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STABILITY AND CONTROL FORCE TESTS OF FOUR- AND SIX-UNIT WING DESIGNS OF LOW ASPECT RATIO AND 20° TRIANGULAR PLAN FORM

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and Elizabeth P. Varney

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ADVANCE CONFIDENTIAL REPORT

STABILITY AND CONTROL FORCE TESTS OF FOUR- AND SIX-UNIT WING DESIGNS OF LOW ASPECT RATIO AND 20° TRIANGULAR PLAN FORM

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SUMMARY

An investigation has been made to obtain force-test data on a wing design suitable for high-speed guided missiles, particularly data on rolling moments produced in yawed and pitched attitudes. Force tests were conducted on two models of a wing design of low aspect ratio and 20° triangular plan form. One model consisted of four wings spaced 90° and the other consisted of six wings spaced 60°.

Results of the tests showed that appreciable rolling moments existed for both the four- and six-unit wing designs in yawed and pitched attitudes but that the rolling moments of the six-unit design were considerably smaller than those of the four-unit design. The values of these moments, which became larger as the angles of attack and yaw were increased, were attributed to partial blanketing of one or more wings by the other wings. Fairly large control deflections were required to trim out the rolling moments produced in the climbing-turn attitudes.

INTRODUCTION

The analysis presented in reference 1 indicates that compressibility effects are delayed by the use of low-aspect-ratio wings of triangular plan form. In connection with the design of such a wing arrangement suitable for use on high-speed guided missiles, the rolling-moment characteristics in yawed and pitched attitudes have been determined.

Force tests were conducted in the Langley free-flight tunnel on two models of the design. One model consisted of four wings spaced 90° and the other consisted of six wings, identical to those of the first model, spaced 60°. Tests were made for a range of angle of attack from 0° to 20° with the models set at an angle of yaw of 0° but rotated in roll about the body axes by 10° increments from one symmetrical condition to the next. Thus, the first model was rotated through 90° and the second was rotated through 60°. In this manner, conditions of sideslip and angle of attack that would be attained in climbing turns were simulated. Particular attention was given to any evidence of rolling moments in these attitudes.

SYMBOLS

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$

C_Y lateral-force coefficient $\left(\frac{\text{Lateral force}}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{Pitching moment}}{qbS}\right)$

C_n yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qbS}\right)$

C_l rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qbS}\right)$

q dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

ρ air density, slugs per cubic foot

V airspeed, feet per second

S wing area, square feet (2.82)

b wing span, feet (1.41)

L rolling moment

N yawing moment

M pitching moment

α angle of attack, degrees

β angle of sideslip, degrees

ϕ angle of roll, degrees

ψ angle of yaw, degrees

δ_{a_R} right-aileron deflection, degrees

δ_e elevator deflection

δ_r rudder deflection

APPARATUS AND MODELS

The force tests were made in the Langley free-flight tunnel with the models mounted on the six-component balance described in reference 2. The models used in the investigation were of triangular plan form with an included angle of 20° and an aspect ratio of about 0.7. The models were made of spruce with each unit of constant thickness except for the leading edge, which was shaped to an elliptical section. Drawings of the four- and six-unit wing models are presented as figure 1. Photographs of the models showing the brackets used to mount the models on the balance strut are shown as figures 2 and 3. These brackets were used to minimize the interference effects of the strut.

For a few tests the four-unit wing model was modified by the installation of a control surface at the trailing edge of one wing. This modification was accomplished by installing a $2\frac{1}{2}$-inch-chord flap. (See fig. 1.)

TESTS

All force tests were made at a dynamic pressure of 4.1 pounds per square foot, which corresponds to an airspeed of about 40 miles per hour and to a test Reynolds number of 510,000 based on an average chord of 2 feet. Tests were made over a range of angle of attack from 0° to 20° with the models rotated by 10° increments from 0° to 90° for the four-unit wing model and from 0° to 60° for the six-unit wing model.

All coefficients are based on a wing area of 2.82 square feet and a wing span of 1.41 feet and are referred to the stability axes (which are identical with the wind axes in the present case because all tests were made at an angle of yaw of 0°) originating 2.67 feet from the apex. The stability axes are a system of axes in which the Z-axis is in the plane of symmetry, perpendicular to the relative wind and directed downward; the X-axis is in the plane of symmetry, perpendicular to the Z-axis and directed forward; and the Y-axis is perpendicular to the plane of symmetry and directed to the right. A sketch of the stability axes is presented as figure 4. Arrows indicate the positive direction of moments, forces, and control-surface deflections.

RESULTS AND DISCUSSION

Application of Results

The angles of attack and sideslip simulated by each test condition can be determined from the test data by using the following relationships:

$$\alpha_{simulated} = \alpha \cos \phi \tag{1}$$

$$\beta_{simulated} = \alpha \sin \phi \tag{2}$$

Dividing equation (2) by equation (1) gives

$$\frac{\beta_{simulated}}{\alpha_{simulated}} = \tan \phi$$

Similarly, the lift and lateral-force coefficients produced by the angles of attack and sideslip simulated in each test condition can be obtained from the lift-coefficient test data by using the following relationships:

$$C_{L_{simulated}} = C_L \cos \phi$$

$$C_{Y_{simulated}} = C_L \sin \phi$$

Any lateral-force coefficients measured in the force tests (for which $\beta = 0^{\circ}$) are evidence of additional lift and lateral force that are probably caused by partial blanketing of one or two of the wings by the other wings. These additional lift and lateral-force coefficients can be obtained from the lateral-force data by using the following relationships:

$$\Delta C_{L_{simulated}} = C_Y \sin \phi$$

$$\Delta C_{Y_{simulated}} = C_Y \cos \phi$$

Four-Unit Wing Design

The force-test data for the four-unit wing design are presented in figure 5 and crossplots of these data against angle of roll are presented in figure 6. The values of C_Y, C_n, and C_l presented in these figures are incremental values taken between an angle of roll of 0° and each succeeding angle of roll. The results in figure 5 show that the slope of the pitching-moment curve increased with increasing angle of attack. At the same time, however, the lift-curve slope increased so that the aerodynamic center did not move appreciably with increasing angle of attack. The increase in lift-curve slope with increasing angle of attack is in agreement with results of tests of low-aspect-ratio wings presented in reference 3.

The data of figures 5 and 6 show that for angles of attack of 5° and 10° no appreciable variation occurred in lift, drag, or pitching-moment coefficients with angle of roll. For angles of attack of 20°, however, the coefficients did vary with angle of roll and were lowest at angles of roll of about 40° or 50° - that is, when the simulated angles of attack and sideslip were about the same magnitude.

The results in figures 5 and 6 also show that appreciable rolling moments, yawing moments, and lateral force were measured in the force tests and varied with angle of roll and angle of attack. These forces and moments are shown in figure 6 to be approximately zero at the symmetrical conditions of angles of roll of 0°, 45°, and 90°. At intermediate angles of roll, however, forces and moments were produced that reached a maximum at angles of roll of about 20° and 65° and that increased with angle of attack. Since the forces and moments are smallest for the symmetrical conditions, the variation of forces and moments is attributed to partial blanketing of one or more wings by the other wings as the model simulated various angles of yaw and pitch.

The data show that in a simulated straight pull-up, a flat turn, or a climbing turn represented by the condition in which the angle of roll is 45°, no lateral force was introduced. For any of the intermediate conditions, however, a lateral force was produced that would cause the missile to deviate from its path, and

additional control would therefore be required to maintain the desired path. In a similar manner, the rolling moments produced in the various climbing-turn attitudes must be balanced by the use of aileron control.

The results of tests made to determine the effectiveness of a control surface installed on one wing of the four-unit design are presented in figure 7. These data show that a small control deflection (less than 10°) in the zero-roll condition produced a larger rolling moment at high angles of attack than at low angles of attack. The results of tests made to determine the effect of blanketing on the control effectiveness are also presented in figure 7 and show a slight decrease in the rolling moment produced by control deflection when the control was on the downwind side.

Six-Unit Wing Design

The results of the force tests of the six-unit wing design are presented in figure 8 and crossplots of the data against angle of roll are presented in figure 9. The lateral data are also incremental values as in the case of the four-unit wing design. The results in figure 8 show that the pitching-moment curve of the six-unit design had characteristics similar to those of the pitching-moment curve for the four-unit design. Figure 8 also shows that the lift curve remained approximately straight throughout the angle-of-attack range. At low angles of attack the lift-curve slope for the six-unit design is about 50 percent greater than that for the four-unit design because the six-unit design has 50 percent more effective lifting-surface area. At the higher angles of attack, however, this increase in lift was not realized, probably because of additional interference effects. The data of figures 8 and 9 show very little variation of the lift, drag, and pitching-moment coefficients with angle of roll for angles of attack of 5° and 10°. For an angle of attack of 20°, however, the lift and pitching-moment coefficients varied considerably and were lowest at angles of roll of 0° and 60°, whereas the drag coefficient remained nearly constant. These variations are attributed to interference effects, as in the case of the four-unit design.

The results presented in figures 8 and 9 show the same general variation of rolling-moment, yawing-moment, and lateral-force coefficients for the six-unit design in the simulated climbing-turn conditions as for the four-unit design, although the variation was not so systematic and the maximum values of the forces and moments were not so large as those of the four-unit design. Although aileron and rudder control would be needed to trim out the forces and moments for the six-unit design, the deflections required would be considerably less than for the four-unit design.

CONCLUDING REMARKS

Stability and control force tests of four- and six-unit wing designs of low aspect ratio and 20° triangular plan form have been made in the Langley free-flight tunnel. From the results of the tests, appreciable rolling moments were found to exist for both the four- and six-unit wing designs in yawed and pitched attitudes but the rolling moments of the six-unit design were considerably smaller than those of the four-unit design. The values of the unsymmetrical forces and moments, which became larger as the angles of attack and yaw were increased, were attributed to partial blanketing of one or more wings by the other wings. Fairly large control deflections were required to trim out the rolling moments produced in the climbing-turn attitudes.

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2. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of the Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR No. 3D17, 1943.

3. Zimmerman, C. H.: Characteristics of Clark Y Airfoils of Small Aspect Ratios. NACA Rep. No. 431, 1932.

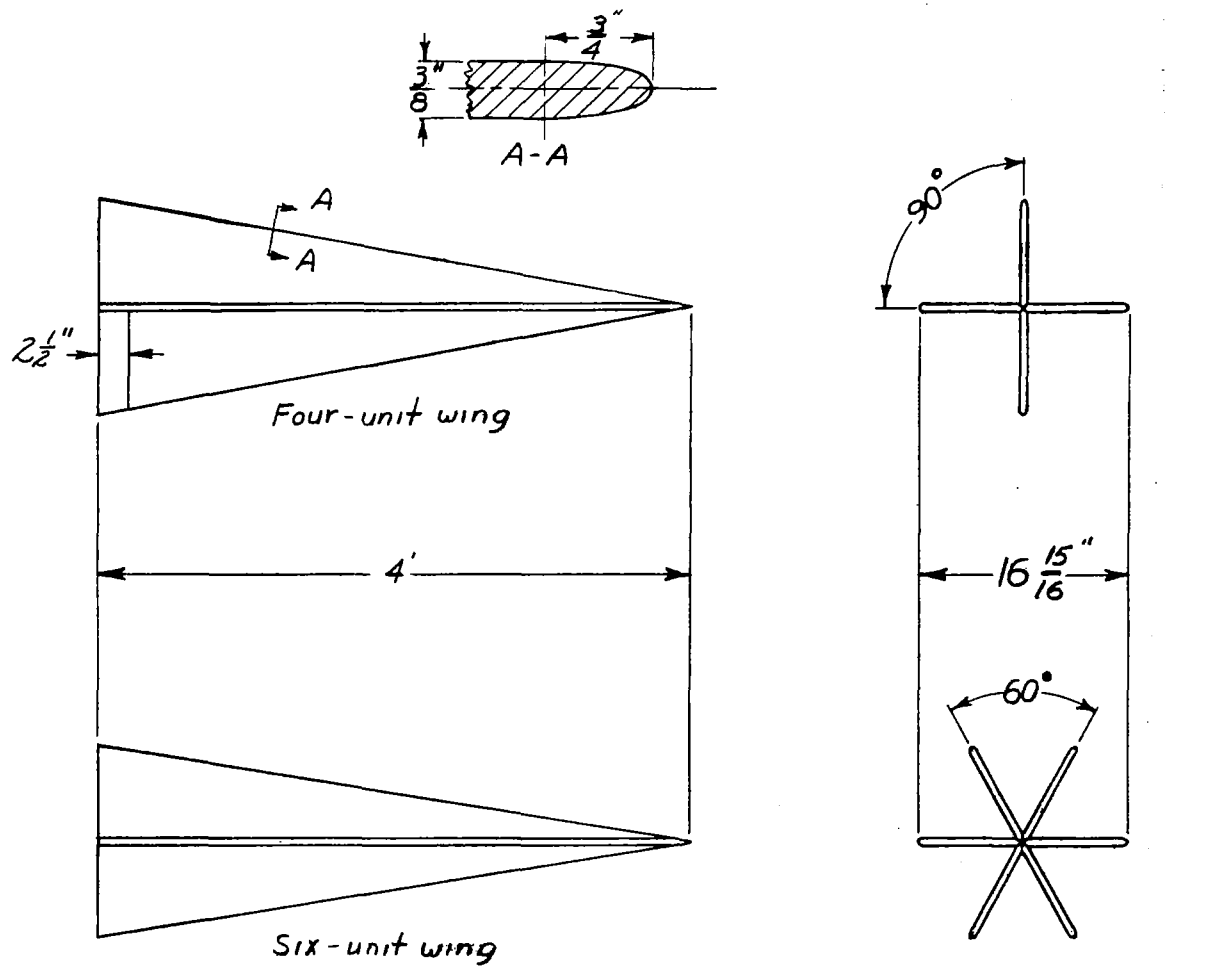

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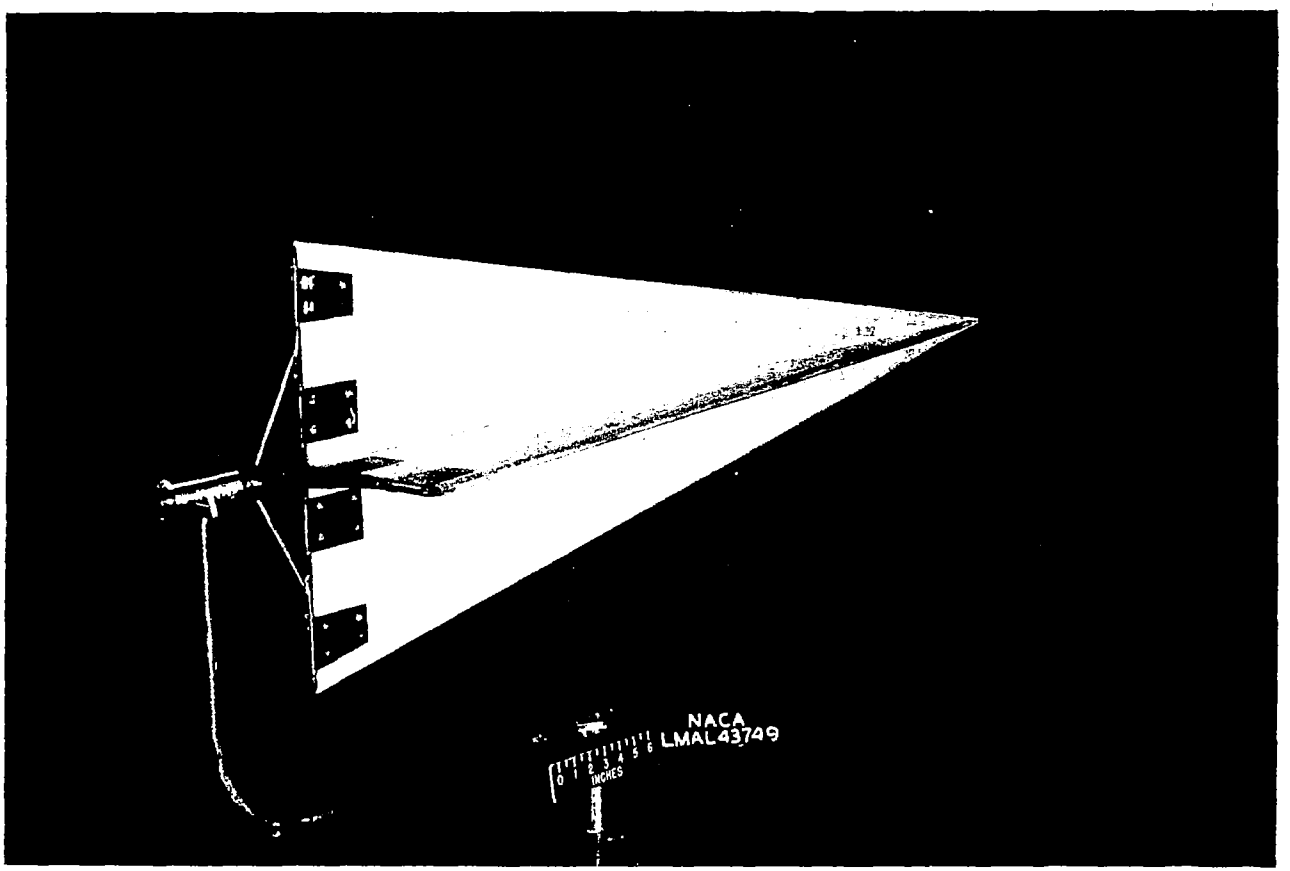
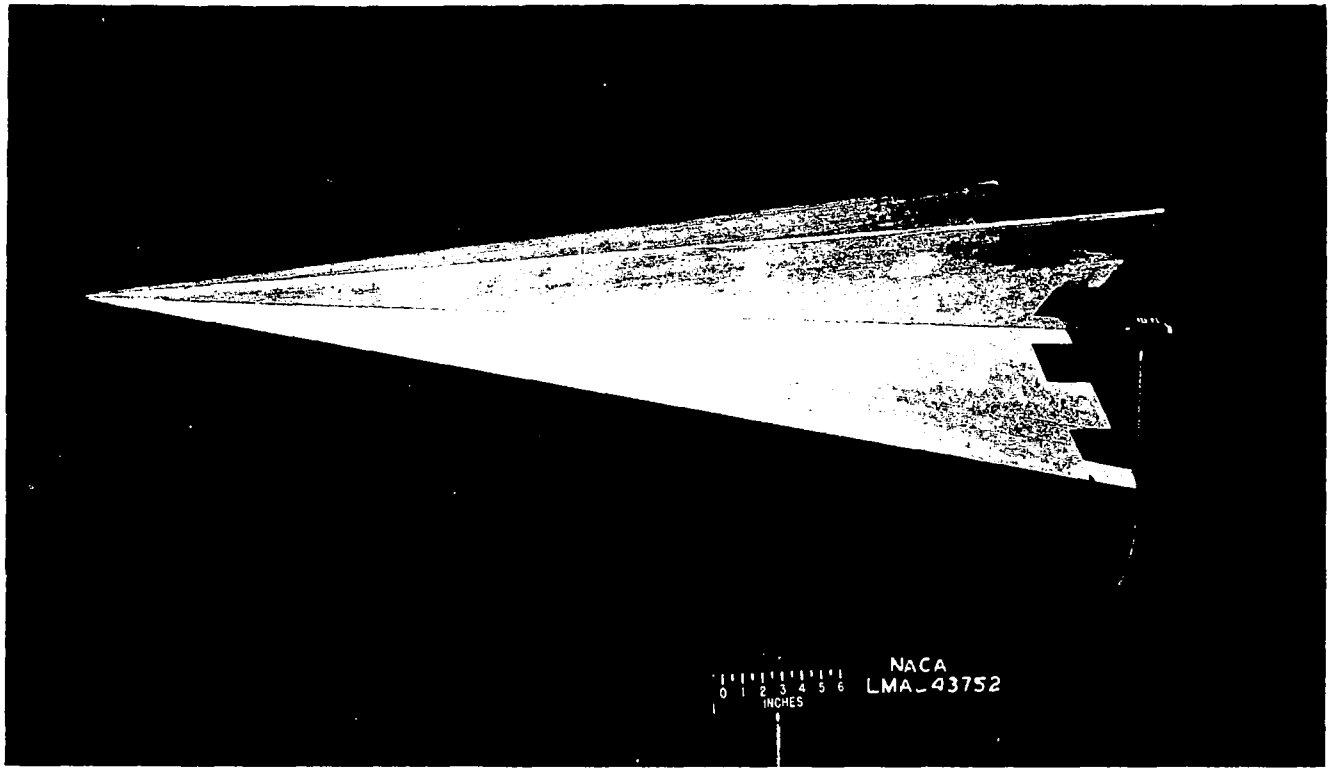
Figure 1.- Four- and six-unit wing designs of low aspect ratio and triangular plan form for guided missiles tested in the Langley free-flight tunnel.



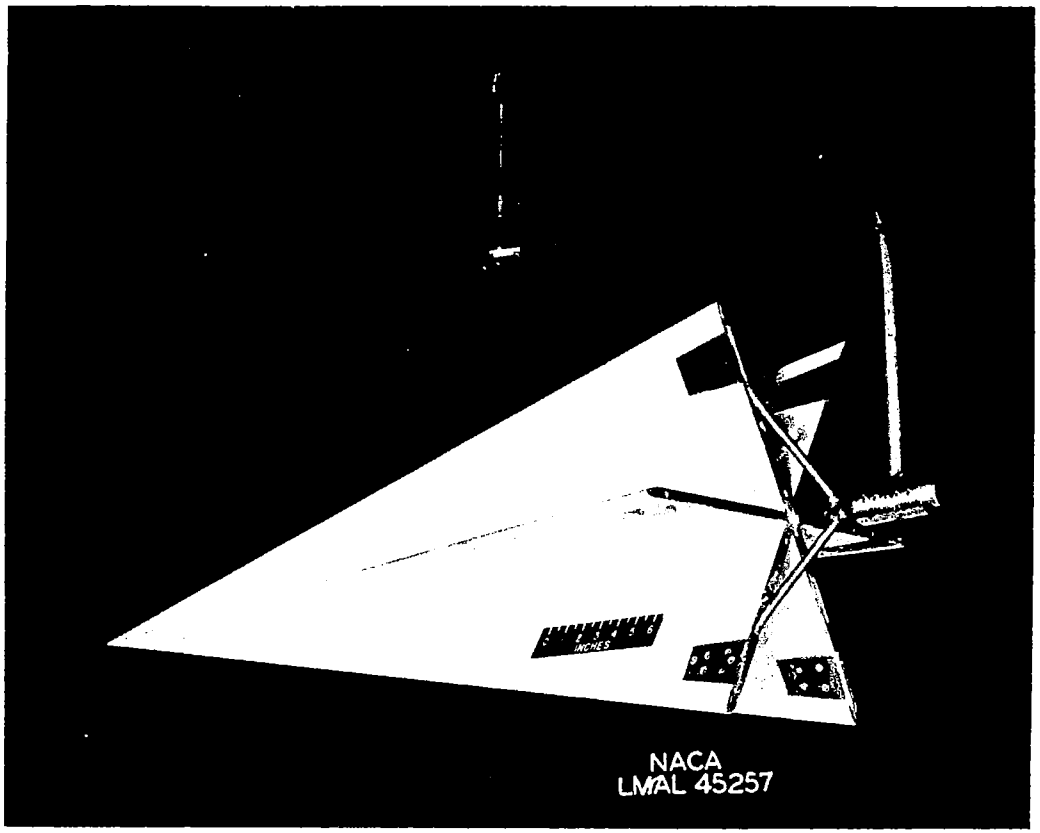
(a) $\phi = 0^{\circ}$.

Figure 2.- Model of four-unit wing design of low aspect ratio and triangular plan form for guided missiles tested in the Langley free-flight tunnel.



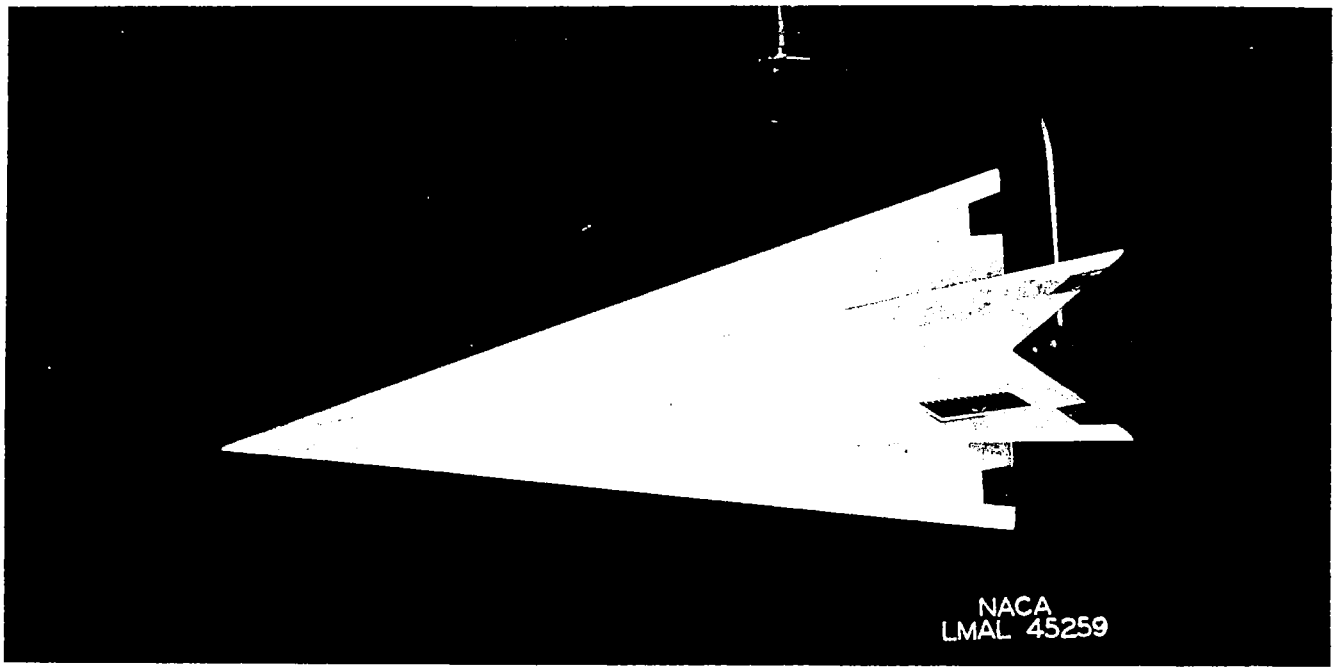
(b) $\phi = 40^{\circ}$.

Figure 2.- Concluded.



(a) $\phi = 0^{\circ}$.

Figure 3.- Model of six-unit wing design of low aspect ratio and triangular plan form for guided missiles tested in the Langley free-flight tunnel.



(b) $\phi = 30^{\circ}$.

Figure 3.- Concluded.

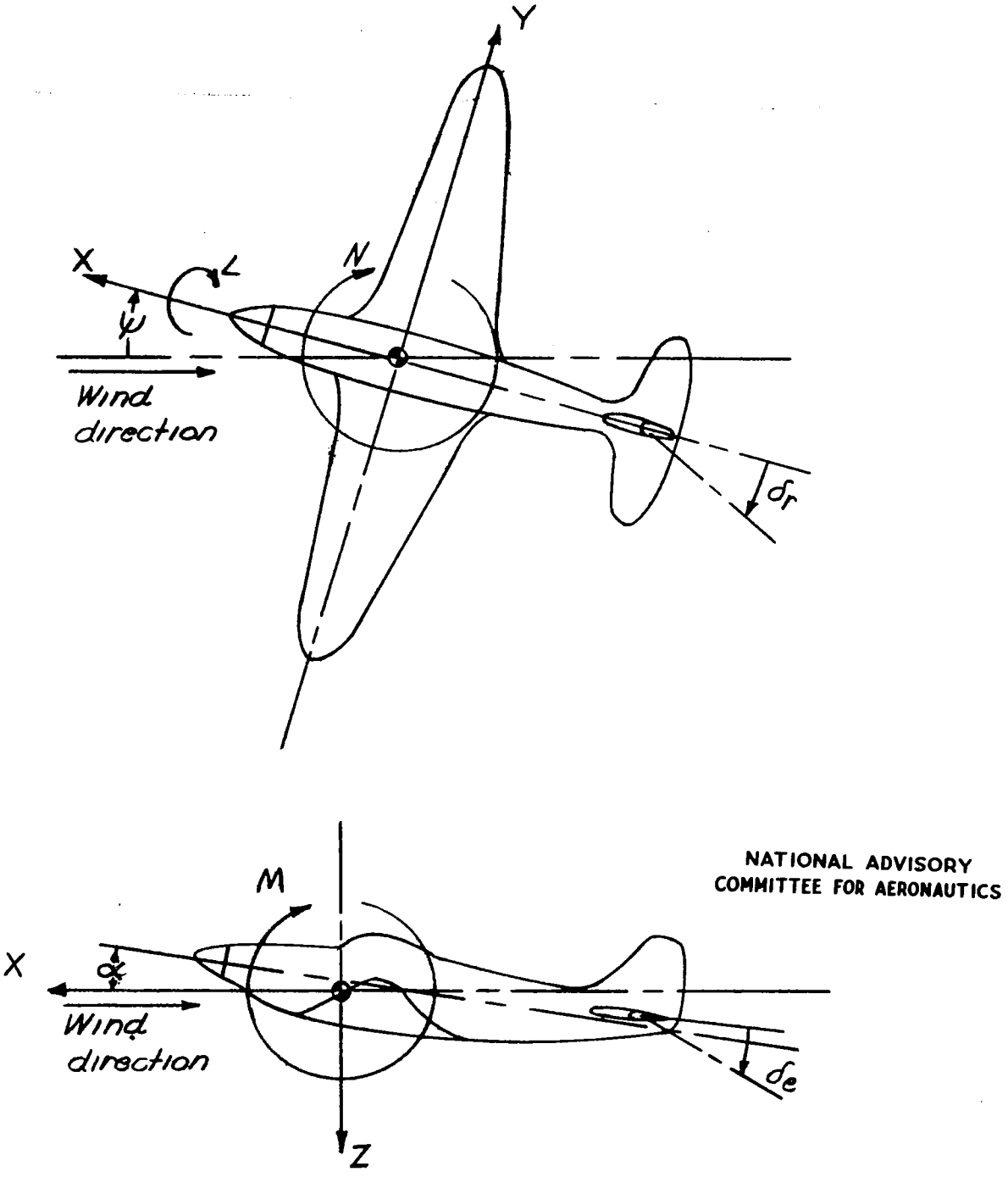
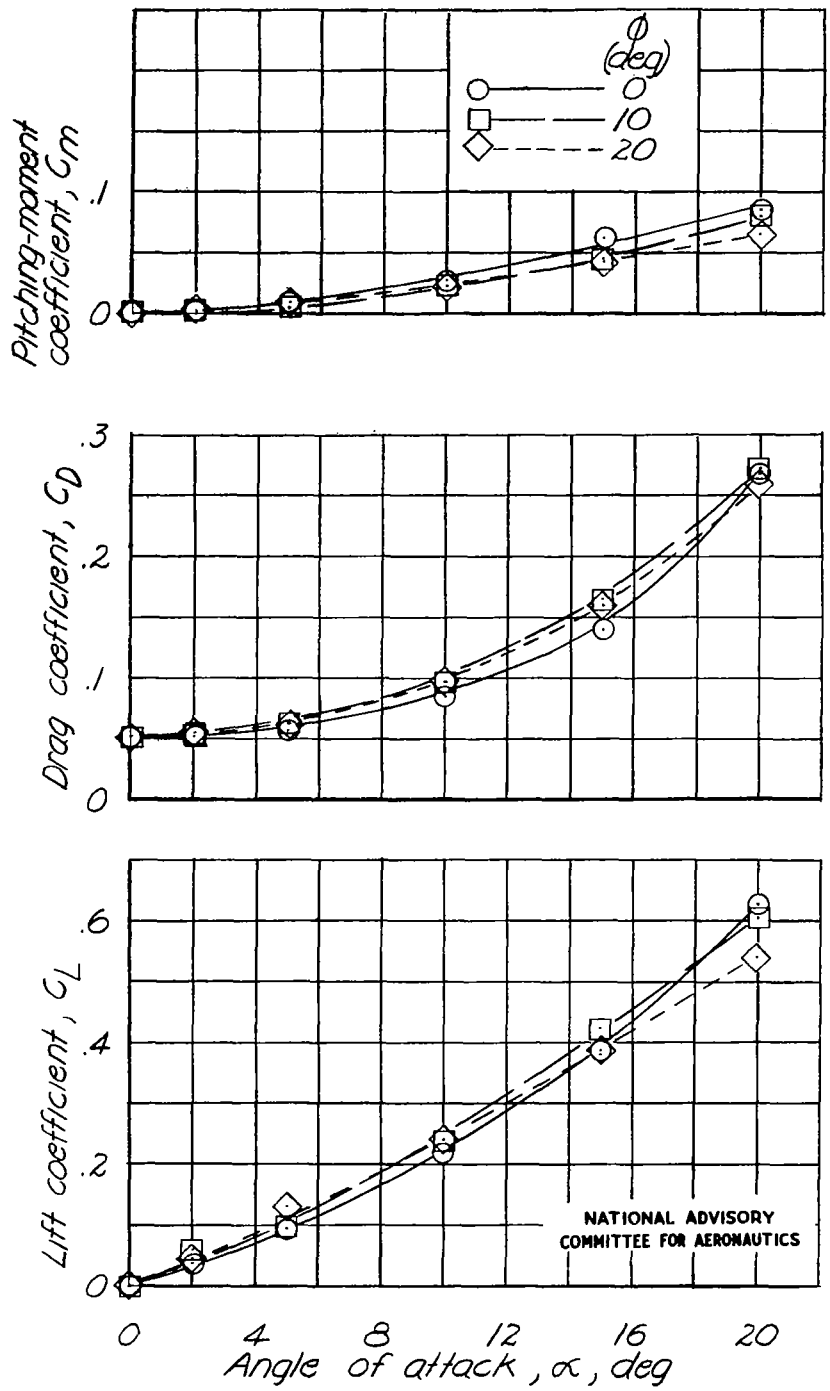
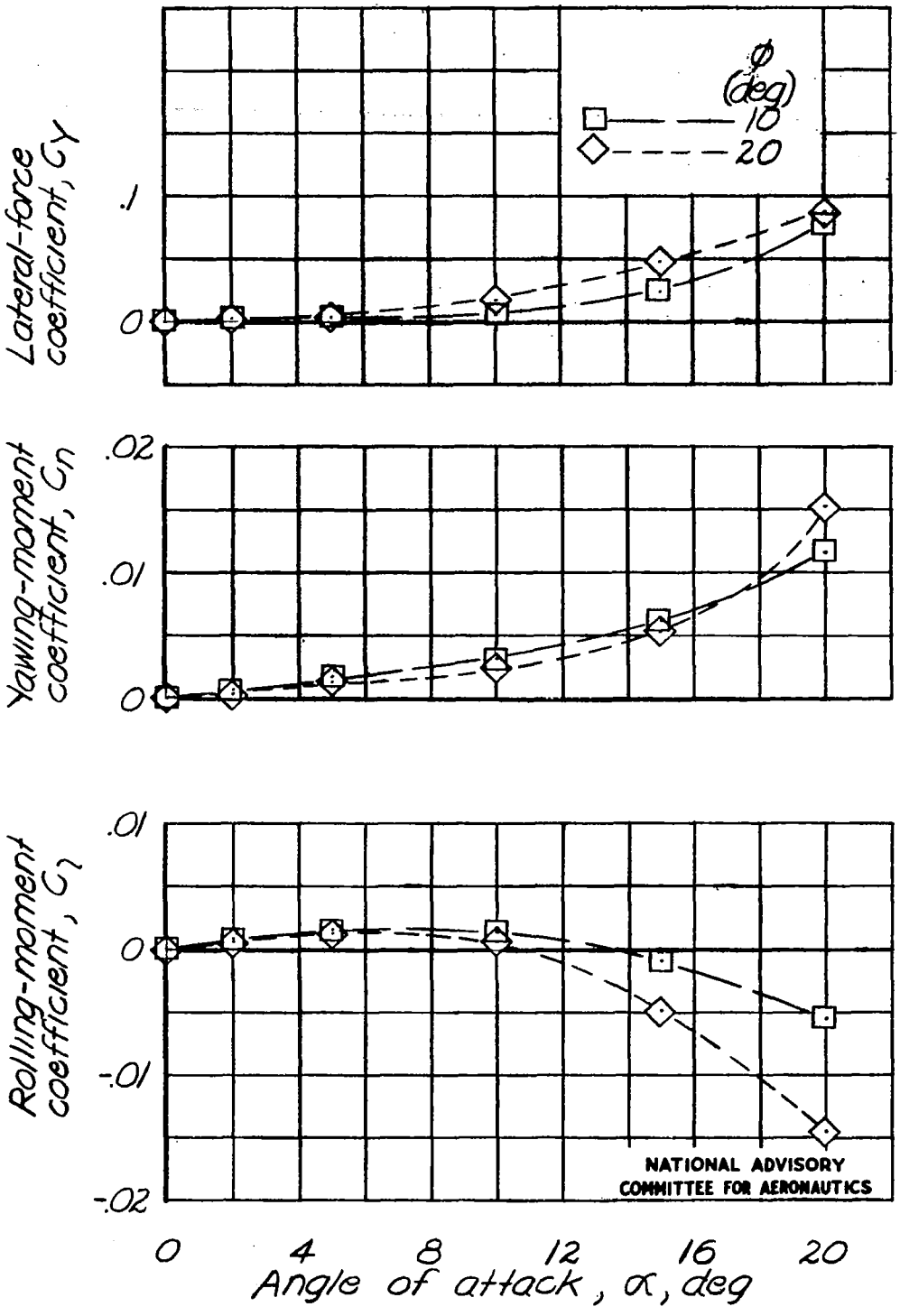


Figure 4.- System of stability axes. Arrows indicate positive directions of moments, forces, and control-surface deflections.



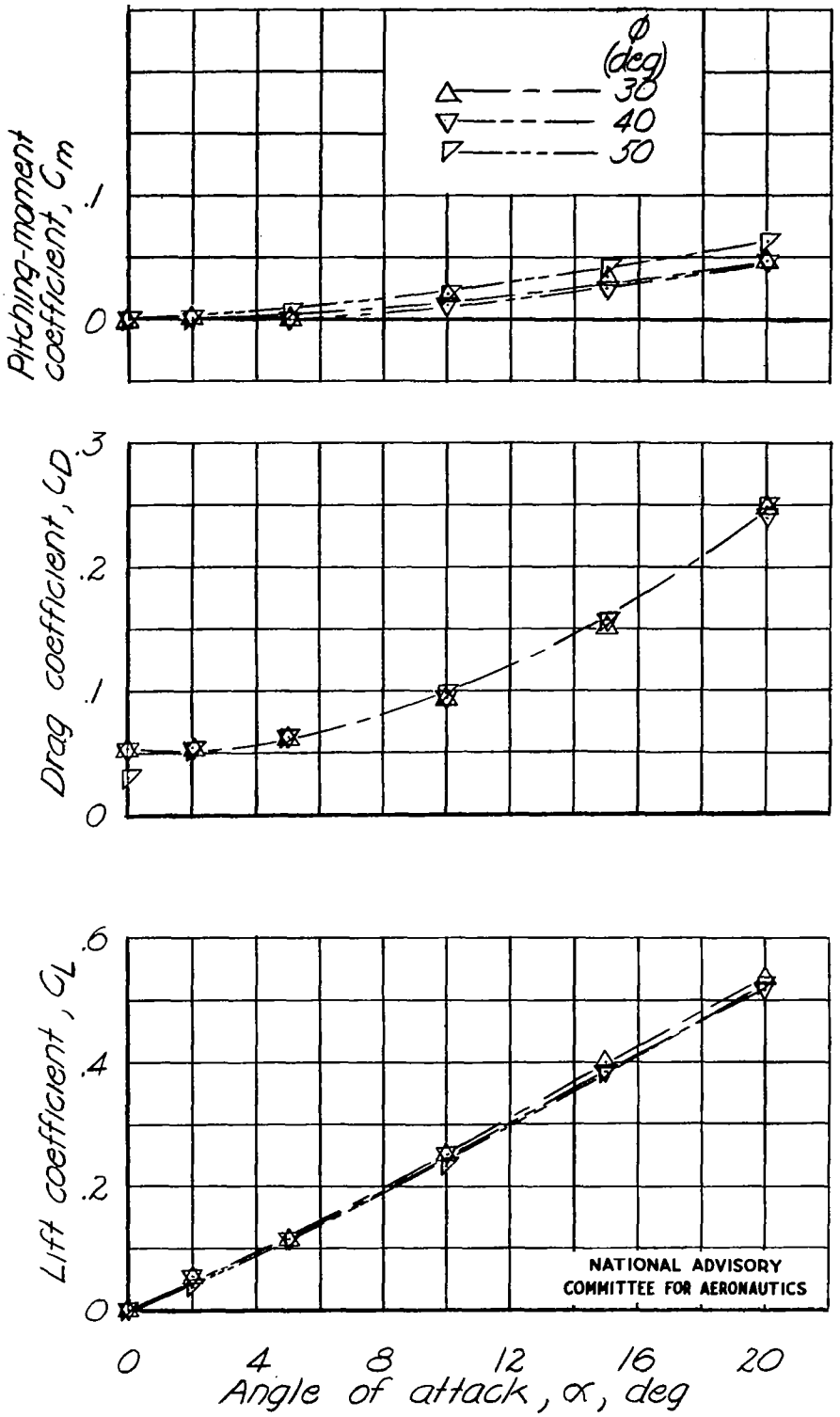
(a) $\phi = 0°, 10°$, and $20°$.

Figure 5. - Aerodynamic characteristics of four-unit wing design of low aspect ratio and triangular plan form for guided missiles as determined from force tests in the Langley free-flight tunnel. $\psi = 0°$; $q = 4.1$ pounds per square foot.



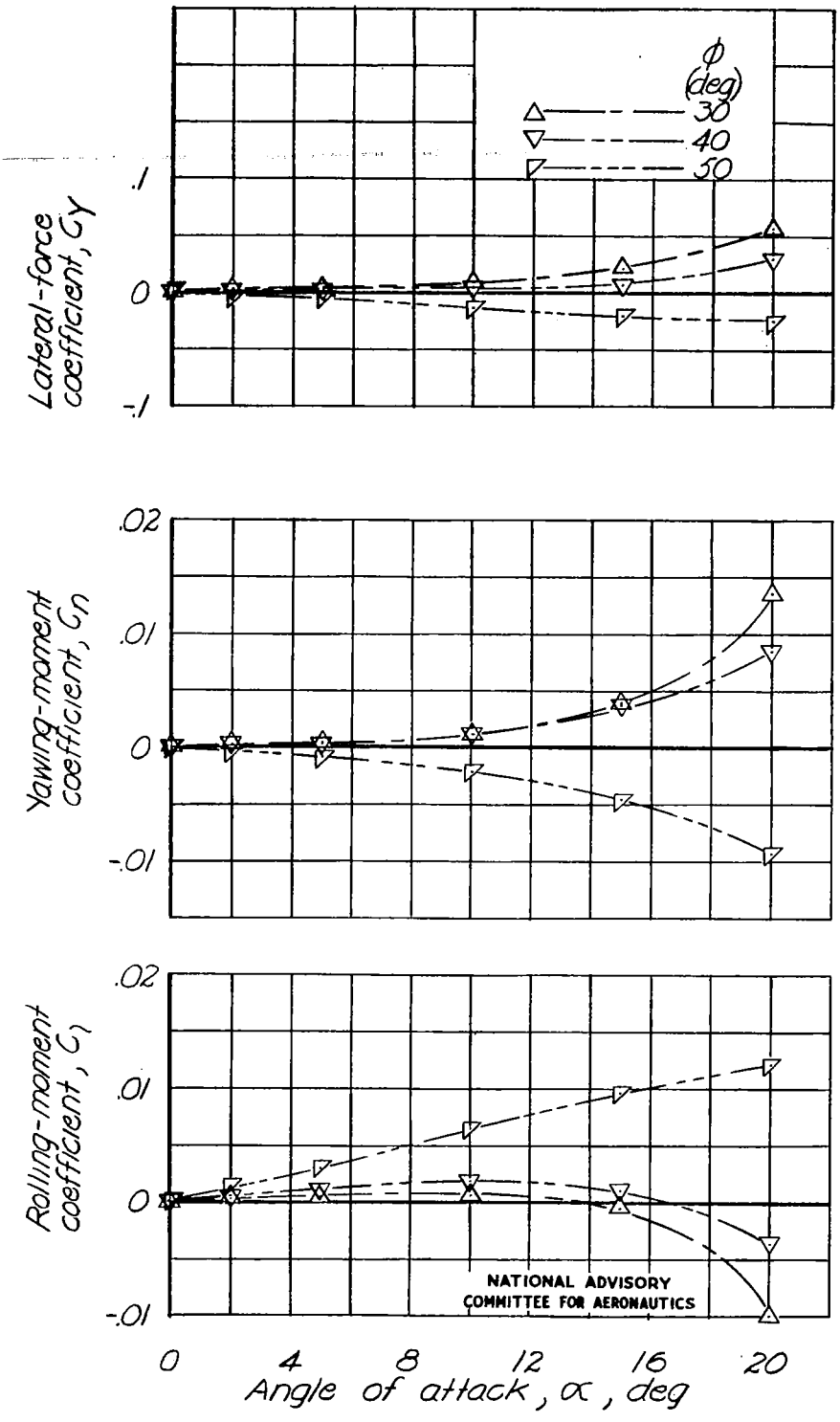
(a) Concluded.

Figure 5.– Continued.



(b) $\phi = 30°, 40°, \text{and } 50°$.

Figure 5.- Continued.



(b) Concluded.

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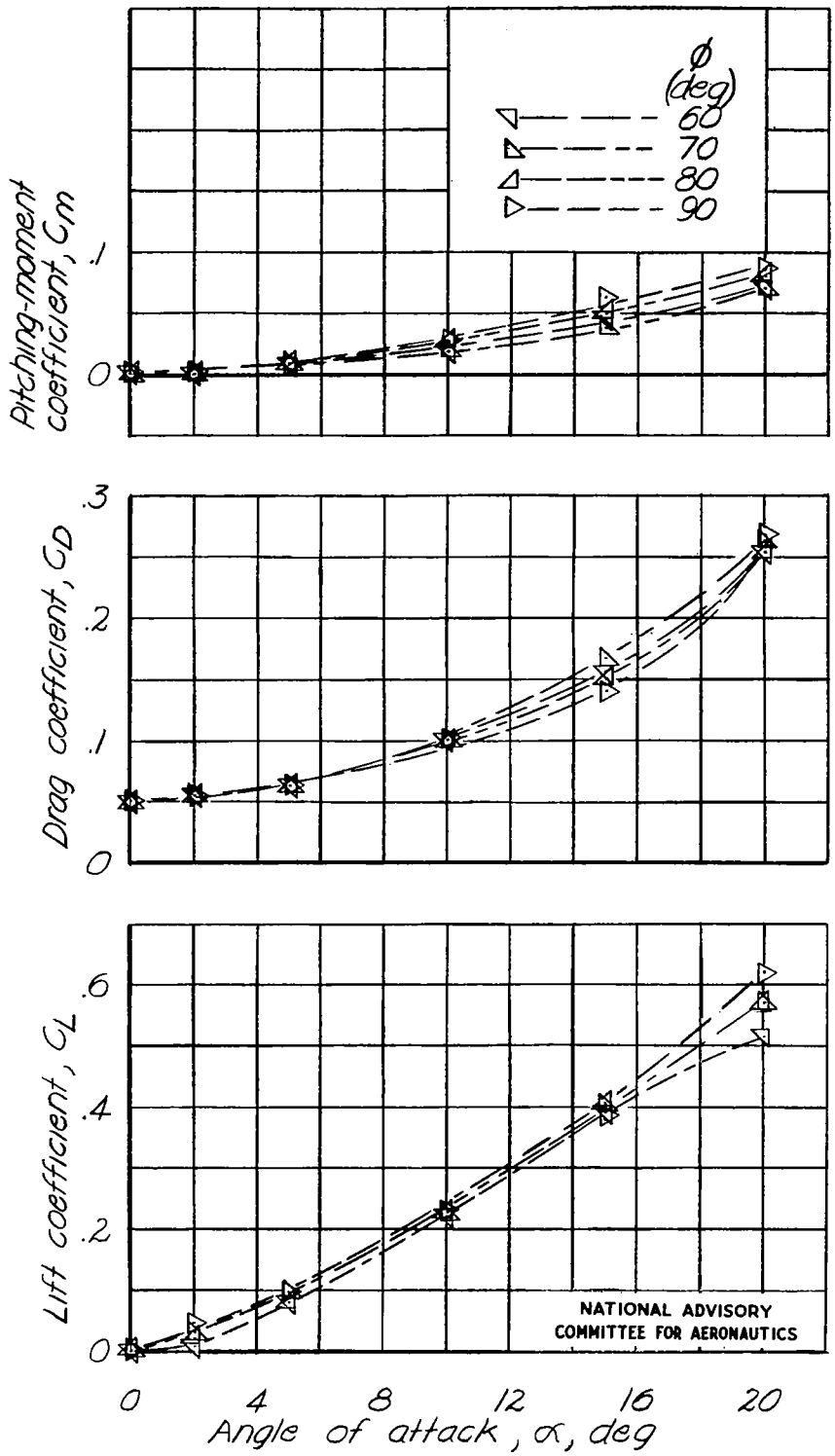
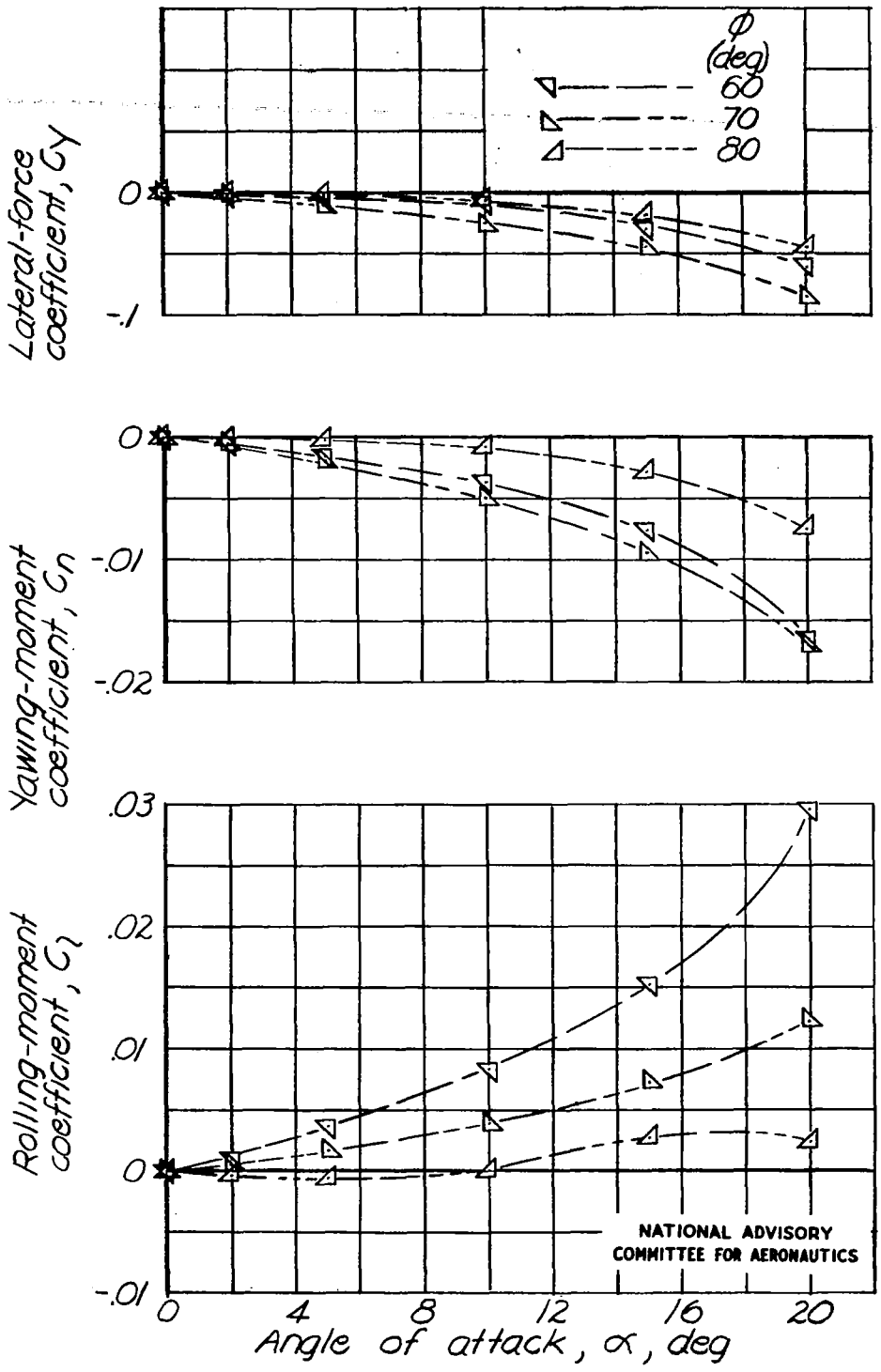


(c) $\phi = 60°, 70°, 80°$, and $90°$.

Figure 5.- Continued.



(c) Concluded.

Figure 5.-Concluded.

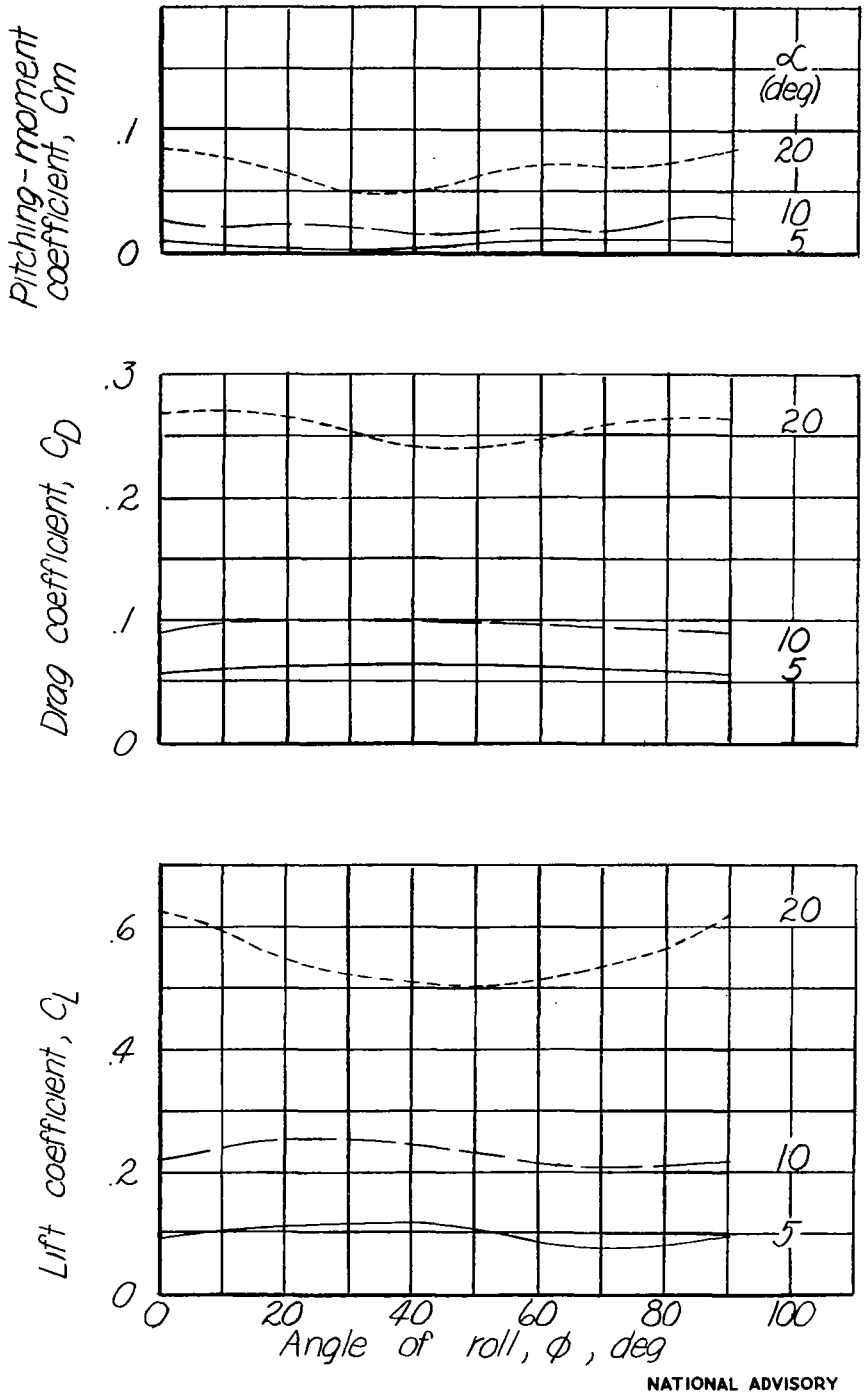


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Figure 6.- Variation of aerodynamic characteristics with angle of roll for four-unit wing design of low aspect ratio and triangular plan form for guided missiles as determined from force tests in the Langley free-flight tunnel. $\psi = 0°$; $q = 4.1$ pounds per square foot.

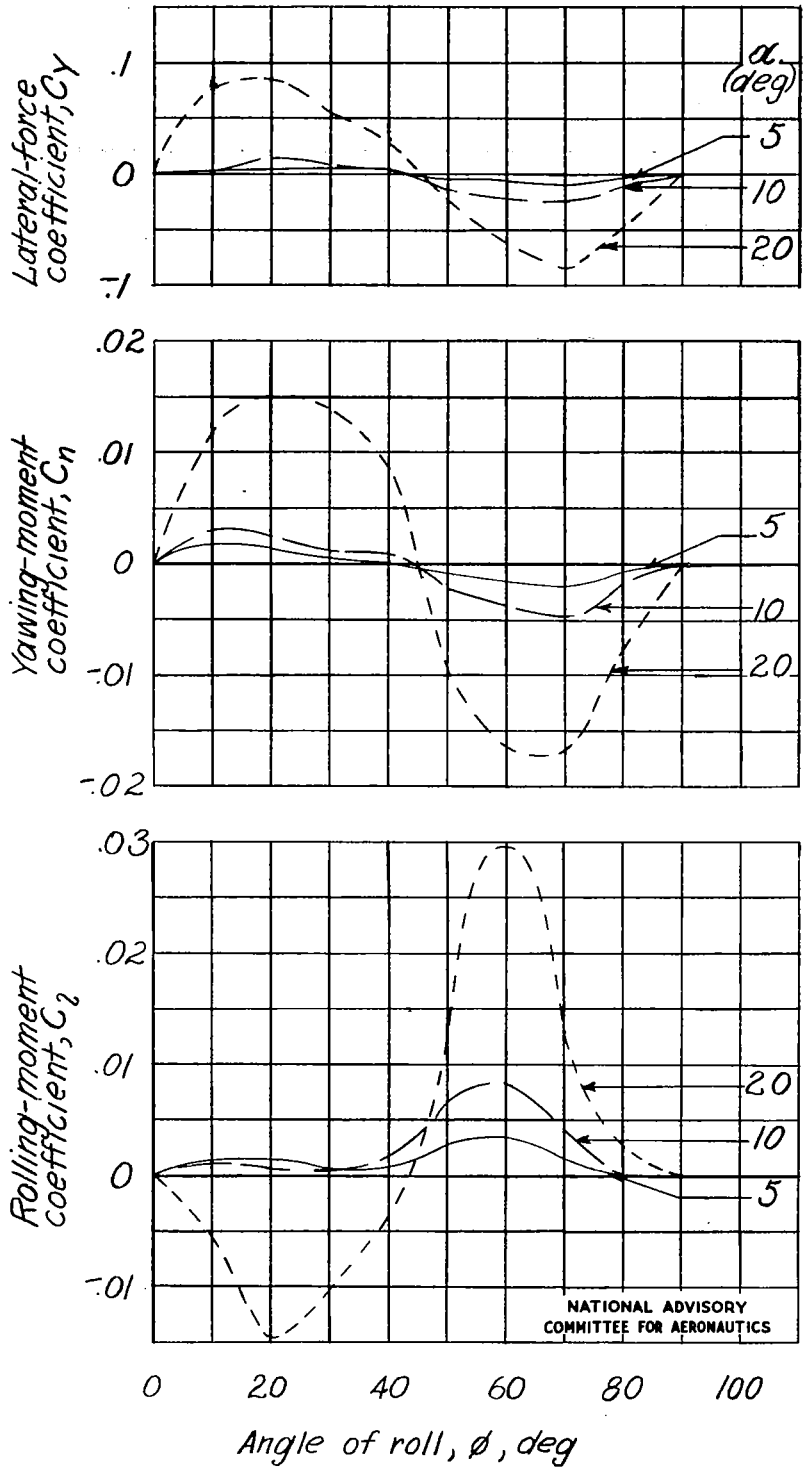


Figure 6.– Concluded.

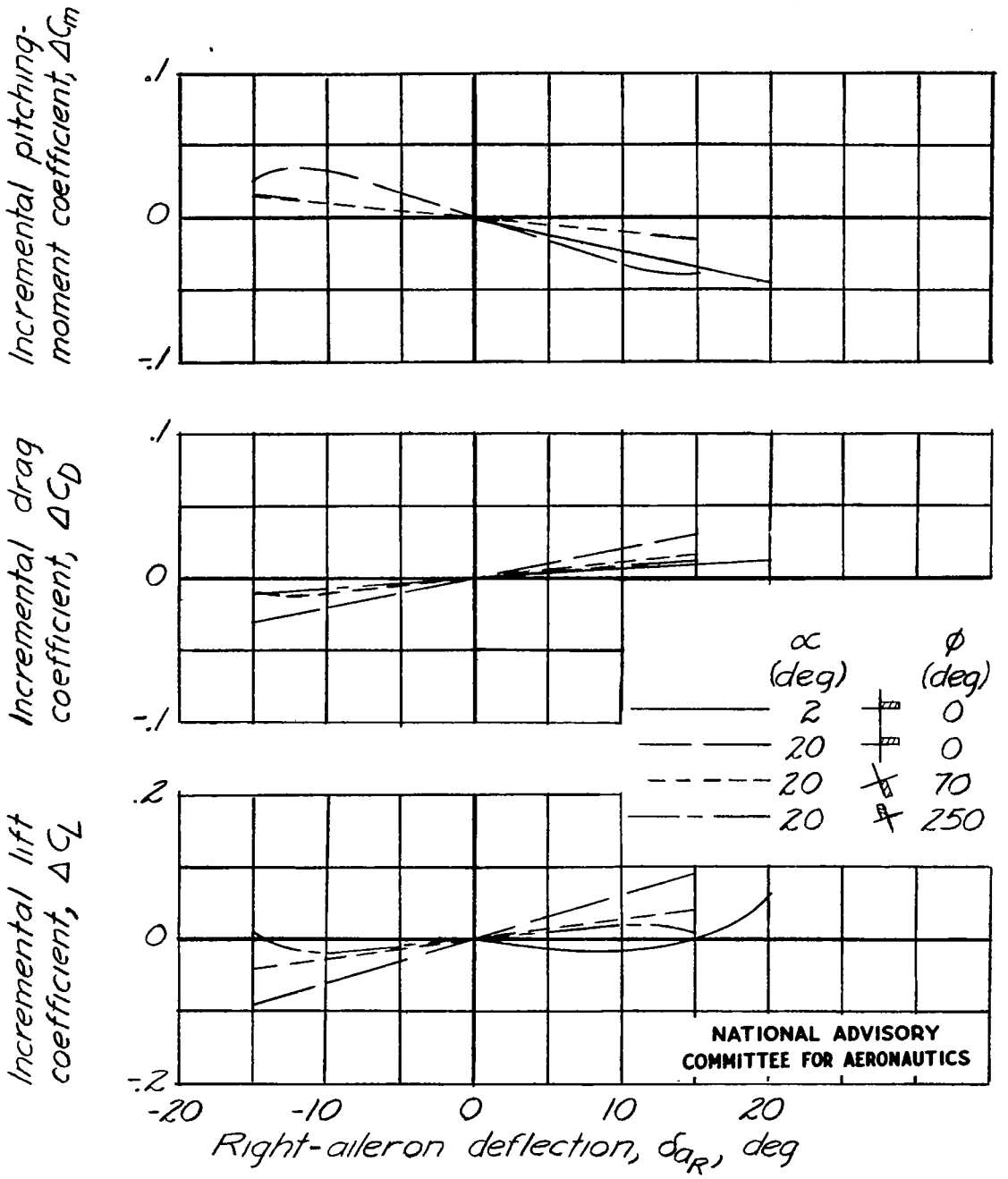


Figure 7.- Control effectiveness of four-unit wing design of low aspect ratio and triangular plan form for guided missiles as determined from force tests in the Langley free-flight tunnel. $\psi = 0°$; $q = 4.1$ pounds per square foot. Control surface on one of four wings; sketches show control positions and negative deflection.

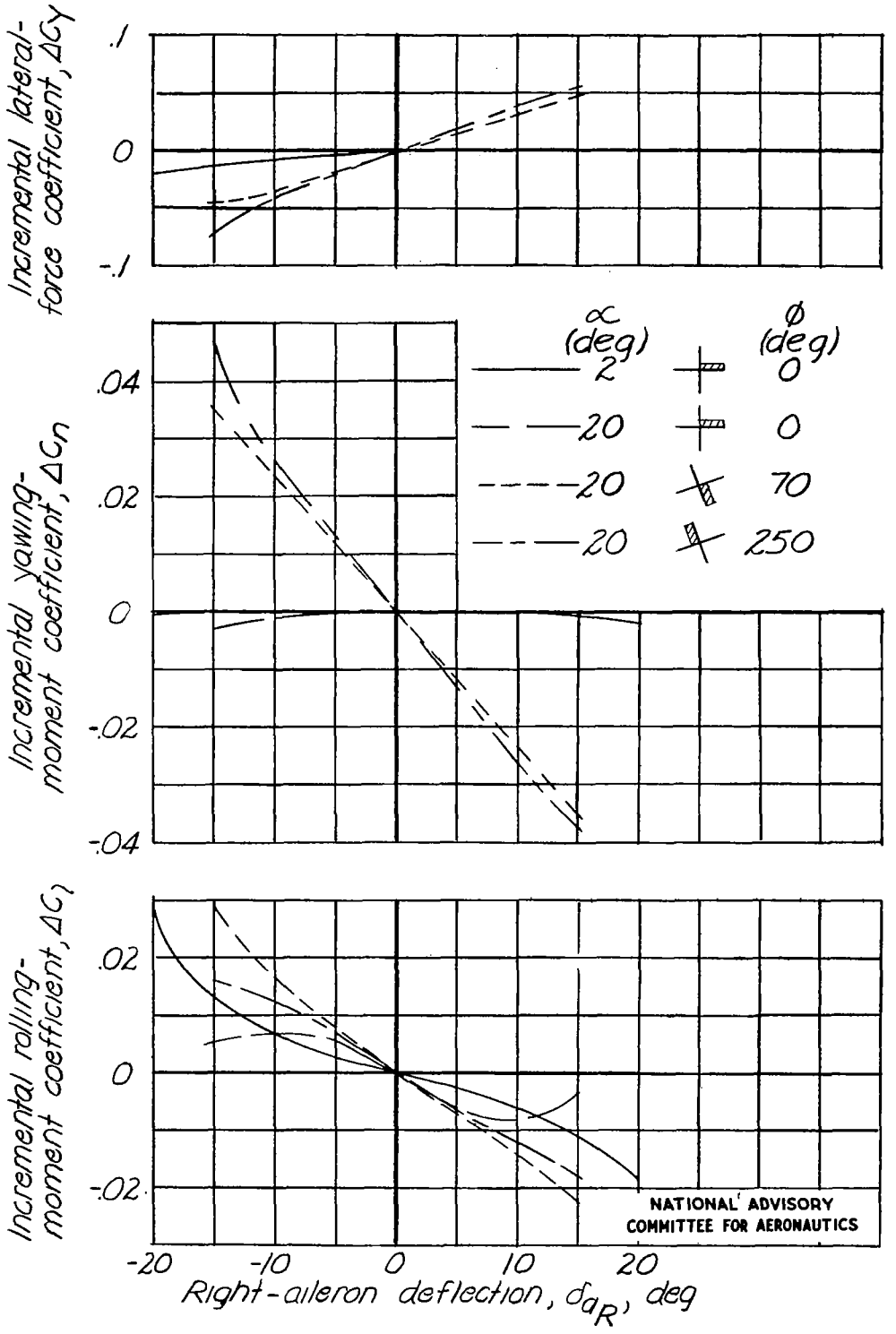
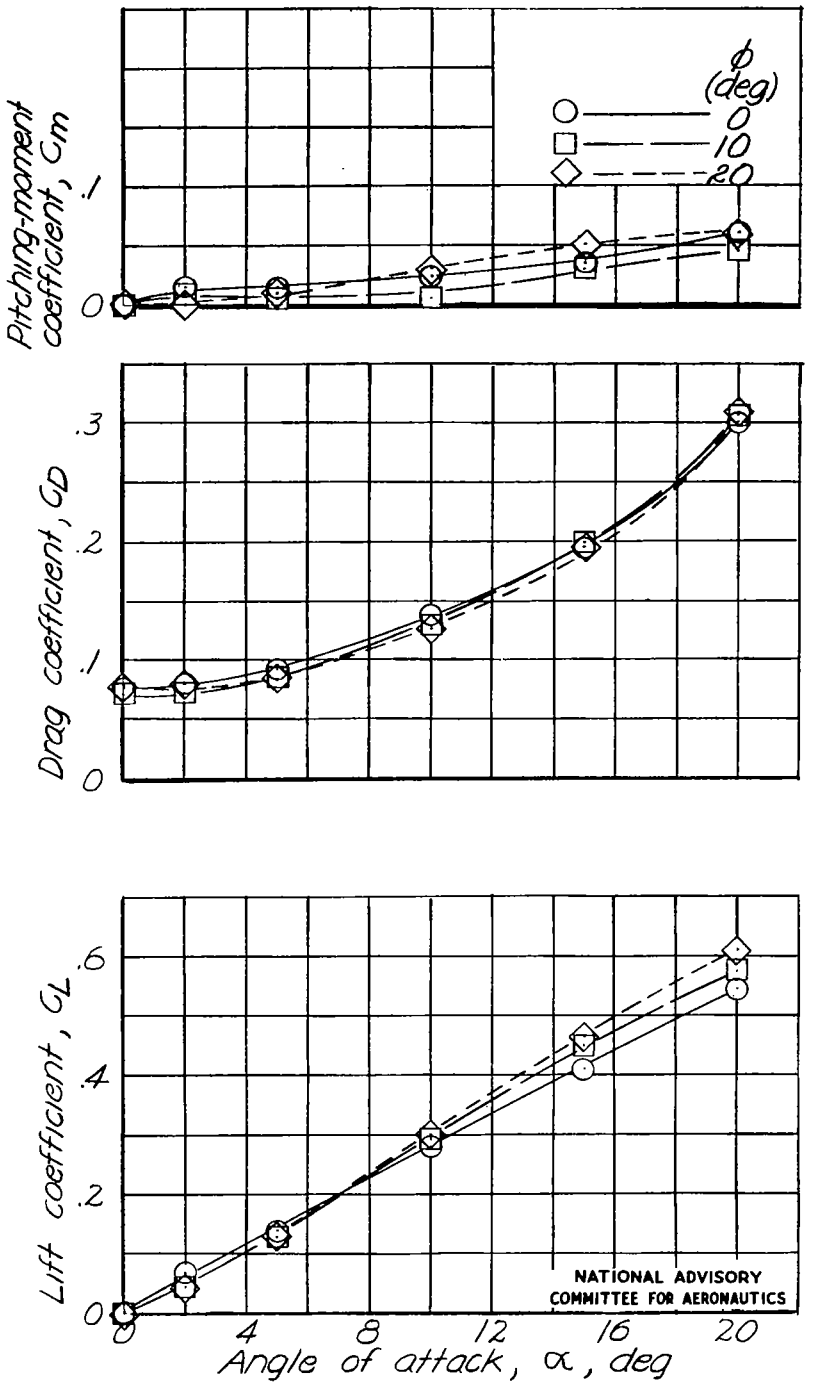


Figure 7.- Concluded.



(a) $\phi = 0°, 10°$, and $20°$.

Figure 8.- Aerodynamic characteristics of six-unit wing design of low aspect ratio and triangular plan form for guided missiles as determined from force tests in the Langley free-flight tunnel. $\psi = 0°$; $q = 4.1$ pounds per square foot.

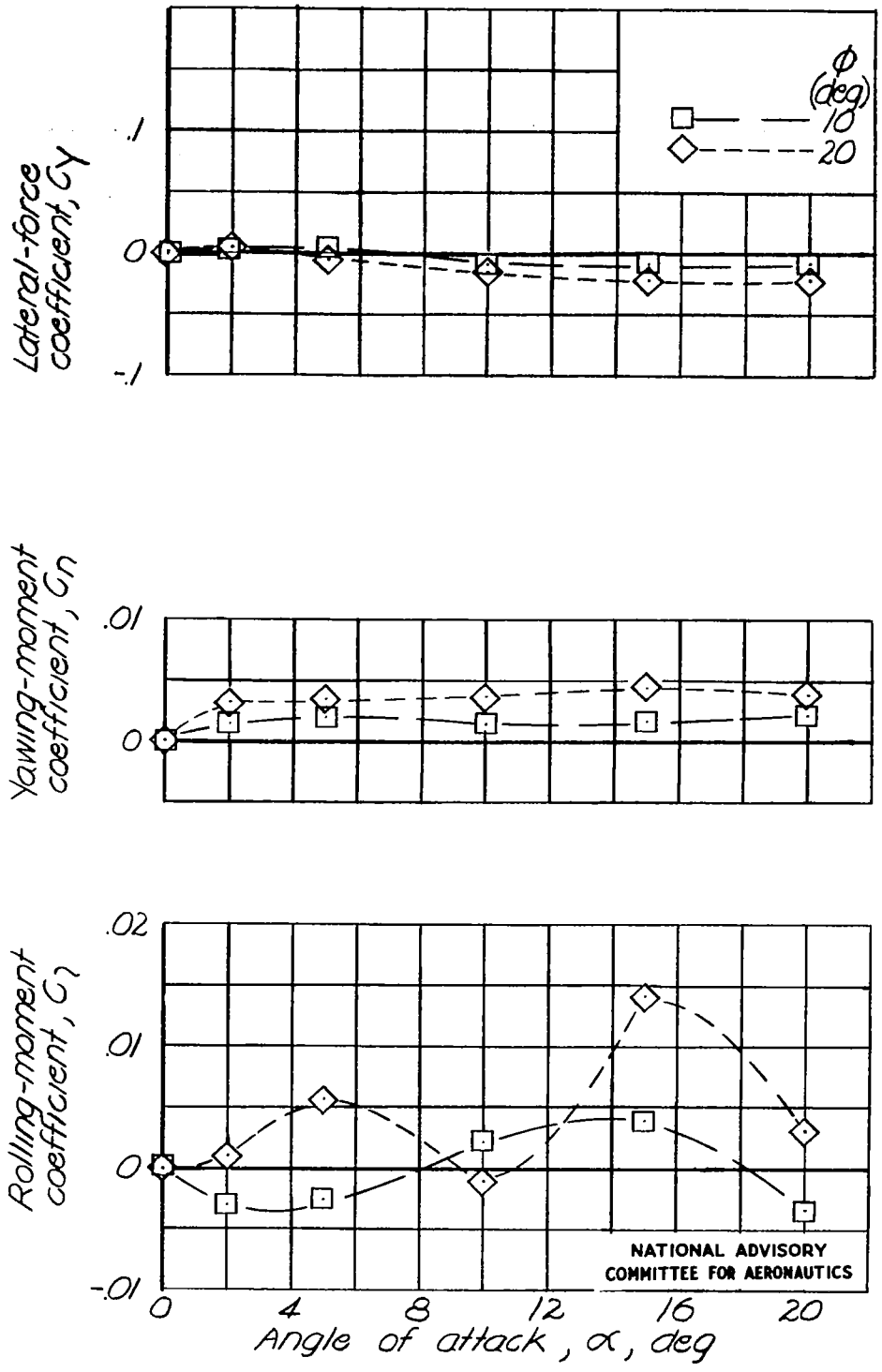


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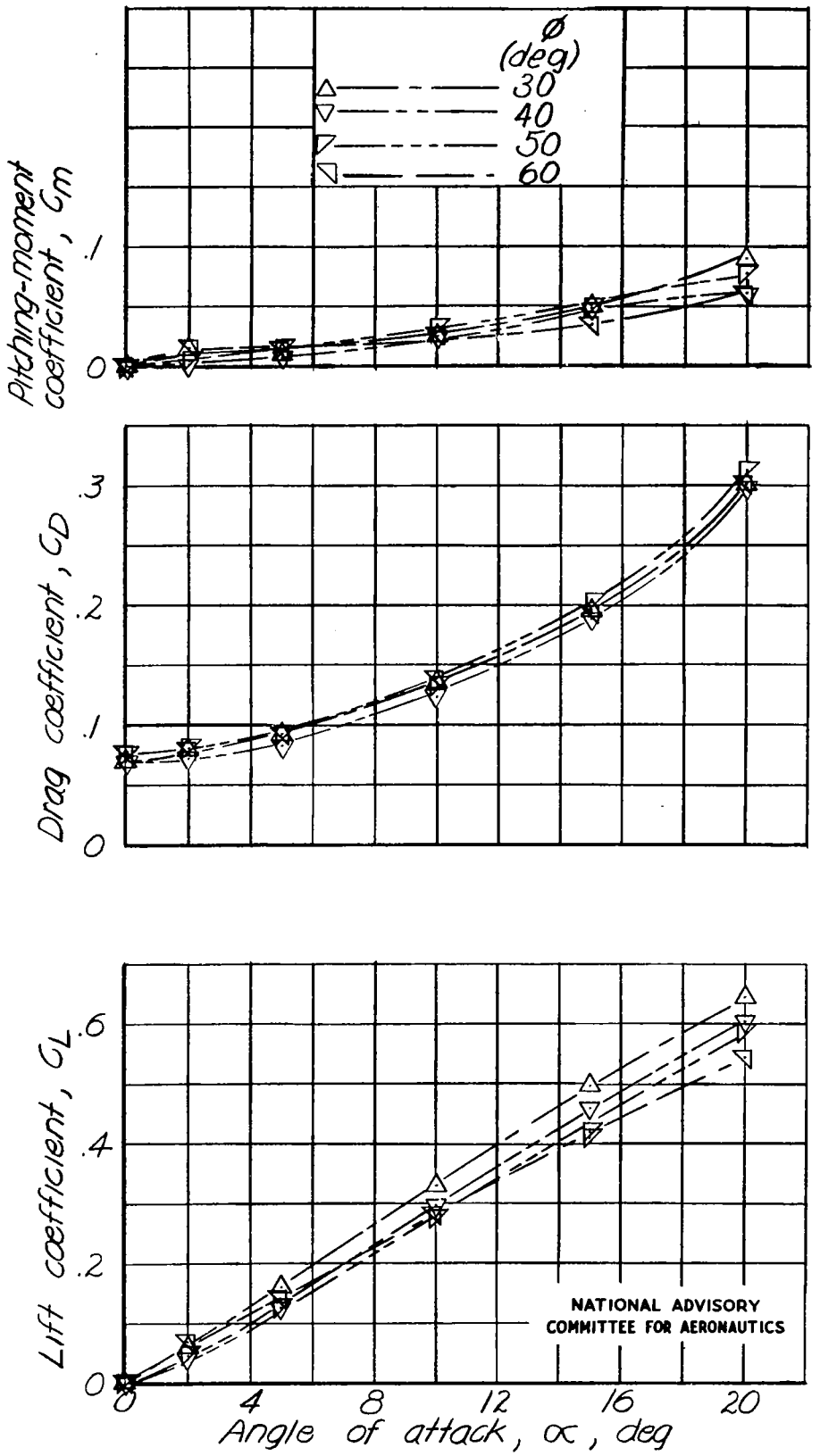
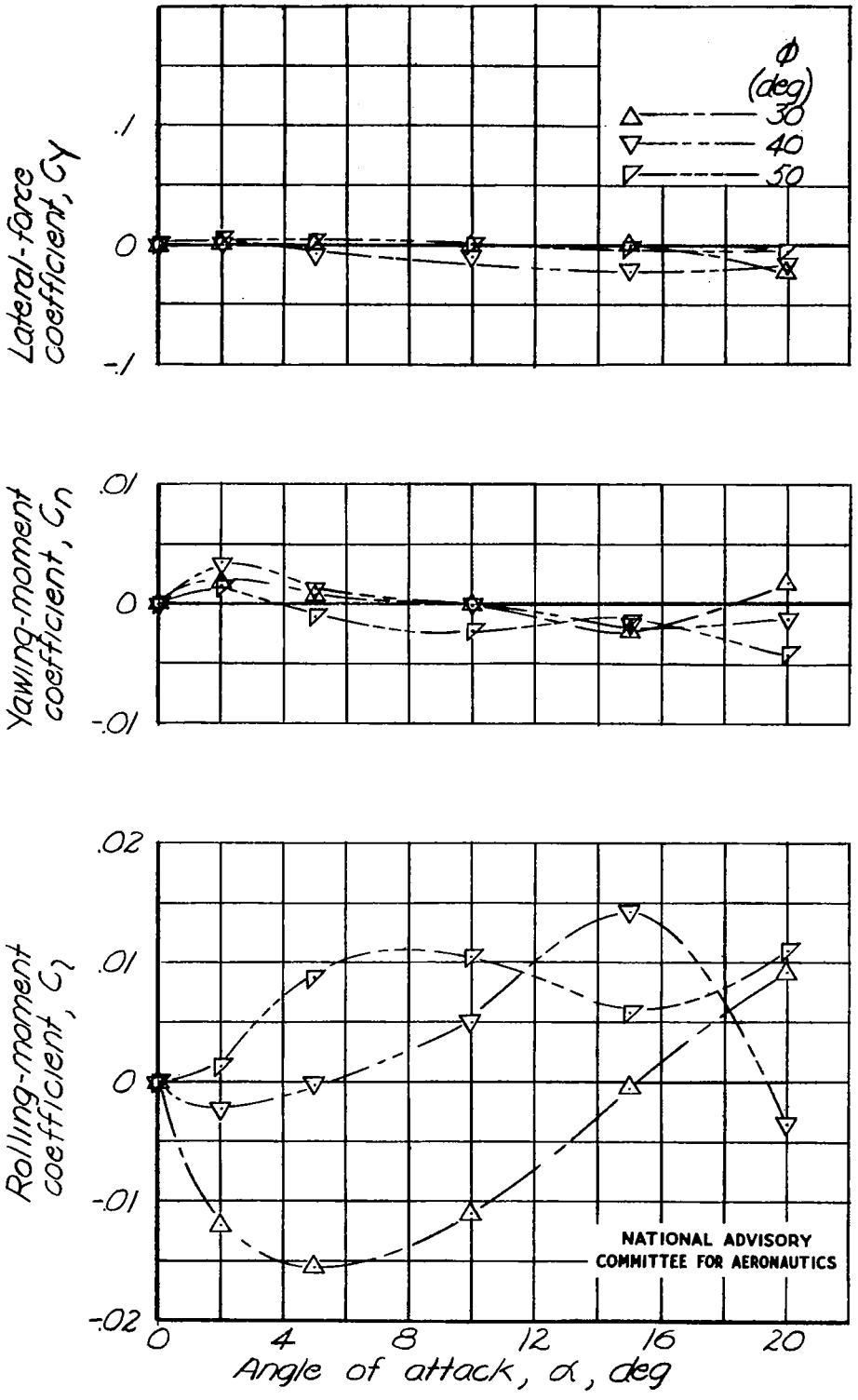
Figure 8. - Continued.



(b) $\phi = 30°, 40°, 50°$, and $60°$.

Figure 8.- Continued.



(b) Concluded.

Figure 8.- Concluded.

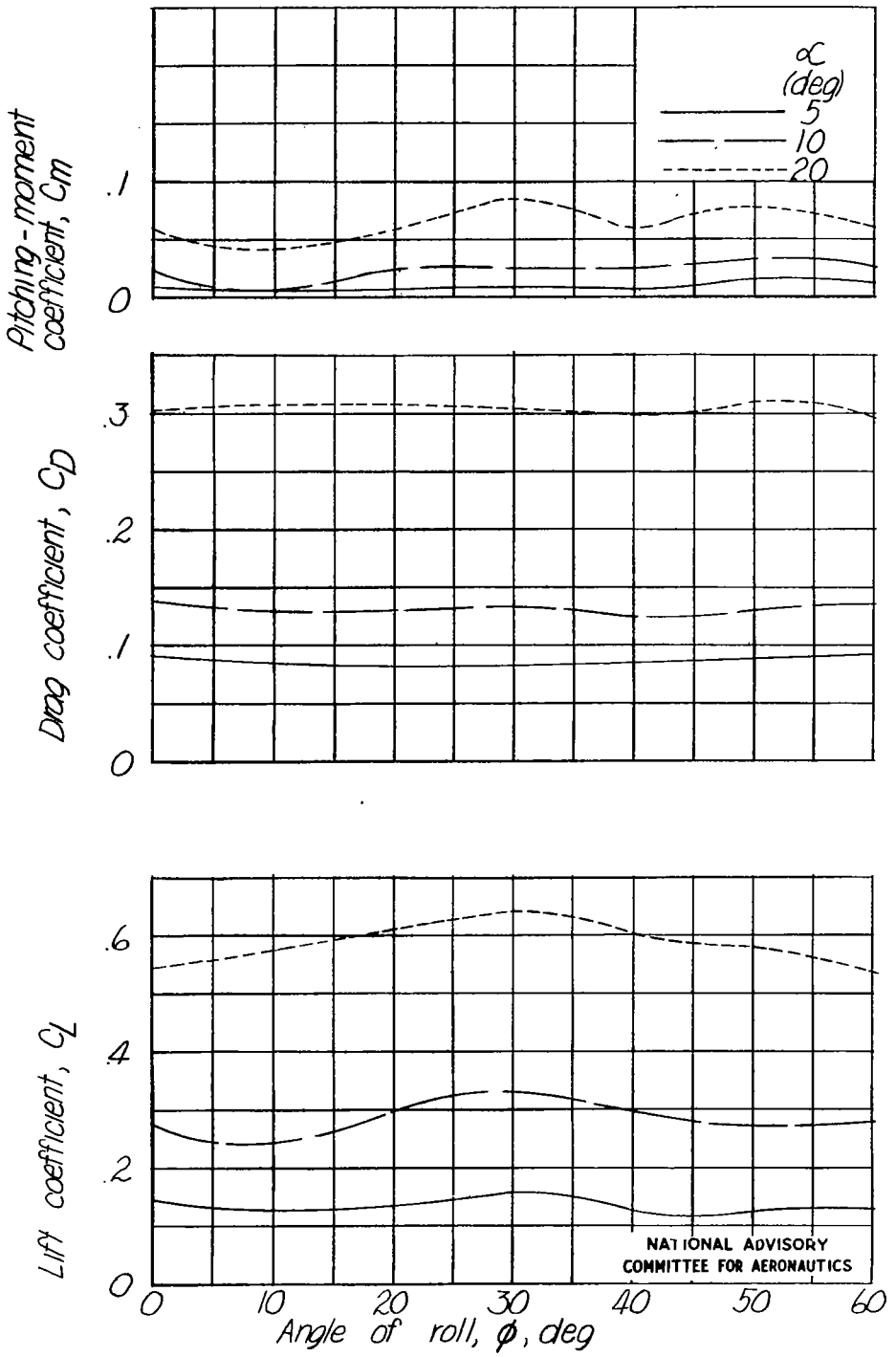


Figure 9.- Variation of aerodynamic characteristics with angle of roll for six-unit wing design of low aspect ratio and triangular plan form for guided missiles as determined from force tests in the Langley free-flight tunnel. $\psi = 0°$; $q = 4.1$ pounds per square foot.

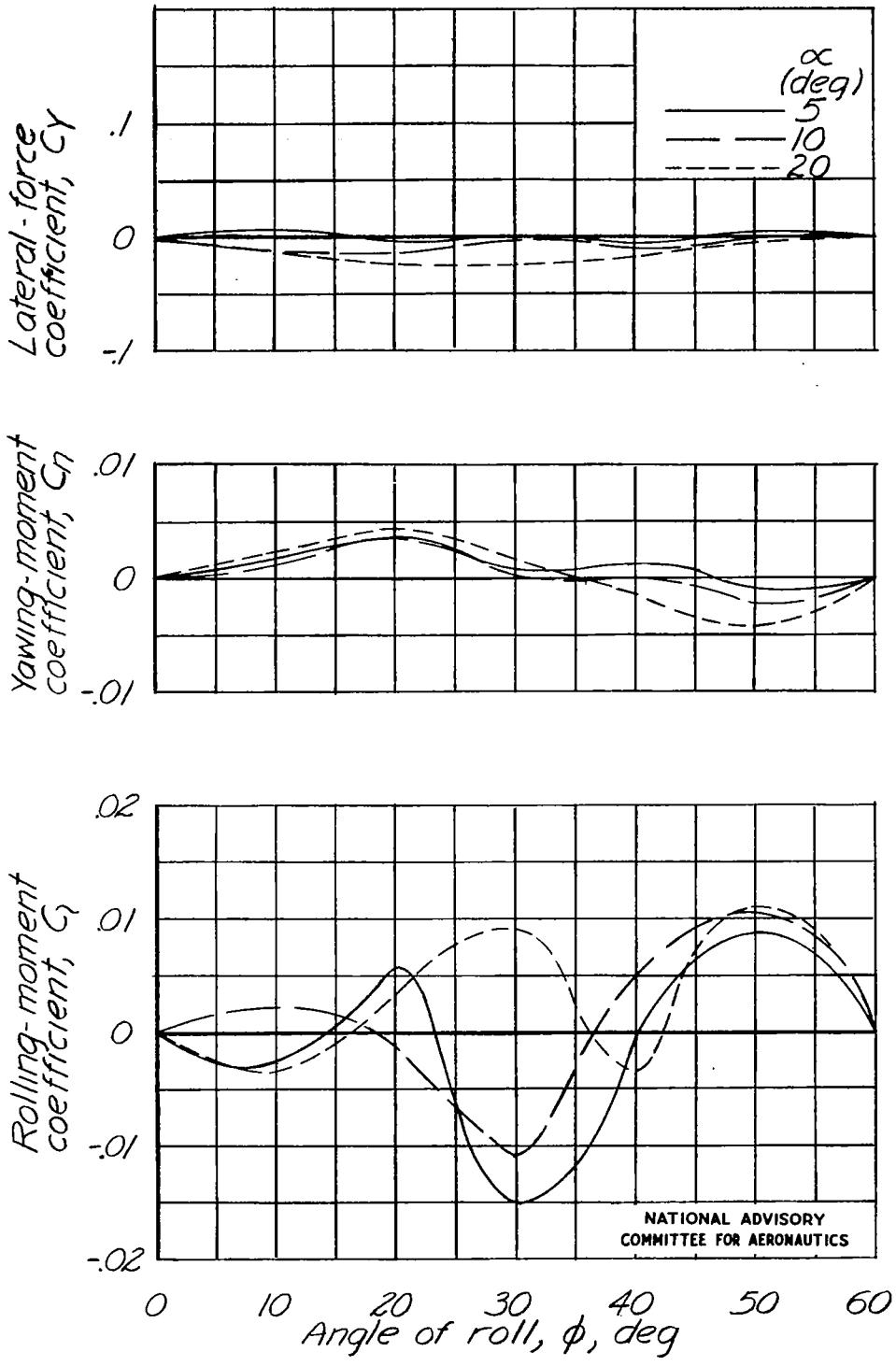


Figure 9.- Concluded.

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