The Chief of the Bureau of Aeronautics
Att: Captain Diehl

1105-5
REPUBLIC
P-47 a/1

DECLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Duplicate

CASE FILE
COPY

[redacted]

FILE: LARGE SCALE MODELS OF ARMY AIRPLANES - PURSUIT

MEMORANDUM REPORT

for

Army Air Forces, Materiel Command

WIND-TUNNEL TESTS OF 1/6-SCALE MODEL OF REPUBLIC P-47C AIRPLANE WITH EXTERNAL WING TANK

By Marvin J. Schuldenfrei and Joseph Weil

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

AERODYNAMICS
COPY

[redacted]

GROUP 4
Downgraded at 3 year intervals; declassified after 12 years

December 17, 1942

MEMORANDUM REPORT

for

Army Air Forces, Materiel Command

WIND-TUNNEL TESTS OF 1/6-SCALE MODEL OF REPUBLIC P-47C AIRPLANE WITH EXTERNAL WING TANKS

By Marvin J. Schuldenfrei and Joseph Weil

INTRODUCTION

In order to increase the range of the Republic P-47C airplane for ferrying purposes it has been proposed that the airplane be equipped with streamlined external wing tanks. This report presents the aerodynamic effect of such wing tanks as determined from tests of a 1/6-scale model in the 7- by 10-foot tunnel of the Langley Memorial Aeronautical Laboratory.

MODEL AND APPARATUS

The model was the same as the one used in the investigation reported in references 1 and 2, and had the extended nose (reference 2). The wing tanks and support fairings were constructed of wood at the Laboratory from a drawing supplied by the Materiel Command. The nominal capacity of each tank, full-size, is 300 gallons. The tanks were located with respect to the wing as shown in figure 1, in accordance with information supplied by the Materiel Command. Photographs of the model equipped with wing tanks are given as figures 2(a) and 2(b).

Details of the original model, model motor, propellers, etc. may be found in reference 3.

TESTS AND RESULTS

Test conditions. - The tests were made in the LMAL 7- by 10-foot tunnel at dynamic pressures of 16.37 and 9.21 pounds per square foot, corresponding to velocities of about 80 and 60 miles per hour. The corresponding test Reynolds numbers are about 1,000,000 and 750,000, based on a mean aerodynamic chord of 14.577 inches. The effective Reynolds numbers are 1,600,000 and 1,200,000 based on a turbulence factor of 1.6.

Coefficients. - The results are presented in the form of standard NACA coefficients of forces and moments based on model wing area, span, and mean aerodynamic chord. All data are referred to the stability axis, and all moments are given about a center of gravity located at 27 percent of the mean aerodynamic chord. The vertical center-of-gravity location is 0.99 inch below the thrust line. The coefficients and symbols used in this report have been defined in reference 1.

Corrections. - All data except those for the flap-down windmilling condition have been corrected for tares caused by the model support strut.

The angles of attack, drag coefficient, and pitching-moment coefficients have been corrected for the effects of the tunnel walls by the methods of references 2 and 3.

Test procedure. - The power-on test procedure was the same as that used in references 1, 2, and 3. The T_c' versus C_L variation as given in reference 3 was modified to account for a new wing loading from data supplied by the Materiel Command according to the following relation:

$$\frac{T_{c_2}'}{T_{c_1}'} = \left[\frac{(W/S)_1}{(W/S)_2}\right]^{3/2}$$

The gross weight and wing loading for various conditions are given in the following table:

Condition	External tanks	Gross weight, lb	Wing loading W/S
Normal	Off	12944	43.15
Ferry	On, empty	12506	41.69
Ferry	On, full	16106	53.69

The variation of thrust coefficient with lift coefficient for the three conditions listed in the table are shown in figure 3. It was shown in reference 1 that the critical condition for longitudinal stability was that corresponding to maximum thrust at any lift coefficient. It is apparent, therefore, that the tank-full thrust condition is less critical than the tank-empty condition with regard to stability, especially since the center of gravity is well below the thrust line with the wing tanks full, which is a more favorable condition for longitudinal stability. The tests were made using power condition A (fig. 3), that for the normal airplane with no external tanks. The thrust variation with the empty tanks was considered close enough to the normal condition so that it was unnecessary to run additional power tests.

TEST PROGRAM AND LIST OF FIGURES

P-47C WITH WING TANKS (1/6-SCALE)

Figure no.	Title	Tank	δ_f	q	Power	Remarks	Test no.
4	Effect on L/D	off	0	16.37	Propeller off	$\psi = 0$	1
		on	0	16.37	---do---	$\psi = 0$	14
5(a)	Effect of tanks in pitch	off	0	16.37	Wm.	$\psi = 0$	2
		on	0	16.37	---do---	$\psi = 0$	15
		off	0	16.37	A	$\psi = 0$	3
		on	0	16.37	---do---	$\psi = 0$	16
(b)		off	40	16.37	Wm.	$\psi = 0$	8
		on	40	16.37	---do---	$\psi = 0$	24
		off	40	9.21	A	$\psi = 0$	9
		on	40	9.21	---do---	$\psi = 0$	25
7(a)	Effect on lateral stability parameters	off	0	16.37	Wm.	$\psi = \pm 5^\circ$	4,6
		on	0	16.37	---do---	$\psi = \pm 5^\circ$	18,21
		off	0	16.37	A	$\psi = \pm 5^\circ$	5,7
		on	0	16.37	---do---	$\psi = \pm 5^\circ$	19,22
(b)		off	40	16.37	Wm.	$\psi = \pm 5^\circ$	10,12
		on	40	16.37	---do---	$\psi = \pm 5^\circ$	27,30
		off	40	9.21	A	$\psi = \pm 5^\circ$	11,13
		on	40	9.21	---do---	$\psi = \pm 5^\circ$	28,31
8(a)	Effect of tanks on yaw	off	0	16.37	Wm.	$\alpha = 11.5$	46
		on	0	16.37	---do---	$\alpha = 11.5$	40
		off	0	16.37	A	$\alpha = 11.2$	47
		on	0	16.37	---do---	$\alpha = 11.2$	41
(b)		off	0	16.37	Wm.	$\alpha = 4.5$	33
		on	0	16.37	---do---	$\alpha = 4.5$	43
		off	0	16.37	A	$\alpha = 4.0$	34
		on	0	16.37	---do---	$\alpha = 4.1$	44
(c)		off	40	16.37	Wm.	$\alpha = 12.1$	35
		on	40	16.37	---do---	$\alpha = 12.1$	37
		off	40	9.21	A	$\alpha = 12.0$	36
		on	40	9.21	---do---	$\alpha = 12.0$	38

Notes:

Landing gear down when $\delta_f = 40^\circ$
$i_T = 2\frac{1}{2}^\circ$
$\beta = 15^\circ$
$\delta_r = \delta_a = \delta_e = 0^\circ$
Power:
Wm. = windmilling
A = take-off power (2000 bhp)

DISCUSSION

Effect of external tanks on L/D. - Range for any given airplane load is a function, among other things, of the lift-drag ratio, L/D, and is a maximum when L/D is maximum to a first approximation. A comparison of L/D_{max} tanks-on with L/D_{max} tanks-off is a measure of the decrease in aerodynamic efficiency resulting from the necessity for carrying the tanks. It may be seen from figure 4 that the maximum L/D decreases from 13.7 to 12.6 due to the addition of the tanks. It may also be noted that the angle for maximum L/D increases slightly with tanks on. This increase is partly caused by a decrease in lift associated with the tanks (due to interference between tanks and wing) and partly caused by the drag of the tanks.

The exact values of L/D mentioned are only approximate because of the relatively low scale of the tests, but it is believed that the relative values are indicative of the relative merits of the two arrangements. Also because of the low scale, it is inadvisable to attempt to determine the full-scale drag of the wing tanks from these data.

Longitudinal Stability. - The effect of the wing tanks as streamlined bodies is to decrease the longitudinal stability of the airplane, the greatest decrease in stability generally occurring at low values of lift coefficient. From figure 4 (propellers off) it may be seen that the addition of the wing tanks effectively moves the aerodynamic center forward about $2\frac{1}{2}$ percent for medium lift coefficients. At maximum lift coefficient, however, the wing tanks have no measurable effect on the longitudinal stability.

The same effect is observed with windmilling propellers (fig. 5(a)) where the forward movement of the aerodynamic center is slightly greater than with propellers off, being approximately $3\frac{1}{2}$ percent for the low values of lift coefficient. Again, at the high-lift coefficients, the tanks have only a slight effect on the longitudinal stability. The dashed-line curve of C_m for tanks off with power A (fig. 5(a)) was interpolated from tests run at $\pm 5^\circ$ yaw because the pitching-moment coefficient curve at zero yaw was found to be in error. The error was believed to be caused by an error in scale readings during the test.

With full power (fig. 5(a)) the forward movement of the aerodynamic center is a maximum, being about 4 percent, at low lift coefficient and decreasing to zero at high C_L. It should be noted that with tanks either off or on the model is practically neutrally stable at high lift coefficients when the center of gravity is at the 27-percent location.

With flaps deflected (fig. 5(b)) the tanks have only a slight detrimental effect at low C_L and no appreciable effect at high C_L with windmilling propellers. However, with full power, flaps deflected 40°, the destabilizing influence of the tanks is greatest at high C_L. The addition of the tanks in this condition would require approximately 5 percent forward movement of the center of gravity for neutral stability.

From the data of figures 5(a) and 5(b), considering only the tanks-on condition for the purposes of this report, the location of the neutral point of the airplane may be determined approximately for the various flight conditions simulated. The stability of the airplane for any given center-of-gravity location may then be determined depending on the location of the center of gravity with respect to the neutral point - if ahead, the airplane is stable; if behind, unstable.

The neutral point location was determined as follows: If the neutral point is the point through which the lift acts and, consequently, about which the stability is neutral, the following approximate equations may be set up:

$$C_{m_{27\text{ percent pt}}} = -rC_L \qquad (1)$$

where r is the distance the neutral point is behind the 27-percent point in percent mean aerodynamic chord. Differentiating with respect to $\overset{C_L}{D_L}$:

$$\frac{\partial C_{m_{27\text{ percent}}}}{\partial C_L} = -r \qquad (2)$$

It is evident that $\partial C_m/\partial C_L$ is the slope of the pitching-moment curves of figures 5(a) and 5(b) taken at each C_L.

Equation (2) indicates then that values for the slopes of the pitching-moment curves as found from figures 5(a) and 5(b) with signs reversed are directly the distances which the neutral point is behind the 27-percent point of the mean aerodynamic chord, in terms of decimal parts of the mean aerodynamic chord. Converting these values to percent mean aerodynamic chord measured from the leading edge of the mean aerodynamic chord is obvious. The curves of neutral point location against lift coefficient for various simulated flight conditions are shown in figure 6.

It must be noted that several simplifying assumptions have been made in this derivation. Among these are the fact that the effect of drag has been neglected in equation (1), and that the cosine of the angle of attack has been assumed to be equal to one. It has also been assumed that the vertical location of the neutral point stays constant with model attitude. The final assumption is that change in trim will not affect the location of the neutral point. This is true for a power-off condition, and is approximately true for the power-on conditions inasmuch as the total elevator deflection required for trim over the speed range is of the order of only a few degrees for normal center-of-gravity locations and should have negligible effect in shifting the neutral point. The curves of figure 6 were also calculated using exact pitching-moment curves referred to a center of gravity at 33.3 percent mean aerodynamic chord. The difference in neutral point location at the most forward locations for various simulated flight conditions was less than 1 percent between the two sets of computations.

The chart is useful as follows: Consider the two centers of gravity specified in notes 1 and 2 in figure 6 for two different tank loadings. It may be seen that when the wing and rear tanks are empty (center of gravity at 28.2 percent mean aerodynamic chord) the airplane is stable for all lift coefficients below $C_L = 0.8$ with full-power, $\delta_f = 0$. With wing tanks alone empty (center of gravity at 30.7 percent mean aerodynamic chord), the airplane is stable below $C_L = 0.5$. It is obviously more desirable to empty the rear tank before emptying the wing tanks.

Emptying the rear tank moves the center of gravity forward about $2\frac{1}{2}$ percent when the wing tanks are empty, and about 2 percent when the wing tanks are full.

Effect of external wing tanks on yaw parameters $\partial C_Y/\partial\psi$, $\partial C_n/\partial\psi$, $\partial C_l/\partial\psi$. - With flaps neutral the external wing tanks give a decided increment in the side force parameter $\partial C_Y/\partial\psi$, but have negligible effect on directional stability $\partial C_n/\partial\psi$ and effective dihedral $\partial C_l/\partial\psi$ for either windmilling or full power conditions (fig. 7(a)).

With the flaps deflected (fig. 7(b)) the external wing tanks give approximately the same increment in side force parameter $\partial C_Y/\partial\psi$, as for the flaps-neutral condition. The directional stability $\partial C_n/\partial\psi$, however, is adversely affected by the addition of the tanks. The effective dihedral is increased somewhat for the windmilling condition and is unaffected for the full-power condition, in the normal flight range with flaps deflected (C_L greater than approximately 0.5).

In general, the greatest effect of the addition of the wing tanks is to increase the side force on the model when yawed, thus requiring an increment of roll above that required for the model without the tanks to trim the model at a given angle of yaw. It is estimated that about 1° of roll per degree of yaw would be required to trim out the effects of the tanks alone at $C_L = 0.2$, and proportionately less roll at higher C_L. It is believed that the effect of the tanks on the directional stability and effective dihedral may be considered negligible.

In the analysis of data presented as parameters of $\partial C_n/\partial\psi$, $\partial C_l/\partial\psi$, and $\partial C_Y/\partial\psi$, where the characteristics of the model have been determined for two angles of yaw (5° and -5°, in these tests), it must be remembered that the results represent an average condition existing between the two angles, and consequently take no account of the characteristics at very small or very large angles of yaw. Inasmuch as some airplanes show marked changes in their aerodynamic characteristics at very small or very large angles of yaw, it is necessary to investigate the entire yaw range for several representative cases as an addition to the yaw-parameter results.

Directional Stability. - The results of a series of yaw tests at a high angle of attack with flaps neutral (fig. 8(a)) show that, with tanks on and propellers windmilling, the directional stability is approximately neutral through zero yaw and for a few degrees either side, a condition which also exists with the tanks off and which has been reported before for this airplane (references 1, 2, and 3). The instability contributed by the tanks for this condition is approximately equal to a value of $\partial C_n/\partial\psi$ of 0.0002, which is very close to the theoretical value for two streamlined bodies of shape similar to the tanks. For the two other conditions investigated, however, ($\delta_f = 0^\circ$ low angle of attack, fig. 8(b), and $\delta_f = 40^\circ$, high angle of attack, fig. 8(c)) the contribution is negligible. It may be noted that these effects of the tanks on directional stability are opposite to those obtained in the discussion of "parameters" in that the tanks here show a destabilizing effect with flaps up and negligible effect with flaps down, probably for the reasons given previously. The general conclusions reached under parameters, with regard to directional stability, remain unchanged, however.

The other components are only slightly affected through the yaw range by the addition of the tanks except as noted in the discussion of figure 7.

Dynamic lateral stability. - While it is impossible, of course, to make dynamic stability measurements in conventional wind tunnels of the type in which these tests were made, the effects may be calculated approximately. Some preliminary calculations for this airplane, using methods of reference 4, indicate that, with fully loaded wing tanks, the airplane may exhibit oscillatory divergence for the windmilling condition with flaps up at medium and high lift coefficients, and with flaps down at high lift coefficients. This results from the large increase in moment of inertia and wing loading caused by the addition of the wing tanks well outboard from the center line of the airplane and is further increased by the increased dihedral effect caused by the lowered center-of-gravity position with full wing tanks. With power-on it is estimated that oscillatory divergence will not occur.

CONCLUSIONS

1. The maximum L/D of the model was reduced from 13.7 to 12.6 by the addition of the wing tanks, and the lift coefficient for maximum L/D was increased from 0.55 to 0.60.

2. The wing tanks shifted the aerodynamic center of the model forward between $2\frac{1}{2}$ and 4 percent of the mean aerodynamic chord depending upon the power and flap condition.

3. With full power, flaps neutral or deflected 40°, and with the simulated condition for tanks on but empty, the model was slightly unstable longitudinally at medium and high lift coefficients about the 27-percent center-of-gravity location.

4. The wing tanks had negligible effects on directional stability and effective dihedral throughout the flight range. The increment of side force per degree of yaw caused by the tanks was approximately constant at all lift coefficients and for all flight conditions. It was estimated that 1° of roll per degree of yaw would be required at $C_L = 0.2$, and proportionately less roll required at higher lift coefficients to trim out the effect of the tanks in sideslip.

5. Some preliminary calculations indicated that the airplane may exhibit oscillatory divergence for the windmilling condition with flaps up at medium and high lift coefficients, and for the windmilling condition with flaps down at high lift coefficients, with fully loaded wing tanks. With power on, the airplane will probably be dynamically stable for all conditions.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 17, 1942.

Marvin J. Schuldenfrei
Marvin J. Schuldenfrei,
Assistant Aeronautical Engineer.

Joseph Weil
Joseph Weil,
Junior Aeronautical Engineer.

Approved:

Elton W. Miller,
Head Mechanical Engineer.

HSB

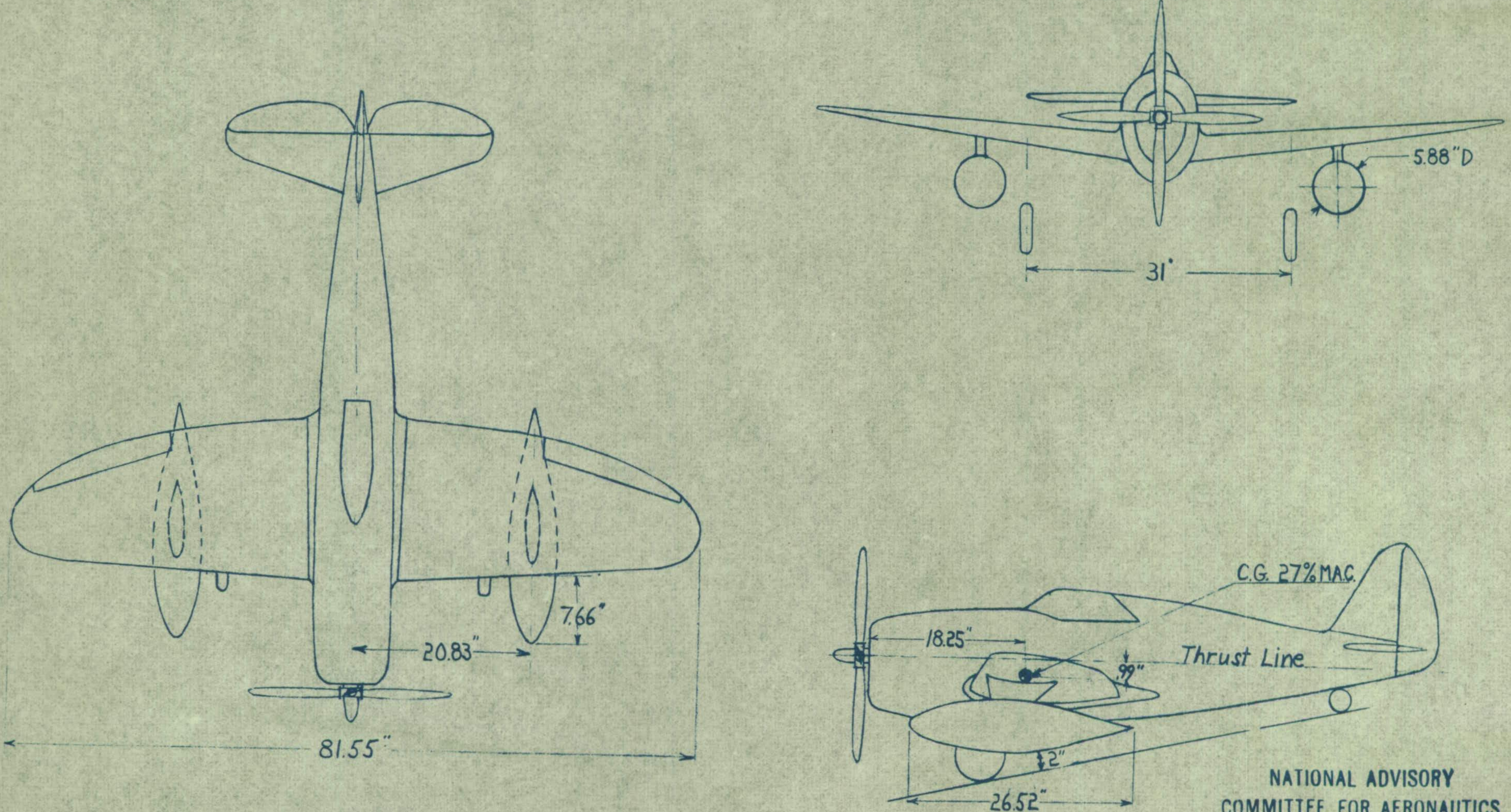
REFERENCES

1. Recant, Isidore G., and Weil, Joseph: Wind-Tunnel Tests of 1/6-Scale Model of P-47B Airplane with 650-Gallon Belly Tank. Memo. rep., Army Air Forces, NACA, Nov. 17, 1942.

2. Recant, I. G.: Wind Tunnel Tests of 1/6-Scale Model of Republic P-47B Airplane with Extended Nose. Memo. rep., Army Air Forces, NACA, Oct. 10, 1942.

3. Recant, I. G.: Wind Tunnel Tests of 1/6-Scale Model of Republic XP-47B Airplane with Power. Memo. rep., NACA, Feb. 11, 1941.

4. Zimmerman, Charles H.: An Analysis of Lateral Stability in Power-Off Flight with Charts For Use in Design. Rep. No. 589, NACA, 1937.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 1-THREE-VIEW DRAWING OF 1/6-SCALE MODEL OF P-47C AIRPLANE WITH EXTERNAL WING TANKS

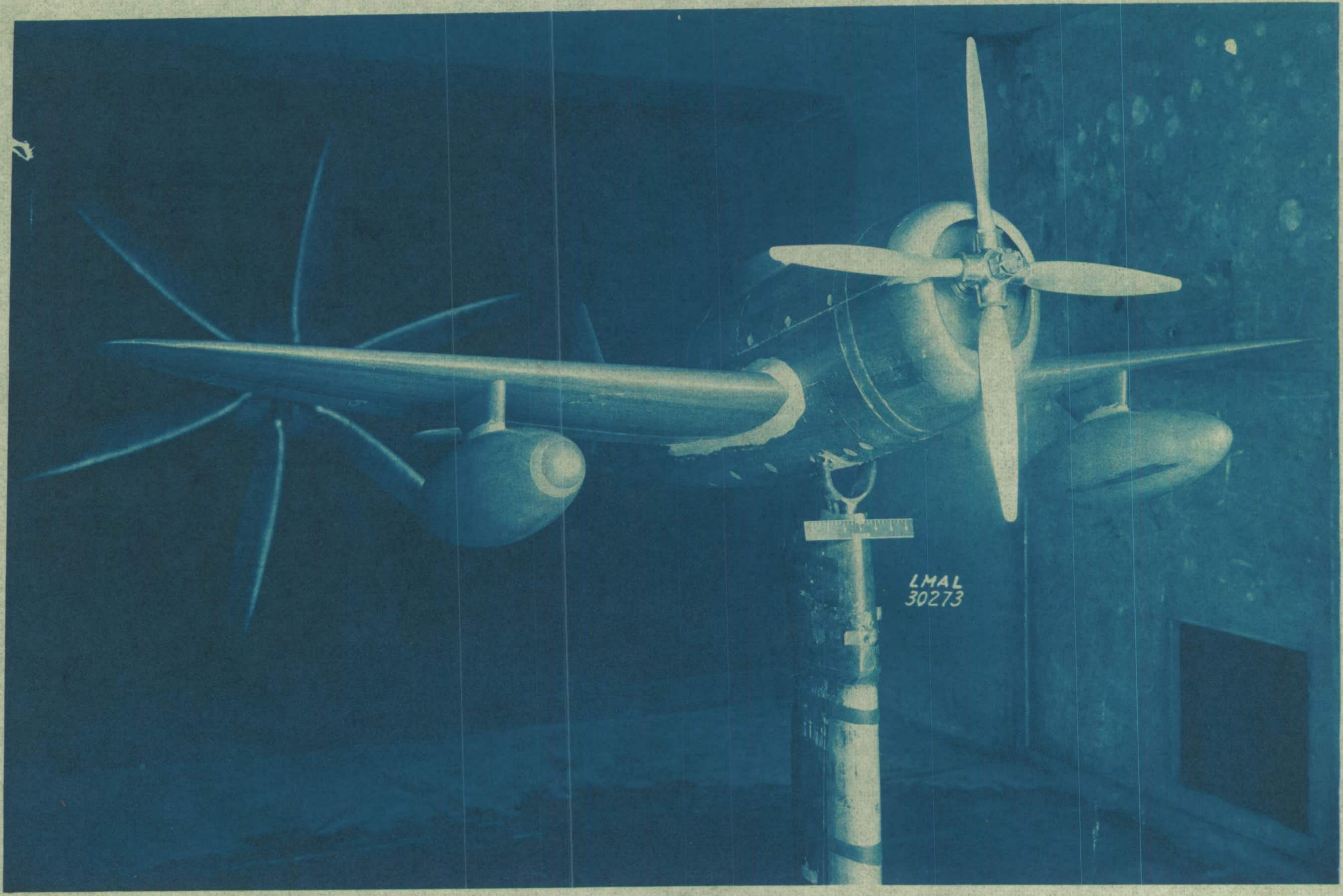


FIGURE 2(A). - REPUBLIC P-47C MODEL (1/6-SCALE) WITH TWO SIMULATED 300-GALLON WING TANKS. $\delta_r = 0^\circ$.

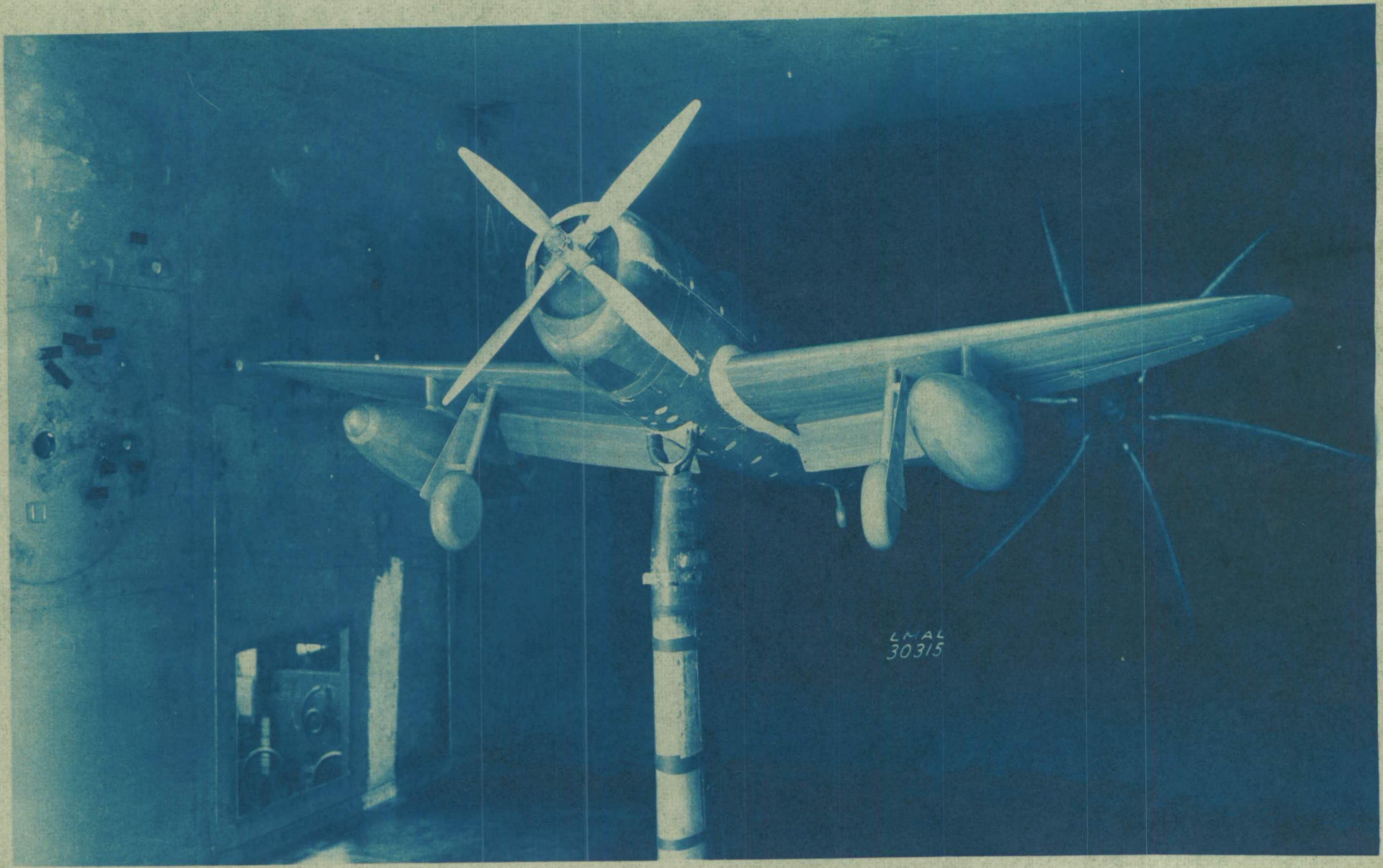


FIGURE 2(B). - REPUBLIC P-47C MODEL (1/6-SCALE) WITH TWO SIMULATED 300-GALLON WING TANKS. $\delta_f = 40^\circ$, LANDING GEAR DEFLECTED.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

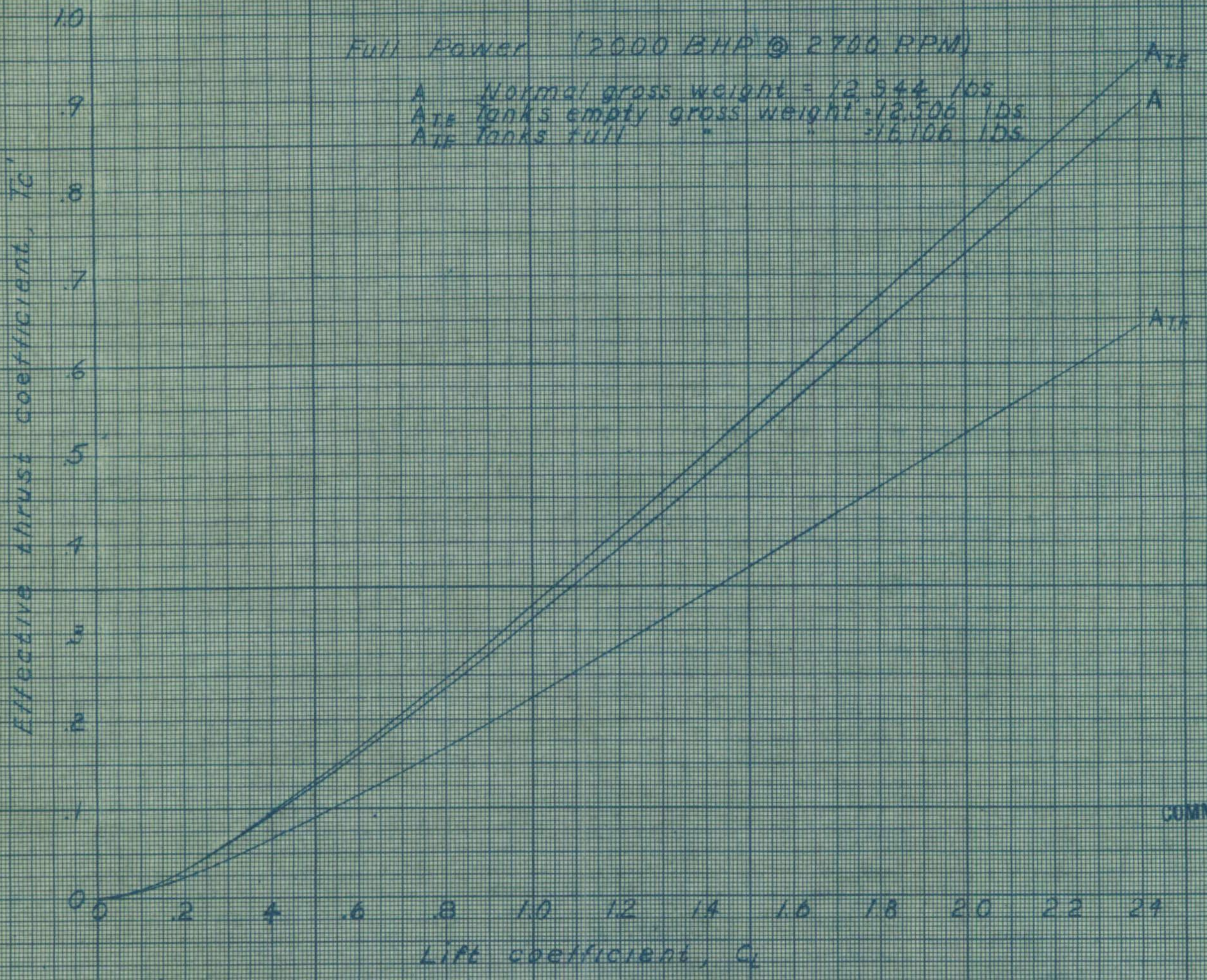


Figure 3- Effective thrust coefficients available at any lift coefficient. Republic P-47C

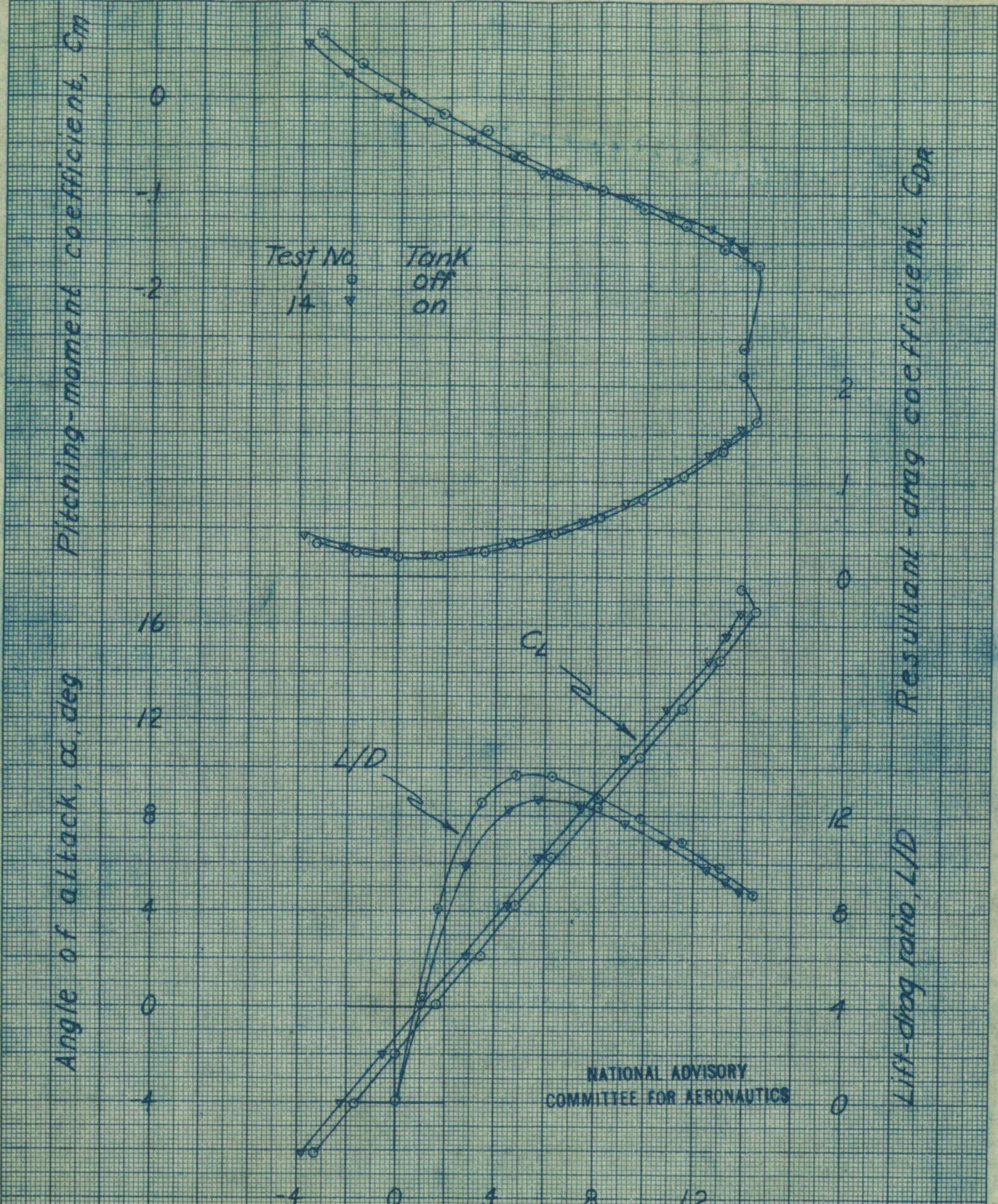
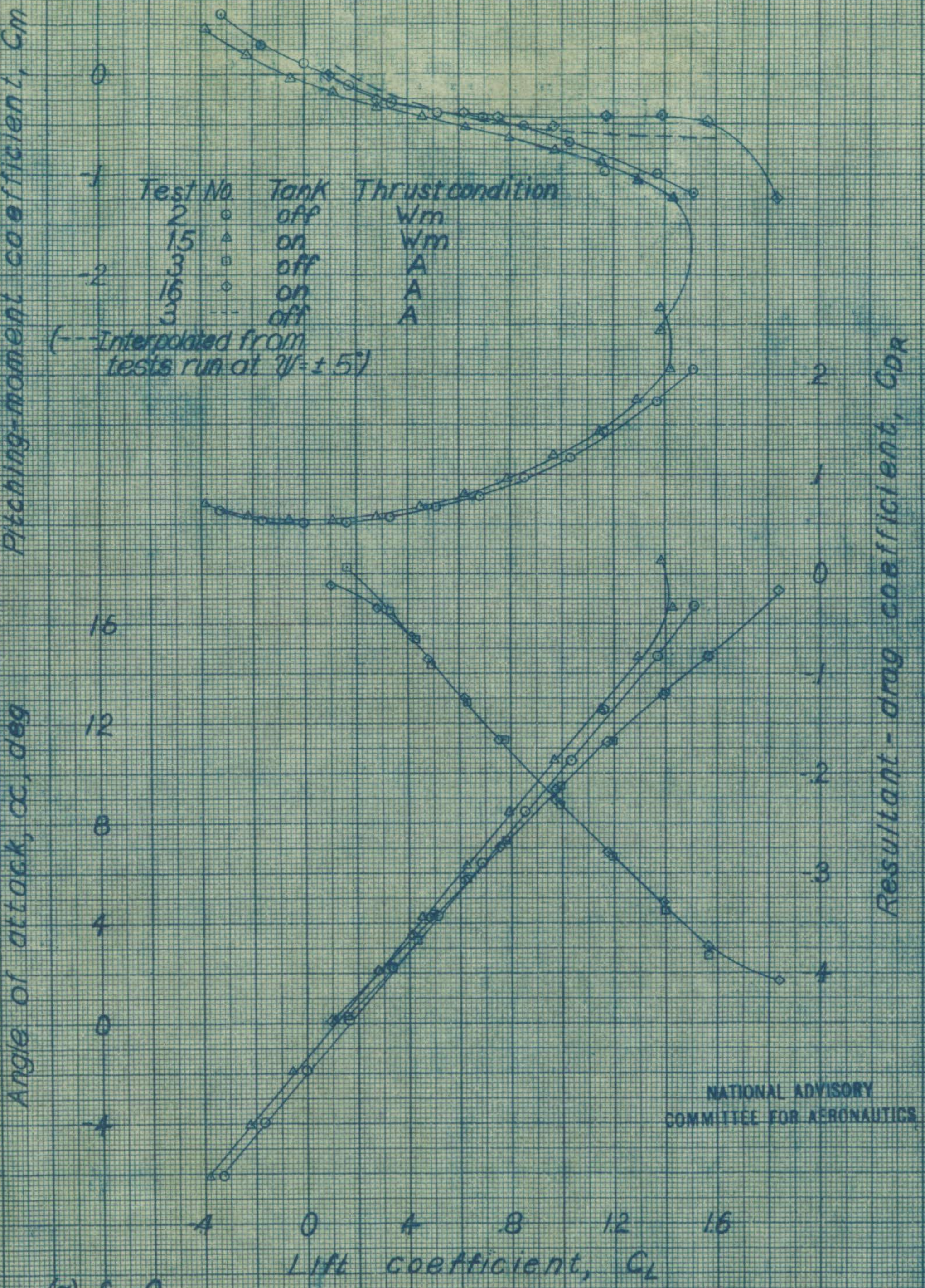
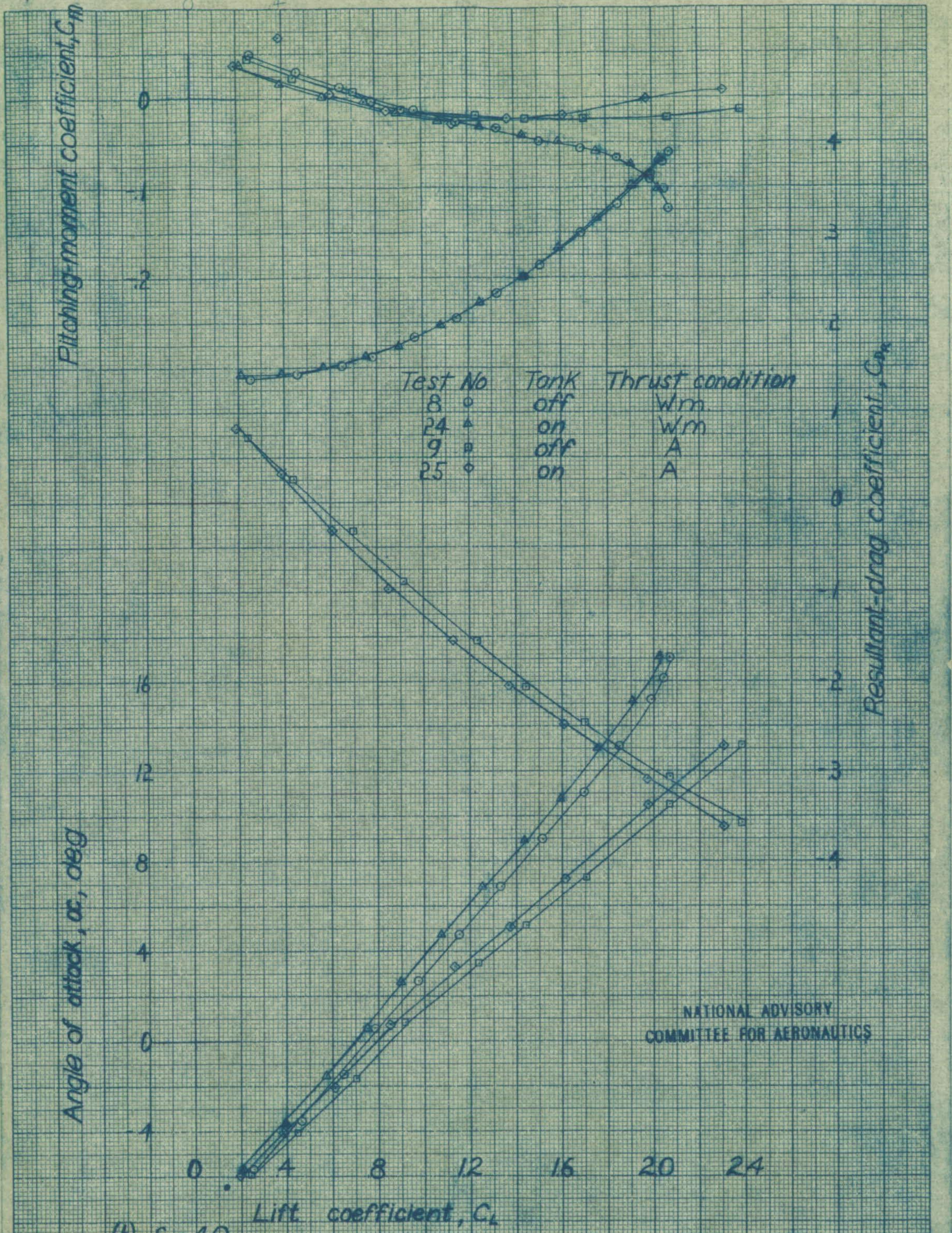


Figure 4 - Effect of external wing tanks on L/D of Republic P-47C model (1/6 scale). Propeller off, q = 16.37 lbs/ft², δf = 0



(a) $\delta_f = 0$

Figure 5 - Effect of external wing tanks on aerodynamic characteristics in pitch of Republic P-47C model. (1/6-scale)



(b) δ_f=40

Figure 5- (concluded)

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

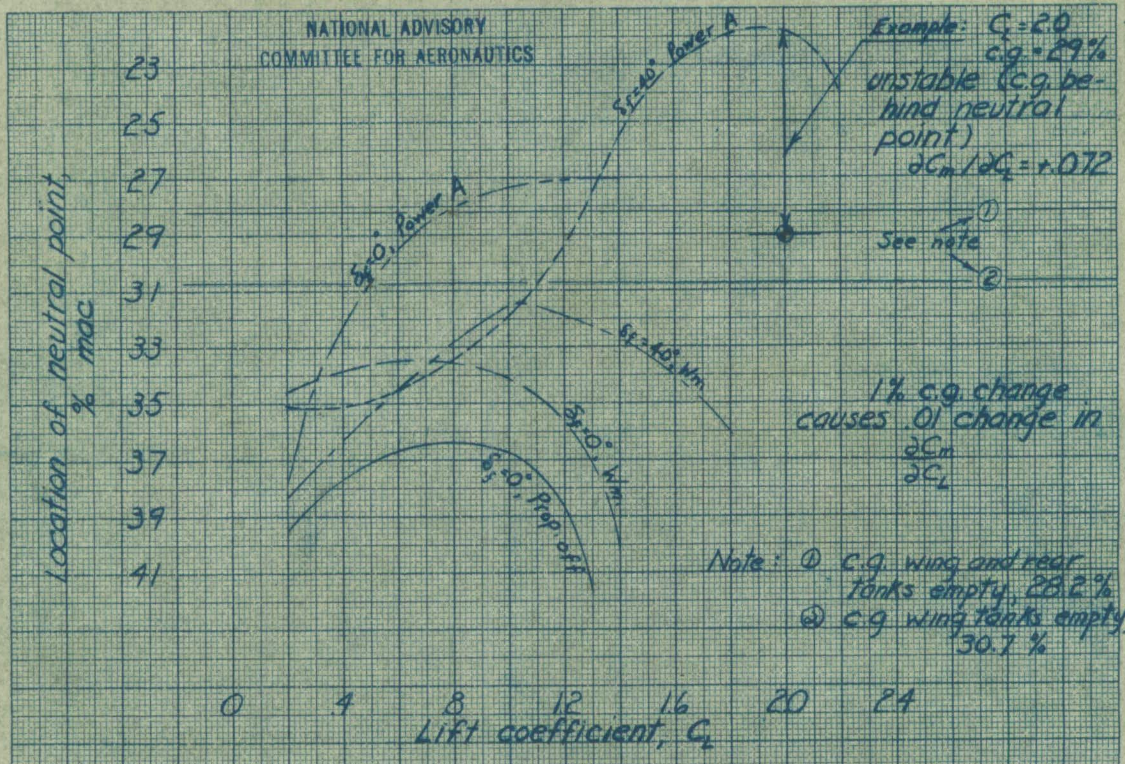
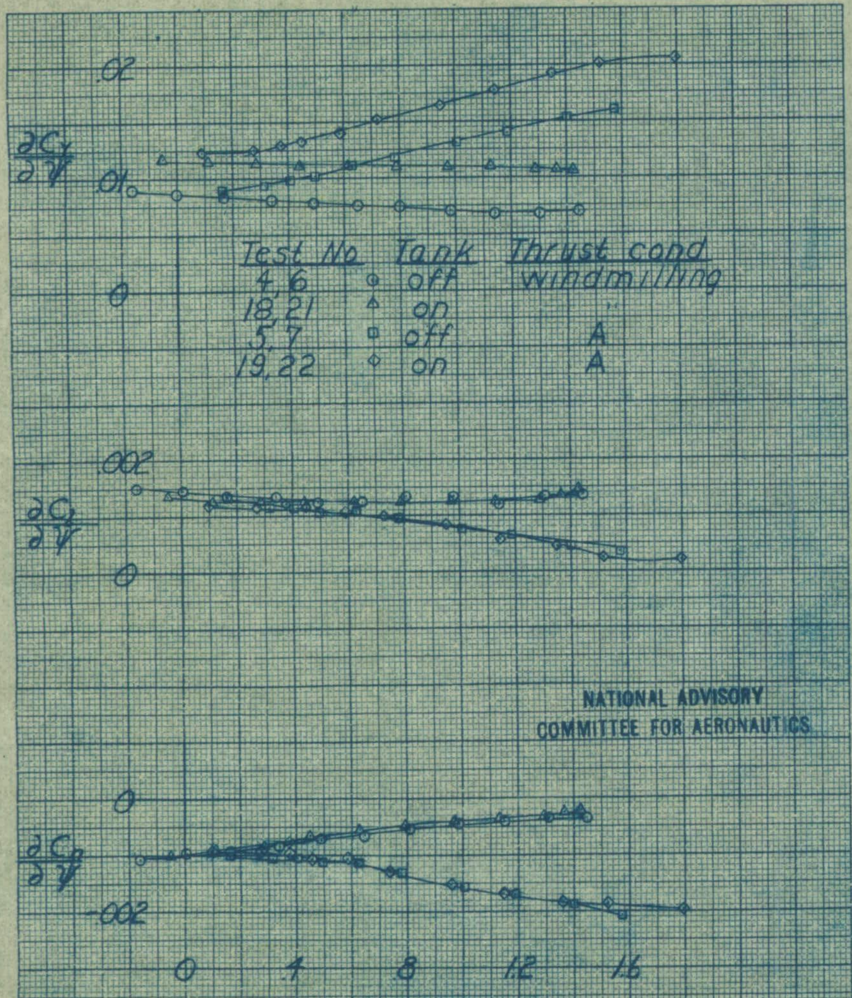
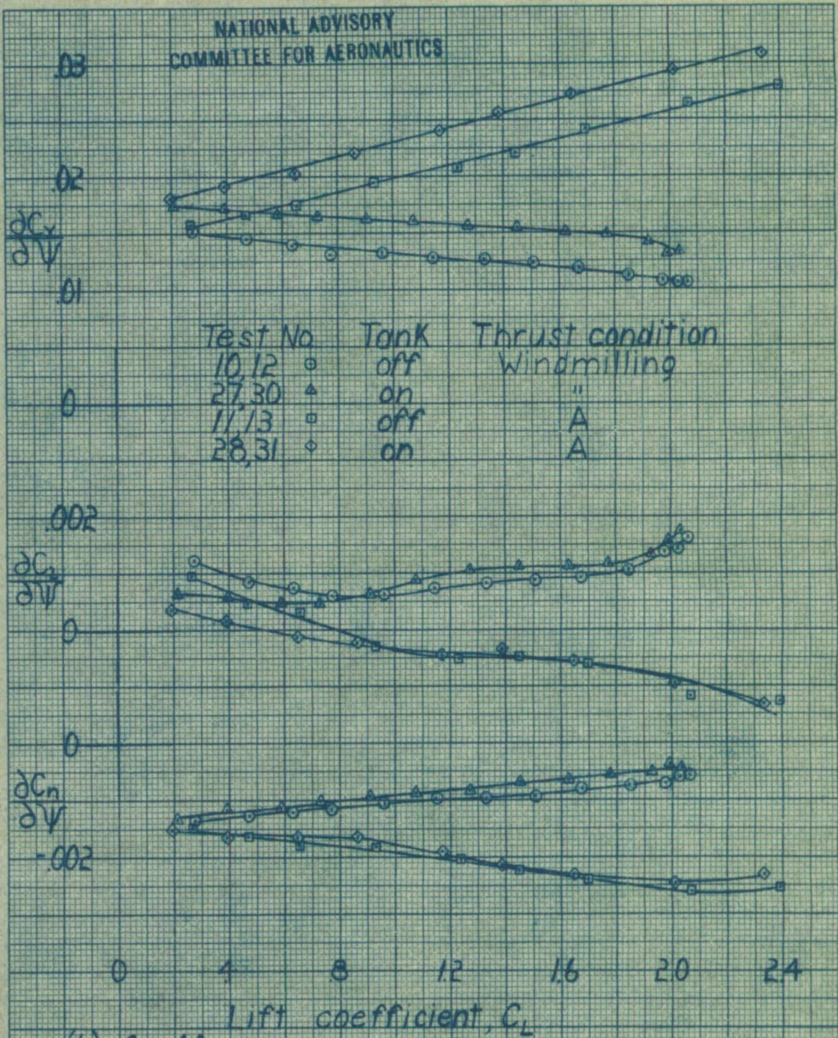


FIG. 6 Location of the neutral point, in % mac, of the Republic P-47C model (1/6-scale) for various flight conditions. Wing tanks on.



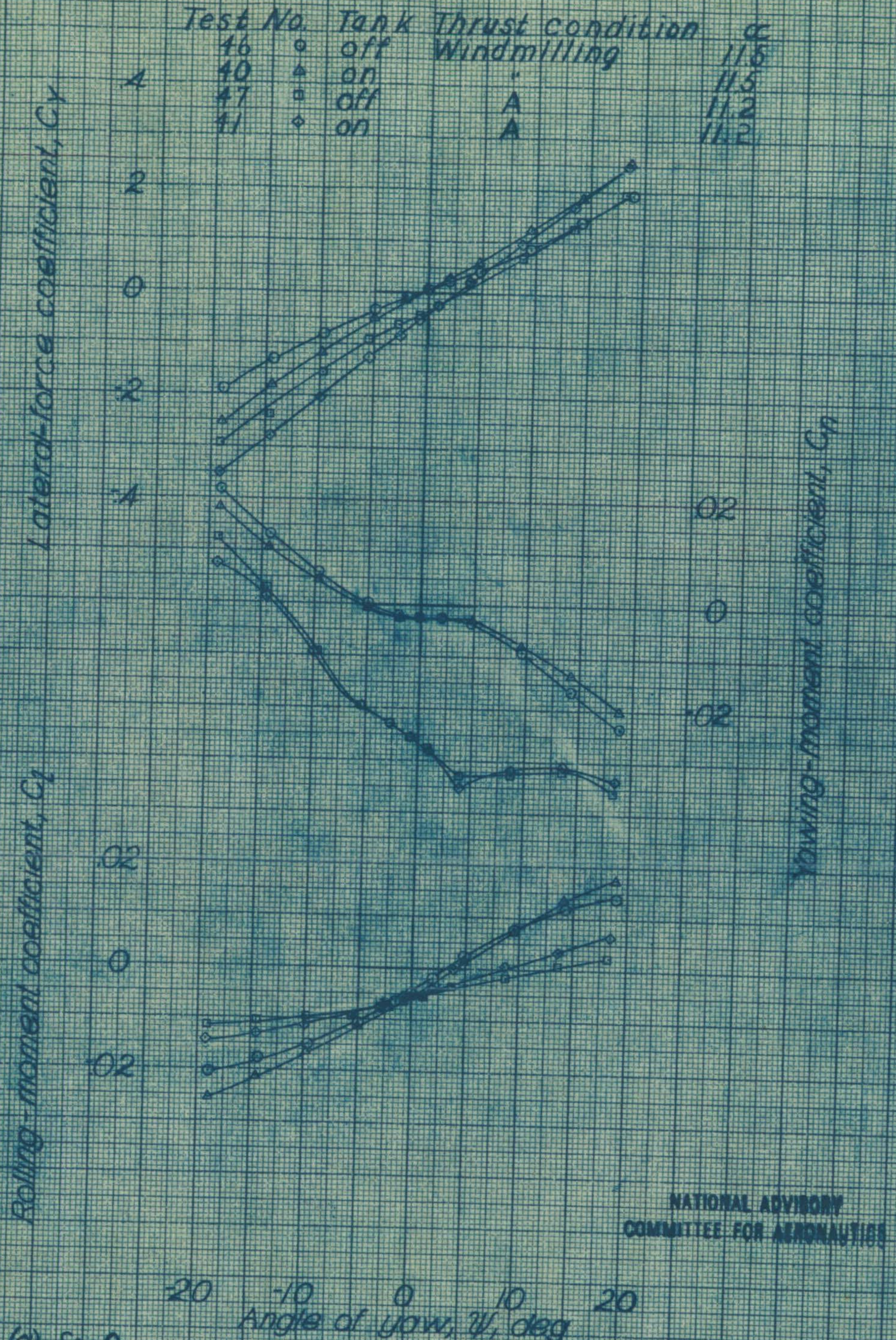
(a) $\delta_f = 0$

Figure 7- Effect of external wing tanks on stability parameters $\partial C_l/\partial\psi$, $\partial C_n/\partial\psi$, $\partial C_Y/\partial\psi$ of Republic P-47C model (1/6 scale)



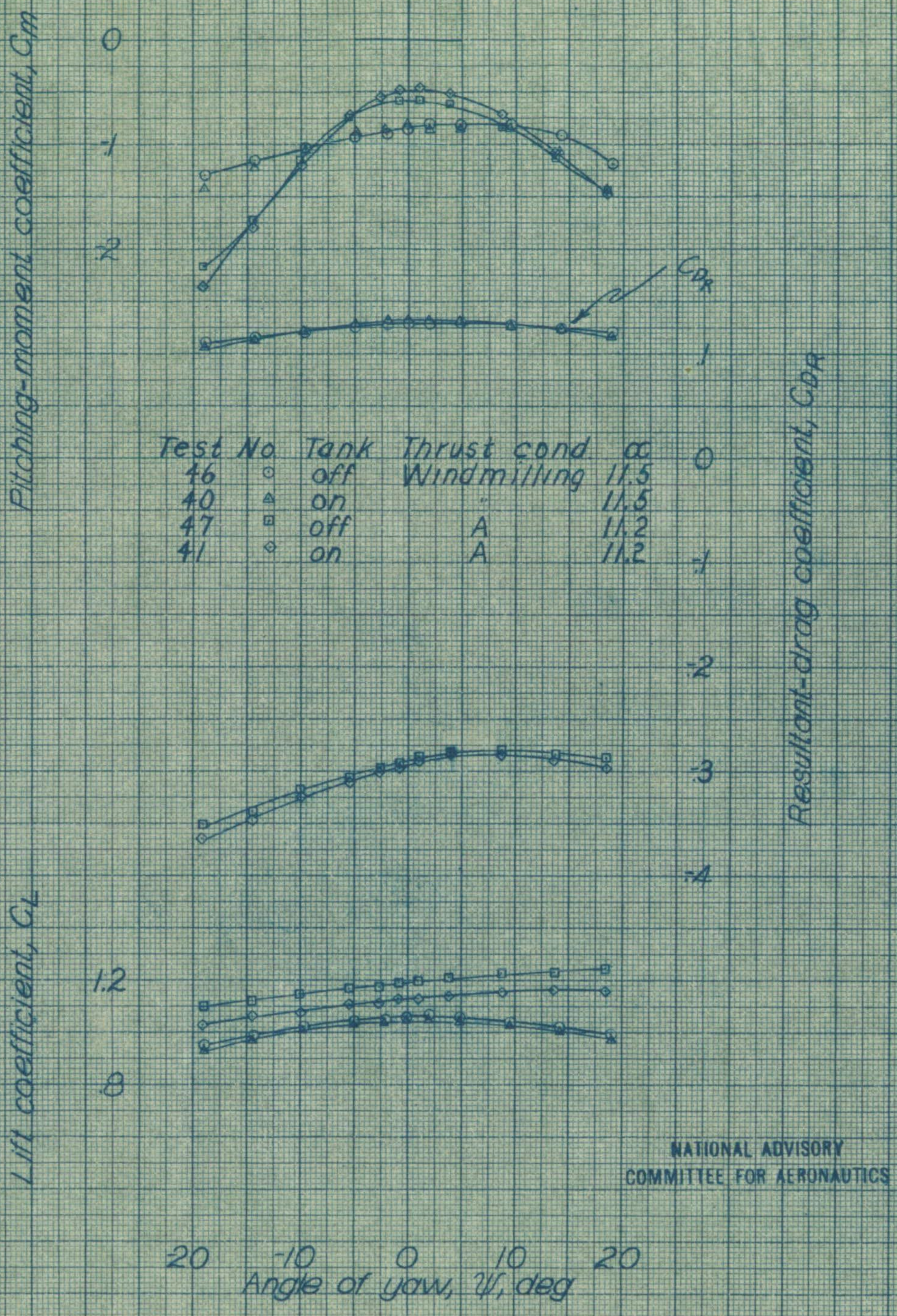
(b) $\delta_f = 40$

Figure 7- concluded



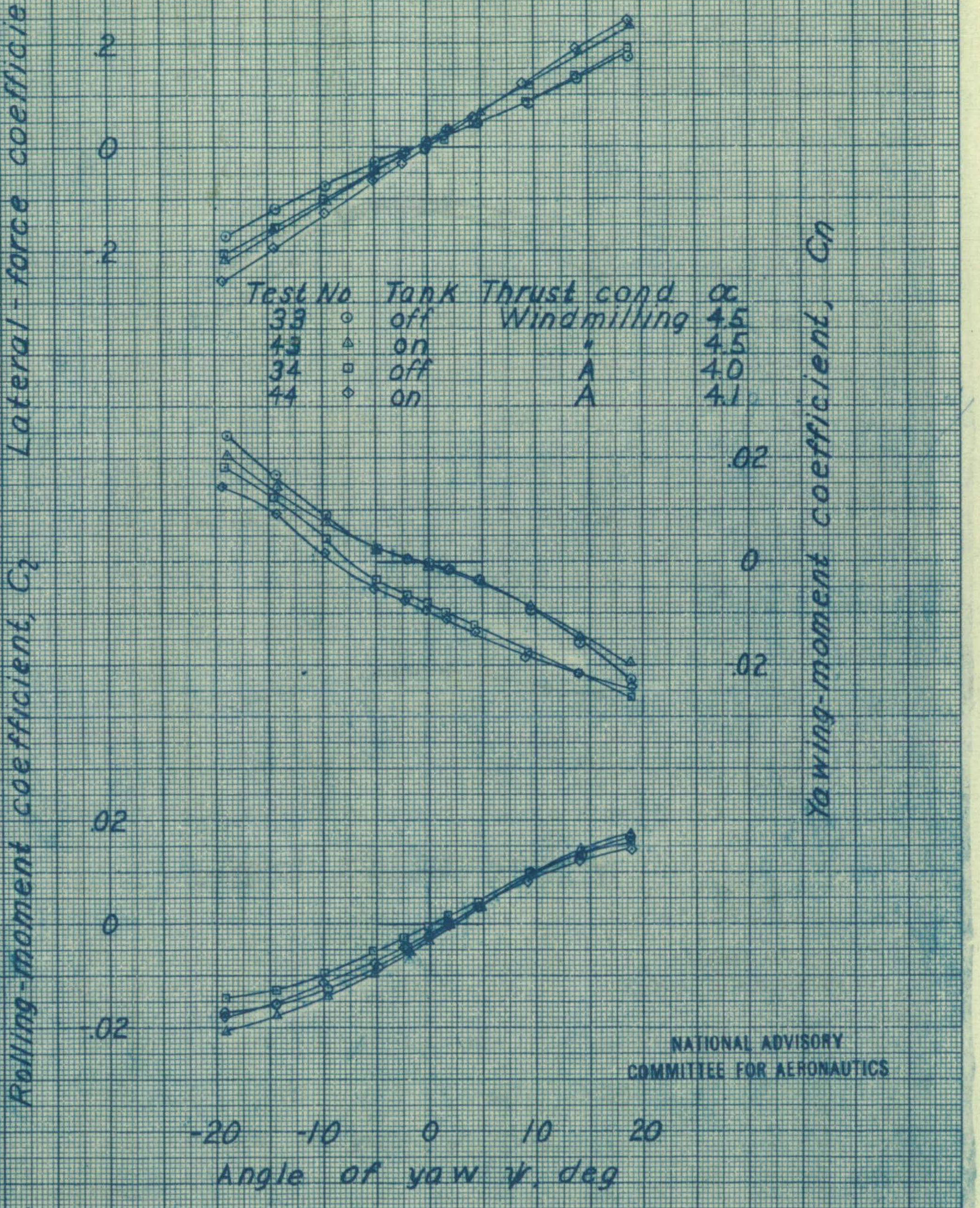
(a) $\delta_r = 0$

Figure 8 - Effect of external wing tanks on aerodynamic characteristics in yaw of the Republic P-47C model (1/4 scale)



(a) concluded

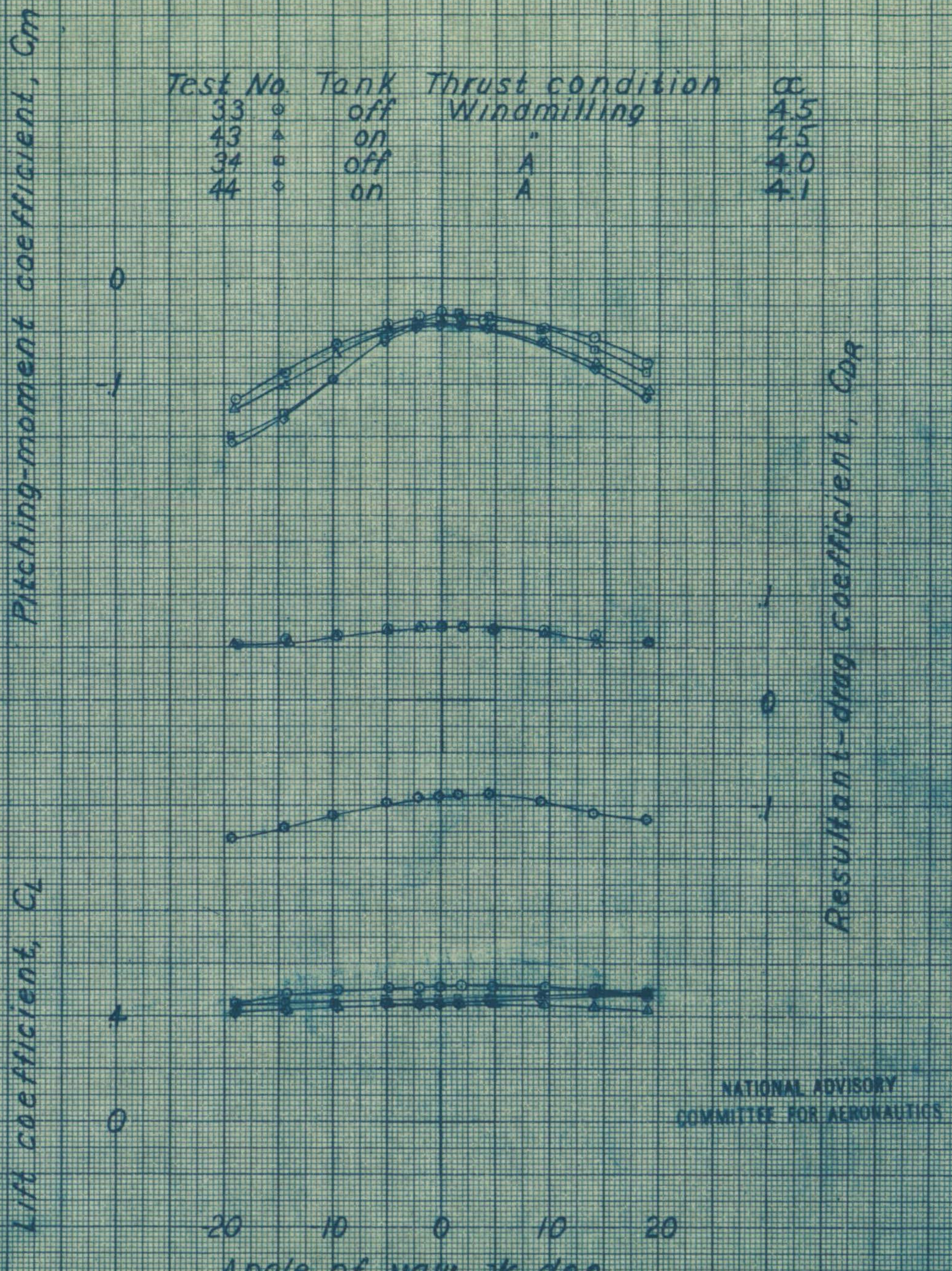
Figure 8 - continued



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

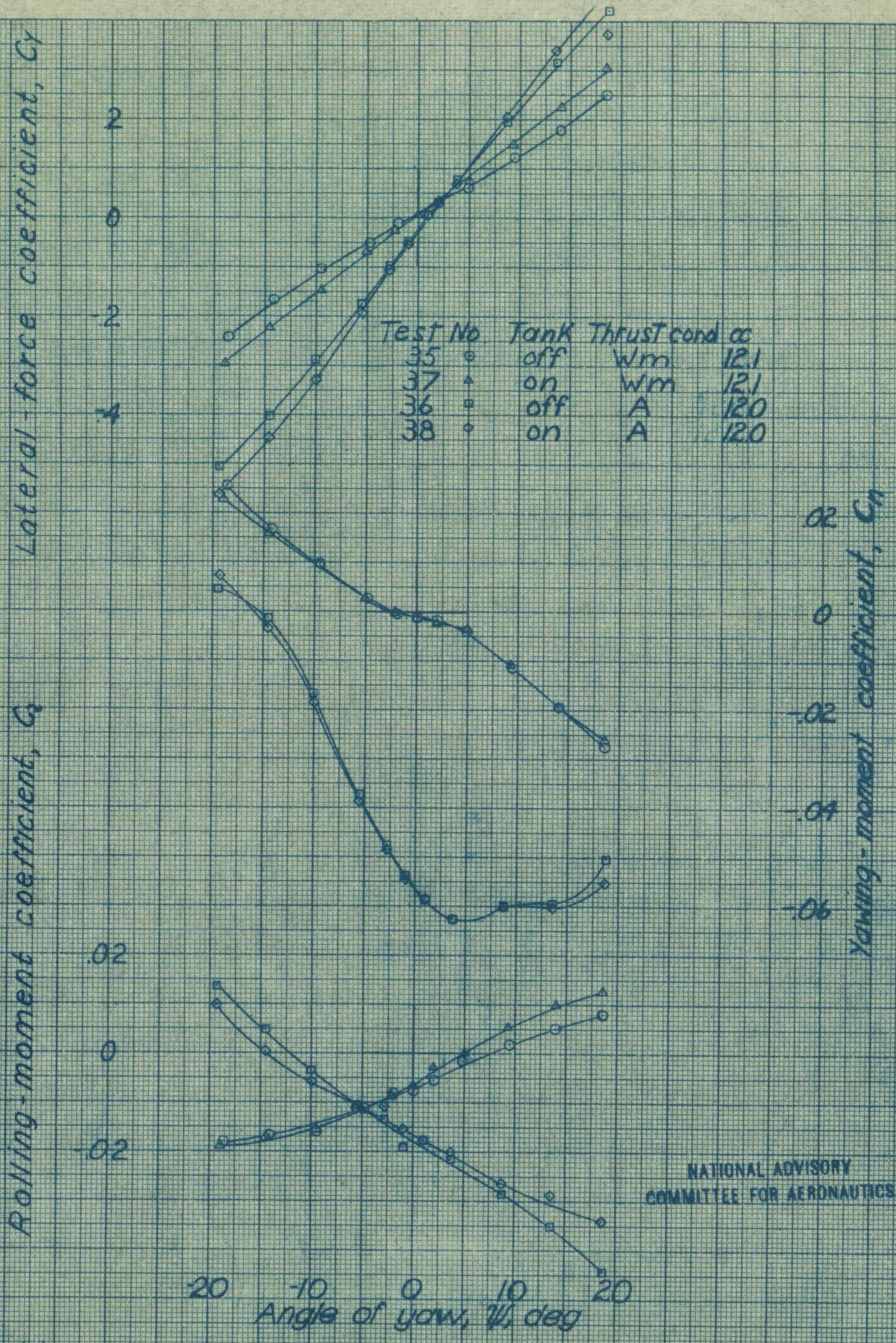
(b) $\delta_f = 0$

Figure 8 - continued



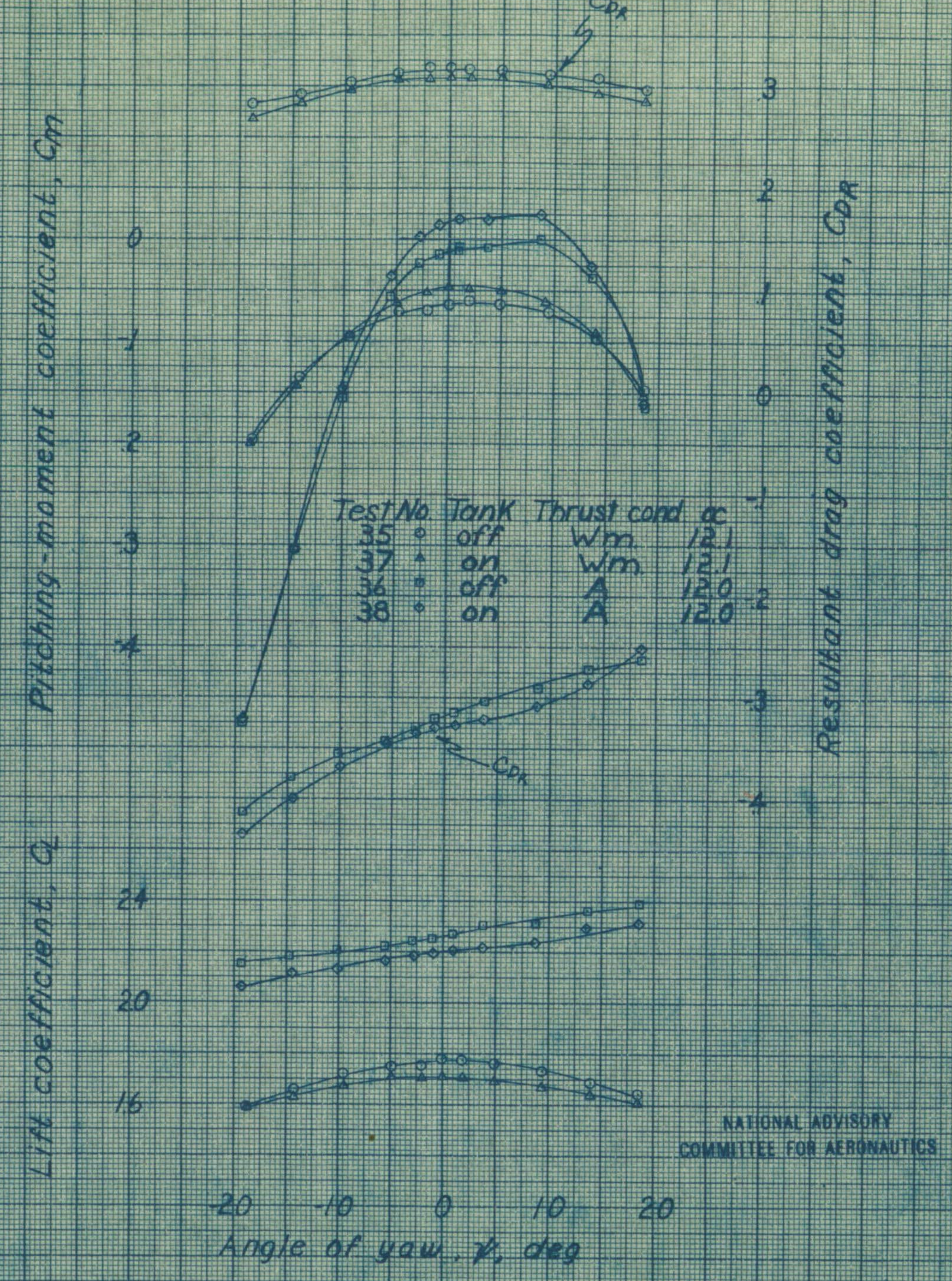
(b) concluded

Figure 8.- continued



(c) $\delta_f = 40$

Figure 8 - continued



(C) concluded

Figure 8 - concluded