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WIND-TUNNEL TESTS OF A WING WITH A TRAILING-EDGE AUXILIARY AIRFOIL USED AS A FLAP

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SUMMARY

This report gives the characteristics of a wing with an auxiliary airfoil mounted near its trailing edge and used as a flap. The tests were made with a 10 by 60 inch Clark Y main airfoil and an N.A.C.A. 0012 flap having a chord equal to 15 percent of the main wing chord. The axis of the flap in all cases was on the flap chord and 20 percent back from its leading edge.

The optimum location of the flap axis relative to the main wing for maximum lift was found to be 1.25 percent of the main wing chord behind the trailing edge and 2.5 percent below the chord. In this position $C_{L_{max}}$ was increased from 1.250 (for the plain wing) to 1.810 at 45° deflection of the flap and $C_{D_{min}}$ was decreased from 0.0155 to 0.0146 at -5° deflection, the coefficient in each case being based on the sum of the flap and wing areas. No serious adverse change in lateral stability was found to result from the use of the flap in the optimum position.

INTRODUCTION

In most of the cases where flaps are employed to increase the maximum lift of a wing they are so constructed as to retract into or become a part of the main wing when in their natural or low-drag attitude. A less common type consists of an auxiliary airfoil which remains external to the main wing at all times. This latter type of flap has been used on certain Junkers airplanes in Germany and tests have been made in this country (reference 1) on a somewhat similar installation known as the Wragg compound wing.

The present report gives the results of tests made by the N.A.C.A. on a Clark Y wing with an auxiliary airfoil, 15 percent of the wing chord wide, mounted in several positions near the trailing edge. The data were obtained in the course of a comprehensive investigation of auxiliary airfoils for use as ailerons and for this reason the information relative to their use as a high-lift device is not complete at all test positions. The scope of the tests, however, included the determination of the maximum lift and minimum drag obtainable and the best value of the climb criterion (L/D at $C_L = 0.7$) at nearly all the positions tested. In addition, more detailed lift, drag, center-of-pressure, and lateral-stability data were obtained with the flap in the most favorable location. The range of locations of the flap axis was from 70 to 110 percent of the wing chord and from 0 to 20 percent below the wing chord. This range includes the flap positions used by both Junkers and Wragg.

APPARATUS

Models.- The main wing was a laminated mahogany Clark Y airfoil having a 10-inch chord and a 60-inch span. The flap had an N.A.C.A. 0012 profile (see table I for ordinates), was made of duralumin, and had a 1.5-inch chord and a span equal to that of the main wing. It was attached to the main wing by seven 1/32-inch sheet-steel brackets. Each bracket carried a hinge pin fitted in a socket located at the 20-percent-chord point of the flap. The angle of the flap to the main wing was set by means of quadrants fixed rigidly in the flap and so arranged that they could be screwed to four of the brackets. The range of deflection available at each location of the flap axis (except where the flap came in contact with the lower surface of the wing) was from the trailing edge up 75° to the trailing edge down 50°, in 5° increments. Figure 1 shows the wing model with the flap mounted in the optimum position.

Wind tunnel.- All the present tests were made in the N.A.C.A. 7 by 10 foot open-jet wind tunnel. In this tunnel the model is supported in such a manner that the forces and moments about the quarter-chord point of the mid section of the model are measured directly in coefficient form. For autorotation tests, the standard force-test tripod is replaced by a special mounting that permits the model to rotate about the longitudinal wind axis passing through the mid-span quarter-chord point. This apparatus is mounted on the balance, and the rolling-moment coefficient can be read directly during the forced-rotation tests. A complete description of the tunnel and its equipment is given in reference 2.

TESTS

The tests were conducted in accordance with the standard procedure, and at the usual dynamic pressure and Reynolds Number employed in the 7 by 10 foot tunnel. The dynamic pressure was 16.37 pounds per square foot, corresponding to an air speed of 80 miles per hour at standard density, and the Reynolds Number was 609,000, based on the chord of the main wing section.

With a few exceptions, short force tests using several flap deflections were conducted at each location of the flap to determine the maximum attainable lift, the minimum drag, and the best value of the climb criterion. At the most favorable location of the flap for maximum lift found by these preliminary tests, the following tests were conducted with the flap in both the high-lift and the low-drag attitudes: 6-component force tests at 0° and 20° yaw; free autorotation tests to determine the angle of attack above which autorotation is self-starting; and forced autorotation tests at 0° and 20° yaw, in which the rolling moment was measured while the wing was rolling at a velocity equal to the maximum likely to be encountered in controlled flight in very gusty air.

The accuracy of the present tests is considered satisfactory except in the range just above the stall, where values of the coefficients are erratic and often poorly defined.

RESULTS

The results of this investigation are presented in the form of contour charts (figs. 2 to 5) showing the effect of the flap-axis location on:

$C_{L_{max}}$ (flap in best attitude for high lift)

$C_{D_{min}}$ (flap in best attitude for low drag)

$\frac{C_{L_{max}}}{C_{D_{min}}}$ (flap in best attitudes for high lift and low drag)

L/D at $C_L = 0.7$ (flap in best attitude for rate of climb)

In addition, lift, drag, and center-of-pressure curves are given in figure 6 for the wing with the flap in the optimum location for $C_{L_{max}}$. Table II presents in condensed form the salient characteristics for each position of the flap axis tested.

The coefficients as plotted and as given in table II may be defined as follows:

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

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

$$C_\lambda = \frac{\lambda}{qbS}$$

where q is the dynamic pressure, S is the total area of wing-plus-flap, b is the wing span, and λ is the rolling moment measured while the wing is rolling. The coefficient C_λ is used as a measure of the degree of lateral stability or instability of a wing under various conditions. In the present case, it is used to indicate the rolling moments developed when a wing is subjected to a rolling velocity equal to the maximum likely to be encountered in controlled flight in very gusty air. This rolling velocity may be expressed in terms of the wing span as:

$$\frac{p'b}{2V} = 0.05$$

where V is the air speed at the center of the wing and p' is the angular velocity in roll about the wind axis.

DISCUSSION

Maximum lift.- The value of the maximum lift coefficient of a wing system may be used as a criterion of the wing area required for a desired landing speed or, conversely, for the landing speed obtained with a given wing area. With the present wing system, consisting of a main airfoil and an auxiliary airfoil used as a flap, a maximum lift coefficient equal to or better than that of a plain wing was obtained with the flap axis located almost anywhere within the limits of the area explored. (See fig. 2.) Forward of about 85 percent of the wing chord the flap reduces the value of $C_{L_{max}}$ below that obtainable with the wing alone. This reduction is apparent until the smaller wing is at least 0.2 chord length below the main wing.

An important increase in $C_{L_{max}}$ is obtained only when the flap axis is within a very limited area just back of and below the trailing edge of the wing. The optimum axis position for a 15-percent-chord flap hinged about a point 0.2 of its width back from its leading edge was 1-1/4 percent chord behind the trailing edge and 2-1/2 percent chord below the chord of the main wing. In this position a maximum lift coefficient of 1.810, based on the whole wing area, or 2.080 based on the main wing area, was obtained with the flap 45° down.

Minimum drag.- The minimum drag coefficient of a wing may be used as a rough criterion of high speed when comparing similar airplanes equipped with wings of equal area. For the plain wing (flap removed) used in these tests the minimum drag coefficient was 0.0155. Figure 3 gives contours of the values of $C_{D_{min}}$ with the flap attached. The fact that certain values of $C_{D_{min}}$ fall below that for the wing alone is due, in varying degrees, to three factors: (1) The minimum drag coefficient of the flap (based on its own area) is less than that of the wing; (2) the flap in some positions is operating in air that moves at a considerably reduced velocity relative to the undisturbed air stream; and (3) a mutual interference effect exists which reduces the value of $C_{D_{min}}$ on the main wing. The minimum drag coefficient of the flap (N.A.C.A. 0012 profile) may be assumed to be about 0.0135. This value is obtained from data given in references 3 and 4, weighted to compensate for the differences in the characteristics of the variable-density wind tunnel and the 7 by 10 foot atmospheric wind tunnel. The reduction in dynamic pressure in a limited area directly below the trailing edge of the main wing has been shown to be in the order of 30 percent (from unpublished data obtained in the

N.A.C.A. full-scale wind tunnel). If the above value for $C_{D_{min}}$ of the flap is assumed to be obtainable in the region of the least dynamic pressure, $C_{D_{min}}$ for the wing-plus-flap becomes 0.0147. Examination of figure 3 and table II shows that noticeably lower values of $C_{D_{min}}$ were obtained at several axis locations, in spite of the fact that the drag of the fixtures supporting the flap is included in all cases. The maximum degree of favorable interference occurred at position F, where a minimum drag coefficient of 0.0141 was obtained. At position C, which was shown to be the optimum with respect to maximum lift, $C_{D_{min}}$ = 0.0146. The difference between these two values of $C_{D_{min}}$ may be taken as just noticeable when it is considered that the probable accuracy of the determination of $C_{D_{min}}$ is about ±0.0002.

Where the same value of $C_{D_{min}}$ for the flap is assumed as in the previous case, but with a location sufficiently removed from the wing to neglect any reduction in velocity or mutual interference effect, the minimum drag coefficient for the system becomes 0.0152. This result shows that a net unfavorable interference occurs with flap locations forward of about the 80-percent-chord point; it also throws some doubt on the accuracy of the $C_{D_{min}}$ value given for position M.

Speed range.- The ratio $\frac{C_{L_{max}}}{C_{D_{min}}}$ is a convenient figure of merit for comparing the effectiveness of different wings in producing a large speed range. Contours of this ratio against axis location are given in figure 4. Owing to the rather small percentage variation in $C_{D_{min}}$, the contours for the speed-range criterion follow closely those shown in figure 2 for $C_{L_{max}}$. The maximum value of the ratio occurs at position F, where a ratio 56 percent greater than that for the plain wing is obtained.

This figure may be compared to that obtained for a Fowler flap reported in reference 5. The Fowler flap had a chord length of 40 percent of the main wing chord and retracted completely within the main wing when in the low-drag attitude. This arrangement gave a ratio of $\frac{C_{L_{max}}}{C_{D_{min}}} = 198$, or 146 percent greater than that for the plain wing.

Comparison may also be made between the present flap arrangement and the Wragg flap as reported in reference 1. In that case the flap was approximately 32 percent of the main wing chord but in other respects the models were similar. The optimum angle for maximum lift was found to be about half of that determined in the present tests, but the nose position of the flap relative to the trailing edge of the main wing and the values of maximum lift coefficients obtained check reasonably well.

Rate of climb.- In order to establish a suitable criterion for the effect of the wing characteristics on the rate of climb of an airplane, the performance curves for a number of types and sizes of airplanes were calculated, and the relation of the maximum rate of climb to the lift and drag curves studied. This investigation showed that the L/D at $C_L = 0.7$ gave a consistently reliable figure of merit for this purpose. This criterion is plotted in the form of contours of the axis location of the flap in figure 5. Highest values of the criterion are about 8 percent less than those for the plain wing; they occur when the flap axis is slightly aft of the optimum location for $C_{L_{max}}$. With the flap in the optimum position for $C_{L_{max}}$ (C) the drop in the rate-of-climb criterion amounts to 10 percent of that for the plain wing.

Optimum position.- The data upon which to base the choice of an optimum position for a 15-percent-chord external flap is not entirely complete without a knowledge of the drag characteristics in the vicinity of maximum lift. However, reference 5 indicates that the drag near $C_{L_{max}}$ does not vary greatly with location of the flap. Consequently, the best position may be taken as that giving the highest lift (position C). Minimum drag at this location is slightly greater than that obtained farther below the wing at position F, but the difference seems unimportant when the accuracy of the determination of $C_{D_{min}}$ is considered together with the very slight difference in the ratio $\frac{C_{L_{max}}}{C_{D_{min}}}$ for the two positions. Inasmuch as the rate-of-climb criterion is the same for the two locations, position C was chosen as the most favorable from all considerations and lateral-stability tests were run with the flap located here only.

Lateral stability.- Lateral stability was measured by determining the initial angle at which autorotation was self-starting under various conditions of roll and yaw, as well as the maximum unstable torques developed when the wing was forced to rotate at a given rate. Such tests were made on the wing with the flap mounted in the optimum position only and set both for high speed and for landing. The results of these tests, presented in table II, show negligible changes in C_λ as compared to the plain wing. Initial angles of instability are approximately the same as those for the plain wing when the flap is in the high-speed attitude. With the flap down, however, and the wing yawed 20°, the wing shows a distinct tendency, at all normal angles of attack, to increase an initial rate of rotation in roll when the roll is in the same direction as the yaw. The significance of this tendency in relation to the lateral-stability characteristics of a complete airplane is largely dependent upon the fin and rudder design, dihedral, and other structural features of the airplane. In general, however, the tendency corresponds to that produced by an increase in dihedral, a change that increases the spiral stability of an airplane but makes it more difficult to maintain a yawed attitude such as might be employed in a cross-wind landing.

CONCLUSIONS

The following conclusions may be drawn concerning the use of a 15-percent-chord auxiliary airfoil flap of symmetrical profile with a straight Clark Y wing. In every case where the term "optimum location" is used reference is made to the position at which the highest value of $C_{L_{max}}$ was obtained.

1. The optimum location of the 20-percent-chord point of the flap (hinge axis) is quite critical. It lies 1-1/4 percent of the main wing chord behind the trailing edge and 2-1/2 percent below the chord.

2. With the flap in the optimum position and deflected 45° down, $C_{L_{max}} = 1.810$ based on the total wing area, or 2.080 based on the area of the main wing. This value represents an increase of 45 percent over that obtained with the plain wing.

3. Favorable interference exists between the wing and the flap (in the high-speed attitude) at all practical locations of the flap axis behind 90 percent of the main wing chord and within 20 percent of the chord line.

4. The flap decreases the rate-of-climb criterion by 10 percent in the optimum location.

5. Lateral stability is unaffected by the flap when mounted in the high-speed attitude at the optimum position. With the flap in the landing attitude and the wing subjected to combined 20° yaw and a rolling velocity such that $\frac{p'b}{2V} = 0.05$, the wing shows an increased tendency toward spiral stability.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 2, 1934.

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TABLE I. AIRFOIL ORDINATES

All Values in Percent Airfoil Chord

Clark Y		
Station	Upper surface	Lower surface
0	3.50	3.50
1.25	5.45	1.93
2.5	6.50	1.47
5	7.90	.93
7.5	8.85	.63
10	9.60	.42
15	10.69	.15
20	11.36	.03
30	11.70	0
40	11.40	0
50	10.52	0
60	9.15	0
70	7.35	0
80	5.22	0
90	2.80	0
95	1.49	0
100	.12	0

Leading-edge radius = 1.50

N.A.C.A. 0012		
Station	Upper surface	Lower surface
0	0	0
1.25	1.89	-1.89
2.5	2.62	-2.62
5	3.56	-3.56
7.5	4.20	-4.20
10	4.68	-4.68
15	5.35	-5.35
20	5.74	-5.74
30	6.00	-6.00
40	5.80	-5.80
50	5.29	-5.29
60	4.56	-4.56
70	3.66	-3.66
80	2.62	-2.62
90	1.45	-1.45
95	.81	- .81
100	.13	- .13

Leading-edge radius = 1.58

TABLE II. CHARACTERISTICS OF A WING WITH A SYMMETRICAL AUXILIARY AIRFOIL USED AS A FLAP

Main wing: Clark Y, 10-inch chord. Auxiliary airfoil: N.A.C.A. 0012, 1.5-inch chord

R.N. = 609,000. Velocity = 80 m.p.h. All coefficients based on area of wing plus flap

Position	Axis location: Percentage main wing chord from L.E.	Axis location: Percentage main wing chord from chord	$C_{L_{max}}$	$C_{D_{min}}$	$\frac{C_{L_{max}}}{C_{D_{min}}}$	L/D at C_L=0.7	Flap setting relative to main wing chord: $C_{L_{max}}$	Flap setting relative to main wing chord: $C_{D_{min}}$	Flap setting relative to main wing chord: Best climb	α $C_{L_{max}}$	α $C_{D_{min}}$	α initial instability in roll	α initial instability in roll at $\frac{p'b}{2V}$ = 0.05: 0° yaw	α initial instability in roll at $\frac{p'b}{2V}$ = 0.05: -20° yaw	Maximum unstable C_λ: 0° yaw	Maximum unstable C_λ: -20° yaw
							deg.	deg.	deg.	deg.	deg.	deg.	deg.	deg.		
	Plain	wing	1.250	0.0155	80.6	15.9	–	–	–	18	-3	17	16	10	0.033	0.092
A	110	0	1.250	.0145	86.2	14.3	10	0	5	17	-3	–	–	–	–	–
B	100	-2.5	1.750	.0147	119.0	–	45	–	–	13	–	–	–	–	–	–
C	101.25	-2.5	1.810	.0146	124.0	14.3	45	-5	5	12	-1	Flap setting -5°: 18	16	12	.036	.081
D	102.5	-2.5	1.704	.0145	117.6	14.6	25	-5	5	13	-1	Flap setting 45°: 14	13	-7	.030	.104
E	101.25	-3.75	1.760	.0143	123.1	–	50	–	–	13	–	–	–	–	–	–
F	100	-5	1.778	.0141	126.1	14.3	50	0	10	14	-3	–	–	–	–	–
G	105	-5	1.542	.0143	107.9	14.6	50	0	10	14	-3	–	–	–	–	–
H	80	-10	1.250	.0154	81.2	14.0	50	0	0	–	-4	–	–	–	–	–
I	100	-10	1.450	.0143	101.4	14.1	50	0	10	–	-3	–	–	–	–	–
J	110	-10	1.440	.0142	101.4	14.4	40	0	5	17	-3	–	–	–	–	–
K	70	-20	1.200	.0155	77.4	14.0	–	0	0	–	-4	–	–	–	–	–
L	90	-20	1.280	.0149	85.8	14.3	–	0	0	–	-3	–	–	–	–	–
M	110	-20	1.280	.0141	90.8	14.1	–	0	0	–	-3	–	–	–	–	–

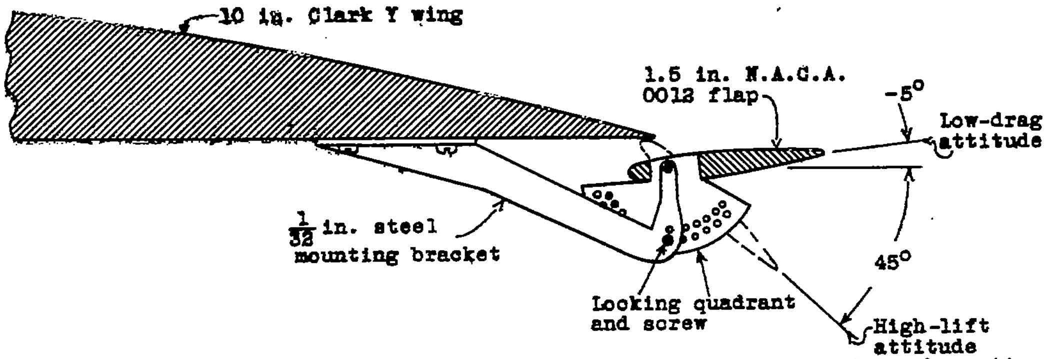

Figure 1.-Longitudinal cross section of wind-tunnel model. Flap mounted in the optimum position.

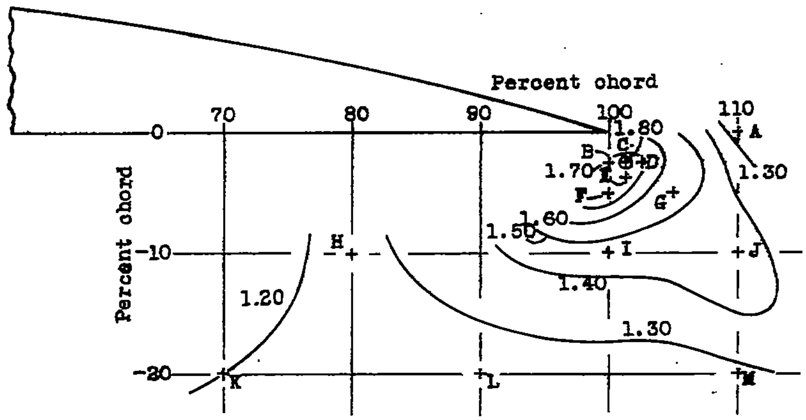

Figure 2.-Contours of $C_{L_{max}}$. Symmetrical, auxiliary airfoil used as a flap. Reference point and flap axis: 20 percent point of flap chord.

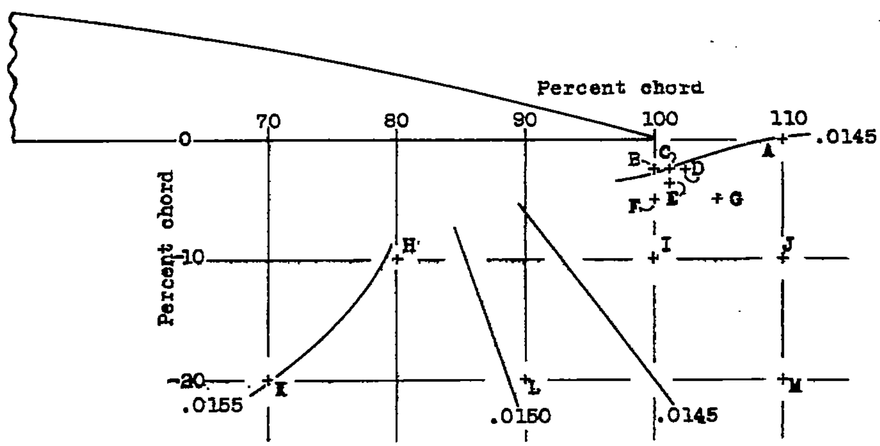

Figure 3.-Contours of $C_{D_{min}}$. Symmetrical, auxiliary airfoil used as a flap. Reference point and flap axis: 20 percent point of flap chord.

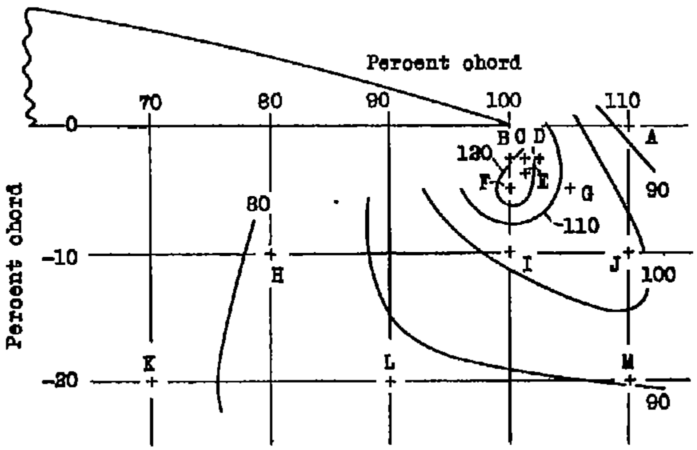

Figure 4.- Contours of the ratio $C_{L_{max}} / C_{D_{min}}$. Symmetrical, auxiliary airfoil used as a flap. Reference point and flap axis: 20 percent point of flap chord.

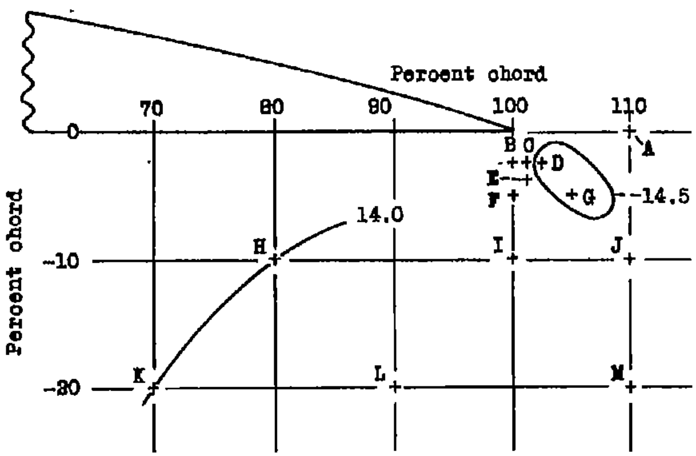

Figure 5.- Contours of L/D at C_L = 0.7. Symmetrical, auxiliary airfoil used as a flap. Reference point and flap axis: 20 percent point of flap chord.

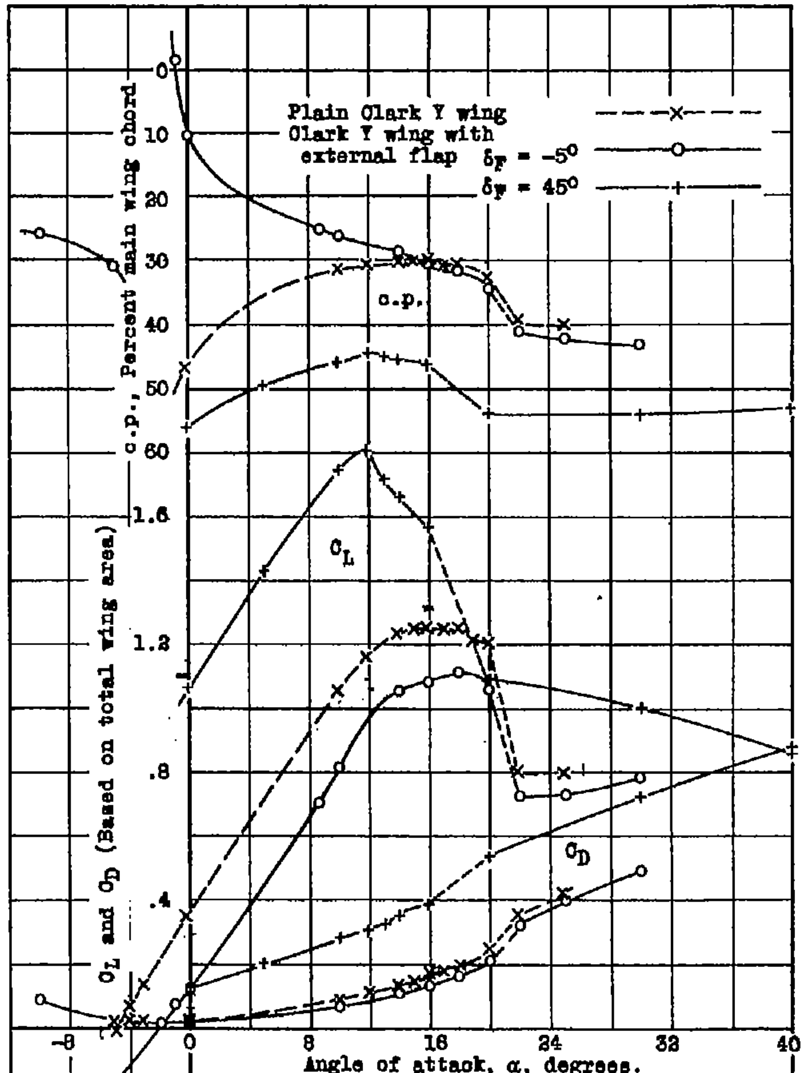

Figure 6.- Lift, drag, and center of pressure. Plain Clark Y wing and Clark Y wing with flap in optimum position (C).