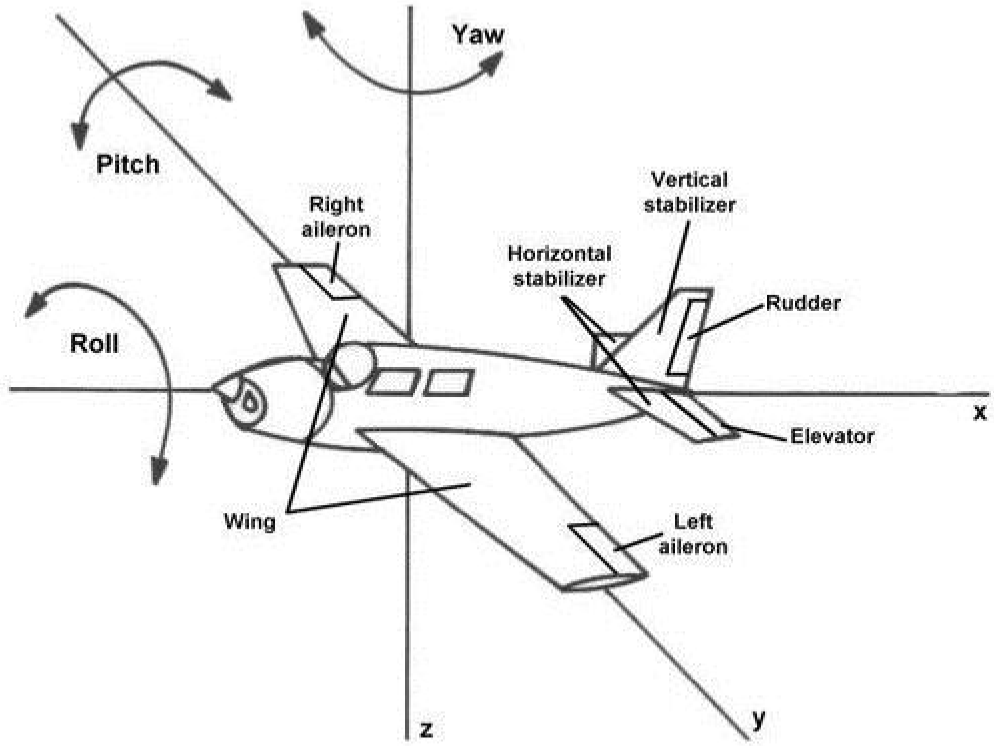
Subject Code & Name**: 19ast302 FLIGHT DYNAMICS** Date: **30. 10.2023**

DAY: **30** TOPIC: ***Adverse yaw – Aileron reversal***

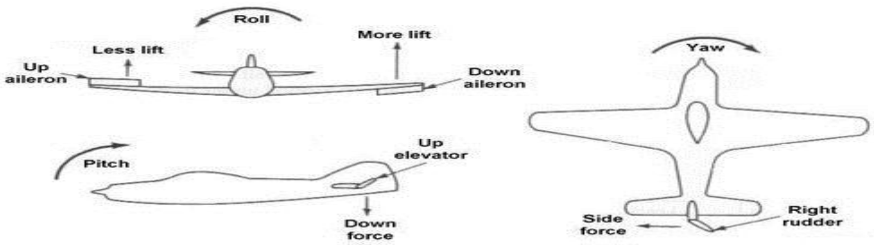
To understand what adverse yaw is, we need to first explain the axes of motion for an airplane. An aircraft in flight can rotate around three different axes, as illustrated below.



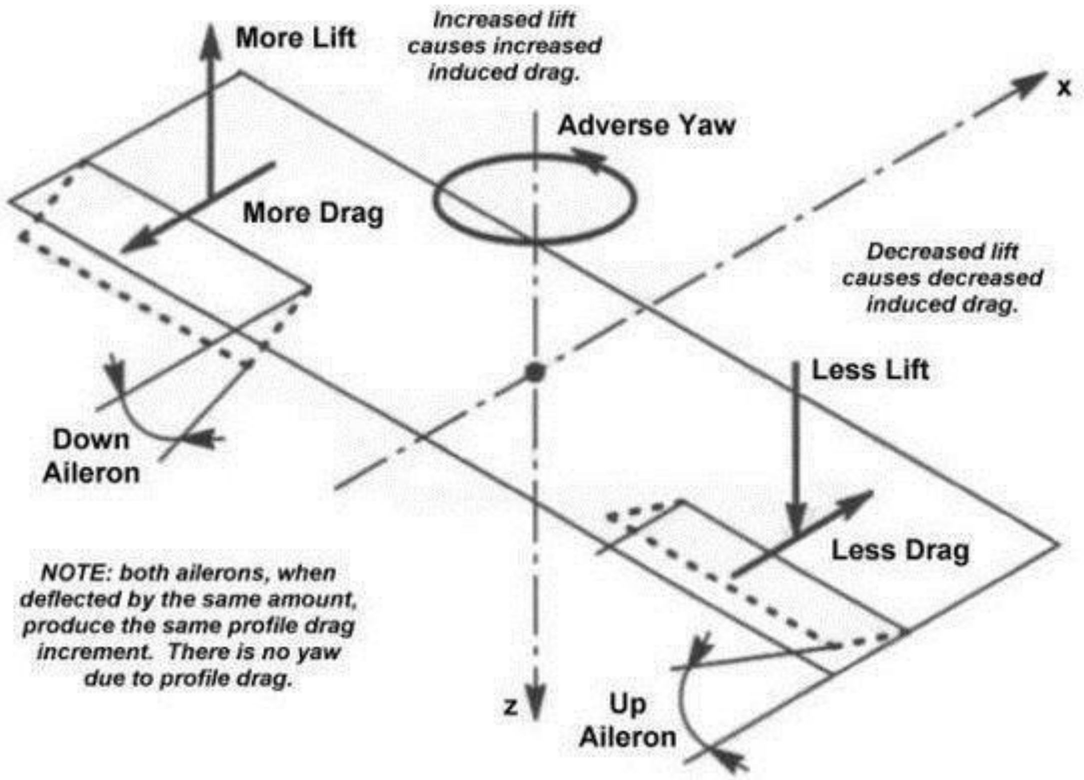
First, the aircraft nose can rotate up and down about the y-axis, a motion known as pitch. Pitch control is typically accomplished using an elevator on the horizontal tail.

Second, the wingtips can rotate up and down about the x-axis, a motion known as roll. Roll control is usually provided using ailerons located at each wingtip.

Finally, the nose can rotate left and right about the z-axis, a motion known as yaw. Yaw control is most often accomplished using a rudder located on the vertical tail.



However, the effect of one control surface is not always limited to just pitch, roll, or yaw alone. When the deflection of one control surface affects more than one of these orientations, we say that the orientations are coupled. The most important of these coupled interactions is adverse yaw. To better understand the concept; let's study a picture of what happens when the pilot deflects the ailerons to roll the aircraft.



Effects caused by aileron deflection

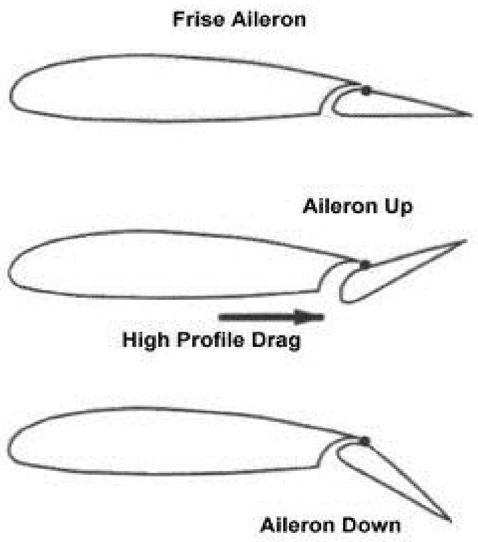
As you can see, the aircraft rols because one aileron is deflected downward while the other is deflected upward. Lift increases on the wing with the downward-deflected aileron because the deflection effectively increases the camber of that portion of the wing. Conversely, lift decreases on the wing with the upward-deflected aileron since the camber is decreased. The result of this difference in lift is that the wing with more lift rols upward to create the desired rolling motion.

Unfortunately, drag is also affected by this aileron deflection. More specifically, two types of drag, called induced drag and profile drag, are increased when ailerons are deployed. Induced drag is a form of drag that is induced by any surface that generates lift. The more lift a surface produces the more induced drag it wil cause (for a given wingspan and wing area). Thus, the wing on which the aileron is deflected downward to generate more lift also experiences more induced drag than the other wing. Profile drag includes all other forms of drag generated by the wing, primarily skin friction and pressure drag. This profile drag increases on both wings when the ailerons are deflected, but the increase is equal when the ailerons are deflected by the same amount. However, the induced drag on each side is not equal, and a larger total drag force exists on the wing with the down aileron. This difference in drag creates a yawing motion in the opposite direction of the rol. Since the yaw motion partially counteracts the desired roll motion, we call this effect adverse yaw.

 # Methods to avoid Adverse Yaw

1. Frise Ailerons:

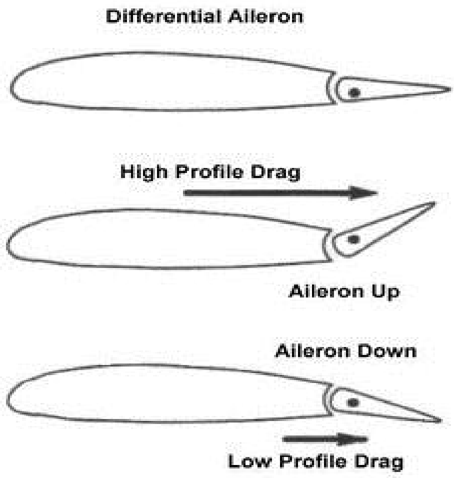
The concept behind this particular kind of aileron is to minimize the profile drag on the wing with the down aileron while increasing the profile drag on the wing with the up aileron. This difference in profile drag counteracts the effect of induced drag thereby creating a yawing motion that at least partially cancels the adverse yaw effect.



Frise ailerons accomplish this differential profile drag by maintaining a smooth contour between the upper surfaces of the wing and aileron, causing very little drag, while the bottom surface of the aileron juts downward to create a large increase in profile drag. Although this approach is simple and does provide some relief, the performance of Frise ailerons is very dependent on operating conditions. For this reason, such ailerons are often only partialy effective at overcoming adverse yaw.

2. Differential Ailerons:

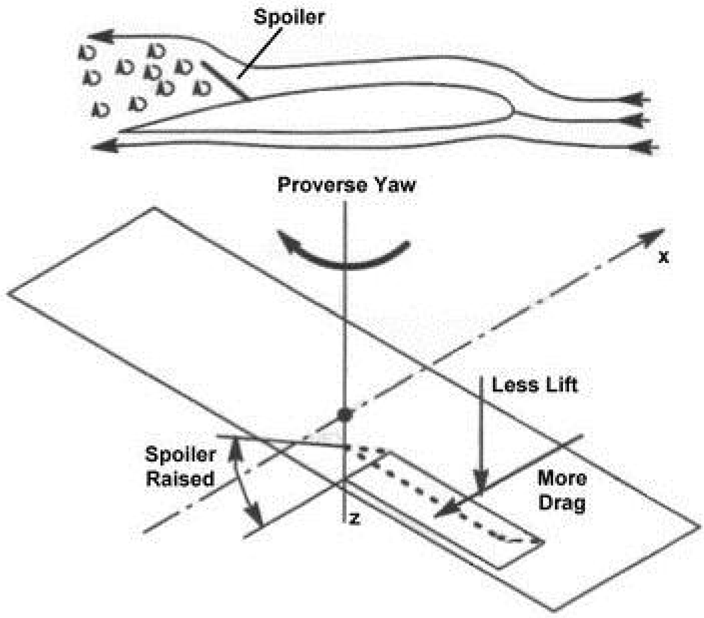
Another approach to solving adverse yaw is to deflect the ailerons by differing amounts. The deflection of the down aileron is typicaly much less than the up aileron so that the additional profile drag is very small compared to that on the up aileron.



As in the case of Frise aileron, this differential profile drag produces a yawing motion that at least partially offsets the adverse yaw, but the effect is limited.

3. Spoilers:

Spoilers are long narrow flat plates typically fitted along the upper surface of both wings. In normal flight, spoilers lie flat and generate no effect on the aerodynamic performance of the wing. However, the spoilers can be raised upward into the airflow to generate large turbulence that reduces the lift and increases the drag on a wing.



When used in coordination with ailerons, a spoiler can be used to reduce the lift and increase the profile drag on the wing with the up aileron. As a result, the wing with the down aileron experiences a large increase in lift and a small increase in drag while the wing with the up aileron experiences a large decrease in lift and a large increase in drag. These effects combine to create the desired roll motion and a complimenting yaw motion that is called proverse yaw.

4. Cross-Coupled Controls:

One of the most effective solutions to adverse yaw is to couple the ailerons and rudder so that both surfaces deflect simultaneously. As the ailerons create a yaw motion in one direction, the rudder automatically deflects to create a yaw motion in the opposite direction. The two effects counteract each other eliminating the undesired yaw. This form of cross-coupling was often built into the cable-and-pulley control systems of older aircraft. The problem was recognized even as early as the Wright brothers who incorporated such controls into the Wright Flyer. In addition, most major aircraft today utilize some sort of computerized fly-by-wire control system, and it is rather trivial to program cross-coupled control measures into the automated systems.

TOPIC: ***AILERONREVERSAL***

Control reversal is an adverse effect on the controllability of aircraft. The flight controls reverse themselves in a way that is not intuitive, so pilots may not be aware of the situation and therefore provide the wrong inputs; in order to roll to the left, for instance, they have to push the control stick to the right, the opposite of the normal direction. A situation occurs at some high speed when the moment is so large that there is total loss of lift when the **aileron** is deflected downward, and the aircraft rols in the reverse direction. This is caled **aileron reversal**. An adverse effect when an aircraft rols in the reverse direction of the **aileron** input.

aileron reversal

A symmetrical section develops an upward aerodynamic force at the aileron hinge point when the aileron is deflected downward. This force acts behind the elastic axis and so produces a nose-

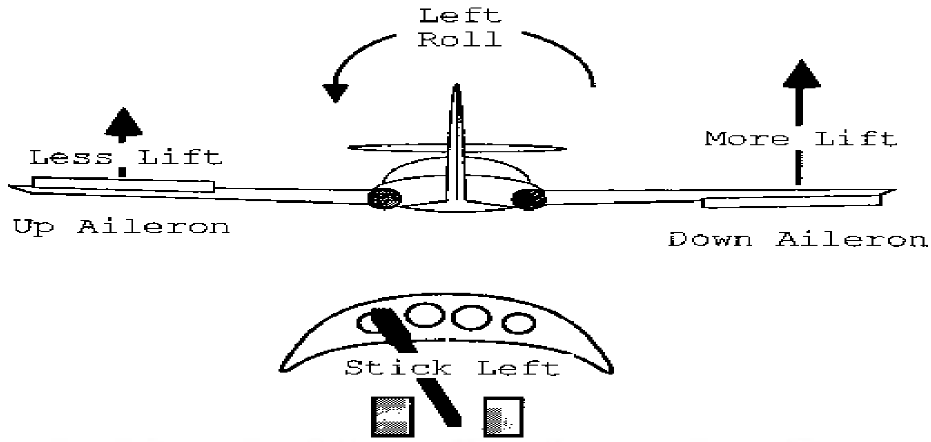
down pitching moment. Because this moment is dependent on square of velocity, its value is higher at higher speed. If the wing lacks sufficient rigidity to resist this pitching moment, i.e., if i t is an elastic wing, its nose will twist downward, its angle of attack will reduce, and the resultant lift will be lowers. A situation occurs at some high speed when the moment is so large that there is total loss of lift when the aileron is deflected downward, and the aircraft rolls in the reverse direction. This is called aileron reversal.

An adverse effect when an aircraft rolls in the reverse direction of the aileron input. This can be caused by the following:

Aerodynamic twisting of the wing caused by ailerons as speed is increased which may reduce, neutralize, or reverse the direction of the lift. Aileron reversal results if the aileron structure is insufficiently stiff in torsion. The effect is most pronounced at near sonic speeds.

In some aircraft, very low speeds. The descending aileron increases the angle of attackof that portion of the wing, resulting install of the wing that should be moving upward and causing it to drop.

TOPIC: ***AILERONREVERSAL***



A number of aircraft, when flying near their maximum speed, are subject to an important aeroelastic phenomenon. No real structure is ideally rigid, and it has static and dynamic flexibility. Wings are usually produced from aerospace materials such as aluminum and composite materials and have structures which are flexible. This flexibility causes the wing to be unable to maintain its geometry and integrity, especially in high-speed flight operations. This phenomenon, which is referred to as aileron reversal, negatively influences the aileron effectiveness.

Consider the right section of a flexible wing with a downward-deflected aileron to create a negative rolling moment. At subsonic speeds, the increment in aerodynamic load due to aileron deflection has a centroid somewhere near the middle of the wing chord. At supersonic speeds, the control load acts mainly on the deflected aileron itself, and hence has its centroid even further to the rear. If this load centroid is behind the elastic axis of the wing structure, then a nose-down twist (α_{twist}) of the main wing surface (about the y-axis) results. The purpose of this deflection was to raise the right wing section. However, the wing twist reduces the wing angle of attack, and leads to a reduction of the lift on the right section of the wing (Figure 12.16). In extreme cases, the down-lift due to aeroelastic twist will exceed the commanded up-lift, so the net effect is reversed. This change in the lift direction will consequently generate a positive rolling moment.

This undesired rolling moment implies that the aileron has lost its effectiveness and the roll control derivative $C_{l_{\delta A}}$ has changed its sign. Such a phenomenon is referred to as aileron reversal. This phenomenon poses a significant constraint on the aileron design. In addition, the structural design of the wing must examine this aeroelasticity effect of the aileron deflection. The aileron reversal often occurs at high speeds. Most high-performance aircraft have an aileron reversal speed beyond which the ailerons lose their effectiveness. The F-14 fighter aircraft experiences aileron reversal at high speed.

Clearly, such aileron reversal is not acceptable within the flight envelope, and must be considered during the design process. A number of solutions for this problem are: (i) make the wing stiffer, (ii) limit the range of aileron deflections at high speed, (iii) employ two sets of ailerons – one set at the inboard wing section for high-speed flight and one set at the outboard wing section for high-speed flight, (iv) reduce the aileron chord, (v) use a spoiler for roll control, and (vi) move the ailerons toward the wing inboard section. The transport aircraft Boeing 747 has three different types of roll control device: inboard ailerons, outboard ailerons, and spoilers. The outboard ailerons are disabled except in low-speed flights when the flaps are also deflected. Spoilers are essentially flat plates of about 10–15% chord located just ahead of the flaps. When the spoilers are raised,

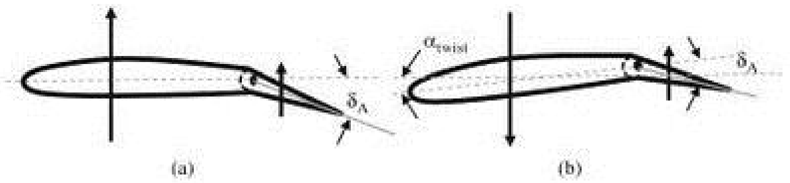


Figure 12.16 Aileron reversal. (a) An ideal and desired aileron; (b) An aileron with aileron reversal