Module-3

Lecture-16

Stick Free Stability and Control

Stick-Free Stability

- Each control surface on an aircraft is mounted through a hinge. A deflection of control surface results in modified aerodynamic moment about the hinge line. The pilot (or some mechanism) must supply adequate force/ moment to counter this hinge moment.

- Moment acting at hinge line of an elevator is to be overcome by pilot exerting a force on the control stick.

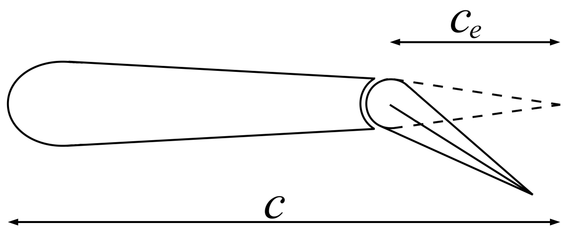

Figure 1: Hinge moment

$$H_e = C_{h_e} \left(\frac{1}{2} \rho_e V^2 \right) S_e c_e$$

where,

S_e - Area aft of the hinge line

c_e - Chord from hinge line to T.E. of flap

Reversible and Irreversible Controls

Reversible Controls

- *In reversible control system, the pilot controls are connected to the control surfaces. This is generally done by using pulleys, cables and push rods.*

- *Therefore, if pilot moves the control stick then the corresponding control surface also sets deflected. Similarly, if control surface is deflected then the control stick also gets deflected.*

Irreversible Controls

- *In irreversible control system, despite the controls are directly connected to surfaces; there is additional boost system that requisite force, moment to the controls.*
- *As a consequence, when pilot moves the stick then the control surface moves. However, movement of control surface will not move the stick.*
- *The boost system is supposed to hold the control surface in a fixed position once it is set at that position.*
- For a reversible system in 'hands off' condition (pilot let go off the stick!) the control surface will float to the position where there is no hinge moment (force or moment applied to the control surface disappear).
- The condition where the hinge moment is equal to zero is called "stick free" condition. It is important to note that under this condition, the aerodynamic characteristics including the neutral point change.

$$C_h = C_{h_o} + C_{h_{\alpha_t}}\alpha_t + C_{h_{\delta_e}}\delta_e + C_{h_{\delta_t}}\delta_t$$

- Let us assume, there is no tab, $\delta_t = 0 \rightarrow C_{h_{\delta_t}}\delta_t = 0$.
- Also let us assume that the tail has symmetric airfoil cross-section

$$C_{h_o} = 0$$

$$C_h = C_{h_{\alpha_t}}\alpha_t + C_{h_{\delta_e}}\delta_e$$

- When elevator is set free, then $C_h = 0$

$$C_h = C_{h_{\alpha_t}}\alpha_t + C_{h_{\delta_e}}\delta_e = 0$$

$$(\delta_e)_{free} = (\delta_e)_{float} = -\left(\frac{C_{h_{\alpha_t}}}{C_{h_{\delta_t}}}\right)\alpha_t$$

- Usually $C_{h_{\alpha_t}}$ and $C_{h_{\delta_t}}$ are negative, so elevator floats up when α_t is positive.

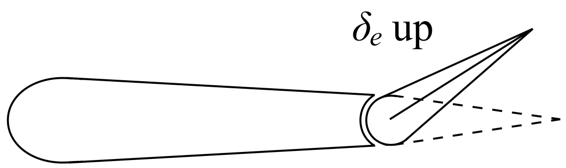

Figure 2: Schematic diagram representing elevator trim

- At trim (hands off), the elevator is (δ_e) up.

$$C_{L_t} = C_{L_{\alpha_t}}\alpha_t + C_{L_{\delta_e}}\left(C_{L_{\delta_e}}\right)_{free}$$

$$C_{L_t} = C_{L_{\alpha_t}}\alpha_t + \left(-\frac{C_{h_{\alpha_t}}}{C_{h_{\delta_t}}}\right)\alpha_t C_{L_{\delta_e}}$$

$$C_{L_t} = C_{L_{\alpha_t}}\left[1 - \frac{C_{L_{\delta_e}}}{C_{L_{\alpha_t}}}\frac{C_{h_{\alpha_t}}}{C_{h_{\delta_t}}}\right]\alpha_t$$

let

$$\frac{C_{L_{\delta_e}}}{C_{L_{\alpha_t}}} = \frac{d\alpha_t}{d\delta_e} = \tau$$

$$C_{L_t} = C_{L_{\alpha_t}}\left[1 - \tau\frac{C_{h_{\alpha_t}}}{C_{h_{\delta_e}}}\right]\alpha_t$$

- So the tail lift curve slope is modified by f,

$$f = \left[1 - \tau\frac{C_{h_{\alpha_t}}}{C_{h_{\delta_e}}}\right]$$

$$C_{L_t} = C_{L_{\alpha_t}} f\alpha_t$$

τ is positive, $C_{h_{\alpha_t}} < 0$ and $C_{h_{\delta_e}} < 0$

$$C'_{L_{\alpha_t}} = C_{L_{\alpha_t}} f$$

which implies $f < 1$

$$C'_{L_{\alpha_t}} < C_{L_{\alpha_t}}$$

This is provided $C_{h_{\alpha_t}} < 0$ and $C_{h_{\delta_e}} < 0$

To derive expression for stick free neutral point we start realizing that stick-fixed case and stick-free case differ by the modified lift curve slope as modeled for stick free case.

$$C_{m_{cg}} = C_{m_o} + \left(\frac{dC_m}{dc_e}\right)C_L \text{ --- --- --- Stick fixed}$$

$$C'_{m_{cg}} = C'_{m_o} + \left(\frac{dC_m}{dc_e}\right)' C_L \text{ --- --- --- Stick free}$$

We know, for stick fixed case,

$$C_{m_o} = C_{m_{ow}} + C_{m_{ot}} + C_{L_{\alpha_t}} V_H \eta\left(i_w - i_t + \varepsilon_o\right)$$

and

$$\frac{dC_m}{dC_L} = \bar{x}_{cg} - \bar{x}_{ac} + \left[\frac{dC_m}{dC_L}\right]_{fs} - \frac{C'_{L_{\alpha t}}}{C_{L_{\alpha w}}} V_H \eta\left(1 - \frac{\partial\varepsilon}{\partial\alpha}\right)$$