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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 427

THE EFFECT OF MULTIPLE FIXED SLOTS AND A TRAILING-EDGE FLAP ON THE LIFT AND DRAG OF A CLARK Y AIRFOIL

By FRED E. WEICK and JOSEPH A. SHORTAL

1932

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/h	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.

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

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 $C_D=\frac{D}{qS}$

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

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 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;
or for a model of 10 cm chord 40 m/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_o, 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.

REPORT No. 427

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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EXECUTIVE COMMITTEE

REPORT No. 427

THE EFFECT OF MULTIPLE FIXED SLOTS AND A TRAILING-EDGE FLAP ON THE LIFT AND DRAG OF A CLARK Y AIRFOIL

By Fred E. Weick and Joseph A. Shortal

SUMMARY

Lift and drag tests were made on a Clark Y wing equipped with four fixed slots and a trailing-edge flap in the 5-foot vertical wind tunnel of the National Advisory Committee for Aeronautics. All possible combinations of the four slots were tested with the flap neutral and the most promising combinations were tested with the flap down 45°. Considering both the maximum lift coefficient and the speed-range ratio $C_{L_{max}}/C_{D_{min}}$, with the flap neutral no appreciable improvement was found with the use of more than the single leading-edge slot. With the flap down 45° a maximum lift coefficient of 2.60 was obtained but the particular slot combination used had a rather large minimum drag coefficient with the flap neutral. With the flap down 45° the optimum combination, considering both the maximum lift coefficient and the speed-range ratio, was obtained with only the two rearmost slots in use. For this arrangement the maximum lift coefficient was 2.44.

INTRODUCTION

As an extension of the investigation of lateral stability and control at low speeds, the National Advisory Committee for Aeronautics has undertaken an investigation of devices intended to increase the maximum lift coefficient. In an investigation conducted by Lachmann (reference 1) a large increase in the maximum lift coefficient was obtained with a highly cambered airfoil equipped with fixed slots but the minimum drag coefficient of the arrangement was high. A relatively low-drag fixed slot near the leading edge of an airfoil has been recently developed by the National Advisory Committee for Aeronautics, with which the maximum lift coefficient of a Clark Y airfoil was increased from 1.30 to 1.75. (Reference 2.)

The present investigation was made to determine the effect on its aerodynamic characteristics of equipping a Clark Y airfoil with several fixed slots similar in shape to the recently developed low-drag fixed slot. The tests were made with all possible combinations of the various slots. In addition, since it was know that a multislot wing could advantageously have greater camber than that of the Clark Y, tests were made with the rear portion deflected downward as a flap.

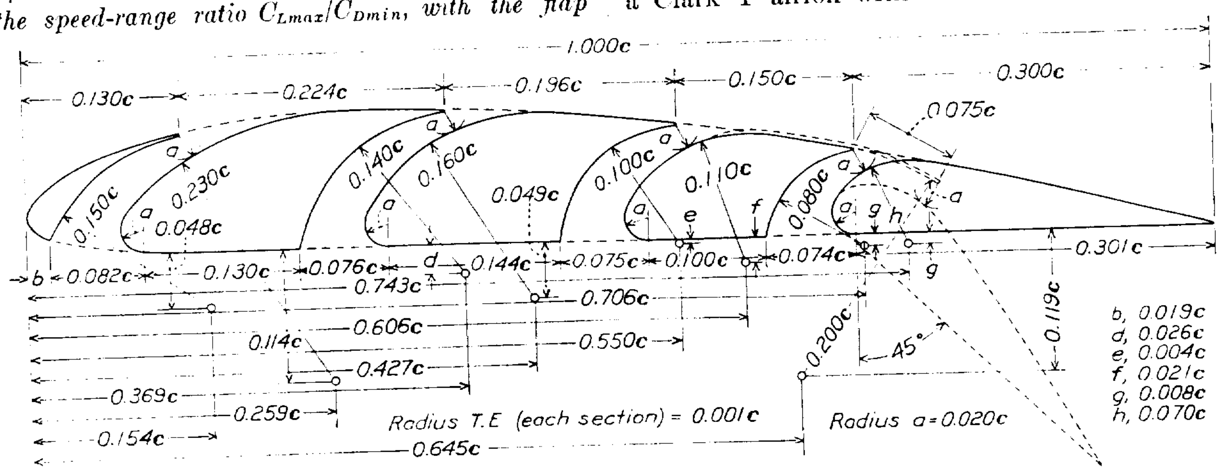


Figure 1.—Section of Clark Y wing with multiple fixed slots and trailing-edge flap

APPARATUS AND METHODS

The tests were made in the N. A. C. A. vertical wind tunnel which has a 5-foot open jet. (Reference 3.) In order to make the results comparable with results of tests in the 7 by 10 foot horizontal tunnel (reference 4), the airfoil chord was fixed at 10 inches, which necessitated the use of a half-span model and "reflection plane" as described in detail in reference 5. The balance arrangement and general test procedure are also described therein.

Four fixed slots similar in shape to the previously developed leading-edge slot of reference 2 were cut through the Clark Y profile as shown in Figure 1.

The gaps indicated by the letter "a" in Figure 1 were all of the same size, 2 per cent of the wing chord. Because of the small size of the leading-edge portion ahead of the front slot, it was made of aluminum alloy. The remaining portions of the wing were made of laminated mahogany. All five portions were rigidly fastened together by means of thin metal plates at both ends. To prevent excessive deflection of the leading-edge portion under load, a small metal clip was used to support it in the center. When not in use, the slots were closed by filling them with Plasticine and fairing to the Clark Y profile.

With the flap neutral, lift and drag tests were made with all possible combinations of the four fixed slots. After these tests had been completed the flap was turned down 45° as shown with dotted lines in Figure 1. With the flap down the rear slot was obviously of poor shape, and in order to improve it a cover plate was provided which is also shown by dotted lines in Figure 1.[1] With the flap down and the improved rear slot in use, lift and drag tests were made with all possible combinations of the other slots. In addition, several combinations were tested with the rear slot closed, including that with all the slots closed, which gave the condition of an ordinary flap on a plain airfoil.

To find the effect of the cover plate on the rear slot, further tests were made with the cover plate removed, first with all the other slots closed and later with the combination giving the highest maximum lift coefficient.

All tests were made at an air speed of 80 miles per hour, giving a Reynolds Number of 609,000 based on the 10-inch chord.

RESULTS AND DISCUSSION

The results are given in terms of the standard absolute coefficients of lift and drag, C_L and C_D, uncorrected for tunnel-wall effect. These coefficients are plotted against angle of attack in Figures 2 to 8, inclusive.

Flap neutral.—The effect of the fore-and-aft location of a single slot is shown in Figure 2 where the results are given for each of the four slots tested separately. From either Figure 2 or Table II, which summarizes the important results with the flap neutral, it can be seen that both the maximum lift coefficient and the minimum drag coefficient decrease as the slot is moved to the rear. The speed-range ratio C_{Lmax}/C_{Dmin} increases as the slot is moved to the rear, the value with the rear slot open being slightly higher than that for the plain wing. (The values with all other slot conditions are lower.)

The rear slot increases both the maximum lift coefficient and the ratio C_{Lmax}/C_{Dmin} when used alone or with the leading-edge slot. With any other combination the rear slot has a detrimental effect on one or both of these factors.

The highest maximum lift coefficient was obtained with the three foremost slots open and the rear one closed. With this condition the maximum lift coefficient was increased from 1.29 for the plain Clark Y to 1.93. This value is not appreciably higher, however, than that obtained with the third slot also closed, 1.90, and is only 9 per cent higher than that obtained with only the front slot open.

The highest speed-range ratio was that obtained with only the rear slot open. The value of the ratio with the arrangement giving the highest maximum lift coefficient was very low. Considering both the maximum lift coefficient and the speed-range ratio, the best combination is probably that with the front and rear slots open, but it is closely approached by the arrangement with the front slot only open. These tests therefore indicate that with an airfoil having the low camber of the Clark Y no substantial gain would be obtained by fitting more slots than one and that at the leading edge.

Flap down 45°.—With the rear portion of the wing used as a flap and turned down 45° the effective camber of the wing is considerably increased and multiple slots might be expected to have a more favorable effect. The important aerodynamic characteristics with the 45° flap are summarized in Table III.

With the rear slot closed the flap becomes a conventional one with a chord 30 per cent of the wing chord. With all the slots closed, making a plain wing with a flap, a maximum lift coefficient of 1.95 was obtained at an angle of attack of 12°, as compared with 1.29 at 15° for the plain wing with flap neutral. With the rear slot closed, every combination of the three forward slots tested gave a maximum lift coefficient close to the value 2.20.

With only the rear slot open without the cover plate, the maximum lift coefficient was reduced from 1.95 with the slot closed to 1.77, while with the cover plate in place the maximum lift coefficient was increased slightly to 1.98. The lift curve for the latter case had two peaks—one at an angle of attack of 5° and a higher one at 12°.

A comparison of Figure 6 with Figure 8 shows that with the flap down the use of the improved rear slot increased the maximum lift coefficient in every case tested. The highest lift coefficient found was 2.60, which was obtained with the first and third slots open also. In this case the use of the improved rear slot raised the value from 2.21 to 2.60. An interesting fact is that with the flap down and the improved rear slot open, opening the slot just ahead of it gave greater improvement than opening either of the two forward slots. In fact, in every case with the third slot open and the improved rear slot in use, the maximum lift

[1] In practice it would be necessary to make this cover plate flexible or to support it on hinges, because of interference with the flap in the neutral position.

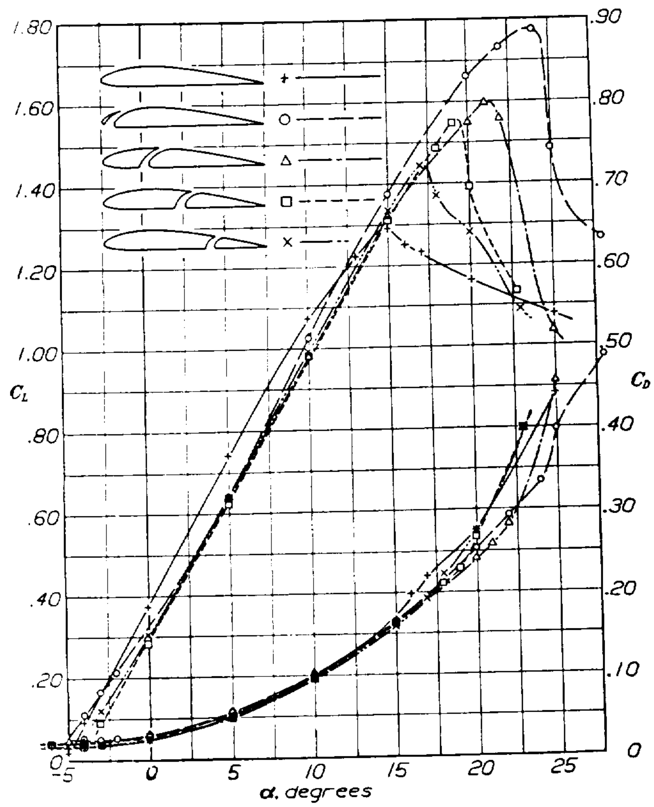


FIGURE 2.—Lift and drag coefficients for a wing with a single fixed slot in various fore-and-aft locations

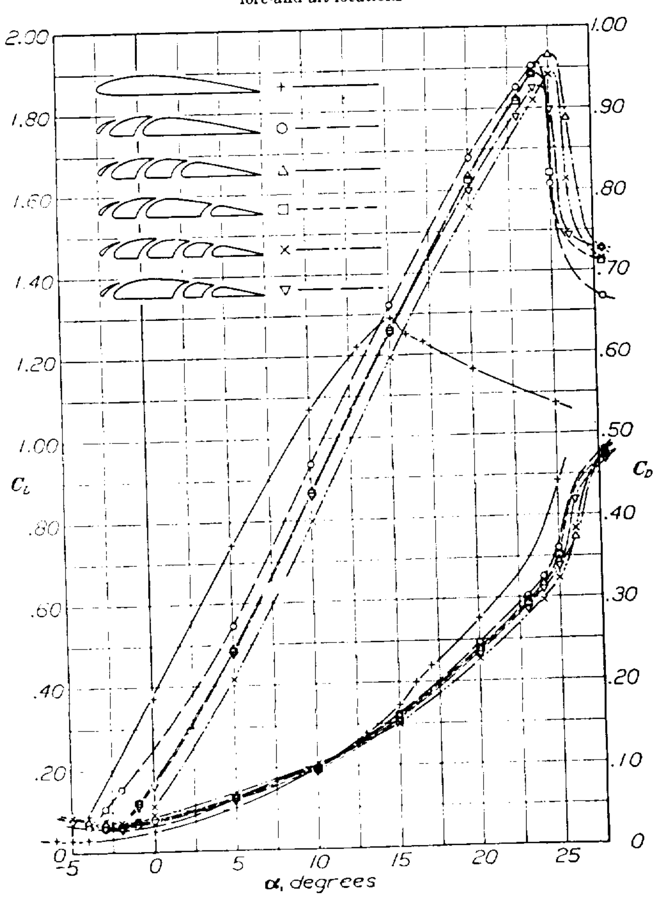


FIGURE 3.—Lift and drag coefficients for a wing with a leading-edge fixed slot and one other fixed slot in various locations

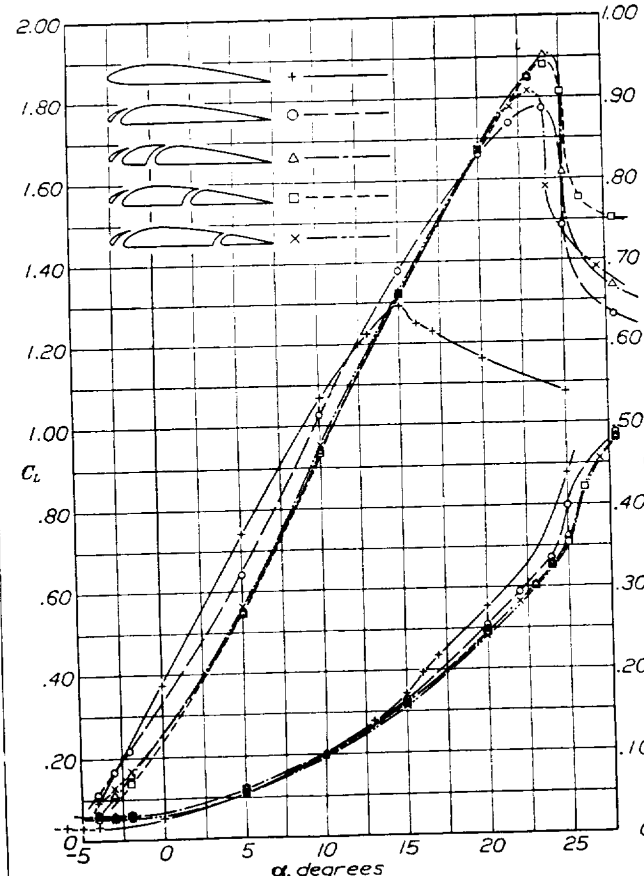


FIGURE 4.—Lift and drag coefficients for a wing with a leading-edge fixed slot and various slot combinations behind

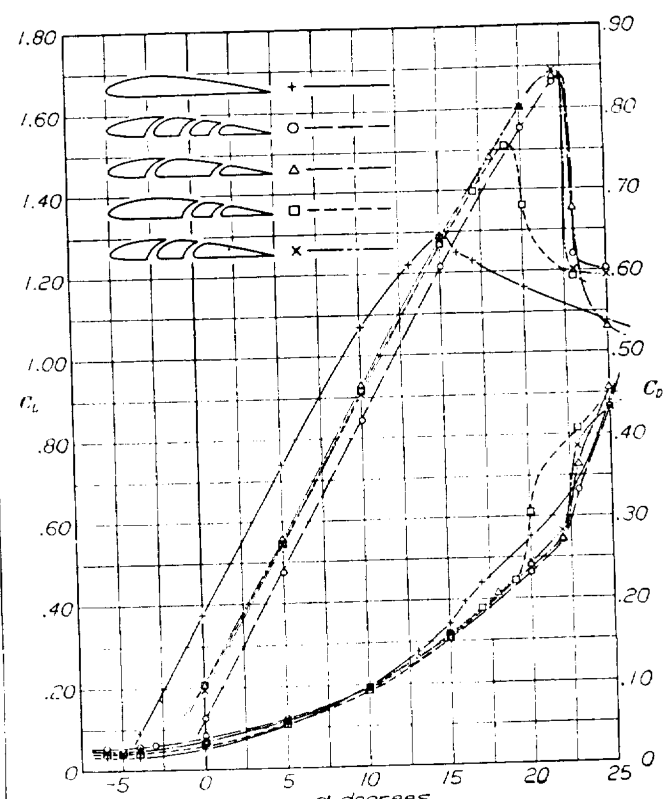


FIGURE 5.—Lift and drag coefficients for a wing with several center and rear fixed slots

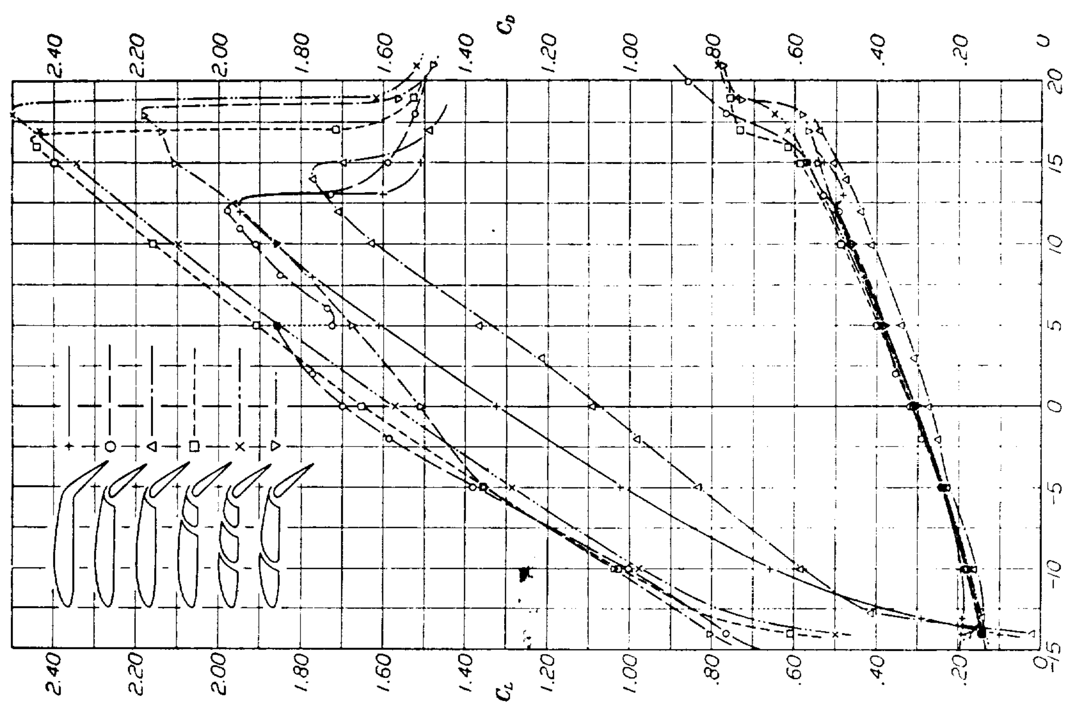


FIGURE 7.—Lift and drag coefficients for a wing with 45° flap and various center and rear fixed slots

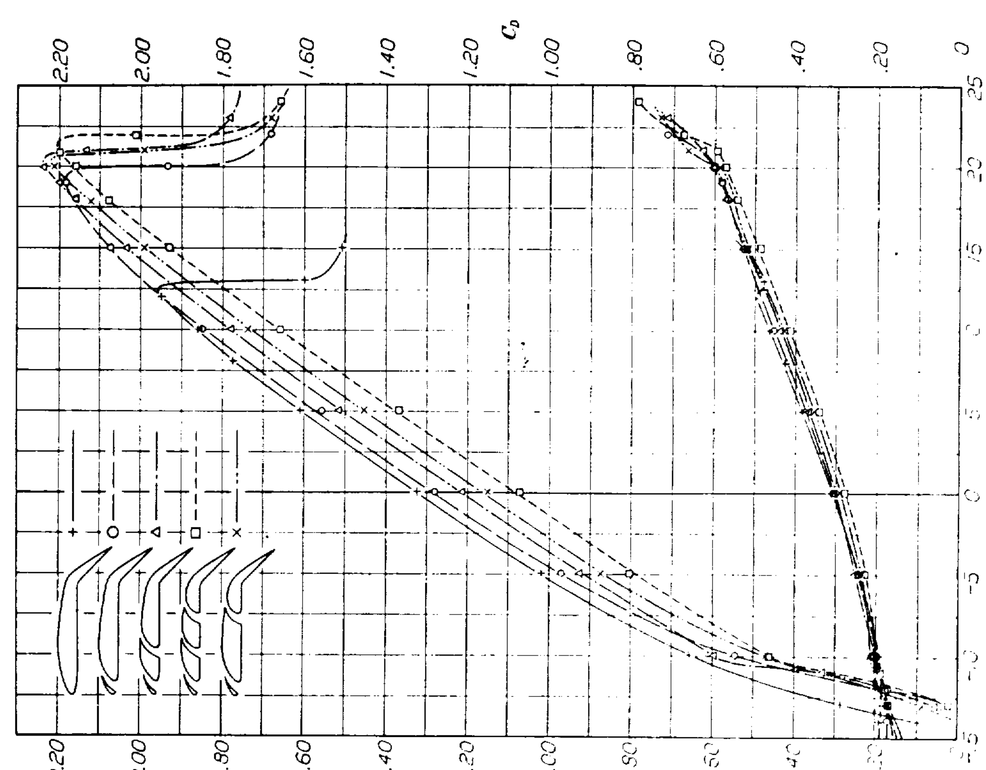


FIGURE 6.—Lift and drag coefficients for a wing with 45° flap and various leading edge and center fixed slots

coefficient was substantially higher than in any case with it closed.

In every case with the improved rear slot open and the third slot closed the lift curve had two peaks. Opening the third slot eliminated the first peak and produced a high value of the maximum lift coefficient. Thus, with the flap down the two rear slots are the important ones, which is in contrast to the case with the flap neutral, for which the front slot is the important one. The highest value of the maximum lift coefficient was obtained, however, with the leadingedge slot open together with the two rear slots, the value in that case being 2.60.

In computing the speed-range ratio $C_{L max}/C_{D min}$ for the cases with the flap deflected, the maximum lift coefficient was taken with the flap down and the minimum drag coefficient was taken with the flap neutral. The highest ratio was obtained by the plain unslotted airfoil, the value being increased from 85.0 for the plain Clark Y to 128.2. The speed-range ratio for the combination giving the highest maximum lift coefficient was only 87.3. The optimum combination, considering both the maximum lift coefficient and the speed-range ratio, is probably the one with only the two rearmost slots open. For this combination the maximum lift coefficient was 2.44 and the speed-range ratio was 117.5.

Application of optimum combination with flap.—On the basis of the coefficients obtained from these wind-tunnel tests, the effect of equipping an ordinary airplane with the optimum combination (the third slot and the improved slotted flap) has been calculated. If the wing area is kept the same, the landing speed should be reduced about 25 per cent and the maximum speed about 3 per cent. If the wing area is reduced 25 per cent the high speed should remain approximately the same and the minimum speed should be reduced about 15 per cent. With a 50 per cent reduction in the wing area the landing speed should remain about the same and the maximum speed should be increased in the neighborhood of 3 per cent. The structure of the wing could be in accordance with customary practice, the rear spar being located just back of the third slot.

CONCLUSIONS

1. Adding more than a single leading-edge slot to the Clark Y airfoil, with its relatively low camber and without a flap, probably would not improve the aerodynamic characteristics sufficiently to compensate for the increased structural difficulties.

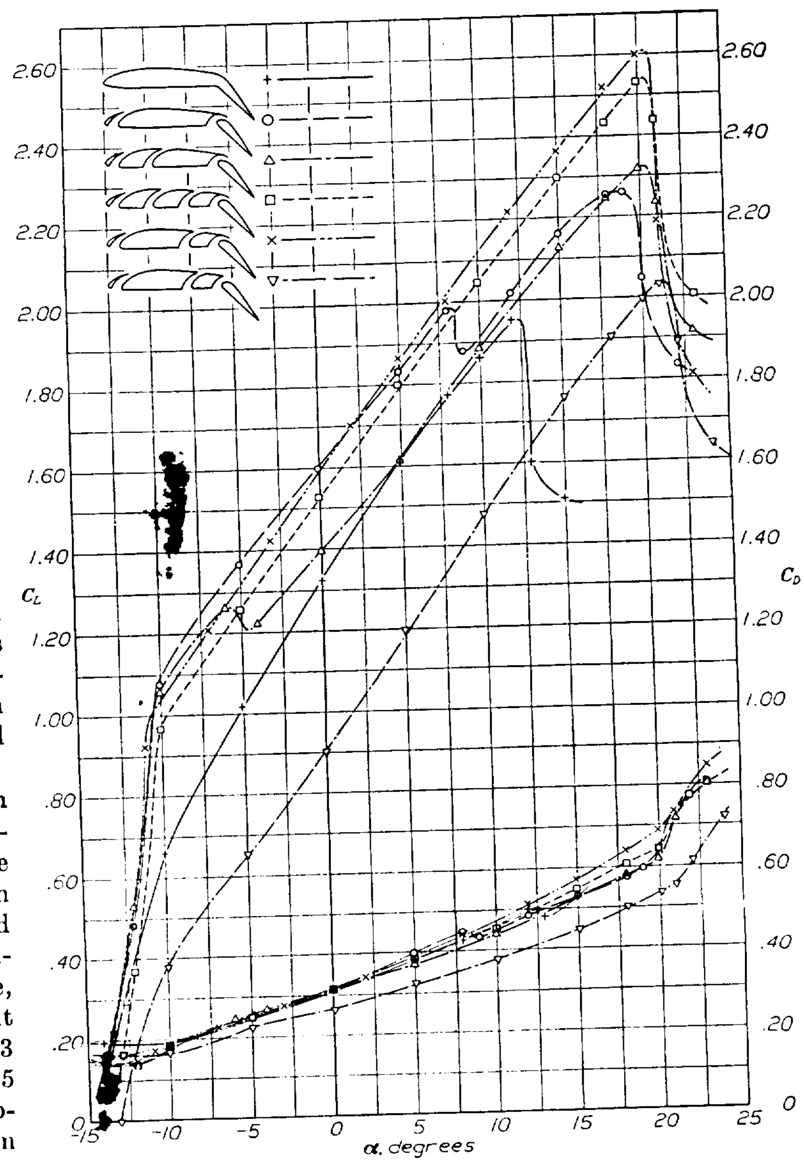


FIGURE 8.—Lift and drag coefficients for a wing with 45° slotted flap and various leading edge and center fixed slots

2. With the improved slotted flap down 45° and the best combination of fixed slots the maximum lift coefficient was increased from 1.29 with the plain Clark Y airfoil to 2.60.

3. The optimum combination tested with the flap down 45°, considering both the maximum lift coefficient and the speed-range ratio, was probably that with only the two rearmost slots open.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *April 6, 1932.*

REFERENCES

1. Lachmann, G.: Results of Experiments with Slotted Wings. T. M. No. 282, N. A. C. A., 1924.
2. Weick, Fred E., and Wenzinger, Carl J.: The Characteristics of a Clark Y Wing Model Equipped with Several Forms of Low-Drag Fixed Slots. T. R. No. 407, N. A. C. A., 1931.
3. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. T. R. No. 387, N. A. C. A., 1931.
4. Weick, Fred E., and Wenzinger, Carl J.: Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. I—Ordinary Ailerons on Rectangular Wings. T. R. No. 419, N. A. C. A., 1932.
5. Wenzinger, Carl J., and Shortal, Joseph A.: The Aerodynamic Characteristics of a Slotted Clark Y Wing as Affected by the Auxiliary Airfoil Position. T. R. No. 400, N. A. C. A., 1931.

TABLE I

ORDINATES FOR CLARK Y AIRFOIL

[All values in per cent airfoil chord]

Station	Ordinates	
	Upper	Lower
0	3.50	3.50
1.25	5.45	1.93
2.50	6.50	1.47
5.00	7.90	.93
7.50	8.85	.63
10.00	9.60	.42
15.00	10.69	.15
20.00	11.36	.03
30.00	11.70	0
40.00	11.40	0
50.00	10.52	0
60.00	9.15	0
70.00	7.35	0
80.00	5.22	0
90.00	2.80	0
95.00	1.49	0
100.00	.12	0

Leading edge radius = 1.50

TABLE II

AERODYNAMIC CHARACTERISTICS OF A CLARK Y WING WITH MULTIPLE FIXED SLOTS

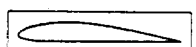
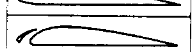
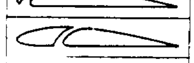
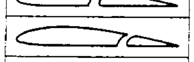
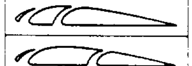
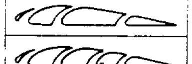
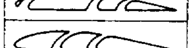
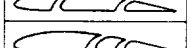
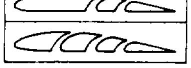
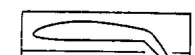
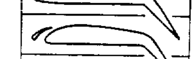
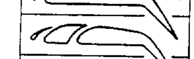
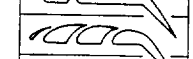
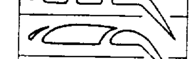
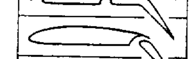
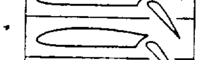
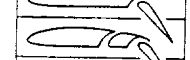
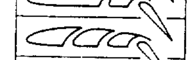
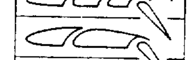
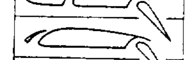
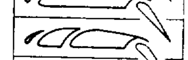
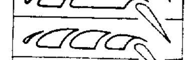
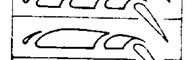
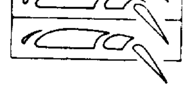
Slot combination	$C_{L_{max}}$	$C_{D_{min}}$	$\frac{C_{L_{max}}}{C_{D_{min}}}$	$\alpha_{C_{L_{max}}}$
	1.291	0.0152	85.0	15°
	1.772	.0240	73.8	24
	1.596	.0199	80.3	21
	1.548	.0186	82.3	19
	1.440	.0164	87.8	17
	1.902	.0278	68.3	24
	1.881	.0270	69.7	24
	1.813	.0243	74.6	23
	1.930	.0340	56.8	25
	1.885	.0319	59.2	24
	1.885	.0363	51.9	25
	1.850	.0298	62.1	24
	1.692	.0228	74.2	22
	1.672	.0214	78.2	22
	1.510	.0208	72.6	19
	1.662	.0258	64.4	22

TABLE III

AERODYNAMIC CHARACTERISTICS OF A CLARK Y WING WITH MULTIPLE FIXED SLOTS AND A SLOTTED FLAP DOWN 45°

Slot combination	$C_{L_{max}}$	$C_{D_{min}}$ [1]	$\frac{C_{L_{max}}}{C_{D_{min}}}$	$\alpha_{C_{L_{max}}}$
	1.950	0.0152	128.2	12°
	2.182	.0240	91.0	19
	2.235	.0278	80.3	20
	2.200	.0340	64.7	21
	2.210	.0270	81.8	20
	1.980	.0164	120.5	12
	1.770	.0164	108.0	14
	2.442	.0208	117.5	16
	2.500	.0258	96.8	18
	2.185	.0214	102.0	18
	2.261	.0243	93.2	19
	2.320	.0319	72.7	20
	2.535	.0363	69.8	20
	2.600	.0298	87.3	20
	2.035	.0298	68.3	21

[1] $C_{D_{min}}$ with flap neutral.

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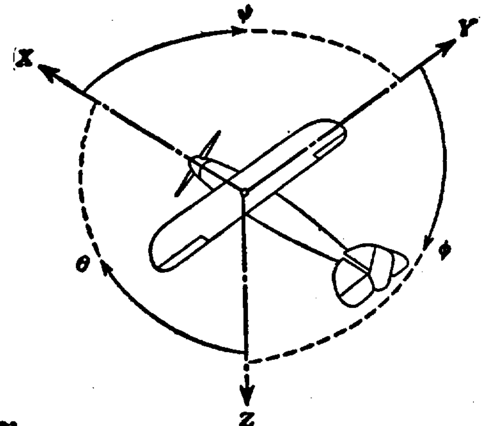

Positive directions of axes an[illegible]d moments) are shown by arrows

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

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qcS} \qquad C_n=\frac{N}{qbS}$$

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 $=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

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.