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by Dennis E. Fuller

Langley Research Center

Langley Station, Hampton, Va.

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EFFECTS OF NOSE SHAPE AND FIN GEOMETRY ON STATIC STABILITY OF A HIGH-FINENESS-RATIO SOUNDING ROCKET

By Dennis E. Fuller
Langley Research Center

SUMMARY

Tests were conducted in the Langley 4- by 4-foot supersonic pressure tunnel to determine the effects of variations in nose shape and fin geometry on the static stability of two sounding rocket models having length-diameter ratios of 18.20 and 23.77. Tests were made at a Mach number of 2.01 for angles of attack from about -4° to 24° and for angles of sideslip from about -5° to 9°. The Reynolds number was 9.8×10^{6} per meter.

The results indicated that significant changes in nose shape and fin geometry had little effect in improving the pitching-moment nonlinearities of the high-fineness-ratio rockets. The fins of higher aspect ratio tended to improve the directional stability and to delay the induced rolling moments to higher angles of attack.

INTRODUCTION

The National Aeronautics and Space Administration is conducting a continuing investigation of the atmospheric environment at extremely high altitudes. This high-altitude research, in many instances, utilizes high-fineness-ratio sounding rockets. One deficiency prevalent in these high-fineness-ratio vehicles is excessive pitching-moment nonlinearity at moderate angles of attack. In an attempt to minimize this undesirable trait, a wind-tunnel investigation has been initiated on two 1/2-scale Arcas research vehicles with fineness ratios of 18.20 and 23.77. Stability tests of these basic configurations have been reported in references 1 and 2. The present investigation included variations in nose shape and increased fin aspect ratio for each of the two test vehicles.

The tests were conducted at a Mach number of 2.01 for angles of attack from about -4° to 24° and for angles of sideslip from about -5° to 9°. The test Reynolds number was 9.8×10^{6} per meter.

SYMBOLS

The aerodynamic forces and moments are referred to the body-axis system with the reference moment center located at 63.37 and 66.36 percent of the body length for configurations 1 and 2, respectively (fig. 1). These moment centers are farther rearward than the flight centers of gravity.

A	maximum cross-sectional area of body, centimeters^2
AR	aspect ratio
C_A	axial-force coefficient, $\frac{\text{Axial force}}{qA}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qAd}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qA}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qAd}$
C_{n_β}	directional stability parameter, $\frac{\partial C_n}{\partial \beta}$, per degree
C_Y	side-force coefficient, $\frac{\text{Side force}}{qA}$
d	body diameter, centimeters
q	free-stream dynamic pressure, newtons per meter^2
r	radius of curvature of nose, centimeters
α	angle of attack, degrees
β	angle of sideslip, degrees

MODELS

One model tested (configuration 1) was representative of the Arcas Robin meteorological rocket vehicle, whereas the other (configuration 2) represented the Arcas vehicle as modified by NASA to accommodate a bioscience payload.

Dimensional details of the 1/2-scale models are presented in figure 1. The basic model consisted of an ogive nose, cylindrical center body, boattailed afterbody, and trapezoidal double-wedge fins. The afterbody boattail ended with a reflex lip. The two configurations, 1 and 2, had length-diameter ratios of 18.20 and 23.77, respectively.

Two nose shapes, one spherical with a 2.907-centimeter radius and the other conical with a 7.5° half-angle, were supplied for configurations 1 and 2 in addition to the basic ogive shape. Configurations 1 and 2 were tested with the basic fins, which had an exposed aspect ratio of approximately 0.7, and also with a set of fins of greater span, which had an exposed aspect ratio of approximately 2.6.

APPARATUS AND TESTS

Tests were conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01. The aerodynamic forces and moments were measured by means of a six-component electrical strain-gage balance housed within the model. The balance, in turn, was fastened to a sting support and thence to the tunnel support system. Tests were made at a stagnation pressure of 85 800 N/m^2 and a stagnation temperature of 316° K. The range of angle of attack was from about -4° to 24° and the range of angle of sideslip was from about -5° to 9°. The Reynolds number was 9.8×10^6 per meter. The stagnation dewpoint was maintained near 244° K to assure negligible condensation effects. In order to obtain turbulent flow, a 0.159-centimeter-wide strip of No. 60 carborundum grains was affixed around the model 1.91 centimeters rearward of the nose and 1.27 centimeters rearward of the leading edge of each fin (measured in the streamwise direction).

CORRECTIONS

Angles of attack and sideslip were corrected for deflection of the balance and sting support as a result of aerodynamic loads. Axial-force data were not corrected to free-stream conditions at the model base.

PRESENTATION OF RESULTS

The results are presented in the following figures:

DISCUSSION

Longitudinal Characteristics

The longitudinal characteristics of the test configurations, including the effects of nose shape and fin aspect ratio, are presented in figures 2 and 3 for configurations 1 and 2, respectively.

The axial-force results (figs. 2(a) and 3(a)) indicate that the lowest values are obtained with the ogive nose shape. The conical nose shape, in comparison with the ogive shape, results in a slight increase in axial force as well as a decrease in forebody volume. The increase in axial force for the conical nose can be attributed to the overall higher forebody slope for this shape. The spherically blunt nose results in a substantial increase in forebody volume and, as expected, has the highest axial-force level of the three shapes tested. As might be expected, the axial-force level is increased by the addition of the fins.

All the configurations tested have a pitch-up tendency beginning at moderate angles of attack as a result of the basic instability of the body alone and the decrease in fin effectiveness at the higher angles of attack. The pitch-up tendency, as might be expected, is more pronounced (and generally occurs at lower angles of attack) for the longer configuration (fig. 3(b)).

Changes in nose shape had little effect on the pitching-moment characteristics except that the blunt nose generally produced the lowest values of stability and initiated the earliest pitch-up tendency. The addition of the fins, of course, progressively increased the level of stability, and with increasing fin aspect ratio the onset of pitch-up was slightly delayed.

A comparison of the aerodynamic-center locations, for low angles of attack, for the various configurations is shown in figure 4. These results indicate that the aerodynamic center is consistently farther forward for the blunt-nose configurations. The aerodynamic-center locations for all the finned configurations, however, are between about 70 and 78 percent of the body length.

Lateral Characteristics

The lateral characteristics are presented in figures 5 and 6 for configurations 1 and 2, respectively, and the directional stability parameter C_{n_β} is summarized in figure 7.

The rolling- and yawing-moment coefficients are generally nonlinear with change in sideslip angle for both configurations 1 and 2. Nose shape has only small effects on these nonlinearities. Both configurations 1 and 2 display large values of rolling moment due to sideslip at the higher test angles of attack. Increasing the aspect ratio of the fins tends to delay these induced rolling moments to higher angles of attack.

Generally, the directional stability (fig. 7) is greater with the high-aspect-ratio fins than with the low-aspect-ratio fins, for both configurations 1 and 2. The blunt nose, in comparison with the conical or ogive nose, causes decreased directional stability. Because of the effects of body length, fin aspect ratio, and nose shape on C_{n_β} (shown in fig. 7), the onset of directional instability is delayed to the highest angle of attack for configuration 1 with the high-aspect-ratio fins and the ogive or conical nose and occurs at the lowest angle of attack for configuration 2 with the low-aspect-ratio fins and spherical nose.

CONCLUSIONS

Static-stability tests were made at a Mach number of 2.01 on 1/2-scale sounding rocket models with variations in nose shape and fin geometry for two body lengths. The results indicate the following conclusions:

1. Significant changes in nose shape and fin geometry had little effect in improving the pitching-moment nonlinearities of the high-fineness-ratio rocket vehicles.

2. The fins of higher aspect ratio tended to improve the directional stability and to delay the induced rolling moments to higher angles of attack.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 5, 1968,
124-07-05-01-23.

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1. Babb, C. Donald; and Fuller, Dennis E.: Static Stability Investigation of a Sounding-Rocket Vehicle at Mach Numbers From 1.50 to 4.63. NASA TN D-4014, 1967.

2. Ferris, James C.: Static Stability Investigation of a Single-Stage Sounding Rocket at Mach Numbers From 0.60 to 1.20. NASA TN D-4013, 1967.

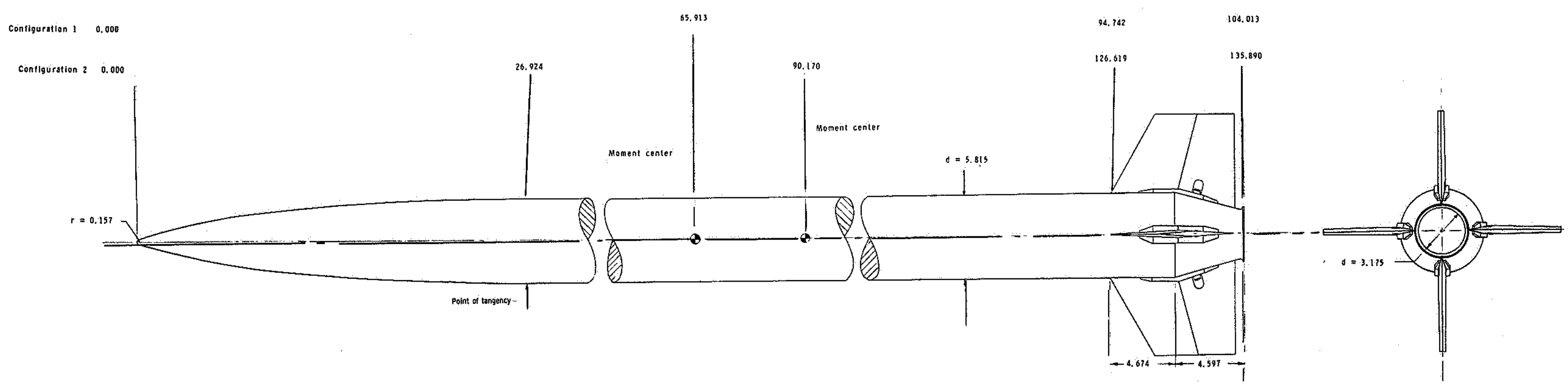


Figure 1.- Model details. (All dimensions are in centimeters.)

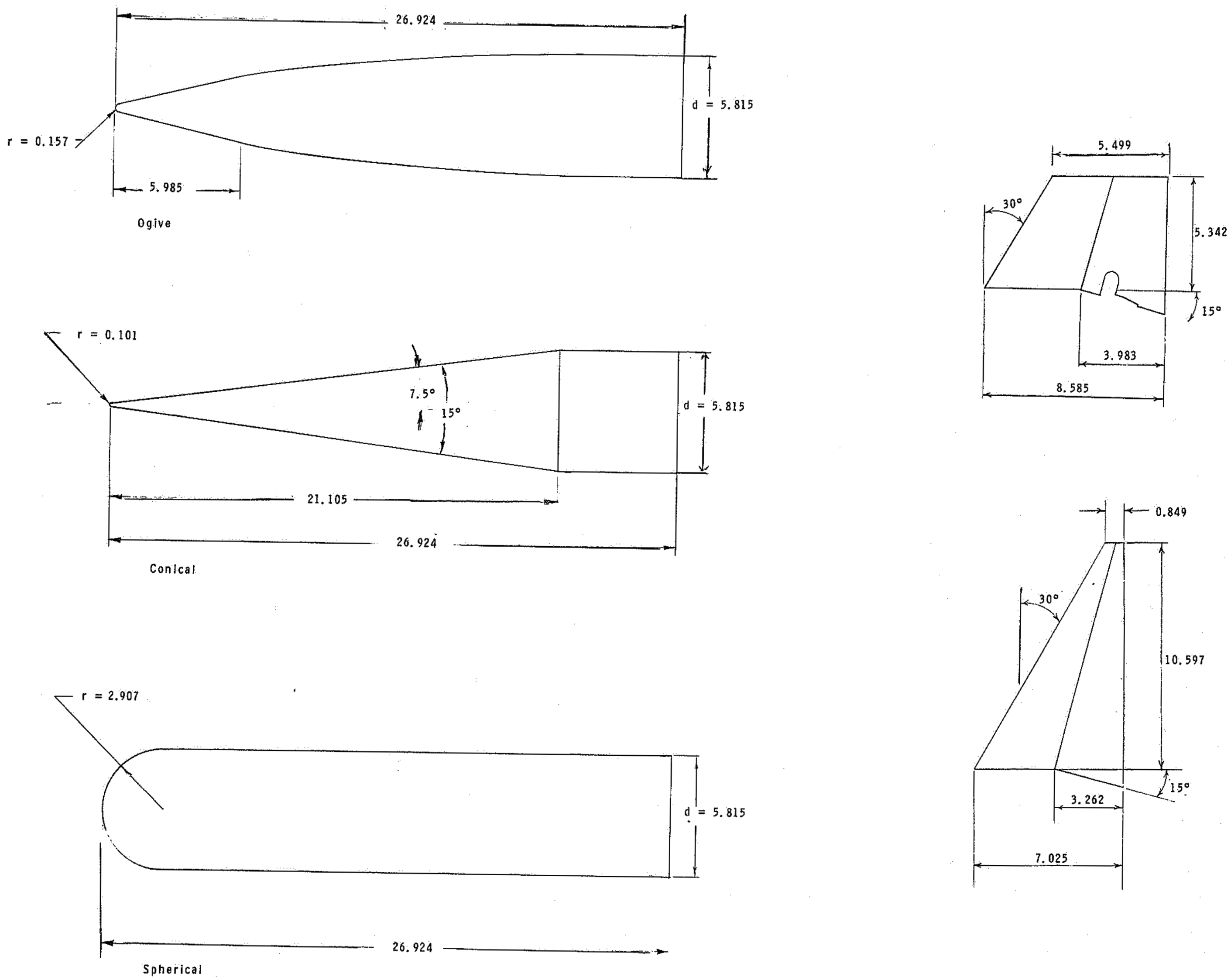
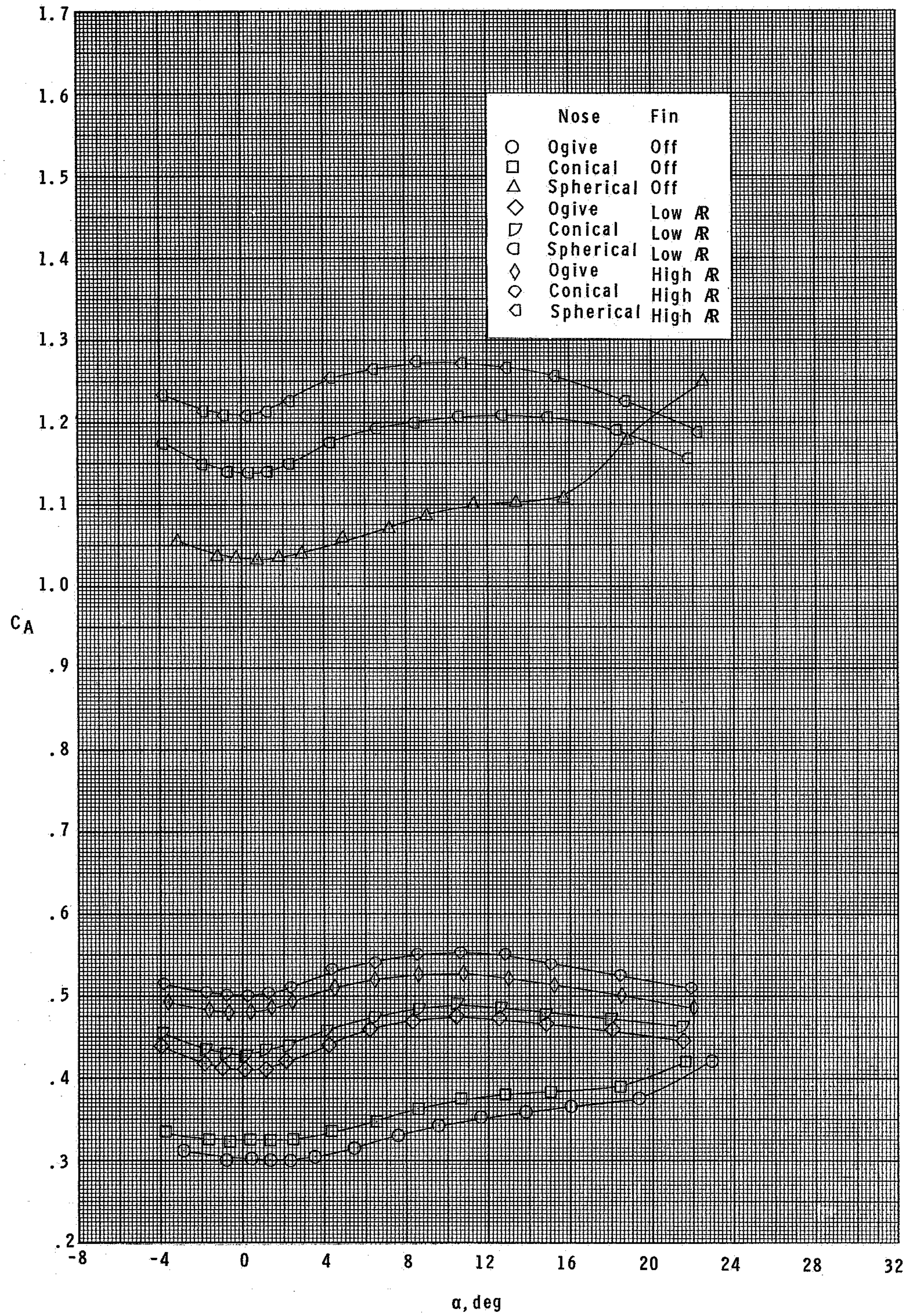
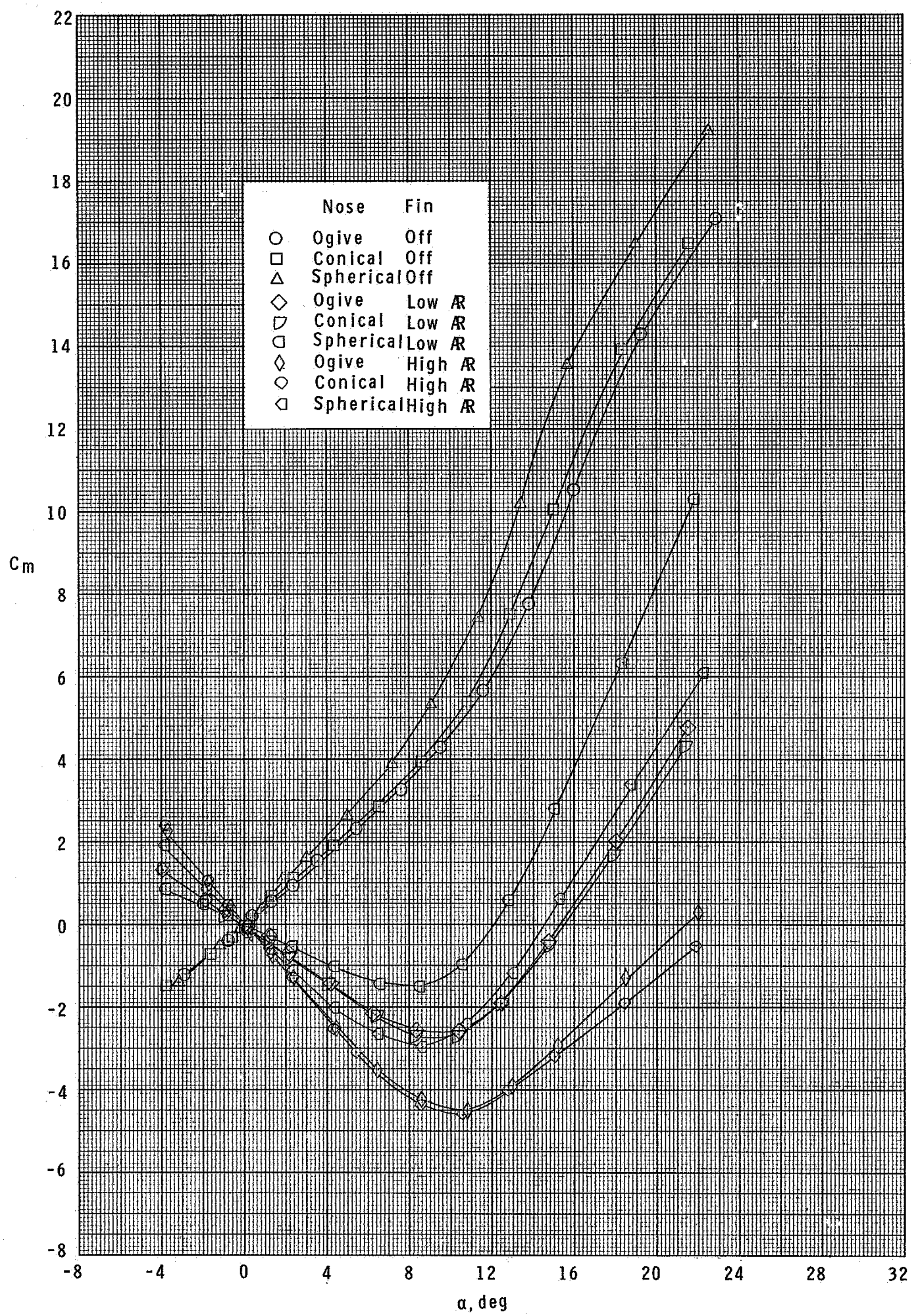


Figure 1.- Concluded.



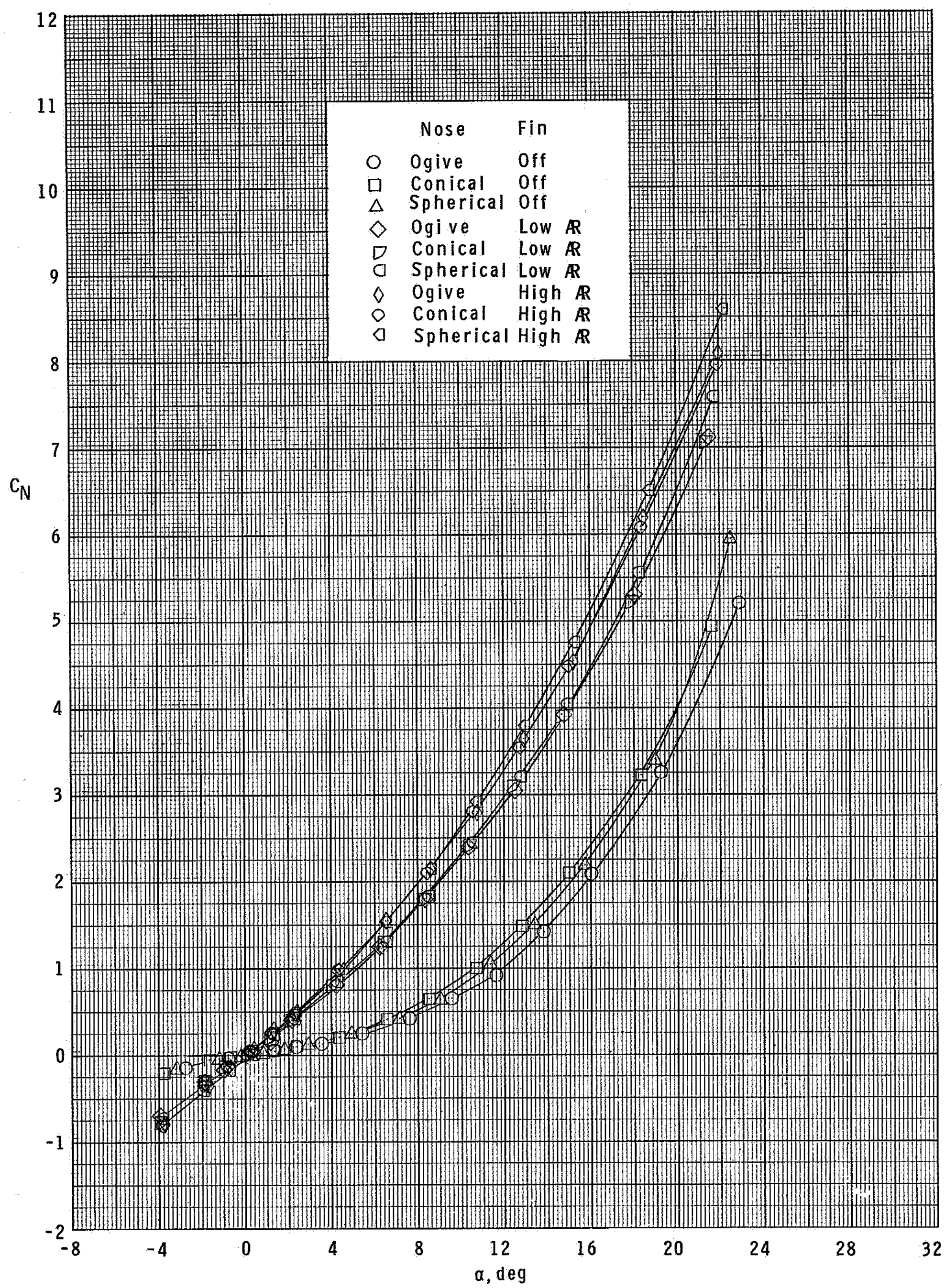
(a) Axial force.

Figure 2.- Aerodynamic characteristics in pitch of configuration 1.



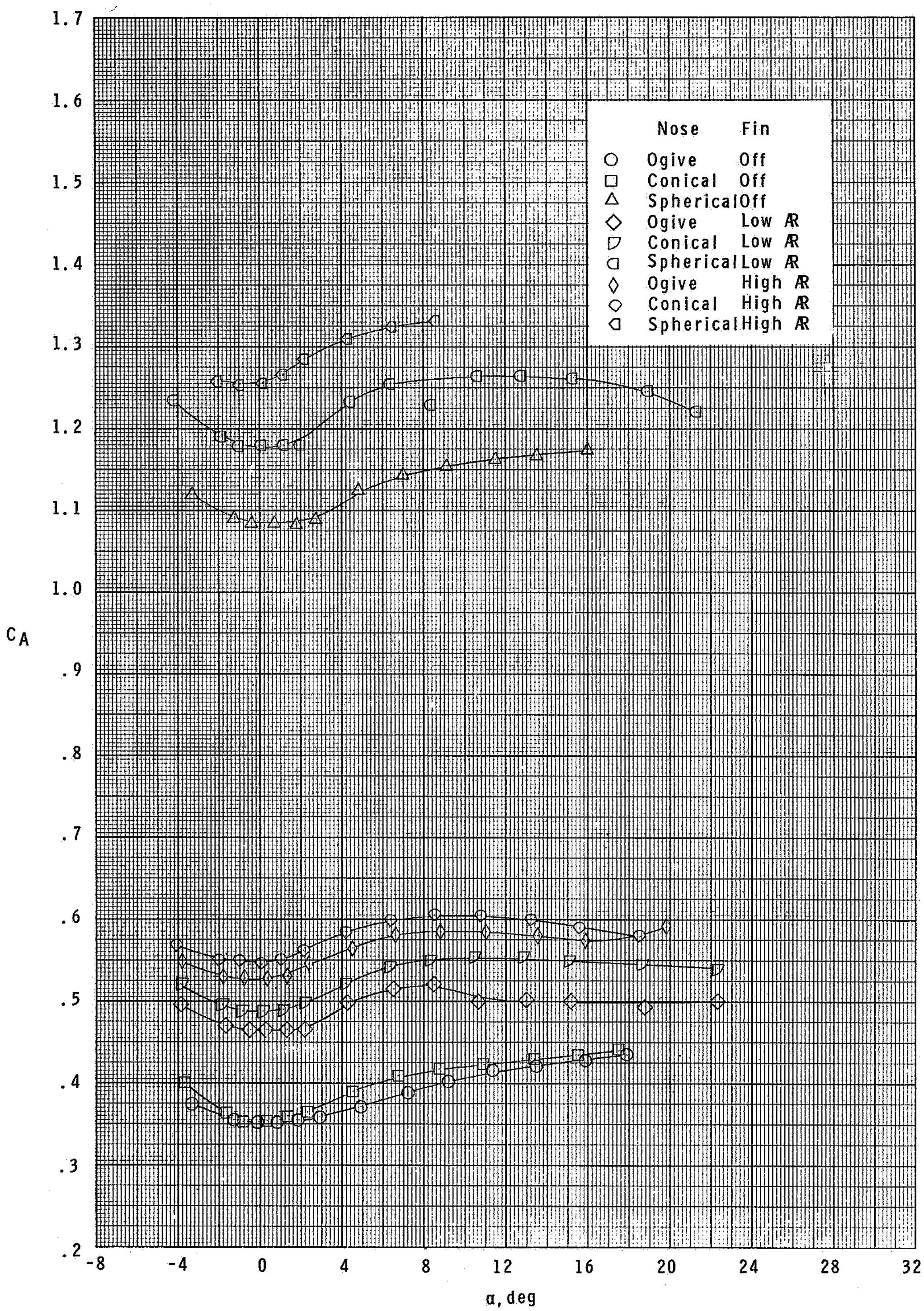
(b) Pitching moment.

Figure 2.- Continued.



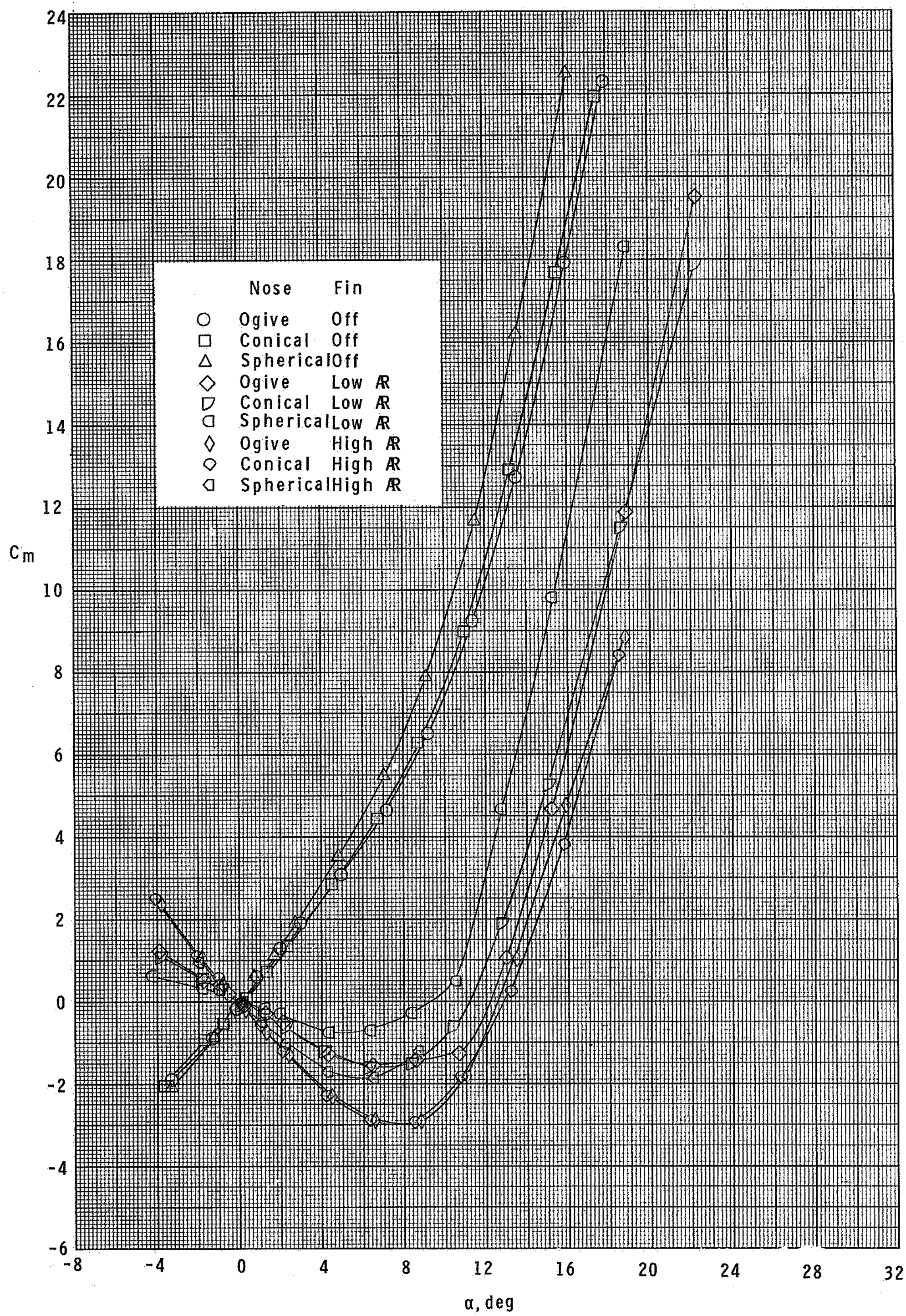
(c) Normal force.

Figure 2.- Concluded.



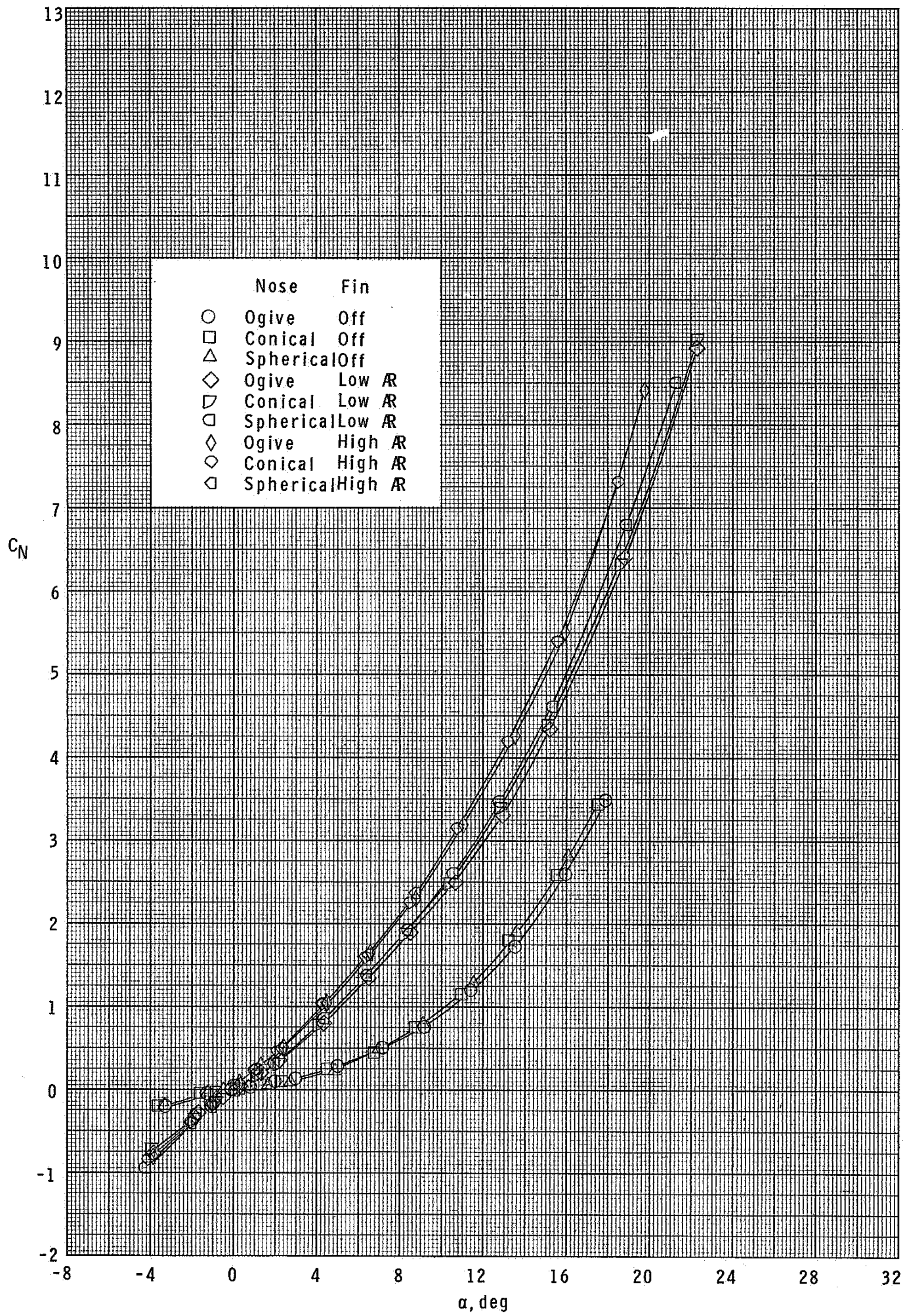
(a) Axial force.

Figure 3.- Aerodynamic characteristics in pitch of configuration 2.



(b) Pitching moment.

Figure 3.- Continued.



(c) Normal force.

Figure 3.- Concluded.

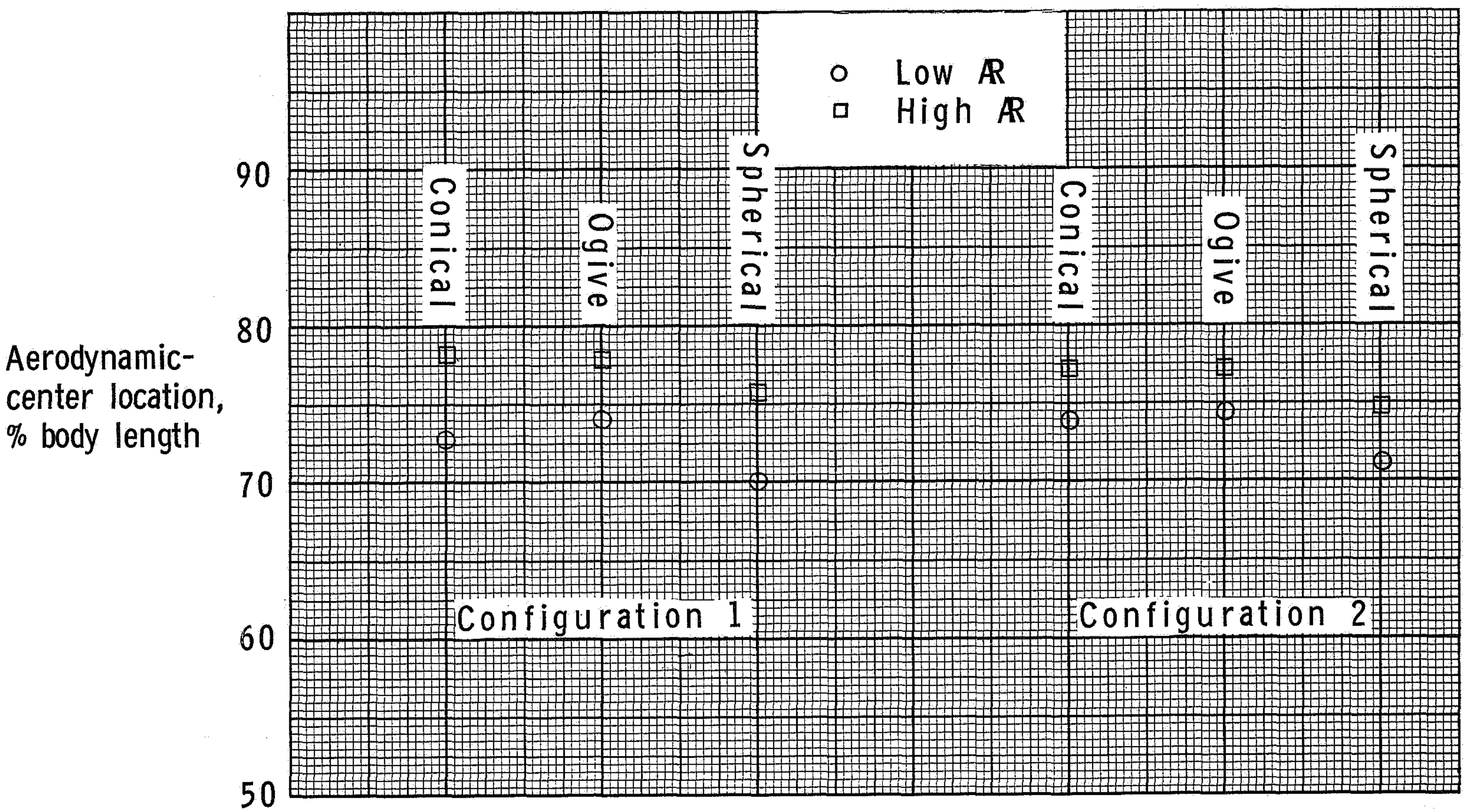
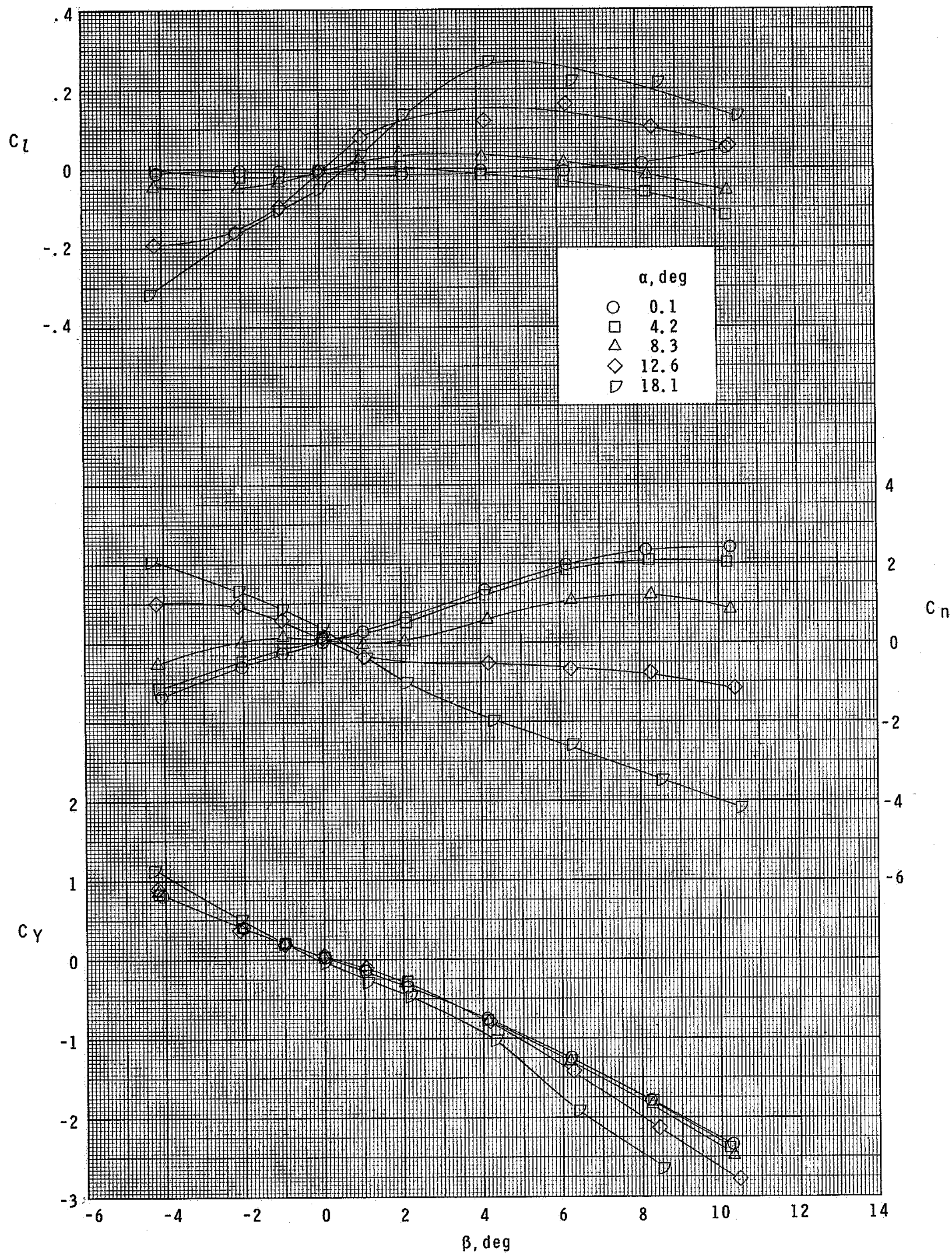
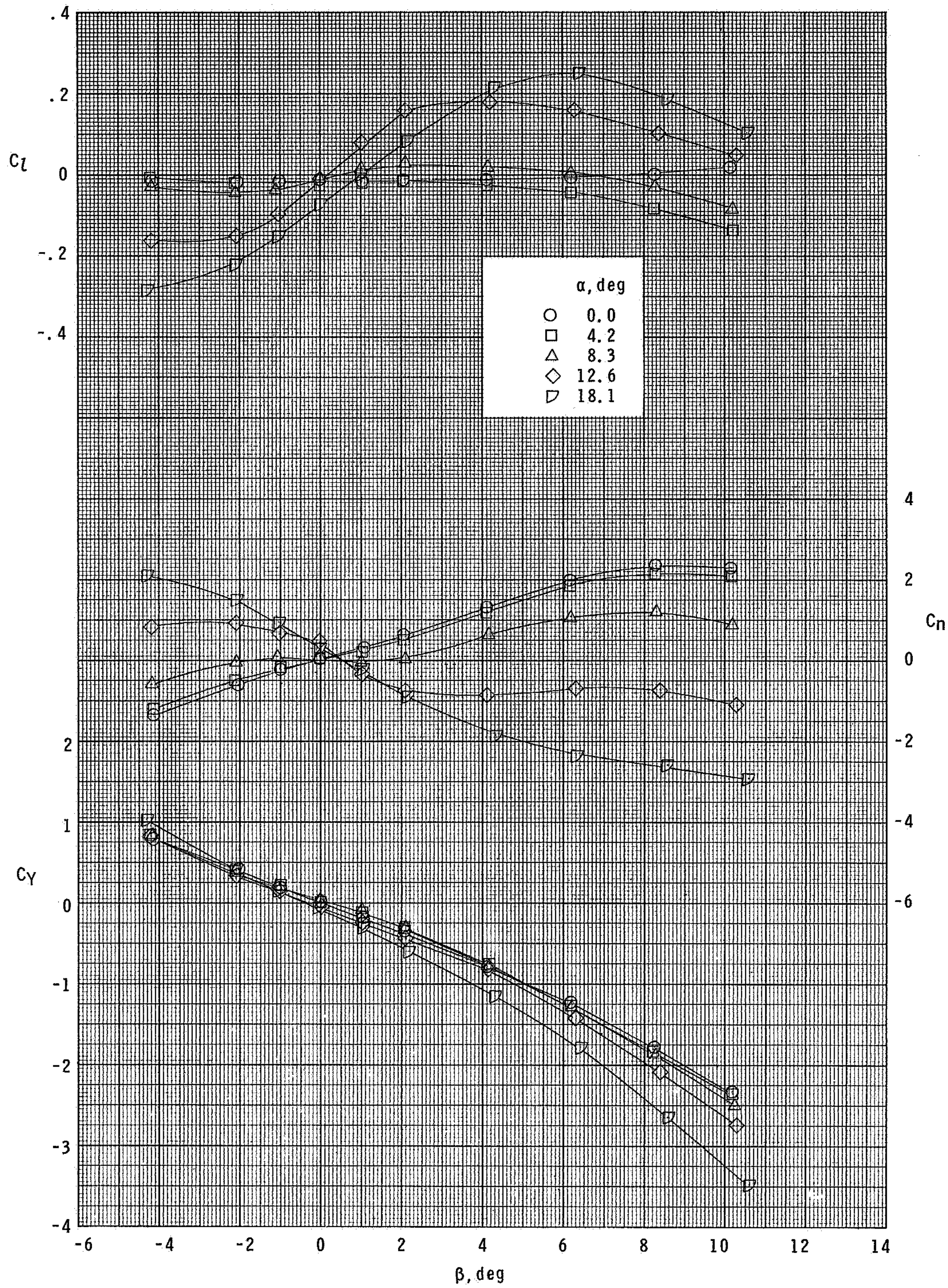


Figure 4.- Effect of nose shape and fin size on aerodynamic-center location (for low angles of attack).



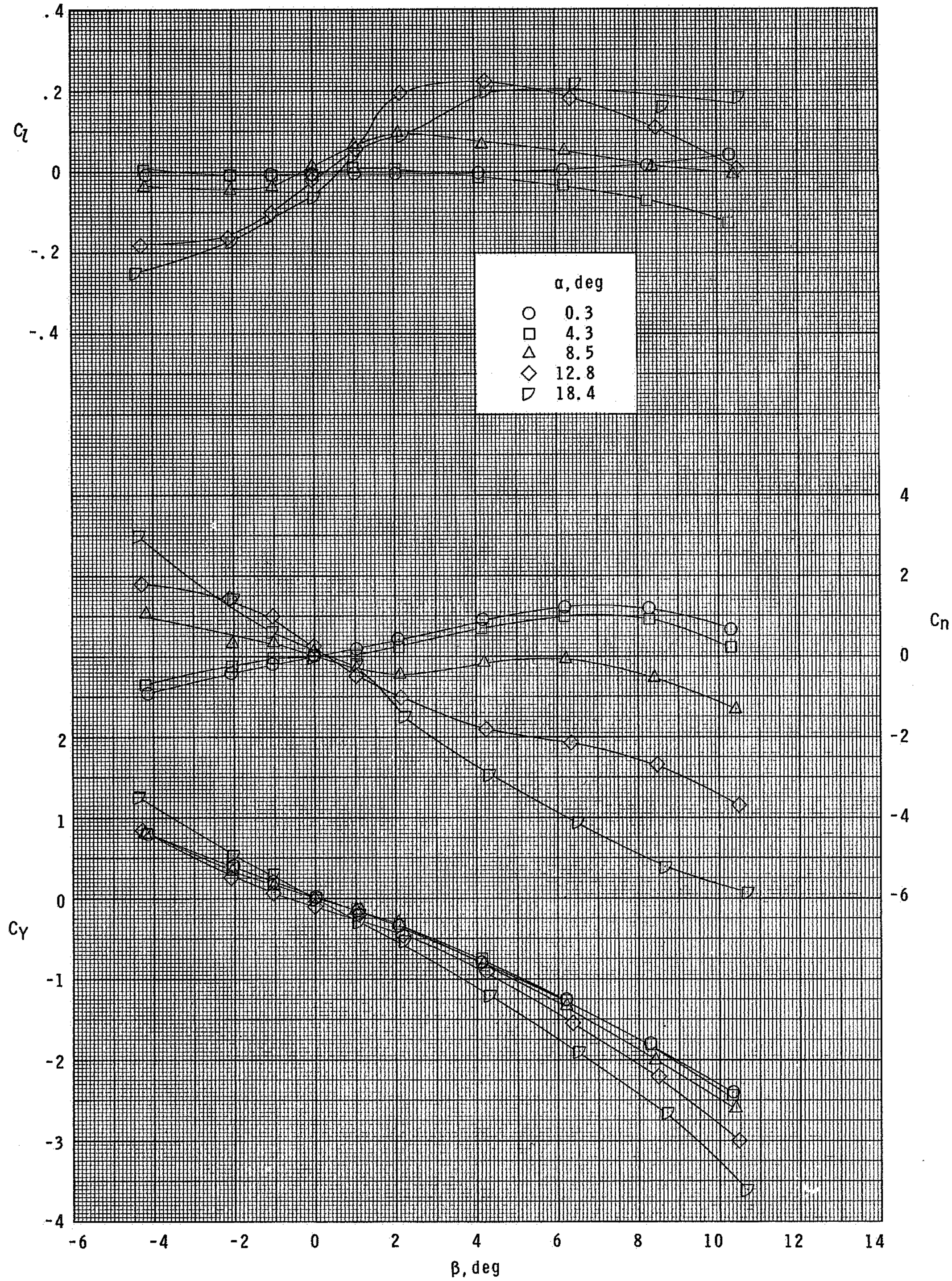
(a) Ogive nose, low-aspect-ratio fins.

Figure 5.- Aerodynamic characteristics in sideslip of configuration 1.



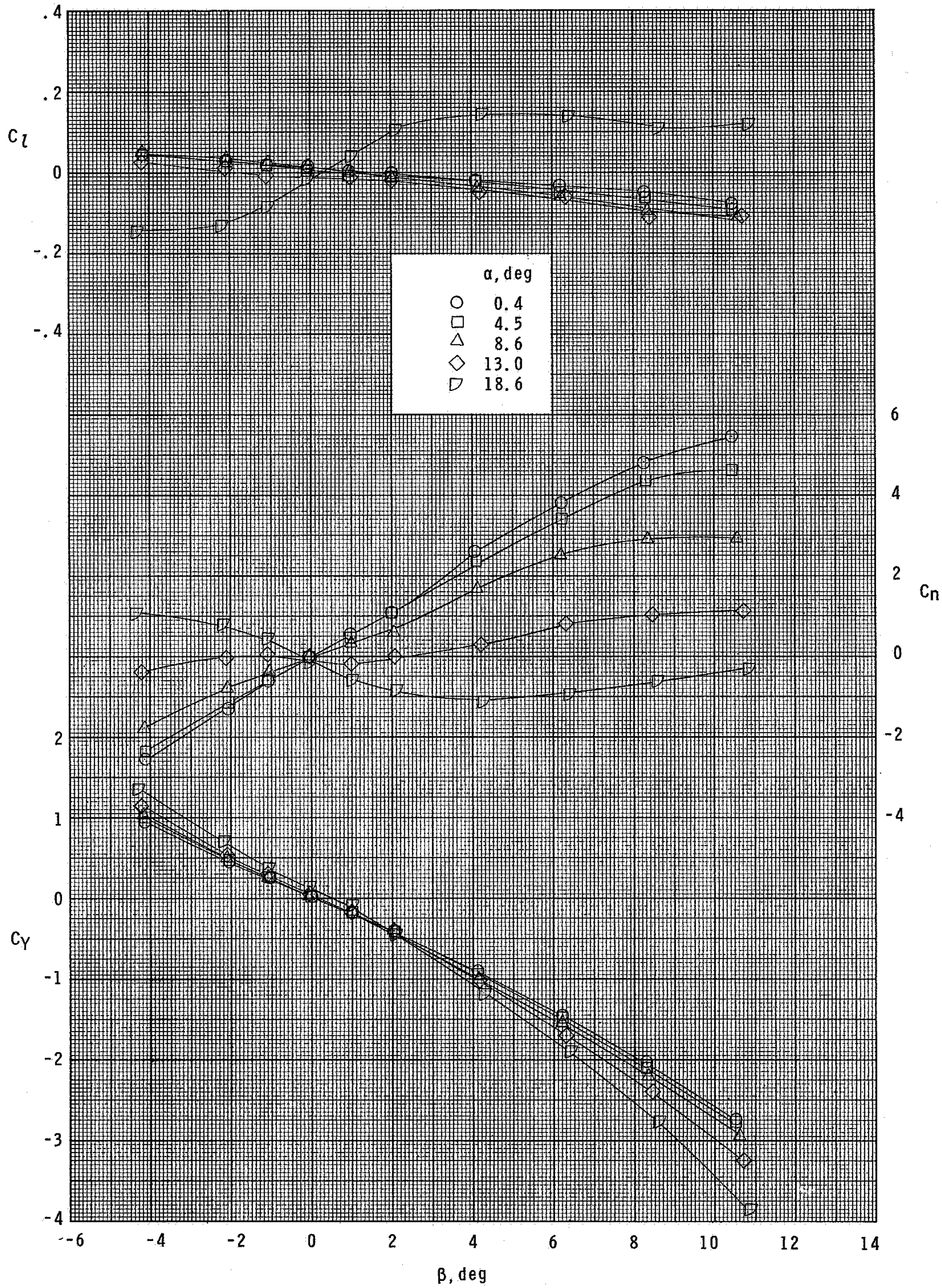
(b) Conical nose, low-aspect-ratio fins.

Figure 5.- Continued.



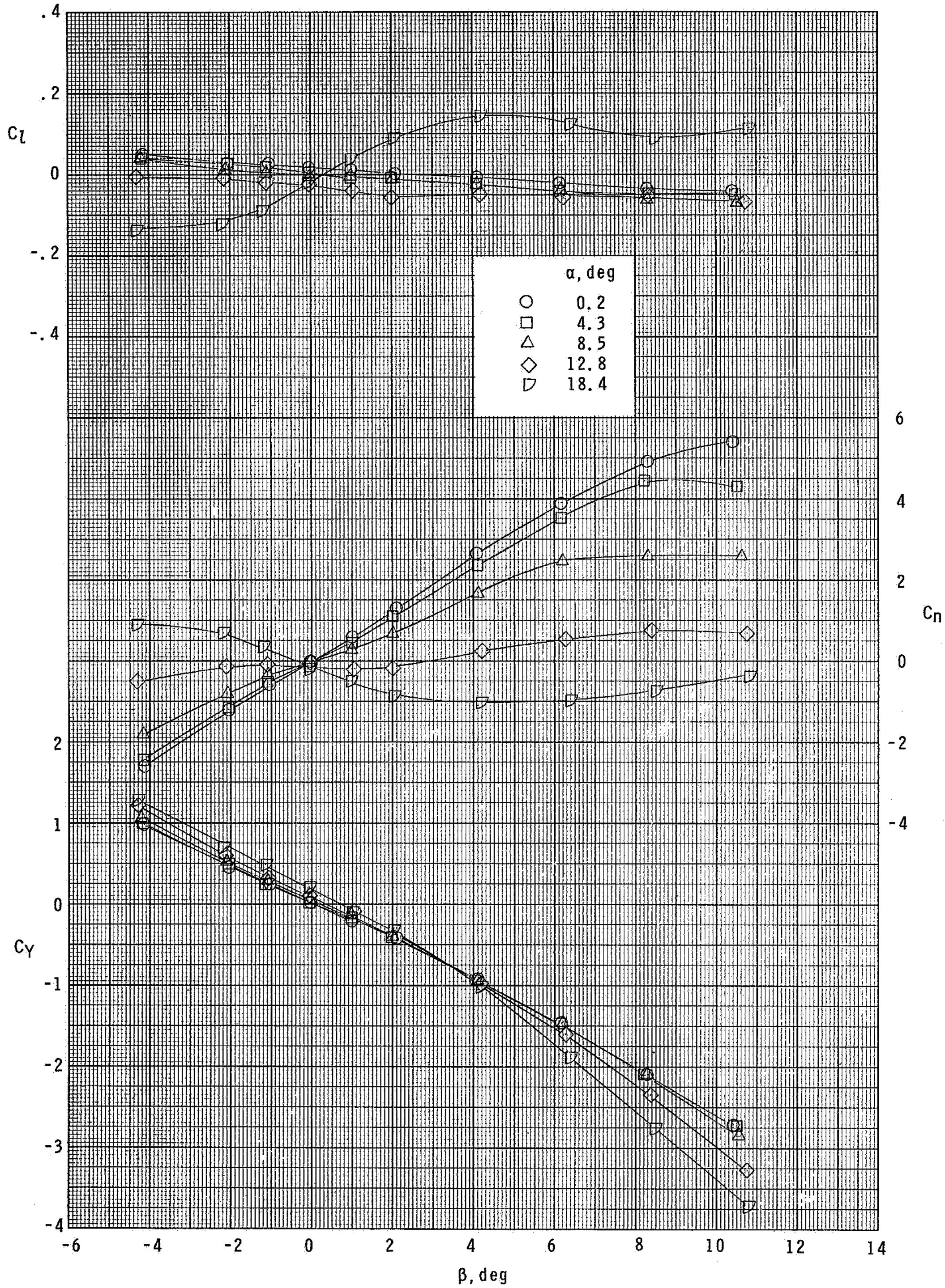
(c) Spherical nose, low-aspect-ratio fins.

Figure 5.- Continued.



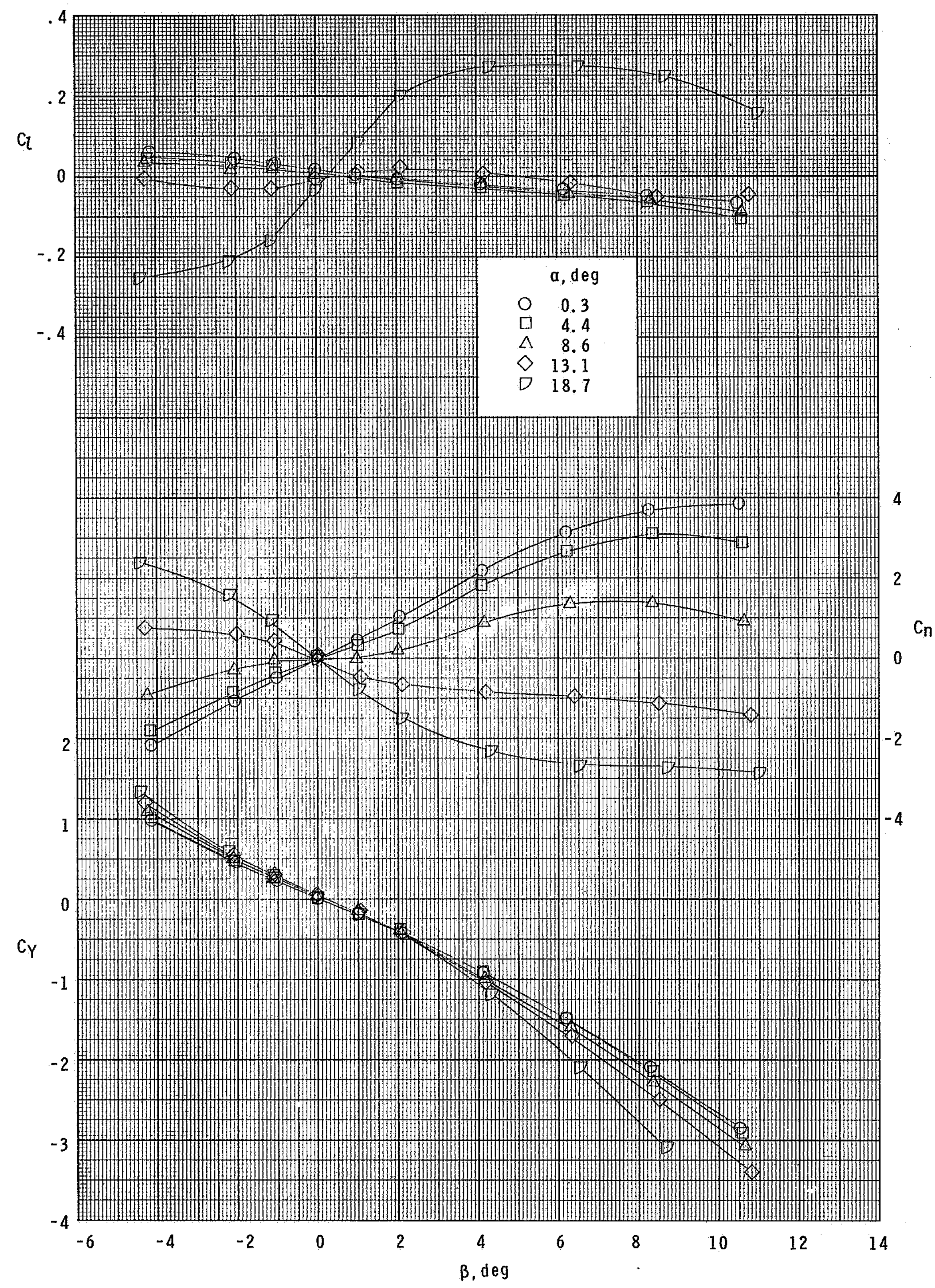
(d) Ogive nose, high-aspect-ratio fins.

Figure 5.- Continued.



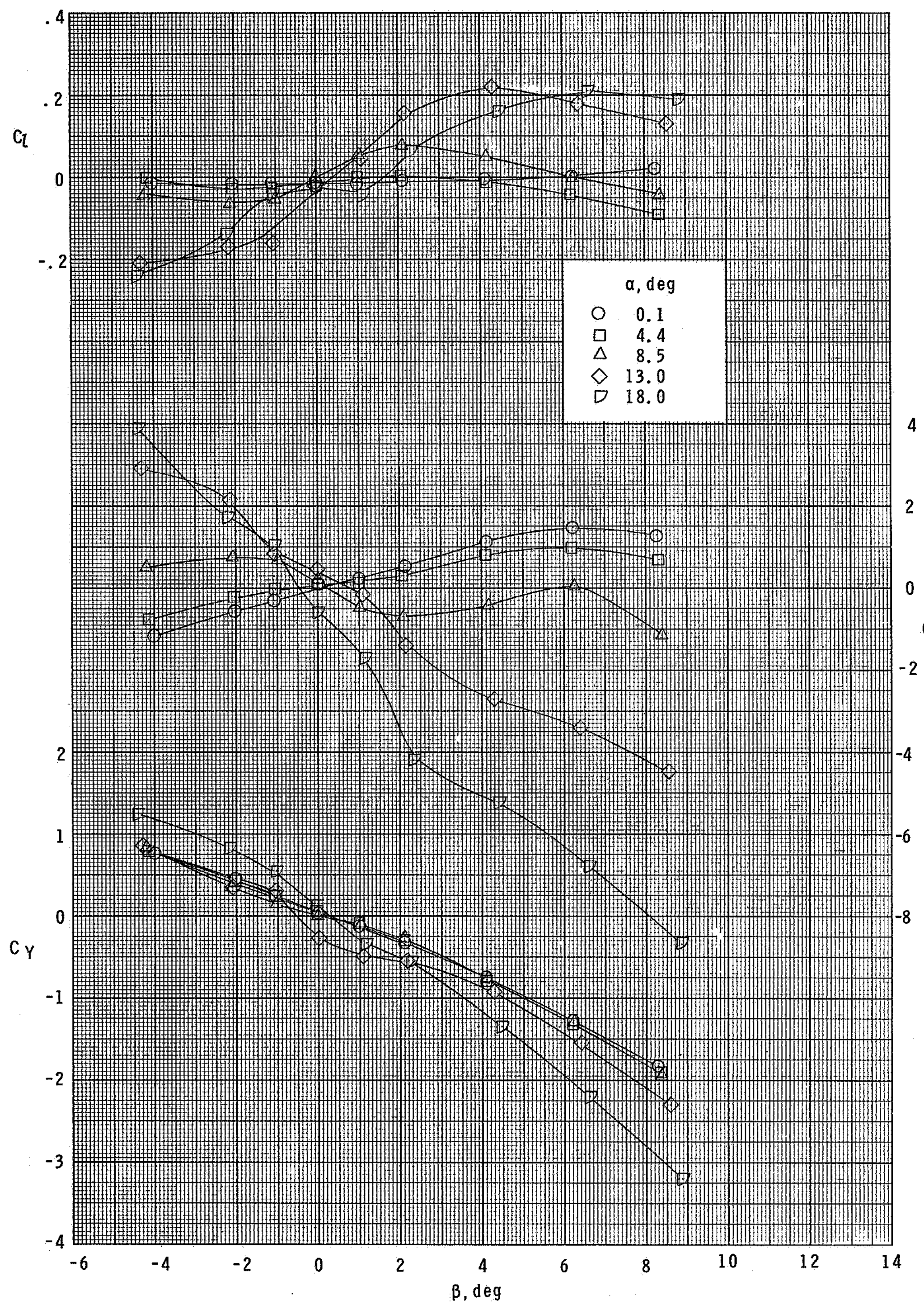
(e) Conical nose, high-aspect-ratio fins.

Figure 5.- Continued.



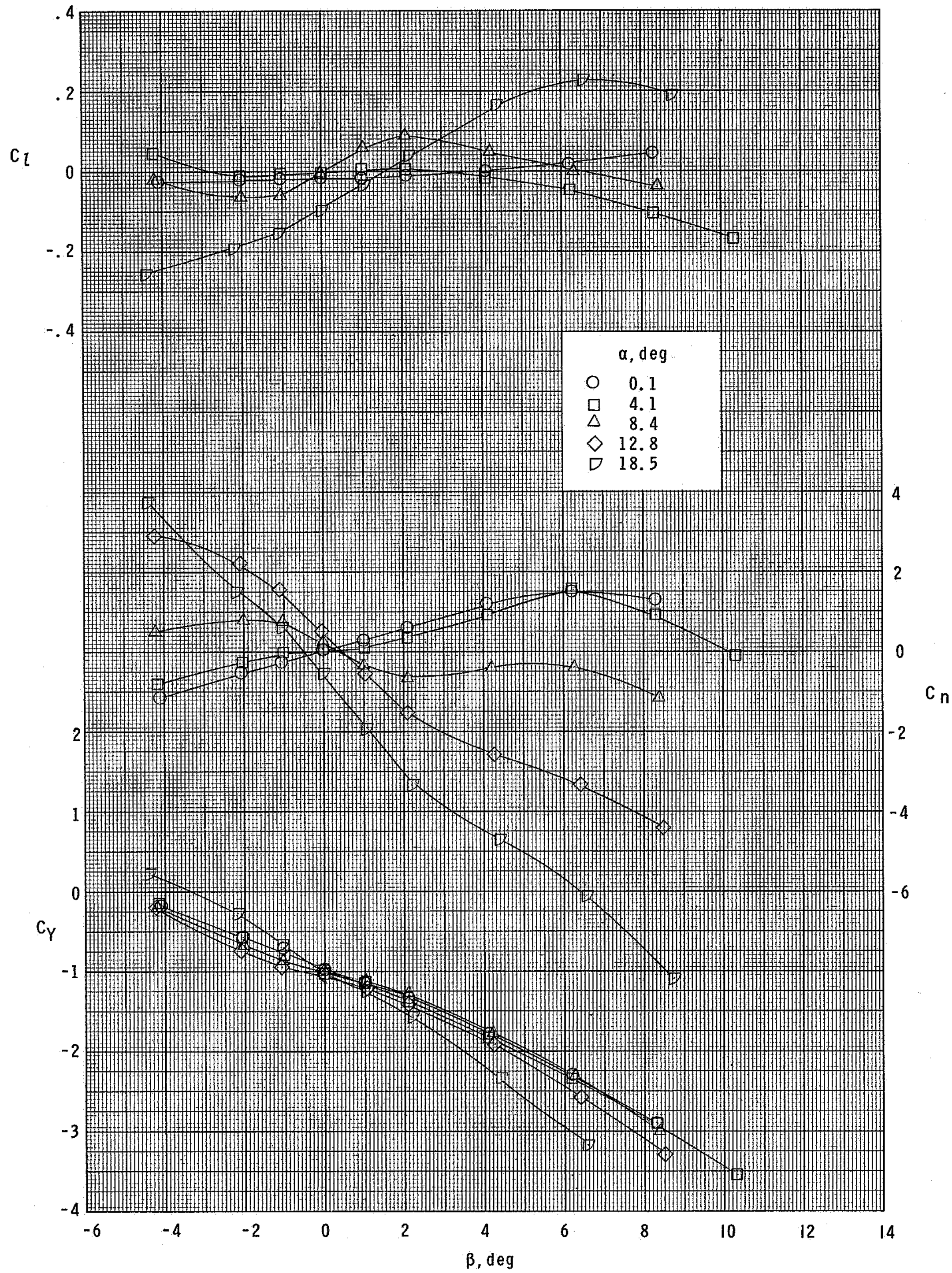
(f) Spherical nose, high-aspect-ratio fins.

Figure 5.- Concluded.



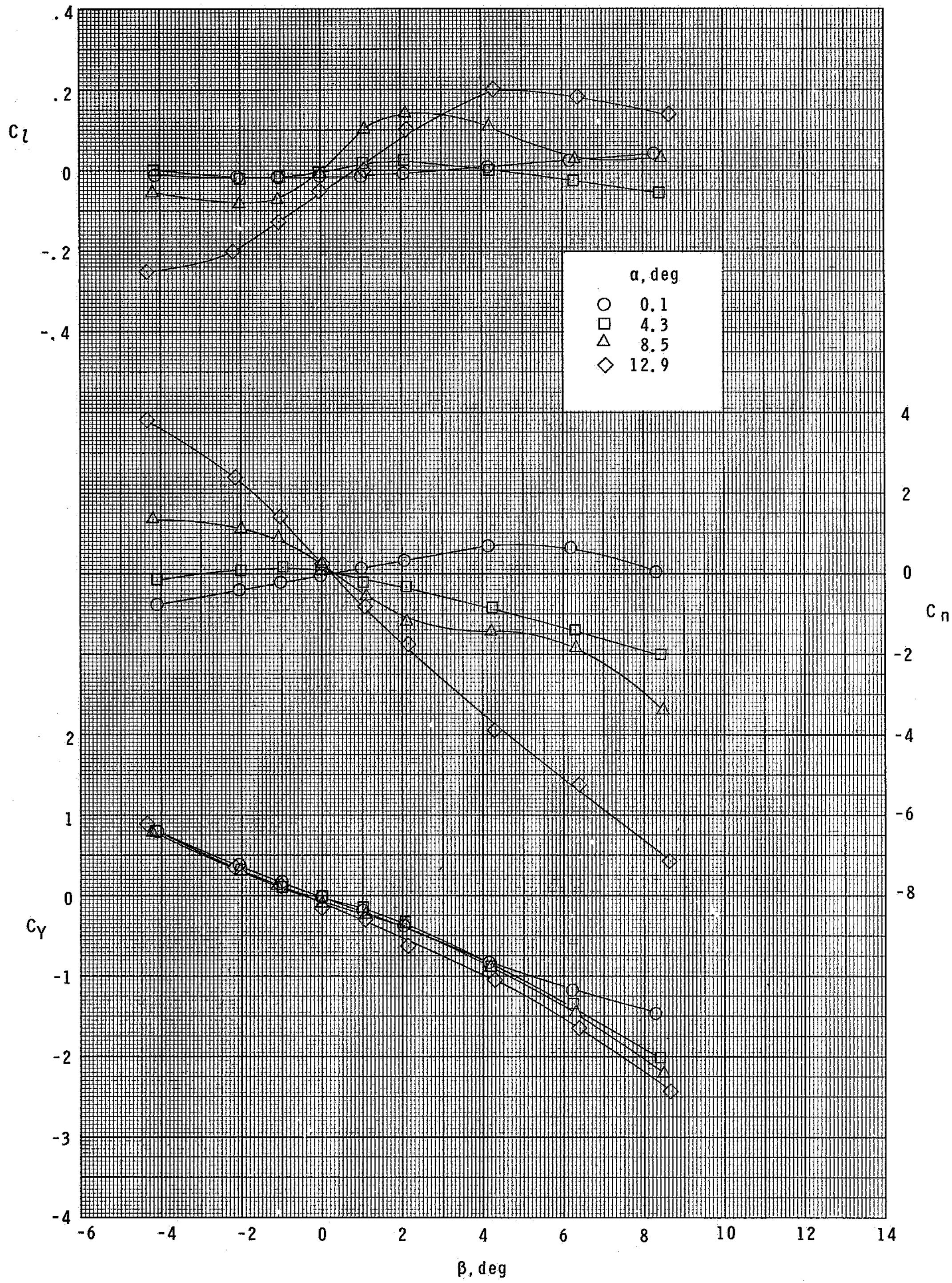
(a) Ogive nose, low-aspect-ratio fins.

Figure 6.- Aerodynamic characteristics in sideslip of configuration 2.



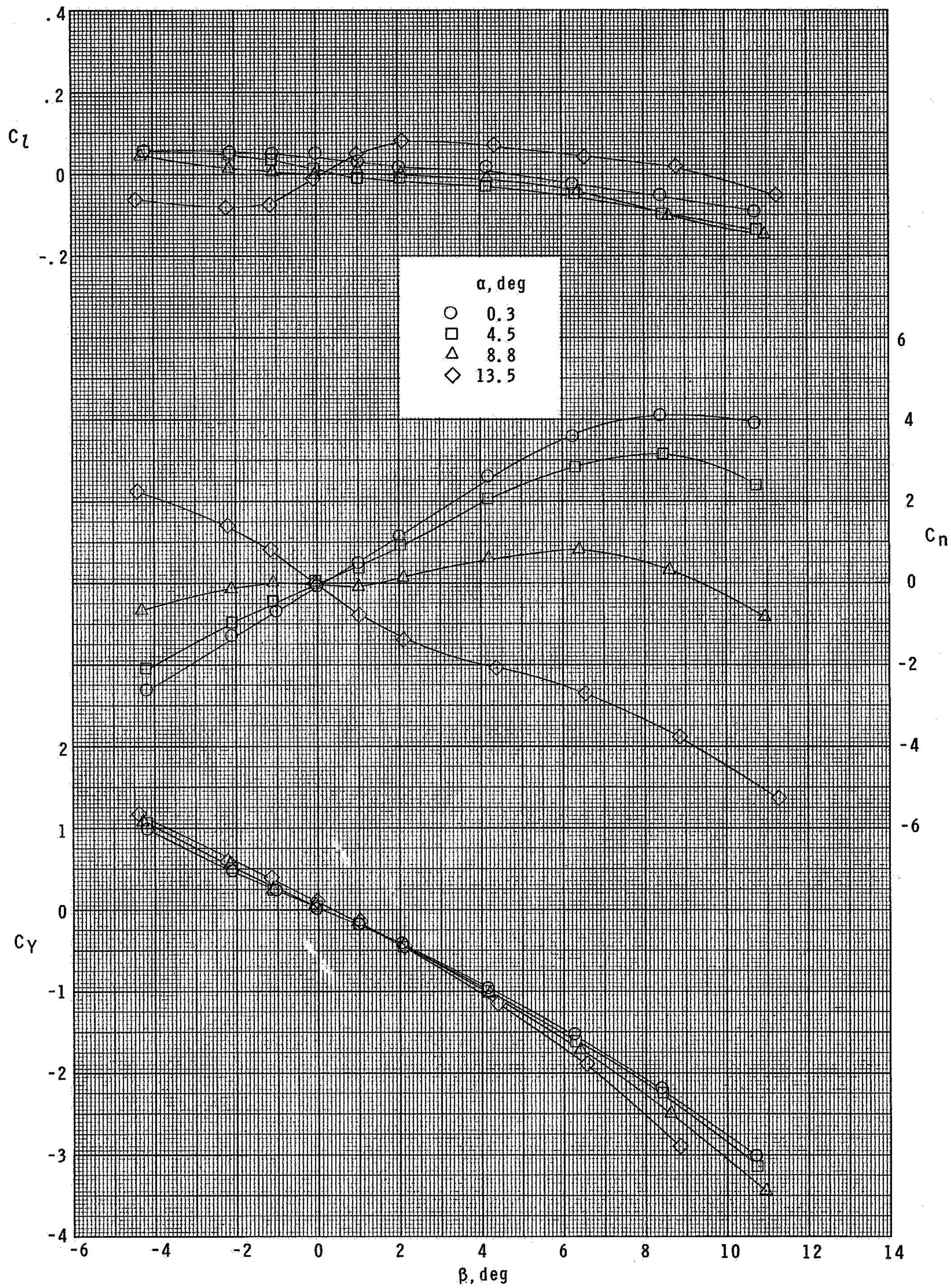
(b) Conical nose, low-aspect-ratio fins.

Figure 6.- Continued.



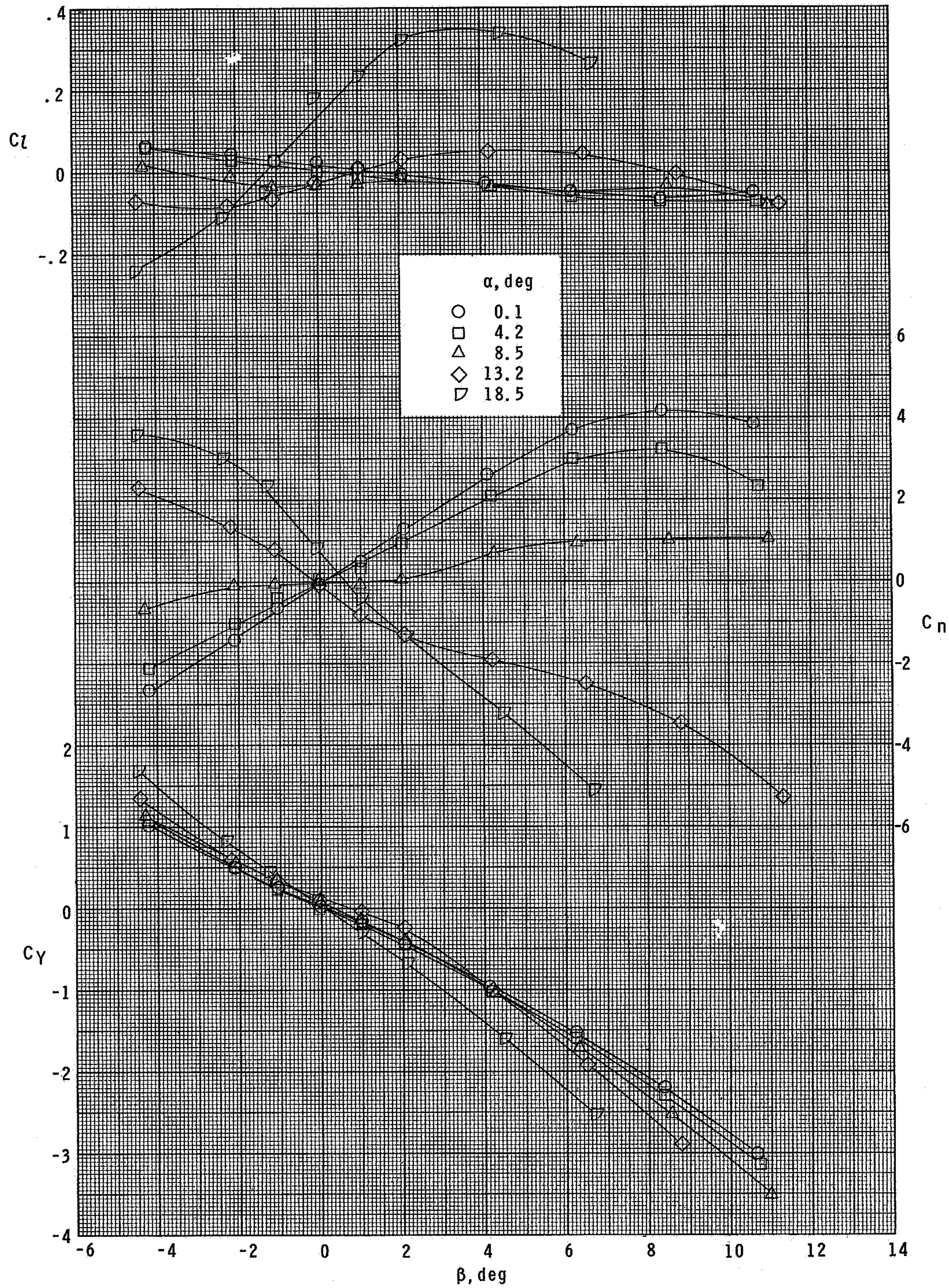
(c) Spherical nose, low-aspect-ratio fins.

Figure 6.- Continued.



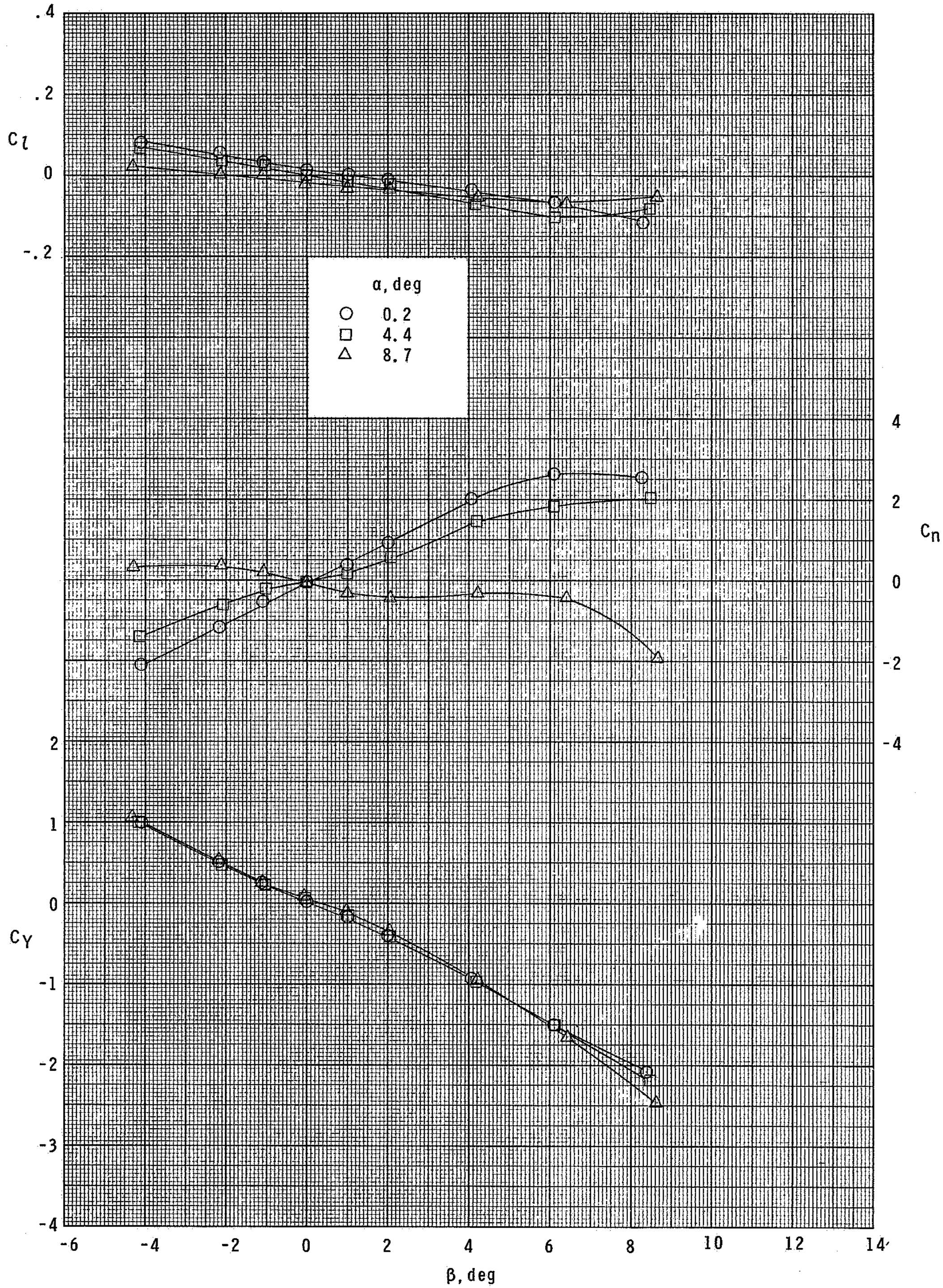
(d) Ogive nose, high-aspect-ratio fins.

Figure 6.- Continued.



(e) Conical nose, high-aspect-ratio fins.

Figure 6.- Continued.



(f) Spherical nose, high-aspect-ratio fins.

Figure 6.- Concluded.

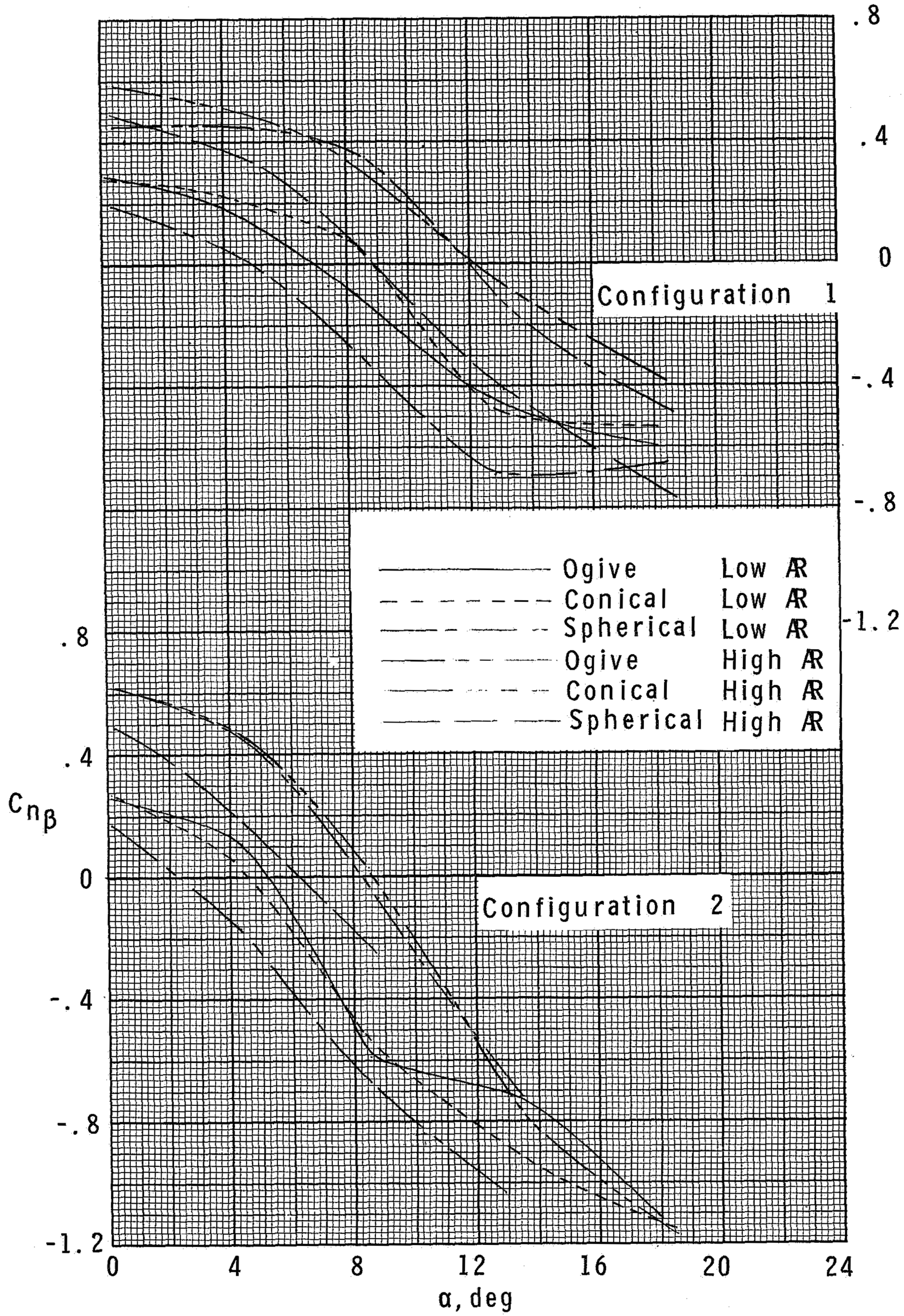


Figure 7.- Effect of nose shape and fin length on directional stability.

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