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RESEARCH MEMORANDUM

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STATIC DIRECTIONAL STABILITY OF A TANDEM-HELICOPTER FUSELAGE

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RESEARCH MEMORANDUM

STATIC DIRECTIONAL STABILITY OF A TANDEM-HELICOPTER FUSELAGE

By Charles C. Smith, Jr.

SUMMARY

An investigation has been made to determine the static directional stability of a fuselage typical of tandem helicopters. The model consisted of a body having an elliptical cross section, a rear rotor pylon which was faired to form a large vertical tail with a very thick airfoil section (approximately 35 percent mean aerodynamic chord), and a small horizontal tail mounted at about the midpoint of the height of the vertical tail.

In the original configuration the model was directionally unstable at angles of yaw less than about 10°. The results of tests on several different modifications to the vertical tail indicate that twin end-plate vertical tails mounted on the tips of the horizontal tail afforded a practical means of making the model directionally stable at small angles of yaw without appreciably increasing the weathercocking tendency at high angles of yaw.

INTRODUCTION

The results of flight tests of a tandem helicopter representative of present trends in tandem-helicopter design indicated that it was directionally unstable at small angles of sideslip. The data of reference 1 indicate that the directional instability was caused by static instability of the fuselage-pylon combination at small angles of sideslip. In order to study the directional stability of this helicopter and find means for improvement, force tests have been made in the Langley free-flight tunnel of a model of the fuselage-pylon combination. These tests included force tests of the model with the original tail, with alterations to the airfoil section of the tail, with various trailing-edge extensions added, and with twin end-plate vertical tails added to the horizontal tail of the original model.

SYMBOLS

All forces and moments were referred to the stability axes which are defined in figure 1. Since in forward flight the critical center-of-gravity location is the most rearward center-of-gravity position, all of the data in this paper have been referred to the most rearward center-of-gravity position except where otherwise noted. The symbols and coefficients used in the present paper are:

S	projected area of hypothetical rotors, square feet
R	radius of hypothetical rotor, feet
α	angle of attack of the fuselage reference line, degrees
V	free-stream velocity, feet per second
ρ	mass density of air, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ψ	angle of yaw, degrees
β	angle of sideslip, degrees $(\beta = -\psi)$
Y	lateral force, pounds
N	yawing moment, foot-pounds
C_n	yawing-moment coefficient (N/qSR)
C_Y	lateral-force coefficient (Y/qS)
C_{n_β}	rate of change of yawing-moment coefficient with angle of sideslip in degrees $\left(\partial C_n/\partial\beta\right)$

APPARATUS AND TESTS

The model consisted of a body having an elliptical cross section, a rear rotor pylon which was faired to form a large vertical tail with a very thick airfoil section (approximately 35 percent mean aerodynamic chord), and a small horizontal tail mounted at about the midpoint of the height of the vertical tail. A sketch of the model used in the investigation is presented in figure 2, and a three-quarter-view photograph of the model is presented in figure 3. A sketch of the vertical tail of the model is shown in figure 4 to illustrate the various modifications to the airfoil and tail area covered in the tests.

Force tests to determine the static directional stability characteristics of the model were made on the six-component balance in the Langley free-flight tunnel. (See reference 2.) Tests were made of the original configuration and of several modified configurations. Some of these modifications were considered as practical means of increasing the directional stability of the model and some were included only to facilitate the study of the directional stability of the model.

Most of the force tests consisted of measurements of the yawing moment and lateral force at angles of yaw between 15° and -15° at 0° angle of attack which is approximately equal to -6° angle of attack of a plane perpendicular to the rotor shafts. In the original configuration the model was also force tested through an angle-of-attack range of 20° to -20° at angles of yaw of 5° and -5° to determine the variation of the directional-stability parameter C_{n_β} with angle of attack. Two of the configurations (the original and the twin-vertical-tail configurations) were also tested through a range of angles of yaw from -10° to 190° to determine the weathercocking tendency at large angles of yaw.

All force tests were made at a dynamic pressure of 3.0 pounds per square foot which corresponds to an airspeed of approximately 34 miles per hour and a Reynolds number of 1,690,000 based on fuselage length. The results of all the force tests have been corrected to the stability axes and are based on the radius and projected area of a hypothetical tandem-rotor arrangement ($S = 28.30$ sq ft and $R = 2.27$ ft). Most of the force-test results were referred to a center-of-gravity position which corresponds to the most rearward center of gravity for a similar full-scale helicopter (52 percent of the distance from the center of the front to the center of the rear rotor hubs). Some of the force-test results were also referred to the center-of-gravity positions corresponding to the normal and most forward center-of-gravity position for a similar full-scale helicopter (50 and 45 percent of the distance from the center of the front to the center of the rear rotor hubs).

RESULTS AND DISCUSSION

Stability of the Original Model

The results presented in figure 5 show that in the original configuration the model was directionally unstable at angles of yaw between about 10° and -10° at 0° angle of attack and was unstable through a somewhat smaller range of yaw at -10° angle of attack. A comparison of these force-test results with the results of tests of a similar model at the David W. Taylor Model Basin (reference 1) is shown in figure 6. This comparison shows that the measured characteristics of the models were similar except for the lateral-force coefficients of the original model.

The variation of the directional-stability parameter C_{n_β} with angle of attack from 20° to -20° is shown in figure 7. These data show that the model was unstable throughout the angle-of-attack range.

In order to illustrate the magnitude of the effect of center-of-gravity position on the directional stability of the model, the data from figure 5 for 0° angle of attack referred to three center-of-gravity positions are presented in figure 8. These three center-of-gravity positions correspond to the most forward, normal, and most rearward center-of-gravity positions for a similar full-scale helicopter. The data show that a forward movement of the center of gravity caused a reduction in the directional instability of the model at small angles of yaw and apparently reduced the angle of yaw at which the model would trim but did not make the model stable. A rearward movement of the center of gravity had the reverse effect on the directional stability of the model.

Causes of Low Directional Stability

The thick airfoil section of the vertical tail was thought to be one of the causes of low directional stability because the data of reference 3 for an NACA 0035 airfoil section indicate that such thick airfoil sections have low lift-curve slopes particularly at small angles of attack. In order to investigate this possible cause of the directional instability of the model, tests were made with a thinner vertical tail (tail A) and also with double-split flaps (area 9) added to the original tail. The effects of tail A and of area 9 on the directional stability of the model are shown by the data presented in figure 9. These data show that the directional instability of the model was reduced approximately 40 percent by the use of tail A. The addition of double-split flaps (area 9) to the original tail of the model caused a reduction in the instability of the model of approximately 80 percent. This effect of the split flaps in increasing the slope of the lift curve of an airfoil has been indicated previously by the data of reference 3 which show that small deflections of a split flap on an NACA 0035 airfoil caused a large increase in the lift-curve slope at low angles of attack. Since the results of the tests with tail A and the double-split flaps indicate that the directional instability of the model did not result entirely from the low lift-curve slope of the vertical tail, it is apparent that the tail volume (tail length × tail area) was insufficient to produce stability.

The thin airfoil section and double-split flaps were not considered as practical modifications for improving the stability of the helicopter because a thinner airfoil section would probably make the vertical tail unsatisfactory for a rear rotor pylon and because the double-split flaps would cause a large increase in drag.

Tests of Some Practical Modifications for

Increasing Directional Stability

The results of tests made to determine the stability of the model with some modifications intended as practical means of increasing the directional stability are shown in figures 10 to 14. The data presented in figure 10 show the effect of a modification to the airfoil section and several different tail extensions on the static directional stability of the model.

Since a thinner airfoil was found to reduce the directional instability of the model but was considered impractical, the original airfoil was modified by adding area 1 which effectively reduced the thickness ratio of the airfoil. Instead of reducing the directional instability, however, this modification actually increased the directional instability. This result may be attributed partly to the fact that the reduction in aspect ratio and geometric moment arm of the tail tended to offset the gain resulting from the reduction in section thickness ratio and the increase in tail area. Another possible cause of the increase in directional instability was interference effects which resulted in a reduction in effective tail moment arm.

With areas 2 and 3 added to the original vertical tail the instability of the model at small angles of yaw was reduced. Adding areas 4, 5, and 6 to the original vertical tail caused the model to be about neutrally stable at small angles of yaw and definitely stable at larger angles of yaw. Adding area 7 to this configuration caused the model to be stable throughout the angle-of-yaw range.

The effect of fairing the trailing-edge extensions into the airfoil of the vertical tail as indicated in figure 4 is shown by the data presented in figure 11. These data indicate that fairing the trailing-edge extension has only a small effect on the directional stability of the model with area 2 added. This result indicates that fairing the other trailing-edge extensions would probably not have much effect on directional stability.

The effect of two ventral fins on the stability of the model is shown in figure 12. The large ventral fin (areas 5 and 6) appeared to contribute more directional stability in proportion to its area than any other of the trailing-edge extensions. Because a ventral fin the size of areas 5 and 6 would decrease the ground clearance which might be needed in autorotative landings, a smaller ventral fin (area 5) was tested. This ventral fin was found to have a negligible effect on the stability of the original model.

The effect of the twin end-plate vertical tails is shown in figure 13. These data show that the model was about neutrally stable at small angles of yaw and was definitely stable at larger angles of yaw with these tails. Twin end-plate vertical tails of larger areas or higher aspect ratios than those tested would, of course, make the model stable throughout the angle-of-yaw range. Figure 14 shows the effect of twin end-plate vertical tails on the directional stability of the model at angles of yaw between -10° and 190°. These data show that twin end-plate vertical tails had little effect on the weathercocking tendency at high angles of yaw. This effect is probably caused by the blanketing effect of the vertical tails on each other. Since an increase in the weathercocking tendency at high angles of yaw is undesirable because it will increase the difficulty of flying sideways or hovering in a cross wind, the twin end-plate vertical tails seem to be a very practical method of increasing the directional stability st small angles of yaw.

CONCLUSIONS

The following conclusions were drawn from the results of an investigation in the Langley free-flight tunnel of the static directional stability of a typical tandem-helicopter fuselage.

1. In the original configuration the model was directionally unstable at angles of yaw less than about 10°.

2. Twin end-plate vertical tails mounted on the tips of the horizontal tail were found to be one practical means of making the model

directionally stable at small angles of yaw without appreciably increasing the weathercocking tendency at high angles of yaw.

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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 3D17, 1943.

3. Bullivant, W. Kenneth: Tests of the NACA 0025 and 0035 Airfoils in the Full-Scale Wind Tunnel. NACA Rep. 708, 1941.

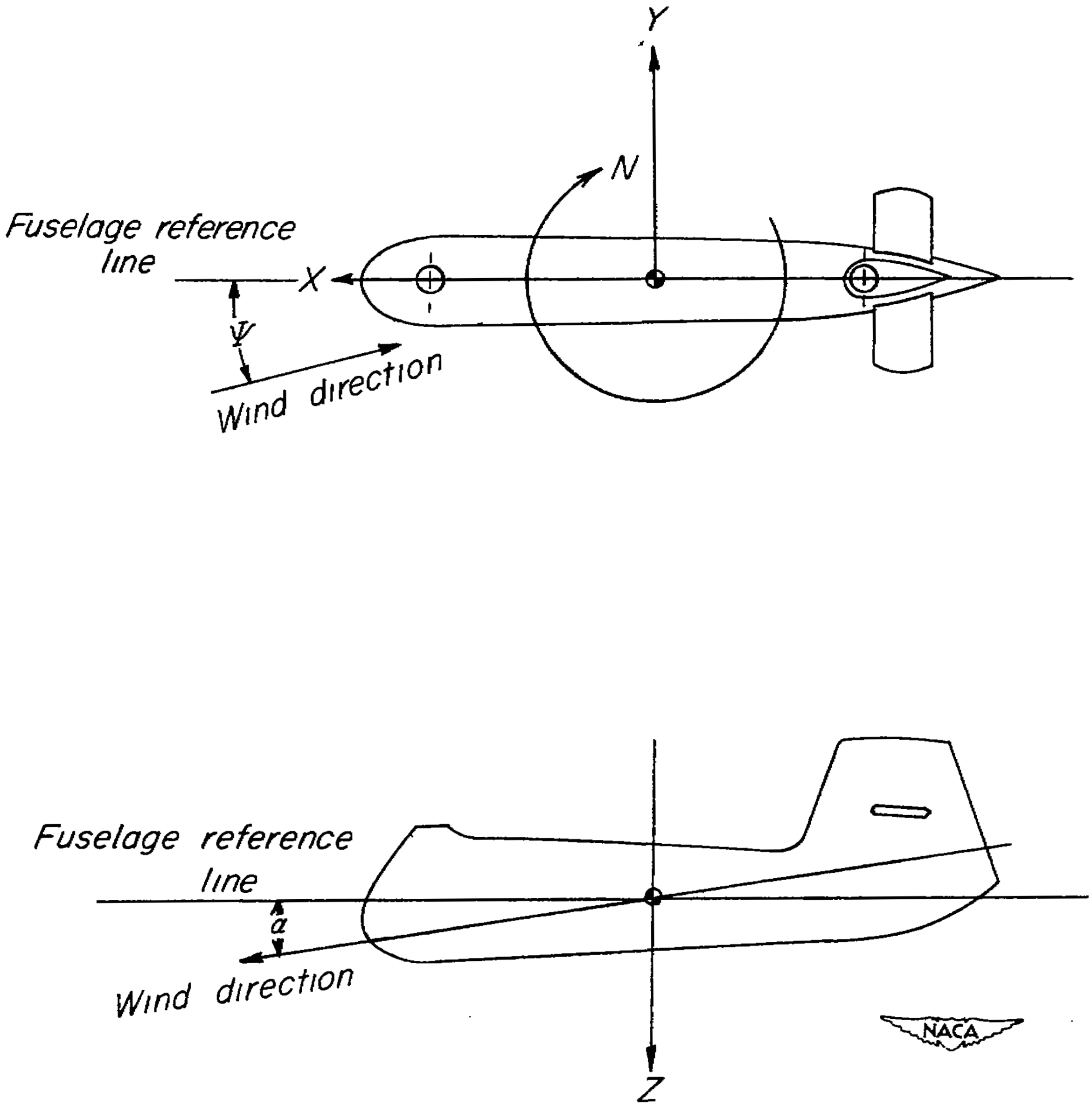


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

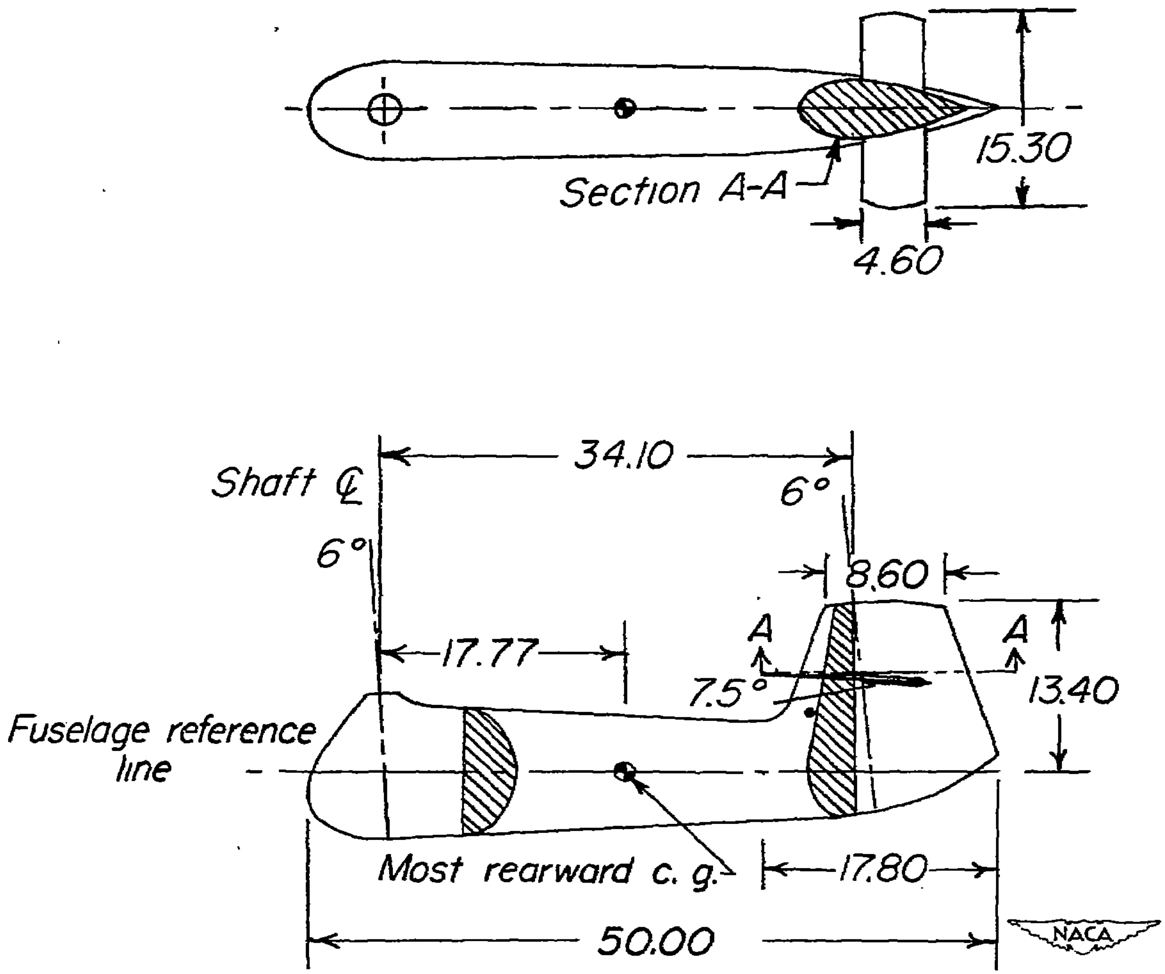


Figure 2.- Top and side view of the model used in the Langley free-flight-tunnel investigation with a section through the vertical tail showing the thick airfoil used. All dimensions in inches.

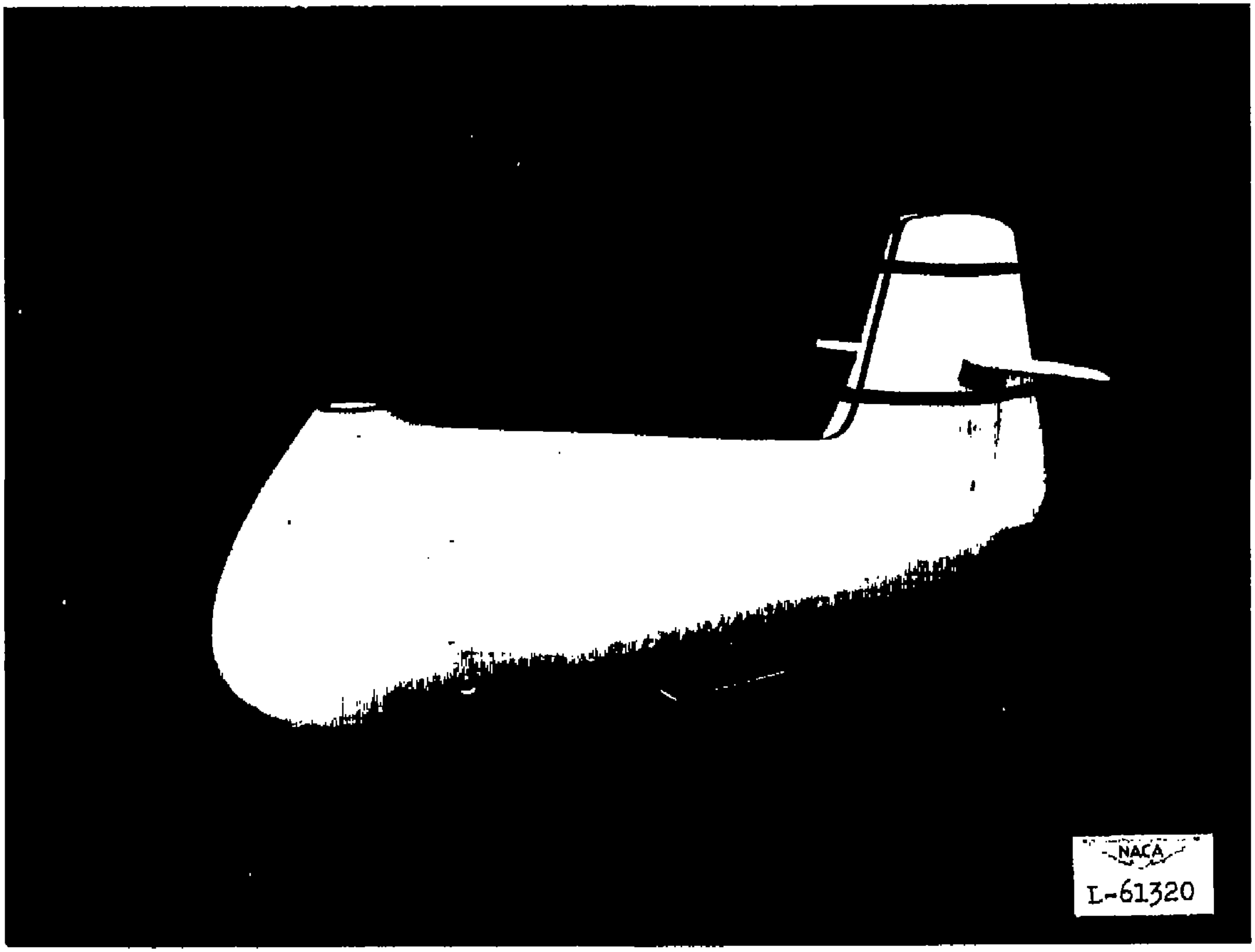


Figure 3.- Three-quarter view of the helicopter model used in the directional-stability investigation.

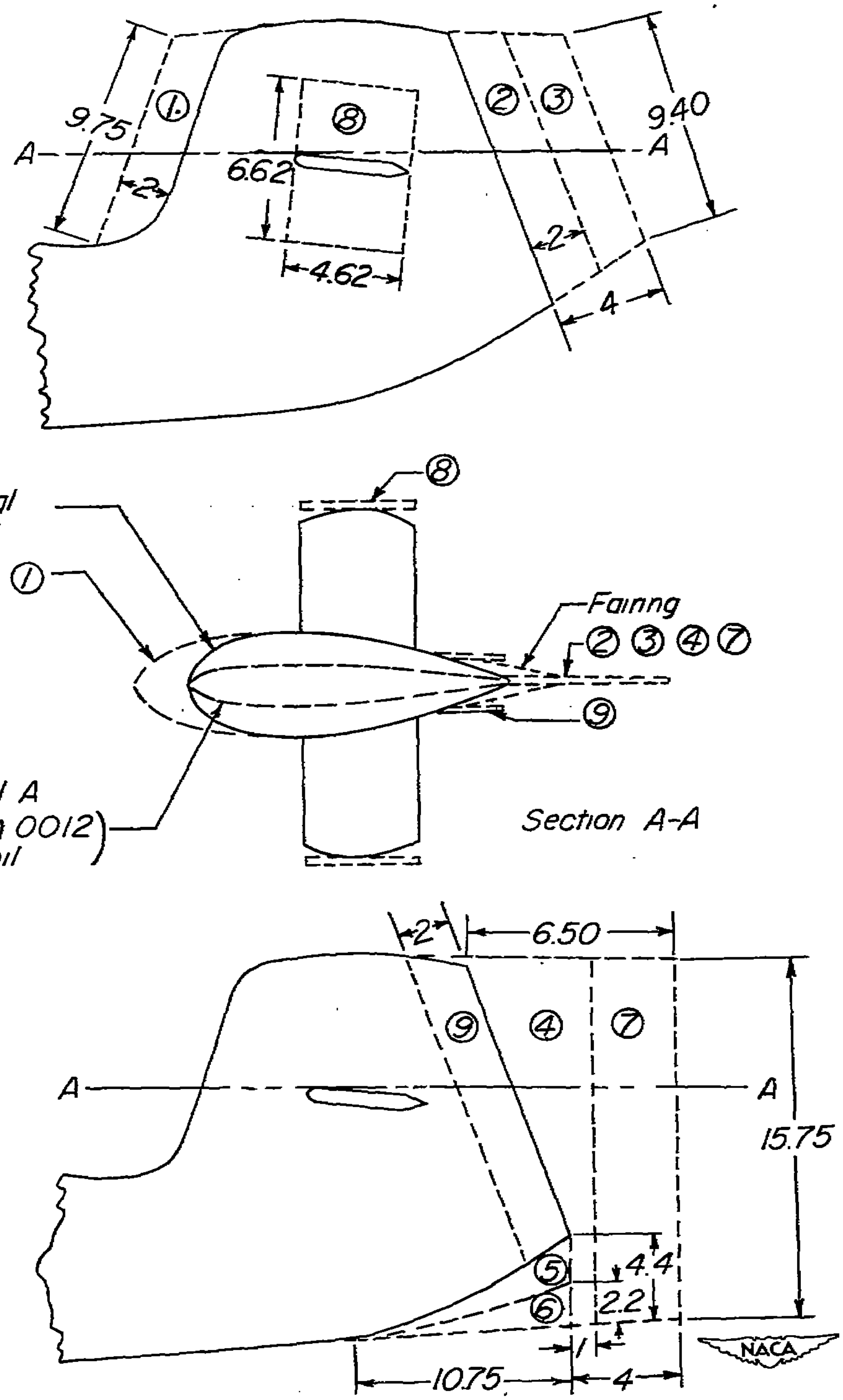


Figure 4.- Vertical tail of the model with modifications used in the Langley free-flight-tunnel investigation. All dimensions in inches.

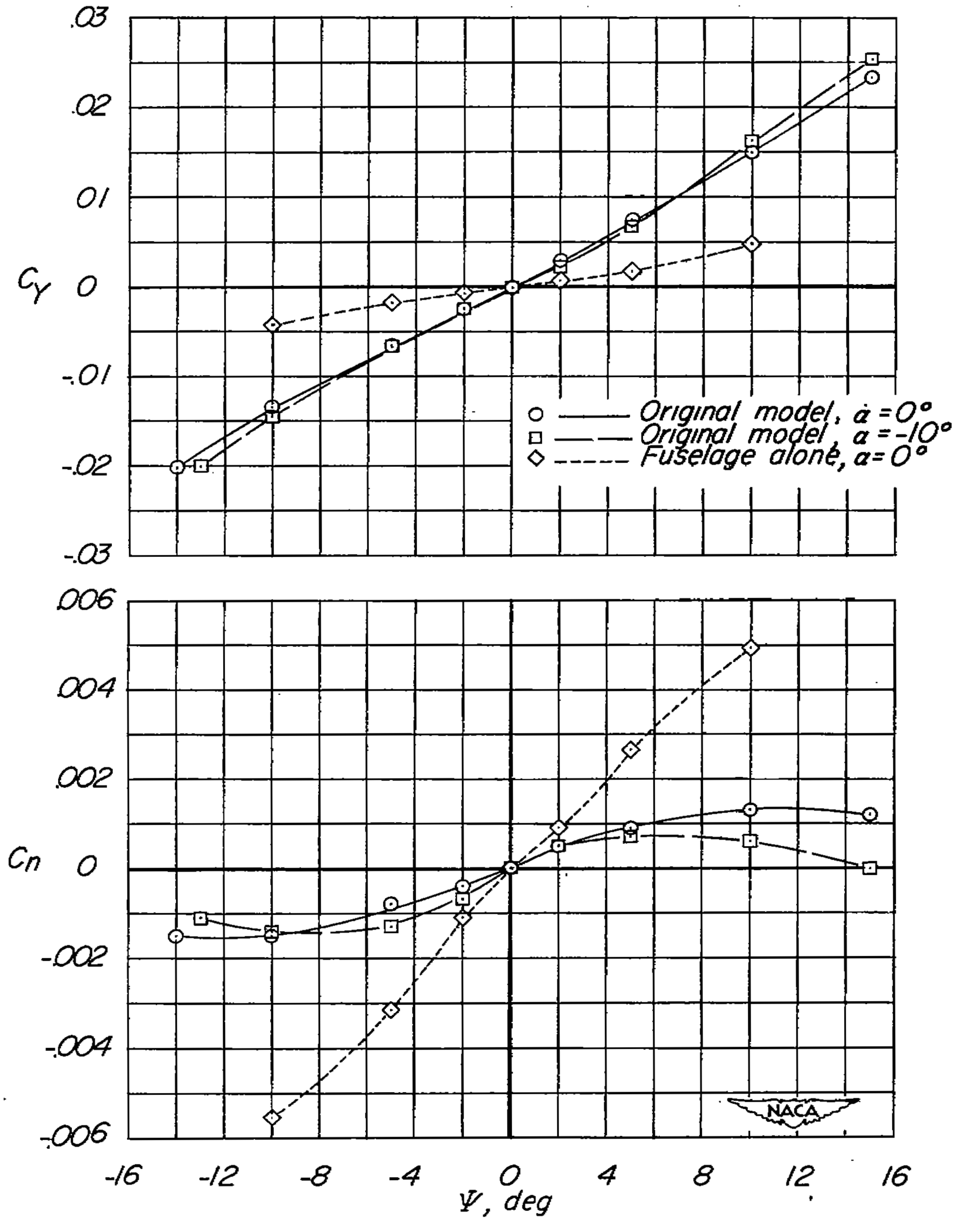
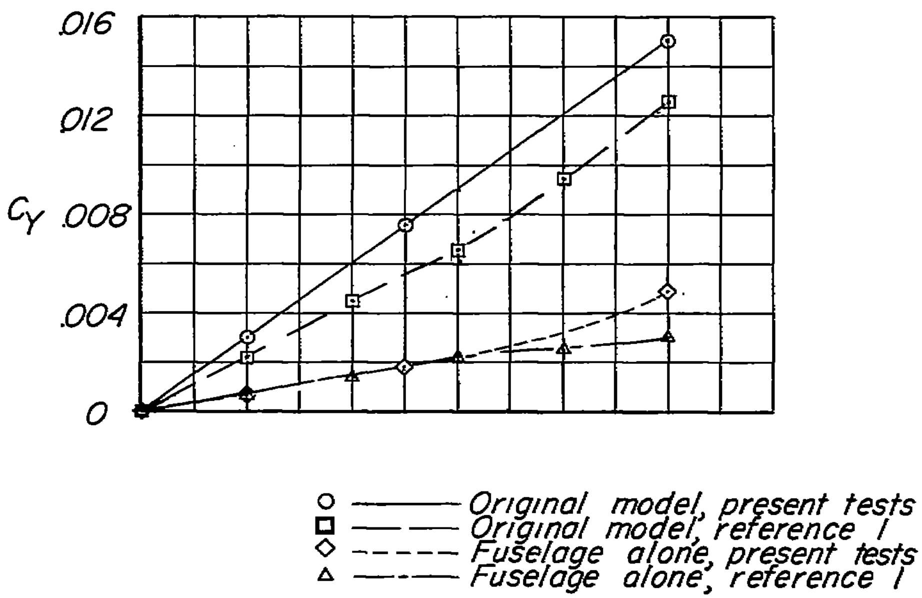


Figure 5.- Directional stability of the original model and fuselage alone for 0° and -10° angle of attack.



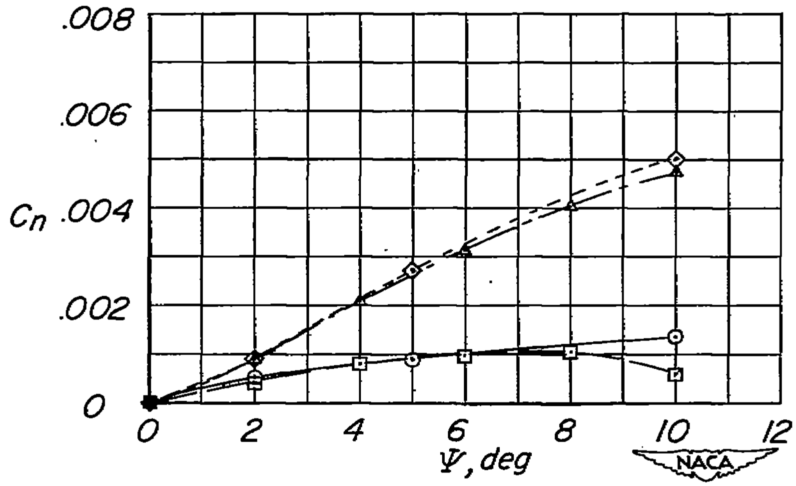


Figure 6.- Comparison of the lateral-force and yawing-moment coefficients of the original model and fuselage alone with the data of reference 1. $\alpha = 0^{\circ}$.

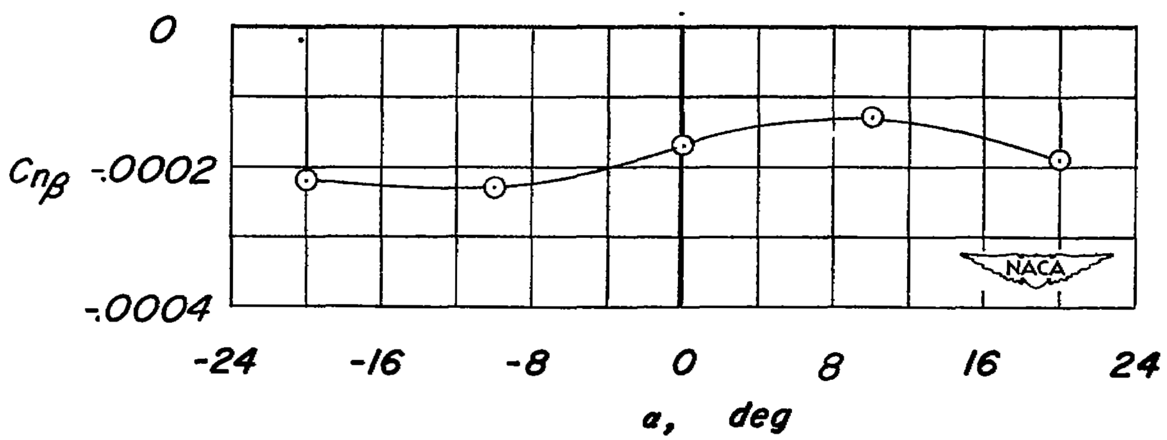


Figure 7.- Effect of angle of attack on the directional stability of the original model. Data obtained from tests made at 5° and -5° angles of yaw.

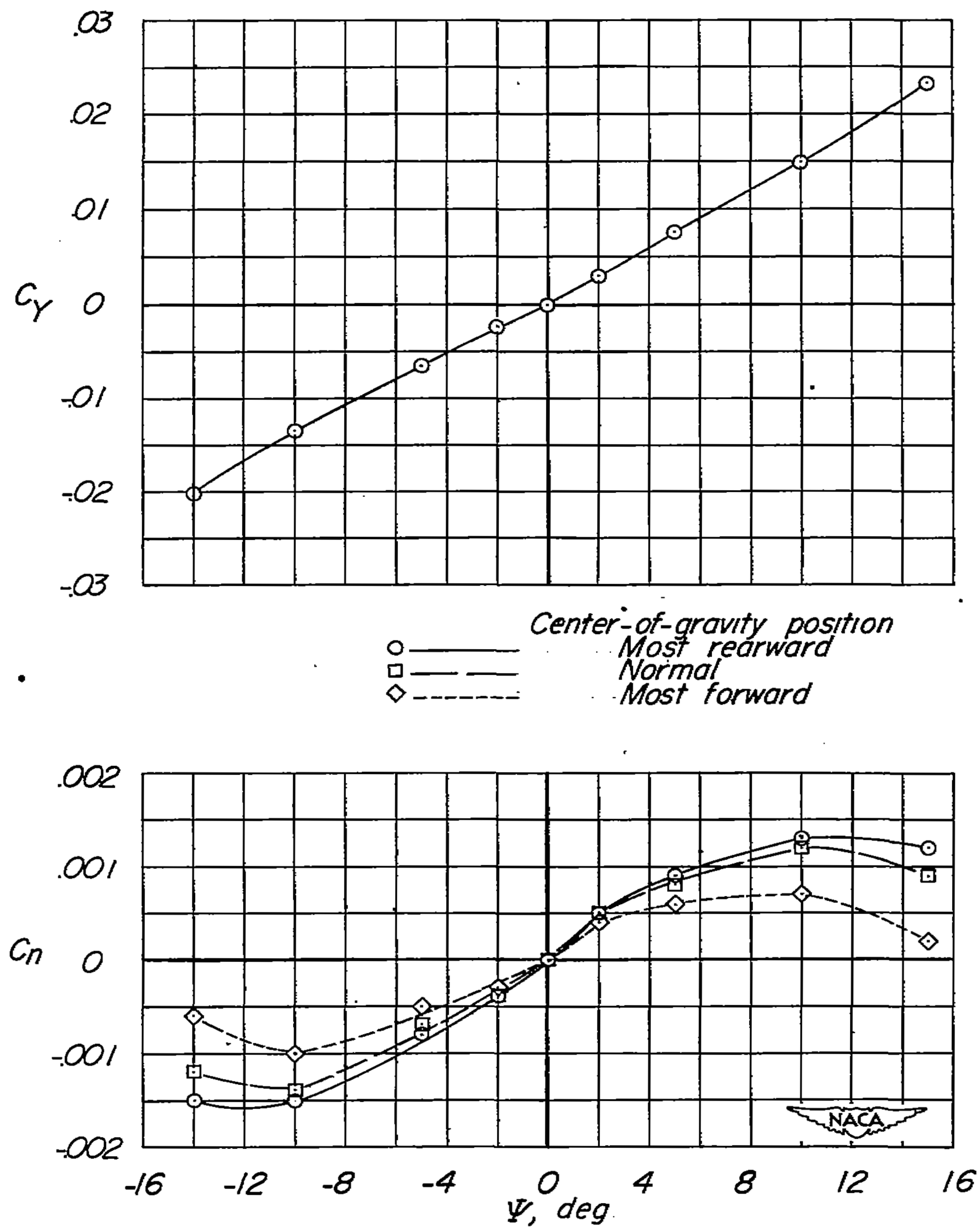


Figure 8.- Effect of center-of-gravity location on the directional stability of the original model. $\alpha = 0^{\circ}$.

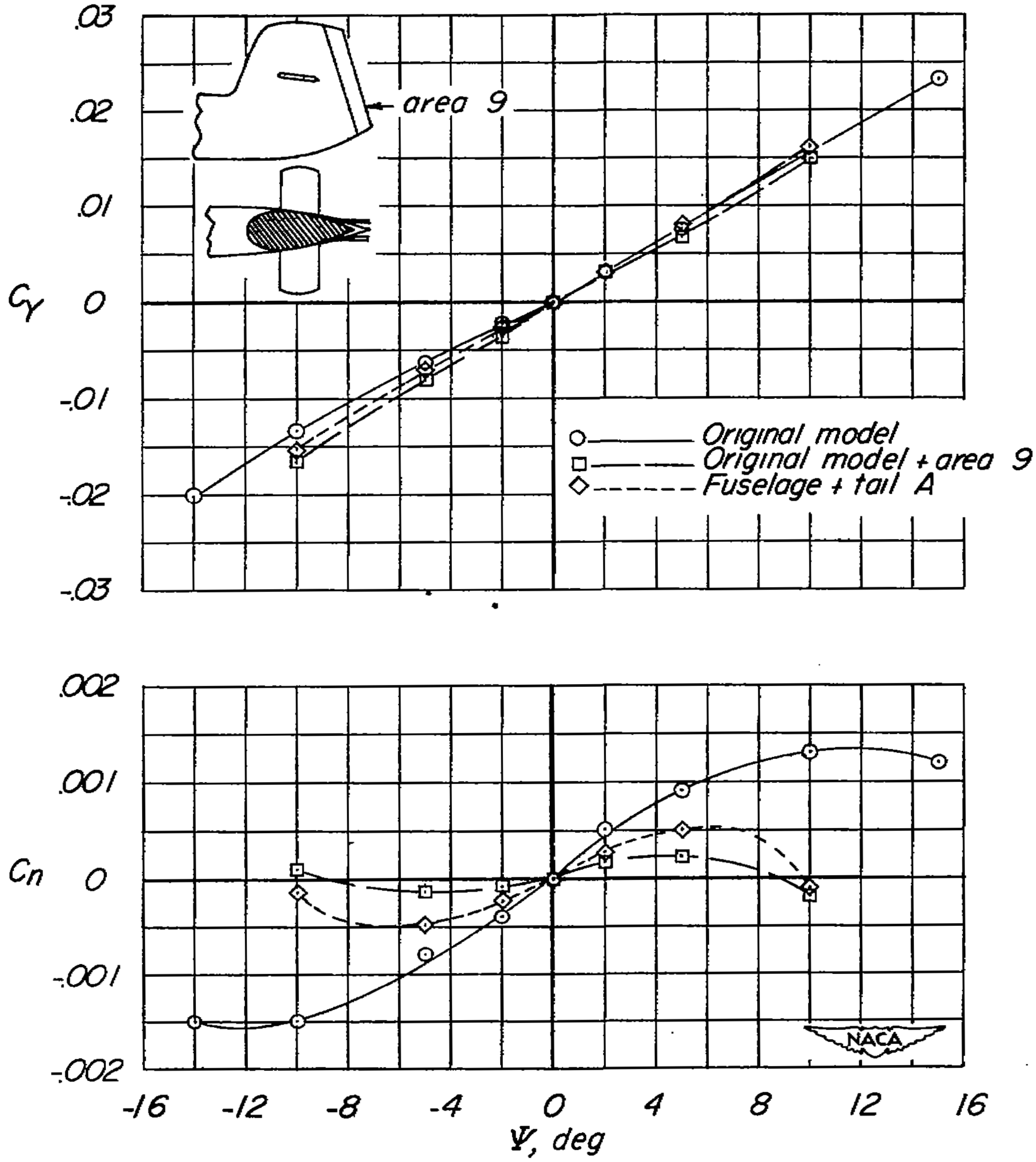


Figure 9.- Effect of modifications to the airfoil of the vertical tail on the directional stability of the model. $\alpha = 0^{\circ}$.

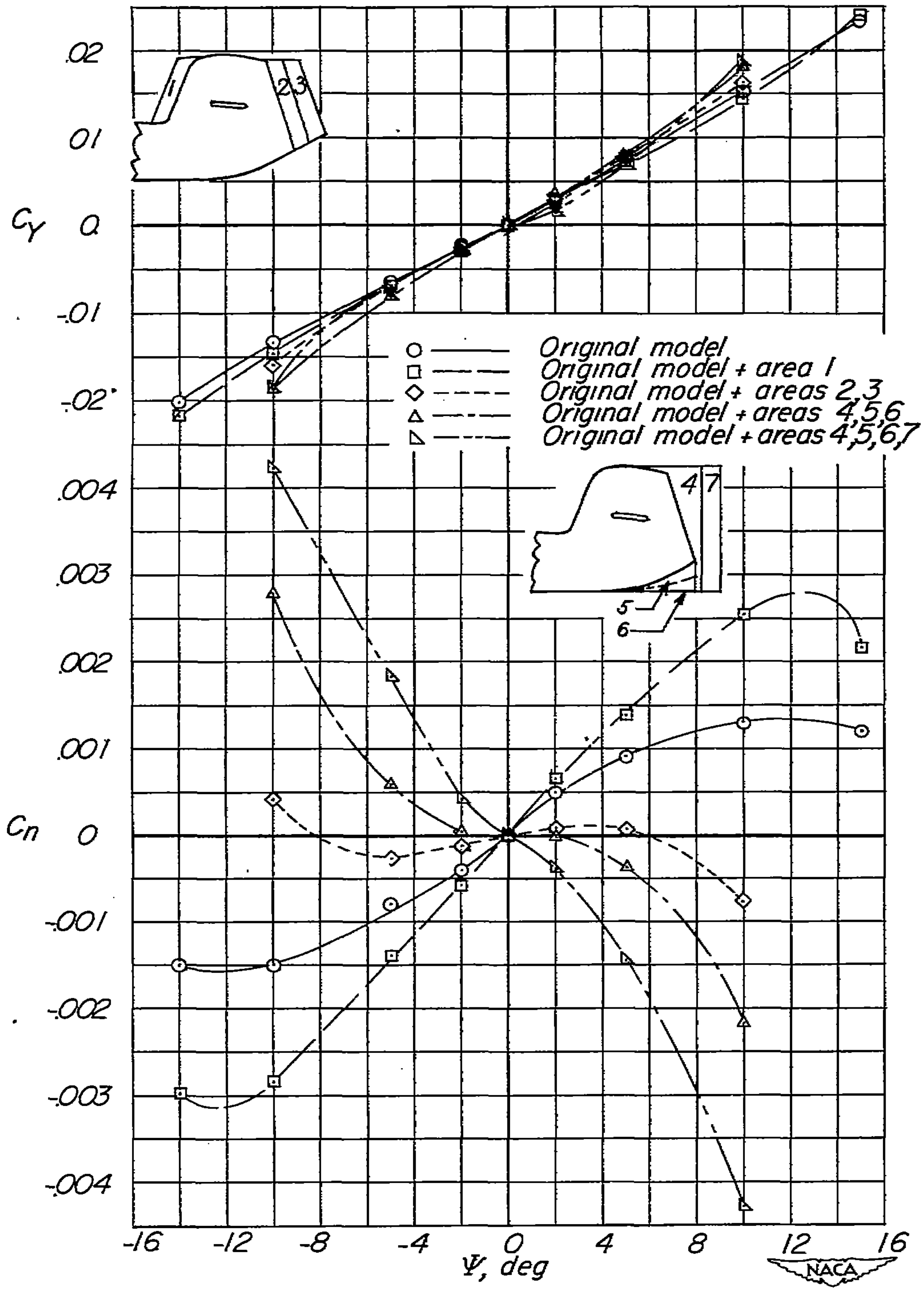


Figure 10.- Effect of a modification to the airfoil section and several different tail extensions on the directional stability of the model. $\alpha = 0^{\circ}$.

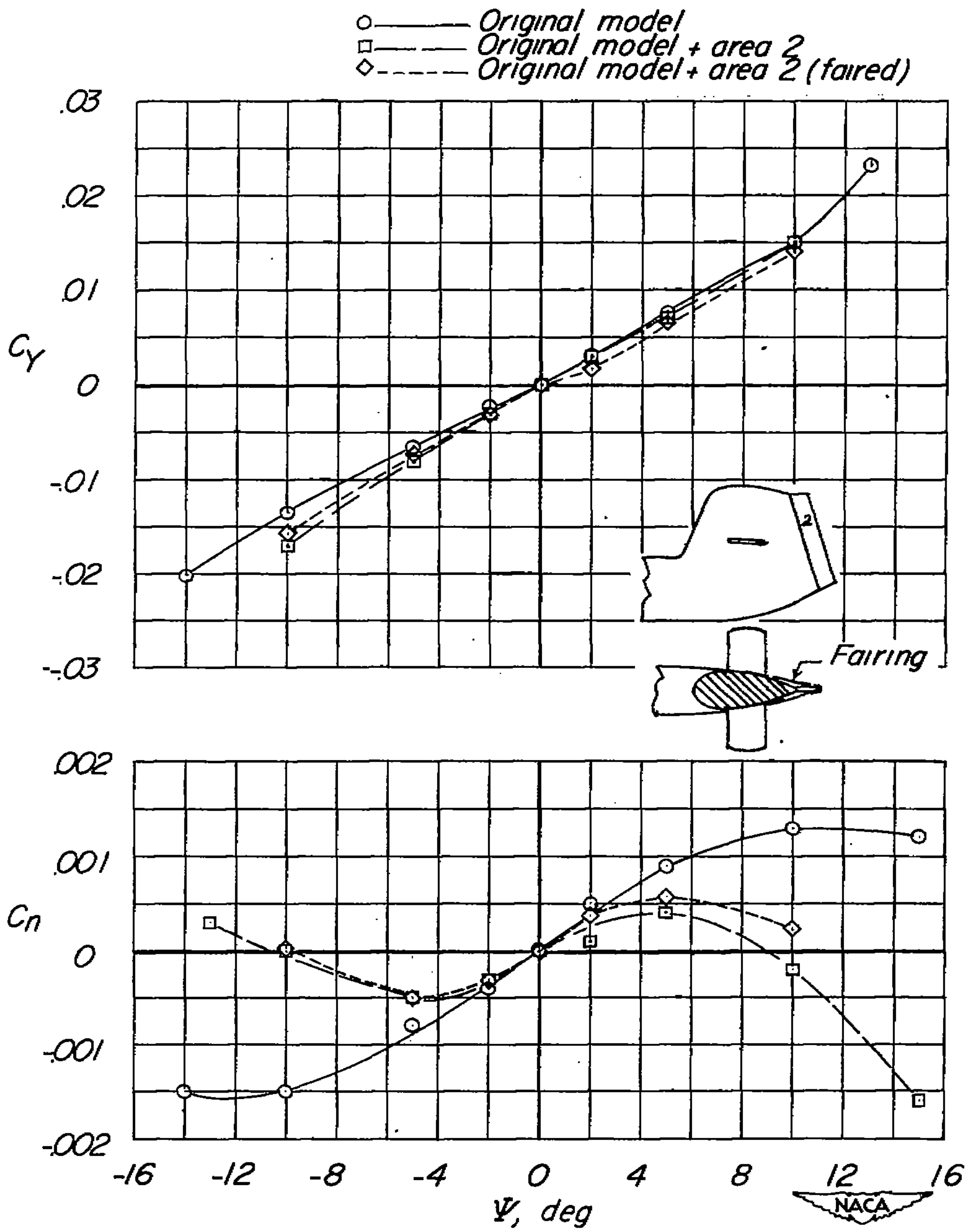


Figure 11.- Effect of fairing trailing-edge extensions on the directional stability of the model. $\alpha = 0^{\circ}$.

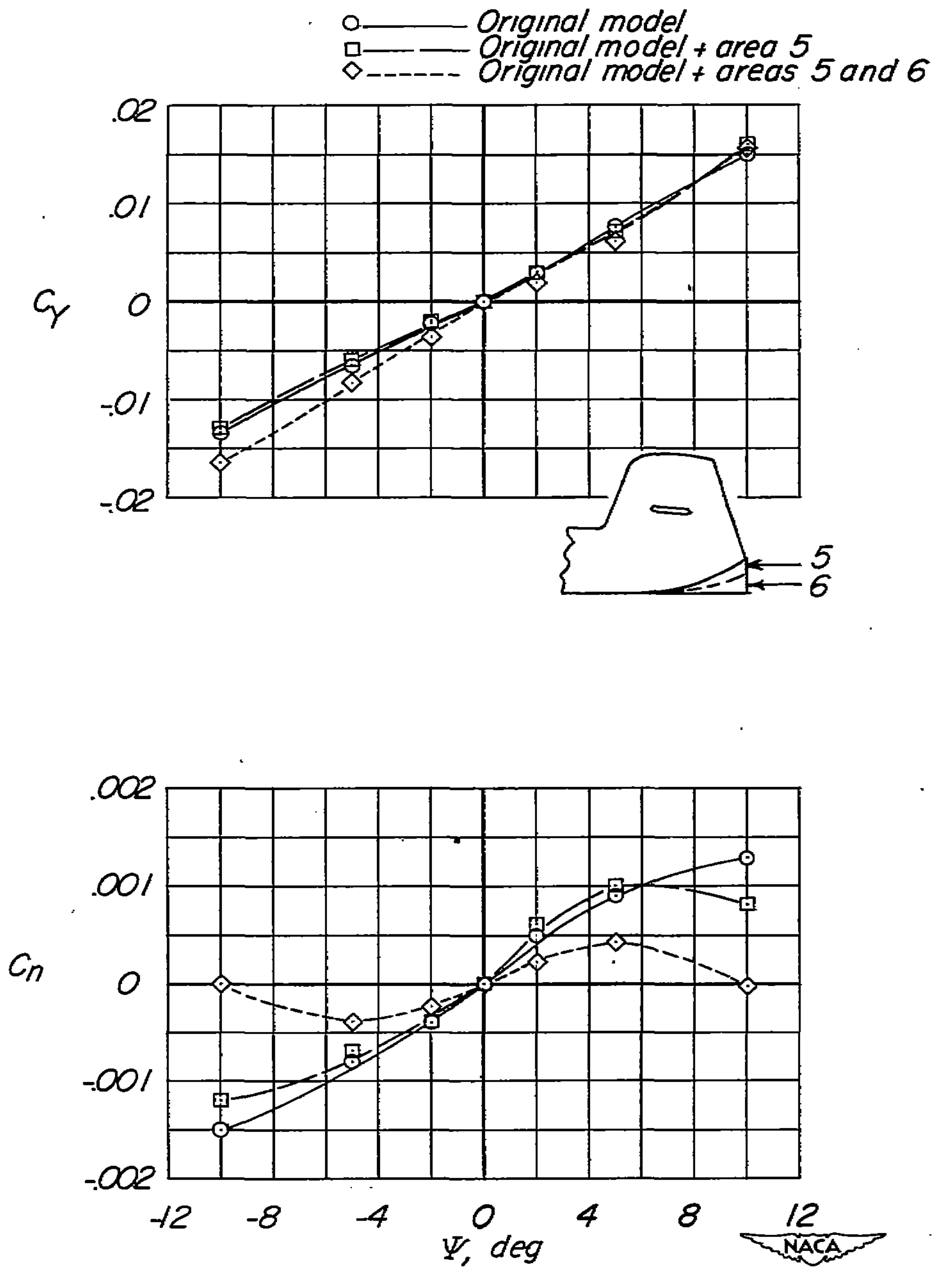


Figure 12.- Effect of ventral-fin size on the directional stability of the model. $\alpha = 0^{\circ}$.

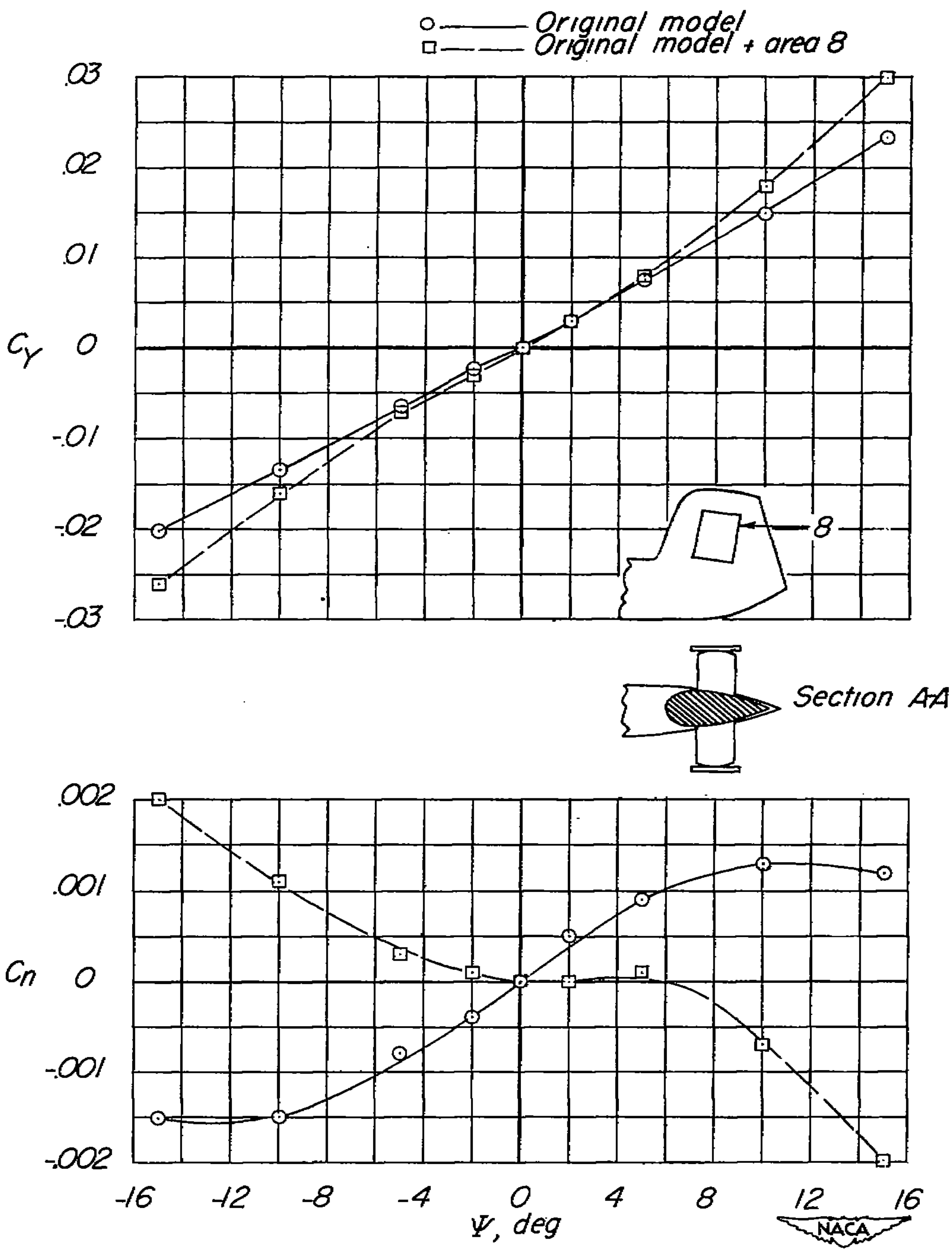


Figure 13.- Effect of twin end-plate vertical tails on the directional stability of the model. $\alpha = 0^{\circ}$.

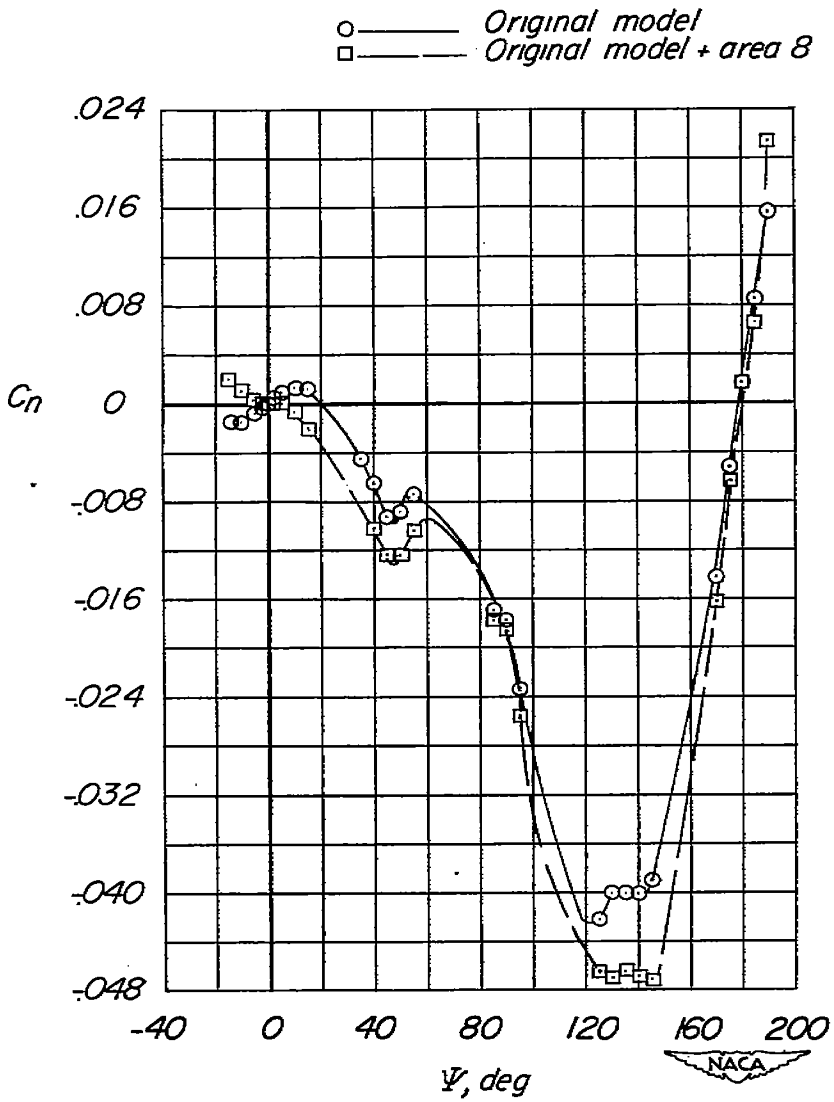


Figure 14.- Effect of twin end-plate vertical tails on the weathercocking tendency of the model at high angles of yaw. $\alpha = 0^{\circ}$.