REPORT No. 611

WIND-TUNNEL INVESTIGATION OF TAPERED WINGS WITH ORDINARY AILERONS AND PARTIAL-SPAN SPLIT FLAPS

By Carl J. Wenzinger

SUMMARY

An investigation was made in the N. A. C. A. 7- by 10-foot wind tunnel to determine the aerodynamic properties of tapered wings having partial-span flaps for high lift and ordinary ailerons for lateral control. Each of two Clark Y wings, tapered 5:1 and 5:3, was equipped with partial-span split flaps of two lengths and with ordinary ailerons extending from the outboard ends of the flap to the wing tips. Measurements of wing forces and moments and of aileron hinge moments were made for the two conditions of flaps neutral and deflected.

With split flaps of equal length both wings had practically the same $C_{L_{max}}$. *If 30 percent of the flap outer span were removed for the installation of ailerons, a reduction in* $C_{L_{max}}$ *of the tapered wings with flaps might be expected of the order of 4 to 7 percent.*

Ailerons of the same span were found to give higher rolling-moment coefficients together with greater adverse yawing-moment coefficients on the 5:3 tapered wing than on the wing tapered 5:1. In addition, ailerons of the same span on the tapered wings tested gave greater rolling-moment coefficients and smaller adverse yawing-moment coefficients at the same lift coefficient when the partial-span flaps were deflected than when they were neutral.

INTRODUCTION

Full-span high-lift devices are seldom used on airplanes at the present time because of the difficulty of obtaining satisfactory lateral control with the lift-increasing device extending along the entire trailing edge of the wing. Several control devices adaptable to wings with a full-span flap have been investigated (references 1 and 2) and a few have shown considerable promise. However, each one has apparently had some disadvantage sufficient to prevent its general use. An arrangement commonly used in practice consists of partial-span flaps extending along the inner portion of the wing span for increasing lift combined with ordinary ailerons extending from the outboard ends of the flap to the wing tips for lateral control. Naturally, such an arrangement does not take advantage of the full potential value of the flap in decreasing the landing speed and steepening the gliding angle at landing.

Some research has already been completed concerning the aerodynamic effects of flaps extending along different portions of the wing span for both rectangular and tapered wings (references 3, 4, and 5). In addition, considerable data are available concerning the characteristics of different sizes of ordinary ailerons on wings of various plan forms (references 6, 7, and 8). There is a scarcity, however, of information regarding the aerodynamic characteristics of wings combined with partial-span flaps and ordinary ailerons.

The investigation described in the present report was made to determine the aerodynamic effects of combinations of flaps and ailerons of various spans. The tests included wings of medium and high taper having split flaps and ordinary ailerons of different spans.

APPARATUS

MODELS

The two models used have been previously tested in connection with the wind-tunnel research described in references 4 and 8. One wing is tapered 5:1 and the other 5:3, the slopes of the leading and trailing edges being equal (figs. 1 and 2). The Clark Y profile is used at all sections along the span, and the maximum ordinates of all the sections are in a horizontal plane on the upper surface. The models are constructed of laminated mahogany; each has a span of 60 inches and a geometrical aspect ratio of 6.0.

The ailerons tapered with the wings, the chord of each aileron at any longitudinal section being 25 percent of the wing chord (c_w) at the same section. The spans of the ailerons first tested were the same as those used in previous tests, 50 percent $b/2$ and 41 percent $b/2$ for the wings tapered 5:1 and 5:3, respectively. The spans were then reduced to 30 percent $b/2$ for each aileron tested, this latter length being considered the shortest desirable. Since earlier tests (reference 6) had shown that the moments caused by both the right and left ailerons could be separately found and added to give the total effect with satisfactory accuracy, the present models were equipped with ailerons only at the right wing tip.

All the ailerons were arranged to lock rigidly to the wing at a given deflection or to rotate freely about their hinge axes, the gap between aileron and wing being sealed with a light grease. Hinge moments of the ailerons were measured by the calibrated twist of a long slender steel rod extending along the hinge axis

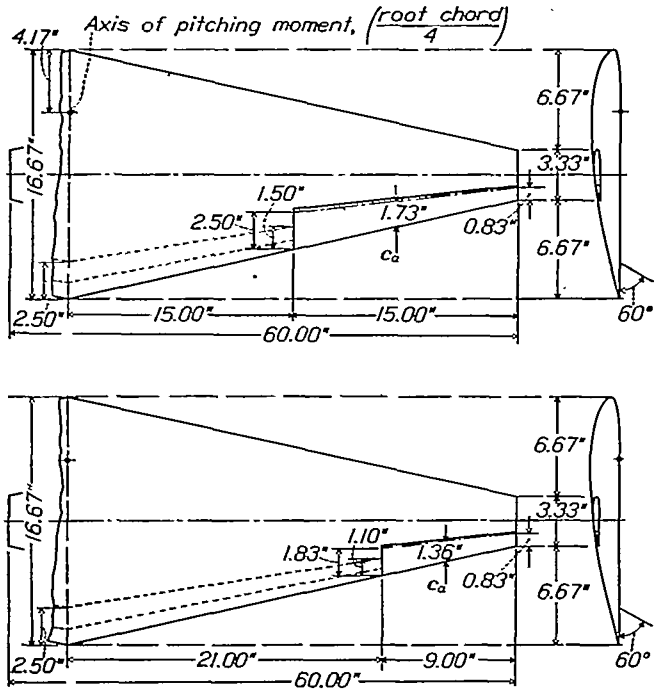


FIGURE 1.—The 5:1 tapered Clark Y wing with $0.25c_w$ tapered ordinary ailerons and $0.15c_w$ tapered partial-span split flaps.

from the aileron to the balance frame outside the air stream.

Simple split flaps that tapered with the wing were used with each model, the flap chord at any longitudinal section being $0.15c_w$ at the same section. In each case the flaps extended along the trailing edge of the wing from the center section to the inboard end of the ailerons, so that partial-span flaps of 0.50, 0.59, and 0.70b were used. Each of the flaps was built of 1/16-inch steel plate and was fastened to the wing model by screws and blocks at an angle of 60°. This angle was the one that gave the highest $C_{L_{max}}$ with the $0.15c_w$ tapered flap in earlier tests (reference 4).

WIND TUNNEL

The N. A. C. A. 7- by 10-foot wind tunnel in which the tests were made had an open jet and a closed return passage. The tunnel and regular 6-component balance are described in detail in reference 9. On this balance the six components of aerodynamic forces and moments are independently and simultaneously measured with respect to the wind axes of the model.

TESTS

The dynamic pressure was maintained constant throughout the tests at 16.37 pounds per square foot corresponding to an air speed of 80 miles per hour at standard sea-level conditions. The average test Reynolds Number was 609,000 based on the mean wing chord of 10 inches; the effective Reynolds Number (test Reynolds Number×the turbulence factor of the wind tunnel) was 609,000×1.4=853,000. (See reference 10.) The angle-of-attack range covered from zero lift to beyond the stall of the wing. Aileron deflections covered from 30° to −30° and were measured in a plane perpendicular to their hinge axes. (Positive deflections are downward and negative, upward.)

Force tests were made first with full-span flaps on the wings as a basis for comparison with the partial-span flaps. Lift, drag, and pitching-moment coefficients were measured for flap deflections of 0° and 60°. The flaps were next cut to the shortest spans used so that the longest ailerons could be tested first. With this arrangement no alterations to the original models were required. Lift, drag, and pitching-moment coefficients were again measured for flap angles of 0° and 60°, ailerons neutral, and then rolling-, yawing-, and hinge-moment coefficients of the ailerons were measured for the same two flap deflections. In all these tests the aileron gaps were sealed with a light grease to prevent any leakage because even a small gap considerably reduces the aileron effectiveness.

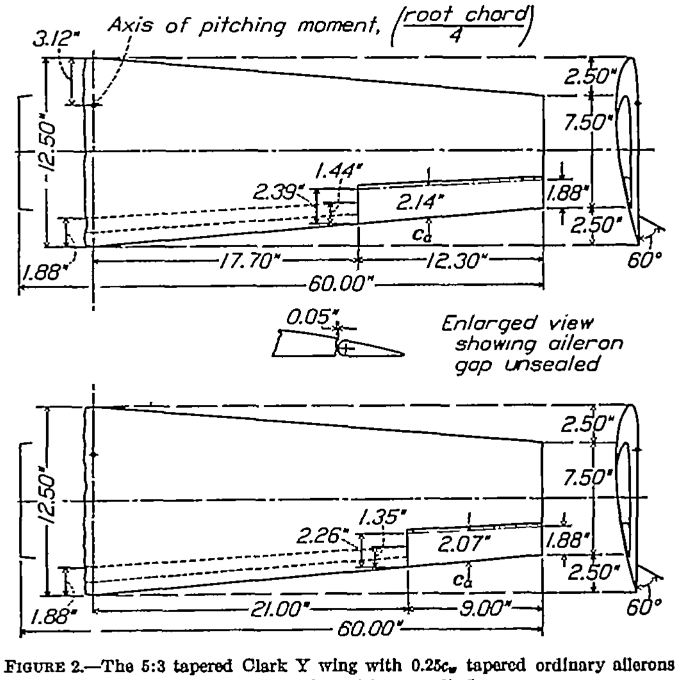


FIGURE 2.—The 5:3 tapered Clark Y wing with $0.25c_w$ tapered ordinary ailerons and $0.15c_w$ tapered partial-span split flaps.

For comparison with results for the aileron gap sealed, a few tests were made with the long aileron having the gap unsealed on the 5:1 tapered wing. In this case rolling-, yawing-, and hinge-moment coefficients of the aileron were measured only for the flap-neutral condition. These data also served for comparison with similar data from the same model obtained about 3 years earlier.

The ailerons were then cut to the shorter spans and the flaps were lengthened. Tests similar to those for the longer ailerons were again made, except that the aileron gaps were always kept sealed.

RESULTS AND DISCUSSION

FORM OF PRESENTATION OF DATA

The test results are given in the form of absolute coefficients of lift and drag, and of pitching, rolling, yawing, and hinge moment:

$$C_L=\frac{\text{lift}}{qS}$$

$$C_D=\frac{\text{drag}}{qS}$$

$$C_{m_{(a.c.)_0}}'=\frac{\text{pitching moment about aerodynamic center [of plain wing}}{qcS}$$

$$C_l'=\frac{\text{rolling moment}}{qbS}$$

$$C_n'=\frac{\text{yawing moment}}{qbS}$$

$$C_h=\frac{\text{hinge moment}}{qc_aS_a}$$

where S is the wing area.
b, the wing span.
c, the mean geometric chord of the wing.
S_a, the area of one aileron.
c_a, the root-mean-square chord of a tapered aileron; i. e., the square root of the mean of the squares of the aileron chords along its span.
q, the dynamic pressure.

All coefficients, except those of hinge moment, were obtained directly from the balance and refer to the wind (or tunnel) axes.

The data were corrected for tunnel effects to aspect ratio 6.0. The standard jet-boundary corrections were applied,

$$\Delta\alpha=\delta\frac{S}{C}C_L\times 57.3\text{, degrees}$$

$$\Delta C_D=\delta\frac{S}{C}C_L^2$$

where C is the jet cross-sectional area. A value $\delta=-0.165$ for the open-jet 7- by 10-foot wind tunnel was used in correcting the test results. An additional correction to the drag data was necessitated by the static-pressure gradient in the open jet. This gradient produced an additional downstream force on the model corresponding to ΔC_D of 0.0019 for the wing tapered 5:1 and ΔC_D of 0.0017 for the wing tapered 5:3.

EFFECT OF FLAP SPAN ON WING CHARACTERISTICS

Lift and drag coefficients for the 5:1 tapered wing with various spans of tapered split flap are given in figure 3, and pitching-moment coefficients in figure 4. Similar data for the 5:3 tapered wing are given in figures 5 and 6. Values of $C_{L_{max}}$ and of C_D and L/D

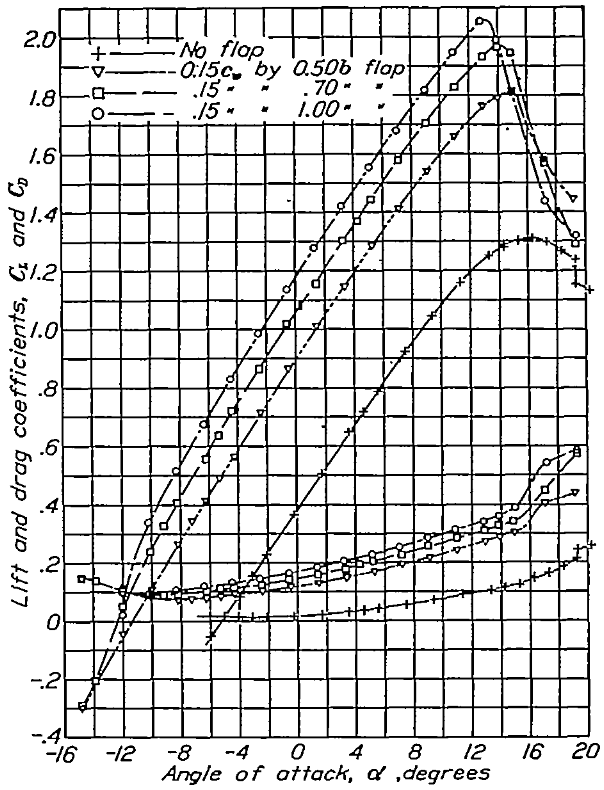


FIGURE 3.—Lift and drag coefficients of 5:1 tapered wing with tapered split flaps of various spans deflected 60°. Aileron neutral.

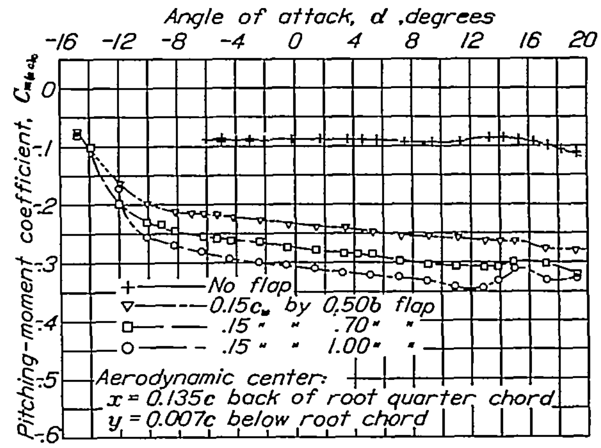


FIGURE 4.—Pitching-moment coefficients of 5:1 tapered wing with tapered split flaps of various spans deflected 60°. Aileron neutral.

at $C_{L_{max}}$ for different flap spans on both the 5:1 and 5:3 tapered wings are plotted in figure 7.

Some aerodynamic characteristics of the tapered wings with split flaps of various spans are compared in table I with similar data for a rectangular wing. (The data for the rectangular wing were taken from reference 3 and corrected for tunnel effects.) It will be noted

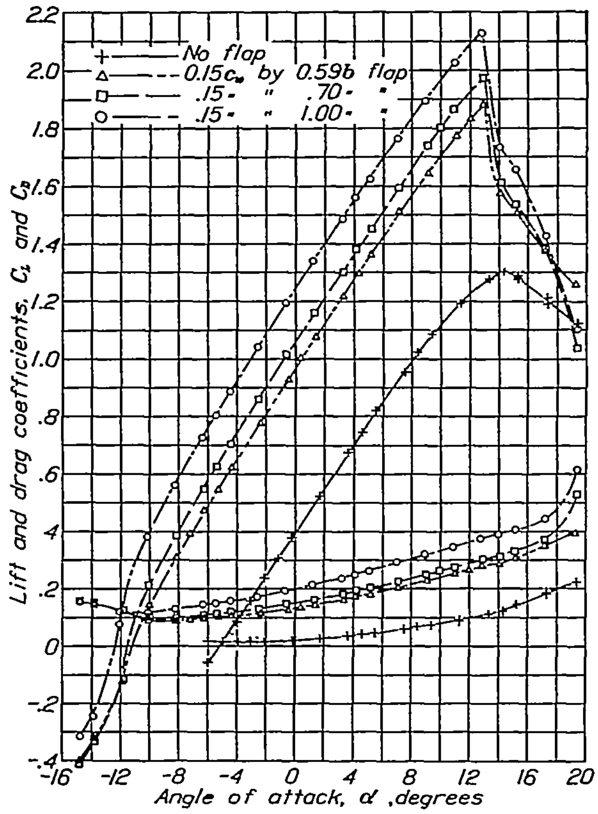


FIGURE 5.—Lift and drag coefficients for 5:3 tapered wing with tapered split flaps of various spans deflected 60°. Aileron neutral.

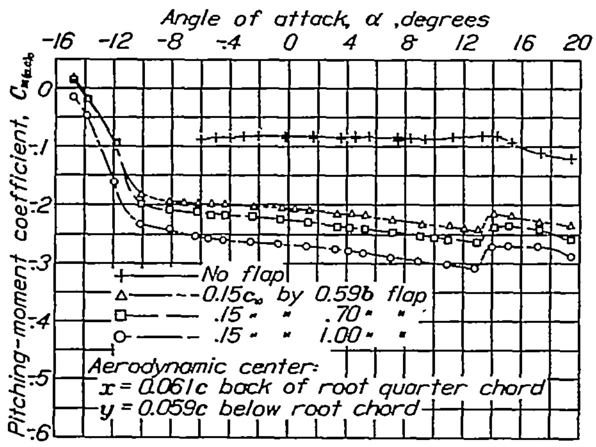


FIGURE 6.—Pitching-moment coefficients for 5:3 tapered wing with tapered split flaps of various spans deflected 60°. Aileron neutral.

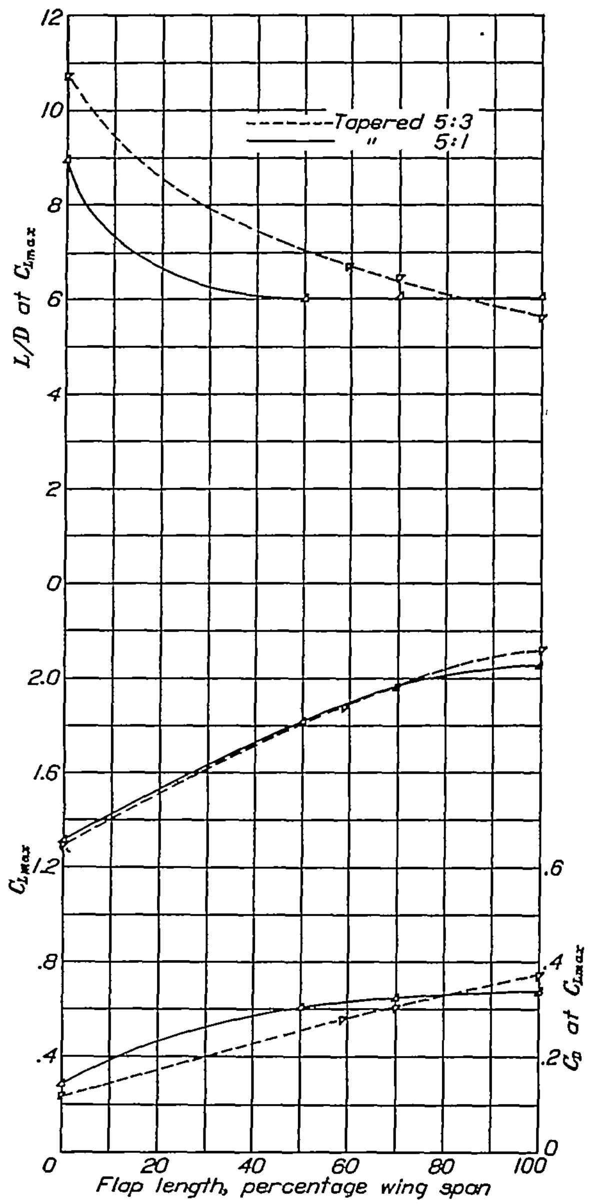
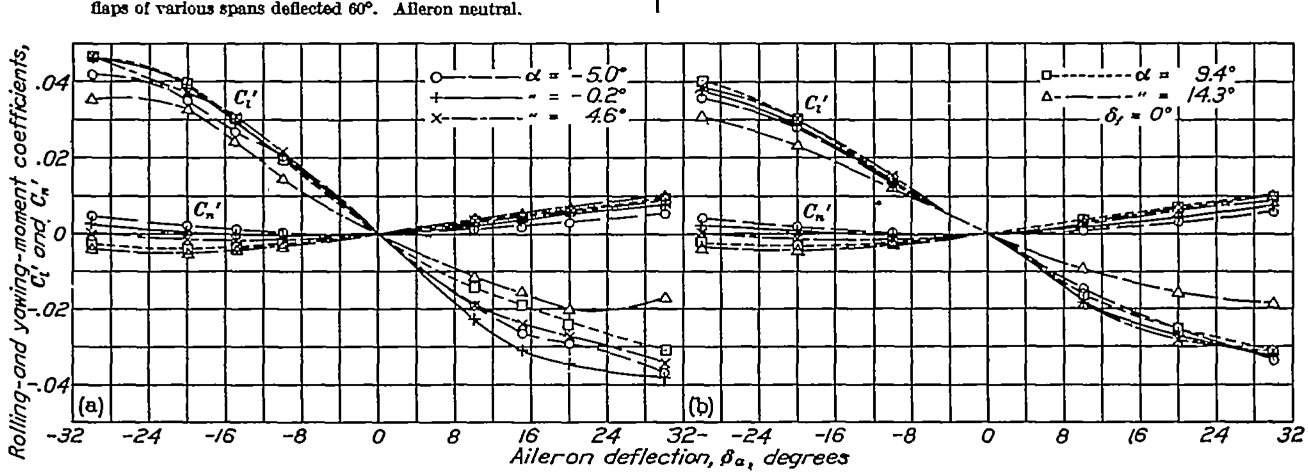


FIGURE 7.—Effect of partial-span split flaps on $C_{L_{max}}$ and on C_D and L/D at $C_{L_{max}}$. The 5:1 and 5:3 tapered wings with 0.15 c_w tapered split flaps deflected 60°.



(a) Aileron gap closed. (b) Aileron gap open.

FIGURE 8.—Rolling- and yawing-moment coefficients of 0.25c_w by 0.50 $\frac{b}{2}$ tapered aileron on 5:1 tapered wing. Flaps neutral.

that the $C_{L_{max}}$ of the plain wings increases slightly with increasing taper but, with full-span flaps deflected, the $C_{L_{max}}$ decreases slightly with increasing taper.

Reducing the flap span from 100 to 70 percent on the 5:1 tapered wing reduced the lift increment $\Delta C_{L_{max}}$ by about 11.5 percent although the actual $C_{L_{max}}$ was reduced about 4 percent. On the 5:3 tapered wing and on the rectangular wing the values are roughly 17 percent reduction in $\Delta C_{L_{max}}$ and 7 percent in $C_{L_{max}}$.

AILERON CHARACTERISTICS, 5:1 TAPERED WING

Rolling- and yawing-moment coefficients due to the $0.25c_w$ by 0.50 $b/2$ tapered aileron, gap closed, are given in figure 8 (a) at five angles of attack for the flap-neutral condition. The results for the gap open between aileron and wing are plotted in figure 8 (b). Comparison of these two figures shows that the rolling-moment coefficient for a given aileron deflection is decreased when the gap is left unsealed, indicating that no leakage should be permitted between aileron and wing for the maximum rolling effect. Comparison of the data for the unsealed aileron (fig. 8 (b)) with those obtained with the same aileron in tests made about 3 years earlier (reference 8) shows good agreement.

The effect on aileron rolling- and yawing-moment coefficients due to deflecting the $0.15c_w$ by $0.50b$ split flap 60° is shown in figure 9. For the two conditions

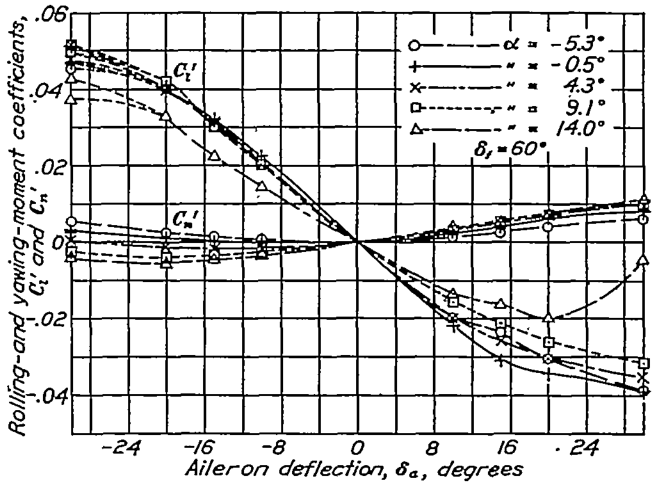
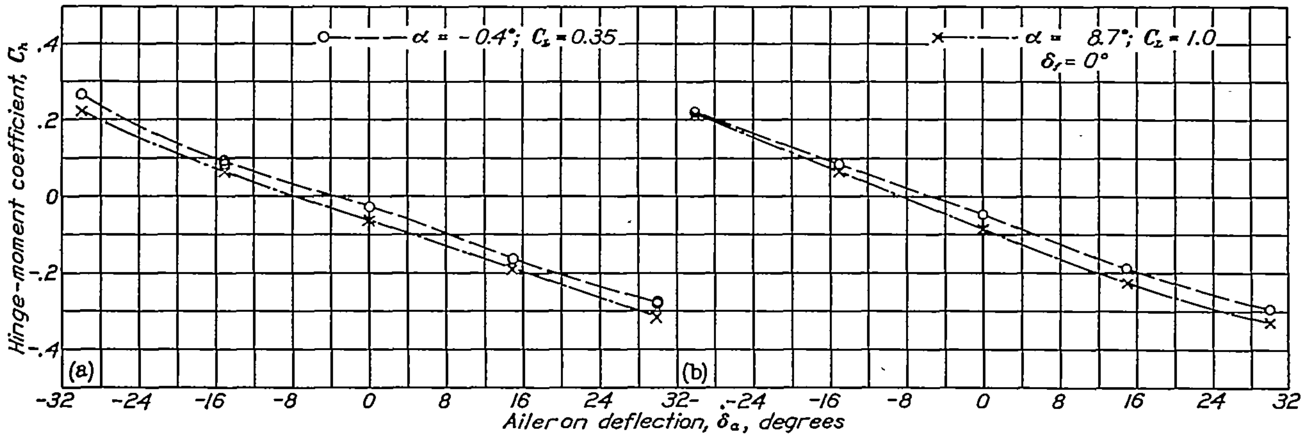


FIGURE 9.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.50\frac{b}{2}$ tapered aileron on 5:1 tapered wing. The $0.15c_w$ by $0.50b$ tapered split flaps deflected 60°.

of flap neutral and flap deflected, the rolling moments due to the up aileron increase directly with aileron deflection to about 20° after which they taper off.



(a) Aileron gap closed. (b) Aileron gap open.

FIGURE 10.—Hinge-moment coefficients of $0.25c_w$ by $0.50\frac{b}{2}$ tapered aileron on 5:1 tapered wing. Flaps neutral.

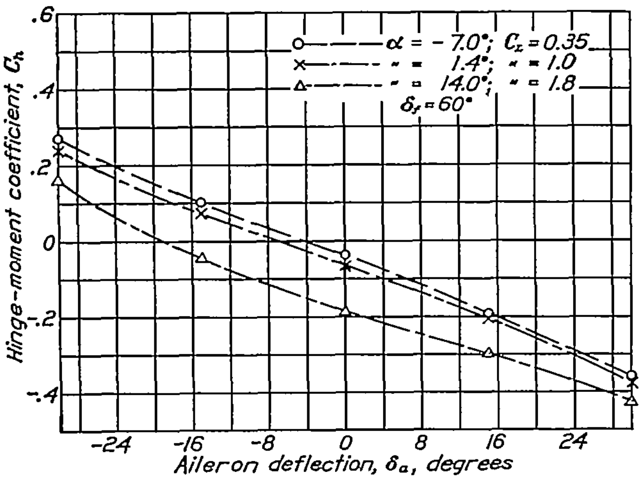


FIGURE 11.—Hinge-moment coefficients of $0.25c_w$ by $0.50\frac{b}{2}$ tapered aileron on 5:1 tapered wing. The $0.15c_w$ by $0.50b$ tapered split flaps deflected 60°.

The moments due to the down aileron increase directly to an aileron angle of about 15° after which they also begin to fall off. In general, when the flap is deflected, the rolling-moment coefficients are increased above the values for the flap-neutral condition. Hinge-moment coefficients of these ailerons increase almost directly with aileron deflection (figs. 10 (a), 10 (b), and 11) for the range tested.

Rolling- and yawing-moment coefficients due to the $0.25c_w$ by 0.30 $b/2$ tapered ailerons are given in figure 12 for the flap-neutral condition and in figure 13 for the $0.15c_w$ by $0.70b$ split flap deflected 60°. Hinge-moment coefficients for the two conditions are given in figures 14 and 15. The variation of rolling moment with aileron deflection is quite similar for these ailerons to that of the longer ones, but the values are considerably less for a given deflection at a given angle of attack. In fact, the reduction in rolling-moment coefficient is almost directly proportional to the decrease in the span of the aileron.

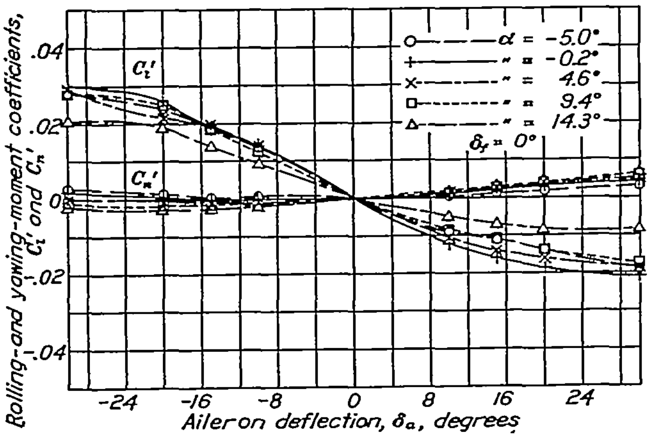


FIGURE 12.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:1 tapered wing. Flaps neutral.

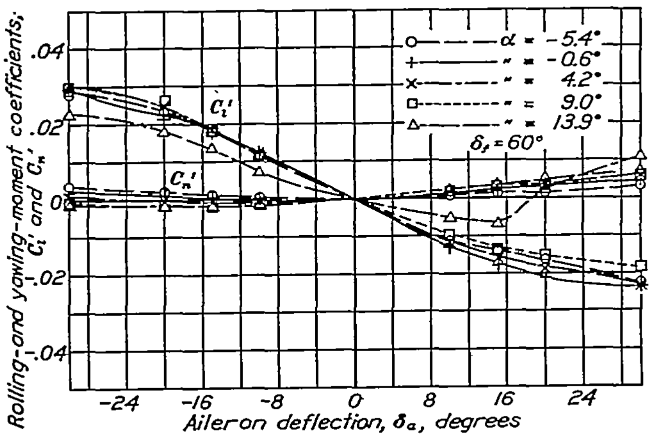


FIGURE 13.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:1 tapered wing. The $0.15c_w$ by $0.70b$ tapered split flaps deflected 60°.

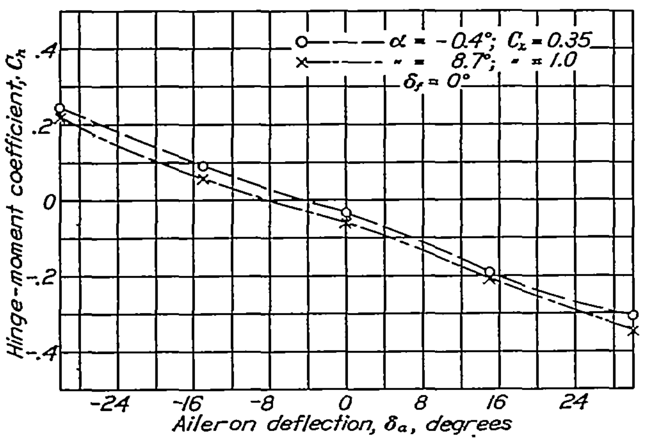


FIGURE 14.—Hinge-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:1 tapered wing. Flaps neutral.

AILERON CHARACTERISTICS, 5:3 TAPERED WING

Rolling-, yawing-, and hinge-moment coefficients of the $0.25c_w$ by $0.41\ b/2$ tapered aileron are given in figures 16, 17, 18, and 19 for various aileron deflections at several angles of attack, the $0.15c_w$ by $0.59b$ tapered split flap both neutral and deflected 60°. Similar plots for the shorter aileron, $0.25c_w$ by $0.30\ b/2$, with the longer flap, $0.15c_w$ by $0.70b$, are given in figures 20, 21, 22, and 23.

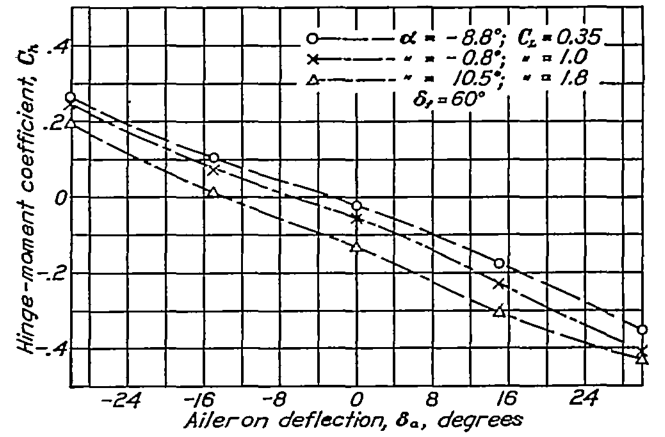


FIGURE 15.—Hinge-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:1 tapered wing. The $0.15c_w$ by $0.70b$ tapered split flaps deflected 60°.

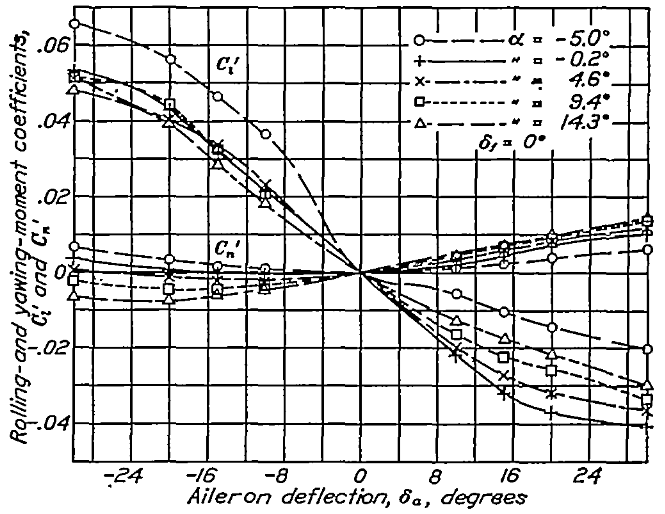


FIGURE 16.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.41\frac{b}{2}$ tapered aileron on 5:3 tapered wing. Flaps neutral.

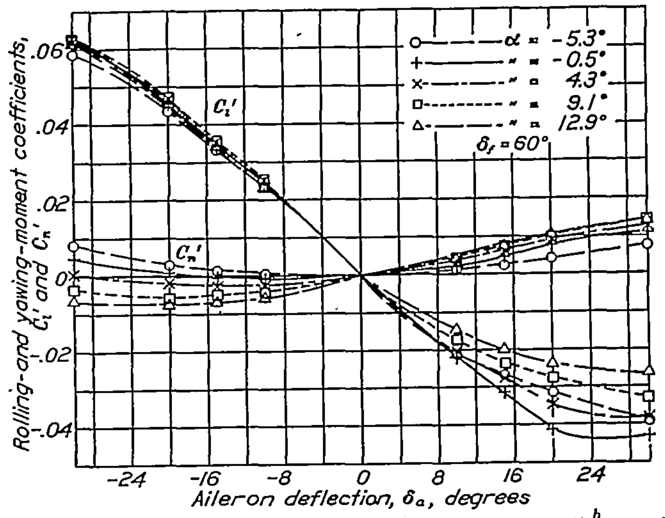


FIGURE 17.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.41\frac{b}{2}$ tapered aileron on 5:3 tapered wing. The $0.15c_w$ by $0.59b$ tapered split flaps deflected 60°.

For the 5:3 tapered wing, the variation of rolling moment with aileron deflection is much the same as that of the ailerons on the 5:1 tapered wing except for the case of the up aileron when the flap is deflected. In this condition on the 5:3 tapered wing the rolling moments due to the up aileron increase almost directly without falling off over the range of deflections tested (0° to 30°). The moments due to the down aileron, however, vary in a manner similar to those on the 5:1 tapered wing. As in the case of the ailerons on the 5:1 tapered wing, the rolling-moment coefficients for the ailerons on the 5:3 tapered wing are somewhat increased when the flap is deflected. In addition, the reduction in rolling-moment coefficient with decreased aileron span is also directly proportional to the decrease in span.

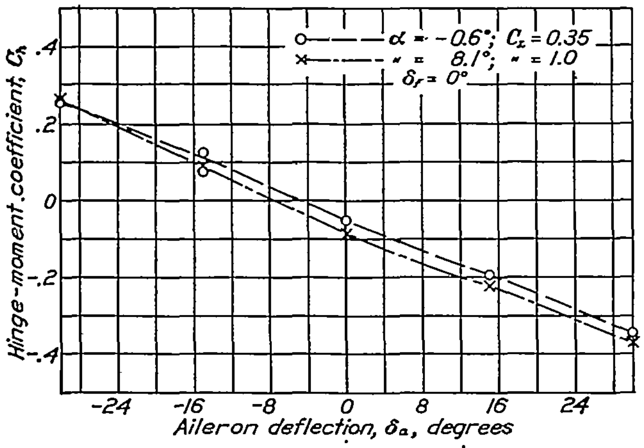


FIGURE 18.—Hinge-moment coefficients of $0.25c_w$ by $0.41\frac{b}{2}$ tapered aileron on 5:3 tapered wing. Flaps neutral.

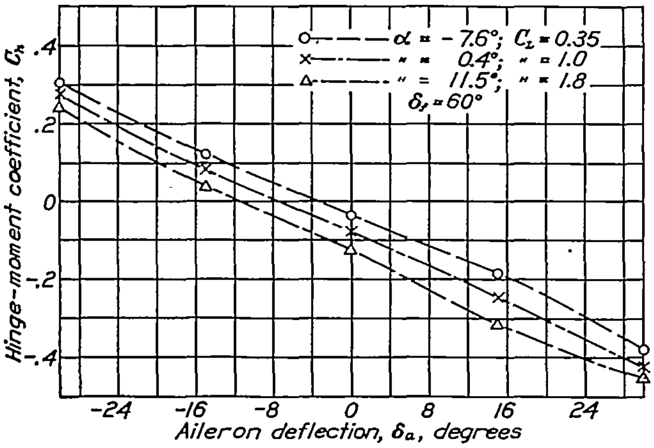


FIGURE 19.—Hinge-moment coefficients of $0.25c_w$ by $0.41\frac{b}{2}$ tapered aileron on 5:3 tapered wing. The $0.15c_w$ by 0.59b tapered split flaps deflected 60°.

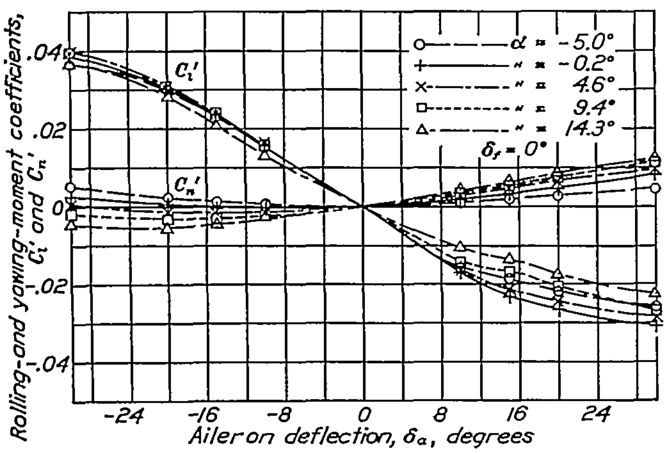


FIGURE 20.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:3 tapered wing. Flaps neutral.

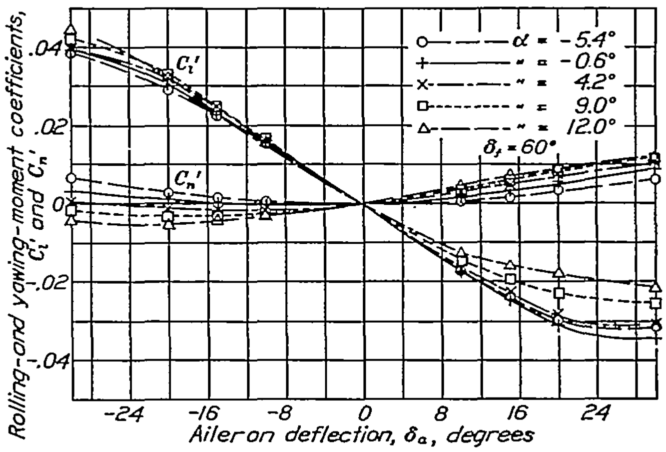


FIGURE 21.—Rolling- and yawing-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:3 tapered wing. The $0.15c_w$ by 0.70b tapered split flaps deflected 60°.

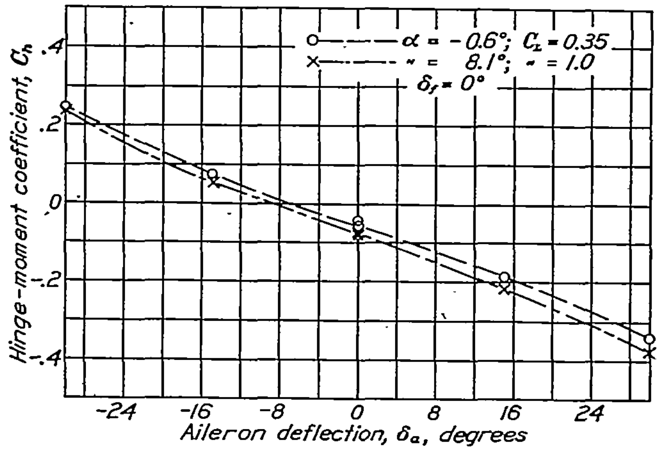


FIGURE 22.—Hinge-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:3 tapered wing. Flaps neutral.

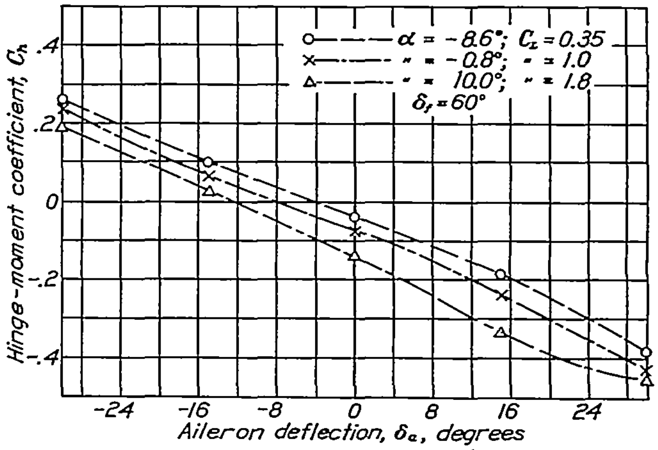


FIGURE 23.—Hinge-moment coefficients of $0.25c_w$ by $0.30\frac{b}{2}$ tapered aileron on 5:3 tapered wing. The $0.15c_w$ by 0.70b tapered split flaps deflected 60°.

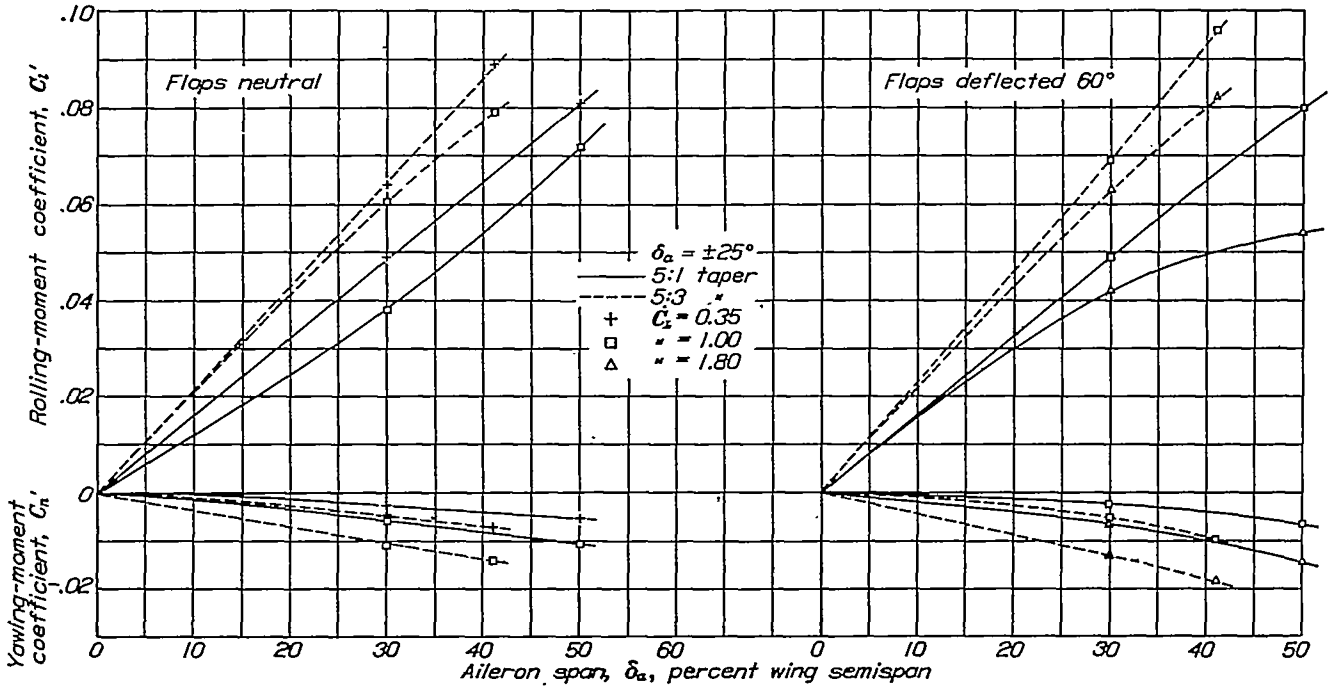


FIGURE 24.—Effect of aileron span on rolling- and yawing-moment coefficients. The $0.25c_w$ tapered aileron with equal up-and-down deflection on tapered Clark Y wings The $0.15c_w$ partial-span split flaps neutral and deflected.

COMPARISON OF THE TAPERED AILERONS ON TAPERED WINGS

The effect of aileron span on rolling- and yawing-moment coefficients with equal up-and-down deflection is shown in figure 24, with the partial-span flaps both neutral and deflected. With the arrangements shown it is evident that ailerons of the same span on the 5:3 tapered wing are capable of giving higher rolling-moment coefficients, together with more adverse yawing-moment coefficients, than those on the 5:1 tapered wing, flaps neutral or deflected. This characteristic may be attributed almost entirely to the difference in area of the ailerons for the sizes investigated on the two wings. The chords of the ailerons are the same percentage of the wing chord so that, since the wings have the same span and area, the aileron on the 5:3 tapered wing has a larger area than an aileron of equal span on the 5:1 tapered wing. At the same lift coefficient of the wing, deflecting the flap has the same general effect as in the case of single ailerons; i. e., the rolling-moment coefficients are increased and the adverse yawing-moment coefficients are decreased for the same aileron deflection.

Previous tests showed (reference 8) that the long tapered ailerons on both the 5:1 and 5:3 tapered wings, flaps neutral, gave rolling moments equal in magnitude to an assumed value that would provide satisfactory lateral control up to the stall. At and beyond the stall, however, the indicated control was poor.

The rolling-moment coefficient corresponding to the foregoing conditions is approximately 0.065 at a lift coefficient of 1.0 for the tapered ailerons and wings in question. In addition, flight tests have shown that in some cases $C_l'=0.04$ gives satisfactory rolling control (reference 11) so that the value of $C_l'=0.065$ may be too high for most of the usual flight conditions.

Decreasing the span of the tapered ailerons to 0.30 $b/2$ gives an aileron that just meets the requirement of the lower rolling-moment coefficient on the 5:1 tapered wing, which is probably the highest taper likely to be dealt with in practice. The use of the highly tapered wing is accompanied by a decreased damping in roll compared with the medium tapered or rectangular wings, so that it seems likely that lower aileron rolling moments will suffice to give the same degree of control. In addition, the reduction in $C_{L_{max}}$ with partial-span flaps is small (about 4 percent), so that the combination appears promising from considerations of both high lift and rolling control.

CONCLUSIONS

1. There was practically no difference in $C_{L_{max}}$ obtained with Clark Y wings tapered 5:1 or 5:3 with equal lengths of split flap.

2. A reduction in $C_{L_{max}}$ of tapered wings with split flaps might be expected of the order of 4 to 7 percent, if 30 percent of the flap outer span were removed for ailerons.

3. Ailerons of the same span on the 5:3 tapered wing gave higher rolling-moment coefficients but also greater adverse yawing-moment coefficients than those on the 5:1 tapered wing, flaps neutral or deflected.

4. Ailerons of the same span gave greater rolling-moment coefficients and smaller adverse yawing-moment coefficients at the same lift coefficient on the tapered wings tested when partial-span split flaps were deflected than when neutral.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *January 14, 1937.*

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TABLE I.—COMPARISON OF RECTANGULAR AND TAPERED CLARK Y WINGS WITH SPLIT FLAPS OF VARIOUS SPANS

Flap span	Flap chord	$C_{L_{max}}$	$\Delta C_{L_{max}}$	$C_{L_{max}}/C_{D_{min}}$	L/D at $C_{L_{max}}$
Rectangular wing [1]					
No flap	----------	1.282	----------	86.7	9.98
Full span	0.20c_w	2.188	0.906	148.0	4.86
0.70b	.20c_w	2.040	.758	138.0	6.03
0.59b	.20c_w	1.940	.658	131.1	6.45
0.50b	.20c_w	1.845	.563	124.7	6.76
5:3 tapered wing					
No flap	----------	1.300	----------	95.5	10.74
Full span	0.15c_w	2.129	0.829	156.6	5.68
0.70b	.15c_w	1.973	.673	145.0	6.50
0.59b	.15c_w	1.881	.581	138.4	6.70
0.50b	.15c_w	1.810	.510	133.1	7.15
5:1 tapered wing					
No flap	----------	1.312	----------	96.5	9.01
Full span	0.15c_w	2.056	0.743	151.1	6.05
0.70b	.15c_w	1.970	.658	144.9	6.05
0.59b	.15c_w	1.895	.583	139.4	6.05
0.50b	.15c_w	1.816	.504	133.5	6.05

[1] Values obtained from data in reference 3, corrected for tunnel effects.

AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s² or 32.1740 ft./sec.²

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

I, Moment of inertia $=mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

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

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu. ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $=\frac{1}{2}\rho V^2$

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

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

D_0, Profile drag, absolute coefficient $C_{D_0}=\frac{D_0}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

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

R, Resultant force

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

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s., the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of c.p. from leading edge to chord length)

α, Angle of attack

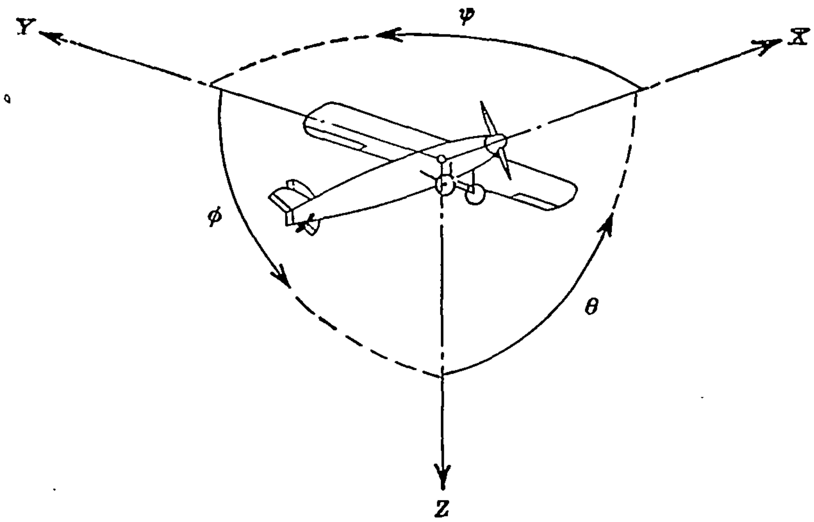
ϵ, Angle of downwash

α_0, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle



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

$C_l=\frac{L}{qbS}$ (rolling) $C_m=\frac{M}{qcS}$ (pitching) $C_n=\frac{N}{qbS}$ (yawing)

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

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$
C_s, Speed-power coefficient$=\sqrt[5]{\frac{\rho V^5}{P n^2}}$
η, Efficiency
n, Revolutions per second, r.p.s.
Φ, Effective helix angle$=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp.=76.04 kg-m/s=550 ft-lb./sec.
1 metric horsepower=1.0132 hp.
1 m.p.h.=0.4470 m.p.s.
1 m.p.s.=2.2369 m.p.h.
1 lb.=0.4536 kg.
1 kg=2.2046 lb.
1 mi.=1,609.35 m=5,280 ft.
1 m=3.2808 ft.

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