NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 343

EFFECT OF VARIATION OF CHORD AND SPAN OF AILERONS ON ROLLING AND YAWING MOMENTS AT SEVERAL ANGLES OF PITCH

By R. H. HEALD, D. H. STROTHER, and B. H. MONISH

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/hr	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s^2 $=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Bureau of Standards

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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SUMMARY

This report presents the results of an extension to higher angles of attack of the investigation described in Reference 1, of the rolling and yawing moments due to ailerons of various chords and spans on two airfoils having the Clark Y and U. S. A. 27 wing sections.

The measurements were made at various angles of pitch but at zero angle of roll and yaw, the wing chord being set at an angle of +4° to the fuselage axis. In the case of the Clark Y airfoil the measurements have been extended to a pitch angle of 40°, using ailerons of span equal to 67 per cent of the wing semispan and chord equal to 20 and 30 per cent of the wing chord. It is planned later to extend the investigation to hinge moments of the ailerons for the conditions covered in the rolling and yawing moment tests.

The work was conducted in the 10-foot wind tunnel of the Bureau of Standards on wing models of 60-inch span and 10-inch chord.

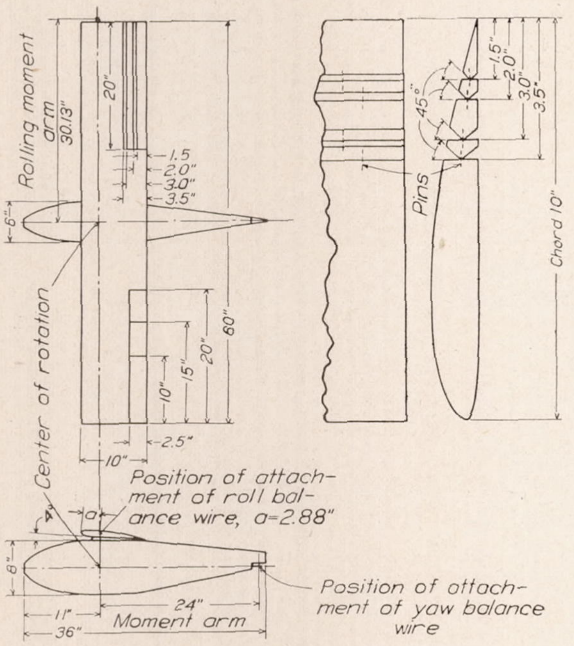
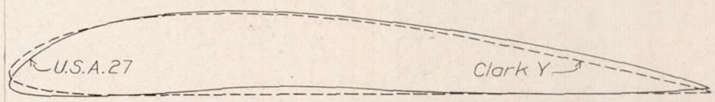


FIGURE 1.—Dimensioned drawing of model

INTRODUCTION

The work was continued through the cooperation of the Aeronautics Branch of the Department of Commerce and the National Advisory Committee for Aeronautics, for the purpose of furthering the knowledge of the rolling and yawing moments due to conventional ailerons on some representative American wing sections.



% chord		0	1.25	2.5	5.0	7.5	10	15	20	30	40	50	60	70	80	90	95	100
U.S.A.27	Up'r.	1.77	3.80	5.07	6.94	8.22	9.19	10.50	11.37	11.97	11.68	10.86	9.54	8.08	6.10	3.69	2.26	0.67
	Lwr.	1.77	0.50	0.36	0.19	0.10	0.02	0.10	0.36	0.93	1.14	0.75	0.28	0.06	0.01	0.12	0.33	0.65
Clark Y	Up'r.	3.62	5.38	6.43	7.83	8.79	9.56	10.63	11.32	11.68	11.37	10.49	9.13	7.34	5.21	2.79	1.50	0.12
	Lwr.	3.58	1.86	1.42	0.91	0.59	0.39	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FIGURE 2.—Profiles and coordinates of Clark Y and U. S. A. 27 wing sections

DESCRIPTION OF APPARATUS AND MODELS

A detailed description of the apparatus and models is given in Reference 1 and a dimensioned sketch of the model is shown in Figure 1. The profiles and coordinates of the wing sections used are given in Figure 2, and a sketch of the method of mounting the model in the tunnel in Figure 3.

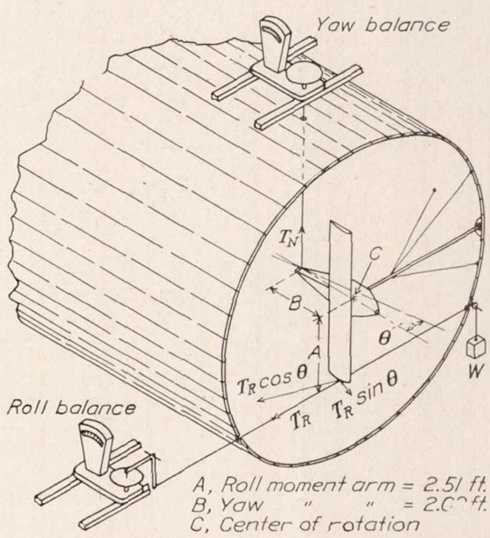


FIGURE 3.—Axonometric drawing of model in tunnel, including sketch of resolution of forces

ARRANGEMENT OF BALANCES

A sketch of the balance arrangement is shown in Figure 3. The model was supported in the tunnel so that the leading edge of the wing was vertical and the rolling and yawing forces read on balances of the pendulum type. The roll and yaw force wires were kept normal to the wind stream.

METHOD OF OBSERVATION

As before, simultaneous measurements of the tension in the roll and yaw balance wires were made at speeds of 40, 58.7, and 80 feet per second (respectively, 27.3, 40, and 54.5 miles per hour). Observations were made at a sufficient number of aileron angles to determine the

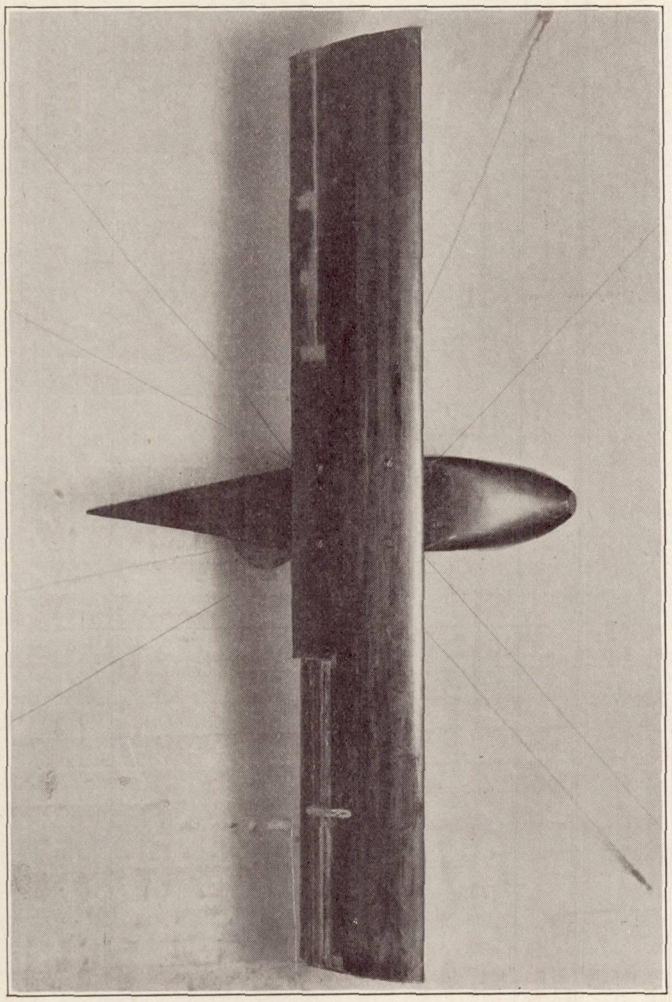


FIGURE 4.—Photograph of model set at 12° pitch in tunnel

characteristics of the curves. The ailerons were set to the desired angle by the use of metal templates and were secured by thin metal strips on the top and bottom of the wing (fig. 4), as it was found that the stiffness of the pins was not sufficient to prevent a change of the aileron angle under the wind pressure.

REDUCTION OF OBSERVATIONS

Small rolling and yawing forces, which appeared to be due to the drag of the balance wires and to a slight asymmetry of the model, were noted at zero aileron angle in all cases. Correction was made for these forces in the reduction of observations.

The results are expressed in the usual absolute coefficients, namely: [1]

$$C_L=\frac{L}{qbS} \text{ and } C_N=\frac{N}{qfS}$$

where C_L and C_N are the absolute rolling and yawing moment coefficients for one aileron.

L and N are respectively rolling and yawing moments in pounds-feet.

$q=\frac{1}{2}\rho V^2=0.001189 V^2$

b = wing span in feet

f = distance from center of rotation of model to end of tail. (NOTE.—This distance was chosen as closely representing the distance from the center of gravity of the airplane to the leading edge of the elevator)

S = wing area in square feet (chord length × span)

V = wind speed in feet per second

ρ = air density = 0.002378 slug per cubic foot at 15° C. and 760 mm. pressure

The results are reduced to body axes as reference axes and the directions are conventional, a moment tending to produce a clockwise rotation as viewed from the pilot's seat being considered positive. The longitudinal axis is the axis of the fuselage, the axis of yaw is perpendicular to the longitudinal axis and to the span of the wing, and the pitch axis is parallel to the wing span. The reduction to body axes is made as follows:

Referring to Figure 3, the roll force resolved parallel to the axis of yaw is $T_R \cos\theta$, where T_R is the net observed tension in the roll wire and θ is the angle of pitch. The rolling moment is $AT_R \cos\theta$. Because of he inclination of the roll wire to the pitch plane, a component $T_R \sin\theta$, having an arm A, enters into the computation of the yawing moment. The yawing moment, therefore, is seen to be $-BT_N+AT_R \sin\theta$. Note that an increase in the yaw balance reading corresponds to a negative yawing moment according to the convention adopted; hence the minus sign.

RESULTS

The signs and values for one aileron given in the tables and plots are for a single aileron on the right wing tip. The combined values were obtained by the direct summation of the values for corresponding aileron settings and are for the condition of right aileron up and left aileron down. The reference axes are body axes with the origin at the center of rotation of the model.

Investigation having shown the scale effects within the speed range of these tests to be small, the use of faired curves through all points representing observed values seemed justified. The values of C_L, C_N, and N/L given in Tables I–XVI and Figures 5–47 were read from the faired curves.

[1] Note that the coefficients are based on wing dimensions which are held constant throughout the investigation: i. e.

$$L=C_L q \text{ times a constant}=20.83\ C_L q$$

and

$$N=C_N q \text{ times a constant}=8.68\ C_N q$$

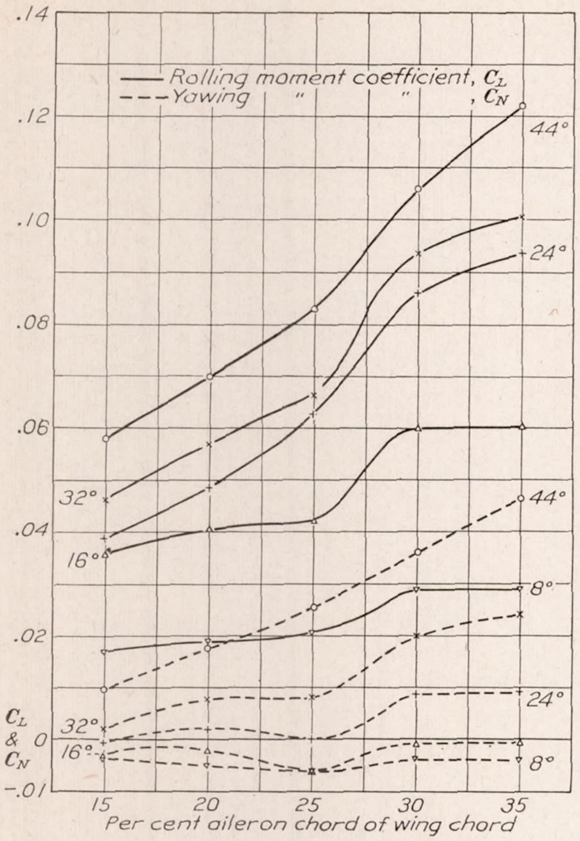


FIGURE 5.—Clark Y wing section. C_L and C_N for up aileron angles versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan)

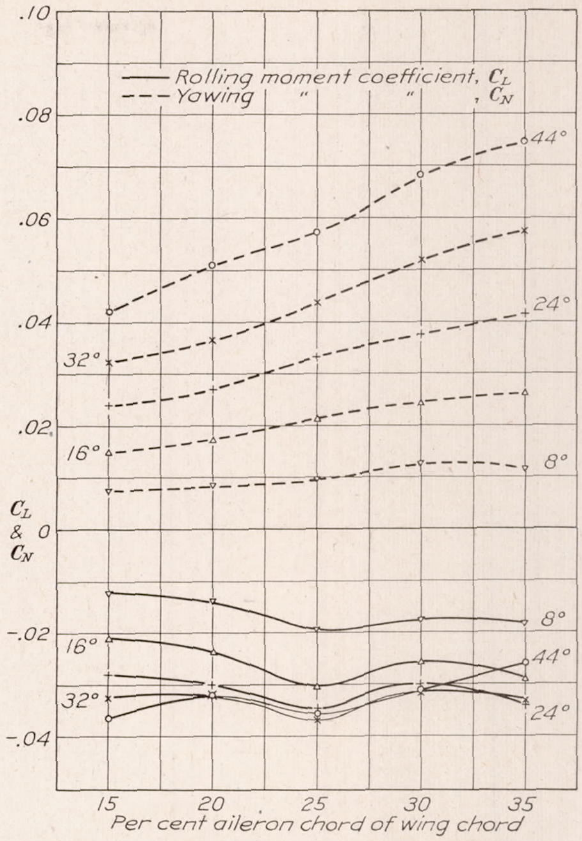


FIGURE 6.—Clark Y wing section. C_L and C_N for down aileron angles versus per cent aileron chord of wing chord. Pitch angle 8°. Span, 20 inches (67 per cent of wing semispan)

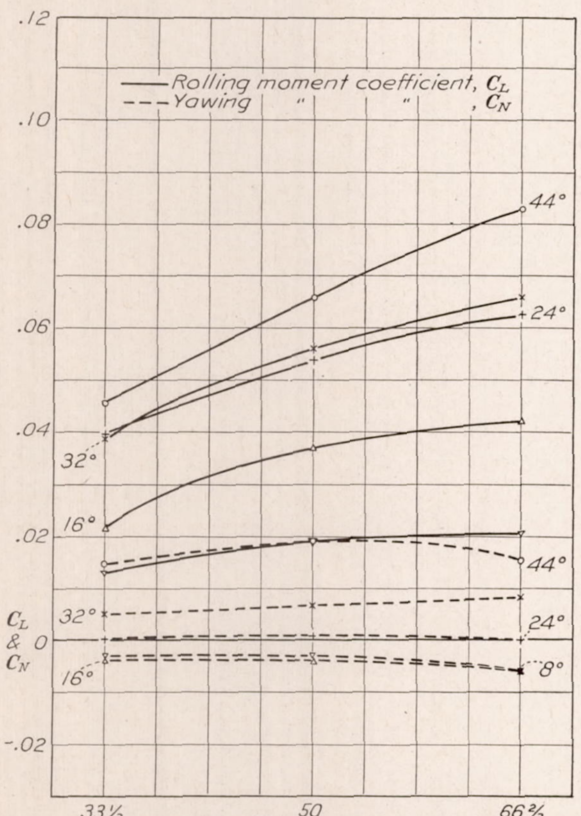


FIGURE 7.—Clark Y wing section. C_L and C_N for up aileron angles versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord)

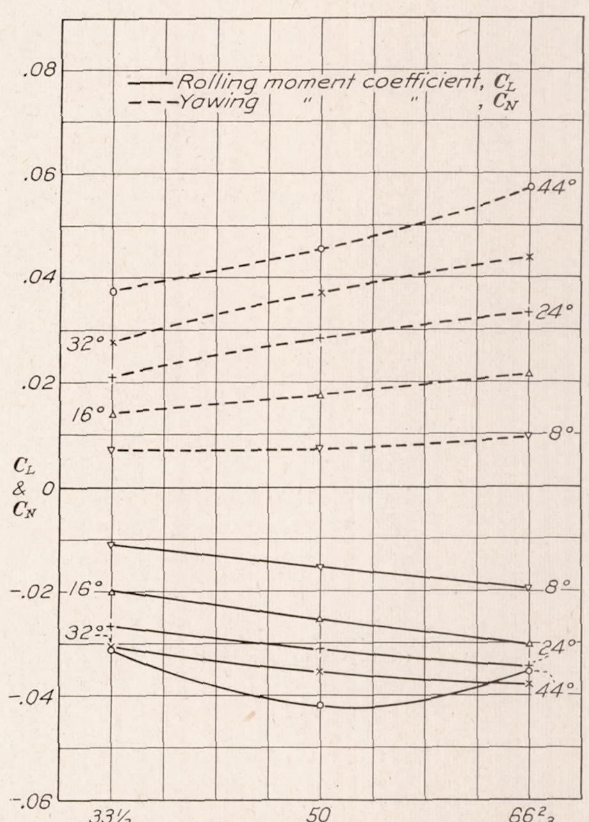


FIGURE 8.—Clark Y wing section. C_L and C_N for down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord)

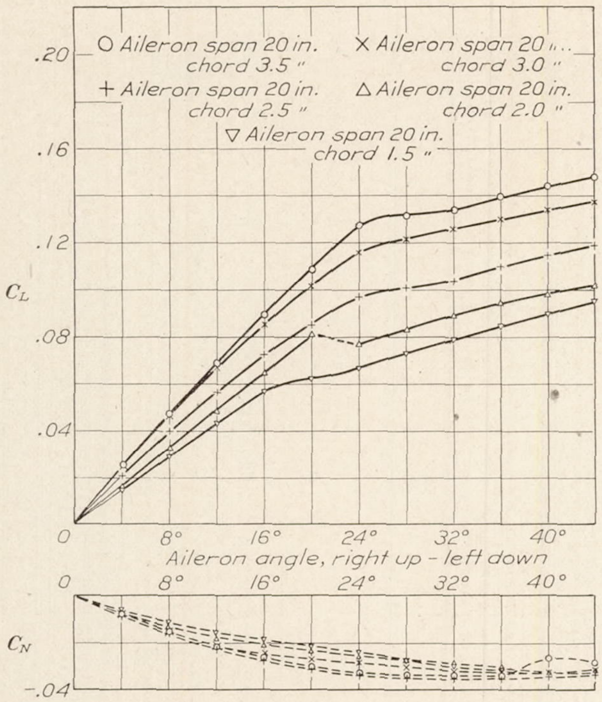


FIGURE 9.—Clark Y wing section. Combined C_L and C_N for varying chord ailerons versus aileron angle. Pitch angle, 8°. Note, $N/L=0.417\ C_N/C_L$

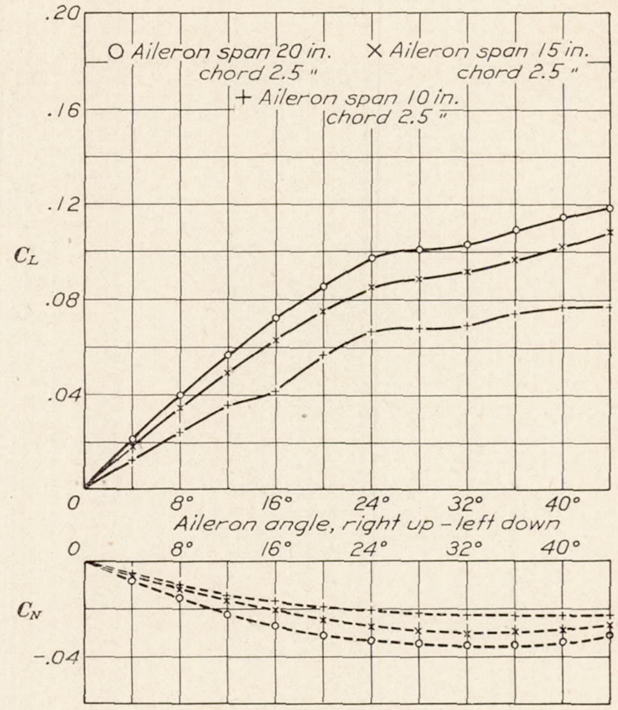


FIGURE 10.—Clark Y wing section. Combined C_L and C_N for varying span ailerons versus aileron angle. Pitch angle, 8°. Note, $N/L=0.417\ C_N/C_L$

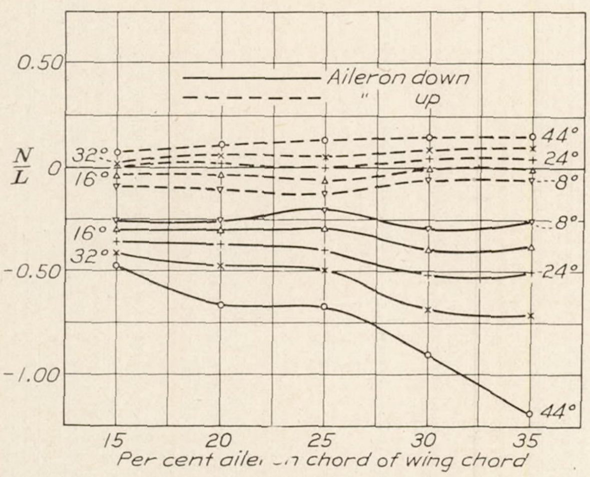


FIGURE 11.—Clark Y wing section. N/L for up and down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

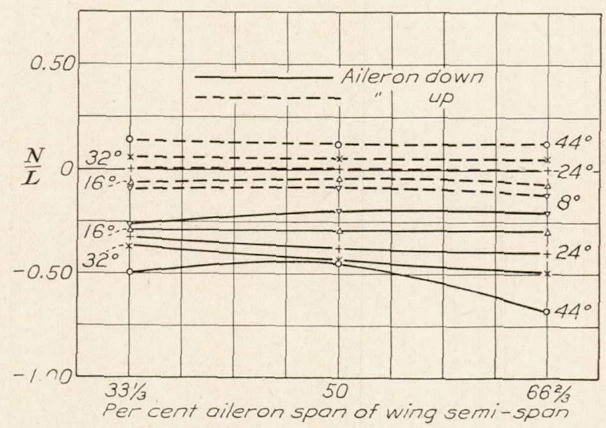


FIGURE 12.—Clark Y wing section. N/L for up and down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

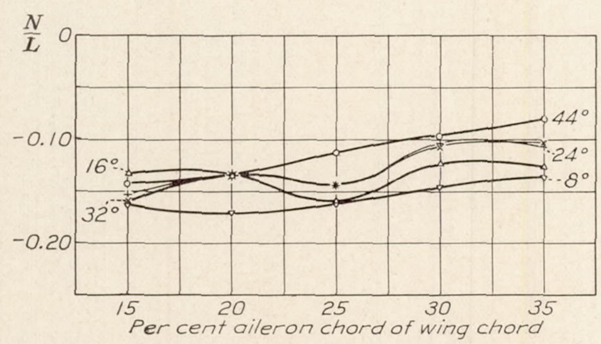


FIGURE 13.—Clark Y wing section. N/L for combined ailerons (right up, left down) versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

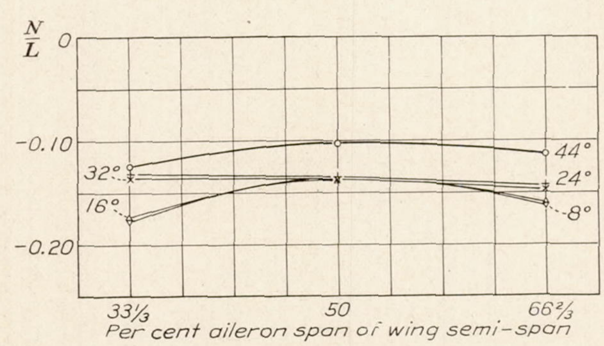


FIGURE 14.—Clark Y wing section. N/L for combined ailerons (right up, left down) versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

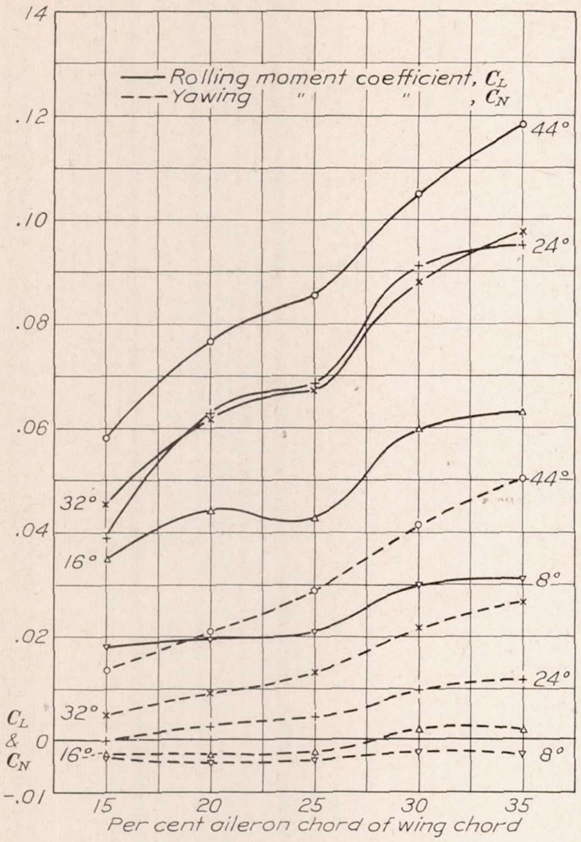


FIGURE 15.—U. S. A. 27 wing section. C_L and C_N for up aileron angles versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan)

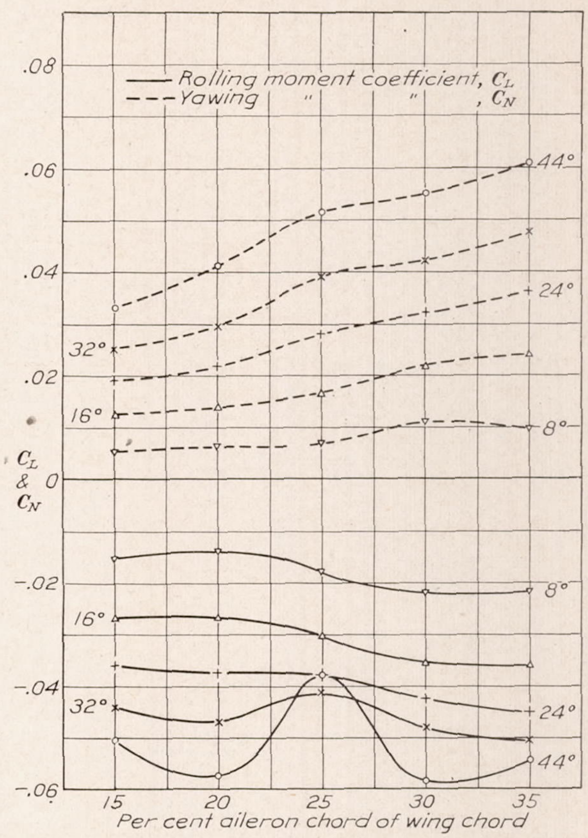


FIGURE 16.—U. S. A. 27 wing section. C_L and C_N for down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan)

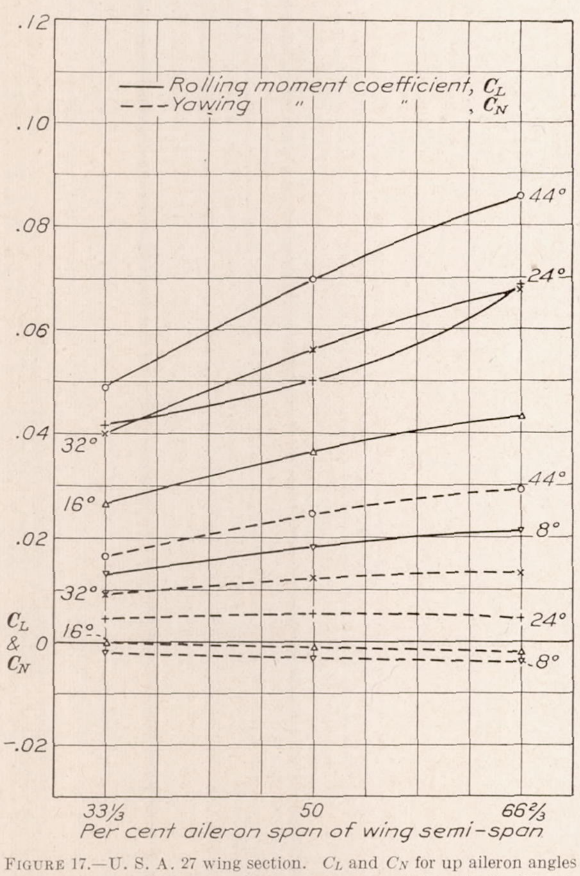


FIGURE 17.—U. S. A. 27 wing section. C_L and C_N for up aileron angles versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord)

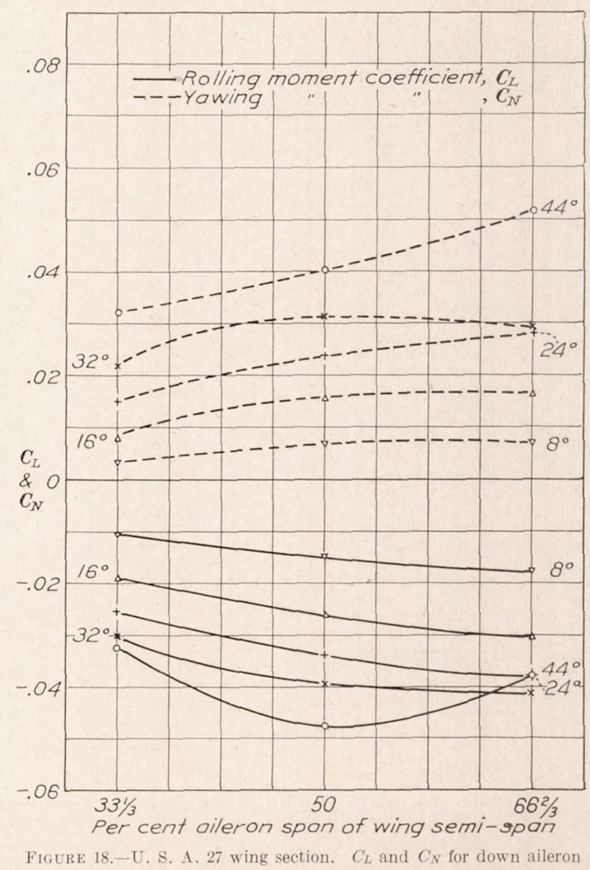


FIGURE 18.—U. S. A. 27 wing section. C_L and C_N for down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord)

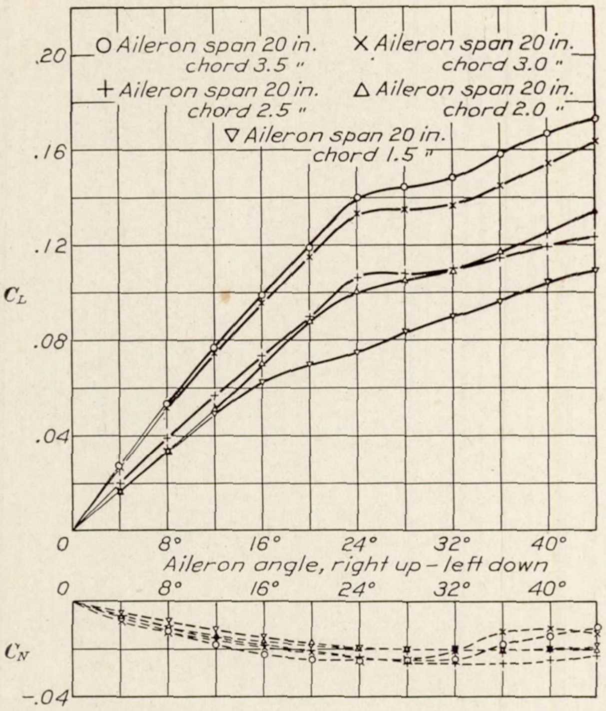


FIGURE 19.—U. S. A. 27 wing section. Combined C_L and C_N for varying chord ailerons versus aileron angle. Pitch angle, 8°. Note, $N/L=0.417\ C_N/C_L$

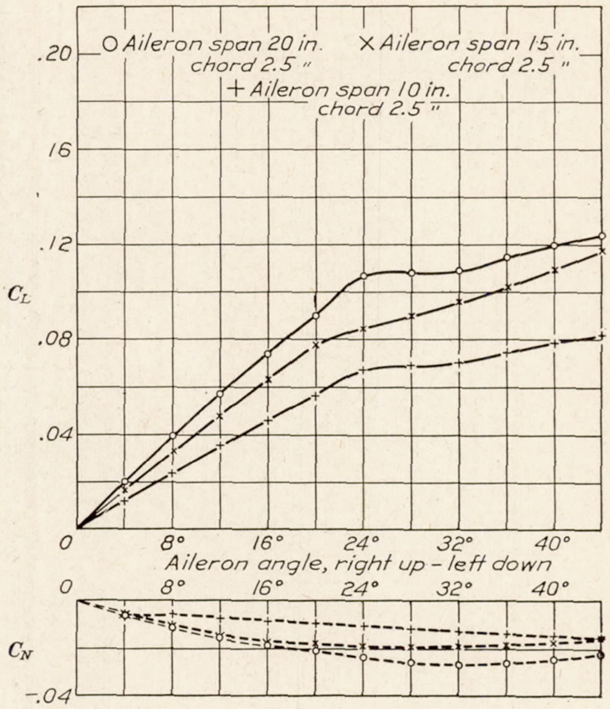


FIGURE 20.—U. S. A. 27 wing section. Combined C_L and C_N for varying span ailerons versus aileron angle. Pitch angle, 8°. Note, $N/L=0.417\ C_N/C_L$

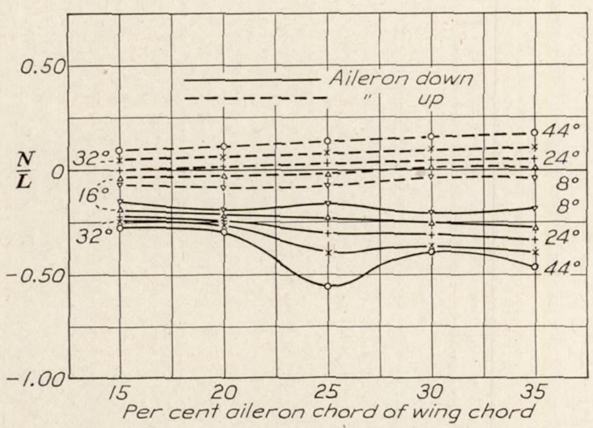


FIGURE 21.—U. S. A. 27 wing section. N/L for up and down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

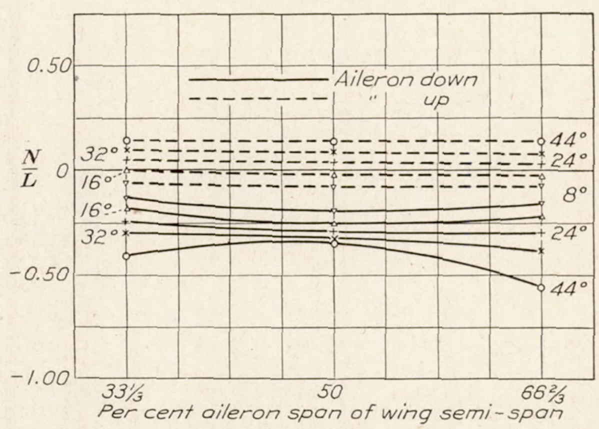


FIGURE 22.—U. S. A. 27 wing section. N/L for up and down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord.) Note, $N/L=0.417\ C_N/C_L$

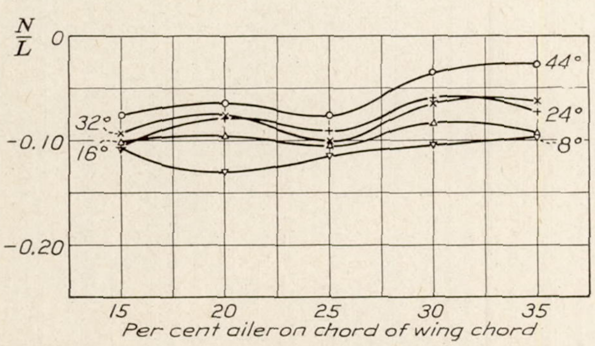


FIGURE 23.—U. S. A. 27 wing section. N/L for combined ailerons (right up, left down) versus per cent aileron chord of wing chord. Pitch angle, 8°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

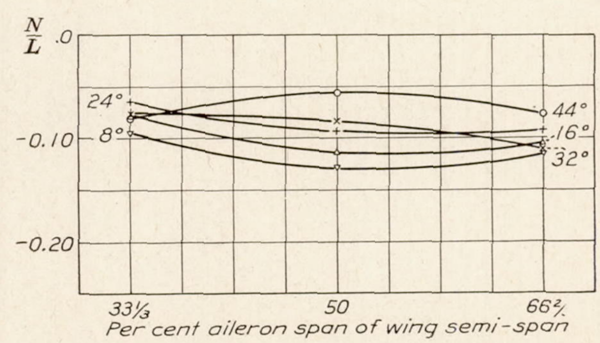


FIGURE 24.—U. S. A. 27 wing section. N/L for combined ailerons (right up, left down versus per cent aileron span of wing semispan. Pitch angle, 8°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

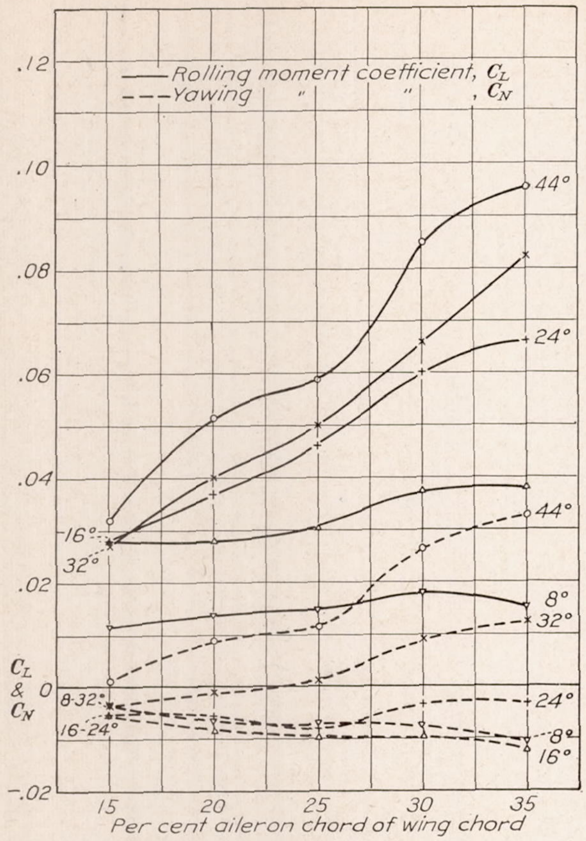


FIGURE 25.—Clark Y wing section. C_L and C_N for up aileron angles versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan)

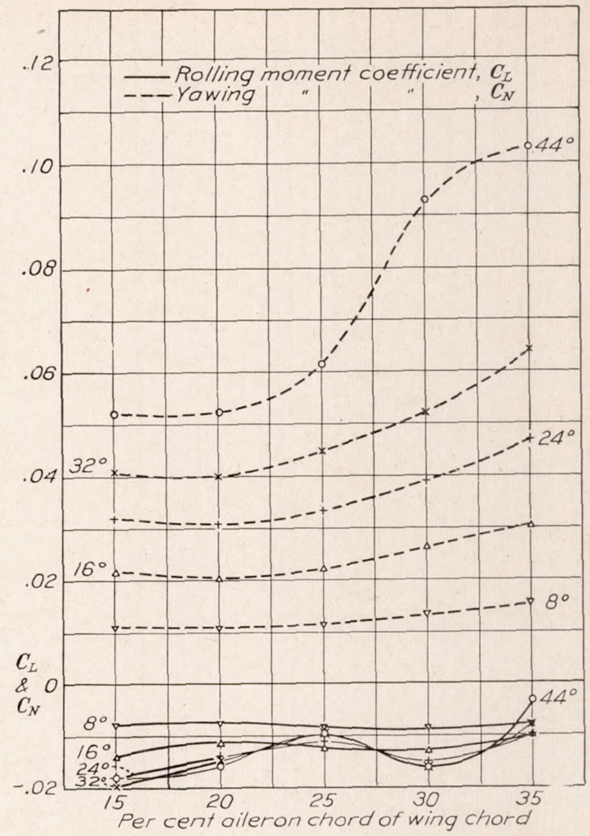


FIGURE 26.—Clark Y wing section. C_L and C_N for down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan)

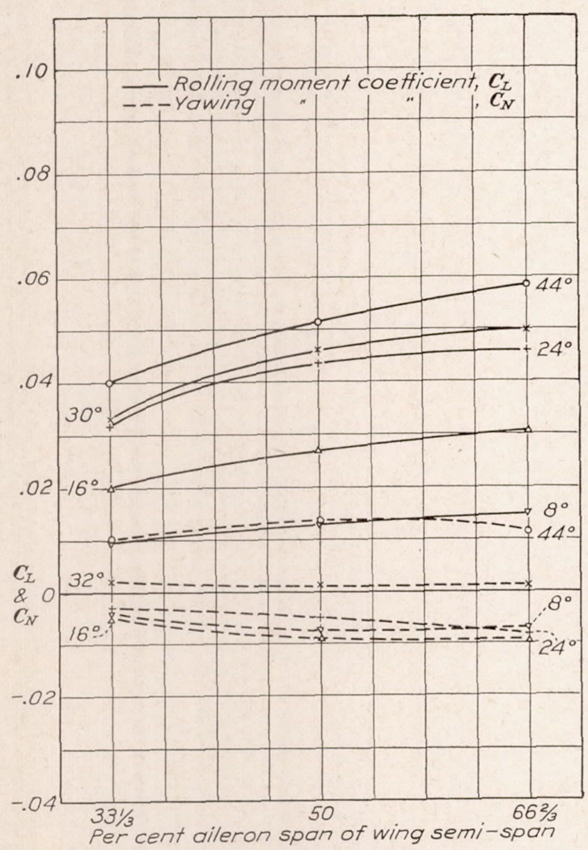


FIGURE 27.—Clark Y wing section. C_L and C_N for up aileron angles versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord)

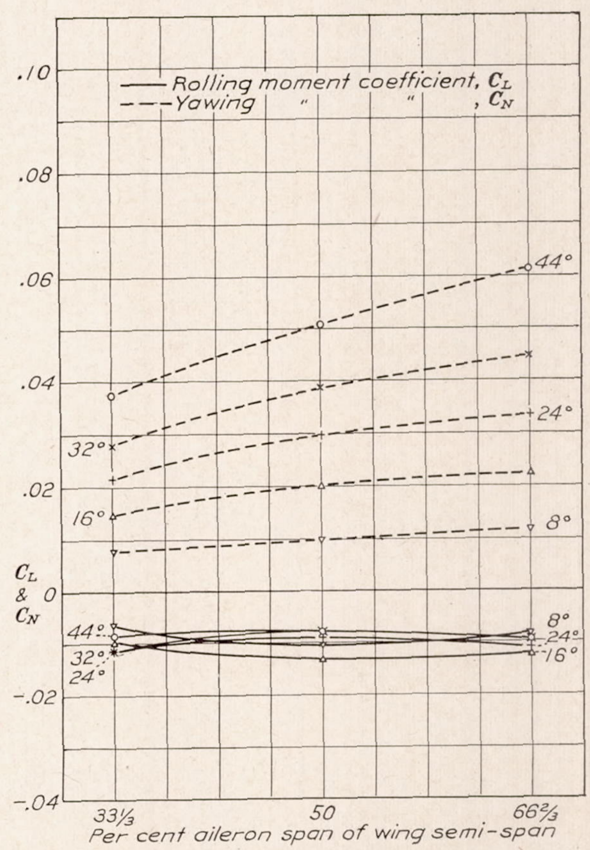


FIGURE 28.—Clark Y wing section. C_L and C_N for down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord)

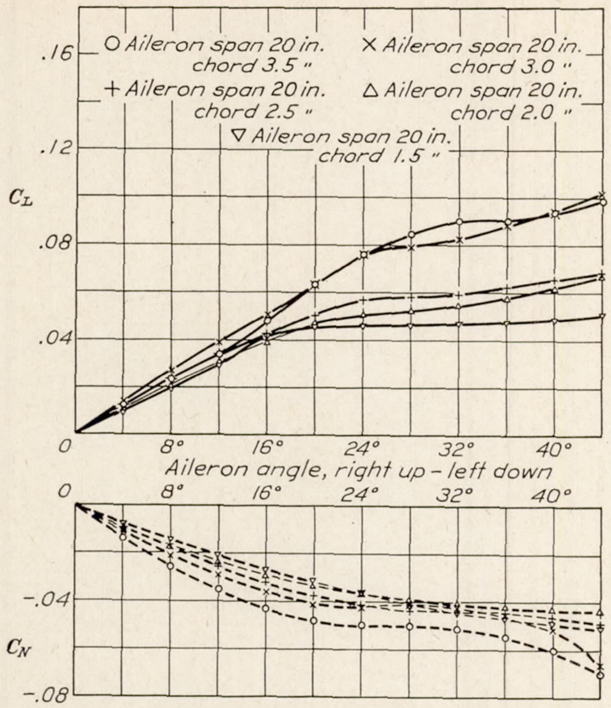


FIGURE 29.—Clark Y wing section. Combined C_L and C_N for varying chord ailerons versus aileron angle. Pitch angle, 12°. Note, $N/L=0.417\ C_N/C_L$

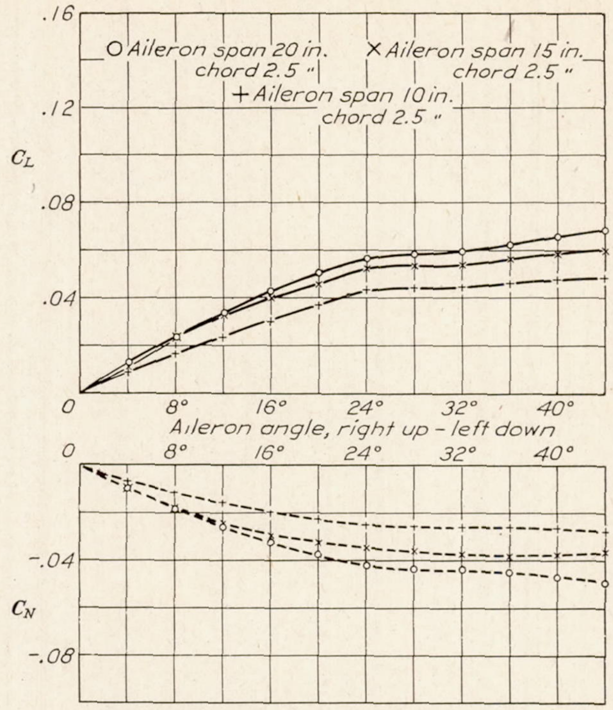


FIGURE 30.—Clark Y wing section. Combined C_L and C_N for varying span ailerons versus aileron angle. Pitch angle, 12°. Note, $N/L=0.417\ C_N/C_L$

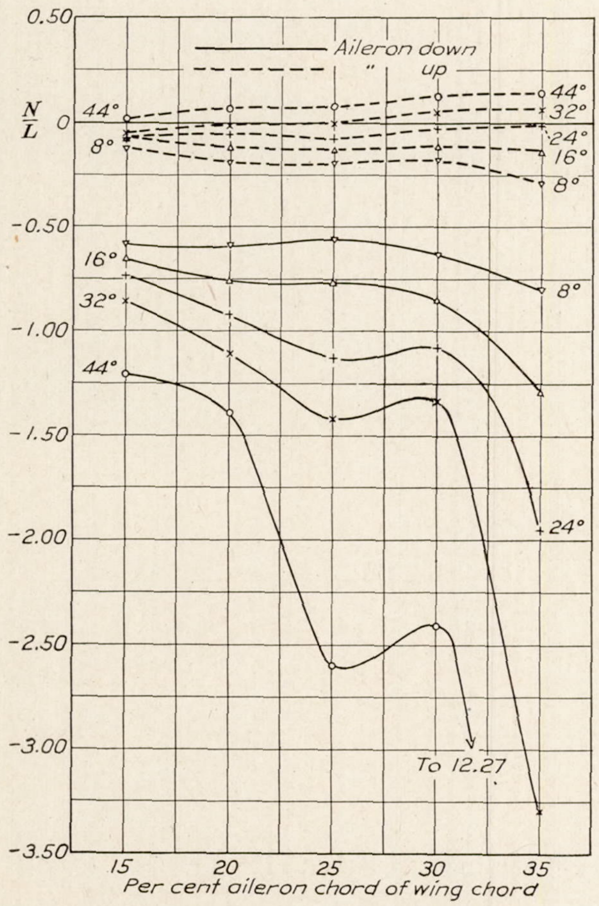


FIGURE 31.—Clark Y wing section. N/L for up and down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

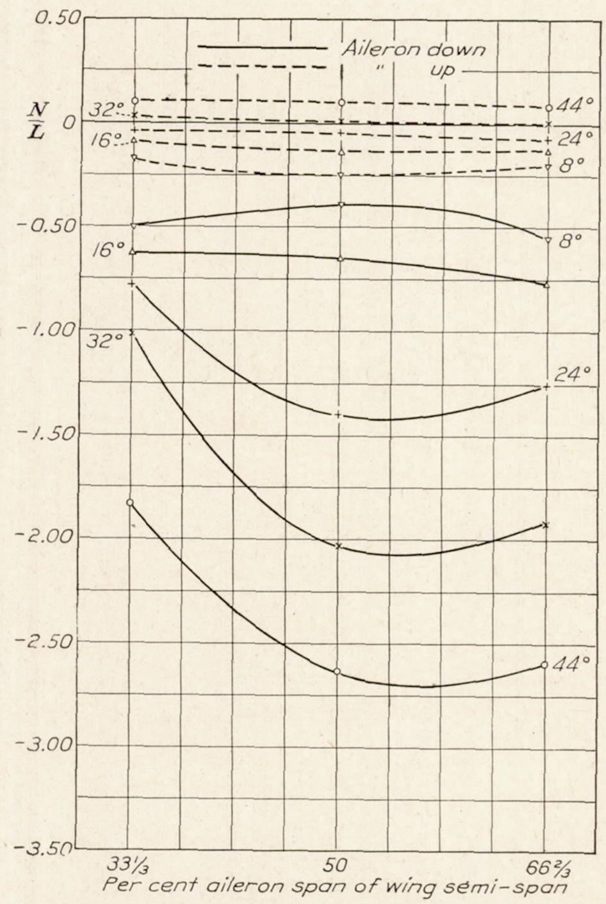


FIGURE 32.—Clark Y wing section. N/L for up and down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

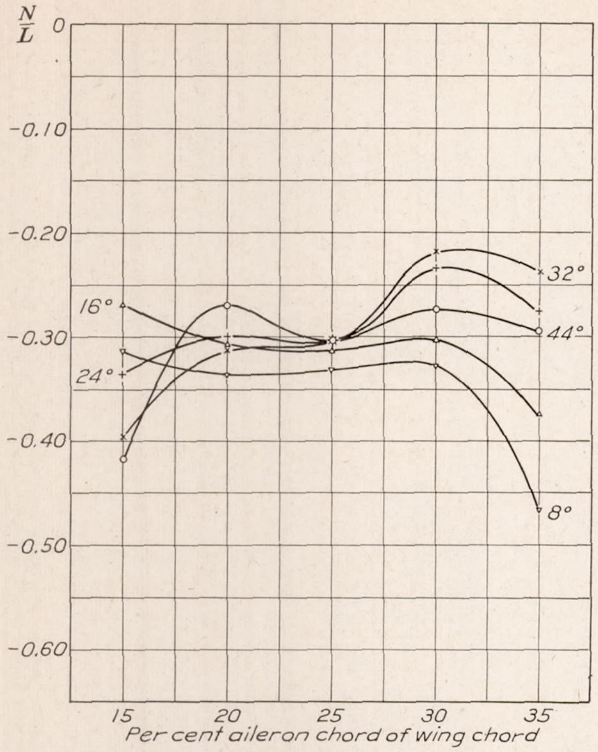


FIGURE 33.—Clark Y wing section. N/L for combined ailerons (right up, left down) versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

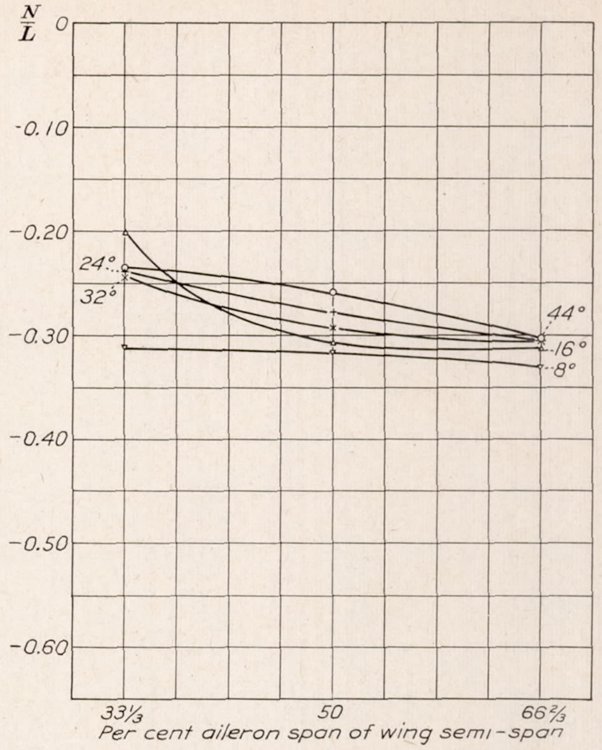


FIGURE 34.—Clark Y wing section. N/L for combined ailerons (right up, left down) versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

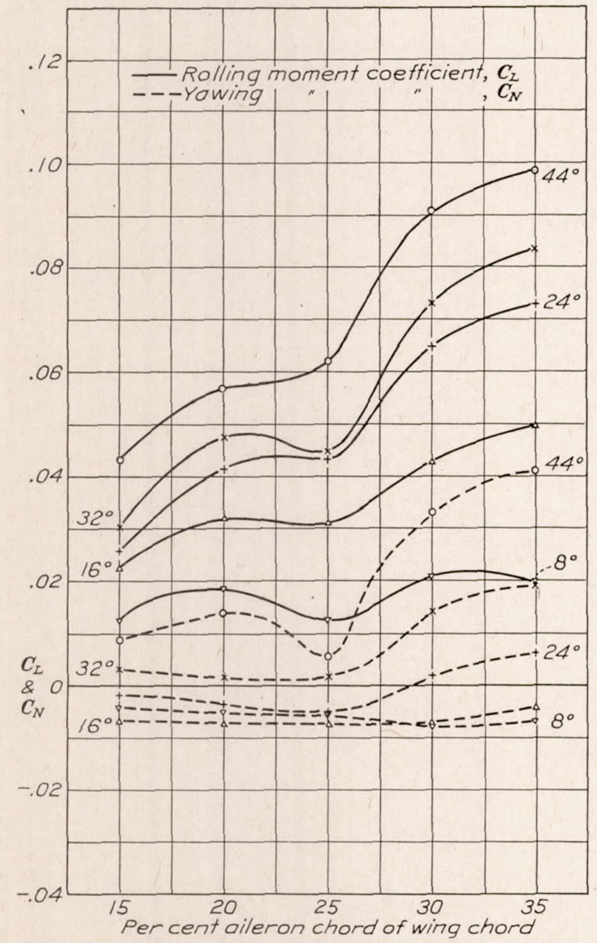


FIGURE 35.—U. S. A. 27 wing section. C_L and C_N for up aileron angles versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan)

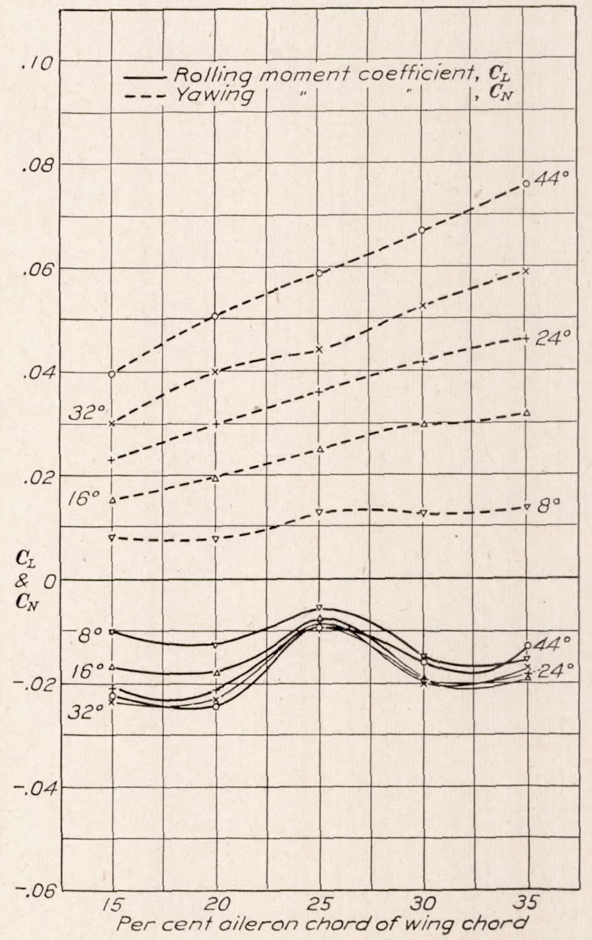


FIGURE 36.—U. S. A. 27 wing section. C_L and C_N for down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 12°. Spa n, 20 inches (67 per cent of wing semispan)

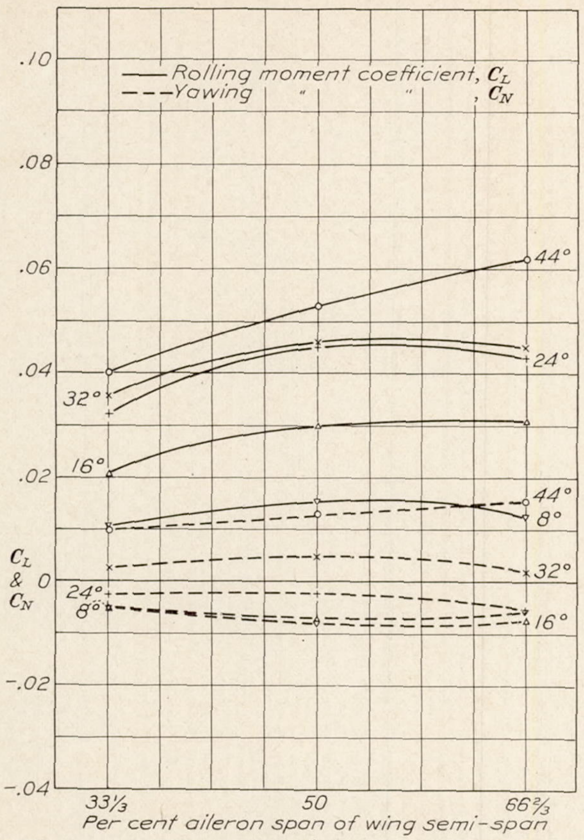


FIGURE 37.—U. S. A. 27 wing section. C_L and C_N for up aileron angles versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord)

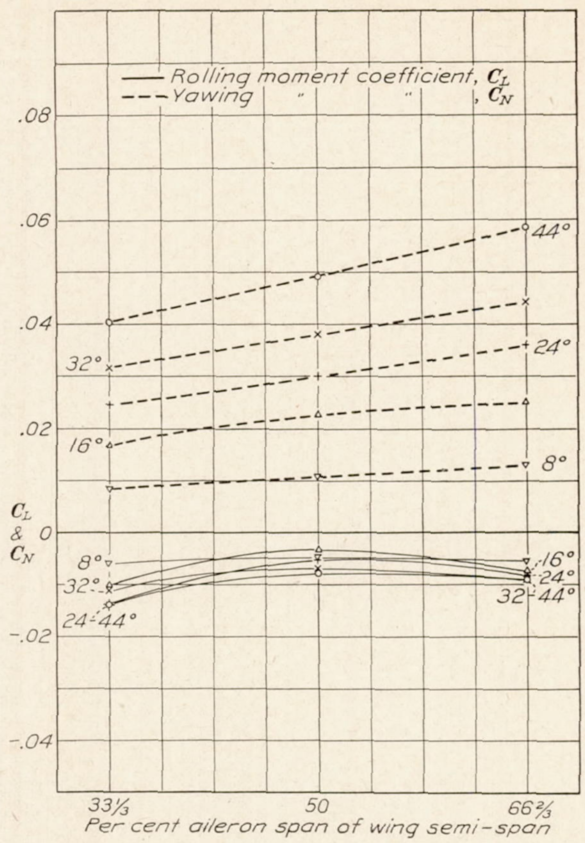


FIGURE 38.—U. S. A. 27 wing section. C_L and C_N for down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord)

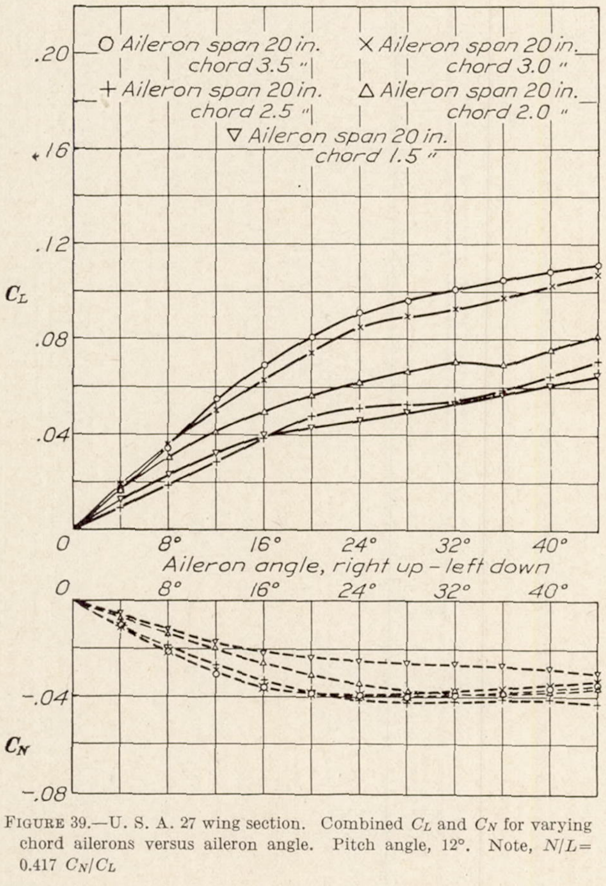


FIGURE 39.—U. S. A. 27 wing section. Combined C_L and C_N for varying chord ailerons versus aileron angle. Pitch angle, 12°. Note, $N/L = 0.417\ C_N/C_L$

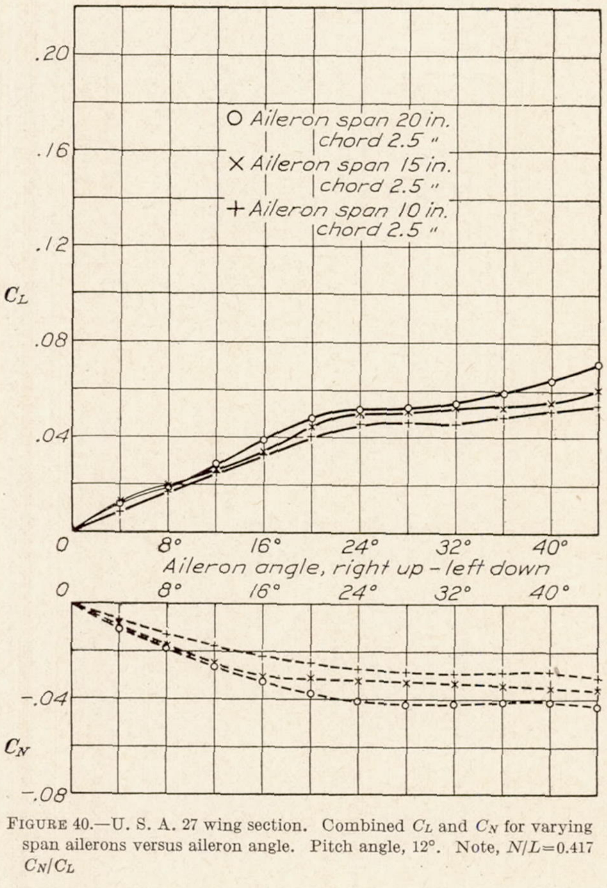


FIGURE 40.—U. S. A. 27 wing section. Combined C_L and C_N for varying span ailerons versus aileron angle. Pitch angle, 12°. Note, $N/L = 0.417\ C_N/C_L$

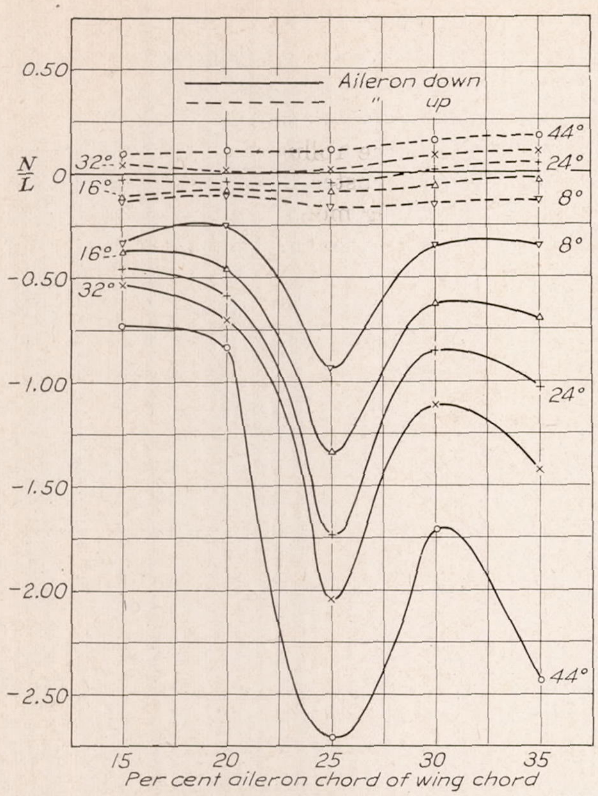


FIGURE 41.—U. S. A. 27 wing section. N/L for up and down aileron angles versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

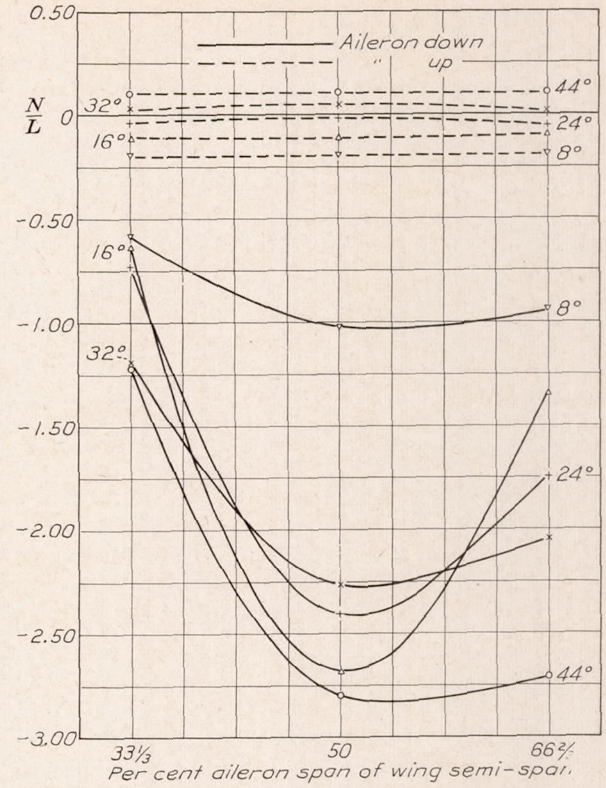


FIGURE 42.—U. S. A. 27 wing section. N/L for up and down aileron angles versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

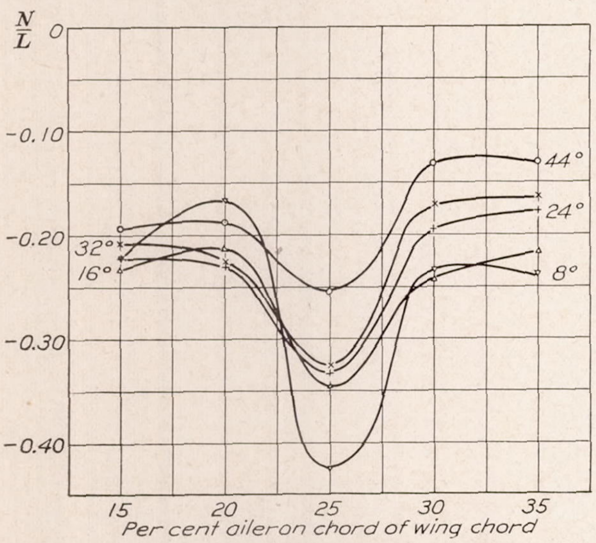


FIGURE 43.—U. S. A. 27 wing section. N/L for combined ailerons (right up, left down) versus per cent aileron chord of wing chord. Pitch angle, 12°. Span, 20 inches (67 per cent of wing semispan). Note, $N/L=0.417\ C_N/C_L$

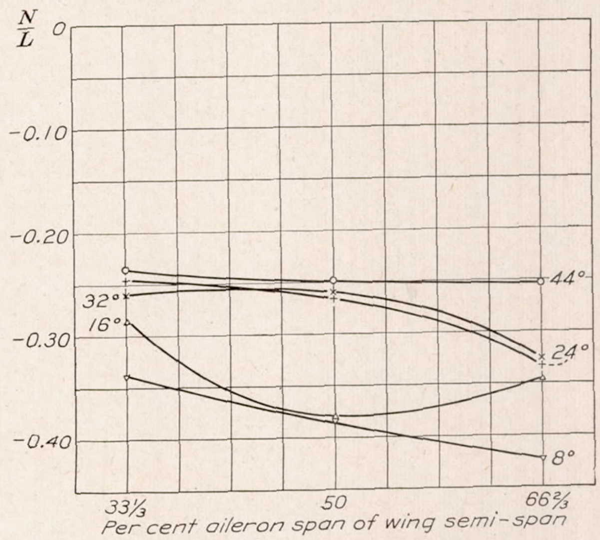


FIGURE 44.—U. S. A. 27 wing section. N/L for combined ailerons (right up, left down) versus per cent aileron span of wing semispan. Pitch angle, 12°. Chord, 2.5 inches (25 per cent of wing chord). Note, $N/L=0.417\ C_N/C_L$

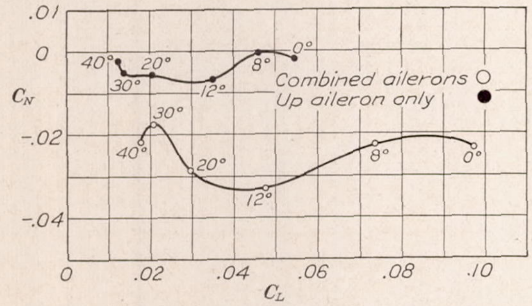


FIGURE 45.—Clark Y wing section. C_L versus C_N for varying pitch angle of 20-inch span by 2-inch chord aileron set at 20° for up only and for combined up and down positions

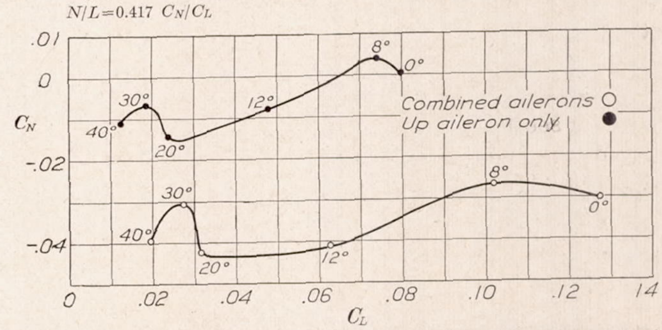


FIGURE 46.—Clark Y wing section. C_L versus C_N for varying pitch angle of 20-inch span by 3-inch chord aileron set at 20° for up only and for combined up and down positions

ROLLING MOMENT COEFFICIENTS FOR A SINGLE AILERON

In Reference 1 attention has been called to the fact that when the fuselage axis is horizontal (angle of attack of wing +4°), the rolling moment produced by a given angular displacement of the aileron upward is greater than that produced by the same downward displacement. British tests (Reference 2), in which a biplane cell was used, show the same tendency but to a lesser degree. Figure 47 shows that the loss in rolling moment of the down aileron is considerably greater than that of the up aileron as the angle of pitch is increased.

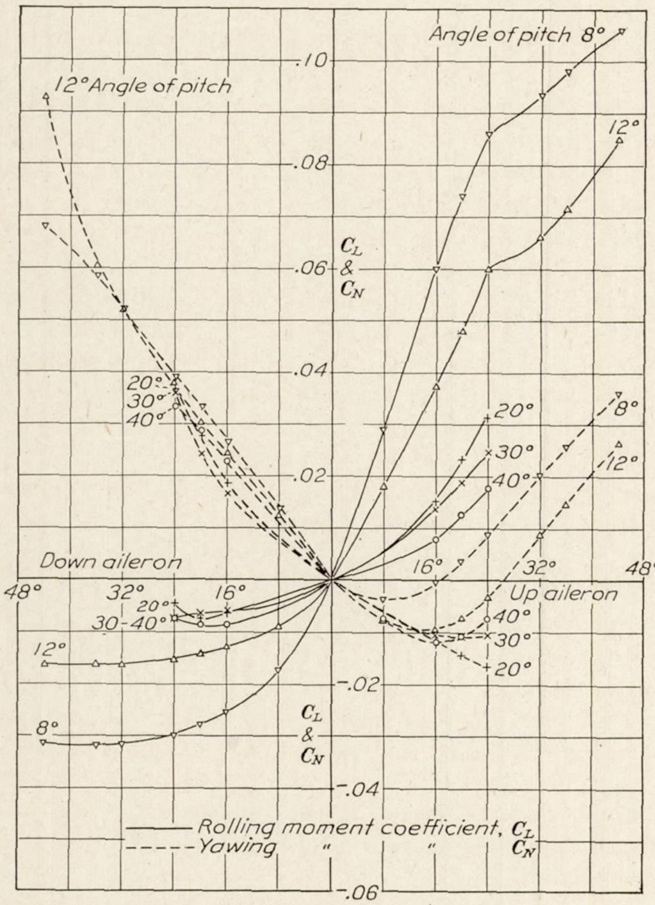


FIGURE 47.—Clark Y wing section. C_L and C_N versus aileron angle for various pitch angles of 20-inch span by 3-inch chord aileron

Figures 5, 15, 25, and 35 show that the rolling moment due to an upward displacement of the aileron increases as the chord of the aileron is increased. The effect of the wing section is not great at an angle of pitch of 8°, but at 12° the same aileron displacement gives a much greater rolling moment on the U. S. A. 27 wing section, presumably because the Clark Y wing section burbles at a somewhat lower angle of attack than the U. S. A. 27 section. The rolling moment caused by a given upward displacement decreases greatly as the angle of pitch increases. (Compare fig. 47.) Figures 7, 17, 27, and 37 show the effect of increasing the span of the aileron. The effects are of the same nature as for increasing chord, except that for the smaller span the difference between the curves for the two wing sections does not appear.

Figures 6, 16, 26, and 36 show the effect of the chord of the aileron on the rolling moment when the displacement is down instead of up. The same aileron gives a greater rolling moment on the U. S. A. 27 section. Figure 6 shows that an increase of aileron angle beyond 24° has little effect on the rolling moment at an angle of pitch of 8° for the Clark Y section. Figure 26 shows that the limit is as low as 8° when the angle of pitch is increased to 12°. The limitations are not as great for the U. S. A. 27 section, again presumably because of the difference in the burbling angles of the two sections. Figures 8, 18, 28, and 38 show the effect of span. The general impression of the whole family of curves is that the downward motion is much less effective than the upward motion in the production of rolling moment.

The points for the aileron of 20-inch span and 2.5-inch chord show a tendency to lie below the curve indicated by the remaining ailerons in Figures 5, 6, 15, 16, 25, 26, 35, and 36. It is believed that this irregularity in the results is to be attributed to the combined effect of asymmetry in the model and asymmetry in the tunnel airflow. It will be recalled from Figure 1 that this aileron (a member of the variable span group) is on the opposite wing tip from the variable chord group. The rolling moment produced by a given angle of the aileron varies rapidly with the angle of pitch, as shown by Figure 47, and a difference in angle of attack of the wing tips of approximately 1° would account for the observed results. It is known that there is a small rotation of the air stream in the tunnel in the proper direction to account for the observed irregularity.

YAWING MOMENT COEFFICIENTS FOR A SINGLE AILERON

The yawing moment coefficients are shown in the same figures as the rolling moment coefficients. Thus Figures 5, 15, 25, and 35 show the yawing moments produced by upward displacements, Figures 6, 16, 26, and 36 by downward displacements for the variable chord group, Figures 7, 17, 27, and 37 show the yawing moments produced by upward displacements, and Figures 8, 18, 28, and 38 by downward displacements for the variable span group. The curves show an approximately linear increase in yawing moment coefficient with increasing chord or span. In all cases the yawing moment coefficients for upward displacements are considerably less than for corresponding downward displacements. For a large range of aileron angles the upward displacement produces a negative yawing moment, corresponding to a decreased drag on the wing tip, after which the yawing moment becomes positive. The maximum negative yawing moment coefficient observed is of the order of 0.010. (Fig. 25.)

The angle of the aileron at which the yawing moment coefficient produced by the upward displacement is again zero decreases with increasing aileron chord for a given angle of attack of the wing and increases with angle of attack for a given aileron. (Tables I, II, III, IV, IX, X, XI, and XII.)

The general impression derived from the yawing moment curves is that the upward displacements produce much smaller yawing moments than the downward displacements.

RATIO OF YAWING MOMENT TO ROLLING MOMENT FOR A SINGLE AILERON

The ratio of rolling moment to yawing moment produced by the ailerons is often called the efficiency of the ailerons. In order to avoid infinite values, we prefer to invert the ratio and use the ratio of yawing moment to rolling moment. The most effective ailerons in the sense of producing the least yawing moment for a given rolling moment are the ones having the smallest value of this ratio.

Figures 11, 12, 21, 22, 31, 32, 41, and 42 show values of this ratio for the single ailerons. It is seen that the ratio is greatest for the downward displacements and that the values increase in general with increasing chord and span of the aileron, with increasing angle of the aileron, and with increasing angle of attack of the wing. For upward displacements the values change sign and are in general small. Thus the upward displacement gives greater effectiveness.

For angles of attack below the angle of maximum lift the decrease of effectiveness (increase of the ratio) for downward displacements is greater for increasing chord than for increasing span. At large angles of attack the differences are less marked than at low angles.

The effectiveness decreases more rapidly with increasing aileron angle at the higher angles of attack.

COMBINED COEFFICIENTS

From the tables and curves the coefficients for any combination of displacements of ailerons on the two wing tips may be computed. The values for equal displacements, with right aileron up and left aileron down, are given in Tables V, VI, VII, VIII, XIII, XIV, XV, and XVI, and in Figures 9, 10, 19, 20, 29, 30, 39, and 40.

The increase of the chord of the ailerons for the purpose of increasing the rolling moment has less and less advantage as the angle of attack is increased. In the neighborhood of the angle of maximum lift the effect of increasing the aileron chord 2.33 times at 20° aileron angle is to increase the rolling moment only 40 per cent in the case of the Clark Y airfoil and 88 per cent in the case of the U. S. A. 27 airfoil. The maximum yawing moment coefficient observed is of the order of 0.050.

Tables V, VI, VII, VIII, XIII, XIV, XV, and XVI also contain values of the ratio of yawing moment to rolling moment for the ailerons combined and Figures 13, 14, 23, 24, 33, 34, 43, and 44 show these values. The values are somewhat irregular, but the effectiveness of the same aileron is clearly greater on the U. S. A. 27 section. For both wing sections the effectiveness in general increases with increasing chord of the aileron at an angle of pitch of 8°, while at an angle of pitch of 12° the effectiveness reaches a maximum for the aileron of 3-inch chord. In the variable span group the effectiveness tends to decrease with an increase of span.

MEASUREMENTS AT ANGLES BEYOND THE ANGLE OF MAXIMUM LIFT

The observations have been carried to angles of pitch up to 40° in the case of the Clark Y airfoil, using ailerons of 20-inch span by 2-inch and 3-inch chord. Figures 45 and 46 show a part of these results, namely, the rolling and yawing moments produced by an aileron displacement of 20° for an upward displacement of one aileron only and for equal upward and downward displacements of both ailerons. It will be seen that the value of the rolling moment coefficients reaches values between 0.010 and 0.020 at an angle of pitch of 40° (angle of attack of wing, 44°). Figure 47 shows the results for the 20-inch span by 3-inch chord aileron. Table XVII gives the values plotted in Figures 45 and 46.

SUGGESTED USE OF UPWARD DISPLACEMENTS ALONE

The results of the investigation indicate very definite aerodynamic advantages in the use of upward displacements alone—i. e., the use of a cam or other mechanical device which would retain the normal down moving aileron in the neutral position while displacing the other aileron upward. While not to be compared to the use of the slot-and-aileron lateral control in effectiveness, the mechanical complications are not as great.

Figures 45 and 46 illustrate the very great reduction of the undesirable yawing moment. Quoting from Reference 3: "The yawing moment is of importance not only because it must be balanced by the use of the rudder if a straight course is to be maintained, but also because the yawing action of the aileron has an indirect effect directly opposed to that of the rolling moment from the same source. If, for example, the right wing of an airplane is low, the normal maneuver in raising it and restoring the wings to the horizontal is to pull down the right aileron and pull up the one on the left, giving a negative rolling moment. In general, however, this movement of the ailerons produces a positive yawing moment, tending to cause the machine to turn to the right; and if unopposed the resulting turn to the right will create a positive rolling moment proportional to the positive value of L_r, the rolling moment due to yaw. L_r has a positive value, it will be remembered, because of the difference of lift between the two wing tips moving at different speeds when the machine is turning.[2] This yawing action becomes especially important at high angles of attack." When upward travel only is employed, the yawing moment is greatly reduced, and with a sufficiently large aileron travel (20° to 30° at stall, 30° to 35° beyond stall) can be reversed in direction so as to assist the turn.

As against this very great advantage there are, of course, certain disadvantages. The rolling moments due to upward travel alone are less than those due to two ailerons combined, and it is necessary to use larger ailerons or greater aileron travel, or possibly both. For purpose of illustration, let us suppose that the aileron of 10-inch span by 2.5-inch chord on the Clark Y wing section is regarded as satisfactory when used combined in the conventional manner with a travel of ±32°. Table VI shows that the rolling moment coefficient at maximum travel at an angle of pitch of 8° is 0.0690, the yawing moment coefficient −0.0225. The rolling moment coefficient at 12° pitch (Table XIV) is 0.0445, the yawing moment coefficient 0.0260. Table X shows that a rolling moment coefficient at 12° pitch of 0.0500 could be obtained with the upward travel of one aileron of the same chord and moving through the same angle, but of 20-inch span, with a yawing moment coefficient of +0.0010, i. e., reversed in sign. The yawing moment coefficient does not exceed −0.0095 in the range of travel of the aileron. At 8° pitch under the same conditions the rolling moment coefficient is 0.0662, the yawing moment coefficient +0.0082. (Table II.)

From the same tables it can be seen that an aileron of 15-inch span by 2.5-inch chord at the same upward displacement will give at 12° pitch a rolling moment coefficient of 0.0460 with a yawing moment coefficient of +0.0010 and at 8° pitch a rolling moment coefficient of 0.0560 with a yawing moment coefficient of +0.0068. This aileron would give satisfactory roll at 12° pitch and 80 per cent of the desired rolling moment at 8° pitch, both with a yawing force which will tend to help the rolling force.

Other possibilities suggest themselves from the tables. It is necessary to study the hinge moments, and measurements of hinge moments are now in progress. The use of the upward motion alone is not suggested as a remedy for all the disadvantageous features of the usual control, but as a step in the direction of better control at low speeds which is worthy of study on full-scale airplanes.

[2] It has been pointed out that this moment is due not only to the difference in speed between the two wing tips resulting from the yawing motion, but also, and in larger measure, to the change in loading along the span which occurs at large angles of attack when the wing is displaced in yaw.

CONCLUSION

It is not possible to trace general relations which are applicable to both wing sections at all angles of attack. For this reason no detailed statements of the effect of varying chord and span, of angle of attack, of wing section, etc., is attempted. We do wish to mention that while one aileron of a given chord and span at a given angular displacement gives almost the same rolling and yawing moment on the Clark Y and U. S. A. 27 wing sections, the differences are sufficiently great and add up in such a manner that the ratio of rolling moment to yawing moment produced by the usual combination of two ailerons is from one and one-half to two times as great on the U. S. A. 27 section as on the Clark Y section. Finally, the use of ailerons which move only upward presents advantages which make this type of control worthy of further study. The design of a mechanism which will give motion of the proper aileron upward with absolutely no motion of the opposite aileron is a difficult matter and in practice it would be easier to combine a large upward movement of one aileron with a small downward movement of the other. The result is an extension of the well-known differential aileron to as large ratios of up travel to down travel as may prove feasible mechanically. While this type of control is not quite as advantageous as one in which there is no downward movement, it still has advantages over the conventional control.

ACKNOWLEDGMENT

We wish to acknowledge the assistance of Mr. W. Hunter Boyd in making the measurements and of Dr. H. L. Dryden in the preparation of the manuscript.

Bureau of Standards,
Washington, D. C., *October 7, 1929*.

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3. Warner, E. P.: Airplane Design—Aerodynamics. (McGraw-Hill, 1927.)

TABLE I.—CLARK Y WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying chord of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values apply to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$.]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0080	−.0025	−0.130	4°	−.0068	+.0038	−0.233
8°	.0170	−.0039	−.096	8°	−.0122	.0076	−.260
12°	.0260	−.0039	−.063	12°	−.0170	.0114	−.279
16°	.0360	−.0030	−.035	16°	−.0210	.0152	−.302
20°	.0372	−.0020	−.022	20°	−.0249	.0195	−.327
24°	.0388	−.0005	−.005	24°	−.0280	.0240	−.358
28°	.0423	+.0005	+.005	28°	−.0305	.0283	−.387
32°	.0462	.0022	.020	32°	−.0326	.0324	−.414
36°	.0500	.0044	.037	36°	−.0342	.0360	−.439
40°	.0540	.0066	.051	40°	−.0355	.0393	−.462
44°	.0582	.0095	.068	44°	−.0365	.0420	−.480

AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0095	−.0031	−0.136	4°	−.0072	+.0042	−0.243
8°	.0190	−.0050	−.110	8°	−.0140	.0086	−.256
12°	.0295	−.0050	−.071	12°	−.0193	.0130	−.281
16°	.0405	−.0030	−.031	16°	−.0238	.0176	−.308
20°	.0460	−.0005	−.004	20°	−.0275	.0222	−.337
24°	.0475	+.0020	+.018	24°	−.0300	.0270	−.375
28°	.0525	.0049	.039	28°	−.0312	.0320	−.428
32°	.0570	.0078	.057	32°	−.0320	.0365	−.476
36°	.0620	.0105	.071	36°	−.0322	.0411	−.532
40°	.0660	.0140	.089	40°	−.0322	.0462	−.598
44°	.0700	.0175	.104	44°	−.0320	.0510	−.664

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0145	−.0028	−0.080	4°	−.0100	+.0060	−0.250
8°	.0290	−.0038	−.055	8°	−.0175	.0125	−.298
12°	.0445	−.0030	−.028	12°	−.0221	.0183	−.345
16°	.0600	−.0008	−.006	16°	−.0255	.0244	−.399
20°	.0740	+.0036	+.020	20°	−.0280	.0305	−.454
24°	.0860	.0088	.043	24°	−.0300	.0375	−.522
28°	.0900	.0140	.065	28°	−.0310	.0446	−.600
32°	.0935	.0200	.089	32°	−.0319	.0520	−.680
36°	.0980	.0258	.110	36°	−.0320	.0583	−.760
40°	.1020	.0310	.127	40°	−.0320	.0635	−.827
44°	.1060	.0360	.141	44°	−.0312	.0680	−.909

AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0145	−.0031	−0.089	4°	−.0108	+.0051	−0.197
8°	.0290	−.0040	−.058	8°	−.0185	.0115	−.259
12°	.0440	−.0030	−.028	12°	−.0246	.0185	−.314
16°	.0600	−.0005	−.004	16°	−.0290	.0263	−.378
20°	.0760	+.0035	+.019	20°	−.0321	.0340	−.441
24°	.0935	.0091	.041	24°	−.0340	.0415	−.509
28°	.0970	.0160	.069	28°	−.0345	.0495	−.598
32°	.1005	.0240	.100	32°	−.0334	.0575	−.718
36°	.1075	.0315	.122	36°	−.0319	.0656	−.857
40°	.1145	.0441	.161	40°	−.0295	.0710	−1.004
44°	.1220	.0460	.157	44°	−.0260	.0745	−1.195

TABLE II.—CLARK Y WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying span of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values apply to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)							
Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0066	−.0018	−0.114	4°	−.0058	+.0035	−0.252
8°	.0131	−.0031	−.099	8°	−.0110	.0071	−.269
12°	.0198	−.0040	−.084	12°	−.0160	.0105	−.274
16°	.0265	−.0034	−.066	16°	−.0200	.0140	−.292
20°	.0330	−.0018	−.023	20°	−.0238	.0177	−.310
24°	.0395	+.0002	+.002	24°	−.0266	.0210	−.329
28°	.0390	.0025	.027	28°	−.0290	.0245	−.352
32°	.0385	.0051	.055	32°	−.0305	.0276	−.377
36°	.0420	.0080	.079	36°	−.0316	.0308	−.406
40°	.0445	.0112	.105	40°	−.0319	.0342	−.447
44°	.0455	.0147	.135	44°	−.0311	.0375	−.503

AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)							
Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0095	−.0028	−0.123	4°	−.0085	+.0031	−0.152
8°	.0190	−.0040	−.088	8°	−.0155	.0072	−.194
12°	.0280	−.0040	−.060	12°	−.0212	.0120	−.236
16°	.0370	−.0030	−.034	16°	−.0255	.0175	−.286
20°	.0460	−.0015	−.014	20°	−.0290	.0232	−.334
24°	.0540	+.0008	+.006	24°	−.0310	.0282	−.379
28°	.0550	.0035	.027	28°	−.0331	.0330	−.416
32°	.0560	.0068	.051	32°	−.0355	.0370	−.435
36°	.0585	.0105	.075	36°	−.0380	.0402	−.441
40°	.0620	.0142	.095	40°	−.0400	.0431	−.450
44°	.0660	.0190	.120	44°	−.0420	.0453	−.450

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)							
Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0102	−.0035	−0.143	4°	−.0110	+.0042	−0.159
8°	.0205	−.0060	−.122	8°	−.0195	.0095	−.203
12°	.0310	−.0070	−.094	12°	−.0258	.0155	−.251
16°	.0420	−.0060	−.060	16°	−.0303	.0215	−.296
20°	.0522	−.0033	−.026	20°	−.0330	.0278	−.351
24°	.0625	0	0	24°	−.0348	.0333	−.399
28°	.0646	+.0038	+.025	28°	−.0361	.0387	−.447
32°	.0662	.0082	.052	32°	−.0370	.0438	−.494
36°	.0720	.0135	.078	36°	−.0375	.0486	−.541
40°	.0775	.0191	.103	40°	−.0370	.0531	−.598
44°	.0830	.0255	.128	44°	−.0356	.0573	−.671

TABLE III.—U. S. A. 27 WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying chord of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values apply to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0088	−.0020	−0.095	4°	−.0080	+.0025	−0.130
8°	.0180	−.0030	−.069	8°	−.0152	.0055	−.151
12°	.0275	−.0030	−.045	12°	−.0215	.0090	−.175
16°	.0350	−.0025	−.030	16°	−.0270	.0125	−.193
20°	.0380	−.0018	−.020	20°	−.0315	.0158	−.209
24°	.0390	0	0	24°	−.0360	.0190	−.220
28°	.0428	+.0021	+.020	28°	−.0405	.0220	−.227
32°	.0455	.0050	.046	32°	−.0440	.0250	−.237
36°	.0500	.0077	.064	36°	−.0474	.0280	−.247
40°	.0540	.0105	.081	40°	−.0500	.0305	−.254
44°	.0580	.0135	.097	44°	−.0503	.0330	−.273

AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0095	−.0026	−0.114	4°	−.0067	+.0030	−0.187
8°	.0195	−.0040	−.086	8°	−.0140	.0065	−.194
12°	.0305	−.0040	−.055	12°	−.0205	.0103	−.210
16°	.0445	−.0025	−.023	16°	−.0265	.0140	−.220
20°	.0560	0	0	20°	−.0320	.0180	−.234
24°	.0630	+.0028	+.019	24°	−.0375	.0218	−.242
28°	.0625	.0060	.040	28°	−.0425	.0255	−.250
32°	.0620	.0094	.063	32°	−.0470	.0293	−.260
36°	.0666	.0130	.081	36°	−.0510	.0332	−.272
40°	.0712	.0170	.100	40°	−.0546	.0372	−.284
44°	.0770	.0210	.114	44°	−.0575	.0412	−.299

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0150	−.0030	−0.083	4°	−.0120	+.0052	−0.181
8°	.0300	−.0022	−.031	8°	−.0220	.0108	−.205
12°	.0450	0	0	12°	−.0295	.0162	−.229
16°	.0600	+.0022	+.015	16°	−.0355	.0215	−.253
20°	.0750	.0056	.031	20°	−.0391	.0270	−.288
24°	.0910	.0098	.045	24°	−.0425	.0320	−.314
28°	.0895	.0148	.069	28°	−.0453	.0370	−.341
32°	.0880	.0215	.102	32°	−.0483	.0420	−.363
36°	.0935	.0335	.149	36°	−.0515	.0465	−.376
40°	.0990	.0390	.164	40°	−.0550	.0510	−.387
44°	.1050	.0412	.164	44°	−.0586	.0550	−.391

AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0155	−.0022	−0.059	4°	−.0115	+.0040	−0.145
8°	.0310	−.0028	−.038	8°	−.0215	.0095	−.184
12°	.0470	−.0010	−.009	12°	−.0295	.0170	−.240
16°	.0630	+.0020	+.013	16°	−.0360	.0240	−.278
20°	.0780	.0060	.032	20°	−.0410	.0300	−.305
24°	.0950	.0115	.050	24°	−.0450	.0360	−.334
28°	.0965	.0177	.076	28°	−.0480	.0420	−.365
32°	.0975	.0255	.109	32°	−.0505	.0476	−.394
36°	.1060	.0345	.136	36°	−.0525	.0525	−.417
40°	.1125	.0425	.157	40°	−.0540	.0570	−.440
44°	.1182	.0500	.176	44°	−.0545	.0610	−.467

TABLE IV.—U. S. A. 27-WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying span of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°, angle of roll, 0°]

[NOTE.—The values refer to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_l$]

AILERON CHORD 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0068	−.0015	−0.092	4°	−.0052	+.0012	−0.096
8°	.0130	−.0020	−.064	8°	−.0105	.0034	−.135
12°	.0198	−.0018	−.038	12°	−.0150	.0056	−.155
16°	.0266	0	0	16°	−.0190	.0085	−.186
20°	.0336	+.0022	+.027	20°	−.0226	.0115	−.212
24°	.0415	.0045	.045	24°	−.0255	.0150	−.245
28°	.0408	.0070	.072	28°	−.0280	.0184	−.274
32°	.0400	.0092	.096	32°	−.0300	.0219	−.304
36°	.0430	.0118	.115	36°	−.0312	.0252	−.337
40°	.0460	.0141	.128	40°	−.0322	.0289	−.374
44°	.0490	.0166	.141	44°	−.0325	.0322	−.413

AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0090	−.0020	−0.093	4°	−.0075	+.0032	−0.178
8°	.0180	−.0032	−.074	8°	−.0150	.0070	−.195
12°	.0270	−.0030	−.046	12°	−.0208	.0118	−.237
16°	.0365	−.0010	−.011	16°	−.0260	.0160	−.257
20°	.0470	+.0020	+.018	20°	−.0308	.0200	−.271
24°	.0500	.0052	.043	24°	−.0340	.0240	−.294
28°	.0530	.0088	.069	28°	−.0368	.0280	−.317
32°	.0562	.0122	.091	32°	−.0395	.0313	−.330
36°	.0600	.0160	.111	36°	−.0418	.0346	−.345
40°	.0648	.0200	.129	40°	−.0445	.0378	−.354
44°	.0695	.0245	.147	44°	−.0475	.0402	−.353

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0105	−.0022	−0.087	4°	−.0095	+.0032	−0.140
8°	.0210	−.0038	−.075	8°	−.0180	.0070	−.162
12°	.0320	−.0038	−.050	12°	−.0248	.0115	−.193
16°	.0430	−.0020	−.019	16°	−.0303	.0165	−.227
20°	.0550	+.0011	+.008	20°	−.0348	.0215	−.258
24°	.0685	.0045	.027	24°	−.0380	.0280	−.307
28°	.0680	.0086	.053	28°	−.0400	.0340	−.355
32°	.0675	.0130	.080	32°	−.0412	.0392	−.397
36°	.0735	.0180	.102	36°	−.0412	.0440	−.447
40°	.0795	.0235	.123	40°	−.0402	.0480	−.499
44°	.0855	.0290	.142	44°	−.0380	.0515	−.566

TABLE V.—CLARK Y WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP, LEFT AILERON DOWN)

[Varying chord of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—$N/L=0.417\ C_N/C_L$]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)				AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0148	−.0063	−0.177	4°	+.0167	−.0073	−0.182
8°	.0292	−.0115	−.164	8°	.0330	−.0136	−.172
12°	.0430	−.0153	−.149	12°	.0488	−.0180	−.154
16°	.0570	−.0182	−.133	16°	.0643	−.0206	−.134
20°	.0621	−.0215	−.144	20°	.0738	−.0227	−.116
24°	.0668	−.0245	−.153	24°	.0775	−.0250	−.135
28°	.0728	−.0278	−.159	28°	.0837	−.0271	−.135
32°	.0788	−.0302	−.160	32°	.0890	−.0287	−.135
36°	.0842	−.0316	−.157	36°	.0942	−.0306	−.136
40°	.0895	−.0327	−.152	40°	.0982	−.0322	−.137
44°	.0947	−.0325	−.143	44°	.1020	−.0335	−.137

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)				AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0245	−.0088	−0.150	4°	+.0253	−.0082	−0.135
8°	.0465	−.0163	−.146	8°	.0475	−.0155	−.136
12°	.0666	−.0213	−.147	12°	.0686	−.0215	−.131
16°	.0855	−.0252	−.123	16°	.0890	−.0268	−.126
20°	.1020	−.0269	−.110	20°	.1081	−.0305	−.118
24°	.1160	−.0287	−.103	24°	.1275	−.0324	−.106
28°	.1210	−.0306	−.104	28°	.1315	−.0335	−.106
32°	.1254	−.0320	−.106	32°	.1339	−.0335	−.104
36°	.1300	−.0325	−.104	36°	.1394	−.0341	−.102
40°	.1340	−.0325	−.101	40°	.1440	−.0269	−.078
44°	.1372	−.0320	−.097	44°	.1480	−.0285	−.080

TABLE VI.—CLARK Y WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP LEFT AILERON DOWN)

[Varying span of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—$N/L=0.417\ C_N/C_L$]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)				AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)				AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------	0°	0	0	----------
4°	+.0124	−.0053	−0.173	4°	+.0180	−.0059	−0.137	4°	+.0212	−.0077	−0.151
8°	.0241	−.0102	−.177	8°	.0345	−.0112	−.135	8°	.0400	−.0155	−.162
12°	.0358	−.0145	−.168	12°	.0492	−.0160	−.136	12°	.0568	−.0225	−.165
16°	.0465	−.0174	−.175	16°	.0625	−.0205	−.137	16°	.0723	−.0275	−.159
20°	.0568	−.0195	−.143	20°	.0750	−.0247	−.137	20°	.0852	−.0311	−.152
24°	.0661	−.0208	−.131	24°	.0850	−.0274	−.135	24°	.0973	−.0333	−.143
28°	.0680	−.0220	−.135	28°	.0881	−.0295	−.141	28°	.1007	−.0349	−.145
32°	.0690	−.0225	−.136	32°	.0915	−.0302	−.134	32°	.1032	−.0356	−.144
36°	.0736	−.0228	−.129	36°	.0965	−.0297	−.128	36°	.1095	−.0351	−.134
40°	.0764	−.0230	−.125	40°	.1020	−.0289	−.118	40°	.1145	−.0340	−.124
44°	.0766	−.0228	−.124	44°	.1080	−.0263	−.102	44°	.1186	−.0318	−.112

TABLE VII.—U. S. A. 27 WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP, LEFT AILERON DOWN)

Varying chord of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—$N/L = 0.417\ C_N/C_L$]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)				AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0		0°	0	0	
4°	+.0168	−.0045	−0.112	4°	+.0162	−.0056	−0.144
8°	.0332	−.0085	−.107	8°	.0335	−.0105	−.131
12°	.0490	−.0120	−.102	12°	.0510	−.0143	−.117
16°	.0620	−.0150	−.101	16°	.0710	−.0165	−.097
20°	.0695	−.0176	−.106	20°	.0880	−.0180	−.085
24°	.0750	−.0190	−.106	24°	.1005	−.0190	−.079
28°	.0833	−.0199	−.100	28°	.1050	−.0195	−.077
32°	.0895	−.0200	−.093	32°	.1090	−.0199	−.076
36°	.0974	−.0203	−.087	36°	.1176	−.0202	−.072
40°	.1040	−.0200	−.080	40°	.1258	−.0202	−.067
44°	.1083	−.0195	−.075	44°	.1345	−.0202	−.063

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)				AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0		0°	0	0	
4°	+.0270	−.0082	−0.127	4°	+.0270	−.0062	−0.096
8°	.0520	−.0130	−.104	8°	.0525	−.0123	−.098
12°	.0745	−.0162	−.091	12°	.0765	−.0180	−.098
16°	.0955	−.0193	−.083	16°	.0990	−.0220	−.093
20°	.1141	−.0214	−.078	20°	.1190	−.0240	−.084
24°	.1335	−.0222	−.069	24°	.1400	−.0245	−.073
28°	.1348	−.0222	−.069	28°	.1445	−.0243	−.071
32°	.1363	−.0205	−.063	32°	.1480	−.0221	−.062
36°	.1450	−.0130	−.037	36°	.1585	−.0180	−.047
40°	.1540	−.0120	−.032	40°	.1665	−.0145	−.036
44°	.1636	−.0138	−.035	44°	.1727	−.0110	−.027

TABLE VIII.—U. S. A. 27 WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP LEFT AILERON DOWN)

[Varying span of aileron. Angle of pitch of airplane, +8°; angle of attack of wing, +12°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—$N/L = 0.417\ C_N/C_L$]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)				AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)				AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0		0°	0	0		0°	0	0	
4°	+.0120	−.0027	−0.094	4°	+.0165	−.0052	−0.131	4°	+.0200	−.0054	−0.113
8°	.0235	−.0054	−.096	8°	.0330	−.0102	−.129	8°	.0390	−.0108	−.115
12°	.0348	−.0074	−.089	12°	.0478	−.0148	−.129	12°	.0568	−.0153	−.112
16°	.0456	−.0085	−.078	16°	.0625	−.0170	−.113	16°	.0733	−.0185	−.105
20°	.0562	−.0093	−.069	20°	.0778	−.0180	−.096	20°	.0898	−.0204	−.095
24°	.0670	−.0105	−.065	24°	.0840	−.0188	−.093	24°	.1065	−.0235	−.092
28°	.0688	−.0114	−.069	28°	.0898	−.0192	−.089	28°	.1080	−.0254	−.098
32°	.0700	−.0127	−.076	32°	.0957	−.0191	−.083	32°	.1087	−.0262	−.101
36°	.0742	−.0134	−.075	36°	.1018	−.0186	−.076	36°	.1147	−.0260	−.095
40°	.0782	−.0148	−.079	40°	.1093	−.0178	−.068	40°	.1197	−.0245	−.085
44°	.0815	−.0156	−.080	44°	.1170	−.0157	−.056	44°	.1235	−.0225	−.076

TABLE IX.—CLARK Y WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying chord of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values refer to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0055	−.0025	−0.190	4°	−.0040	+.0056	−0.584
8°	.0115	−.0035	−.127	8°	−.0080	.0112	−.582
12°	.0185	−.0045	−.101	12°	−.0110	.0168	−.637
16°	.0280	−.0050	−.074	16°	−.0140	.0220	−.656
20°	.0290	−.0050	−.072	20°	−.0165	.0270	−.682
24°	.0280	−.0050	−.074	24°	−.0180	.0320	−.742
28°	.0272	−.0045	−.069	28°	−.0191	.0365	−.797
32°	.0270	−.0035	−.054	32°	−.0198	.0410	−.864
36°	.0278	−.0018	−.027	36°	−.0198	.0450	−.948
40°	.0296	−.0002	−.003	40°	−.0189	.0488	−1.078
44°	.0330	+.0010	+.013	44°	−.0179	.0520	−1.212

AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0070	−.0035	−0.208	4°	−.0040	+.0055	−0.509
8°	+.0140	−.0065	−.194	8°	−.0077	.0110	−.596
12°	.0210	−.0080	−.159	12°	−.0098	.0160	−.682
16°	.0280	−.0080	−.119	16°	−.0114	.0210	−.768
20°	.0350	−.0070	−.083	20°	−.0128	.0260	−.848
24°	.0368	−.0055	−.062	24°	−.0140	.0310	−.923
28°	.0382	−.0035	−.038	28°	−.0145	.0355	−1.020
32°	.0400	−.0010	−.010	32°	−.0150	.0400	−1.111
36°	.0428	+.0020	+.019	36°	−.0152	.0445	−1.220
40°	.0460	.0052	.047	40°	−.0156	.0485	−1.295
44°	.0515	.0090	.073	44°	−.0158	.0525	−1.384

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0092	−.0047	−0.213	4°	−.0055	+.0070	−0.530
8°	.0180	−.0076	−.176	8°	−.0090	.0136	−.630
12°	.0275	−.0092	−.140	12°	−.0113	.0202	−.745
16°	.0372	−.0095	−.107	16°	−.0130	.0267	−.857
20°	.0480	−.0080	−.069	20°	−.0145	.0330	−.949
24°	.0600	−.0032	−.022	24°	−.0152	.0390	−1.070
28°	.0630	+.0030	+.020	28°	−.0160	.0450	−1.172
32°	.0660	.0090	.057	32°	−.0162	.0520	−1.337
36°	.0720	.0148	.086	36°	−.0163	.0605	−1.546
40°	.0780	.0205	.110	40°	−.0162	.0720	−1.852
44°	.0850	.0265	.130	44°	−.0161	.0930	−2.410

AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0076	−.0068	−0.373	4°	−.0050	+.0077	−0.642
8°	.0152	−.0105	−.288	8°	−.0080	.0155	−.809
12°	.0245	−.0120	−.204	12°	−.0090	.0230	−1.066
16°	.0380	−.0120	−.132	16°	−.0100	.0310	−1.293
20°	.0535	−.0095	−.074	20°	−.0101	.0390	−1.610
24°	.0660	−.0030	−.019	24°	−.0100	.0470	−1.960
28°	.0752	+.0050	+.028	28°	−.0091	.0550	−2.520
32°	.0823	.0125	.063	32°	−.0081	.0640	−3.295
36°	.0823	.0195	.099	36°	−.0070	.0740	−4.410
40°	.0890	.0265	.124	40°	−.0052	.0865	−6.940
44°	.0955	.0330	.144	44°	−.0035	.1030	−12.27

TABLE X.—CLARK Y WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying span of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values apply to either right or left aileron, the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0045	−.0025	−0.232	4°	−.0038	+.0040	−0.439
8°	.0095	−.0040	−.175	8°	−.0066	.0080	−.506
12°	.0145	−.0045	−.129	12°	−.0089	.0110	−.535
16°	.0200	−.0045	−.094	16°	−.0100	.0150	−.626
20°	.0260	−.0040	−.064	20°	−.0110	.0182	−.690
24°	.0315	−.0030	−.040	24°	−.0115	.0215	−.780
28°	.0323	−.0010	−.013	28°	−.0117	.0248	−.884
32°	.0330	+.0020	+.025	32°	−.0115	.0280	−1.015
36°	.0350	.0050	.060	36°	−.0110	.0310	−1.175
40°	.0372	.0075	.084	40°	−.0102	.0340	−1.390
44°	.0400	.0100	.104	44°	−.0085	.0373	−1.830

AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0062	−.0045	−0.303	4°	−.0055	+.0050	−0.379
8°	.0130	−.0078	−.250	8°	−.0105	.0100	−.397
12°	.0195	−.0092	−.197	12°	−.0131	.0155	−.494
16°	.0270	−.0090	−.139	16°	−.0131	.0205	−.652
20°	.0350	−.0070	−.083	20°	−.0108	.0255	−.986
24°	.0435	−.0050	−.048	24°	−.0090	.0300	−1.390
28°	.0448	−.0021	−.020	28°	−.0080	.0345	−1.800
32°	.0460	+.0010	+.009	32°	−.0080	.0389	−2.028
36°	.0480	.0045	.039	36°	−.0085	.0429	−2.105
40°	.0498	.0090	.075	40°	−.0085	.0465	−2.281
44°	.0515	.0135	.109	44°	−.0080	.0505	−2.630

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0075	−.0040	−0.222	4°	−.0050	+.0060	−0.500
8°	.0150	−.0072	−.200	8°	−.0086	.0115	−.558
12°	.0230	−.0090	−.163	12°	−.0110	.0170	−.645
16°	.0305	−.0095	−.130	16°	−.0122	.0225	−.770
20°	.0382	−.0095	−.104	20°	−.0122	.0280	−.958
24°	.0460	−.0083	−.075	24°	−.0111	.0335	−1.259
28°	.0480	−.0046	−.040	28°	−.0102	.0391	−1.599
32°	.0500	+.0010	+.008	32°	−.0097	.0447	−1.921
36°	.0530	.0055	.043	36°	−.0091	.0502	−2.300
40°	.0556	.0090	.067	40°	−.0092	.0558	−2.530
44°	.0585	.0115	.082	44°	−.0098	.0612	−2.600

TABLE XI.—U. S. A. 27 WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying chord of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values refer to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$]

AILERON SPAN 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0068	−.0020	−0.123	4°	−.0055	−.0035	−0.266
8°	.0125	−.0040	−.133	8°	−.0100	.0080	−.334
12°	.0178	−.0058	−.136	12°	−.0140	.0120	−.357
16°	.0225	−.0065	−.120	16°	−.0168	.0155	−.385
20°	.0240	−.0040	−.070	20°	−.0190	.0195	−.428
24°	.0255	−.0018	−.029	24°	−.0208	.0230	−.461
28°	.0277	+.0008	+.012	28°	−.0225	.0265	−.491
32°	.0301	.0032	.044	32°	−.0233	.0300	−.537
36°	.0333	.0060	.075	36°	−.0240	.0331	−.575
40°	.0375	.0080	.089	40°	−.0238	.0362	−.634
44°	.0430	.0090	.087	44°	−.0225	.0395	−.732

AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0100	−.0030	−0.125	4°	−.0070	+.0030	−0.179
8°	.0185	−.0049	−.110	8°	−.0125	.0075	−.250
12°	.0258	−.0060	−.097	12°	−.0158	.0138	−.364
16°	.0320	−.0062	−.081	16°	−.0180	.0195	−.452
20°	.0370	−.0060	−.068	20°	−.0200	.0250	−.521
24°	.0415	−.0045	−.045	24°	−.0213	.0300	−.588
28°	.0450	−.0022	−.020	28°	−.0225	.0352	−.652
32°	.0475	+.0016	+.014	32°	−.0235	.0400	−.710
36°	.0460	.0060	.054	36°	−.0240	.0440	−.764
40°	.0515	.0098	.079	40°	−.0245	.0476	−.810
44°	.0570	.0140	.102	44°	−.0245	.0506	−.861

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0105	−.0052	−0.207	4°	−.0085	+.0055	−0.270
8°	.0210	−.0078	−.155	8°	−.0150	.0125	−.348
12°	.0320	−.0085	−.111	12°	−.0181	.0214	−.493
16°	.0430	−.0070	−.068	16°	−.0197	.0295	−.625
20°	.0540	−.0032	−.025	20°	−.0201	.0360	−.746
24°	.0650	+.0022	+.014	24°	−.0203	.0420	−.863
28°	.0695	.0082	.049	28°	−.0201	.0475	−.985
32°	.0730	.0145	.083	32°	−.0196	.0525	−1.115
36°	.0790	.0205	.110	36°	−.0188	.0575	−1.275
40°	.0850	.0267	.131	40°	−.0177	.0625	−1.473
44°	.0910	.0330	.151	44°	−.0163	.0670	−1.710

AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0085	−.0042	−0.206	4°	−.0088	+.0060	−0.284
8°	.0200	−.0068	−.142	8°	−.0155	.0135	−.363
12°	.0365	−.0070	−.080	12°	−.0187	.0235	−.524
16°	.0500	−.0040	−.033	16°	−.0192	.0320	−.694
20°	.0620	+.0010	+.007	20°	−.0190	.0395	−.867
24°	.0730	.0068	.039	24°	−.0186	.0460	−1.030
28°	.0782	.0130	.069	28°	−.0180	.0530	−1.227
32°	.0835	.0195	.097	32°	−.0172	.0590	−1.430
36°	.0885	.0260	.123	36°	−.0160	.0650	−1.694
40°	.0935	.0335	.149	40°	−.0148	.0705	−1.986
44°	.0985	.0410	.174	44°	−.0130	.0760	−2.438

TABLE XII.—U. S. A. 27 WING SECTION—C_L, C_N, AND N/L FOR ONE AILERON

[Varying span of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values apply to either right or left aileron; the signs refer to the right aileron. $N/L=0.417\ C_N/C_L$]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	- - -	0°	0	0	- - -
4°	+.0052	−.0030	−0.241	4°	−.0035	+.0040	−0.476
8°	.0105	−.0050	−.199	8°	−.0061	.0085	−.581
12°	.0160	−.0052	−.136	12°	−.0087	.0130	−.623
16°	.0210	−.0052	−.103	16°	−.0111	.0168	−.631
20°	.0264	−.0043	−.068	20°	−.0138	.0205	−.619
24°	.0320	−.0025	−.033	24°	−.0140	.0245	−.730
28°	.0338	0	0	28°	−.0130	.0282	−.904
32°	.0355	+.0025	+.029	32°	−.0110	.0315	−1.195
36°	.0380	.0060	.066	36°	−.0110	.0347	−1.315
40°	.0395	.0090	.095	40°	−.0120	.0376	−1.307
44°	.0400	.0100	.104	44°	−.0138	.0404	−1.221

AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	- - -	0°	0	0	- - -
4°	+.0078	−.0040	−0.214	4°	−.0045	+.0050	−0.463
8°	.0152	−.0072	−.198	8°	−.0045	.0110	−1.020
12°	.0226	−.0082	−.151	12°	−.0039	.0175	−1.870
16°	.0300	−.0080	−.111	16°	−.0035	.0225	−2.680
20°	.0375	−.0050	−.056	20°	−.0042	.0260	−2.582
24°	.0450	−.0020	−.019	24°	−.0052	.0300	−2.405
28°	.0455	+.0015	+.014	28°	−.0062	.0340	−2.288
32°	.0460	.0050	.045	32°	−.0070	.0380	−2.263
36°	.0458	.0078	.071	36°	−.0072	.0418	−2.420
40°	.0472	.0105	.093	40°	−.0076	.0455	−2.496
44°	.0530	.0130	.102	44°	−.0073	.0490	−2.800

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

Aileron up				Aileron down			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	- - -	0°	0	0	- - -
4°	+.0055	−.0035	−0.288	4°	−.0038	+.0068	−0.746
8°	.0125	−.0056	−.187	8°	−.0058	.0130	−.934
12°	.0215	−.0070	−.136	12°	−.0070	.0192	−1.144
16°	.0310	−.0072	−.097	16°	−.0078	.0250	−1.340
20°	.0400	−.0070	−.073	20°	−.0082	.0305	−1.552
24°	.0430	−.0052	−.050	24°	−.0086	.0360	−1.745
28°	.0440	−.0020	−.019	28°	−.0090	.0405	−1.875
32°	.0450	+.0018	+.017	32°	−.0090	.0440	−2.040
36°	.0500	.0065	.054	36°	−.0090	.0475	−2.200
40°	.0555	.0112	.084	40°	−.0090	.0522	−2.418
44°	.0620	.0155	.104	44°	−.0090	.0585	−2.710

TABLE XIII.—CLARK Y WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP, LEFT AILERON DOWN)

[Varying chord of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—$N/L=0.417\ C_N/C_L$]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)				AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0095	−.0081	−0.356	4°	+.0115	−.0090	−0.326
8°	.0195	−.0147	−.314	8°	.0217	−.0175	−.336
12°	.0295	−.0213	−.301	12°	.0308	−.0240	−.325
16°	.0420	−.0270	−.268	16°	.0394	−.0290	−.307
20°	.0455	−.0320	−.293	20°	.0478	−.0330	−.288
24°	.0460	−.0370	−.335	24°	.0508	−.0365	−.300
28°	.0463	−.0410	−.369	28°	.0527	−.0390	−.309
32°	.0468	−.0445	−.397	32°	.0550	−.0410	−.311
36°	.0476	−.0468	−.410	36°	.0580	−.0425	−.306
40°	.0485	−.0490	−.421	40°	.0616	−.0433	−.293
44°	.0509	−.0510	−.418	44°	.0673	−.0435	−.270
AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)				AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0147	−.0117	−0.332	4°	+.0126	−.0145	−0.480
8°	.0270	−.0212	−.327	8°	.0232	−.0260	−.467
12°	.0388	−.0294	−.316	12°	.0335	−.0350	−.436
16°	.0502	−.0362	−.301	16°	.0480	−.0430	−.374
20°	.0625	−.0410	−.274	20°	.0636	−.0485	−.318
24°	.0752	−.0422	−.234	24°	.0760	−.0500	−.274
28°	.0790	−.0420	−.222	28°	.0843	−.0500	−.247
32°	.0822	−.0430	−.218	32°	.0904	−.0510	−.238
36°	.0883	−.0457	−.216	36°	.0893	−.0545	−.255
40°	.0942	−.0515	−.228	40°	.0942	−.0600	−.266
44°	.1011	−.0665	−.274	44°	.0990	−.0700	−.295

TABLE XIV.—CLARK Y WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP, LEFT AILERON DOWN)

[Varying span of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—$N/L=0.417\ C_N/C_L$]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)				AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)				AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------	0°	0	0	----------
4°	+.0083	−.0065	−0.327	4°	+.0117	−.0095	−0.338	4°	+.0125	−.0100	−0.334
8°	.0161	−.0120	−.311	8°	.0235	−.0178	−.316	8°	.0236	−.0187	−.331
12°	.0234	−.0155	−.276	12°	.0326	−.0247	−.316	12°	.0340	−.0260	−.319
16°	.0300	−.0145	−.201	16°	.0401	−.0295	−.307	16°	.0427	−.0320	−.312
20°	.0370	−.0226	−.255	20°	.0458	−.0325	−.296	20°	.0504	−.0375	−.310
24°	.0430	−.0245	−.238	24°	.0525	−.0350	−.278	24°	.0571	−.0418	−.305
28°	.0440	−.0258	−.245	28°	.0528	−.0366	−.289	28°	.0582	−.0437	−.313
32°	.0445	−.0260	−.244	32°	.0540	−.0379	−.293	32°	.0597	−.0437	−.305
36°	.0460	−.0260	−.236	36°	.0565	−.0384	−.284	36°	.0621	−.0447	−.300
40°	.0474	−.0265	−.233	40°	.0583	−.0375	−.268	40°	.0648	−.0468	−.301
44°	.0485	−.0273	−.235	44°	.0595	−.0370	−.259	44°	.0683	−.0497	−.303

TABLE XV.—U. S. A. 27 WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP, LEFT AILERON DOWN)

[Varying chord of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—N/L=0.417 C_N/C_L]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

AILERON CHORD, 1.5 INCHES (15 PER CENT OF WING CHORD)				AILERON CHORD, 2 INCHES (20 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0123	−.0055	−0.186	4°	+.0170	−.0060	−0.147
8°	.0225	−.0120	−.222	8°	.0310	−.0124	−.167
12°	.0318	−.0178	−.233	12°	.0416	−.0198	−.198
16°	.0393	−.0220	−.233	16°	.0500	−.0257	−.214
20°	.0430	−.0235	−.228	20°	.0570	−.0310	−.227
24°	.0463	−.0248	−.223	24°	.0628	−.0345	−.229
28°	.0502	−.0257	−.213	28°	.0675	−.0374	−.231
32°	.0534	−.0268	−.209	32°	.0710	−.0384	−.226
36°	.0573	−.0271	−.197	36°	.0700	−.0380	−.226
40°	.0613	−.0282	−.192	40°	.0760	−.0378	−.207
44°	.0655	−.0305	−.194	44°	.0815	−.0366	−.187

AILERON CHORD, 3 INCHES (30 PER CENT OF WING CHORD)				AILERON CHORD, 3.5 INCHES (35 PER CENT OF WING CHORD)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------
4°	+.0190	−.0107	−0.235	4°	+.0173	−.0102	−0.244
8°	.0360	−.0203	−.235	8°	.0355	−.0203	−.239
12°	.0501	−.0299	−.246	12°	.0552	−.0305	−.230
16°	.0627	−.0365	−.243	16°	.0692	−.0360	−.217
20°	.0741	−.0392	−.221	20°	.0810	−.0385	−.198
24°	.0853	−.0398	−.195	24°	.0916	−.0392	−.178
28°	.0896	−.0393	−.183	28°	.0962	−.0400	−.174
32°	.0926	−.0380	−.171	32°	.1007	−.0395	−.164
36°	.0978	−.0370	−.158	36°	.1045	−.0390	−.155
40°	.1027	−.0358	−.145	40°	.1083	−.0370	−.142
44°	.1073	−.0340	−.132	44°	.1115	−.0350	−.131

TABLE XVI.—U. S. A. 27 WING SECTION—COMBINED VALUES OF C_L, C_N, AND N/L (RIGHT AILERON UP, LEFT AILERON DOWN)

[Varying span of aileron. Angle of pitch of airplane, +12°; angle of attack of wing, +16°; angle of yaw, 0°; angle of roll, 0°]

[NOTE.—N/L=0.417 C_N/C_L]

AILERON CHORD, 2.5 INCHES (25 PER CENT OF WING CHORD)

AILERON SPAN, 10 INCHES (33 PER CENT OF WING SEMISPAN)				AILERON SPAN, 15 INCHES (50 PER CENT OF WING SEMISPAN)				AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)			
θ	C_L	C_N	N/L	θ	C_L	C_N	N/L	θ	C_L	C_N	N/L
0°	0	0	----------	0°	0	0	----------	0°	0	0	----------
4°	+.0087	−.0070	−0.335	4°	+.0123	−.0090	−0.305	4°	+.0093	−.0106	−0.475
8°	.0166	−.0135	−.339	8°	.0197	−.0182	−.385	8°	.0183	−.0186	−.424
12°	.0247	−.0182	−.307	12°	.0265	−.0257	−.404	12°	.0285	−.0262	−.383
16°	.0321	−.0220	−.286	16°	.0335	−.0305	−.380	16°	.0388	−.0322	−.346
20°	.0402	−.0248	−.254	20°	.0417	−.0310	−.310	20°	.0482	−.0375	−.324
24°	.0460	−.0270	−.245	24°	.0502	−.0320	−.266	24°	.0516	−.0412	−.333
28°	.0468	−.0282	−.251	28°	.0517	−.0325	−.262	28°	.0530	−.0425	−.334
32°	.0465	−.0290	−.260	32°	.0530	−.0330	−.260	32°	.0540	−.0422	−.326
36°	.0490	−.0287	−.244	36°	.0530	−.0340	−.268	36°	.0590	−.0410	−.296
40°	.0515	−.0286	−.233	40°	.0548	−.0350	−.266	40°	.0645	−.0410	−.265
44°	.0538	−.0304	−.236	44°	.0603	−.0360	−.249	44°	.0710	−.0430	−.253

TABLE XVII.—CLARK Y WING SECTION—C_L AND C_N FOR ONE AILERON

[Aileron set at 20°. Angle of yaw, 0°; angle of roll, 0°]

[NOTE.—The values refer to either right or left aileron, the signs refer to the right aileron]

AILERON SPAN, 20 INCHES (67 PER CENT OF WING SEMISPAN)

Aileron chord, 2 inches (20 per cent of wing chord)					
Aileron up			Aileron down		
θ	C_L	C_N	θ	C_L	C_N
8°	+0.0460	−0.0005	8°	−0.0275	−0.0222
12°	.0350	−.0070	12°	−.0128	.0260
20°	.0203	−.0055	20°	−.0090	.0234
30°	.0138	−.0052	30°	−.0071	.0125
40°	.0125	−.0022	40°	−.0054	.0197

Aileron chord, 3 inches (30 per cent of wing chord)					
Aileron up			Aileron down		
θ	C_L	C_N	θ	C_L	C_N
8°	+0.0740	+0.0036	8°	−0.0280	+0.0305
12°	.0480	−.0080	12°	−.0145	.0330
20°	.0239	−.0145	20°	−.0077	.0227
30°	.0187	−.0066	30°	−.0087	.0240
40°	.0124	−.0110	40°	−.0069	.0282

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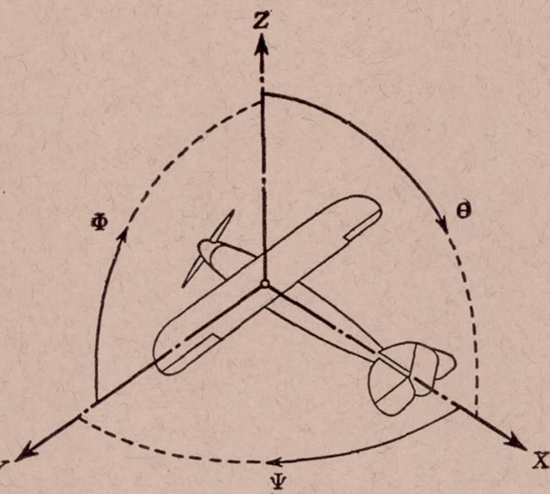

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \qquad C_M = \frac{M}{qcS} \qquad C_N = \frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\ V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute, r. p. m.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.