Roll Control

The persistent problem of adverse yaw and how aircraft designers continue to seek a solution

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Roll control—movement about the lateral axis—is usually achieved through the use of ailerons, surfaces which—simply stated—are designed to alter the lift characteristics of wing panels. When deflected downward, an aileron increases wing camber, which results in additional lift (and drag). Conversely, an aileron deflected upward reduces camber, which decreases lift (and drag).

An unfortunate by-product of aileron application is adverse yaw, a characteristic that causes the nose of an aircraft to yaw opposite to the direction of roll. As an airplane enters a left bank, for example, the nose tends to yaw to the right.

Adverse yaw can be countered with a force produced by coordinated application of rudder. In one sense, a rudder is used to enter and recover from turning flight, partly because of an undesirable characteristic of aileron design.

Adverse yaw is commonly attributed to the difference in drag between the oppositely deflected ailerons. When banking into a left turn, for example, the downward aileron on the right wing creates more drag than the other. The result is a tendency to yaw to the right.

Pilots may be surprised to learn that, although this drag differential is a *partial* cause of adverse yaw, it usually is not the *primary* cause.

Figure 1 shows a pair of wings being rolled into a right bank. Notice that the right, descending, wing experiences a relative wind that approaches from ahead of and *below* the wing. This is because the wing simultaneously is moving forward (because of airspeed) and *downward* (because of rolling action).

Since lift always acts perpendicular to the relative wind, we see that the lift vector leans somewhat forward, which pulls the descending wing forward.

Conversely, the left, ascending wing, encounters a relative wind that comes from ahead of and *above* the wing. This is because this wing simultaneously is moving forward and *upward.*

The resultant lift leans somewhat rearward, which has a dragging or retarding effect on the ascending wing.

When rolling into any turn, therefore, it is the force of lift which pulls forward on the low wing and retards the high wing. The result is adverse yaw, the tendency of an airplane's nose to move one way when a pilot wants to go the other. This effect is most noticeable

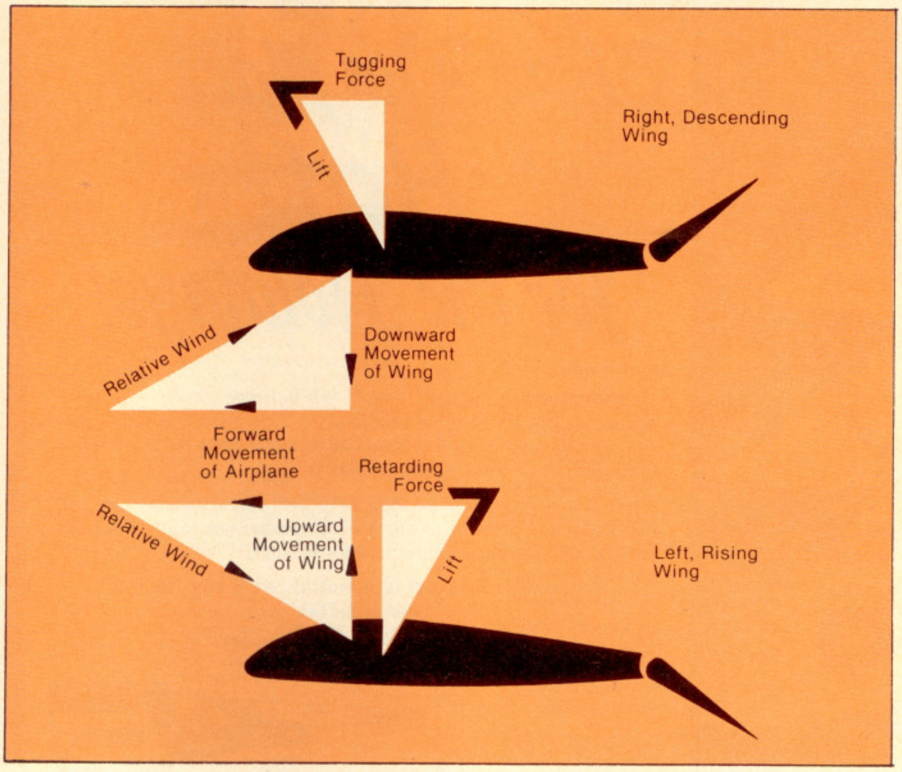

Figure 1: Forces on the wings in a right turn are diagramed (angles exaggerated) to show that, due to the angle at which the relative wind meets the wings, the outside wing is subjected to retarding forces, the inside wing to tugging forces.

during slow flight.

Early designers were frustrated by their inability to eliminate or satisfactorily counter adverse yaw, but the battle did lead to some amusing contrivances. One was the "Slotcum-Aileron" (Figure 2a). During a left turn, for example, the aileron on the left wing rose conventionally. But as the aileron of the right wing deflected downward, an interconnected slat on the leading edge of only that wing opened to form a slot. The purpose of this was to improve airflow over the rising wing. This also had the desired effect of reducing drag on that wing (primarily at large angles of attack) which decreased adverse yaw; the result was improved roll control in the correct direction and less tendency to yaw in the wrong direction.

Such a design, however, was unpopular because of its cost and complexity.

In 1928, L.G. Frise introduced a revolutionary aileron that has become commonplace in the general aviation fleet. The Frise aileron (Figure 2b) incorporates a leading-edge lip that extends below the wing and drags against the relative wind, but only when the aileron is deflected upward. This has the effect of increasing total drag on the wing being lowered during a turn entry and counters much—but not all—of the greater drag created by the opposite, rising wing. The result is a significant reduction of adverse yaw. When the Frise aileron is lowered, the lip remains hidden behind the wing structure to prevent adding to the already excessive drag of a rising wing.

The Frise design also is a partially balanced control. The aileron pivots about a hinge line that is aft of the surface's leading edge. In other words, when the aileron moves up, the leading edge moves down. In this way, air flowing beneath the wing pushes against the projected lip of the aileron which helps to raise the aileron farther. Aerodynamic forces, therefore, are used to assist a pilot in moving the ailerons and control wheel forces are reduced.

To further reduce adverse yaw effect, differential movement can be designed into the aileron system. The controls can be rigged in such a way that the aileron which is "up" is deflected more than the "down" aileron on the opposite wing. In this way, aileron drag on the descending wing is increased, which helps to equalize the drag of both wings.

A *fully* balanced pair of ailerons (Figure 2c) projects a leading edge into the airstream when deflected up *or* down. Properly designed, these enable a pilot to roll an airplane using little more than his fingertips. A disadvantage to this design is that excessive balance can lead to overcontrolling and aileron "snatching," an unnerving situation in which the ailerons tend to deflect more than a pilot wants them to.

Another popular design is the slotted aileron (Figure 2d). At large angles of attack, high-pressure air from beneath the wing flows through a carefully designed slot that is formed by the aileron's leading edge and the contoured, aft wing section. This improves airflow above the aileron during slow flight and increases aileron effectiveness.

To prevent ailerons from fluttering dangerously (like a flag on a windy day), lead weights often are placed within an aileron's leading edge. In days of old, such a "counterbalance" frequently was placed outside the aileron. Similar counterweights were used on elevators and rudders as well.

Aileron effectiveness, also called aileron power, is determined by multiplying the area of both ailerons by the distance of the center of one aileron from the airplane's longitudinal axis. That is, aileron power is achieved by designing large surfaces that are as far from the fuselage as possible.

Does aileron proportion have any effect on its effectiveness? Not much. An aileron with a long span and a narrow chord has about the same effect as one having a short span and wide chord, everything else being equal.

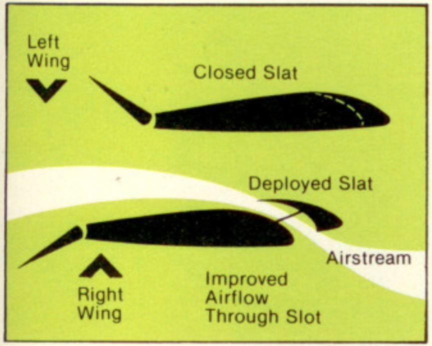

Figure 2a.

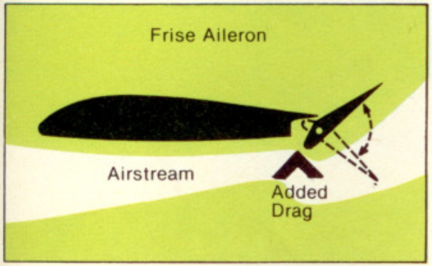

Figure 2b.

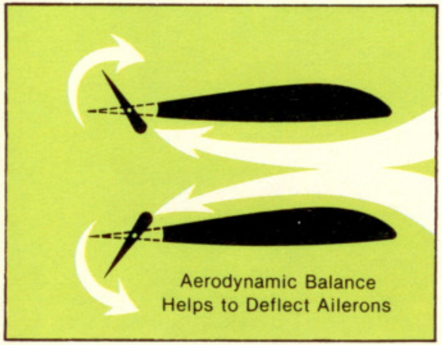

Figure 2c.

Figure 2d.

Another question is often asked: Should ailerons be large and move a small number of degrees, or should they be small with a large deflection? This depends on what the designer wants to accomplish. Big ailerons that needn't be moved much require lower control wheel forces than small ailerons with large deflections.

One fascinating and ingenious aileron system was designed into the New Zealand Aerospace Industries "Airtourer." Moving the control stick laterally not only defects the ailerons, but causes asymetric *flap* deflection as well. Voila! Full span ailerons—with flaps up or down. Roll response truly is outstanding.

Although aileron design has advanced considerably, a pair of practical ailerons has yet to be designed that will *totally* negate adverse yaw. (Adverse yaw, however, can be eliminated by using asymetrically deployed spoilers for roll control.)

Also, the pilot frequently can be relieved of having to apply rudder by interconnecting this control and the ailerons with a bungee cord. In this way, moving the control wheel simultaneously moves the rudder. But, since adverse yaw effect increases during slow flight and rudder effectiveness decreases, even this scheme fails to totally resolve the problem.

Today, when an airplane is made to roll, coordinated use of the ailerons and the rudder is still required. □