N 62 65793

MR October 1944

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

October 1944 as
Memorandum Report

FLIGHT TESTS OF A PURSUIT AIRPLANE FITTED WITH AN EXPERIMENTAL BELLOWS-TYPE BOB WEIGHT

By John R. Spreiter and James M. Nissen

Ames Aeronautical Laboratory
Moffett Field, California

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

CONFIDENTIAL MEMORANDUM REPORT

for the

Air Technical Service Command, U.S. Army Air Forces

FLIGHT TESTS OF A PURSUIT AIRPLANE FITTED WITH AN EXPERIMENTAL BELLOWS-TYPE BOB WEIGHT

By John R. Spreiter and James M. Nissen

SUMMARY

Flight tests were conducted to determine the longitudinal stability characteristics of a pursuit airplane when flown with and without an experimental bellows-type bob weight. The bellows-type bob weight was designed to utilize a column of gasoline in the auxiliary fuselage fuel tank as a variable bob weight in such a manner that the stick-free longitudinal stability of the airplane remained essentially constant despite center-of gravity movements due to variations of the amount of fuel in the auxiliary tank.

With the experimental bob weight installed, the stick-free static stability remained approximately constant irrespective of the shift in center of gravity resulting from a change in fuel quantity in the auxiliary fuselage fuel tank. The bob weight shifted both the stick-free neutral point and the stick-free neutral maneuvering point rearward, while the stick-fixed static longitudinal stability remained unchanged. Although the bob weight functioned satisfactorily, its performance could have been enhanced by the reduction of the friction in the mechanism.

INTRODUCTION

To increase the range of pursuit aircraft it is often convenient to install an auxiliary fuel tank in the fuselage. In most installations, however, the location of such a fuel tank must be far aft in the fuselage and, hence, such a modification adversely affects the longitudinal stability of the airplane. The investigation reported herein was conducted to provide a means of retaining satisfactory longitudinal-stability and -control characteristics regardless of the location of an auxiliary fuselage fuel tank or the amount of fuel in the auxiliary tank.

Since the stability of the airplane varies with the amount of fuel carried in the fuselage fuel tank, a variable-weight type of bob weight was proposed. In the bob-weight installation which was tested, termed a "bellows" type, the variable inertia force was obtained by applying the varying amount of fuel in the fuselage tank to a piston built into the fuel tank and linked to the elevator control system. The addition of the usual constant-weight-type bob weight to the control system was not considered desirable for this particular problem, inasmuch as one of sufficient mass to provide satisfactory maneuvering stick forces when the fuselage tank was full would result in stick forces which would be objectionably large when the airplane was flown with the fuel tank empty.

This report presents the results of flight tests at the Ames Aeronautical Laboratory of a test airplane equipped with a bellows-type bob-weight installation designed to provide essentially constant longitudinal-stability and -control characteristics despite center-of-gravity changes due to varying amounts of fuel in an auxiliary fuselage fuel tank. To facilitate construction and testing of the bob-weight installation, the bob-weight system was designed for use with water rather than gasoline and was tested on that basis.

Representative effects of a bellows-type bob weight on the stability of the airplane as flown with gasoline in the standard fuselage tank are summarized.

DESCRIPTION OF APPARATUS

The test airplane in which the bellows-type bob weight was installed is a conventional single-place, single-engine, low-wing cantilever monoplane with conventional landing gear and partial-span plain flaps. A three-view drawing of the test airplane is shown in figure 1 and two photographs are shown in figures 2 and 3.

The nature of the bob-weight installation is shown in the diagrammatic sketch of figure 4. To simplify the construction of the experimental installation, the standard tank was replaced by a dummy tank containing water. Details of the tank, piston, bellows, and operating mechanism are shown in figures 5, 6, and 7. The variation of elevator angle and bob-weight-piston position with stick position is shown in figure 8. Figure 9 shows the variation of average head of water on the bob-weight piston with inclination of the airplane thrust axis to liquid level for the two quantities of water used in the tests. The force ratio of weight on the piston to stick force was approximately 3.8 to 1, resulting in a stick-force increment of one-half pound for each inch of water above the piston.

The cylinder around the piston shown in figures 4 and 5 was designed to prevent sudden changes of force on the piston due to splashing and surging of the liquid. An orifice was provided near the bottom of the cylinder to permit the liquid levels inside and outside the cylinder to be approximately equal.

A large vent tube was attached to the top of the tank directly over the piston, allowing the air to flow freely in and out of the tank as the piston was moved. To prevent having a force due to air pressure on the piston, the tube was extended to vent into the same region as the bottom of the piston.

Although an effort was made to keep the friction of the mechanism low, it was found after construction that excessive friction existed in the piston-rod guides, if the guides were not oiled frequently. It was apparent that the friction characteristics could have been made satisfactory by use of ball bearings in the piston-rod guide, but lack of time prevented making this alteration.

INSTRUMENTATION

Standard NACA instruments were used to record photographically, as a function of time, the following variables: elevator position, elevator control force, normal acceleration, airspeed, and inclination of the thrust axis to the liquid level.

The elevator-position recorder was connected to the cable system in the rear of the fuselage. Elevator control forces were measured by an indicating dial in addition to the standard NACA recording instrument. A free-swiveling airspeed head was mounted about one chord length ahead of the wing near the tip. All airspeeds reported herein are indicated airspeeds computed by the following formula:

$$V_i = 1703\left[\left(\frac{H - p}{p_o} + 1\right)^{0.286} - 1\right]^{\frac{1}{2}}$$

where

V_i indicated airspeed in miles per hour

H free-stream total pressure

p free-stream static pressure

p_o standard atmospheric pressure at sea level

A pendulum-type inclinometer was used to determine the inclination of the airplane thrust axis to the mean water level in the fuselage tank.

TESTS, RESULTS, AND DISCUSSION

Tests of the airplane were made to determine the turning-flight stability, static stability, dynamic stability, and maneuvering characteristics at three center-of-gravity positions with the bob weight both connected and disconnected. All tests were made with flap and gear up, normal rated power, and with the coolant flap locked in its equilibrium position at the trim speed. For each of the tests conducted in this investigation, the airplane was ballasted to bring the center of gravity to approximately the position it would have occupied in the standard airplane having a fuel level equal to the water level used in these tests. This ballasting was made necessary by the replacement of the standard fuselage tank by the dummy tank.

The test conditions were as follows:

Bob-weight condition	Center-of-gravity position	Center-of-gravity position (percent M.A.C.)	Height of water level in fuselage tank (in.)	Gross weight before flight (lb)
Disconnected	Forward	25.6	0	8550
Connected	Forward	25.6	0	8550
Disconnected	Intermediate	29.3	8	8775
Connected	Intermediate	28.8	8	8725
Disconnected	Rearward	31.2	16	8925
Connected	Rearward	31.2	16	8925

Throughout the remainder of the report, the test conditions will be specified by stating the bob-weight condition and the center-of-gravity position as shown in the above table.

The lift coefficients used in the neutral-point determination were calculated by the following formula:

$$C_L = \frac{WA_Z}{qS}$$

where

C_L airplane lift coefficient

W airplane weight (lb)

A_Z acceleration factor, $\left(\frac{\text{normal acceleration measured, ft/sec}^2}{g}\right)$

q $\frac{1}{2}\rho V^2$, free-stream dynamic pressure (lb/sq ft)

S gross wing area (sq ft)

Effect of the Bellows-Type Bob Weight on the Stability in Steady Turning Flight

The longitudinal-stability characteristics in turning flight were determined from measurements made during steady unstalled turns at 150 and 250 miles per hour. Curves showing the results of the tests are presented in figure 10.

The curves of figure 10 for the airplane with the bob weight disconnected indicate that the airplane was stable at the forward center-of-gravity location, was definitely unstable at the rearward center-of-gravity position, and had approximately neutral stick-fixed stability at 250 miles per hour at the intermediate center-of-gravity position.

With the bob weight connected the curves of figure 10 indicate that the airplane possessed stick-free stability in all the conditions tested. As would be expected, the stick-fixed stability remained unaffected by the bob weight.

A comparison of the curves of figure 10 for the bob-weight-connected conditions with those for the disconnected conditions shows that the bob weight added approximately 1 pound per g to the stick-force gradient with the fuselage tank empty and 7.5 pounds per g with the tank full.

Since the unstable stick-force gradients are encountered at rearward center-of-gravity positions corresponding to certain weights of gasoline in the standard fuselage tank, it may be seen that the stabilizing control-force-gradient increments vary in a manner consistent with constant stability requirements. This may be contrasted with the usual type of constant-weight bob weight which adds a constant increment of control-force gradient at all center-of-gravity positions.

The computed curves shown as dashed lines in figure 10 were calculated from formulas listed in the appendix for the effect of a bob weight and showed good agreement with the experimental curves except for the condition with 8 inches of water in the fuselage tank. It is believed that this deviation may be due to the cylinder trapping an additional quantity of liquid over the piston while the airplane was descending immediately before performing the steady turns.

Figure 11 presents the variation of elevator control-force gradient with center-of-gravity position. The curves for the bob-weight-disconnected condition were determined from figure 10 for the three experimental center-of-gravity positions. Because data for the bob-weight-connected conditions were obtained at only one center-of-gravity position for each water level, it was necessary to establish the curves of elevator force gradient for each water level and acceleration factor by drawing lines through the single experimental points parallel to the curves for the normal airplane at the corresponding acceleration factor.

The variation of the stick-free neutral-maneuvering-point position (center-of-gravity position for zero stick-force gradient) with acceleration factor is shown in figure 12. At 250 miles per hour, the bob weight moves the neutral maneuvering point aft approximately 0.5 percent mean aerodynamic chord when the tank is empty, and about 6.0 percent when the tank is full. The neutral maneuvering point is shifted a slightly greater distance during turns at 150 miles per hour.

Effect of the Bellows-Type Bob Weight on the Static Stability in Steady Straight Flight

The static stability of the airplane with and without the bob weight was determined in steady straight flight at speeds ranging from 120 to 440 miles per hour while the airplane was trimmed for zero stick force at 300 miles per hour. Curves showing these characteristics are presented in figure 13.

The elevator control-force curves for the airplane with the bob weight disconnected indicate that the airplane had stick-free stability throughout the entire speed range tested at the forward center-of-gravity position, but that the airplane exhibited stick-free instability at low speeds with the center of gravity at the intermediate and rearward positions. At speeds over 300 miles per hour, the airplane retained positive stick-free stability at even the most rearward tested center-of-gravity positions.

The elevator control-force curves for the airplane with the bob weight connected indicate that the stick-free stability of the airplane was increased so that the airplane was stable in all the conditions tested.

The computed curves shown in figure 13, which were calculated by using the formulas listed in the appendix, show good agreement with the experimental curves at high speeds and poorer, but acceptable, agreement at low speeds. The latter variation is believed to be due to errors introduced in calculating the dynamic pressure at the tail by the momentum theory.

Figures 14 and 15 present the steps used in determining the stick-free neutral-stability points from the static-stability data. The ratio of stick force to impact pressure was plotted as a function of lift coefficient in figure 14. The slopes of these curves were then plotted in figure 15 as a function of center-of-gravity position. The curves for the airplane with the bob-weight disconnected were determined from figure 14 for the three center-of-gravity positions. Because data for the bob-weight-connected conditions were obtained at only one center-of-gravity position for each water level, it was necessary to establish the curves for the bob-weight-connected conditions of figure 15 for each water level and lift coefficient by drawing lines through the single experimental points parallel to the curves for the normal airplane at the corresponding lift coefficients.

The stick-free neutral point, which is the center-of-gravity position at which

$$\frac{\partial F/q_c}{\partial C_L} = 0$$

where

F stick force

q_c impact pressure

is shown in figure 16 plotted as a function of lift coefficient. Because of the scatter and very low stick forces in the original data shown in figure 13, the accuracy of the neutral-point determination is questionable. However, since the same method was used throughout, the trend of the change in neutral-point location due to the bob weight should be correct. The bob weight moved the neutral point aft approximately 0, 2.0, and 4.5 percent mean aerodynamic chord, respectively, with 0, 8, and 16 inches of water in the fuselage tank.

The variation of elevator angle with speed, which gives an indication of the stick-fixed static stability of the airplane, is shown in figure 13. The slopes of the curves indicate that the bob weight did not affect the stick-fixed stability of the airplane. The small change in elevator angle caused by the bob weight is due to the different tab settings required to trim. At speeds below 300 miles per hour, the airplane was nearly neutrally stable, stick fixed, at the intermediate center-of-gravity position, but at higher speeds, it appeared to be unstable, stick fixed, at all center-of-gravity positions tested.

The elevator angle to trim in straight flight is shown in figure 17 as a function of lift coefficient. In figure 18 the slopes of the curves for values of C_L above 0.2 are plotted against center-of-gravity position. This figure indicates that the neutral point is at 28.4 percent mean aerodynamic chord. Only values corresponding to lift coefficients greater than 0.2 were plotted in this figure, because the slopes for lower lift coefficients were changing rapidly and were difficult to determine. At lower lift coefficients, it was apparent, however, that the stick-fixed neutral point would move forward.

Effect of the Bellows-Type Bob Weight on Dynamic Stability

To determine the effect of the bellows-type bob weight on the control-free dynamic stability of the airplane, time histories were recorded of the airplane and elevator motions resulting from suddenly deflecting and releasing the elevator. Tests were conducted with each experimental configuration at speeds of 150, 250, and 350 miles per hour. Representative time histories of these manuvers recorded at the highest speed tested are plotted in figure 19.

The oscillations of the airplane with the bob weight disconnected are shown (figs. 19(a) and 19(b)) to dampen satisfactorily when the center of gravity is as far aft as the intermediate position. At the rearward center-of-gravity position, however, figure 19(c) for the bob-weight-disconnected condition shows that the airplane tended to remain in accelerated flight until the pilot resumed control. In all cases the elevator angle damped quickly to its steady value.

With the bob weight connected figure 19 shows that the oscillations were damped at all center-of-gravity positions tested. However, instead of the elevator returning to its trim position immediately after being released, figures 19(b) and 19(c) show that it had a tendency, increasing with the amount of water in the fuselage tank, to remain in a downward position for a short time following its release after an abrupt pull-up before returning to the trim angle. This resulted in the airplane pitching down more than did the normal airplane. It is believed that this effect is caused by the high friction between the piston rods and the plain sliding bearings. By providing roller-type bearings or other low-friction bearings, it is believed the undesirable friction could be eliminated.

Effect of the Bellows-Type Bob Weight on the Characteristics in Maneuvers

Time histories during abrupt turns were made for the airplane in each test condition. Figure 20 shows time histories for the normal airplane at the forward and rearward center-of-gravity positions and for the airplane with the bob weight connected at the rearward center-of-gravity position.

The curves of figure 20 for the bob-weight-disconnected condition show that the normal airplane has a stable variation of control force during a rapid turn at the forward center-of-gravity position. At the rearward center-of-gravity position, however, the curves show that the control forces reverse, and that the airplane would tend to reach still higher acceleration factors if the controls were released.

With the bob weight connected and with the center of gravity in the rearward position, figure 20 shows that the control-force variation is similar to that of the normal airplane at the forward center-of-gravity position. Although somewhat high stick forces are necessary to start a change in acceleration factor, it is believed that this undesirable feature is caused by high friction in the mechanism and could be eliminated by using low-friction bearings on the piston rods.

In addition to these tests, loops, slow rolls, and other maneuvers were performed to obtain the pilots' opinions of the effect of the bellows-type bob weight in maneuvers. No undesirable features were mentioned in the pilots' reports on these tests which have not been previously discussed. It is believed that all of the undesirable features encountered with the bellows-type bob weight can be attributed directly to the friction between the piston rods and their plain sliding bearings.

Effect of Bellows-Type Bob Weight Summarized for Standard Airplane

In order to show the effect of a bellows-type bob weight on the stability of the airplane as actually flown with gasoline in the standard fuselage tank, corrections have been made to the test data obtained with the experimental installation. Curves showing the representative variation of the stick-free static margin and stick-force gradient with amount of fuel in the fuselage tank are presented in figures 21 and 22. These figures show the effects of a bob weight having the same operating linkage as the experimental bob weight but having a piston area of 72.7 square inches located with its center line $9\frac{1}{2}$ inches forward of the center line of the standard fuselage tank. Such an installation would produce the same effect with gasoline as the experimental bob weight produced with water. The center-of-gravity position with the fuselage tank empty was taken to be a 0.255 mean aerodynamic chord.

Figure 21 is a cross plot made from figure 11 showing the variation of stick-force gradient with amount of gasoline in the tank for the airplane with and without the bob weight during steady 4g turns at 250 miles per hour. The control-force gradient of the normal airplane is shown to decrease rapidly as the quantity of fuel in the fuselage tank is increased, becoming unstable when the tank is approximately half full, but the airplane with the bob weight connected exhibits a stable, nearly constant control-force gradient for all quantities of fuel. Although figure 21 is determined for 4g steady turns at 250 miles per hour, similar curves could be obtained at other speeds and acceleration factors.

Figure 22 is a cross plot made from figure 16 showing the variation of stick-free static margin with amount of gasoline in the tank for the air lane with and without the bob weight during steady flight at 250 miles per hour. The static margin for the normal airplane decreases rapidly, indicating a large decrease in stick-free static stability as the amount of fuel in the fuselage tank is increased. The static margin for the airplane with the bob weight connected is more nearly constant, indicating that the airplane in this condition has a smaller stick-free stability change than the normal airplane. Although figure 22 is for a speed of 250 miles per hour, similar curves could be obtained at other speeds.

CONCLUSIONS

1. The test airplane was longitudinally stable without a bob weight when flown at a forward center-of-gravity position corresponding to no gasoline in the standard auxiliary fuselage fuel tank, but was unstable at a center-of-gravity position corresponding to a fully serviced auxiliary tank.

2. With the addition of the experimental bellows-type bob weight tested, the stick-free longitudinal stability of the airplane with the auziliary tank full was almost equal to the stick-free stability with the tank empty. By slight redesign of the bob-weight mechanism the stability could be made equal.

3. The experimental bellows-type bob weight with 0, 8, and 16 inches of water in the fuselage tank caused the stick-free neutral maneuvering point to move aft approximately 0.5, 4.0, and 6.0 percent mean aerodynamic chord, respectively.

4. The experimental bellows-type bob weight with 0, 8, and 16 inches of water in the fuselage tank caused the stick-free static stability neutral point to move aft approximately 0, 2.0, and 4.5 percent mean aerodynamic chord, respectively.

5. The stick-fixed neutral point was found to be at 28.4 percent mean aerodynamic chord for speeds less than 300 miles per hour with or without the bellows-type bob weight.

6. Excessive friction existed in the piston-rod guides of the mechanism if the guides were not oiled frequently. It was apparent that the friction characteristics could have been made satisfactory by the use of ball or other frictionless type bearings in the piston-rod guides.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., October 10, 1944.

APPENDIX

Calculated Effects of Bellows-Type Bob Weights

The longitudinal-stability characteristics of an airplane with power on cannot be computed accurately from theory at present but must be determined experimentally. If the stability characteristics are known, however, the changes caused by the addition of a bellows-type bob weight to the elevator control system can be readily calculated.

The increments of stick force produced in straight flight by a bob weight may be computed by the procedure described in reference 1, provided the variation of stick force with indicated airspeed is known for several trim speeds. Because sufficient data to use this method were not obtained during the flight tests, the computed curves were determined from the stick-force curves for the normal airplane by adding stick-force increments calculated by the following formula:

$$\Delta F = A_{Z_{trim}}\left(F_W + K_1 H_{trim}\right)\left(1 - \frac{q_t}{q_{t_{trim}}}\right)$$

$$+ K_1\left(A_Z H - A_{Z_{trim}} H_{trim}\right)$$

$$+ F_W\left(A_Z - A_{Z_{trim}}\right)$$

where

ΔF increment of pullstick force, pounds

A_Z normal acceleration factor

F_W pull stick force required to balance the static weight of the bob-weight mechanism, pounds

K_1 ratio of required balancing pull stick force to the head of liquid acting on the bob-weight piston, pounds per inch

H head of liquid acting on the piston, inches

q_t dynamic pressure at the tail $\left(\frac{1}{2}\rho V^2\right)_{tail}$, pounds per square foot

Subscript

trim values of the variable at the time the airplane is trimmed to zero stick force

The dynamic pressure at the tail in power-on flight was computed using the following equation derived from the momentum theory:

$$q_t = q + \frac{550 bhp\ \eta}{V A}$$

where

q_t dynamic pressure at the tail, pounds per square foot

q free-stream dynamic pressure, pounds per square foot

bhp engine brake horsepower

η propeller efficiency

V true airspeed

A area of the propeller disk

In using this formula, it was assumed that there are no losses and that the tail is within the slipstream. A value of 0.80 was assumed for the propeller efficiency.

An examination of the first equation will show that the fore and aft location of the piston in the tank will have a secondary influence on the longitudinal stability of the airplane. If the piston is near the front of the tank, the term $K_1 A_Z H$ will grow larger as the airplane is nosed down to obtain higher speeds, tending to lessen the effect of the bob weight in increasing the static stability of the airplane. In steady turns, the stabilizing bob-weight effect is increased at high speeds and decreased at low speeds. The converse is true if the piston is fitted in the aft end of the tank.

If a constant pressure is applied to the liquid as is done in some fuel-tank installations, the following term should be added to the equation:

$$\Delta F = F_p \left[1 - \frac{q_t}{q_{t_{trim}}} \right]$$

where

F_p pull stick force required to balance the additional pressure acting on the bob-weight piston, pounds

Any positive pressure inside the tank would therefore produce an increment of stick force tending to stabilize the airplane in steady straight flight, but would not affect the airplane in turning flight. It would produce exactly the same effect as a spring pulling the elevator downward.

REFERENCE

1. Phillips, William H.: Effect of Spring and Gravity Moments in the Control System on the Longitudinal Stability of the Brewster XSBA-1 Airplane. NACA ARR, April 1942.

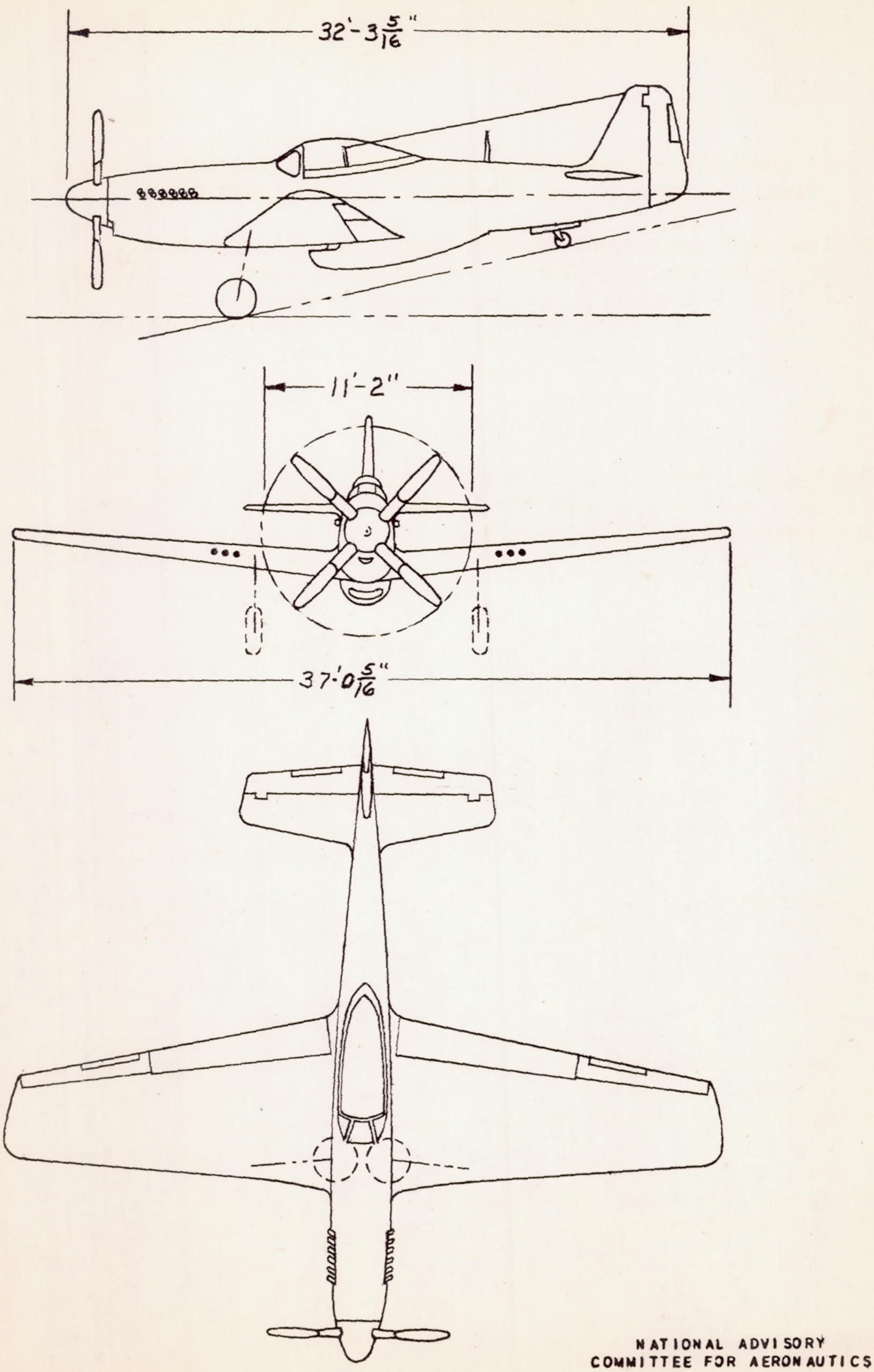


Figure 1.-Three-view drawing of the test airplane.

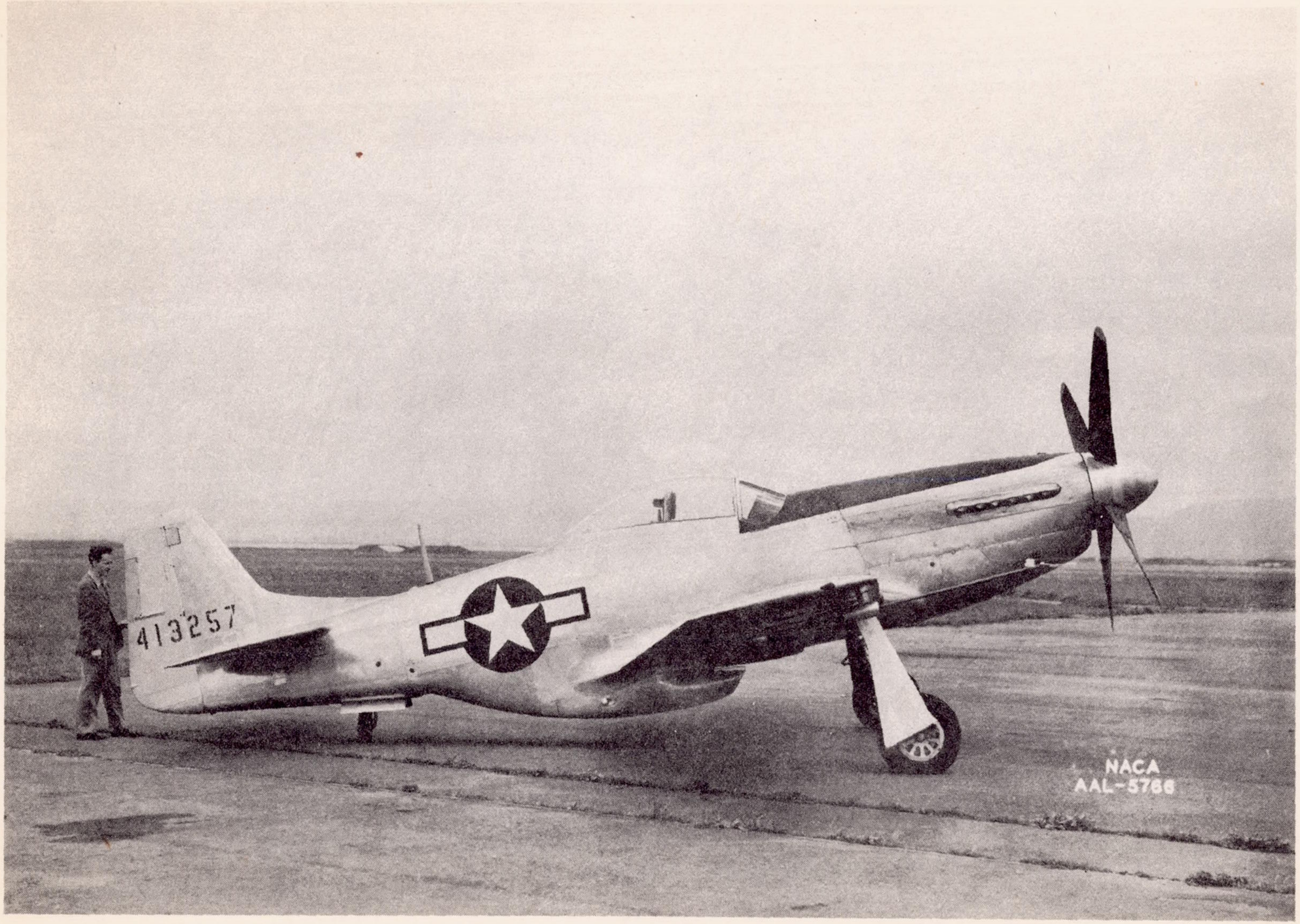


Figure 2.- Side view of the test airplane

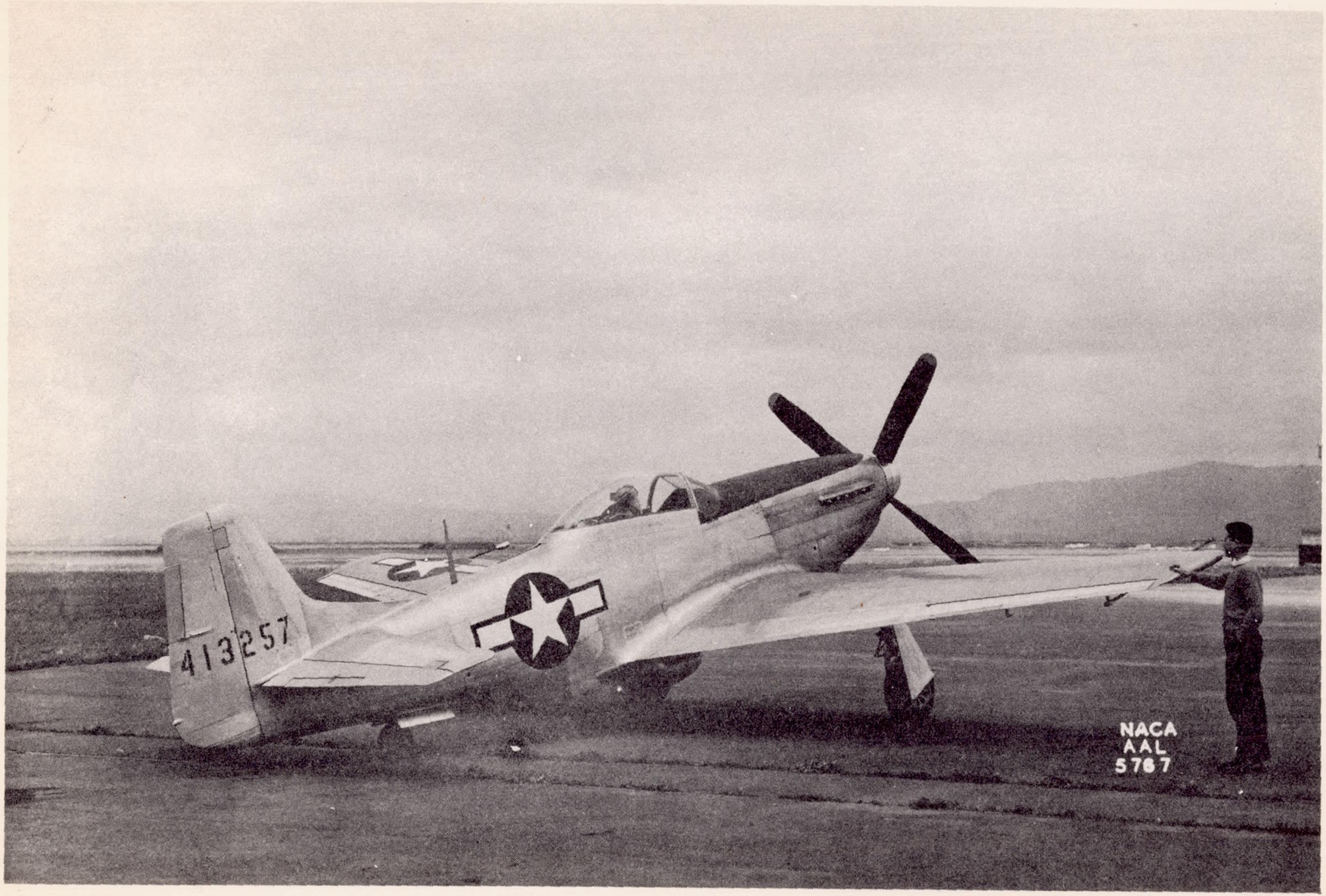


Figure 3.- Three-quarter rear view of the test airplane

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

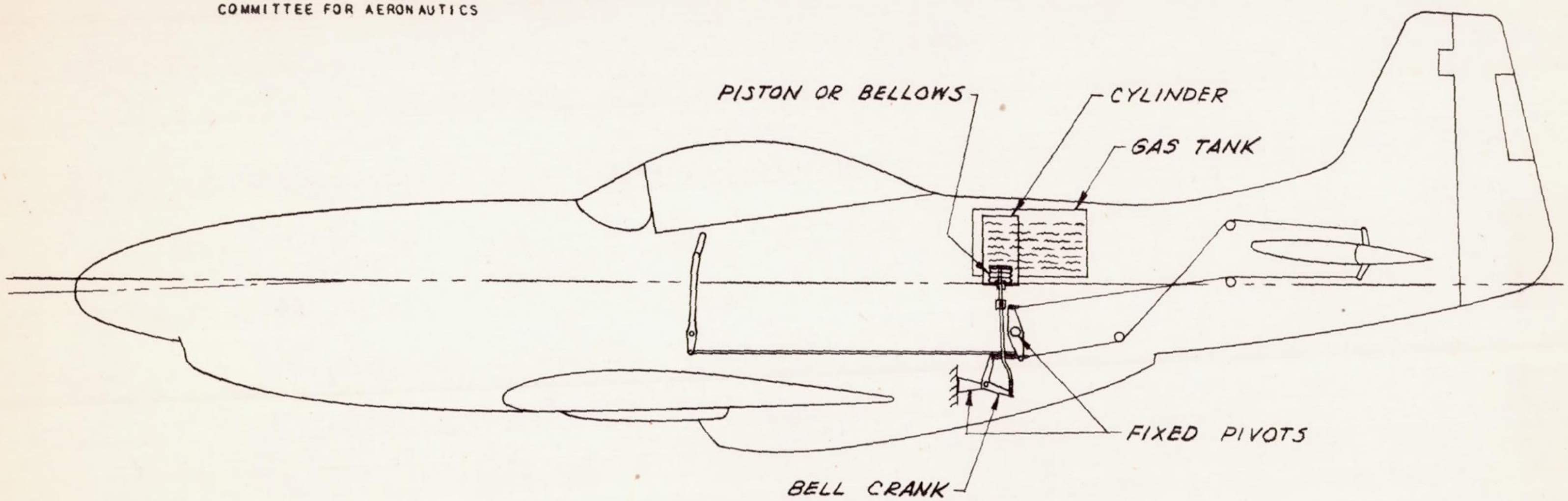
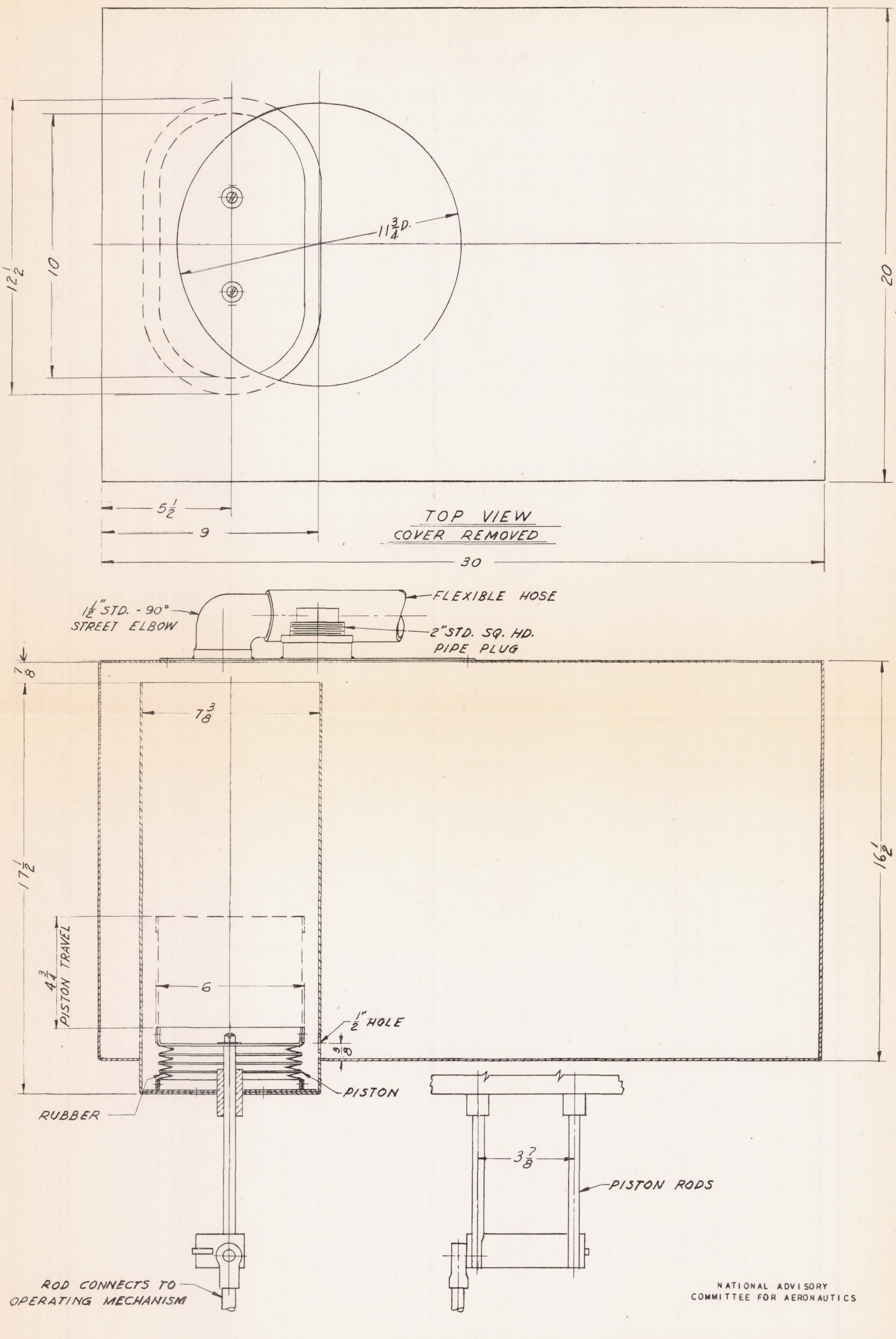
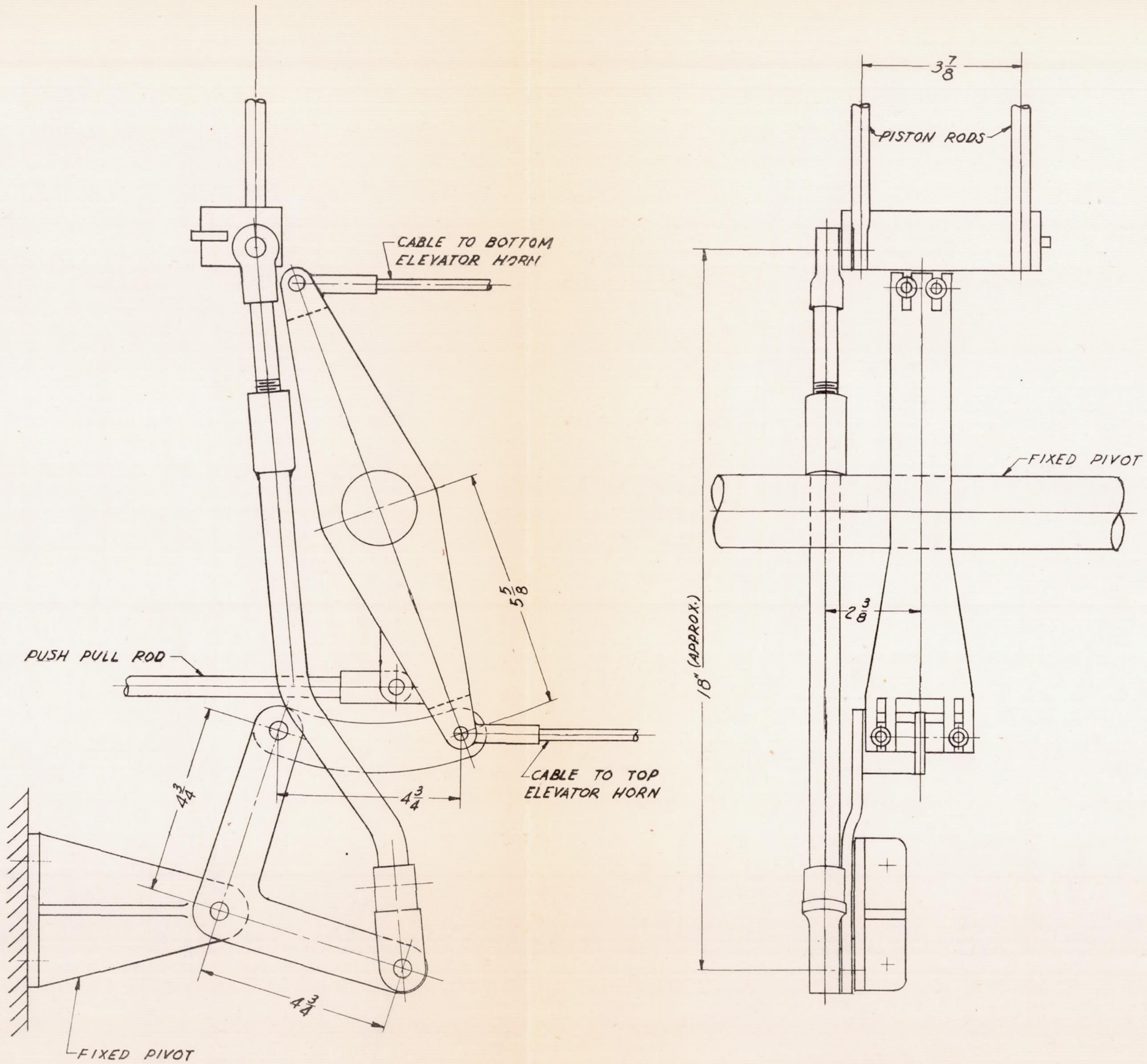


FIGURE 4. DIAGRAMMATIC SKETCH OF THE BELLOWS-TYPE BOB-WEIGHT INSTALLATION.



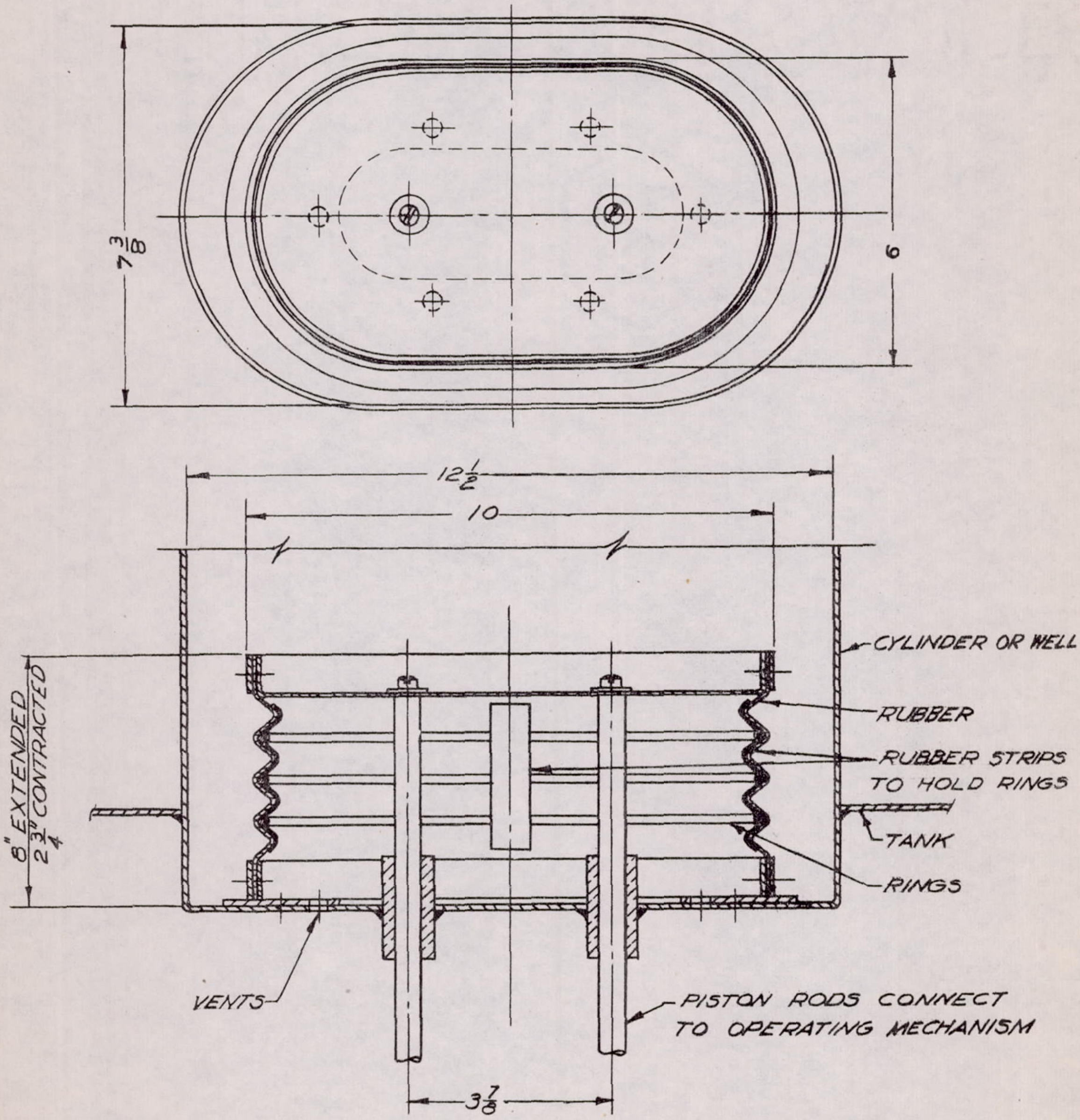
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 5.- DETAILS OF THE BELLOWS-TYPE
BOB-WEIGHT PISTON AND TANK INSTALLATION.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 6.- DETAILS OF THE BELLOWS-TYPE
BOB-WEIGHT OPERATING MECHANISM.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 7.- DETAILS OF THE BELLOWS-TYPE
BOB-WEIGHT BELLOWS AND PISTON.

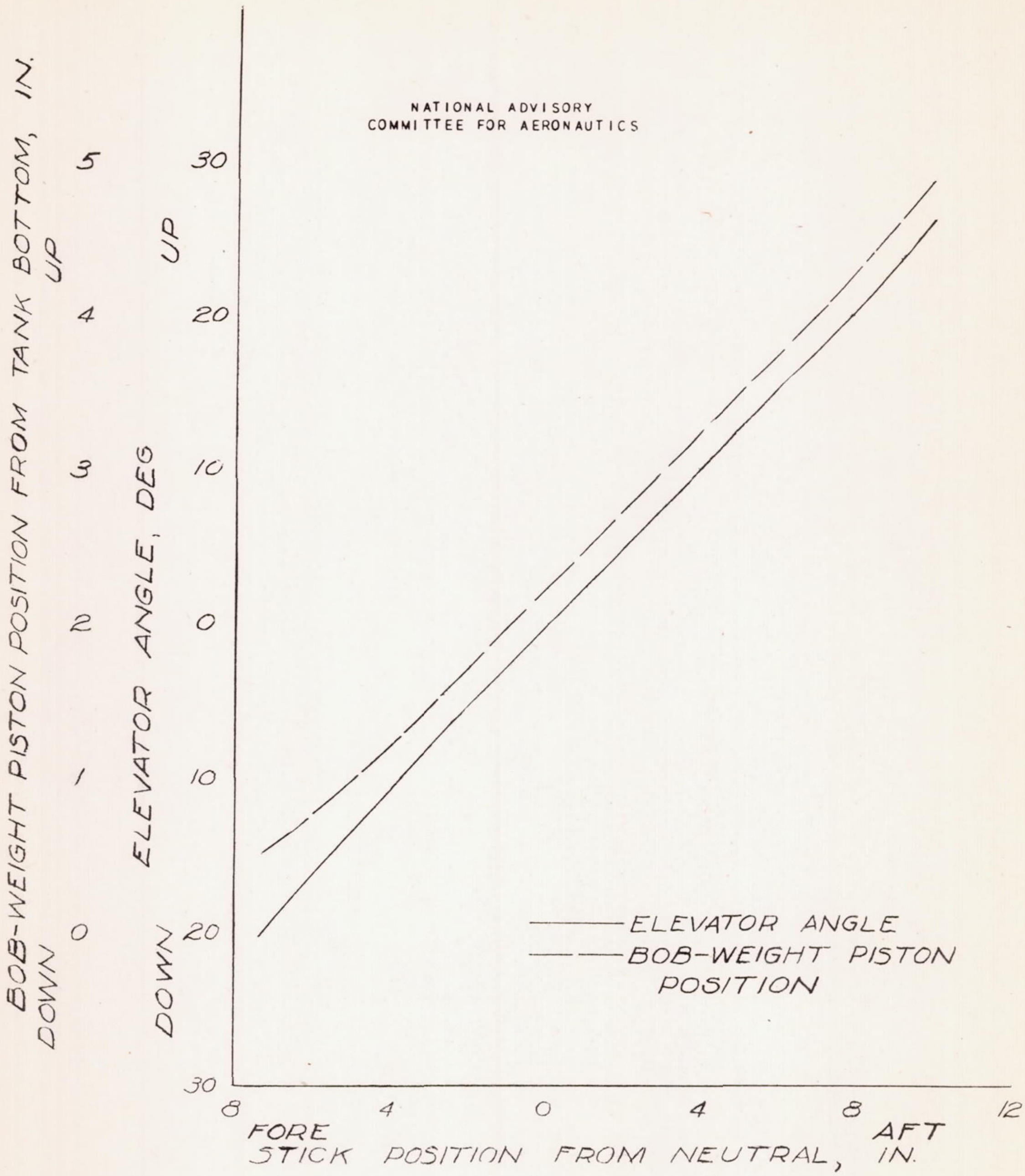


FIGURE 8 – VARIATION OF BOB-WEIGHT PISTON POSITION AND ELEVATOR ANGLE WITH POSITION OF THE TOP OF THE CONTROL STICK.

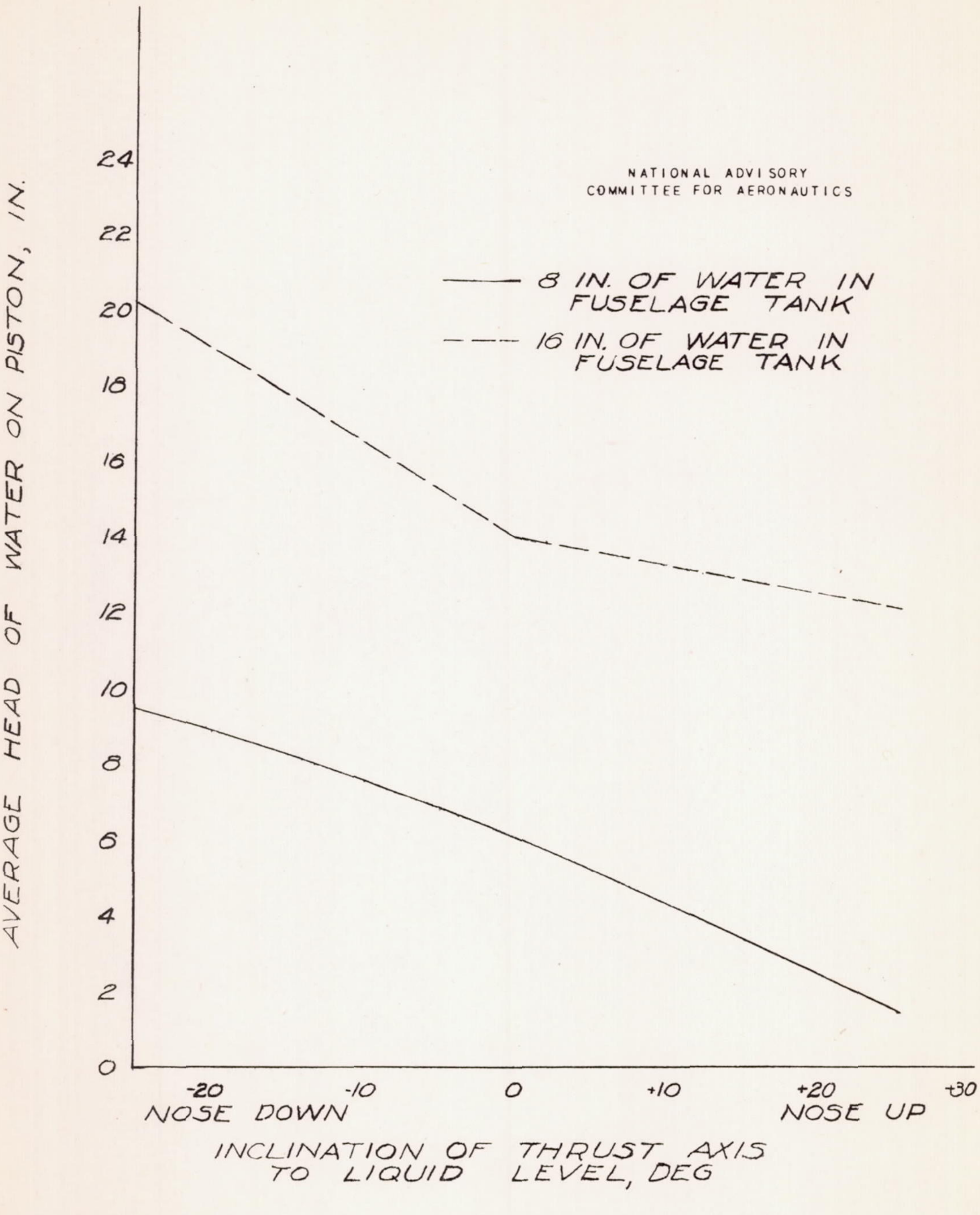
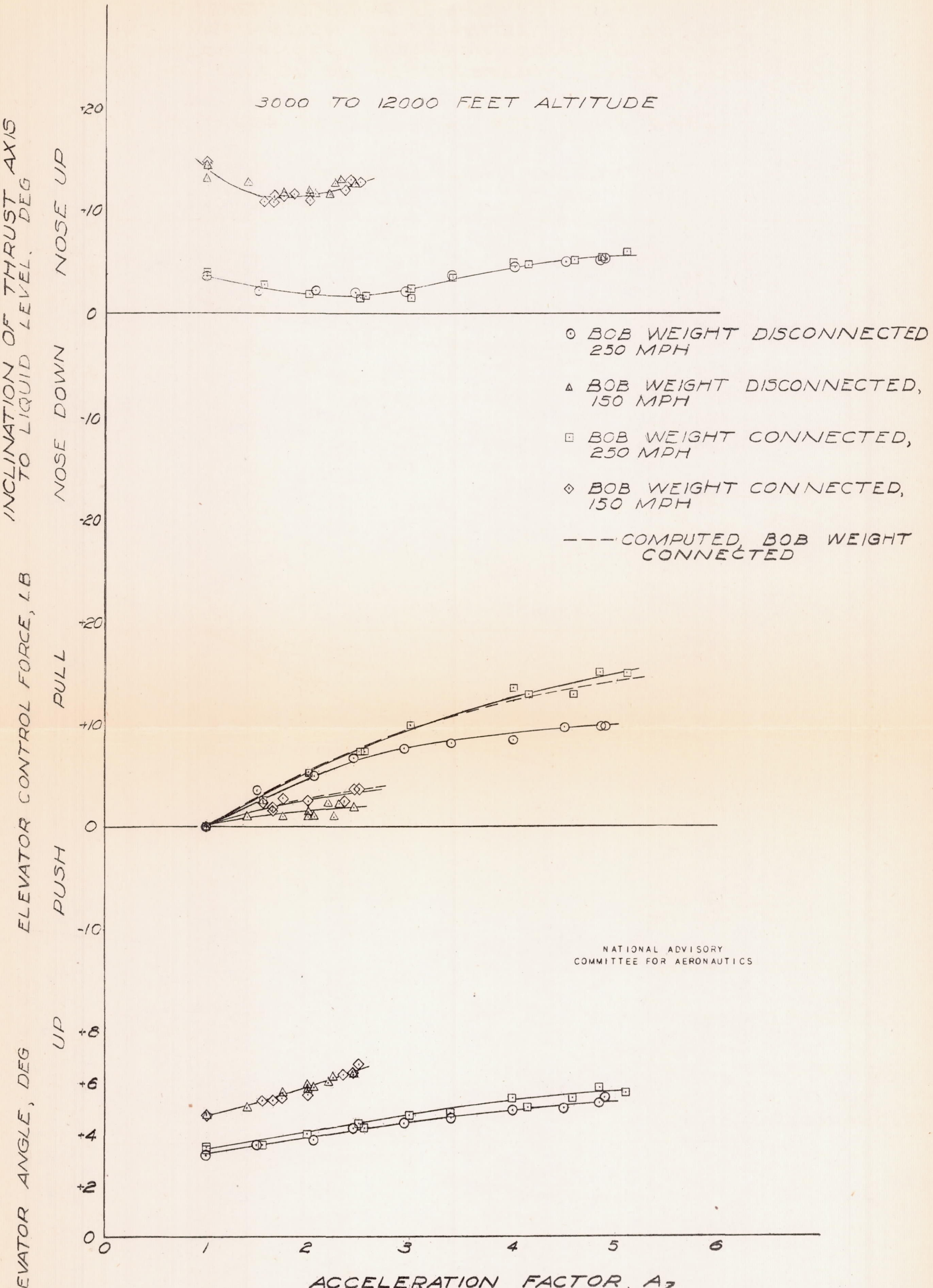
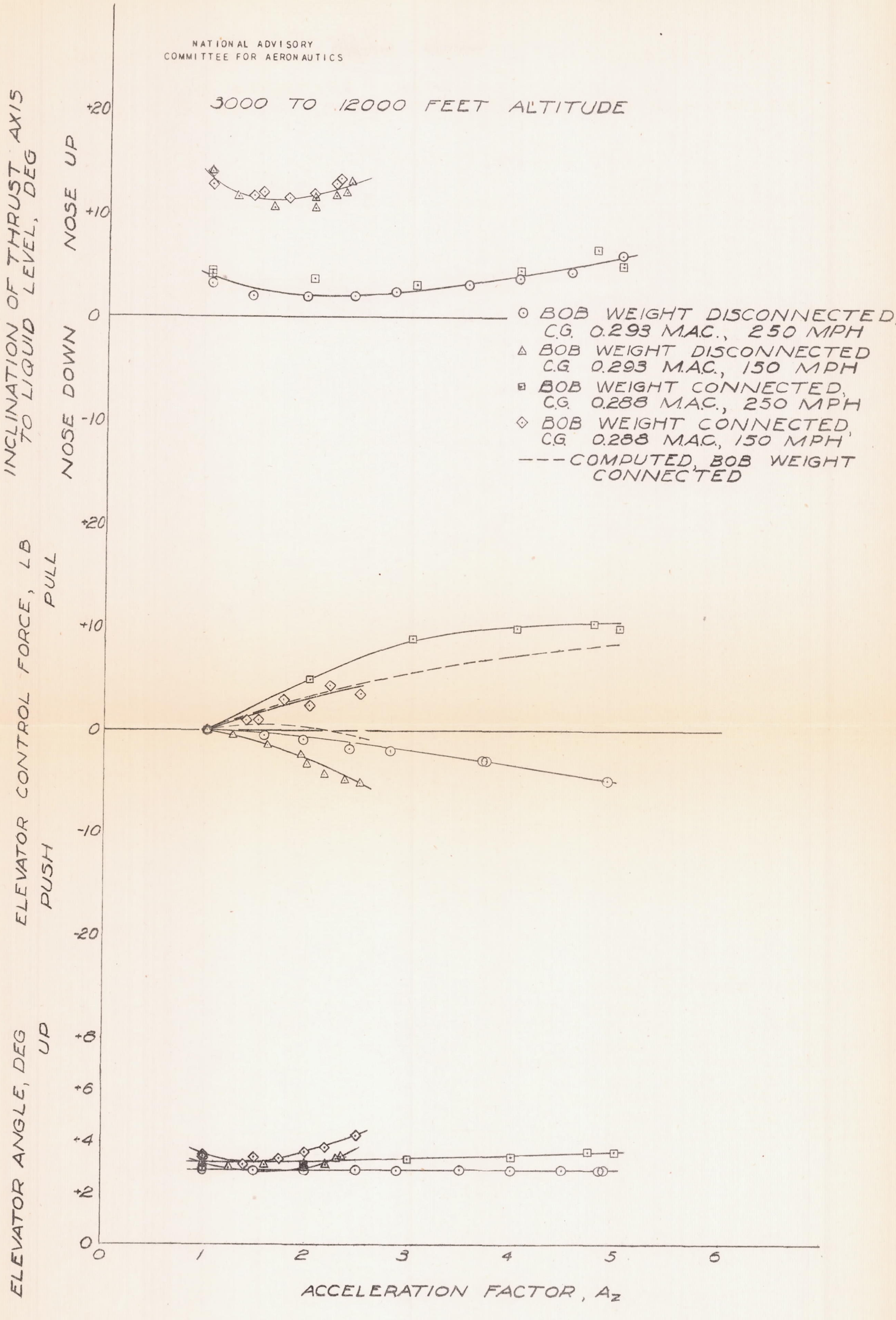


FIGURE 9.- VARIATION OF AVERAGE HEAD OF WATER ON BOB-WEIGHT PISTON WITH INCLINATION OF THRUST AXIS TO LIQUID LEVEL.



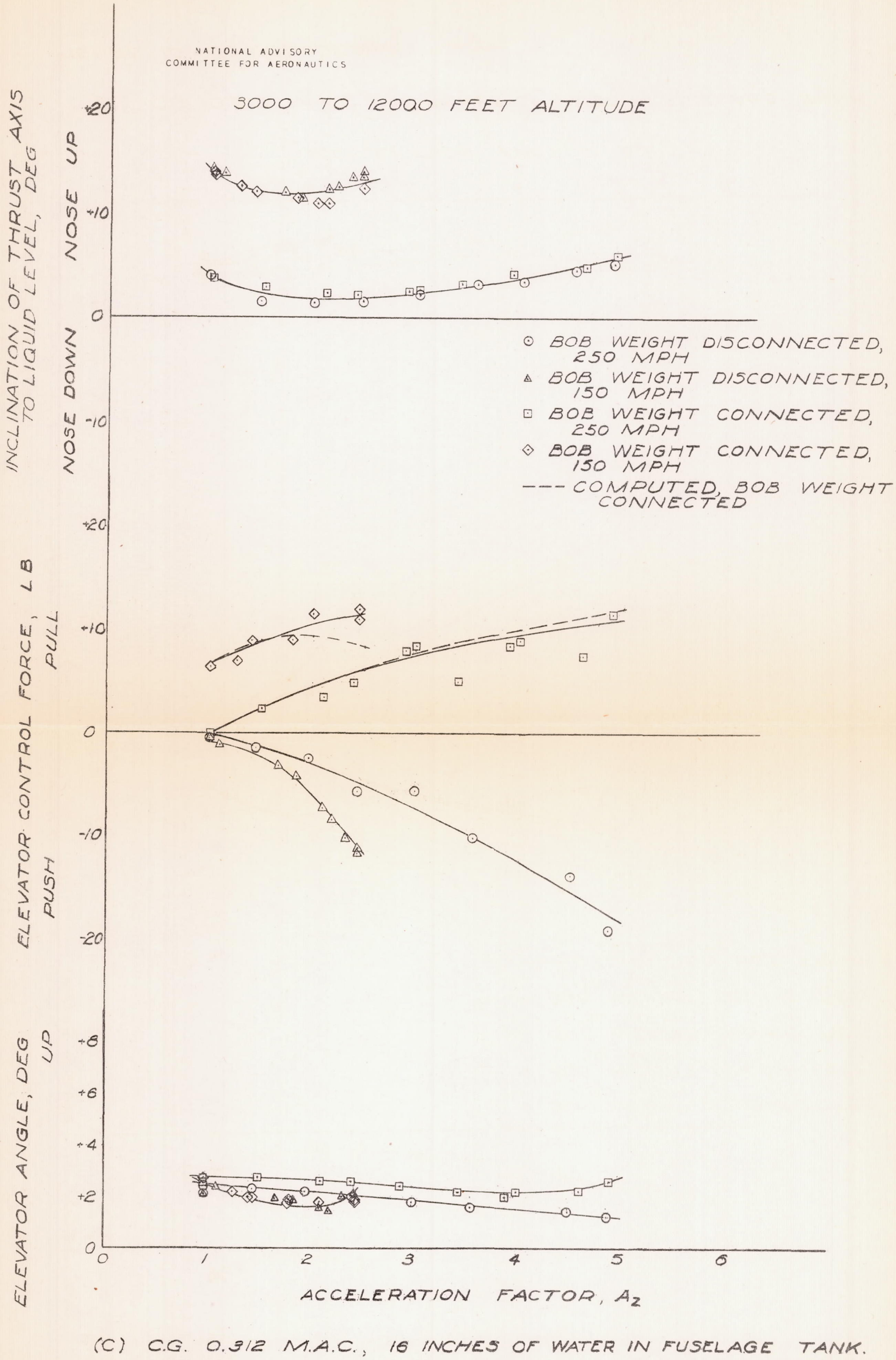
(a) C.G. 0.256 M.A.C., FUSELAGE TANK EMPTY

FIGURE 10 - EFFECT OF ACCELERATION FACTOR ON ELEVATOR ANGLE, ELEVATOR CONTROL FORCE, AND INCLINATION OF THRUST AXIS TO THE LIQUID LEVEL. TURNING FLIGHT.



(b) C.G. ABOUT 0.29 M.A.C., EIGHT INCHES OF WATER IN FUSELAGE TANK

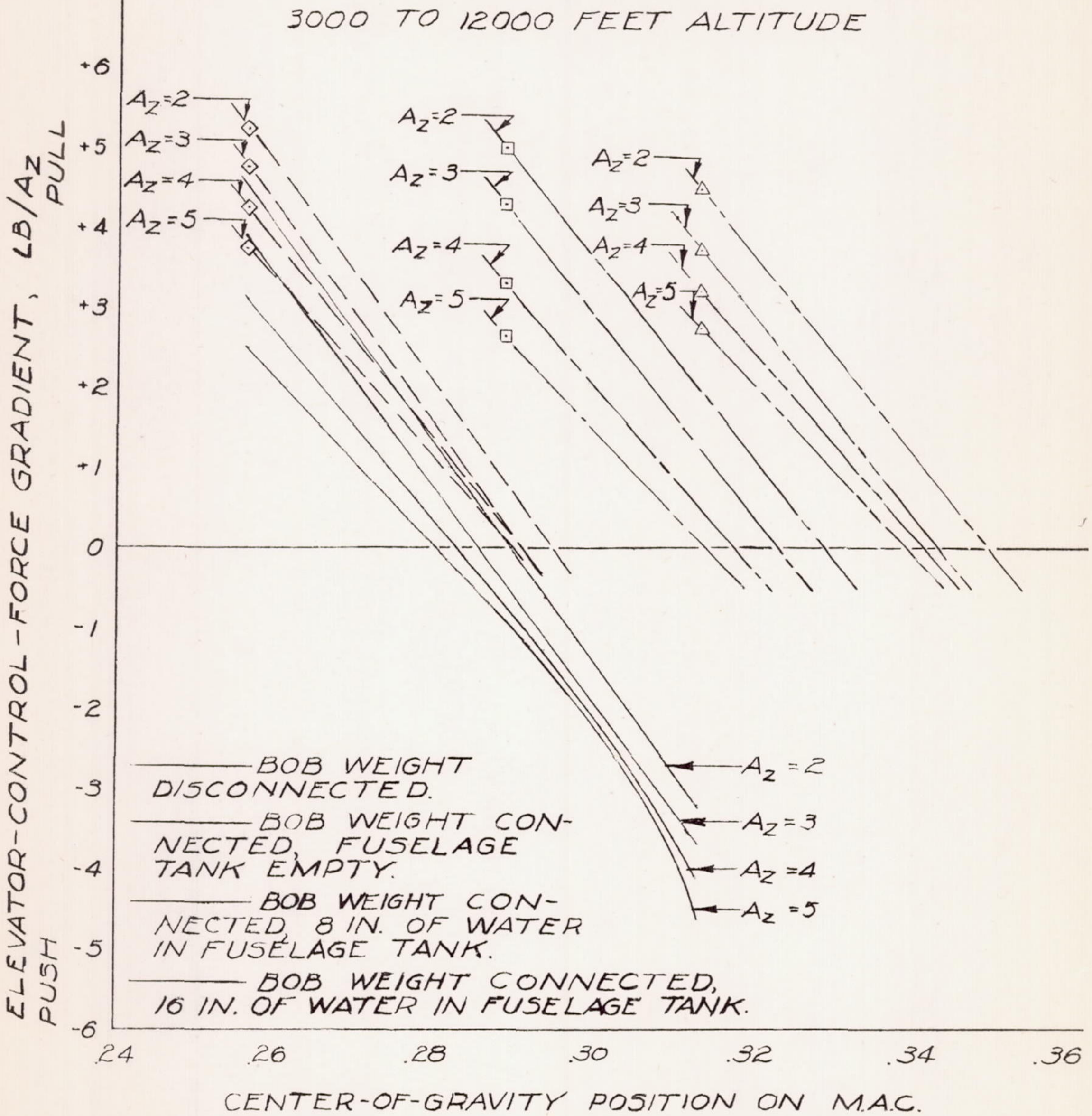
FIGURE 10.- CONTINUED.



(C) C.G. 0.312 M.A.C., 16 INCHES OF WATER IN FUSELAGE TANK.

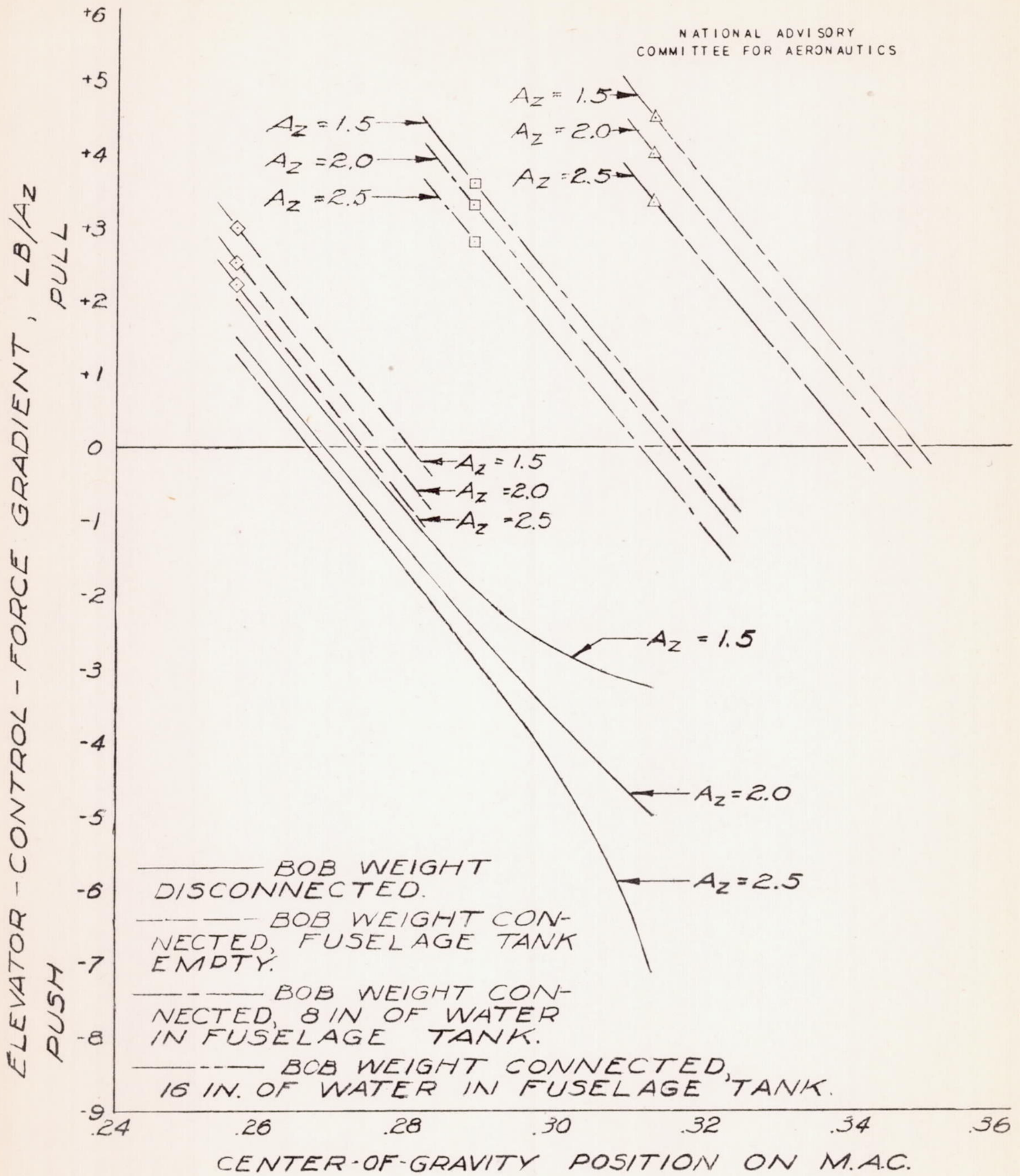
FIGURE 10.- CONCLUDED.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(a) 250 MILES PER HOUR.

FIGURE 11. - VARIATION OF ELEVATOR CONTROL-FORCE GRADIENT WITH CENTER-OF-GRAVITY POSITION. TURNING FLIGHT.



(b) 150 MILES PER HOUR.

FIGURE 11.- CONCLUDED.

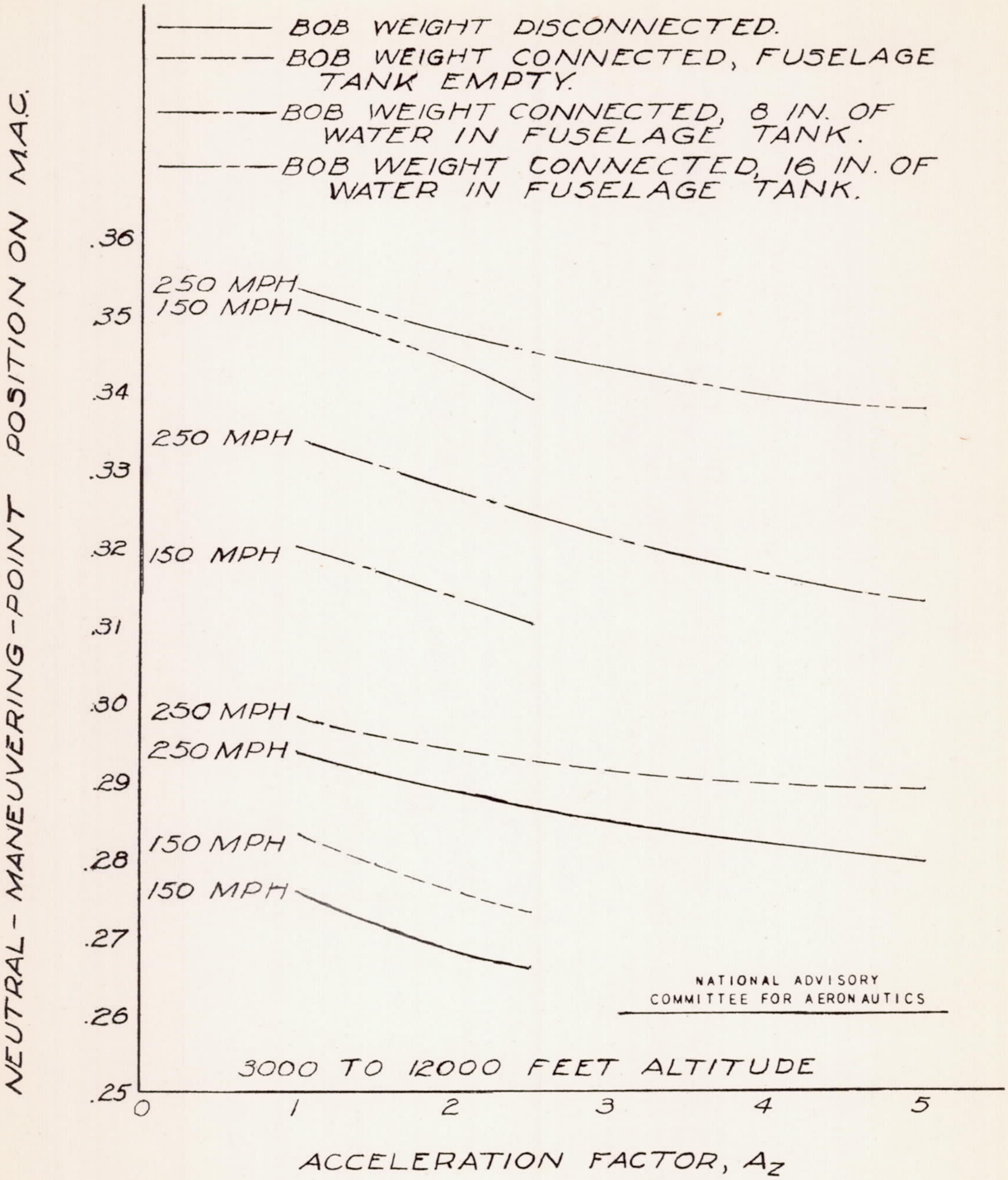
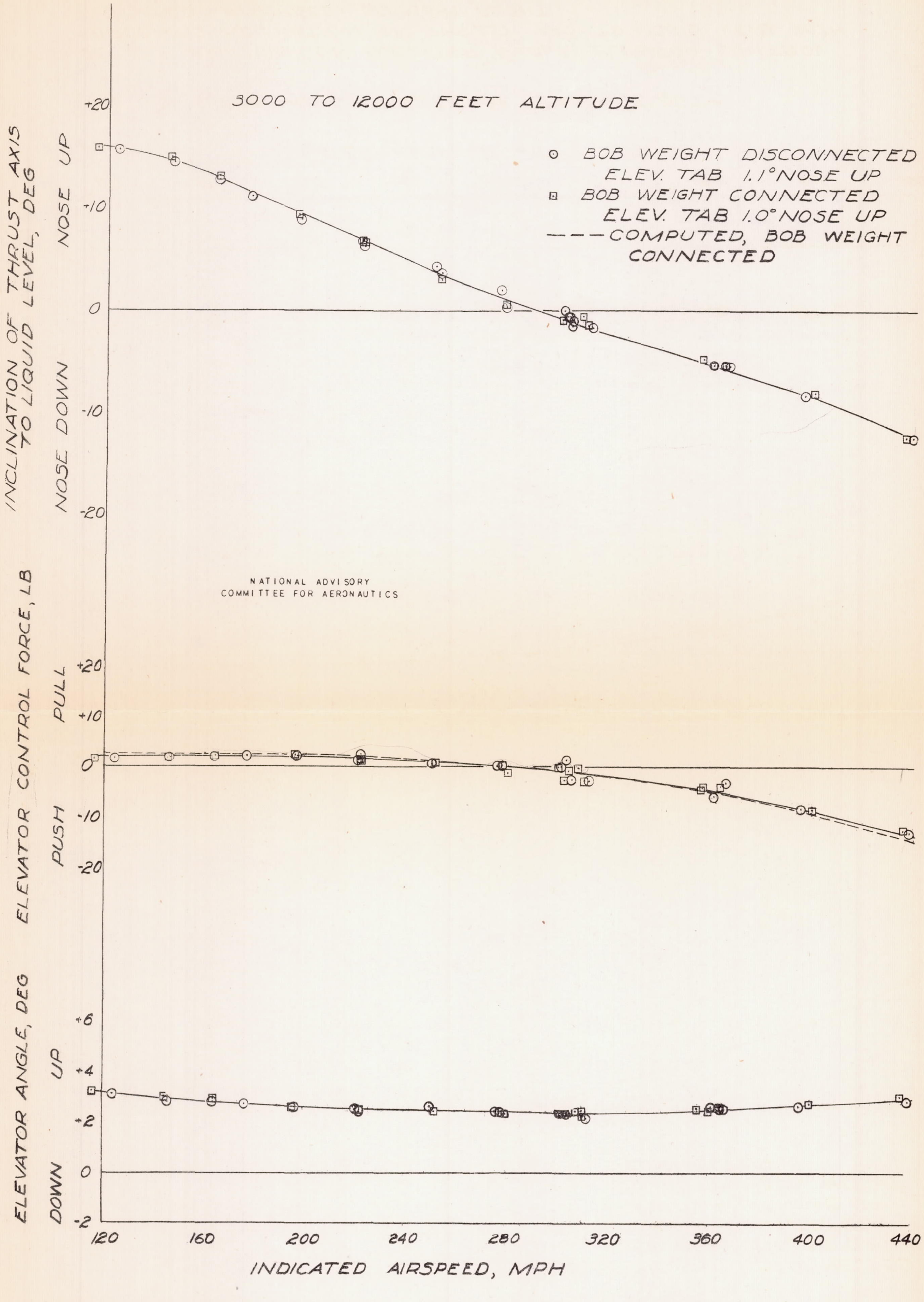
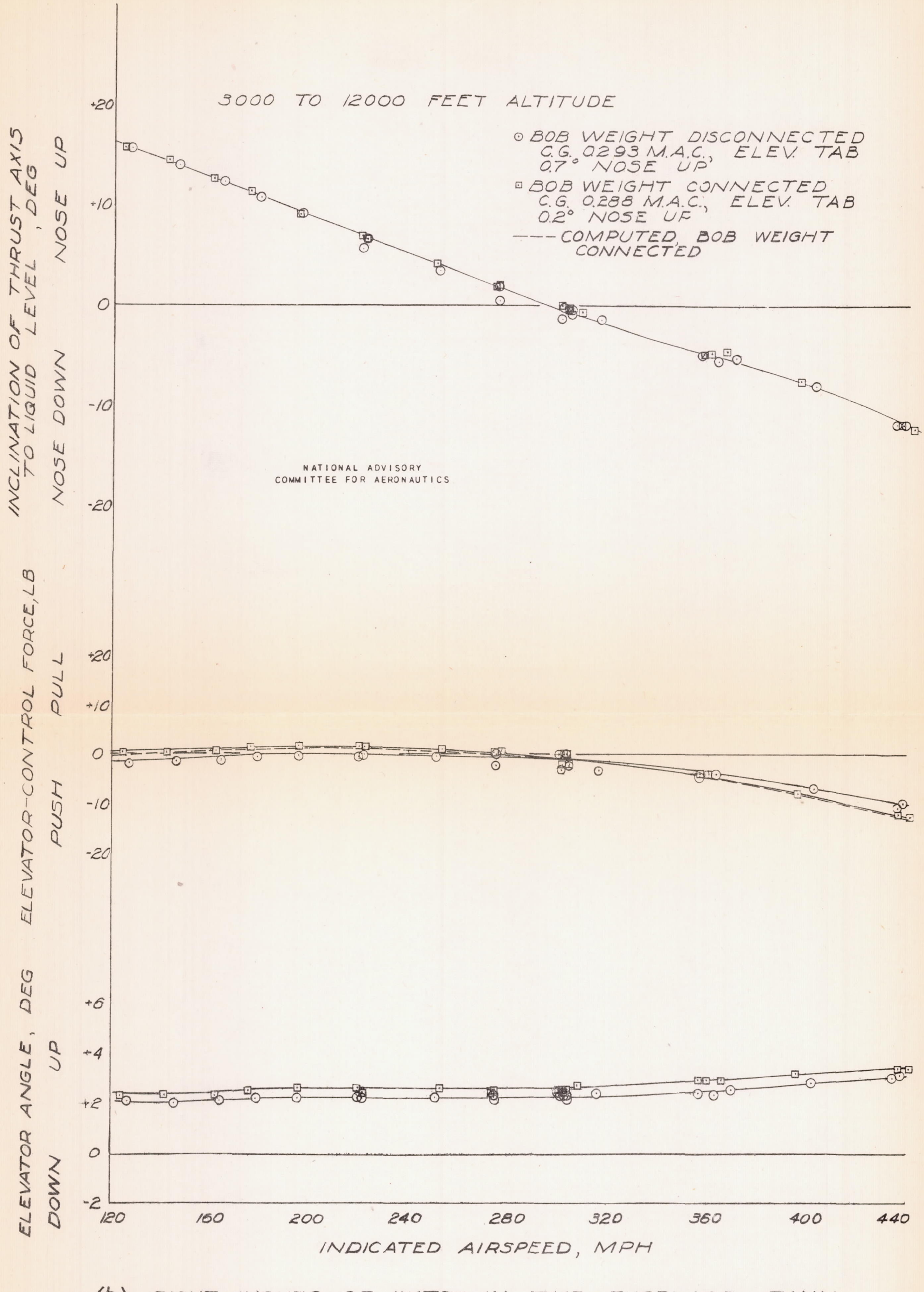


FIGURE 12.- VARIATION OF STICK-FREE NEUTRAL-MANEUVERING-POINT POSITION WITH NORMAL ACCELERATION FACTOR. TURNING FLIGHT.



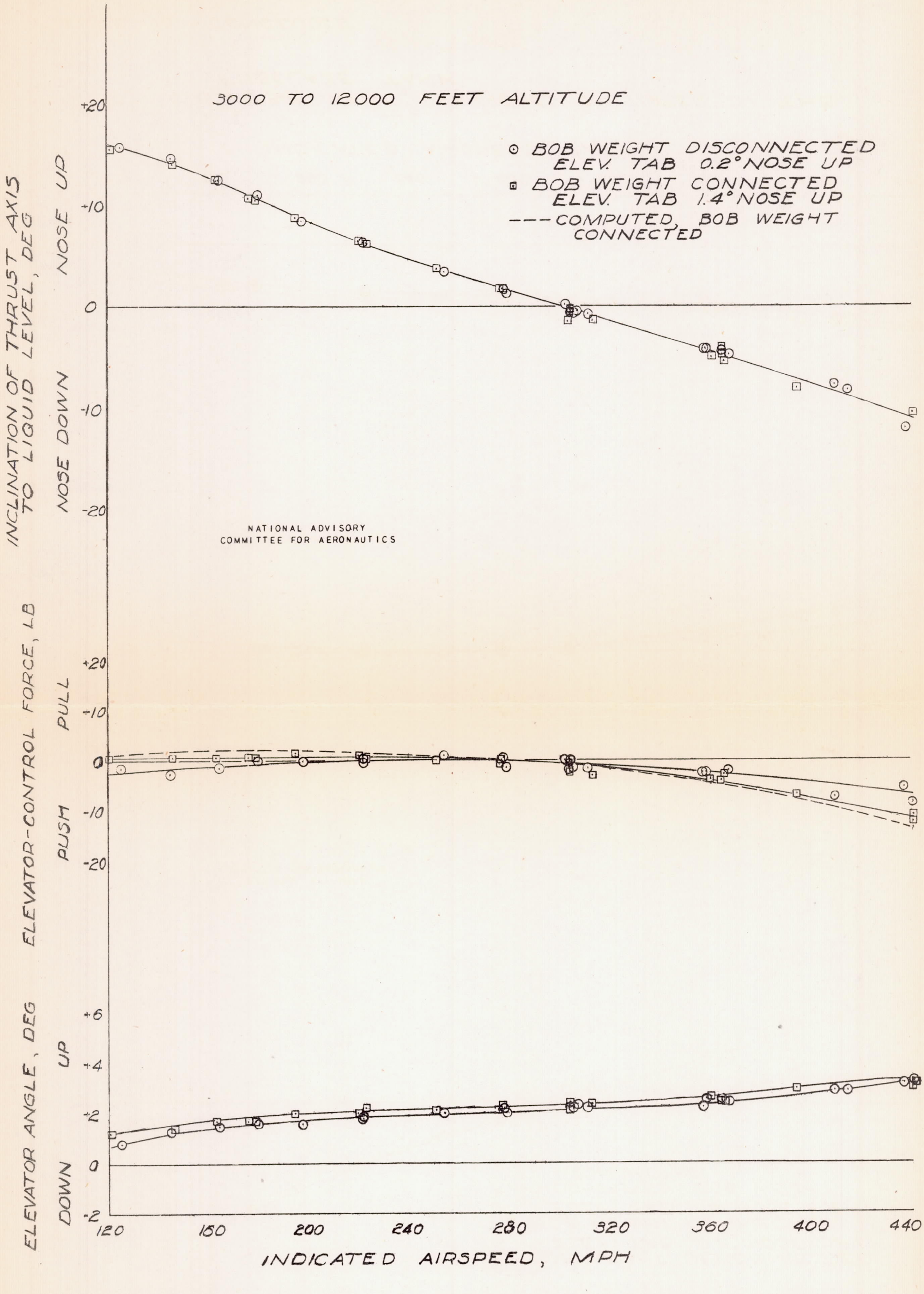
(a) C.G. 0.256 M.A.C., FUSELAGE TANK EMPTY.

FIGURE 13.– VARIATION OF ELEVATOR ANGLE, ELEVATOR CONTROL FORCE, AND INCLINATION OF THRUST AXIS TO LIQUID LEVEL WITH INDICATED AIRSPEED. STRAIGHT FLIGHT.



(b) EIGHT INCHES OF WATER IN THE FUSELAGE TANK.

FIGURE 13.- CONTINUED.



(c) C.G. 0.312 M.A.C., 16 INCHES OF WATER IN THE FUSELAGE TANK.

FIGURE 13. - CONCLUDED

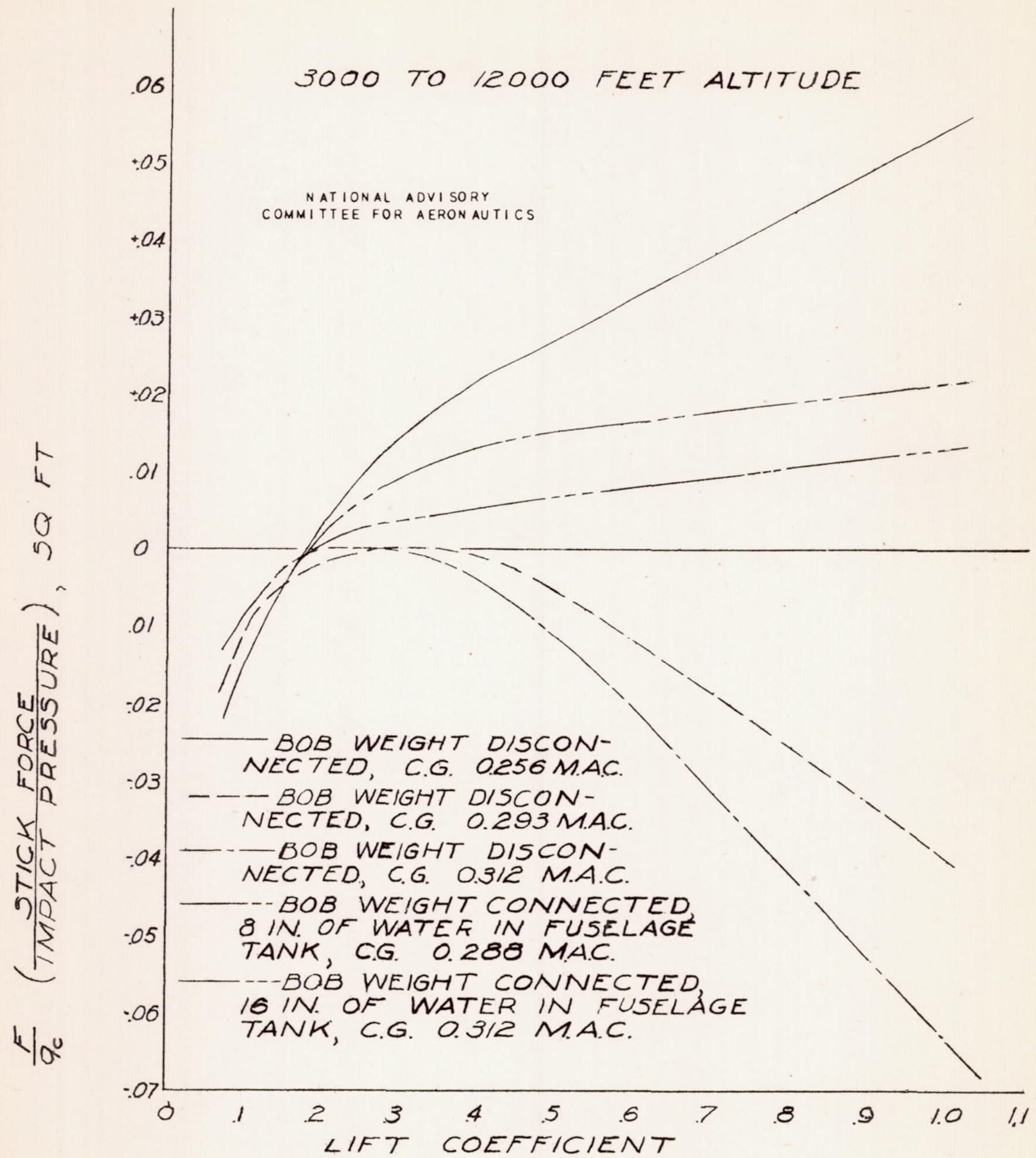


FIGURE 14.– VARIATION OF STICK FORCE/IMPACT PRESSURE WITH LIFT COEFFICIENT. STRAIGHT FLIGHT.

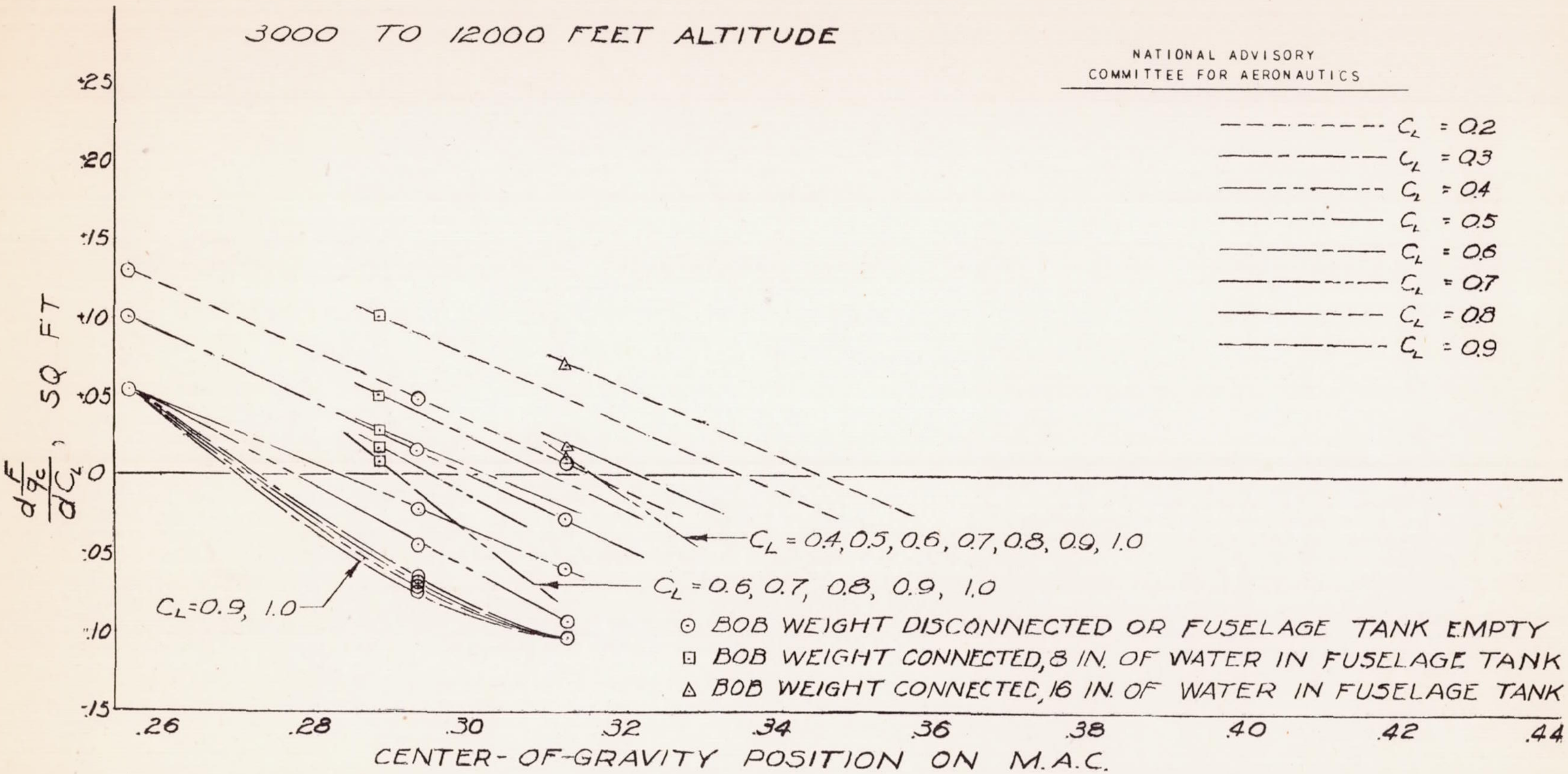


FIGURE 15.– VARIATION OF $\frac{d\frac{F}{q_c}}{dC_L}$ WITH CENTER-OF-GRAVITY. STRAIGHT FLIGHT.

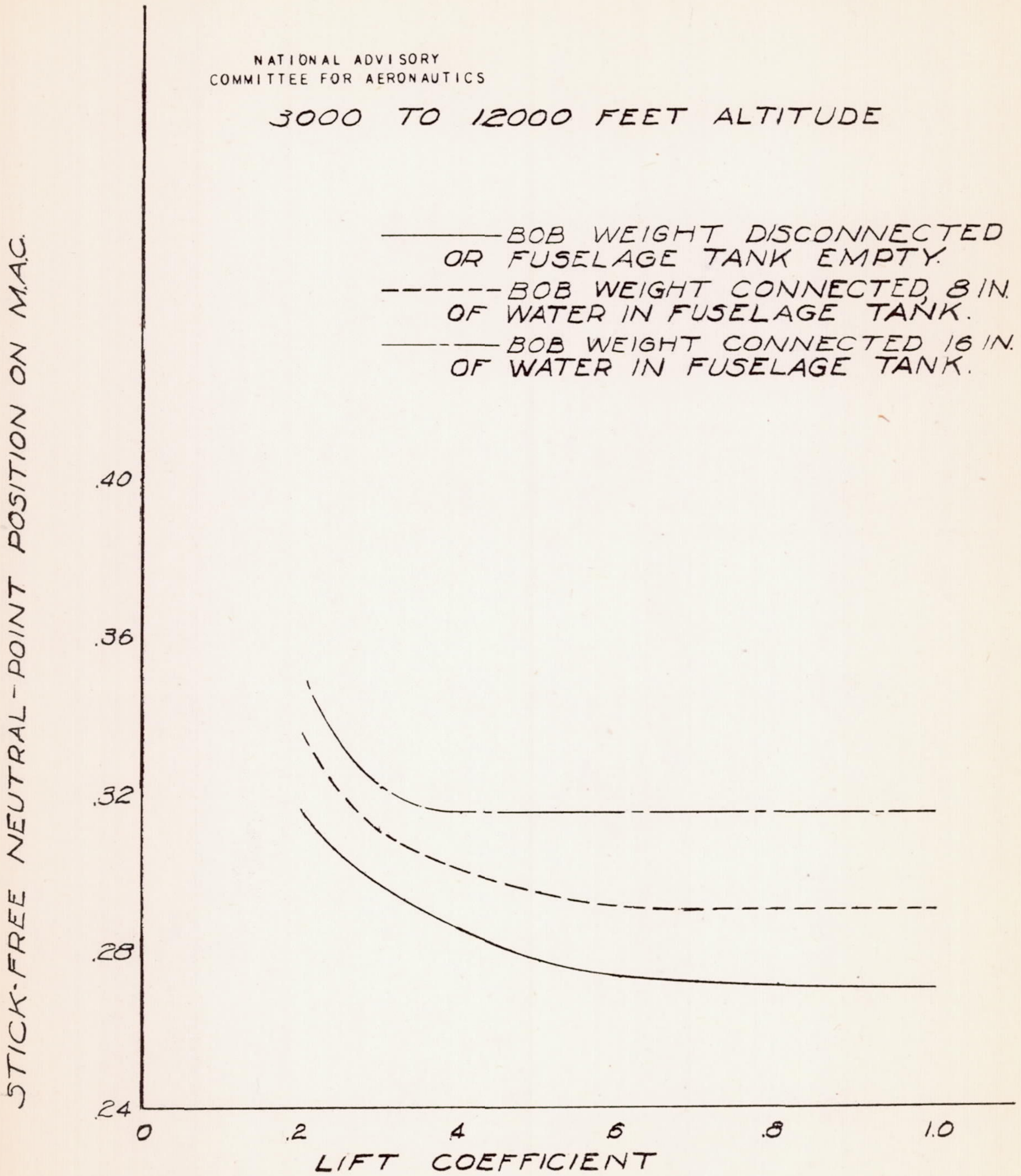
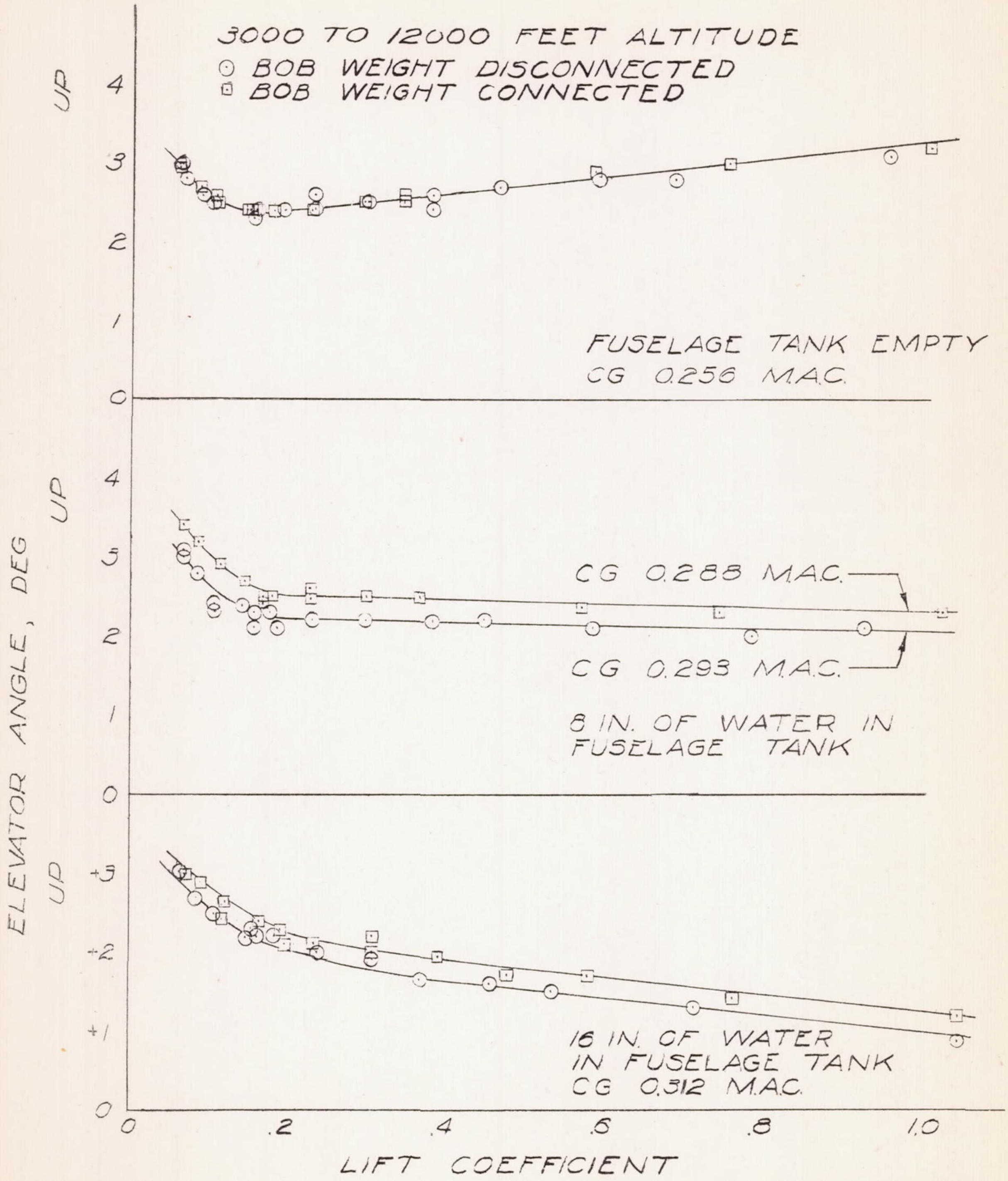


FIGURE 16. - VARIATION OF STICK-FREE NEUTRAL-POINT POSITION WITH LIFT COEFFICIENT STRAIGHT FLIGHT.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 17.- VARIATION OF ELEVATOR ANGLE WITH LIFT COEFFICIENT. STRAIGHT FLIGHT.

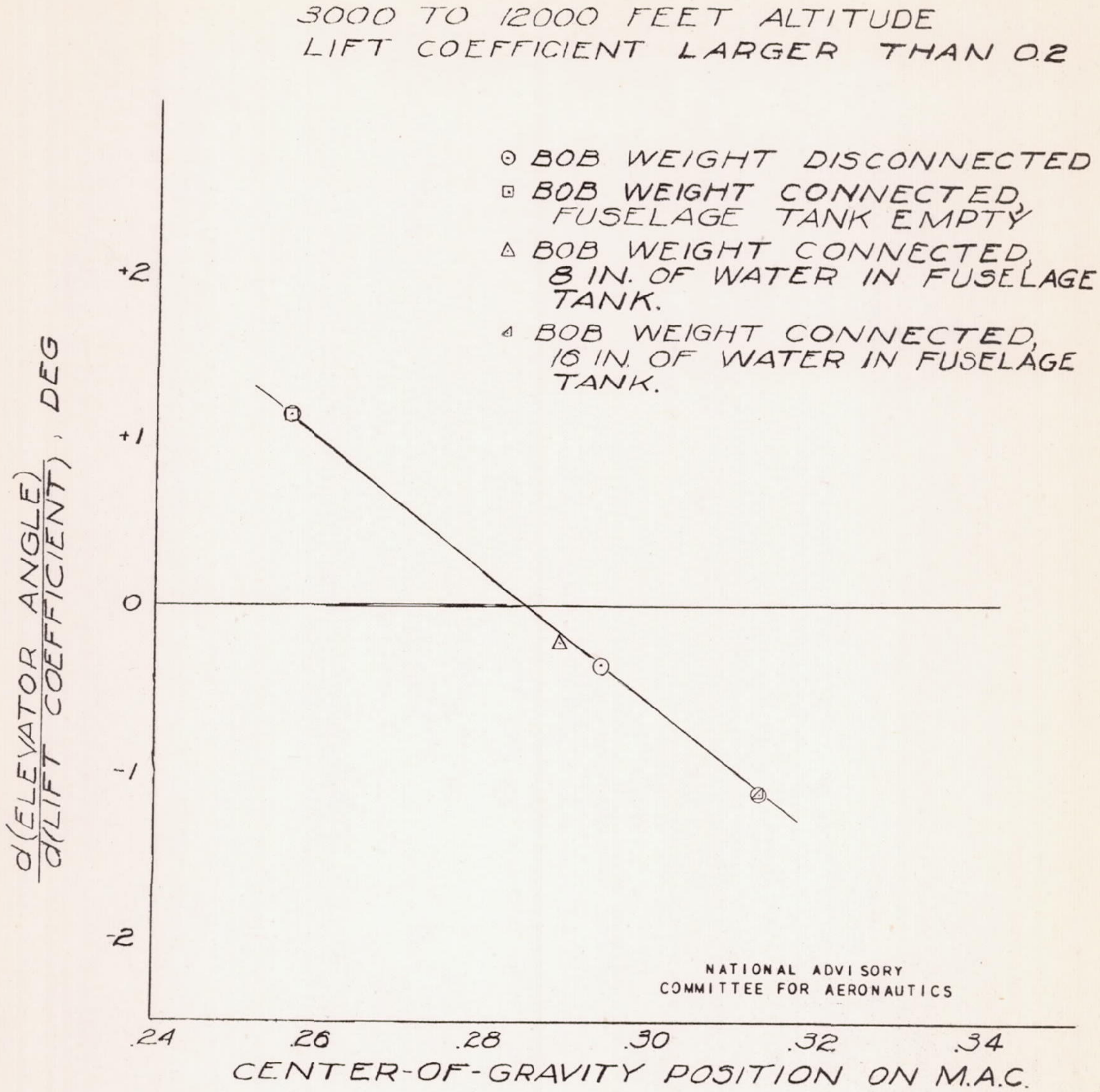
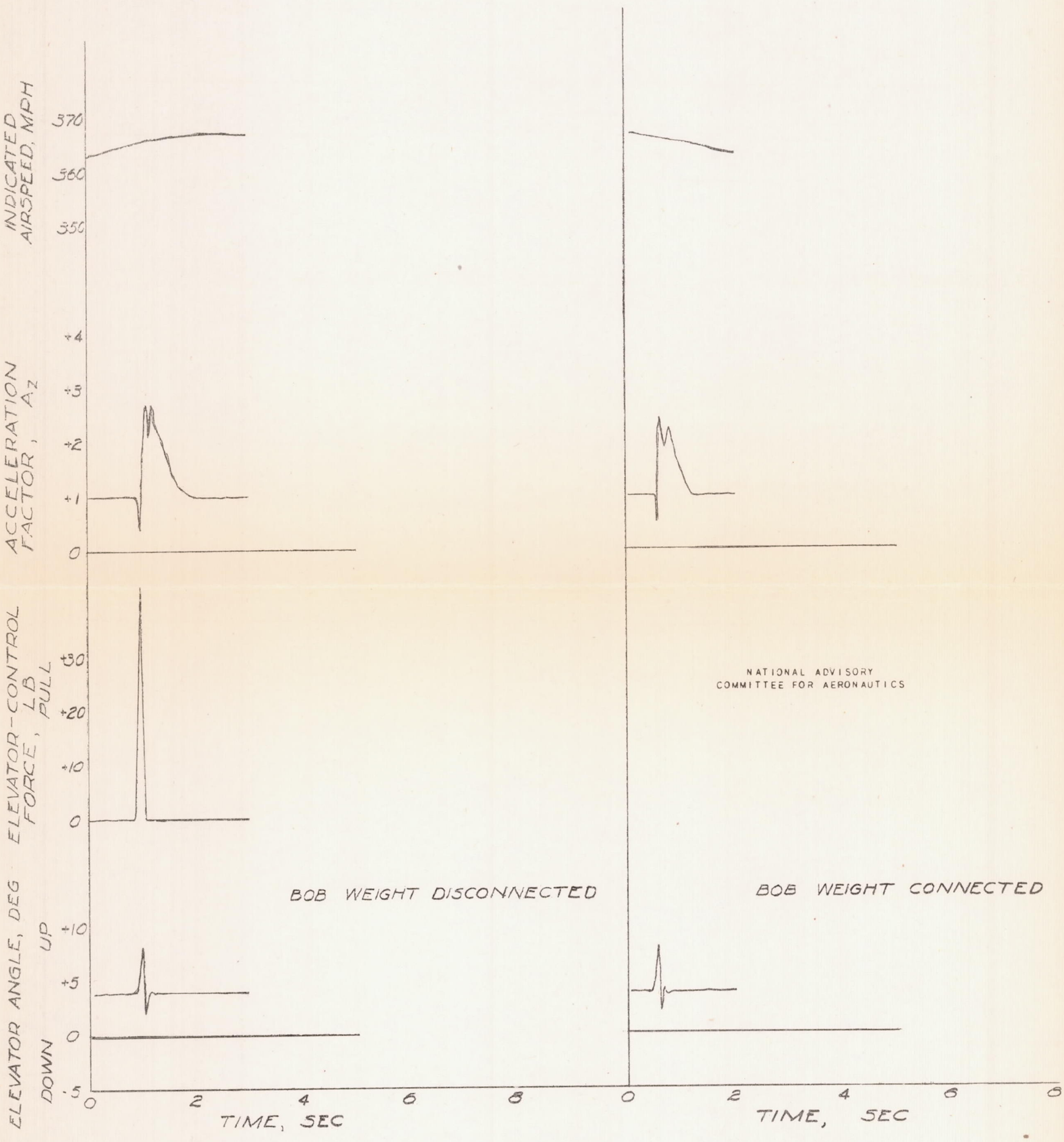
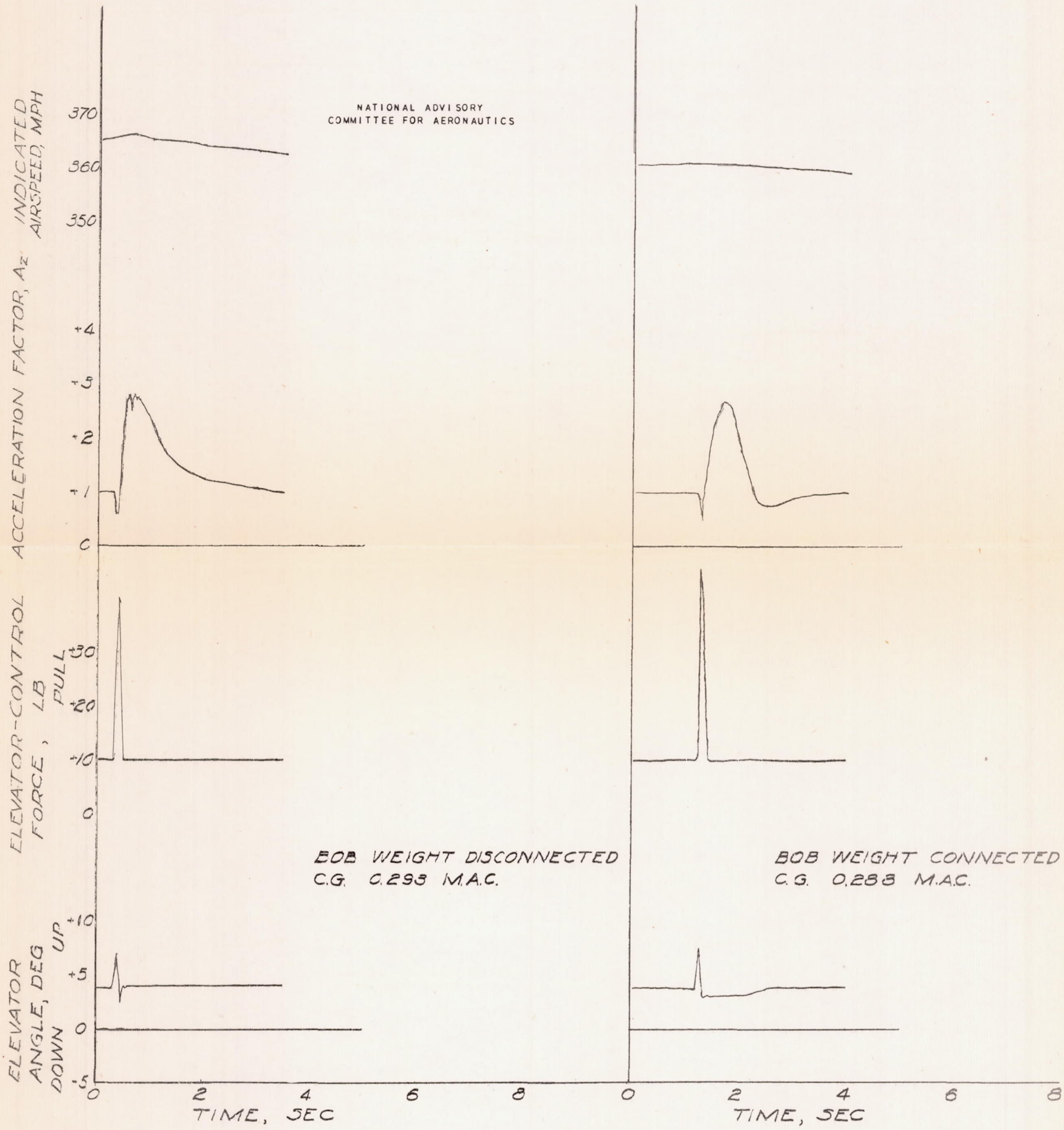


FIGURE 18.– VARIATION OF $\frac{d(\text{ELEVATOR ANGLE})}{d(\text{LIFT COEFFICIENT})}$ WITH CENTER-OF-GRAVITY POSITION. STRAIGHT FLIGHT.



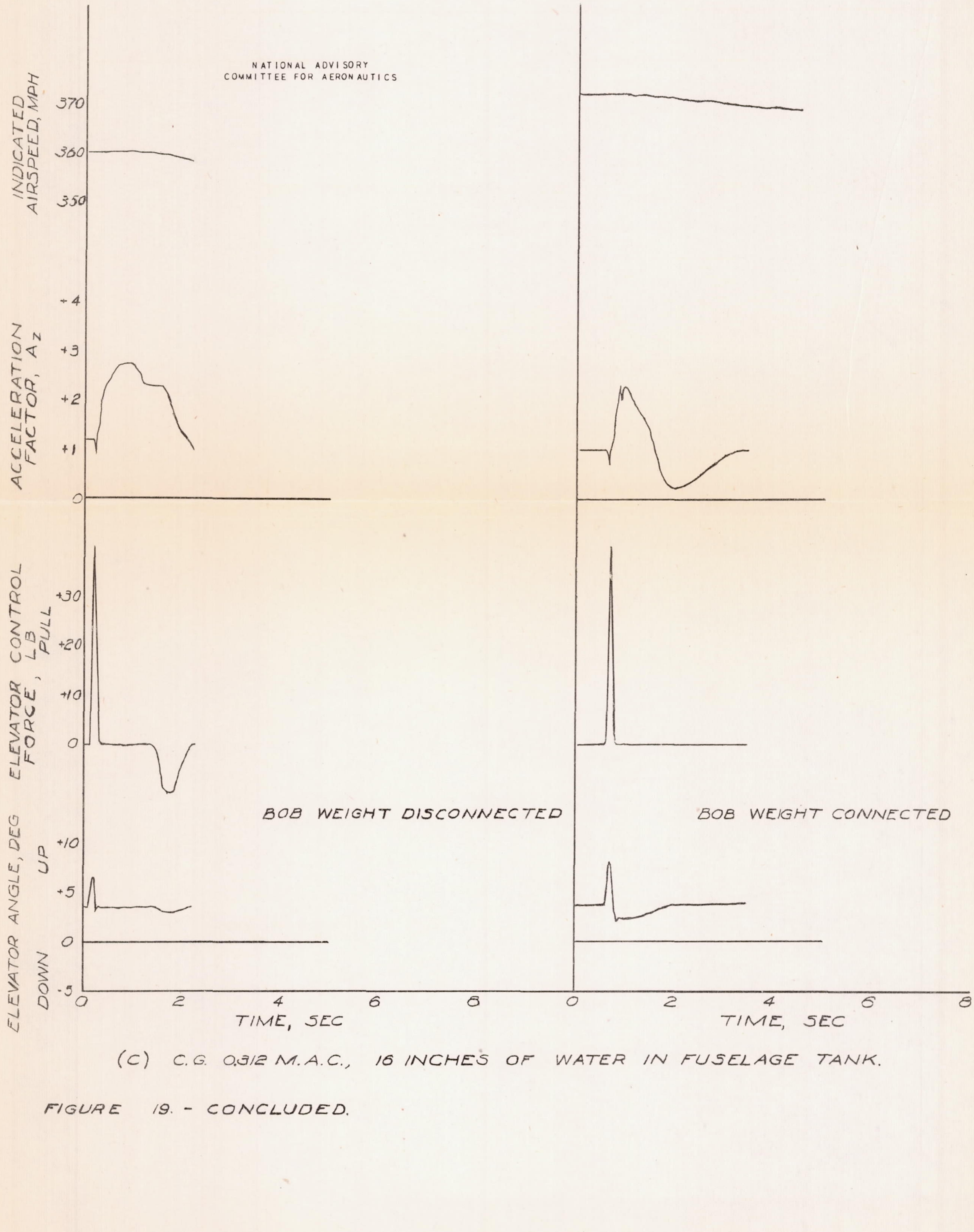
(a) C.G. 0.256 M.A.C., FUSELAGE TANK EMPTY.

FIGURE 19.- TIME HISTORIES OF SHORT-PERIOD OSCILLATIONS RESULTING FROM AN ABRUPT PULL-UP AND RELEASE.



(b) C.G. ABOUT 0.29 M.A.C., EIGHT INCHES OF WATER IN FUSELAGE TANK.

FIGURE 19. - CONTINUED.



(C) C.G. 0.312 M.A.C., 16 INCHES OF WATER IN FUSELAGE TANK.

FIGURE 19. - CONCLUDED.

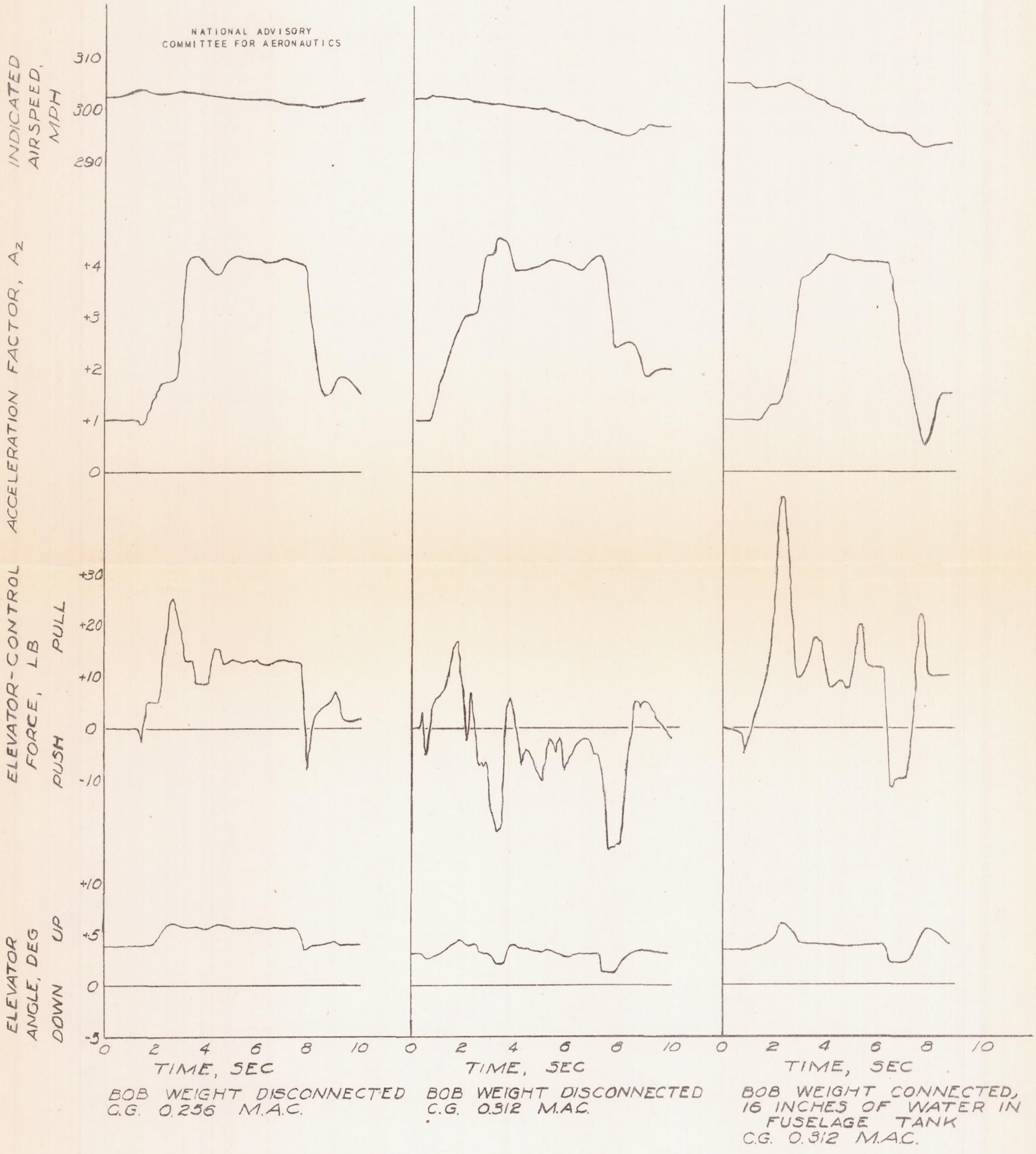


FIGURE 20.- TIME HISTORIES DURING RAPID RIGHT TURNS.

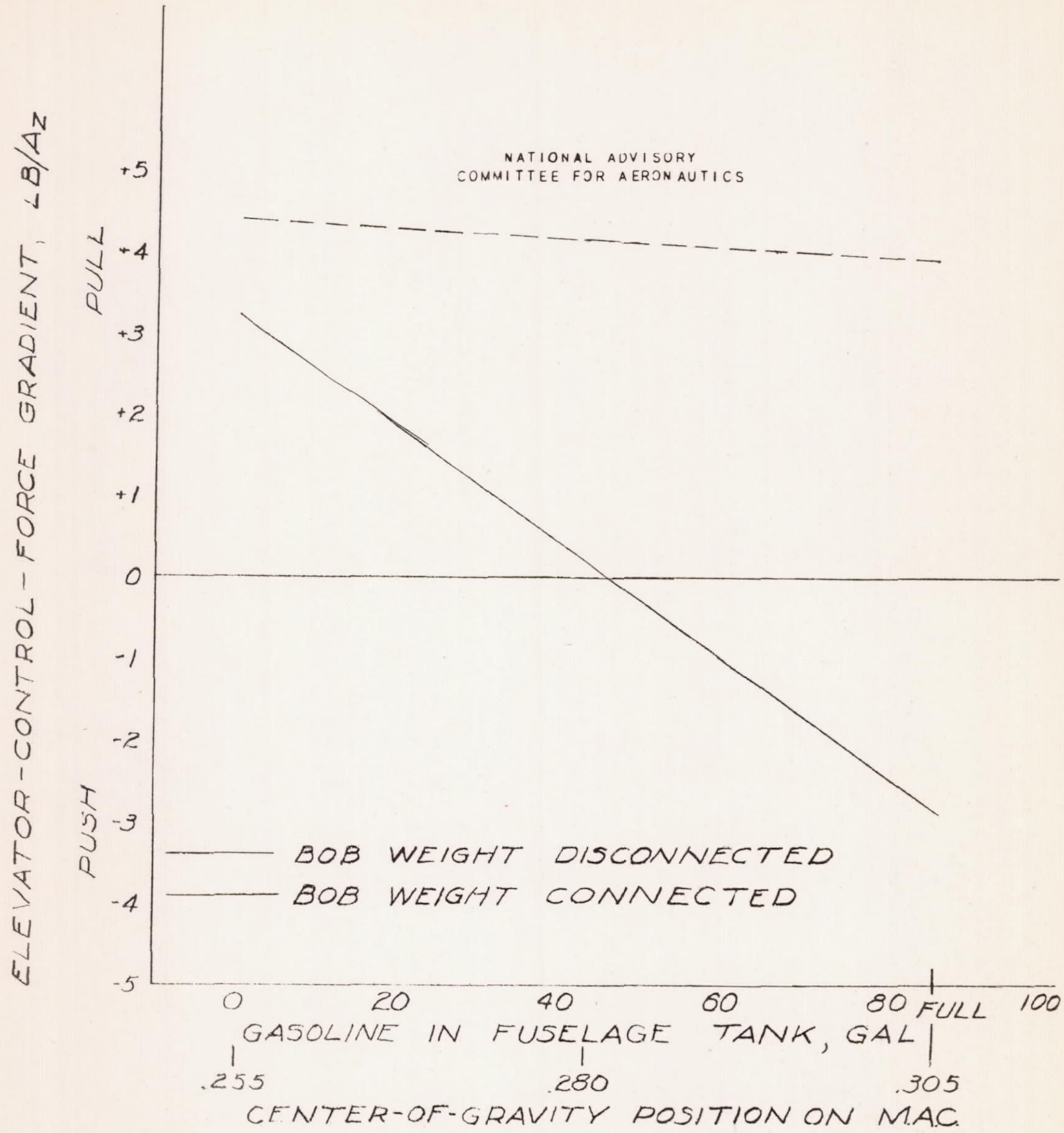


FIGURE 21.— VARIATION OF ELEVATOR CONTROL-FORCE GRADIENT WITH THE AMOUNT OF GASOLINE IN THE STANDARD FUSELAGE TANK. DURING 4G STEADY TURNS AT 250 MILES PER HOUR.

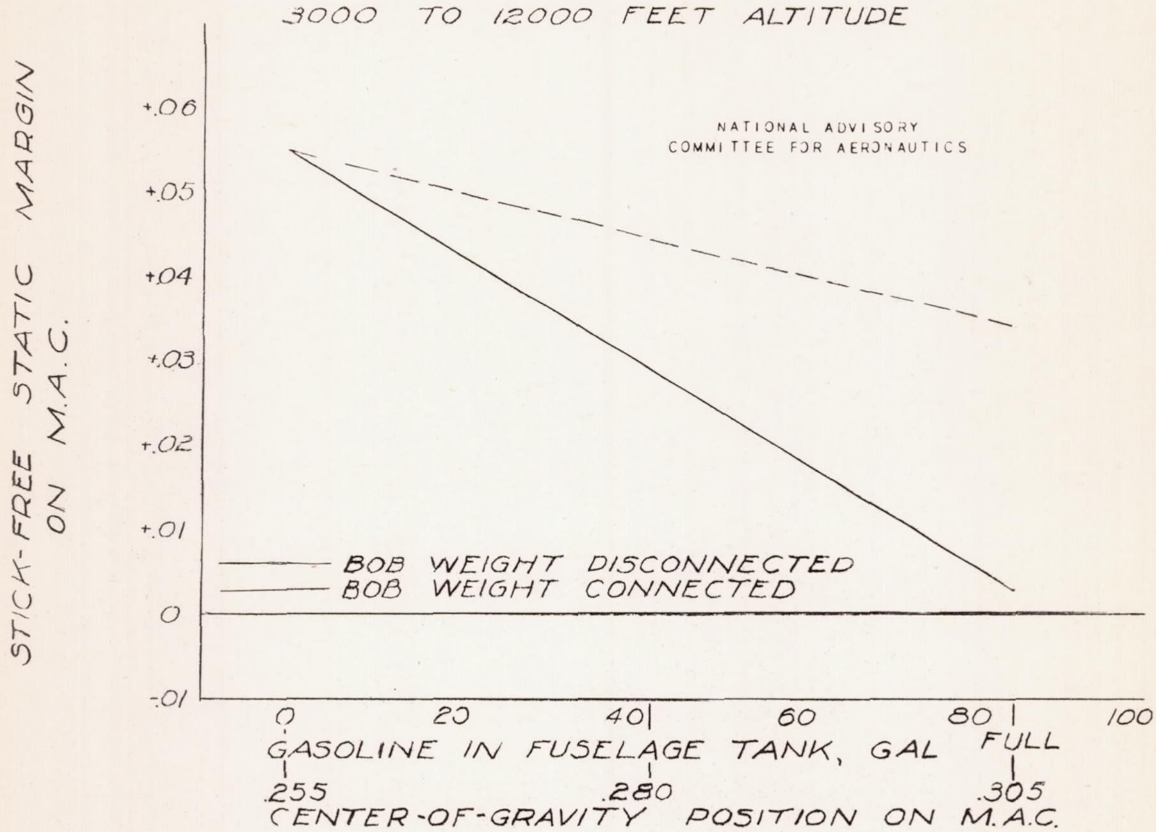


FIGURE 22.— VARIATION OF STICK-FREE STATIC MARGIN WITH AMOUNT OF GASOLINE IN THE STANDARD FUSELAGE TANK DURING STRAIGHT FLIGHT AT 250 MILES PER HOUR.