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EFFECTS OF A MILITARY CARGO POD AND TAIL FINS ON THE AERODYNAMIC CHARACTERISTICS OF A LARGE WIDE-BODY TRANSPORT MODEL

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16 Abstract

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At a test Reynolds number of 1.08×10^6, the addition of the pod results in an increase in total drag of approximately 20 percent. Trim drag due to the pod is very small. Although the pod produces a significant decrease in directional stability, the addition of the tip fins restores some of the stability, particularly at the lower angles of attack.

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SUMMARY

Wind tunnel tests have been conducted on a 0.03-scale model of a large wide-body commercial aircraft to determine the effects on the static aerodynamic characteristics resulting from the attachment of a belly pod for the long-range deployment of outsize military equipment. Also investigated was the effectiveness of horizontal-tail tip fins in augmenting directional stability.

At a test Reynolds number of 1.08×10^6, the addition of the pod results in an increase in total drag of approximately 20 percent. Trim drag due to the pod is very small. Although the pod produces a significant decrease in directional stability, the addition of the tip fins restores some of the stability, particularly at the lower angles of attack.

INTRODUCTION

For several years military strategists of the United States have voiced concern about the need for increased airlift capability during a limited-warfare conflict, particularly with regard to Western Europe. Until the size of the military fleet is significantly increased, utilization of commercial aircraft on a temporary basis may be necessary during emergency operations. Although currently-operational military and commercial transports can carry most military equipment in the airlift inventory, the Lockheed C-5A is the only aircraft capable of the deployment of outsize cargo (defined as that too large for the Lockheed C-141). However, the present C-5A fleet numbers only about 77 aircraft; production has ceased, and is very unlikely to be resumed. Hence, the most critical shortfall in airlift capability at present is that related to the long-range deployment of outsize equipment.

Various solutions to the outsize-cargo problem have been proposed, each involving the extensive modification of commercial wide-body aircraft. These suggested alterations include increasing the fuselage upper-lobe diameter, lowering the main deck, increasing the size of the loading-door openings, swinging the tail cone for rear-end loading, and strengthening the main-deck floor. However, the overall systems cost of a fleet incorporating such modifications would likely be prohibitively high due to the high modification cost, loss of operator revenue during modification, significantly higher operating cost, likely decrease in resale value of the less efficient aircraft, and the cost of the design and construction of new loading equipment for lifting the heavy cargo to the height of the aircraft main deck.

In order to minimize aircraft modification and the adverse effect on the efficiency of commercial operations, a preliminary study was conducted to determine the feasibility of mating an outsize-cargo pod to the underside of a large wide-body aircraft. The design-mission specifications, descriptions of the configurations considered, and the study results are reported in reference 1. No distinct problems were identified which might render the concept impracticable.

Since the concept appeared to be feasible, tests were conducted in the Langley V/STOL wind tunnel using a 0.03-scale model of the carrier aircraft with the retractable-gear pod of reference 1. In order to augment directional stability, horizontal-tail tip fins similar to those used on the NASA aircraft employed in transporting the Space Shuttle were also tested. The purpose of this paper is to present the results of the investigation.

SYMBOLS

The longitudinal and lateral-directional characteristics are referenced to the stability- and body-axis systems, respectively. All moments are referred to the quarter-chord point of the wing mean aerodynamic chord (see fig. 1(a)).

b — wing span, 1.790 m

C_D — drag coefficient, $\frac{\text{Drag}}{qS}$

C_L — lift coefficient, $\frac{\text{Lift}}{qS}$

C_l — rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

C_{l_β} — effective-dihedral parameter, $\frac{\Delta C_l}{\Delta\beta}$, per degree

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_n — yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_{n_β} — directional-stability parameter, $\frac{\Delta C_n}{\Delta\beta}$, per degree

C_y side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{y_β} side-force parameter, $\frac{\Delta C_y}{\Delta \beta}$, per degree

c_f tip-fin chord

$\bar{c}$ wing mean aerodynamic chord, 0.250 m

i_t horizontal-tail incidence angle (positive with trailing edge down), deg

q free-stream dynamic pressure

S reference wing area, 0.460 m^2

t thickness

χ longitudinal dimension, measured from tip fin leading edge

α angle of attack, referred to fuselage reference line, deg

β angle of sideslip, referred to fuselage reference line, deg

Model and Apparatus

Drawings of the 0.03-scale model of the large wide-body aircraft with the cargo pod are presented in figure 1(a). Details of the horizontal-tail tip fins are shown in figure 1(b). Photographs of the model mounted in the Langley V/STOL tunnel are presented in figure 2. Boundary layer transition strips approximately 0.30 cm wide and composed of No. 60 abrasive grit were placed 2.54 cm rearward of the leading edges of the wing, tail surfaces, and the cargo pod. A transition strip also was located on the fuselage 5.08 cm rearward of the nose apex.

The wind tunnel section has a height of 4.42 m, a width of 6.63 m, and a length of 14.24 m. The model was sting supported and employed a six-component strain-gage balance for the measurement of forces and moments. The angle of attack was determined by use of an accelerometer mounted within the model fuselage.

Tests, Drag Accuracy, and Corrections

All tests without the horizontal-tail tip fins on the model were conducted at a free-stream dynamic pressure of 2.394 kPa, which corresponds to a velocity of 62.3 m/sec and a Reynolds number, based on the wing mean aerodynamic chord, of 1.08×10^6. All tests with the tip fins on were performed at a dynamic pressure of 479 Pa, a velocity of 28.0 m/sec, and a Reynolds number of 0.48×10^6. The angle-of-attack range was from approximately -4^o to 24^o. The angle of sideslip ranged from about -10^o to 10^o.

Mixed laminar and turbulent flow existed over much of the model at the lower Reynolds number. Hence, longitudinal data are not presented for this portion of the tests since the drag coefficients are not representative of fully-turbulent-flow conditions. Based on balance calibration and data repeatability, the accuracy of the higher Reynolds number drag coefficients presented herein is believed to be approximately ± 0.0006.

Blockage corrections were applied to the data utilizing the method of reference 2. Jet-boundary corrections to angle of attack and drag were applied in accordance with the method of reference 3.

DISCUSSION

The effects of horizontal-tail incidence on the longitudinal aerodynamic characteristics of the carrier aircraft and the aircraft/pod configurations are shown in figures 3 and 4, respectively. The effects of tail incidence on drag coefficient are small at lift coefficients less that approximately 0.6. From preliminary performance studies, it is estimated that the cruise lift coefficient for the aircraft/pod configuration would be in the range of 0.3 to 0.4. For this C_L range, the data of figure 4(b) indicate that the configuration would trim at a tail incidence of less than one degree. For this trim position, the drag polars of figure 4(a) indicate that trim drag is very small. The effects on the longitudinal characteristics of adding the pod to the carrier aircraft are shown in figure 5. In the aforementioned lift coefficient range for the composite configuration, the addition of the pod results in an increase in drag of approximately 20 percent at the test Reynolds number of 1.08×10^6. Although the pod causes a slight decrease in pitching-moment coefficient over most of the angle-of-attack range, the decrease is appreciable at angles of attack between 18 and 22 degrees.

Variations of the lateral and directional characteristics with angle of sideslip at $\alpha = 0$ and 10^o, and $i_t = 0$ are presented in figure 6 for the basic aircraft, aircraft/pod, and aircraft/pod/fins configurations. The data are relatively linear between $\beta = \pm 5$ degrees. Data at these angles were used to compute the lateral- and directional-stability derivatives of figure 7.

Generally, there is a decrease in C_{y_β} as components are added. Although the pod produces a significant decrease in directional stability, the addition of the tip fins restores some of the stability, particularly at the lower angles of attack. The pod has an adverse effect on the effective dihedral at angles of attack above approximately 15 degrees; however, these effects are partly offset by the addition of the fins.

CONCLUSIONS

Wind tunnel tests have been conducted on a 0.03-scale model of a large wide-body commercial aircraft to determine the effects on the static aerodynamic characteristics resulting from the attachment of a belly pod for the long-range deployment of outsize military equipment. Also investigated was the effectiveness of horizontal-tail tip fins in augmenting directional stability. The conclusions are summarized as follows: (1) At a test Reynolds number of 1.08 x 10^6, the addition of the pod results in an increase in total drag of approximately 20 percent. (2) Trim drag due to the pod is very small. (3) Although the pod produces a significant decrease in directional stability, the addition of the tip fins restores some of the stability, particularly at the lower angles of attack.

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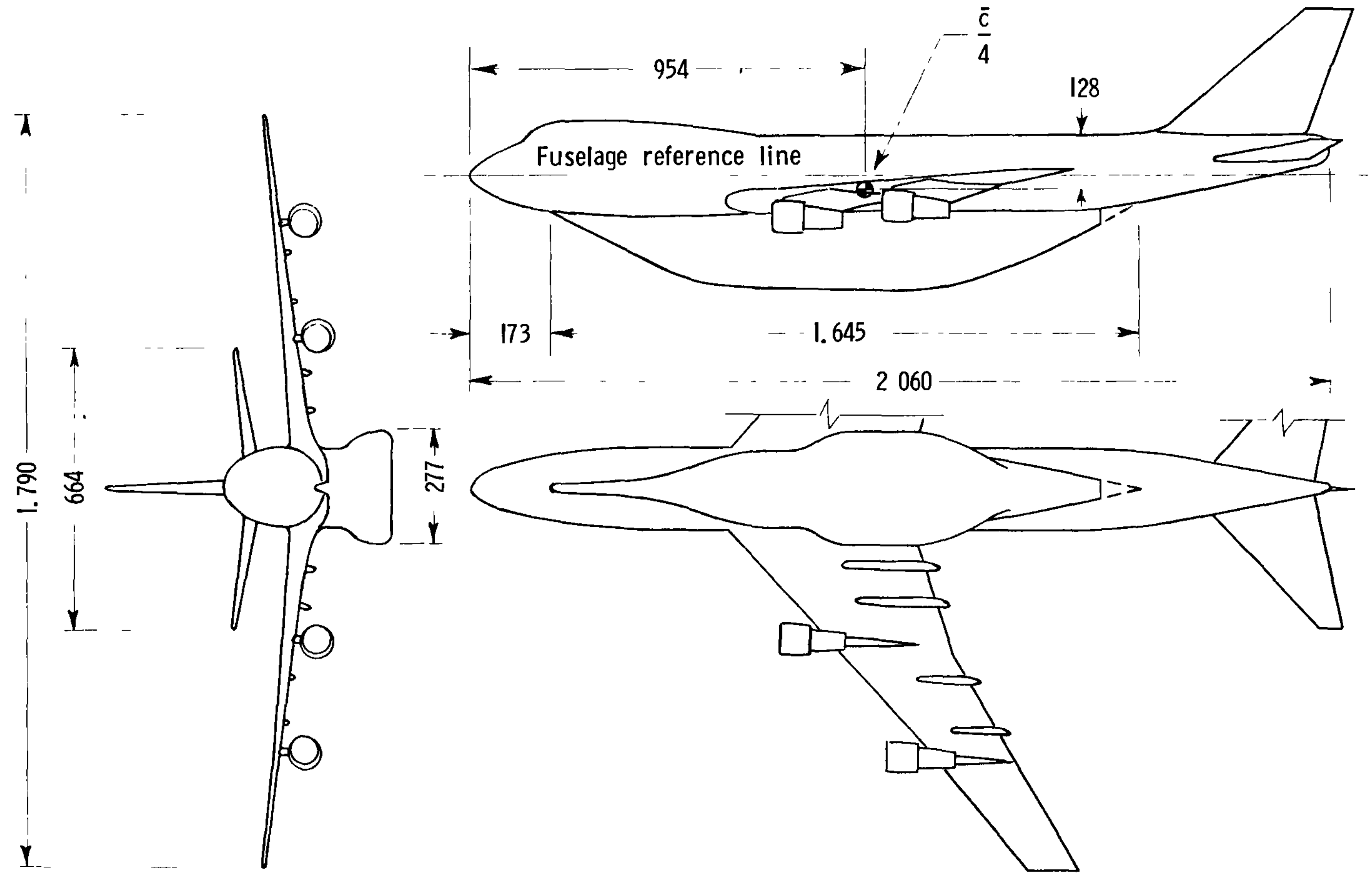
1. Quartero, C. B.; Washburn, G. E.; and Price, J. E.: Boeing 747 Aircraft With External Cargo Pod. NASA CR-158932, 1978.

2. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA Rep. 995, 1950. (Supersedes NACA RM A7B28).

3. Gillis, Clarance L.; Polhamus, Edward C.; and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA WR L-123, 1945. (Formerly NACA ARR L5G31).



(a) Aircraft/pod configuration.

Figure 1. - Model geometry. Dimensions are in meters.

Fin airfoil thickness distribution

$\frac{x}{c_f}$	$\frac{t}{c_f}$
0.0000	0.0000
.0050	.0140
.0125	.0210
.0250	.0279
.0500	.0396
.0750	.0477
.1000	.0547
.2000	.0745
.3000	.0850
.4000	.0896
.5000	.0885
.6000	.0780
.7000	.0605
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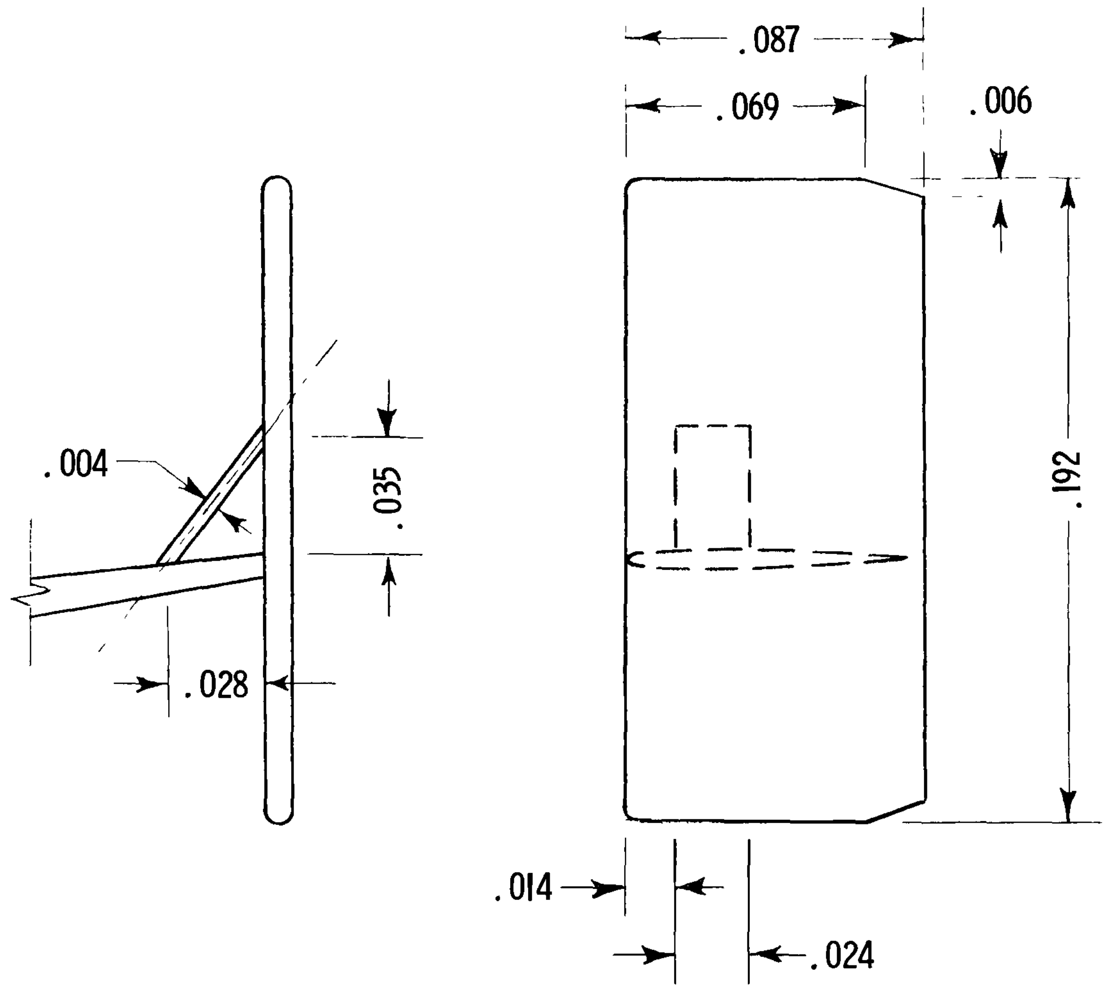
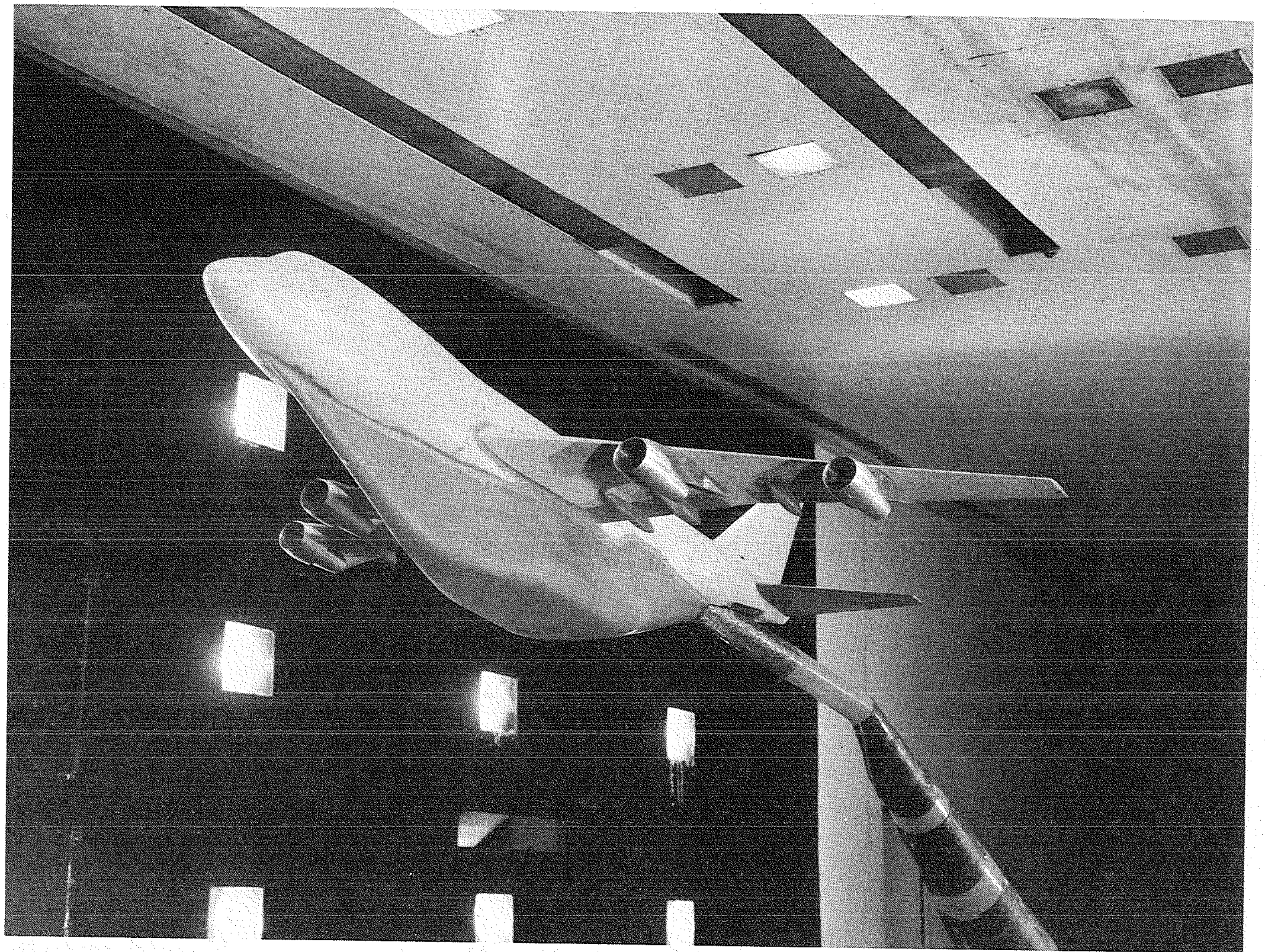
.9000	.0221
1.0000	.0035



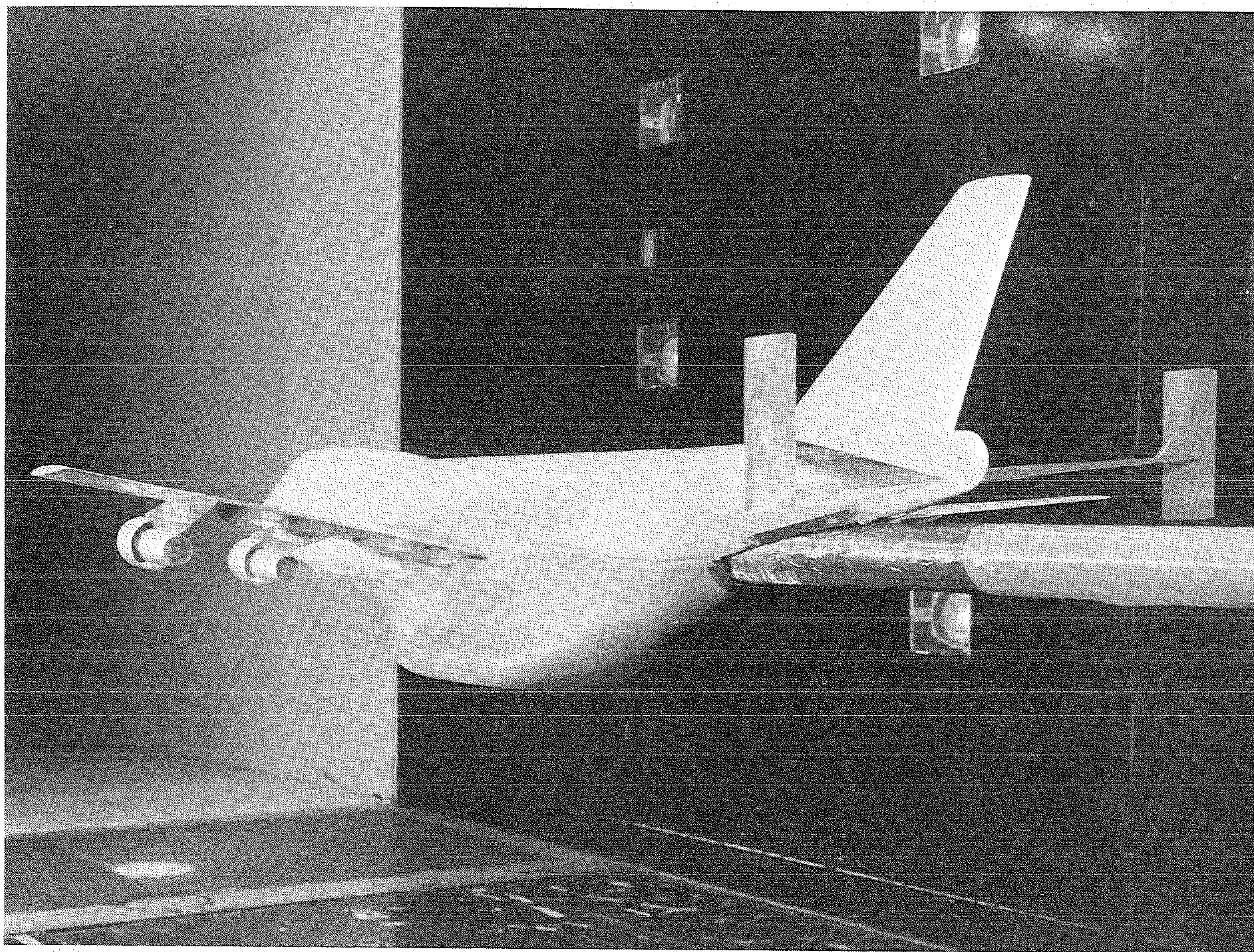
(b) Horizontal-tail tip fins.

Figure 1. - Concluded.



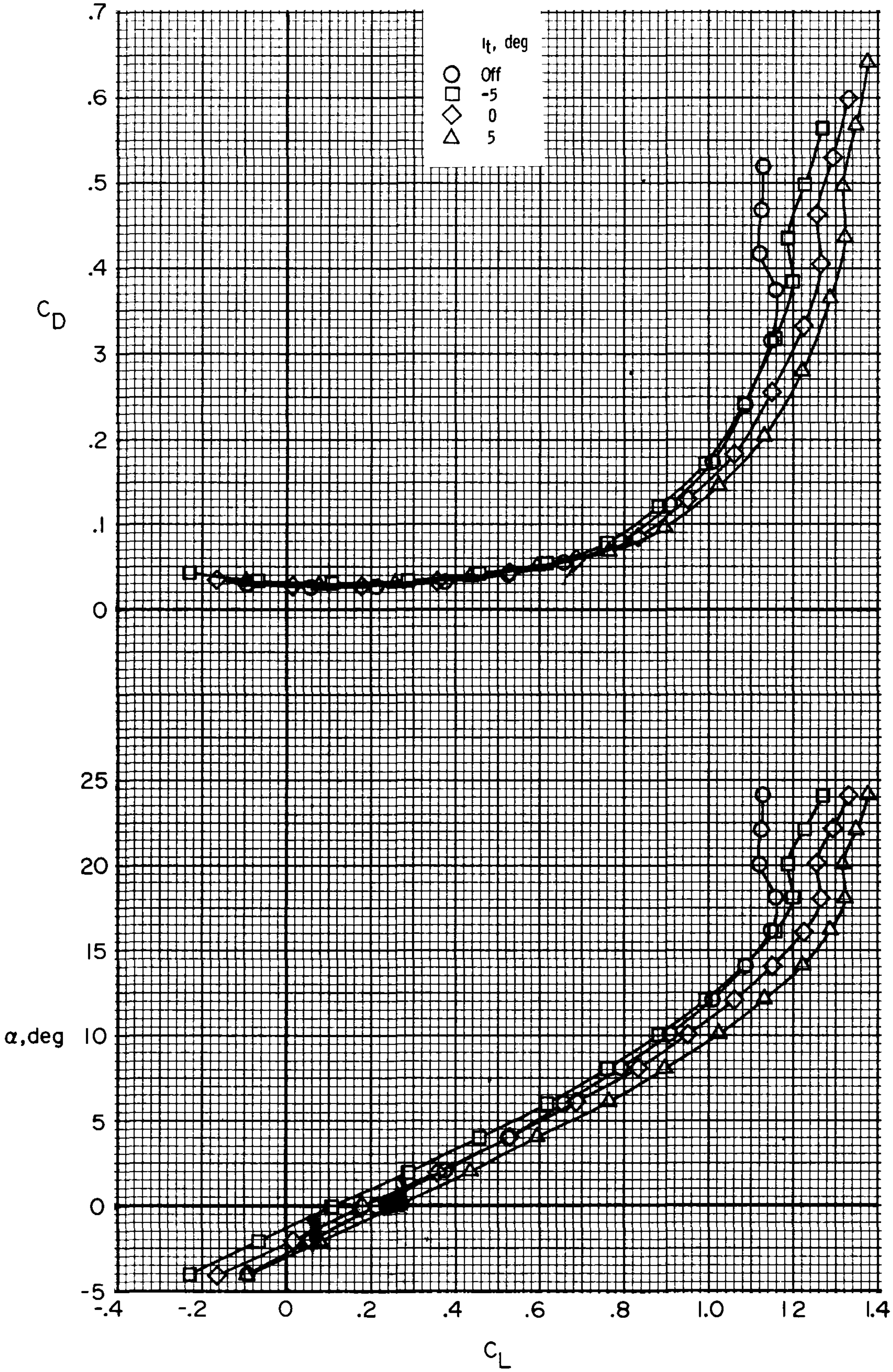
(a) Aircraft/pod configuration without horizontal-tail tip fins.

Figure 2. - Model installed in tunnel.



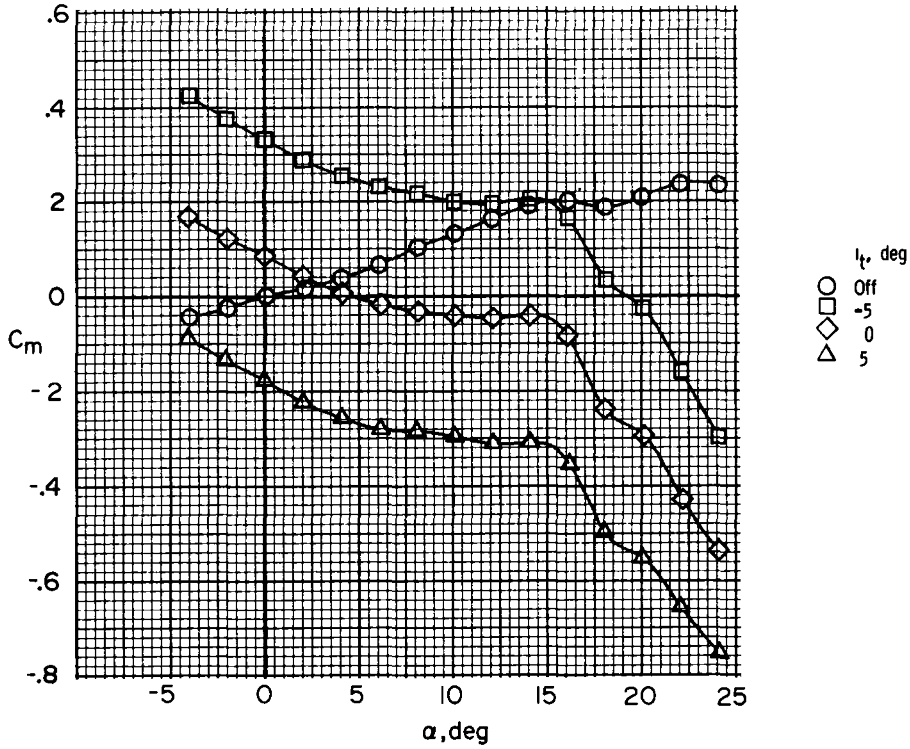
(b) Aircraft/pod configuration with horizontal-tail tip fins.

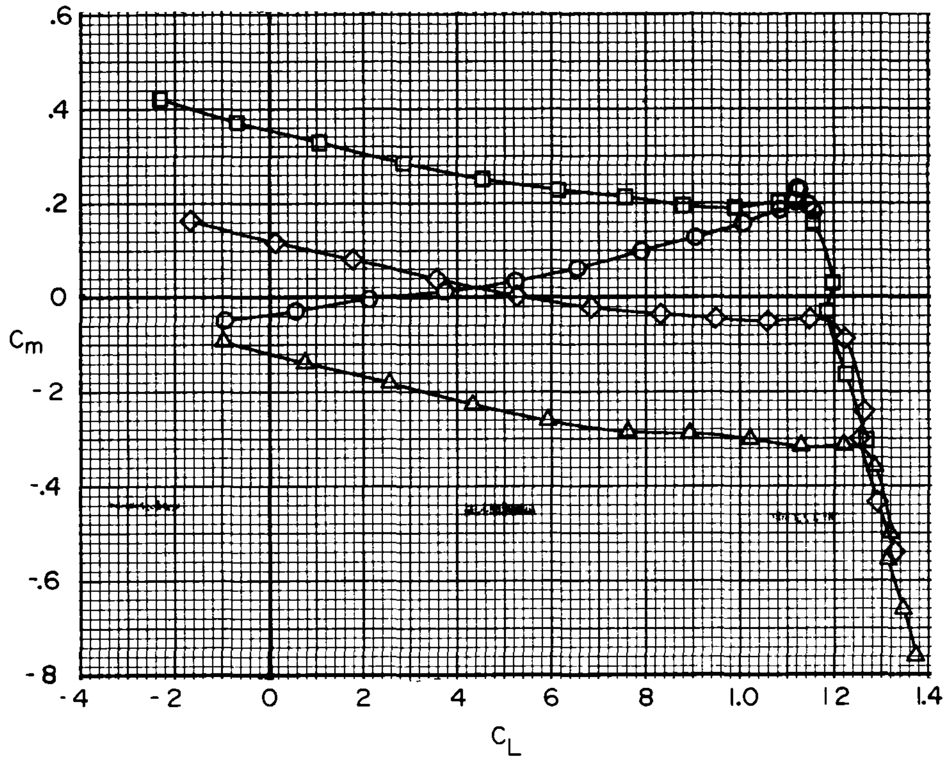
Figure 2. - Concluded.



(a) Lift and drag coefficients

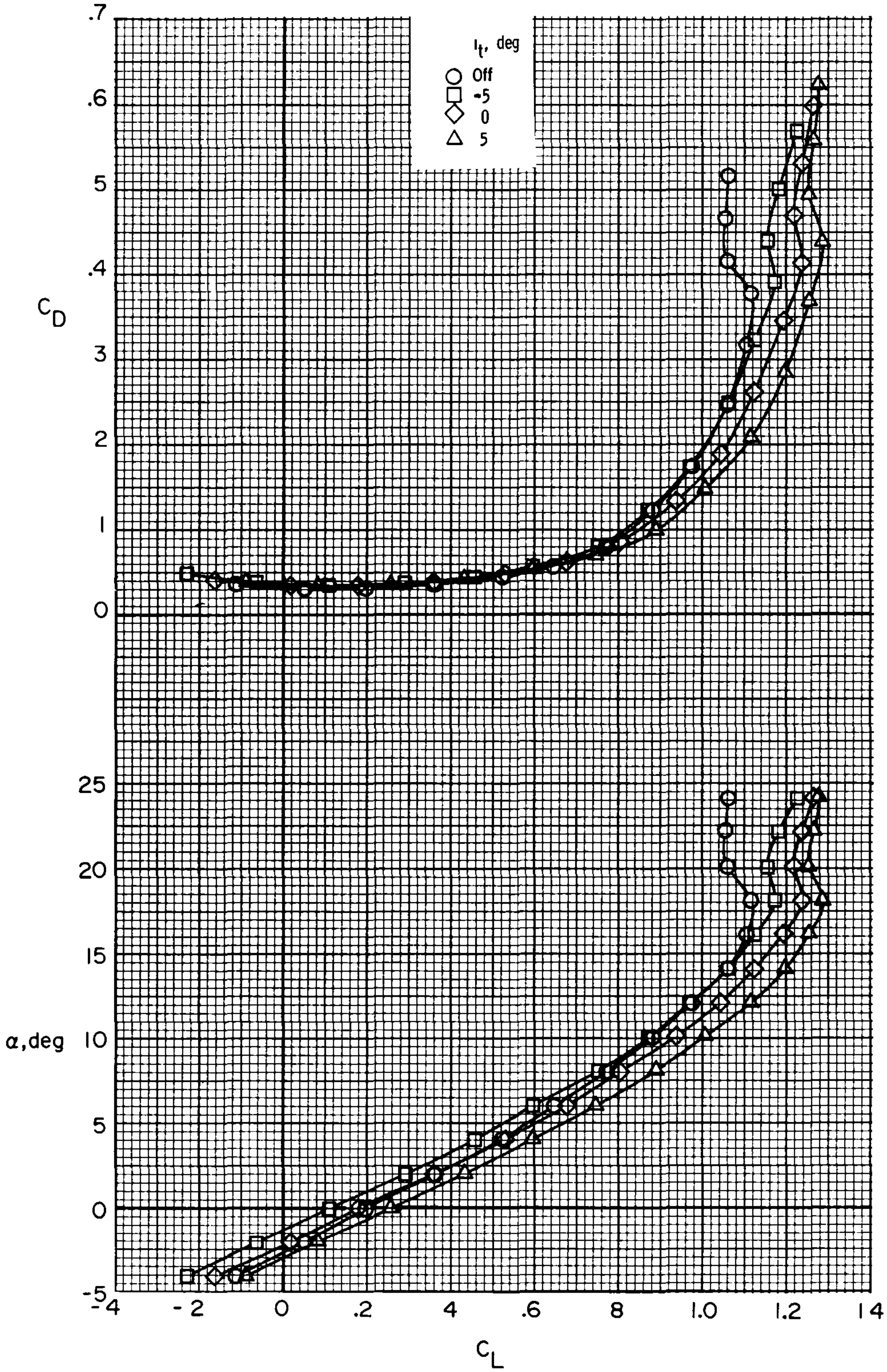
Figure 3.- Effect of horizontal-tail incidence on the longitudinal aerodynamic characteristics of the carrier aircraft model.





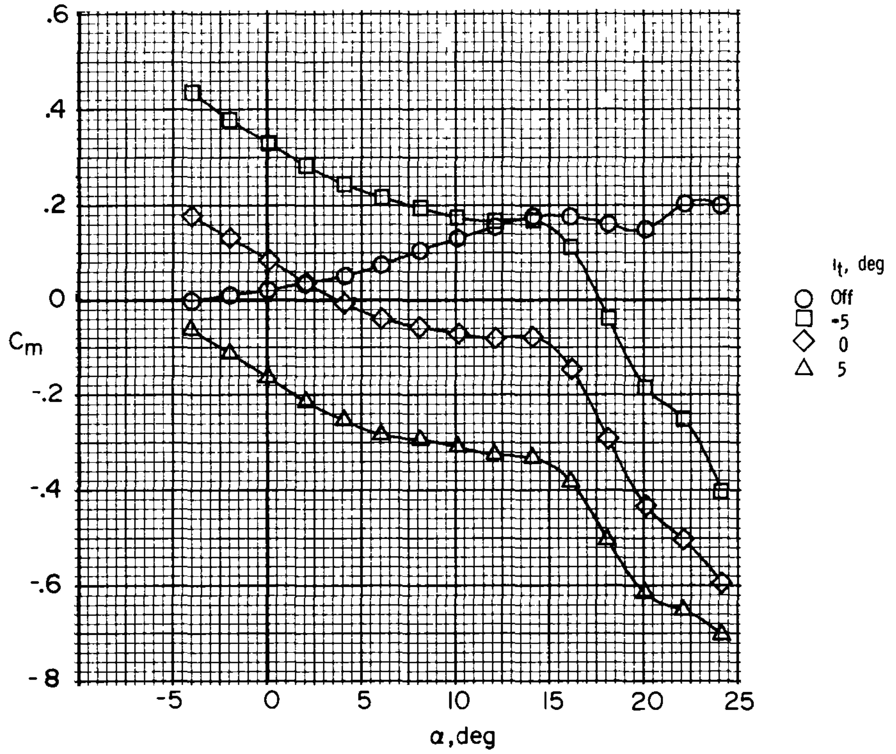
(b) Pitching-moment coefficient

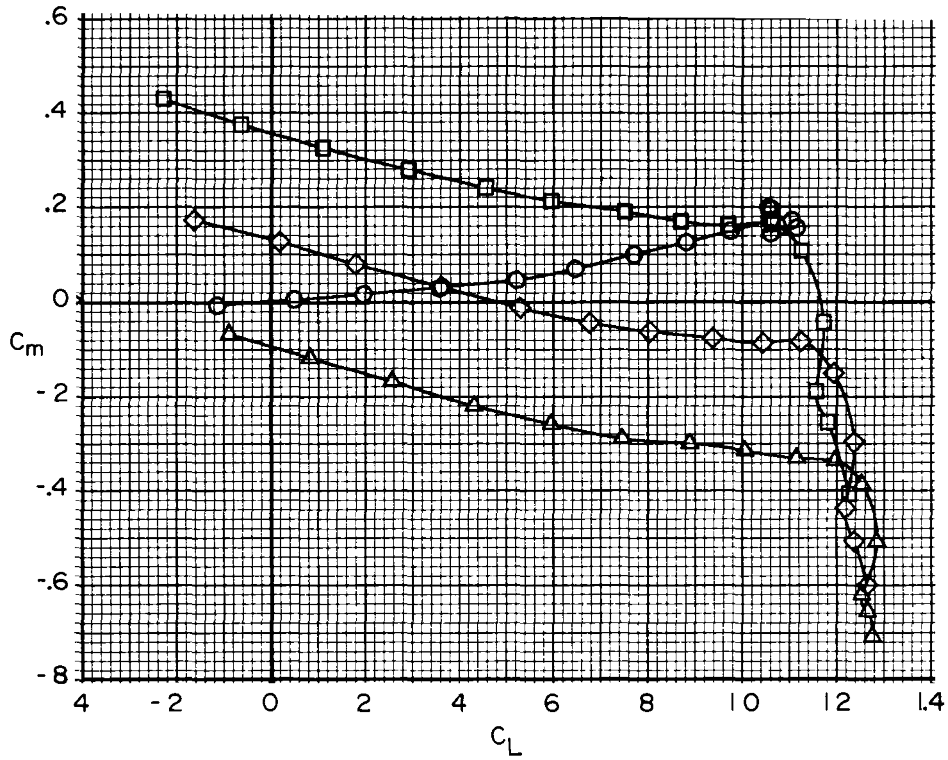
Figure 3.- Concluded.



(a) Lift and drag coefficients

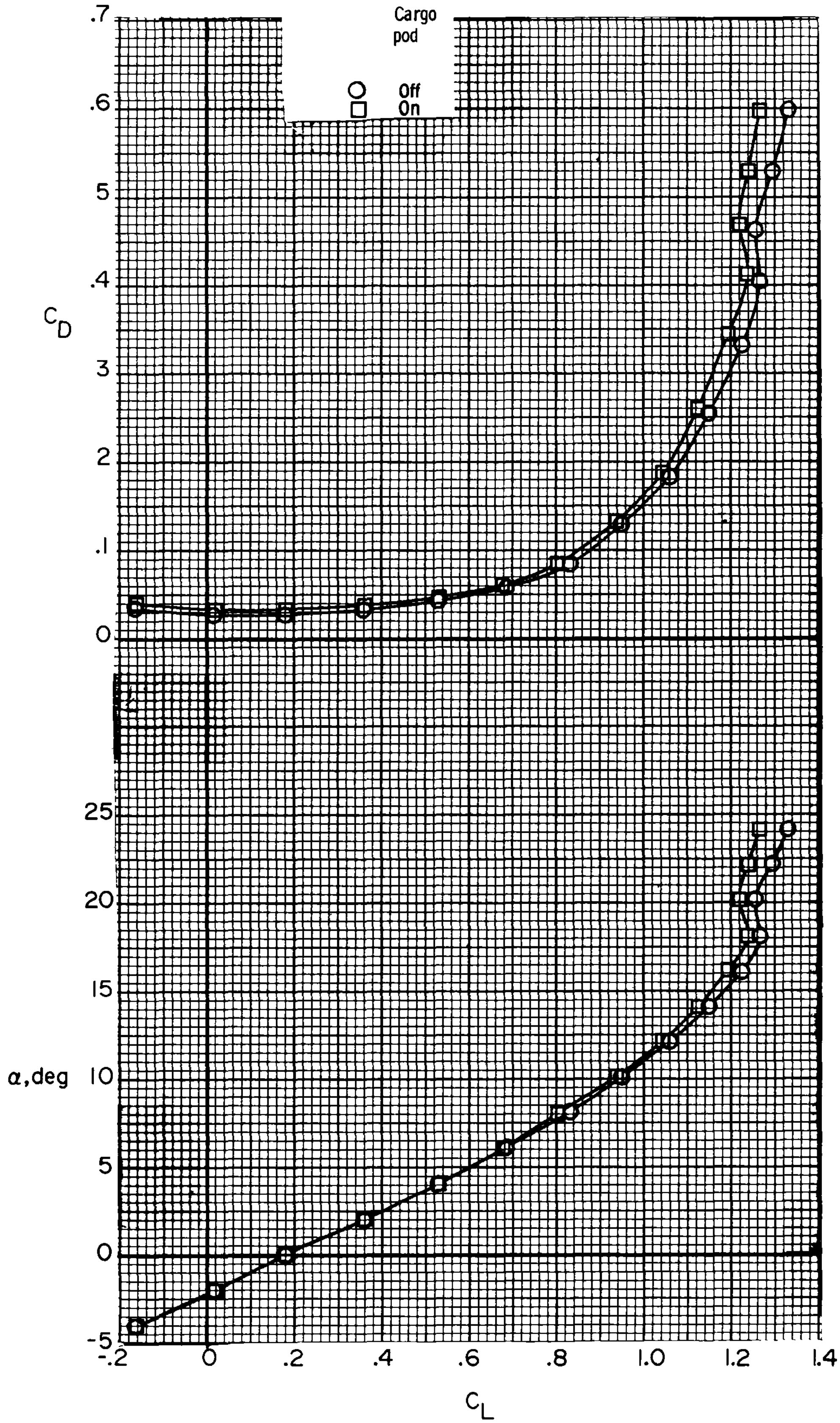
Figure 4.- Effect of horizontal-tail incidence on the longitudinal aerodynamic characteristics of the carrier aircraft model with the cargo pod attached.





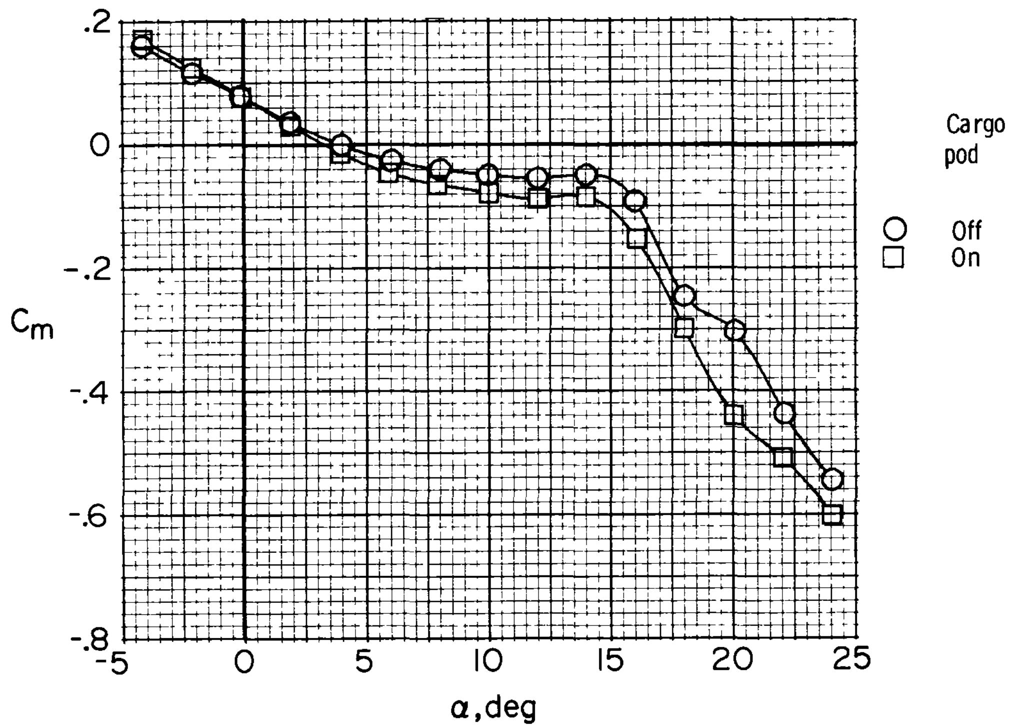
(b) Pitching-moment coefficient

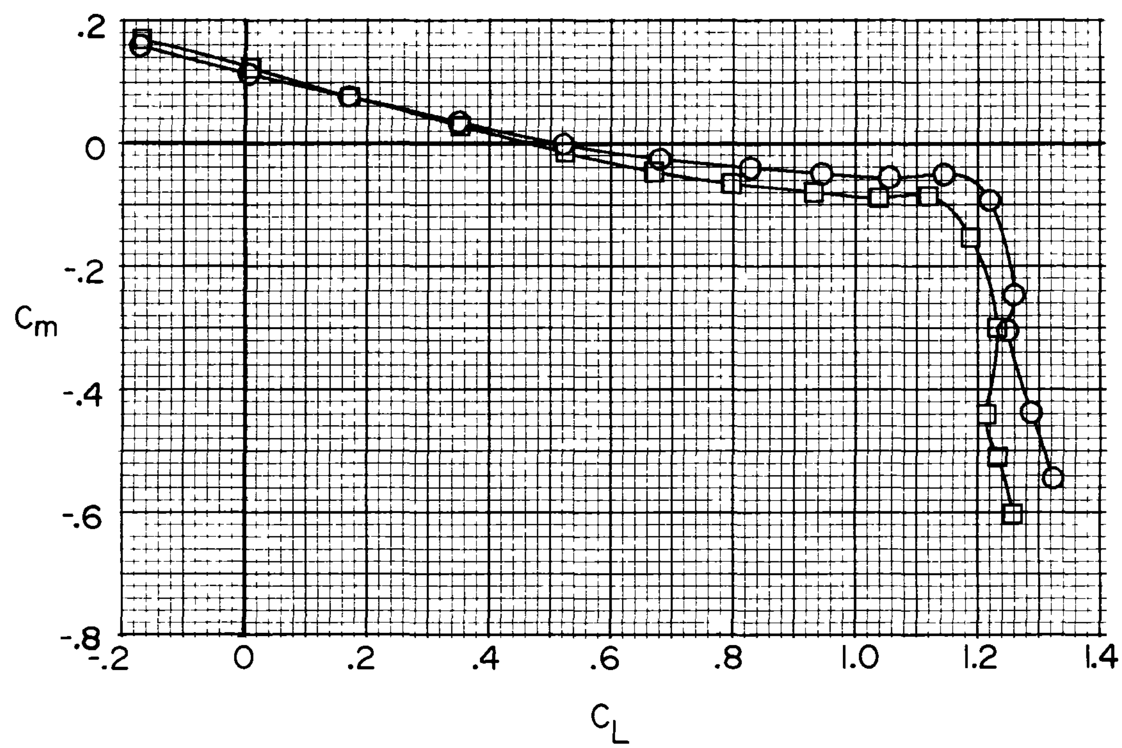
Figure 4.- Concluded.



(a) Lift and drag coefficients.

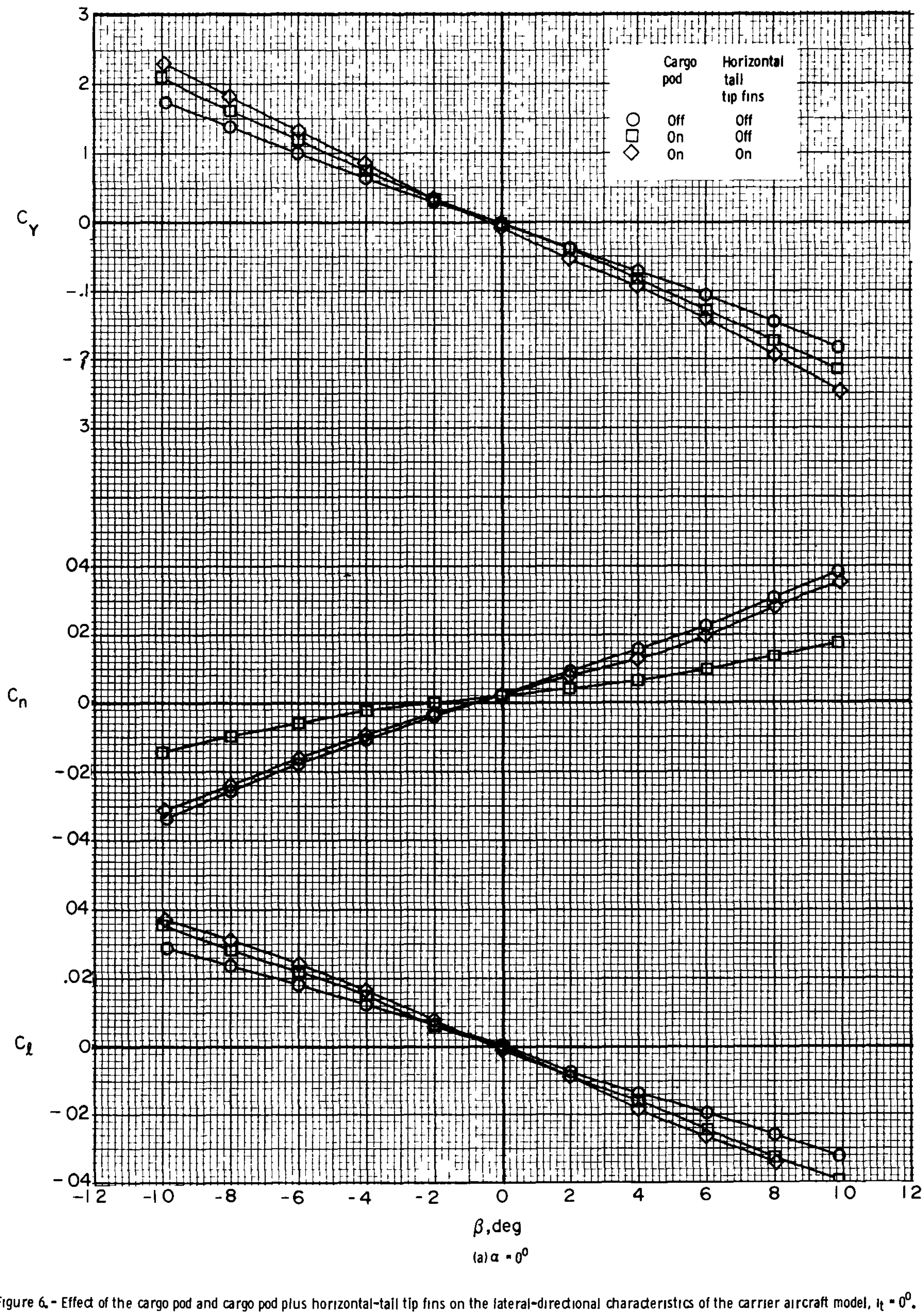
Figure 5.- Effect of the cargo pod on the longitudinal aerodynamic characteristics of the carrier aircraft model, $i_t = 0^0$.





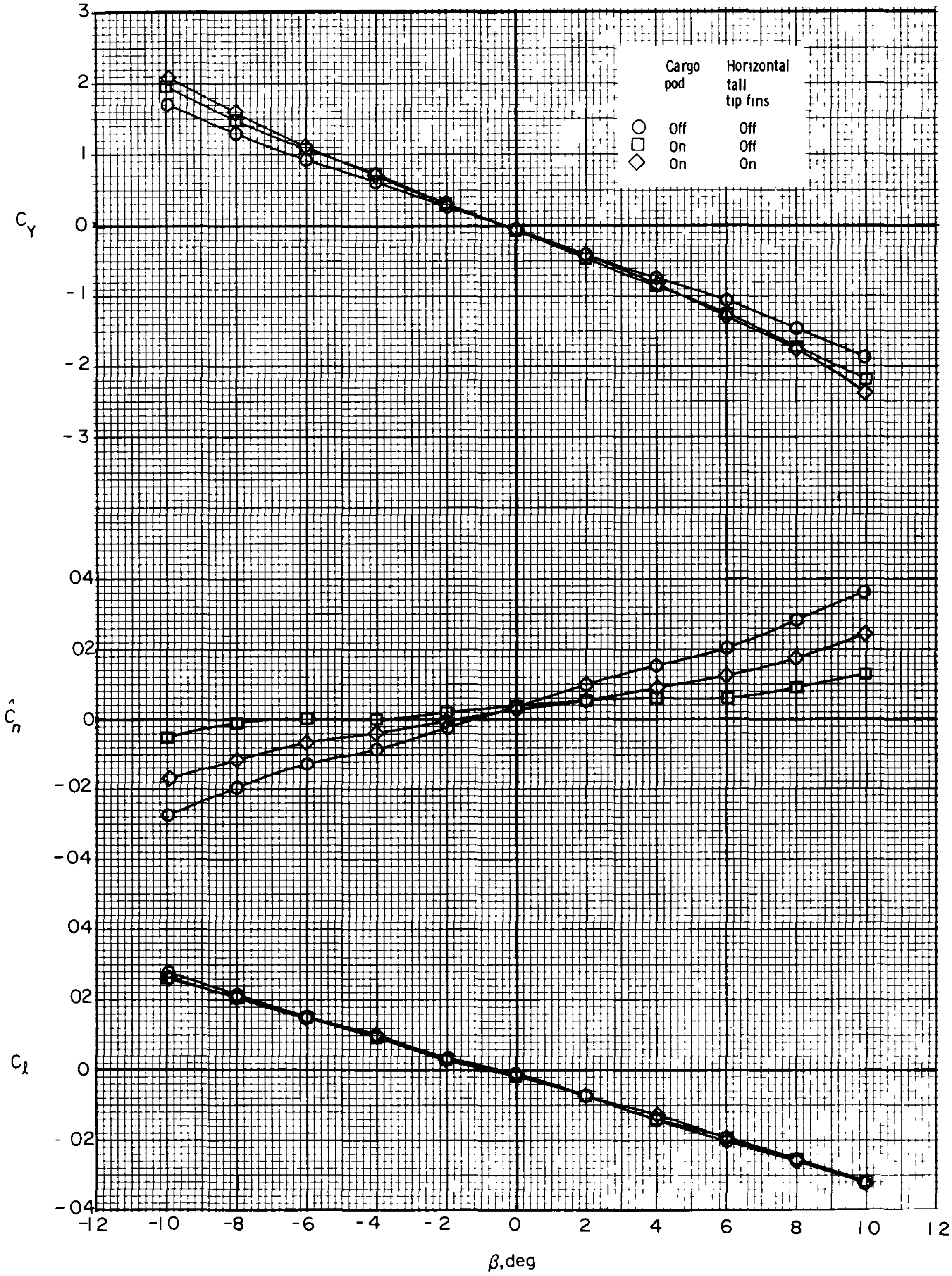
(b) Pitching-moment coefficient.

Figure 5.- Concluded.



(a) $\alpha = 0^0$

Figure 6. - Effect of the cargo pod and cargo pod plus horizontal-tail tip fins on the lateral-directional characteristics of the carrier aircraft model, $i_t = 0^0$.



(b) $\alpha = 10^0$

Figure 6.- Concluded

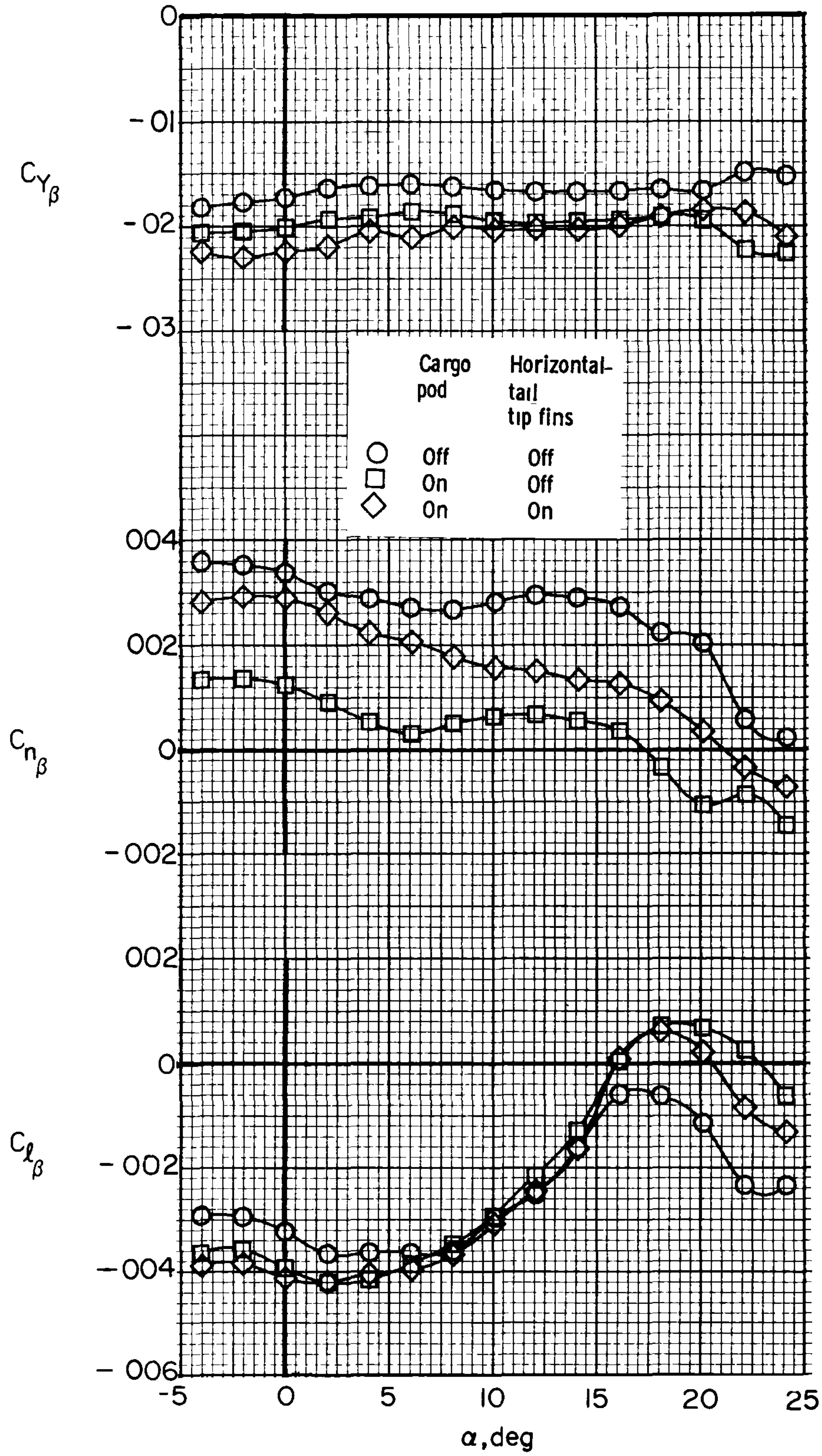


Figure 7.- Effects of the cargo pod and cargo pod plus horizontal-tail tip fins on the lateral-directional stability derivatives of the carrier aircraft model; $i_t = 0^0$.

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