DRAG REDUCTION IN SAILPLANES

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With Part II, continued from page 13 of the June issue of SOARING, we conclude **Drag Reduction in Sailplanes.** Once again, to Dr. Wortmann, the author, and to Sailplane & Gliding, we offer our most sincere thanks.

SO far, considerations dealing with the choice of sailplane planform and profiles have not left the designer much freedom. As far as profile selection is concerned he is largely dependent on wind-tunnel measurements, whereas in planform choice, although he can obtain some advantage over present designs, he can, on the whole, not expect to achieve a large overall improvement. In contrast the prospect of maintaining laminar flow, leading directly to a reduction in skin friction, offers much greater possibilities.

A wing with a fully turbulent boundary layer can have skin friction values twice as large as a wing with at least a partially laminar boundary layer. The principle of maintaining laminar flow thus offers the most powerful means available for the reduction of drag and can be applied with advantage to any aircraft. Naturally, to exploit the possibilities fully, the design must be developed with this principle in mind right from its inception.

The thin "laminar" boundary layer, which builds up on the surface of a body subjected to an airflow, normally thickens continuously with streamwise distance along the body. The initially stable flow (flow that is insensitive to disturbances) soon becomes unstable. The transition of this unstable flow to turbulent flow depends on the degree of instability as well as the size of the disturbances which either already exist in the free stream or which are created on the surface of the body.

These disturbances, apart from large ones which cause turbulence immediately, become amplified in an unstable boundary layer, a phenomenon taking both a certain time and distance. It is obvious that the larger the initial disturbance, the sooner turbulence will occur under otherwise similar conditions. If the disturbances, which in the free atmosphere originate only from imperfections in the surface, i.e., roughness and waviness, are sufficiently small, the amplification rate becomes the dominant parameter. On rigid and impervious wings this amplification rate depends on the pressure gradient in the flow direction.

A favorable pressure gradient, for example, can stabilize the laminar boundary layer to such an extent that transition is delayed to $Re=15\times10^6$. The Reynolds Number is based on the distance between the wing leading edge and the transition point. [At a velocity of $U=40$ m/s (145 km/h), $Re=15\times10^6$ gives a chord of 5.6m.!] With a positive, unfavorable pressure gradient, transition can be as far forward as $Re=2\times10^4$, that is to approximately 1/700 its previous value. For zero-pressure gradients, as for example on a flat plate, the transition Reynolds Number is around 3×10^6.

km/h	(kts)	m/s	Re/m
72	(39)	20	1.33×10^6
108	(58)	30	2.00×10^6
144	(78)	40	2.66×10^6

The significance of these Reynolds numbers for gliders can easily be seen from the above table which gives Reynolds Numbers for a chord of one meter at three different speeds. Even when flying fast (40 m/s), a wing of this chord maintains fully laminar flow with zero-pressure gradient. Only with a chord of 1.1 meters would the Reynolds Number become 3×10^6 and turbulence set in. On the other hand, fully developed turbulence can occur after a distance of one cm. at a flow velocity of 20 m/s if a positive pressure gradient exists on the wing. If one wishes, for example, to maintain laminar flow on a two meter length of fuselage, one requires a slight negative pressure gradient to stabilize the boundary layer. Put another way, on a sailplane *wing*, transition always occurs downstream of the minimum pressure point, whereas on a smooth *fuselage*, transition will already occur before the pressure minimum because of the higher Reynolds Number.

The pressure distribution is governed by the profile and the incidence of the wing. It can be seen that an exact knowledge of the relationship between the profile shape and the pressure distribution, obtained either theoretically or experimentally, is an important aid in achieving laminar flow.

On the other hand one can see from the transition Reynolds Numbers that maintaining laminar flow in the speed range of sailplanes with favorable pressure distribution is relatively simple providing that it is possible to keep a second influence, namely that of disturbances in the laminar boundary layer, sufficiently small.

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Fortunately the composition of the atmosphere is such that practically no disturbances in the boundary layer derive from this source. Many glider pilots are of the opinion that the roughness of thermals has a detrimental effect on the laminar profile. Gusts, however, primarily change the incidence of the aircraft, and this effect is probably the main cause of the adverse influence of gusts. Disturbances originating in the free stream affecting the laminar boundary layer can normally only occur on control surfaces submerged in the turbulent wake of the wings.

Disturbances are thus caused mainly by surface imperfections such as roughness and waviness. Fortunately the boundary layer is well behaved and reacts to such things only when their height reaches a certain magnitude. The limiting height above which transition is influenced is called the critical roughness height (k) and is approximately 1/13 the boundary-layer thickness. Figure 12 gives critical roughness height for a flat plate of one meter chord with two typical Reynolds Numbers. If one wishes to transform these values for other chords (c) and Reynolds Numbers $Re=\frac{U_\infty c}{\nu}$* one can use the expression

* U = Aircraft velocity; ν = Kinematic viscosity.