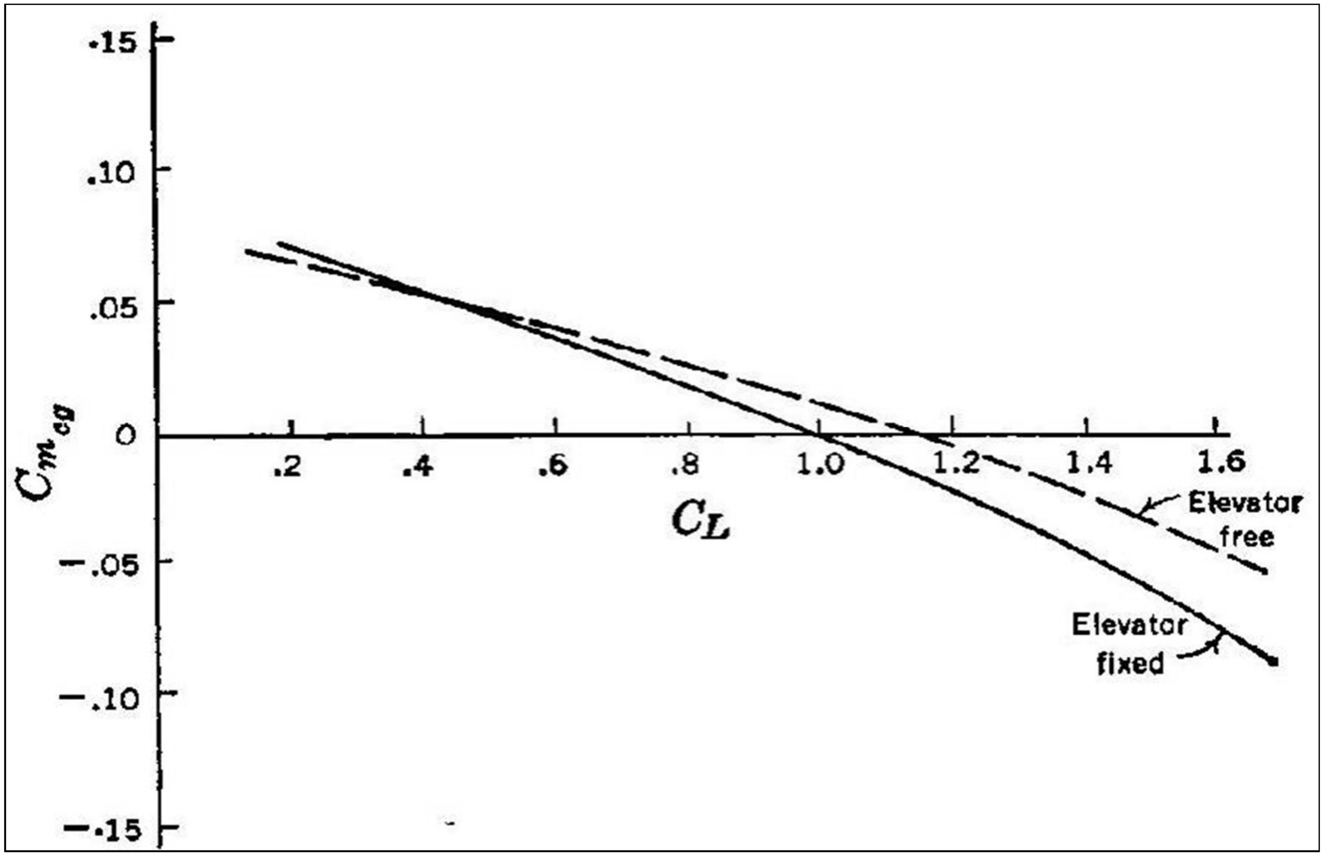
Typical Impact of Free Elevator

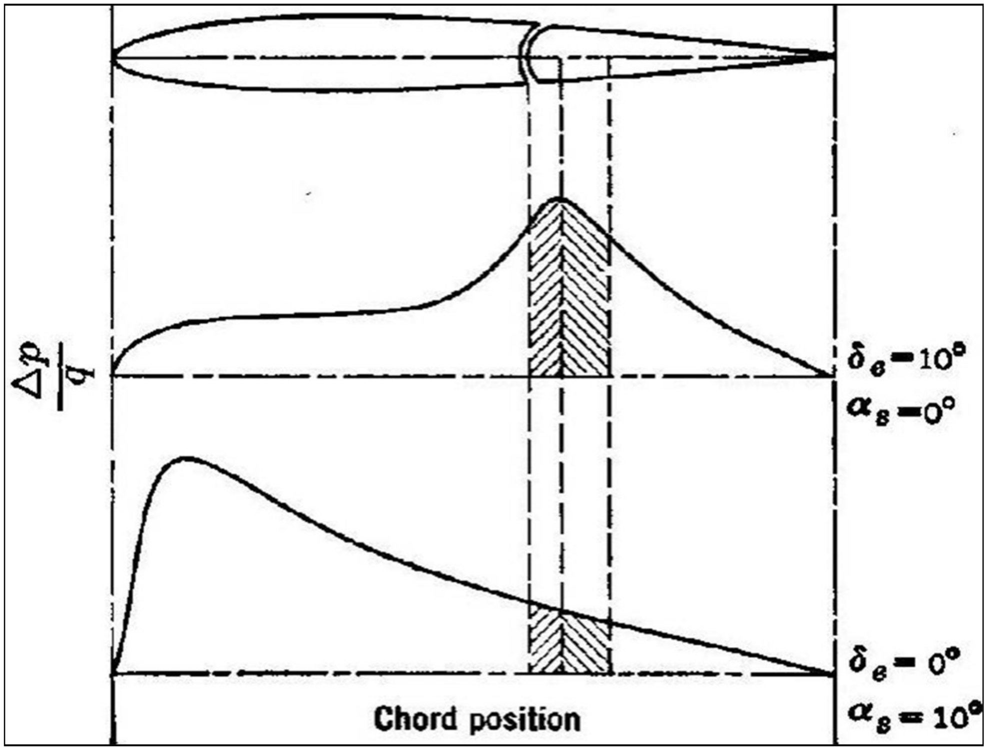


Aerodynamic Balancing Concept

In order to minimize the impact of a free **elevator** on the stability, there is a need to **minimize** its floating.

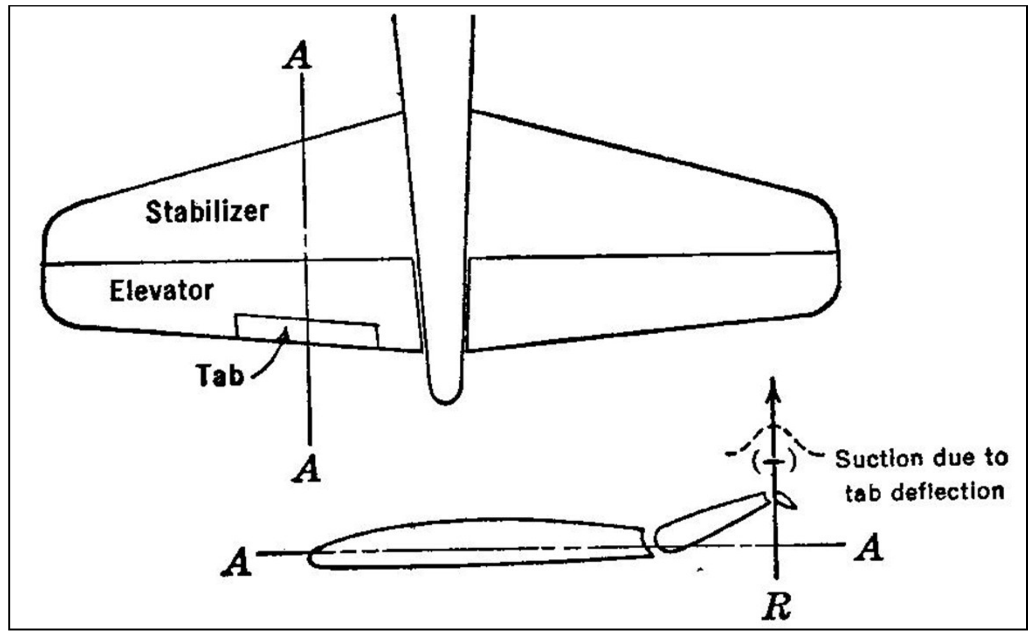
One way to achieve this is to 'aerodynamically **balance'** the elevator, by making '$C_{h\alpha}$' nearly **zero**.

This is possible if the net resultant of forces **due** to 'α' and 'δ' passes through the hinge **line**, as shown alongside.



Application of Trim Tabs

Another way to prevent floating, without **shifting** the hinge line, is to add a small surface **at** the elevator training edge called '**tab**' or **'**trim tab**',** as shown alongside.

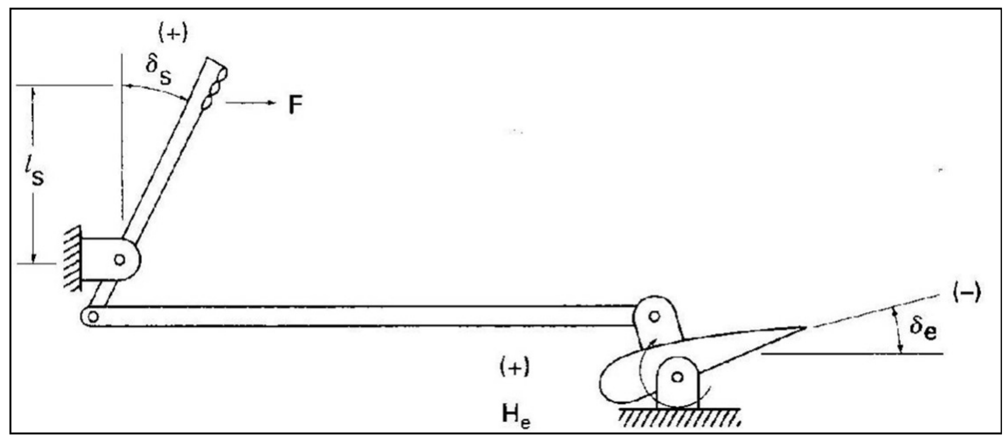


Stick Force Concept

In practice, HM is always kept small, which is **finally** cancelled through manual application of **'trim** tab**'.**

This is done to give the pilot a positive feel for **forces** required to change trim conditions, **which** is an important flight control system **design** criterion.

In view of the above, pilot experiences a **reaction** force while attempting to deflect the **stick**, as shown alongside.



Stick Force Formulation and Features

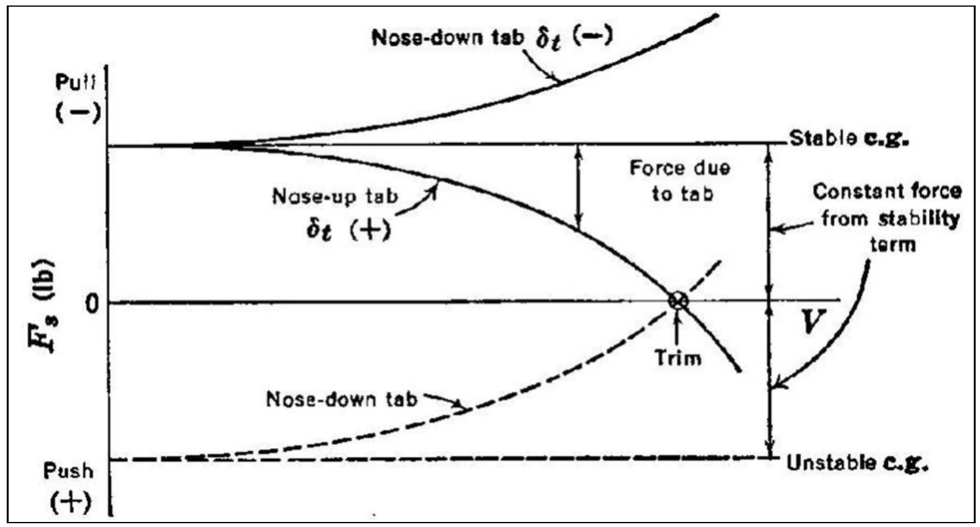
$$\text{Work Done} = \frac{F_s \times l_s \times \delta_s}{2} = \frac{HM \times \delta_e}{2} \rightarrow F_s = HM\frac{\delta_e}{\delta_s l_s} = -G \cdot HM$$

$$F_s = -GQ\eta_T S_e c_e C_h = -GQ\eta_T S_e c_e \left(C_{h0} + C_{h\alpha}\alpha + C_{h\delta}\delta_e + C_{h\delta_t}\delta_t \right)$$

$$\delta_e = \delta_{e0} - \left(\frac{dC_m}{dC_L} \right)_{fixed} \times \frac{C_L}{C_{m\delta}}; \quad K = -G\eta_T S_e c_e; \quad A = C_{h0} + C_{h\alpha}\alpha + C_{h\delta}\delta_{e0}$$

$$F_s = KQ\left[A + \frac{C_{h\alpha}C_L}{a_w}(1-\varepsilon_\alpha) - \left(\frac{dC_m}{dC_L} \right)_{fixed} \times \frac{C_{h\delta}C_L}{C_{m\delta}} + C_{h\delta_t}\delta_t \right]$$

$$F_s = KQA - K\frac{W}{S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L} \right)_{free} + KQC_{h\delta_t}\delta_t; \quad \frac{dF_s}{dV} = K\rho V\left(A + C_{h\delta_t}\delta_t \right)$$



Stick Force Trim Solution

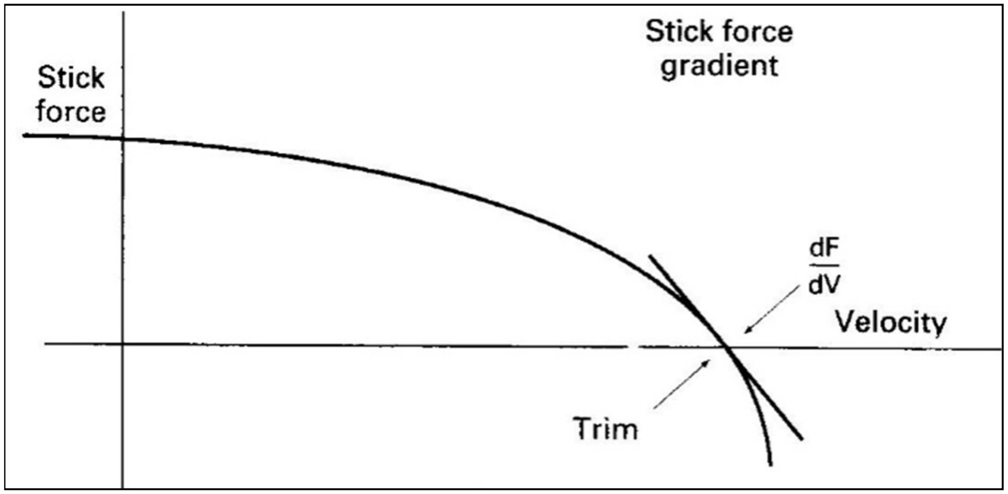
$$F_s = KQ_{trim}A - K\frac{W}{S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free} + KQ_{trim}C_{h\delta_t}\delta_t = 0$$

$$C_{h\delta_t}\delta_t = \frac{W}{Q_{trim}S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free} - A$$

$$F_s = KQ\times\left(\frac{W}{Q_{trim}S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free}\right)A - K\frac{W}{S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free}$$

$$F_s = K\frac{W}{S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free}\times\left(\frac{V^2}{V_{trim}^2} - 1\right)$$

$$\frac{dF_s}{dV} = K\frac{2W}{S}\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free}\times\frac{V}{V_{trim}^2}$$



Stick Force Stability

Stick force gradient with speed is a measure of **change** in stick force needed to **change** the aircraft speed**.**

If the gradient is < 0, then if the aircraft slows **down**, a positive stick force is **generated**, which creates a nose down **moment**, leading to higher speed, and vice versa.

This behaviour helps the pilot to fly hands-off **even** in the presence of speed **disturbances.**

Stick Forces Under Manoeuvre

It is known that during a trimmed flight, stick forces are **driven** to zero, in order to reduce the pilot effort**.**

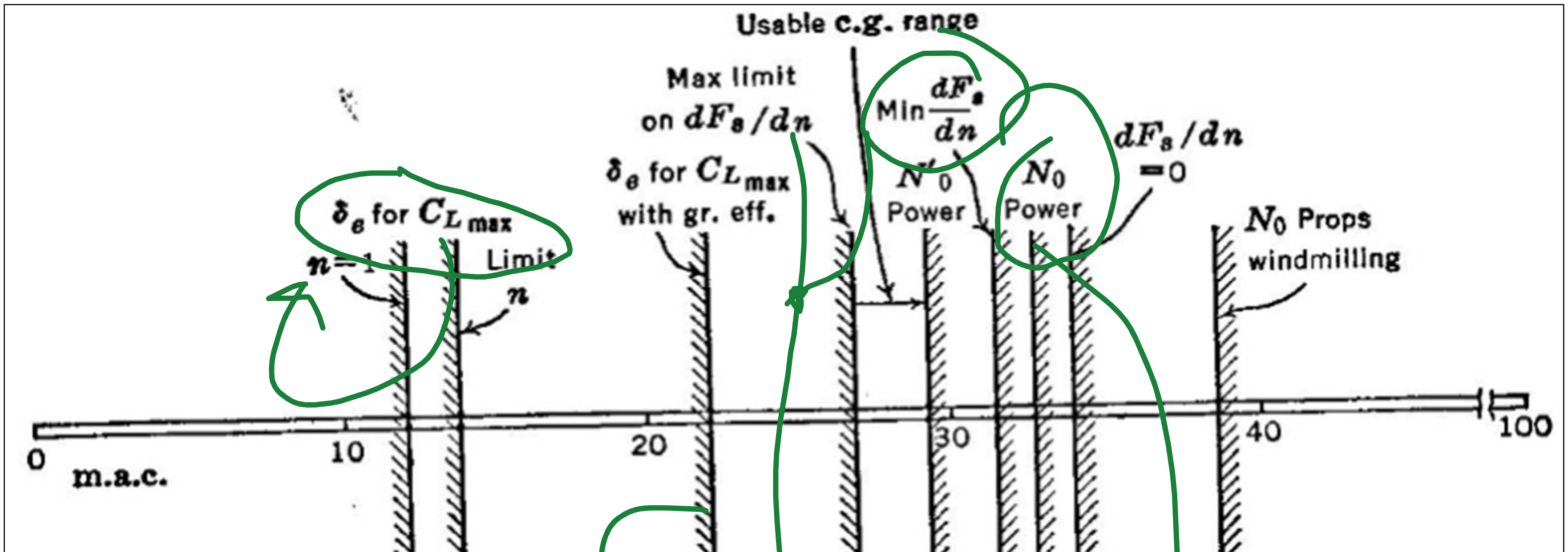
However, when performing manoeuvres (particularly **in** fighter aircraft), pilot effort for a specific 'n' is an **important** design input.

It has been found through studies that pilots rate the **manoeuvring** capability of an aircraft through the stick force **gradients**, which need to be suitably moderated.

$$F_s = K\left(\frac{W}{S}\right)\times\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free}\times\left(\frac{V^2}{V_{trim}^2}-n\right) + Kgl_T\frac{\rho}{2}(n-1)\times\left(C_{h\alpha}-\frac{1.1C_{h\delta}}{\tau}\right)$$

$$\left(\frac{dF_s}{dn}\right)_{pull-up} = K\left(\frac{W}{S}\right)\frac{C_{h\delta}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{free} + Kgl_T\frac{\rho}{2}\times\left(C_{h\alpha}-\frac{1.1C_{h\delta}}{\tau}\right)$$

Aircraft Symmetric Stability and Control Summary



landing gear down affect

F_s per g limit

NP location