7- BY 10-FOOT WIND TUNNEL

BOUNDARY-LAYER CONTROL FOR DRAG REDUCTION

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At this Laboratory there are two nearly identical 7- by 10-foot wind tunnels. Both are capable of airspeeds of 300 miles per hour, and are well suited for the investigation of a wide variety of research projects. Some of the most difficult problems in connection with the design of transonic and supersonic airplanes are concerned with the provision of adequate stability and control at low speed. Thus, the advent of higher airplane speeds has intensified the need for research in the low-speed field.

One of the many problems now under investigation is a study of the boundary layer of wings, which is the thin layer of retarded air immediately adjacent to the surface. Attempts to gain a complete understanding of the behavior of the boundary layer have occupied the attention of theoretical and experimental investigators for many years, but the problem is far from being completely solved. It has been shown that the characteristics of wings may be improved by artificially controlling the boundary layer. The drag may be reduced to give higher airplane speeds, and the maximum lift and stalling characteristics may be improved to give better performance at the low speeds necessary for take-off and landing. The results of some recent experiments with boundary-layer control are the subject of the talks here today. I will discuss the boundary layer in relation to both the drag and the stalling characteristics of wing sections, and the next speaker will demonstrate an application of boundary-layer control for improving the stall.

The manner in which the boundary-layer flow affects the skin-friction drag of a wing can be shown with the aid of this chart (fig. 8(b)).

The boundary layer at this point on the surface of the wing is represented diagrammatically to a greatly enlarged scale. The velocity of the flow is represented by the horizontal lines. Two types of flow are represented by the two colors. The orange lines represent the velocity distribution of a turbulent boundary layer. Notice that the velocity close to the surface is relatively high. This means the air will exert a high degree of shearing force or friction on the wing. The blue lines represent a laminar boundary layer. The velocity near the surface is less, and consequently, there will be less drag on the surface than is the case with the turbulent boundary layer. It is evident, therefore, that it would be desirable to have laminar flow over the entire wing. Unfortunately, this is not possible with any simple airfoil. Sooner or later in the flow along the surface of the wing, the laminar boundary layer becomes unstable and changes to the turbulent type. In actual practice it is very difficult to maintain laminar flow over as much as 50 percent of the wing surface.

Several theoretical investigations have demonstrated the possibility of stabilizing the laminar boundary layer by means of suction through a porous surface. The calculations indicated that a very small volume of suction flow was required, and a model was built at the Langley Laboratory to investigate the findings experimentally. A diagram of the model is shown on this chart (fig. 8(c)). The skin of the model was constructed of porous bronze, and air from the entire surface was sucked into the interior. In order to maintain nearly uniform flow through the surface, it was found necessary to divide the model into several compartments.

The variation of drag with volume flow through the surface is shown here. As the volume flow is increased, the external drag is reduced to about one-sixth of the drag of the plain airfoil. Measurements indicated that the boundary-layer flow was laminar to the trailing edge. This, of course, cannot be achieved without some penalty. The total drag of the airfoil should include the power required for the suction, expressed in terms of drag. The addition of this factor results in this curve of total drag. The minimum point on the curve is below the drag of the plain airfoil, but as the volume flow is increased, the total drag increases rapidly. The rate of air flow required to give minimum drag in the experiment was considerably greater than the value predicted by theory. If the required flow rate can be reduced, the total drag will, of course, also be reduced.

Further studies are planned using a surface of different porosity. It is hoped to realize extensive laminar boundary layers with flow rates which approach more nearly the low values indicated by theory.

Another phase of the boundary-layer problem is related to the stalling characteristics of wings. The stall of a wing is the result of separation of the boundary layer from the surface, and the manner in which this occurs determines the behavior of an airplane near maximum lift. It is desirable, of course, that the stall be gentle, but of greater importance is an adequate warning to the pilot of the impending stall. Frequently the warning is given by a shaking or buffeting of the airplane. This feature has been characteristic of most airplanes with relatively thick wing sections.

Modern high-speed airplanes, however, are employing thinner wing sections than has been customary in the past. Frequently these airfoils stall abruptly accompanied by a sudden loss of lift. Such a stall is dangerous in that it gives no advance warning to the pilot, and may result in an uncontrollable roll-off with considerable loss of altitude. Several recently designed airplanes have had difficulties of this sort.

The manner in which airfoils of different thickness ratios stall is shown on this chart (fig. 8(d)). The upper figure is representative of thicker airfoils such as those used in relatively slow, conventional airplanes. The stall is the result of separation of the turbulent boundary layer. The stalled area originates at the trailing edge and progresses forward with increasing angle of attack. The variation of lift with angle of attack is shown here. For this airfoil the peak of the curve is well rounded and there is no sudden loss of lift. Airfoils of this type usually provide a good stall warning, and the stall itself is gentle.

The middle airfoil is moderately thin representative of those used in current high-speed designs. The stall originates at the leading edge as the result of complete separation of the laminar boundary layer, and occurs abruptly when the critical angle of attack is reached. The peak of the lift curve is sharp, and the sudden loss of lift would result in poor stalling characteristics.

The bottom airfoil is representative of the very thin airfoils with sharp leading edges such as those under consideration for use with supersonic designs. The stall is the result of a localized separation of flow near the leading edge. The flow separates from the surface, then reattaches farther downstream. As the angle of attack is increased, the extent of the separated region increases. This results in nearly constant lift with increasing angle of attack. However, the value of the maximum lift is considerably lower than those of the other two airfoils.

In an attempt to overcome these undesirable properties of thin airfoils, a study of methods of improving both the maximum lift and stalling characteristics is currently in progress. One method which has shown favorable results is boundary-layer control. This investigation will now be discussed by our next speaker, Mr. ______________.

BOUNDARY-LAYER CONTROL FOR INCREASING LIFT

Donald Gault, John Kelly, or Leonard Rose

The idea of boundary-layer control for increasing the maximum lift of wings is not new. Numerous experimental investigations date back 20 years or more. These investigations were directed toward delaying separation of the turbulent boundary layer from the rear portion of relatively thick airfoil sections. By the use of openings in the wing surface, designed either to remove the boundary layer by suction or to re-energize it with a jet of high-velocity air, substantial increases in maximum lift were demonstrated in the Laboratory. If applied to an airplane, the landing speed and consequently the distance required to land could be reduced. However, because simpler high-lift devices have, in the past, been capable of providing reasonably satisfactory airplane landing speeds, no practical applications of boundary-layer control have resulted.

Recently there has been renewed interest in boundary-layer control for increasing the maximum lift of projected supersonic airplanes with very thin wing sections, and for improving the stalling characteristics of current high-speed airplanes employing moderately thin wing sections. The effectiveness of boundary-layer control in delaying the leading-edge type of flow separation, such as is exhibited by moderately thin airfoils, will be demonstrated in the wind tunnel. This application of boundary-layer control differs from the earlier experiments in that the control is applied near the leading edge of the wing.

The experimental setup for the model is shown schematically on this chart (fig. 8(e)). The airfoil section is an NACA, symmetrical, low-drag type, 12 percent thick. Near the leading edge in the upper surface is a narrow, spanwise slot. The air induced for boundary-layer control passes through this slot into a hollow space within the model; thence through a mercury seal, an orifice-type flow meter, and is ejected to the outside atmosphere by a variable-speed centrifugal pump.

The midspan section of the demonstration model is covered with short tufts of thread which indicate the direction of flow. When the model stalls, the separated air flow will cause the tufts to oscillate violently. A mild fluttering of the tufts is indicative of rough flow only, not complete separation. At the present time the slot, which is in the surface nearest to you, is closed by a removable strip.

To demonstrate the type of stall characteristic of the basic wing without a suction slot, the tunnel will be started and the angle of attack increased until the critical value is exceeded. The angle of attack is shown by the indicator.

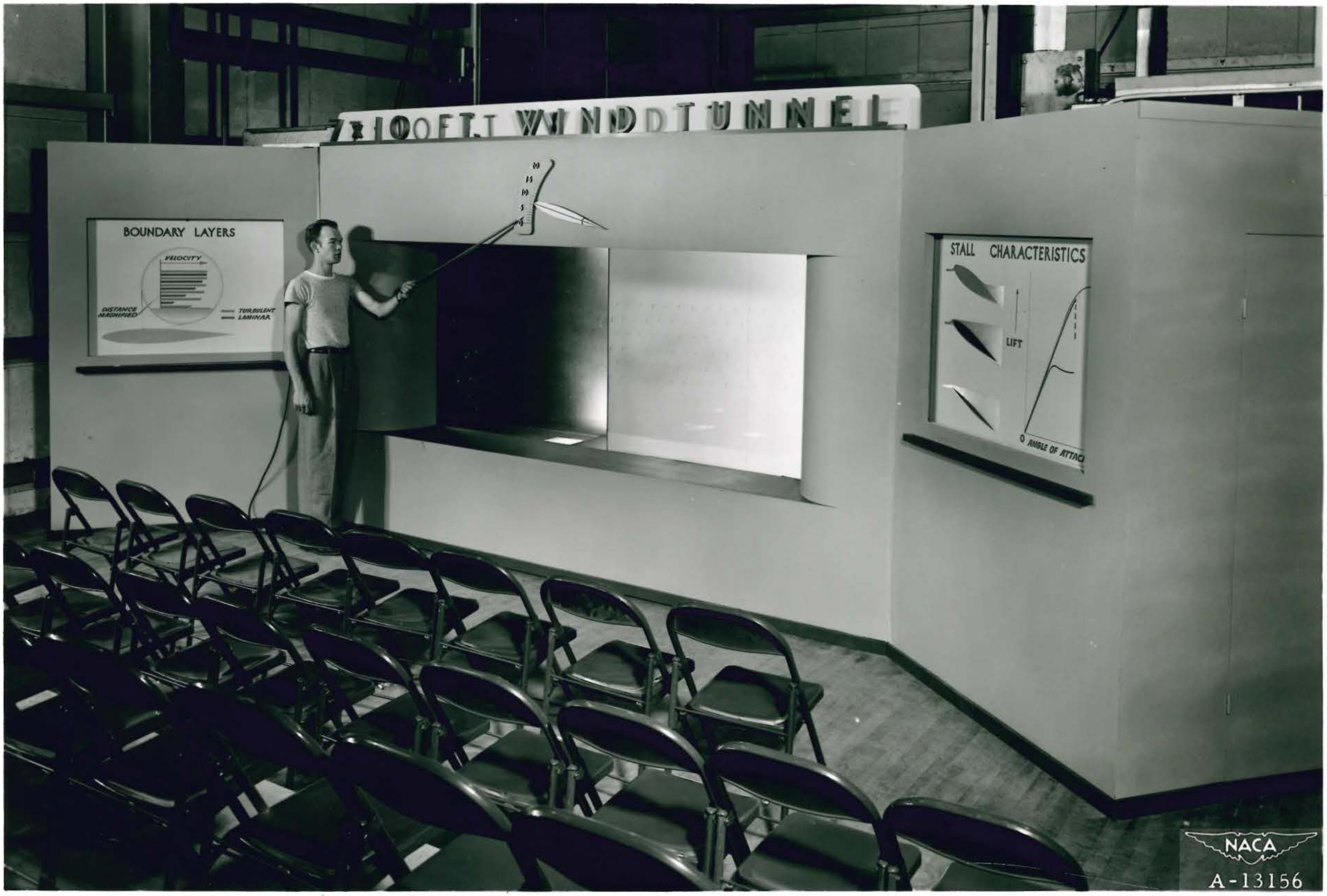
This chart shows the relationship between angle of attack and lift (fig. 8(f)). The basic airfoil will stall sharply, accompanied by a sudden loss of lift when the critical angle of attack is exceeded. The tufts on the model will all show separation of flow simultaneously. Detailed measurements of the boundary layer have indicated that this type of stall originates at the leading edge. Without stopping the tunnel or changing the angle of attack, the strip closing the suction slot will be removed and the suction pump brought into action. The flow will reattach to the surface of the model, and the tufts once again will indicate an unstalled condition. The angle of attack, and correspondingly the lift, can be further increased until the model stalls again at higher values of both angle of attack and lift. This time, separation of flow will first appear at the trailing edge, then progress forward along the chord with increasing angle of attack. The effect on the lift is to round over the peak of the lift curve similar to that of a thicker airfoil and to produce a less abrupt stall.

(Demonstration is made with the salient points reiterated. Tunnel is stopped.)

The increment of maximum lift depends on the volume of the suction flow. The maximum lift increases with the flow rate; rapidly at first, then at a diminishing rate. The largest value of maximum lift obtained in this initial investigation was about 30 percent above the maximum lift of the plain airfoil. The volume of the suction flow for this lift increase is not large. For example, the suction volume required to land a jet fighter with boundary-layer control is estimated to be less than one-tenth of the maximum air consumption of the jet engine.

In addition it has been found that the location and width of the suction slot are important. The slot on the demonstration model is believed to be about optimum for this particular airfoil. In order to circumvent the critical problem of determining the optimum slot location, an application of porous or area suction has been investigated at the Langley Laboratory. For this investigation a porous bronze sheet replaced the first 4-1/2 percent of the upper surface of the airfoil. The results obtained with this method were similar to those obtained with a single slot. The increment of maximum lift was not as great, but the experiment was a first attempt. No doubt the effectiveness of the method will be increased as more experience is gained.

In conclusion, boundary-layer control offers inviting possibilities for (1) reducing drag, and (2) improving the stalling and maximum-lift characteristics of thin wings suitable for high-speed airplanes.



(a) General view.

Figure 8.– 7– by 10–foot wind–tunnel exhibit.

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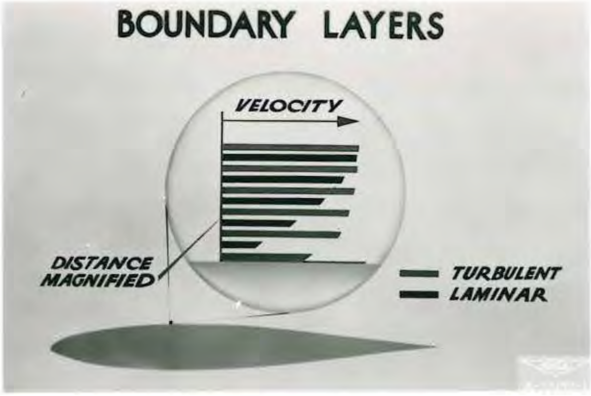
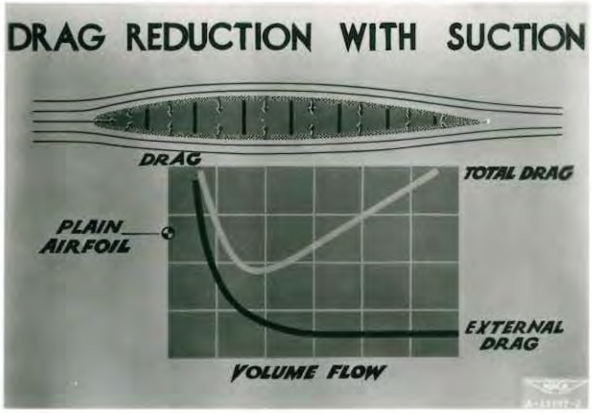
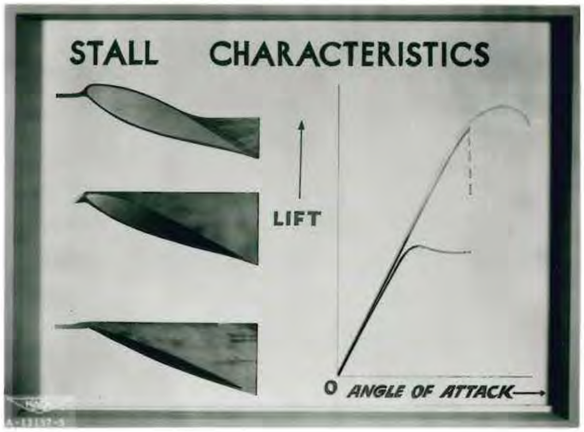


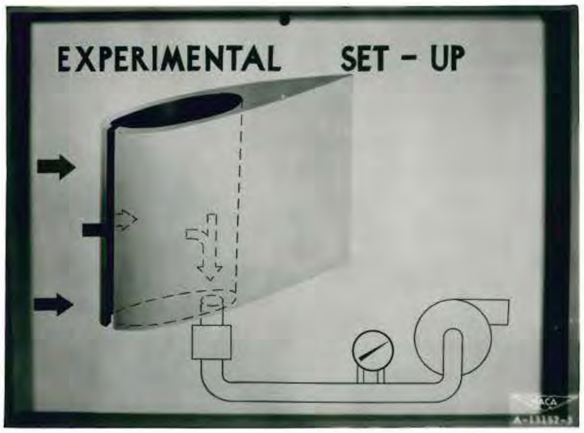
(b) First chart.



(c) Second chart.



(d) Third chart.



(e) Fourth chart.

(f) Fifth chart.

Figure 8.- Concluded.