AILERON DIFFERENTIAL; SOME POSSIBLE EFFECTS ON PERFORMANCE

Turning a sailplane should be a simple thing to do, right? Well, it should be, but it isn't. Several aerodynamic quirks get in the way of achieving automatic smooth coordinated turns. In this column we'll explore these quirks as they apply to both tailed and tailless designs, and give some suggestions for improving matters.

To begin, there are three types of drag which affect a sailplane in flight. First there is friction drag, created as the air moves along the surface of the model. It is friction drag which slows the air next to the aircraft surface, rapidly building a thick boundary layer. The second type of drag is form drag, caused by the changes in pressure over the skin as the air flows across it. The third and last form of drag occurs any time lift is generated. This induced drag or vortex drag is created by any lifting surface. It is especially strong at the end of the wing, where air is free to move from the lower to upper surface around the wing tip.

Friction drag and form drag are closely related and usually considered together by the term profile drag. Profile drag increases with greater velocity.

A slow flying glider must operate at a high C_L to generate sufficient lift to remain in the air, while the same glider flying at a higher velocity can stay aloft while generating a lower C_L. Induced drag therefore increases with greater C_L.

There is thus an interesting relationship between profile and induced drag. At low speeds induced drag is high and profile drag is low, while at high speeds profile drag is high and induced drag is low. This is an important consideration to keep in mind.

To give a comprehensive example of profile and induced drag, consider a wire and an airfoil moving through the air together (Figure 1).

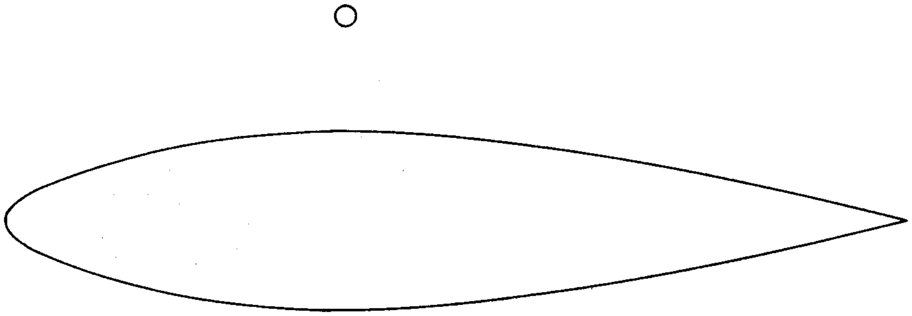


FIGURE 1

The airfoil has greater friction drag but less form drag than the wire; the airfoil's overall profile drag is less than the profile drag of the wire. This holds true even when the airfoil's thickness is up to 10 times greater than the wire's diameter. As expected, both the wire and the airfoil will experience increased profile drag as their velocity is increased.

Technically, the wire's induced drag is always zero because it is not capable of producing lift, no matter what its angle of attack. The induced drag of the airfoil, on the other hand, can change markedly as angle of attack is increased and the section begins generating lift.

Taking profile and induced drag together, you can see there are certain circumances (low speed and high C_L) where the airfoil's overall drag may be significantly higher than the wire's. Yet in high speed flight the airfoil would have significantly less overall drag.

Now let's get back to turning our sailplane. In turning, our sailplane rotates upon all three geometric axes: the sailplanes banks, pitches, and yaws. As evidence for this, consider the control actions required for a coordinated turn. We must bank the 'plane with ailerons (roll) and gently apply up elevator (pitch) and rudder (yaw) to bring the 'ship around. But there's a problem. We certainly don't want to fly with the fuselage yawed to the relative airflow as this is a high drag condition. Yet it seems we need to apply more rudder than necessary to get the 'ship turning in a coordinated way.

Since the rudder creates large amounts of drag as well, we want to eliminate moving this "barn door" more than is absolutely necessary. So we begin looking for reasons as to why such inordinately large rudder movement is required. This quest leads us back to aileron movement, and profile and induced drag.

Most are familiar with the Eppler 214 airfoil, and it serves as a good example for explanation. In Figures 2, 3, and 4 we see the E 214 with no aileron deflection, then downward deflection, and finally upward deflection.

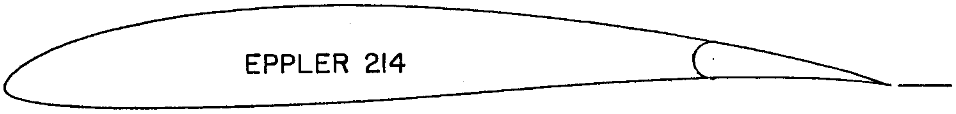


FIGURE 2

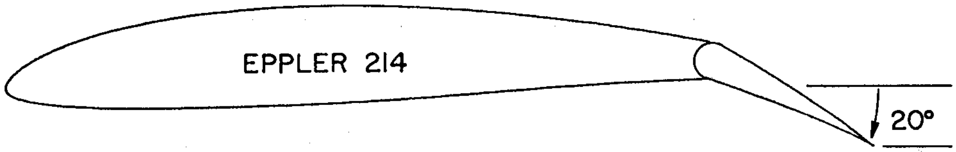


FIGURE 3

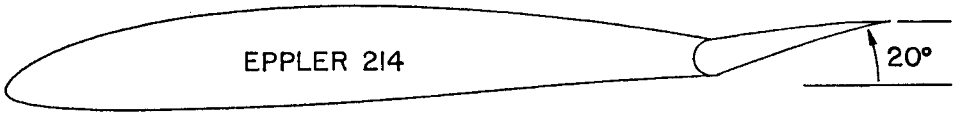


FIGURE 4

With no aileron deflection, the E 214 has a certain amount of profile drag. As the aileron is deflected downward, both profile and induced drag increase. Profile drag increases due to the hinge line and abrupt contour change, while induced drag increases due to the increased lift generated. The overall drag of the wing with aileron deflected downward is greater than the wing with no aileron deflection.

But what of the overall drag as the aileron is deflected upwards? Profile drag will again increase due to the irregularities in the surfaces, but since the wing is now generating less lift, induced drag will be reduced. The overall effect is for the rising wing (aileron down) to have more drag than the falling wing (aileron up). The sailplane therefore tends to yaw toward the rising wing, directly opposite to what we want! This action is termed adverse yaw, and it takes a large rudder movement to counteract it.

A common solution to the dilemma of adverse yaw has been to modify the control linkage so the aileron's deflection is always proportionally greater when moving upward. This so called differential is effective at inhibiting the drag increase of the rising wing through reduced downward aileron movement, while increasing the drag of the descending wing through increased upward aileron movement (Figures 5 and 6). Adverse yaw and the required large counteracting rudder movement are thus both greatly reduced, giving an overall reduction in total drag.

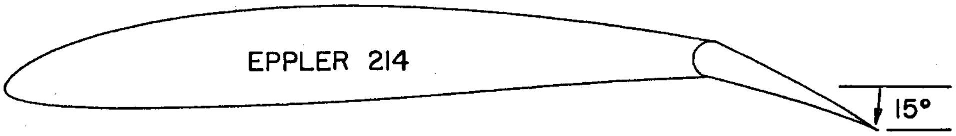


FIGURE 5

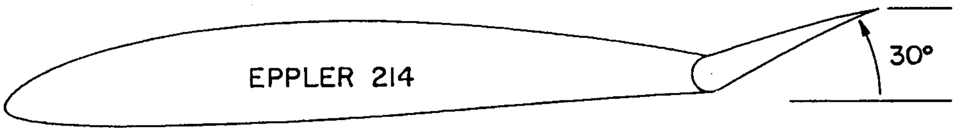


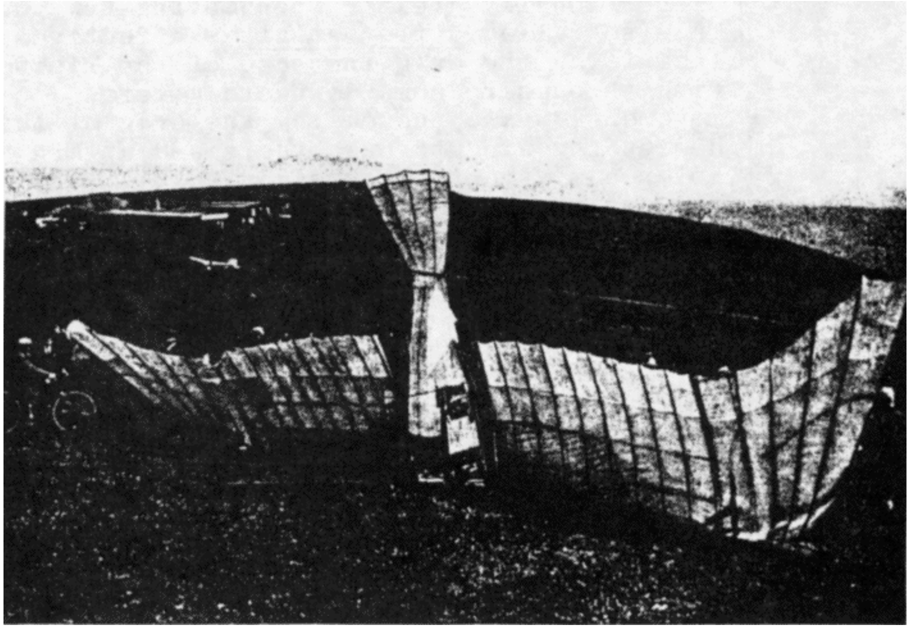
FIGURE 6

There has been a tendency among tailless enthusiasts to set up their swept 'wings with differential in the aileron function, just as with their tailed 'ships. It is our opinion this is an incorrect action, and there are two reasons for our making this statement.

Since the elevons, combining aileron and elevator functions, are behind the CG, the first thing which comes to mind is the obvious change in pitch forces which results from aileron function differential. This is because the upward moving elevon, with its greater deflection, applies a significantly larger down force than the upward force generated by the opposite aileron.

But there is another factor which is not so clearly seen - the effect of aileron movement on the induced drag of the wing tips.

On a swept wing tailless, the wing tips are applying a down force on the aircraft structure during flight. This is directly opposite to what is happening at the wing tip of a conventional sailplane. When thinking about the wing tip's induced drag, we must therefore visualize an inverted airfoil.



Photograph from Howard Siepen

PROOF THAT MAN STILL HAS MUCH TO LEARN FROM BIRDS ABOUT FLYING

Men shape their planes like birds and soar in imitation of them, but tailspins, sideslips, and crashes, unknown to birds, are inseparable from man's adventures in an element not his own, be he ever so skillful.

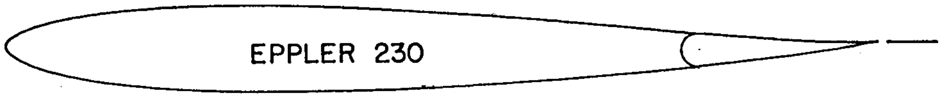


FIGURE 7

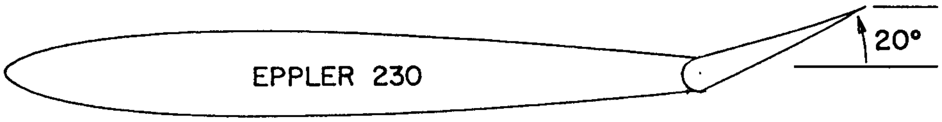


FIGURE 8

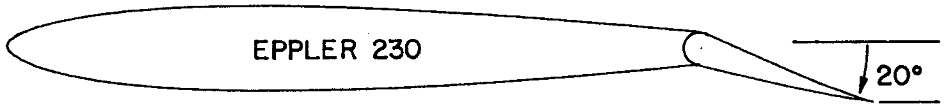


FIGURE 9

Looking at Figure 7, note the shape of the airfoil; such reflexed sections are commonly used on swept wing tailless. These sections, looking very much like inverted normally cambered sections, do not begin developing upward lift until their angle of attack is substantially positive. The wing tip's induced drag is thus related to its downward lift. This means an upward deflected aileron near the wing tip of a swept wing tailless (Figure 8) is producing more induced drag than the same aileron deflected an equal amount downwards (Figure 9)! Adverse yaw should therefore not exist, and aileron function differential will do nothing but harm in this situation.

In the case of a plank design, the wing tips are not generating a downward lifting force. Rather, the entire wing uses a reflexed section. (See Figure 10 for a typical example.) While the reflex produces the downward stabilizing force necessary for flight, the airfoil itself produces a relatively strong upward lifting force.

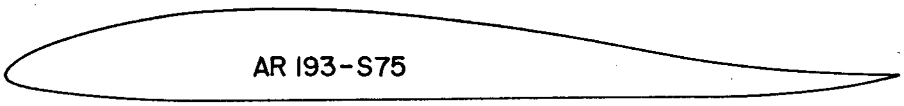


FIGURE 10

Raising one elevon therefore increases profile drag over and above the drag ordinarily created by the section's reflex, but induced drag will decrease because of the overall reduction in lift. How these two forces balance out is dependent upon control surface deflection angle and specific airfoil. Aileron function differential may therefore be needed in some circumstances, but watch for a pitch up as aileron function is applied.

As an example, Jim Marske's Pioneer II-D (schematically shown in Figure 11) utilizes 2:1 aileron differential. Since the quarter chord line sweeps forward, however, the ailerons are so close to the CG their deflection does not affect pitch significantly. In plank designs with no quarter chord sweep (Figure 12) or slightly rearward sweep (Figure 13), the ailerons will be proportionally more distant from the CG, and pitch will be more greatly affected as the moment gets larger.

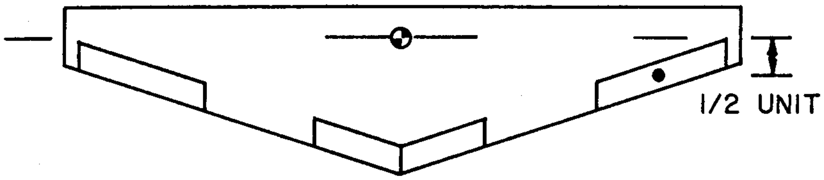


FIGURE 11

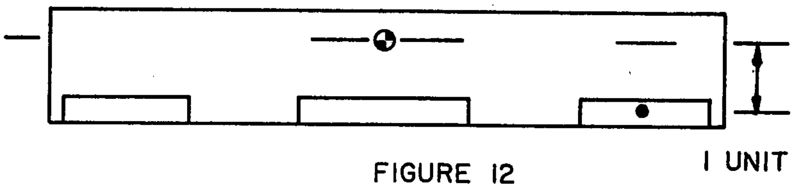


FIGURE 12

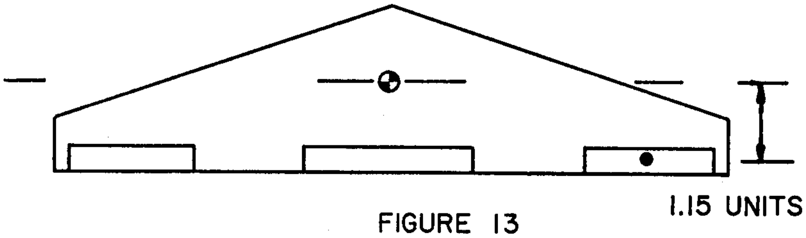


FIGURE 13

In a thermal turn, with elevons deflected slightly upward, the plank is flying with effective washout at the wing tips, while the wing root is generating near maximum lift. A centrally mounted elevator does not allow this beneficial situation to occur, and this explains why the best performing plank designs utilize elevons rather than a central elevator and outboard ailerons.

Since most flyers are now moving to computerized transmitters, with a servo driving each aircraft surface, it is becoming increasingly easy to experiment with aileron differential. If you are flying a tailless design with a computer radio, try reducing the amount of differential you are using. You might just find a substantial performance increase. We would appreciate hearing the results of your experiments!