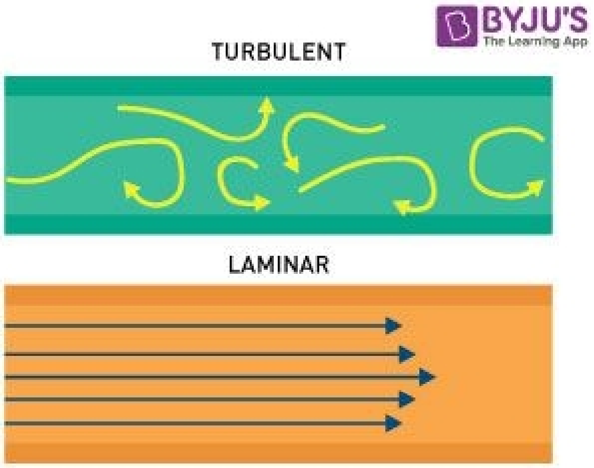
Model glider books by Martin Simons: Turbulators

This is more material from Martin Simons' excellent books, this time on the subject of turbulators. The Reynolds Number is central to fluid flow and has always been a bit of a mystery to me. Aircraft designers use scale models in their wind tunnel experiments so their experience is relevant to us. There will be more about the Reynolds Number in a future article but as Martin mentions it I have quoted a brief account from another source.

From https://byjus.com/physics/reynolds-number/
"Reynolds number is a dimensionless quantity that is used to determine the type of flow pattern as laminar or turbulent while flowing through a pipe. Reynolds number is defined by the ratio of inertial forces to that of viscous forces.

"If the Reynolds number calculated is high (greater than 2000), then the flow through the pipe is said to be turbulent. If Reynolds number is low (less than 2000), the flow is said to be laminar.

"The Reynolds number is named after the British physicist Osborne Reynolds. He discovered this while observing different fluid flow characteristics like flow of a liquid through a pipe. He also observed that the type of flow can transition from laminar to turbulent quite suddenly."



From here on all text and images are from Martin's books, in this case just two.

From 'Model Flight'

Figure 3.23 Laminar and turbulent boundary layers

3.18 Laminar and turbulent flow

In search of lower drag, much attention has been given, in recent times, to the flow of air within the boundary layer, the layer of air which is dragged along by friction with the skin of the wing rather than simply flowing past it. The boundary layer is often decisive in deciding when a wing stalls, since separation begins first in this layer. Within the boundary layer, two very different kinds of flow occur, laminar and turbulent (Figure 3.23).

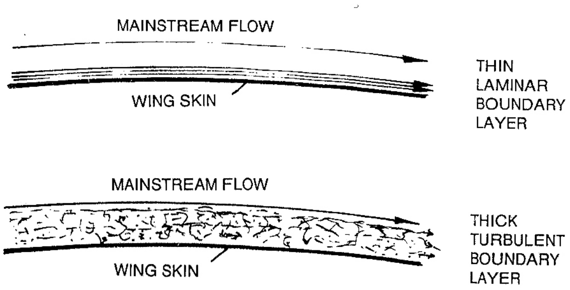


Figure 3.23 Laminar and turbulent boundary layers

A *laminar* boundary layer is one in which the flow near to the skin of the wing is arranged in very thin sheets or laminae which slide smoothly over one another with very little frictional resistance. A laminar boundary layer creates little skin drag. A *turbulent boundary* layer is very disturbed, particles moving up, down and sideways rapidly. This creates more frictional drag on the wing surface. The turbulent boundary layer is also thicker than a laminar one, so the general streamlined flow outside the boundary layer has to pass over what is, in effect, a thicker shape than if the boundary layer is all laminar. This increases form drag.

On full-sized aircraft, the boundary layer over a wing usually begins laminar, but after a very short distance, the smooth sliding flow breaks up and the boundary layer becomes turbulent (Figure 3.24).

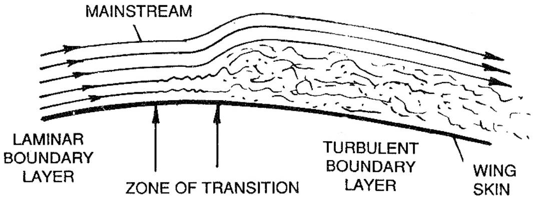


Figure 3.24 Boundary layer transition on full-sized aircraft

A rough visual impression of what happens may be obtained by observing the way water spreads out over a smooth surface, such as a bath or sink bottom, when a tap is turned on. The flow is laminar at first, but at some distance from the point where the jet of fluid strikes the surface transition occurs and turbulent flow, with an increase in depth, prevails. The boundary layer over a wing, although invisible, closely resembles this. Once transition takes place, the process cannot be reversed, so high skin drag continues on a wing aft of the transition, all the way to the trailing edge. (Experiments have been done with suction through small holes in the wing, to remove the turbulent boundary layer after it forms. This can restore laminar flow, but it soon changes again to turbulent. The suction has to continue to the trailing edge.)

Quite small defects, such as rivet heads and barely detectable dimples in the wing skin, fly specks and paint chips, can spoil even the small amount of laminar flow that exists. Hence full-sized aircraft often fly with fully turbulent boundary layers.

3.19 Scale effects

A few centimetres behind the leading edge of a large aeroplane the boundary layer usually becomes turbulent. Although the skin drag is high, at least the main airflow is not forced away from the surface. Model wings behave differently from full-sized ones in this respect. On a model wing, the few centimetres of laminar flow may extend from the leading edge to some point quite well aft on the wing, how far depending on the *chord* of the wing at each point, and the *speed of* flight. This at first sounds as if a model should have an advantage, in terms of profile drag.

Unfortunately this is not the case. A laminar boundary layer on a model wing, just because it does create less skin drag and has less transfer of flow energy to the wing, tends to separate from the surface altogether as soon as the point of minimum pressure (maximum flow speed) is passed. In the worst case, this separation is total. The wing stalls very early. Slow free flight models with thick wings and small chords suffer from such premature stalling and perform badly. With radio controlled models, if the wing is not too thick, what normally happens is the formation of *separation bubbles* (Figure 3.25).

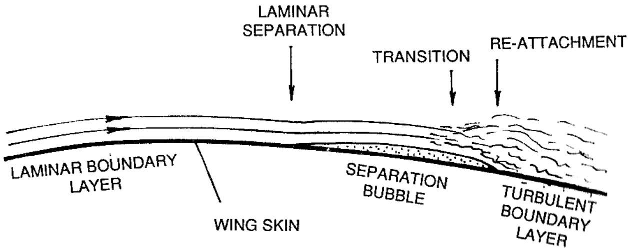


Figure 3.25 Formation of separation bubble

When the laminar boundary layer leaves the wing skin, after a short delay it usually breaks up into a turbulent layer, which is thicker. This increase of thickness allows it to reattach to the wing. Underneath the separated area is a ‘bubble’ of stagnant air which does not move downstream with the flow, but remains on the wing, with a circulation of its own. The separation bubble may be several centimetres long in the chordwise direction, and on a small model may cover most of the upper wing surface. There will usually be a lower surface bubble too.

The larger the wing, and the faster it flies, the less important these separation bubbles become. They do occur on full sized sailplanes, but on a large wing at high flying speed, a small separation bubble has little influence. On a model wing, flying slowly with small chord, such a bubble can cause a very serious deterioration in performance. It creates an effective disturbance to the mainstream airflow and this creates additional form drag. The effect of a separation bubble may be likened to opening a small airbrake, a few millimetres high, all the way from wing tip to wing tip, on the model. Model wings are therefore never as efficient as full sized ones.

3.20 Turbulators

It sometimes improves the performance of a small chord, slow flying model if the formation of a separation bubble can be prevented by triggering boundary layer transition before the minimum pressure point is reached on the wing. This can sometimes be done by using *turbulators* (Figure 3.26).

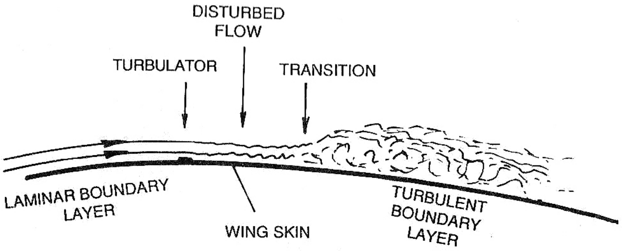


Figure 3.26 Forced boundary layer transition with turbulator

These are very thin strips of narrow tape, stuck onto the wing spanwise, some small distance ahead of the point where the separation bubble would be expected to develop. The turbulator should not be too thick, since if it is so, it might have a worse effect on performance than the separation bubble itself. There is some evidence to suggest that laying the tape in a fine sawtooth or zig zag fashion produces a greater effect. It is also thought by some model fliers that using a slightly rough wing covering material, such as fabric lightly doped, instead of very glossy film or paint finish, helps to bring about boundary layer transition. Very little definite information is available here as a guide, but turbulators are worth trying if there is any doubt about the performance of a particular model.

The tape strips can be placed in position and removed fairly easily, and the resulting change in model behaviour observed. The idea of using several turbulators or boundary layer *invigorators* one behind the other is also worth investigation. The intention is not to promote turbulent flow over the whole wing, but to preserve the laminar boundary layer over the forward part of the skin as far as it is safe to do so, then to cause transition just before the laminar separation point. Turbulators may be worthwhile on both upper and lower wing surfaces and experiment is, at present, the best means of finding out where they should be placed.

The separation bubble problem is only one aspect of the scale effect. Another problem is caused by the inherent viscosity of the air. Movement through viscous fluids, like treacle, is much more difficult than through less viscous substances like water or air. Although air is not very viscous, none the less it has a certain stickiness. For a very large aeroplane, this is relatively unimportant, but for small creatures, such as gnats and midges, flying is extremely difficult. To such small wings the air seems almost like treacle. To compensate, small insects beat their wings at extremely high rates, so the rate of airflow over their surfaces is quite high. Model aeroplanes come between these extremes, not so small as insects, but not so fast as full-sized aeroplanes. In relation to size of wing and speed, the relative viscosity of the air increases drag at all times. The fast flying model with large wing chord always has an advantage over the small, slow one with narrow chord for this reason, quite apart from the separation bubble effects mentioned above. Viscosity effects are felt more strongly by thick wings, which is another reason for using thin aerofoils on models, when minimum drag is required.

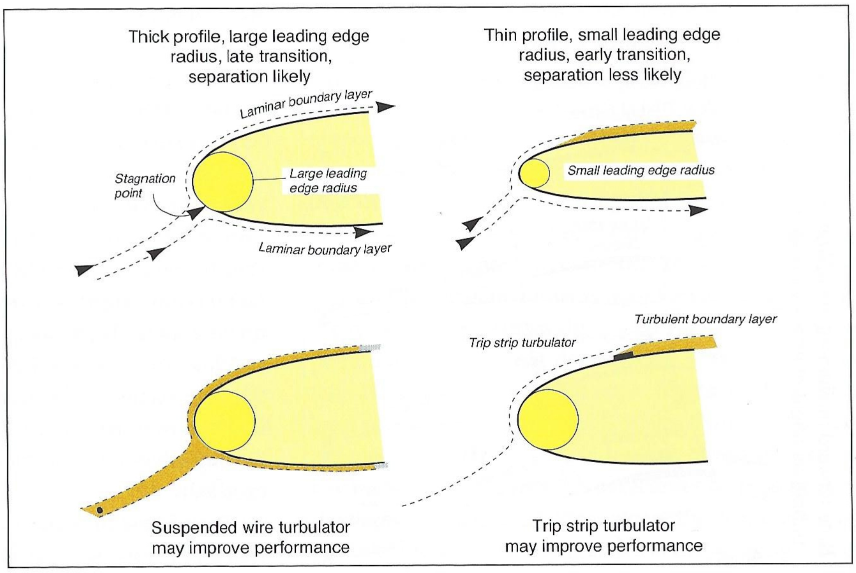
The scale effect is often expressed in terms of the Reynolds number or **Re**. Full-sized powered light aeroplanes fly at Re numbers greater than 1,000,000, sailplanes and ultralight aeroplanes rather less than this at their lower speeds. Pylon racing models and multitask sailplanes reach Re about 500,000 at their maximum speeds and widest wing chords. Most sports models fly at Re about 100,000 up to 300,000. Gnats and other small insects are down in the 5 to 10,000 Re range.

From ‘Model Aircraft Aerodynamics’

8.4 THE LEADING EDGE RADIUS

The reason for the low critical Re of these [] profiles was, Schmitz argued, their combination of very small nose or leading edge radius and relatively small upper surface curvature. The stagnation point of the airflow near the leading edge of a wing at a positive angle of attack is always slightly below the geometric leading edge. The boundary layer begins its journey over the upper surface by flowing around the leading edge itself. At high angles of attack, the flow in this neighbourhood is even slightly upstream (Fig. 8.7).

Figure 8.7 Flow near a wing leading edge.



From near stagnation, the boundary layer moves towards a low-pressure region on the upper surface and accelerates. If the profile has a smoothly rounded leading edge of large radius, as thick airfoils usually do, the boundary layer can follow this curve easily and remains laminar. If the leading edge radius is small, the boundary layer is compelled to flow round a very sharp curve or even a knife-like edge, changing direction very sharply while accelerating rapidly towards the low pressure point which, on profiles of this early kind, lies only a small distance behind the leading edge. The boundary layer inertia may be expected to overcome the viscous forces at this sudden change of direction and separate from the wing surface. It reattaches immediately the corner is passed, but a very small separation bubble, what Schmitz called a ‘rolled over vortex’, forms in the boundary layer. The small leading edge radius thus introduces some artificial turbulence into the airflow, encouraging early transition. The reattachment is not instantaneous. A separation bubble forms and the boundary layer reattaches some distance aft of the leading edge.

8.5 TURBULATORS

The effect of the sharp leading edge is very similar to that of a turbulator wire in the main stream ahead of the leading edge. A similar effect is obtained by mounting, on or just behind the leading edge, a raised 'trip strip' or leading edge turbulator, which may be of various forms and sizes. In each case, what is required is a brief separation bubble followed by turbulent reattachment downstream. A turbulator that is too small will not achieve the early transition, but one, which is too large, may itself cause flow separation.

Once the boundary layer has been forced into turbulence, it remains important that it should not separate from the upper surface. A profile with a turbulator or sharp leading edge still requires the air to flow against an adverse pressure gradient once it has passed the minimum pressure point. A thin profile presents a less formidable task to the boundary layer, so separation may be avoided, on the upper surface. On the underside, at high angles of attack flow separation is unlikely since once the stagnation point is passed, the flow tends to follow the surface of a thin profile closely. At low angles of attack underside separation is very likely behind the leading edge, but reattachment is still probable before the trailing edge.

8.6 SEPARATION BUBBLES

Schmitz did not investigate in detail the size of separation bubbles over his airfoils, and as shown in Fig. 8.3, these may be very extensive. The Go 801 profile tested by Kraemer is of smaller thickness than the N60 (10% as against 12.6%). It has a slightly smaller nose radius, but greater camber (7% at 35% compared with 4% at 40%). It thus comes somewhat closer to the thin curved plate profile, and its critical Re is slightly lower than that of N60. Some detailed measurements made by Charwat at the University of California in 1956-57 showed that a profile of the shape shown in Figure 8.8, with the small nose radius of 0.7%, also exhibited separation bubbles very similar to those of the 801 profile. The airfoil in this case, designed by Seredinsky following one of Schmitz's suggestions, was based on a profile of orthodox type, but the underside of the leading edge was cut away to produce a profile with room for wing spars, yet with the advantages of a small leading edge radius. In these tests, a separation bubble formed over about 35 to 40% of the chord. Above 7° angle of attack the bubble moved forward. Turbulent flow separation occurred over the rear prior to the stall, but the profile worked well.

The effect of the separation bubbles formation and movement is of considerable significance. The bubble is sufficiently large to divert the main airstream over the upper surface round a longer path, just as if the profile was more cambered. It has been established that a profile with the maximum camber point well forward develops a high maximum lift coefficient. The result of this effective camber increase *together with bubble movement forward* at high angles of attack, is to increase the slope of the lift curve above that which is predicted by theory. Such evidence as there is from model operations tends to confirm that some airfoils on small free flight models behave erratically. This may be attributable to shifting of the separation bubble, and its flattening effect on the chordwise pressure curve, to and fro on the wing as the angle of attack varies slightly. The fluctuating pressures over the profile cause sharp changes of the pitching moment that is already large because of the high camber of such wings. The hysteresis loop is caused by the bursting and re-forming of the separation bubble. A model in this critical Re region, capable of stable flight in smooth air, may become uncontrollable in rough conditions. These factors come together with the inherently pitch-sensitive qualities of the high aspect ratio wing to make the model sailplane operators difficulties more severe. Providing these problems can be overcome, there is no doubt that, for high performance at very low wing Re, thin, small leading-edge-radius profiles, appropriately cambered, are excellent.

By adding turbulators to thicker profiles, the low speed performance may be improved. The turbulators used by Schmitz and others were usually wires mounted ahead of the leading edge on light outriggers. For practical models, wires may be replaced by thin elastic or plastic strings. These are, however, a nuisance in operation and the leading edge ‘trip strip’ is easier to manage. Such strips have the advantage that they may be lightly pinned or ‘tack glued’ in various positions for trial, and moved or changed in size to give best results. If the critical Re of the profile chosen is already low turbulators cannot have much influence on still air performance. However, by triggering separation at a fixed point on the wing, they probably stabilise the position of the separation bubble, reducing the fluctuations of moment coefficient. The result should be an improvement in controllability of the model.

8.7 THE EFFECTS OF STRUCTURE AND SURFACE

Models constructed on traditional lines may in effect have turbulators built in. The sag of tissue or other thin covering behind the leading edge spar between the ribs creates a bump in the profile. This may have a beneficial effect on transition, and the good performance of some small, light models can be explained only in this way. Among his tests on the Go 801 Kraemer included tests of a paper-covered model which showed that sub-critical flow prevailed down to Re 42,000, comparable with the same airfoil with a turbulator wire. Wind tunnel results on a number of balsa wood and tissue covered wings, carried out at Stuttgart University and reported by Dr. D Althaus *(Profilpolaren* fur *den Modelflug, Vol.* 2) have shown the same effect at free flight model wing sizes and speeds. This suggests that attempts by modellers to preserve very accurate profiles over the front part of low *small* model wings are sometimes misguided. The simple tissue- or film-covered leading edge may prove more efficient than one with a perfect surface, especially if the wing profile used is on the thick side with a large leading edge radius. It should be emphasised, nevertheless, that when the model is large enough or fast enough to avoid sub-critical Re problems, turbulators and surface irregularities at the leading edge cause drag to rise and **cl** max [coefficient of lift] to fall. This may be confirmed by study of the many other wind tunnel test results now available.

The Seredinsky type of wing (Fig. 8.8) resembles the wing profile of some larger soaring birds. Although difficult to construct, it may prove effective on smaller models, or models with very high aspect ratio and small iving chords. The leading edge is similar to that of a simple curved plate, but the thickening of the profile on the underside provides room for a strong main spar without much effect on the upper surface flow.

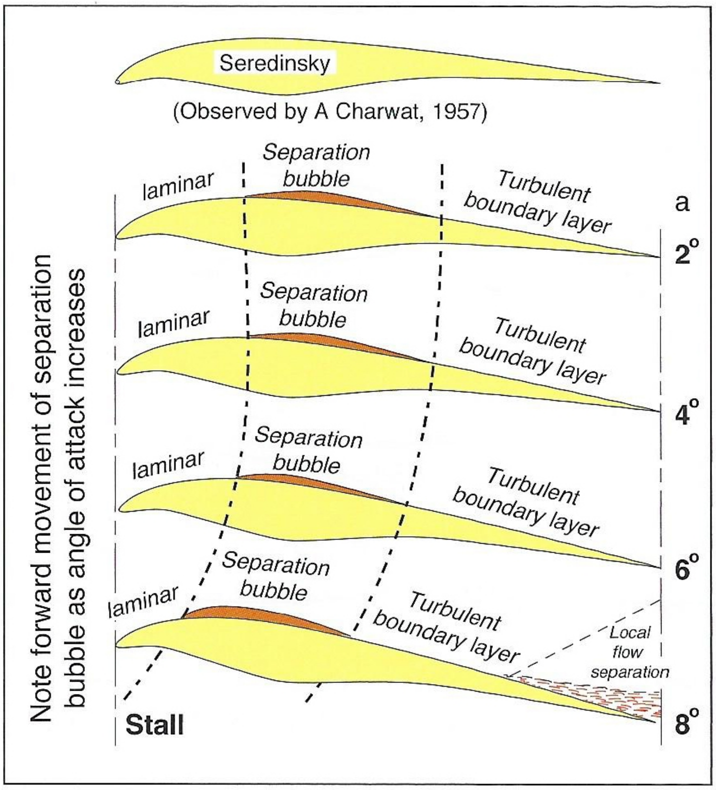


Figure 8.8 Separation and re-attachment on the Seredinsky profile.

8.8 BOUNDARY LAYER INVIGORATORS

Research by Martyn Presnell in a wind tunnel at Hatfield showed that improvements in the performance of freeflight model sailplanes and rubber driven airplanes can be achieved by the use of multiple ‘trip strips’ or, in Presnell’s terminology, ‘invigorators’.

Test wings using the Benedek 6356b were constructed from materials like those used in a typical FI A (A2) sailplane model. Balsa wood wing ribs and spars were used, the framework being covered with tissue paper, doped. In one case, the forward third of the wing was skinned with thin sheet balsa. Not only were lift and drag forces measured, but some flow visualisation tests were done. These involve coating the test wing with pigmented kerosene to reveal the nature of the boundary layer. Where the boundary layer is turbulent the kerosene evaporates rapidly, leaving a film of pigment. Within the laminar separation bubble, evaporation is less rapid so the flow of the air nearest the wing skin can be seen as the liquid moves upstream {}. In the fully laminar flow regions the kerosene remains liquid longer and flows in the normal downstream direction. The flow separation point and reattachment downstream of the bubble can then be discovered for each angle of attack.

(Modellers have sometimes noticed that, when flying in the late afternoon or early evening at dew fall, dew deposited on a wing before flight will still sometimes be present after the flight on the leading edges where the flow is laminar, but evaporates from the rear parts of the wing where turbulent boundary layers are expected.) In Presnell's tests the addition of a single turbulator at 5% of the wing chord improved the measured lift and drag figures, as expected, at Reynolds numbers below 40,000, although the separation bubble was still present. The turbulator consisted of a thin strip of adhesive plastic tape 0.15mm thick and 0.75mm wide, running spanwise.

It was then found that the addition of further strips of the same thin tape at various positions on the chord aft of the turbulator resulted in further improvements of lift and drag figures. The best results at Re below 70,000 were found with five of these invigorators in the positions shown in Figure 8.9. The original 5% turbulator remained in place throughout.

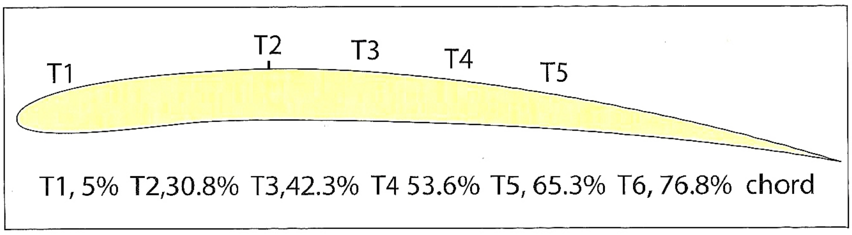


Fig 8.9
Benedek 6356b airfoil with turbulator and invigorators. From Martin Presnell

Presnell noted that placing an invigorator within the separation bubble, as revealed by the kerosene, made no detectable difference. The first invigorator must be placed just aft of the reattachment point and the others spaced over the rear part of the wing in the turbulent boundary layer. The exact mechanism of the invigorators is not fully understood at present. It may be that they aid the already turbulent boundary layer to remain attached to the wing after the bubble has been passed. Presnell pointed out that several leading contest model flyers used invigorators with success.

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