrust forces about the airplane center of gravity. In order to obtain the maximum benefit from a given degree of tilt, the point of rotation of the engine installation obviously should be as far forward as possible. As shown in figure 5 in the present test installation the thrust moment arm would have been 43 percent larger if the engine could have been rotated about the propeller hub rather than the firewall. The movement of the stick-fixed neutral point would have been increased roughly from 1.2 to 2.5 percent M.A.C. Unfortunately the position of the point of rotation is usually fixed fairly well aft because of the necessity of avoiding complicated cowling and fuselage nose structure changes.

It should be emphasized that it is necessary to simulate the full-scale airplane installation very carefully when powered wind-tunnel models are used to evaluate a proposed application of tilt. It is very important to insure that the thrust moment arm is constant, that is, that the particular position of the center of gravity with respect to the thrust line is held constant.

The tilt modification is obviously less effective and flexible than the bungee, particularly when applied to an existing airplane.

CONCLUSIONS

The following conclusions have been drawn from consideration of the modifications as methods of improving the static longitudinal-stability characteristics of an existing airplane:

1. The elevator stick-force bungee was the simpler and more effective modification, although objectionable stick-force changes with speed in the high-speed range and with power were induced by the large increments in elevator trim-tab angle required. The stick-force changes with power could have been reduced by moving the elevator trim tabs outboard to reduce the effect of the slipstream.
2. Even though desirable reductions in the stick-force changes with power were obtained, the engine-tilt modification was not effective enough in this application to warrant using it solely to increase static stability. The effectiveness would have been increased if the engine installation could

have been rotated about the propeller hub rather than a point farther aft on the firewall.

3. The effects of both the bungee and tilt modifications could be computed with satisfactory accuracy for a preliminary evaluation of a proposed modification.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., December 2, 1946.

APPENDIX

SYMBOLS

Standard NACA symbols used throughout this report are as follows:

A_z	the ratio of the net aerodynamic force along the airplane Z-axis (positive when directed upward) to the weight of the airplane
C_{h_e}	elevator hinge-moment coefficient
C_{h_δ}	rate of change of elevator hinge moment with elevator angle at constant airplane lift coefficient
$\partial C_m / \partial C_L$	rate of change of airplane pitching moment with airplane lift coefficient at T_0 for constant power
C_L	airplane lift coefficient
C_m	airplane pitching-moment coefficient
D	propeller diameter, feet
F_e	elevator stick force (pull force positive), pounds
H.A.C.	mean aerodynamic chord, feet
q	dynamic pressure ($\frac{1}{2}\rho V^2$), pounds per square foot
T	axial propeller thrust, pounds
T_0	thrust coefficient ($T/\rho V^2 D^2$)
V	true airspeed, feet per second
V_i	indicated airspeed, miles per hour, defined by the usual formula by which standard airspeed meters are calibrated

V_{SL}	airplane stalling speed in the landing configuration (flaps and gear down)
δ_e	elevator angle measured with respect to the horizontal stabilizer (down-elevator positive), degrees
δ_t	elevator trim-tab angle measured with respect to the elevator (down-tab positive), degrees
stick force per g	$\frac{\text{change in elevator stick force from trim}}{\text{change in } A_z \text{ from trim}}$

Special subscripted symbols used in appendix B are as follows:

F_e	elevator stick force at any speed with the bungee installed
F_{e0}	elevator stick force at any speed without the bungee installed
$dF_e/d\delta_t$	rate of change of elevator stick force with trim-tab angle at constant airspeed

The value of the above quantities at a given airspeed is specified by placing the quantity in brackets and appending one of the following subscripts:

$V_{i\text{trim}}$	trim airspeed (F_e and $F_{e0} = 0$)
V_{i_1}	some arbitrary airspeed $V_{SL} < V_{i_1} < V_{i\text{trim}}$
$V_{i\text{max}}$	maximum level-flight airspeed

Thus

$(F_e)_{V_{i_1}}$	elevator stick force with bungee installed at an arbitrary airspeed $V_{SL} < V_{i_1} < V_{i\text{trim}}$
-------------------	---

- F_{eB} increment of elevator stick force due to addition of bungee spring identified as the force required to hold the stick in neutral with no load on the control surfaces
- $\Delta\delta_t$ change in elevator trim-tab angle required to restore trim ($F_e=0$) with the bungee installed at a given trim speed and in a condition specified by the subscripts
- Subscripts
- PA power-approach condition
- P power-on clean condition
- L landing condition

APPENDIX B

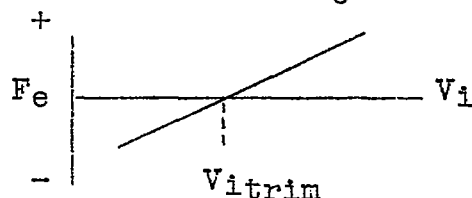
FLIGHT-TEST METHOD OF SELECTING A SATISFACTORY BUNGEE INSTALLATION

Given an airplane with unsatisfactory stick-free stability characteristics, a flight-test method of selecting a satisfactory corrective bungee installation is presented in the following outline:

I. Selection of bungee installation.

- A. Flight-test data required (measured at normal center-of-gravity position in critical condition, in this case power-approach).

1. Variation of F_{e0} with V_i

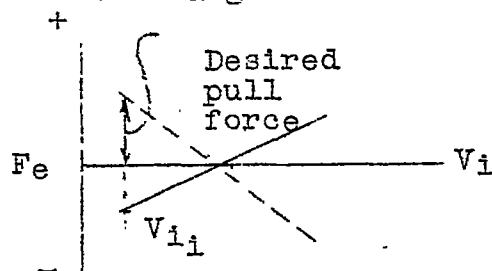


2. $dF_e/d\delta_t$ at $V_{i_{trim}}$ and V_{i_1}

3. Stick-force friction (should be < 2 pounds)

- B. Determine desirable pull force at V_{i_1} from pilot's comment or criteria such as presented in reference 4 where stick-force equals $-0.05 (V_{i_1} - V_{i_{trim}})$ provided that the friction is less than 2 pounds.

- C. The desired change is



Note that the desired stick-free characteristics are approximated by specifying the force at only two speeds, V_{i_1} and $V_{i_{trim}}$; the exact stick-force gradient is not determined. The change is produced by changing the trim-tab angle an amount $\Delta\delta_t$ and adding a constant bungee spring force F_{eB} identified as the elevator stick-force required to hold the control stick in neutral with

no load acting on the surface. The effect of these two changes on the stick force at a given airspeed is

$$F_e = F_{e0} + F_{eB} + (dF_e/d\delta_t)\Delta\delta_t$$

D. The equations for the two specified points on the desired stick-force variation with indicated airspeed are

$$\text{at } V_{i1}, (F_e)_{V_{i1}} = (F_{e0})_{V_{i1}} + F_{eB} + (dF_e/d\delta_t)_{V_{i1}} \Delta\delta_{tPA} \quad (1)$$

$$\begin{aligned} \text{at } V_{i\text{trim}}, (F_e)_{V_{i\text{trim}}} &= (F_{e0})_{V_{i\text{trim}}} + F_{eB} \\ &+ (dF_e/d\delta_t)_{V_{i\text{trim}}} \Delta\delta_{tPA} \end{aligned} \quad (2)$$

Noting that both $(F_e)_{V_{i\text{trim}}}$ and $(F_{e0})_{V_{i\text{trim}}}$ are zero by definition, solving equation (2) for F_{eB} and substituting in equation (1)

$$F_{eB} = -\left(\frac{dF_{e0}}{d\delta_t}\right)_{V_{i\text{trim}}} \Delta\delta_{tPA}$$

$$\Delta\delta_{tPA} = \frac{(F_e)_{V_{i1}} - (F_{e0})_{V_{i1}}}{\left(\frac{dF_e}{d\delta_t}\right)_{V_{i1}} - \left(\frac{dF_e}{d\delta_t}\right)_{V_{i\text{trim}}}}$$

II. Consideration of possible unsatisfactory induced effects.

A. Flight-test data required.

1. Stick-force change at $V_{i\text{trim}}$ due to cutting power from the power-approach condition to the landing condition without retrimming, $\Delta F_{e\text{power}}$.
2. Stick-force change encountered in increasing speed from $V_{i\text{trim}}$ to $V_{i\text{max}}$ in power-on clean condition, $\Delta F_{e\text{speed}}$.
3. $dF_e/d\delta t$ at $V_{i\text{trim}}$ in the landing condition and at $V_{i\text{max}}$ and $V_{i\text{trim}}$ in the power-on clean condition.

B. Stick-force change with power with bungee installed will be

$$\Delta F_{e\text{power}} = \Delta F_{e\text{power}}$$

$$+ \Delta \delta t_{\text{PA}} \left[\left(\frac{dF_e}{d\delta t} \right)_{L V_{i\text{trim}}} - \left(\frac{dF_e}{d\delta t} \right)_{\text{PA} V_{i\text{trim}}} \right]$$

$\Delta F_{e\text{power}}$ should be < 35 pounds.

C. Ability to trim in landing condition with bungee installed. Tab angle required for trim in landing condition with bungee installed will be

$$\delta t_L = \delta t_{L_0} + \Delta \delta t_{\text{PA}} + \Delta F_e \times \frac{1}{(dF_e/d\delta t)_{L V_{i\text{trim}}}}$$

δt_L must be within tab-angle range.

- D. Stick-force changes with speed. Stick-force change due to increasing speed from $V_{i\text{trim}}$ to $V_{i\text{max}}$ in the power-on clean condition with the bungee installed will be

$$\Delta F_{e\text{speed}} = \Delta F_{e\text{ospeed}}$$

$$+ \Delta \delta t_p \left[\left(\frac{dF_e}{d\delta t} \right)_{P_{V_{i\text{max}}}} - \left(\frac{dF_e}{d\delta t} \right)_{P_{V_{i\text{trim}}}} \right]$$

$\Delta F_{e\text{speed}}$ should be < 35 pounds.

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1. Hunter, Paul A., and Reeder, John P.: Flight Measurements to Determine Effect of a Spring-Loaded Tab on Longitudinal Stability of an Airplane. NACA Wartime Rep. L-210. (Originally issued as NACA ARR No. L5120, 1946.)
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3. Goett, Harry J., and Delany, Noel K.: Effect of Tilt of the Propeller Axis on the Longitudinal-Stability Characteristics of Single-Engine Airplanes. NACA ACR No. 4E29, Nov. 1944. (Classification changed to Unclassified.)
4. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. Wartime Rep. L-276. (Originally issued as NACA ACR, April 1941.)

TABLE I.- BASIC DIMENSIONAL DATA OF THE TEST AIRPLANE.

Item	Wing	Horizontal tail	Vertical tail
Area, sq ft.....	275	63.86	31.35
Span, ft.....	40	17.5	6.79
Aspect ratio.....	5.82	4.45	1.45
Taper ratio.....	0.5	0.667	0.353
M.A.C., in.....	87.55	49.3	61.95
Dihedral of chord plane, deg.....	7.5	0	---
Incidence of root chord to thrust line, deg.....	1	1.5	---
Geometric twist, deg.....	0	0	0
Root section.....	65,2-117(a=1.0)	65,2-015 modified	63,2-012 modified
Tip section.....	65,2-115(a=0.5)	65,2-015 modified	63,2-012 modified
Percent straight line..	0	65	84.55
Tail length, ft (from 0.25 M.A.C. of wing to 0.25 M.A.C. of tail).....	-----	17.46	18.69
Tail volume, $\frac{l_H S_H}{S_{wtw}}, \frac{l_V S_V}{S_{wbw}}$	-----	0.600	0.054

TABLE II.— DIMENSIONAL CHARACTERISTICS OF THE MOVABLE SURFACES OF THE TEST AIRPLANE.

Item	Elevators	Rudder	Flaps	Ailerons
Area aft of hinge line (sq ft, both sides)	20.84	8.92	39.6	12.8
Area affected by movable surface (sq ft)	58.83	26.44	165.4	72.0 (approx.)
Span (ft, one side)	7.85	5.98	10.03	7.54
M.A.C. (ft)	1.365	1.532	---	0.958
Hinge-line location (percent chord)	65.0	---	---	11.5 in. from trailing edge
Aerodynamic balance and type of flap	Internally sealed between hinges (fig. 1)	Overhanging sealed	Double slotted	Sealed internal
Travel (deg)	12.5 down 27.5 up	29.6 right and left	35 down	22 up, 13 down
Tabs	Trim (area 1.27 sq ft, each; span 1.812 ft) 25° travel up and down	Trim (area 0.506 sq ft span 1.5 ft) 25° travel right and left	---	Trim on left aileron only (area 0.89 sq ft, span 2.81 ft) 15° travel up and down

TABLE III.- MODIFICATION CONFIGURATIONS AND EVALUATIONS.

20

Approximate center of gravity location (percent H.A.C.)	Bungee force (lb)	Engine tilt (deg)	Figure number	Evaluation	Remarks
27	---	---	8	Unsatisfactory	Unstable in power-approach condition, unfavorable stick-force gradient at low speeds in power-on clean condition.
21.5	---	---	9	Marginally satisfactory	Neutral stability in power-approach condition, stick-force changes with power larger than desirable
27	9.5	---	10	Satisfactory	Stick-force changes with power and with speed in the high-speed range larger than desirable.
27	---	4	11	Marginally satisfactory	Neutral stability in power-approach condition, unfavorable stick-force gradient at low speeds in the power-on clean condition.
27	9.5	4	12	Marginally satisfactory	Airplane cannot be trimmed in power approach condition, stick-force changes with power and speed in the high-speed range larger than desirable, excessive stick force required to land.

NACA TN No. 1260

TABLE IV.- STICK-FORCE CHANGES DUE TO POWER AND TO SPEED IN THE HIGH-SPEED RANGE.

Center of gravity (percent M.A.C.)	Bungee force (lb)	Tilt	Flaps	δt (deg)	Stick force changes		
					^a Power in power-approach condition (lb)	^b Power in power-on clean condition (lb)	^c Speed in power-on clean condition (lb)
27	None	None	Double-slotted	4 Nose up	4.0	3.5	-11.0
21.5	None	None	Double-slotted	16 Nose up	11.5	5.0	-16.5
27	9.5	None	Double-slotted	18 Nose up	11.0	8.0	-20.0
27	None	4°	Double-slotted	8 Nose up	3.5	1.5	-10.0
27	9.5	4°	Double-slotted	Full nose up	^d 10.0	4.0	-26.0
27	None	None	Single-slotted	3.5 Nose down	1.5	---	---
27	7.5	None	Single-slotted	6 Nose up	6.5	---	---

^a Measured at trim speed (1.15 V_{SL}) while reducing brake horsepower from 730 to 0.^b Measured at trim speed while reducing brake horsepower from 1030 to 0.^c Measured from trim speed, 170, to 350 miles per hour.^d Could not be trimmed at 1.15 V_{SL} in power-approach condition.

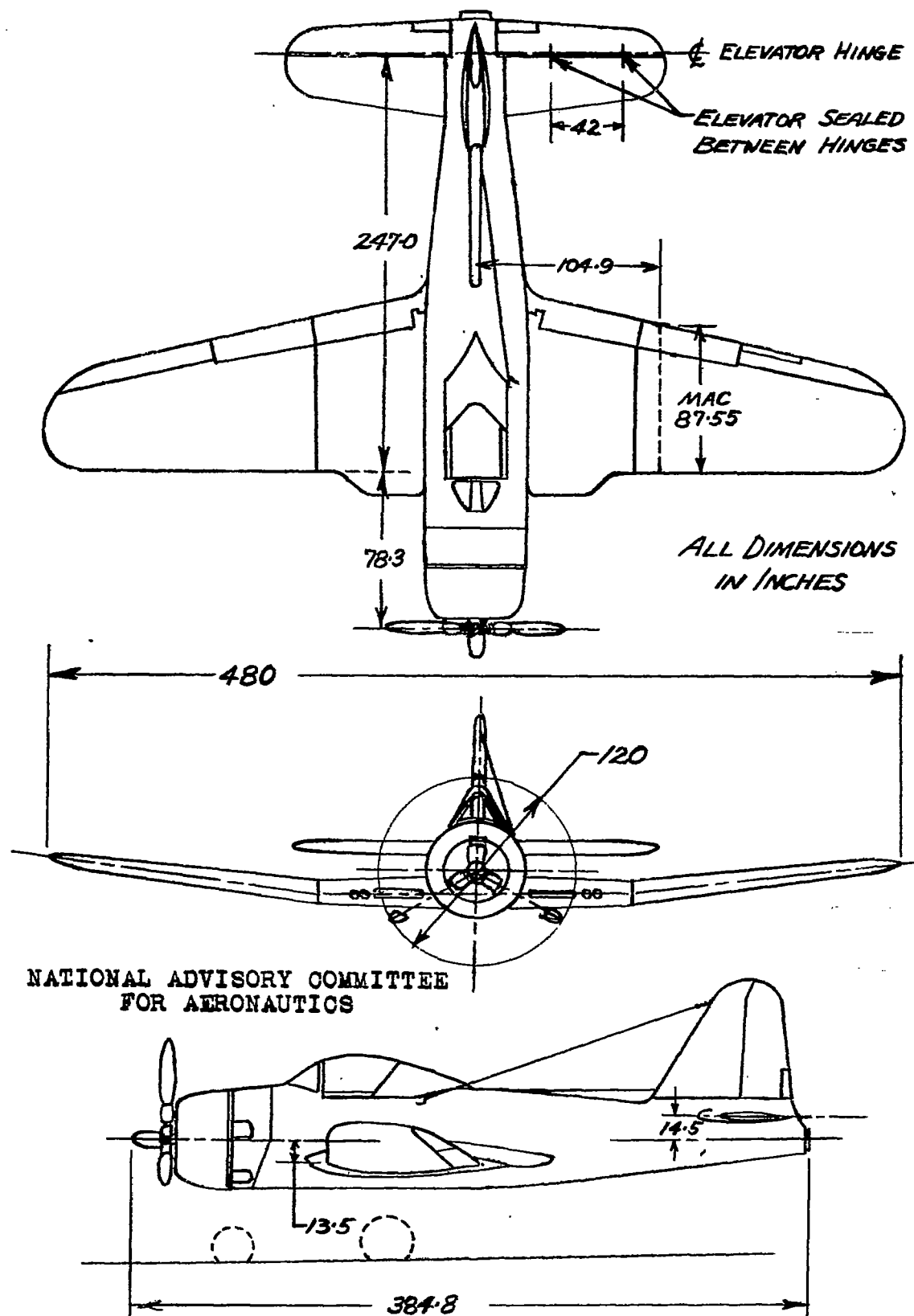
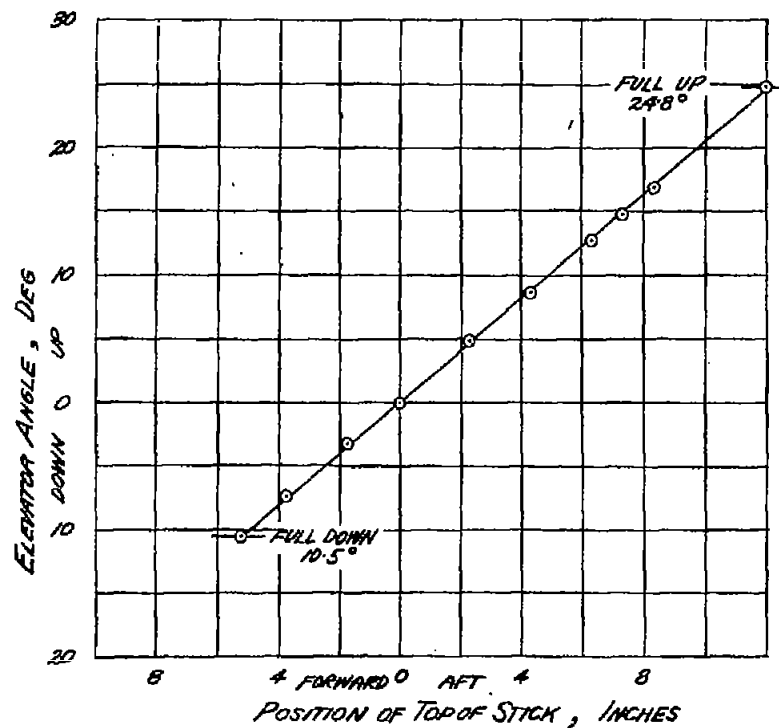


FIGURE 1. — GENERAL ARRANGEMENT OF THE TEST AIRPLANE.



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FIGURE 2. — ELEVATOR CONTROL GEARING.

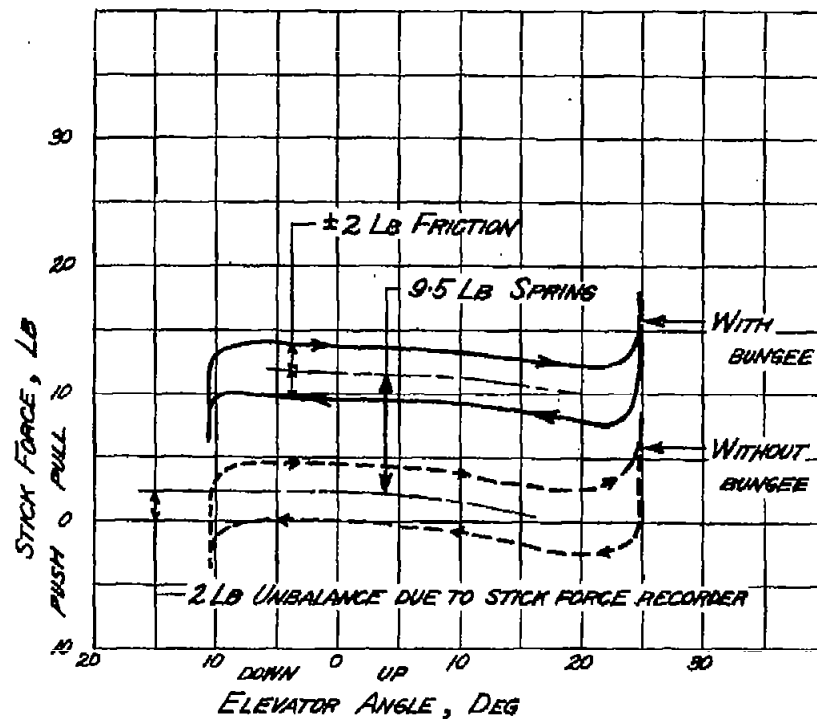


FIGURE 3. — STICK-FORCE VARIATION WITH STICK
MOVEMENT AT NO-LOAD CONDITION FOR
ELEVATOR CONTROL SYSTEM WITH AND
WITHOUT BUNGEE.

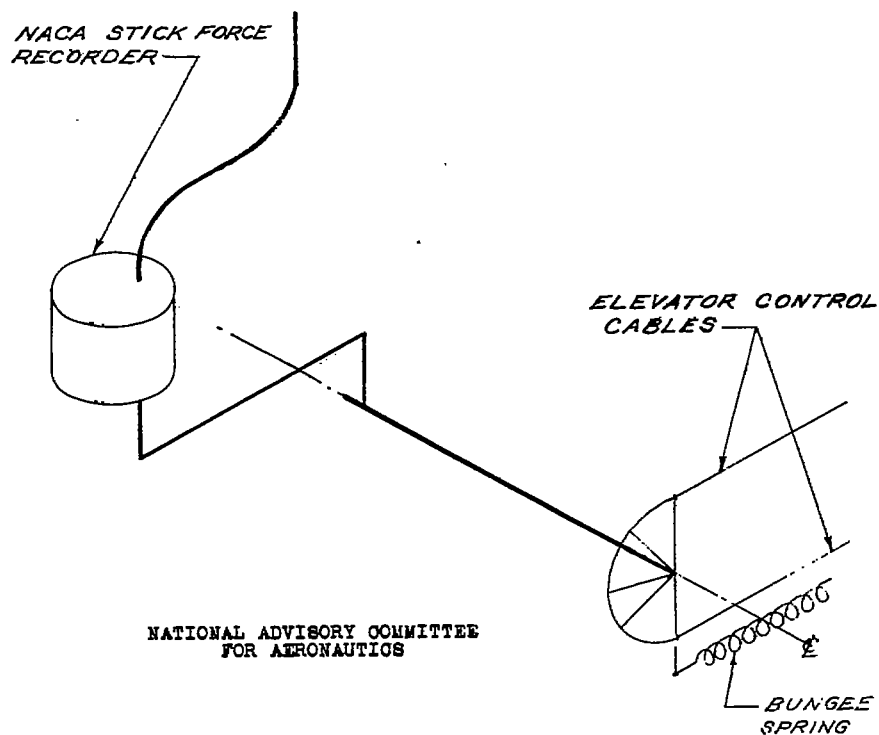


FIGURE 4. — SCHEMATIC DIAGRAM OF ELEVATOR STICK FORCE BUNGEE AND NACA STICK FORCE RECORDER INSTALLATION.

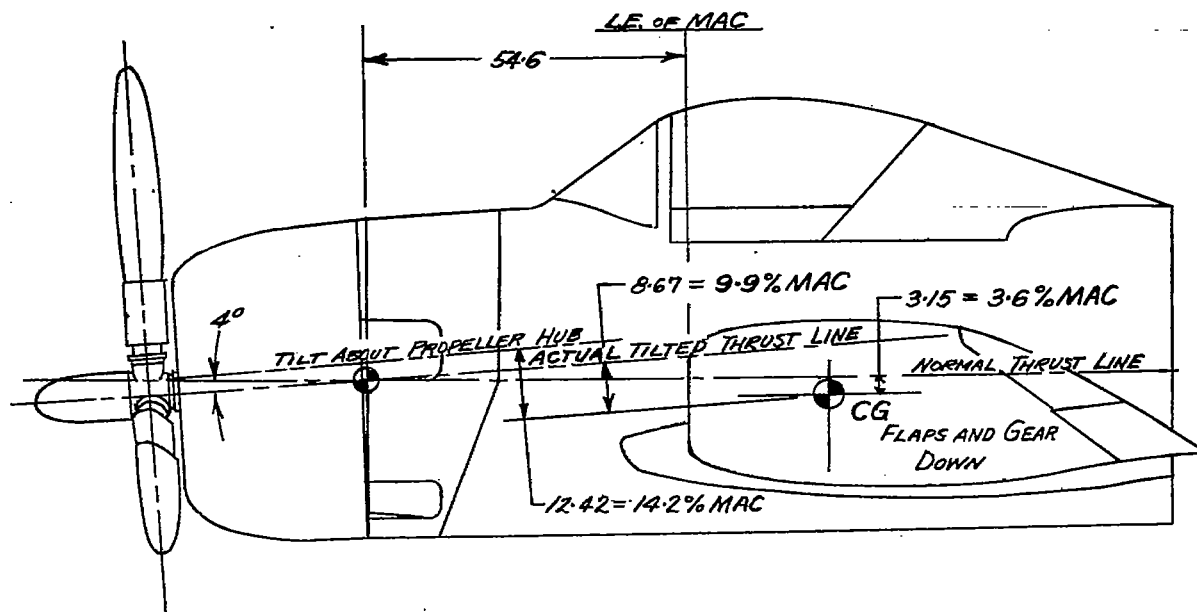


FIGURE 5. — THE GEOMETRY OF THE ENGINE-TILT MODIFICATION.

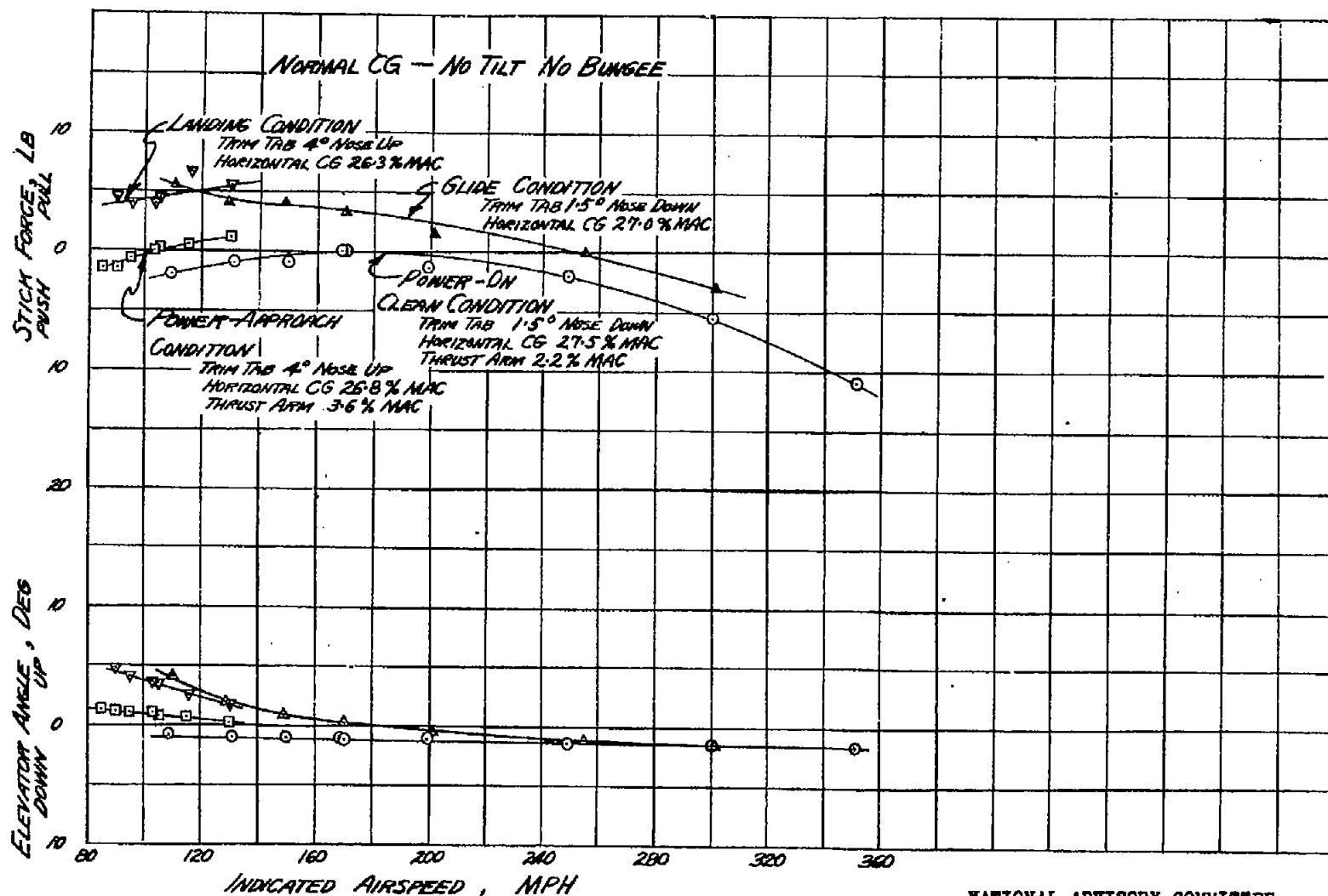


FIGURE 6. — STATIC LONGITUDINAL STABILITY AT NORMAL CG (27% MAC) WITHOUT ENGINE TILT OR STICK FORCE BUNGEE.

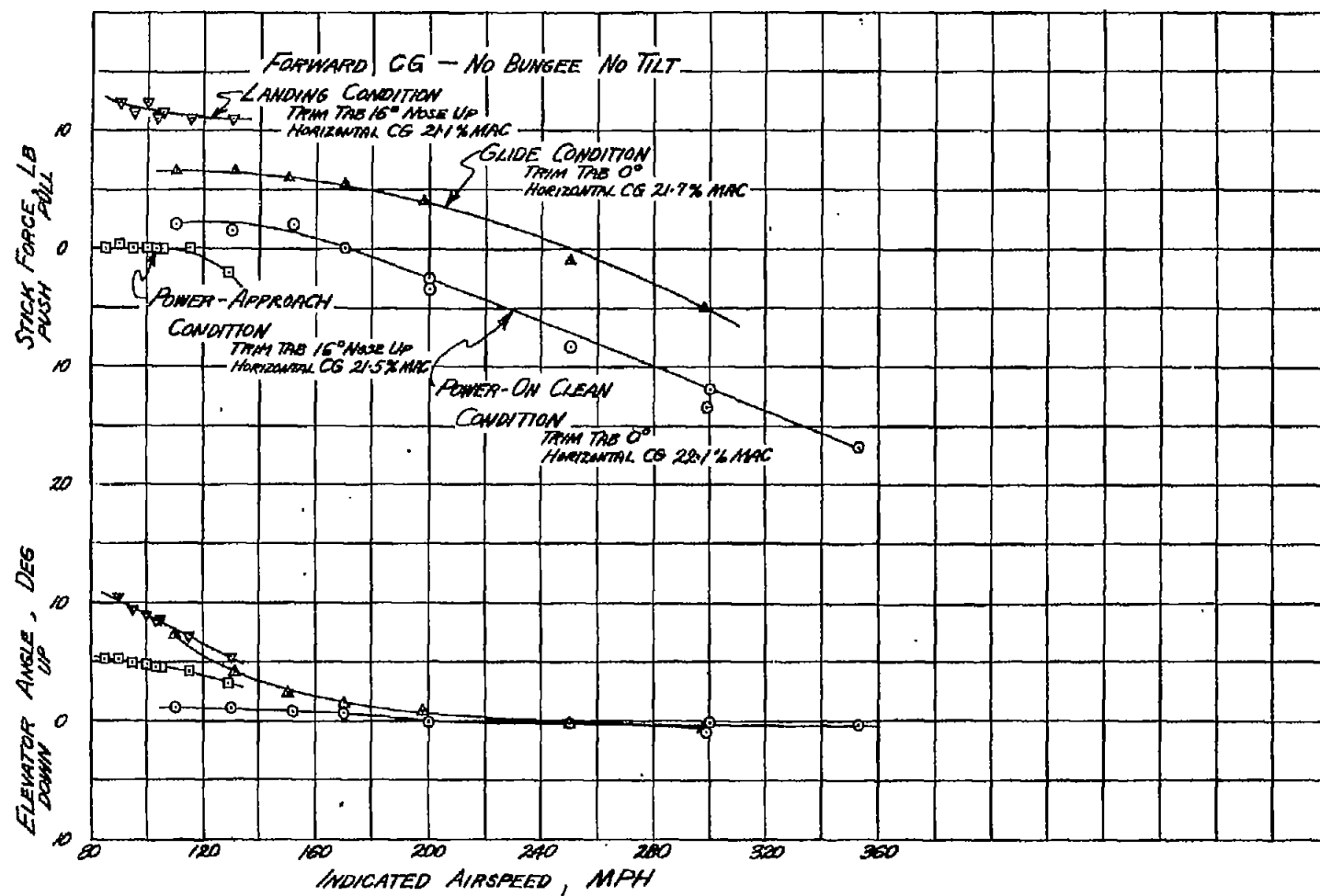
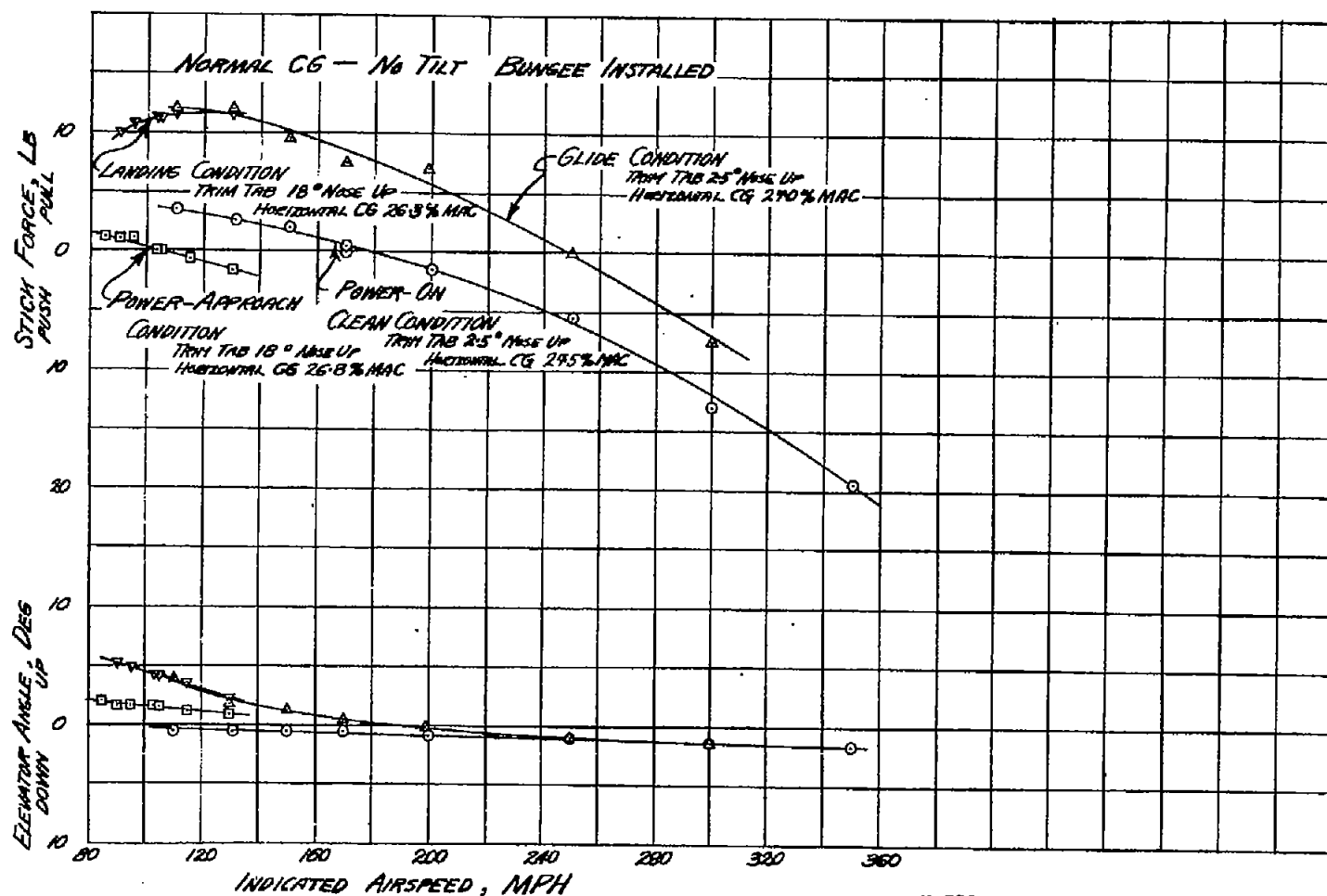
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FIGURE 7. — STATIC LONGITUDINAL STABILITY CHARACTERISTICS AT CG = 22% MAC,
NO ENGINE TILT OR STICK FORCE BUNGEE.



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FIGURE 8. — STATIC LONGITUDINAL STABILITY AT NORMAL C.G. WITH ELEVATOR STICK FORCE BUNGEE INSTALLED AND NO ENGINE TILT.

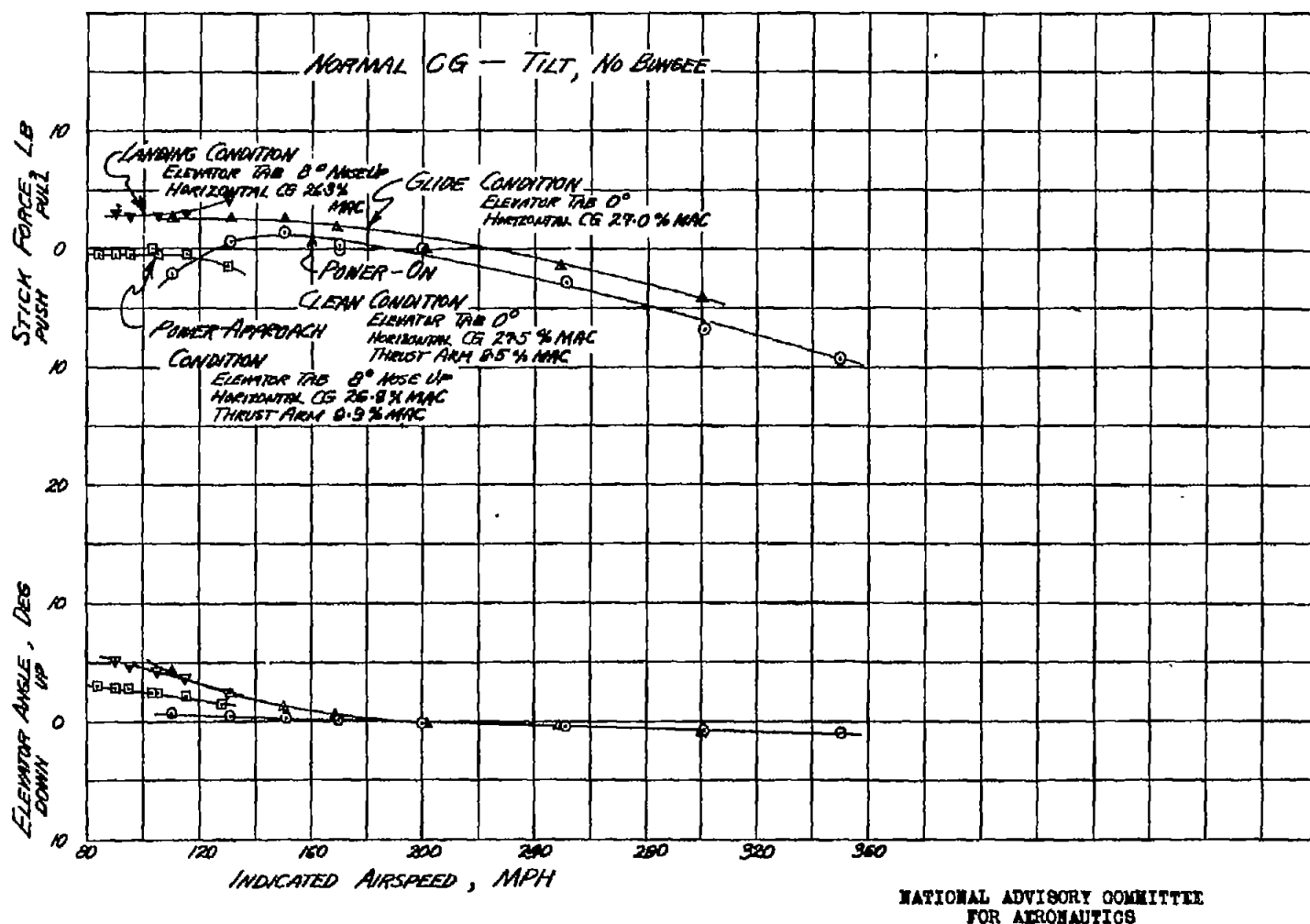


FIGURE 9. — STATIC LONGITUDINAL STABILITY AT NORMAL CG WITH TILTED ENGINE, WITHOUT STICK FORCE BUNGEE.

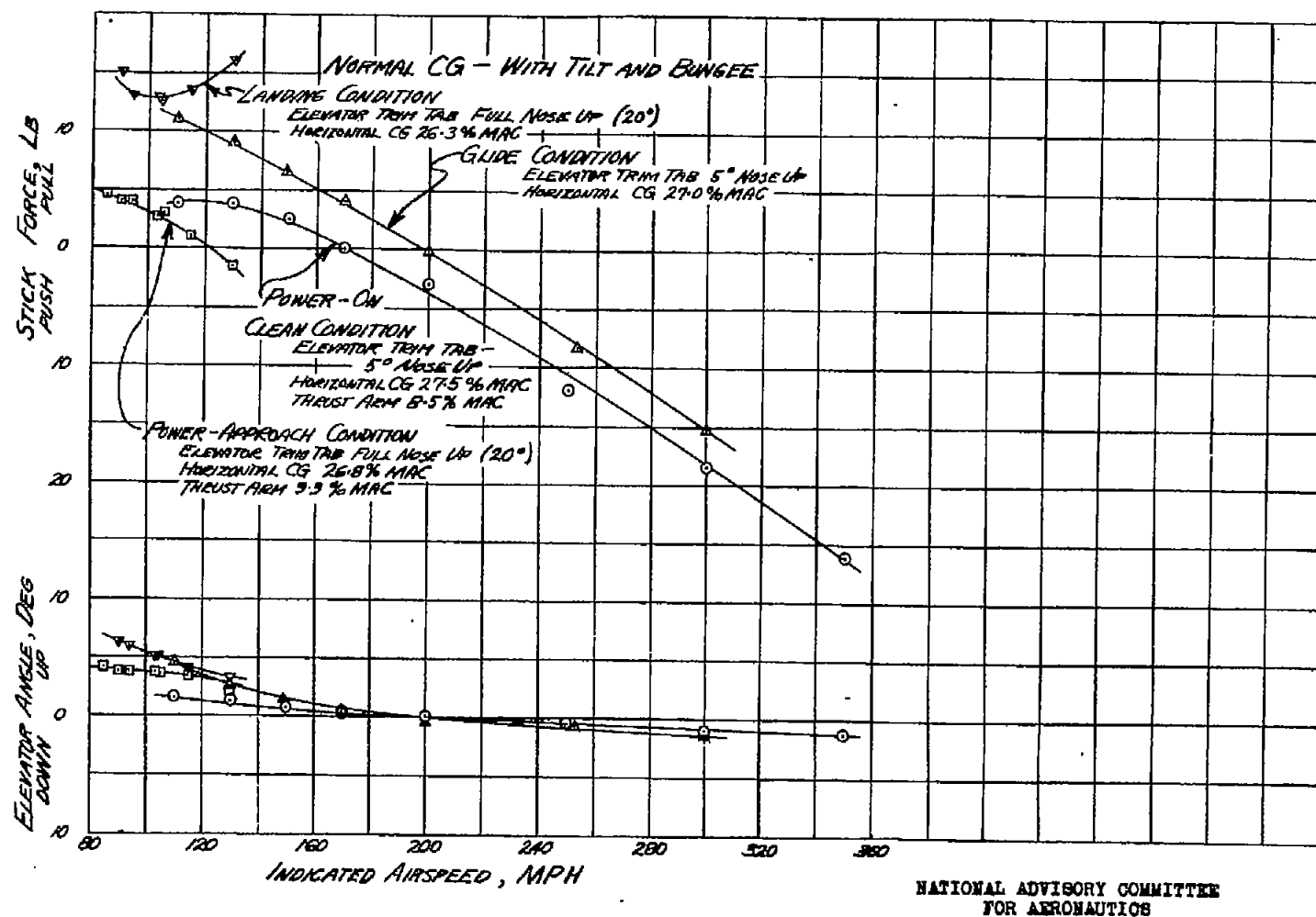


FIGURE 10. — STATIC LONGITUDINAL STABILITY AT NORMAL CG WITH BOTH ENGINE TILT AND STICK FORCE BUNGEE MODIFICATIONS.

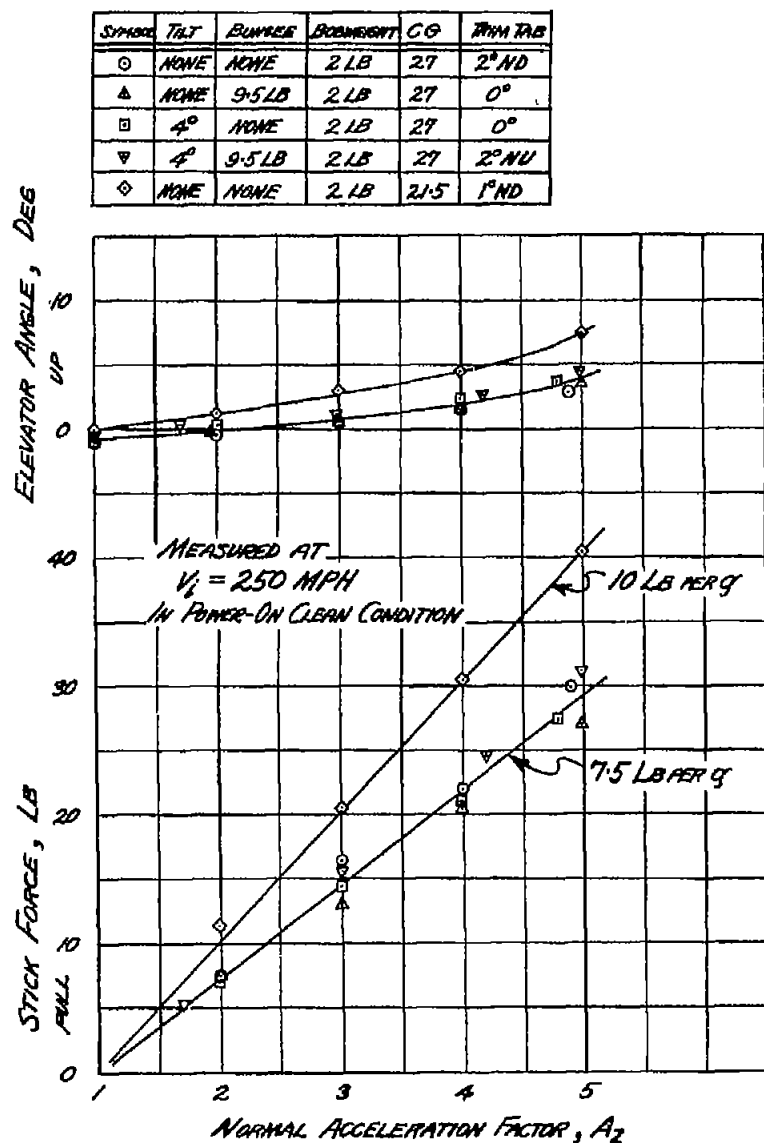
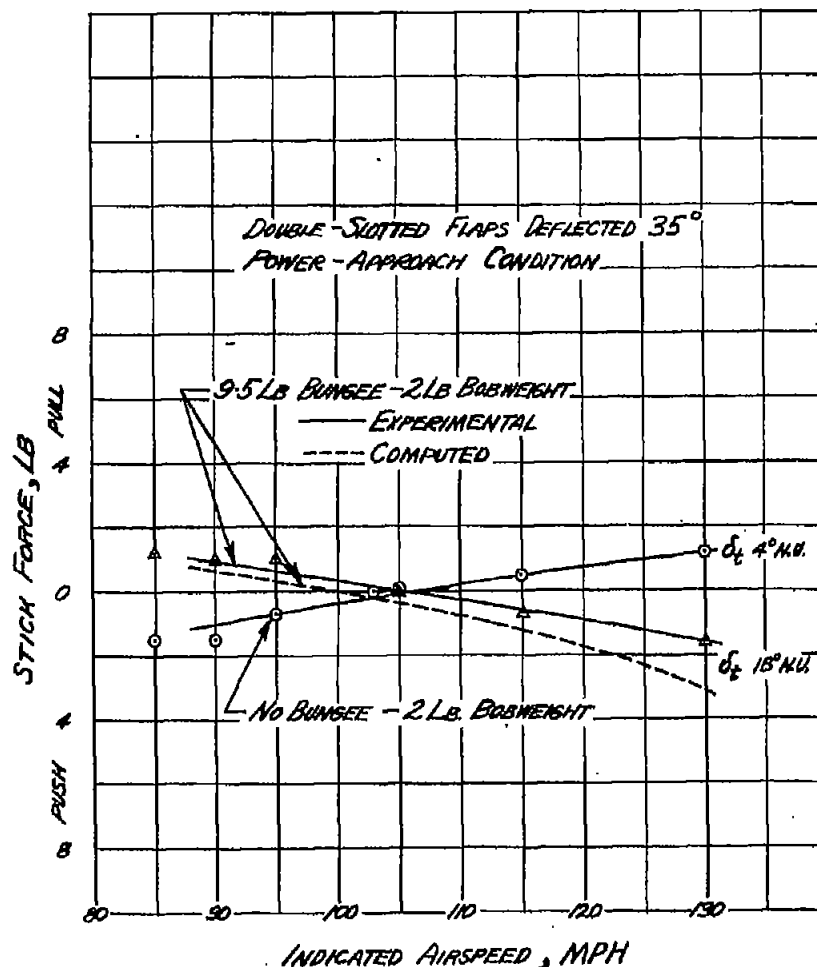
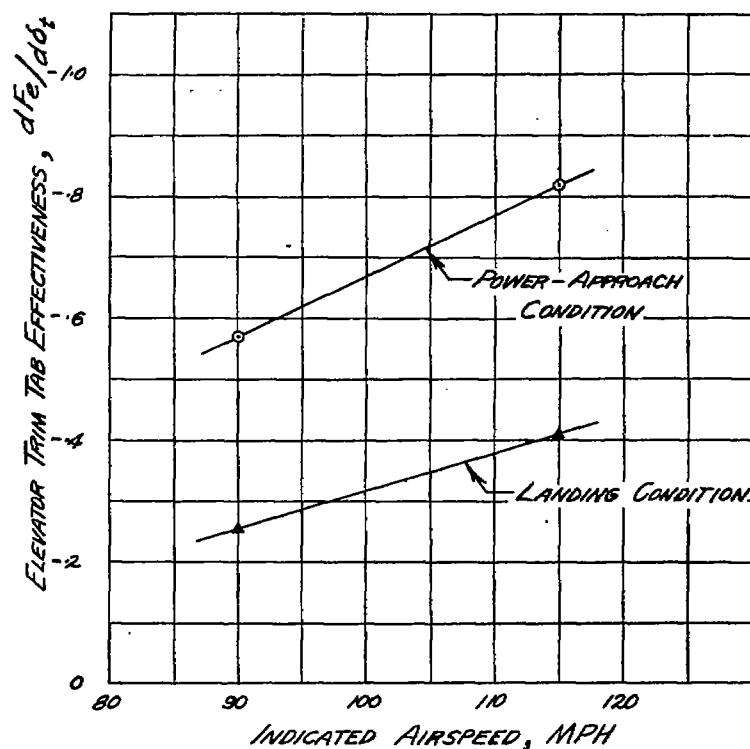


FIGURE 11. — THE EFFECT OF THE TWO MODIFICATIONS ON THE STICK-FORCE CHARACTERISTICS OF THE AIRPLANE IN MANEUVERING FLIGHT.



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FOR AERONAUTICS

FIGURE 12. — THE EFFECT OF AN ELEVATOR STICK FORCE BUNGEE ON THE STICK-FREE STATIC LONGITUDINAL-STABILITY CHARACTERISTICS OF THE AIRPLANE IN THE POWER-APPROACH CONDITION.



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FIGURE 13. — ELEVATOR TRIM-TAB EFFECTIVENESS
OF THE TEST AIRPLANE.

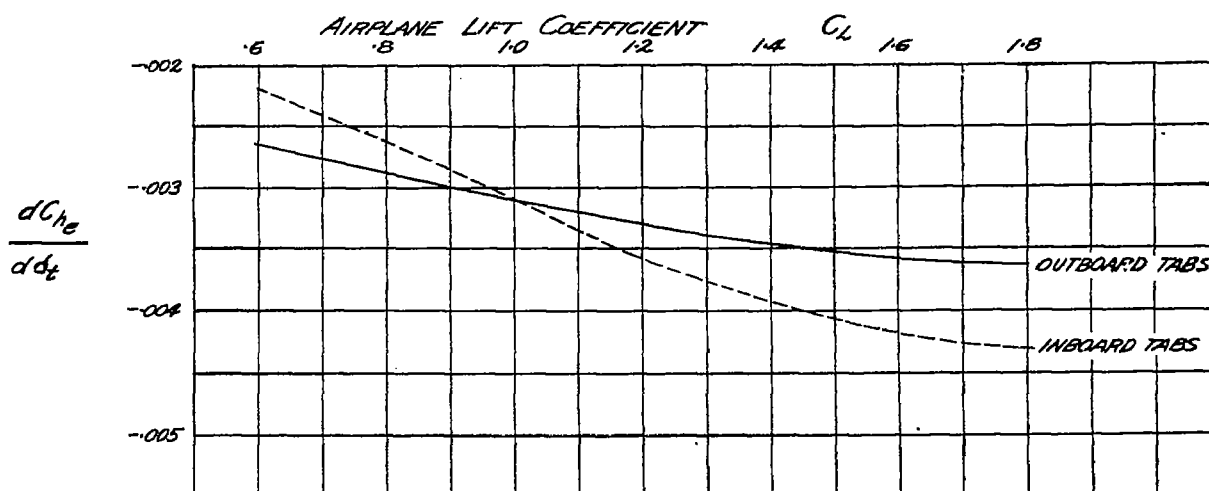


FIGURE 14. — ELEVATOR TRIM-TAB EFFECTIVENESS FOR INBOARD AND OUTBOARD
TAB LOCATIONS, TEST AIRPLANE IN THE POWER-APPROACH CONDITION.

INCREMENT IN AIRPLANE PITCHING MOMENT COEFFICIENT, ΔC_m

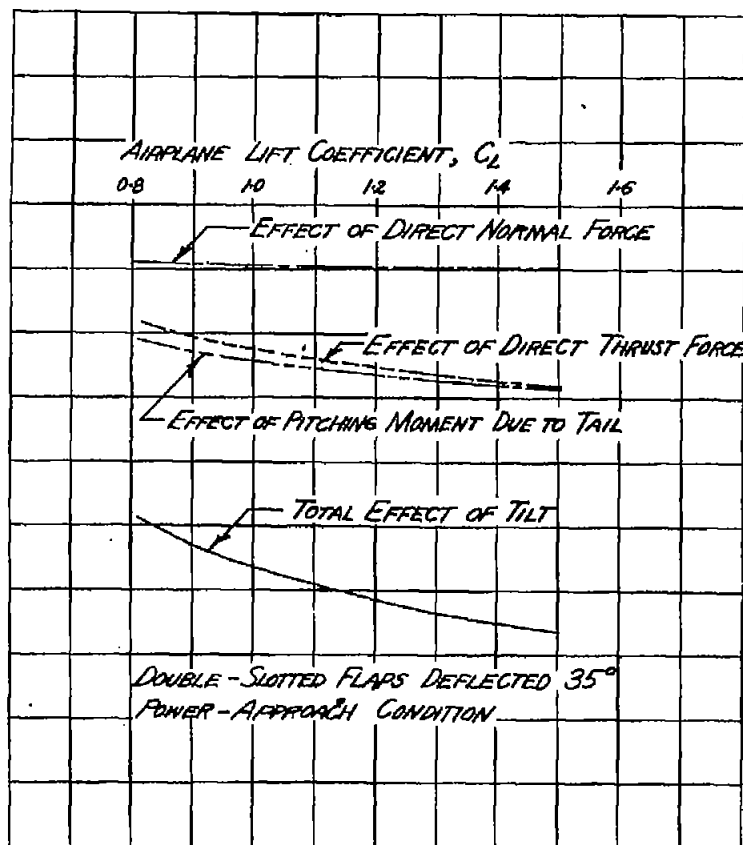


FIGURE 15. — THE EFFECT OF ENGINE TILT ON THE AIRPLANE PITCHING MOMENT.

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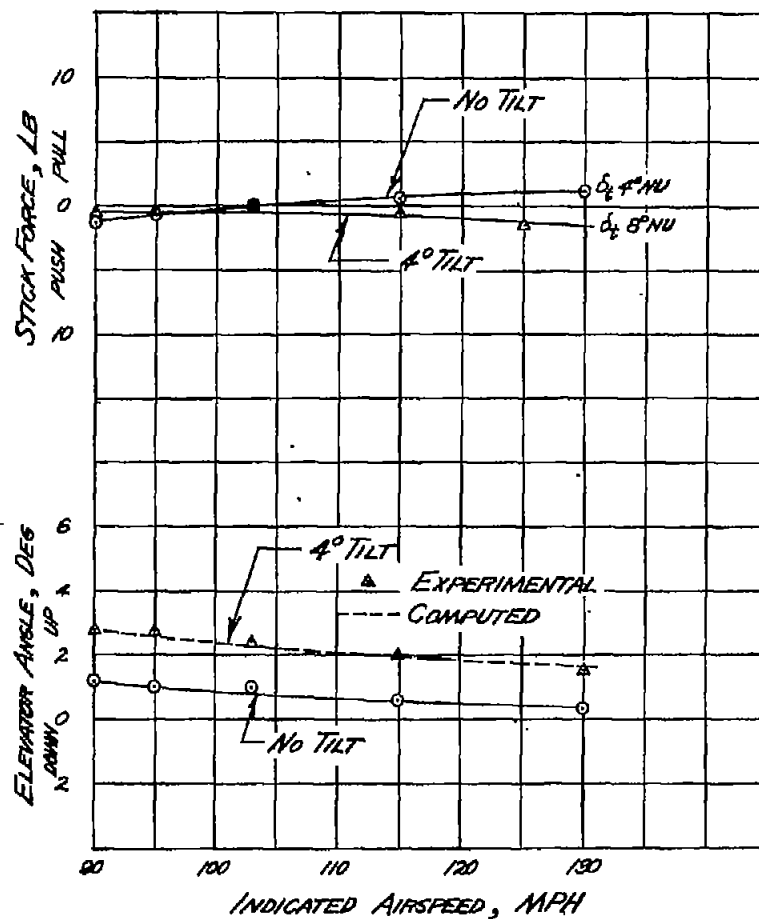


FIGURE 16. — THE EFFECT OF ENGINE TILT ON THE STATIC LONGITUDINAL-STABILITY CHARACTERISTICS IN THE POWER-APPROACH CONDITION.

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ABSTRACT

Flight tests were conducted to evaluate an elevator stick-force bungee and engine tilt as methods of improving the longitudinal-control characteristics of an existing airplane. Particular emphasis was placed on measuring the effect on the stick-free stability in the power-approach condition. The stick-force bungee was the simplest and most effective modification. It is indicated, however, that when large changes in elevator trim-tab angle are required, objectionable stick-force changes with speed and power will be induced.

* Airplanes - Flight tests (08450.3)

T-2, HQ, AIR MATERIEL COMMAND

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