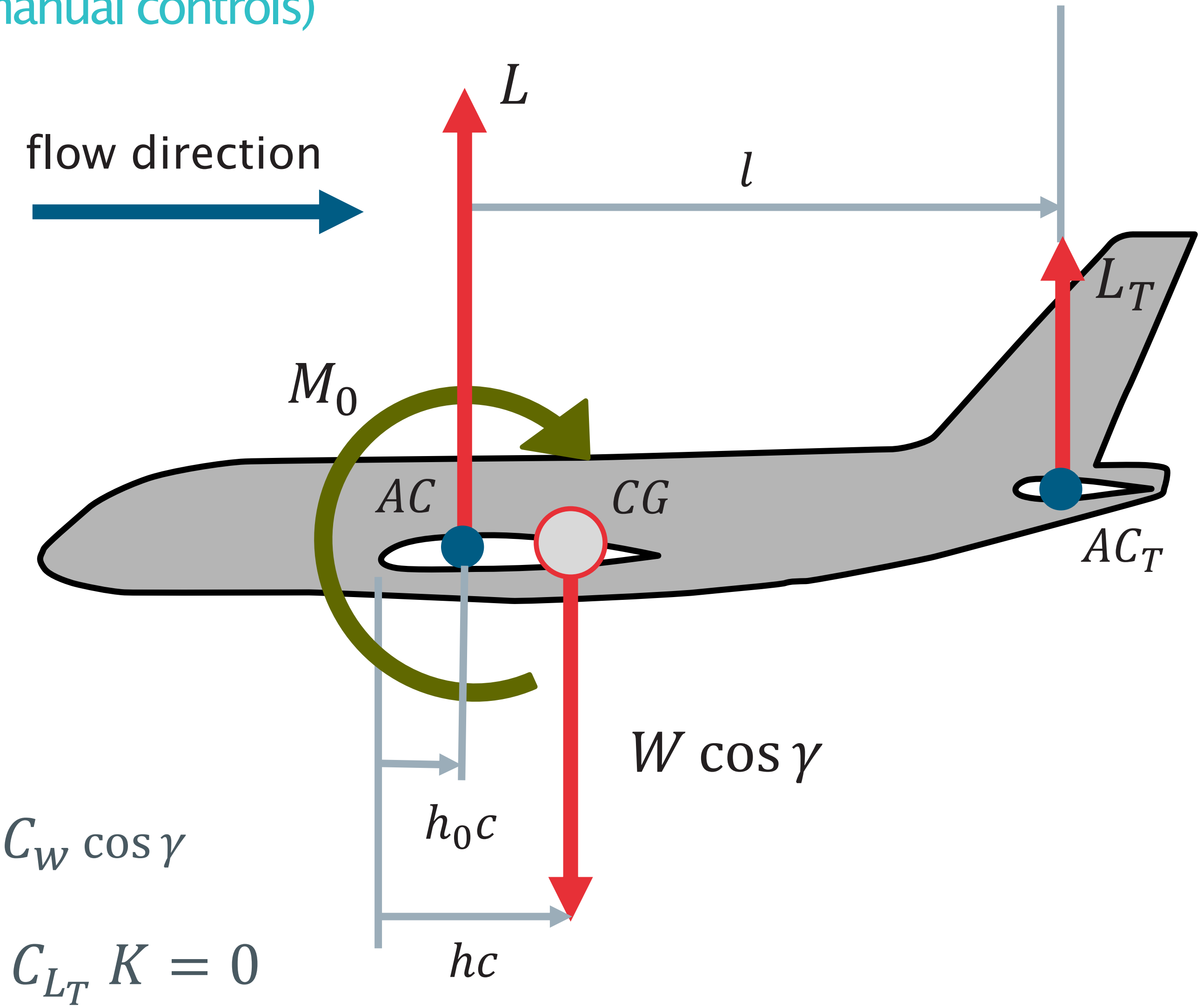
SESA2025 Mechanics of Flight
Stick Fixed versus Stick Free

Lecture 1.2

Consider an aircraft flying in trimmed conditions

(A small aircraft with manual controls)



$$C_{L^*} = C_L + C_{L_T}\frac{S_T}{S} = C_W \cos\gamma$$

$$C_{M_0} + C_{L^*}(h - h_0) - C_{L_T} K = 0$$

Consider an aircraft flying in trimmed conditions

(A small aircraft with manual controls)

Two ways for a pilot to keep an aircraft in equilibrium (trimmed):

- Using the yoke (controls the elevator directly)
- Using the trim tab (controls the elevator indirectly)

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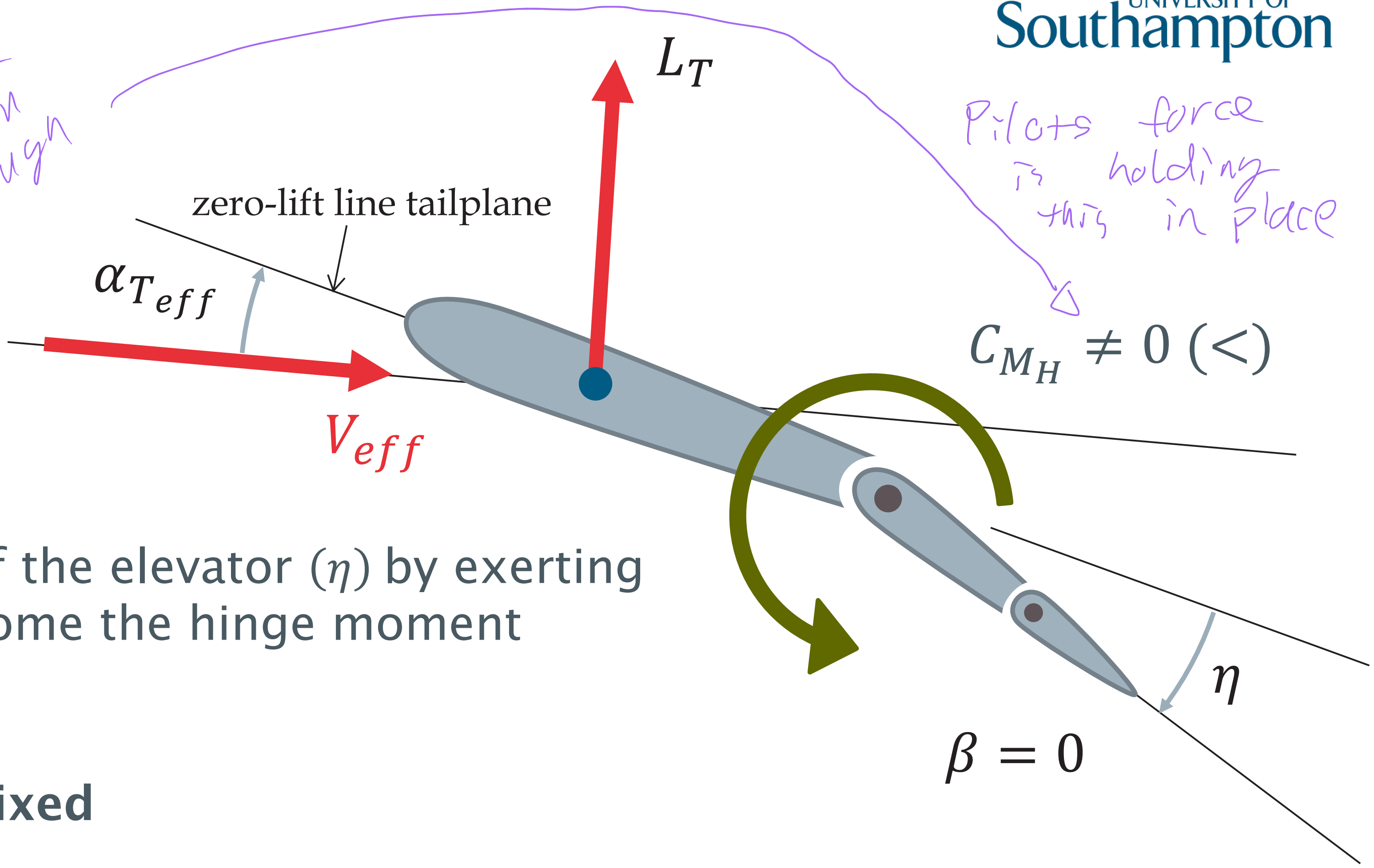
Tail plane

Stick Fixed

— pilot is actively applying force on elevator through control



- The pilot sets the position of the elevator (η) by exerting a force on the yoke to overcome the hinge moment
- $C_{M_H} \neq 0$
- This is referred to as **Stick Fixed**
- The trim tab angle (β) is assumed to be zero
- High pilot effort ($C_{M_H} \neq 0$ + attention)

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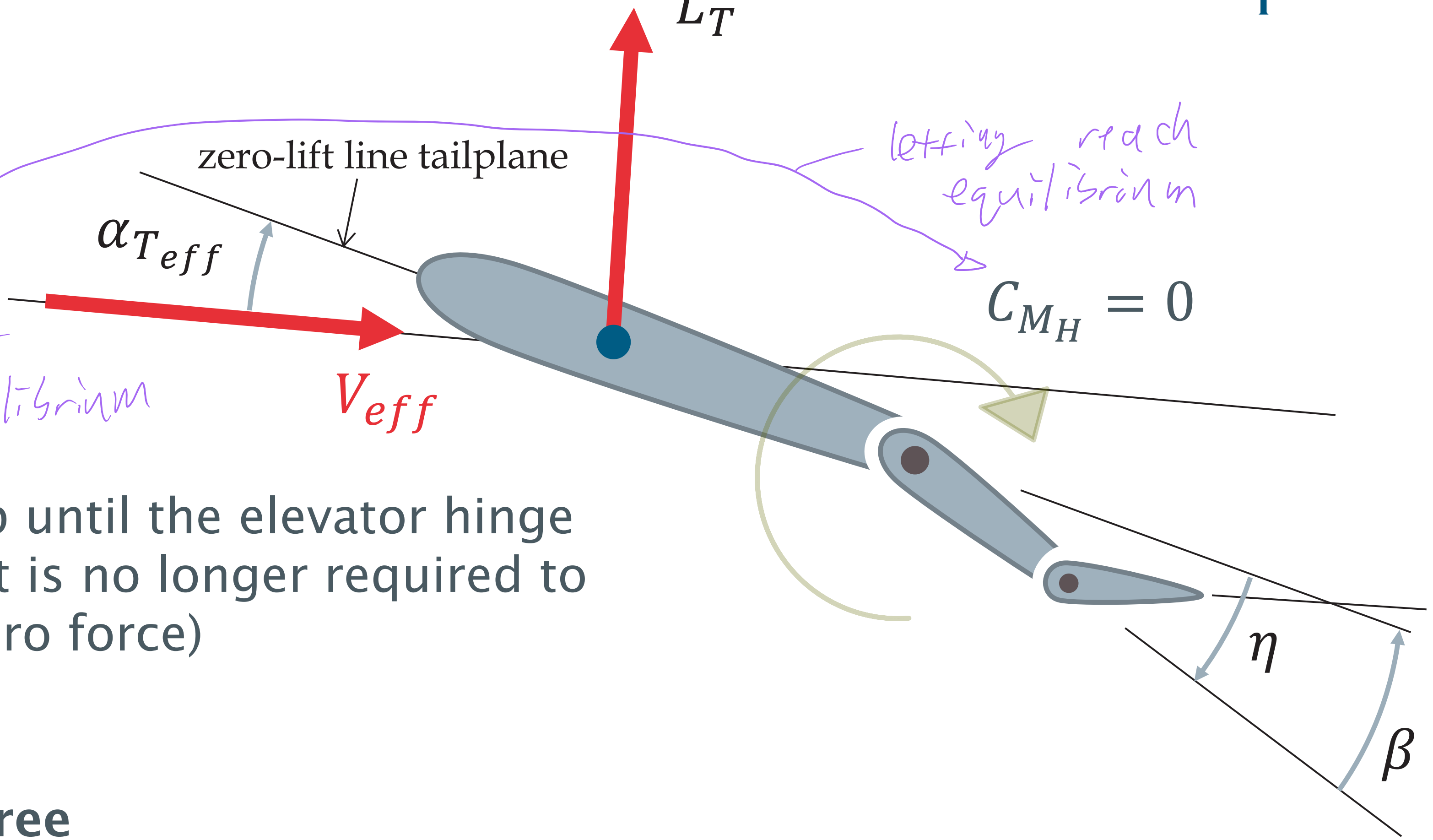
Tail plane

Stick Free

Pilot not needed to hold elevator with force because they let it rest in equilibrium



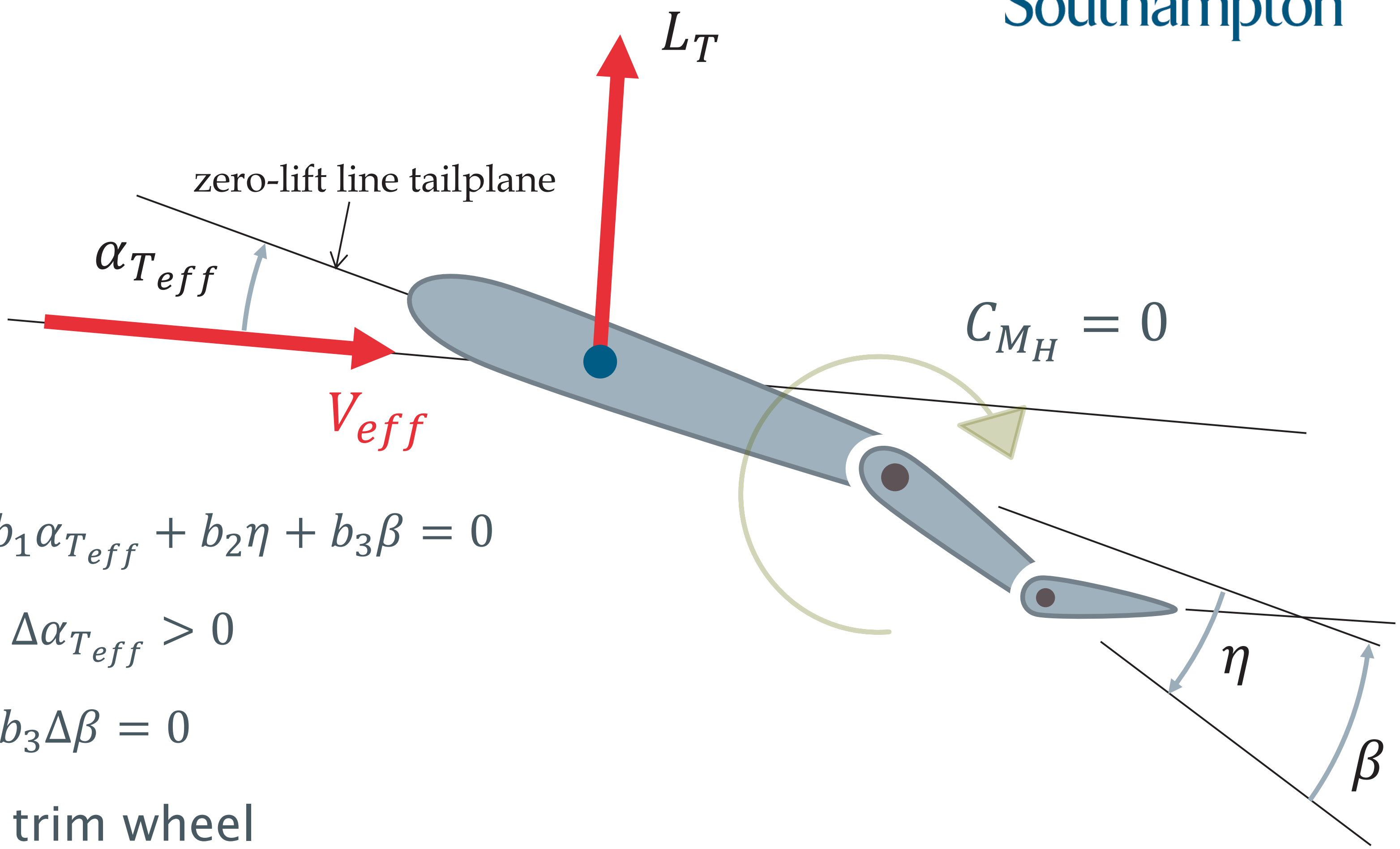
letting reach equilibrium

- The pilot rotates the trim tab until the elevator hinge moment is zero and the pilot is no longer required to exert a force on the yoke (zero force)
- $C_{M_H} = 0$
- This is referred to as **Stick Free**
- Reduced pilot effort
- Elevator can float during, e.g., a gust encounter

fluttering bad

Tail plane

Stick Free – floating elevator



- The hinge moment is $C_{M_H} = b_1\alpha_{T_{eff}} + b_2\eta + b_3\beta = 0$
- Assume the gust produces a $\Delta\alpha_{T_{eff}} > 0$
- But $\underbrace{\Delta C_{M_H}}_{}= b_1\Delta\alpha_{T_{eff}} + b_2\Delta\eta + b_3\Delta\beta = 0$
- $\Delta\beta = 0$ since it's fixed by the trim wheel
- b_1 and b_2 are negative, solve for $\Delta\eta$
- $\underbrace{\Delta\eta = -\Delta\alpha_{T_{eff}}\frac{b_1}{b_2} < 0}_{\text{measure of floatyness}}$ $\longrightarrow$ $b_1 = \frac{\partial C_{M_H}}{\partial\alpha_{T_{eff}}}$ $\longrightarrow$ floating tendency

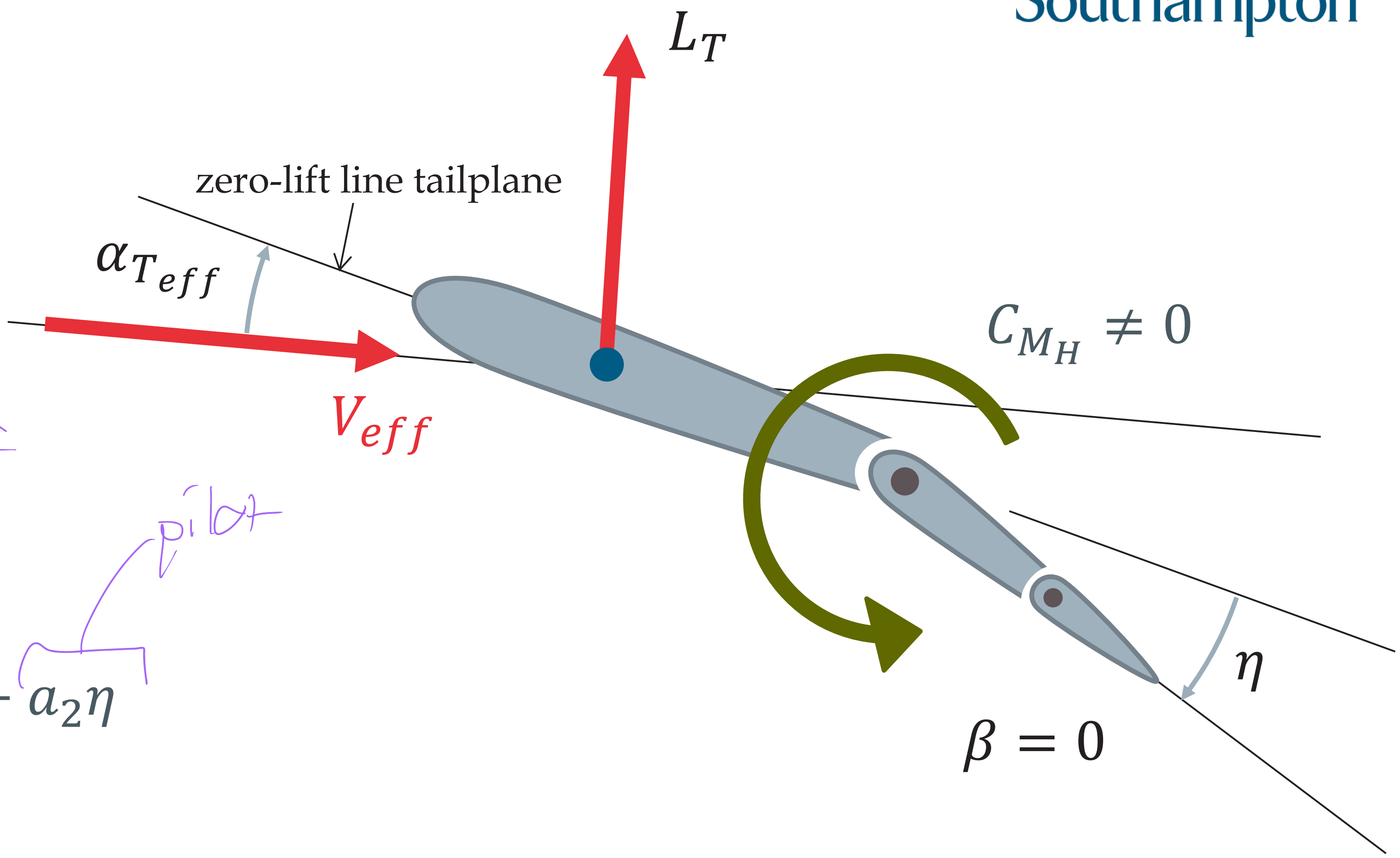
not tending

trim tab ∴=0

controls directly how much elevator floats with changing AoA (possibly induced by gusts)

Tail plane

Stick Fixed



With $\beta = 0$ (assumed)

– Lift model

$$C_{L_T} = \overbrace{a_1 \alpha_{T_{eff}}}^{\text{aircraft}} + \overbrace{a_2 \eta}^{\text{pilot}}$$

– Hinge moment model

$$C_{M_H} = \underbrace{b_1 \alpha_{T_{eff}}}_{\text{aircraft}} + \underbrace{b_2 \eta}_{\text{pilot}}$$

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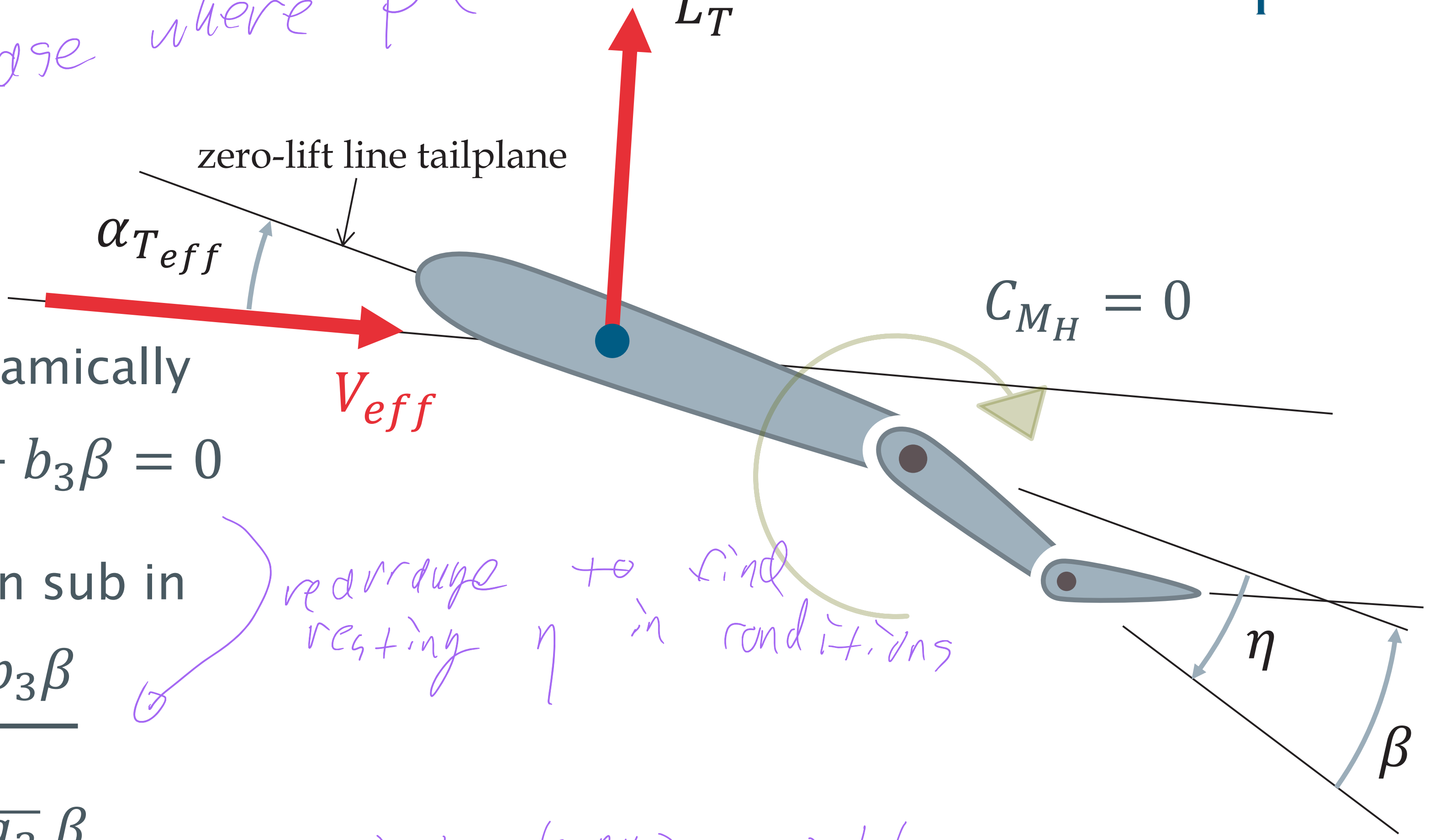
Tail plane

Stick Free

now consider case where $\beta \neq 0$



Balance hinge moment aerodynamically

$$C_{M_H} = b_1 \alpha_{T_{eff}} + b_2 \eta + b_3 \beta = 0$$

Solve for elevator position, then sub in

rearrange to find resting η in conditions

$$\eta = \frac{-b_1 \alpha_{T_{eff}} - b_3 \beta}{b_2}$$

$$C_{L_T} = \overline{a_1} \alpha_{T_{eff}} + \overline{a_3} \beta$$

convenient cleanup variables

where

$$\overline{a_1} \stackrel{\text{def}}{=} a_1 - a_2 \frac{b_1}{b_2} \,;\; \overline{a_3} \stackrel{\text{def}}{=} a_3 - a_2 \frac{b_3}{b_2}$$

Example

and some numbers …

Measurements of the aero characteristics of a 2D section of a tail plane show that:

$$a_1 = 2\pi\, rad^{-1}$$
$$a_2 = 3.5\, rad^{-1}$$
$$a_3 = 1.1\, rad^{-1}$$
$$b_1 = -0.1\, rad^{-1}$$
elevator
$$b_2 = -0.7\, rad^{-1}$$
trim tab
$$b_3 = -1.3\, rad^{-1}$$

Do these numbers make sense ??

Recall that:

relative size of tail to main wing related

$$C_{L_T} = a_1\alpha_{T_{eff}} + a_2\eta + a_3\beta \quad \text{Stick fixed}$$

$$C_{L_T} = \overline{a_1}\alpha_{T_{eff}} + \overline{a_3}\,\beta \quad \text{Stick free}$$

$$C_{M_H} = b_1\alpha_{T_{eff}} + b_2\eta + b_3\beta \qquad \overline{a_1} \stackrel{\text{def}}{=} a_1 - a_2\frac{b_1}{b_2}\ ;\ \overline{a_3} \stackrel{\text{def}}{=} a_3 - a_2\frac{b_3}{b_2}$$

The rate of change of C_{L_T} with $\alpha_{T_{eff}}$ is

makes sense because stick free has more variable geometry

$$a_1 = 6.28\, rad^{-1} \quad \text{Stick fixed}$$

$$\overline{a_1} = 5.78\, rad^{-1} \quad \text{Stick free}$$

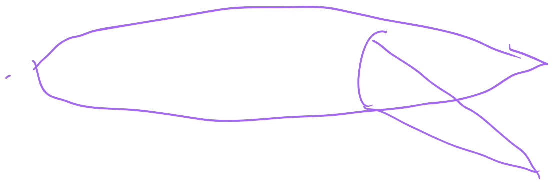
- The tailplane produces less lift per unit change of angle of attack!
- Lower pitch stiffness, worse stability characteristics
- Use horn balance to reduce floating tendency

Other means of trim

i.e. other types of tail planes

- Aircraft requires trim at a variety of speeds, CG locations, payloads, altitudes, ..
- Various other tail plane solutions are possible, with pros and cons
- All of them need to achieve some control on the lift generated by the plane

(draw missing from notes!)



Other means of trim

Fixed tail

The tail plane of a Pilatus Porter PC-6

- OK if longitudinal manoeuvrability is not a desired design requirement
- PROS:
  - Lighter
  - Cheaper
  - Structurally easier to design
  - Safer in case of failure
- CONS
  - Limited control because relatively small change possible
  - Higher drag associated to trim
- Lift model $a_2 < a_1$

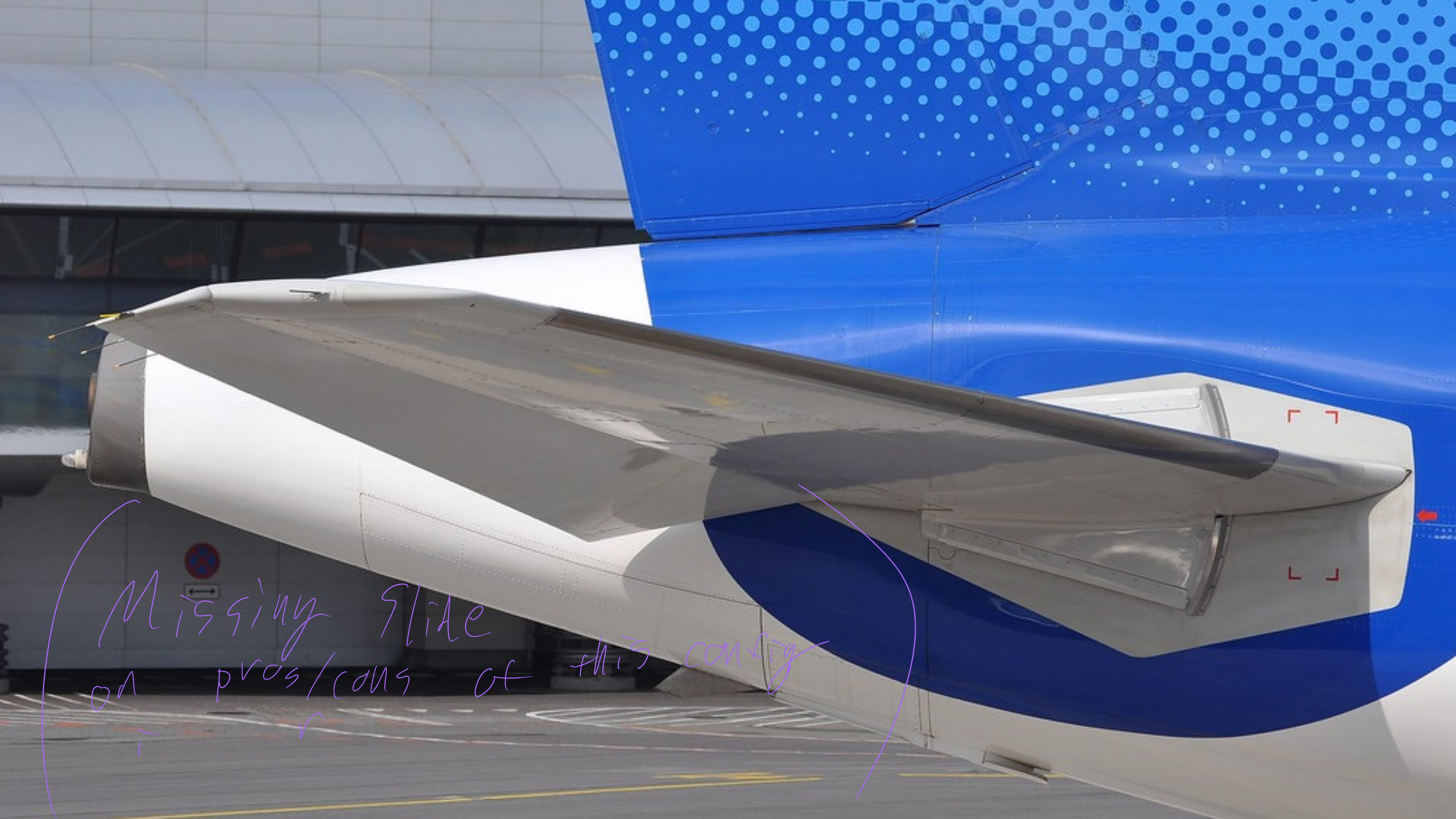
Other means of trim

All-moving tail – All-flying – Stabilator

F-16 jet, with stabilators deflected upwards

- Change the installation angle α_s
  - For trim and control (high rotation rates)
- PROS:
  - Higher trimming power
  - Wider range of CG movements
  - Lower drag, as elevator and stabilizer are aligned when aircraft is trimmed
- CONS
  - Structural design?

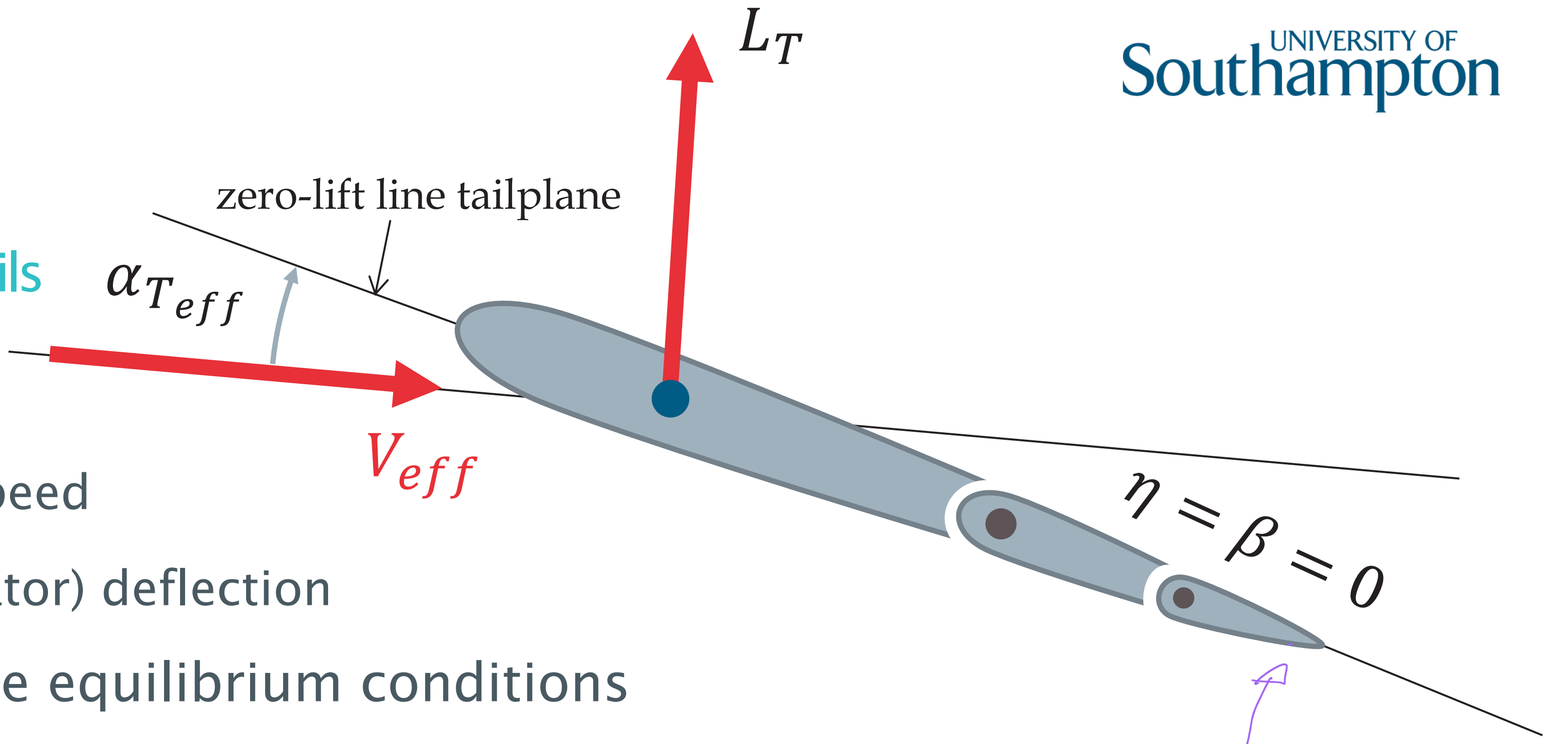

US MILITARY POWER



Missing slide on pros/cons of this config

Tail setting angle

Example calculation for adjustable tails



- Primary requirement
  - nullify $C_{M_{CG}}$ at the cruising speed
  - no control surface (i.e. elevator) deflection
- Example calculation: from the equilibrium conditions

$$C_{L^*} = C_L + C_{L_T}\frac{S_T}{S} = C_W \cos\gamma \quad \text{and} \quad C_{M_0} + C_{L^*}(h - h_0) - C_{L_T} K = 0$$

- The tail plane lift model becomes

$$C_{L_T} = a_1 \alpha_{T_{eff}} \cancel{+ a_2\eta + a_3\beta}$$

- Noting that

known

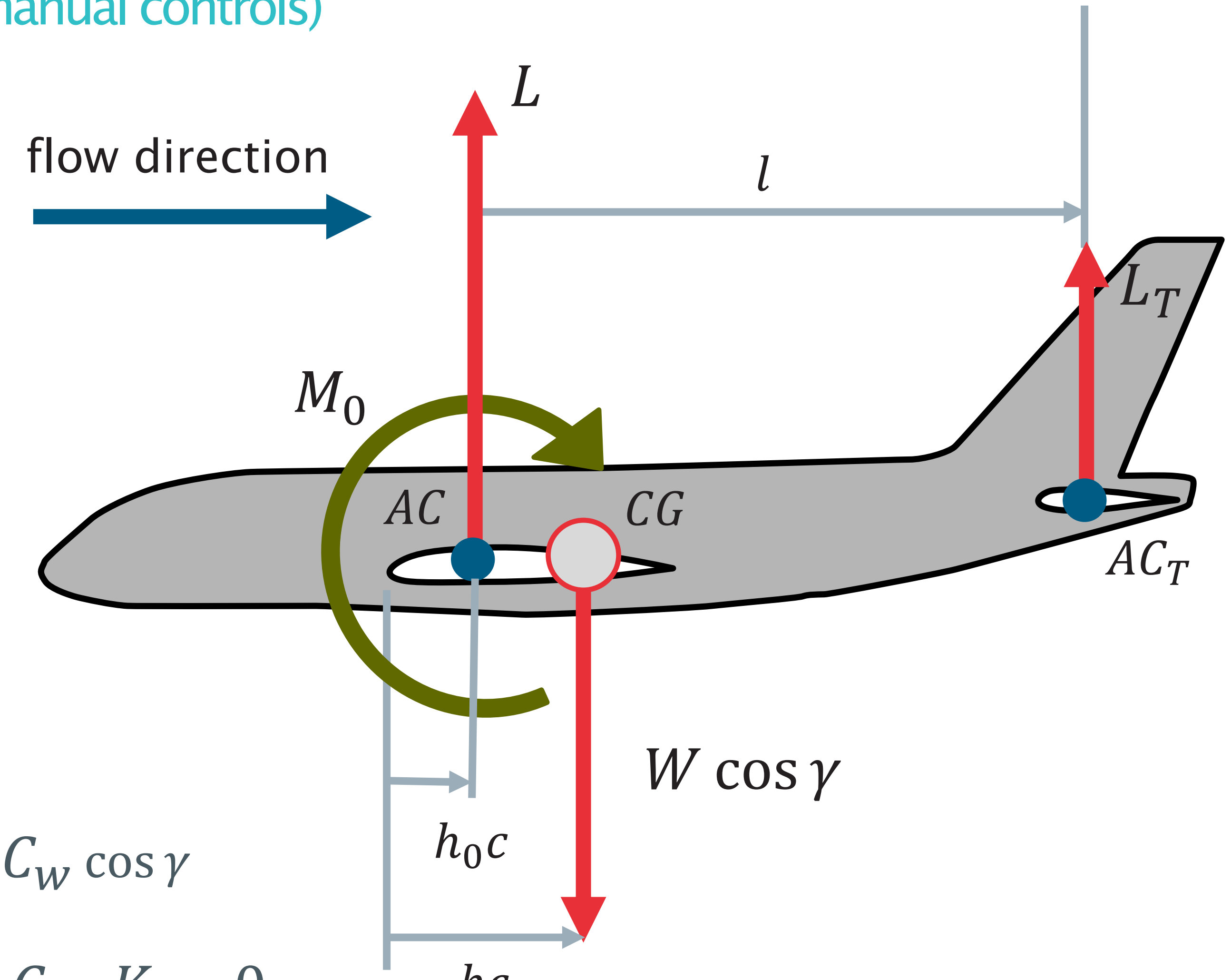
known

$$\alpha_{T_{eff}} = \alpha + \alpha_s - \varepsilon - \varepsilon_T$$

- We solve for α_s, with α obtained from $C_L = C_{L_\alpha}(\alpha - \alpha_0)$

Consider an aircraft flying in trimmed conditions

(A small aircraft with manual controls)



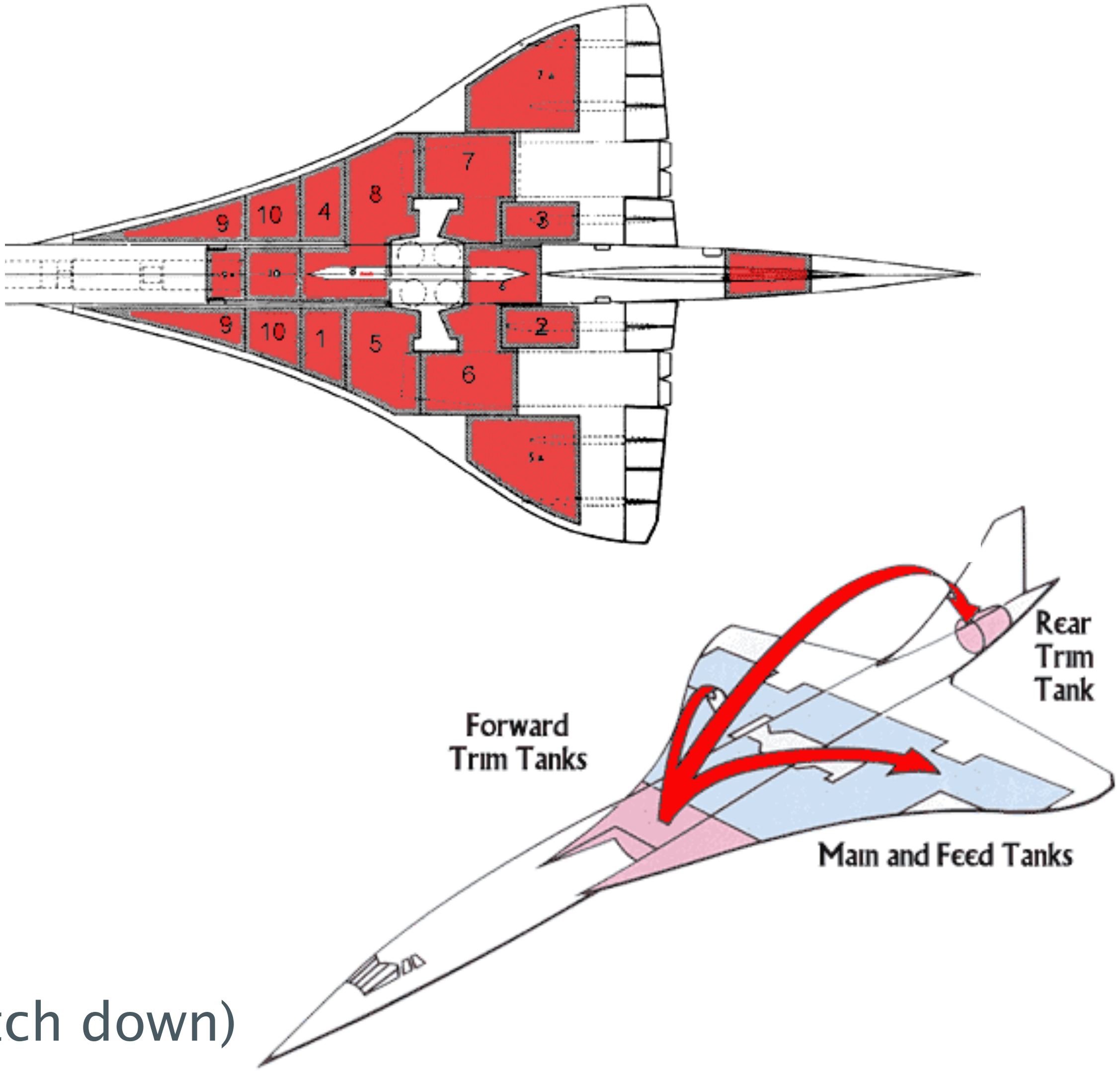
$$C_{L^*} = C_L + C_{L_T}\frac{S_T}{S} = C_W\cos\gamma$$

$$C_{M_0} + C_{L^*}(h - h_0) - C_{L_T}K = 0$$

Other means of trim

Moving the CG

The Aérospatiale/BAC Concorde (1976/2003)



- At critical Mach, the CP shifts rearwards (pitch down)
- Shift fuel fore-and-aft for CG control at {tran, super}sonic speed **with no drag penalty**