The Deturbulator Tape

(Revised 1/31/2012)

Introduction

A spin off of The Deturbulator Project (*www.deturbulator.org*) is a simple, cheap, easy to install modification that can add as much as 15% to the performance of some gliders. This article gives an overview of the concept, installation instructions, the testing that lead to this modification and a simple, non-numerical explanation of a theory that may explain how it works.

Overview

Fig. 1 shows a normal transition from laminar to turbulent flow that is typical of glider wings and other airfoils that operate at similar airspeeds.

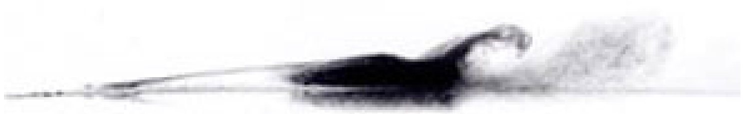

Figure 1: Smoke Image of Transition from Laminar to Turbulent Flow (Greg Cole and Prof. Mueller, Notre Dame)

This flow structure degrades performance in three ways. First, it increases the effective thickness of the wing, resulting in greater "form" drag. Second, because the reattachment angle is steep, the flow strikes the surface in a violent explosion of turbulence, adding to the energy transferred from the airframe to the trailing wake. Third, skin friction drag is increased because of the high level of initial turbulence in the reattached downstream flow. If the detached flow could be coerced to stay close to the surface and to reattach gently, at a grazing angle, these negative effects would be substantially reduced. This is the effect of a properly sized rear-facing step located near the leading edge of the wing where the pressure gradient is very steep.

Traditional turbulator strips (normally, thick zig-zag tapes with sharp edges) trip the flow near the front of the transition zone where the flow is still close enough to the surface for the turbulator strip to reach it. This eliminates the transition bubble and the steep, violent reattachment by prematurely tripping the flow from laminar to turbulent. But, there is a penalty since this method increases the surface area exposed to turbulent flow, thereby increasing skin friction. It now appears that there is another way to tame the transition, one that does not turbulate the flow but deturbulates it instead, thereby eliminating the penalty and adding new efficiencies.

Applied to the top surface, this method has produced odd polars (performance graphs) with very large performance swings that are extremely sensitive to very small changes in airspeed, making the glider difficult to fly effectively. All such measurements to date have been made with the step in one position only. I anticipate that moving the step aft a small amount will control this behavior at the cost of reducing the performance boost. However, substantial improvement has been measured with a step on the lower surface alone. This can be achieved at virtually no cost, with little effort and without significantly distorting the polar. It merely requires a tape of the correct width and thickness at the right place below the leading edge of the wing.

All testing to date had been done on a Standard Cirrus glider. This glider uses a **Wortmann FX S 02-196** airfoil (Fig. 2) at the wing root. This airfoil transitions linearly from the root to the inboard end of the aileron where a **Wortmann FX 66-17 A II-182** (Fig. 3) is reached. This airfoil remains constant over the outer wing panel, except for a narrowing chord and a washout twist of .75 degrees. All gliders with similar airfoils stand to benefit more or less as Standard Cirrus gliders do.

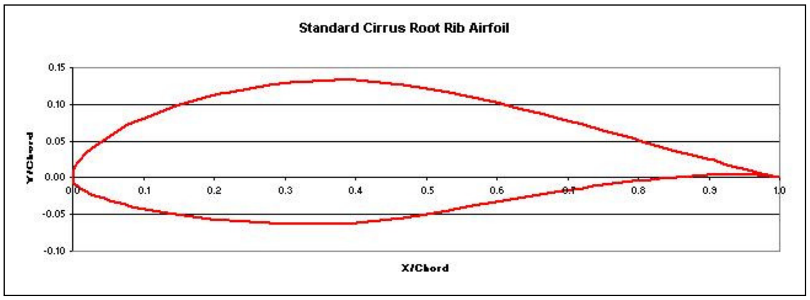

Figure 2: FX S 02-196 Standard Cirrus Root Airfoil

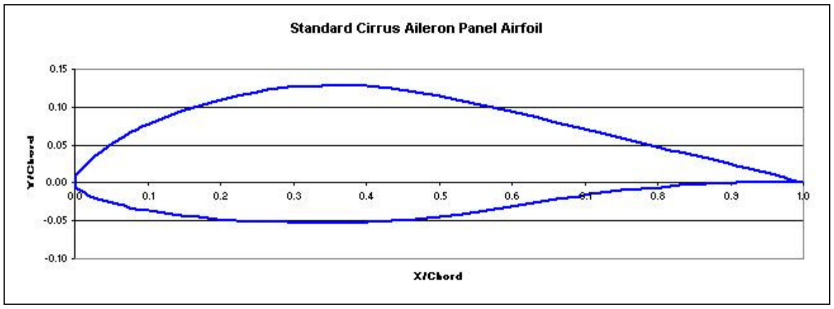

Figure 3: FX 66-17 A II-182 Standard Cirrus Outer Panel Airfoil

It is an open question whether this mod will work on modern, laminar airfoils. It is not hard to measure glider performance changes using a flight data recorder, so it should not take long for volunteers to begin producing results. A manual on measuring performance by the sink rate method and a spreadsheet for reducing and plotting the data may be obtained for a small fee from *www.oxaero.com/Oxaero-Performance.asp*. The funds help cover project expenses. If you don't want to pay, then you can download the files from *www.deturbulator.org/files.asp*.

Calibrating a glider's airspeed system is fundamental to measuring performance, but it is difficult because it requires calibrated apparatus and rare skills. However, this is not necessary for comparing before and after measurements on the same glider as long as you realize that the sink rate plot will be distorted horizontally and absolute glide ratios will not be accurate. This reduces the skills needed to picking good weather conditions and holding target airspeeds precisely for a minute. A minimum of three measurements are usually needed to average out scatter in the data from convection in the air. The spreadsheet provides for this. If you will be taking measurements, please report your results (*www.deturbulator.org/Contact.asp*) for posting on the Deturbulator Project website so it may serve as a clearing house for results on various glider types.

Installation

First, obtain a roll of smooth tape that is 1/2" (12mm) wide and .003" (76um) thick. The thickness is critical. It must be very close to .003" (76 um). Much thicker and it will trip the flow, thinner and it will lose effectiveness. Suitable tape may be obtained at *www.oxaero.com/Oxaero-Performance.asp*.

Next, mark a guideline 45 degrees below the nose of the wing. The point of this is to ensure that the relative wind sees the forward edge of the tape as a step up at all airspeeds. Then, given the thinness of the tape, the leading edge will have no significant effect. But, if the flow sees the forward edge as a step down, there will be a large loss of performance from top surface effects. To mark the guideline, first, level the wings in the chordwise direction. Jack up the tail until the leading and trailing edges are the same distance from the floor. Then, wrap some carbon paper around the base of an inclinometer and place it beneath the leading edge of the wing at an angle if 45 degrees, as shown in Fig. 4. Finally, slide the inclinometer along the wing while holding the angle at 45 degrees.

Figure 4: Marking the Guideline

All that remains is to apply the tape with the forward edge along the guideline. Avoid wrinkles and bubbles. Also, of course, make sure the tape's edges are not damaged in any way. Complete the job by pressing the tape down firmly and smoothing out any roughness or sharpness on the edges. It is not necessary for the rear edge to be sharp. A rounded step works fine.

Figure 5: Applying the Tape

This installation is not hard to do. It requires no special skills and can easily be done in less than an hour.

Testing

Since 2005, a large number of flights have been made with a two inch wide tape around the leading edge of a Standard Cirrus wing. Most of these flights were for measuring sink rate's in order to determine the functioning of a Deturbulator panel located at the reattachment point on the top surface of the wing. These measurements began showing positive results only when the leading edge tape was installed.

Dick Johnson tested this configuration in December of 2006 and found **13%** improvement at 50 kts indicated airspeed after averaging measurements from six flights. After discarding the three flights with the largest deviations, he got **18%**. A close look at his individual flights reveals deviations that are four to five times larger than the greatest Dick normally gets. Patterns in the data indicated that these deviations were not random. A year later, I recorded data that replicated one of the most extraordinary of Dick's flights, feature for feature. This confirmed Dick's measurement. Later, a third measurement further confirmed both of them. These are shown in Fig. 6 below.

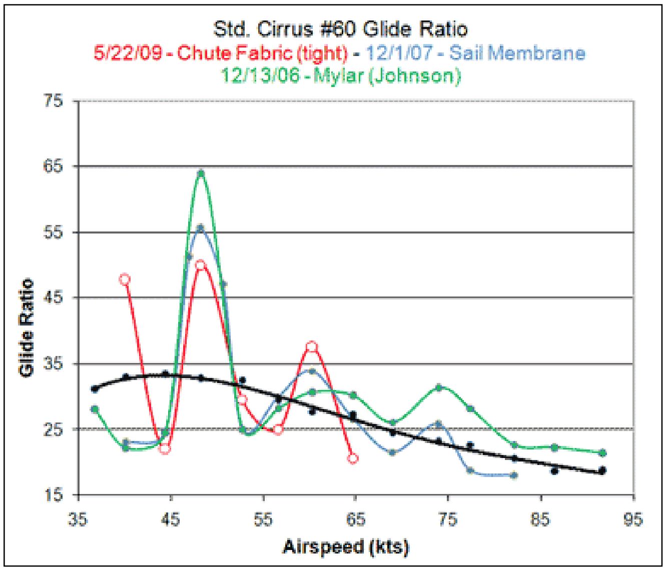

Figure 6: Peaked Polars with a Full Leading Edge Tape and Functioning Deturbulator Panels

Then, in 2010, wanting to know the effect of the leading edge tape alone, I took a series of measurements that agreed with prior ones in which the Deturbulator panels were not functioning. These produced similar polars with a deep performance notch (loss) precisely at 49 kts indicated airspeed and large improvements only one to two knots on each side. One, taken after I lost 34 pounds, produced a notch at 51 kts. These are shown in Fig. 7 below.

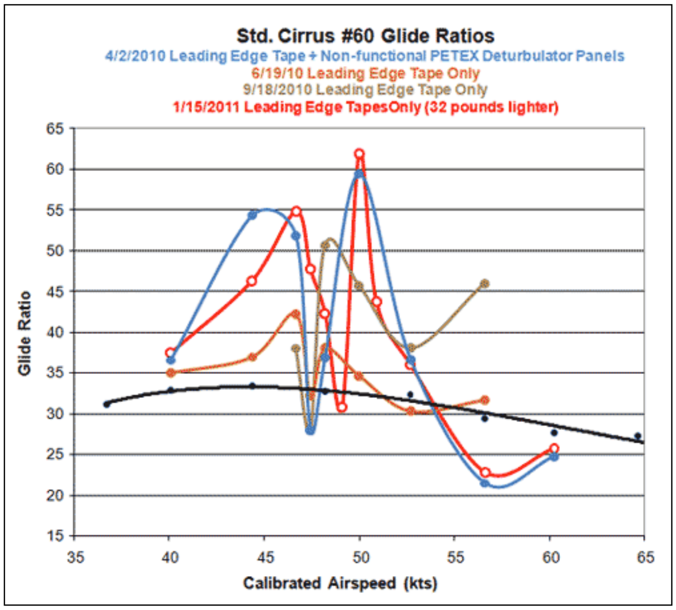

Figure 7: Notched Polars with Only a Full Leading Edge Tape

Although the two types of polar in Figs. 6 and 7 repeated they did not repeat consistently and they made the glider impractical for normal flying. Their only value was in demonstrating a concept.

Assuming that the notch was a top surface issue, I decided to test a lower-surface-only configuration. Thinking that the forward edge of the tape would be harmless at the nose of the wing, I removed the tape above the nose and left the lower part intact. The result (Fig. 8) was encouraging, disappointing and very revealing.

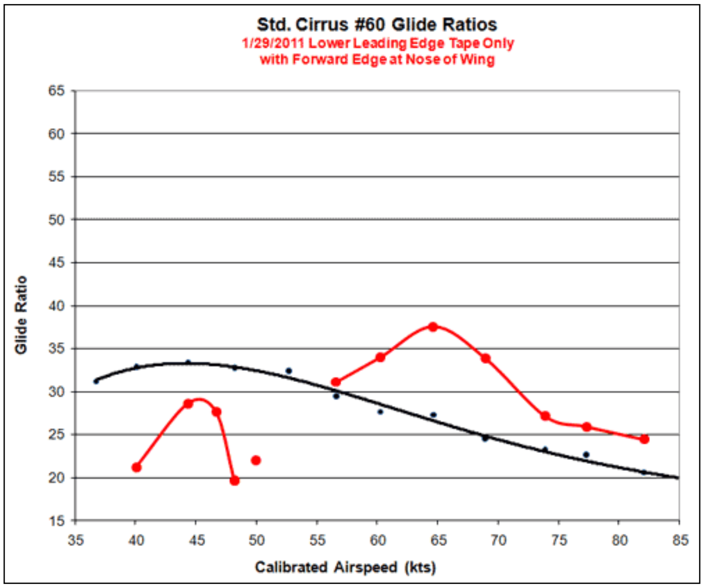

Figure 8: Glide Ratio Polar for Standard Cirrus
With Tape from Nose of Wing Down

All speeds above 60 kts saw a very nice improvement. But, lower speeds produced a severe loss. Also, the notch, that I thought was a top surface effect, remained. I did not take close points in that region because I was not expecting a notch. Also, inexplicably, I omitted the 55 kt point. So, that region of the curve is poorly defined. Nevertheless, the notch was clearly still present. Was it a bottom surface effect after all?

The main clue to what actually occurred came from noticing that 60 kts is the zero angle-of-attack (AOA) speed. All slower speeds have a positive AOA, causing the relative wind to see the forward edge of the tape as a step down, even though the relative wind is nearly perpendicular to the surface. However, from 60 kts up the relative wind saw the forward edge as a step up and that obviously had little or no detrimental effects.

The next experiment was obvious. I ripped of the old tape and replaced it with a narrower tape that was far enough under the nose of the wing that the relative wind would see its forward edge as a step up at every speed. This tape had essentially the same thickness and the width placed the rear edge about where the rear edge of the old tape was located.

The result (Fig. 9) met expectations. The low speed loss was corrected and the notch disappeared, indicating that it was a top surface effect after all. This is very revealing, as it shows that the top surface detachment point could be as far forward as the nose of the wing, but the effect of detaching the flow too far forward is hugely detrimental. Testing conditions were not good, so Fig. 9 shows a lot of scatter. Nevertheless, it clearly indicates a moderate improvement across all airspeeds from stall to 85 kts indicated.

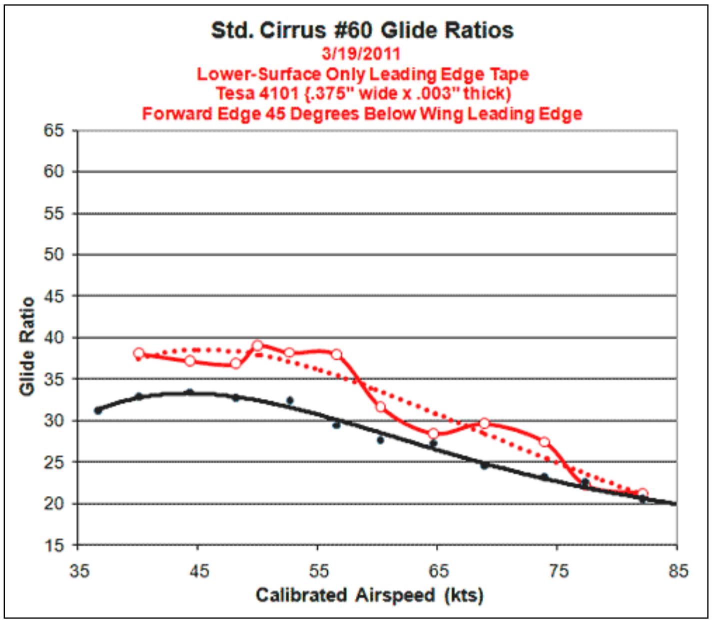

Figure 9: Glide Ratio Polar for Standard Cirrus With 1/2" Wide, .003" Thick Tape Located 45 Degrees under Nose of Wing

Given the history of measurements that led to this result, I have every confidence that further measurements will confirm and smooth this data. To help visualize the likely outcome, I fit a third order polynomial to the data in Fig. 9 (the dashed line). The actual polar may be lumpier than the curve fit, so the dashed line should be taken only as a rough indication of reality.

Humidity Dependence

Before going on to speculate about a theory for the leading-edge tape phenomenon, a curious thing about the notched polars in Fig. 7 needs to be considered. A reason for the wide variation in the amplitude swings needs to be considered. The fact that all four polars have the same shape, except for the amplitude of the L/D swings, suggests that the measurements are real and that there must be a dependency on some as yet unnoticed variable. Air density is not likely an issue since the measurements are vs. indicated, not true, airspeed. So there is an automatic adjustment, since the same stagnation pressure exists, regardless of the altitude at which the measurements were taken, for each speed. Although I may be overlooking something here, I moved on to consider humidity. Since the glider was not equipped with a humidity sensor, it was not possible to have accurate readings. Nevertheless, the general atmospheric conditions as a function of altitude are available in archival weather sounding websites and these include relative humidity. So, I measured the glide ratio delta from the bottom of the notch to the highest peak on either side of the notch for each of the four notched polars. These are depicted as pink vertical lines that are labeled A, B, C and D in Fig 9a below.

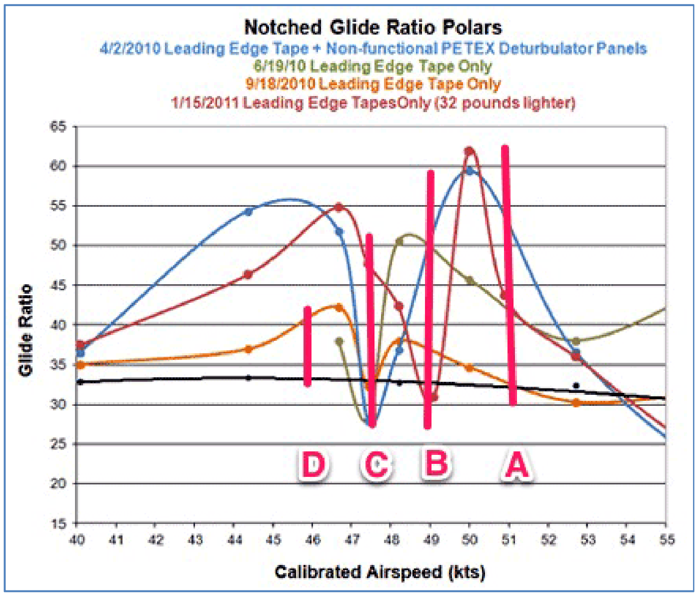

Figure 9a: Four Notched Polars with different Amplitude Deltas

Relative humidity readings as a function of altitude were found on the same days as the flight tests. Three of these were taken at Little Rock, AR, about 80 miles to the west of the glider port where the test flights occurred. One was taken from Jackson, MS, about 150 miles to the South. These distances put uncertainty in the results; however, the apparent dependency is so strong, that using the regional relative humidity aloft seems to be close enough to point out a real dependency. These are plotted in Fig. 9b below.

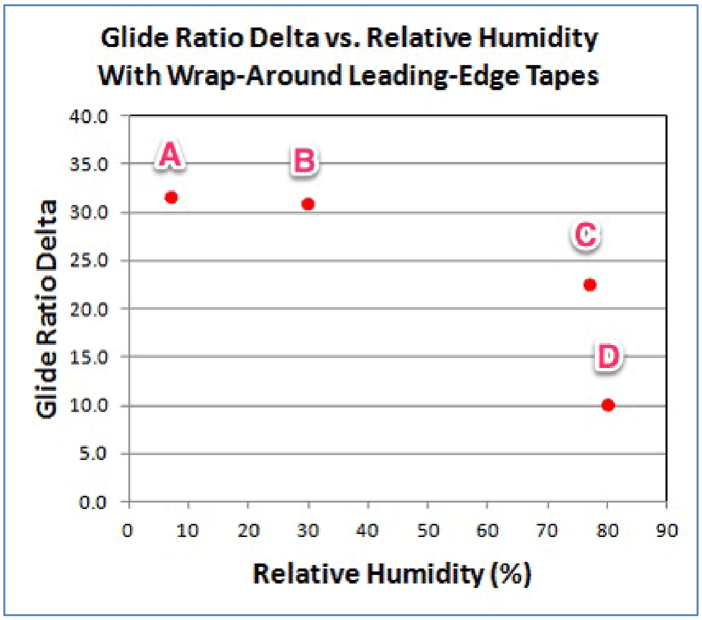

Figure 9b: Dependency of Amplitude Deltas on Relative Humidity

Assuming that Fig. 9b illustrates a real dependency, the implications are significant. It has been shown that air viscosity falls off with increasing relative humidity. If that is the mechanism that leads to the loss off of performance improvement, when the relative humidity goes over say 70%, then it is the case that the marginal detachment of the laminar boundary behind the tape does indeed occur over a bed of rolling vortices. Viscosity is required to create the vortices from the shear forces behind the tape. This implies a further condition that appears to have been seen when the tapes were installed on some other gliders. It is necessary for the thin leading edge boundary layer to be laminar and there must be sufficient skin friction on the wing surface behind the tape. In one instance a glider was carefully tested, but with tape that had a rough surface. There was no effect on performance at all. In another case, the wing surface was waxed and initial measurements failed, but after removing the was from the forward 50% of the wing surface, measurements consistently showed 15% improvement at 50 kts. Both of these cases involved a lower surface only tape.

It should be noted that no humidity dependency has yet been found for the lower surface phenomenon that consistently produces performance improvements of about 15% only.

Theory

The first thing to say about "deturbulation" theory is that it remains for professional aerodynamicists to work it out. I believe that when they have studied deturbulator steps, deturbulator panels and overall, wing flow dynamics they will produce a family of deturbulated airfoils that are optimized for gliders, UAVs, general aviation and wind turbines. Land vehicles may also benefit. Reynolds number, surface shape, roughness and waviness will limit applications.

With that disclaimer, here are my views. They may be proven wrong. No matter. The main thing is that deturbulation works. Fig. 10 shows a crude Navier-Stokes demonstration of a rear-facing leading-edge (deturbulator) step showing particle flow lines and the velocity field colored blue to yellow with increasing flow speed.

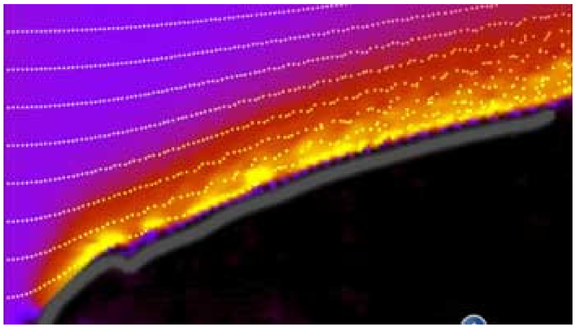

Figure 10: Velocity Field near Deturbulator Step

To understand what is going on, it is necessary to appreciate the importance of the strong pressure gradient near the leading edge of a wing. Fig. 11 plots upper and lower surface pressure profiles for a Wortmann airfoil. These are normalized to +1 that is shown at the bottom of the graph. Decreasing values go upward. All values above the zero line are suction values. The solid line applies to the top surface and the dashed line applies to the bottom surface.

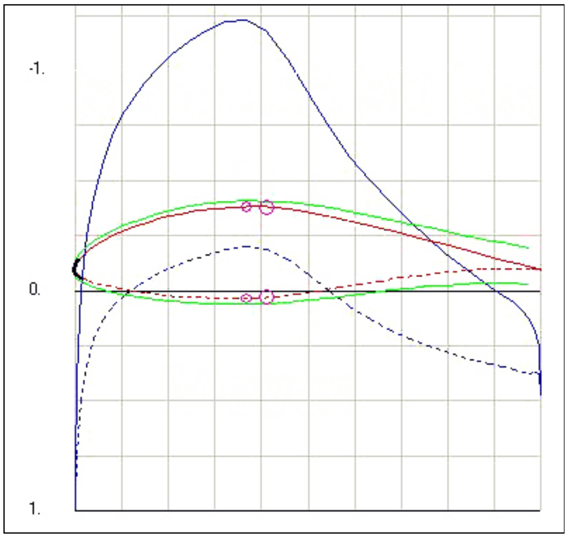

Figure 11: Pressure Profiles for a Wortmann Airfoil

Naturally, the pressure is highest at the stagnation point, where the flow strikes the surface head on. At that point, all of the velocity vectors of the particles in the flow stream are normal to the surface and exert the greatest pressure (force per unit area) on the surface.

As the stream is forced away from the stagnation point, it aligns with the surface and the pressure falls off rapidly because the momentum (velocity times mass) of the particles becomes parallel to the surface. Once the boundary layer is essentially parallel to the surface, the momentum of the particles tries to keep the flow moving in a straight line that departs from the cambered surface. As shown in Fig. 1, this eventually leads to a tangential departure from the surface. The detached flow then moves under the influence of pressure from the onrushing free stream flow. This curves the trajectory back to the surface where it collides at a steep angle, producing a circulation bubble and much turbulence in the downstream flow.

Now, let us insert a small, rear-facing step very close to the stagnation point where the pressure gradient (recovery rate) is very strong (Fig. 11). The figure illustrates a 2 inch wide tape wrapped around the nose of the wing. This is drawn to scale in order to accurately show the steepness of the top and bottom pressure gradients where the tape edges are located. This was the configuration when the measurements in Fig. 7 were taken. The present mod effectively provides only the lower rear-facing step. The step height is critical, as the step will trip the flow if it is too high and it will lose effectiveness with reduced height. For glider airspeeds, .003" (76 um) is about right.

Now, we need to consider the effects of viscosity. This property may be thought of as a clinging of the molecular layers in the flow. Classic theory says that the layer touching the surface sticks. The next layer, influenced by the layers above and below, moves at a retarded speed, and so on until the free stream speed is reached at the top of the boundary flow (green lines in Fig. 11). Thus, ahead of the step, the surface imparts a viscous shear force that retards the bottom of the boundary flow. But, when the flow reaches the rear-facing step, its momentum will not permit it to turn abruptly to follow the surface. This produces three effects.

First, the skin friction disappears, allowing the bottom of the flow to accelerate unimpeded under the influence of the strong pressure gradient. The accelerated boundary flow may be viewed as a flat jet of air carrying greater momentum than normal. To be sure, the mere diversion of the flow around the nose of the wing and the associated pressure gradient accelerate the boundary flow beyond the free stream speed. But, the rear-facing step frees the bottom of the boundary layer to accelerate to much greater speeds, thus increasing the momentum of the boundary flow. Assuming that this condition continues to the thickest part of the wing, where the pressure gradient reverses (higher pressure downstream), then the acceleration continues to that point, albeit at a decreasing rate.

Second, the accelerating flow is detached from the surface behind the step, well ahead of its normal departure point.

These two effects produce a modified boundary flow that, because of increased momentum, is straighter and is influenced less by the free stream and more by the angle of its departure from the surface. Fortunately, this angle can be controlled.

Finally, a low pressure zone is created in the shadow of the step. This tries to pull the accelerating flow toward the surface. However, because of viscosity, the high speed flow above imparts a shear to the thin layer between it and the surface. This creates a bed of rolling turbules that constitute the bottom layer of the modified boundary flow. Think of this as a "slip layer" because it may be compared a layer of roller bearings that allows the high speed flow above to slip over the surface without imparting a frictional drag force to the wing. At some point downstream, this faster, straighter detached boundary flow will depart from the slip layer and return to the surface where it will reattach as turbulent flow.

The true picture is more complicated than this and reveals a means of controlling the departure angle of the modified boundary flow. Notice in Fig. 12 the local high pressure zone behind the step where the flow rubs the surface before detaching. The size of this “local contact zone” depends on airspeed. Since it exerts a shear force to the bottom of the detaching flow, it sets the departure angle, trajectory and reattachment angle. For the top surface, the size and effect of the local contact zone depends critically on airspeed. On the lower surface, it is not so critical.

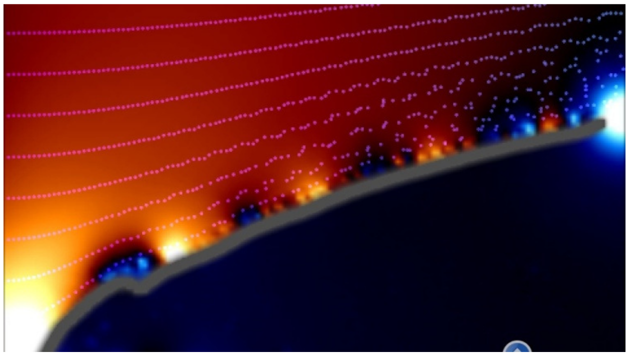

Figure 12: Pressure Field near Deturbulator Step

Another way to control the detached flow path is to move the tape fore or aft on the wing. This changes the strength of pressure gradient and angle of the flow where it detaches from the surface. Figs. 8 and 9 suggest that moving the step forward increases the momentum of the detached flow and gives it a trajectory that is higher; whereas, moving it aft reduces these effects. I believe that the testing to date has been done with the top surface step too far forward for practical use. Moving it aft slightly may eliminate the performance notch (Fig. 7) at the price of reduced performance improvement.

Now, we come to the good part. How does the modified trajectory of the detached flow differ from original one pictured in Fig. 1? To answer that question, I can point to in-flight performance measurements and oil-flow visualizations. First, look at two oil-flow images. Fig. 13 shows oil accumulated by a normal lower surface transition bubble.

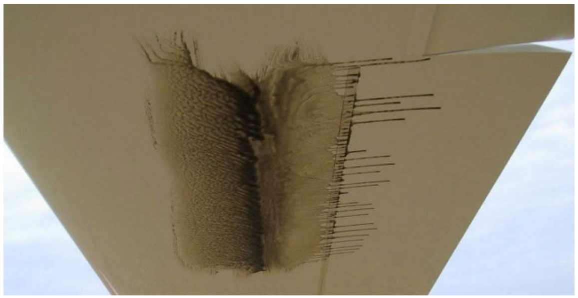

Figure 13: Normal Lower Surface Oil-Flow Image

And, Fig. 14 shows a similar image, but modified with a deturbulator tape at the leading edge of the wing.

Figure 14: Modified Lower Surface Oil-Flow Image

The latter case shows no hint of a transition bubble. This suffices to make the case that a rear-facing step of about .003 inches on the lower surface near the leading edge markedly improves the efficiency of the boundary flow over the bottom surface.

Finally, the modified polar in Fig. 9 shows a moderate improvement that seems consistent with the modified boundary flow described above. Of course, only a realistic numerical analysis can say for sure. And, that will have to wait. In any case, something about the lower surface flow must have changed to account for the improved performance.

From the explanation above, three mechanisms can be identified that combine to produce the large measured performance improvements.

1. The area near the leading edge of the wing that is exposed to laminar, high pressure skin friction is reduced.
2. Flattening the separation height reduces form drag.
3. The gentile, grazing angle reattachment begins the region of attached turbulent flow with no initial turbulence, resulting in less energy lost in the trailing wake.

Conclusion

Attached laminar flow has been the goal of aerodynamics since the introduction of laminar airfoils nearly seven decades ago. Now, it appears that there is another technique that potentially offers much more improvement. The simplest form of this method is a rear-facing step of the right height near the leading edge on the lower surface of an airfoil. This simple device can be added to existing wings cheaply and easily, merely by attaching a strip of tape of the right thickness. This works on Standard Cirrus Wortmann wings and likely also on other similar wings. Applicability to modern airfoils remains to be determined. A formal theory remains to be worked out by aerodynamicists. After that, it is easy to imagine a family of airfoils designed specifically to maximize deturbulator efficiency for many applications.