Lecture 2 – Control Reversal of the typical section

Consider now the typical aerofoil section with a ______________________________ attached at the ___________________________________ as shown in the figure.

Figure 1 – Typical aerofoil with a control surface

The section is allowed to ________________________________ as indicated by the rotation spring located at the _____________________________________. There is another degree-of-freedom, which is the ___________________________________ indicated by ______, defined as ____ (trailing edge down).

Deflecting the aileron in the positive β direction will cause a change in the pressure distribution pattern over the section, hence resulting in

1. _______________________________________ and
2. _______________________________________

Both aerodynamic loadings are evaluated at the _____________________________.

The effects of these changes are

1. the extra lift works towards __________________ motion of the aerofoil
2. the negative pitching moment works towards _________________________ motion of the aerofoil

From this analysis, it can be seen that there will come a point where with an increase in airspeed will result in both of these forces cancel each other out and the aileron becomes ineffective, i.e. aileron deflection β does not produce extra lift.

Analysis of Aerodynamic Forces

Let us consider the rotational equilibrium of the aerofoil in figure 1.

__________________________ [EQN.1]

where e is the distance between the elastic axis and the aerodynamic centre. Recalling that the lift and pitching moment of a two-dimensional aerofoil are given by

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When the aileron is deflected by β, the effective camber will produce a change in lift and moment. Assuming that the angles α and β are small so they are in the linear region, we obtain

____

[EQN.2]

____

where

- $C_{L\alpha}$ Lift curve slope of the aerofoil, i.e. $dC_L/d\alpha$
- $C_{L\beta}$ Lift curve slope of the aileron, i.e. $dC_L/d\beta$
- $C_{M\beta}$ Moment curve slope of the aileron, i.e. $dC_M/d\beta$. Note that $C_{M\beta} < 0$
- C_{M0} Zero lift pitching moment. $C_{M0} = 0$ for a symmetric aerofoil

Now, let us substitute the aerodynamic terms into the equilibrium equation in rotation (equation 1) to give

____

Recall that $\alpha = \alpha_r + \theta$. We can rewrite the above expression as

____

Note the existence of divergence. Substitute the expression for θ into equation 2a to obtain

____

Let us now consider the __________________ in the above expression, especially the term in the brackets involving β.

- The first term $C_{L\beta}\beta$ is ____.

  It directly gives an increase in lift with a change in angle β.

- The term $C_{L\beta}\dfrac{cqSC_{L\alpha}C_{M\beta}}{kC_{L\beta}}\beta$ is more complex but it clearly represents the

  _______________________________________. Recall that $C_{M\beta} < 0$,

  therefore for a positive change in aileron angle β, this term is ____________ and causes a decrease in lift.

At low speed (small value of q), the increase in β will result in higher lift, so the aircraft control works as intended. However as the flow speed increases, and so does the dynamic pressure q, there will come a point where the aeroelastic effects dominate, hence the rate of change of lift with respect to β vanishes, i.e.

________________________ [EQN.3]

We can determine the dynamic pressure where control reversal begins by equating the terms in the brackets in the numerator to be zero, to obtain

____

____

The term q_R is always positive because $C_{M\beta} < 0$, $C_{L\beta} > 0$ and $C_{L\alpha} > 0$. Finally, the reversal speed is given by

____

The parameters affecting the reversal speed are shown in the expression above. The most direct method to increase the reversal speed is to increase the ______________ ____________________ of the wing but that will inevitably incur a structural weight penalty. Therefore, a common solution is to position the aileron __________________ _____________________ to benefit from the higher torsional stiffness than the section near the wing tip.

Aileron Effectiveness

The aileron effectiveness can be measured by

$$\eta = \frac{\text{actual change in lift per unit change in } \beta}{\text{change in lift per unit change in } \beta \text{ for a rigid wing}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Taking the $\left(\frac{dC_L}{d\beta}\right)$ expression from [EQN.3], we obtain

____

For a perfectly rigid wing, both q_R and q_D are infinite, so the effectiveness _________.