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BOUNDARY LAYER REMOVAL BY SUCTION

By O. Schrenk

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By O. Schrenk

INTRODUCTION

The removal by suction of the boundary layer as a means of preventing the break-down of flow is so universally known in its physical principle as to require no further discussion. On the other hand, it might be appropriate to call attention to a second physical phenomenon which is often coupled with the actual boundary layer removal by suction, but which is aerodynamically entirely unrelated to it. This is the so-called "sink effect" of the suction. In the sense of the potential theory a suction orifice is a sink. Upstream the sink effects a velocity increase, downstream a velocity decrease of the principal flow. Both die out with increasing distance from the sink, leaving a pressure variation as shown in figure 1. Before and behind the suction point the pressure rise, to be overcome by the flow, decreases, and a certain part of the total pressure rise disappears, in fact, completely. The sink effect of the suction is therefore a distortion of the pressure variation, which in turn affects the formation of the boundary layer again in a favorable sense. Naturally it plays no important part on the sink effect whether the sucked-out fluid is merely boundary layer material or not.

On the realization of the total effect the simple boundary-layer removal by suction and the sink effect may participate in very different measure from one case to the next. The entire problem has been explored thoroughly at Göttingen. These results have been recently augmented by studies carried out under the direction of Professor Ackeret at Zürich.

It should be stressed, however, that a theory of boundary layer removal by suction, which can be mathematically carried out in individual examples, would constitute

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*"Grenzschichtabsaugung." Luftwissen, vol. 7, no. 12, Dec. 1940, pp. 409-14.

a great relief and help for experimental labor. The number of variables in suction experiments is always very great and might be considerably reduced by appropriate calculations.

Of late the interest on suction has also tended toward the possibility of improving such flows at which no danger of separation exists, i.e., to reduce the friction drag from surfaces. Such a drag reduction is hoped for from the laminar friction layer achieved through suction. It is a theoretically possible, though not very promising, way of raising the performance with turbulent boundary layers even without preserving laminar flow, to speed up the frictionally retarded layer next to the wall enough so that it is at rest again relative to its surrounding. But, if it succeeds through suction to keep the friction layer laminar at the same time, it results in

1. A very material reduction of the air entrained by the friction, for which a re-acceleration comes into question;

2. A very effective shear stress reduction.

It is questionable only whether the flow can be kept laminar by suction. Attempts known so far have, at any rate, adduced no positive results. Further exploration of the transition problem itself is also urgently desired.

Practical Aspects of Suction

The following is a brief survey of the points of view according to which suction tests on wings should be evaluated. This discussion is limited to the aspect of increase of maximum lift.

Next to the lift, the suction volume Q with the nondimensional factor $c_Q = \frac{Q}{vF}$ and the suction pressure p with $c_p = \frac{p}{(\rho/2)v^2}$ are the most important quantities. They define the pure sucking-in power, which on the airplane is supplemented by the power losses and the discharge power. These two quantities increase considerably with the volume especially by reason of the restricted space in modern aircraft and may easily become a multiple of the sucking-in power.

Magnitude of volume, pressure, and power govern the type and the dimensions of the suction system and the way of the power supply. If the suction power for direct withdrawal from the relative wind (by fixed or rotating suction devices) is too great, special driving mechanisms or energy accumulators must be provided or the power branched off from the propeller drive.

The maximum lift of the suction wing is no fixed factor but a function of the blowing-out volume. Greater volumes give higher maximum lift, but on raising c_a beyond a certain measure the volume generally rises faster than the lift, so that the theoretically obtainable lift coefficients up to around $c_a = 6$ are not likely to be utilized for this very reason.

Lastly, suction results must be checked for logical blower loading in all flight stages, i.e., to assure that a certain power reserve exists at all speeds above v_{min} and that the blower is able to handle the then existing suction pressure.

To what extent the suction is advantageous for the take-off when the power is branched off from the main drive remains in every case a problem of a special check. The suction lowers the take-off speed and the thrust. The effects on the take-off run must be checked also, with due consideration in the total balance to the sink resistance associated with the blowing-out and the reaction of the blowing-out.

Since the airfoils suitable for high-lift suction are inferior in profile drag, up to the present at least, to the orthodox airfoils of fast airplanes, the profile drag of the former at low c_a is also an important factor in the evaluation. For the design of the landing gear and the dimensions of the horizontal tail surface the angles of attack and the wing moments employed to attain the lift are of great importance.

As concerns the flight characteristics involved with suction, there are several particular and not unimportant problems which, briefly, comprise:

1. The behavior of a suction airplane at stalling;

2. Landing with suction stopped, especially emergency landing in unprepared terrain;

3. Sudden failure of suction during slow flight.

Among the modern high-lift devices the Fowler flap comes closest to the suction wing as far as performance is concerned. As to the suction itself, a recheck of all the cited points of view is necessary for any eventual drawbacks, although it is superior to the Fowler flap in maximum lift and simplicity of wing design.

RESULTS OF TESTS

Drag Reduction

While unusually thick airfoils (~40 percent thickness ratio) could be materially improved according to earlier tests, various attempts with airfoils of customary thickness have so far given no appreciable improvement, with exception of the experimental airplane built by Miles, in England (fig. 2). The upper surface of his wing is covered for the greater part with perforated sheet metal. Separate longitudinal channels convey the suction air to the blower in the fuselage. According to the drawing, the airfoil thickness at the root amounts to about 20 percent. An evaluation of the flight tests gave a profile drag reduction of about 22 percent. This figure, if it includes the blower performance, is more favorable than the results published elsewhere.

High-Lift Measurements

We recall the Göttingen high-lift measurements on the airfoil with 40 percent thickness. It afforded lift coefficients up to 5 without difficulties, but any further increase seemed impossible.

A cursory check with this airfoil on the basis of $c_p = 0.017$ and $c_Q = -2$ for $c_a = 4$ gives, for a 30-ton airplane of 100-square-meter wing area, a suction volume of 60 cubic meters per second at minimum speed. The sucking-in power with no allowance for the efficiency amounts to 120 horsepower. All in all, a horsepower of from 250 to 300 horsepower should be sufficient for such aircraft with suction over the total surface. This example gives the power required under especially favorable assumptions. For designs with thinner airfoils and suction flaps, as involved in practical design, the power will be more unfavorable. Total power values can be estimated only under a great many special assumptions without general validity.

Suction profiles of normal thickness without flap need, according to U.S. and similar German studies, no large suction volumes for moderate lift increases (up to $\Delta c_a \approx 0.5$). But for great c_a increases the volumes grow enormously. Of the results of new U.S. suction profile studies, nothing has been published so far.

More recently, some exhaustive studies have been made on suction-flap airfoils at Göttingen. Flapped airfoils (fig. 3) have the following advantages over simple suction profiles:

1. Lower suction volume;

2. Smaller angles of attack;

3. Higher c_a values by stopped suction.

The suction-flap airfoils share the high wing moments with the Fowler flaps.

Figures 3 and 4 compare the results of a profile of 20-percent and one of 12-percent thickness, both with reversed curvature in the mean line. The worsening with decreasing thickness is exceptionally severe. With suitably chosen shapes and at larger Reynolds number, the values for thin airfoils can perhaps be improved, but the special difficulties of the suction on thinner airfoils are plainly visible.

The marked relationship between the results and the airfoil form is shown in another test on an airfoil similar to the NACA 6218 (figs. 5 and 6). The larger Reynolds number and especially the airfoil shape have improved the result considerably. The earlier results are indicated by thin lines for comparison. Other tests disclosed a marked susceptibility even to minor form changes. This supports the belief that the clearing-up of these flow problems and the exact knowledge of the form effects might furnish the possibility for further performance improvements.

The Suction Airplane AF1 of the Aerodynamic Laboratory

Having accumulated various wind-tunnel data on suction-flap airfoils, the AVA decided to test the theory on an actual airplane in flight. Various engineers and pilots of the AVA collaborated, among them Mr. Wöckner, the designer and first test pilot, Dr. H. B. Helmbold, Dr. M. Kohler, Dr. W. Flügge, Dr. J. Stüper, and the writer.

The flight-test program was intended to clear up

1. The possibility and the efficiency of the suction in flight;

2. The effect of suction on the flight characteristics;

3. The effect of suction stoppage, especially of sudden stoppage during slow flight;

4. Comparison of flight test and wind-tunnel data.

Figure 7 is a general arrangement drawing of the airplane with a wing loading of about 55 kg/m² (11.3 lb/sq ft). The suction flaps extended over the total span. The propeller output amounted to about 220 horsepower, the suction power approximately 20 horsepower. Some of the features, especially the end plates and the ailerons suspended below the wings, were not essential for the suction but merely served for the special instrumental purposes and as a matter of safety while testing a new principle, since the behavior of the flow and the sources of danger could not be entirely foreseen.

The suction fan was mounted in the fuselage (fig. 8). The air passed between the spars to the fuselage. Figures 9 and 10 are two different views of the machine. The tests were accomplished without incident due to the suction as such. The suction created no unrest or uncertainty in the action of the machine at normal flight attitudes. The behavior at stall and by sudden stoppage of suction was very carefully checked. In a slow stall the airplane tipped violently and suddenly over the wing, but it did not continue into a spin; instead it picked up speed again very quickly. This point is being given special attention in the future.

However, if the suction was suddenly stopped a little below maximum c_a, the machine did not tip sideways but slightly forward. Then it assumed a stationary flight attitude without suction. An accidentally unexpected stopping of the suction near the ground could be controlled by the throttle.

The most important result is that the flight-test data and the wind-tunnel data on suction profiles are substantially in agreement. The lift values found in the model test can be actually flown and used as a basis for the design. To visualize the action of the suction, the flow conditions with and without suction on the upper surface were photographed; figures 12 to 15 are sections of the film.

This article is merely intended as a brief outline of the state of research on suction, a problem that is still far from being solved. Whether it will be possible to overcome all the obstacles depends upon the actual testing in practice. Undoubtedly, many efforts in the line of research and design will be necessary.

Translation by J. Vanier,
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for Aeronautics.

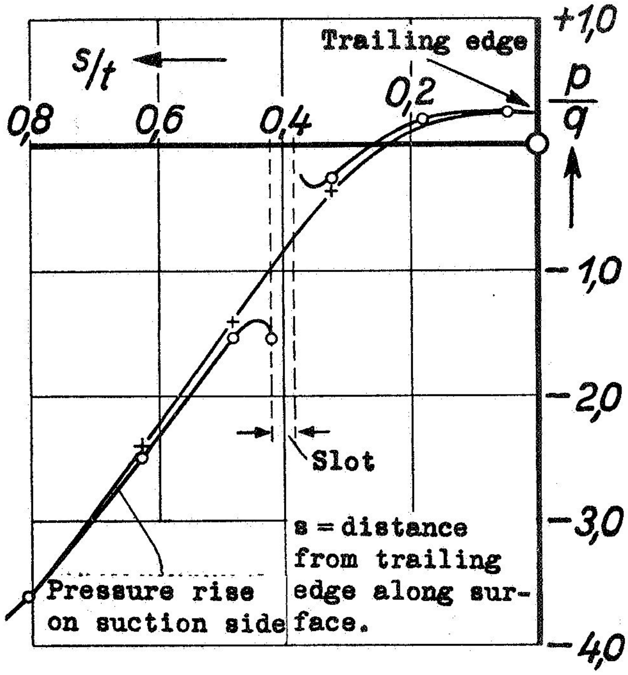


Figure 1.- Sink effect of the suction.

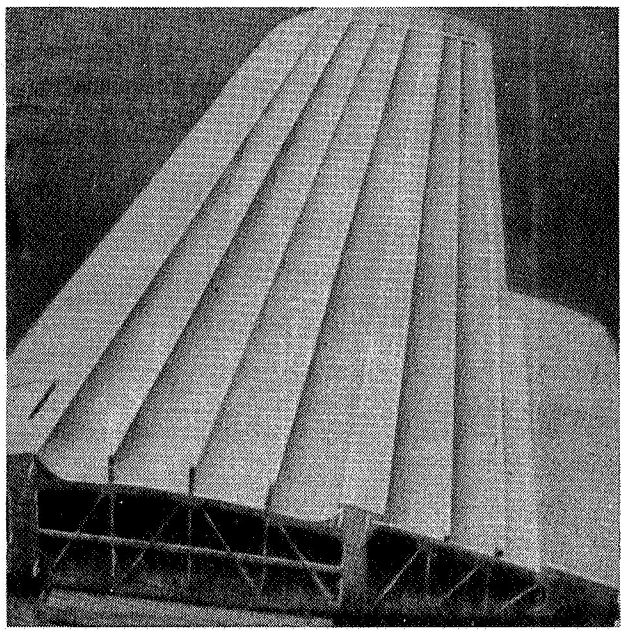


Figure 2.- View of the Miles experimental airplane,wing covering removed.

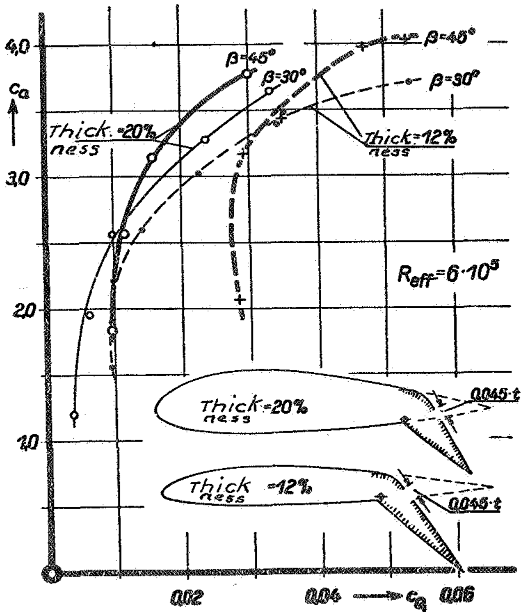


Figure 3.- Lift and suction volume on flapped airfoils of various thicknesses.

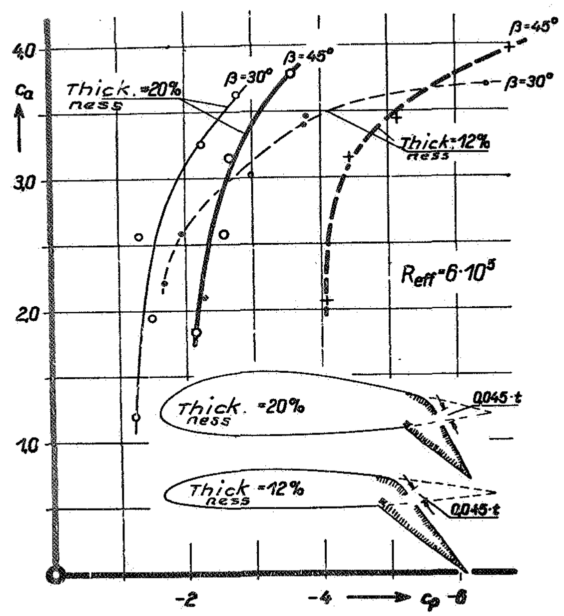


Figure 4.- Suction pressure and lift of flapped airfoils of figure 3.

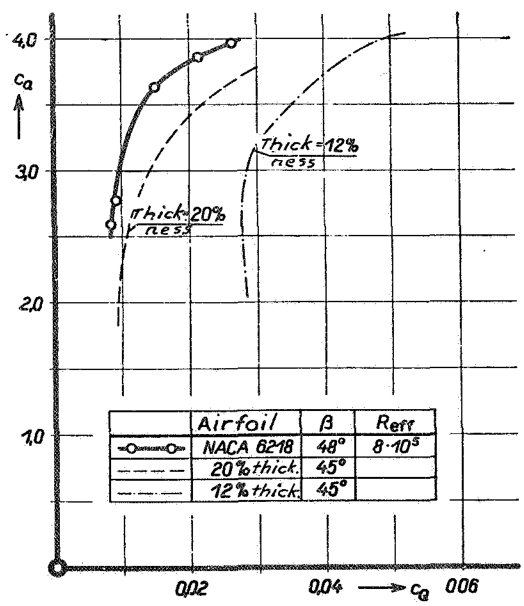


Figure 5.- Lift and suction volume of NACA airfoil 6218 ($\beta = 48°$). (The values for $\beta = 45°$ of the airfoils of figs.3 and 4 are shown for comparison).

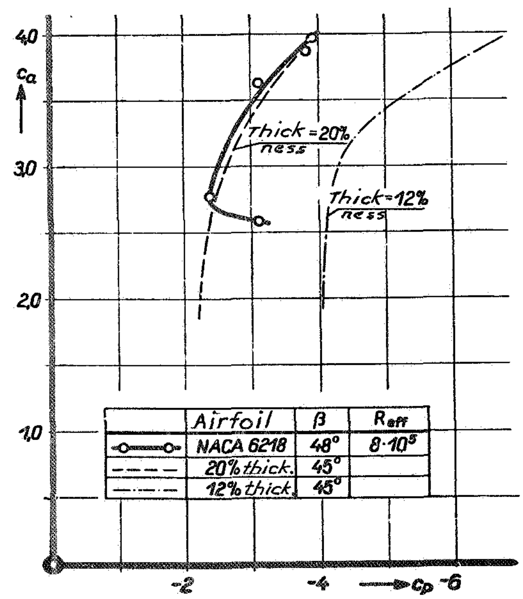


Figure 6.- Suction pressure and lift of NACA airfoil 6218 (β=48°). (comparative curves as in fig. 5).

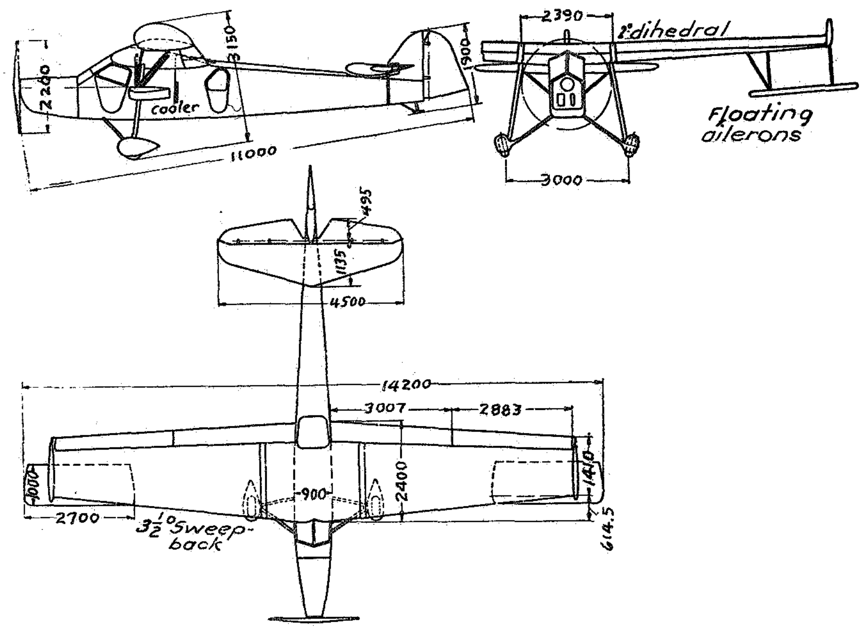


Figure 7.- General arrangement drawing of the AF1 suction type airplane.

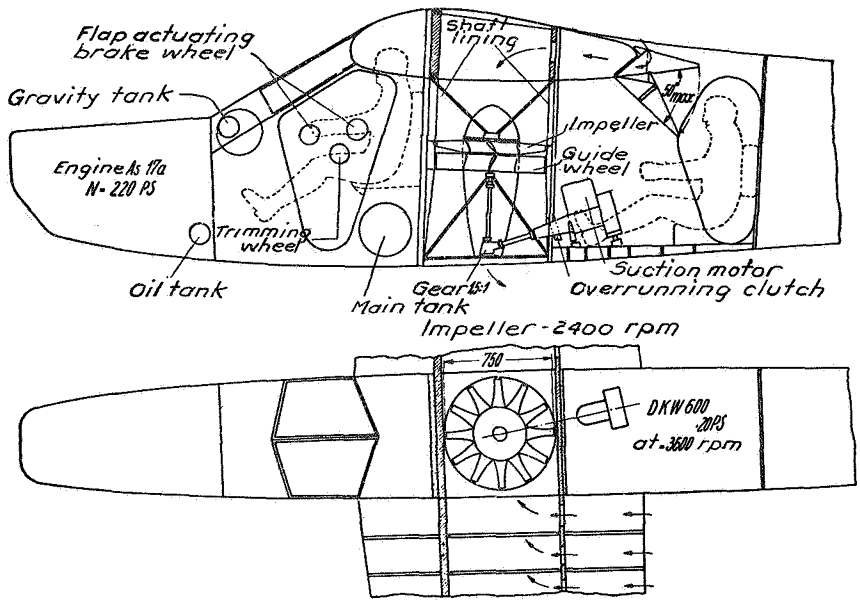


Figure 8.- Diagrammatic sketch of suction drive.

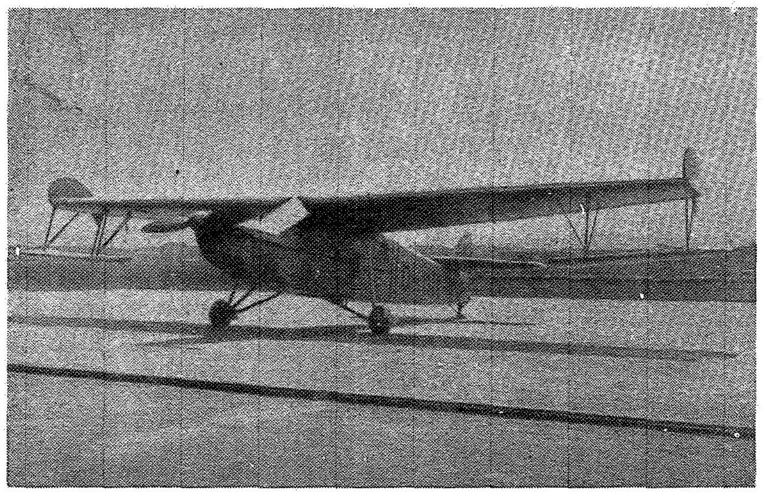


Figure 9.

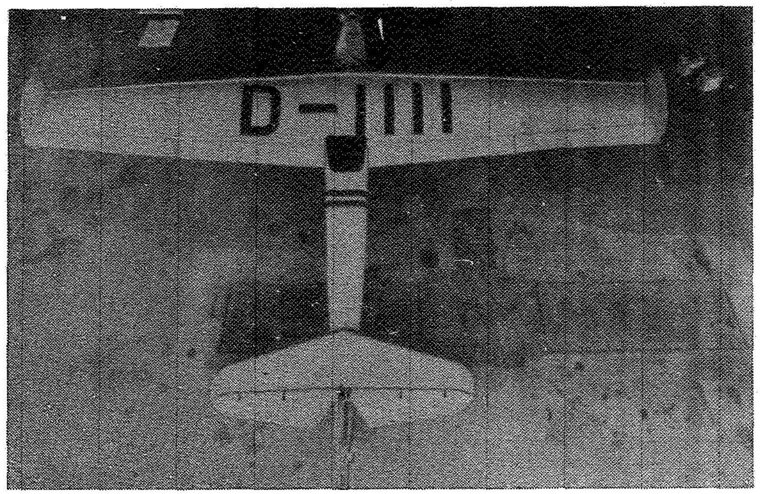


Figure 10.

Figures 9,10.- Views of the AFl airplane.

No suction

Suction

$\delta_f=10^{\circ}$

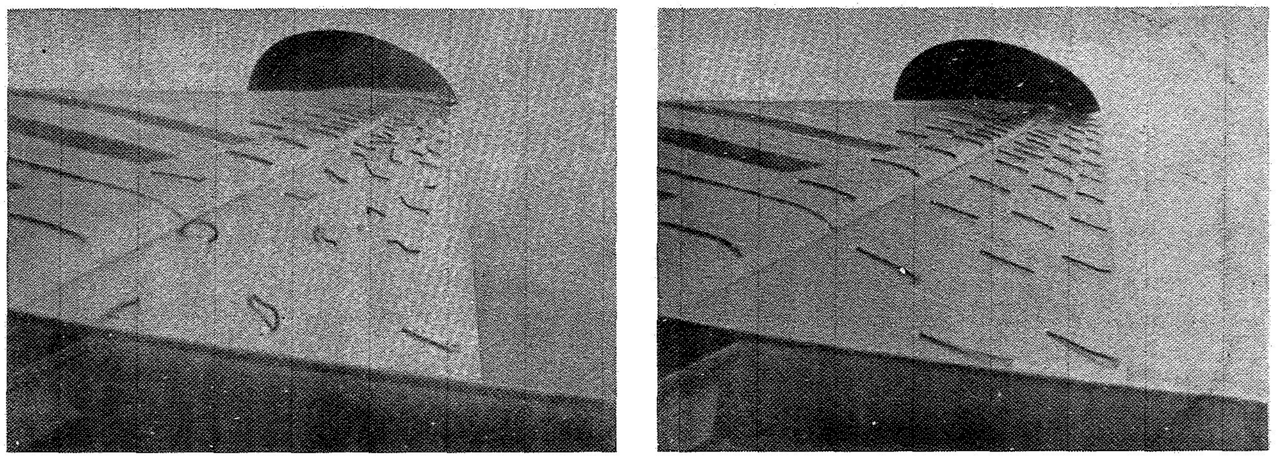


Figure 11.

Figures 11 to 15.- Flow conditions on upper surface of wing with various flap deflections.

$\delta_f = 20^\circ$

No suction

Suction

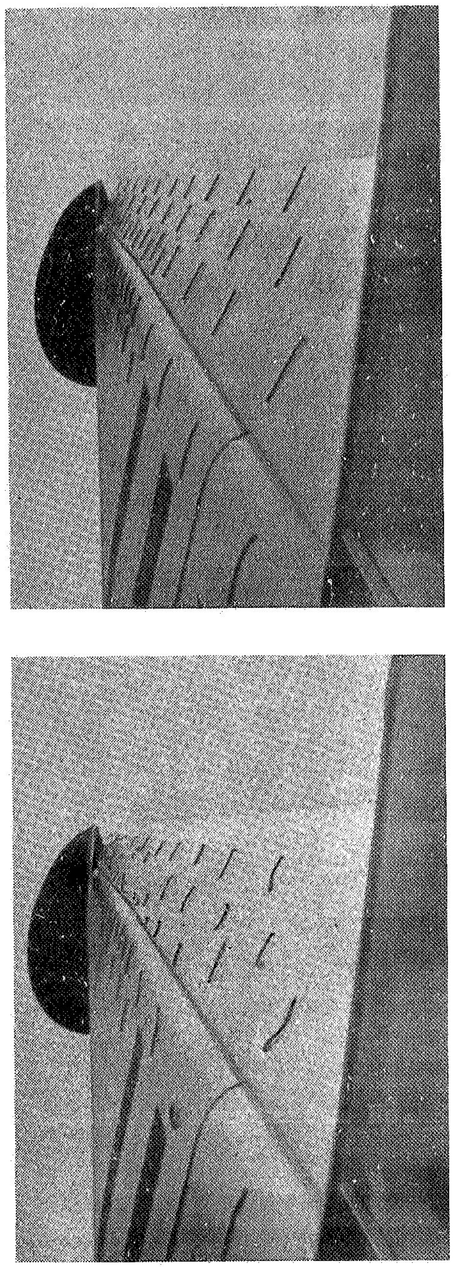


Figure 12.

$\delta_f = 30^\circ$

No suction

Suction

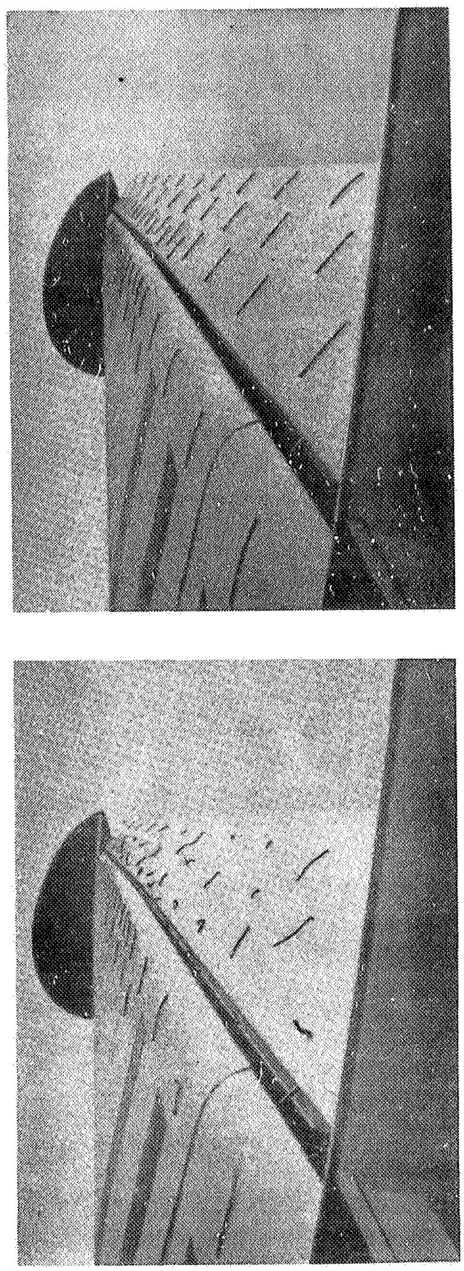
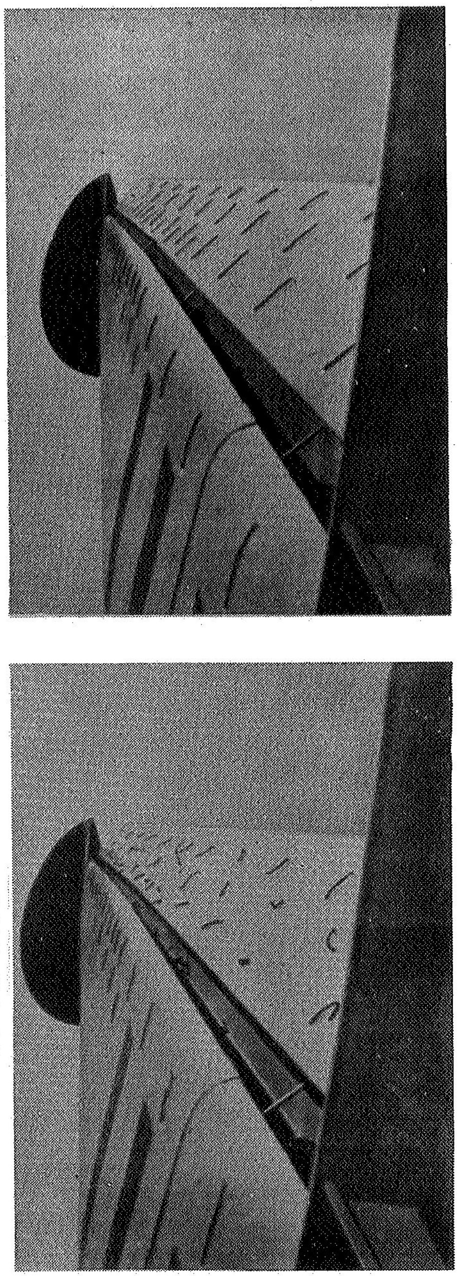
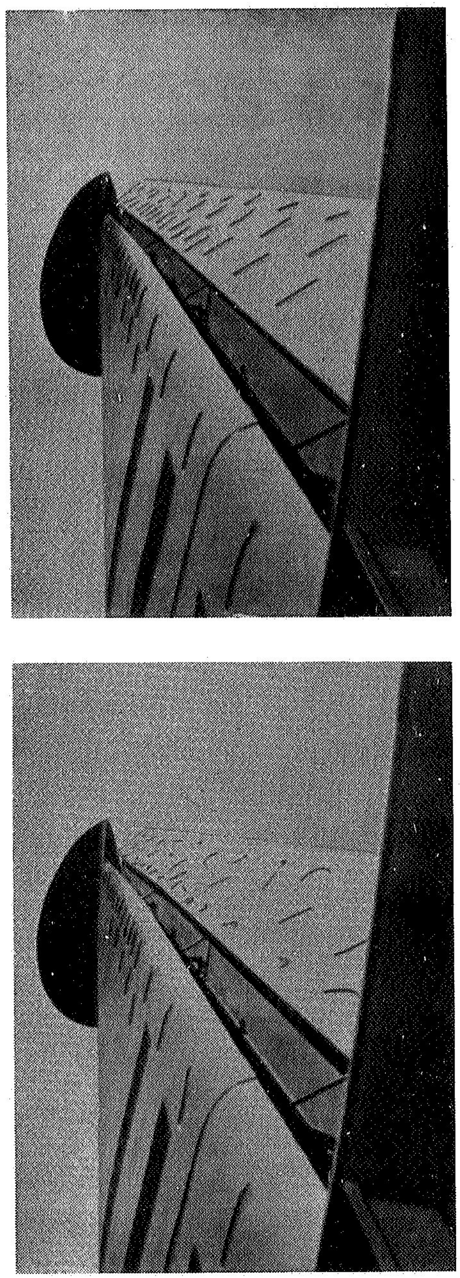


Figure 13.



$\delta_f = 40^\circ$

Figure 14.



$\delta_f = 50^\circ$

Figure 15.