A new wing planform with improved low-speed performance

by WIL SCHUEMANN

Figures and selected photos by the author

Figure 28 — AS-WS 12 Wing

Michelle Silver

Introduction

I have been exploring an area of sailplane design which to my knowledge has not heretofore been examined. Using a new theory, I have been able to considerably improve the climb and zoom performance of my AS-W12 through a redesign of the sailplane's wing planform. I have no plans to pursue the subject further and will report on what I have done in the hope that others, who have access to suitable computer programs and wind tunnel facilities, will be encouraged to further study the idea to both verify the theory and to provide the design optimizations needed to fully exploit its potential.

While contemplating reporting on the work I've done, I found myself in the unenviable position of not feeling completely comfortable about writing a formal technical paper because I have acquired less data than I consider necessary to fully substantiate the theory presented here. At the same time it is appropriate that I should report on the idea I've developed, especially since I do not plan to pursue its development further. The only alternative to a formal technical paper was a less formal presentation to the entire Society. To enhance the paper's understandability to those with only a passing acquaintance with aerodynamics, a detailed introductory section has been included; but this has extended the paper's overall length.

The idea to be presented here was developed in an attempt to explain a relatively large number of puzzling observations I have made about sailplane performance. Several years ago Bob Lamson (chairman of the SSA Technical Board and designer of the *Alcor* sailplane) and I were discussing these observations, many of which he had also experienced. It turned out that he had been having similar discussions with Gerhard Waibel, the noted Schleicher designer; it was Bob's impression that Gerhard had been influenced in the design of the AS-W 20 by similar observations. At that time we all agreed that the most likely explanation of the observations was that an interaction between the dynamic bending wing and the gust spectra of the atmosphere was favoring the performance of sailplanes with more flexible wings. Part of my interest in the subject resulted from having clipped my AS-W 12 wingspan to 15 meters and having subsequently experienced climb and zoom problems. The idea that flexible wings might be inherently better than stiff wings was distressing to me — my clipped AS-W 12 probably had the stiffest wings of any 15 meter sailplane. In the intervening years I have tried several methods of improving the climb and zoom performance of the AS-W 12 with considerable success. But these experiments were raising doubts in my mind about the theory of the interaction of dynamic wing bending and atmospheric gust spectra. In this article I will present an alternate explanation for the observations.

Observations

During the 20 years I have been flying sailplanes, a number of seemingly anomalous observations have been noted by myself and others. The following is a listing of the observations which are pertinent to this discussion.

(1) The oldest observation is that Open Class sailplanes can usually zoom much higher than 15-meter sailplanes. An analysis of this phenomenon shows that no obvious sailplane differences can explain the magnitude of the effect.

(2) Another less well-defined observation is that sailplanes with stiff wings do not penetrate turbulence as well as sailplanes with more flexible wings.

(3) A related and also ill-defined observation is that sailplanes with flexible wings can be flown more aggressively in thermals without suffering performance degradation.

The inverse of this observation is that sailplanes with stiff wings give the pilot more "feedback" about the thermal. But the nature of the feedback is not well-defined. The first order time constant for a flexible wing is about 1/10 of a second compared to about 1/20 of a second for stiff wings. That's a small time difference. The difference in experienced "g" loads caused by the gusts should be small, too. What is the pilot of the sailplane with the stiff wings sensing?

(4) Tuft movies were taken by the late Doug Gaines and myself to study the airflow near the trailing edge of the top surface of the wing at low speeds. As the wing lift coefficient is increased, the breakdown of attached flow often takes the following form: A region about 3 to 4 inches wide along the trailing edge, extending from the tip to the root, suddenly shows a strong flow of air moving along the surface from the tip to the root. This flow is at right angles to the main flow across the wing. The appearance and disappearance of this trailing-edge flow seems to start or stop simultaneously over the entire semispan. It appears that the separation area becomes a "duct" through which air is funneled from the tip to the root. When present, this separation causes increased drag and decreased lift. But why does the separation usually appear over the entire semi-span?

(5) The empirically-determined optimum wingtip chord is smaller than the theoretically optimum chord. Everything else being equal, sailplanes with "theoretically" optimum tip chords typically do not seem to climb as well as sailplanes with much smaller tip chords.

(6) The generation of 15-meter sailplanes developed since about 1975 exhibits a wide range of wing flexibility. Generally, the sailplane with the more flexible wing has dominated the competitions. Yet flight tests do not show any significant difference in performance between any of these sailplanes.

(7) Sailplane designers have long known that changes in the sweep of sailplane wings of one-half degree forward or aft are sufficient to cause a quite noticeable modification to a sailplane's stall behavior. A straighter leading edge gives gentle stall behavior while a straighter trailing edge provides a more abrupt stall. It is not immediately obvious why such a small amount of sweep should have a significant effect on sailplane behavior near the stall.

(8) It is common in model aircraft to employ polyhedral in the design of freeflights and gliders. The degree of polyhedral is extreme. It has always been assumed that the polyhedral promoted improved spiral stability and thereby improved the performance of models so equipped. Recent radio-controlled stunt (pattern) and competition sailplane models have been increasingly using a straight (unswept) trailing edge. Hand launched gliders often have a straight trailing edge with an elliptically tapered leading edge. In short, the empirically-developed optimum wing planforms of the model builders differ considerably from the planform normally used on sailplanes.

(9) Finally, we come to the saga of WS. Five years ago I clipped my AS-W 12 wingspan to 15 meters. The result was a dramatic loss of climb performance. Sealing everything, flying faster, and trying harder helped some. Installing winglets produced a dramatic improvement, though they did not completely eliminate the problem. Theoretical calculations showed that winglets on sailplanes are totally inappropriate. NASA's touting of winglets is more public relations than serious technical work. Yet on WS they were partially alleviating some problem. The height of the winglets did not seem very important. There was little noticeable performance difference for winglets between 12 and 36 inches tall. The dramatic improvement effected by the presence of even a short winglet suggested the presence of some drag increase mechanism operating at the wingtip which the operation of the winglet largely prevented.

(10) The AS-W 12 dilemma stimulated my interest in bird wingtips. Sailplane wing planforms are fundamentally similar to those of full-sized powered aircraft, although such aircraft typically operate at higher Reynolds numbers and have never been optimized for climb efficiency. Since birds operate at lower Reynolds numbers than sailplanes do, and are likely optimized for efficiency, the design of sailplane wing planforms should probably reflect some blend of bird wing planforms and full-scale aircraft wing planforms.

I spent considerable time with camera in hand either waiting for certain types of birds to fly overhead or racing along in my car trying to find a way to get under birds so I could obtain pictures of their wing planforms in both climb and cruise regimes. (See photos, page 1.) Within the groups of birds which spend most of their time in the air, I found there are two general types of wing planforms present when these birds were climbing or maneuvering. The first is highly tapered, noticeably sweptback, with a very small chord, or even a pointed tip. The second has little taper and a large chord, somewhat sweptback, and somewhat rounded tip. The tip consists of a large number of individual feathers. These feathers are arranged side by side, one behind the other, with their tips pointed out and back. In flight, the tip feathers toward the rear of the wing are placed higher than the front tip feathers so that each feather flies above the wake of the preceding feather. It could be argued that these tip feathers are an array of the relatively pointed and sweptback wingtips of the first group of birds. The trailing edge of all these birds is straight (unswept) when climbing.

A Possible Explanation

So much for the observations. One fine sunny Saturday morning in 1980, during my recent short stay in Texas, I was reflecting on the above when a theory for reconciling all the miscellaneous information and observations occurred to me. The theory was promising enough to cause me to modify the wing planform of my AS-W 12 with the result that its climb and zoom performance now seems at least equal to the best 15-meter ships, in spite of their higher aspect ratios.

The Theory

In the past, a large amount of time and money has been expended in the study of the air flow around aircraft and particularly around airfoils. In low-speed aerodynamics this airfoil research has been concerned with straight-line flow. This is because the flow over the wing is assumed to move essentially in a straight line from the leading edge to the trailing edge, and because low-speed wings have high aspect ratios and are unswept. Eppler's and Wortmann's airfoils for sailplanes are currently the best-known result of the continuing study of the flow around low-speed airfoils. Designers of full-scale powered aircraft, which often have short and/or swept wings, and designers of reentry vehicles, are both deeply involved in studying both longitudinal and lateral air flows because the lateral flows are very important in understanding the behavior of those vehicles. In sailplanes the lateral flows are usually very small and have therefore been ignored. However, in one limited but critical situation these small lateral flows may exert a disproportionately large influence upon the performance we are able to obtain from our sailplanes. Interestingly, if the theory to be presented is correct, one of the unanticipated characteristics of the highly-developed sailplane airfoils we now use will be a somewhat increased sensitivity to the effects of certain small lateral flows present on our wings, especially near the wingtips.

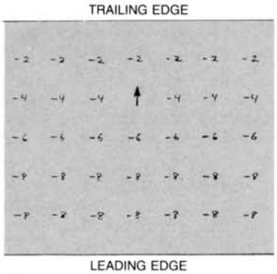


Figure 1 — Straight Wing Pressure Field

Some Basic Aerodynamics

Figure 1 shows a top view of a piece of sailplane wing with some hypothetical pressures superimposed on it. Negative numbers indicate lower pressures relative to static pressure. The magnitude of the numbers indicates the amount of pressure change from static pressure. The numbers shown correspond to an approximation of the pressures which might exist on the top of a wing when climbing. The numbers are all negative since when climbing the pressures on top of the wing are less than static pressure. The airflow, in this case, is from the leading edge in a straight line to the trailing edge of the wing. In all the figures used in this article depicting the top of the wing, the air will be flowing from the bottom of the figure toward the top. A molecule of air at the location of the arrow moving toward the trailing edge would see a considerable pressure change in the longitudinal direction. The pressure behind the molecule (−6) would be lower than the pressure ahead of it (−2) and so the molecule would be decelerating. If the molecule looked left and right it would see equal pressures (both −4) and hence would not be deflected left or right.

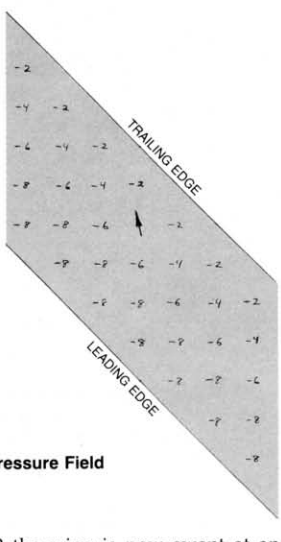


Figure 2 — Swept Wing Pressure Field

In Figure 2 the wing is now swept at an angle to the airflow. A molecule located at the arrow still sees the longitudinal pressure field which is decelerating the molecule. But when the molecule looks left and right it no longer sees equal pressures on the left and right. Now there is lower pressure on the left (−6) and higher pressure on the right (−2). The molecule is therefore deflected to the left as it moves toward the trailing edge.

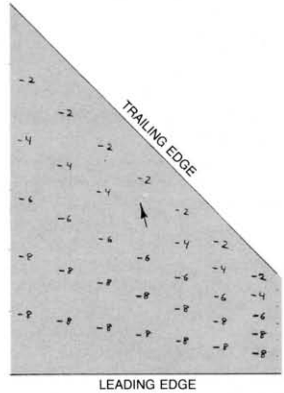


Figure 3 — Tapered Wing Pressure Field

Figure 3 shows a piece of a tapered wing with the hypothetical pressures on it. Notice that the forward sweep of the trailing edge causes the molecule to experience the same kind of left-right pressure difference as present in Figure 2 and so again the molecule is deflected to the left. As the amount of trailing edge forward sweep is increased, the magnitude of the left-right pressure difference near the trailing edge and the resulting deflection of the molecule to the left will increase.

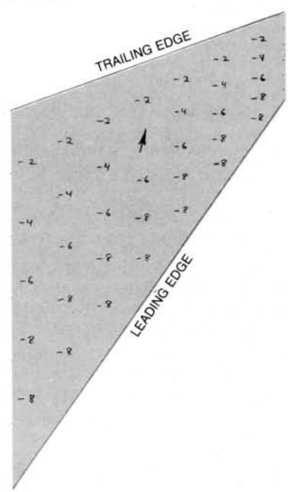


Figure 4 — Aft Swept Tapered Wing Pressure Field

Figure 4 shows the effect of sweeping the tapered wing aft. Notice that the direction of the left-right pressure difference is reversed. The lower pressure is now on the right (−5) and the higher pressure is on the left (−3). In this situation the molecule will be deflected to the right.

Therefore by adjusting wing taper and sweep we can control the left-right pressure field near the trailing edge of the wing. This adjustment of sweep and taper will play an important role in the new theory presented here for improving the climb and zoom performance of our sailplanes.

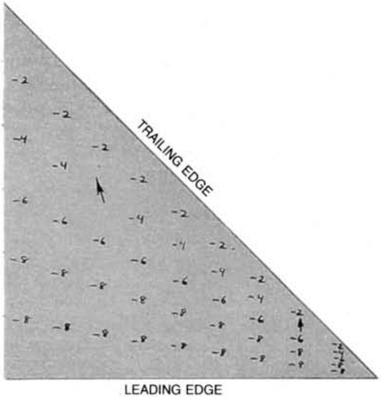


Figure 5 — Pointed Wingtip

Figure 5 shows the pressures on the top of a wing near a pointed wingtip. The pressure field is not significantly different than those shown earlier for the tapered wing (Figure 3). When moving toward the tip, the pressure changes occur over smaller and smaller distances. The molecule moving from the leading edge to the trailing edge is therefore exposed to the left-right pressure field for a shorter time and is thereby deflected less in the left-right direction. An analogy to this situation would be if you were trying to deflect a ball which is rolling steadily down the middle of a street toward the curb. The longer you pushed against the side of the ball the greater would be the change in its direction of travel. If you could only push for a moment your ability to deflect the ball would be minimal.

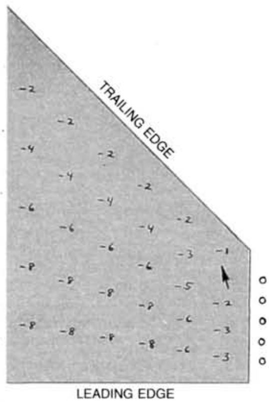


Figure 6 — Normal Wingtip

Figure 6 shows a more normal wingtip. The zeros to the right of the wingtip denote static pressure there. Notice that when the pointed wingtip is cut off, the left-right pressure field becomes much stronger in the area of the tip. The strong left-right pressure differences cause the molecules on the top of the wing near the tip to be strongly deflected toward the wing root. This deflection of molecules is responsible for the kind of drag called induced drag. The deflection increases as the amount of lift the wing generates increases because the pressure field on the wing has to become stronger to generate the increased lift. It is also important to note that as the wingtip chord is increased, the time required for the air to move from the leading edge to the trailing edge is increased. For a wingtip with a larger chord, the left-right pressure field's influence on the air molecule is present for a longer time and the deflection of the air toward the wing root is increased. In addition, notice that the left-right pressure field is present from the leading edge to the trailing edge, instead of only on the back half of the wing, as had been the case in Figures 1 through 5. The combination of all these factors guarantees that the maximum airflow deflection will always occur at the wingtip. This behavior of the airflow at the wingtip will be seen to be a major factor in a drag-producing process which we will find can be eliminated by a redesign of the wing planform.

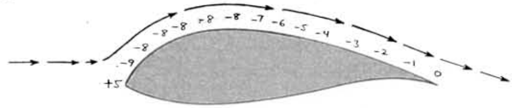


Figure 7 — Airflow over Wing

Now we will look at another behavior of the air flow around a wing. Figure 7 shows a side view of the flow around the airfoil with the pressures noted again. The length of the arrows is indicative of the velocity of the air as it flows over the upper surface of the wing. Notice that our molecule will be decelerated as it approaches the leading edge because of the high positive pressure there. As it rounds the leading edge and moves along the first part of the upper surface, the low pressure in front of the molecule and the high pressure behind it causes the molecule to accelerate rapidly. Approaching the thickest part of the wing, the molecule is just coasting along because the pressure changes are small there. Then, as the molecule continues toward the trailing edge, the molecule is slowed back down because of higher pressures in front of it and lower pressures behind it. The molecule, when it leaves the trailing edge, is moving about as fast as it was when it approached the wing.

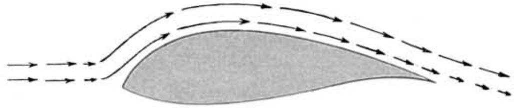


Figure 8 — Airflow over and in Contact with Wing

Figure 8 shows an additional complication. The layer of air touching the wing is not only acted upon by the pressure field, it is also slowed down because it drags along the surface of the wing. So the air touching the wing will be moving slower than the rest of the air which moves by the wing. This means that the layer of air touching the wing takes more time to move from the leading edge to the trailing edge. This air will also leave the wing moving more slowly than when it approached the wing. The velocity loss is responsible for the kind of drag called wing profile drag.

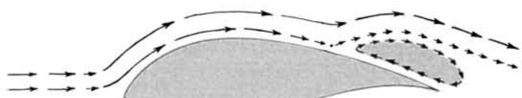


Figure 9 — Airflow over Wing with a Separation

Figure 9 shows another complication. As lift is increased, the layer of air touching the wing will come to a complete stop before reaching the trailing edge. It then lifts off the surface and is dragged along by the faster moving air farther from the surface. This is termed a separation and is characteristic of the beginning of the stall. The air between the separated flow and the surface of the wing is largely trapped and rotates as shown. It should be noted that the only connection between the air within the separation and the air flowing over the wing occurs at the interface between the two. The air moving over the separation "drags" the air at the top of the separation toward the trailing edge. It is this "dragging" that keeps the air in the separation rotating.

We now have acquired all the theoretical background necessary to piece together the chain of events which can lead to an unnecessary drag increase when climbing or zooming our sailplanes.

Figure 10 — Flow Streamlines over Straight Wing

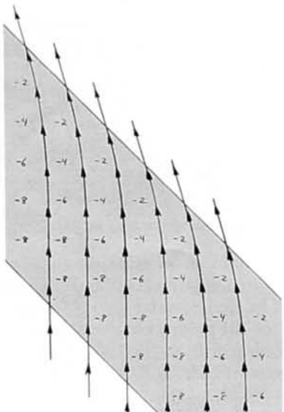


Figure 11 — Flow Streamlines over Swept Wing

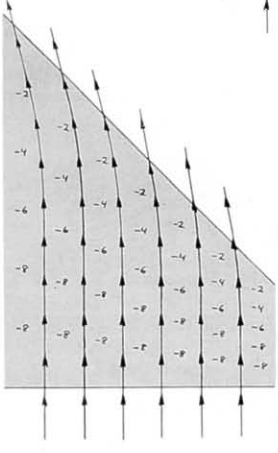


Figure 12 — Flow Streamlines over Tapered Wing

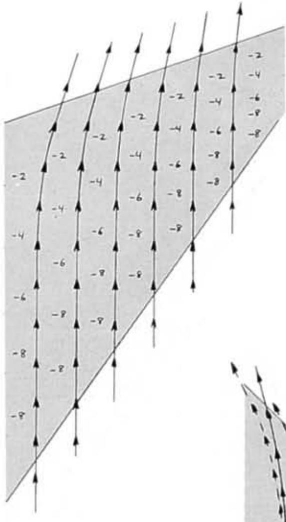


Figure 13 — Flow Streamlines over Tapered Aft Swept Wing

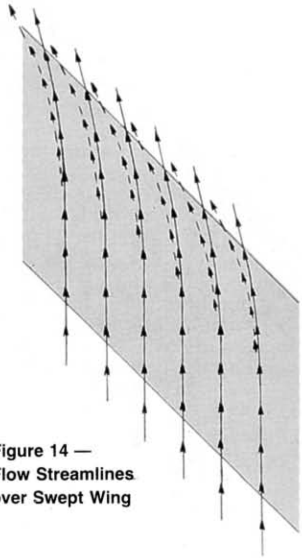


Figure 14 — Flow Streamlines over Swept Wing

Figure 10 is the same as Figure 1 except the flow streamlines are shown. Because there is no left-right pressure field, the air flows straight from the leading edge to the trailing edge. Figure 11 repeats Figure 2. The wing is now swept and the presence of the left-right pressure field causes the deflection of the flow streamlines to the left. Figure 12 repeats Figure 3 and again shows the deflection of the flow streamlines to the left because of the left-right pressure field. Figure 13 repeats Figure 4 and shows that the reversed left-right pressure field on the swept tapered wing causes the flow streamlines to be deflected to the right.

We've stated that the degree of deflection of the air is greater if the air is moving slower because the air will be exposed to the left-right pressure field longer. Figure 14 repeats Figure 11 but this time we include both the air which flows above the wing and the air which crosses the wing in contact with its surface. We've noted that the air in contact with the wing's surface is going to be moving more slowly, especially as it approaches the trailing edge. The flow streamlines for the majority of air flowing over the wing are shown solid while the flow streamlines for the slower moving air in contact with the surface of the wing are shown dashed. The air next to the surface of the wing is deflected more. We've also discussed that, as more lift is generated, the air in contact with the surface slows down further, and if enough lift is generated, this air can nearly

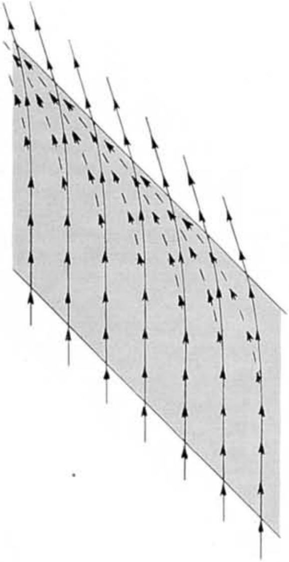


Figure 15 —
High Lift Flow Streamlines over Swept Wing

come to a complete stop. Figure 15 illustrates that this can result in the air next to the surface being deflected so far as to be flowing nearly parallel to the trailing edge of the wing. This can occur because the slower moving air is deflected by the left-right pressure field for a much longer time. Additionally, once the streamline is deflected by the lateral pressure field, the longitudinal pressure field is able to continue the deflection of the streamline. This can be understood by imagining a streamline flowing from right to left parallel to the trailing edge. The pressure to the left of the streamline will be lower than the pressure to the right, and hence the longitudinal pressure field is able to contribute to the deflection of the streamlines.

Figure 16 shows the flow streamlines on the wingtip. This corresponds to Figure 6. The streamlines are strongly deflected toward the root of the wing. Figure 17 adds the flow streamlines for the air which is in contact with the surface of the wing. Here again, the air in contact with the wing is deflected more and, if the tip chord is larger, the amount of deflection of the air in contact with the surface would be correspondingly greater. If, in addition, the amount of lift generated were increased, the streamlines for the air in contact with the surface would be even further deflected. The combination of these factors is easily capable of deflecting the streamlines so as to cause them to flow parallel to the trailing edge.

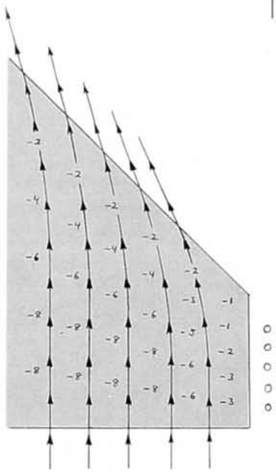


Figure 16 —
Flow Streamlines over Wingtip

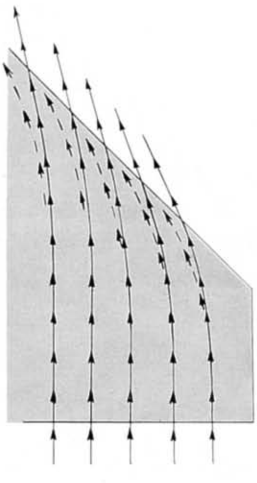


Figure 17 —
High Lift Flow Streamlines over Wingtip

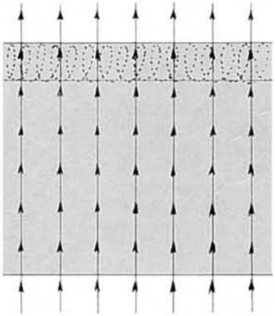


Figure 18 —
Flow Streamlines on Straight Wing with Trailing Edge Separation

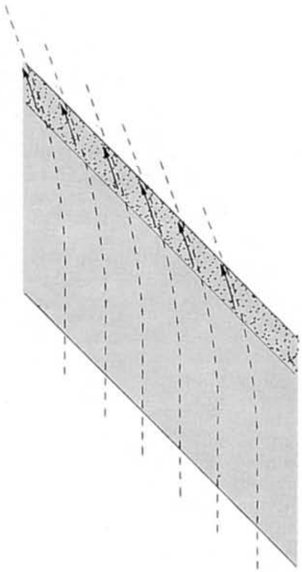
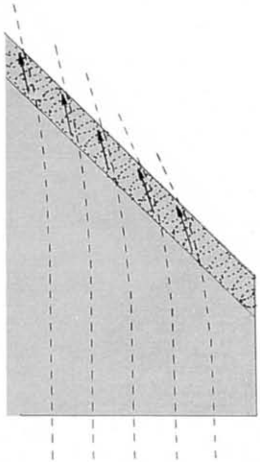


Figure 19 —
Swept Wing with Separation

Figure 18 is a top view of the wing shown in Figure 10, but with a separation present along the trailing edge which is shown graphically. The flow streamlines moving over the top of the separation cause it to rotate as already shown in Figure 9. The air in the separation goes around and around without moving left or right. Figure 19 repeats Figure 14 with a separation present along the trailing edge. As the air moves over the top of the separation, this time something distinctly interesting occurs. The air within the separation is moved toward the left of the wing as it is being "dragged" along by the air moving over the separation. This causes air within the separation to be transported along the trailing edge. The movement of the air at the top of the separation, which is in contact with the air flowing over the wing and is being "dragged" along by it, is shown as a solid arrow. The air within the separation describes a spiral motion as it moves from right to left. Figure 20 shows the

Figure 20 — Flow Streamlines over Wingtip with Trailing Edge Separation



same behavior for a wingtip with a trailing edge separation. Any increased positive sweep of the trailing edge, increased lift, or increased tip chord will cause a greater deflection of the streamlines. This will increase the flow along the trailing edge within the separation because the air moving over the separation "drags" the air near the top of the separation farther to the side as it crosses the separation. The result is that air within the separation spirals at a steeper angle. The more the air moving over the wing is deflected, the more exaggerated the spiral within the separation becomes and the more rapid is the motion of air within the separation toward the wing root.

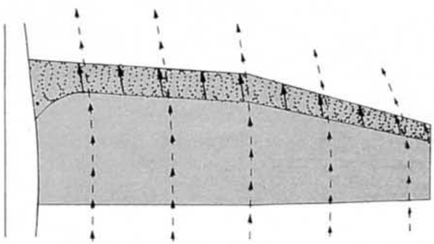


Figure 21 — Conventional Wing with Separation along Trailing Edge

Figure 21 shows the top view of a conventional wing with a small trailing edge separation present. Air from the wingtip region is carried through the duct formed by the separation to the root of the wing. As the air arrives at the root, it piles up and enlarges the area of the separation at the root, thereby causing an increase in drag. In addition, the presence of the separation along the entire trailing edge both decreases lift and increases drag over the entire wingspan.

Where the Separation Starts

Separations begin when air is moving too slowly across the wing and/or when the wing is being asked to generate too much lift. Both of these conditions are most pronounced at the inboard wingtip when circling to climb. The inboard tip is moving more slowly because it is nearer the center of the circle and the inboard tip is also being asked to generate lots of lift in order to hold the inboard wingtip up. In this situation the inboard aileron is usually deflected downward, which creates a kink in the upper surface of the wing. All of this combined virtually guarantees that in circling flight a separation will form first at the inboard wingtip.

Figure 22 — Small Separation at the Wingtip

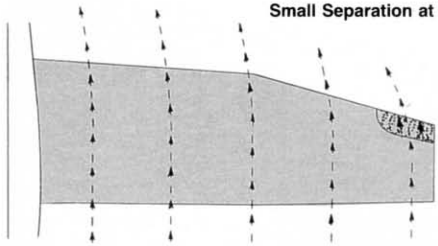


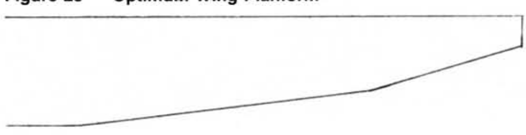
Figure 22 shows a top view of a wing with a small separation present at the wingtip. We now know that the air in this small separation will be swept toward the wing root by the air flowing over the separation. But the spiraling air in the separation immediately runs into air farther inboard which is still in contact with the wing surface and moving toward the trailing edge. Since this air moving toward the trailing edge is barely able to stay attached to the wing anyway, the air within the separation moving toward the root causes the flow moving toward the trailing edge to lift off the surface, thereby increasing the length of the separation. With the separation lengthened, the flow toward the fuselage within the separation becomes stronger and is better able to continue to extend itself toward the fuselage until the entire length of the trailing edge is separated. It is very possible that the flow at the wingtip in contact with the wing surface, which has been deflected sufficiently to be flowing nearly parallel to the trailing edge, is absorbed by the separation and becomes the source of air which is moving along the inside of the separation.

The small initial separation at the wingtip, by itself, would not have created a serious drag problem. But, because air in the separation is "dragged" toward the wing root, a local problem at the wingtip can end up spreading along the entire trailing edge causing increased drag and decreased lift. If it were possible to eliminate the "dragging" of the air in the separation toward the wing root, then the tendency of the separated area to spread would be reduced and the climb efficency of the sailplane would be improved.

The Solution

The lateral motion of air within separations can be prevented by adjusting wing sweep, wing taper, and wingtip chord. The requirement is that the air flowing off the trailing edge be moving at right angle to it as seen from the wing's planform. Figure 23 shows such a wing. The trailing edge

Figure 23 — Optimum Wing Planform



is straight. The rapid increase in wing taper near the tip in combination with a small tip chord will effectively neutralize the effects of the pressure field normally present at the wingtip and illustrated in Figure 6. Such a wing will be able to generate more lift at lower drag than a wing with a conventional planform because small separations in one location are not likely to propagate along the trailing edge, thereby involving the entire wing semispan and wing root unnecessarily.

AS-W 12 Problem Description

After shortening the wing of the AS-W 12, the original clipped planform was as shown in Figure 24. The wingtip chord was 19 inches and the root chord was 37 inches. This is a taper ratio of 1.95 and not very different from several high-performance sailplanes (the various *Astirs*, HP's, etc.) produced in the recent past. The aileron was shorter than on a conventional sailplane, but quite adequate aileron control power was available. The wing was stiffer than most other high-performance sailplane wings, but, except for the lack of the extra upsweep at the tip present on some of the more flexible-winged sailplanes, the dihedral was normal. The combination of the above factors produced a significant loss of climb performance. Note that the trailing edge was swept forward which we now see is undesirable. The large tip chord was responsible for a considerable deflection of the streamlines in the area of the tip. Finally, the shorter aileron with a larger chord probably required a somewhat larger deflection when climbing. The combination of all these factors substantially increased the probability of a premature separation at the inboard wingtip. The premature separation, when it occurred, was acted upon by the highly-deflected air flow at the tip "dragging" over the separated area. The separation was then spread from the tip to the root of the wing and the result was a premature loss of climb efficiency over the entire semispan. Figures 25 and 26 show frames from a series of 16 mm inflight movies wherein the clipped wing was tufted to do flow visualization in 48 flight conditions. These frames are from a sequence showing the left wing during a left turn at 45 knots. The presence of the lateral flow along the trailing edge is quite visible.

Figure 24 — AS-W 12 Wing after Shortening to 15 Meters

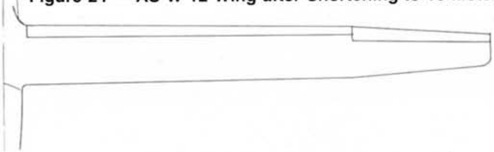
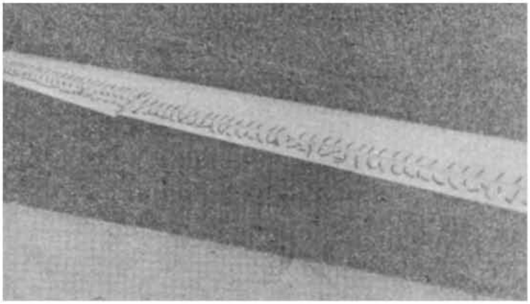


Figure 25 — Visualization of Lateral Flow along Trailing Edge



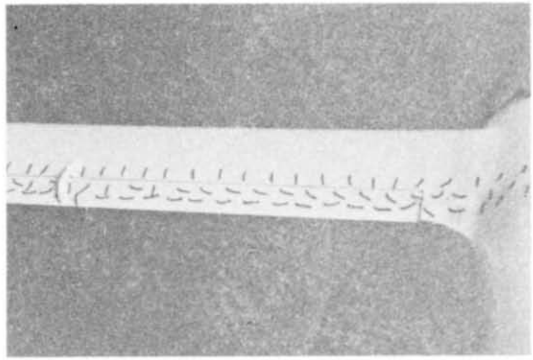
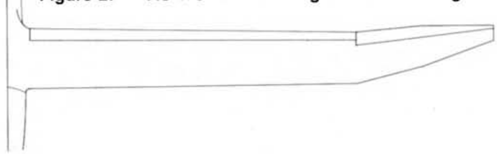


Figure 26 — Visualization of Lateral Flow along Trailing Edge

The Practical Embodiment of This Idea

To modify an already existing wing so as to produce the desirable planform shown in Figure 23 would involve a complete rebuild of the wing. Since the principal problem was in the area of the wingtip, it was decided to rebuild only the wing outboard of the aileron-flap junction. The resulting wing planform is shown in Figure 27. On the inboard portion of the wing there remains a small forward sweep of the trailing edge. On the outboard portion of the wing it was decided to retain the straight aileron hinge line to simplify construction. The combination of the needed taper distribution and the straight hinge line caused a small kink to appear in the trailing edge in the middle of the aileron. This kink may have a desirable effect in that the slight sweepback of the inner portion of the aileron will tend to neutralize any problems caused by the slightly forward-swept trailing edge of the central portion of the wing. No compromises were made in the design of the critical tip portion of the wing. The resulting wing is a good approximation to the desired planform and a large improvement over conventional planforms. A picture of the finished wing is shown in Figure 28.

Figure 27 — AS-WS 12 with Wing Planform Change



Results

The only testing accomplished since the completion of the modification program occurred at the 15-Meter Nationals in Elmira last summer. I think it can be said that everyone was impressed with the climb performance of the ship. An improvement in aileron control effectiveness was noted. Generating the normally high sink rates while slipping wasn't possible, indicating reduced separation on the trailing wing. It appeared that the climbing ability of the AS-WS 12 was at least equal to the other sailplanes when both were at the same wing loading. Because of the AS-WS 12's lower aspect ratio, this implies that the AS-WS 12 was considerably more efficient at generating lift. The ship exhibited a very definite grooviness when climbing. Yaw stability was exceptional when climbing, as well as in straight flight. I observed no undesirable stall characteristics except when I employed extreme stall/spin/slip entries. And what I saw under such extreme circumstances was not any worse than the behavior of the original unmodified AS-W 12. Altogether, it is a very pleasant ship to fly. More quantitative assessments of the ship's actual performance could only be obtained by further testing. I doubt if I will ever do such testing because I am more interested in how well the ship performs overall against the other ships in a contest environment. I was quite pleased by what I observed at Elmira and I have other projects to finish which are more important to me than further testing of the AS-WS 12.

Resolution of the Anomalous Observations

I am going to make the statement that sweeping a wing aft and giving a wing upsweep are in many ways aerodynamically equivalent. For those who want to figure out why, I'll point out that an upswept wing at a high positive angle of attack will experience an increase in the outward flow of air on the upper surface. Imagine a wing with extreme dihedral and you will quickly conclude that the outflow will be present. The outward flow relative to the wing planform on an upswept wing is equivalent to the flow on an aft-swept wing relative to its planform.

I also will make the statement that the lift coefficient generated during the initiation of a zoom is similar to the lift coefficient needed for climbing. Therefore the considerations important to the inboard wing when climbing can be important to the entire span when zooming. Referring now to the list of anomalies at the outset of this article:

Anomaly (1) is explained because Open Class sailplanes have substantially more upsweep, which is equivalent to sweepback, at the wingtip when climbing and zooming, and they usually have less forward sweep of their trailing edge because of higher aspect ratios. The Open Class ships therefore are less likely to incur the performance penalty from a premature separation along the trailing edge than are 15-meter sailplanes with their stiffer wings, more forward-swept trailing edges, and normally larger tip chords;

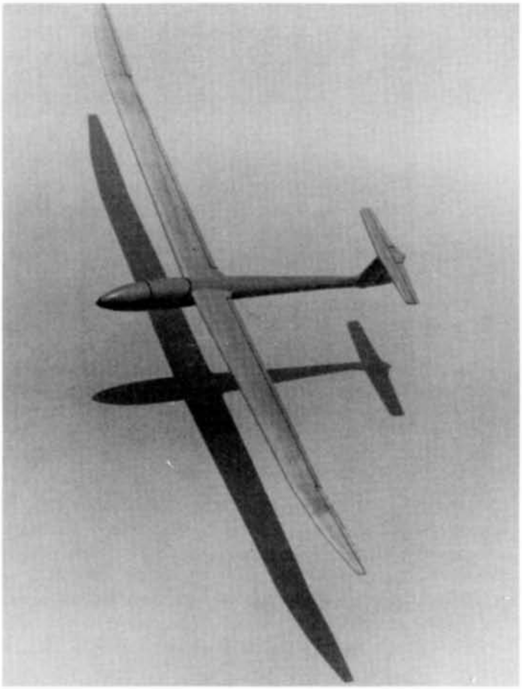
(2) has the same explanation as (1) except that in this case the "g" loads which might precipitate the trailing-edge separation are partly generated by the turbulence and partly by the pilot's response to the turbulence;

(3) also refers back to (1). The difference in sailplane response to a gust when thermaling or cruising is likely due to the trailing-edge separation precipitated when encountering the gust. This might take the form of an abrupt change in lift and/or wing pitching moment, perhaps even as a momentary chop if the separation induced were unsteady, and possibly include a change in the "sound" of the sailplane. The pilot's involuntary response to any of these events might increase the magnitude of the perceived effect;

(4) has been covered;

(5) has to do with the powerful effect larger wingtip chords have on the initiation and spread of a separation inward from the wingtip;

(6) is explained because still-air in-flight testing would seldom precipitate the problem outlined here. There are several possible exceptions to this statement. A number of sailplanes have been found to have a bistable sink rate at low speeds. It is possible that a narrow separation along the trailing edge, originating at the wingtip, could be bistable and would explain such data. If straight-and-level flight testing in still air were able to precipitate a span-wide, trailing-edge separation, then the separation would certainly be present when thermaling.



The shadow silhouette of Wil Schuemann's model of his modified AS-W 12 emphasizes its break with traditional high-performance planform geometry.

An Open Class sailplane tested recently showed considerably worse performance than expected after the wingtip extensions were removed. This particular sailplane has considerable forward sweep to the trailing edge and the removal of the extensions would have increased the tip chord of the remaining wing. The combination of the larger tip chord and forward trailing edge sweep could have triggered a narrow full-span separation along the trailing edge which would have caused the unexpected performance reduction. The apparent presence of a bistable sink rate at low speeds for this sailplane, even when the tip extensions are installed, adds credibility to this possibility;

(7) is explained by realizing that slightly forward-swept wings flown near a stall will likely have a flow of air, through the separation along the trailing edge, from the tip to the root of the wing. The arrival of this air at the wing root will disrupt the flow over the root of the wing. Disrupting the flow at the root first contributes substantially to benign stall behavior. A slightly swept-back wing will not supply the air to the root, and may allow air to flow from the root to the tip along the trailing edge. This might stabilize the flow at the root. If slight sweepback would lead to the tip stalling first or to the entire wing stalling simultaneously, the stall behavior would understandably be more abrupt;

(8) should be fairly obvious. The polyhedral employed on models is an extreme example of an upswept sailplane wing. The lower Reynolds numbers of the models would make them even more susceptible to the problem we are talking about. Model builders have been able to empirically determine the two correct solutions to the problem, partly because they build and test thousands of different models

each year. We average one or two new sailplanes each year, and therefore probably acquire knowledge more slowly in some areas of aerodynamic design.

(9) has been covered;

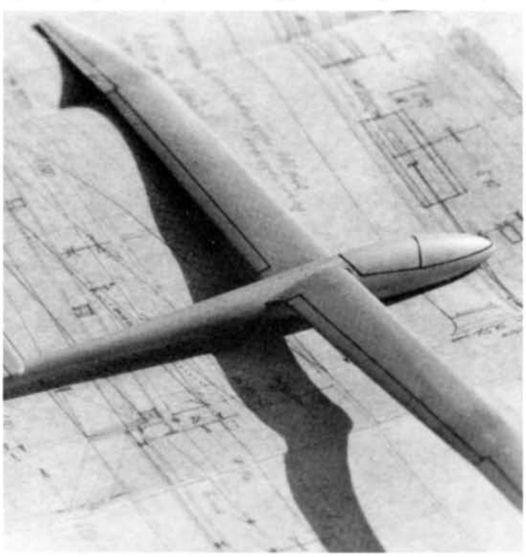
(10) should be obvious. Nature some time ago developed the correct wing planform for efficient climb performance. The pointed wings of the swallows and gulls are obviously consistent with the ideas presented above. The multiple tip feathers of the soaring birds are arranged so as to move air along and off the ends of the tip feathers, thereby reducing the chance of a separation forming at the tip of the wing on the upper surface. This arrangement gives soaring birds efficient climb performance in spite of their low aspect ratio wings.

A Few Additional Comments

The first is that the type of airfoil on a sailplane would have some influence as to whether a wing exhibits this separation phenomena. The choice of airfoil would be most critical near the wingtip.

Secondly, this phenomenon is hard to study. The pictures in Figures 25 and 26 which show the tufts pointed inward along the trailing edge would not show anything unusual if the sailplane were to be climbed at the normal thermaling speed, even with the problem presumably present. To obtain those pictures required flying somewhat slower than is normal when thermaling. When a separation is thin, the tufts rise up into the faster moving air and disguise the fact that a separation is present. This is illustrated graphically because some of the tufts along the trailing edge are dragged aft *over* the separation while adjacent tufts, buried within the separation, show the flow toward the wing root. If the resolution in the pictures were good enough, the rising of the tuft off the surface would announce the presence of the separation but unfortunately would tell little or nothing about the presence of lateral flow within the separation. Such resolution is difficult to obtain with the kinds of cameras most of us are able to use for in-flight movie taking. It also might be possible to use ultra thin tufts which would remain within the separation, but photographing them, especially over any large fraction of the span, would be difficult because of their low visibility.

The model symbolizes the bridge between theory and reality as it rests upon the shop drawings that ultimately produce the finished aircraft.



The best technique for observing separations involves the use of a liquid consisting of fuel oil and a slow-drying solvent mixed with a marker such as carbon black. The liquid is brushed on the wing and then the sailplane is flown steadily at the desired flight condition. The flow of air on the surface of the wing creates streaks showing the pattern of the flow adjacent to the surface. Such tests would clearly show the presence of the separation but are difficult to conduct. In Germany they are painting the sailplane wing on the ground and then airtowing at the speed for which they wish to obtain the flow patterns. Since we are largely talking about low-speed circling flight, this technique would have to be approached with some trepidation.

Another technique would be to paint the wing on the ground, cover it with paper to prevent drying, and then strip the paper off in the air to expose the painted surface after establishing the desired flight condition. A photograph in a paper titled "On the Design of Some Airfoils for Sailplane Application," by Boermans and Selen shows the use of this type of flow visualization on a section of a sailplane tested in a wind tunnel. It was presented at the XVII OSTIV Congress at Paderborn in May 1981 and also appeared in the September 1981 issue of *Technical Soaring*. The presence of the flow deflection in this photograph was completely incidental to the purpose of their paper — research on the drag implications of bug impacts and boundary-layer tripping. The importance of the flow deflection to wing planform design considerations was apparently not realized. I am sure that the archives of wind tunnels contain vast numbers of similar photos from wind tunnel tests of real wings. Perhaps some of *Soaring*'s readers will know of wind tunnel studies of drag measurements at various yaw angles and involving photos with the wing operating near maximum lift and with flaps retracted. Particularly interesting would be data on the AT-6, DC-3, B-29, B-36, F-14, or F-111, all of which were designed with straight trailing edges.

The final remark is that Bob Buck recently sent me a photograph of the new Dornier turbo-prop aircraft which has a "new high-technology wing." The wing planform, though of low aspect ratio, is remarkably similar to the planform of the soaring birds described earlier. So perhaps others are also thinking along similar lines.

Conclusion

I am hoping this article will stimulate the interest of those researchers with access to wind tunnels and computers to expand and refine what I have presented here. The most important and difficult task will be the coupling of the three-dimensional wing-flow programs and the airfoil boundary-layer programs so as to be able to simultaneously optimize the airfoils, upsweep curve, and the planform of a sailplane. Hopefully it will be possible to determine a single solution optimal over the entire range of operating conditions of interest to us. The real world is seldom so accommodating. But an improved analytical tool would be available to guide the educated guesses of the sailplane designer. Another hope would be that this work would permit answering the irksome and long-standing question of what is the best wingtip shape. And finally, the ideas presented here suggest that the two-dimensional flow around airfoils, which has always been presumed in the design of the airfoils we use, often does not exist in the vicinity of the wingtip when operating the wing at high lift coefficients. The airfoil design programs may have to be modified to include the effects of lateral flow in the boundary layer.