NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1317

WIND-TUNNEL INVESTIGATION OF THE EFFECT OF WING-TIP FUEL TANKS ON CHARACTERISTICS OF UNSWEPT WINGS IN STEADY ROLL

By Harry E. Murray and Evalyn G. Wells

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington
June, 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1317

WIND-TUNNEL INVESTIGATION OF THE EFFECT OF WING-TIP FUEL TANKS ON CHARACTERISTICS OF UNSWEPT WINGS IN STEADY ROLL

By Harry E. Murray and Evalyn G. Wells

SUMMARY

Tests have been made to determine the effects of wing-tip fuel tanks on the rolling characteristics of unswept wings. The investigation included the determination of damping in roll, aileron effectiveness, and lateral maneuverability of a tapered and of a rectangular wing. Two tank sizes and two tank locations, which were believed to be representative of tank installations used at the present, were investigated.

Results of tests indicated that wing-tip fuel tanks of sizes generally used at present increased the damping in roll and the aileron effectiveness of the wings investigated as much as 44 percent and 16 percent, respectively. Because the damping in roll tended to increase more than the aileron effectiveness, a decrease in lateral maneuverability of as much as 20 percent resulted from the installation of the tanks. The effect of the tanks increased with tank size and was generally greater for tanks mounted out on the tips than for tanks mounted down under the tips.

INTRODUCTION

The necessity of increasing the range of small aircraft has led to the use of external, droppable fuel tanks. The most favorable location of the tanks, particularly at high Mach numbers, appears to be near the wing tips in spite of the fact that from consideration of maneuverability wing-tip fuel tanks may be objectionable because of possible effects on moments of inertia and aileron rolling power. Unpublished test results have indicated that wing-tip fuel tanks of sizes generally employed at the present can increase the lift-curve slope of a wing approximately 15 percent and reduce the induced drag at cruising lift coefficients sufficiently to compensate approximately for the increased parasite drag resulting from the tanks.

Tests were therefore made of a rectangular wing and of a tapered wing, each with an aspect ratio of approximately 6, to determine the damping in roll. Tests were made of each wing with wing-tip fuel tanks of two sizes and of each wing without tanks. The effect of aileron deflection in producing rolling moments was also measured on the tapered wing. The rolling-flow method of reference 1 was used.

SYMBOLS

C_l	rolling-moment coefficient $\left(\frac{L}{qSb}\right)$
ΔC_l	increment of rolling-moment coefficient
C_{l_p}	damping-moment coefficient in roll $\left(\frac{\partial C_l}{\partial(pb/2V)}\right)$
C_{l_δ}	aileron rolling effectiveness $\left(\frac{\partial C_l}{\partial \delta}\right)$
L	rolling moment about wind axis
S	wing area
b	span of basic wing without tanks
V	free-stream velocity
ρ	air mass density
q	free-stream dynamic pressure $\left(\frac{\rho V^2}{2}\right)$
p	rolling velocity of wing about wind axis
$pb/2V$	wing-tip helix angle
δ	aileron deflection; positive down
α	angle of attack
D	maximum diameter of tip tank
λ	taper ratio $\left(\frac{\text{Tip chord}}{\text{Root chord}}\right)$

APPARATUS AND MODEL

Tests were made in the 6-foot circular test section of the Langley stability tunnel which is provided with rotating vanes to rotate the flow and thus to simulate rolling flight with a stationary model. A description of the rolling-flow apparatus and its operation along with an experimental verification of the method is presented in reference 1.

Two model wings were used for the tests. The geometric characteristics of the wings are given in the following table:

Rectangular wing:

Area, square inches	361
Span, inches	48
Mean geometric chord, inches	7.52
Aspect ratio	6.38
Airfoil section	NACA 23012

Tapered wing ($\lambda = 0.333$):

Area, square inches	384
Span, inches	48
Mean geometric chord, inches	8
Aspect ratio	6.00
Airfoil section	NACA 66,2-216
Aileron span, inches	12
Aileron chord, fraction local wing chord	0.20
Aileron gap	Sealed

The wing-tip fuel tanks were obtained by revolving about the chord line an NACA 66_3-018 airfoil section of basic thickness modified by fairing straight lines from the trailing edge to tangent points on each side of the airfoil. Two sizes of tanks which had lengths of one-third and one-sixth of the wing span (termed the large and small tanks, respectively) were tested. The tanks were attached to the wings in the out and down locations which are defined in figures 1 and 2. Photographs of the large tanks in the two locations are presented as figure 3.

TESTS

Rolling moments were measured at various angles of attack and various rates of roll for the rectangular and tapered wings and also at various aileron deflections with zero rolling velocity for the tapered wing. Tests were made at a dynamic pressure of 64.3 pounds per square foot, which corresponds to an airspeed of 159 miles per hour at standard sea-level atmospheric conditions. The Reynolds numbers based on the mean geometric chord were 940,000 and 1,000,000 for the rectangular wing and for the tapered wing, respectively.

No jet-boundary corrections were applied to the data; however, corrections were estimated for both the rolling moment and the angle of attack. The rolling-moment correction was determined from boundary induced velocity computed by the method outlined in reference 2 for a circular tunnel. The computation showed the measured rolling moments to be approximately 0.9 percent high. Because this correction is within the experimental error of the measurements, it was not applied to the data. The correction to the angle of attack was obtained from a chart in reference 3. The corrected angle of attack is of the order of 5 percent larger than the geometric angle of attack. Because the lift characteristics of the wings were not available, the angle-of-attack correction had to be based on an estimated lift-curve slope and cannot be rigorously applied to the data.

RESULTS AND DISCUSSION

Results of the tests are presented in figures 4 to 7. In general, those data show for all tank configurations an approximately linear variation of rolling-moment coefficient with $pb/2V$. These results serve to show the general magnitude of the tank effects. In any particular case the effects will depend to some extent upon the nature of the fairing between the tanks and the wing.

Effect of Wing-Tip Fuel Tanks on the Damping-Moment Coefficient in Roll

The variation of the damping-moment coefficient in roll C_{l_p} with angle of attack for various tank configurations on the tapered and on the rectangular wing is shown, respectively, in figures 8(a) and 8(b). A reasonable agreement is shown in these figures between the measured values of C_{l_p} at small angles of attack for the tanks-off condition and values obtained by lifting surface theory from reference 4 (based on a section lift-curve slope of 0.10 per degree). Figure 8 shows that the effect of tanks on C_{l_p} increases with the size of the tanks and is considerably greater for the tanks-out configuration than for the tanks-down configuration. Figure 9 presents the variation of C_{l_p} with tank size for two angles of attack and indicates that the large tanks in the out location increase C_{l_p} about 44 percent at small angles of attack.

Effect of Wing-Tip Fuel Tanks on Aileron Rolling-Moment Effectiveness

The variation of rolling-moment coefficient with aileron deflection for one aileron is shown in figure 5. Tho slopes of these curves through zero deflection C_{l_δ} are an indication of the effectiveness of the aileron in producing a rolling moment. Figure 9 shows that C_{l_δ} is generally increased by the addition of tanks and that the increase amounts to about 16 percent for the large tanks.

Effect of Wing-Tip Fuel Tanks on Lateral Maneuverability

If the motion of the airplane is constrained to one degree of freedom, that is, to rolling, and if transient effects are neglected, the derivative $\frac{d(pb/2V)}{d\delta}$ is an indication of the lateral maneuverability of the airplane. Figure 9 shows that $\frac{d(pb/2V)}{d\delta}$ decreased generally with increasing tank size; the decrease is about 20 percent for the large tanks out. This decrease results from the tendency of the damping in roll to increase faster with tank size than does the aileron rolling effectiveness.

Origin of Effect of Wing-Tip Fuel Tanks

In order to obtain some information regarding the origin of the effect of wing-tip fuel tanks, the damping moment of the isolated tanks was obtained by supporting the tanks on a 4-foot-span $\frac{3}{8}$-inch-diameter round rod and by measuring tho rolling moment for the rod-tanks combination and for the rod alone. The difference between the two measurements is assumed to be the damping moment of the isolated tanks and is shown in figure 7 along with the damping of the tapered wing with and without the tanks. Also shown is the effect of the tanks in the presence of the wing which is obtained by subtracting the damping of the wing alone from that of the wing with tanks. Figure 7 indicates that a large part of the effect of tanks results from interference or end-plate effect between the tanks and the wing. Data corresponding to that of figure 7, for the rectangular wing, lead to the same conclusion.

CONCLUSIONS

Wind-tunnel tests have been made to determine the effect of wing-tip fuel tanks on the rolling characteristics of unswept wings. Two tank sizes and two tank locations were investigated. The following conclusions were indicated:

1. Tanks of sizes generally used at present increased the damping in roll and the aileron effectiveness of the wings investigated as much as 44 percent and 16 percent, respectively. Because the damping in roll tended to increase more than the aileron effectiveness, a decrease in lateral maneuverability of as much as 20 percent resulted from the installation of the tanks.

2. The effect of the tanks increased with tank size and was generally greater for tanks mounted out on the tips than for tanks mounted down under the tips.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., April 4, 1947

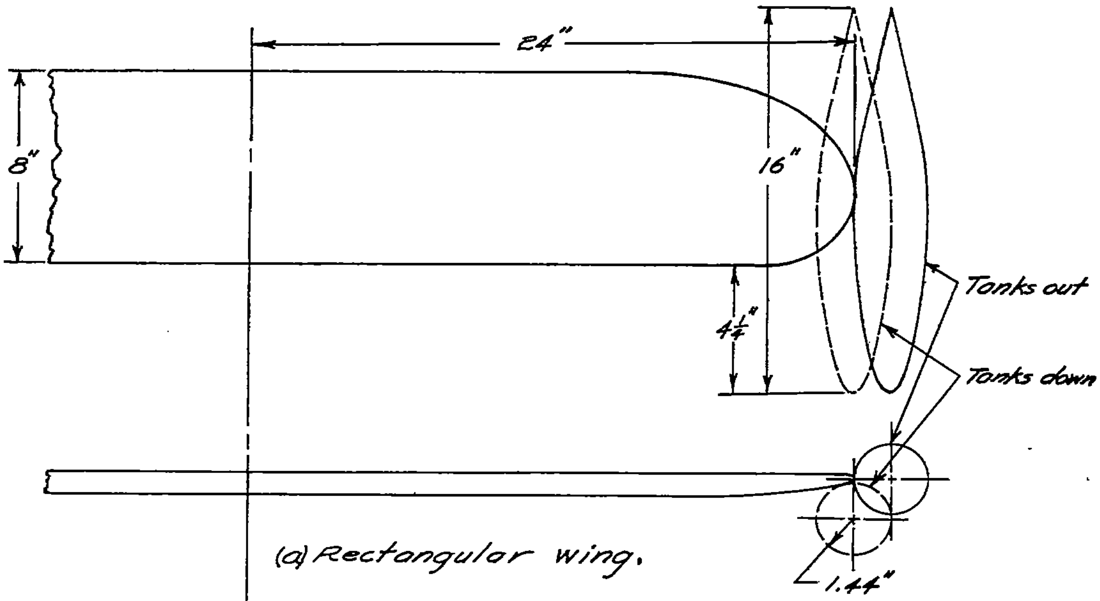
REFERENCES

1. MacLachlan, Robert, and Letko, William: Correlation of Two Experimental Methods of Determining the Rolling Characteristics of Unswept Wings. NACA TN No. 1309, 1947.

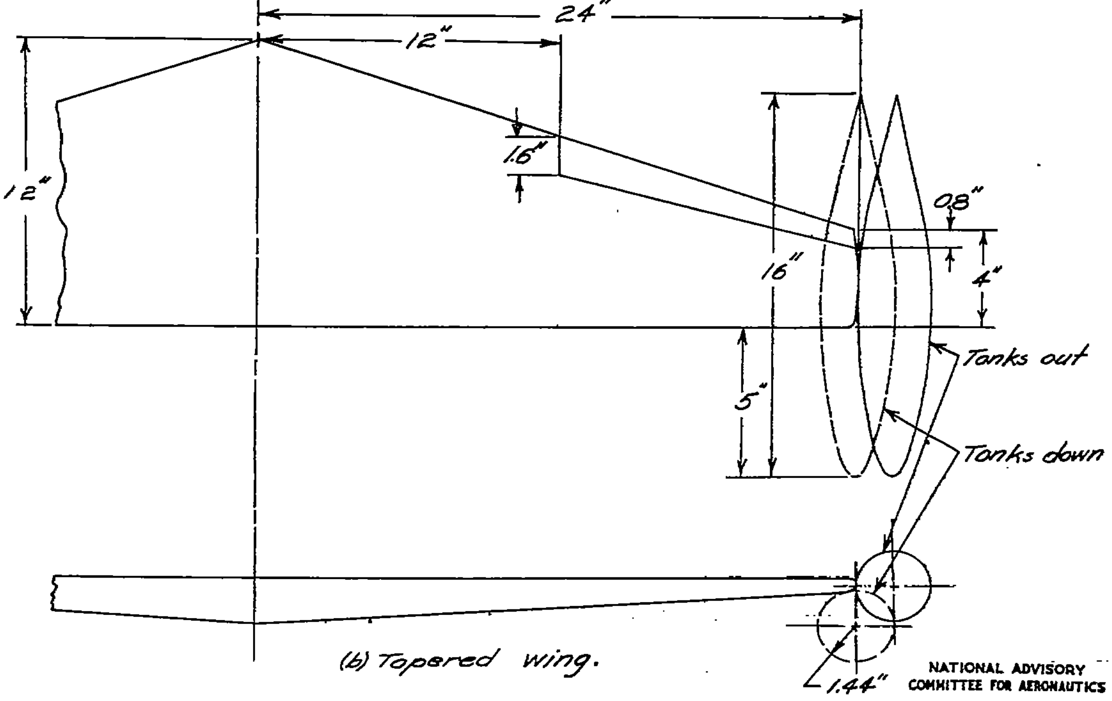
2. Glauert, H.: The Elements of Aerofoil and Airscrew Theory. Cambridge Univ. Press, 1937, p. 190.

3. Silverstein, Abe, and White, James A.: Wind-Tunnel Interference with Particular Reference to Off-Center Positions of the Wing and to the Downwash at the Tail. NACA Rep. No. 547, 1935.

4. Swanson, Robert S., and Priddy, E. LaVerne: Lifting-Surface-Theory Values of the Damping in Roll and of the Parameter Used in Estimating Aileron Stick Forces. NACA ARR No. L5F23, 1945.

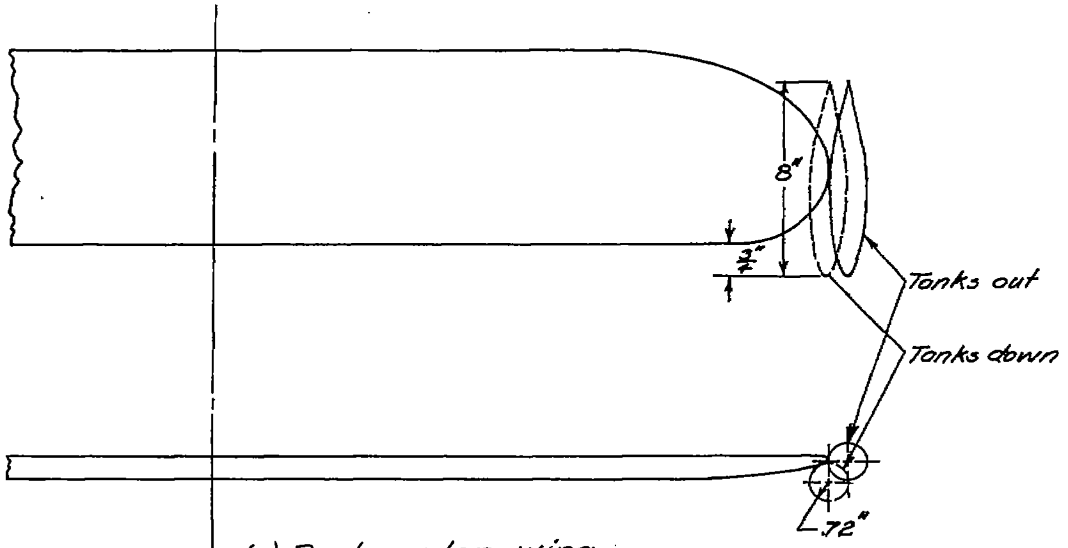


(a) Rectangular wing.

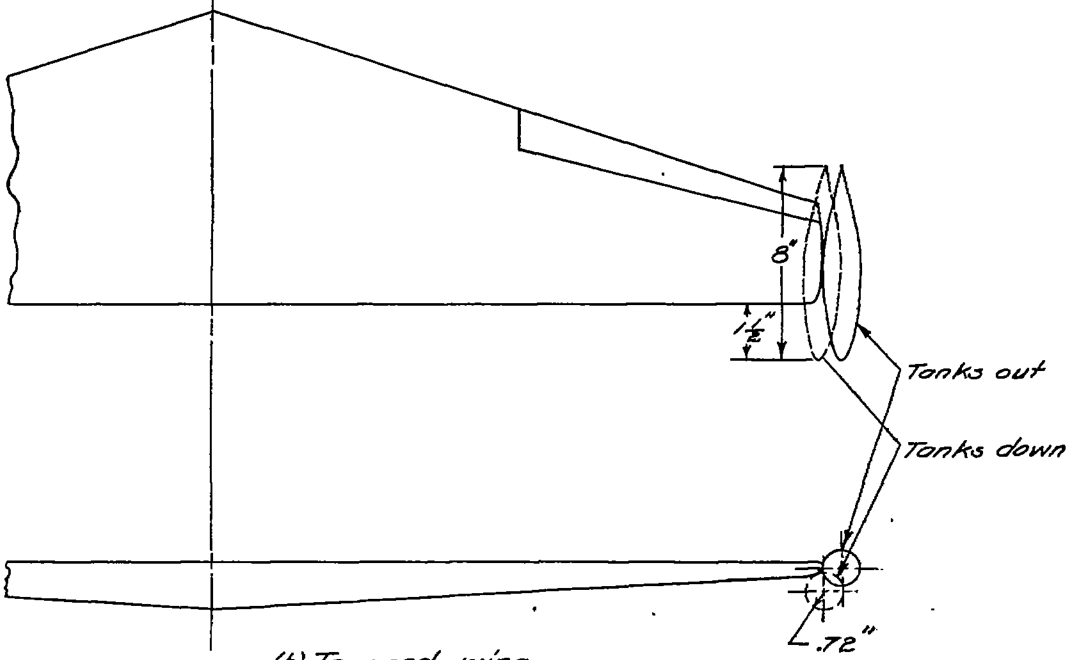


(b) Tapered wing.

Figure 1. - Rectangular and tapered wings with large tanks.



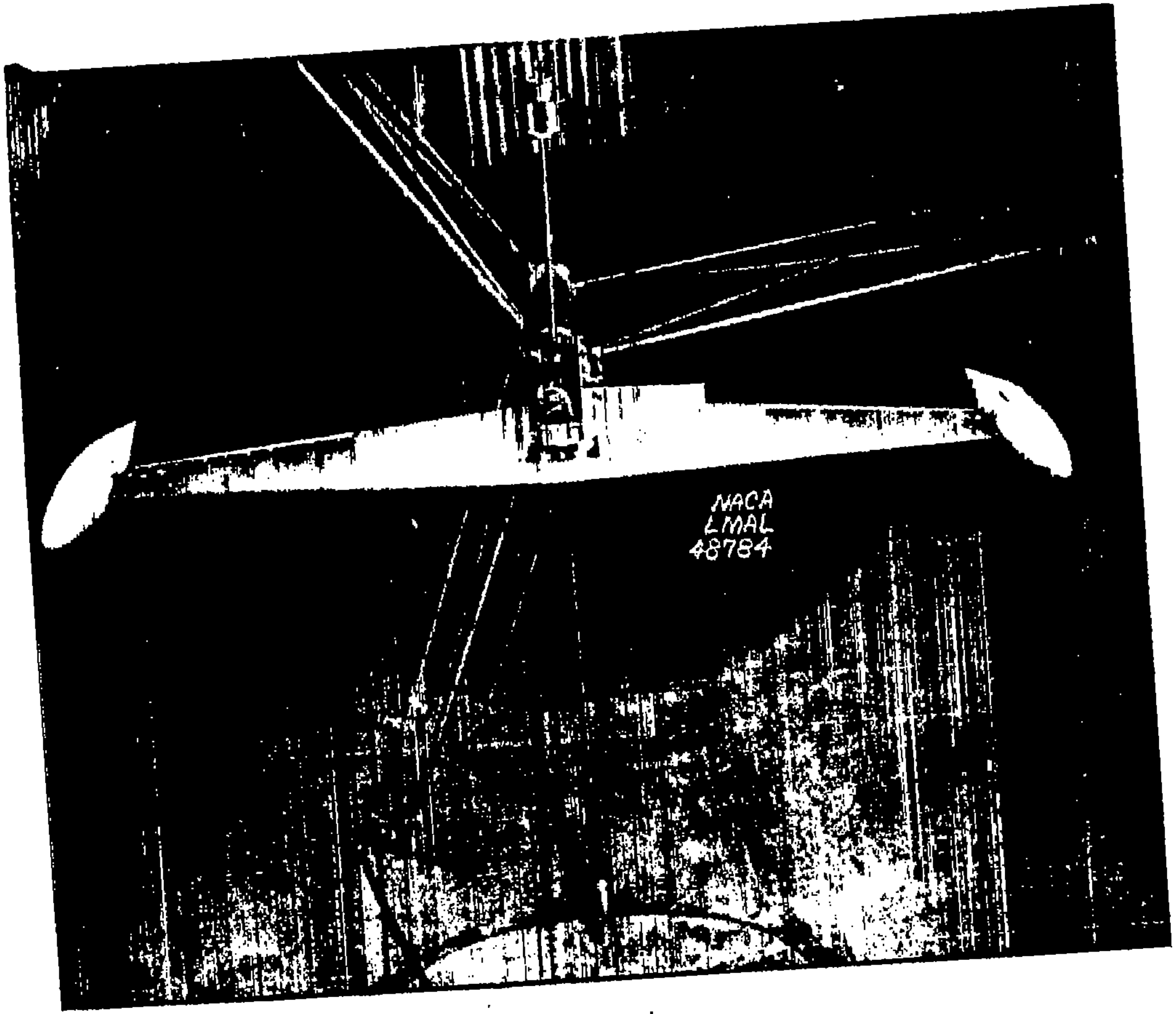
(a) Rectangular wing.



(b) Tapered wing.

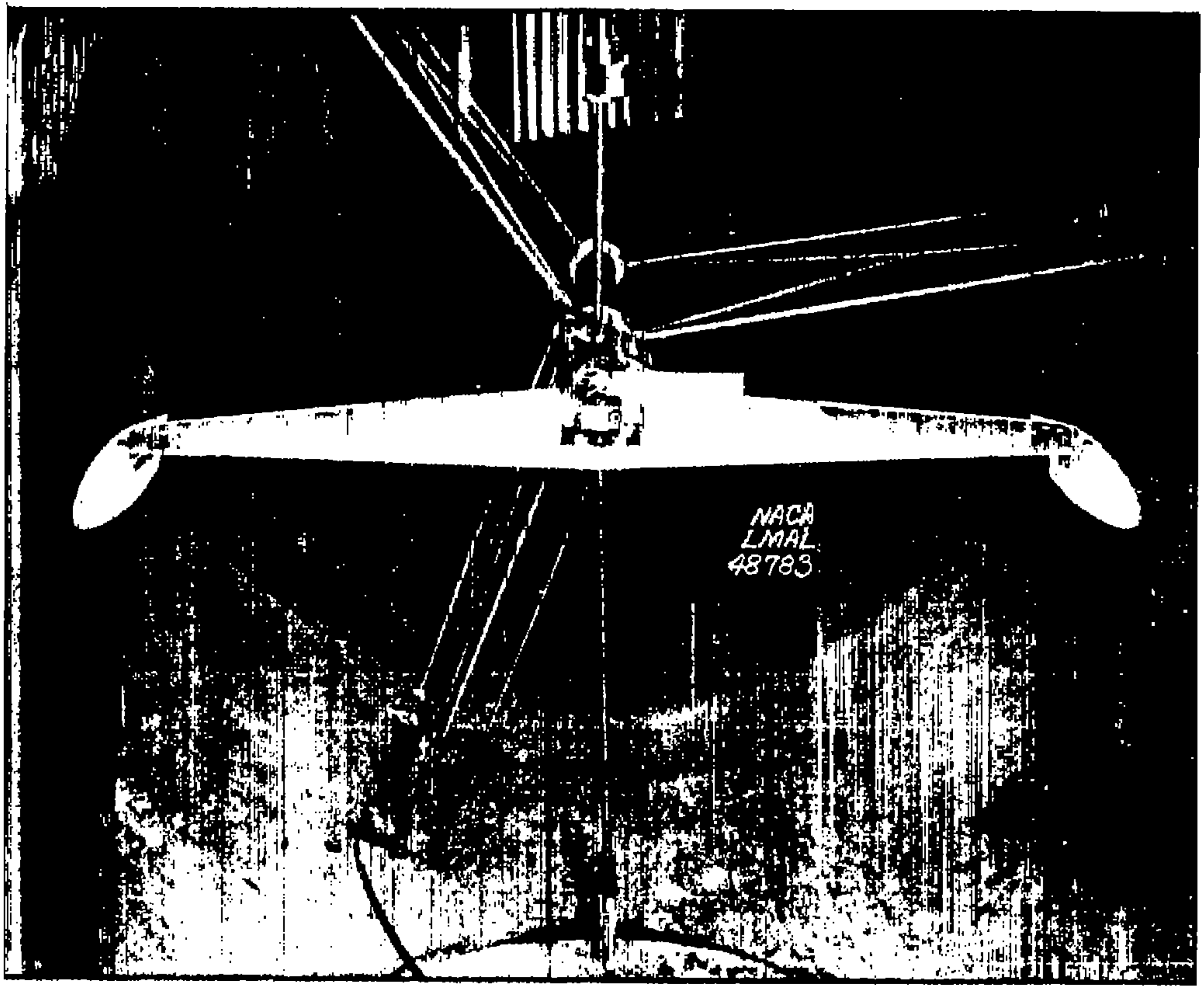
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 2.- Rectangular and tapered wings with small tanks.



(a) Tanks out.

Figure 3.- Tapered wing with large tanks mounted in the 6-foot circular test section of the Langley stability tunnel.



(b) Tanks down.

Figure 3.- Concluded.

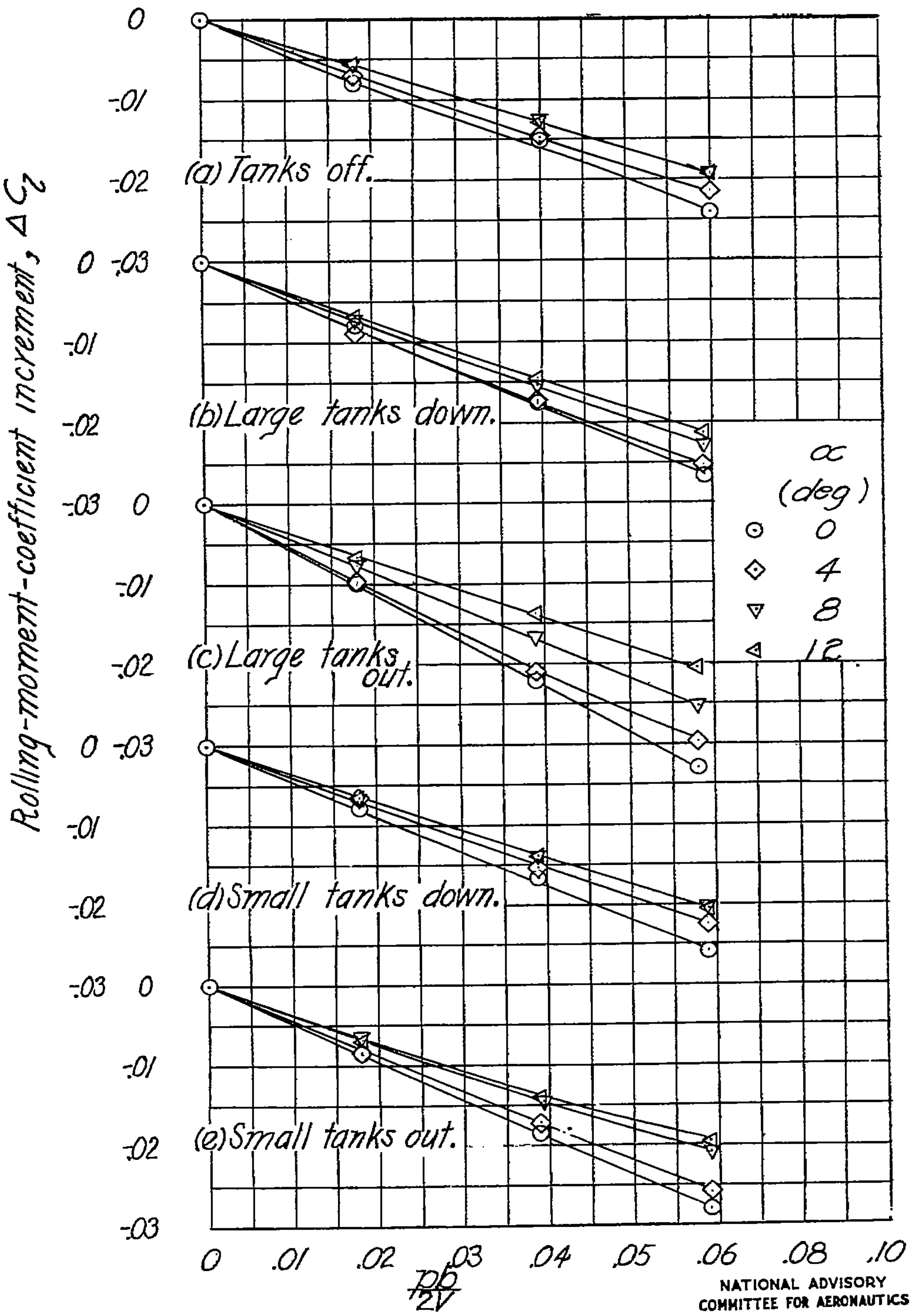


Figure 4.- Variation of rolling-moment-coefficient increment with wing-tip helix angle for tapered wing.

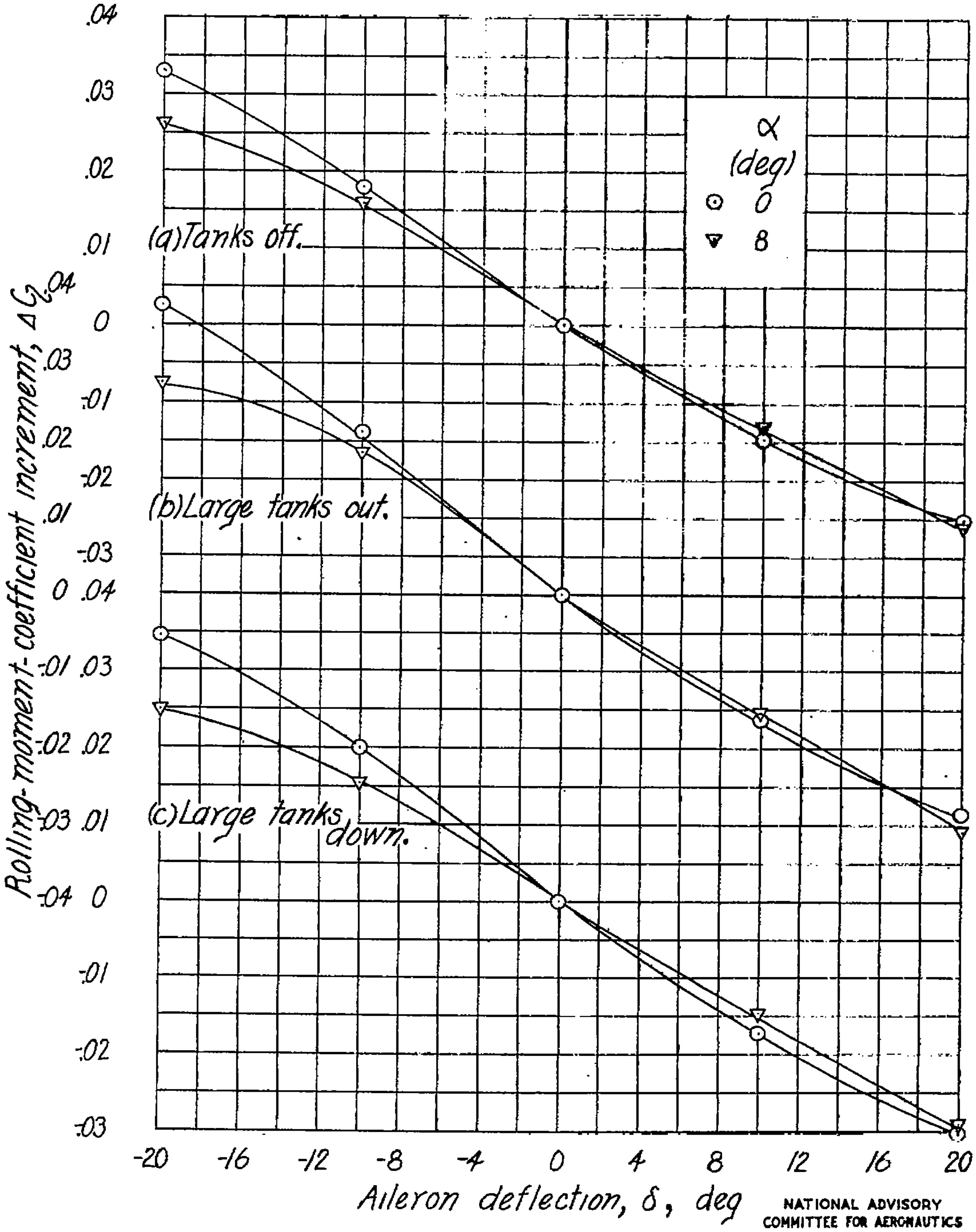


Figure 5.- Variation of rolling-moment-coefficient increment with deflection of one aileron. $\frac{pb}{2V}=0$.

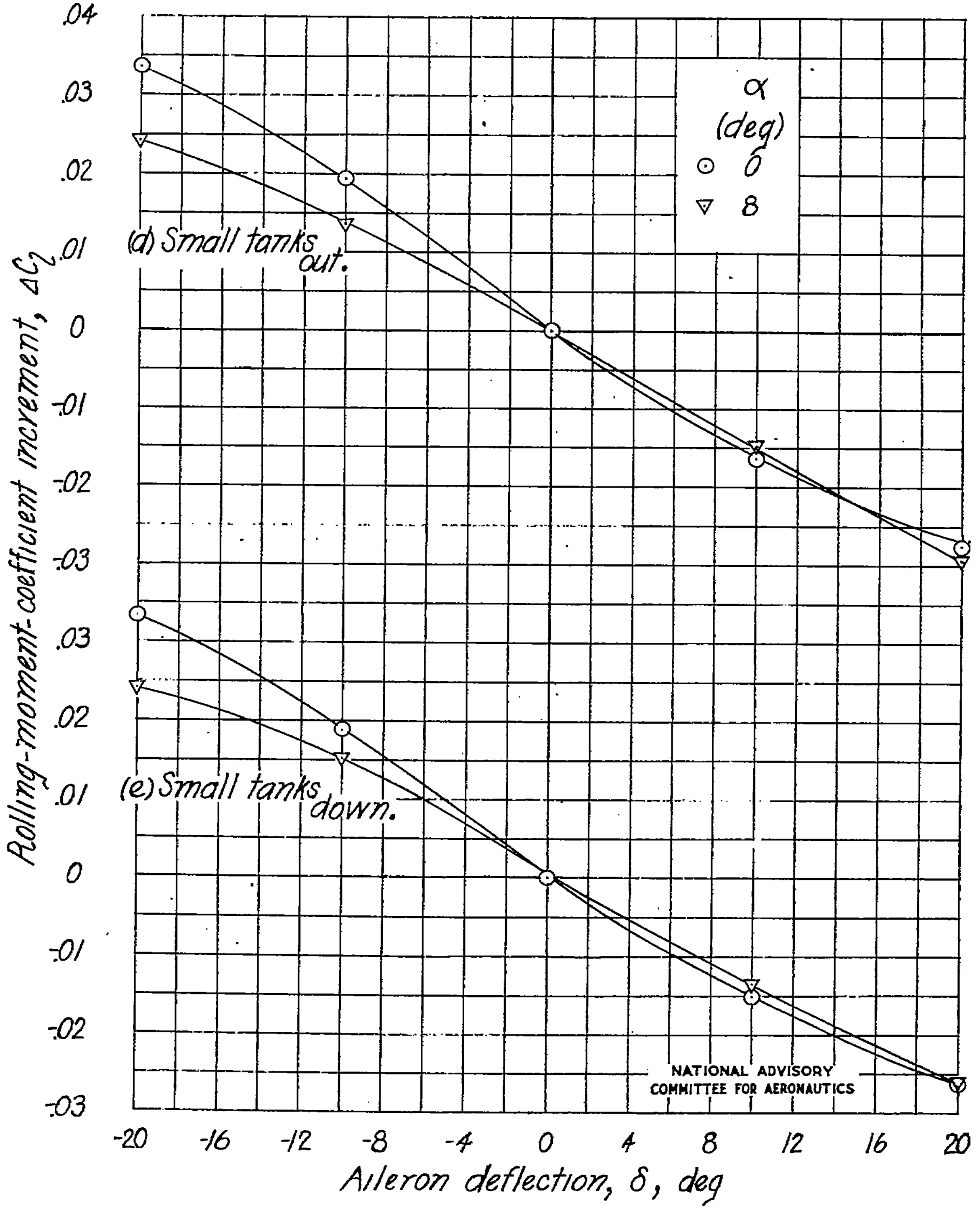
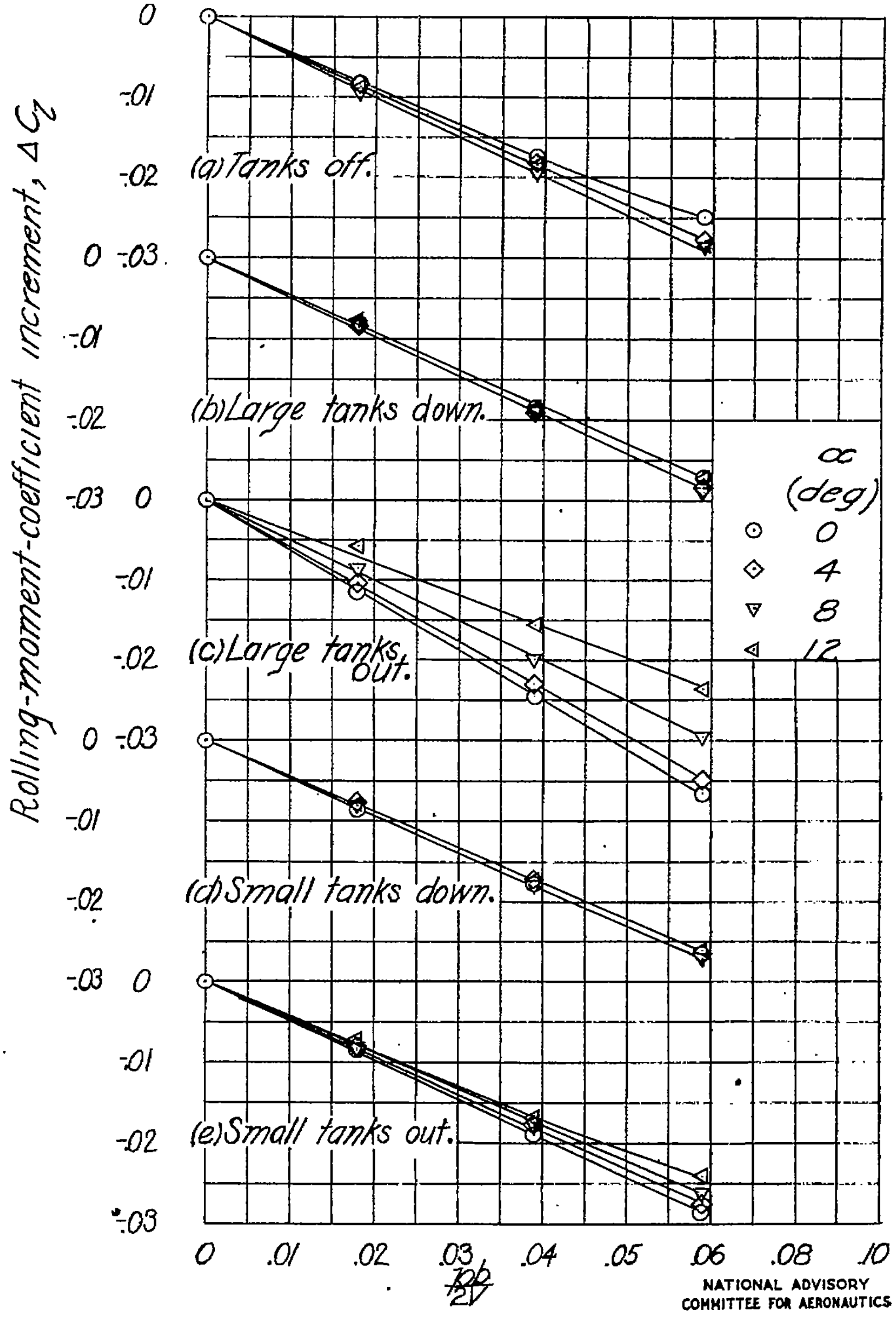
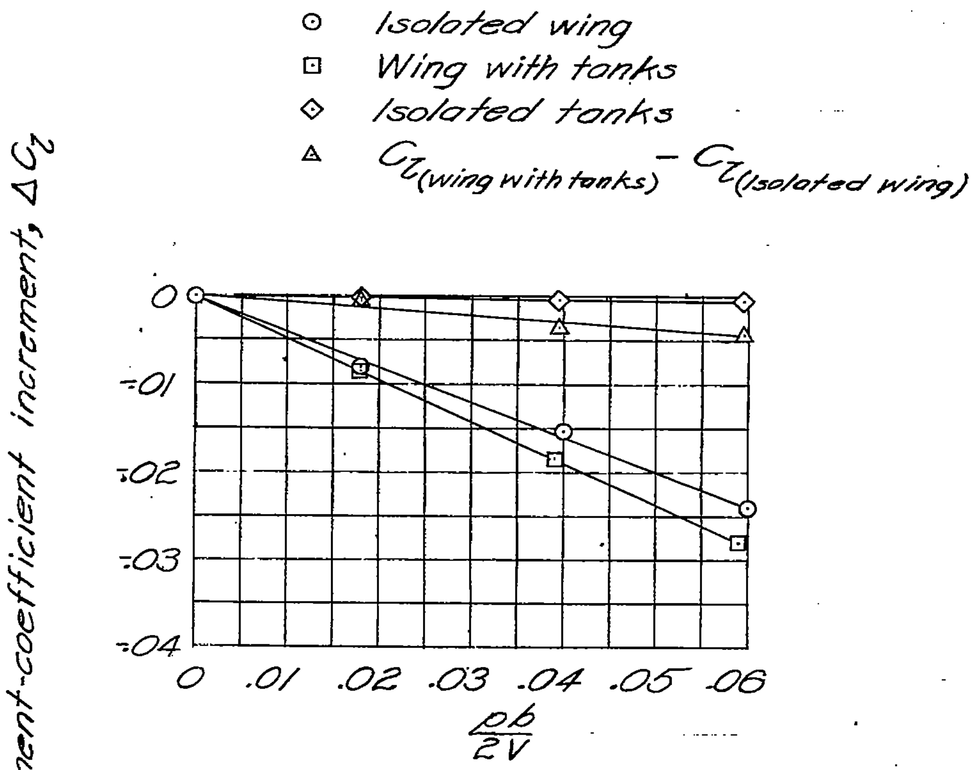


Figure 5.- Concluded.

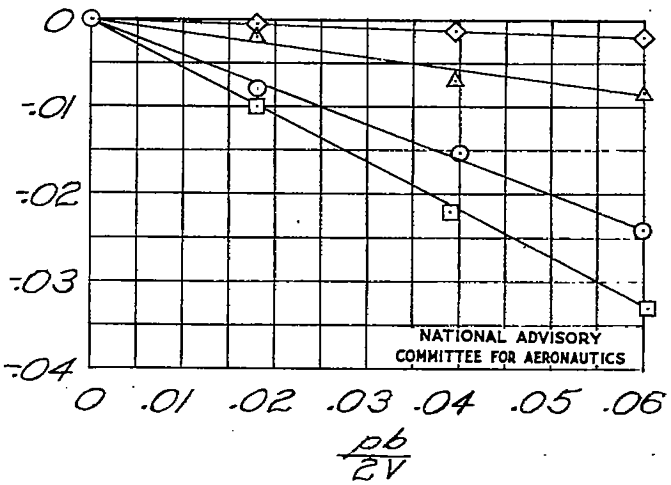


NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 6.- Variation of rolling-moment-coefficient increment with wing-tip helix angle for rectangular wing.

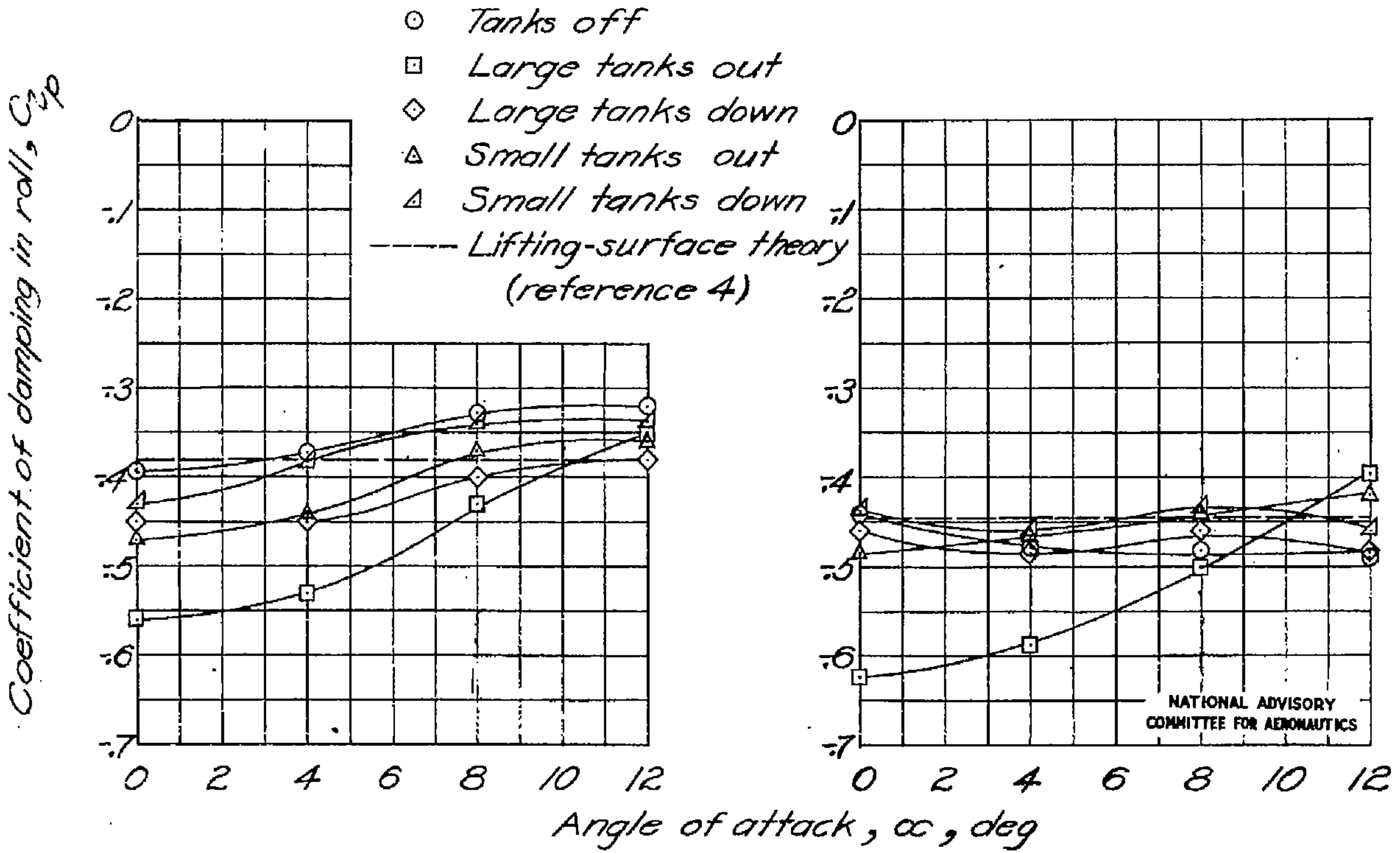


(a) Small tanks out.



(b) Large tanks out.

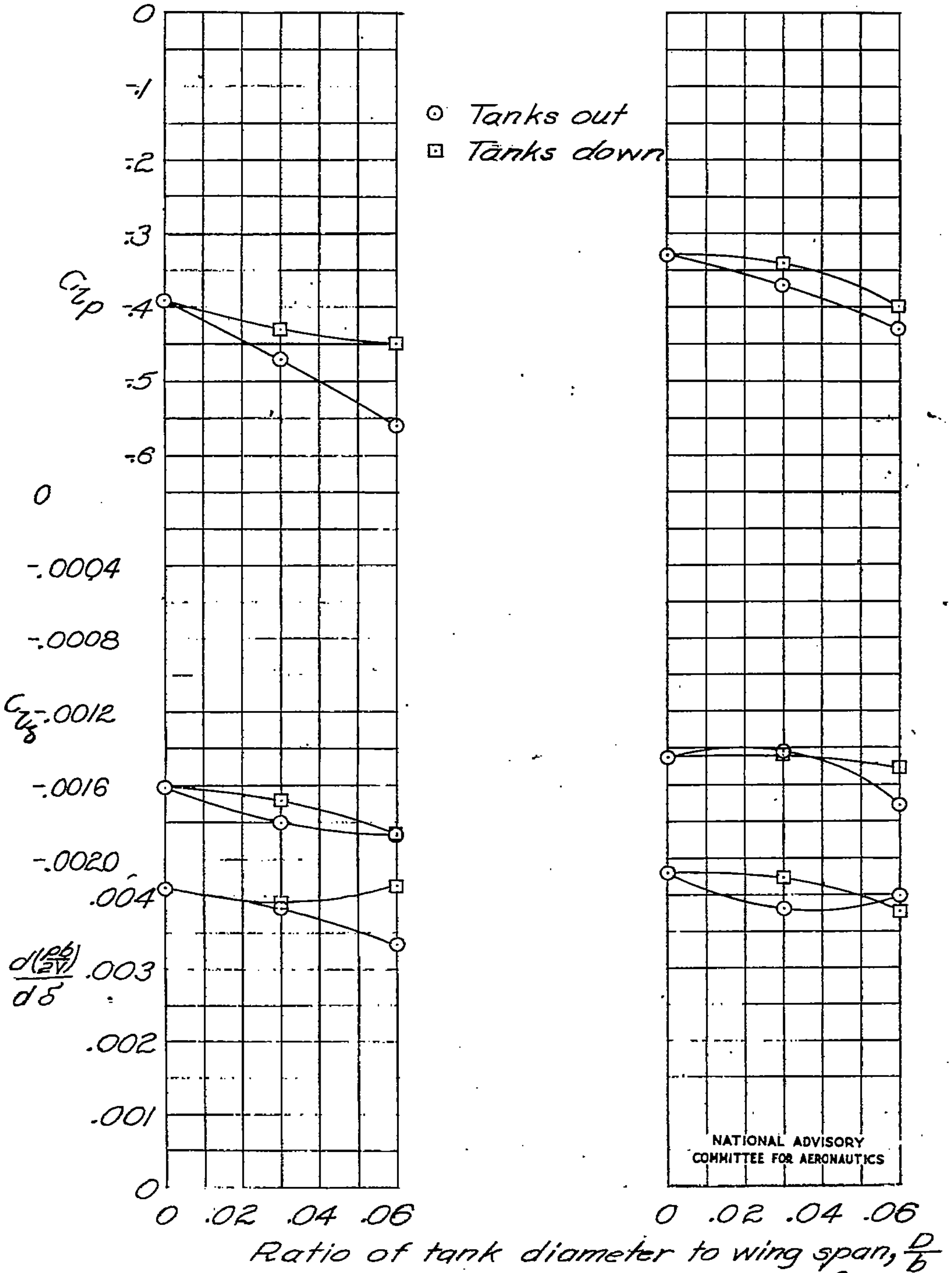
Figure 7.- Damping in roll of isolated tanks and of tapered wing with tanks at tips.



(a) Tapered wing.

(b) Rectangular wing.

Figure 8.- Variation of the coefficient of damping in roll with angle of attack. $\delta = 0°$.



(a) $\alpha = 0°$. (b) $\alpha = 8°$.

Figure 9.- Effect of tank size on the damping in roll, aileron effectiveness, and lateral maneuverability.