RESEARCH MEMORANDUM

EXPLORATORY INVESTIGATION OF EXTERNAL STORES ON THE AERODYNAMIC CHARACTERISTICS OF A 1/16-SCALE MODEL OF THE DOUGLAS D-558-II RESEARCH AIRPLANE AT A MACH NUMBER OF 2.01

By Norman F. Smith

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

As a part of a coordinated investigation of stores on the Douglas D-558-II research airplane in the wind tunnel and in flight, an investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 on a 1/16-scale model of this airplane equipped with various store configurations. The investigation was exploratory in nature and shows overall effects of stores upon the airplane characteristics but does not provide breakdown data necessary to isolate these effects.

The drag measured for all store configurations tested is high, from two to three times the free-air drag estimated for the store and pylon. Changes in pylon thickness, store size, profile, and location produced changes in drag which were small in relation to the magnitude of the interference drags which prevailed for all configurations.

Moderate changes in longitudinal stability and trim lift were measured. The directional stability was decreased by one-third by the small store installation. These effects are shown to be due largely to the substantial interference produced by the various stores.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting a coordinated investigation of stores on the Douglas D-558-II research airplane. The program includes wind-tunnel tests of models of various store configurations at subsonic, transonic, and supersonic speeds at the Langley Laboratory and flight tests of the airplane with selected store configurations at the High-Speed Flight Research Station at Edwards Air Force Base, Calif.

This paper presents the results of an investigation of the aerodynamic characteristics of a 1/16-scale model of the Douglas D-558-II airplane with various store configurations at a Mach number of 2.01 in the Langley 4- by 4-foot supersonic pressure tunnel.

It should be noted that this investigation was exploratory in nature and was, therefore, somewhat abbreviated. Although overall effects of the stores on the airplane characteristics are shown, the model breakdown data necessary to isolate and identify these effects were not obtained.

COEFFICIENTS AND SYMBOLS

The results of this investigation are presented in terms of standard NACA coefficients of forces and moments which are referred to the stability axis system (fig. 1). The moment center is located at 25 percent of the wing mean aerodynamic chord. The coefficients and symbols used are defined as follows:

C_L	lift coefficient, $-Z/qS$
C_X	longitudinal-force coefficient ($C_X = -C_D$ for $\beta = 0^\circ$), X/qS
C_D	drag coefficient, Drag/qS
ΔC_{D_F}	drag-coefficient increment for store and pylon, based upon store frontal area
C_m	pitching-moment coefficient, $M/qS\bar{c}$
C_l	rolling-moment coefficient, L/qSb
C_Y	lateral-force coefficient, Y/qS
C_n	yawing-moment coefficient, N/qSb
X	force along X-axis
Y	force along Y-axis
Z	force along Z-axis
D	drag

L	moment about X-axis
M'	moment about Y-axis
N	moment about Z-axis
q	free-stream dynamic pressure
S	total wing area, including that submerged in body, 0.684 sq ft
F	frontal area of store
b	wing span
$\bar{c}$	wing mean aerodynamic chord, $\int_0^{b/2} c^2 dy \Big/ \int_0^{b/2} c\, dy = 5.46$ in.
M	Mach number
α	angle of attack of body center line, deg
β	angle of sideslip, deg
i_t	stabilizer incidence angle with respect to body center line, deg
C_L/C_D	lift-drag ratio

MODELS AND TESTS

A three-view drawing of the basic model is presented in figure 2. The small store is shown in order to illustrate the position and relative size of this store. The model wing, which was constructed of steel, had 35° of sweep of the 30-percent-chord line of the unswept panel, an aspect ratio of 3.57, a taper ratio of 0.565, and NACA 63-010 airfoil sections normal to the 30-percent-chord line. The horizontal stabilizer, which was the only control surface deflected in these tests, was manually set.

The model differs somewhat from that tested previously in the investigations of references 1 and 2 in that a canopy and an enlarged vertical tail have been provided to simulate the present flight airplane. Detailed geometric characteristics of the model are given in reference 3. Other geometric differences between model and airplane remain, however. The thickness of the model wing-tip airfoil section is 10 percent instead of

12 percent and the diameter of the rearward part of the fuselage, or model base, is enlarged 25 percent to provide clearance around an ample sting support.

Three stores of different size but of the same nondimensional profile were tested and are shown in figure 3. These stores were designed with the Douglas Aircraft Company, Inc., store ordinates, and will hereinafter be referred to as the small, medium, and large DAC stores. The small and medium stores (and fins) correspond to the 1,000- and 2,000-pound low-drag general-purpose bombs (Bureau of Ordnance sketch 239593). The large store corresponds to the Douglas Aircraft Company, Inc., 150-gallon fuel store. The store lengths used covered the range from 1.39 to approximately twice the length of the wing mean aerodynamic chord. The fineness ratio of the DAC stores was approximately 8.6.

The dimensions and ordinates for the small store having a different profile are given in figure 4. This store had the ellipse-cylinder-cone shape originated by the Wright Air Development Center and will be referred to hereinafter as the small WADC store. The length of this store was the same as that of the small DAC store; however, the fineness ratio was approximately 7.8.

All stores were equipped with four stabilizing fins oriented as shown in figure 4. Figure 5 shows the dimensions of the fins used on the four stores tested.

The stores were mounted on 66° sweptforward pylons of constant maximum thickness and constant streamwise chords (figs. 3 and 4). All stores were tested on pylons which had a streamwise thickness ratio of 7.6 percent, whereas the small DAC store was also tested on pylons with a thickness ratio of 4.3. The ordinates (fig. 3) for the "thick" pylon were derived from the DAC ordinates, whereas those for the "thin" pylon were derived from the WADC ordinates. The pylons were hand-filed from brass to approximately the ordinates shown.

The distance from store upper surface to wing lower surface was approximately the same for all stores and was slightly more than the diameter of the small DAC store (fig. 3).

All stores were tested at the 61-percent-semispan station. In addition, the small DAC store was tested at the 44.3-percent-semispan station, the position of which was obtained by moving the store and pylon parallel to the leading edge of the wing. The stores in all cases were mounted in pairs, one store on each wing panel. Figure 6(a) shows a general view of the complete model with stores installed and figure 6(b) shows the series of stores investigated.

Forces and moments on the entire model with and without stores and pylons were measured by means of a six-component strain-gage balance housed within the fuselage. All configurations were tested in pitch up to an angle of attack of about 13°, whereas the small DAC store was tested in sideslip up to angles of 10°. The tests were conducted in the Langley 4- by 4-foot supersonic pressure tunnel.

TEST CONDITIONS AND ACCURACY

The conditions for the tests were as follows:

Mach number	2.01
Reynolds number, based on wing $\bar{c}$	1.46×10^6
Stagnation pressure, lb/sq in. abs	13
Stagnation temperature, °F	100
Stagnation dewpoint, °F	<-25
Mach number variation in test section	±0.015
Flow angle variation in horizontal or vertical plane, deg	±0.1

The angle of attack was corrected for the deflection of the balance and sting under load. No corrections have been applied to the data for tunnel air-flow variations. The model base pressure was measured and the chord-force measurements were corrected by adjusting the base pressure to the free-stream static pressure.

The estimated errors in the data presented are as follows:

C_L	±0.004
C_D (see text)	±0.001 to ±0.002
C_m	±0.0007
α, deg; β, deg	±0.1
i_t, deg	±0.1
C_Y	0.002
C_n	0.0005
C_l	0.0003

The estimated error in drag coefficient is relatively high for these tests because of the low sensitivity of the balance relative to the chord-force increments measured. Although the possible error is estimated to be as high as ±0.002, it is felt that the small amount of scatter measured and the reproducibility of the data indicate that the error for most of the data presented is ±0.001 or less.

RESULTS

The longitudinal aerodynamic characteristics of the basic model and of the model with the small, medium, and large DAC stores are shown in figure 7. Similar data for the model with and without the small DAC stores and with the horizontal stabilizer deflected to -6° are given in figure 8. The effects of moving the small stores inboard from the 61-percent-semispan station to the 43.4-percent-semispan station are shown in figure 9. The effect of changing support pylon thickness is shown in figure 10. A comparison of the characteristics of the model equipped with small stores having different profiles is shown in figure 11. Figure 12 presents the lateral aerodynamic characteristics of the model with and without the small stores. For all data presented herein, except where otherwise specifically noted, the stores are mounted at the 61-percent-semispan station on the thick pylon with $i_t = 0$.

Figure 13 presents the incremental drag coefficients for the stores and pylons, based upon store frontal area. The measured slopes of the pitching-moment curves $\partial C_m/\partial C_L$ are also listed.

In figure 14 are presented the variations of C_L/C_D with lift coefficient for the complete model with and without the three DAC stores.

DISCUSSION

Longitudinal Characteristics

Drag.- At low values of lift coefficient, the small and large DAC stores increase the drag of the basic airplane by about 10 and 20 percent, respectively. (See fig. 7). It should be noted that the drag coefficient of the basic airplane is high, about 0.07. The incremental drag coefficient based upon frontal area of the particular store is shown to be high, ranging from approximately 0.4 to 0.7 at $C_L = 0$ (fig. 13). It will be noted that, on the basis of the accuracy quoted previously, the ΔC_{D_F} values shown in figure 13 are, in the strictest sense, accurate only to one significant digit. The second digit is shown, however, for information and because of possible significance. The drag coefficient for the isolated DAC store at this Mach number has been measured in free flight (refs. 4 and 5) and found to be about 0.2 based upon frontal area, or less than half of that measured in the present tests for the pylon-mounted stores. Published data from tests of similar finned bodies, such as reference 6, show similar results. The drag increment measured above the isolated-store value is due to pylon drag and mutual interference of the various components.

By assuming a free-air drag coefficient for the isolated DAC shape of 0.2 based upon frontal area and a drag coefficient for the pylon of 0.02 based upon pylon lateral area, the magnitude of the interference drag is estimated to be 40 and 50 percent of the drag increment measured for the small and large store, respectively. Thus, the interference drags produced by the small and large store are approximately 4 and 10 percent, respectively, of the drag of the basic airplane.

The level of the incremental drag measured in these tests, two to three times the isolated-store drag, is in general agreement with the findings of reference 7. In this reference, drag values of these magnitudes were shown to be generally encountered for store positions in regions where the peak cross-sectional areas for the wing, fuselage, and store approached coincidence when the configuration was sectioned or viewed along Mach lines.

The effect of moving the small DAC store inboard to the 44.3-percent-semispan station is shown in figure 9 to be small and detrimental at this Mach number. Although a small improvement resulted in the transonic $(M = 1)$ area diagram (not presented) when the store was moved inboard along the wing leading edge, no decrease in drag was obtained at $M = 2$.

The use of 4.2-percent-thick support pylons in place of the 7.5-percent-thick pylons (figs. 10 and 13) resulted in a small decrease in incremental store drag at low lifts. Above $C_L = 0.3$ there was no measurable drag difference. The exact magnitude of the drag reduction at low lifts is obscured somewhat by accuracy limitations.

The WADC store (figs. 11 and 13) gave a drag increment based upon frontal area approximately 30 percent higher (at low lifts) than that for the DAC store of the same length. A small portion of this difference is chargeable to the lower fineness ratio of the WADC store, but the bulk of the difference is due to the different profile with probably some increased unfavorable interference.

Lift.- The addition of stores lowers the lift of the basic configuration slightly, but the amount of change in angle of attack for zero lift and in lift-curve slope is insignificant for all store configurations.

Lift-drag ratio.- The effects of three sizes of stores upon the lift-drag ratio of the basic airplane are shown in figure 14 to be of the same magnitude as the effects upon the drag.

Pitching moment.- The pitching moment at a given angle of attack (or lift coefficient) is changed in a positive direction by the addition of stores and pylons. Inasmuch as the change in pitching moment produced by the drag of the store is in the opposite direction and is very small, the result obtained must be due to interference effects, that is, the effect of the store and pylon on the wing pressures and on the flow over the fuselage and tail. The large interference pitching moments are consistent with the large interference drags discussed earlier. Because of the brief, exploratory nature of this investigation insufficient data were obtained to isolate fully the factors involved.

From an examination of the store-wing geometry (figs. 2 and 3) it can be seen that the store produces lower pressures over most of the chord on that portion of the wing lower surface immediately above the store. Because this portion of the wing is behind the center of gravity, a positive increment in pitching moment is produced. The positive shift in moment increases as the store size increases (fig. 7) because the larger store increases the extent and intensity of the low-pressure region on the lower surface of the wing.

Moving the store to the inboard position (fig. 9) moves the moment in a negative direction because the portion of the wing affected is moved forward with respect to the center of gravity. Changing the store profile or the pylon thickness (figs. 10 and 11) had but little effect upon the pitching-moment characteristics up to moderate values of lift coefficient.

The stability of the model is shown to be increased (fig. 13) by addition of the small and medium DAC stores and to be slightly decreased for the large stores. These changes are due to changes in the flow field of the complete configuration, but inasmuch as tests were not made with the horizontal tail off, the causes of these changes cannot be isolated.

Stabilizer effectiveness.- Measurement of the stabilizer effectiveness $\overline{\Delta C_m/\Delta i_t}$ at constant values of angle of attack from figures 7 and 8 shows that the small DAC store has no measurable effect upon this parameter.

Lateral Characteristics

The most important effect on the lateral characteristics of adding the stores (fig. 12) is a decrease in directional stability of about one-third. This decrease cannot be explained in terms of forces on the store installation, since the center of pressure of store and pylon is behind the center of gravity of the airplane at low angles of sideslip and the store forces should tend to increase the directional stability. Also, calculation of the increment in lateral force which might be expected from stores and pylons (by assuming lift-curve slopes of 0.1 for the store, from ref. 8, and 0.04 for the pylon) gives values which are about four times those measured.

CONCLUSIONS

As a part of a coordinated investigation of stores on the Douglas D-558-II research airplane in the wind tunnel and in flight, an investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 on a 1/16-scale model of this airplane equipped with various store configurations. The following conclusions are provided:

1. The incremental drag measured for all store configurations tested is high, from two to three times the free-air drag estimated for the store and pylon. A previous correlation, based upon the area rule, showed similar high drags for numerous other investigations of stores in similar positions.

2. Changes in pylon thickness, store size, profile, and location produced changes in the drag which were small in relation to the magnitude of the interference drags which prevailed for all configurations.

3. Moderate changes in longitudinal stability and trim lift were measured, largely because of interference produced by the various stores; however, because of the exploratory nature of the investigation, insufficient data were obtained to isolate and explain fully these changes. The effect of the stores upon the lift characteristics and upon horizontal-stabilizer effectiveness was insignificant.

4. The directional stability was decreased by one-third by the installation of the small DAC store and pylon.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 10, 1954.

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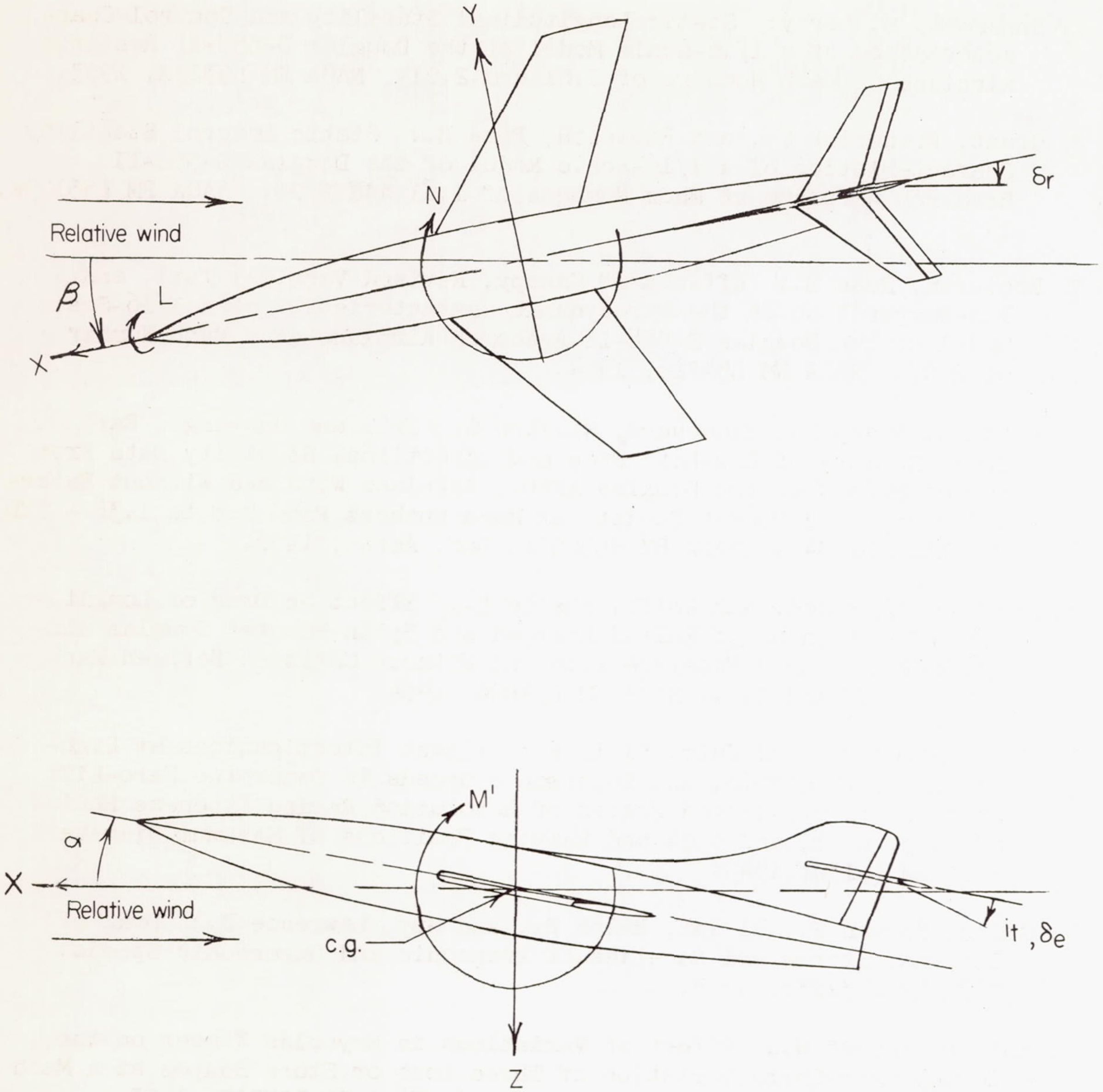


Figure 1.- System of stability axes. Arrows indicate positive values.

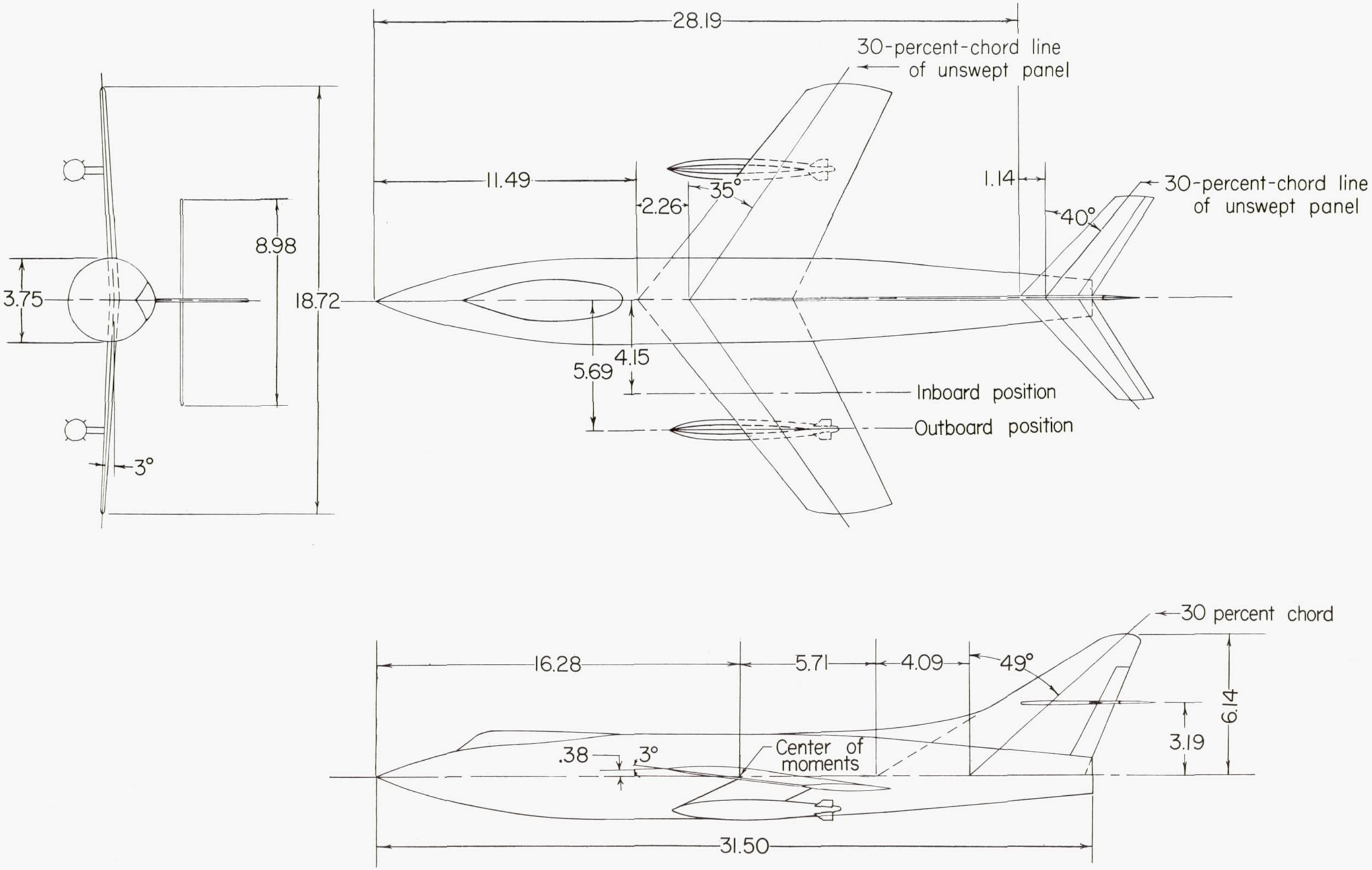
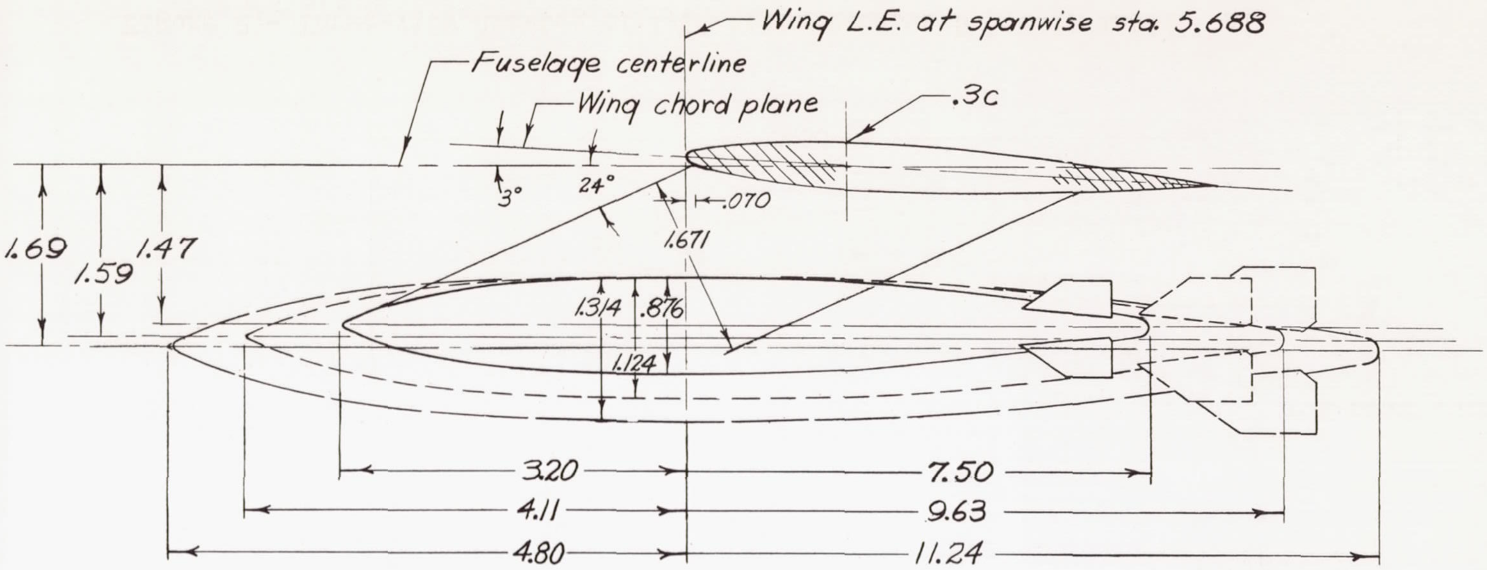
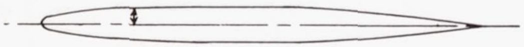


Figure 2.- Three-view drawing of 1/16-scale Douglas D-558-II model. All dimensions are in inches.





Pylon Ordinates (in.)

Thick Pylon

Station	Ordinate	Station	Ordinate
0	0		
L.E. rad.	.017	1.407	.156
.031	.032	str. line	
.063	.045	2.41	.156
.156	.070	2.56	.155
.313	.096	2.72	.151
.468	.114	2.88	.144
.625	.128	3.03	.134
.782	.138	3.19	.121
.938	.146	3.34	.105
1.195	.152	3.66	.066
1.250	.155	3.97	.021
		4.12	0

Thin Pylon

Station	Ordinate
0	0
.2	.0575
.4	.0758
.6	.0855
.852	.0895
str. line	
3.195	.0895
4.26	0

Cut off at sta.
4.26 with radius = .013

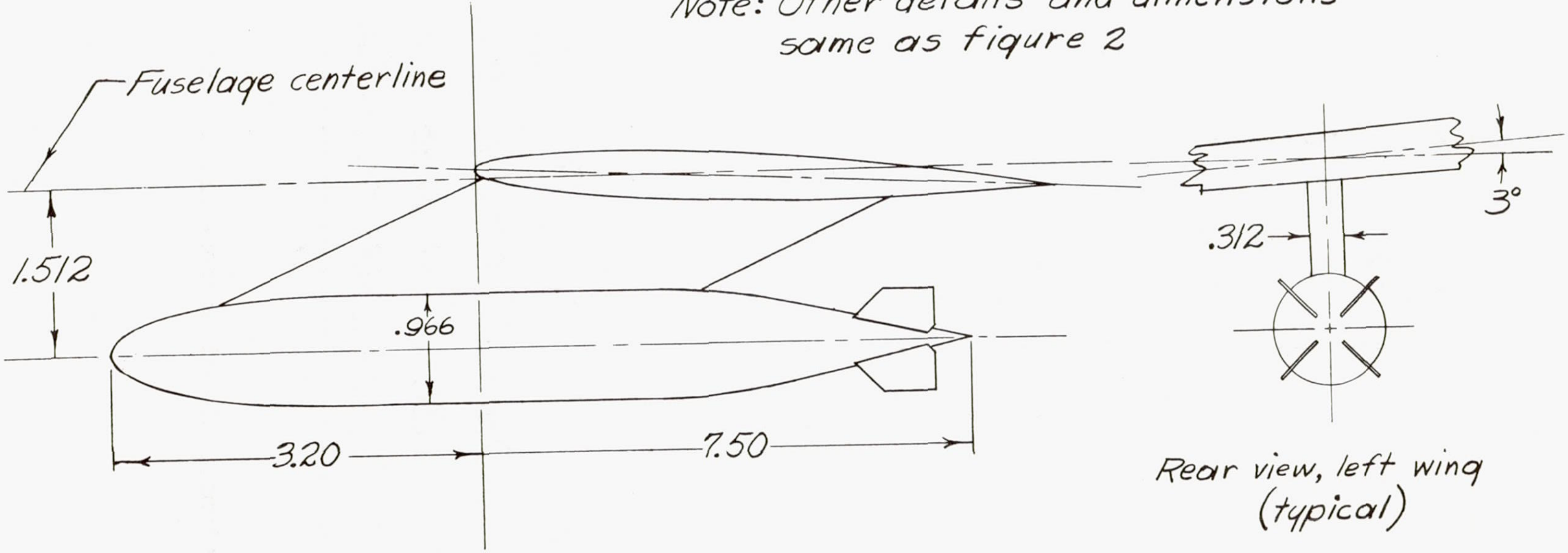
Store Ordinates
(percent length)

Station	Radius	Station	Radius	Station	Radius
0	0				
1.94	.946	32.50	5.785	74.72	4.334
4.72	2.033	35.28	5.833	77.50	4.023
7.50	2.869	42.50	5.833	80.28	3.693
10.28	3.513	49.72	5.833	83.06	3.347
13.06	4.016	52.50	5.812	85.83	2.989
15.83	4.416	55.28	5.749	88.61	2.621
18.61	4.745	58.06	5.646	91.39	2.246
21.39	5.026	60.83	5.507	93.61	1.944
24.17	5.272	63.61	5.332	95.83	1.630
26.94	5.485	66.39	5.125	98.06	1.208
29.72	5.661	69.17	4.888	100.00	0
		71.94	4.623		

L.E. radius = 0.83; T.E. radius = 0.55.

Note: ordinates for section parallel to free stream.

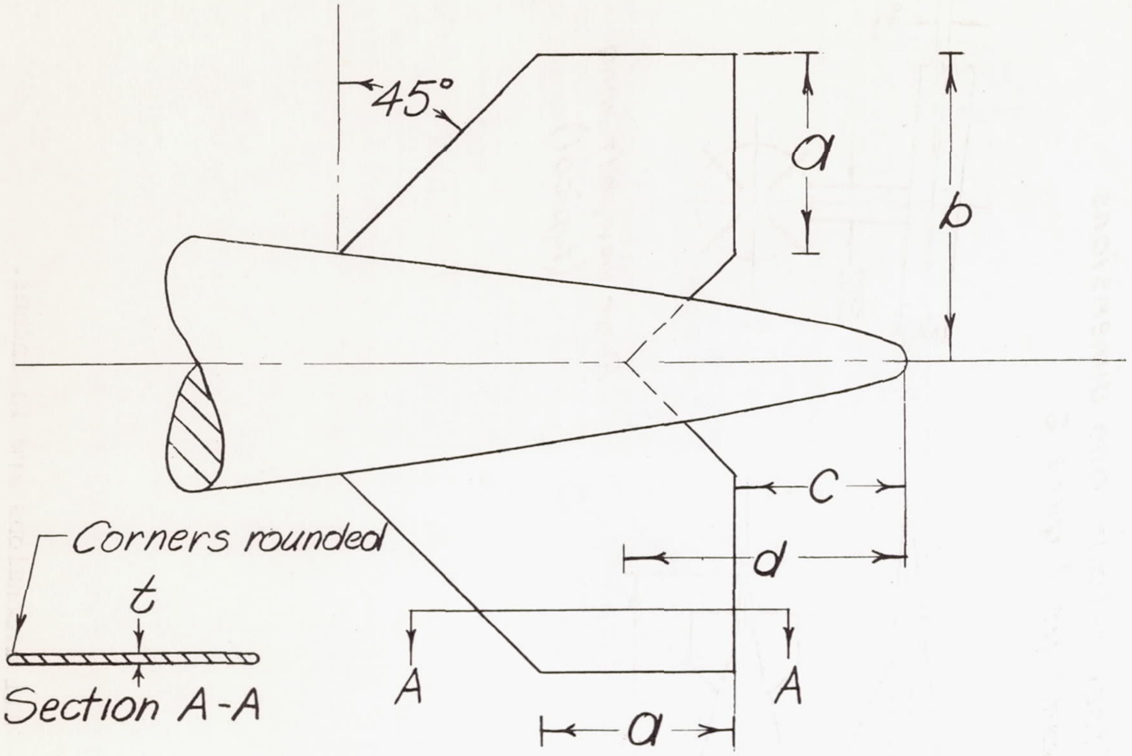
Figure 3.- Details of three DAC stores and pylon. All dimensions are in inches.


Note: Other details and dimensions same as figure 2

Store Ordinates
(in.)

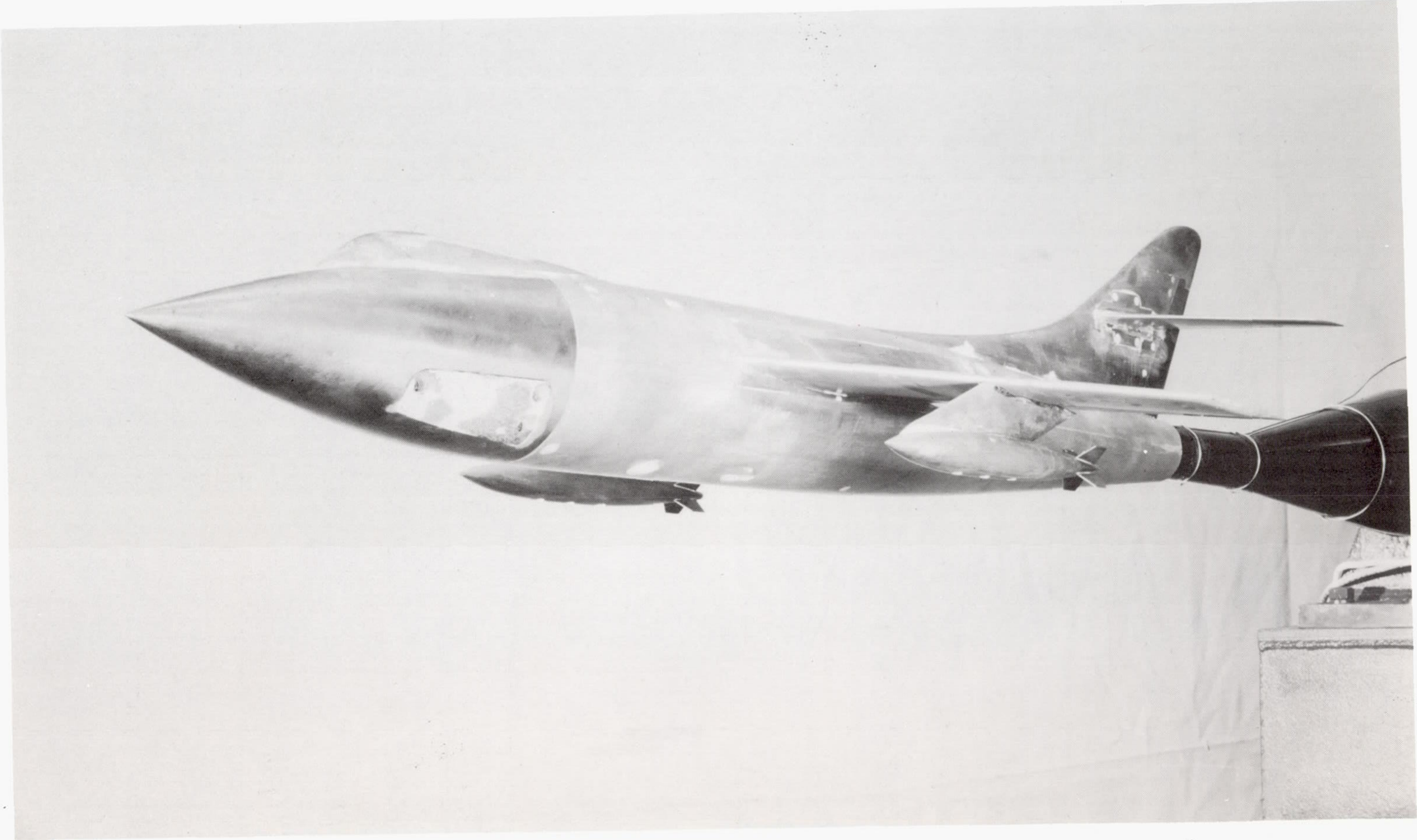
Station	Radius	Station	Radius
0	0		
.0835	.141	1.927	.483
.1670	.196	Cylindrical	
.251	.238	4.61	.483
.335	.272	4.77	.480
.418	.301	4.86	.478
.503	.326	5.03	.471
.670	.363	5.25	.455
1.087	.434	5.45	.434
1.296	.455	5.88	.364
1.506	.471	5.94	.354
1.607	.478	Straight line	
1.753	.480	7.50	0

Figure 4.- Details of WADC store. All dimensions are in inches.



Store	a	b	c	d	t
Small	0.450	0.613	0.337	0.500	1/32
Medium	.587	.791	.294	.498	3/64
Large	.690	1.092	.593	.995	1/16

Figure 5.- Store fin dimensions. All dimensions are in inches.



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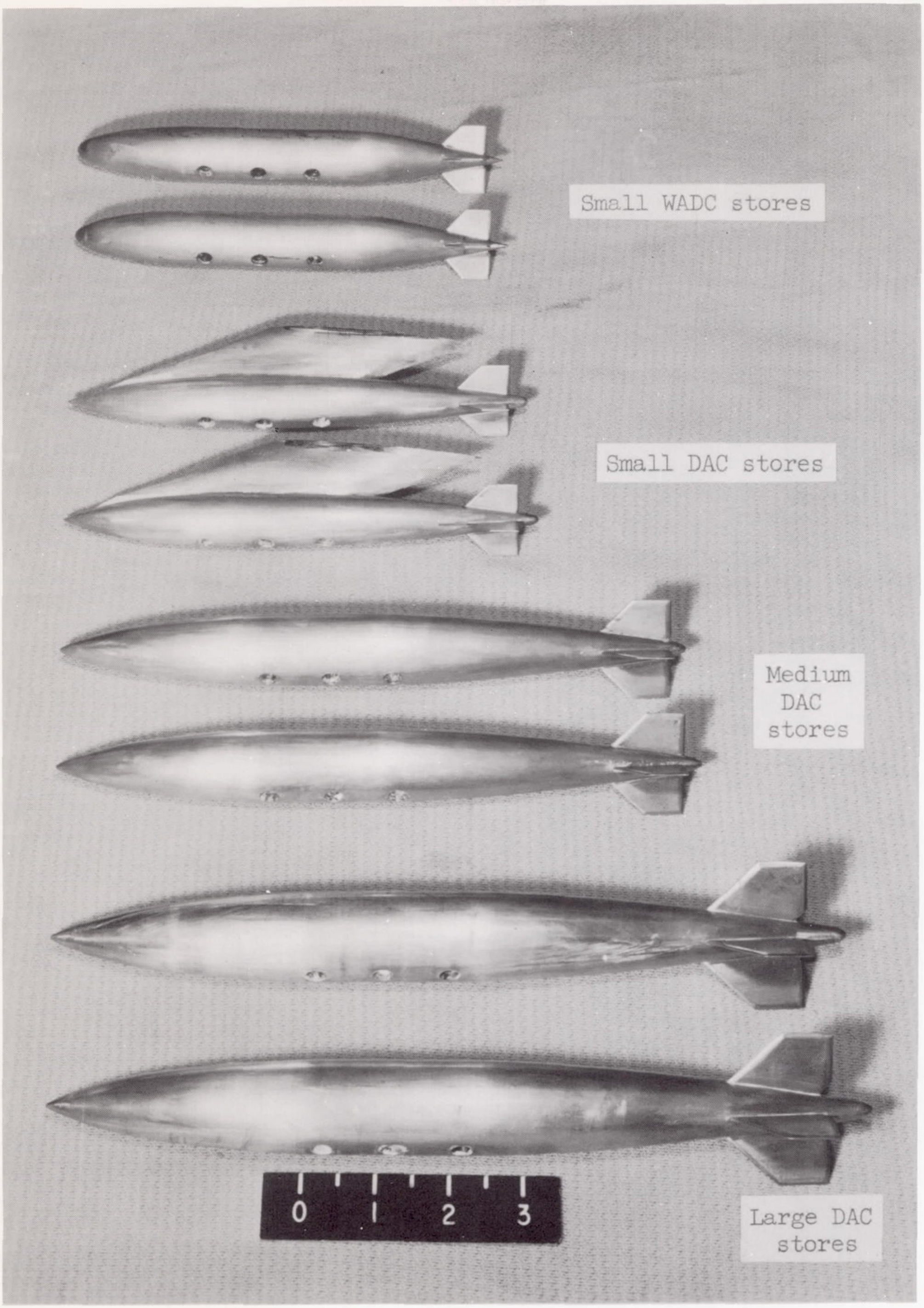
(a) Complete model with small DAC store shown.

Figure 6.- Photographs of 1/16-scale model.



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(b) Stores and pylons.

Figure 6.- Concluded.

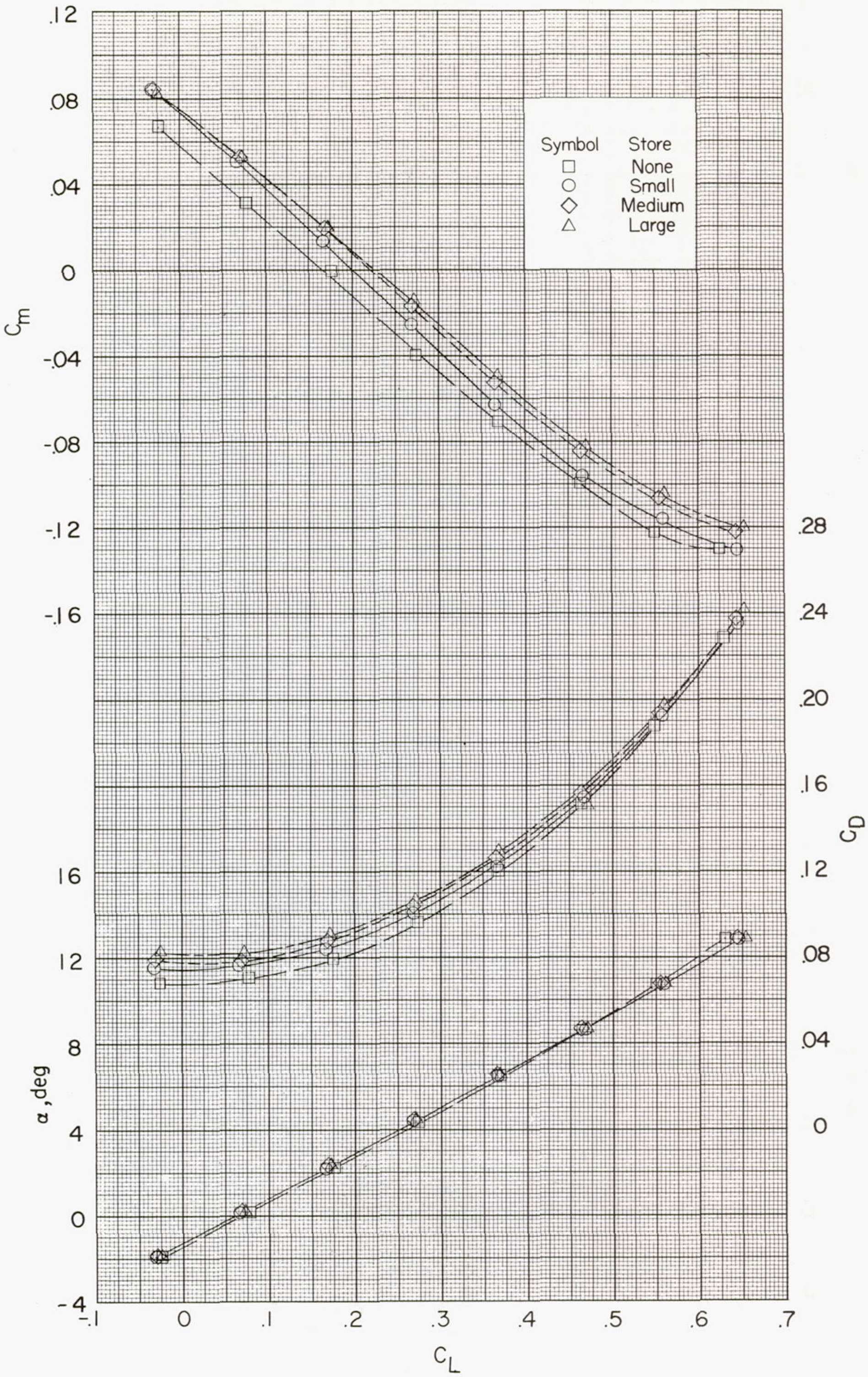

Figure 7.- Lift, drag, and pitching-moment characteristics of model with DAC stores of three sizes. Thick pylon; outboard position; $i_t = 0^{\circ}$.

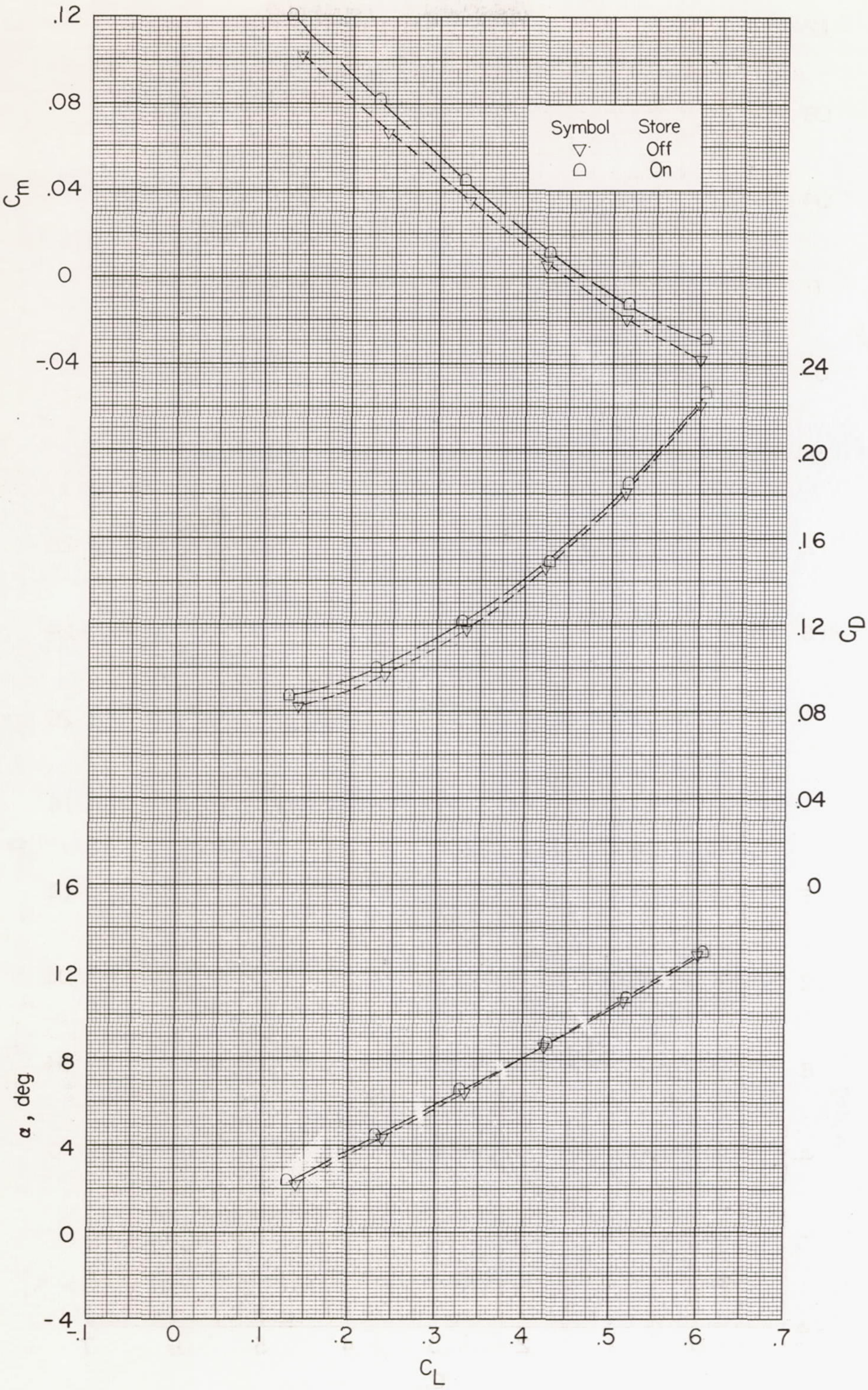

Figure 8.- Lift, drag, and pitching-moment characteristics of model with and without small DAC store. Thick pylon; outboard position; $i_t = -6^\circ$.

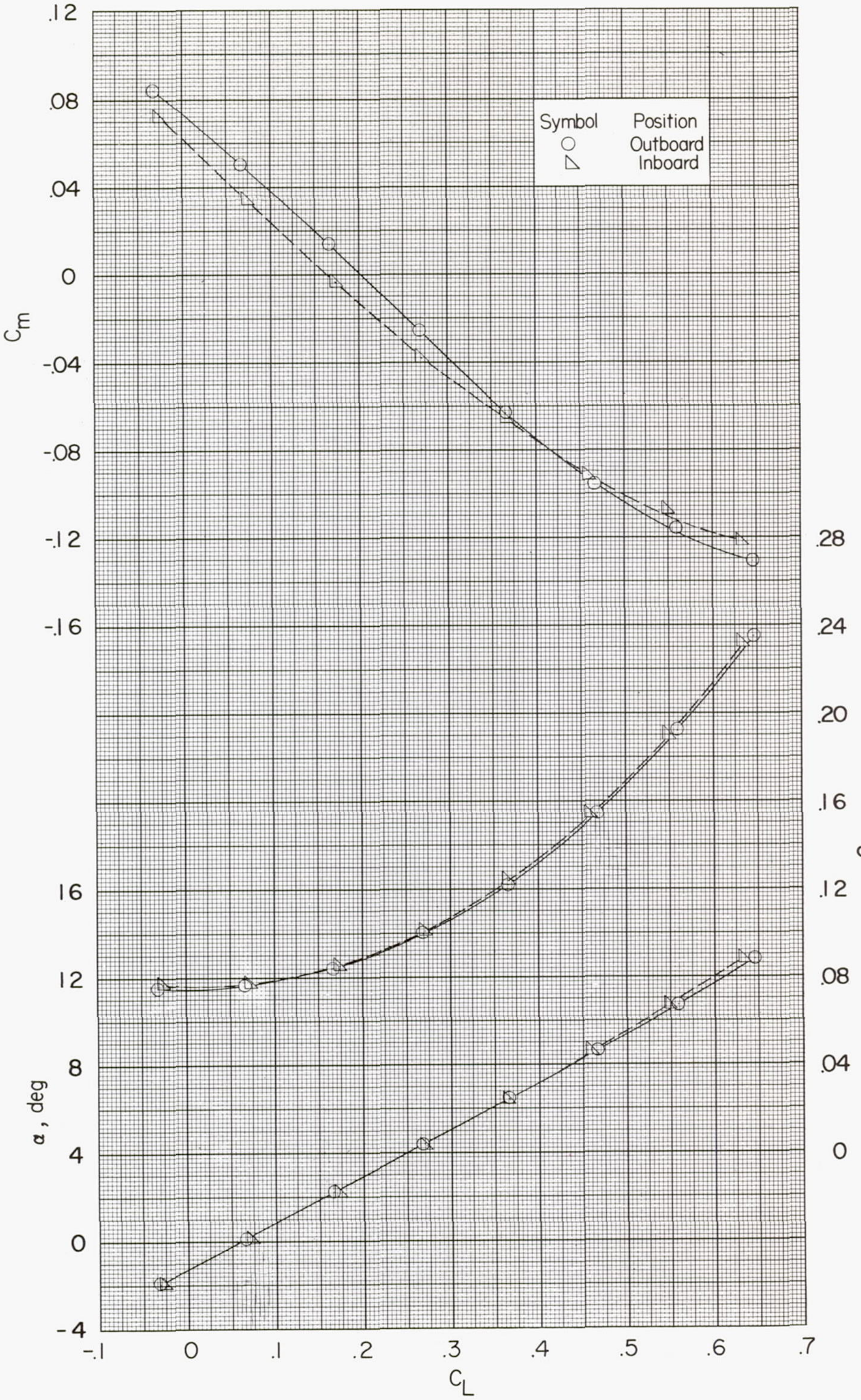

Figure 9.- Lift, drag, and pitching-moment characteristics of model with small DAC store in two spanwise positions. Thick pylon; $i_t = 0^{\circ}$.

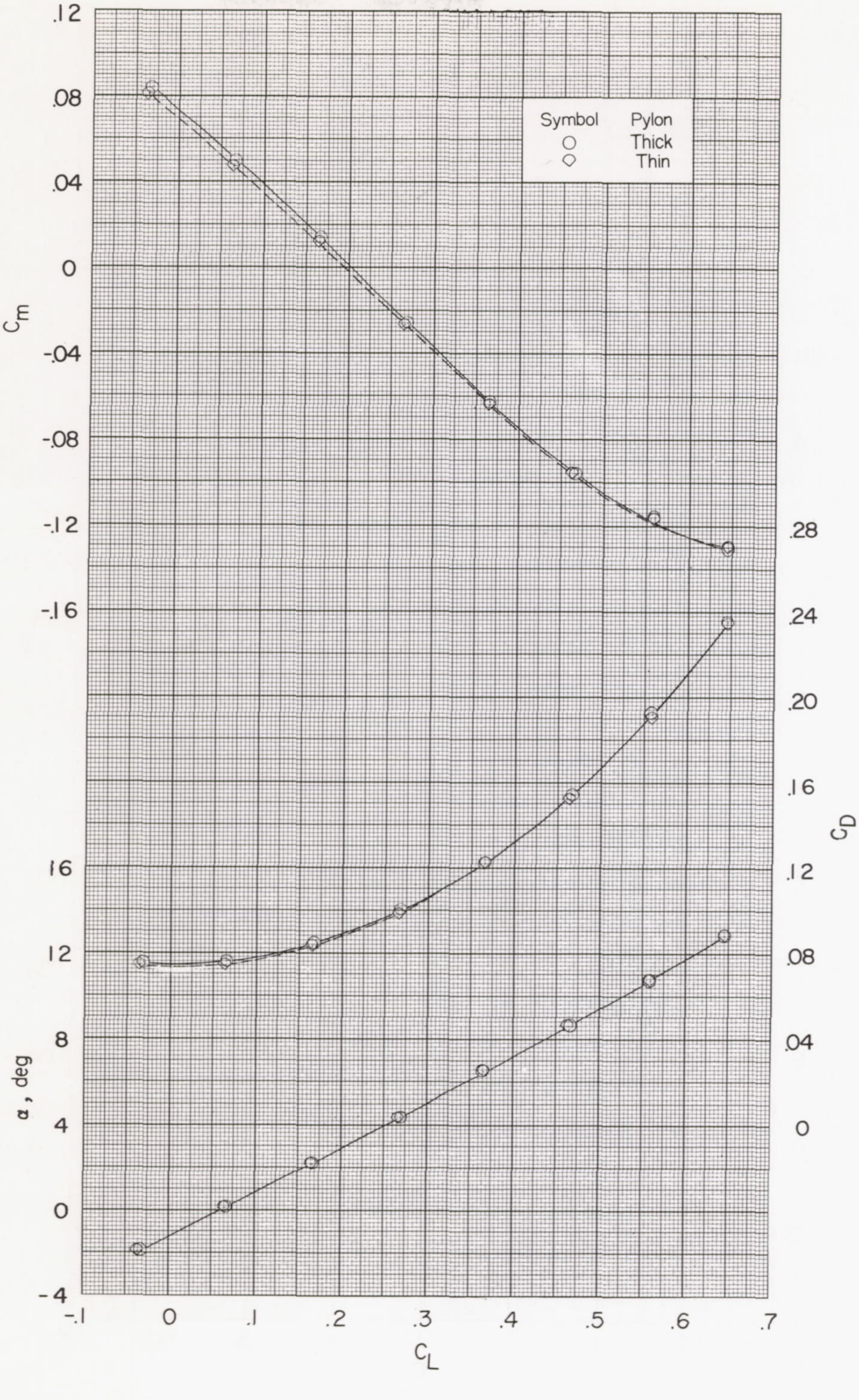

Figure 10.- Lift, drag, and pitching-moment characteristics of model with small DAC store mounted on pylons of two different thicknesses. Outboard position; $i_t = 0^{\circ}$.

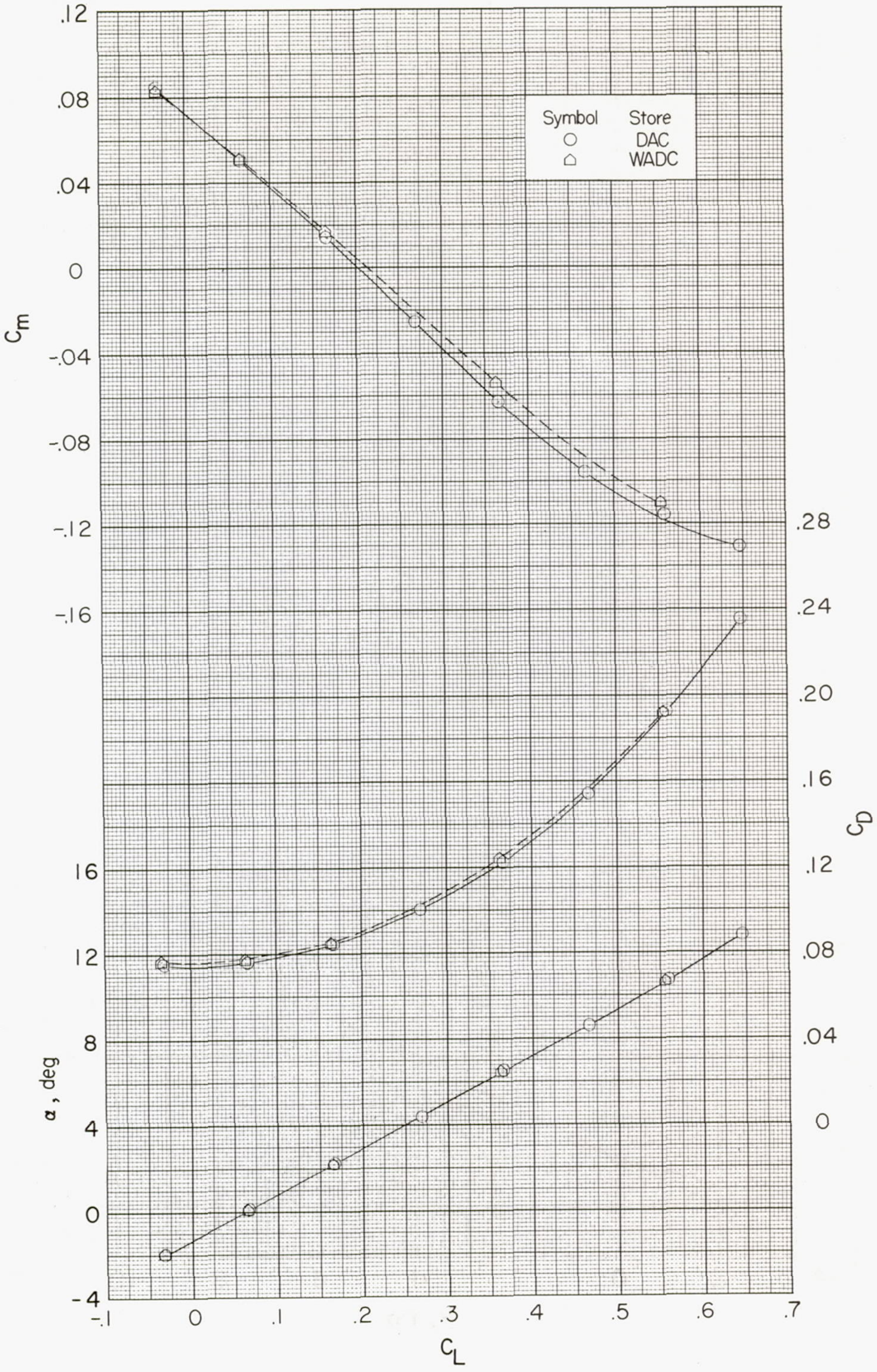

Figure 11.- Lift, drag, and pitching-moment characteristics of model with small stores of different profile. Thick pylon; outboard position; $i_t = 0^{\circ}$.

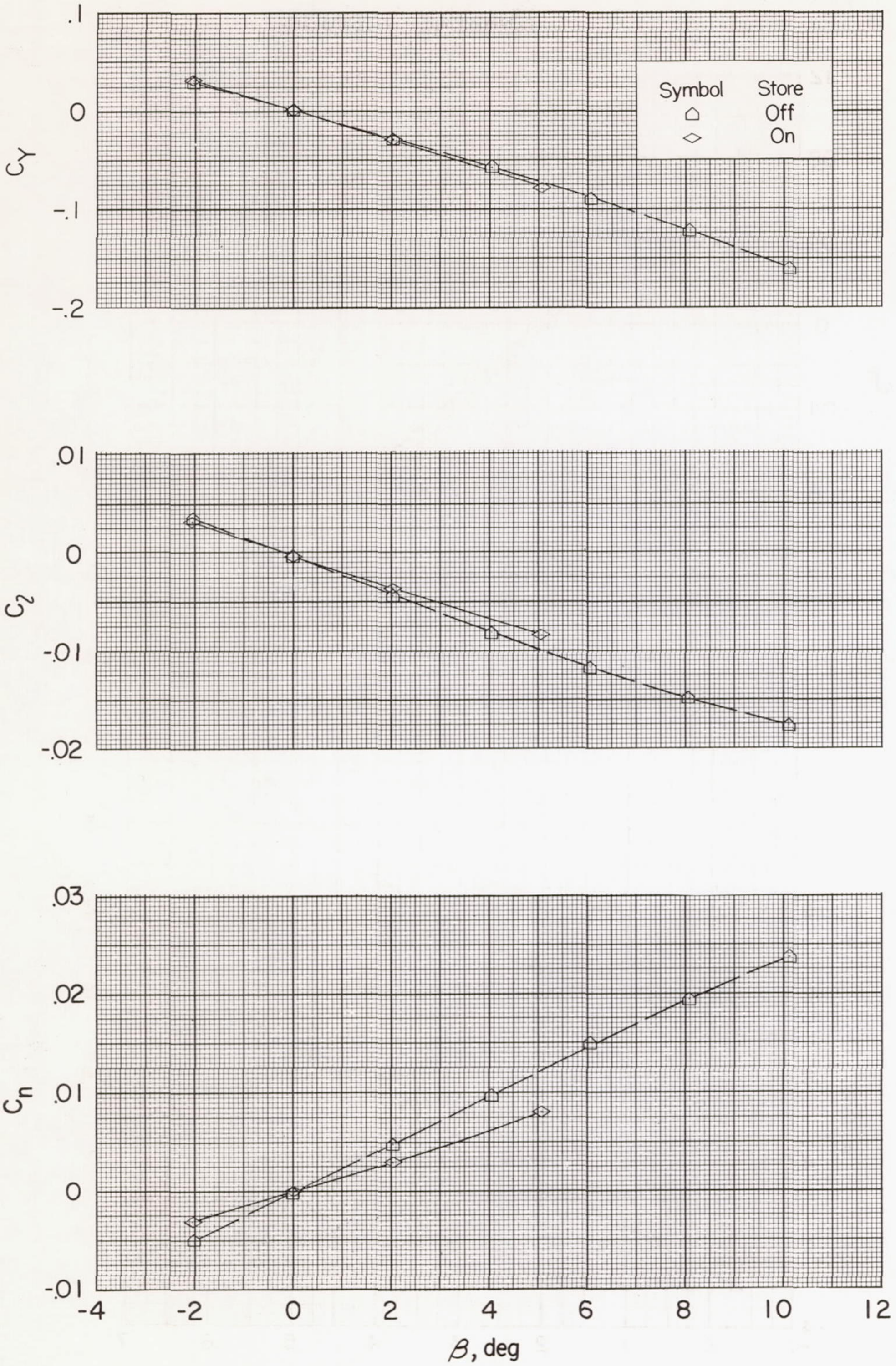

Figure 12.- Lateral stability characteristics of model with and without small DAC store. Thick pylon; outboard position; $\alpha = 0^{\circ}$; $i_t = 0^{\circ}$.

Store	ΔC_{D_F}			$\frac{\partial C_m}{\partial C_L}$
	$C_L = 0$	$C_L = 0.2$	$C_L = 0.4$	$C_L = 0.2$
Small DAC	0.53	0.49	0.29	-0.380
Medium DAC	.47	.47	.32	-.364
Large DAC	.49	.44	.33	-.340
Small WADC	.69	.65	.49	-.356
Small DAC, inboard	.65	.53	.37	-.350
Small DAC, thin pylon	.41	.45	.29	-.362
Store off				-.352

Figure 13.- Incremental drags and pitching-moment-curve slopes for model with various store configurations. Note that drag data are accurate to only one significant digit. The second digit is shown for information and possible significance.

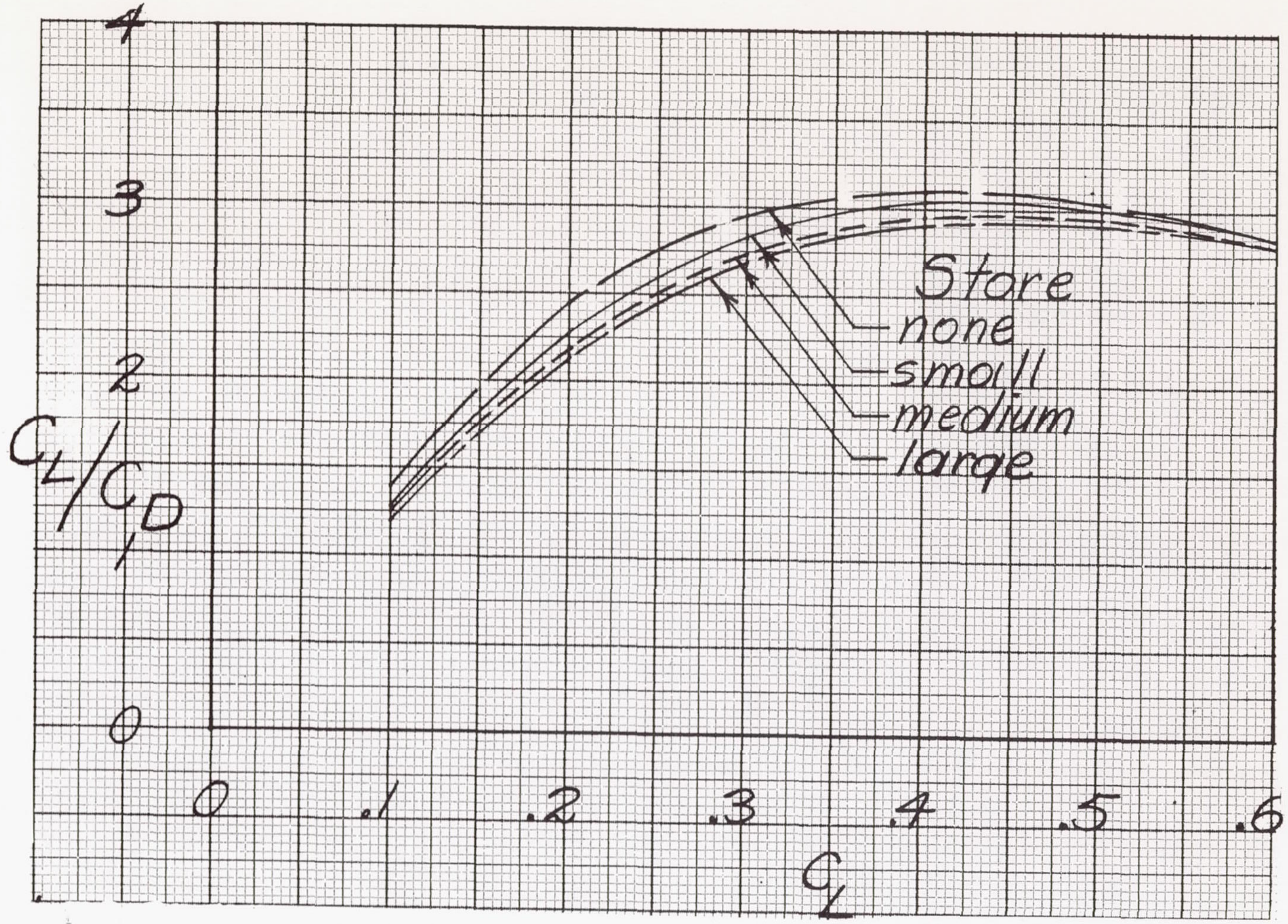

Figure 14.- Lift-drag ratios for configuration with DAC stores of three sizes.

NACA-Langley