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WIND-TUNNEL TESTS OF SEVERAL ARRANGEMENTS OF EXTERNAL AUXILIARY FUEL TANKS ON A FIGHTER-TYPE AIRPLANE

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WASHINGTON

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WIND-TUNNEL TESTS OF SEVERAL ARRANGEMENTS OF EXTERNAL AUXILIARY FUEL TANKS ON A FIGHTER-TYPE AIRPLANE

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SUMMARY

An investigation was conducted in the NACA 19-foot pressure tunnel to determine the aerodynamic effects of several arrangements of external auxiliary fuselage and wing tanks of large fuel capacity on a fighter-type airplane. Model tank arrangements of several configurations designed to hold 150 to 350 gallons of fuel were attached to a typical fighter-type airplane model for this investigation. One tank arrangement tested, of 350-gallon fuel capacity, consisted of rectangular cross-section fuselage and wing tanks mounted flush against the under surface of the airplane model. The other tank arrangements tested were hung under the fuselage and wing surfaces of the model by single struts. They were of circular cross section and of two sizes, designed for 150-gallon and 300-gallon fuel capacity full scale.

The rectangular tank arrangement of 350-gallon fuel capacity has the greatest adverse aerodynamic effect on the airplane and is the least desirable of all the configurations tested. The circular wing-tank arrangement of 300-gallon fuel capacity is not so desirable aerodynamically as either of the circular fuselage-tank arrangements inasmuch as interference effects between the wing surface and the tanks may become large with small intervening space. Flap and aileron deflections may aggravate this effect. The circular fuselage-tank arrangements of 150-gallon and 300-gallon fuel capacity showed the least effect on the aerodynamic characteristics of the airplane with a change in the maximum value of lift-drag ratio from 2.0 to 4.8 percent, respectively. Tank angles of incidence and vertical distances from the adjacent airplane surfaces, within reasonable limits, had a negligible effect.

None of the tank configurations tested had an appreciable effect on the longitudinal stability when the normal fixed center of gravity of the airplane was used as a reference. The angles of trim changed slightly but no definite trend was ascertained.

INTRODUCTION

External auxiliary fuel tanks of large capacity, which may be appended to the airplane without materially affecting its aerodynamic characteristics, are of great interest as a device for increasing range. Several military fighter airplanes now in service have flown with external auxiliary fuel tanks of small capacity for this purpose.

This paper presents the results of tests made in the NACA 19-foot pressure tunnel of several arrangements of model external auxiliary fuel tanks with full-scale capacities from 150 to 350 gallons. Range, take-off, and climb are not included in the discussion because each airplane requires a unique solution depending upon propulsive efficiency, specific fuel consumption, amount of fuel load, altitude of operation, aerodynamic characteristics of the airplane, and power characteristics of the engine, etc. It is the purpose of this paper to show, primarily, the effects of the specific fuel-tank arrangements investigated on the aerodynamic characteristics of the airplane model. The tanks were tested at various vertical distances and angles of incidence relative to the chord line of the wing. The results are indicative of the trends that may be expected with similar installations on other pursuit and fighter types of airplanes.

MODEL AND TESTS

Several arrangements of external auxiliary fuel tanks were tested on the $\frac{1}{2.75}$-scale model of the Vought-Sikorsky F4U-1 airplane in the 19-foot pressure tunnel. (See figs. 1 to 4.) This airplane model was chosen because of its availability and because it represents a typical fighter-type airplane. The general view of the model given in figure 1 shows the method of mounting in the wind-tunnel test section. General dimensions are given in figure 5.

Tanks of rectangular cross section.- Models of a rectangular fuselage tank of 200-gallon capacity and of two smaller rectangular wing tanks of 75-gallon capacity were attached to the airplane model flush with the under surfaces of the fuselage and wings, respectively. The general proportions of these tanks are rectangular when viewed from the front as shown in figure 1. This arrangement was suggested by the Army Air Forces, Materiel Command. The principal dimensions of these tanks and their positions on the model are given in figures 5, 6, and 7. The wing tanks were placed 57.5 inches from the center line of the airplane model. No fillets were used between the tanks and the airplane surfaces.

Tanks of circular cross section.- Models of a large fuselage tank of circular cross section and two smaller wing tanks of similar shape designed to hold 300 and 150 gallons, respectively, were attached to the model by struts as shown in figures 2, 3, and 4. These tanks are similar bodies of revolution, ellipsoidal in shape from the nose back to 70 percent of the total length, and then tapering conically to the trailing end with a fineness ratio of 6. The principal dimensions of these tanks and their positions on the airplane are given in figures 8, 9, 10, and 11. All the attaching struts have a cross-sectional shape similar to the longitudinal cross section of the tanks, with a length of 9.5 inches. No fillets were used at the places of attachment of the struts.

The wing tanks were also placed 57.5 inches spanwise from the center line of the model. The vertical position of the large fuselage tank (300-gal capacity) was such as to insure ground clearance with the shock absorbers and tires fully deflected in the three-point attitude. Three tank angles of incidence were tested in this position. The tank was then raised approximately one-third its diameter and again tested at three angles of incidence. The small fuselage tank (150-gal capacity) was tested at the same vertical positions as the large tank relative to the tank center line, but for only one angle in each position. The wing tanks (150-gal capacity) were tested at two vertical positions and two angles of incidence at each position. The distance from the lower surface of the wing to the center line of each tank at the hinge point, for the first position, was approximately the maximum diameter of the tank. Each tank was raised about one-third its diameter for the second position. The tanks were turned inboard 2° relative to the plane of symmetry so as to face directly into the resultant wind stream in cruising flight for each position tested.

Test conditions.- The tests were made in the NACA 19-foot pressure tunnel at atmospheric pressure and at a dynamic pressure of approximately 25 pounds per square foot. The test Reynolds number based on the mean aerodynamic chord of the wing was approximately 2,500,000.

Test procedure.- In all the runs, lift, drag, and pitching-moment measurements were made through an angle-of-attack range from -4° through the stall. The several configurations tested (see table I) differ only in tank arrangement. The runs were made without power and with the airplane control surfaces locked in the neutral position.

RESULTS AND DISCUSSION

The results of the tests of the several arrangements are summarized in table I for values of lift coefficient of 0.2 and 0.5, which correspond approximately to the high speed and the cruising speed of the airplane, respectively. Figures 12 to 16 are typical plots showing variation of lift, drag, and pitching-moment coefficients for the general arrangements tested including the plain model.

Symbols

C_L lift coefficient (L/qS)

C_D drag coefficient (D/qS)

C_m pitching-moment coefficient about center of gravity $(M/qS\bar{c})$ (center-of-gravity location used is 6.80 in. above and 2.87 in. behind model support points when geometric angle of attack of wing is 0°)

L/D ratio of lift to drag

ΔC_D difference between drag coefficient of model with tanks and that of plain model

ΔC_{D_T} drag coefficient of tank arrangement based on total frontal area of tanks $[\Delta C_D(S/S_T)]$

ΔD tank arrangement drag increment at 100 miles per hour, pounds

where

L lift

D drag

M pitching moment

q dynamic pressure in undisturbed stream, pounds per square foot

S wing area (41.6 sq ft)

S_T total frontal area of tank arrangement, square feet

$\bar{c}$ mean aerodynamic chord (2.85 ft)

and

α geometric angle of attack of root chord corrected for jet-boundary interference effects, degrees

ϕ angle between chord line of wing and center line of circular tank, degrees

d distance between lower surface of the airplane and center line of tank, inches

Drag

Rectangular tanks.- The rectangular tank arrangement is the least desirable of the arrangements tested. The values of ΔC_D for this arrangement were more than 200 percent higher than these values for any of the other arrangements investigated. For a change in the value of C_L from 0.2 to 0.5, ΔC_D showed a greater variation for this arrangement than for any other; it changed from 0.0054 to 0.0064. This result was due to the fact that the minimum drag occurred at a lower value of lift coefficient for the rectangular tanks than for the other configurations tested. Figure 17 shows variations of the tank-arrangement drag coefficient based on the total frontal area.

Circular tanks.- The circular fuselage-tank arrangements have the smallest values of ΔC_D. The large circular tank gave slightly higher values than the small circular tank but it must be remembered that it has twice the fuel capacity. The tank angles of incidence and vertical position had small effects on the values of ΔC_D obtained for each arrangement. The circular wing-tank arrangement had slightly more drag than the fuselage tanks, and this result may be due to interference effects between the tanks and the wing surfaces. It would seem more desirable to have the vertical distance of the wing tanks as large as feasible to avoid these interference effects, which may be large with the ailerons or flaps deflected. A small improvement would be expected with fillets between the struts and attached surfaces.

Figure 17 shows the variation of the drag coefficients of the several tank arrangements based on their total frontal area with the lift coefficient of the airplane. The frontal areas of the circular tanks of various lengths are given in figure 18.

Maximum Lift Coefficient

The rectangular tanks decreased the value of the maximum lift coefficient of the plain airplane model from approximately 1.40 to 1.29. The values of maximum lift coefficient for the circular tank were not decreased so much, as they all fell in a range of from 1.32 to 1.35 with the exception of two arrangements, one of the large circular fuselage tank and one of the circular wing-tank arrangement, which gave values of $C_{L_{max}}$ of 1.36 and 1.31, respectively. (See table I.) Inasmuch as all maximum values of C_L obtained fell within these limits it may be said that the addition of any arrangement of tanks had a small effect on the maximum lift coefficient of the plain airplane. The average decrease is about 4 percent. This decrease would indicate a slight effect on the landing speed with tanks empty and with flaps and controls properly set.

Maximum L/D

The percentage change of the maximum value of L/D for the airplane when tanks are attached will not necessarily be the same for any other fighter-type airplane. The maximum values of L/D of the model tested varied from 14.16 for the airplane without tanks to 11.94 for the airplane with rectangular tanks. The addition of the rectangular tanks lowered the maximum value of L/D by 15.7 percent. The addition of the circular fuselage tanks lowered the maximum value of L/D by 2 percent for the best arrangement. The values of d and ϕ of the circular fuselage tanks had small effects on the maximum values of L/D. The best arrangement of circular wing tanks lowered the maximum value of L/D by 4.8 percent. Here again changes in the values of d and ϕ had little effect on the change of $(L/D)_{max}$. The optimum arrangement of circular wing tanks, with the tanks farther away from the wing surface and at approximately zero angle of attack at the cruising condition (d = 8.16 in. and $\phi = 6.0^{\circ}$), showed slightly better aerodynamic characteristics, however, than the other circular wing-tank arrangements.

The results of these tests show that the addition of external auxiliary fuel tanks for any conventional fighter airplane should increase the range from 2500 to 3500 miles.

Longitudinal Stability

Center-of-gravity location.- The tanks of rectangular cross section were attached to the airplane model in a manner suggested by the Army Air Forces, Materiel Command. The center-of-gravity location for each of these tanks fully loaded is shown in figure 5. The normal center of gravity of the plain airplane would be lowered and moved rearward with the addition of these tanks. Figures 9 and 10 show the center-of-gravity location of the circular cross-section tanks fully loaded relative to the normal fixed center of gravity of the plain airplane. All the circular tanks were so attached that their center-of-gravity positions were directly under the center of gravity of the plain airplane at the high-speed condition for all the configurations tested. The position of the resultant center of gravity would thus be lowered and moved ahead with the airplane flying in the region of $(L/D)_{max}$ with tanks full. This condition would tend to increase the negative values of dC_m/dC_L and would therefore give more longitudinal stability. The resultant center-of-gravity location will vary with the weight of fuel in the tanks. This effect will depend upon the geometry of the tank installation. As the weight of the fuel is diminished during flight, the center-of-gravity location will move forward if the tanks are pointed downward and rearward if the tanks are pointed upward. If this effect is serious in any installation, a suggested remedy would be to divide the tanks into several compartments. The fuel could thus be drained simultaneously and progressively from each end to the center of the tanks. The determination of the center-of-gravity location of the complete airplane with external auxiliary fuel tanks involve other weight variables such as the weight of the empty tanks and the necessary additional structure for attachment, which are matters of specific design.

Pitching-moment coefficients.- The typical pitching-moment-coefficient curves presented in figures 12 to 16 have been referred to the fixed normal center of gravity of the plain airplane to facilitate comparisons of the aerodynamic effects on the airplane longitudinal stability due to the addition of external auxiliary fuel tanks. There is no appreciable change in dC_m/dC_L because of the addition of the tanks. The trim angles vary, however, but no definite trends are apparent.

CONCLUSIONS

1. The rectangular tanks were the least desirable of the tank arrangements investigated because of comparatively large adverse aerodynamic effects on the airplane.

2. The circular wing tanks showed a tendency to decrease the maximum value of the lift-drag ratio with a decrease in the distance between the wing surface and the tanks. This effect was apparently due to interference and may become more pronounced with flap and aileron deflections.

3. The circular fuselage tank angle of incidence and vertical distance from the airplane surface, within reasonable limits, had a negligible effect on the aerodynamic characteristics of the complete airplane.

4. The addition of circular fuselage tanks of 150-gallon and 300-gallon fuel capacity lowered the maximum

value of the lift-drag ratio of the airplane from 2.0 to 4.8 percent, respectively. These tank arrangements are considered the most desirable of the configurations investigated.

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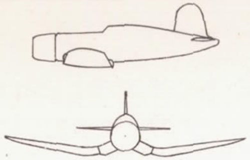
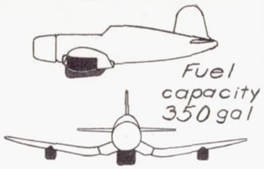
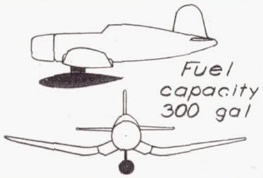
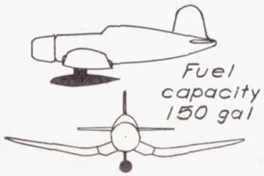
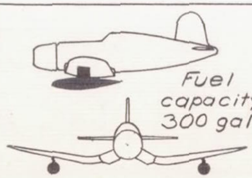
TABLE I.- SUMMARY OF RESULTS

Configuration	Tank		$C_{L_{max}}$	$(L/D)_{max}$	$C_L = 0.2$					$C_L = 0.5$				
	d (in.) (a)	ϕ (deg) (b)			C_D	ΔC_D	L/D	C_{D_T} (c)	ΔD (lb) (d)	C_D	ΔC_D	L/D	C_{D_T}	ΔD (lb)
	—	—	1.395	14.16	0.0191	—	10.42	—	—	0.0354	—	14.12	—	—
 Fuel capacity 350 gal	—	—	1.292	11.94	0.0245	0.0054	8.16	0.1296	5.75	0.0418	0.0064	11.26	0.1536	6.81
 Fuel capacity 300 gal	12.81	6.4	1.335	13.80	0.0205	0.0014	9.71	0.0912	1.49	0.0372	0.0018	13.40	0.1172	1.92
		9.1	1.358	13.79	.0207	.0016	9.66	.1042	1.70	.0369	.0015	13.54	.0976	1.60
		11.1	1.349	13.61	.0205	.0014	9.76	.0912	1.49	.0372	.0018	13.44	.1172	1.92
	9.31	6.1	1.329	13.49	.0208	.0017	9.62	.1107	1.81	.0373	.0019	13.44	.1237	2.02
		8.9	1.325	13.66	.0206	.0015	9.66	.0977	1.60	.0370	.0016	13.51	.1042	1.70
		11.1	1.333	13.62	.0209	.0018	9.52	.1172	1.92	.0368	.0014	13.59	.0912	1.49
 Fuel capacity 150 gal	12.81	5.7	1.340	13.88	0.0200	0.0009	10.00	0.0930	0.96	0.0367	0.0013	13.62	0.1344	1.38
	9.31	5.6	1.340	13.80	.0197	.0006	10.15	.0517	0.53	.0365	.0011	13.70	.1137	1.17
 Fuel capacity 300 gal	8.16	2.7	1.310	13.25	0.0212	0.0021	9.44	0.1086	2.23	0.0381	0.0027	13.12	0.1396	2.88
		6.0	1.326	13.47	.0215	.0024	9.30	.1240	2.56	.0377	.0023	13.26	.1189	2.45
	5.74	2.7	1.329	13.11	.0214	.0023	9.35	.1189	2.45	.0384	.0030	13.02	.1550	3.19
		5.1	1.327	13.40	.0216	.0025	9.26	.1292	2.66	.0383	.0029	13.05	.1499	3.09

[a] d, distance from airplane lower surface to center of gravity of the tank.
[b] ϕ, angle between center line of tank and chord line of wing.
[c] C_{D_T}, drag coefficient of tank arrangement based on frontal area of tanks.
[d] ΔD, tank arrangement drag increment at 100 mph.

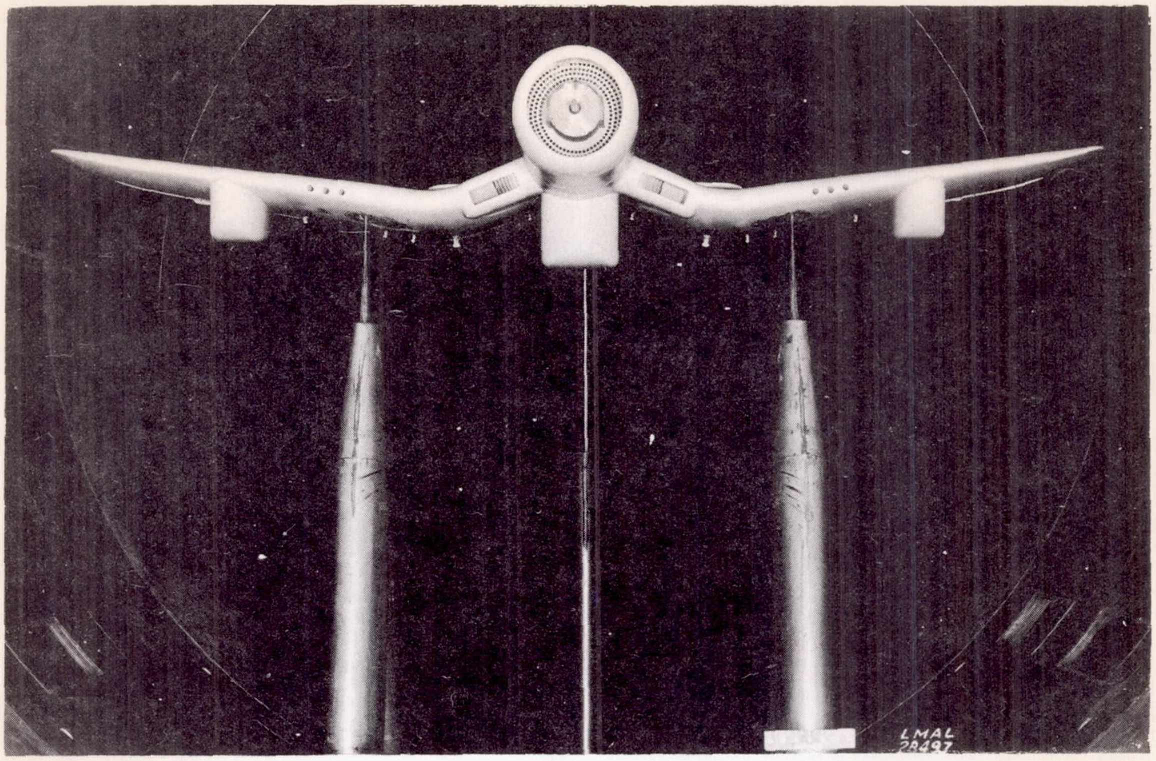


Figure 1.- Airplane model with the rectangular external auxiliary fuel tanks.

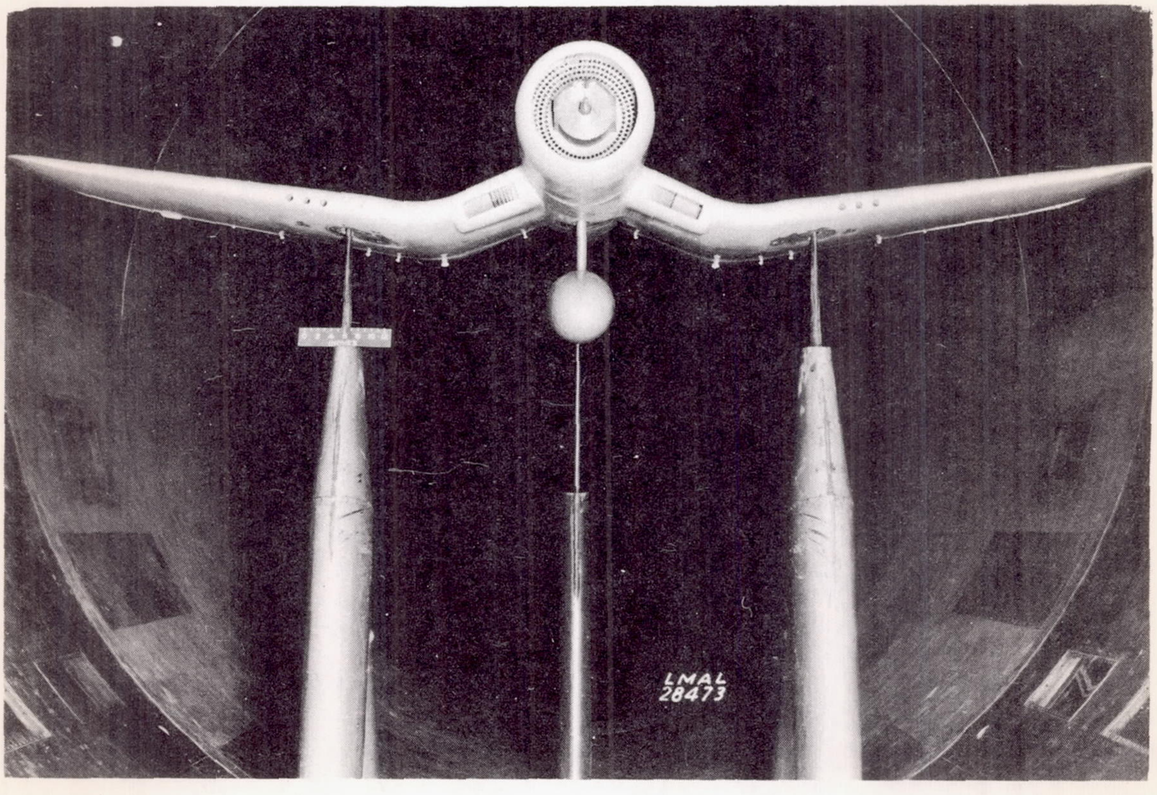


Figure 2.- Airplane model with the large circular external auxiliary fuel tank under the fuselage.

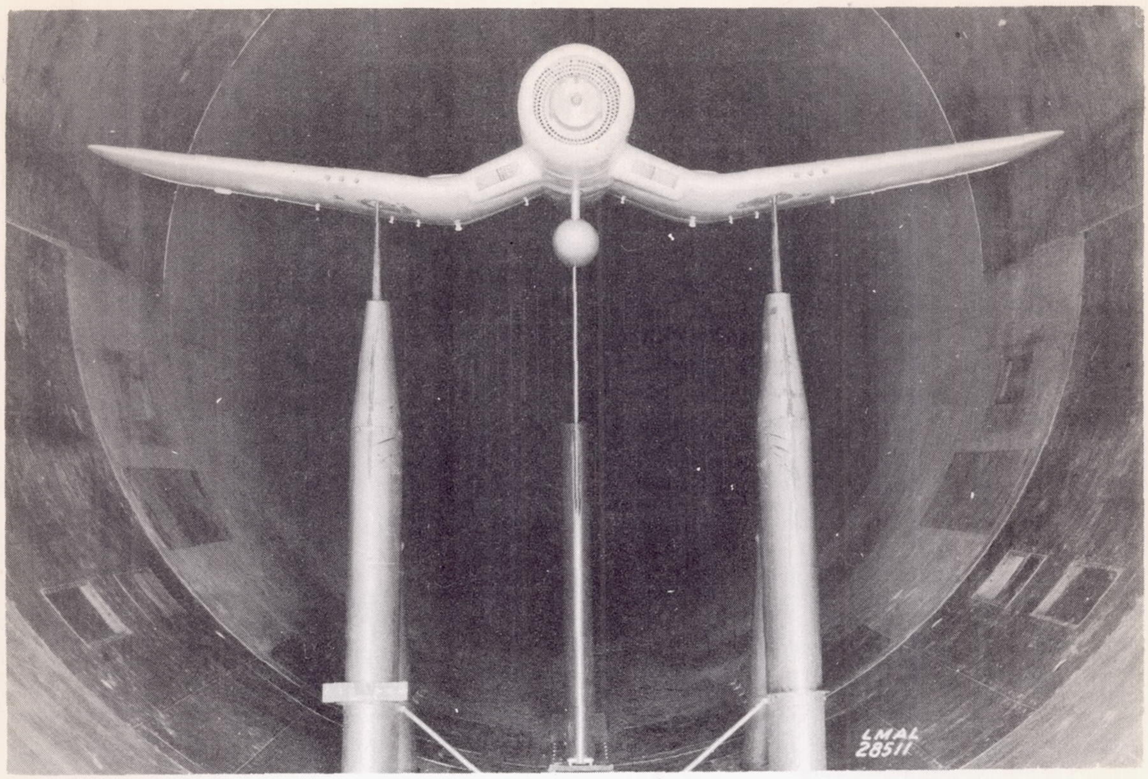


Figure 3.- Airplane model with the small circular external auxiliary fuel tank under the fuselage.

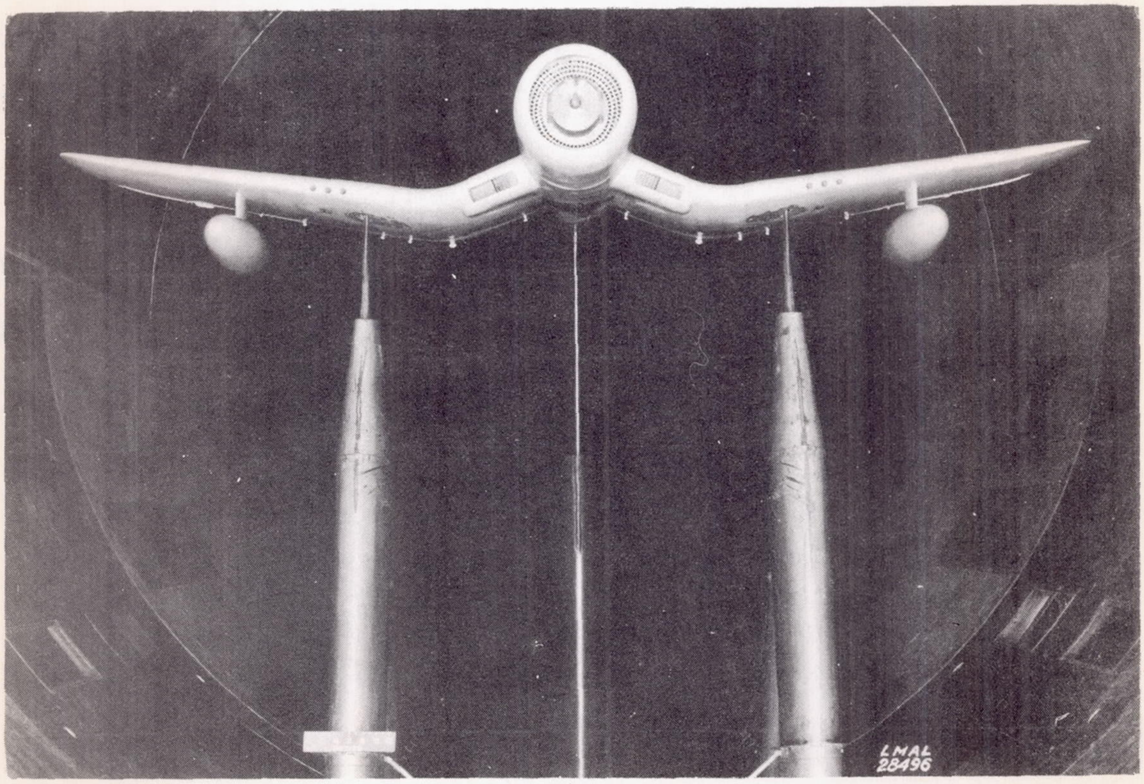


Figure 4.- Airplane model with the circular external auxiliary fuel tanks under the wing.

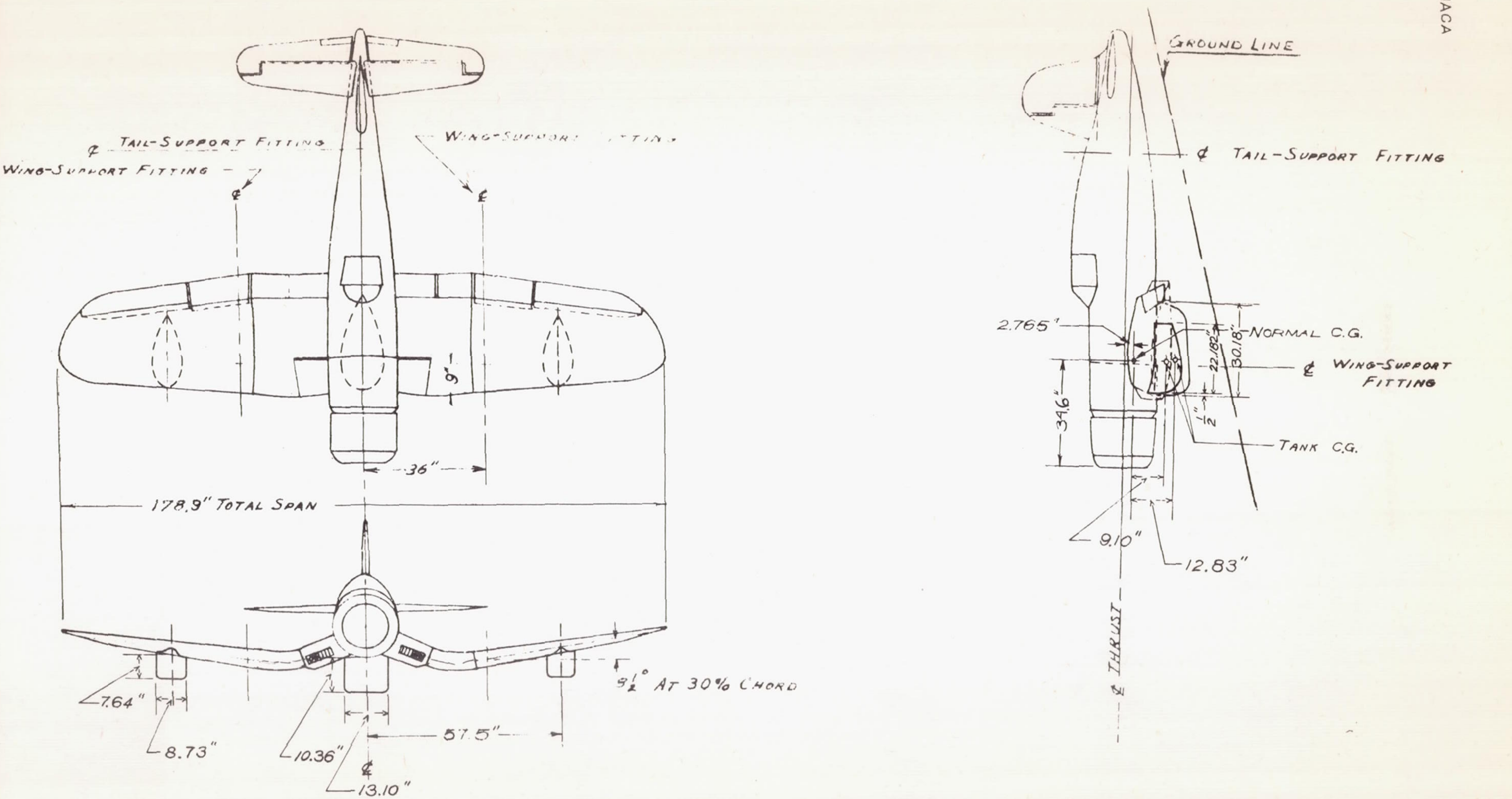
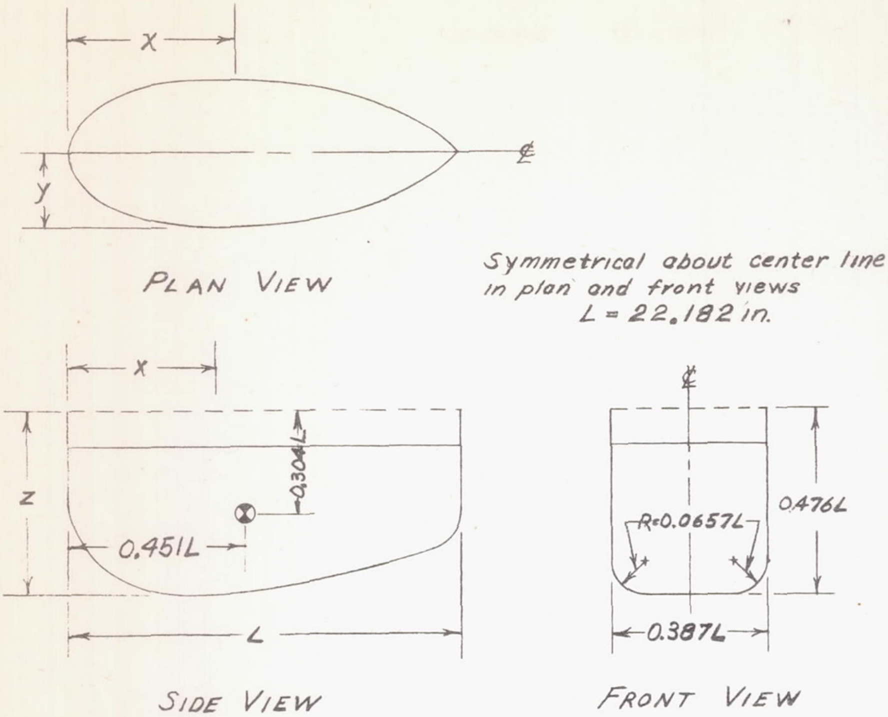
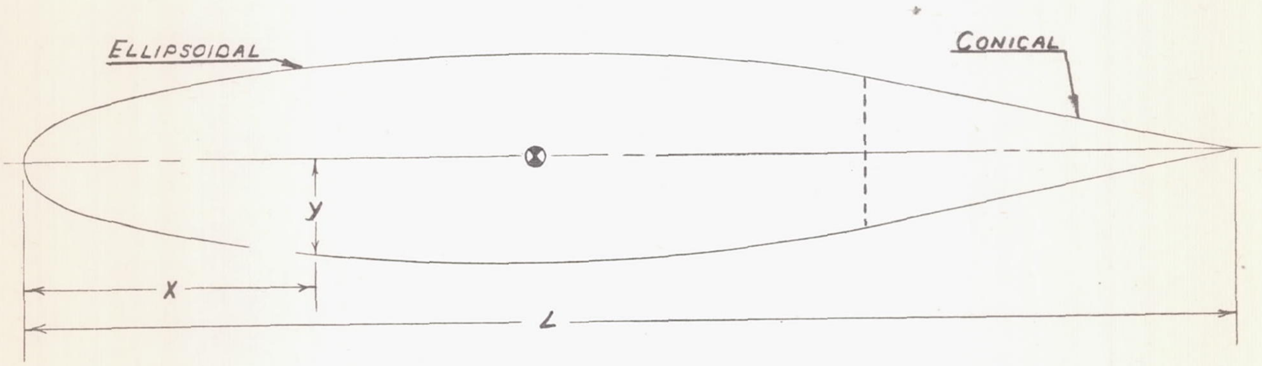


Figure 5.- Plan and elevation views of the F4U-1 airplane model with the rectangular external auxiliary fuel tanks.



X (% of L)	y (% of L)	Z (% of L)
0	0	26.30
.25	2.35	28.50
.50	3.61	29.62
.75	4.39	30.45
1.00	4.87	31.10
5.00	9.92	38.88
10.00	18.53	42.75
15.00	15.93	45.25
20.00	17.37	46.60
25.00	18.31	47.40
30.00	18.95	47.60
40.00	19.35	47.15
50.00	18.76	45.79
60.00	17.86	43.92
70.00	16.19	41.88
80.00	13.17	39.60
85.00	11.24	38.25
90.00	8.47	37.00
95.00	4.96	34.95
98.00	2.13	33.02
100.00	0	29.31

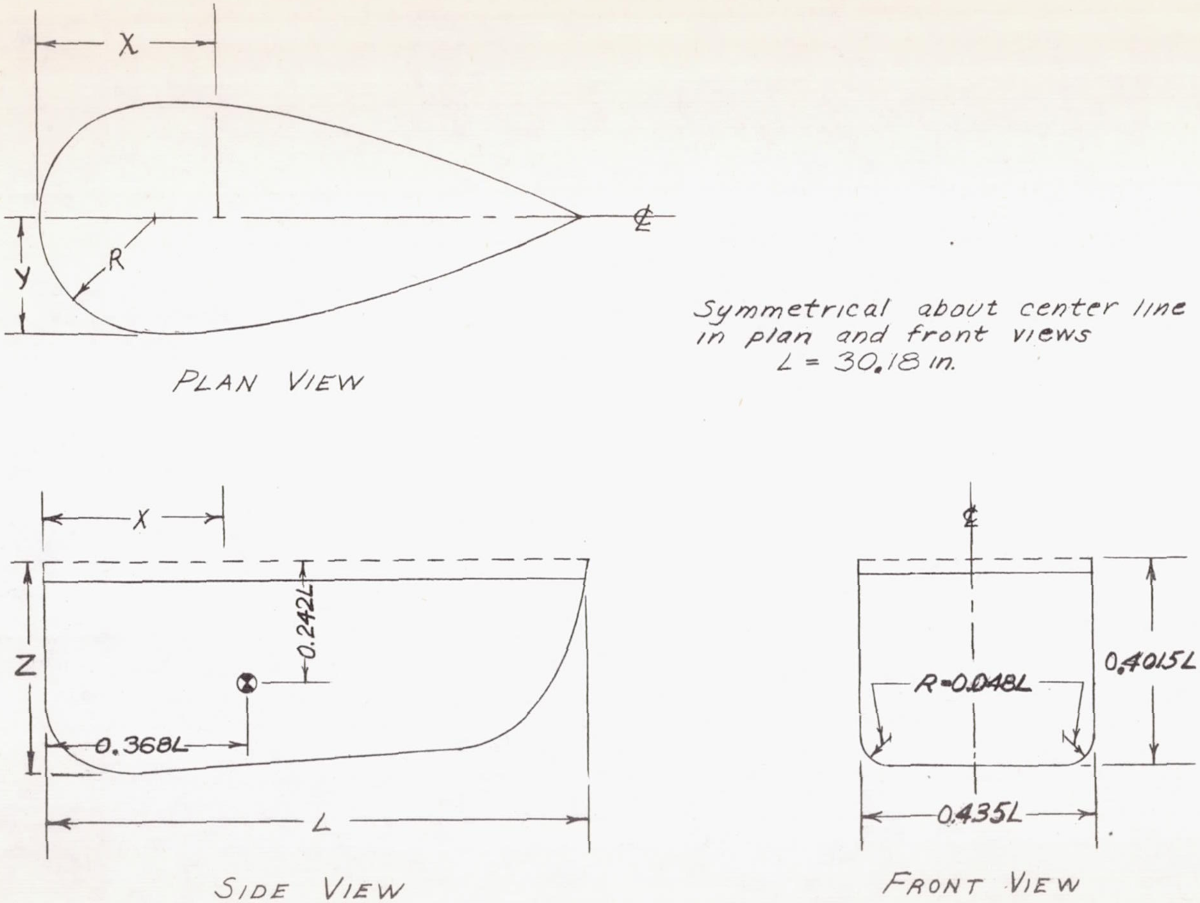
Figure 6.- Plan and elevation views of the small rectangular external auxiliary fuel tanks for the wing.



SMALL AUXILIARY FUEL TANK, L = 51.5 IN.
LARGE AUXILIARY FUEL TANK, L = 64.89 IN.
C. G. LOCATION = 0.42 L, FROM NOSE.

Sta. X, % of L	0	1.25	2.50	5.00	10.00	15.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00
Ord. Y % of L	0	2.04	2.85	3.96	5.54	6.46	7.12	8.00	8.33	8.17	7.48	6.11	4.08	2.04	0

Figure 8.- Sketch showing general dimensions of the circular tanks.



X (% of L)	Y (% of L)	Z (% of L)
0	0	30.70
.25	.30	32.23
.50	4.88	32.80
.75	5.67	33.40
1.00	6.50	33.77
5.00	13.80	37.40
10.00	18.25	39.10
15.00	20.60	39.95
20.00	21.70	40.15
25.00	21.75	40.00
30.00	21.75	39.70
40.00	21.01	38.90
50.00	18.95	38.10
60.00	16.30	37.35
70.00	13.05	36.60
80.00	9.25	35.61
85.00	7.30	33.50
90.00	5.15	29.29
95.00	2.85	22.00
98.00	1.36	16.20
100.00	0	4.68
R = 21.75 % of L		

Figure 7.- Plan and elevation views of the large rectangular external auxiliary fuel tank for the fuselage.

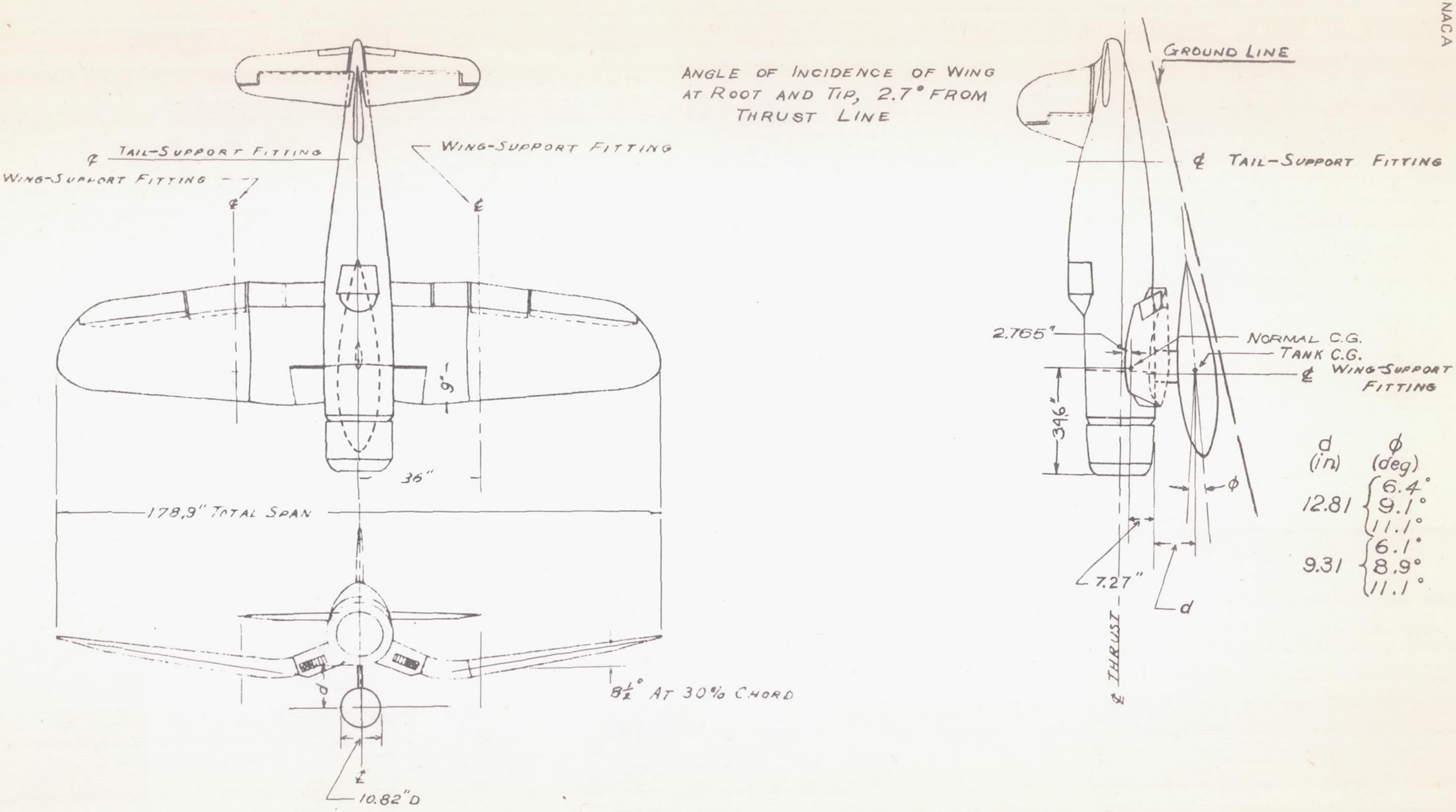


Figure 9.- Plan and elevation views of the airplane model with the large circular external auxiliary fuel tank for the fuselage.

NACA

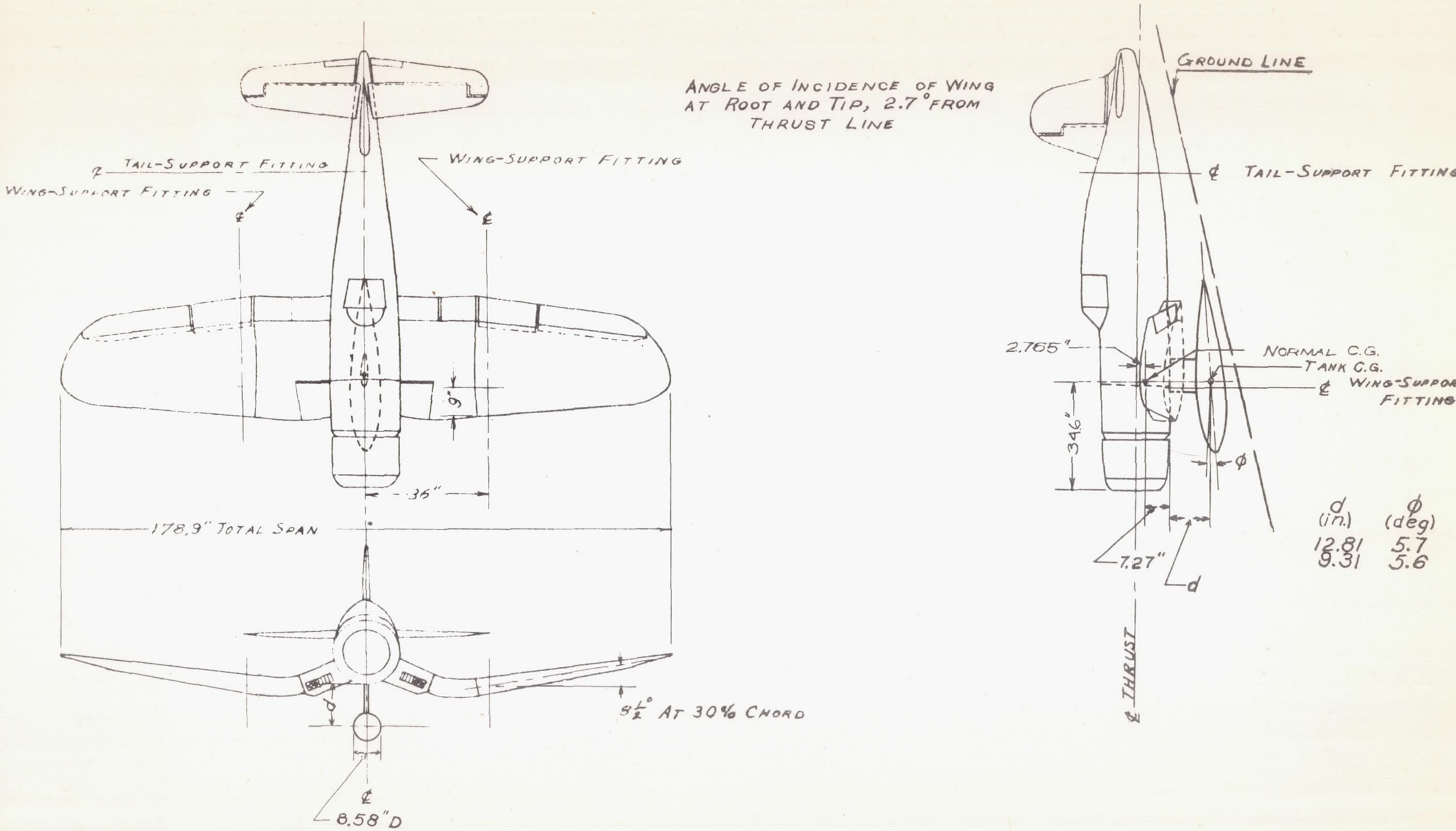


Figure 10.- Plan and elevation views of the airplane model with the small circular external auxiliary fuel tank for the fuselage.

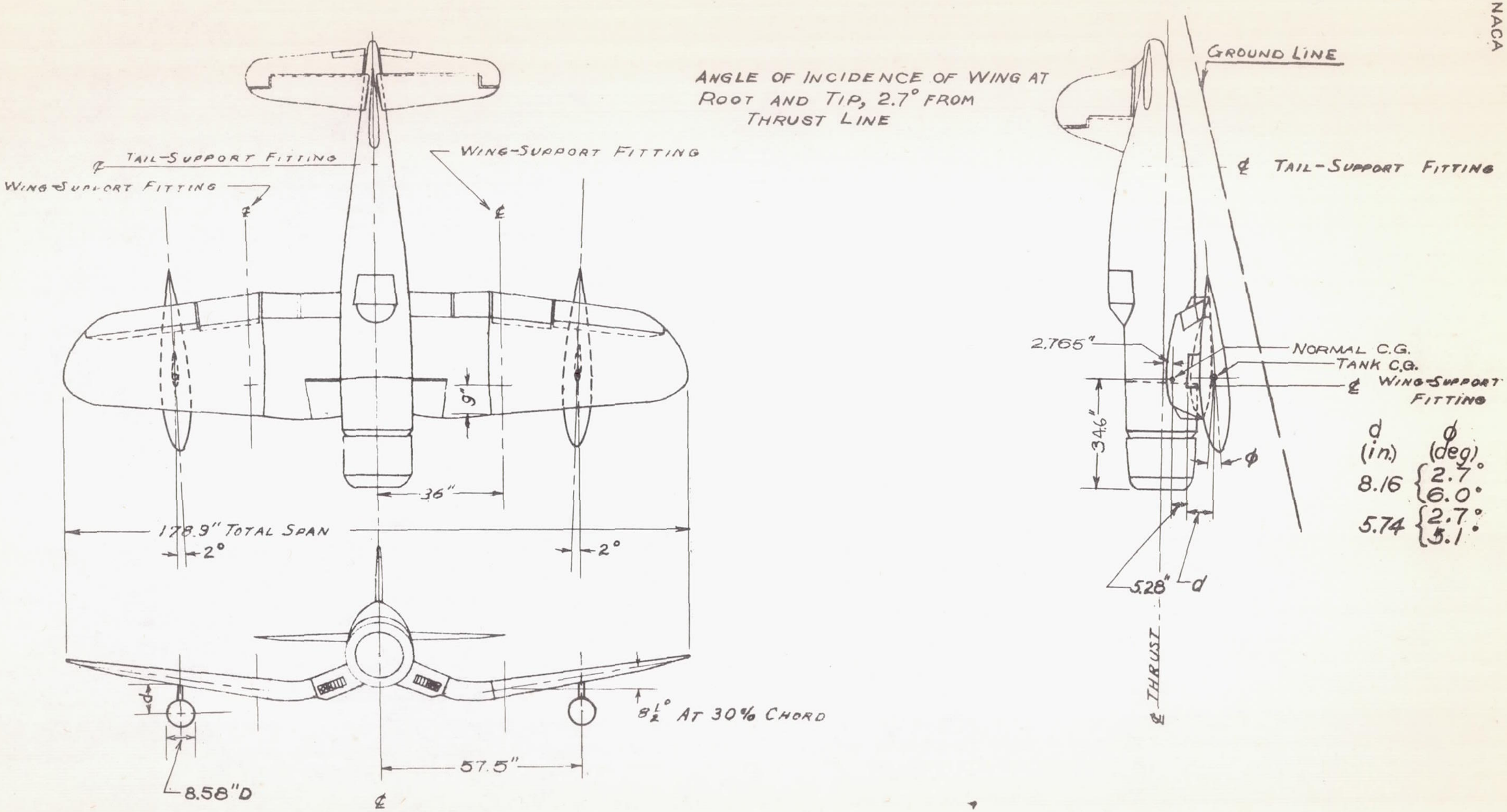


Figure 11.- Plan and elevation views of the airplane model with the circular external auxiliary fuel tanks for the wing.

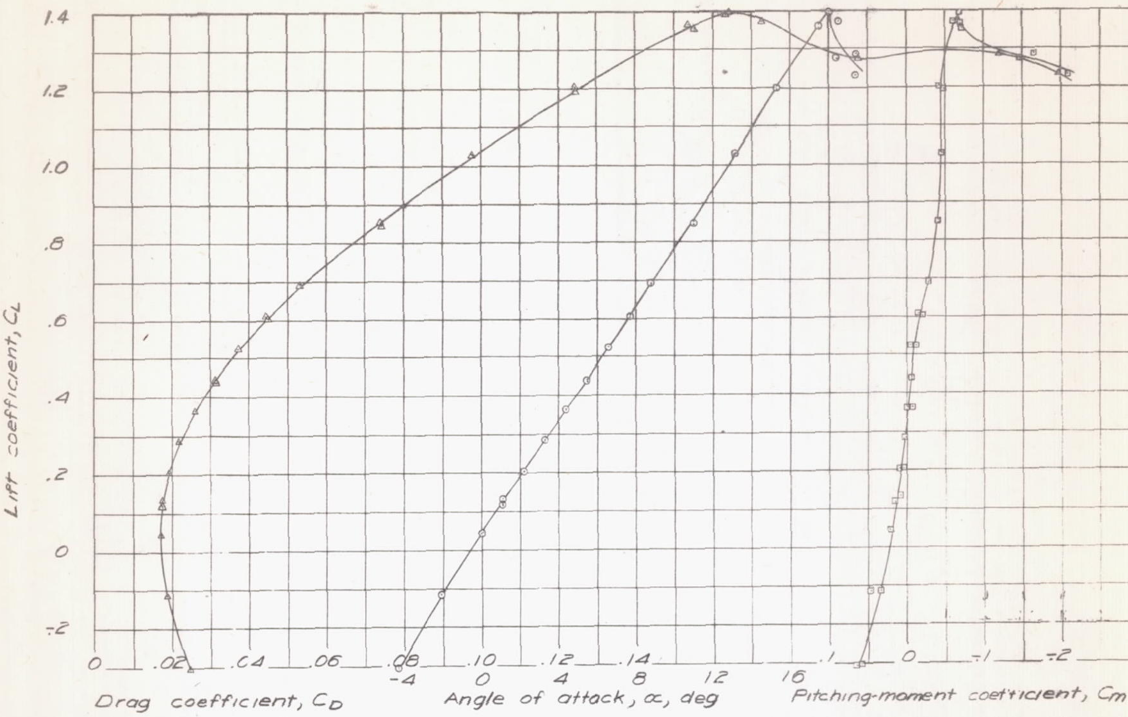


Figure 12.- Variation of C_D, α, and C_m with C_L for the airplane model without external auxiliary fuel tanks.

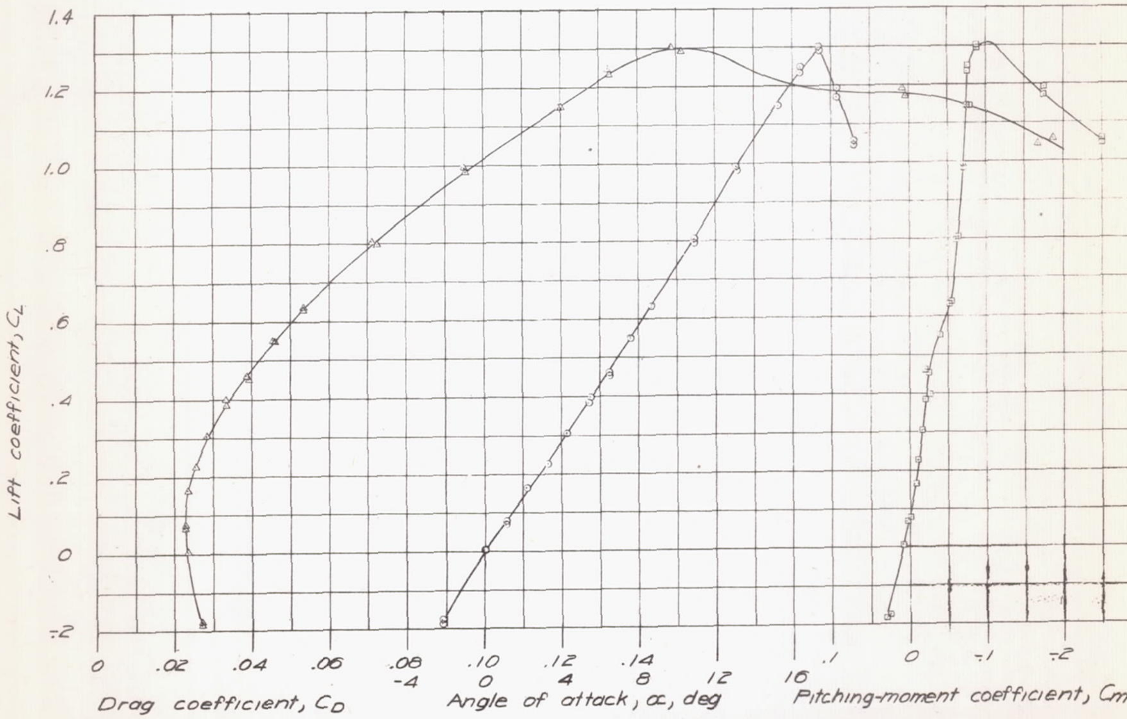


Figure 13.- Variation of C_D, α, and C_m with C_L for the airplane model with the rectangular external auxiliary fuel tanks.

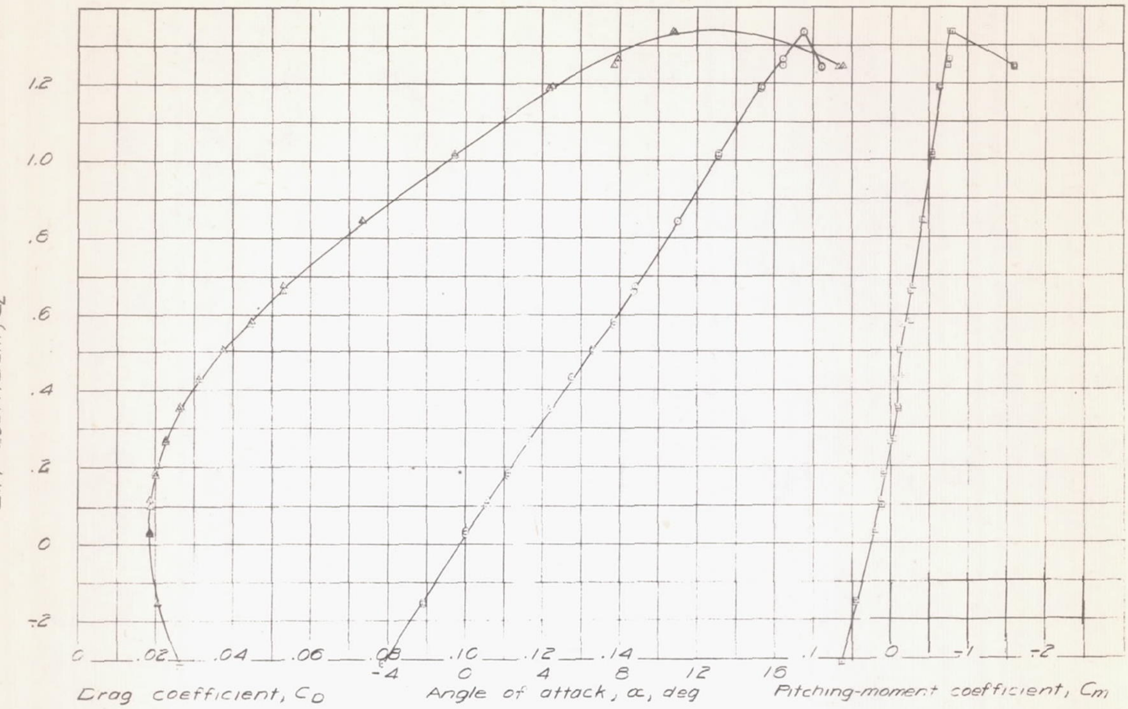


Figure 14.- Variation of C_D, α, and C_m with C_L for the airplane model with the large circular external auxiliary fuel tank for the fuselage. d=12.81 in.; φ=6.4°.

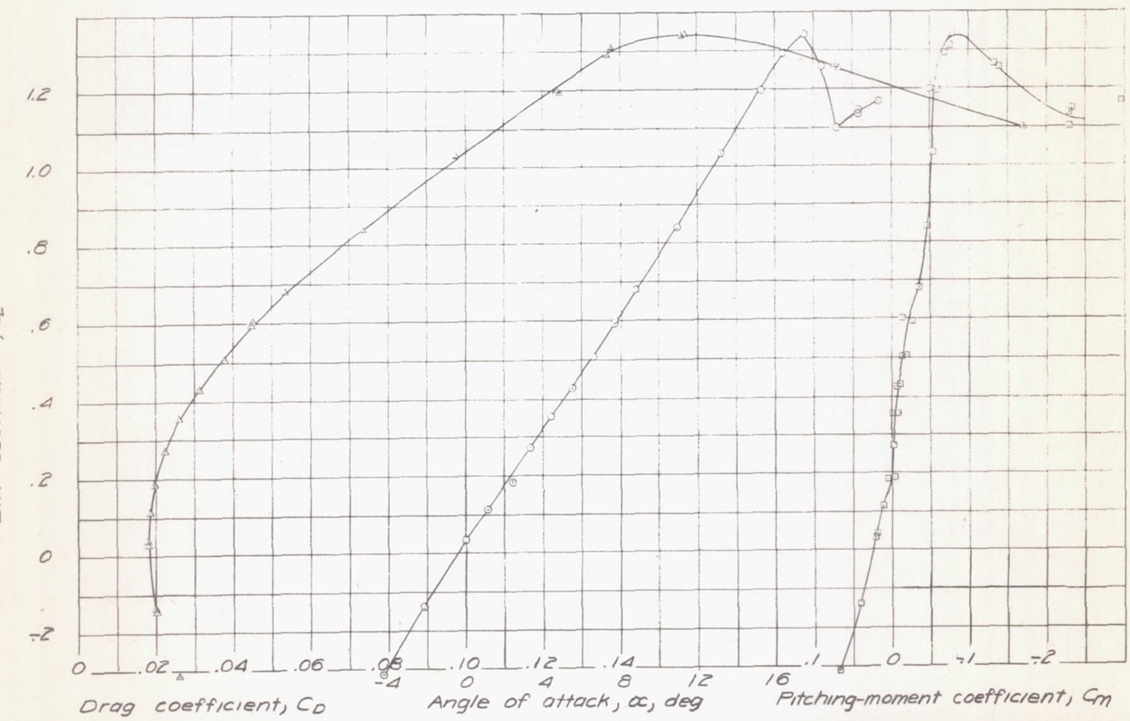


Figure 15.- Variation of C_D, α, and C_m with C_L for the airplane model with the small circular external auxiliary fuel tank for the fuselage. d=12.81 in.; φ=5.7°.

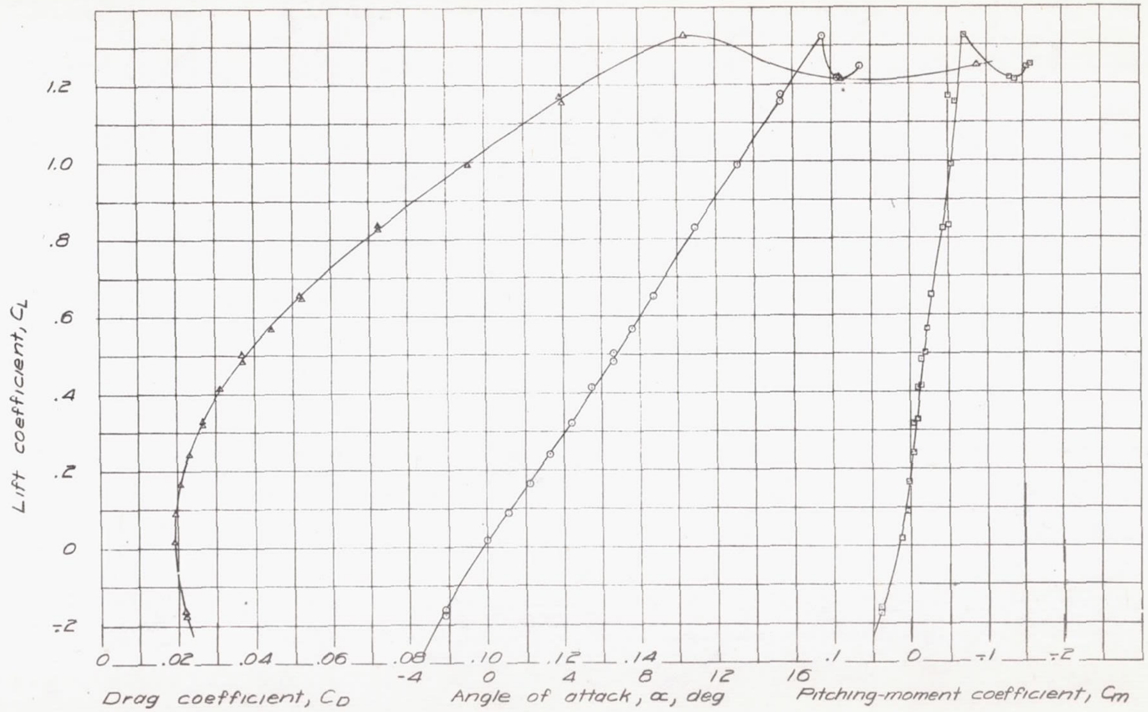


Figure 16.- Variation of C_D, α and C_m with C_L for the airplane model with the small circular external auxiliary fuel tanks for the wings. d=8.16 in.; φ=6.0°.

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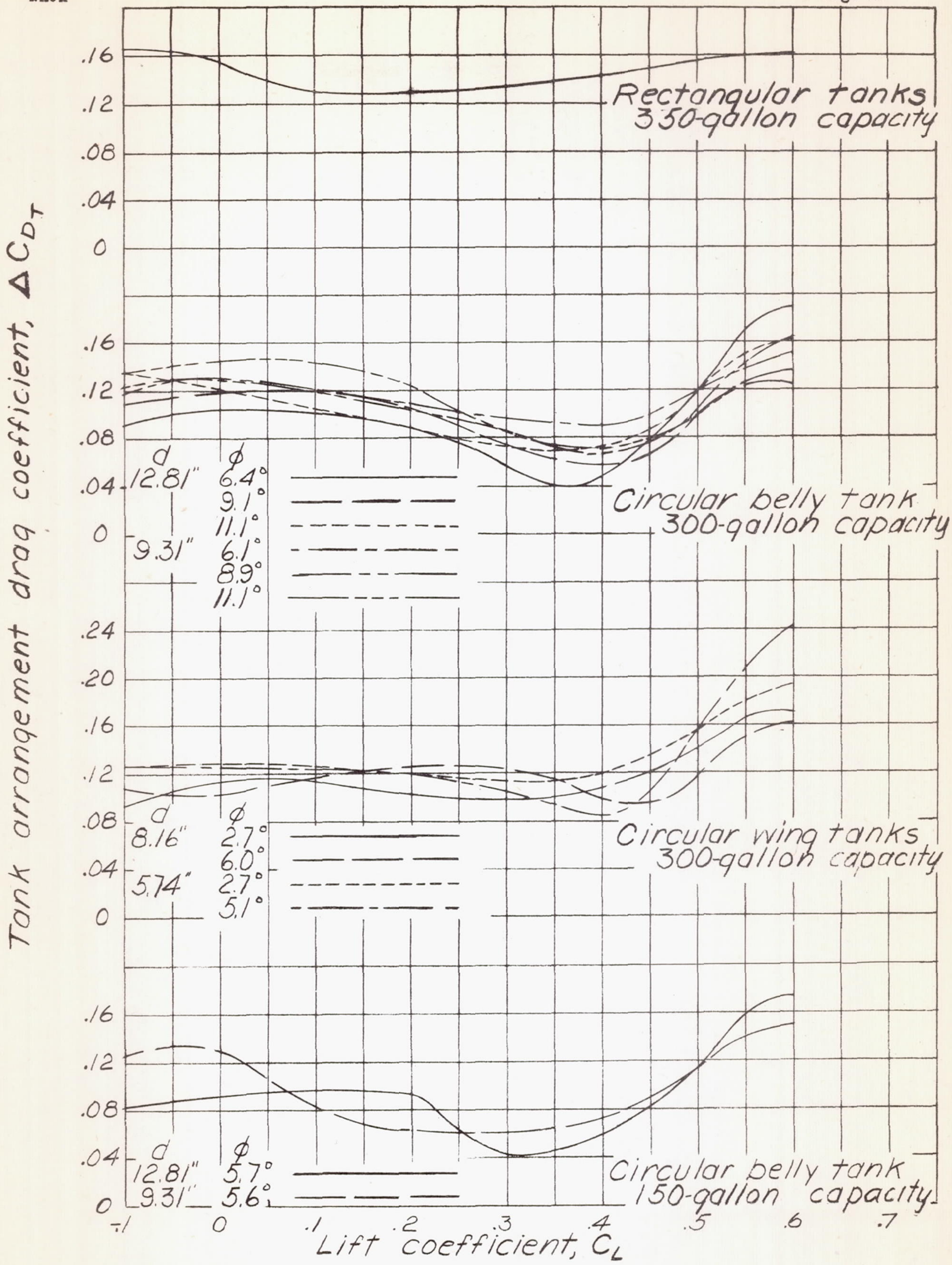

Figure 17.- Variation of ΔC_{D_T} with C_L.

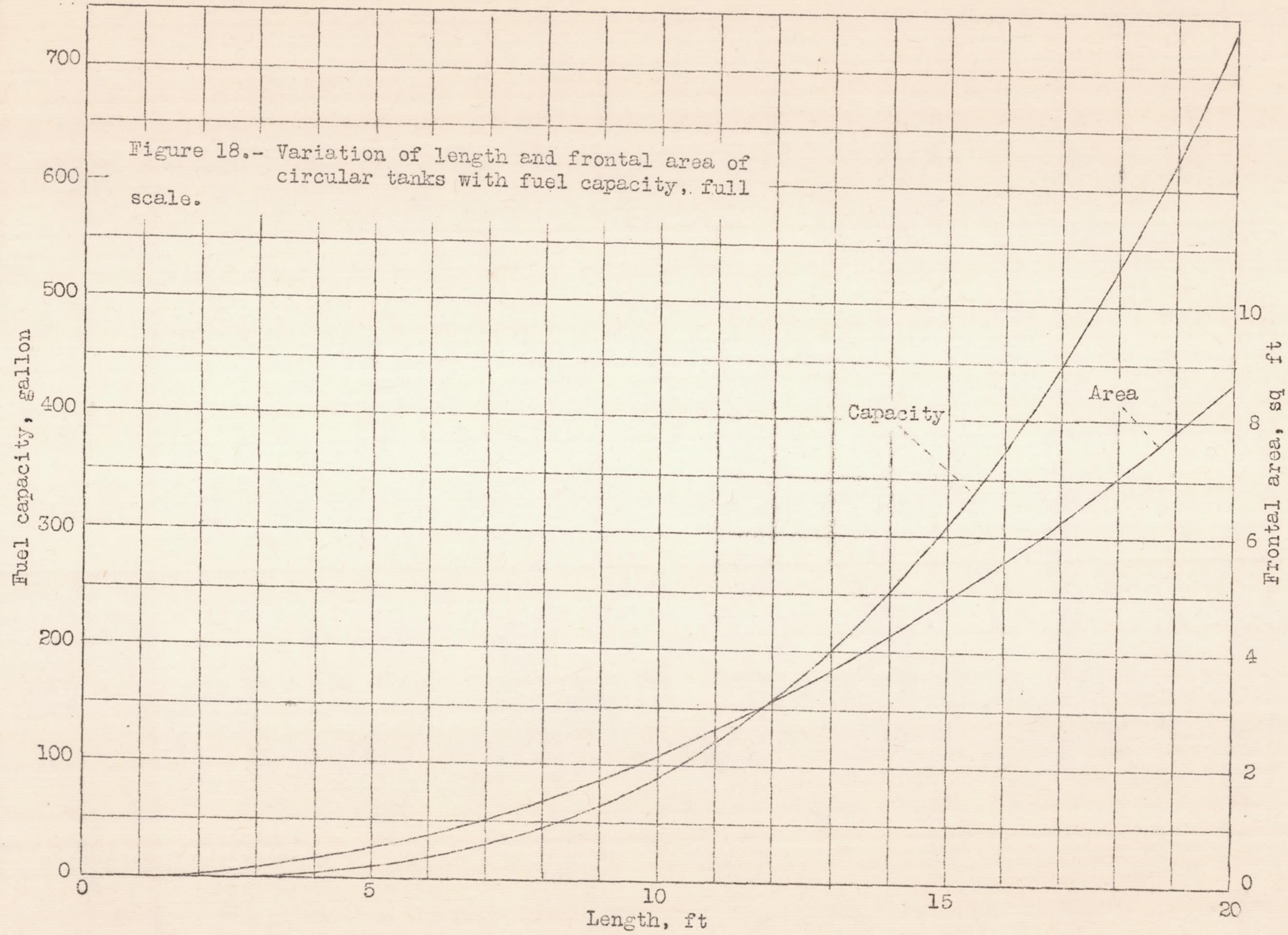

Figure 18.- Variation of length and frontal area of circular tanks with fuel capacity, full scale.