

$$mg(h - h_{nwbc})\bar{c} + M_{owb} = L_t \bar{l}_t$$

$$L_t = \frac{M_{owb} + mg(h - h_{nwbc})\bar{c}}{\bar{l}_t}$$

*Mowb* è molto maggiore del momento creato dal peso quindi la frazione è negativa ed è per questo che abbiamo un piano di coda deportante

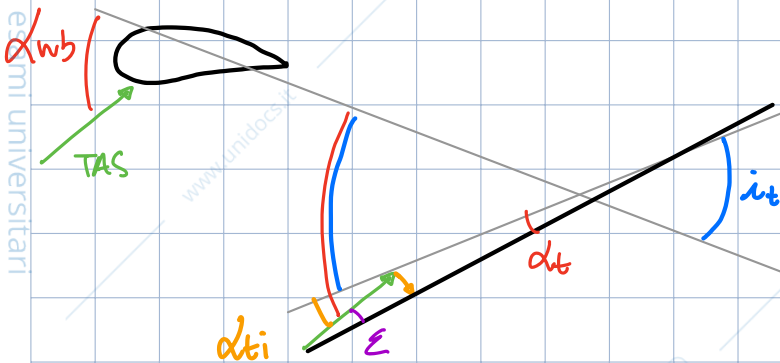
Portanza  $L = L_{wb} + L_t$

$$\frac{1}{2} \rho S V^2 C_L = \frac{1}{2} \rho S V^2 C_{Lwb} + \frac{1}{2} \rho S_t V_t^2 C_{Lt}$$

$$/ \frac{1}{2} \rho S V^2$$

$$C_L = a_{wb} \alpha_{wb} + a_t^* \alpha_t \frac{S_t}{S} \frac{V_t^2}{V^2}$$

$$= a_{wb} \alpha_{wb} + a_t \alpha_t \frac{S_t}{S}$$



$$\alpha_t = \alpha_{ti} - \epsilon$$

$$= \alpha_{wb} + i_t - \epsilon_0 - \frac{\partial \epsilon}{\partial \alpha} \alpha_{wb}$$

$$\epsilon = \epsilon_0 - \frac{\partial \epsilon}{\partial \alpha} \alpha_{wb}$$

*L'angolo di calceamento è < 0 (ie)*

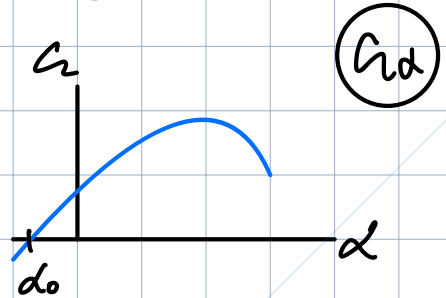
$$\alpha_t = \alpha_{wb} \left( 1 - \frac{\partial \epsilon}{\partial \alpha} \right) + (i_t - \epsilon_0)$$

$$C_L = a_{wb} \alpha_{wb} + a_t \frac{S_t}{S} \left[ \alpha_{wb} \left( 1 - \frac{\partial \epsilon}{\partial \alpha} \right) + (i_t - \epsilon_0) \right]$$

$$= a_{wb} \alpha_{wb} + a_t \frac{S_t}{S} \alpha_{wb} \left( 1 - \frac{\partial \epsilon}{\partial \alpha} \right) + a_t \frac{S_t}{S} (i_t - \epsilon_0)$$

$$= a_{wb} \left[ 1 + \frac{a_t}{a_{wb}} \frac{S_t}{S} \left( 1 - \frac{\partial \xi}{\partial \alpha} \right) \right] \alpha_{wb} + a_t \frac{S_t}{S} (i_t - \varepsilon_0)$$

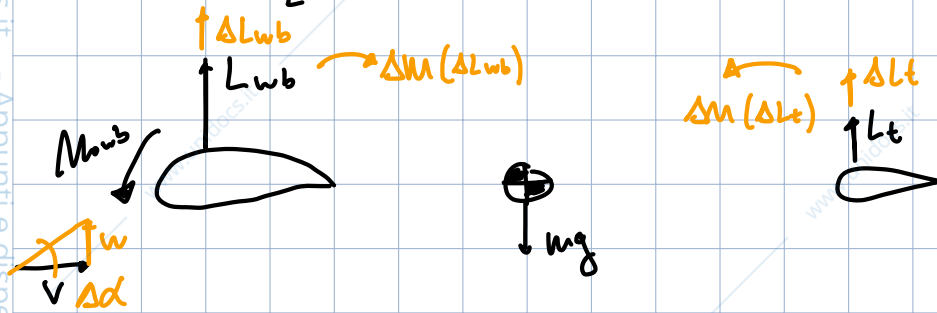
$C_{L\alpha}$



$$C_L = C_{L\alpha} \alpha_{wb} + a_t \frac{S_t}{S} (i_t - \varepsilon_0)$$

$$C_L = C_{L\alpha} (\alpha - \alpha_0)$$

$$C_L = C_{L\alpha} \left[ \alpha_{wb} + \frac{a_t}{C_{L\alpha}} \frac{S_t}{S} (i_t - \varepsilon_0) \right] \rightarrow \alpha_0 = - \frac{a_t}{C_{L\alpha}} (i_t - \varepsilon_0) \frac{S_t}{S}$$



Per essere stabile  $|\Delta M(\Delta L_t)| > |\Delta M(\Delta L_{wb})|$

$$\Delta L_t \bar{l}_t > \Delta L_{wb} (h - h_{nwb}) \bar{c} \quad l_t = \bar{l}_t - (h - h_{nwb}) \bar{c}$$

$$\Delta L_t \bar{l}_t - \Delta L_t (h - h_{nwb}) \bar{c} > \Delta L_{wb} (h - h_{nwb}) \bar{c}$$

$$\Delta L_t \bar{l}_t > \Delta L (h - h_{nwb}) \bar{c}$$

per trovare il PN i momenti sono uguali

$$\Delta L_t \bar{l}_t = \Delta L (h - h_{nwb}) \bar{c}$$

$$h_n = h_{nwb} + \frac{\Delta L_t}{\Delta L} \frac{\bar{l}_t}{\bar{c}}$$

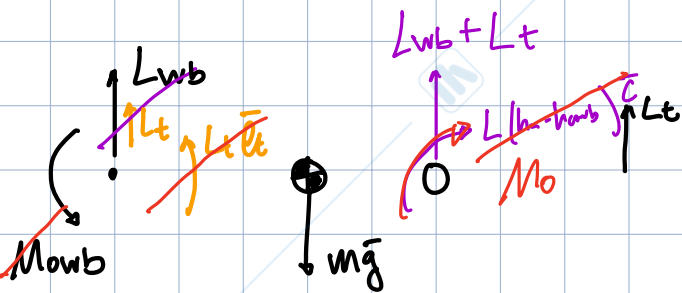
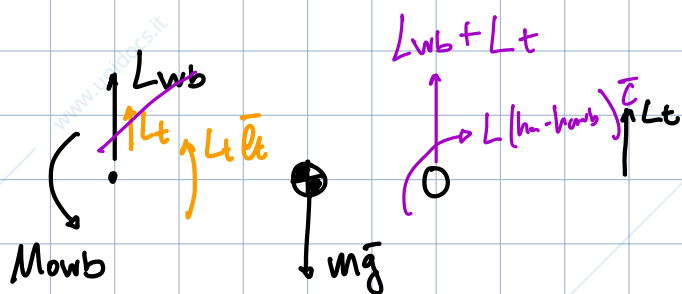
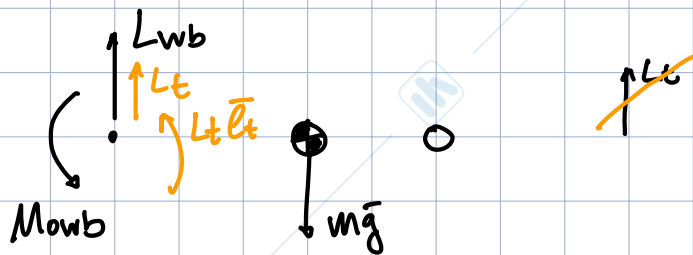
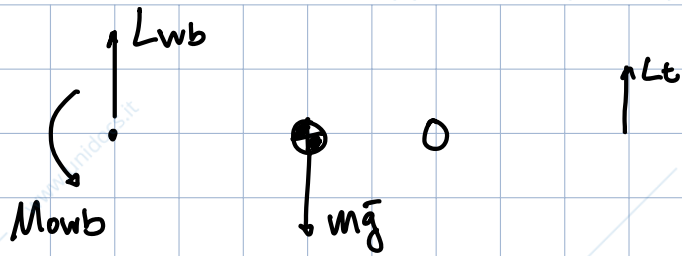
$$\Delta L_t = \Delta L_{wb} \left( 1 - \frac{\partial \xi}{\partial \alpha} \right)$$

$$\Delta L_{wb} = \Delta L_{wb}$$

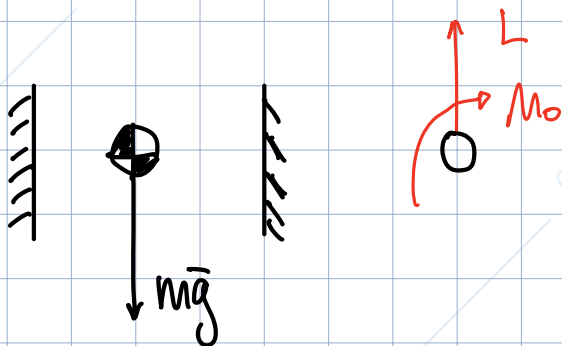
$$= h_{nwb} + \frac{\frac{1}{2} \rho S V_e^2 \Delta C_{L_t} \bar{l}_t}{\frac{1}{2} \rho S V_e^2 \Delta C_L \bar{c}} = h_{nwb} + \frac{S_t}{S} \frac{V_e^2}{V} \frac{a_t}{C_{L\alpha}} \frac{\Delta C_{L_t}}{\Delta C_{L_{wb}}} \frac{\bar{l}_t}{\bar{c}}$$

$$= h_{nwb} + \frac{S_t}{S} \frac{a_t}{C_{L\alpha}} \frac{\Delta C_{L_{wb}} \left( 1 - \frac{\partial \xi}{\partial \alpha} \right)}{\Delta C_{L_{wb}}} \frac{\bar{l}_t}{\bar{c}}$$

$$h_n = h_{nwb} + \frac{a_t}{C_{L\alpha}} \left( 1 - \frac{\partial \xi}{\partial \alpha} \right) \bar{V}_t$$



$$M_o = M_{owb} + L(h_n - h_{nw}) \bar{C} - L_t \bar{l}_t$$



$$M = M_o - L(h_n - h) \bar{C}$$

$$M = M_o + L(h - h_n) \bar{C} \quad \frac{1}{2} \rho v^2 \bar{C}$$

$$C_{un} = C_{uo} + C_a(h - h_n) \alpha$$

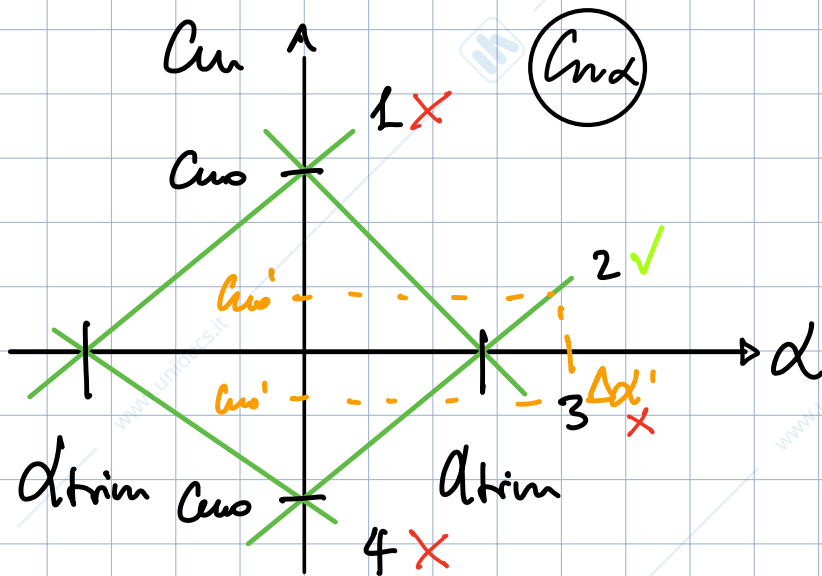
$$C_{un} = C_{uo} + C_a \alpha d$$

N.B.  $C_a(h - h_n) = C_a \alpha d$

$C_a \alpha < 0$  se il CG si trova davanti al PN quindi se ho

Una raffica dal basso verso l'alto,  $L$  aumenta e il momento creato è negativo, quindi picchiante, ovvero comportamento stabile. Se  $CG = PN$  non ho variazione di momento, velivolo neutro, se  $CG$  dietro  $PN$  allora il velivolo è instabile.

$$h - h_n = MS \text{ (Margine di Stabilità)}$$



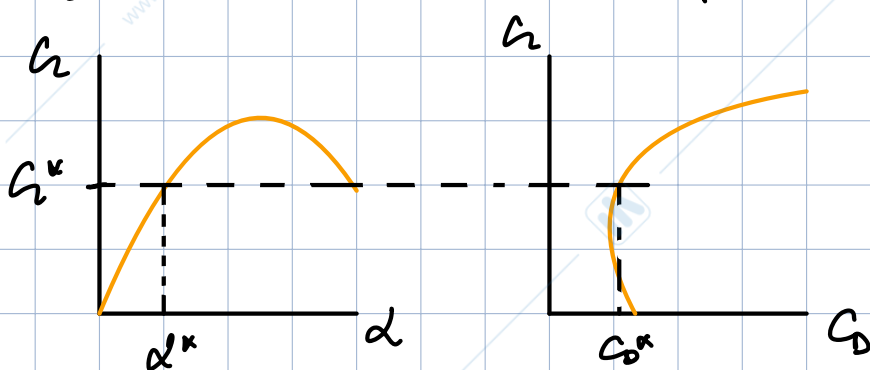
La retta verde è la pendenza  $C_{m\alpha}$

Le rette 1 e 4 danno un  $\Delta trim < 0$  e quindi un assetto picchiante e quindi non stabile. Devo capire qual è quella giusta tra la retta 2 e la 3.

- $C_m = C_{m0} + C_{m\alpha} \alpha$   
 $0 = C_{m0} + C_{m\alpha} \alpha$  Condizioni di trim  
 $\alpha = -\frac{C_{m0}}{C_{m\alpha}} \Rightarrow$  i segni devono essere discordi
- introduciamo un disturbo  $\Delta \alpha'$ , il momento picchiante ( $C_m < 0$ ) è dato dalla retta 2 che è quella giusta.

Partiamo da una condizione di volo  $(h, v)$

$$\frac{1}{2} \rho S v^2 C_L = mg \rightarrow C_L^* = \frac{2mg}{\rho S v^2}$$



Adesso conosco  $\alpha^*$  e  $C_D^*$  che mi dà  $T$

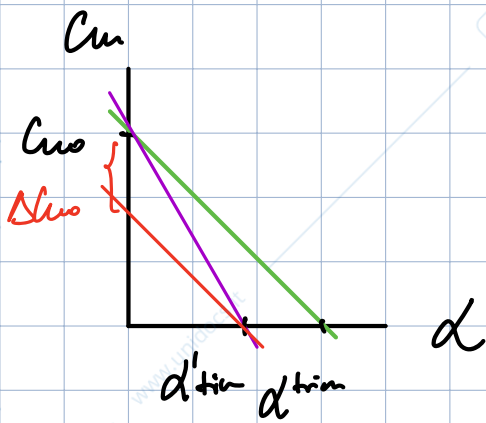
- $C_L^* \leq C_L^{max}$
- $T \leq T_d^{max}$

Se fisso solo la quota ( $Q$ ) al posto delle condizioni di volo ho  $\infty$  soluzioni questo perché ho usato il modello di punto materiale.

$$M^{(a)} + M^{(b)} + M^{(c)} = 0$$

$$C_{uo} + C_{ua} d = 0 \quad d = - \frac{C_{uo}}{C_{ua}}$$

$$\text{mag} = \frac{1}{2} \rho S V^2 C_{ua} \left[ - \frac{C_{uo}}{C_{ua}} \right] \quad \text{ho } \alpha^\circ = 1 \text{ soluzioni}$$



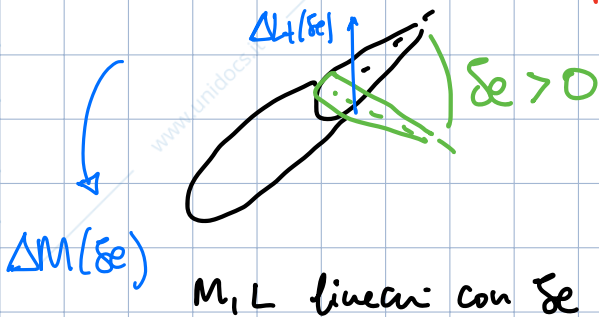
Così però ho solo una condizione di volo stabile e questo non è utile

Se voglio volare ad  $d_{trim}$  devo cambiare la pendenza della retta  $C_{ua}$  e questo è ottenibile spostando il CG ( $h-h_u$ ), non conviene però.

Un altro modo per volare ad  $d_{trim}$  è quello di spostare  $C_{uo}$  mantenendo invariata la pendenza  $C_{ua}$ .

$$C_u = C_{uo} + C_{ua} d + \Delta C_{uo} = 0$$

$\Delta C_{uo}$  è indipendente dalla condizione di volo e ci viene dato da un apparato sul piano di coda



$$\begin{cases} L = L_{wb} + L_t + \Delta L_t(\xi) \\ L = C_{La} + C_{L\xi} \xi \\ C_u = C_{uo} + C_{ua} d + C_{u\xi} \xi \end{cases}$$

per l'equilibrio:

$$\begin{bmatrix} C_{La} & C_{L\xi} \\ C_{ua} & C_{u\xi} \end{bmatrix} \begin{bmatrix} d_{trim} \\ \xi_{trim} \end{bmatrix} = \begin{bmatrix} C_L \\ -C_{uo} \end{bmatrix}$$

$$d_{trim} = \frac{C_L C_{u\xi} + C_{L\xi} C_{uo}}{C_{La} C_{u\xi} - C_{L\xi} C_{ua}}$$

$$\xi_{trim} = \frac{-C_{La} C_{uo} - C_L C_{ua}}{C_{La} C_{u\xi} - C_{L\xi} C_{ua}}$$

$(C_{uo})$

$$M_0 = M_{0wb} - L_t \bar{c}_0 + L (h - h_{nwb}) \bar{c} \quad \sim = \frac{a_t}{C_{\alpha}} \left(1 - \frac{\partial \xi}{\partial \alpha}\right) \bar{V}_H$$

$$C_{no} = C_{nowb} - a_t \frac{\sigma_t^2 V_t^2}{S} \frac{\bar{c}_t}{\bar{c}} dt + C_{\alpha} (h - h_{nwb}) d$$

$$C_{no} = C_{nowb} - a_t \bar{V}_H dt + C_{\alpha} \frac{a_t}{C_{\alpha}} \left(1 - \frac{\partial \xi}{\partial \alpha}\right) \bar{V}_H d$$

$$d_t = d_{nwb} \left(1 - \frac{\partial \xi}{\partial \alpha}\right) + (i_t - \xi_0)$$

$$d = d_{nwb} + \frac{a_t}{C_{\alpha}} (i_t - \xi_0) \frac{S_t}{S}$$

$$C_{no} = C_{nowb} - a_t \bar{V}_H d_{nwb} \left(1 - \frac{\partial \xi}{\partial \alpha}\right) - a_t \bar{V}_H (i_t - \xi_0) + C_{\alpha} \frac{a_t}{C_{\alpha}} \left(1 - \frac{\partial \xi}{\partial \alpha}\right) \bar{V}_H d$$

$$C_{no} = C_{nowb} - a_t \bar{V}_H \left(1 - \frac{\partial \xi}{\partial \alpha}\right) [d_{nwb} - d] - a_t \bar{V}_H (i_t - \xi_0)$$

$$C_{no} = C_{nowb} - a_t \bar{V}_H \left(1 - \frac{\partial \xi}{\partial \alpha}\right) \frac{a_t}{C_{\alpha}} (i_t - \xi_0) \frac{S_t}{S} - a_t \bar{V}_H (i_t - \xi_0)$$

$$C_{no} = C_{nowb} - a_t \bar{V}_H (i_t - \xi_0) \left[ \frac{a_t}{C_{\alpha}} \left(1 - \frac{\partial \xi}{\partial \alpha}\right) \frac{S_t}{S} + 1 \right]$$

$C_{no}$  NON dipende da  $d$

$C_{LSE}$

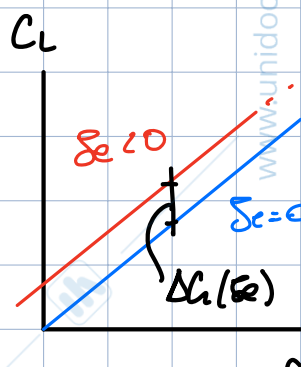
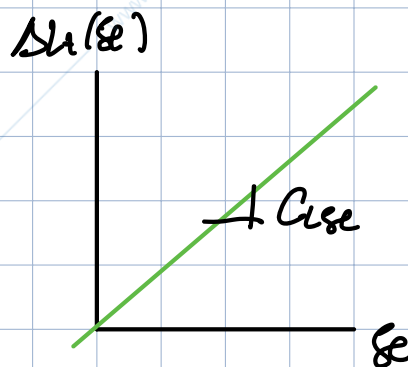
$$L = L_{wb} + L_t + \Delta L_t$$

$$C_L = C_{Lwb} + C_{L_t} \frac{S_t}{S} + \Delta L_t(\xi_e)$$

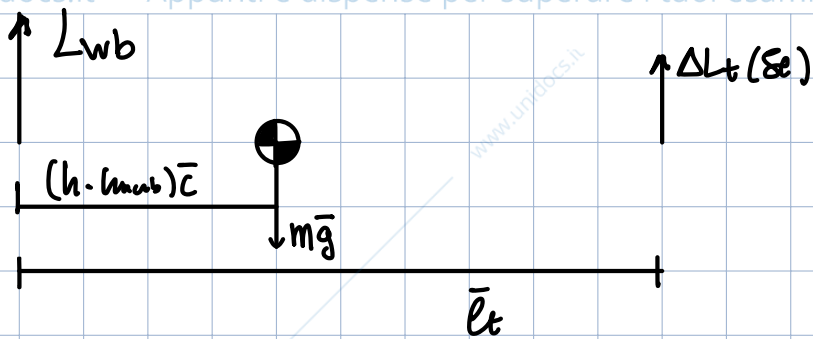
$$\Delta L_t(\xi_e) = \frac{1}{2} \rho \sigma_t^2 V_t^2 a e^* \xi_e$$

$$\Delta L_t(\xi_e) = \frac{S_t}{S} \frac{V_t^2}{2} a e^* \xi_e = a e \frac{S_t}{S} \xi_e = C_{LSE} \xi_e$$

$$C_{LSE} = a e \frac{S_t}{S}$$



$C_{mse}$



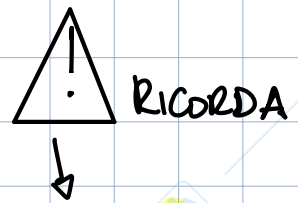
$$\Delta M(\delta e) = -\Delta L_t \bar{l}_t + \Delta L_t (h - h_{sub}) \bar{c}$$

$$\Delta C_m(\delta e) = -\Delta C_{it} \frac{S_t V_t^2}{S} \frac{\bar{l}_t}{\bar{c}} + \Delta C_{it} (h - h_{sub}) \frac{S_t V_t^2}{S} \frac{1}{\bar{c}}$$

$$= -\Delta C_{it} \bar{V}_H \frac{V_t^2}{V^2} + \Delta C_{it} (h - h_{sub}) \frac{S_t}{S} \frac{V_t^2}{V^2}$$

$$= \left[ -a_e \bar{V}_H + a_e \frac{S_t}{S} (h - h_{sub}) \right] \delta e$$

$$= \left[ -a_e \bar{V}_H + C_{ise} (h - h_{sub}) \right] \delta e$$



$$C_{mse} = C_{ise} (h - h_{sub}) - a_e \bar{V}_H$$

$$C_{mse} = -C_{ise} \frac{\bar{l}_t}{\bar{c}}$$

$$\delta e = -\frac{C_{id} C_{mo} + C_i C_{nd}}{C_{ia} C_{ise} - C_{ise} C_{ia}}$$

$$\delta e = -\frac{C_{id} C_{mo} + C_i C_{ia} (h - h_m)}{C_{ia} C_{ise} - C_{ise} C_{ia} (h - h_m)}$$

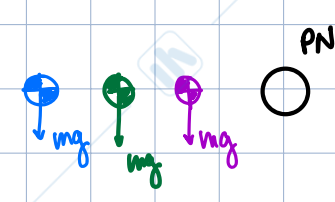
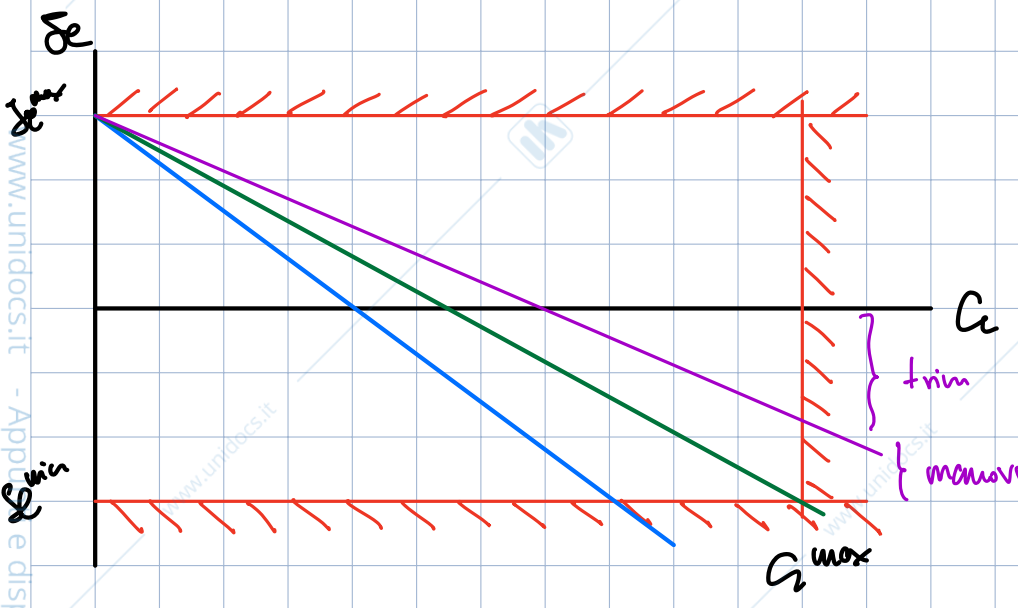
$$\delta e = -\frac{C_{mo} + C_i (h - h_m)}{C_{ise} (h - h_{sub}) - a_e \bar{V}_H - C_{ise} (h - h_m)}$$

$$\delta e = -\frac{C_{mo} + C_i (h - h_m)}{C_{ise} (h_m - h_{sub}) - a_e \bar{V}_H}$$

$$[C_{se}(h_u - h_{nw}) - C_e \bar{V}_H] \delta e = -C_{mo} - C_e (h - h_u)$$

Variable  
Costante  
parametrico

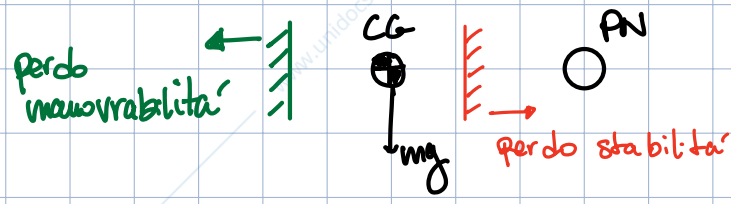
2 ⊖  
1 ⊕ perché  $\bar{V}_H$  prevale  $\Rightarrow \frac{2}{1} \oplus = \text{Cost}$



mi lascio in  $\delta e$  così che quando sono in condizione di stallo ho ancora un margine di manovra

La retta blu non mi soddisfa perché quando sono in condizione di  $\delta e_{trim}^{min}$  non ho raggiunto  $h_{max}$ . Vario la pendenza della retta variando  $(h - h_u)$

Da qui capisco che il CG ha un limite anteriore oltre il quale perdo manovrabilità



$C_{Ltrim}$

$$\alpha_{trim} = \frac{C_{Luse} + C_{Lmo}}{C_{Duse} - C_{Dmo}}$$

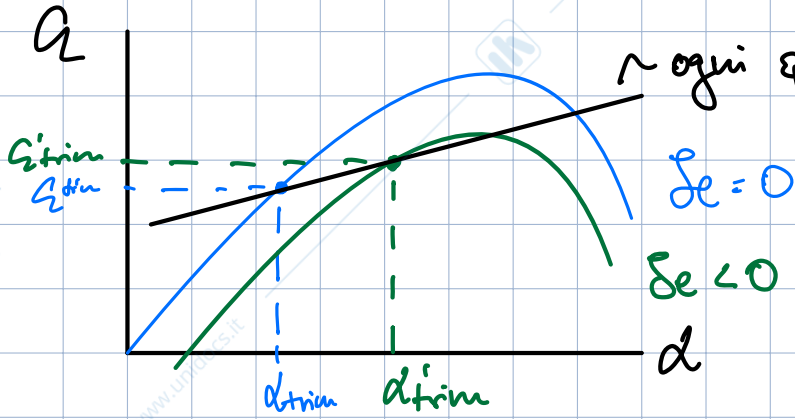
$$(C_{Duse} - C_{Dmo}) \alpha_{trim} = C_{Luse} + C_{Lmo}$$

$$C_{Ltrim} = \frac{C_{Duse} - C_{Dmo}}{C_{use}} \alpha_{trim} - C_{Lmo}$$

$$C_{Ltrim} = C_{D^*} \alpha_{trim} - C_{L^*}$$

$$G_d^* = \frac{G_d [C_{use} - G_{se}(h - h_n)]}{C_{use}} = G_d - \frac{G_{se}}{C_{use}} (h - h_n) G_d$$

$$G_d^* = G_d \left[ 1 - (h - h_n) \frac{G_{se}}{C_{use}} \right]$$



~ ogni punto di questa retta è un punto di trim

$$G_d G_{se} \frac{\bar{L}_t}{C} - G_d G_{se} (h - h_n)$$

$$G_d G_{se} \left[ \frac{\bar{L}_t}{C} - (h - h_n) \right]$$

$$\frac{\bar{L}_t}{C} > 1 \quad (h - h_n) < 1 \quad G_d G_{se} > 0 \Rightarrow C_{nd} G_{se}$$

$$\bar{V}_H = \frac{S_t}{S} \frac{\bar{L}_t}{C}$$

$$\delta_{trim} = - \frac{C_{no} G_d + C_{nd} C_{trim}}{C_d C_{use} - C_{nd} G_{se}} \approx - \frac{C_{no} G_d + C_{nd} C_{trim}}{C_d C_{use}} *$$

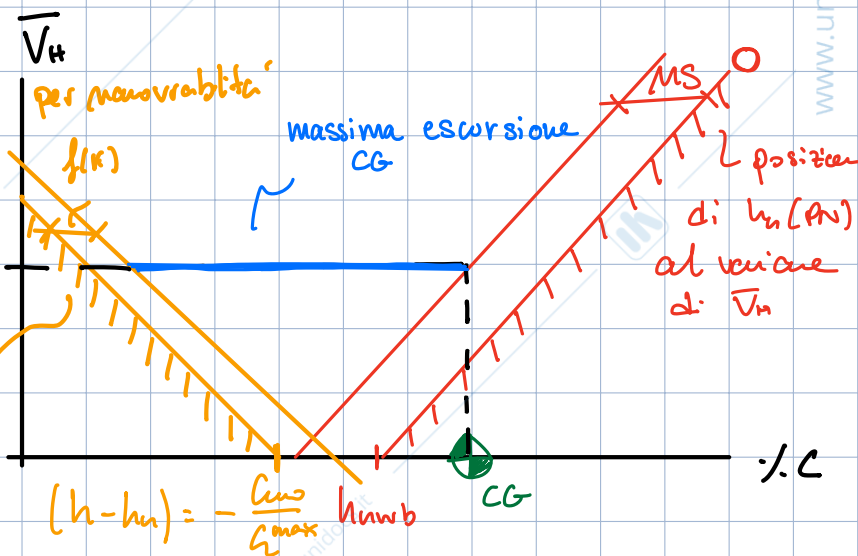
$$= - \frac{C_{no} G_d + G_d (h - h_n) C_t}{G_d C_{use}} = \frac{C_{no} + C_t (h - h_n)}{C_d \bar{V}_H} * = \delta_e$$

$$* C_{use} = G_{se} (h - h_{nwb}) - a_e \bar{V}_H \approx - a_e \bar{V}_H \quad C_t = C_{max}$$

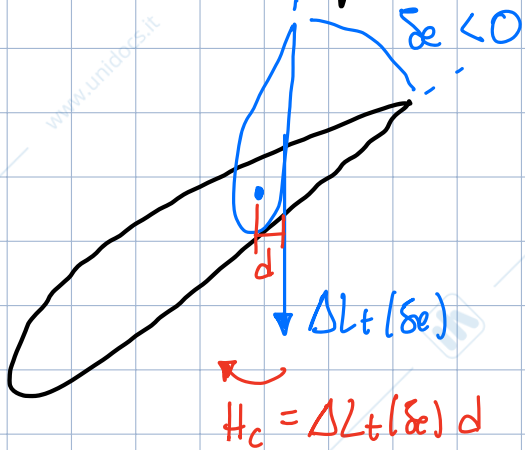
pesa di pic

$$\begin{cases} (h - h_n) = \frac{a_e \bar{V}_H}{C_{max}} \delta_{et} - \frac{C_{no}}{C_{max}} \\ (h_n - h_{nwb}) = \frac{C_t}{C_d} \left( 1 - \frac{\partial \delta}{\partial d} \right) \bar{V}_H \end{cases}$$

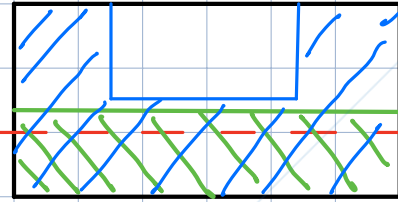
posizioni oltre il quale non ho più manovrabilità



# Comandi equilibratore

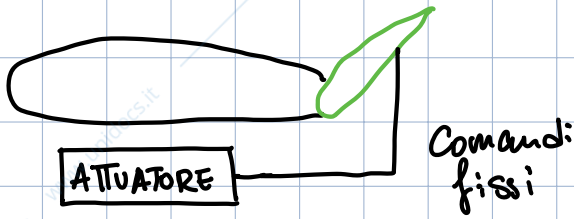


Per combattere  $H_c$  devo applicare una forza al volante oppure posso avere una geometria che annulli  $H_c$  o infine degli attuatori.

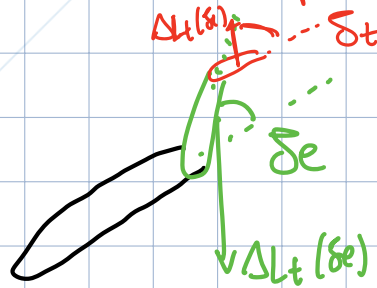
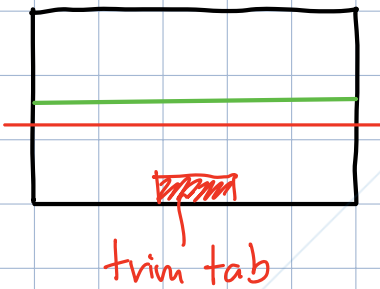


Quello blu mi azzera  $d$  e quindi anche  $H_c$

~ Quello verde mi lascia un momento  $H_c$

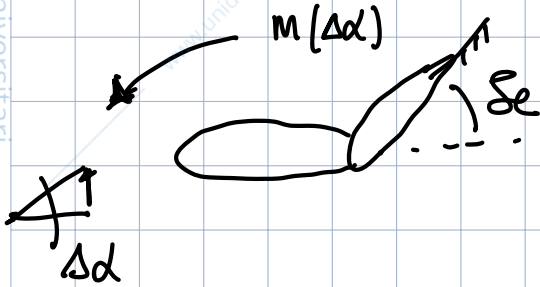


Un'ultima soluzione e' quella del compenso aerodinamico



$\Delta L_t(\delta_e) < \Delta L_t(\delta_e)$   
ma ha un braccio maggiore quindi  $H_c \rightarrow 0$

## Stabilità comandi fissi



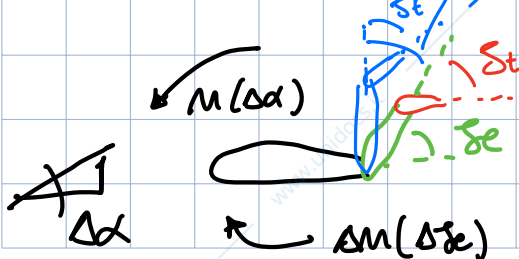
$\delta_e$  non cambia sotto raffica e quindi neanche  $L_{tail}$

$$\Delta L_z = C_{L\alpha} \Delta \alpha + C_{L\delta_e} \Delta \delta_e$$

$$C_{L_t} = C_{L\alpha} \alpha_t + C_{L\delta_e} \delta_{e_t}$$

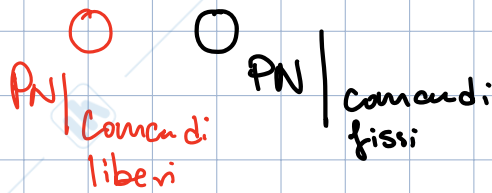
## Comandi liberi

sotto raffica



Il sistema eq-trim e in equilibrio col flusso quindi cambia sotto raffica il  $\delta_e$  (e non il  $\delta_t$  perché quello e' fisso). Il  $\Delta \delta_e$  mi crea un momento opposto a quello stabilizzante e quindi azzera

$$C_{in} = C_{mo} + C_{in} d + C_{in} \delta_e + C_{in} (\delta_t)$$



"  
 $C_{in} \delta_t$

MS comandi liberi

$$H_e = \frac{1}{2} \rho S_e v^2 C_{he} C_e$$

$$C_{he} = b_0 + b_1 d + b_2 \delta_e + b_3 \delta_t$$

$\frac{\partial C_{he}}{\partial d}$        $\frac{\partial C_{he}}{\partial \delta_e}$        $\frac{\partial C_{he}}{\partial \delta_t}$

$$d_t = d_{nb} \left( 1 - \frac{\partial \xi}{\partial d} \right) + (i_t - \xi)$$

$$d_{nb} = d - \frac{a_t}{C_{rd}} (i_t - \xi_0) \frac{S_t}{S}$$

$$d_t = \left( d - \frac{a_t}{C_{rd}} (i_t - \xi_0) \frac{S_t}{S} \right) \left( 1 - \frac{\partial \xi}{\partial d} \right) + (i_t - \xi)$$

$$= d \left( 1 - \frac{\partial \xi}{\partial d} \right) - \frac{a_t}{C_{rd}} \frac{S_t}{S} (i_t - \xi_0) \left( 1 - \frac{\partial \xi}{\partial d} \right) + (i_t - \xi)$$

$$= d \left( 1 - \frac{\partial \xi}{\partial d} \right) + (i_t - \xi_0) \left[ 1 - \frac{a_t}{C_{rd}} \left( 1 - \frac{\partial \xi}{\partial d} \right) \frac{S_t}{S} \right]$$

$$C_{he} = b_0 + b_1 \left\{ d \left( 1 - \frac{\partial \xi}{\partial d} \right) + (i_t - \xi_0) \left[ 1 - \frac{a_t}{C_{rd}} \left( 1 - \frac{\partial \xi}{\partial d} \right) \frac{S_t}{S} \right] \right\} + b_2 \delta_e + b_3 \delta_t$$

$$C_{he} = C_{heo} + C_{hed} d + b_2 \delta_e + b_3 \delta_t = 0$$

$$C_{heo} = b_0 + b_1 (i_t - \xi_0) \left[ 1 - \frac{a_t}{a_d} \left( 1 - \frac{\partial \xi}{\partial d} \right) \frac{\delta_t}{s} \right]$$

$$C_{hed} = b_1 \left( 1 - \frac{\partial \xi}{\partial d} \right)$$

$$C_{he} = 0$$

$$\delta_e \Big|_{\text{free}} = -\frac{1}{b_2} (C_{heo} + C_{hed} d + b_3 \delta_t)$$

$$\delta_t \Big|_{\text{trim}} = -\frac{1}{b_3} (C_{heo} + C_{hed} d + b_2 \delta_e)$$

$$\Delta \delta_e = -\frac{1}{b_2} C_{hed} \Delta d$$

$$\Delta G = G_d \Delta d + G_{\delta_e} \Delta \delta_e$$

$$\Delta G = G_d \Delta d + G_{\delta_e} \Delta \delta_e$$

$$\Delta G = G_d \Delta d + G_{\delta_e} C_{hed} \left( -\frac{\Delta d}{b_2} \right)$$

$$= \underbrace{\left( G_d - G_{\delta_e} \frac{C_{hed}}{b_2} \right)}_{G_d'}$$

$$\Delta G = \underbrace{\left( G_d - G_{\delta_e} \frac{C_{hed}}{b_2} \right)}_{G_d'} \Delta d$$

$G_d'$

$$C_{na} = C_a (h - h_{n'})$$

$$C_{na} = C_a (h - h_n) \quad h - h_n = \frac{C_{na}}{C_a} \quad h = h_n + \frac{C_{na}}{C_a}$$

$$h - h_{n'} = \frac{C_{na'}}{C_{a'}}$$

$$h_n - h_{n'} = \frac{C_{na'}}{C_{a'}} - \frac{C_{na}}{C_a} = \frac{b_2 C_{na} - C_{na} \frac{C_{ea}}{b_1}}{b_2 C_a - C_{na} \frac{C_{ea}}{b_1}} - \frac{C_{na}}{C_a}$$

$$h_n - h_{n'} = \frac{(\cancel{b_2 C_{na}} - C_{na} \frac{C_{ea}}{b_1}) C_a - (\cancel{b_2 C_a} - C_{na} \frac{C_{ea}}{b_1}) C_{na}}{(b_2 C_a - C_{na} \frac{C_{ea}}{b_1}) C_a}$$

$$= \frac{C_{na} C_{na} \frac{C_{ea}}{b_1} - C_a C_{na} \frac{C_{ea}}{b_1}}{C_a}$$

$$h_{n'} = h_n + \frac{C_{na}}{C_a} \frac{C_a C_{na} \frac{C_{ea}}{b_1} - C_a C_{na} \frac{C_{ea}}{b_1}}{b_2 C_a - C_{na} \frac{C_{ea}}{b_1}}$$

$$\delta_{trim} = -\frac{1}{b_3} (C_{na} + C_{na} \alpha + b_2 \delta_{trim})$$

$$\alpha_{trim} = \frac{C_{na} C_{na} + C_{na} C_{trim}}{\Delta_{trim}}$$

$$\delta_{trim} = \frac{-C_{na} C_a - C_{na} C_{trim}}{\Delta_{trim}}$$

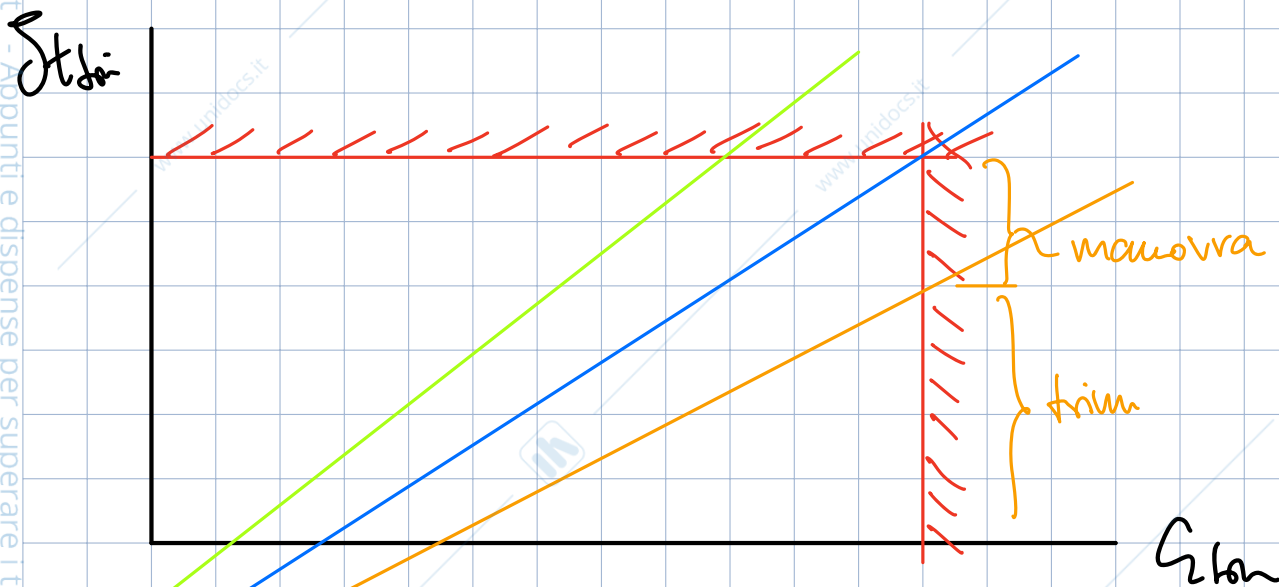
$$\delta_{trim} = -\frac{1}{b_3} \left( C_{na} + C_{na} \frac{C_{na} C_{na} + C_{na} C_{trim}}{\Delta_{trim}} - b_2 \frac{C_{na} C_a + C_{na} C_{trim}}{\Delta_{trim}} \right)$$

$$= -\frac{1}{b_3} \left[ C_{na} + \frac{C_{na}}{\Delta_{trim}} (C_{na} C_{na} - b_2 C_a) + \frac{C_{trim}}{\Delta_{trim}} (C_{na} C_{na} - b_2 C_a) \right]$$

$$C_{u'd} = C_{u'd} - \frac{C_{u'se} C_{he}}{b_2}$$

$$C_{u'se} C_{he} - b_2 C_{u'd} = -C_{u'd} b_2$$

$$\delta t_{trim} = -\frac{1}{b_3} \left[ C_{he0} + \frac{C_{u'o}}{\Delta} (C_{u'se} C_{he} - b_2 C_{u'd}) - \frac{C_{u'trim}}{\Delta} b_2 C_{u'd} (h - h_{u'}) \right]$$



equil. brio  $C_{he} = C_{he0} + C_{he} \delta t_{trim} + b_2 \delta t_{trim} + b_3 \delta t$

$\hookrightarrow 0 = C_{he0} + C_{he} \delta t_{trim} + b_2 \delta t_{trim} + b_3 \delta t_{trim}$

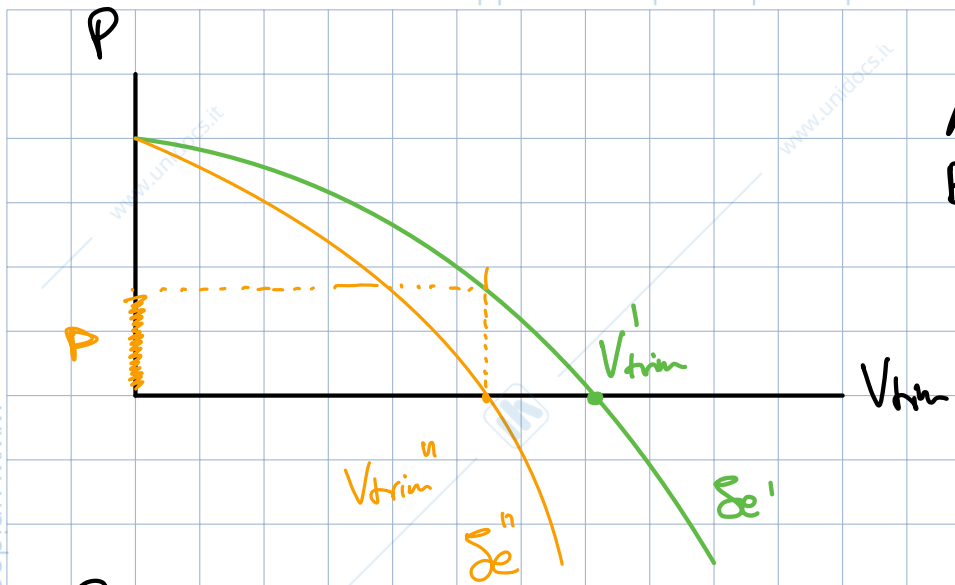
$$C_{he} = b_3 (\delta t - \delta t_{trim})$$

Sforzo di banana  $P = G_{He} = G \frac{1}{2} \rho S_e V_{air}^2 C_e b_3 (\delta t - \delta t_{trim})$

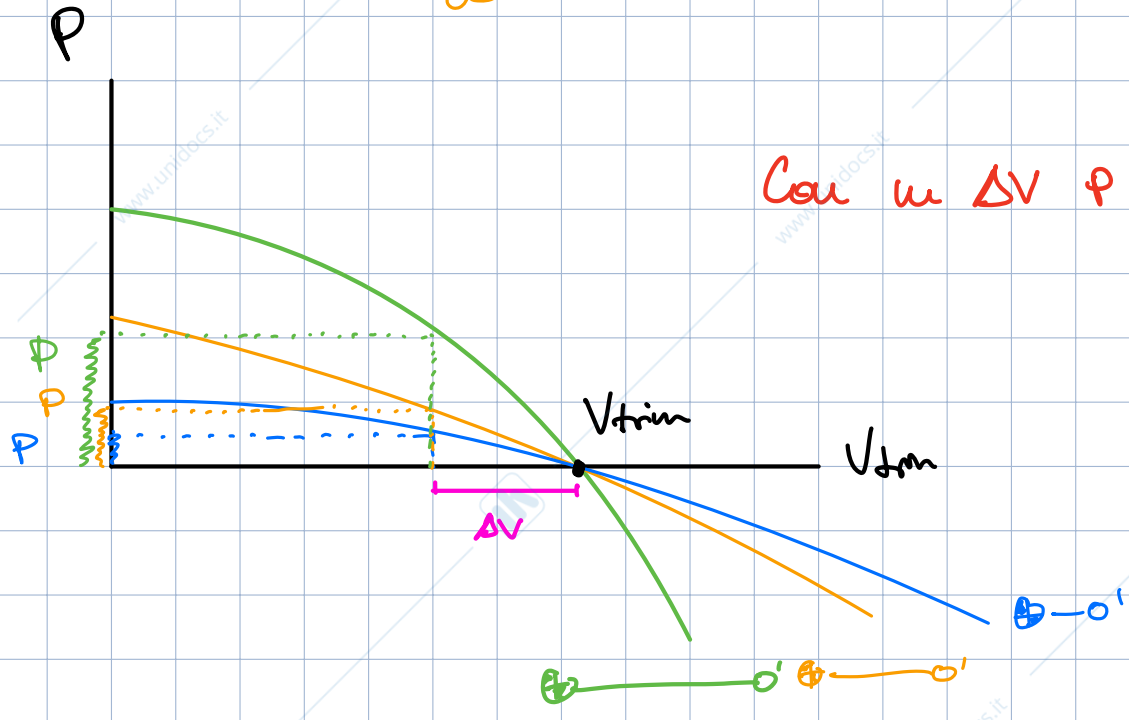
$$P = A + \frac{1}{2} \rho V_{trim}^2 B \quad A = A (h - h_{u'}) \quad B = B (\delta t)$$

A = Cost  
B = Var

Se  $V_{trim}$  diminuisce e non agisco sul tab devo agire con un forza P

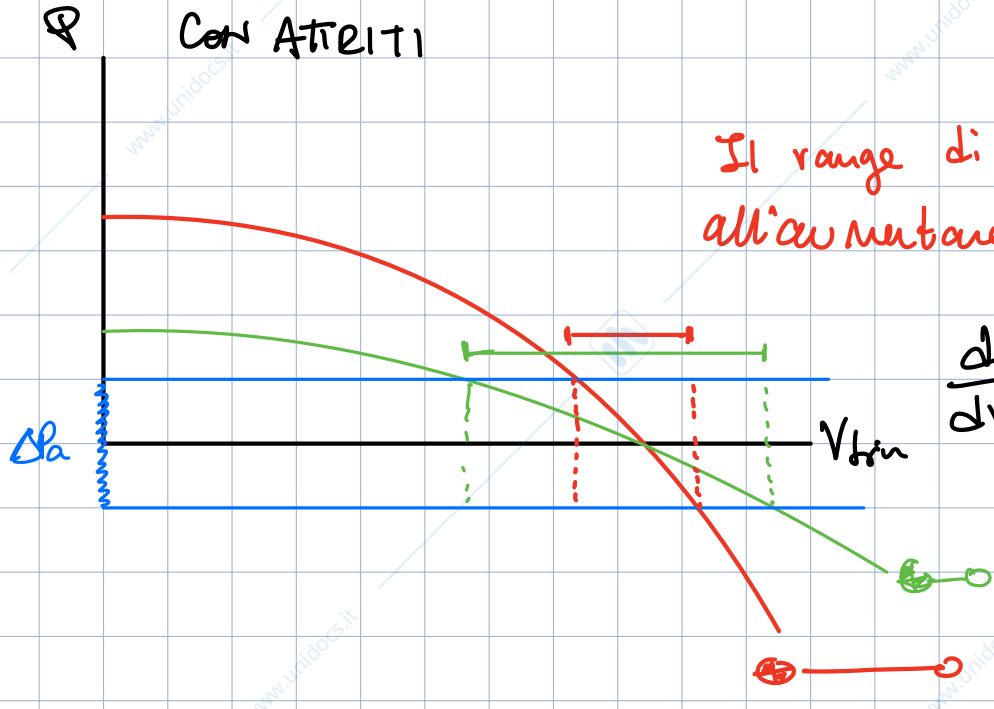


Con un  $\Delta V$  P ↑ con il MS



Con Affetti

Il range di equilibrio diminuisce all'aumentare della stabilità dell'a/u



$$\frac{dP}{dV_{trim}} \Big|_{P=0} = QV_{trim} B$$

$$QV_{trim} \left( -\frac{2A}{QV_{trim}^2} \right)$$

$$= -\frac{2A}{V_{trim}}$$

$P=0$      $A = -\frac{1}{2} QV_{trim}^2 B$      $B = -\frac{2A}{QV_{trim}^2}$

Pendenza della curva nel punto di trim, dipende da  $V_{trim}$  e da  $A$ .  $A = A(h-h_0)$  quindi se

voglio un range di incertezza ridotto non devo tirare troppo indietro CG.

## DEFINIZIONI

**Stabilità longitudinale:** Attitudine dell'a/m a tornare nella sua posizione originale a seguito di un disturbo senza l'intervento del pilota.

**Stabilità direzionale:** Attitudine dell'a/m a seguire naturalmente la direzione del vento (galleggiamento)

**Stabilità laterale:** Attitudine che ha l'a/m a livellare le ali a seguito di un disturbo

**Controllabilità:** Possibilità di trovare più posizioni di volo stabile.

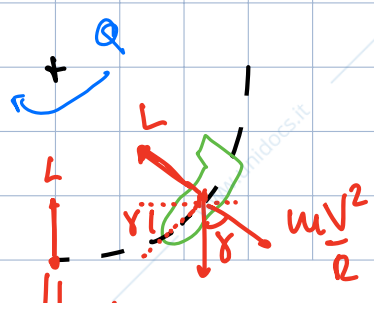
## MANOVRA BILITÀ

$u=1 \quad C_m = C_{m0} + C_{m\alpha} \alpha + C_{m\delta} \delta_e = 0$

$u \neq 1 \quad C_m = C_{m0} + C_{m\alpha} \alpha + C_{m\delta} \delta_e + \Delta C_m(u) = 0$

$\hookrightarrow \Delta \delta_e(u)$

$V = QR$



$L = u \frac{V^2}{R} + mg \cos \gamma = mg \left( \frac{V^2}{gR} + \cos \gamma \right)$

$u = \frac{L}{mg} = \frac{V^2}{gR} + \cos \gamma$

$$mg \downarrow \frac{mv^2}{R} \quad mg$$

$$u_{max} = \frac{v^2}{gR} + 1 = \frac{vQ}{g} + 1 \quad ; \quad \frac{u-1}{v} g = Q$$

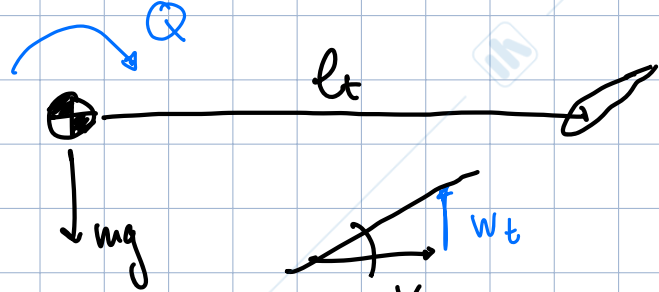
$$Q = \frac{2v\hat{q}}{c}$$

$$\hat{q} = \frac{Qc}{2v}$$

⚠ RICORDA QUESTE DUE  $\hat{q} = \frac{c(u-1)g}{2v^2}$

$$\Delta G \simeq \Delta G_t(\hat{q})$$

$$\Delta G_m = \Delta G_{int}(\hat{q})$$



$$\Delta G_t = \frac{S_t}{S} a_t \Delta d_t = \frac{S_t}{S} a_t \frac{Q l_t}{v} = \frac{S_t}{S} a_t \frac{2v\hat{q}}{c} \frac{l_t}{v}$$

$$= \frac{S_t}{S} a_t 2 \frac{l_t}{c} \hat{q}$$

$$W_t = v \Delta d_t$$

$$\Delta d_t = \frac{W_t}{v} = \frac{Q l_t}{v}$$

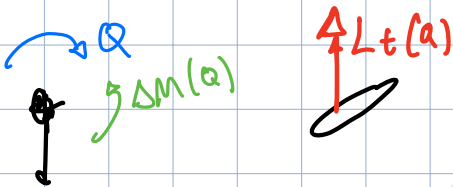
$$= \frac{2\hat{q} l_t}{c}$$

$$\frac{\partial G_t}{\partial Q} = a_t \frac{S_t}{S} \frac{l_t}{v}$$

$$\frac{\partial G_t}{\partial \hat{q}} = 2 a_t \frac{S_t}{S} \frac{l_t}{c} = 2 a_t V_H \quad C_{qg} = 2 a_t V_H$$

$$u=1 \quad G_{trim} = G_d d_{trim} + G_{se} \delta e_{trim}$$

$$u \neq 1 \quad \Delta G = G_d \Delta d + G_{se} \Delta \delta e + C_{qg} \hat{q}$$



$\Delta M(a)$  è un effetto di smorzamento e tende ad abbattere la causa che lo genera

$$\Delta M = -\Delta L_t(a) l_t$$

$$\Delta G_m = -\frac{S_t}{S} \frac{v_t^2}{v^2} a_t \frac{l_t}{c} \Delta d_t = -a_t \frac{S_t}{S} \frac{l_t}{c} \Delta d_t$$

$$= -a_t \frac{S_t}{S} \frac{l_t}{c} \frac{2\hat{q}l_t}{c} = -2a_t \frac{S_t}{S} \frac{l_t}{c} \frac{l_t}{c} \hat{q}$$

$$\frac{\partial \Delta C_u}{\partial \hat{q}} = -2a_t \frac{l_t}{c} V_H = -C_{1q} \frac{l_t}{c} = C_{1q}$$

$$\Delta C_u = C_{1d} \Delta d + C_{1se} \Delta se + C_{1q} \hat{q}$$

$$\begin{cases} C_{1d} \Delta d + C_{1se} \Delta se + C_{1q} \hat{q} = C_L(u-1) \\ C_{1d} \Delta d + C_{1se} \Delta se + C_{1q} \hat{q} = 0 \end{cases}$$

$$\begin{cases} C_{1d} \Delta d + C_{1se} \Delta se + C_{1q} \hat{q} = 0 \end{cases}$$

$$\frac{g_c}{\sqrt{2}} = \frac{C_{1e}}{\mu}$$

$$\left. \begin{array}{l} \text{---} \\ \text{---} \end{array} \right\} = \frac{2W = C_{1e}}{\sqrt{2} V^2 (u-1)}$$

$$\left. \begin{array}{l} \text{---} \\ \text{---} \end{array} \right\} = C_{1e}(u-1) - C_{1q} \frac{\bar{c}_g}{2V^2} (u-1)$$

$$\text{---} = -C_{1q} \frac{\bar{c}_g}{2V^2} (u-1)$$

$$\left. \begin{array}{l} \text{---} = C_{1e}(u-1) - C_{1q} \frac{C_{1e}}{2\mu} (u-1) = C_{1e}(u-1) \left[ 1 - \frac{C_{1q}}{2\mu} \right] \\ \text{---} = -C_{1q} \frac{C_{1e}}{2\mu} (u-1) \end{array} \right\}$$

$$\Delta se = \frac{1}{\Delta C_u} \left\{ -C_{1d} C_{1q} \frac{C_{1e}}{2\mu} (u-1) - C_{1d} C_{1e} (u-1) \left[ 1 - \frac{C_{1q}}{2\mu} \right] \right\}$$

$$\frac{\Delta se}{(u-1)} = -\frac{C_{1e}}{\Delta C_u} \left\{ \frac{C_{1d} C_{1q}}{2\mu} + C_{1d} - \frac{C_{1d} C_{1q}}{2\mu} \right\}$$

$$= - \frac{C_{we}}{\Delta_{low}} \left\{ C_{w\alpha} + \frac{1}{2\mu} (C_{w\alpha} C_{wq} - C_{w\alpha} C_{wq}) \right\}$$

$$= - \frac{C_{we} C_{w\alpha}}{\Delta_{low}} \left\{ (h - h_w) + \frac{1}{2\mu} [C_{wq} - (h - h_w) C_{wq}] \right\}$$

$$= - \frac{C_{we} C_{w\alpha}}{\Delta_{low}} \left\{ 2\mu (h - h_w) + C_{wq} - C_{wq} (h - h_w) \right\} \frac{1}{2\mu}$$

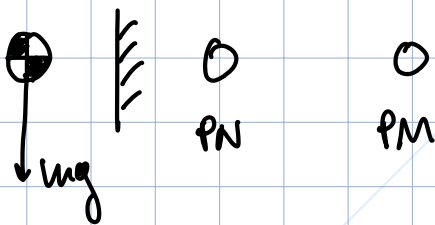
$$\frac{\Delta \delta e}{(u-1)} = - \frac{C_{we} C_{w\alpha}}{\Delta_{low} 2\mu} (2\mu - C_{wq}) \left[ (h - h_w) + \frac{C_{wq}}{2\mu - C_{wq}} \right]$$

NON dipende da  $h$

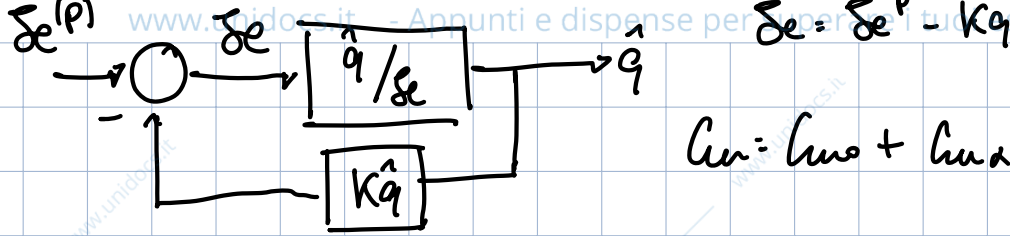
dipende da  $h$

$$\frac{\Delta \delta e}{(u-1)} = 0 \quad \text{per} \quad h = h_{cm} = h_w - \frac{C_{wq}}{2\mu - C_{wq}}$$

posizione del CG tale per cui posso passare da volo livellato a manovra con  $\Delta \delta e = 0$



PITCH DAMPER: aumento di stabilità, modifica artificiale  $C_{wq}$



$$\delta e = \delta e^{(p)} - K\hat{q}$$

$$C_u = C_{u0} + C_{u\alpha} \alpha + C_{uq} \hat{q} + C_{u\delta} \delta e$$

$$C_u = C_{u0} + C_{u\alpha} \alpha + C_{uq} \hat{q} + C_{u\delta} (\delta e^{(p)} - K\hat{q})$$

$$C_u = C_{u0} + C_{u\alpha} \alpha + [C_{uq} - C_{u\delta} K] \hat{q} + C_{u\delta} \delta e^{(p)}$$

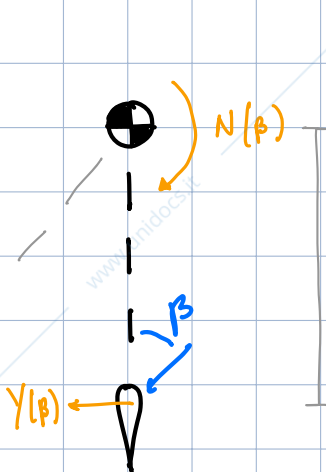
$C_{uq}' \rightarrow$  modificato in retroazione

## STABILITA' DIREZIONALE



$\beta$  angolo di sideslip

$$U = TAS \sin \beta \quad \beta = \frac{U}{TAS} \quad \beta \uparrow \text{ per } U \uparrow, TAS \downarrow$$

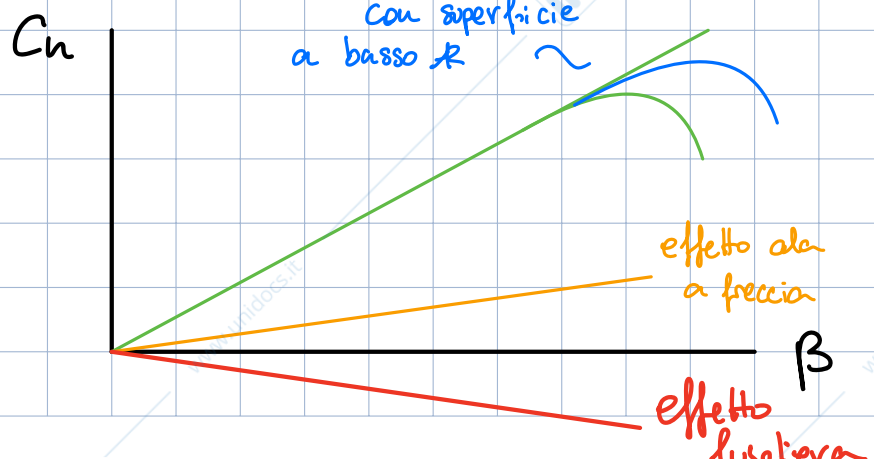


$$N(\beta) = \frac{1}{2} \rho S V^2 C_n b$$

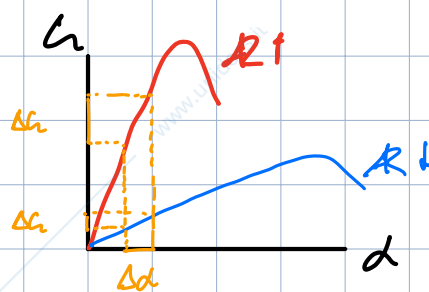
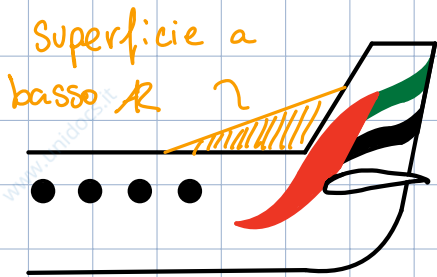
$\sim$  span

$$C_n(\beta) = C_{n0} + C_{n\beta} \beta$$

con superficie a basso  $R$



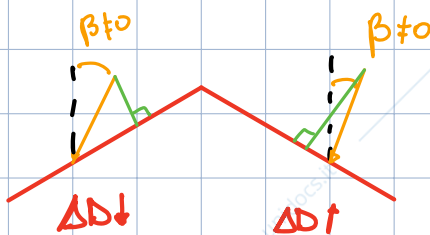
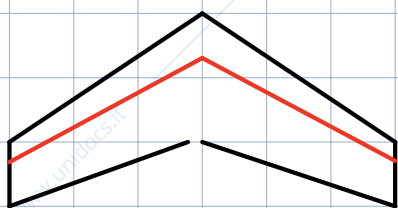
Siccome l'impennaggio verticale è un profilo alare a  $\beta$  elevati inizia a perdere linearità, per aumentare la regione lineare posso aggiungere una superficie a basso  $R$  davanti l'impennaggio cos



di vederlo meno sensibile ai disturbi. Dal grafico  $Cl-\alpha$  è facile notare che con  $R1$  ho un  $\Delta Cl$  migliore.

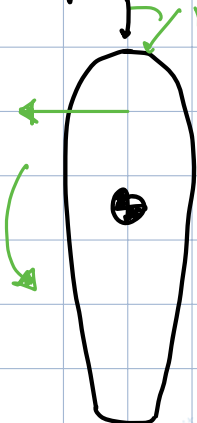
L'ala e la fusoliera hanno dei loro effetti sulla stabilità

- ala a freccia



Se considero le componenti perpendicolari alla corda non che quella a dx e' maggiore e quindi si crea un momento di imbardata positivo stabile

- fusoliera



Crea una forza che si applica a circa 1/3 della sua lunghezza, questo crea un momento instabile.

Gli effetti della fusoliera e dell'ala a freccia si annullano a vicenda

Posso avere dei fenomeni di interferenza e quindi l'angolo effettivo  $\alpha_F$  che devo considerare risulta essere:

$$\alpha_F = \beta - \sigma$$

$$\sigma = \sigma_0 + \frac{\partial \sigma}{\partial \beta} \beta \quad \alpha_F = \beta - \sigma_0 - \frac{\partial \sigma}{\partial \beta} \beta$$

$$Y_F \approx L_F$$

$$Y_F = \frac{1}{2} \rho S_F V_F^2 a_F \alpha_F$$

$$C_{YF} = \frac{S_F V_F^2}{S V^2} a_F \left[ \beta \left( 1 - \frac{\partial \sigma}{\partial \beta} \right) - \sigma_0 \right]$$

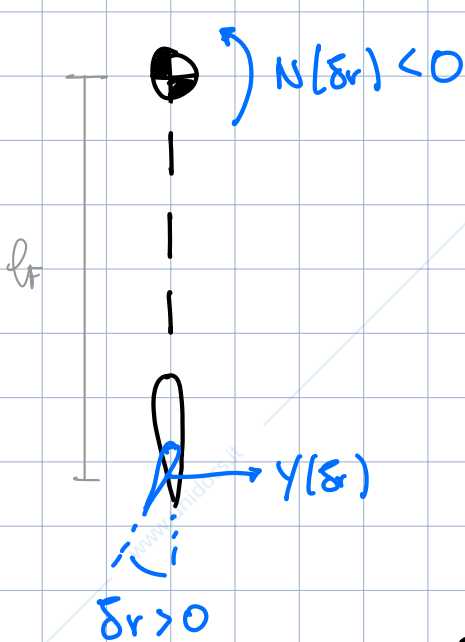
$$= a_F \frac{S_F}{S} \left[ \beta \left( 1 - \frac{\partial \sigma}{\partial \beta} \right) - \sigma_0 \right]$$

$$\frac{\partial G}{\partial \beta} = C_{Y\beta} = a_F \frac{S_F}{S} \left( 1 - \frac{\partial \sigma}{\partial \beta} \right)$$

$$N = Y_F l_F \quad C_u = \frac{S_F}{S} \frac{V_F^2}{V} a_F^* \left[ \beta \left( 1 - \frac{\partial \epsilon}{\partial \alpha} \right) - \sigma_0 \right] \frac{l_F}{b}$$

$$\frac{\partial C_u}{\partial \beta} = C_{u\beta} = a_F \left( 1 - \frac{\partial \epsilon}{\partial \alpha} \right) V_v \quad N(\beta) \quad C_{u\beta} > 0$$

### CONTROLLABILITÀ deflessione di parti mobili



$$Y(\delta r) = \frac{1}{2} l S_F V_F^2 a_{\delta r}^* \delta r$$

$$C_{Y(\delta r)} = \frac{S_F}{S} \frac{V_F^2}{V} a_{\delta r}^* \delta r$$

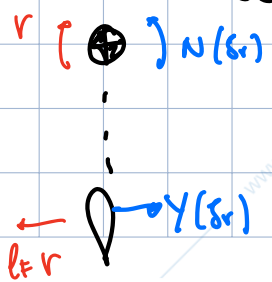
$$\frac{\partial C_{Y(\delta r)}}{\partial \delta r} = C_{Y\delta r} = a_{\delta r} \frac{S_F}{S}$$

$$N(\delta r) = -Y(\delta r) l_F = \frac{1}{2} l^2 S_F V_F^2 C_{u\beta} b$$

$$C_u(\delta r) = -\frac{S_F}{S} \frac{V_F^2}{V^2} a_{\delta r}^* \delta r \frac{l_F}{b}$$

$$\frac{\partial C_u(\delta r)}{\partial \delta r} = C_{u\delta r} = -a_{\delta r} V_v$$

Anche qui ho un effetto di smorzamento come nel beccheggio



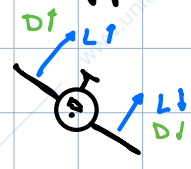
$$C_u = C_{u\beta} \beta + C_{u\delta r} \delta r + C_{u\dot{r}} \dot{r} = 0 \quad *$$

$$C_Y = C_{Y\beta} \beta + C_{Y\delta r} \delta r = 0$$

✱ Posso aggiungere degli effetti secondari quali:

- imbandata indotta:

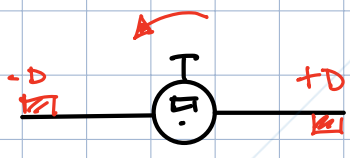
$$C_{npP}$$



Se viro a sx la scivola dx va più veloce, crea più portanza e più resistenza quindi imbanda verso sx

- imbardata dovuta alla deflessione degli alettone

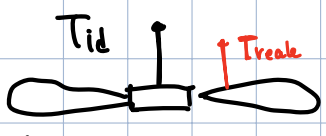
$$C_{nsaSa}$$



Con gli alettone aperti, l'alettone rivolto verso il basso crea più resistenza e quindi si crea un momento imbarcato

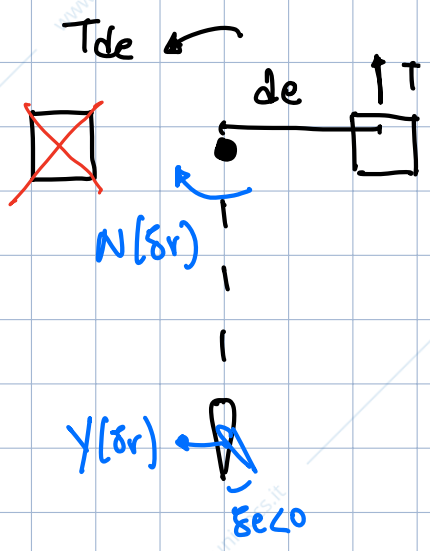
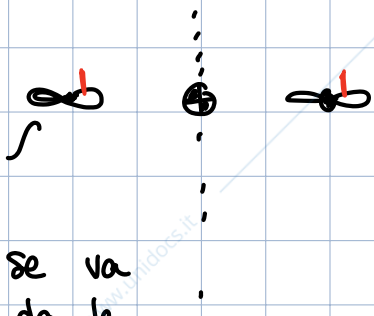
$$C_n = C_{np\beta} + C_{nsr} \delta_r + C_{nr} r + C_{npP} + C_{nsa} S_a$$

### AVARIA DI SPINTA



elica che ruota in senso orario rispetto al pilota

motore critico  
 ↓  
 e' quello che se va in avaria mi da la condizione peggiore



equilibrio  $T_{de} = N(\delta_r)$

$$T_{de} = N(\delta_r)$$

$$\frac{1}{2} \rho S V^2 C_{nsr} \delta_r b = T_{de}$$

$$V_{mc} = \sqrt{\frac{2 T_{de} N(\delta_r)}{\rho S C_{nsr}^{max} b}}$$

velocità di

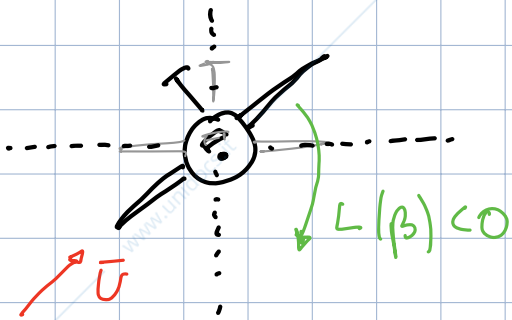
minimo controllo  $> V_{st}$



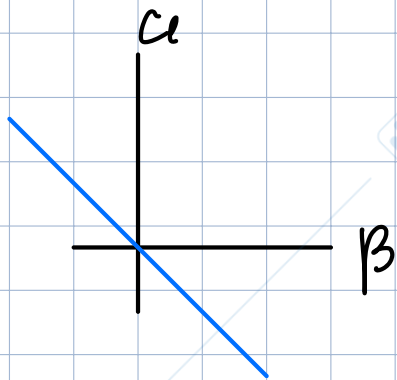
In  $V'$  non riesco ad equilibrare  $T_{de}$

Per abbassare  $V_{me}$  in fase di progetto  $\left\{ \begin{array}{l} \text{aumento } \delta_r^{max} \\ \text{aumento } C_{usr} \text{ aumentando } l_f \end{array} \right.$

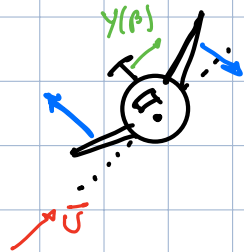
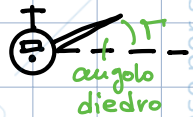
STABILITA' LATERALE - affidare dell'a/m a livellare le ali dopo un disturbo



$$L(\beta) = \frac{1}{2} \rho S V^2 C_l \beta \Rightarrow C_l \ominus \quad C_l = C_{l0} \ominus + C_{l\beta} \beta \ominus$$

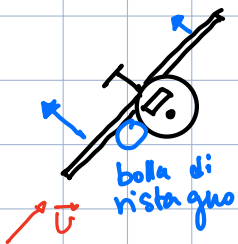


EFFETTO DIEDRO: Caratteristiche di progetto che danno stabilita' laterale



La semiala dx viene colpita con incidenza  $\tau$  mentre quella dx con  $-\tau$ , si crea una portanza e una deportanza

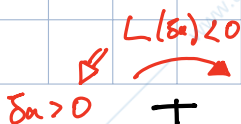
che tendono a far livellare l'a/m. In più ogni piano verticale che si trova sopra il CG ha un effetto stabilizzante.



Anche se ho ala alta ho un effetto stabilizzante, questo perché si crea una bolla di ristagno sotto l'ala inclinata che tende a livellare l'a/m.

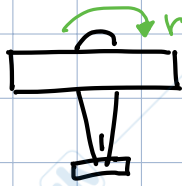
$$C_l = C_{l\beta} \beta \ominus + C_{l\delta_a} \delta_a \ominus + C_{l\dot{p}} \dot{p} \ominus$$

) L'effetto di smorzamento  
 ) degli alettoni



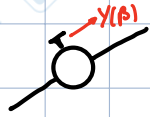
\* Posso aggiungere degli effetti secondari quali:

• rollio indotto  
 $C_{er} r$



Se ho un'imbar data positiva la semiala  $s_{\alpha}$  crea più portanza che fa rollare l'a/m

• rollio indotto da  $\beta$   
 $C_{e\beta} \beta$



Con  $Y(\beta)$  sopra il CG ho un rollio indotto

$$C_l = C_{l\beta} \beta + C_{l\alpha} \alpha + C_{lp} p + C_{er} r + C_{e\beta} \beta$$

N. B.

$$C_{nd} < 0$$

$$C_{n\beta} > 0$$

$$C_{e\beta} < 0$$

Questi due coefficienti sono inversi dallo stesso disturbo ma agiscono su due assi differenti  $\rightarrow$  con la raffica laterale ho imbar data e rollio