

THE YAW STRING METHOD OF TINKERING WITH SAILPLANE WING DESIGN

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Submitted to the SSA office.

SUMMARY

I know you won't believe this, but I actually fine-tuned my Ventus B wing to my style of flying by putting turbulator tape at different test positions on the upper surface of the outer 12 feet of one wing and recording the amount of good and bad yaw at low and high airspeeds. When I found the desired compromise chordwise position, I put tape on the entire wing. I wouldn't waste your time reporting the small amount of change to an already outstanding Ventus wing, except I believe the test method is well worth spreading around. Any sailplane owner who wants to tinker with turbulator tape on his wing can use it. It does not require a great background in aerodynamics, sophisticated test instruments, or getting oil in your aileron seals. It just requires an inquiring mind and the time to make multiple test flights. I tinkered for most of two soaring seasons of pleasure flights, and no flight was devoted entirely to this test.

INTRODUCTION

I stumbled onto this method quite by accident. Back in the '80s when Carl Ekdahl was still flying his Libelle, he did extensive drag rake analysis on his wing. As a result, he put turbulator tape on the underside of his wing from wing root to the inboard end of the aileron at about the 75% chord position. I simply measured where his tape was and put tape at the same position on my Libelle wing. It appeared to cruise better than other Libelles, but I made no attempt to validate the amount of improvement.

Sometime later, I damaged a wing during a land-out. During my first few flights of the repaired Libelle, I couldn't help but notice it had a considerable amount of crab at cruise airspeeds, with the recently repaired wing showing more drag than the other wing. I finally noticed the tape had been removed during the repair. I put tape back on, and it has flown straight and true ever since (even taking sixth place one day in the 1996 Standard Class Nationals). I was amazed that the difference in drag between turbulator tape and no turbulator tape inboard of the ailerons would cause that much yaw. One would expect even more yaw if the tape was limited to the outer portion of one side of a sailplane wing. I filed this experience away in my sailplane memory bank.

When Carl bought an ASW-27, I eagerly took his Ventus B off his hands and renamed it PC2. Hereafter, I will use "PC2" instead of "Ventus B" because my comments refer only to that specific sailplane and not necessarily to all Ventus Bs. I immediately fell in love with the way PC2 penetrated at high speed and made altitude during por-

poise maneuvers. But I hated the way it thermalized. I was too accustomed to pulling back on the stick of my Libelle until just above the stall and corkscrewing around near the core of a thermal. I could not come close to doing this in PC2. To get maximum performance takes an entirely different thermalizing technique, to which I'm not sure I want to adapt. I think a related problem occurs during landing round-out: the sailplane appears to sink into the runway abruptly with flying speed still remaining, even while increasing pitch attitude.

The wing on PC2 appears to have a sharp increase in drag starting four to five knots above the stall with no other indications in the airframe. The sailplane sounds alright, feels alright, and controls alright; it just starts sinking at a rapidly increasing rate as stall is approached. I have trouble judging where this increased sink rate starts when I am in a steep turn trying to center a small thermal. To avoid the high sink rate, I must set target speed of four to eight knots above the stall, which I think makes the turn radius too wide for most tight Rocky Mountain thermals.

In my unsophisticated mind, the wing appears to have a laminar flow bubble that starts separating well above stall speed. My objective in tinkering with PC2's wing was to trip the laminar flow to turbulent flow before it started to bubble, thus improving the way it thermalized, provided I could do that without incurring too large a penalty at the high speed end. I reasoned that I normally spend a lot more time thermalizing than I do penetrating at over 120 knots. I am willing to give up some penetrating ability at the extreme high speed end, if I can thermal better at the low speed end.

TEST METHOD SUMMARIZED

1. Install a very accurate yaw string. On the inside of the canopy, trace a centerline and tie marks to at least 10 degrees each side of centerline at 2 degree intervals.
2. Clean the wing and test the "baseline" sailplane without any tape. Make sure the yaw string naturally stays centered in level flight at all airspeeds from V-stall to V-max.
3. Punch out a series of "V's" on a 12 foot strip of 3/8" wide business labeling Dymo tape. Use more expensive zigzag tape for final adjustments.
4. Mark accurate chord positions on the outer 12' of one wing.
5. Install the tape with the pointed end of each "V" facing forward. Be careful not to flatten the "V's" when pushing down the tape (push hardest on the edges).
6. Test fly. Record yaw indications at crucial airspeeds/conditions. Drag differences not large enough to cause a noticeable yaw are assumed to be too small to worry about.
7. Install new tape at a new position. Clean up the old tape residue and restore to baseline conditions, including polish and wax.
8. Test fly again. Record yaw indications at crucial airspeeds.

9. Continue steps 7 and 8 until you are satisfied with the compromise.

PREPARE THE SAILPLANE

Measuring the Wing Chord. The chord positions reported in this article may not be absolutely accurate when measured according to aerodynamic definition. Since I was experimenting with relative positions along the wing chord, I wasn't fussy about absolute measurements. I am comfortable I achieved the compromise I wanted because I used the same procedure each time to define the chord positions. Figure 1 shows the crude method I used.

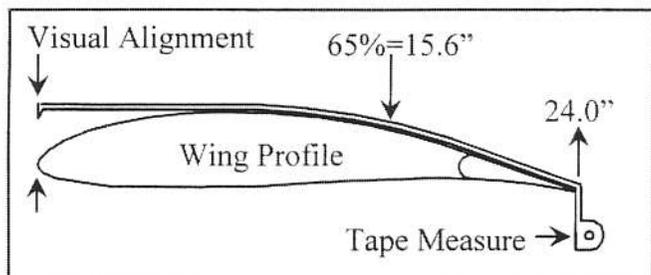


Figure 1. Measuring the Wing Chord.

(1) While standing behind the wing, lay a tape measure along the wing surface parallel to the fuselage line with the zero end of the tape at the front and the tape housing end drooped over the trailing edge; (2) push the tape down onto the wing near the center so the forward part extends approximately level; (3) lean forward and "eyeball" the zero end of the tape at the leading edge of the wing; (4) hold the tape down along the rear surface of the wing and read the chord length; (5) calculate the % chord value desired, e.g., $24 \times 65 = 15.6$; (6) put a pencil mark at that value.

Where to measure the Wing Chord. The tape should lay in straight lines between points defined by discontinuities (break points) in the wing's plan form (see Figure 2).

I recorded very accurate chord measurements at the four break point positions and used an Excel spreadsheet to create a table of measurements for 60%-70% chords at 1% increments for the four positions. Then I held the tape

across the break point position with the chord measurement value at the trailing edge, selected the applicable % chord value from the table, and made a pencil mark at that tape measure value.

Turbulator Tape. Since plain labeling tape sold in business stores had been successful on the Libelle, I decided to use it again. Besides, it was cheap — about \$1.60 for a 12 foot roll of 3/8" wide Dymo tape. I could punch out an entire roll in about 10 minutes, and it was good exercise for my hands. I made an important discovery by being lazy and using the same strip of tape at too many wing positions: the letter indentations tend to lose sharpness before the glue loses its effectiveness (provided you use acetone to clean the narrow strip along the wing planned for the tape). More about tape thickness and using acetone later.

Compared to the straight-edged labeling tape, the shape of the professionally made zigzag tape used by the sailplane community would appear to do a better job of stirring up the laminar flow boundary at low speeds/high angle of attack (AOA) and to present less drag at high speed/low AOA. This tape is too expensive (roughly 11 times the cost per foot than Dymo tape) to replace very often. Consequently, I decided to do initial investigations with Dymo tape and make final adjustments with the zigzag tape.

Installing the Tape. After marking the positions for laying the tape, I used a rag dampened with acetone to clean a narrow strip where the tape would lie. I had to use more acetone on a rag to clean up tape residue after removing a strip of tape. I discovered that the acetone cleaned everything from the surface, including wax. After experiencing problems on early flights, it finally occurred to me to go back and wax this part of the wing after removing tape from the 55% and 60% chord positions. I hadn't realized that wax was so important to laminar flow. I also discovered that tape laid on a waxed wing stuck good enough for one test flight and was a lot less messy to remove. To provide a straight edge between break point measurements, I used some of my wife's "button hole" thread, which is slightly thicker and stronger than normal sewing thread. I even put wax on a rag and pulled the thread through it to coat the thread and reduce the amount of fur sticking out. Then I stretched the thread beyond either

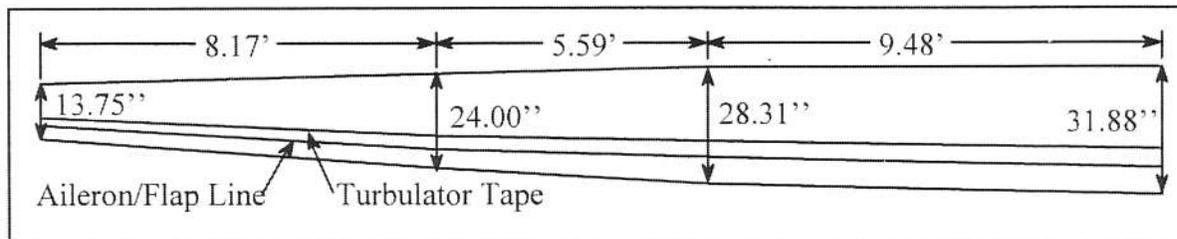


Figure 2. Break Points in Left Wing Plan Form.

end of the segment to lay down turbulator tape, so the hold down plastic tape for the thread would be outside that segment. With only a moderate amount of tightness, the thread stayed straight between points. I did only one straight segment at a time, then moved the thread position.

RESULTS

On the baseline test with no tape installed, the yaw string stayed centered at all airspeeds. On straight ahead stalls, it broke clean with no wing drop; higher sink rate was noticeable 3-5 knots above the stall. In turning stalls in both directions at 45 degrees of bank, the inside wing stalled first.

My first evaluation flight (Flight 2) was with Dymo tape with "V" lettering 0.019" (0.48 mm) high on the outer 12' of the right wing at 65% chord. On takeoff, the right wing leaped into the air before the left wing as if a gust of wind had hit it. While wings level, good yaw (taped wing moving forward) started about 3 knots above stall for flap setting at 0, +1 and +2, increasing to 10 degrees about 1 knot above the stall. At stall, the sailplane yawed further left and the left wing dropped off. In turning stalls at 45 degrees bank, the left wing always stalled first, even in a right turn. The yaw string stayed centered at all airspeeds from 55 knots to 110 knots. At 120 knots, bad yaw (taped wing moving aft) started creeping in, increasing to about 3 degrees at 130 knots. This was a very encouraging test flight.

I kept experimenting. One flight had tape at 60% chord on one wing and 55% chord on the other side. Low speed results were excellent. I could not stall the sailplane in wings-level flight. It munched along three to four knots slower than in the baseline test, but would not fully stall. In turning stalls, it broke away from the wing with the tape at 55%. On the other hand, bad yaw could be detected at cruise speeds as low as 85 knots. I had trouble cruising with a DG-400. An idea finally penetrated my brain, "Why pay 30 kilobucks to upgrade from a Libelle to a Ventus, then add 70 cents worth of tape to the Ventus wing to turn it into a Libelle?" I leave to someone else the opportunity to investigate the effect of turbulator tape forward of the 60% chord position on the upper surface of a Ventus wing.

After 15 test flights with various types of tape at various chord positions, I finally settled on tape type, thickness and location. From a pure profile drag standpoint, I didn't want a very thick strip of straight edge tape laid out on the top of the wing acting as a long spoiler. I wanted zigzag tape just barely thick enough to trip laminar flow to turbulent flow at the desired chordwise position and at thermaling airspeeds. I used tape 0.40 mm (0.016") thick on the outer 12 feet of wing and 0.50 mm (0.20") thick on the inner wing portion. The leading edge of the tape was at 64% chord position, which put the crotch at 65%-66%. With this tape on only one wing, good yaw was noticeable about four knots above stall and bad yaw was not noticed until almost 120 knots [Note. After settling on the 64% chord position, I measured a DG-600 wing's turbula-

tor tape at 66.7%.]

With tape on both wings, the yaw string stayed straight down the centerline at all airspeeds; the sailplane was difficult to stall in level flight; when it did stall, it did not drop off to a particular side. Level flight stall speed was reduced more than one knot compared to the baseline. PC2 also appears to land much smoother: it does not sink into the runway with flying speed still remaining. In the few pleasure flights to date, PC2 climbed as well as some pilot-sailplane combinations that out climbed PC2 in the past, and it appeared to penetrate at speeds up to 120 knots as well as it did prior to adding the tape. I am perfectly happy with the small changes to PC2's performance as a result of the turbulator tape on the upper surface of the wing.

I also did limited testing of the 16.6 m wingtip extensions. Initial results show that laying 0.40 mm thick zigzag tape tapering from 63% chord length inboard to 60% outboard gave good yaw at low speed and no yaw at up to 125 knots. Yaw testing with these wingtip extensions was not as precise as with 15 m winglets, because yaw stability was not as good, particularly in turns. So, I am not as confident with these results as I am with 15 m results.

OTHER LESSONS LEARNED

Valuable Unplanned Lesson. A relatively simple test plan was complicated by too many unwanted variables that affected the wing's laminar flow characteristics more than turbulator tape position. Unwanted variables include atmospheric conditions, tape thickness, tape residue, removing wax while cleaning tap residue, loose fairing tape or any wing surface imperfection such as bugs, hangar dust, or water spots.

Many flights were basically wasted proving that the wing surface must be polished, waxed, and cleaned to a shiny look and smooth feel or it will not allow laminar flow to occur over the designed extent of chord. Stated another way, imperfections on the wing surface make turbulator tape on rear parts of the chordline irrelevant.

If you plan to experiment with turbulator tape, you must appreciate that tape location and thickness are extremely critical, and the way they interact makes it difficult to optimize either. On the one hand, tape mounted well forward on the upper surface may help thermaling flight, but it negates the designer's hard efforts to achieve maximum laminar flow; consequently, flight at all cruising speeds will suffer. The further forward the tape, however, the less thickness required to trip the boundary layer. On the other hand, tape mounted too far aft, close to where the natural high-AOA laminar flow bubble starts to bulge, needs to be much thicker, probably even thicker than theory predicts, to trip laminar flow. The unnecessarily thick tape results in unnecessary drag at low AOA (high airspeed).

Furthermore, any hangar dust collected overnight will cause the high-AOA bubble leading edge to move forward. If you "cut it too fine" and mount tape only slightly ahead of the natural high-AOA bubble on a clean wing,

the tape will be "hidden" under the high-AOA bubble of a dusty wing, as if it were not even there. Yet the tape will still create drag at low AOA. It's a touchy trade-off, which might explain why more sailplanes don't leave the factory with turbulator tape installed on the upper wing surface. Something else to consider. It may well be that Gerhard Waibel is on to something in his design criteria for the ASW-28 (Reference A). He says aerodynamicists assume air is non-turbulent and have worked very hard to develop laminar flow wind tunnels to test their airfoils. On the other hand, weather people say that all air is turbulent to some degree, even the clear air outside of thermals. Hence, designers should concentrate on profiles that are tolerant of rough air.

This was made clear to me on two successive flight, one in wave and the other in thermals. The flight in wave was with 0.4 mm thick tape at 64% chord on the outer 12' of the right wing. I messed around in tertiary and secondary wave while carefully slowing down to stall speed with flaps at +1, then penetrated between waves at 100-130 knots with -2 flaps, working my way to the primary wave. Good yaw started at least 4 knots above stall. Bad yaw was not noticeable until airspeed was above 120 knots. These results, in the laminar flow conditions established by the wave, were the best and cleanest I ever saw during the test.

The next flight was in thermal conditions. Zigzag tape 0.5 mm thick had been added to the inboard part of the right wing at 64% chord, in other words, tape was on the entire right wing instead of just the outer 12 feet of wing. Low and high speed results were appreciably the same as on the previous flight. I could see no improvements by adding tape to the inner portion of the wing. If anything, results could have been slightly worse after adding tape to the inboard half of the wing. Could it be because this flight was made in non-laminar conditions?

Unfortunately, I never tested tape conditions for both flights in the same weather conditions, either laminar or turbulent. That is a good candidate for follow-on testing.

I have no academic credentials to add to the turbulent air versus non-turbulent air debate. I do know, however, that on a majority of days when sailplanes fly, lift is provided by thermals, not wave or ridge (which can be turbulent near the ridge and almost laminar away from the ridge). Whatever the atmospheric conditions, the sailplane wing will be required to sustain low-speed flight while in lift and high-speed flight while not in lift. Hence, I plan to continue most low-speed flight while in lift and high-speed flight while not in lift. Hence, I plan to continue most low-speed tests in whatever lift I can find and most high-speed runs in whatever neutral air I can find away from the lift. When making crucial tape changes I will make special effort to make both comparison flights in the same atmospheric conditions, primarily conditions supporting thermals.

CONCLUSIONS

1. The Ventus wing (at least PC2's) is sensitive to minor imperfections on the surface. A polished and waxed sur-

face, recently washed and buffed to a shiny look at smooth feel (upper and lower surface) is necessary to achieve maximum laminar flow performance. If acetone or similar cleaners are used anywhere on the surface, that part of the wing should be polished and waxed again.

2. The Ventus designer/manufacturer achieved a very effective trade-off between thermaling and penetrating performance. This trade-off can be adjusted slightly toward better thermaling by using zigzag turbulator tape on the upper surface of the wing at the 64%-66% chord position.

3. Turbulator tape thickness and location are very critical when used to trip a laminar flow bubble on a modern sailplane wing. The way the two variables interact compounds the problem of optimizing either one.

4. The "yaw string method" is easy to use on similar investigations of other aircraft, provided the tester is careful to control unwanted variables. A pilot can investigate options by exploiting this simple fact: drag difference between the left and right wing equals yaw.

POSSIBLE FOLLOW-ON TESTS

1. Inboard Wing. Most tape location testing in this series was limited to the outer 12' of wing. I should take the time (and cost) to remove all tape, then selectively add it to different chord locations on the inboard part of one wing and test results in atmospheric conditions supporting thermals. In addition to finding option thickness and location, this investigation should either add credence to or discredit conclusions regarding turbulent versus non-turbulent air.

2. Lower Surface Turbulator Tape. The zigzag tape on the under side of PC2's wing is at a constant distance forward of the aileron/flap line. This not not at a constant chord position. Can this tape position be adjusted to improve normal cruise performance with minimum degradation to high-speed cruise flight? What tape thickness is best for inboard and outboard sections.

3. Winglet Tape Thickness. PC2 has th 0.4 mm zigzag tape on the winglets. Per Dick Johnson in Reference B, this may be too thick, creating unnecessary rag. Would home-mad zigzag tape 0.229 mm/.009" thick do the job? Would the slight drag difference that far out on the wing create noticeable yaw?

4. Any suggestions? Please e-mail me at acechase@flash.net. (Complete test results are available from the same e-mail address.)

REFERENCES

A. "ASW-28 Design Considerations," a briefing by John Murray at the 2000 Soaring Convention.

B. "Are Your Turbulators Too Large," R. H. Johnson, Soaring Magazine, January, 1995