Aircraft Design I
Loads
Flight (Loads) envelope

Aircraft loads

- What is the source of loads?
- How to compute this ?
- What values are critical?
- What we have to do, when critical case is difficult to compute?

Load factor

$$n = \frac{P_z}{Q} = \frac{L}{W}$$

Load factor what is the value?

straight level flight $Pz = Q$, thus $n=1$

turn
$$n = \sqrt{\left(\frac{\Omega V}{g}\right)^2 + 1}$$

regular turn
$$n = \sqrt{\frac{q\pi Ae}{W/S}\left(\left(\frac{T}{W}\right)_{\max} - \frac{qC_{D0}}{W/S}\right)}$$

max. lift coefficient $C_{L,max}$
$$n = \frac{\rho V^2 S C_{L\max}}{2W}$$

What is in the regulations?

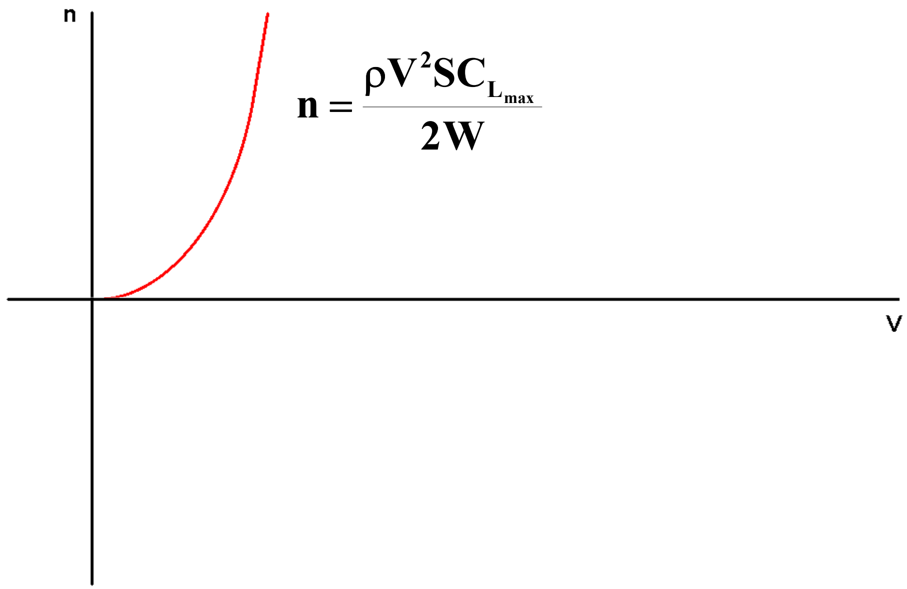
There are two groups of loads:

- control,
- gust.

Regulations require to compute the flight envelope n(V)

Control loads

Control loads



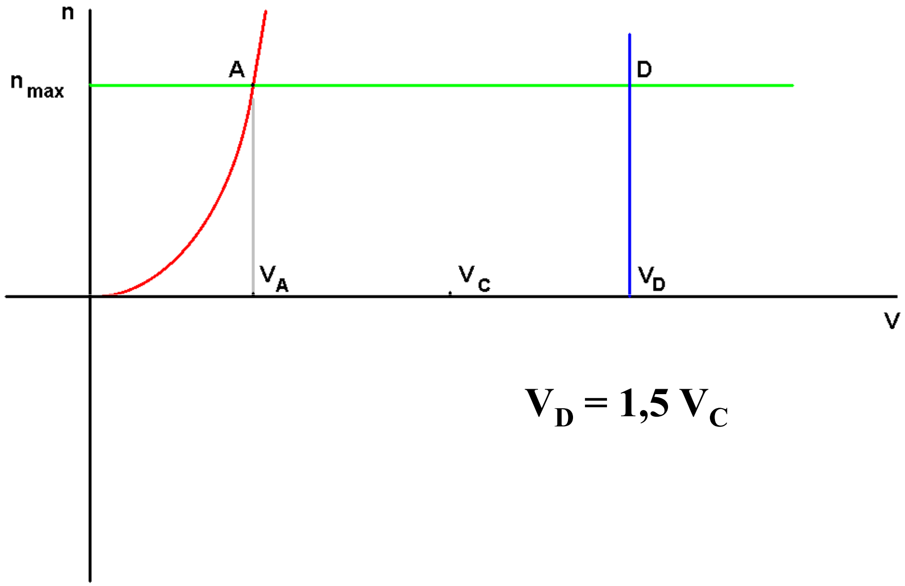
$$n = \frac{\rho V^2 S C_{L_{max}}}{2W}$$

Control loads

Standard Airworthiness Certification Regulations

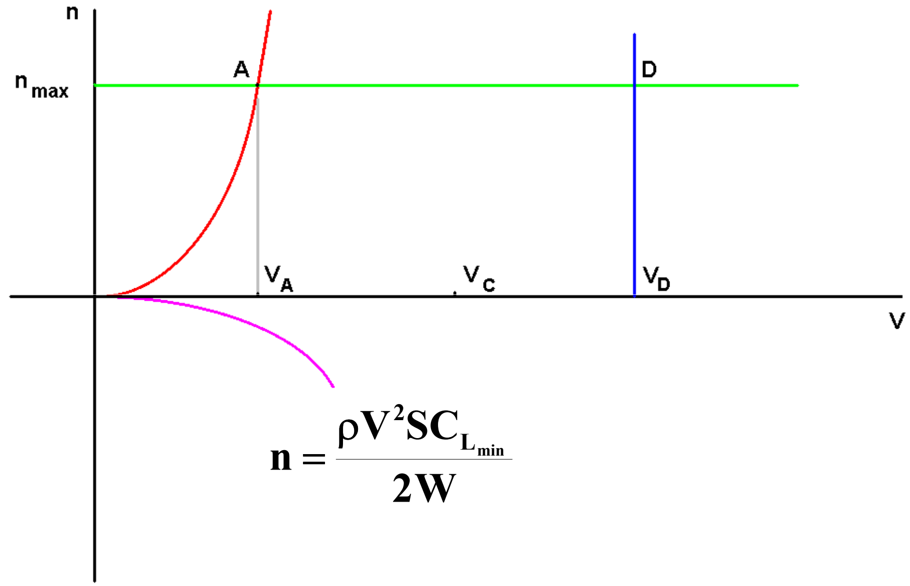
FAR 23
FAR 25
JAR 22
JAR-VLA

Control loads



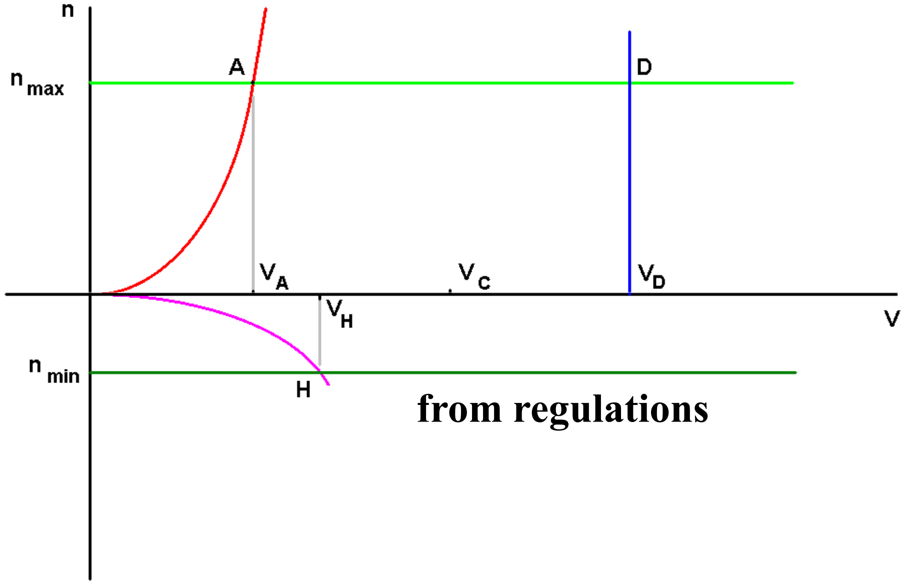
$$V_D = 1{,}5\ V_C$$

Control loads



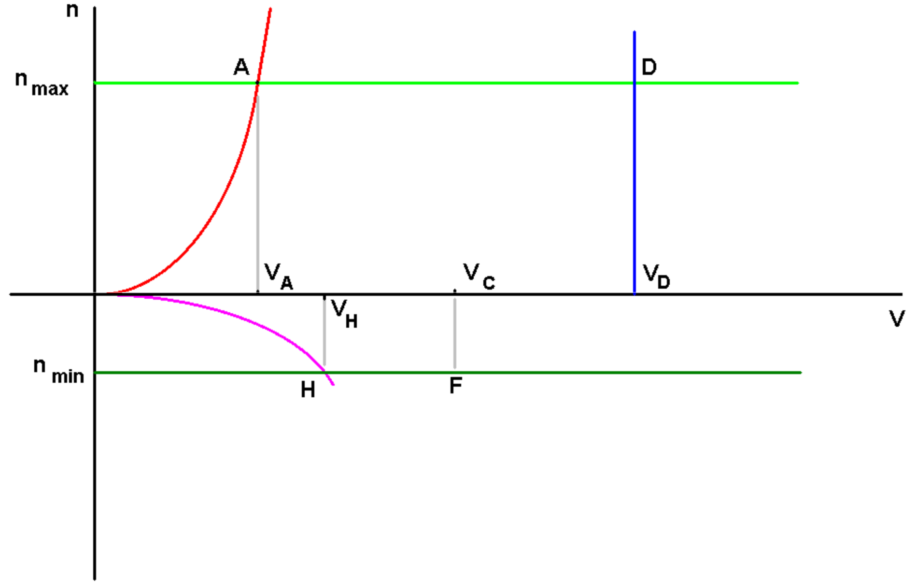
$$n = \frac{\rho V^2 S C_{L_{min}}}{2W}$$

Control loads

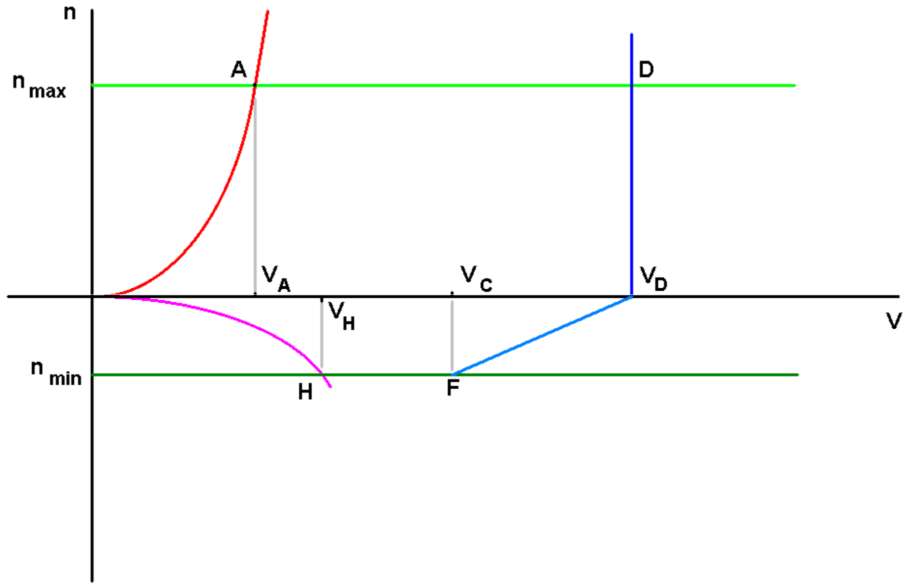


from regulations

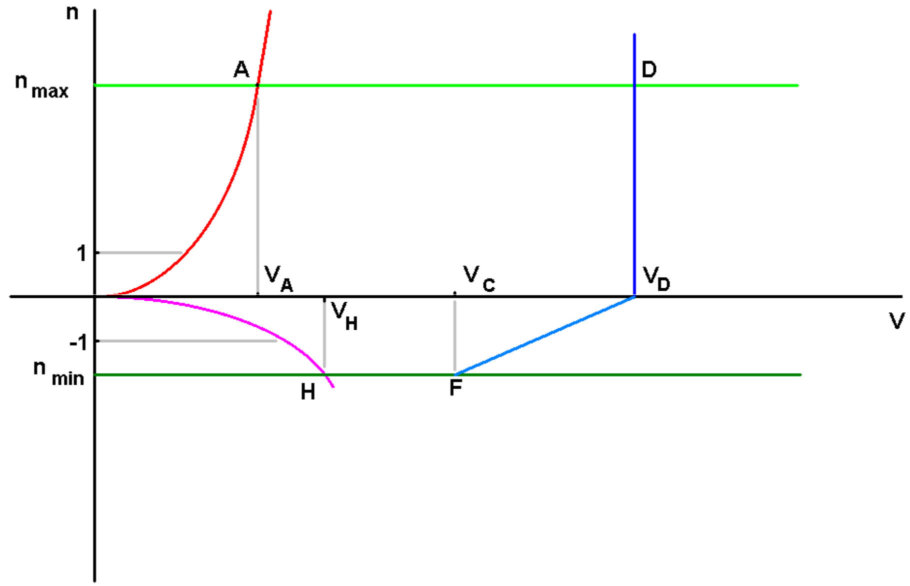
Control loads



Control loads



Control loads



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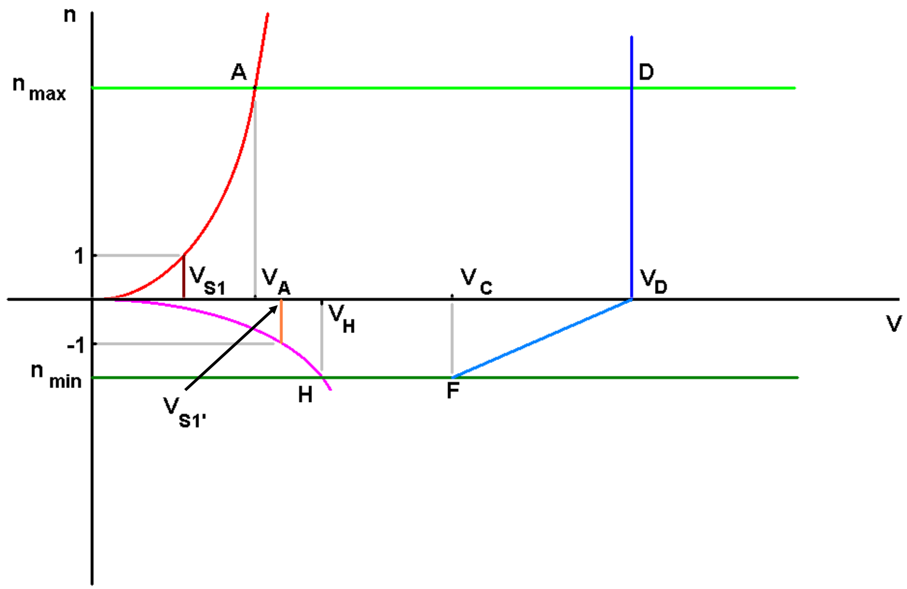
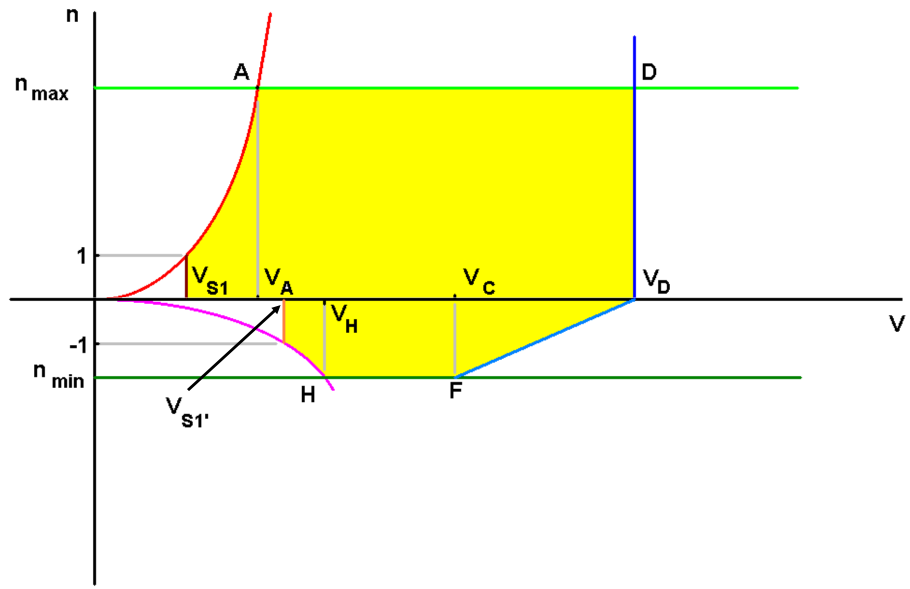
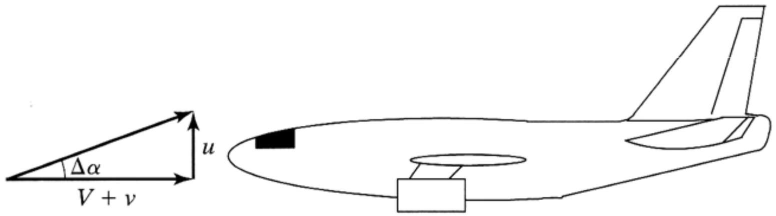


Control loads



Gust loads



Corke

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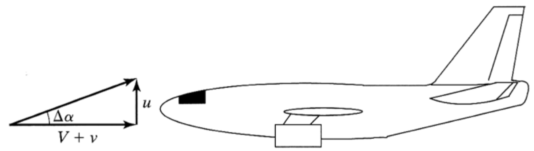
u i v are small comparing to V

$$V + v \simeq V.$$

$$\Delta\alpha = \tan^{-1}\frac{u}{V} \simeq \frac{u}{V}.$$



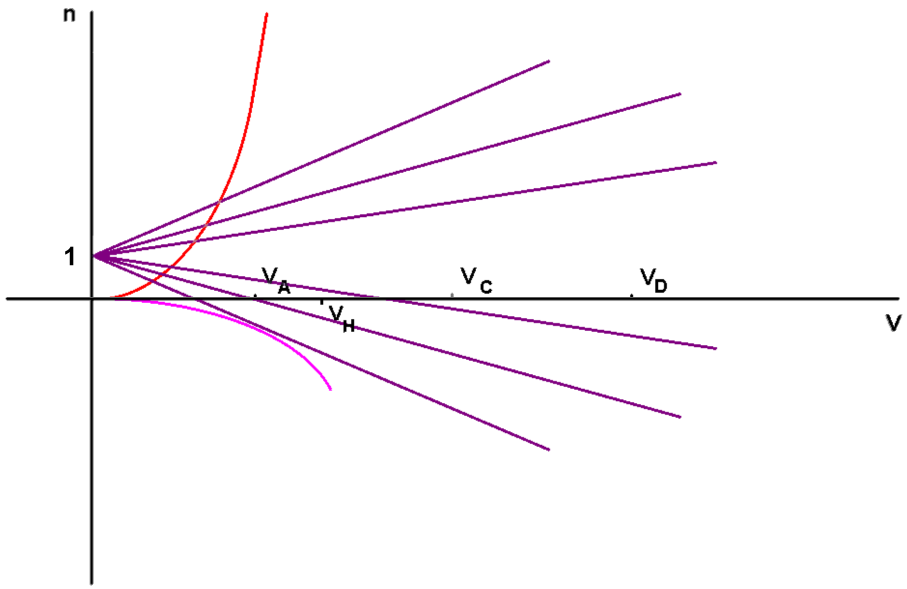
Corke

$$\Delta L = \frac{1}{2}\rho V^2 S C_{L_\alpha}\Delta\alpha = \frac{1}{2}\rho V S C_{L_\alpha} u.$$

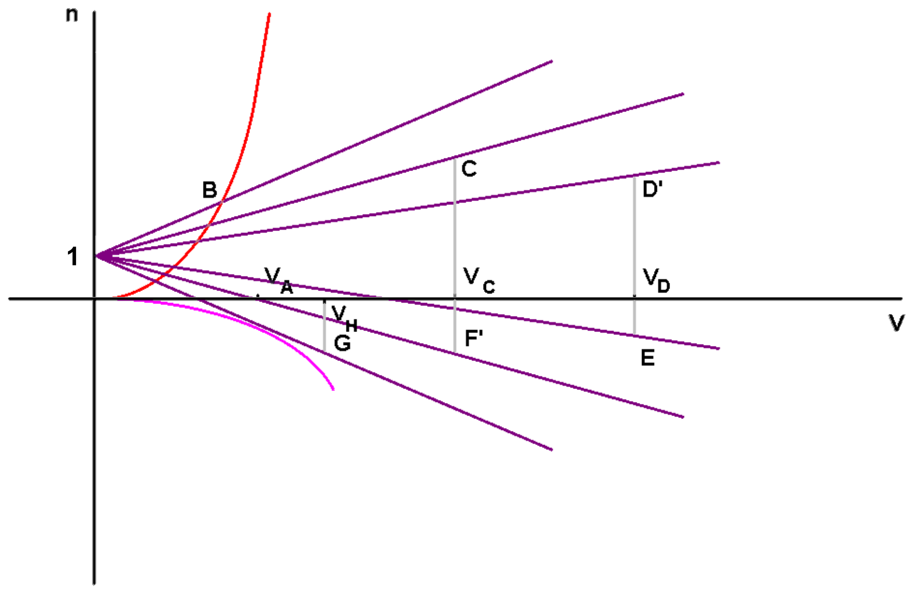
$$\Delta n = \frac{\rho u V C_{L_\alpha}}{2W/S}$$

$$n_{\text{peak}} = n + \Delta n.$$

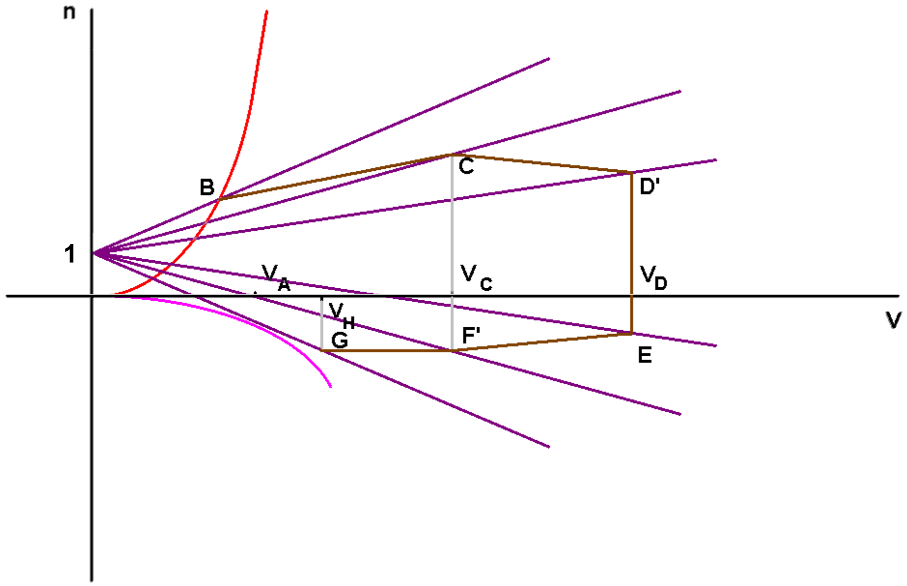
Gust loads



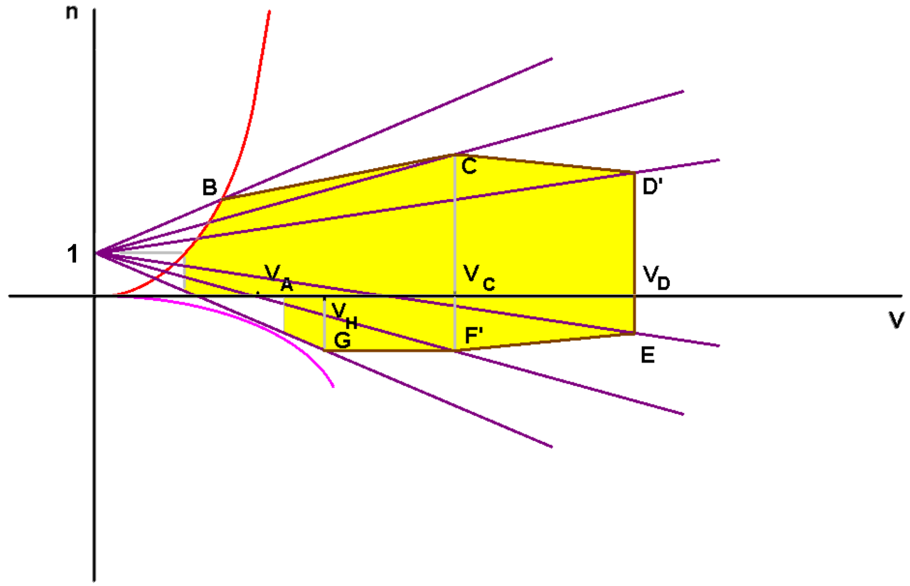
Gust loads

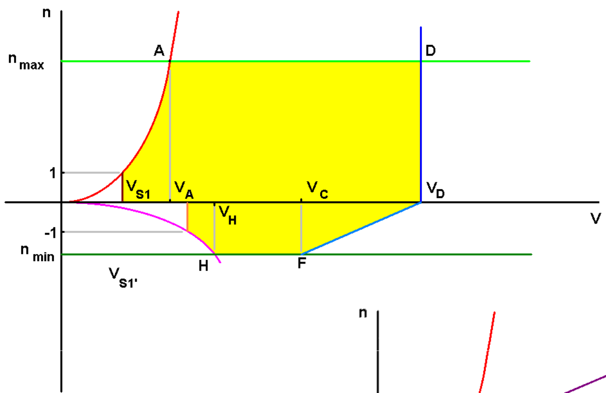


Gust loads

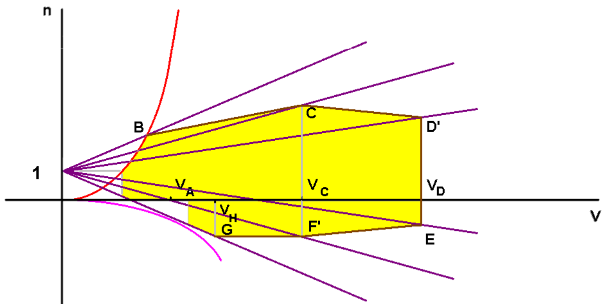


Gust loads

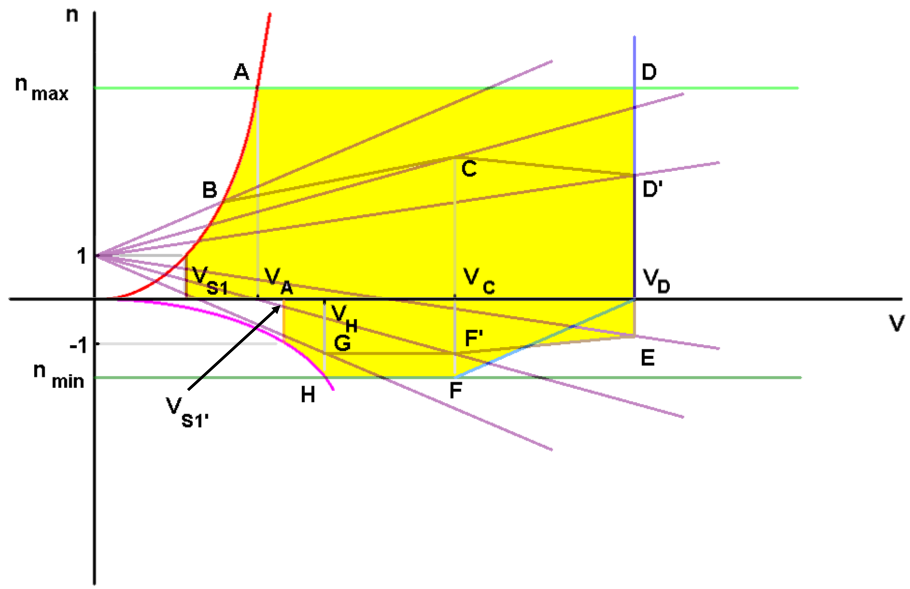


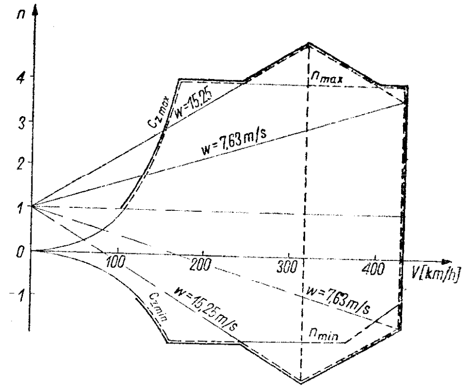


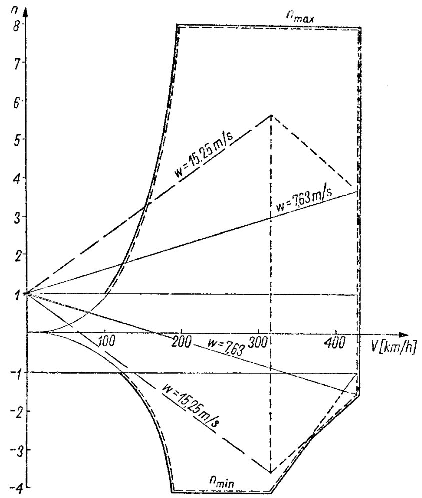
What now?



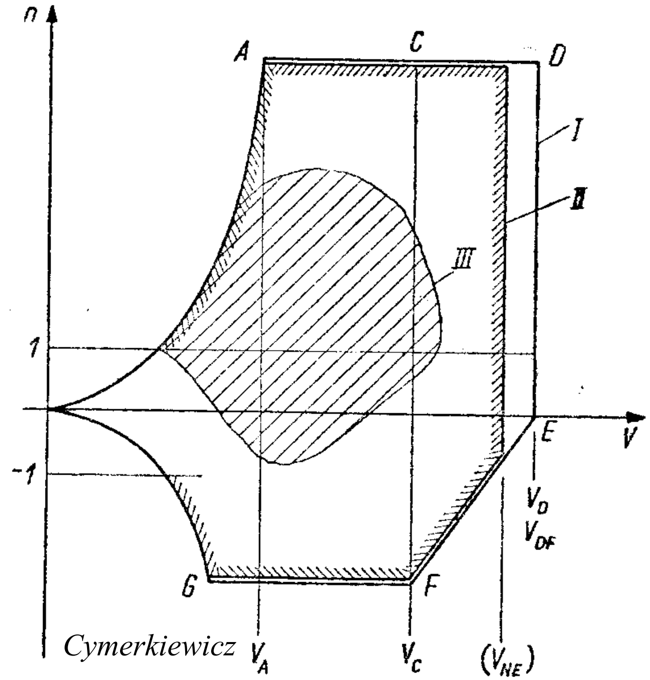
Envelope



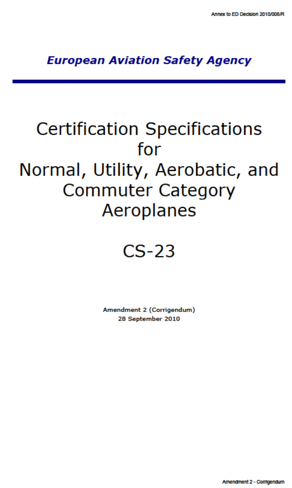




Cymerkiewicz



Look to the regulations CS-23



Annex to ED Decision 2010/008/R

European Aviation Safety Agency

Certification Specifications
for
Normal, Utility, Aerobatic, and
Commuter Category
Aeroplanes

CS-23

Amendment 2 (Corrigendum)
28 September 2010

Amendment 2 - Corrigendum

Factor of safety

- **CS 23.303 Factor of safety**

Unless otherwise provided, a factor of safety of

1,5 must be used

Lift distribution on the wing

How compute the real wing load having *n(V)*

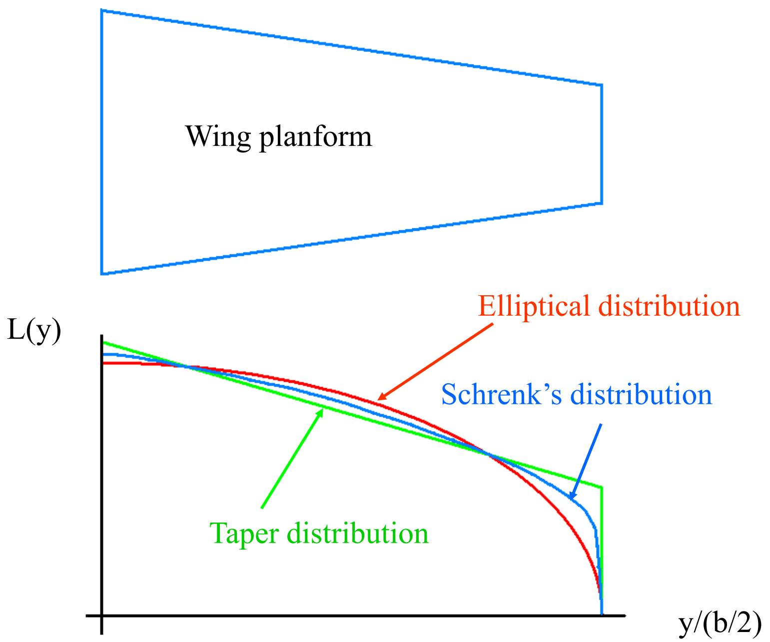
For elliptical wing

Chord vs. wingspan

$$c(y) = \frac{4S}{\pi b}\sqrt{1-\left(\frac{2y}{b}\right)^2}$$

Lift distribution

$$L^E(y) = \frac{4L}{\pi b}\sqrt{1-\left(\frac{2y}{b}\right)^2}$$



For taper wing

Chord vs. wingspan:

$$c(y) = c_r\left[1-\frac{2y}{b}(1-\lambda)\right]$$

Non-real taper lift distribution:

$$L^T(y) = L_r\left[1-\frac{2y}{b}(1-\lambda)\right]$$

Total lift force:

$$L = \int_{-b/2}^{b/2} L(y)dy = 2L_r\int_0^{b/2}\left[1-\frac{2y}{b}(1-\lambda)\right]dy$$

For taper wing

Total lift force: $$L = \frac{L_r b(1+\lambda)}{2}$$

Root „Lift force” $$L_r = \frac{2L}{b(1+\lambda)}$$

Non-real taper lift distribution : $$L^T(y) = \frac{2L}{b(1+\lambda)}\left[1 - \frac{2y}{b}(1-\lambda)\right]$$

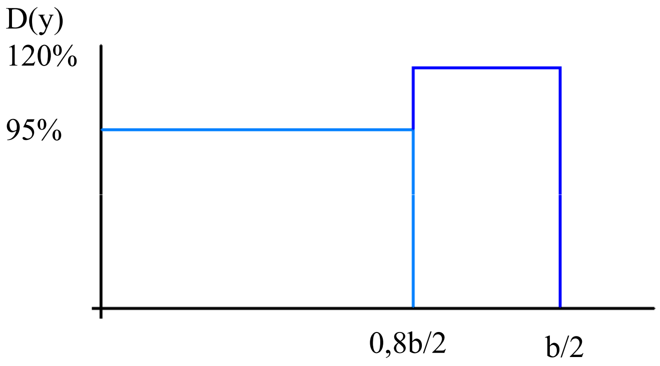
For taper wing

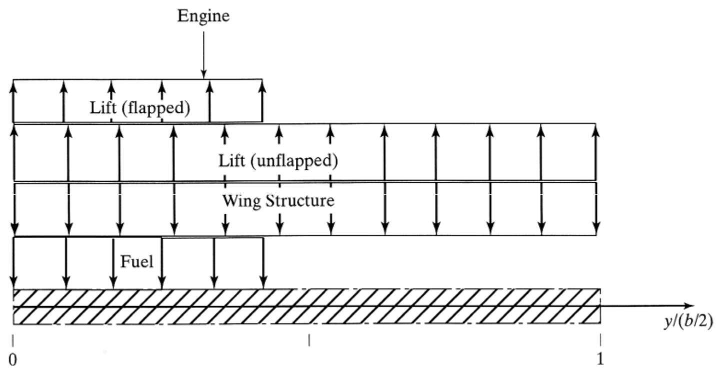
Schrenk’s lift distribution:

$$\bar{L}(y) = \frac{1}{2}\left[L^T(y) + L^E(y)\right]$$

$$L^E(y) = \frac{4L}{\pi b}\sqrt{1 - \left(\frac{2y}{b}\right)^2}$$

$$L^T(y) = \frac{2L}{b(1+\lambda)}\left[1 - \frac{2y}{b}(1-\lambda)\right]$$





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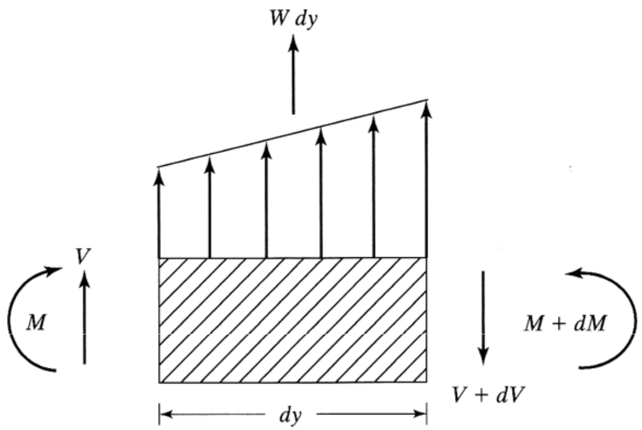


Corke

Unit load

shearing force

bending moment

$$W = \frac{dV}{dy} \qquad V = \frac{dM}{dy}$$

$$V = \int W dy$$

$$M = \int V dy.$$

or after approximation

$$V = \sum_i^N W_i \Delta y$$

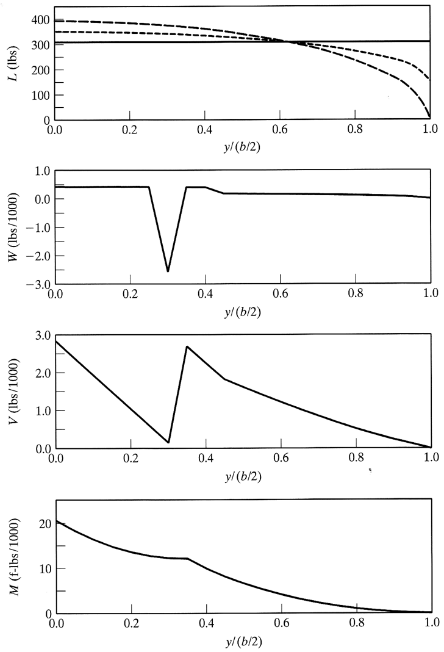
$$M = \sum_i^N V_i \Delta y,$$

Shearing force distribution

$$
\begin{aligned}
V_1 &= 0; \\
V_2 &= W_1 + W_2; \\
V_3 &= W_1 + W_2 + W_3 = V_2 + W_3; \\
V_4 &= V_3 + W_4; \\
&\vdots \\
V_N &= V_{N-1} + W_N.
\end{aligned}
$$

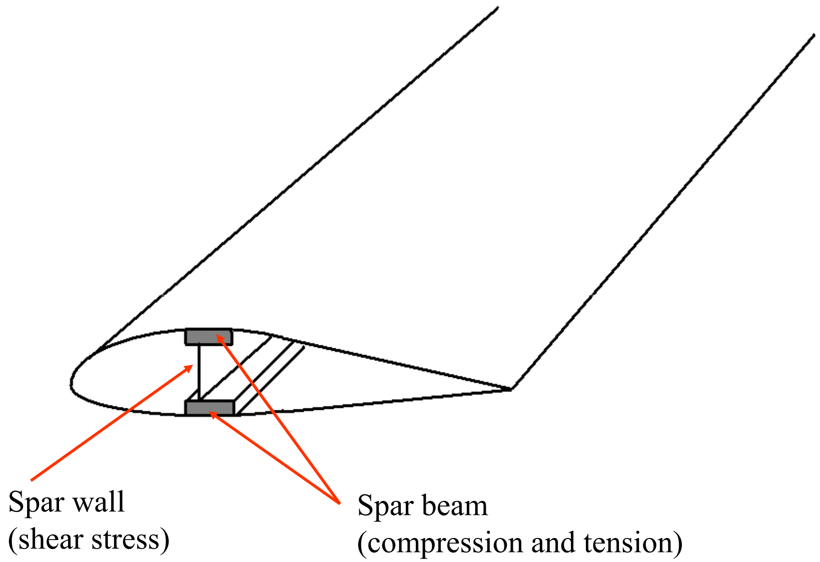
Bending moment distribution

$$
\begin{aligned}
M_1 &= 0; \\
M_2 &= V_1 + \Delta y V_2; \\
M_3 &= V_1 + \Delta y V_2 + \Delta y V_3 = M_2 + \Delta y V_3; \\
M_4 &= M_3 + \Delta y V_4; \\
&\vdots \\
M_N &= M_{N-1} + \Delta y V_N.
\end{aligned}
$$



L (lbs)
400
300
200
100
0
y/(b/2)
W (lbs/1000)
1.0
0.0
−1.0
−2.0
−3.0
V (lbs/1000)
3.0
2.0
1.0
0.0
M (f-lbs/1000)
20
10
0.0
0.2
0.4
0.6
0.8
1.0

Corke



Spar wall
(shear stress)
Spar beam
(compression and tension)