LOW-SPEED RESEARCH ON HIGH-SPEED WINGS

by

40- by 80-foot Tunnel

INTRODUCTORY SPEECH

The discussion you have just heard at your last stop has shown the advantages of using wing sweep in achieving high flight speeds The use of wing sweep does however introduce problems which become particularly troublesome at low flight speeds. For example consider the problems associated with landing. (1) This chart shows the starting points and the paths required to make a perfect power-off landing at these points, by an airplane having a straight wing and by the same airplane having a swept wing. Use of the swept wing increases by 50 percent the vertical distance, and doubles the horizontal distance. The length of the arrows shows that, at the point of contact the airplane with the swept wing has a landing speed almost twice that of the airplane with the straight wing. All these facts make it clear that the pilot landing the airplane with the swept wing must fly a greater distance at higher speeds and accordingly his landing problems are greatly increased.

It is our purpose here to show first how research has provided an understanding of the physical reasons underlying these low speed flight problems, and then for three example wings to show how application of this understanding has brought improvement. However, in the limited time available it is possible to present only a brief and simplified discussion.

(2) Sweeping a wing enables higher flight speeds to be reached by reducing the effective wing speed. This action can be shown on this chart which shows for the straight wing and for the swept wing, the speeds that are significant or effective in producing forces on the wing. In each case it is the speed which is at right angles to the wing. For the airplane with the straight wing, this is the same as the speed of the airplane. For the airplane with the swept wing, this speed is less than that of the airplane. Thus, because the maximum amount of lift which can be carried depends on the effective wing speed, it can be said that the very factor which makes sweep useful at high speeds inherently reduces the maximum lift of the airplane with the swept wing when it has the same forward speed as the airplane with the straight wing. For instance, if the swept wing shown had 45° of sweep, the same forward speed, and the same wing area as the straight wing, the maximum lift of the swept wing would be only 50 percent of that of the straight wing.

The difficulty of reaching higher lifts on swept wings has been increased by the use of thin wing sections which have low drag at high speeds but also lower maximum lifts. (3) This chart illustrates why the maximum lift of thin wing sections is lower than that of the thicker wing sections used until recently. This lower maximum lift is the result of a different type of air flow appearing on the upper surface of the wing as maximum lift is reached. The air flow is smooth over the upper surface of the thick section until the point of separation is reached near the trailing edge; thus lift is maintained over the forward portion of the section. In contrast, the air first separates from the upper surface of the thin section at its leading edge with the result that lift is lost over the whole upper surface.

Another problem associated with the use of sweep arises from the effect it has on the distribution of lift along the wing span. (4) This chart compares the distribution of lift along the span of a straight wing airplane and along the span of a swept wing airplane, both at maximum lift. Note that maximum lift is reached simultaneously by most of the wing sections along the span of the straight wing so that each section carries its maximum lift. On the swept wing, maximum lift is reached by wing sections near the tip before the other wing sections reach their maximum lift. Thus, the maximum lift of the swept wing is reduced both because of the low maximum lift of the wing sections, and because the wing sections do not all carry maximum lift at the same time.

In summary it has been shown that the use of thin swept wings on high speed airplane designs has resulted in low speed flight problems. (5) The underlying physical causes of these problems have been shown to be a reduction of effective wing speed due to sweep, a reduction in maximum lift of thin wing sections due to a change in flow pattern at maximum lift, and a distortion of the distribution of lift along the span of the wing. The next three speakers will discuss ways in which these problems are being attacked, and illustrate the measure of success so far realized.

CAMBER AND TWIST ON A WING SWEPT 45°

In order to improve the low-speed characteristics of swept wings the lift capabilities of thin wing sections must be increased. To achieve this improvement in lift on a wing swept back 45°, camber was used. The effect of camber, as illustrated on this chart, is to shift the point of separation from the leading edge to the trailing edge, thus, securing the advantages of high lift, which the thick wing section has over the thin uncambered section.

In order to realize the increase in lift due to camber all along the wing span it was necessary to increase the lift near the wing root. This was accomplished by twisting the wing so that the sections near the fuselage had a higher angle of attack and therefore approached the lift of the tip region. This chart shows the change in the distribution of lift along the span of the wing when it was twisted an amount acceptable in high speed flight. It can be seen that while the truly uniform lift distribution is not realized, it is more closely approached by the twisted wing than by the wing with no twist.

To illustrate the effects of camber and twist on a wing swept 45°, movies will be shown which depict the effects of the air flow: first, over a wing without camber and twist, and then, on a wing with camber and twist. The tufts used to depict the flow over the wing are short lengths of wool yarn affixed to the wing so as to trail with the air flow. In these views since there is no flow of air, the tufts, of course, merely hang. Presently, the airstream in the tunnel will be brought up to test speed.

You are now observing the tuft action on the wing without camber and twist as the lift is being steadily increased. At low lift the flow is smooth and the tufts are relatively steady and indicate the direction of flow on the wing surface. Above a lift coefficient of 0.6 the violent motion of the tufts indicates separation of flow which begins at the wing tip and spreads toward the wing root.

Now, compare <u>that</u> tuft action with <u>this</u> of the cambered, twisted wing. The pictures are starting at the same lift coefficient at which the previous wing showed separation. The stall of this wing will be seen to be more uniform since more sections of the wing reach maximum lift simultaneously. In this case no evidence of violent separation appears until the maximum lift coefficient of 1.09 is reached, clearly indicating that the flow separation on the wing is markedly changed.

The improvements due to camber and twist are illustrated on this chart, which shows the perfect power-off landing flares for the two wings. Note that both the landing speed and length of landing path have been reduced.

Other means to improve the lift of swept wings investigated by the NACA are shown in these photographs of the left wing panel of a swept-back wing. The first is a simple chord-extension flap on the leading edge. The second is a Krueger-type flap, and the third, an extended and drooped Handley-Page slat. The latter two are essentially means of providing camber to the wing.

Mr.____________ will now discuss the triangular wing.

Experimental and theoretical studies show that the triangular wing possesses great potentialities for use on supersonic interceptor-type airplanes. However, as in the case of the swept wing, the characteristics which lead to the excellent high speed performance, namely sweep and wing thinness, also lead to undesirable low-speed flight characteristics.

Among the NACA studies directed at this low-speed problem is that being done at the 40- by 80-foot wind tunnel using the triangular wing model shown here. For this wing, as for that discussed by the previous speaker, use has been made of camber and twist to improve the low-speed characteristics. However, in this case it was necessary to provide a method of varying the camber and twist in flight since the amounts required at low speeds are far greater than required, or acceptable, at high speeds. This necessity of varying the camber and twist in flight means that only an approximation to the optimum theoretical amounts could be made. Shown here is a view of the wing with a combination of leading-edge and trailing-edge flaps. These flaps were used to produce the effects of camber and twist in the manner shown here on cross sections of the wing taken at several points out along the span. From these cross sections you will note that deflecting both the leading-edge and trailing-edge flaps effectively cambers all sections except near the wing tip and also produces the effect of twist in this manner. That this is a compromise can be noted in particular in that no camber is realized on the tip.

Shown here is the wing with leading-edge and trailing-edge flaps deflected as used for this investigation of the effects of camber and twist.

Tuft movies have been taken of this left side of the wing to show the changes effected in the flow over the wing by use of the flaps. Without the flaps deflected the sections near the tip reach their maximum lift very early and flow separation occurs without affecting the continual rise of lift over the remainder of the wing. With increasing wing lift the separation spreads toward the center of the wing. At the maximum attitude found by flight tests to be acceptable at landing, the air flow over the major portion of the wing has separated.

With the flaps deflected and at the same landing attitude shown for the wing without flaps, the resulting lift coefficient is over 50-percent greater than the lift coefficient of the wing without flaps. Only the tip sections show evidence of flow separation, a result of the lack of camber at the tip, while the flow over the remainder of the wing is unseparated.

A more quantitative measure of improvement is shown in this comparison of the landing flare of the two wings. An improvement can be seen for the wing with flaps over that of the wing without flaps.

In view of the promise shown by these results, research is still being conducted along these lines since it is felt that the best arrangement has not yet been reached and hence these results represent only a step toward a solution of this low-speed problem.

The next speaker will present a discussion of a wing swept back 63°.

The importance of increasing the lift capabilities of thin wing sections has been emphasized. The difficulty of achieving this is far greater as wing sweep is increased to reach higher maximum speeds. On wings such as the one swept back 63°, shown here being placed into the wind tunnel, the difficulty has increased to a point that warrants the use of the complex but highly effective procedure of removing the boundary-layer air by suction to delay the occurrence of air-flow separation. The manner in which the boundary-layer air is removed to improve maximum lift is shown on this chart. The maximum lift of thin sections is limited by separation of the air flow from the leading edge as shown here. It is known, however, that if boundary-layer air is removed from the wing surface over the area just behind the wing leading edge then the air flow will remain smooth over the surface to a higher angle of attack and will produce higher lift. To achieve this result the air must be removed at all points over this critical area which makes it necessary to use a porous surface such as indicated here. The porous material through which the boundary-layer air is drawn from the surface can be seen extending along the entire leading edge. The extent of the porous surface on the wing and the manner in which the air is removed by the pump in the fuselage is shown in this chart.

The effectiveness of this method of boundary-layer control in eliminating flow separation on this wing will be illustrated by means of movies of the tuft action. Pictures have been taken of the tufts attached to this left wing panel. The first pictures show relatively smooth flow over the surface. This is followed by the occurrence of the air-flow separation at the tip sections. Then the air-flow separation spreads inboard as the lift coefficient is increased. The area of separation is now well established. The suction pump is being brought up to speed. The tufts show smooth flow, first at the inboard section and then over the entire wing indicating that the separation of the air flow has been eliminated. The pump is now being slowly brought to a stop and it may be seen that air-flow separation again appears at the wing tip and spreads inboard Violent movement of the tufts shows that separation has occurred over the greater part of the wing.

What the elimination of this air-flow separation means in terms of landing an airplane which has wings swept back 63° is shown by this chart. The horizontal distance and vertical distance to complete the landing flare have been reduced by 50 percent and the landing speed has been reduced by 35 percent.

Because this method of boundary-layer control seems to offer considerable promise in the way of improving the lift of the thin wings required of high speed airplanes, we have chosen to demonstrate its action in some detail. The research model under discussion is now in the wind tunnel. To demonstrate the effect of boundary-layer control we will operate the wind tunnel and run a typical test on the model and, with the aid of this demonstration model, illustrate the results of the test. This 1/3 scale demonstration model is similar in all respects to the left wing panel of the research model in the wind tunnel. This represents the fuselage and the root of the wing. This is the porous material on the surface over the leading edge extending from the root to the tip. These glass tubes containing water are connected directly to the pressure orifices at similar positions along the span of the wing in the wind tunnel. By comparing the height of the water in each tube across a line of tubes, the type of air flow over the wing can be determined. This chart shows the typical pressure distributions which will be observed as you watch the variation of the height of the water in the tubes. This pressure distribution is for the case of unseparated air flow over the surface for a relatively high angle of attack and this pressure distribution is for the case of separated air flow occurring at the leading edge. Note the high lifting pressure at the leading edge for the case of unseparated air flow. The angle of attack in degrees of the model in the tunnel is shown by this indicator. The air is now flowing through the wind tunnel at test speed of 80 miles per hour. As the angle of attack of the model in the wind tunnel is increased, shown by the indicator, the pressure distributions for unseparated air flow appear. At this angle of attack the peak lifting pressure is at the leading edge, but is low and will not increase further with angle of attack since at higher angles the air flow will separate as indicated by the decrease in peak pressures. All the sections now show pressure distributions for separated air flow. The angle of attack is being increased further and the suction will be applied to remove the boundary-layer air. The sound of the pump coming up to speed can be heard, and the lifting pressures at the leading edge can now be seen to be rising. The pressure distributions are now for unseparated air flow with high peak lifting pressures at the leading edge at a considerably higher angle of attack than was previously attained without separation. The pump speed is now being reduced. A steady drop in the pressures at the leading edge shows that the pressure distribution for air flow separation is again returning. It is thus evident that this form of boundary-layer control is very effective in delaying the occurrence of air flow separation in the difficult case of wings with a large amount of sweep and with thin wing sections.

This demonstration completes your visit to the 40- by 80-foot wind tunnel.

Display for Presentation of "Low-Speed Research on High-Speed Wings"
by 40- by 80-Foot Tunnel

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