Corso Progetto Generale Velivoli

Progetto Piano Verticale

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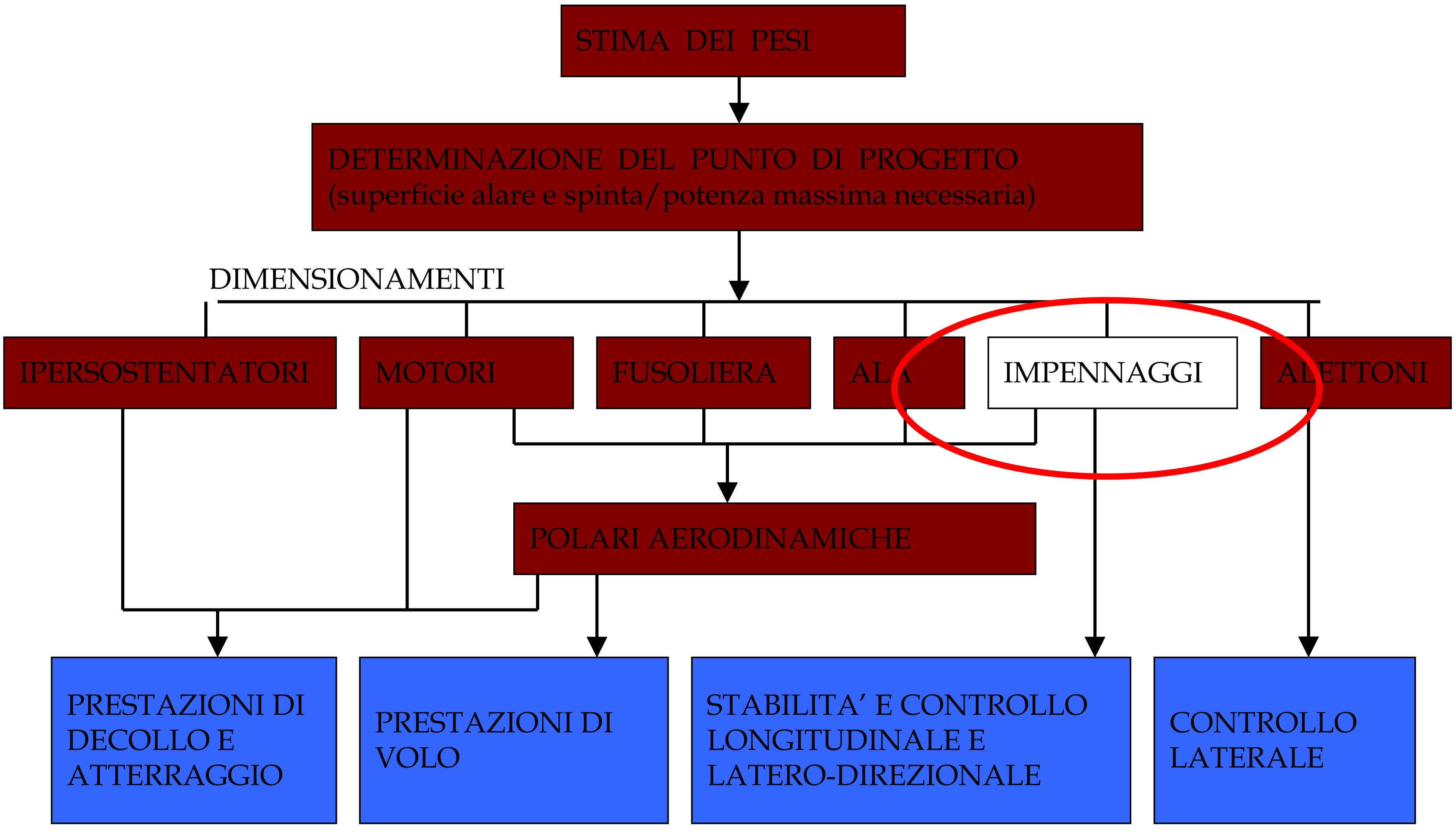
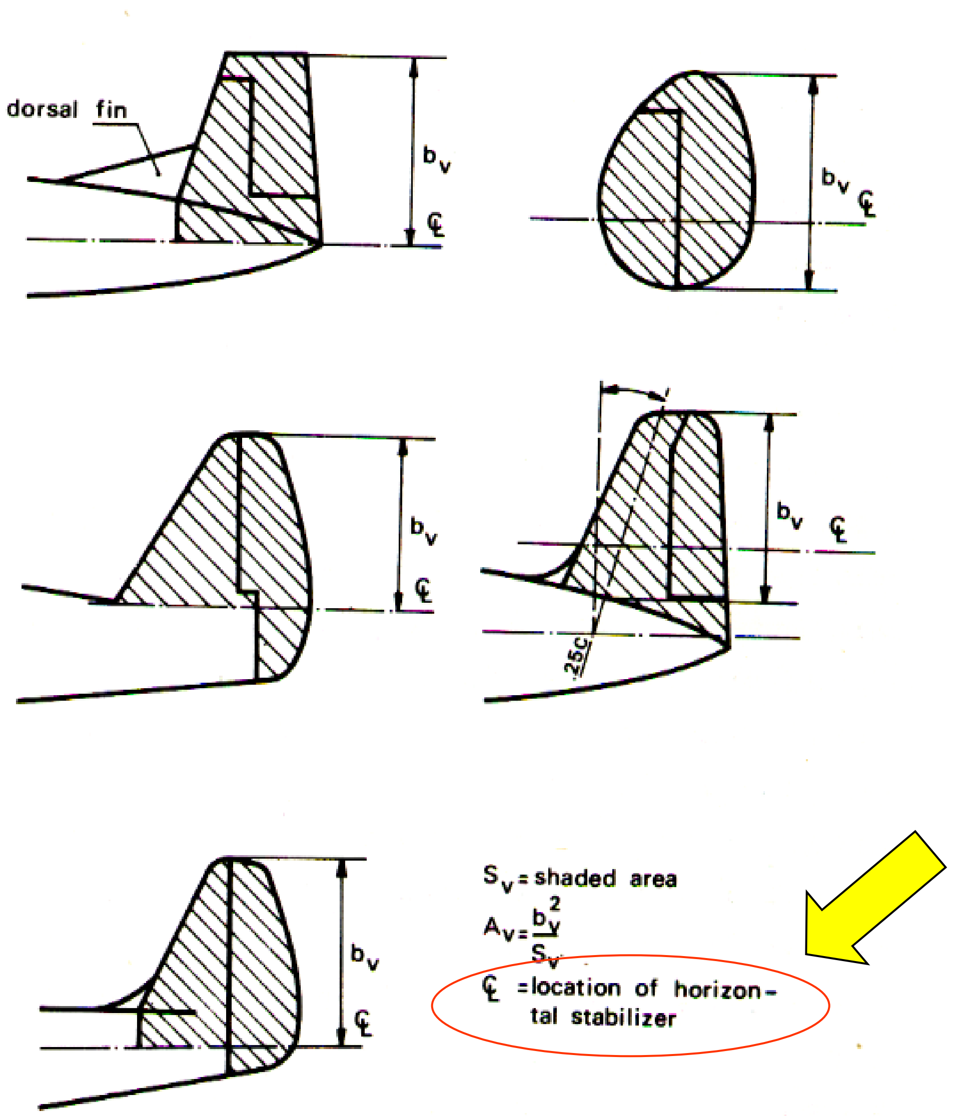
PROGETTO PRELIMINARE



The design of the vertical tail

Definitions of vertical tail area



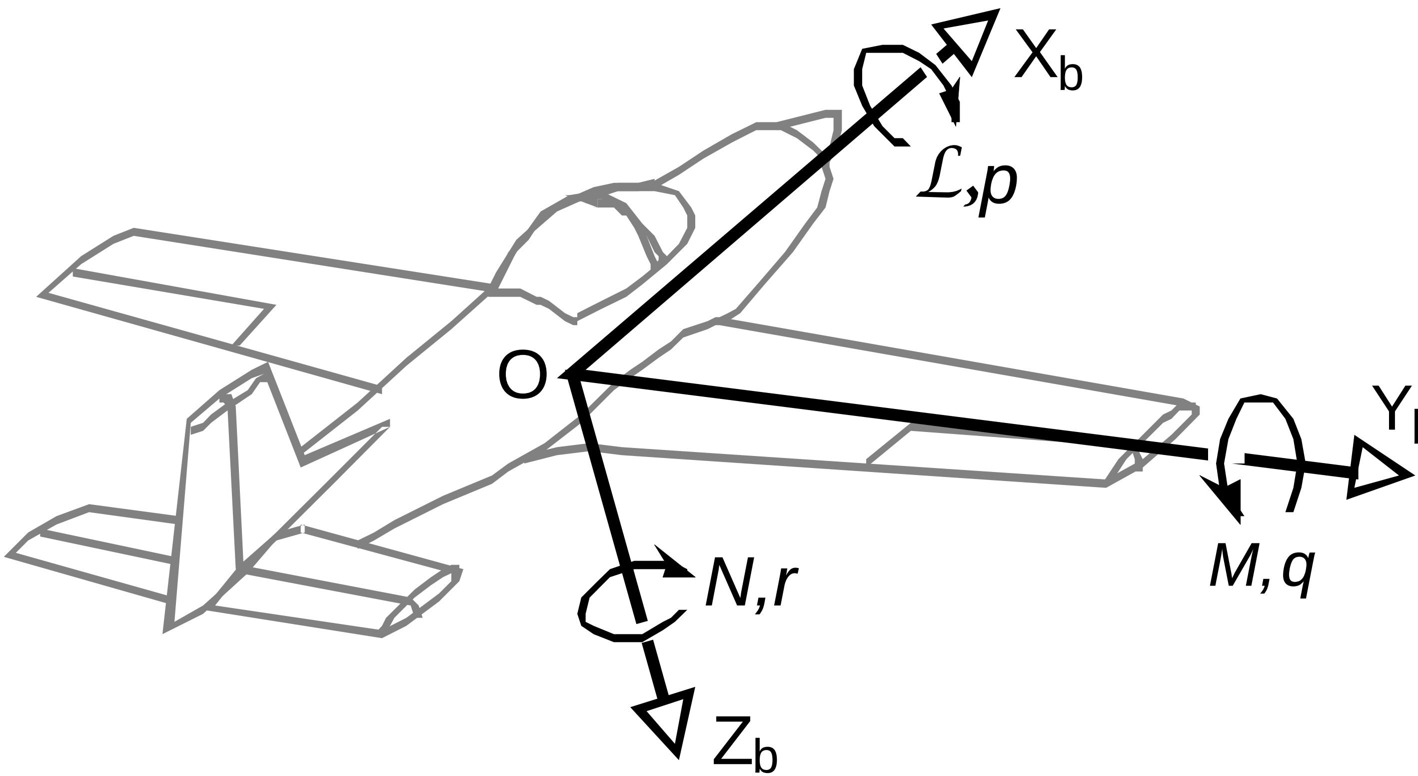
Synthesis Fig. 9-20

Vertical tail design criteria

- Directional and lateral stability (static and dynamic)
- Multiengine aircraft must still be controllable after engine failure. Transient behavior must be adequate and steady flight possible.
- Controllability in crosswind landings (20Knots)
- Spin resistance ensured for light aircraft

The vertical tail design is generally more complex because of the difficulty in calculating lateral direction aerodynamic characteristics (aircraft at sideslip) and the need to look at dynamic stability

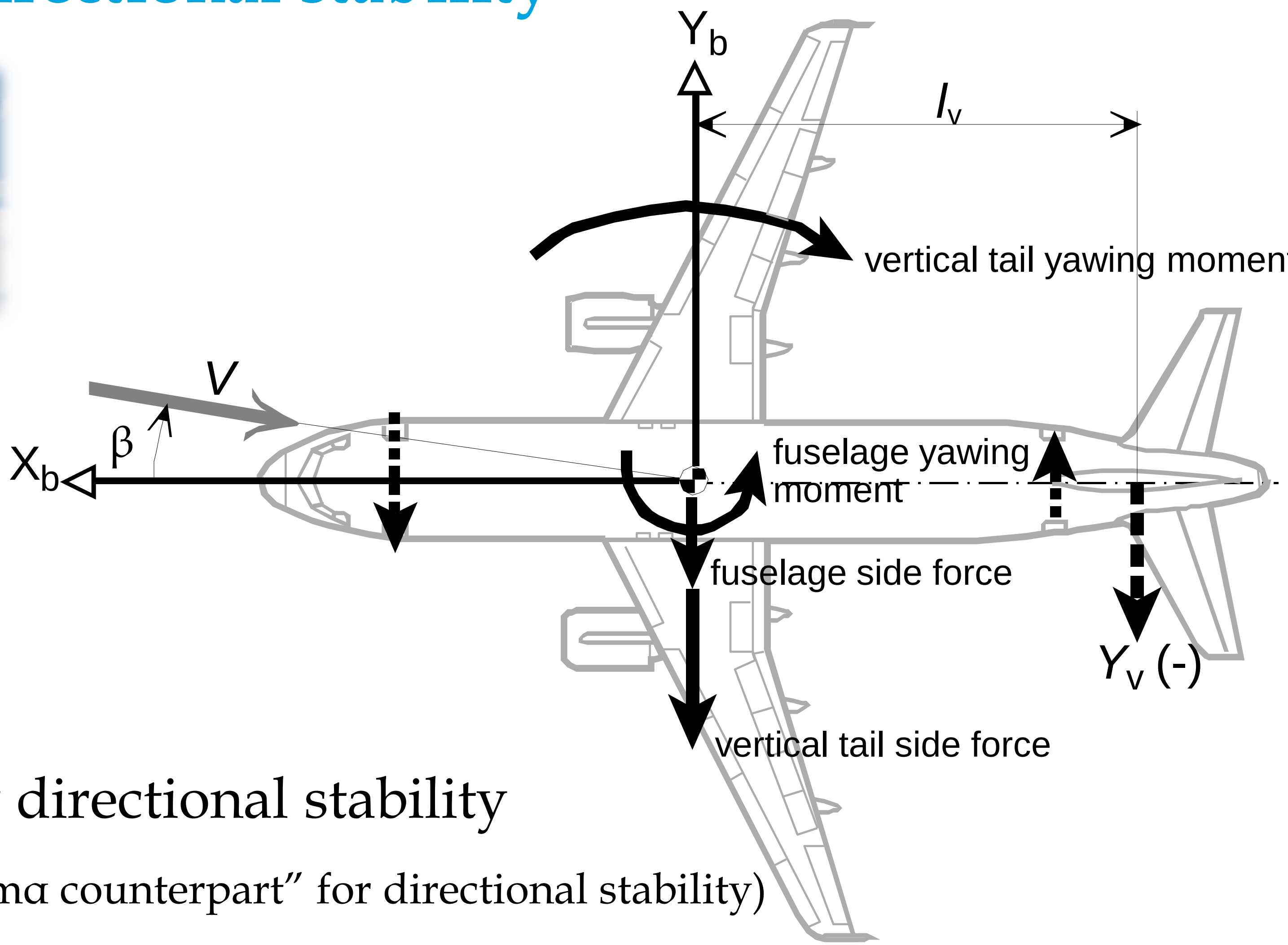
Definitions – moments and angular rates



body axis system, moments and rotational velocities

Directional stability

Weathercock stability



$Cn_\beta > 0$ for directional stability

(this is the "Cmα counterpart" for directional stability)

Lateral-Directional coupling

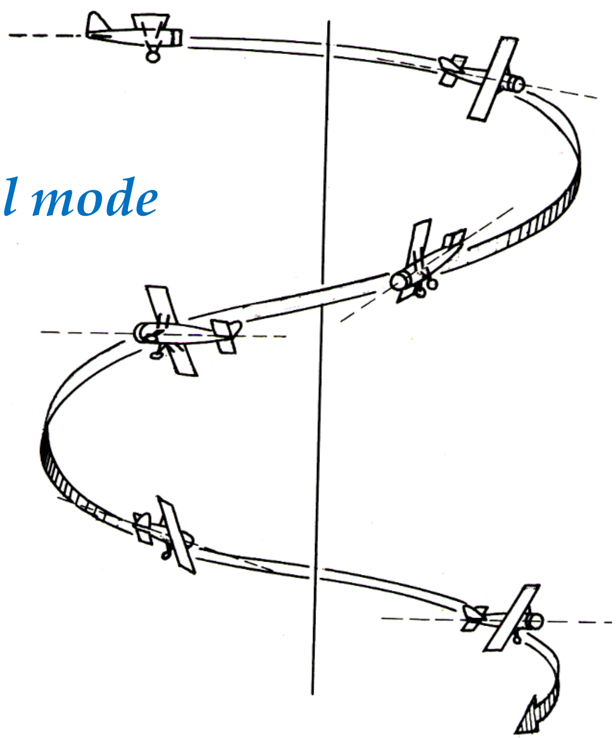
• The forces acting on the vertical tail also generate a rolling moment.
• When the aircraft is set a certain bank angle, it tends to “slip aside”, hence a sideslip angle is generated.
 the lateral and directional characteristics of an aircraft are coupled. It is not possible to consider one aspect without accounting for the other.

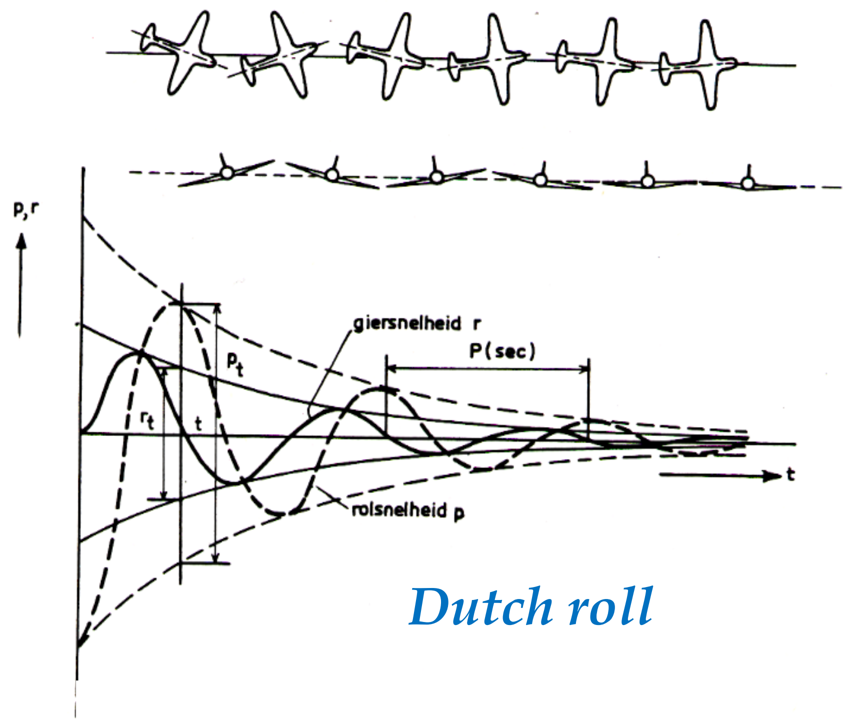
Long vertical tails increase the later-directional coupling.
• Multiple shorter fins could be convenient in this respect.
• Large aircraft with long vertical tail, use **split rudders**, where only the rudder segment next to the fuselage is used at high speed.

Directional stability

Directional (dynamic) stability is often the critical design case for aircraft with **fuselage-mounted engine(s)**, rather than directional control.
Two lateral/directional eigen-motions can be distinguished:

Spiral mode





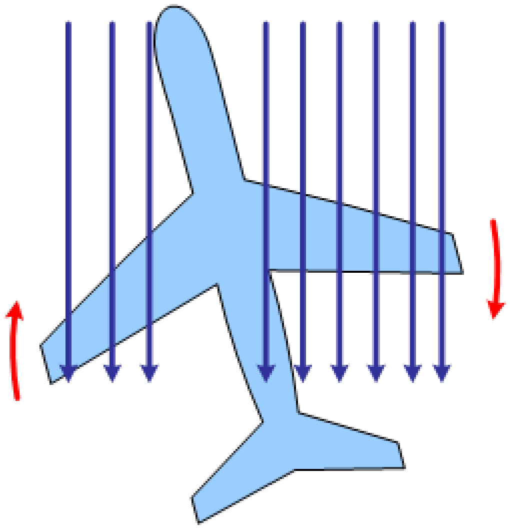
Dutch roll

Gerlach

Directional stability

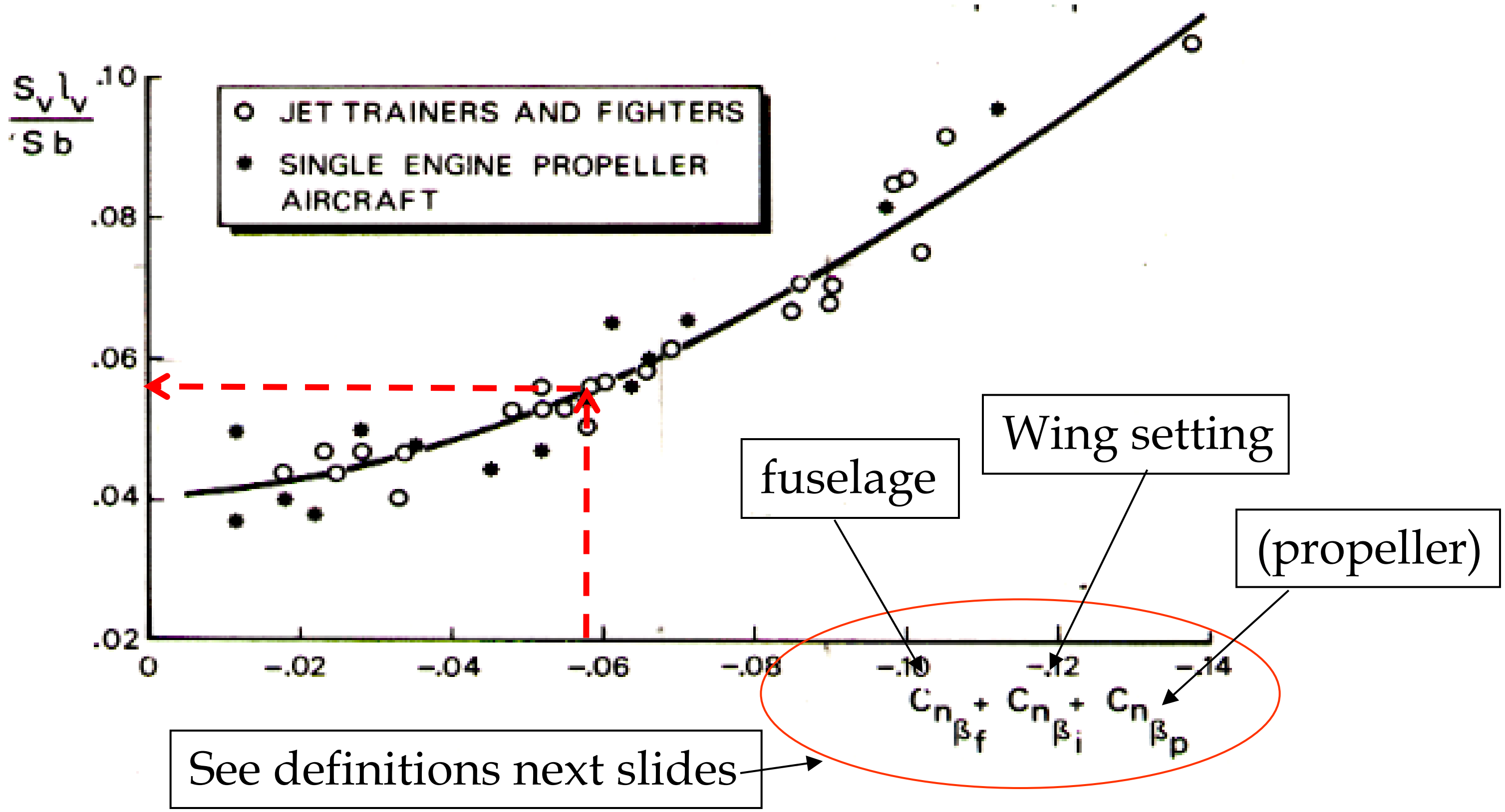
The term ***Dutch roll*** refers to a tendency for an aircraft to roll whenever there is yaw. It is a form of dynamic instability that exploits the a/c lateral-directional coupling.

Swept wing aircraft are particularly susceptible to Dutch Roll:



As the right wing moves forward (yaw), the sweep angle is lowered and lift increased. The aircraft will roll and then slip aside. At the same time the drag on the forward wing will increase, thereby yawing the forward wing back, hence starting the oscillations.

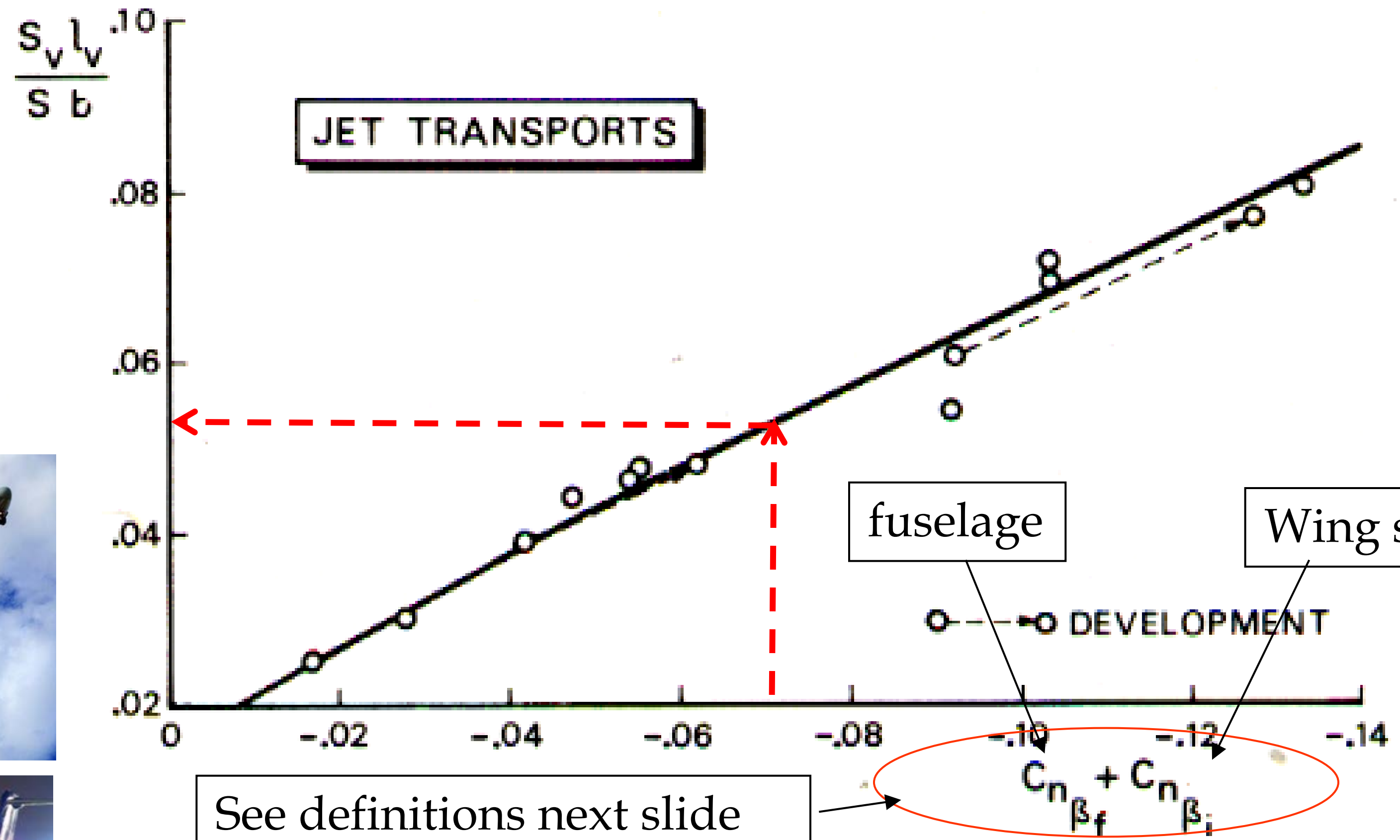
Fast vertical tail sizing for directional stability of fuselage mounted engines aircraft

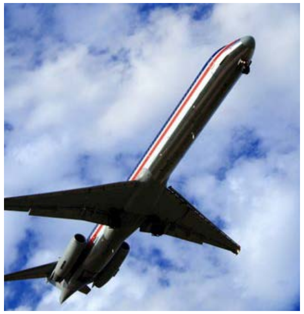


jet trainers and fighters, single engine propeller aircraft

Source Torenbeek

Fast vertical tail sizing for directional stability of <u>fuselage mounted</u> engines aircraft





See definitions next slide

large jet transports with fuselage-mounted engines

Source Torenbeek

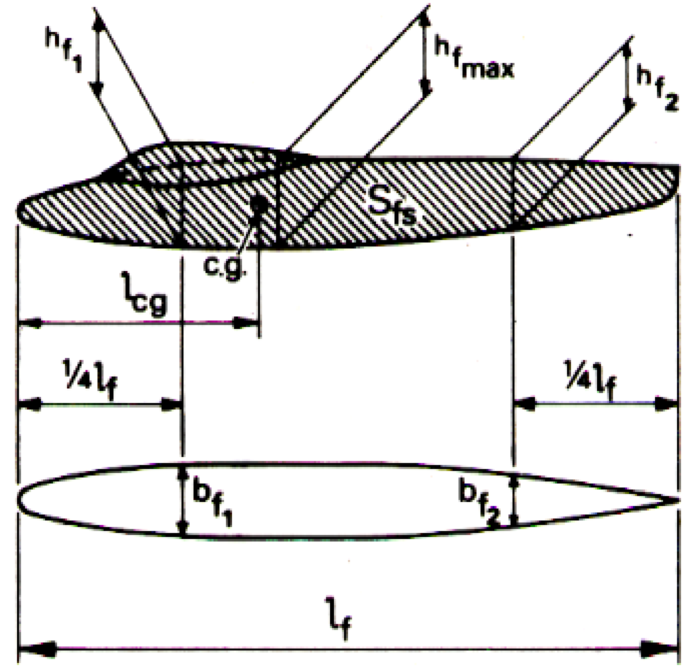
Directional stability - definitions

fuselage

$$C_{n_{\beta_f}} = -k_\beta \frac{S_{fs} l_f}{Sb} \left(\frac{h_{f_1}}{h_{f_2}} \right)^{1/2} \left(\frac{b_{f_2}}{b_{f_1}} \right)^{1/3}$$

where, for $l_f / h_{f_{max}} > 3.5$,

$$k_\beta = 0.3 \frac{l_{cg}}{l_f} + 0.75 \frac{h_{f_{max}}}{l_f} - 0.105$$



propeller

$$C_{n_{\beta_p}} = -0.053 \; B_p \sum \frac{l_p D_p^{\,2}}{Sb}$$

Wing setting

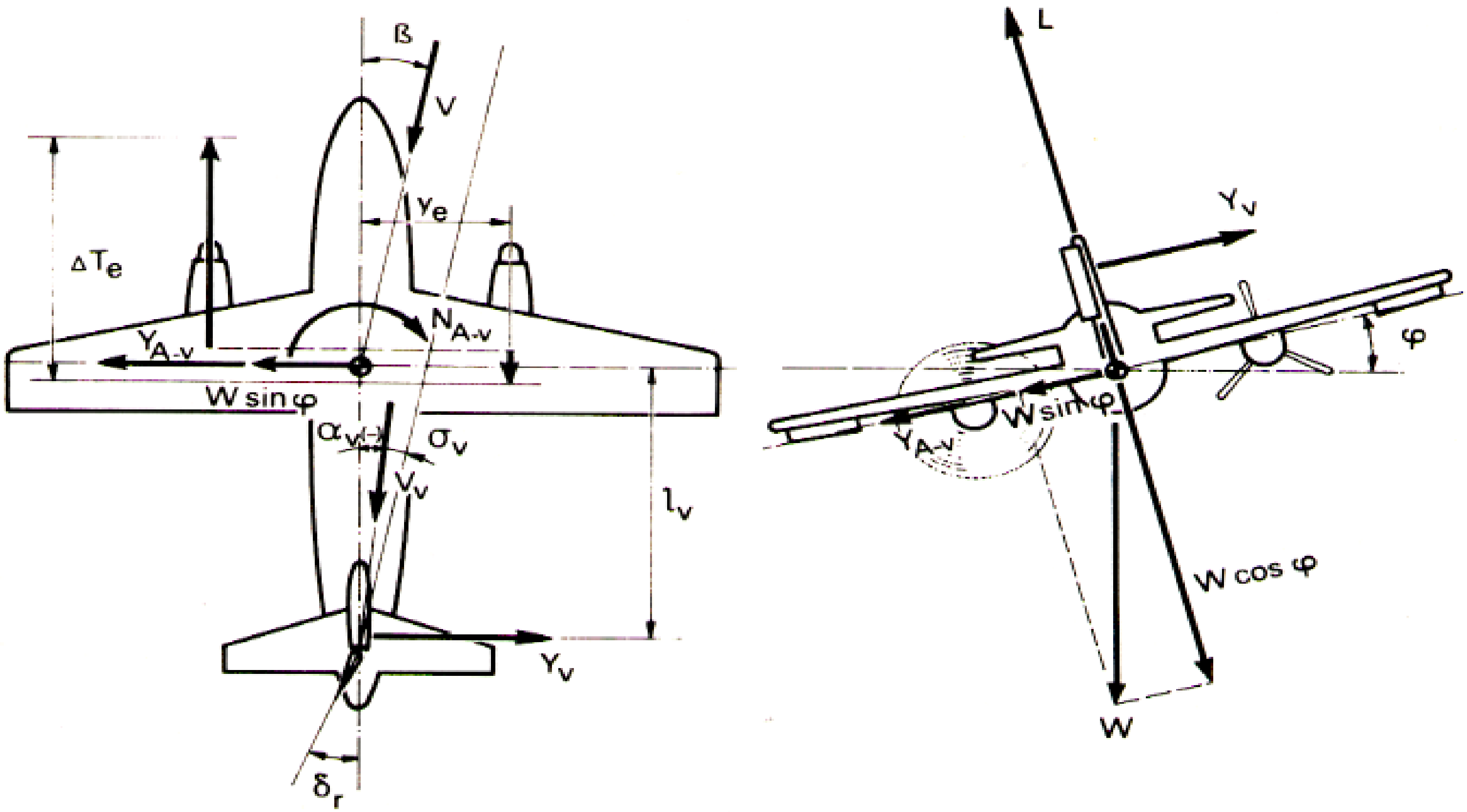
$$C_{n_{\beta_i}} =$$

-0.017, high wing
+0.012, mid wing
+0.024, low wing

Source Torenbeek

Directional control after engine failure

The critical design case for wing-mounted engines is **control** after engine failure at V_{MCA}.



Source Torenbeek

Directional control after engine failure

N-1 flight is a combination of slipping and banking

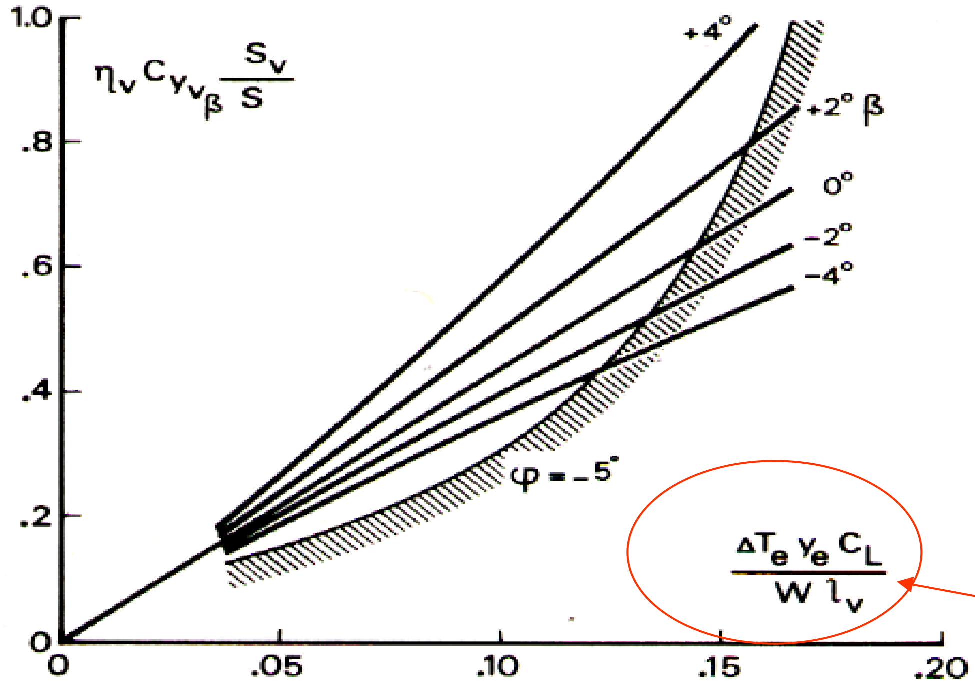


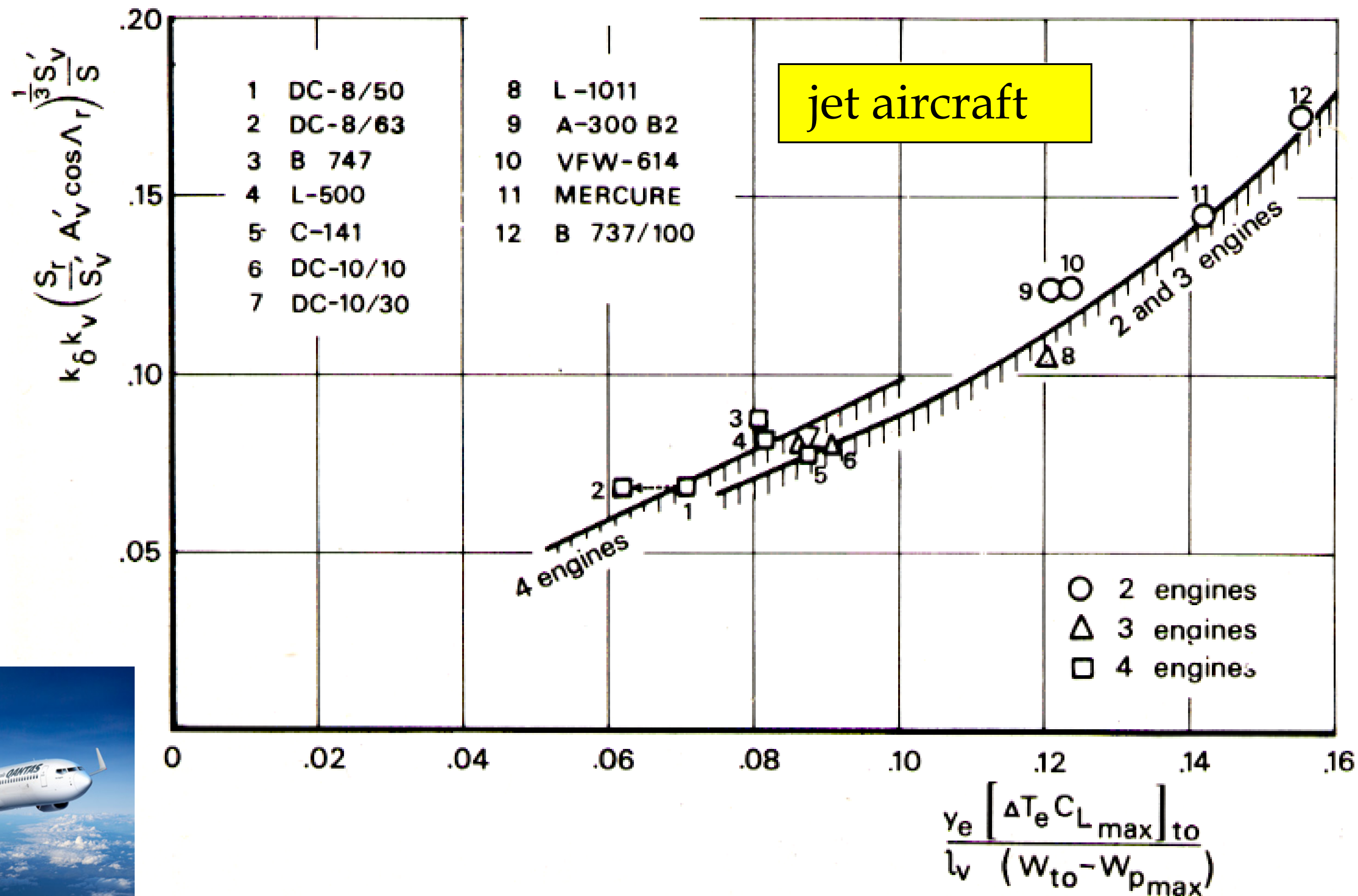
Fig. 9-22. Effect of sideslip on vertical tailplane area required to cope with engine failure

For a given thrust imbalance, different sideslip angles will require different vertical tail size and lift coefficients

Geometric definitions in previous slide

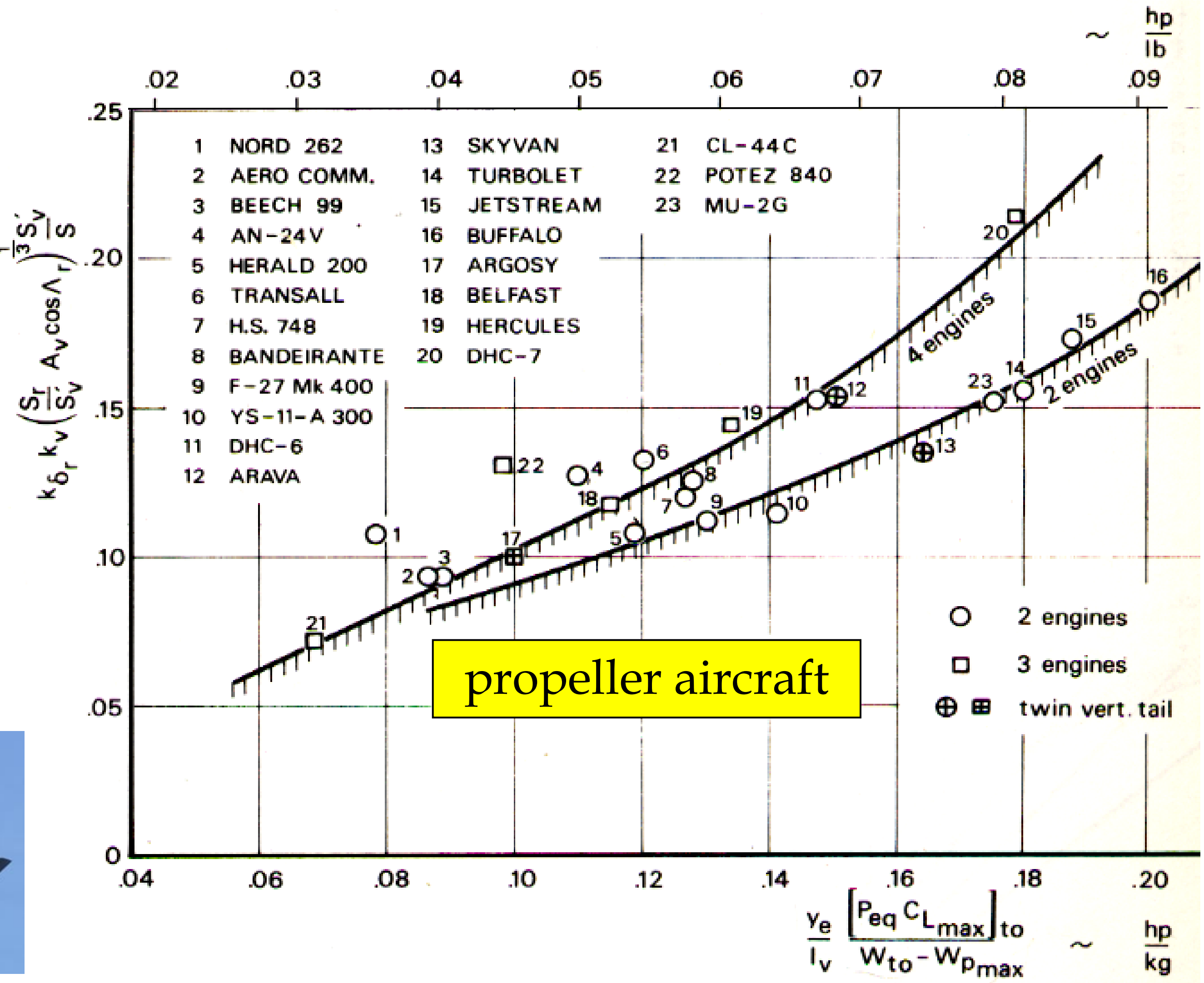
Synthesis

Fast Vertical tail sizing for <u>wing mounted</u> jet engines



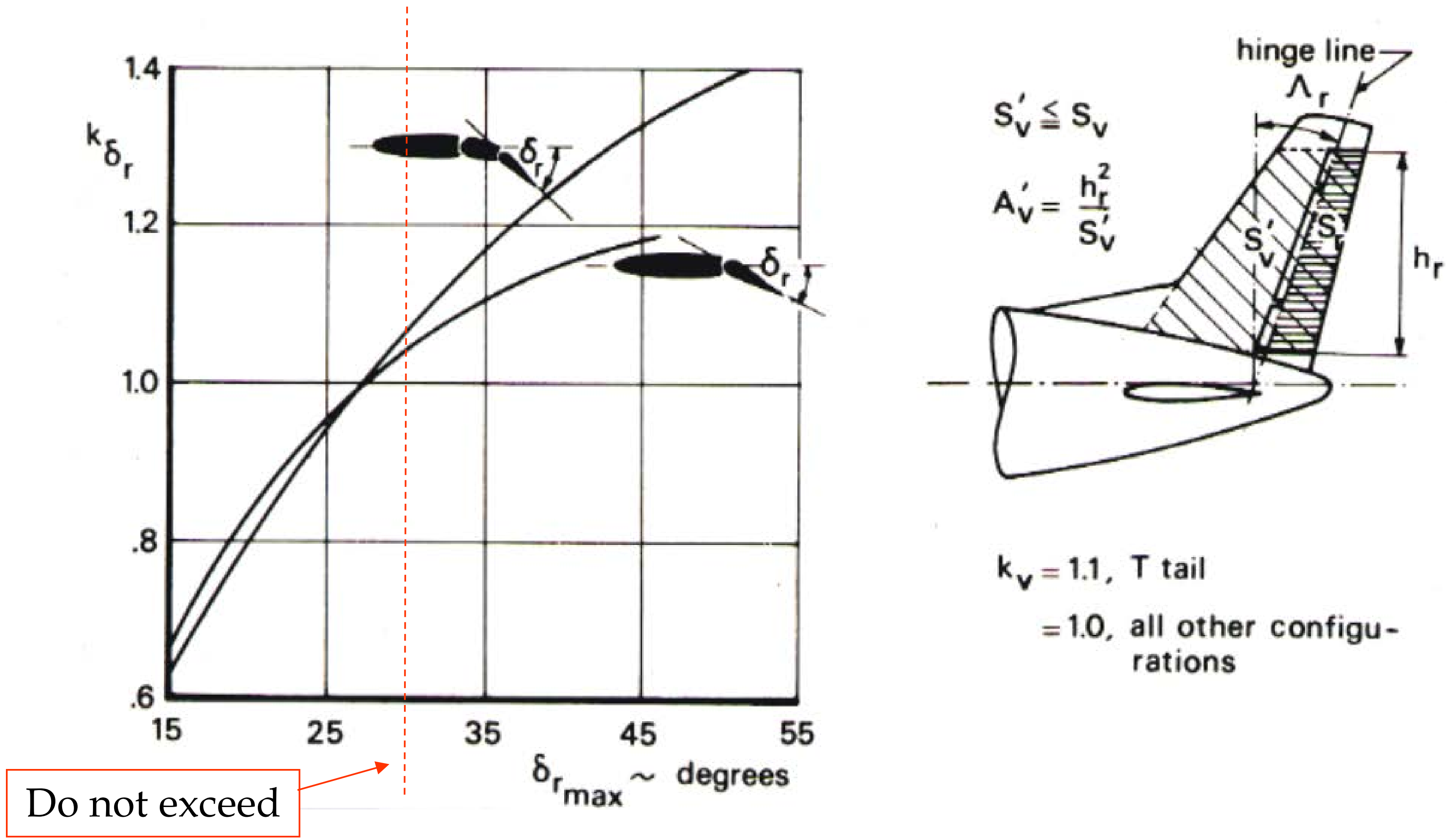
Synthesis Fig. 9-23

Fast Vertical tail sizing for wing mounted prop engines



Synthesis Fig. 9-23

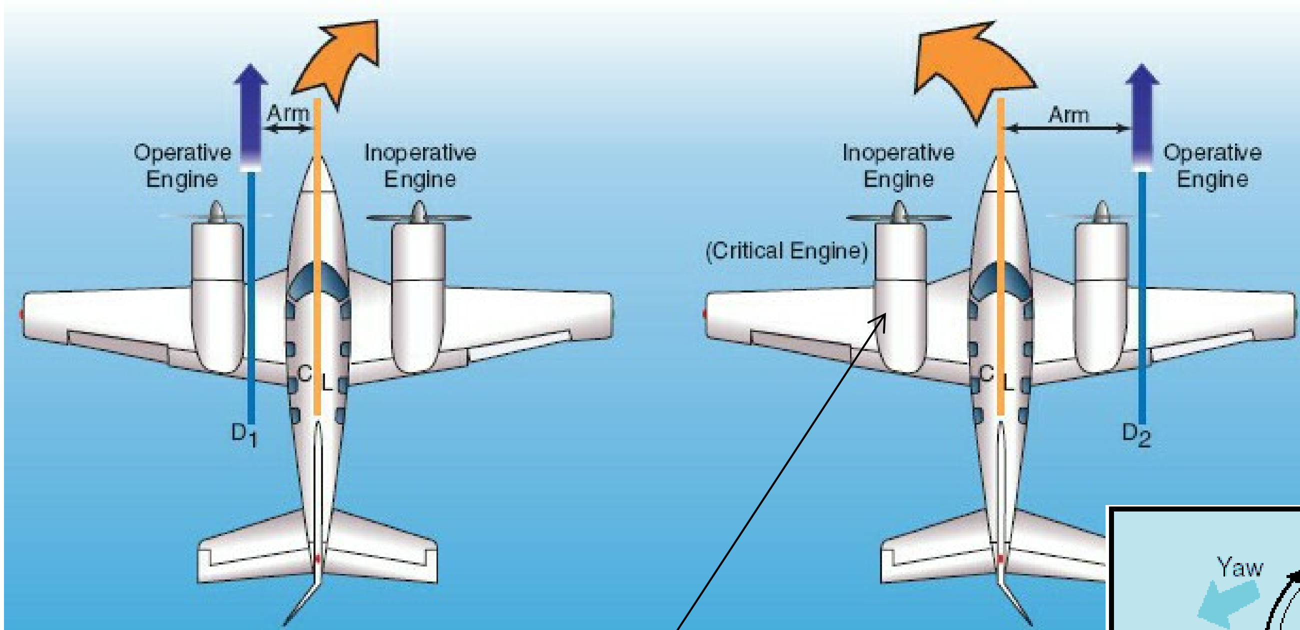
Directional control power



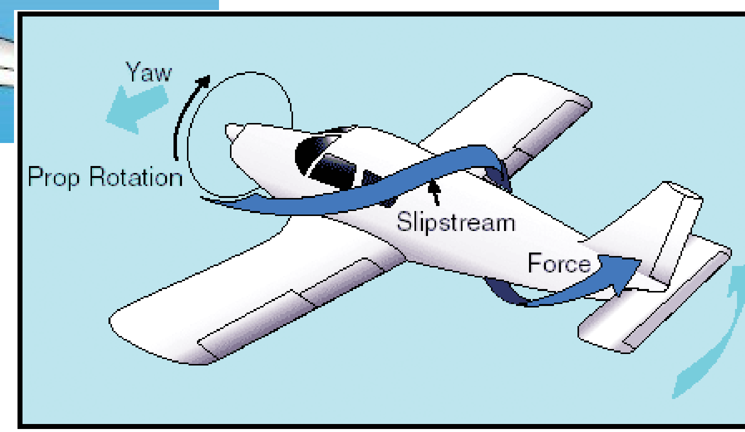
Synthesis Fig. 9-23

Propulsion effects - propellers

The P-factor and corkscrewing effect and the critical engine concept



Critical engine



In the examples all propellers rotating clockwise
(as seen by the pilot)

Source http://en.wikipedia.org/wiki/Critical_engi

Other requirements on directional control

- N-1 take-off (V_{MCG}) or crosswind landing is highly dynamic and in ground effect and cannot be dealt with analytically.
- The requirement for take-off is that the aircraft may not veer-off the centerline by more than 30 ft.
- For landing a demonstrated maximum crosswind capability is part of the certification and noted in the Airplane Flight Manual.

Synthesis Eq. 9-68

Vertical tail layout – spin resistance

For aerobatic and some utility a/c, sufficient spin resistance and recovery is required. Staggering the fin and stabilizer may help:

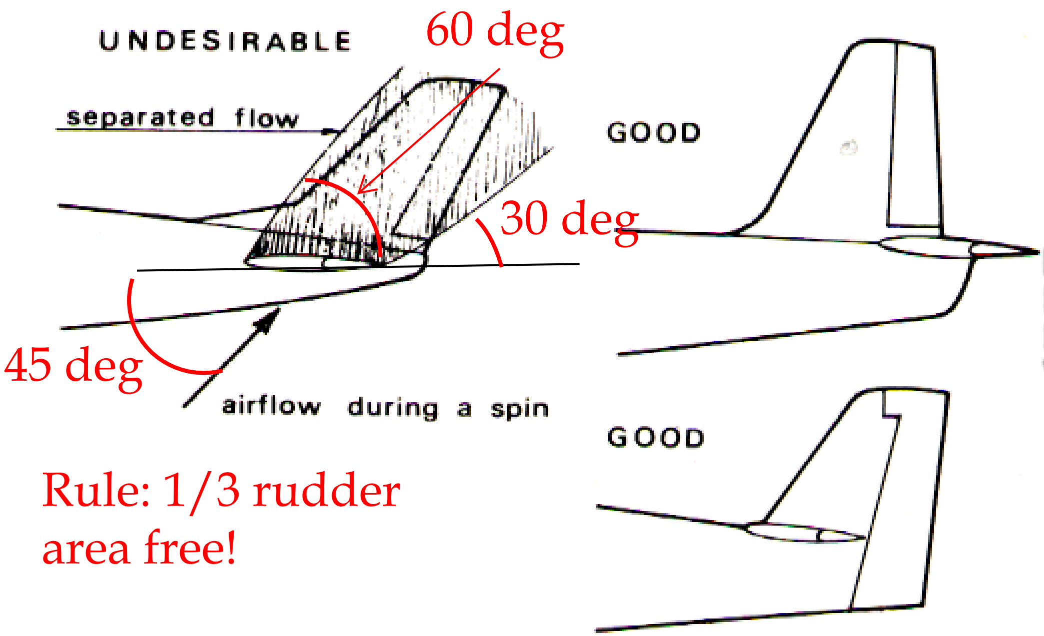
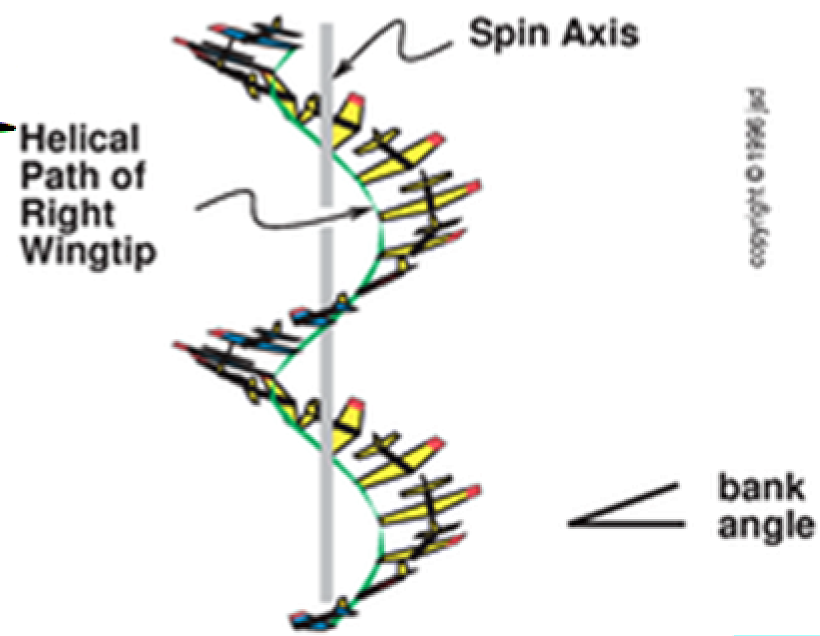


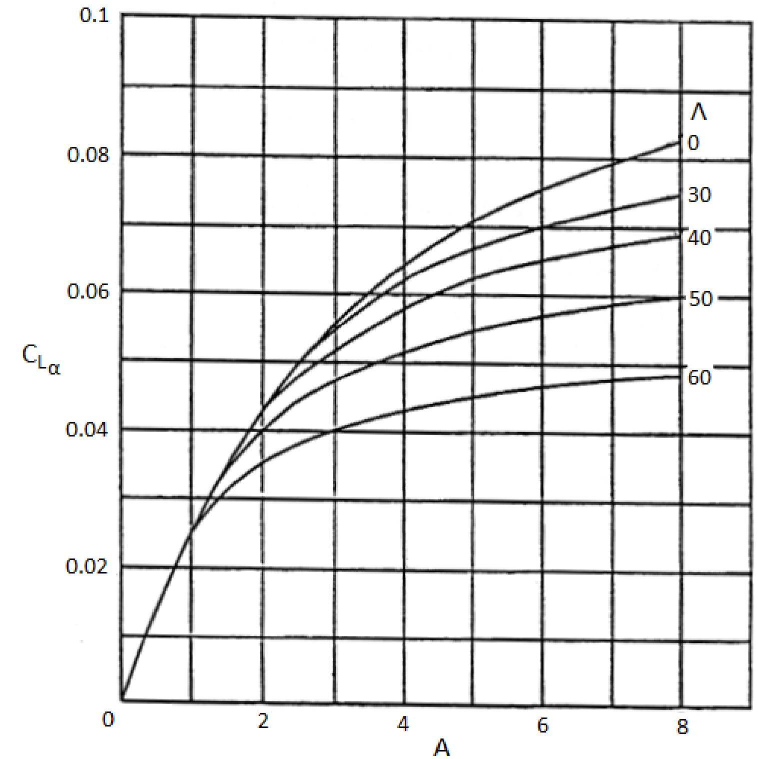
Fig. 2-27. Effectiveness of the rudder during a spin

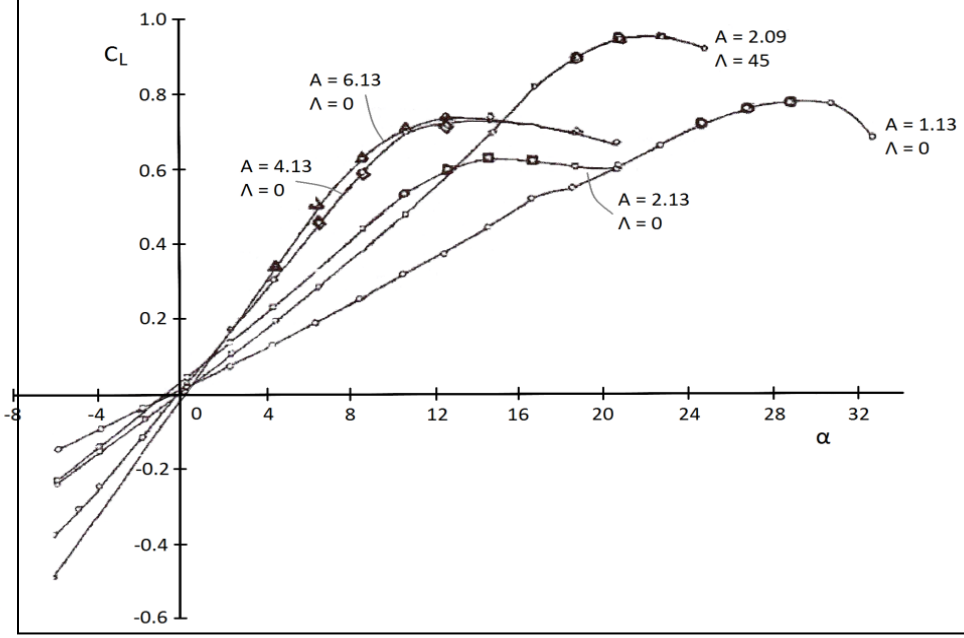


Sources pics Torenbeek and http://www.av8n.com/how/htm/spins.html#fig-steady-spi

Vertical tail design

- in order to cope with large slip angles (up to 25°) fins have
  - ✓ low aspect ratio's,
  - ✓ large leading edge sweep,
  - ✓ dorsal fins.
- For low aspect ratios sweep does not reduce the lift gradient
- For low aspect ratios lift depends not on area, but on (height)^2 only



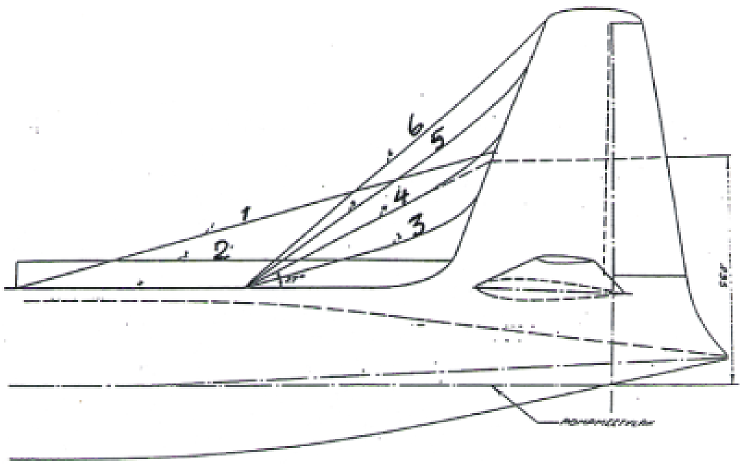


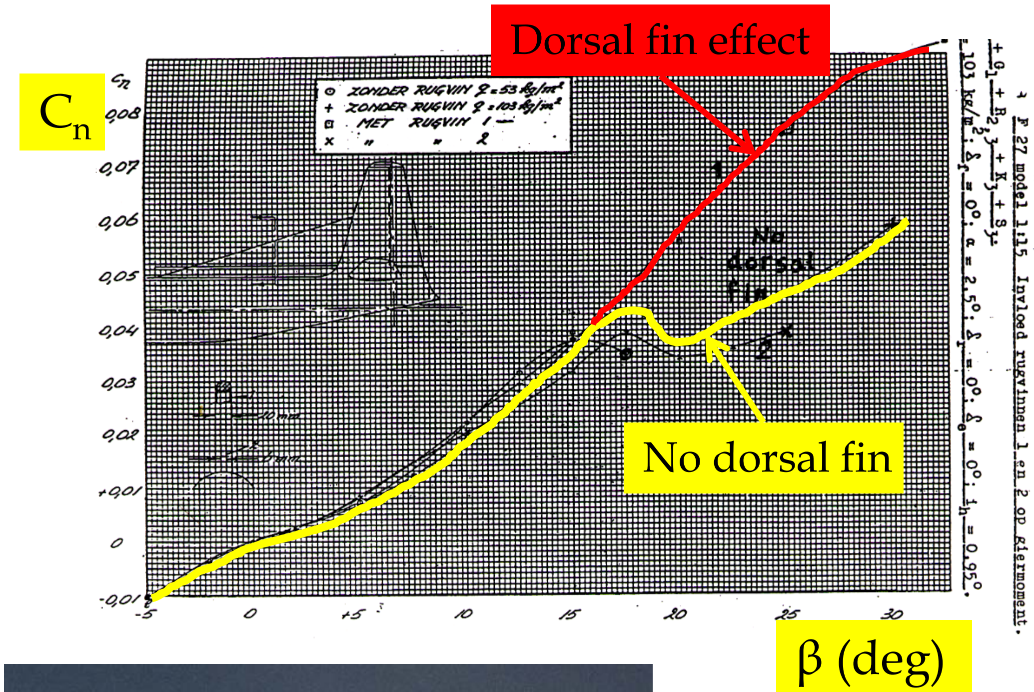
$$L = C_{L_\alpha}\alpha\frac{1}{2}\rho V^2 S = \frac{\pi A}{2}\alpha\frac{1}{2}\rho V^2 S =$$

$$= \frac{\pi}{2}\frac{b^2}{S}\alpha\frac{1}{2}\rho V^2 S = \frac{\pi}{2} b^2\alpha\frac{1}{2}\rho V^2$$

Vertical tail design

Dorsal fin effect on stall angle and maximum sideforce:





The dorsal fin exploits the same principle as the leading edge extensions (LEX) used on air superiority fighters to sustain high angles of attack

Vertical tail geometry

Swept vertical tail with dorsal fins on slow aircraft are not just a fancy look, but highly functional!

Vertical tail design parameters

Jet aircraft

- aspect ratio: 1.9 for low-set horizontal tails
  1.2 – 1.5 for T-tails
- taper ratio: 0.3 for low-set tailplanes
  0.6 – 0.8 for T-tails
- sweep: 35-45 degrees

Propeller aircraft

- aspect ratio: 1.6 – 1.8
- taper ratio: 0.3 for low-set horizontal tails
  0.5 – 0.7 for T-tails
- sweep: 25-45 degrees

Find plenty of vertical tailplane data (volume coefficient and other geometry parameters) in the document ONLINE horizontal and vertical tail combined

The design of the V tail (butterfly tail)

V-tail configuration aircraft

Beech Bonanza


Fouga magister


Predator


Eclipse 400

Cirrus jet

Why or why not a V-tail configuration?

The **V-tail** (or butterfly tail) presents a number of advantages and disadvantages when compared to conventional design.

Advantages:

• lighter design due to the reduced amount of parts and components (□lower inertia loads on the tail boom at landing)

• Almost same wetted surface but less aerodynamic drag, because of the less interference between empennages and fuselage. Also better span loading due to longer span of the empennages

• Less risk of debris impact while rolling on the ground

• less engines exhaust and wing downwash impingement

Disadvantages:

• More complex system to decouple the lateral and longitudinal control

• Higher torsion loads on fuselage than a conventional tail to generate the same lateral or vertical force

• Adverse yaw-roll coupling when correcting for sideslip angles (no problem for inverted V-tail)

V-tail configuration sizing

In order to size a V-tail it is sufficient to compute the required horizontal and vertical tail surface as for a conventional tail.
In order to guarantee the same stability and control authority* the total surface of the V-tail will have to be equal to the sum of the horizontal (Sh) and vertical (Sv) surface computed for a conventional surface ($S_{VT-TOTAL}=S_h+S_v$).
Hence the surface S_{VT} of each one of the two empennages is simply obtained as follow:

$$S_{VT}=0.5(S_h+S_v)$$

$$\text{Tail-dihedral}=\text{atan}(S_v/S_h)*180/\pi$$

Definition of the V-tail dihedral angle**

IL Progetto del Piano Verticale

1) INDIVIDUARE LE INCOGNITE

2) VALUTARE LE CONDIZIONI di Progetto

Incognite di progetto 1

1) b_v apertura del piano dalla linea di riferimento

2) c_{root} corda di radice del piano

3) c_{tip} corda di estremità del piano (o rapp. di rastremaz.)

4) Λ_v angolo di freccia del piano

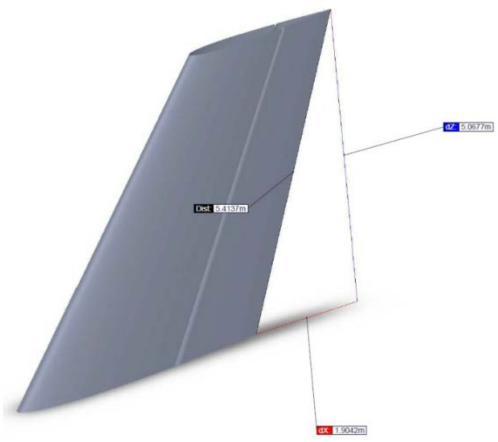
5) profilo

6) i_v angolo calettamento del piano (≠ 0 per monom. elica)

si può usare anche aletta

7) N° delle derive

Questi parametri definiscono la FORMA IN PIANTA

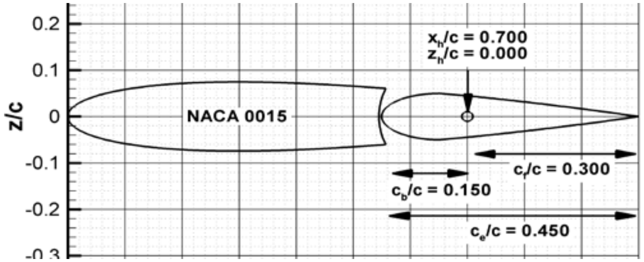


Incognite di progetto 2

8) cr/c (oppure **cf/c)**

9) cb/c bilanciamento

10) $\boldsymbol{\delta_r}$ deflessioni p. mobile(+-25° o 30°)



11) $\mathbf{G_{trasm}} = \boldsymbol{\Delta_{\delta\_trasm}}$ **/ Δdef_piano**

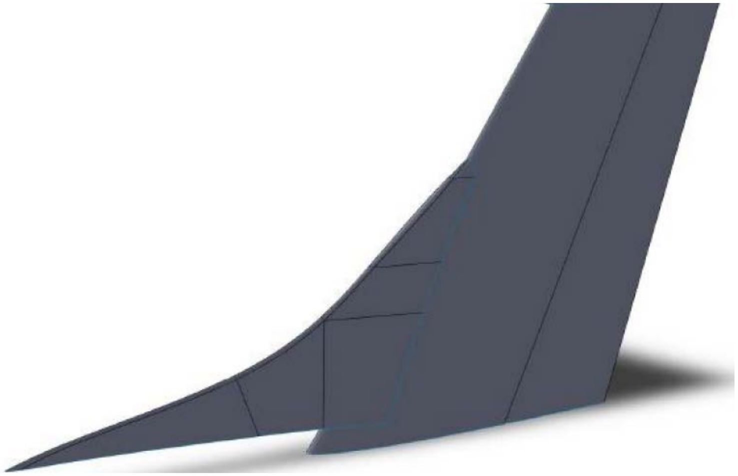
12) Posizione (Xacv, Zacv)

13) TAB
- **Trim(solitamente)**
- **Anti-tab**

14) Estensione TAB

15) Deflessione TAB

16) Dorsal fin (presente o meno)



Definita
GEOMETRIA - CONTROLLO

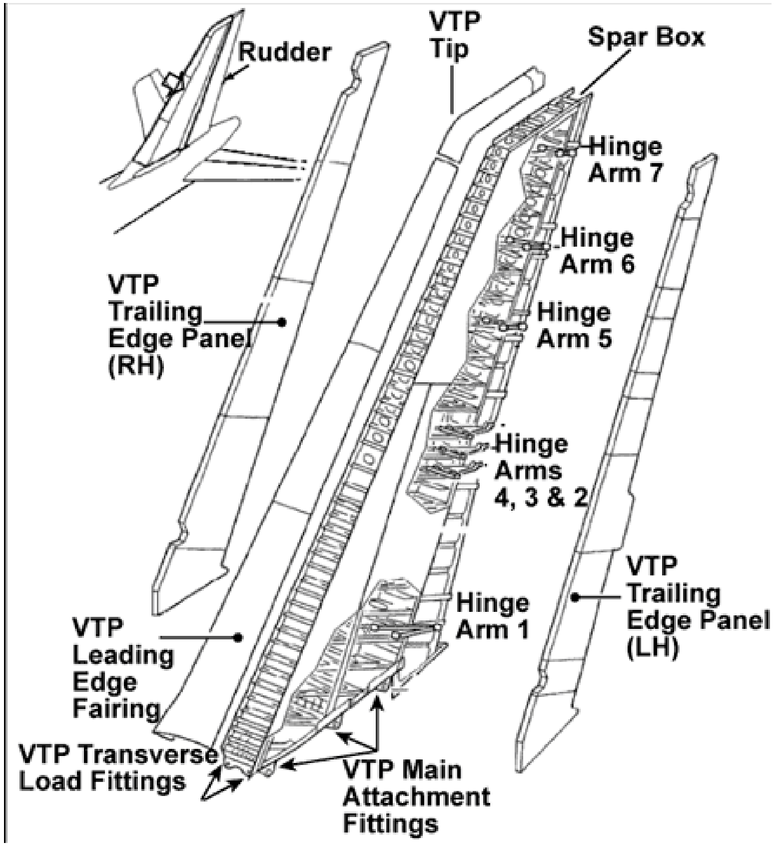
Incognite di progetto 3

17) Materiale costruzione

18) Posizione longheroni(struttura)

19) Costi

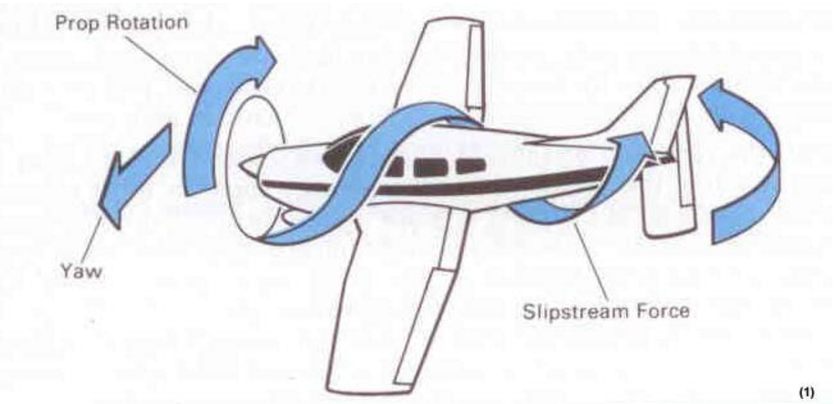
20) DOC incidenza



Progetto completo

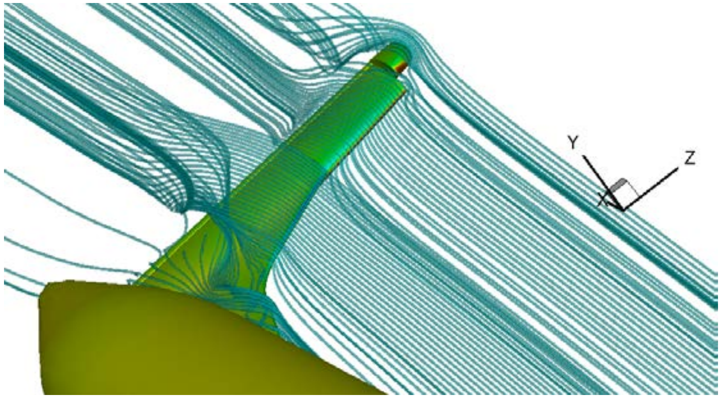
Note

- iv: si inserisce per monomotori ad elica a causa del fenomeno “slipstream”- aletta

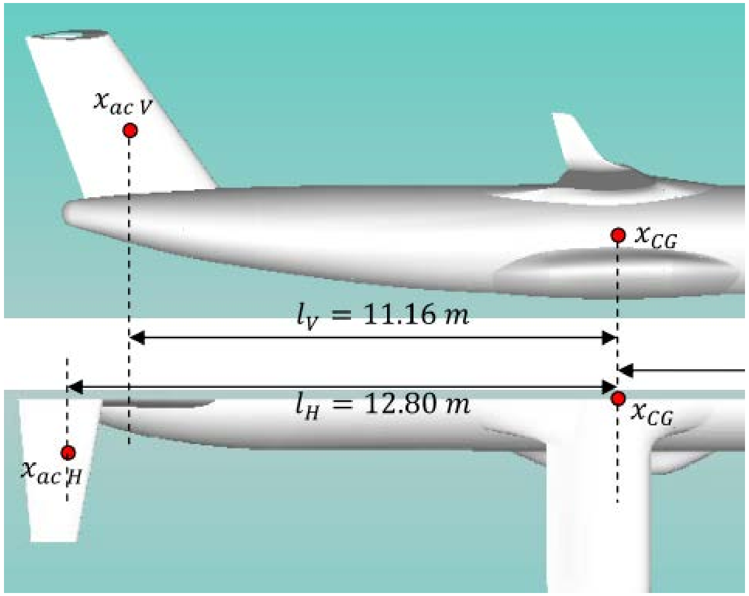


- La dorsal fin è introdotta per

1) aumentare stabilità
2) beta di stallo
3) prevenire rudder lock



Incognite principali



- Sv
- bv

ARtail

- cr/c →Sr/Sv
- δr

Condizioni di progetto

Condizioni di VOLO critiche in cui i valori di una o più incognite sono massime(critiche per il progetto)

CONDIZIONI DI EQUILIBRIO

CONDIZIONI DI NON EQUILIBRIO(Manovra)

SFORZI

Condizioni di progetto

- **Condizioni di equilibrio**
  - Decollo(VMC) E **PIANTATA MOTORE**
  - Atterraggio
  - Crociera
  - Stallo (raggiungimento dello stallo)
  - Rollio (prestazione di rollio)
  - Sforzi pedaliera

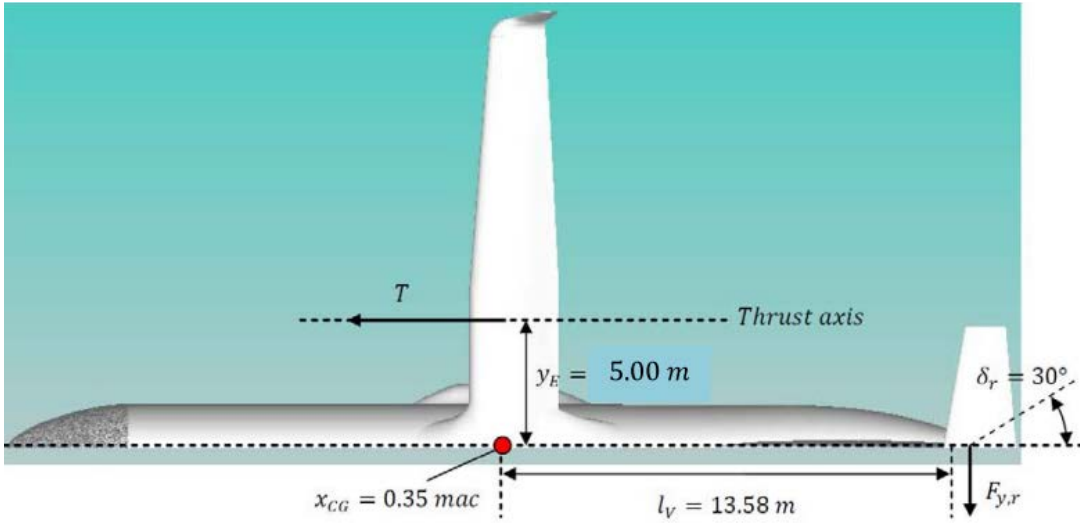
Per tutte le fasi bisognerebbe valutare se con delta rudder max si riescano ad equilibrare 20° di derapata

- **Vite (monomotori)**

Decollo

- Verificare alla VMC la **Piantata Motore Critico (spinta a max TO)**
  - **- CD0 è maggiore in questa condizione**

La VMC è regolamentata. Non è unica, esiste quella in volo, al suolo ecc.

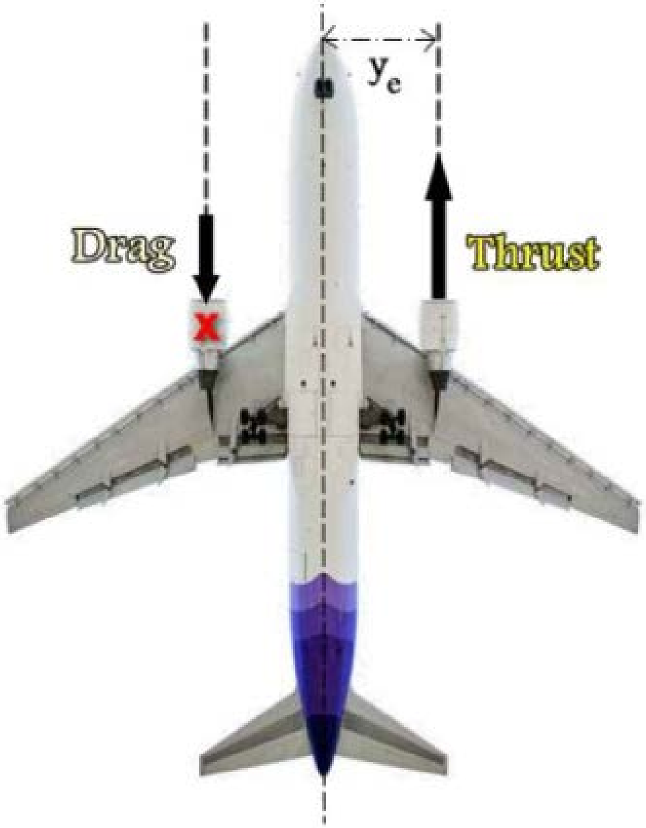


Atterraggio

- **Verificare se con delta rudder max si riescano ad equilibrare alti(20°) angoli di derapata**

  – Critico il baricentro max. arretrato
  – Critico motore in avaria(in atterraggio è meno gravoso)
  – L'efficacia della parte mobile τ si abbassa ad alti angoli di deflessione del rudder (passa da 0.6/0.5 a 0.4/0.3)

Esempio – Decollo con piantata motore



$$T = \left(1 - 2 \cdot 10^{-3} \cdot V_\infty\right) \cdot \frac{T_{0\_TOTALE}}{2}$$

$$T = \left(1 - 2 \cdot 10^{-3} \cdot V_\infty\right) \cdot \frac{22700 \cdot 9.81}{2} = 111344 - 222.7 \cdot V_\infty$$

$$M_T = T \cdot y_e = 629094 - 1258 \cdot V_\infty \qquad (\mathrm{N} \cdot \mathrm{m})$$

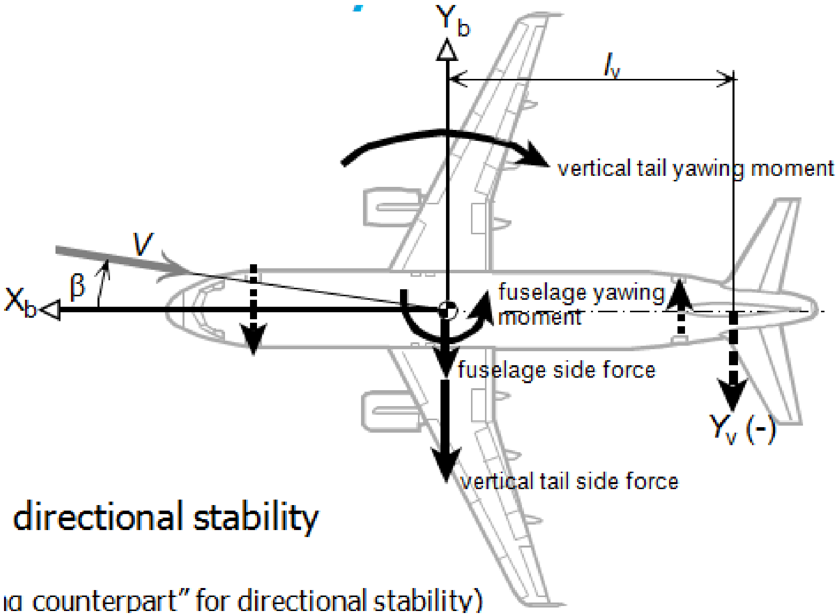
$$V_{S-TO} = \sqrt{\frac{2 \cdot W}{\rho \cdot S_w \cdot C_{L\max -TO}}}$$

$$V_{S-TO} = \sqrt{\frac{2 \cdot 74000 \cdot 9.81}{1.225 \cdot 124 \cdot 2.1}} = 67.5 m/s$$

$$V_{mc} = 1.1 \cdot V_{S-TO} = 74.2 m/s$$

Esempio – Decollo con piantata motore

$$M_v = Y_v \cdot l_v = C_{Yv} \cdot q_v \cdot S_v \cdot l_v = a_v \cdot \tau_v \cdot \delta_r \cdot \eta_v \boxed{\cdot q_\infty \cdot S_v} \cdot l_v$$



$$C_{L\alpha} = \frac{1}{57.3} \cdot \frac{C_{l\alpha} \cos\Lambda}{\sqrt{1 - M^2 + \left[\frac{C_{l\alpha} \cos\Lambda}{\pi \cdot AR_{eff}}\right]^2} + \frac{C_{l\alpha} \cos\Lambda}{\pi \cdot AR_{eff}}}$$

$$AR_{eff.} = AR_{geom.} \cdot Avf/Av[1 + K_{VH}(Avfh/Av - 1)]$$

$$M_v = a_v \cdot \tau_v \cdot \delta_r \cdot \eta_v \cdot q_\infty \cdot S_v \cdot l_v$$

$$M_v = 2.808 \cdot 0.36 \cdot (25/57.3) \cdot 0.950 \cdot \frac{1}{2} \cdot 1.225 \cdot V_\infty^2 \cdot S_v \cdot 18.1$$

$$M_v = 4.645 \cdot V_\infty^2 \cdot S_v$$

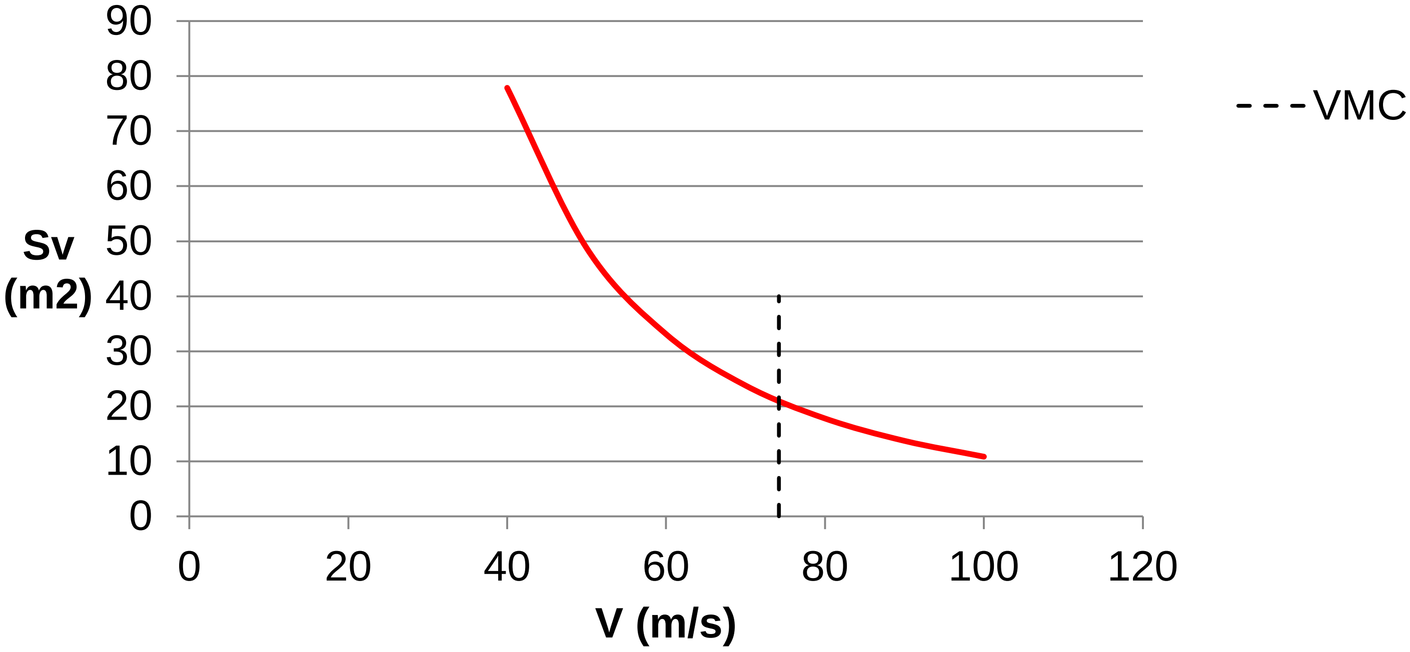
$$M_v = M_T$$

$$4.645 \cdot V_\infty^2 \cdot S_v = 629094 - 1258 \cdot V_\infty$$

$$S_v = \frac{629094 - 1258 \cdot V_\infty}{4.645 \cdot V_\infty^2}$$

Equilibrio all'imbardata – scelta dimensione PV in base alla VMC

$$M_v = M_T \qquad\qquad S_v = \frac{629094 - 1258 \cdot V_\infty}{4.645 \cdot V_\infty^2}$$

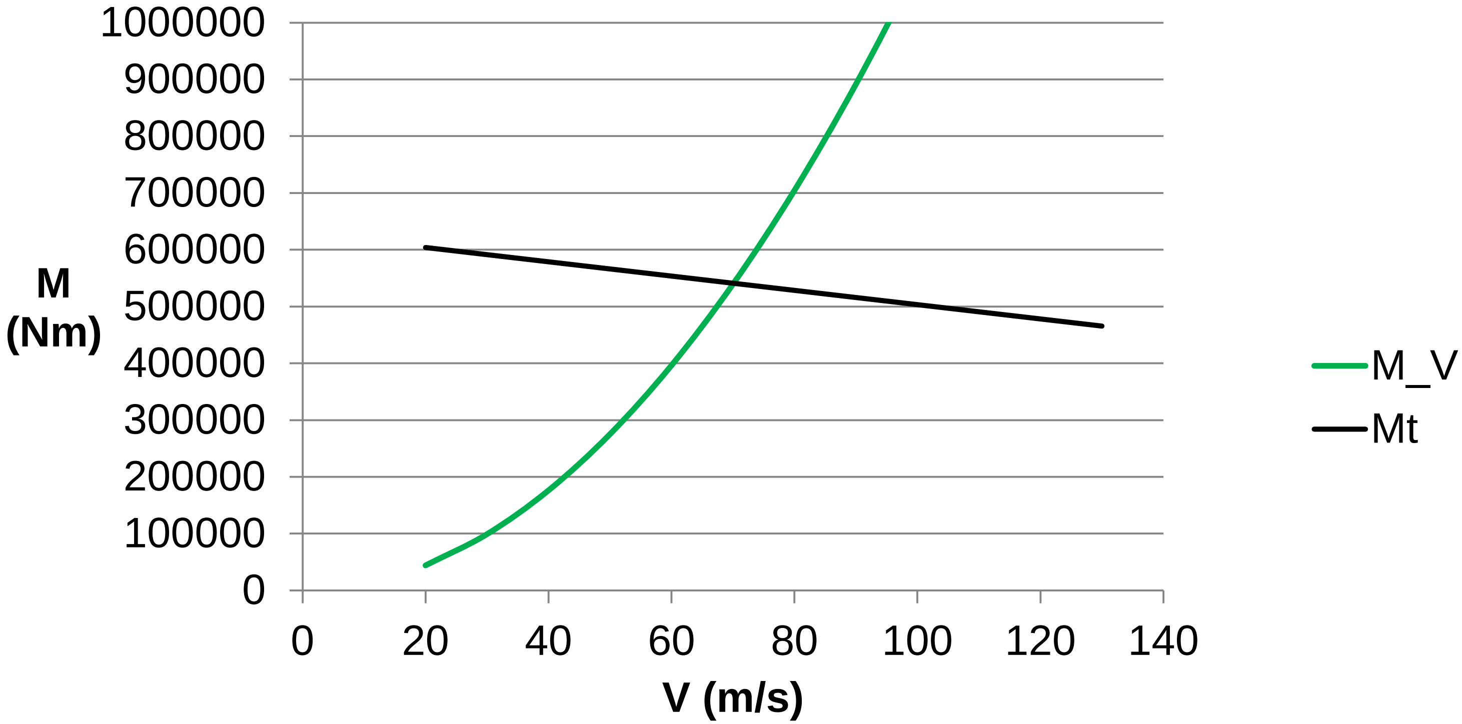


Esempio – Decollo con piantata motore

Per una data Sv si ha equilibrio ad una V

$$M_v = M_T$$

$$4.645 \cdot V_\infty^2 \cdot S_v = 629094 - 1258 \cdot V_\infty$$



Verifica alla raffica

$$CN = CN\beta \cdot \beta + CN\delta r \cdot \delta r = 0$$

$$C_{n\beta} = C_{n\beta\_v} + C_{n\beta\_fus} + C_{n\beta\_w}$$

$$\boxed{C_{n\beta\_v} = -k_v a_v \cdot \left(1 + \frac{d\sigma}{d\beta}\right) \cdot \eta_v \cdot \frac{S_v}{S_w} \cdot \frac{l_v}{b_w} = -k_v a_v \cdot \left(1 + \frac{d\sigma}{d\beta}\right) \cdot \eta_v \cdot V_V}$$

$$\boxed{C_{N_{\delta_r}} = -a_v \cdot \tau_v \cdot \eta_v \cdot \frac{l_v S_V}{Sb} = -a_v \cdot \tau_v \cdot \eta_v \cdot V_v = 0.001419 \quad 1/\deg}$$

$$\delta r = -\frac{C_{N_\beta} \cdot \beta}{C_{N_{\delta r}}} \qquad \beta max = -\frac{C_{N_{\delta r}}\delta r}{C_{N_\beta}}$$