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No. 714

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A SIMPLE METHOD FOR INCREASING THE LIFT OF AIRPLANE WINGS BY MEANS OF FLAPS*

By Eugen Gruschwitz and Oskar Schrenk

Aerodynamic considerations led us, not long ago, to investigate a device which seemed to promise a contribution to the problem of reducing the landing speed of an airplane. We have subsequently learned that similar devices had already been proposed and investigated by others, but it seems advisable, nevertheless, to report our results, if only to call attention to this hitherto hardly considered possibility and to present it for discussion. Our results are better than those hitherto obtained, and the line of reasoning on which our investigation was based, along with the physical explanation, also affords, under certain conditions, the opportunity for further improvement or for similar applications. The problem is to create, in landing, a region of turbulence on the lower side of the wing near the trailing edge by some obstacle to the air flow.

The devices tested by us consisted of flaps of varying chord and position (fig. 1), the chord s being equal to the distance of the pivot from the trailing edge. The three flaps tested had chords respectively equal to 5, 10 and 20 percent of the wing chord, the flap angle β being set at 30, 60, 90 and 120 degrees.

Figures 2 to 4 show the results of the tests in the large wind tunnel. The 5-percent flap (figs. 2a to 2c) increased the maximum c_a from about 1.25 to 1.73 with flap angles $\beta = 60$ and 90°. The 10-percent flap yielded $c_a = 2$ for $\beta = 60^\circ$; $c_a = 2.06$ for $\beta = 90^\circ$; and appreciably less for $\beta = 120^\circ$. At the same time the wing served as an air brake. The additional profile drag for $\beta = 90^\circ$ was about

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*"Ueber eine einfache Möglichkeit zur Auftriebserhöhung von Tragflügeln." Zeitschrift für Flugtechnik und Motorluftschiffahrt, vol. 23, no. 20, October 28, 1932, pp. 597-601. Abstract of lecture by Oskar Schrenk at the twenty-first annual meeting of the W.G.L. (Wissenschaftliche Gesellschaft für Luftfahrt), Berlin, 1932.

5 times and for $\beta = 60^\circ$ about 2.5 times the profile drag of the smooth wing. The 20-percent flap yielded $c_a = 2.18$ for $\beta = 90^\circ$ and $c_a = 2.15$ for $\beta = 60^\circ$. The single plotted point for $c_a = 2.22$ (fig. 2c) was obtained with the same arrangement, but with the addition of small terminal disks at both ends of the deflected flap, which created, fore and aft of the flap, pressure conditions less affected by the edge effects.

It was to be expected that the moment lines would be shifted greatly toward the right (figs. 3a to 3c). This displacement is not so detrimental, however, as would appear at first glance, because the flap was used only for high c_a values, at which the c.p. falls in the region occupied by it in normal flight. In designing an airplane, these conditions could also be influenced, within certain limits, by the choice of a basic profile with suitable location of the c_m line.

The maximum lifts of all the devices tested occur at about the same angle of attack as the maximum lift for $\beta = 0^\circ$ (figs. 4a to 4c). Hence the landing angle of attack with increased c_a remains within the normal limits. Moreover, flaps can be used on the inner side of the ailerons without causing any trouble with the angle of attack.

The reported c_a values were obtained with the wing raised, (i.e. with increased angle of attack) while it stood in the wind. Starting with the condition of detached flow, we investigated the behavior of the wing in two cases, namely, for $s/t = 0.05$ and 0.20 with the flap position $\beta = 90^\circ$ and found that the flow already adhered on the upper side of the wing at 0.5° below the value corresponding to the $c_{a\ max}$ of the raised wing.

The considerable lift increase was due in lesser degree to the dynamic effect on the lower side of the wing, but more to the conditions on the upper side, and indeed through two concurrent circumstances:

1. A negative pressure prevails in the turbulent retion behind the obstacle, which is simultaneously the terminal pressure at the trailing edge of the upper side. The pressure level of the whole upper side sinks simultaneously with the terminal pressure on the same side, just as reported by J. Ackeret years ago for wings with cutaway trailing edges (reference 1).

2. With the lowering of the terminal pressure, not only the whole pressure level is lowered, but the pressure increase, which the flow can withstand with respect to the boundary layer, also becomes steeper and, on the whole, greater. The following consideration led us to this conclusion and consequently to the investigation. The pressure increase which can be overcome in a retarded flow, depends on the processes in the boundary layer. This is determined by the velocity and pressure variation along the surface. In order to estimate the attainable pressure increase, it must be referred to a standard dynamic pressure. There is little sense in using the flight dynamic pressure remote from the wing, since the flow of the boundary layer is not affected by it. It would be better to choose, as the physically sensible reference pressure, the pressure at any point of the surface, e.g., that at the trailing edge of the wing. A rough approximation can then be made on the assumption that the ratio between the pressure increase and reference pressure has a constant value. If, for example, the pressure at the trailing edge is doubled by any device, the pressure increase itself, or, which amounts to the same thing, the dynamic pressure at every point of the wing is doubled. Any lowering of the static pressure at the trailing edge, as caused by the turbulent region, means, according to the law of Bernoulli, an increase of the same amount in the dynamic pressure.

This line of reasoning is justified by figure 5, in which two pressure distributions about wings (converted to unit dynamic pressure) are plotted, which were recently measured in connection with other pressure-distribution tests. The curve with hatched inclosure was obtained without, and the other with a deflected flap. In both cases the conditions are those occurring just before the separation of the flow. On the whole, they agree very well with the above-mentioned consideration, though the suction point at the leading edge is somewhat larger and the pressure in the middle of the wing is somewhat lower than was estimated.

A similar line of reasoning was employed by Professor Betz in 1922 for explaining the phenomena of slotted wings (reference 2). The leading-edge slat of a slotted-wing system is in the negative-pressure region at the leading edge of the main wing, so that the negative-pressure level of the leading-edge slat can be higher and the pressure rise steeper.

Our reasoning shows that the $c_{a\ max}$ values attainable by like devices are approximately proportional for different profile shapes to the $c_{a\ max}$ values of the basic profiles. This probably holds good also for the case when the $c_{a\ max}$ of the basic profile has already been raised artificially by other means. This proportionality makes the application of our principle, combined with slotted wings or the removal of the boundary layer by suction, seem very promising.

As already mentioned, we learned subsequently of several experiments with flaps which could be let down on the lower side of the wing. Two or three years ago experiments were tried in Japan with a flap which could be let down by a small angle (reference 3). The c_a values reached aproximatedly 1.8 Almost the same device was investigated in the Göttingen laboratory in 1923 for a private firm, it having been suggested by experiments with wings with cutaway trailing edges. The question was not investigated further at that time.

Moreover, Professor Betz, unbeknown to us, has suggested, in an article not yet published, another device for increasing the lift according to the same principle. This consisted in using the trailing edge of a wing attached to the main part as a rotatable body after the manner of an aileron and capable of being deflected downward by an angle of 90 degrees. For this device also, we recently made a few lift determinations with the aid of pressure-distribution measurements. Figure 6 shows the result, along with the results obtained by the same method with the smooth wing and with the ten-percent flap deflected downward. The two curves for the wings with cutaway trailing edges differ by the flap chord s. The lift values given here are all somewhat higher, as local values in a mean wing section, than the previously shown results corresponding to polar measurements. If one is interested more in the aerodynamic effect than in the practical application to flight, he can also refer the c_a values of the cutaway wings to the shortened chord instead of to the original chord and thus obtain the $c_{a\ max}$ values indicated by the dash lines in figure 6, the upper one of which is especially high, owing probably to the very great flap chord.

Lastly we tried a few check tests on negative-pressure development by obstacles with the following results.

1. The shape of the obstacle is not very important as regards the effect. The important thing is the development of a turbulent wake.

2. It is likewise unimportant for the negative-pressure development, as to whether there is an air space between the main wing and the obstacle.

3. The maximum negative pressures are not immediately behind the obstacle, but from one to two widths of the obstacle downstream. Hence one has a rather free hand in its application and can, for example, apply it at the rear spar and, in any case, forward of the aileron.

It is obvious to us that a series of technical and structural problems still requires elucidation. Among the most important are questions of stability and of the efficacy of the control surfaces. We considered it our task first to establish a few aerodynamic facts and we thought it worth while to report our results and call attention to these possibilities.

Translation by Dwight M. Miner,
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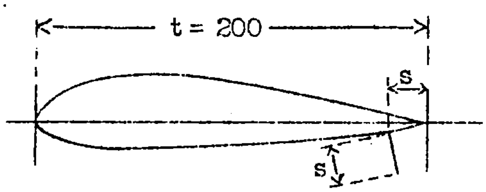


Figure 1.- Profile of wing tested with flap.

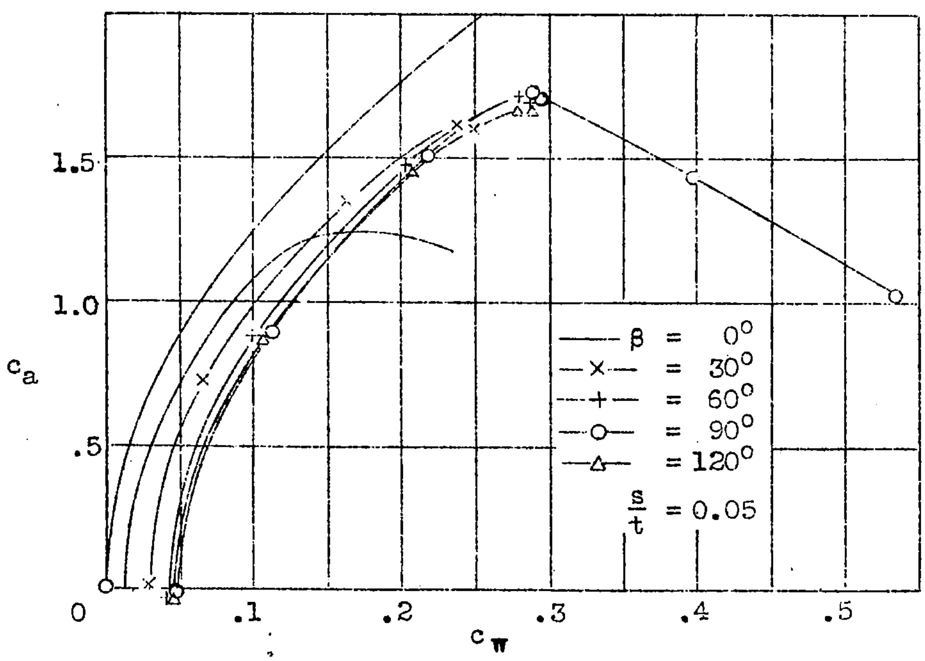


Figure 2a.- Polars of wing with flaps for various values of β. (β = angle between flap and surface of wing). Flap chord s = 0.05 t (t = wing chord)

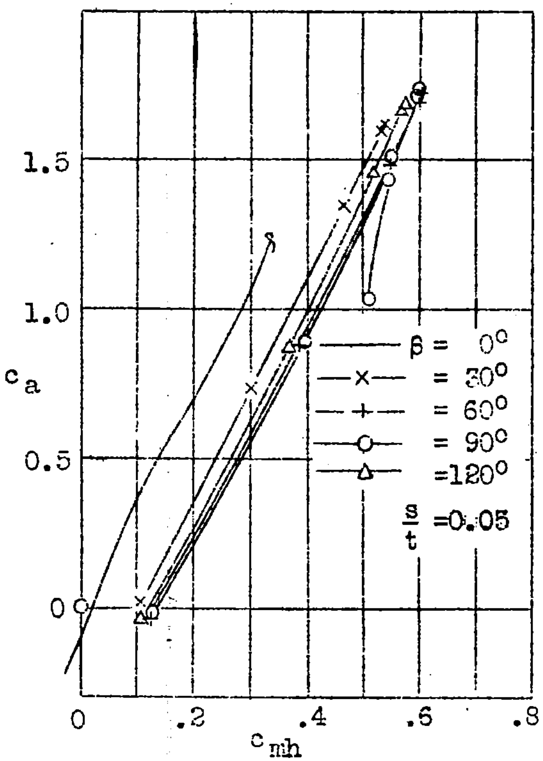


Figure 3a.- Moment curves of wing with flap. s = 0.05 t

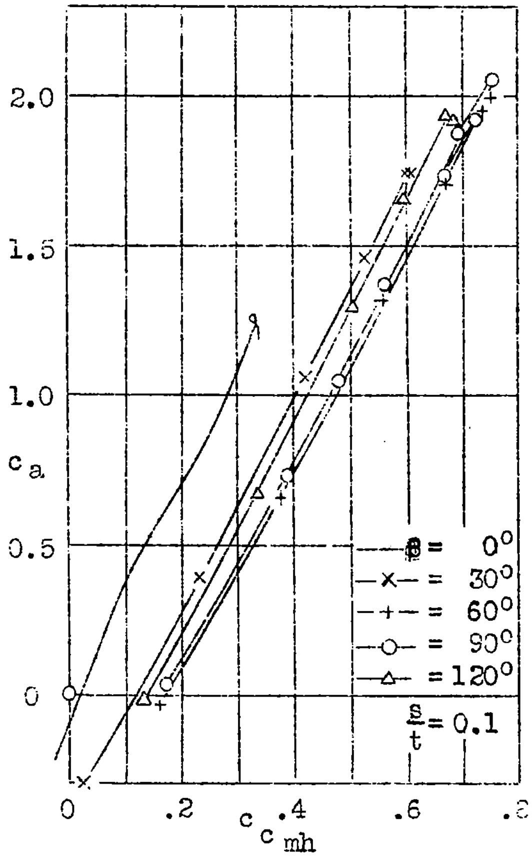


Figure 3b.- Moment curves of wing with flap. s = 0.1 t

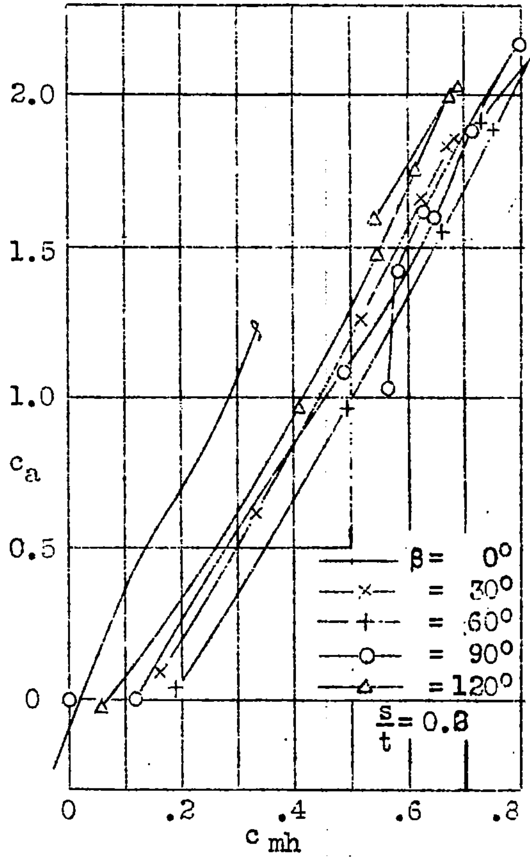


Figure 3c.- Moment curves of wing with flap. s = 0.2 t

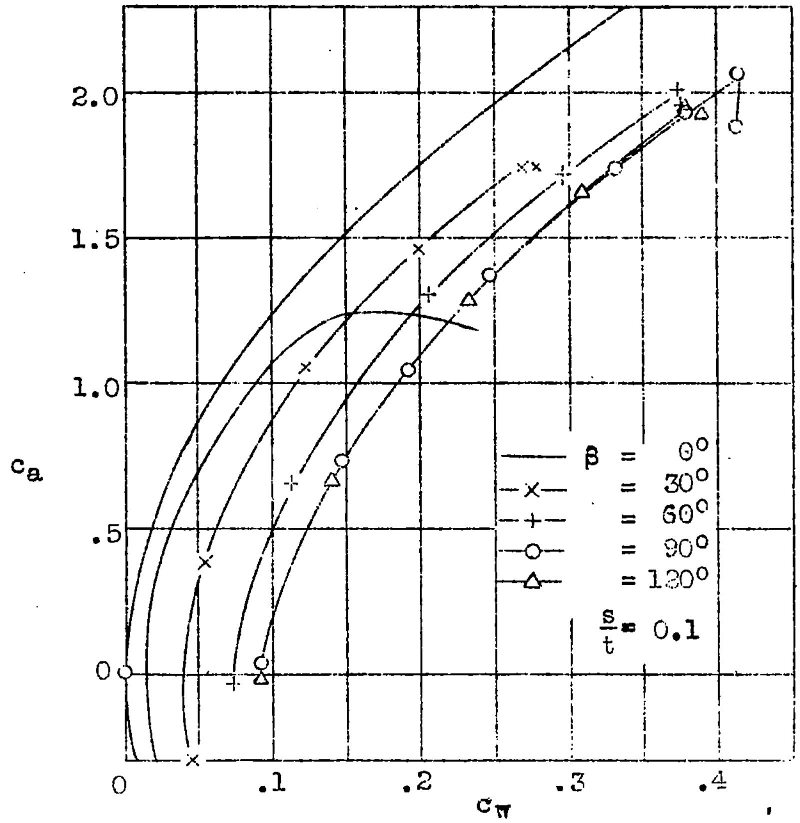
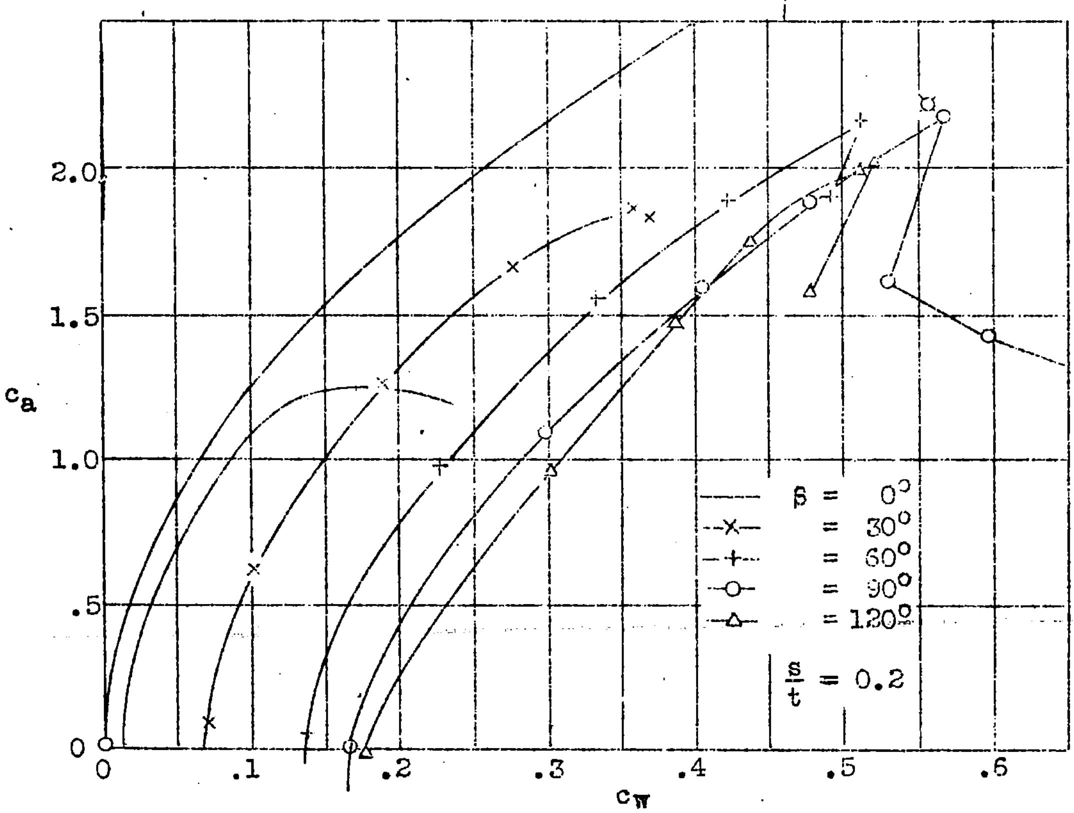


Figure 2b.- Polars of wing with flap. Flap chord s = 0.1 t

Figure 2c.- Polars of wing with flap. Flap chord s = 0.2 t



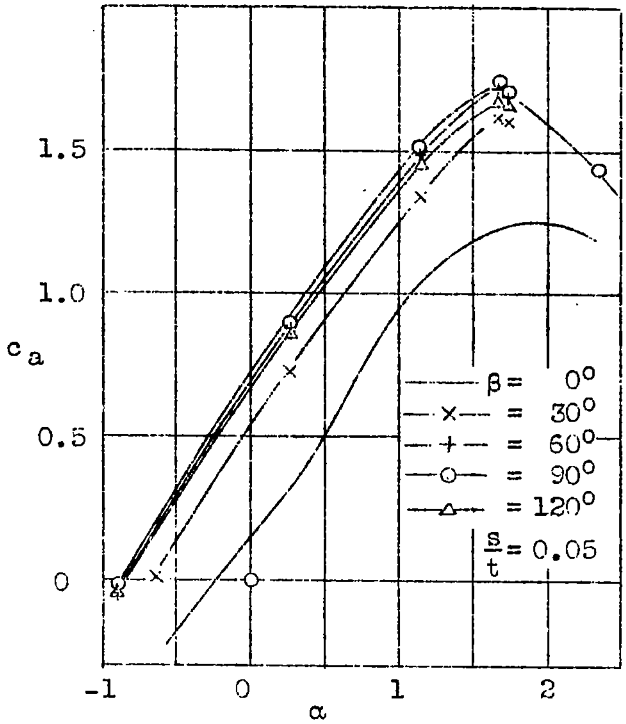


Figure 4a.- Lift coefficients of wing with flaps vs angle of attack α. s = 0.05 t

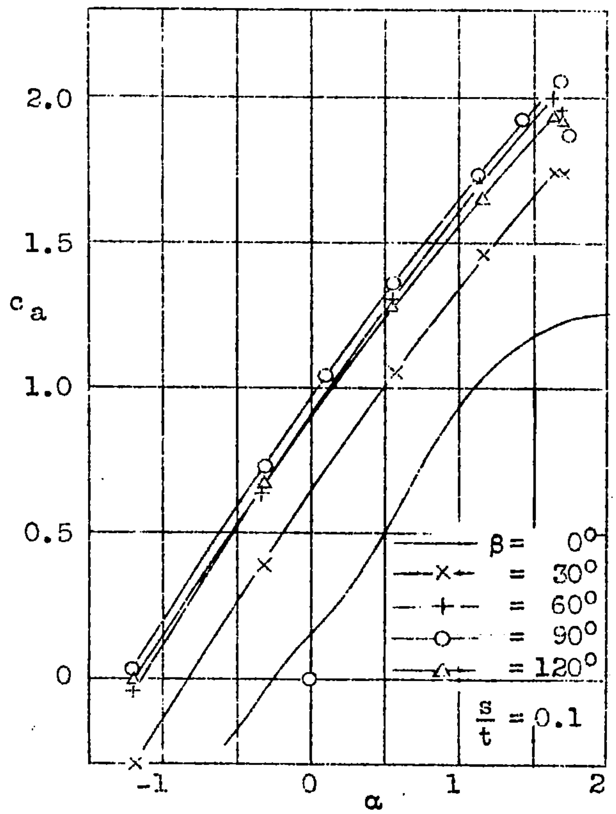


Figure 4b.- Lift coefficient of wing with flaps vs angle of attack α. s = 0.1 t

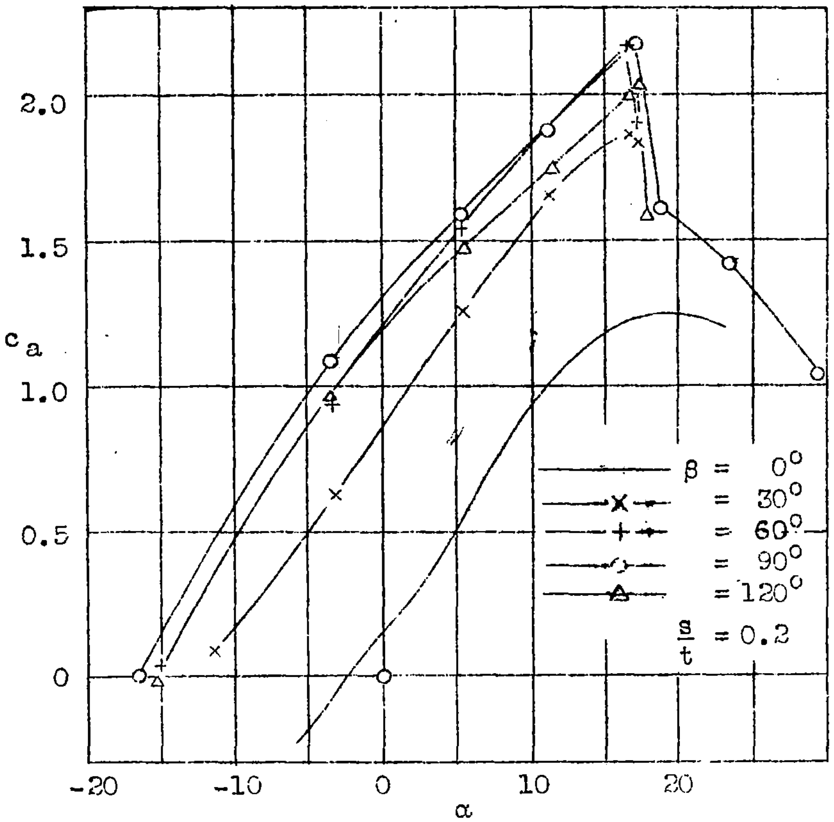


Figure 4c.- Lift coefficients of wing with flaps vs angle of attack α s = 0.2 t

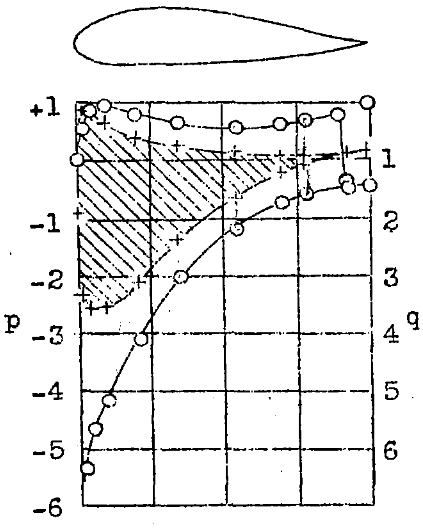
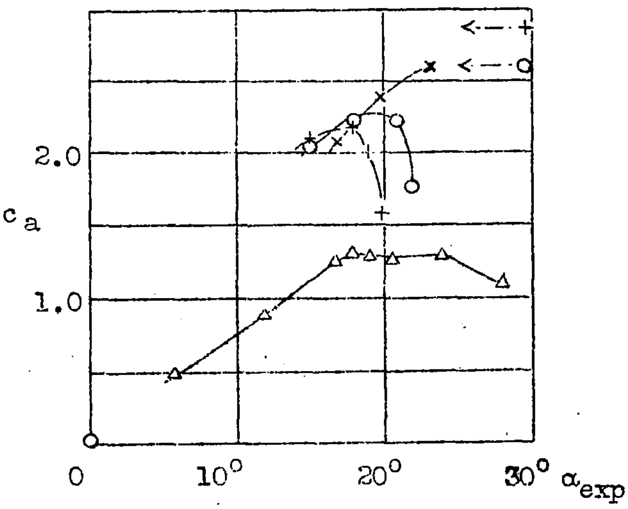


Figure 5.- Pressure distribution about smooth wing (hatched) and about wing with flap according to figure 1(circle).



○ s/t =.20 Cutaway wing
\+ s/t =.28 Cutaway wing
× s/t =.10 Flap deflected downward
△ = Smooth wing

Figure 6.- Lift values obtained from pressure-distribution measurement vs experimental angle of attack.