WIND TUNNEL

Does the shape of a wing's trailing edge make a difference in performance?

BY BARNABY WAINFAN

Reader Quentin Durham of Orinda, California is puzzled about a detail of the design of the Q-200 he is building. He writes: "The plans for my Q-200 call for distinctly square trailing edges, but this goes against everything I learned back in my Cleveland balsa model building days. What's going on?"

The shape of a wing's trailing edge can have a significant effect on its lift and drag. Trailing-edge shaping also has a dramatic effect on the hinge moments generated by control surfaces. Sometimes, very small changes in trailing-edge shape can affect the stability or the amount of force required to move a control surface.

When a wing is not stalled, the air flows smoothly over its surface. The only place flow separation is desirable is at the extreme trailing edge of an airfoil. For an airfoil to produce lift, the airflow must separate cleanly at the trailing edge and flow smoothly downstream from it. Named after the man who first described it mathematically, this is known as the *Kutta Condition*.

The maintenance of the Kutta Condition is vital to the production of lift. If airflow remains attached and wraps around the trailing edge rather than separating cleanly, lift is lost. The Kutta Condition is why, as designer John Roncz says, "All good airfoils are round in front and pointy in back." A sharp trailing edge ensures that the flow will separate and flow downstream.

Among the trailing-edge shapes that maintain the Kutta Condition are those that are sharp and those that are square-cut, like those described in Quentin Durham's letter. Although a square-cut trailing edge has two sharp corners instead of one, both are too sharp for the airflow to follow. Airflow on the upper surface separates from the upper corner and airflow along the bottom surface separates from the lower corner.

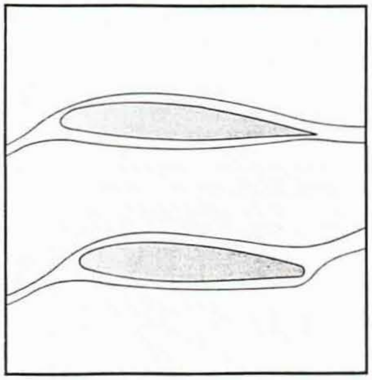

Figure 1. While airflow leaves a sharp trailing edge cleanly, on a round trailing edge, it wraps around and causes a loss of lift.

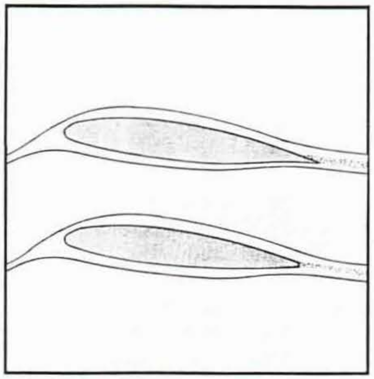

Figure 2. The wake from an airfoil with a sharp trailing edge can flow upward, causing a loss of lift, but the wake from an airfoil with a squared trailing edge remains behind the wing.

Sharp Trailing Edges

The angle between the upper and lower surfaces of an airfoil at its trailing edge is called the *wedge angle* or *included angle*. It can have a great effect on the aerodynamic characteristics of an airfoil. As the wedge angle increases, flow separation upstream of the trailing edge becomes more likely. If it is too large, airflow will separate forward of the trailing edge, causing increased drag, loss of lift and the possibility of unstable or nonlinear hinge moments on control surfaces.

In general, the wedge angle of a low-speed airfoil is a compromise between aerodynamics and ease of construction. In theory, the trailing edge of the ideal airfoil is sharp, with the upper and lower surfaces parallel at the trailing edge. A zero wedge angle between the surfaces necessitates making the airfoil extremely thin in the area just ahead of the trailing edge, which is essentially impossible to do.

The next best option for a designer is a sharp trailing edge with a relatively small wedge angle, which works well but is difficult to build and easy to damage.

Square-Cut Trailing Edges

A newer approach to trailing-edge design is the square-cut trailing edge, which makes the building process a lot easier. A thick trailing edge is stronger, stiffer and easier to build than a thin, sharp one. Now to answer Durham's question: What effect does squaring the trailing edge have on the aerodynamics of the wing?

When a square-cut trailing edge provides a clean separation of the airflow from the airfoil, the vital Kutta Condition is maintained. But if the upper- and lower-surface airflows separate from their respective sides of the trailing edge, they create a wake of separated flow in the region behind the vertical portion of the trailing edge that causes drag. In many cases, this drag caused by the separated wake may be offset by a reduction in drag or increase in lift on the rest of the airfoil caused by squaring off the trailing edge.

When an airfoil with a sharp trailing edge has a non-zero wedge angle, the air flowing near the trailing edge has a problem. Air following the upper surface is going one way, while air following the lower surface is flowing in a direction that is different by the amount of the trailing-edge wedge angle.

The two airstreams cannot cross over at the trailing edge; they must be parallel as they leave the airfoil. To become parallel, the two airstreams must leave the surfaces of the airfoil upstream from the point of the trailing edge.

In other words, an airfoil with a finite trailing-edge angle will always have a small zone of separated flow near its trailing edge that will form a wake similar to that formed behind a squared-off trailing edge. When the airfoil is placed at a lift-producing positive angle of attack, the wake moves upward slightly. This has the same aerodynamic effect as reducing the camber of the airfoil—it reduces lift.

When a designer creates an airfoil with a squared-off trailing edge, he is, in effect, filling in the separated zone on an airfoil with a sharp trailing edge. The wake is moved from the surface of the airfoil to behind the trailing edge, where it stays put despite changes in angle of attack.

As a result, an airfoil with a square-cut trailing edge has a higher lift-curve slope than one with a pointed, finite wedge angle, and it produces slightly more lift at the same angle of attack. The advantages of a chopped trailing edge can be increased if both surfaces of an airfoil are parallel at the trailing edge, and the thickness of a squared-off trailing edge makes this structurally possible.

The drag of an airfoil with a squared-off trailing edge will not increase noticeably until the thickness of the trailing edge exceeds about 0.5% of its chord. By creating an airfoil with a square-cut trailing edge, a designer can produce a section that is structurally superior and aerodynamically as good as one with a sharp trailing edge.

Arbitrarily sharpening the trailing edge of an airfoil with a squared-off trailing edge is not advisable. Doing so will structurally weaken the trailing edge and most likely increase rather than decrease drag. It will also have an undesirable effect on the feel of the controls.

A chopped trailing edge affects the hinge moments of control surfaces. Filling in the separated zone near the trailing edge of a square-edged airfoil increases the aerodynamic effectiveness of the part of the control surface farthest from the hinge, causing the control response to be crisper and more effective. And because the wake is filled in, the control surface does not have to move as far to cause a change in lift—they are, in effect, more effective, especially at small deflections.

The second effect of a square trailing edge is increased hinge moment. A surface with a square-cut trailing edge will feel heavier, which is one way of curing controls that are extremely sensitive.

Adding small, forward-pointing wedges to both sides of a control surface is a way of creating a squared-off trailing edge and making it feel heavier. The feel of controls can be adjusted by altering the size of the wedges and the amount of trailing edge they cover. If the total height of the pair of wedges is less than 0.5% of the chord, they will cause little or no drag increase.

Shape Ahead of the Trailing Edge

The shape of the airfoil ahead of the trailing edge can be concave, convex or flat. A convex aft end is more likely to cause premature flow separation and increased drag. A relatively flat-sided aft end is better, but one that is slightly concave usually creates the least drag.

Unfortunately, concave or cusped trailing edges are the most difficult to build. There is a temptation to simply draw a straight line over the cusp and fill in the concavity, but this can lead to flow separation and increased drag. Like most features of airfoil design, cusping can be overdone. If the trailing edge area is too concave, the flow will separate ahead of the concavity. Control surfaces that are convex on both sides are more likely to be unstable or flutter than those that are concave or flat-sided.

A word of advice to builders: Relatively small changes can have significant effects, so do not arbitrarily modify the shape of an airfoil without first checking with an aerodynamicist.

On some highly aft-cambered airfoils, the aft end is concave on one side and convex on the other. While this does not cause any major flutter problems, it does cause ailerons to try to float upward, putting increased loads on the controls. This is not a major problem on a large airplane with hydraulic controls, but on a lightplane it can lead to pulley failure and cable stretch. ❑

Aerodynamics questions of a general nature should be sent to "Wind Tunnel," c/o KITPLANES, P.O. Box 6050, Mission Viejo, CA 92690.