SNS COLLEGE OF TECHNOLOGY

(An Autonomous Institution)

DEPARTMENT OF AEROSPACE ENGINEERING

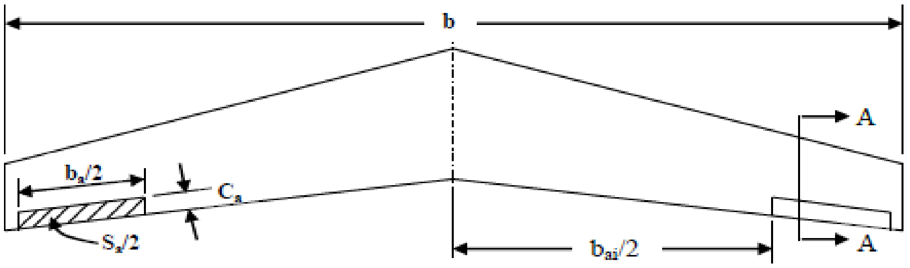
Subject Code & Name**: 19ASB302 FLIGHT DYNAMICS** **Date: 27. 10.2023**

DAY: **29** TOPIC: **Aileron power – Coupling between rolling moment and yawing moment**

The primary function of an aileron is the lateral (i.e. roll) control of an aircraft; however, it also affects the directional control. Due to this reason, the aileron and the rudder are usually designed concurrently. Lateral control is governed primarily through a roll rate (P). Aileron is structurally part of the wing, and has two pieces; each located on the trailing edge of the outer portion of the wing left and right sections. Both ailerons are often used symmetrically, hence their geometries are identical. Aileron effectiveness is a measure of how good the deflected aileron is producing the desired rolling moment. The generated rolling moment is a function of aileron size, aileron deflection, and its distance from the aircraft fuselage centerline. Unlike rudder and elevator which are displacement control, the aileron is a rate control. Any change in the aileron geometry or deflection will changes the roll rate; which subsequently varies constantly the roll angle.

The deflection of any control surface including the aileron involves a hinge moment. The hinge moments are the aerodynamic moments that must be overcome to deflect the Control surfaces. The hinge moment governs the magnitude of augmented pilot force required to move the corresponding actuator to deflect the control surface. To minimize the size and thus the cost of the actuation system, the ailerons should be designed so that the control forces are as low as possible.

In the design process of an aileron, four parameters need to be determined. They are: 1. aileron plan form area (S_a); 2. Aileron chord/span (C_a/b_a); 3. Maximum up and down aileron deflection ($\pm \delta_{Amax}$); and 4. Location of inner edge of the aileron along the wing spans (b_{ai}). Figure 12.10 shows the aileron geometry. As a general guidance, the typical values for these parameters are as follows: $S_a/S = 0.05$ to 0.1, $b_a/b = 0.2$-0.3, $C_a/C = 0.15$-0.25, $b_{ai}/b = 0.6$-0.8 and $\delta_{Amax} = \pm 30$ degrees. Based on this statistics, about 5 to 10 percent of the wing area is devoted to the aileron, the aileron-to-wing-chord ratio is about 15 to 25 percent, aileron-to- wing-span ratio is about 20-30 percent, and the inboard aileron span is about 60 to 80 percent of the wing span.



Top-view of the wing and aileron

Side-view of the wing and aileron (Section AA)
Geometry of aileron

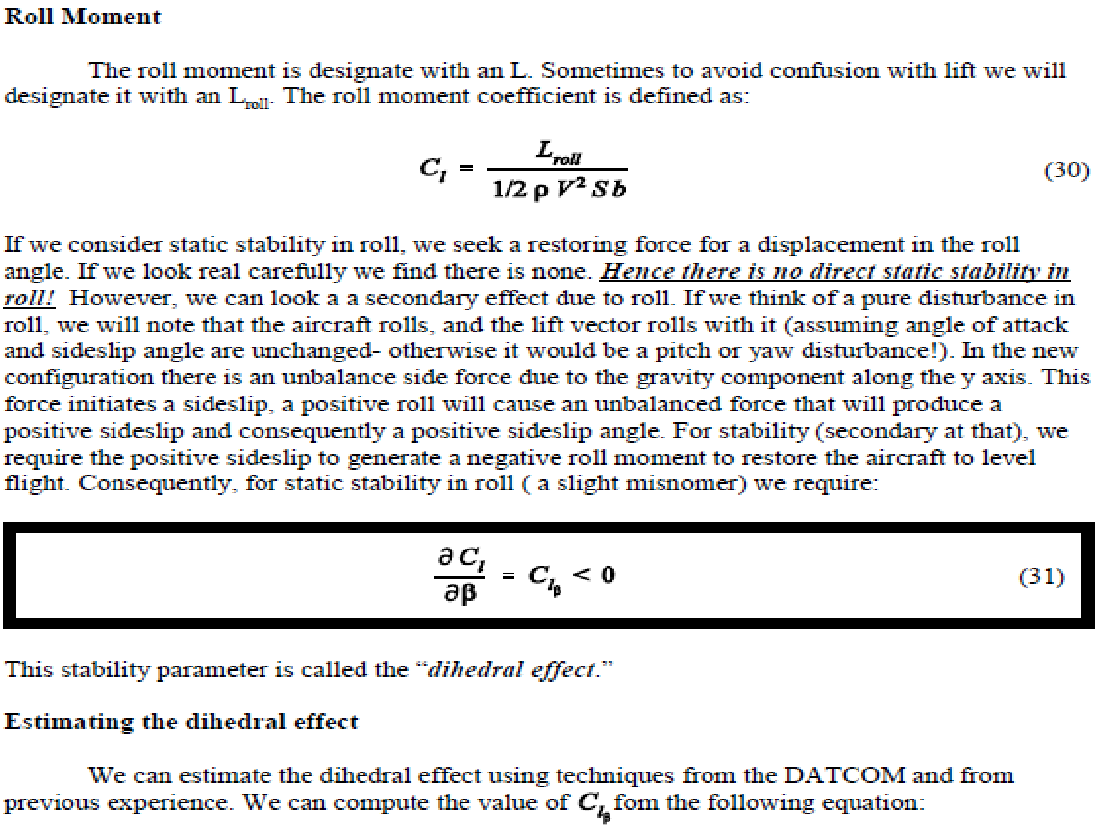
Factors affecting the design of the aileron are:

1. the required hinge moment,
2. the aileron effectiveness,
3. aerodynamic and mass balancing,
4. flap geometry,
5. the aircraft structure, and
6. Cost.

Aileron effectiveness is a measure of how effective the aileron deflection is in producing the desired rolling moment.

Aileron effectiveness is a function of its size and its distance to aircraft center of gravity. Hinge moments are also important because they are the aerodynamic moments that must be overcome to rotate the aileron. The hinge moments governs the magnitude of force required of the pilot to move the aileron. Therefore, great care must be used in designing the aileron so that the control forces are within acceptable limits for the pilots. Finaly, aerodynamic and mass balancing deals with techniques to vary the hinge moments so that the stick force stays within an acceptable range. Handling qualities discussed in the previous section govern these factors. In this section, principals of aileron design, design procedure, governing equations, constraints, and design steps as well as a fully solved example are presented.

TOPIC: ***<u>Rolling Moment</u>***



Roll Moment

The roll moment is designate with an L. Sometimes to avoid confusion with lift we will designate it with an L_{roll}. The roll moment coefficient is defined as:

$$C_l = \frac{L_{roll}}{1/2\,\rho\,V^2 S b} \qquad (30)$$

If we consider static stability in roll, we seek a restoring force for a displacement in the roll angle. If we look real carefully we find there is none. ***<u>Hence there is no direct static stability in roll!</u>*** However, we can look a a secondary effect due to roll. If we think of a pure disturbance in roll, we will note that the aircraft rolls, and the lift vector rolls with it (assuming angle of attack and sideslip angle are unchanged- otherwise it would be a pitch or yaw disturbance!). In the new configuration there is an unbalance side force due to the gravity component along the y axis. This force initiates a sideslip, a positive roll will cause an unbalanced force that will produce a positive sideslip and consequently a positive sideslip angle. For stability (secondary at that), we require the positive sideslip to generate a negative roll moment to restore the aircraft to level flight. Consequently, for static stability in roll (a slight misnomer) we require:

$$\boxed{\frac{\partial C_l}{\partial \beta} = C_{l_\beta} < 0 \qquad (31)}$$

This stability parameter is called the "*dihedral effect*."

Estimating the dihedral effect

We can estimate the dihedral effect using techniques from the DATCOM and from previous experience. We can compute the value of C_{l_β} fom the following equation:

$$C_{l_\beta} = C_{L_{\beta_{wb}}} + C_{l_{\beta_{vt}}} \tag{32}$$

The contribution from the wing-body (mostly from the wing) can be determined from charts and graphs in the DATCOM and in Etkin and Reid. The main equation is:
For AR > 1

$$C_{l_{\beta_{wb}}} = C_L \left[\left(\frac{C_{l_\beta}}{C_L} \right)_{\Lambda_{1/2}} K_{M_a} + \left(\frac{C_{l_\beta}}{C_L} \right) \right]_a + \Gamma \left(\frac{C_{l_\beta}}{\Gamma} K_{m\Gamma} \right) + \theta \tan\Lambda_{1/4} \left(\frac{\Delta C_{l_\beta}}{\theta \tan\Lambda_{1/4}} \right) \tag{33}$$

where θ = the wing twist, negative for washout
Γ = the wing dihedral angle

The four ratios that appear in the ( ) along with the two parameters K_x are determined from charts in the DATCOM or Etking and Reid.

The vertical tail contribution to C_{l_β}

The vertical tail contribution to the dihedral effect can be established with simple geometry. The rolling moment due to the vertical tail is given by:

$$\begin{aligned} L_{roll_{vt}} &= -L_{vt} z_{vt} \\ &= -a_{vt} \alpha_{vt} 1/2 \rho V_{vt}^2 S_{vt} z_{vt} \end{aligned} \tag{34}$$

where z_{vt} is measured positive down, and the vertical tail lift is positive in the positive y direction. If we divide by $\bar{q} S b$ and take the derivative with respect to the sideslip angle, β, we get the desired expression:

$$\boxed{C_{l_{\beta_{vt}}} = a_{vt} \eta_{vt} \frac{S_{vt} l_{vt}}{S b} \left(1 - \frac{\partial \sigma}{\partial \beta} \right) \frac{z_{vt}}{l_{vt}} = C_{n_\beta} \frac{z_{vt}}{l_{vt}}} \tag{35}$$

Roll Control

For basic calculations, we can assume that the rolling motion is purely about the x axis. It that's the case, we can estimate the maximum sustained roll rate by looking at a simple roll moment balance. In general, the roll moment equation of motion is given by:

$$L_{roll} = I_x \dot{p} = 0 \tag{36}$$

where it is equal to zero for the steady state case. Dividing through by $\bar{q} S b$ we see that the requirement is that $C_l = 0$. We can write this expression in terms of the aileron deflection and roll rate as

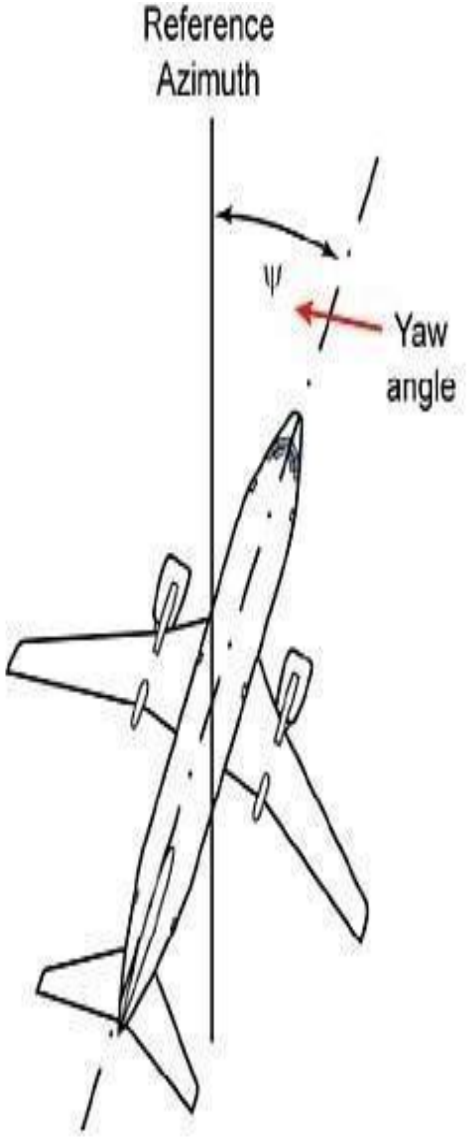
$$C_l = C_{l_p} \hat{p}_{ss} + C_{l_{\delta_a}} \delta_a = 0 \tag{37}$$

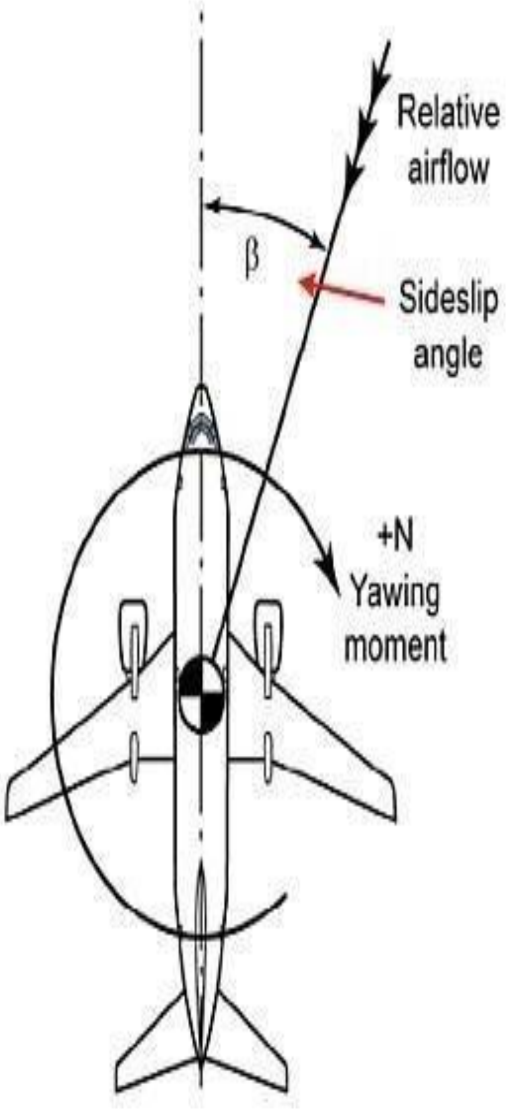
where $\hat{p} = \dfrac{p b}{2 V}$ is the non-dimensional roll rate. Then the steady state roll rate for a given aileron deflection is given by:

$$\boxed{\begin{aligned} \hat{p}_{ss} &= -\frac{C_{l_{\delta_a}}}{C_{l_p}} \delta_a \\ p_{ss} &= \hat{p}_{ss} \frac{2 V}{b} \end{aligned}} \tag{38}$$

The **yaw moment** is the **moment** about the z body axis and is positive if it moves the nose of the plane to the right. The big contributor to the **yaw moment** is the vertical tail. Active **Yaw Control** (AYC) is an automobile feature that uses an active differential to transfer torque to the wheels that have the best grip on the road (torque vectoring).

Unlike traditional mechanical limited-slip differentials, an AYC is electronically **controlled** Imagine three lines running through an airplane and intersecting at right angles at the airplane's center of gravity. Rotation around the front-to-back axis is called roll. Rotation around the side-to-side axis is called pitch. Rotation around the vertical axis is called **yaw**.





Yaw Moment Equation

The yaw moment is the moment about the z^{body} axis and is positive if it moves the nose of the plane to the right. The big contributor to the yaw moment is the vertical tail. We can write the yaw moment equation in a similar manner to the way we wrote the pitch-moment equation by considering the contributions from the wing-body combination and from the vertical tail. If we take moments about the center of gravity we have:

$$N = N_{wb} - L_{vt} l_{vt} \cos \alpha_{vt} - D_{vt} l_{vt} \sin \alpha_{vt} \tag{1}$$

where l_{vt} is the vertical tail length, the distance from the cg to the aerodynamic center of the vertical tail, L_{vt}, D_{vt} are the lift and drag of the vertical tail, and α_{vt} is the angle of attack of the vertical tail measured positive so as to create a positive side force. If we make the usual assumptions such as that α_{vt} is a small angle, and that $D_{vt} << L_{vt}$, we can reduce Eq. (1) to the form:

$$N = N_{wb} - L_{vt} l_{vt} \tag{2}$$

and

$$N = N_{wb} - C_{L_{vt}} 1/2 \rho V_{vt}^2 S_{vt} l_{vt} \tag{3}$$

where S_{vt} is the vertical tail area. Dividing by $1/2 \rho V^2 S b$ we obtain the yaw-moment equation in coefficient form:

$$\begin{aligned} C_n &= C_{n_{wb}} - C_{L_{vt}} \eta_{vt} \left(\frac{S_{vt} l_{vt}}{S b} \right) \\ &= C_{n_{wb}} - C_{L_{vt}} \eta_{vt} \forall_{vt} \end{aligned} \tag{4}$$

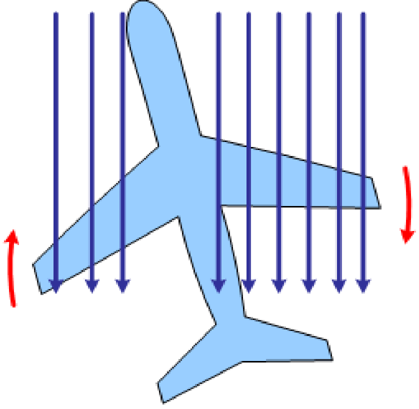
If we let the vertical tail lift coefficient depend on a vertical tail lift curve slope and a rudder deflection we can write it as:

$$C_{L_{vt}} = a_{vt} \alpha_{vt} + a_r \delta_r \tag{5}$$

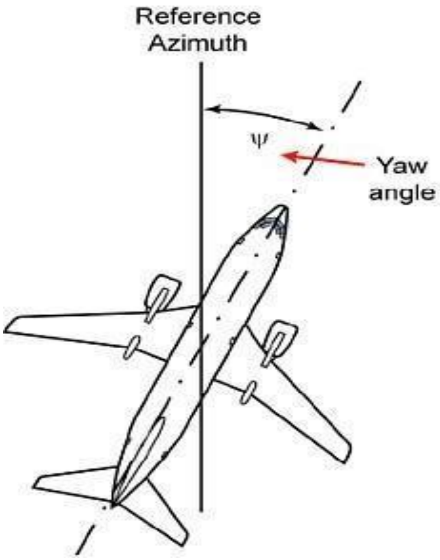
where a_{vt} and a_r are the vertical tail lift curve slope and rudder "lift curve slope" respectively. In addition we can write the vertical tail angle of attack in terms of the vehicle side slip angle, β, and the side-wash angle, σ, as:

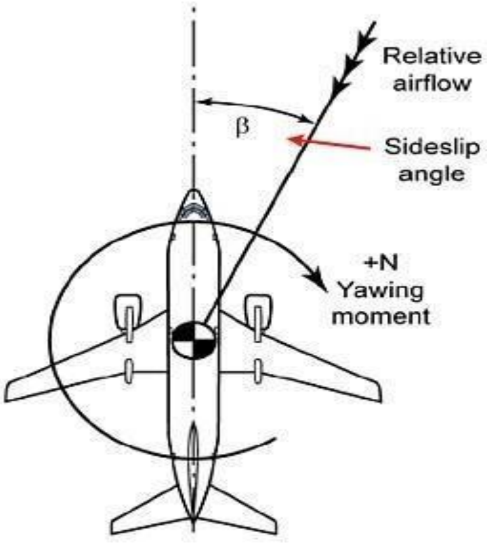
$$\alpha_{vt} = -\beta + \sigma \tag{6}$$

TOPIC: ***<u>Coupling between rolling moment and yawing moment</u>***



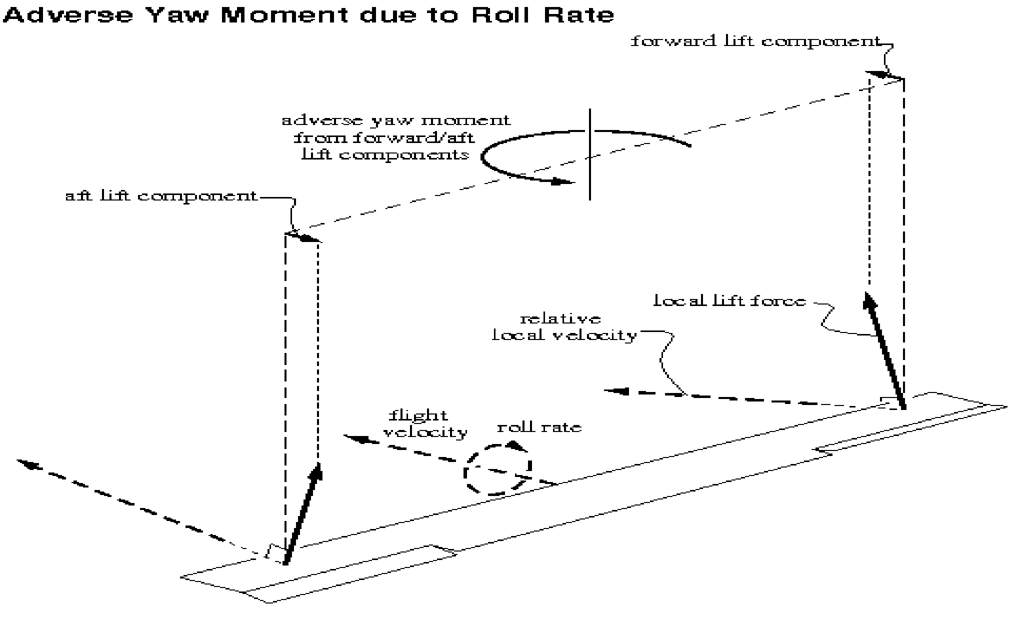
As right wing migrates forward (yaw), sweptback design produces a simultaneous increase in lift. As the wing's lift increases, induced drag increases, resulting in wing returning rearward.





Dutch roll is a type of aircraft motion, consisting of an out-of-phase combination of "tail- wagging" and rocking from side to side. This yaw-roll coupling is one of the basic flight dynamic modes (others include phugoid, short period, and spiral divergence).

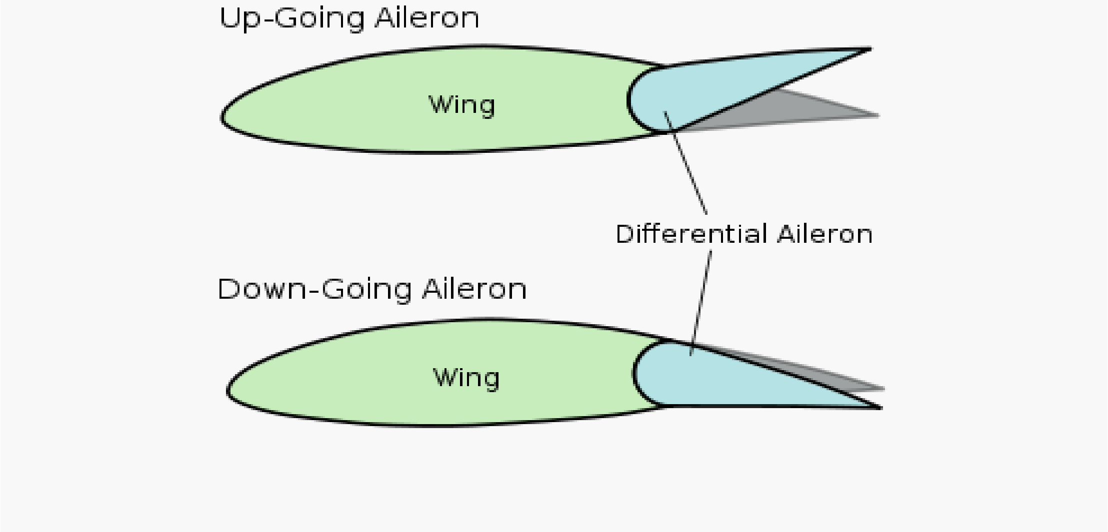
Adverse yaw is the natural and undesirable tendency for an aircraft to yaw in the opposite direction of a roll. It is caused by the difference in profile drag between the upward and downward deflected ailerons, the difference in lift and thus induced drag between left and right wings, as well as an opposite rotation of each wing's lift vector about the pitch axis due to the rolling trajectory of the aircraft. The effect can be greatly minimized with ailerons deliberately designed to create drag when deflected upward and/or mechanisms which automatically apply some amount of coordinated rudder. As the major causes of adverse yaw vary with lift, any fixed-ratio mechanism will fail to fully solve the problem across all flight conditions and thus any manually operated aircraft will require some amount of rudder input from the pilot in order to maintain coordinated flight.



Yaw stability

A strong directional stability is the first way to reduce adverse yaw.[6] This is influenced by the vertical tail moment (area and lever arm about gravity center).

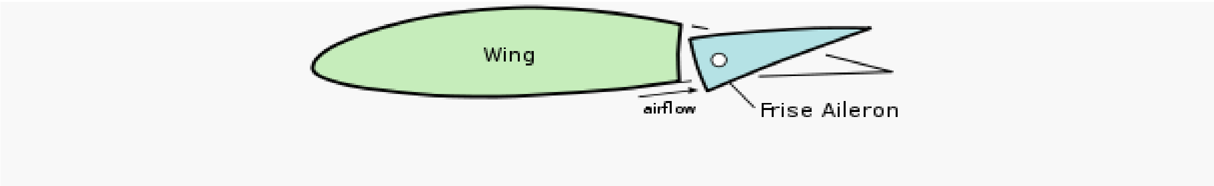
Differential aileron deflection



The geometry of most aileron linkages can be configured so as to bias the travel further upward than downward. By excessively deflecting the upward aileron, profile drag is increased rather than reduced and separation drag further aids in producing drag on the inside wing, producing a yaw force in the direction of the turn. Though not as efficient as rudder mixing, aileron differential is very easy to implement on almost any airplane and offers the significant advantage of reducing the tendency for the wing to stall at the tip first by limiting the downward aileron deflection and its associated effective increase in angle of attack.

Most airplanes use this method of adverse yaw mitigation — particularly noticeable on one of the first well-known aircraft to ever use them, the de Haviland Tiger Moth training biplane of the 1930s — due to the simple implementation and safety benefits.

Frise ailerons



Frise ailerons are designed so that when up aileron is applied, some of the forward edge of the aileron will protrude downward into the airflow, causing increased drag on this (down-going) wing. This will counter the drag produced by the other aileron, thus reducing adverse yaw.

Unfortunately, as well as reducing adverse yaw, Frise ailerons will increase the overall drag of the aircraft much more than applying rudder correction. Therefore they are less popular in aircraft where minimizing drag is important (e.g. in a glider).

Note: Frise ailerons are primarily designed to reduce roll control forces. Contrary to the illustration, the aileron leading edge has to be rounded to prevent flow separation and flutter at negative deflections.[That prevents important differential drag forces.

Roll spoilers

On large aircraft where rudder use is inappropriate at high speeds or ailerons are too small at low speeds, roll spoilers (also called spoilerons) can be used to minimise adverse yaw or increase roll moment. To function as a lateral control, the spoiler is raised on the down-going wing (up aileron) and remains retracted on the other wing. The raised spoiler increases the drag, and so the yaw is in the same direction as the roll.[9]