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EXPERIMENTAL AND CALCULATED CHARACTERISTICS OF THREE WINGS OF NACA 64-210 AND 65-210 AIRFOIL SECTIONS WITH AND WITHOUT 2° WASHOUT

By James C. Sivells

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

FOR REFERENCE

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EXPERIMENTAL AND CALCULATED CHARACTERISTICS OF THREE WINGS OF NACA 64-210 AND 65-210 AIRFOIL SECTIONS WITH AND WITHOUT 2° WASHOUT

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SUMMARY

An investigation has been conducted to determine some of the effects of airfoil section and washout on the experimental and calculated characteristics of 10-percent-thick wings. Three wings of aspect ratio 9 and ratio of root chord to tip chord 2.5 were tested. One wing had NACA 64-210 sections and 2° washout, the second had NACA 65-210 sections and 2° washout, and the third had NACA 65-210 sections and 0° washout. It was found that the experimental characteristics of the wings could be satisfactorily predicted from calculations based upon two-dimensional data when the airfoil contours of the wings conformed to the true airfoil sections with the same high degree of accuracy as the two-dimensional models. Small construction errors were found to cause large discrepancies in the values of maximum lift coefficient. The most significant effect of changing the airfoil section from an NACA 65-210 section to an NACA 64-210 section was to increase the maximum lift coefficient by about 10 percent, although the abruptness of the stall was also increased. The addition of 2° washout to the NACA 65-210 wing increased the angle of attack for zero lift as expected but was not sufficient to improve materially the stalling characteristics. The other characteristics of the wings were essentially unaffected by the change in airfoil section or by the addition of washout.

INTRODUCTION

One means of increasing the critical speed of an airplane wing is to decrease the thickness of the airfoil sections. Decreasing the airfoil thickness below about 12 percent, however, reduces the maximum lift coefficient of the section (reference 1). Furthermore, the use of thinner airfoil sections increases the structural problems encountered in the airplane design. As is usually the case in airplane design, some compromises must be made between these conflicting

desiderations. For example, an airfoil thickness of 10 percent represents a reasonable compromise between the aerodynamic and structural considerations involved in the design of a long-range, high-speed airplane.

Although the two-dimensional characteristics of several thin airfoil sections have been presented in reference 1, very little data at relatively high Reynolds numbers have been available on the three-dimensional characteristics of wings incorporating such sections. An investigation has therefore been conducted in the Langley 19-foot pressure tunnel to determine some of the effects of airfoil section and washout on the maximum lift and stalling characteristics of 10-percent-thick wings. Three wings were investigated: The first having NACA 64-210 sections and 2° washout, the second having NACA 65-210 sections and 2° washout, and the third having NACA 65-210 sections and 0° washout. The plan form of all three wings was typical of that for wings of a long-range, high-speed airplane in that the aspect ratio was 9 and the ratio of root chord to tip chord was 2.5. Presented herein are the experimental aerodynamic characteristics of the three wings, together with their characteristics calculated from two-dimensional data according to the method of reference 2.

COEFFICIENTS AND SYMBOLS

The coefficients and symbols used herein are defined as follows (consistent units):

C_L lift coefficient (L/qS)

$C_{L_{max}}$ maximum value of lift coefficient

C_D drag coefficient (D/qS)

C_{D_o} profile-drag coefficient (D_o/qS)

$C_{D_{o_{min}}}$ minimum value of profile-drag coefficient

C_m pitching-moment coefficient $(M'/qS\bar{c})$

where

L lift

D drag

$(L/D)_{max}$	maximum value of ratio of lift to drag
D_o	profile drag
M'	pitching moment about $0.25\bar{c}$
q	dynamic pressure of free stream $\left(\frac{1}{2}\rho V^2\right)$
S	wing area (24.94 sq ft)
$\bar{c}$	mean aerodynamic chord $\left(\frac{2}{S}\int_0^{b/2} c^2\,dy\right)$ (herein, $\bar{c}$ = 1.769 ft)
ρ	mass density of air
V	airspeed
c	local wing chord
b	wing span (15 ft)
y	spanwise coordinate

and

α	corrected angle of attack of root chord, degrees
$\alpha_{(L=0)}$	angle of attack for zero lift, degrees
R	Reynolds number $(\rho V\bar{c}/\mu)$
M	Mach number (V/a)
μ	coefficient of viscosity
a	sonic velocity
$dC_L/d\alpha$	slope of lift curve in linear range, per degree
$C_{m(L=0)}$	pitching-moment coefficient for zero lift
dC_m/dC_L	slope of pitching-moment curve in linear range
c_l	section lift coefficient
$c_{l_{max}}$	maximum value of section lift coefficient

MODELS AND TESTS

The three wings were constructed of solid steel and were geometrically similar except for airfoil section and washout. One wing had NACA 64-210 sections and 2° washout, the second had NACA 65-210 sections and 2° washout, and the third had NACA 65-210 sections and 0° washout. The ratio of root chord to tip chord was 2.5 and the aspect ratio was 9. The sweep and dihedral at the 0.25 chord line were 0° and 3°, respectively. The wings with washout had uniform twist about the 0.25 chord line inasmuch as corresponding elements of the root and tip sections were connected with straight lines. The wings were smooth and fair and conformed to the true contour to within 0.003 inch over the forward 30 percent of the wing and within 0.008 inch over the rearward portions. The general dimensions of the wings are given in figure 1.

The tests were conducted with the air in the tunnel compressed to approximately 34 pounds per square inch absolute pressure. The tests were made at a dynamic pressure of approximately 85 pounds per square foot, corresponding to a Reynolds number of approximately 4,400,000 and a Mach number of about 0.17.

The aerodynamic forces and moments were measured by a simultaneously recording, six-component balance system. The profile drag was determined from the force test data and also by the wake-momentum method from surveys of the air flow in the wake of the wing at 19 spanwise stations. The stalling characteristics were determined from observations of the behavior of tufts attached to the upper surface of the wings behind the 0.30 chord line.

RESULTS AND DISCUSSION

All data have been reduced to standard nondimensional coefficients. Corrections have been applied to the force and moment data to account for the tare and interference effects of the model support system. Stream-angle and jet-boundary corrections have been applied to the angle of attack and to the drag coefficients.

Comparison of Experimental and Calculated Characteristics

Force and moment characteristics.- The experimental and calculated lift, drag, and pitching-moment characteristics are shown in figures 2 to 4. A summary of the data in these figures is given in table I. The calculated characteristics were obtained

by the use of the method of reference 2, which takes into account the nonlinearity of the section lift curves. All section data used in the calculations were obtained from reference 1. In general, the agreement between the experimental and the calculated characteristics is considered to be very satisfactory. This good agreement was possible, however, only after extreme care was taken to make the wing contours conform to the true airfoil contours with the same high degree of accuracy as the two-dimensional models. That this extreme care was necessary was indicated by preliminary tests of the NACA 65-210 wings in which large discrepancies in maximum lift coefficient were found to be due to small errors in construction, particularly around the leading edge of the wings.

The main discrepancies between the experimental and calculated characteristics occur at the upper end of the low-drag range where the calculated curves show a more extensive low-drag range than the experimental curves. This effect is probably due to the spanwise spread of transition which was not taken into account in the calculations. The reasonableness of this explanation is indicated by the fact that the low-drag range obtained from the wake surveys agrees, in general, with that obtained from the force tests. (The profile-drag coefficients obtained from force tests were determined by subtracting the calculated induced-drag coefficients from the total-drag coefficients.) The difference in the extent of the low-drag range is also reflected in the values of $(L/D)_{max}$ since these values, in every case, were obtained at the upper end of the low-drag range. This result emphasizes the need of preserving laminar flow as far as possible in order to obtain high values of $(L/D)_{max}$.

Stalling characteristics.- The stalling characteristics of the three wings are shown in figure 5. The values of lift coefficient shown were obtained with tufts in place on the wing. In order to predict the stalling characteristics of the wings, the characteristics calculated according to the method of reference 2 and presented in figure 6 may be used. This figure shows the spanwise variation of the maximum lift coefficient which each section is capable of reaching in two-dimensional flow and the variation of section lift coefficient for the wing when some section first reaches its maximum value. According to reference 3 the maximum lift coefficient of the wing is reached when the curves first become tangent; the point of tangency of the two curves indicates the spanwise position of the initial stall, and the rate of divergence between the curves serves as an indication of the manner in which the stall spreads. From a comparison of figures 5 and 6, it can be seen that these wings stall approximately as predicted.

Effect of Airfoil Section

A comparison of figures 2 and 3 shows that the minimum profile-drag coefficient of the NACA 64-210 wing is slightly higher (about 0.0004) than that of the NACA 65-210 wing and the maximum lift-drag ratio is correspondingly lower than that of the NACA 65-210 wing. The most significant effect of the difference in airfoil section is, however, the approximately 10-percent increase in maximum lift coefficient for the NACA 64-210 wing over that for the NACA 65-210 wing.

From figure 5 it may be seen that the stall of the NACA 64-210 wing began slightly farther inboard than that of the NACA 65-210 wing but was more abrupt and was accompanied by a greater loss in lift. Figure 6 indicates that the stall of the NACA 64-210 wing should have begun slightly farther outboard than that of the NACA 65-210 wing but the differences in spanwise position in either case are small. Both figures indicate that beyond maximum lift there is slightly less stalled area at the wing tips of the NACA 64-210 wing.

Effect of Washout

Except for the expected change in the angle of attack for zero lift, there are no practical differences in the characteristics of the two NACA 65-210 wings with and without 2° washout (figs. 3 and 4). High-speed tests made at the Ames Aeronautical Laboratory of similar wings also showed negligible effect of 2° washout. A larger amount of washout would, however, probably make some difference, but the amount of washout that could be tolerated without introducing harmful effects at high Mach numbers is not known.

The 2° washout was not enough to improve materially the stalling characteristics of the NACA 65-210 wings, although the spanwise position of the incipient stall was moved somewhat inboard because of the washout. A larger amount of washout should effect a significant improvement by moving the stall farther inboard.

CONCLUSIONS

From the results of an investigation of the experimental and calculated characteristics of three 10-percent-thick tapered wings, the following conclusions may be drawn:

1. The experimental characteristics of the wings could be satisfactorily predicted from calculations based upon two-dimensional data when the airfoil contours of the wings conformed to the true airfoil contours with the same high degree of accuracy as the two-dimensional models from which the data were obtained. Small errors in construction were found to cause large discrepancies in the values of maximum lift coefficient

2. The most significant effect of changing the airfoil section from an NACA 65-210 section to an NACA 64-210 section was to increase the maximum lift coefficient by about 10 percent, although the abruptness of the stall was also increased.

3. The addition of 2° washout to the NACA 65-210 wing increased the angle of attack for zero lift as expected but was not sufficient to improve materially the stalling characteristics.

4. The other characteristics of the wings were virtually unaffected by the change in airfoil section or by the small amount of washout.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., August 25, 1947

REFERENCES

1 Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.

2. Sivells, James C., and Neely, Robert H.: Method for Calculating Wing Characteristics by Lifting-Line Theory Using Nonlinear Section Lift Data. NACA TN No. 1269, 1947.

3. Anderson, Raymond F.: Determination of the Characteristics of Tapered Wings. NACA Rep. No. 572, 1936.

TABLE I

SUMMARY OF RESULTS OBTAINED FROM TESTS IN THE LANGLEY 19-FOOT PRESSURE TUNNEL OF THREE 10-PERCENT THICK WINGS

$[R \approx 4.4 \times 10^6;\ M \approx 0.17]$

Wing	$C_{L_{max}}$		$dC_L/d\alpha$		$\alpha_{(L=0)}$		$(L/D)_{max}$	
	Experimental	Calculated	Experimental	Calculated	Experimental	Calculated	Experimental	Calculated
64-210 wing 2° washout	1.35	1.36	0.086	0.083	-1.0	-1.1	38.8	38.8
65-210 wing 2° washout	1.21	1.24	.085	.085	-1.0	-1.0	39.4	41.0
65-210 wing 0° washout	1.23	1.22	.085	.085	-1.3	-1.5	38.0	41.6

Wing	$C_{D_{o_{min}}}$			$C_{m_{(L=0)}}$		dC_m/dC_L	
	Force tests	Wake surveys	Calculated	Experimental	Calculated	Experimental	Calculated
64-210 wing 2° washout	0.0043	0.0044	0.0045	-0.037	-0.040	0	-0.010
65-210 wing 2° washout	.0040	.0039	.0041	-.035	-.035	0	-.010
65-210 wing 0° washout	.0044	.0039	.0041	-.037	-.035	0.004	-.006

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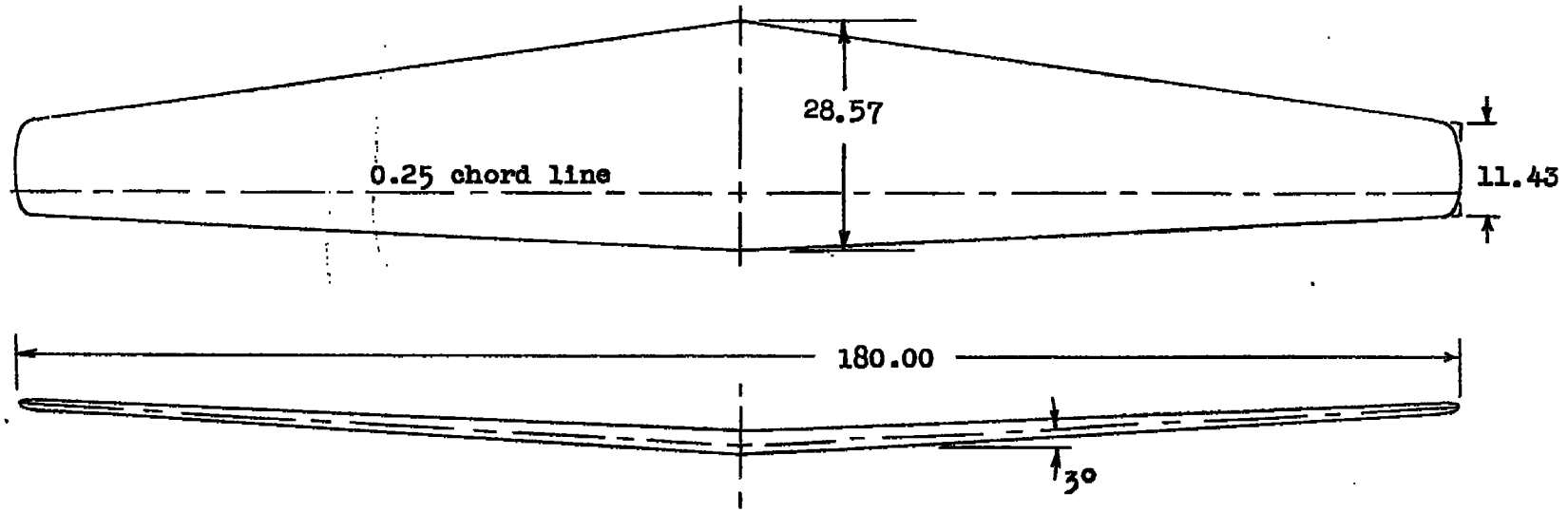

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Figure 1.- General dimensions of 10-percent-thick wings tested in Langley 19-foot pressure tunnel. Aspect ratio, 9; ratio of root chord to tip chord, 2.5. (All dimensions are in inches.)

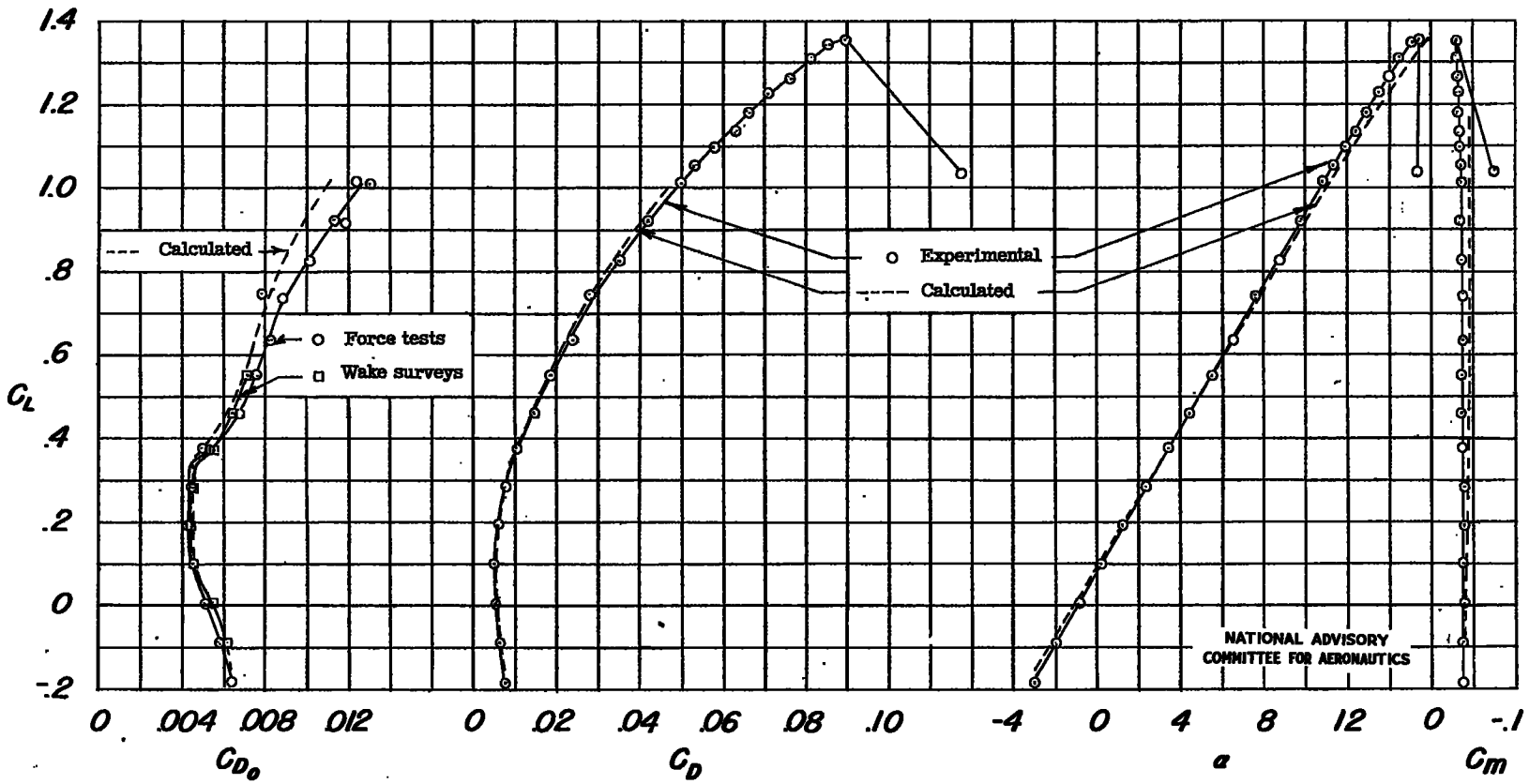


Figure 2.- Experimental and calculated characteristics of wing having NACA 64-210 airfoil sections. Washout, 2°; aspect ratio, 9; ratio of root chord to tip chord, 2.5; $R \approx 4.4 \times 10^{6}$; $M \approx 0.17$.

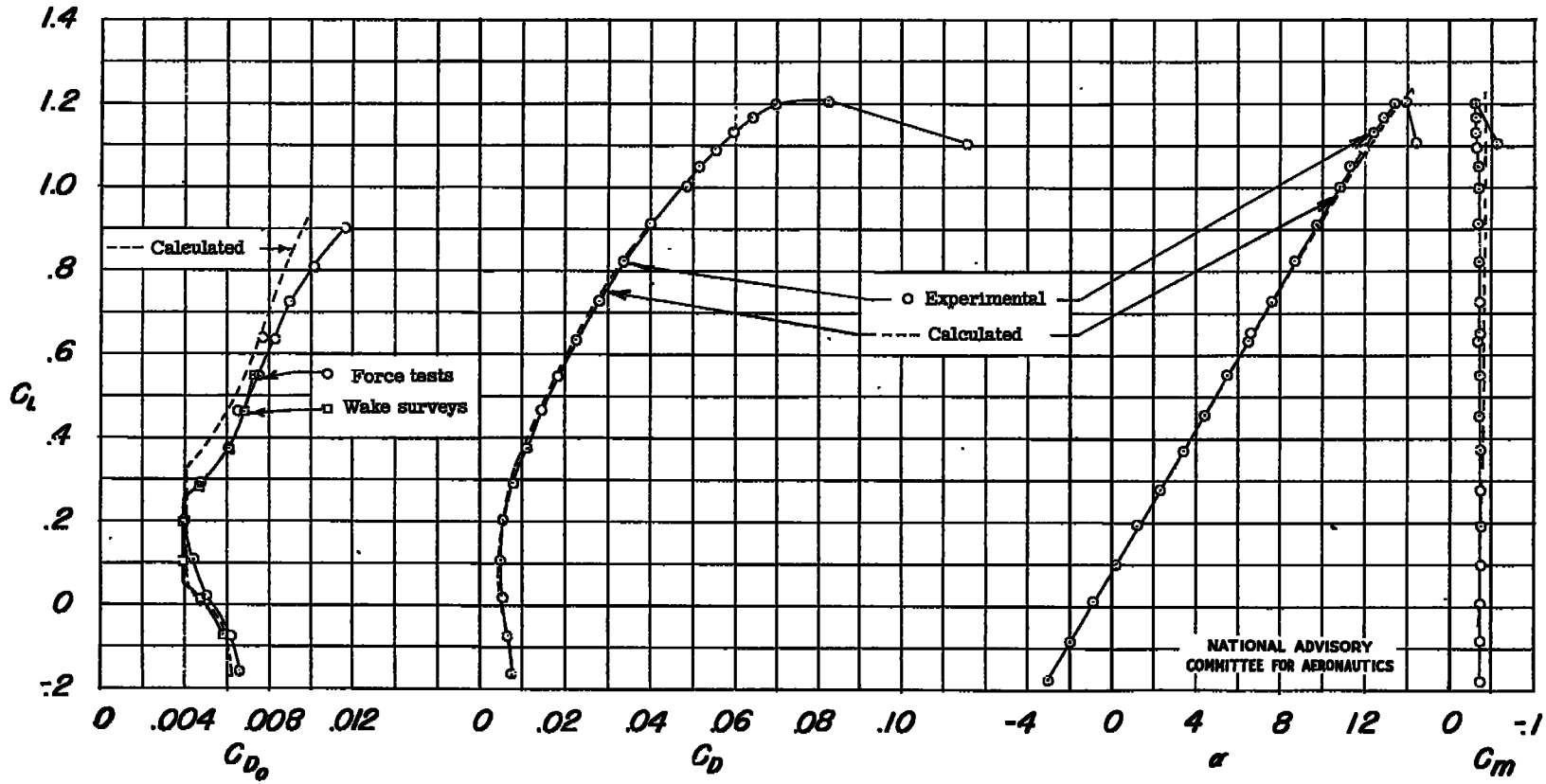


Figure 3.- Experimental and calculated characteristics of wing having NACA 65-210 airfoil sections. Washout, 2°; aspect ratio, 9; ratio of root chord to tip chord, 2.5; $R \approx 4.4 \times 10^{6}$; $M \approx 0.17$.

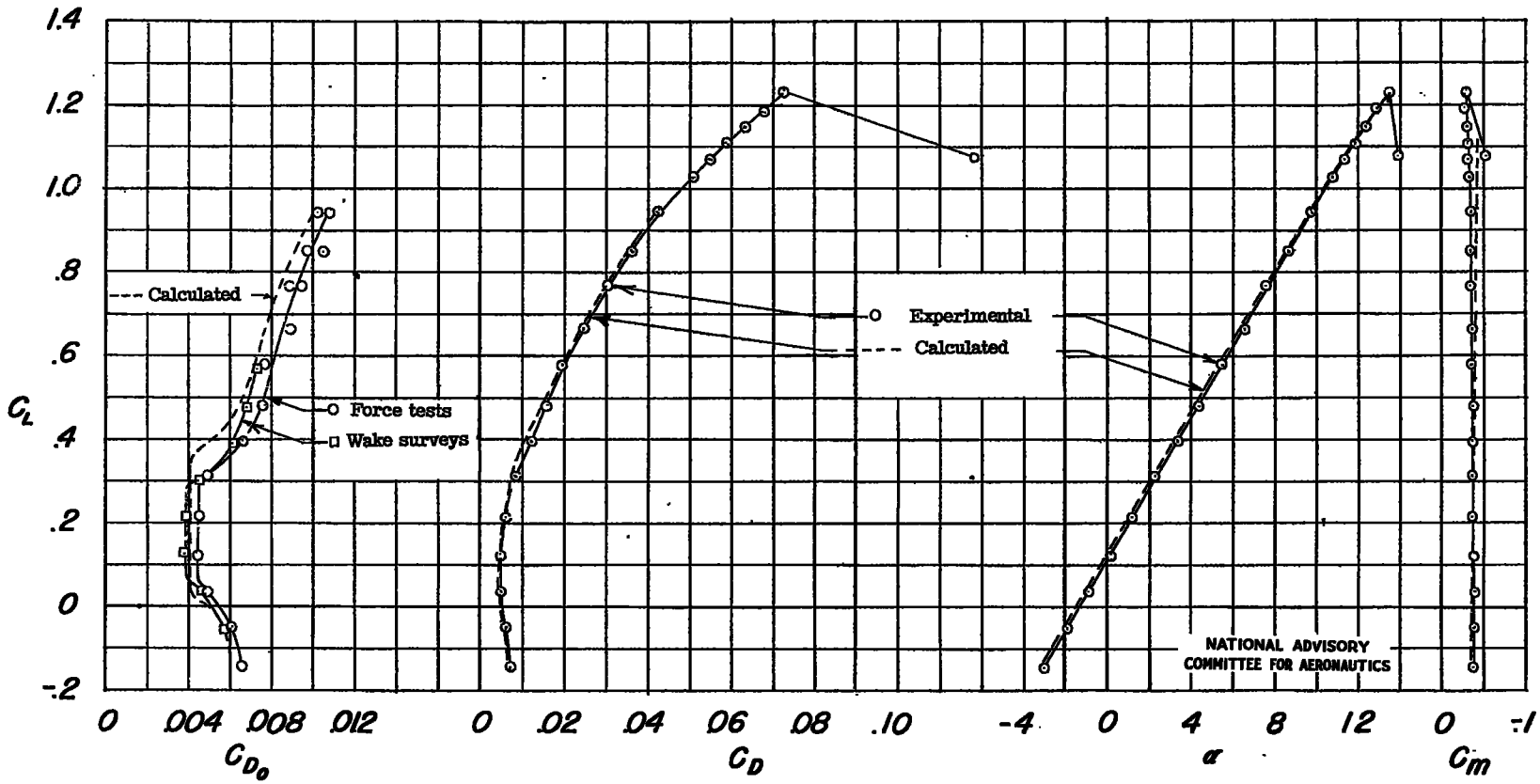


Figure 4.- Experimental and calculated characteristics of wing having NACA 65-210 airfoil sections. Washout, 0°; aspect ratio, 9; ratio of root chord to tip chord, 2.5; $R \approx 4.4 \times 10^6$; $M \approx 0.17$.

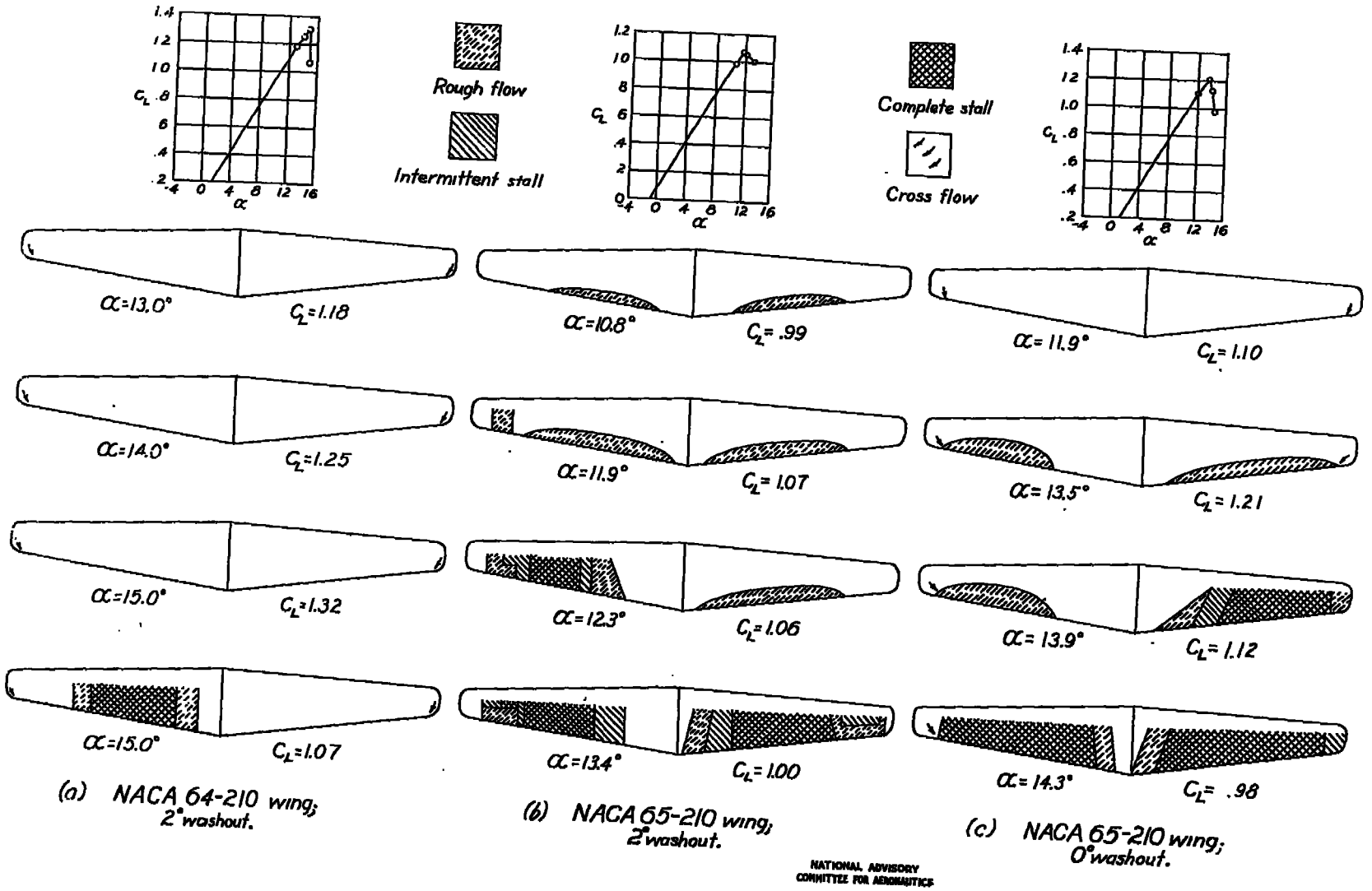
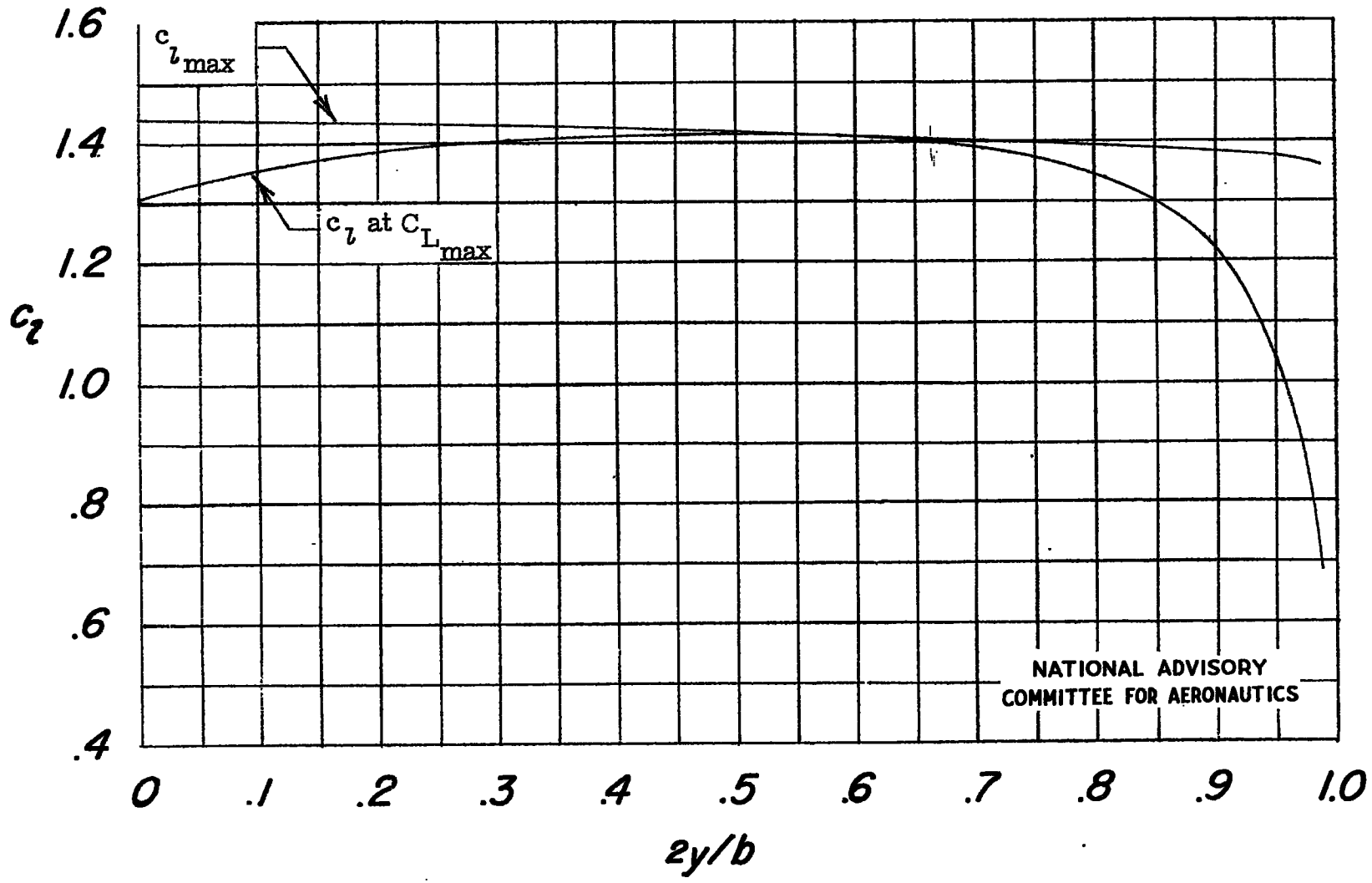
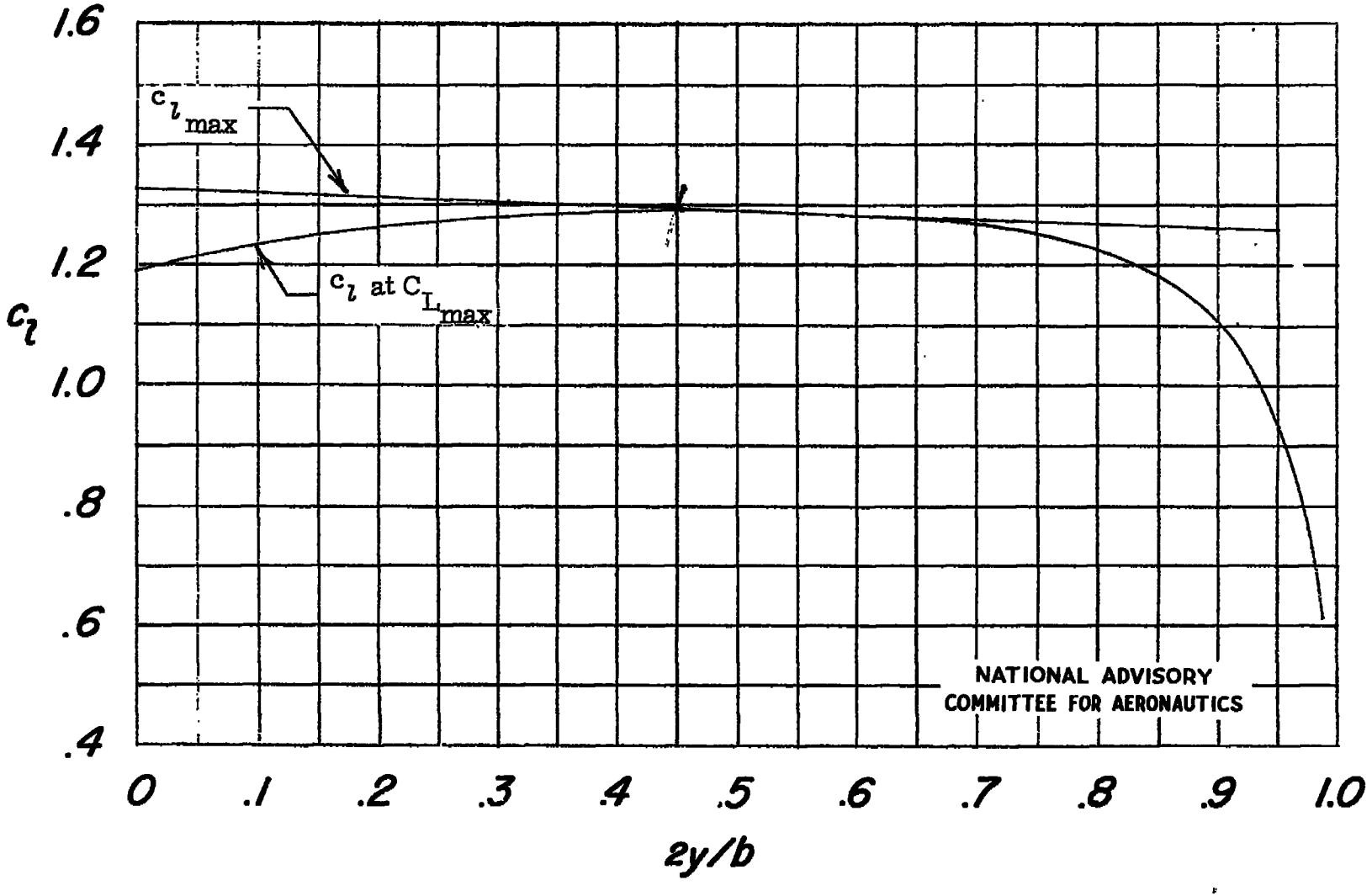


Figure 5.- Stalling characteristics of wings of aspect ratio 9 and ratio of root chord to tip chord 2.5. $R \approx 4.4 \times 10^6$; $M \approx 0.17$.



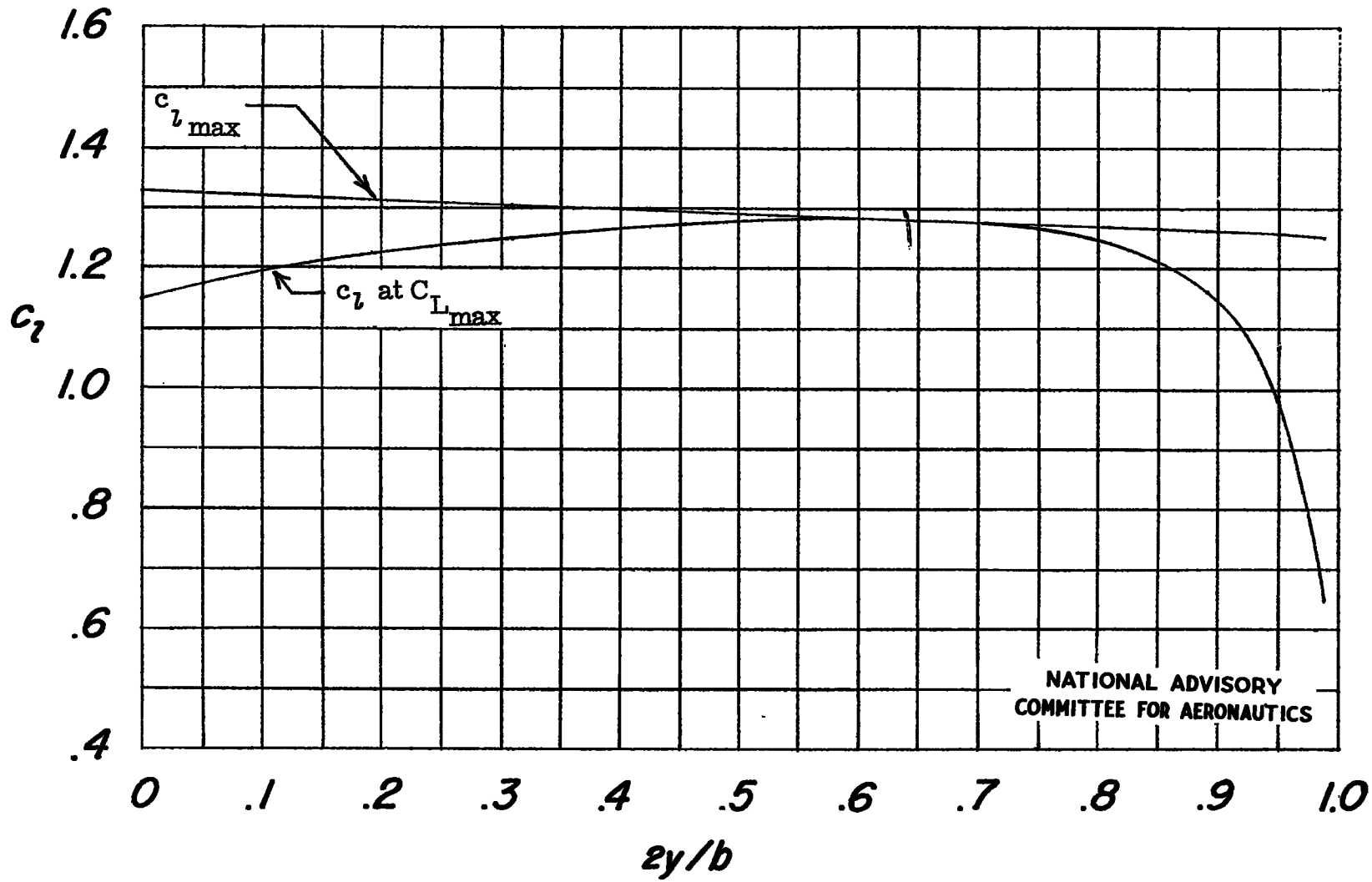
(a) NACA 64-210 sections, 2° washout.

Figure 6.- Spanwise variation of maximum section lift coefficient and section lift coefficient at maximum wing lift coefficient for wings of aspect ratio 9 and ratio of root chord to tip chord 2.5. $R \approx 4.4 \times 10^6$.



(b) NACA 65-210 sections, 2° washout.

Figure 6.- Continued.



(c) NACA 65-210 sections, 0° washout.

Figure 6.- Concluded.