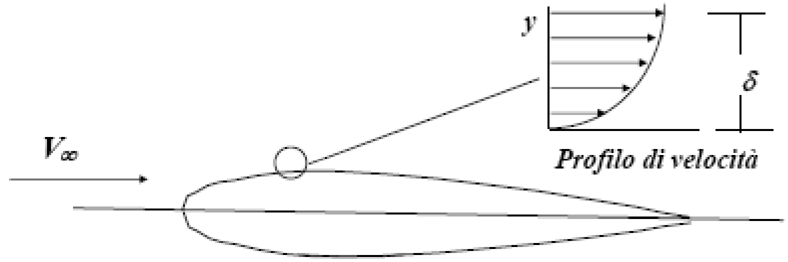
CORSO PGV
Riepilogo di MECCANICA DEL VOLO

Dalla Polare di resistenza alle polari tecniche del Velivolo (Curve di spinta e potenza necessaria al volo)

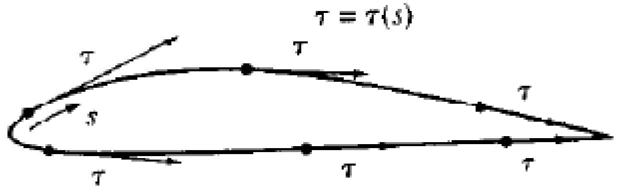
Prof. F. Nicolosi

Sorgenti di resistenza aerodinamica

$$\tau_w = \mu\left(\frac{dV}{dy}\right)_{y=0}$$



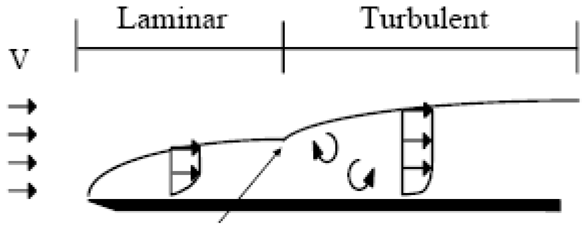
⇒**Resistenza di attrito**
(Skin friction)

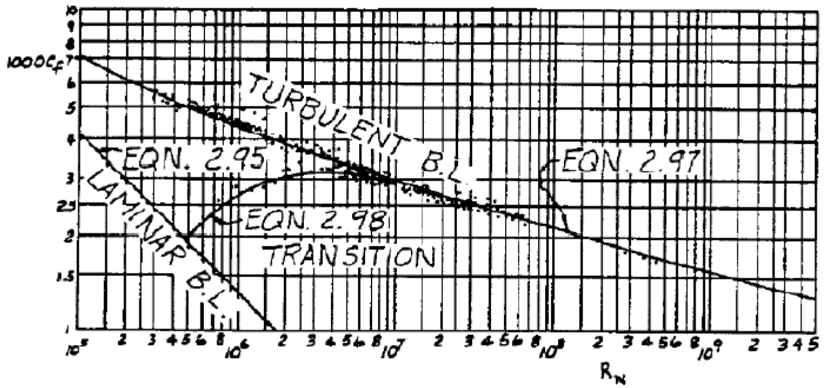


(b) Shear stress distribution

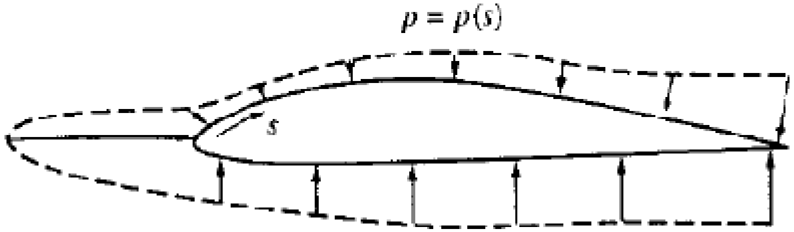
Turbulent skin friction coeff.

$$c_f = \frac{0.455}{(\log_{10} R_N)^{2.58}}$$

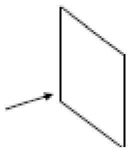




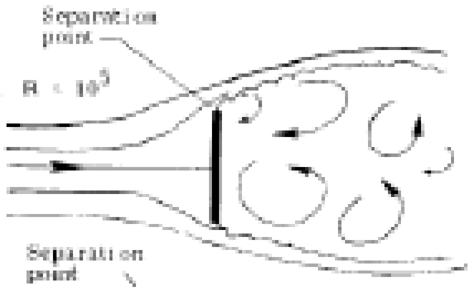
⇒**Resistenza di scia (pressione)**
(form drag , pressure drag) – tipica di escrescenze, carrelli, e profilo ad incidenza



(a) Pressure distribution (schematic only; distorted for clarity)



Lastra piana rettangolare
Cd =1.20
Sempre Re=10^5)

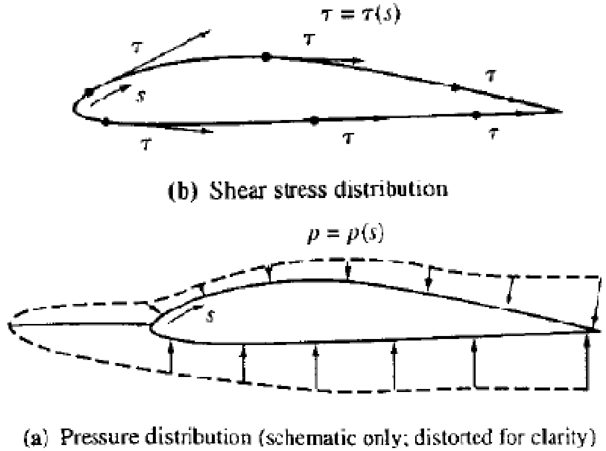


Sorgenti di resistenza aerodinamica

⇒**Resistenza di attrito**
(Skin friction)

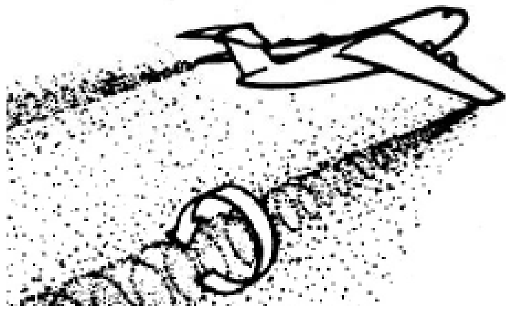
⇒**Resistenza di scia (pressione)**
(form drag , pressure drag)

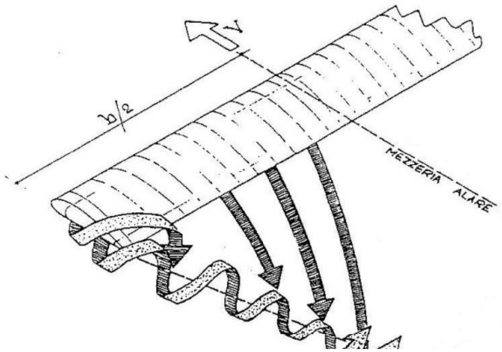
2-D



⇒ **Resistenza indotta**
(Vortex drag)

3-D



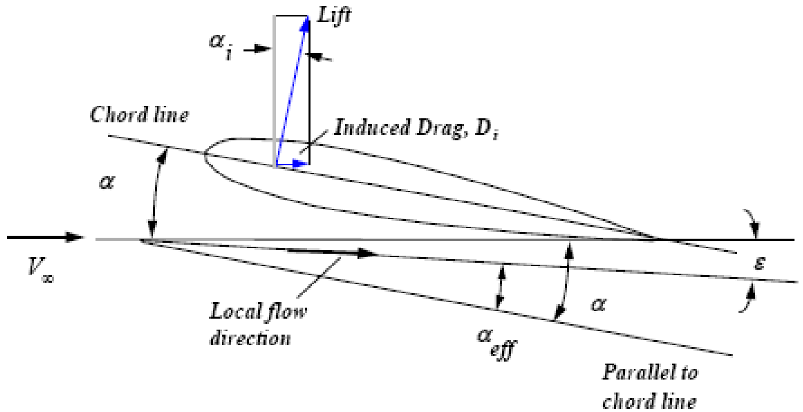


Il parametro delta tiene conto di distribuzione di portanza non-ellittica.

$$\alpha_i = \frac{C_L}{\pi AR}$$

alfa indotto ala ellittica

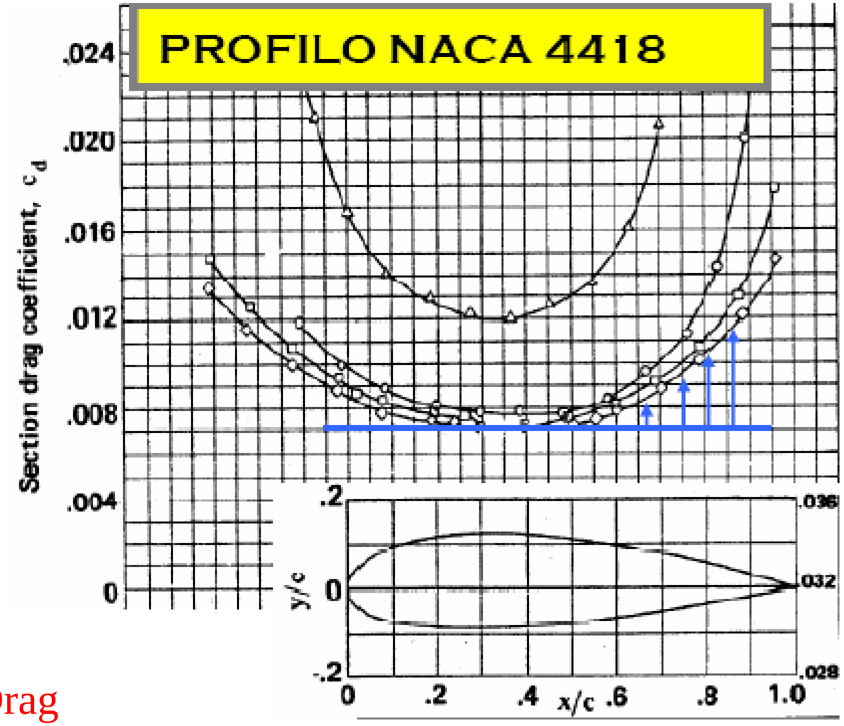
$$C_{D_i} = \frac{C_L^2}{\pi AR}(1+\delta)$$

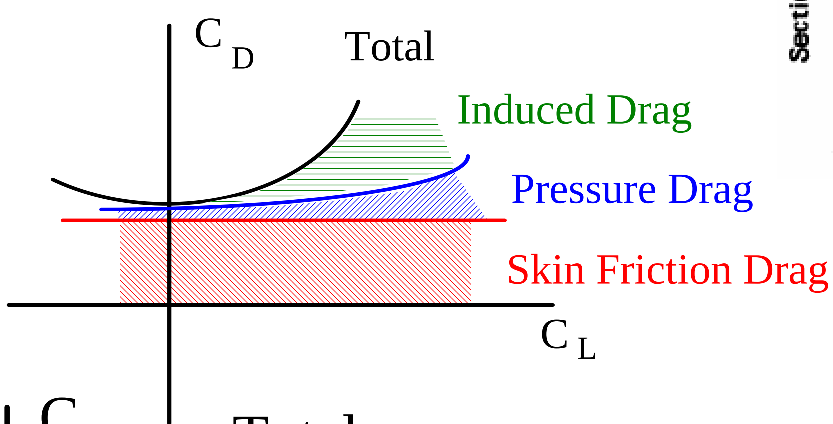


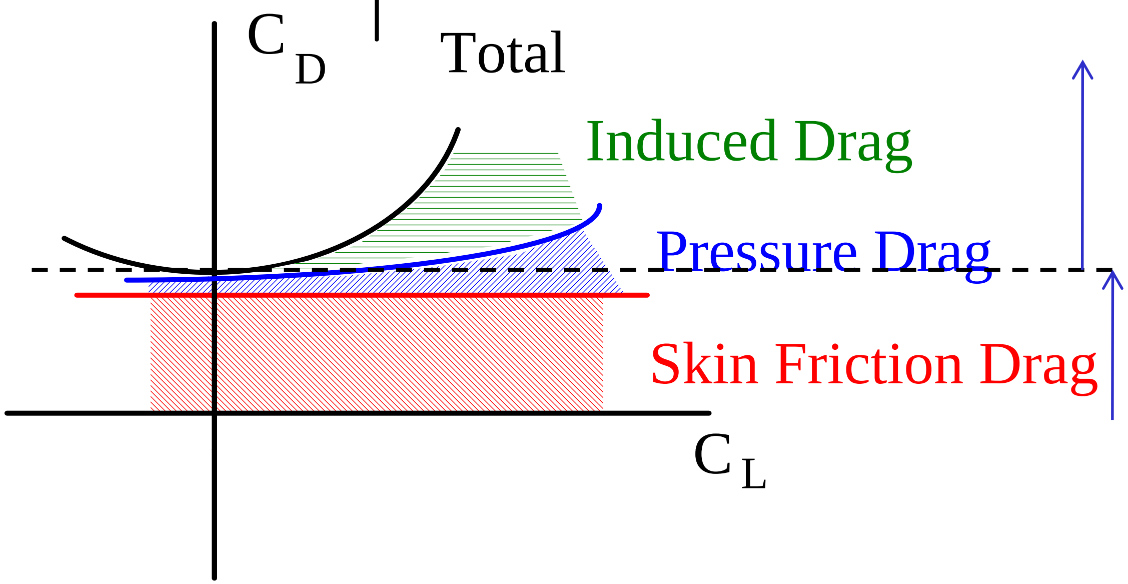
Sorgenti di resistenza aerodinamica

⇒ **POLARE INCOMPRIMIBILE**

A rigore, in modo molto marginale, anche la resistenza di attrito varia con l'assetto (CL).
La resistenza di pressione varia con l'assetto principalmente per effetto del profilo alare e della fusoliera.







Coeff resist dovuta alla portanza
(somma della vortex drag e della variazione della parassita con l'assetto)

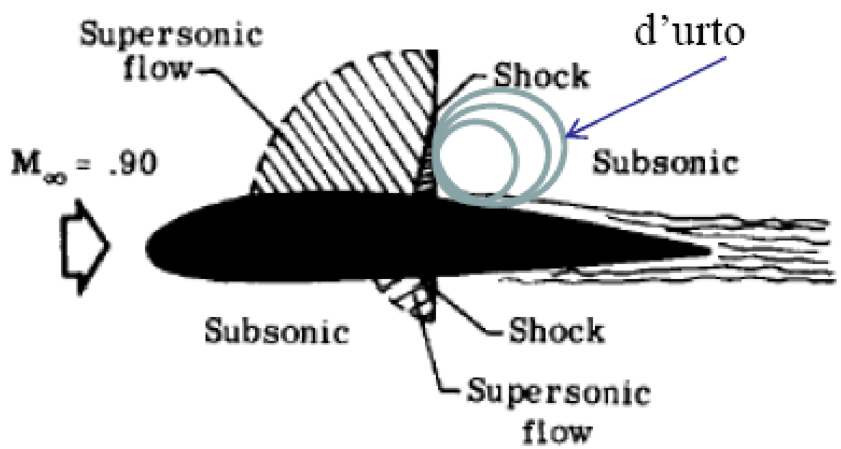
Coeff resist parassita (CL=0)

Sorgenti di resistenza aerodinamica

CAMPO COMPRIMIBILE

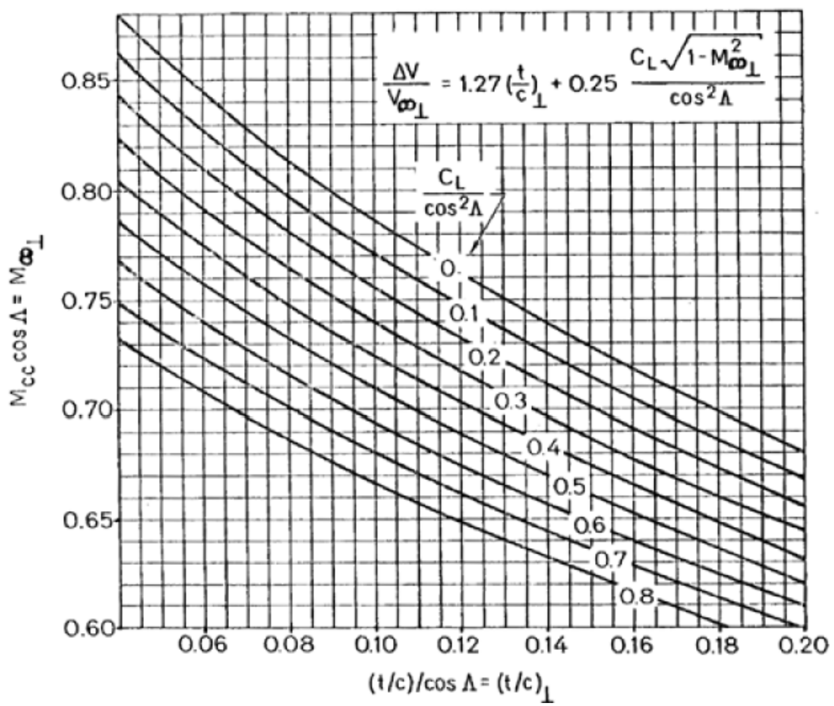
⇒Resistenza d’onda (wave drag)

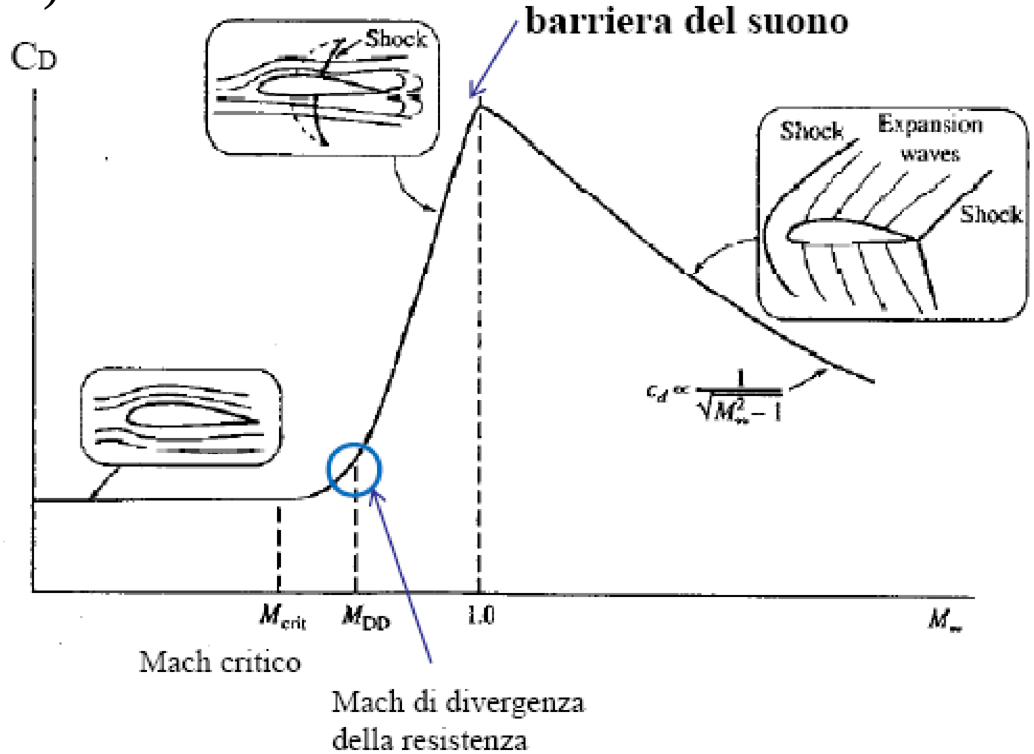
E’ una resistenza principalmente di pressione. L’onda d’urto interagisce con lo strato limite e provoca separazione con scia, resistenza di pressione e “buffeting”.



Il Mach cr e M_{DD} dipendono da:

- Assetto (CL), freccia ala, spessore perc (t/c),
  tipo di profilo (profili supercritici)

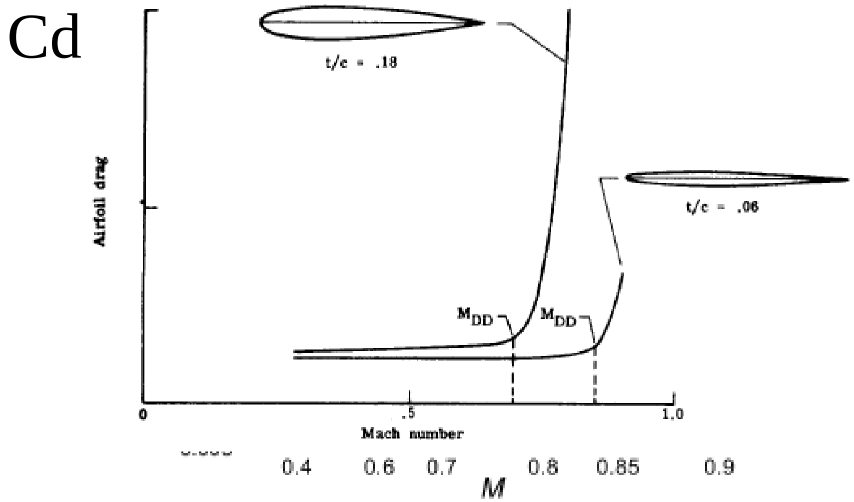




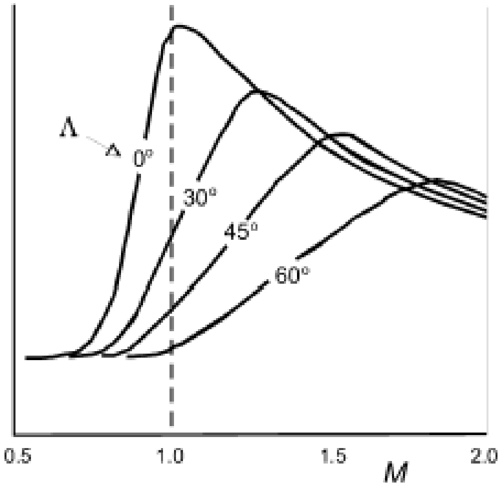
Sorgenti di resistenza aerodinamica

Il Mach cr e M_{DD} dipendono da:

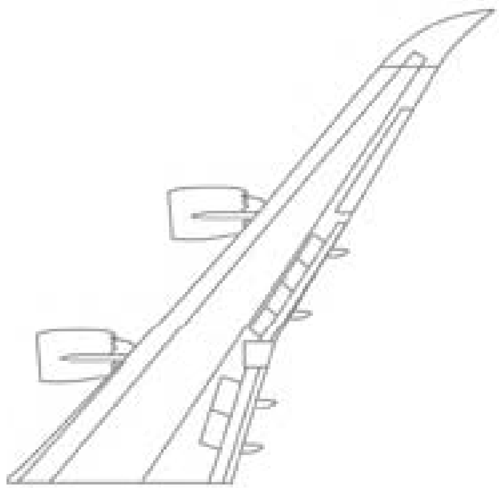
- Assetto (CL), freccia ala, spessore perc (t/c),tipo di profilo (profili supercritici).

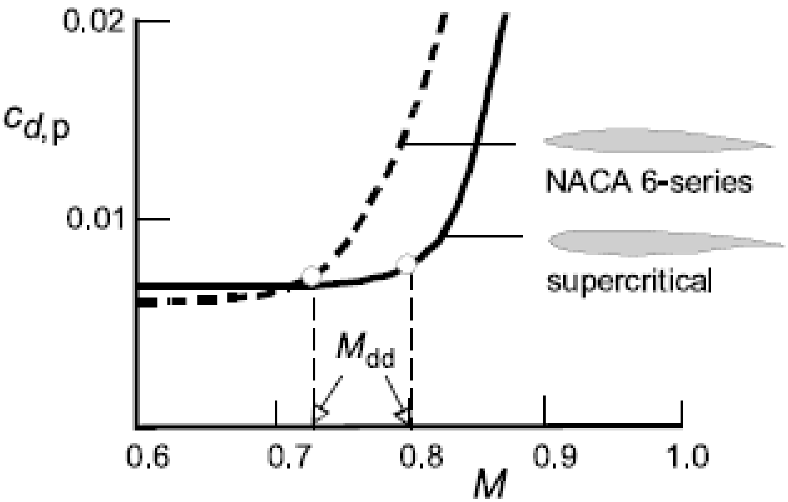


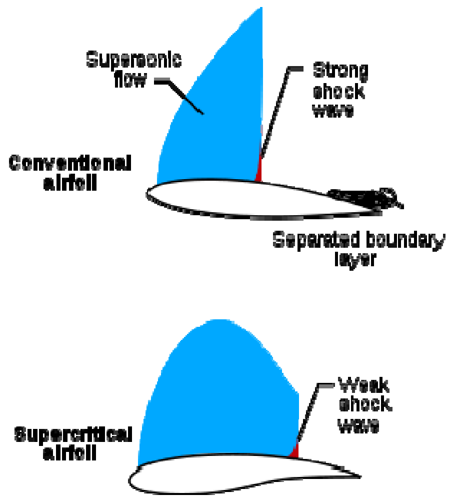
(a) Effect of section thickness



(b) Effect of sweep angle





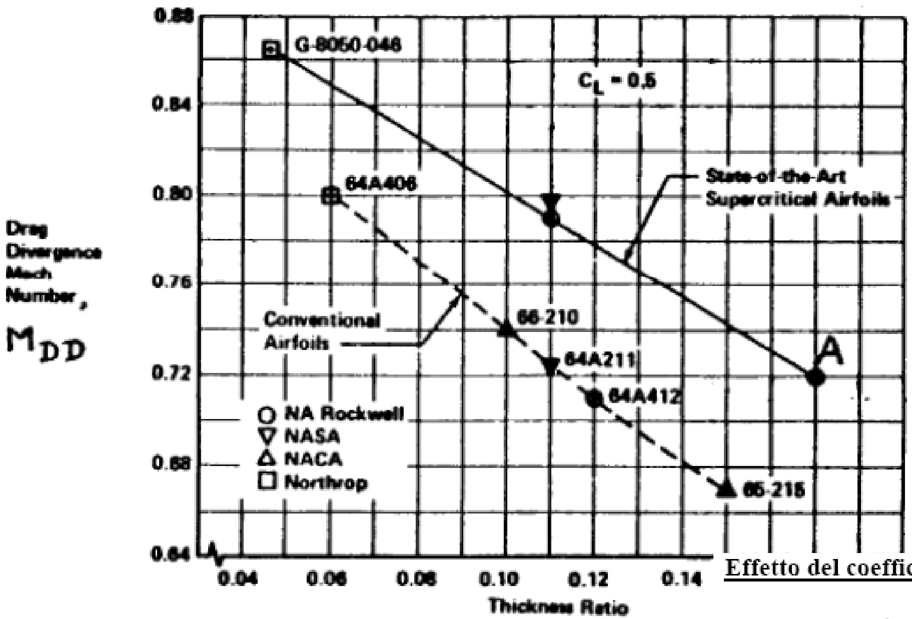


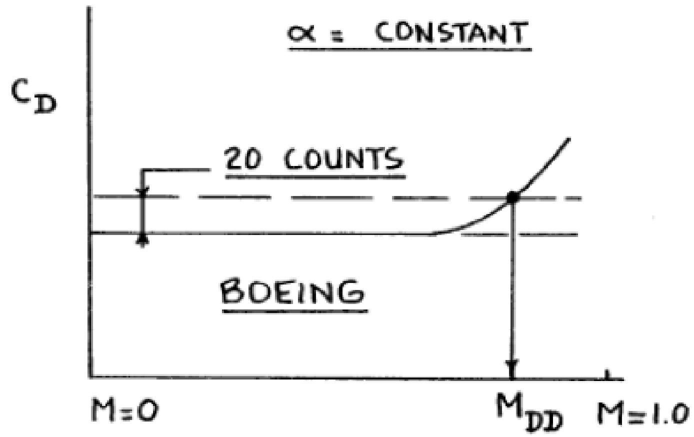
Sorgenti di resistenza aerodinamica

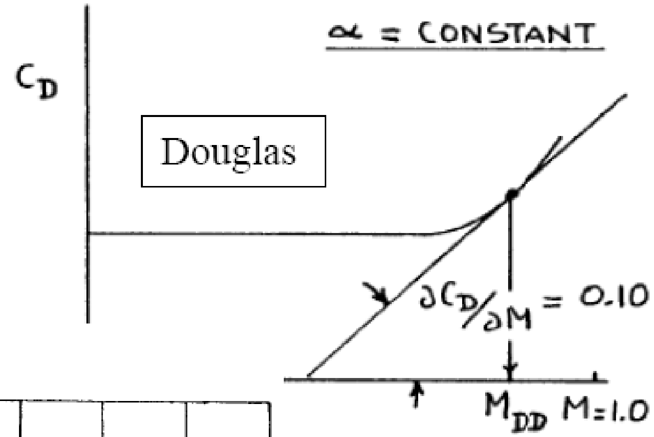
CAMPO COMPRIMIBILE

⇒Mach di divergenza

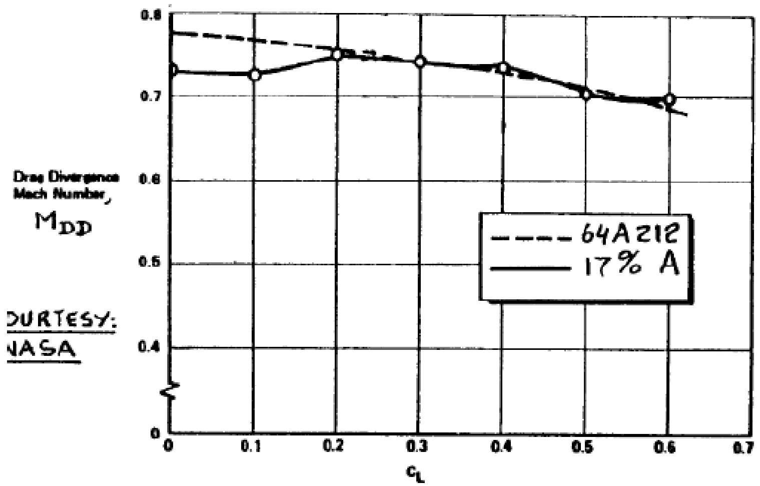
Dati riferiti al PROFILO







Effetto del coefficiente di portanza



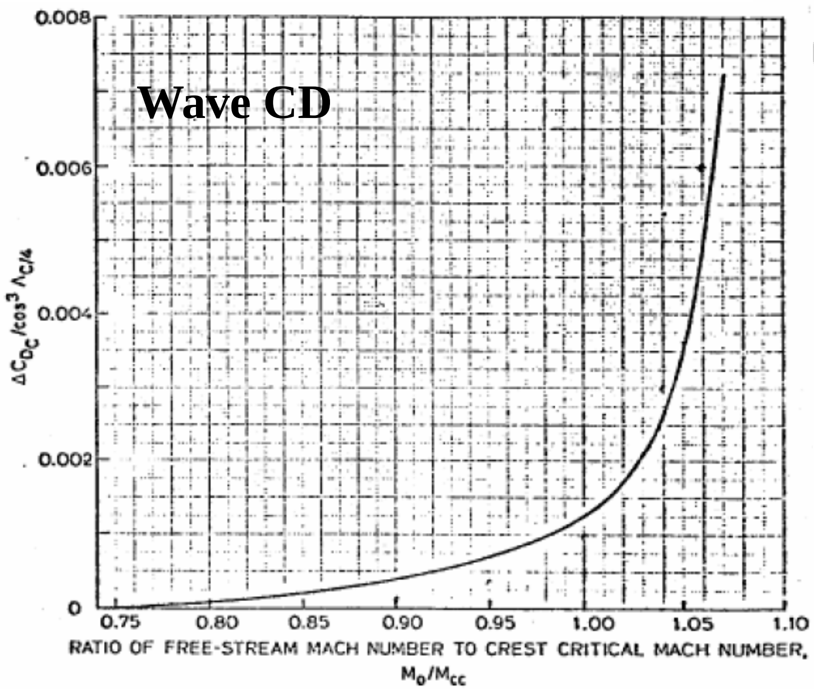
For modern (aft-loaded) airfoils:

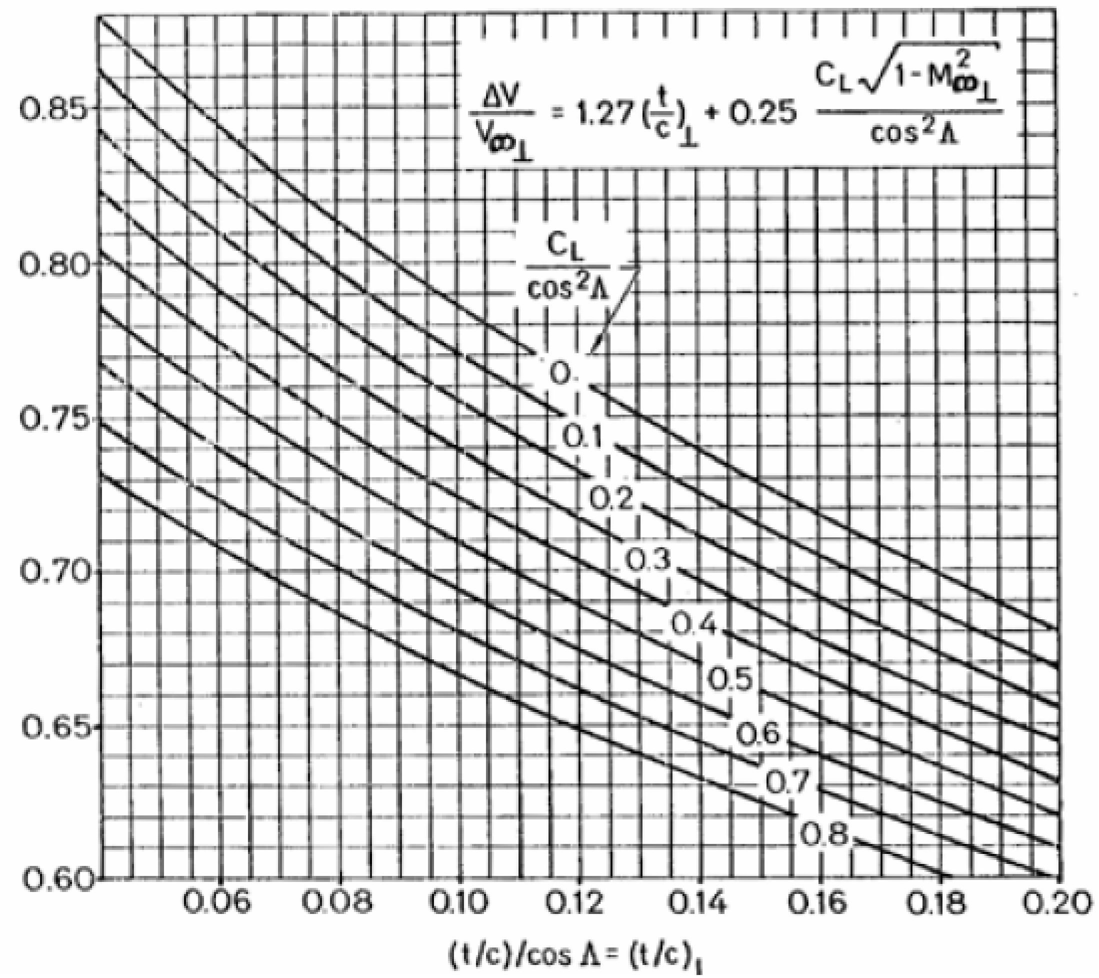
$$M_{DD} = 0.95 - (t/c)_{max} - c_l/10$$

Sorgenti di resistenza aerodinamica

CAMPO COMPRIMIBILE – Wave Drag

$$M_{DD} = M_{cc} \cdot \left[1.02 + 0.08 \cdot \left(1 - \cos \Lambda_{\frac{c}{4}} \right) \right]$$





Il diagramma vale per profili peaky

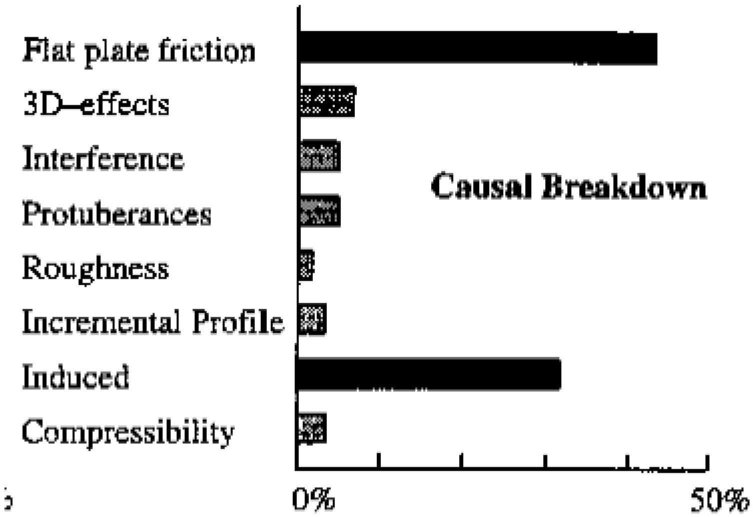
Profili supercritici => aggiungere 0.03 o 0.04

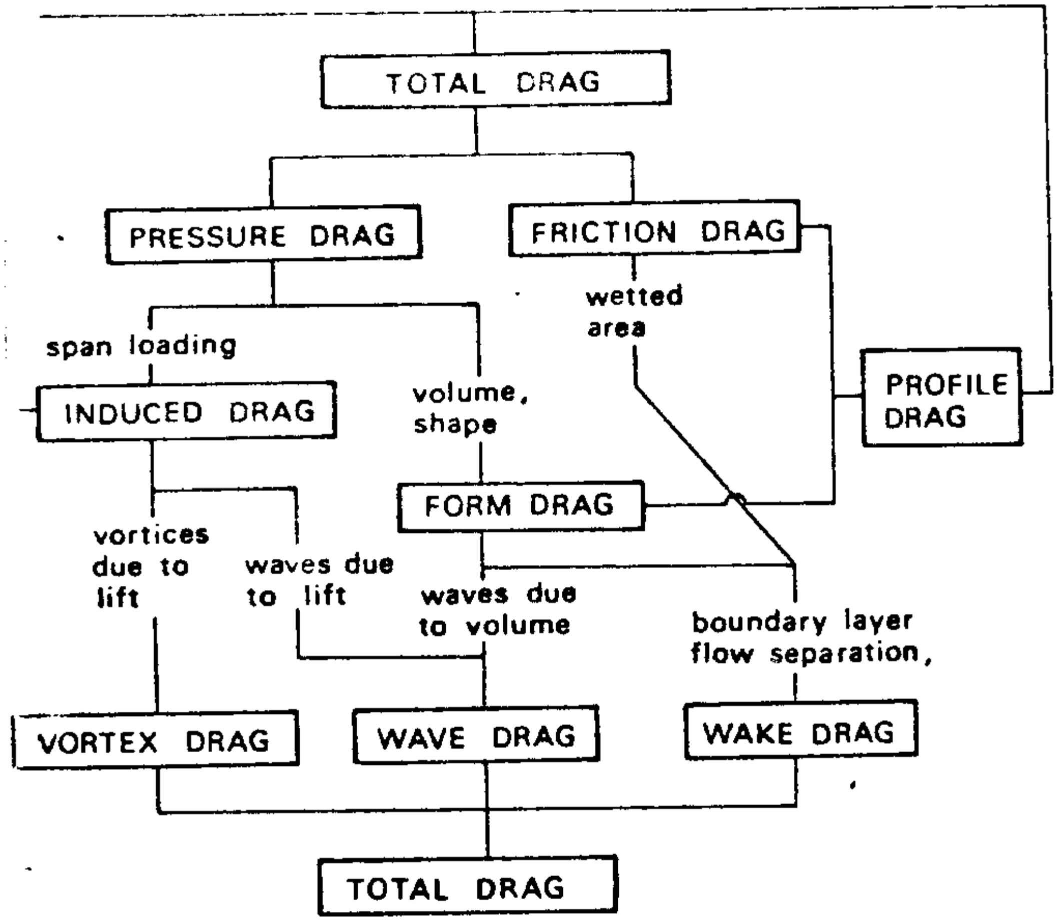
Profili supercritici aggressivi si rende necessario un aumento di 0.06.

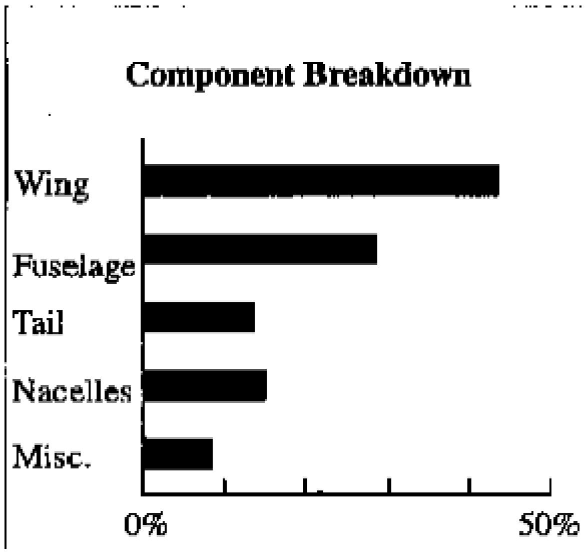
Polare di resistenza

Breakdown CAUSALE

(vel trasp jet in crociera)



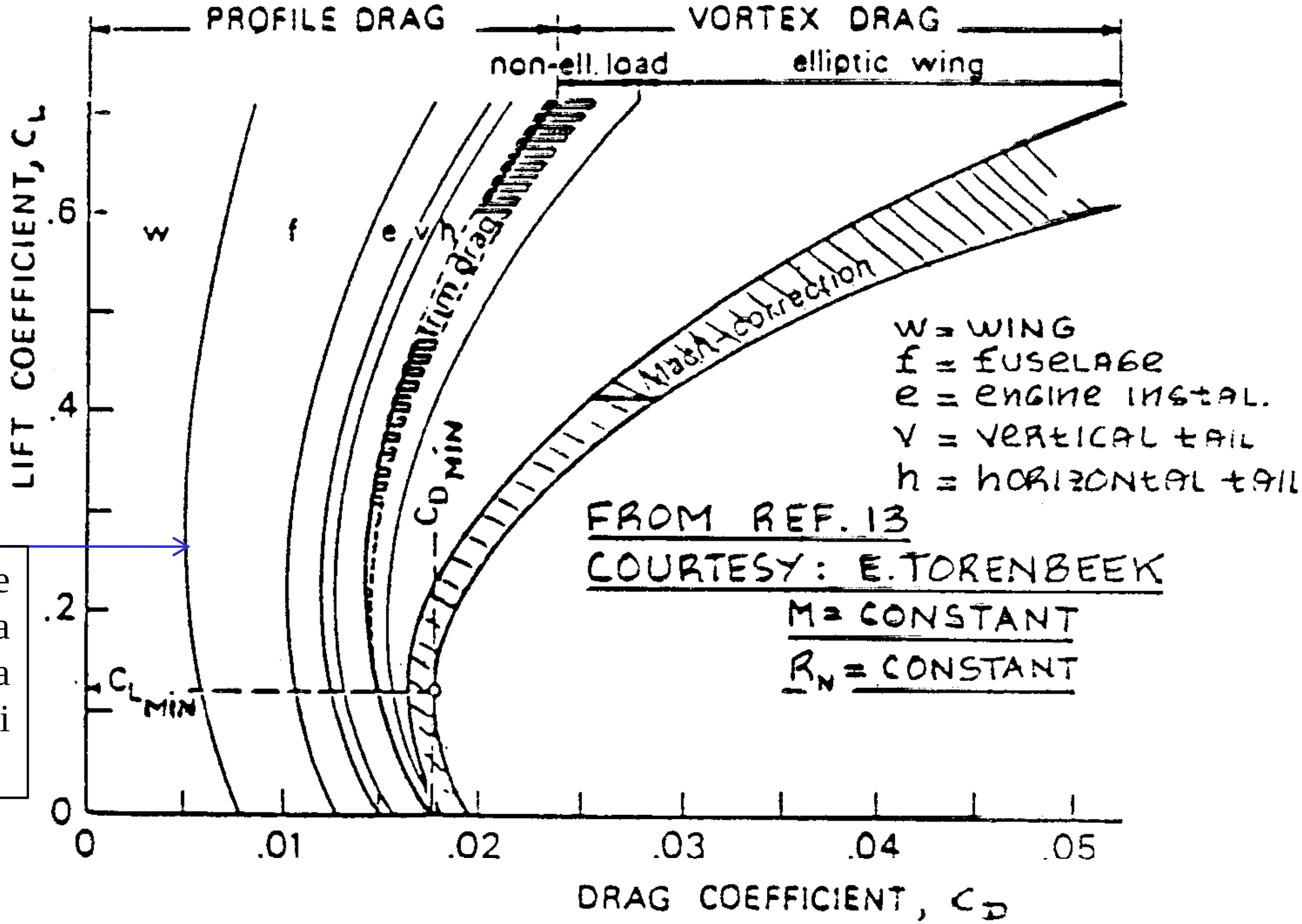




Breakdown per componenti

(vel trasp jet in crociera)

Polare di resistenza



Il profilo alare curvo ha resistenza viscosa minima a Cl>0 (Cl di crociera).

Polare di resistenza

Resistenza a portanza nulla + resistenza dovuta alla portanza.
Si introduce **il fattore di Oswald "e"** (tipicamente =0.8).

Si "modella" la polare di resistenza con una legge parabolica.

$$K = \frac{1}{\pi AR \cdot e}$$

Molto spesso, anche i risultati sperimentali, mostrano che, graficati considerando come variabile il CL al quadrato, mostrano una tendenza lineare in un ampio range di assetti.

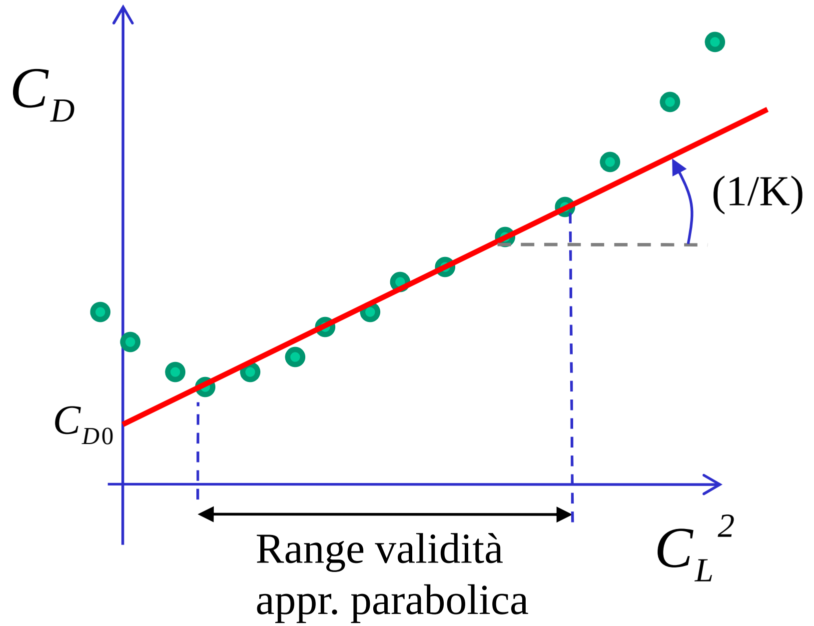
<u>Velivolo Completo</u>:

$$CD = CDo_{TOT} + \frac{CL^2}{\pi AR}\left[1 + \delta + (Kv_w + Kv_f + Kv_N)\pi AR\right]$$

Effetti viscosi

$$CD = CDo + \frac{CL^2}{\pi \cdot AR \cdot e}$$

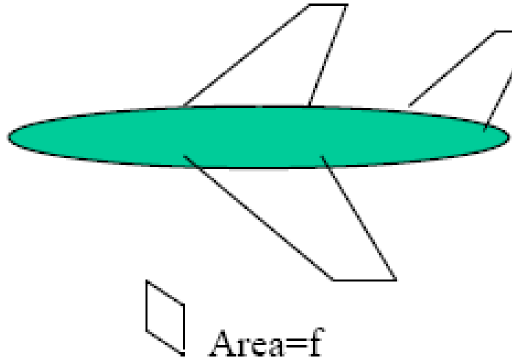
$$C_D = C_{D0} + K \cdot C_L{}^2$$



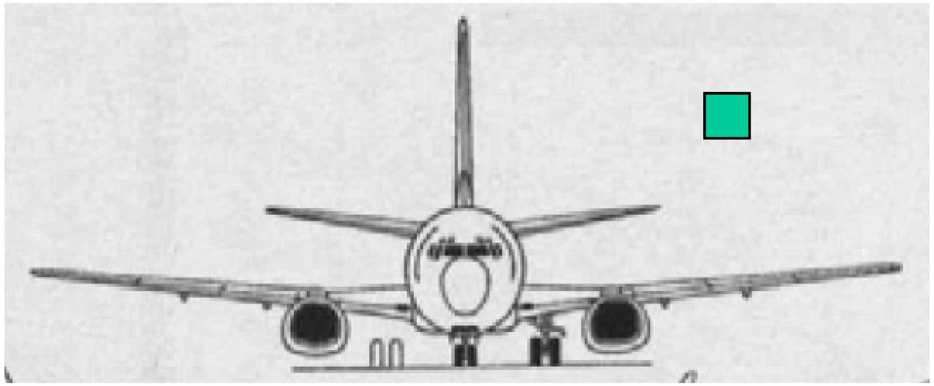
Polare di resistenza

Area parassita equivalente

f=CDo S   [mq]



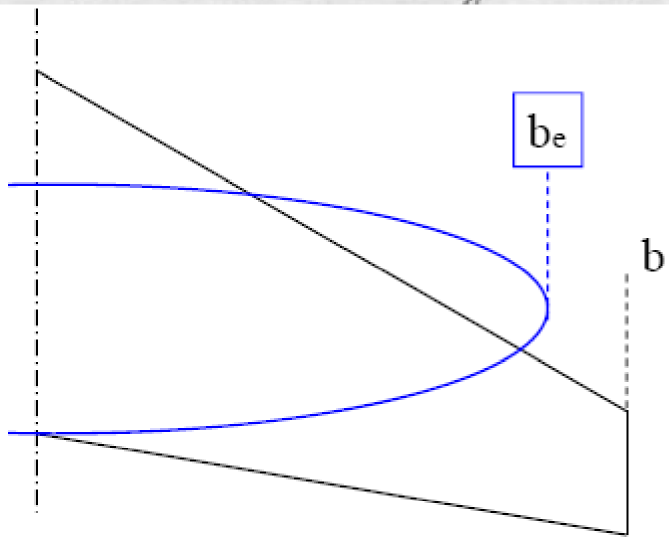
La reale misura della resistenza parassita
è l'area parassita equivalente f



Apertura alare efficace

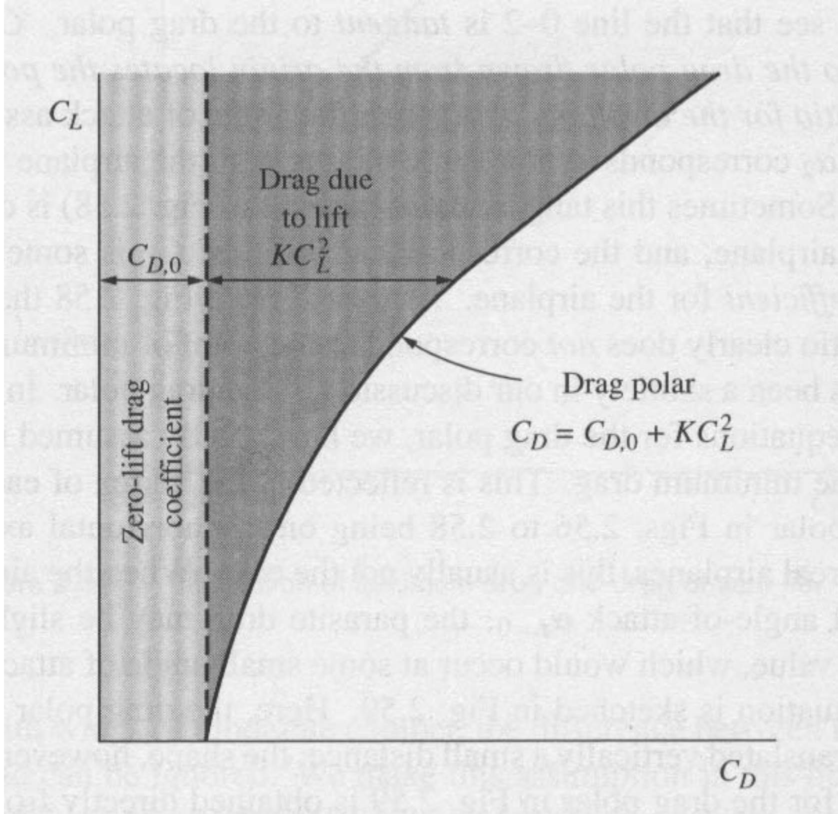
$$AR_e = AR\,e = \frac{b^2}{S}e = \frac{b_e^2}{S}$$

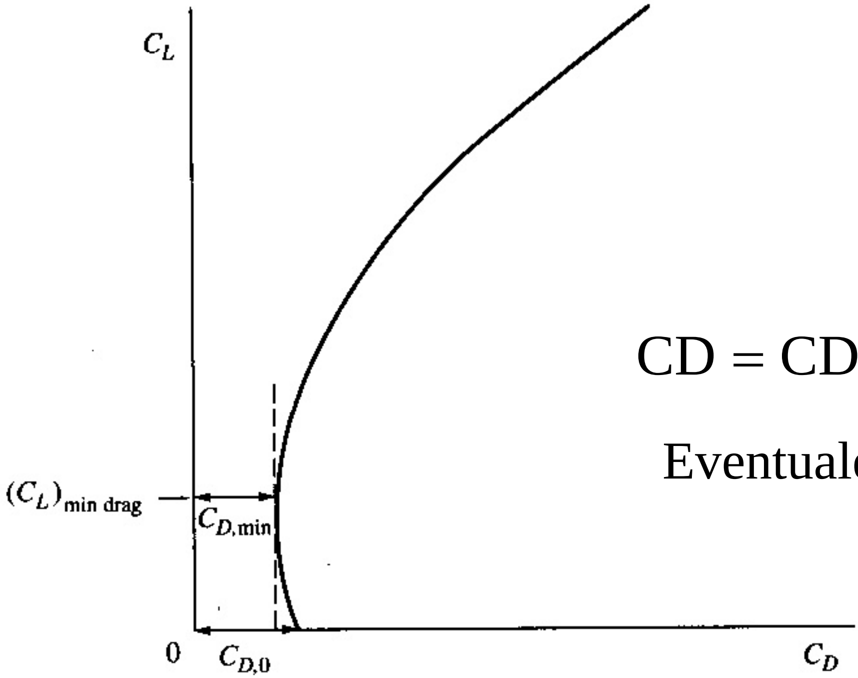
$$b_e = b\sqrt{e}$$



Polare di resistenza

$$C_D = C_{D0} + K \cdot C_L^{\ 2}$$

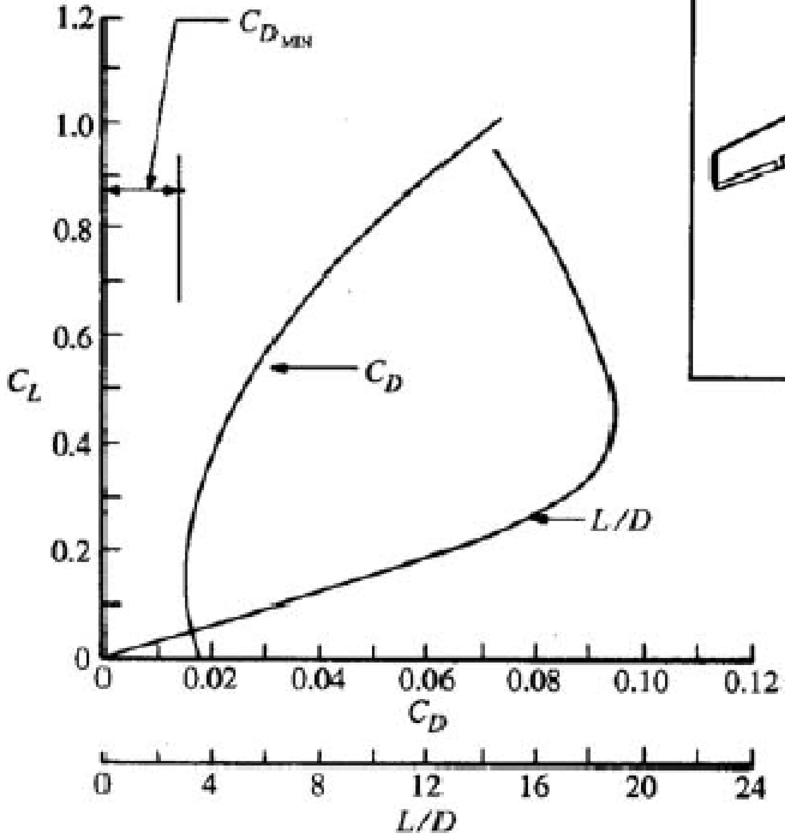


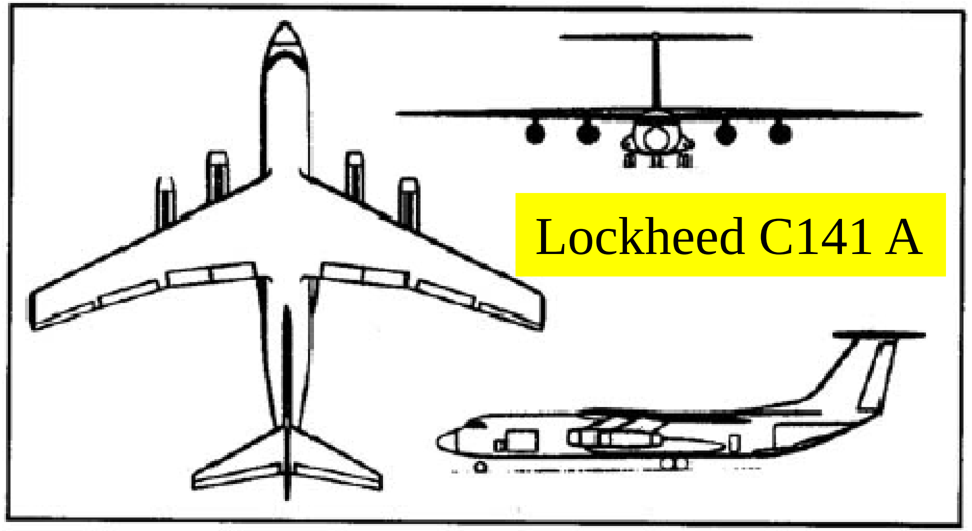


$$\mathrm{CD} = \mathrm{CD}_{\min} + \mathrm{K}\left(\mathrm{CL} - \mathrm{CL}_{\text{min\_drag}}\right)^2$$

Eventuale Polare parabolica ad asse spostato

Polare resistenza





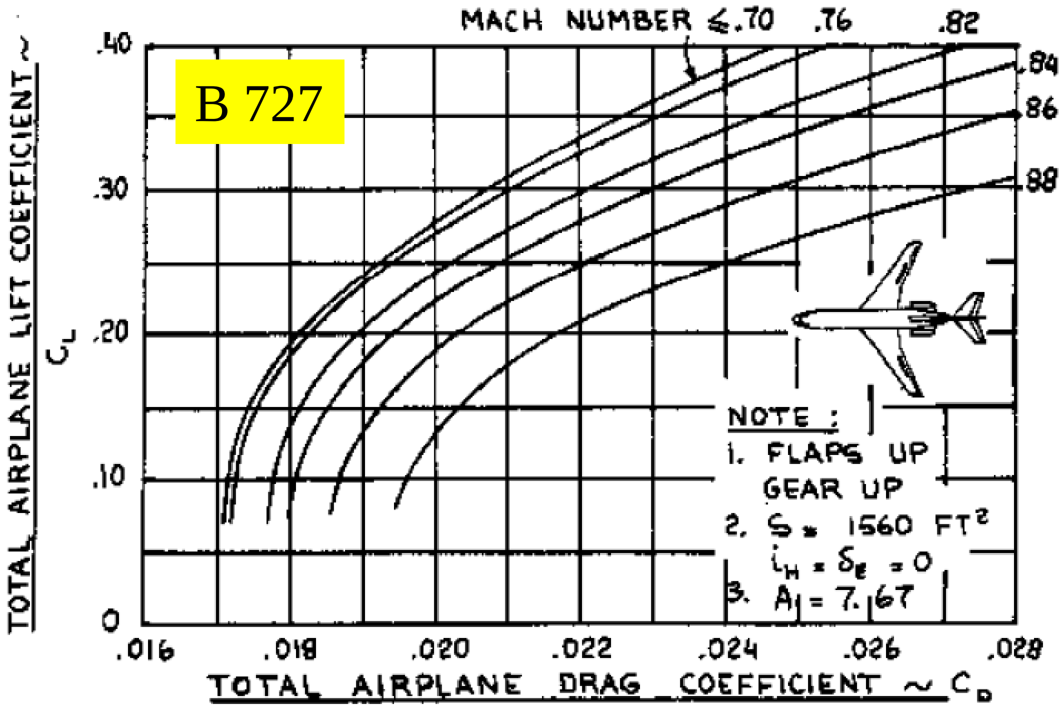


Figure 5.12 Drag Polars: Boeing 727-100

Polare resistenza

Valori del C_{D0}

- Cessna , circa 0.0280 - 0.0320
- ATR , circa 0.0290
- Bimotore elica carr retr : 0.0270
- business jet : 0.0240
- trasp jet : 0.0200 - 0.022
- moderno trasp jet : 0.0160-0.0190

SI MISURA in decimillesimi
(0.0001 = **1 drag count**)

Quindi il C_{D0}
Varia tra 180 e 320 counts per i velivoli citati.

Il **fattore Oswald** è tra 0.70 e 0.85 (dipende da rastremazione, freccia, AR, e da eventuali winglet).

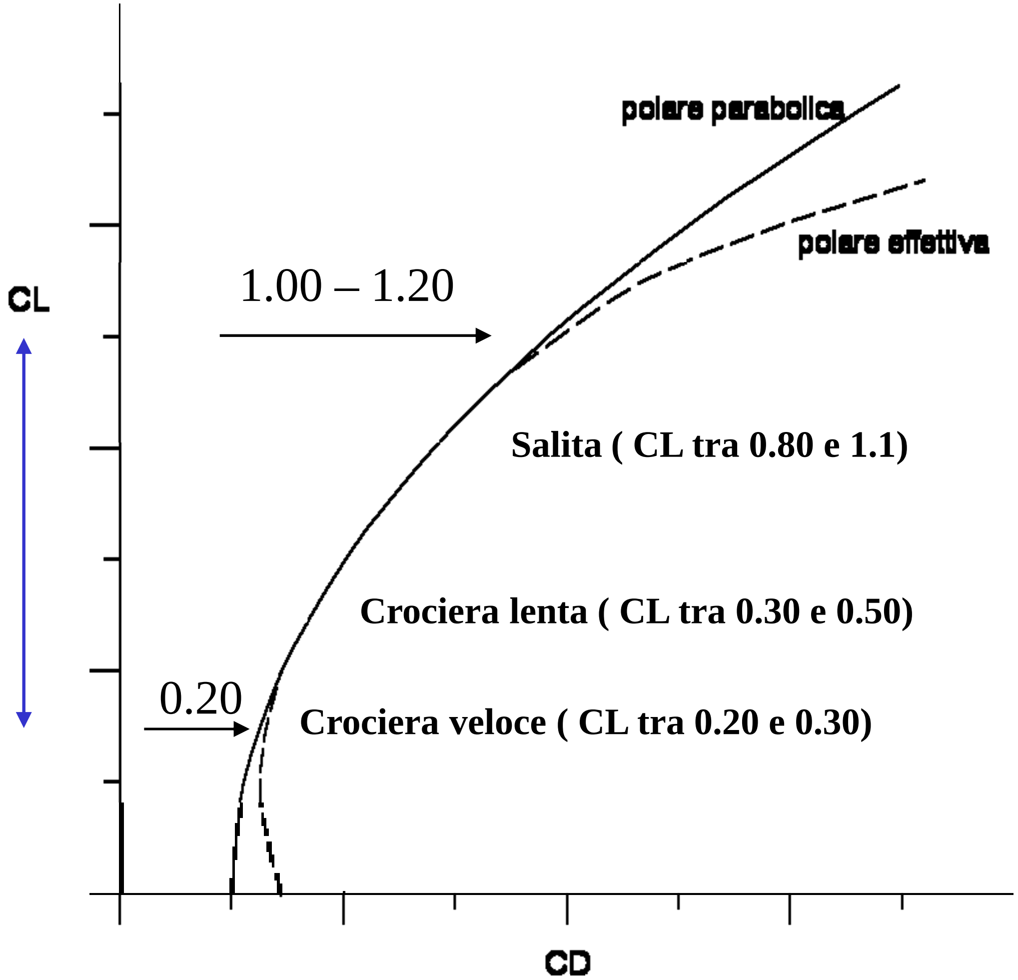
Table 5.4 Summary of Drag Data for Various Airplanes

Type	Wing Area, S	Aspect Ratio	$\frac{S_{wet}}{S}$	Drag Polar	e	$\left(\frac{C_L}{C_D}\right)_{max}$ @ C_L
	ft^2			$C_{D_0} + \frac{C_L^2}{\pi A e}$		
C–150	160	7.0	?	$0.0327 + 0.0592C_L^2$	0.77	11.3 @ 0.74
C–172	174	7.5	3.7	$0.0281 + 0.0552C_L^2$	0.77	12.7 @ 0.71
C–180	174	7.5	?	$0.0246 + 0.0572C_L^2$	0.75	13.3 @ 0.66
C–182	174	7.5	4.0	$0.0293 + 0.0506C_L^2$	0.84	13.0 @ 0.75
C–185	174	7.5	?	$0.0207 + 0.0494C_L^2$	0.86	15.6 @ 0.65
C–310	175	7.3	4.6	$0.0263 + 0.0596C_L^2$	0.73	12.6 @ 0.66
Skyrocket	183	6.7	?	$0.0163 + 0.0579C_L^2$	0.82	16.3 @ 0.53
Saab 340	450	11.0	?	$0.0285 + 0.0362C_L^2$	0.80	15.6 @ 0.89
DC 9–30	1,001	6.8	6.5	$0.0211 + 0.0450C_L^2$	0.81	16.7 @ 0.50
B 707–320	3,050	7.1	5.0	$0.0131 + 0.0650C_L^2$	0.70	19.6 @ 0.45
A–340	3,908	9.5	?	$0.0165 + 0.0435C_L^2$	0.77	18.5 @ 0.60
B 767	3,050	8.0	?	$0.0135 + 0.0592C_L^2$	0.67	17.2 @ 0.50
C–17	3,800	7.2	?	$0.0175 + 0.0510C_L^2$	0.87	16.4 @ 0.55
Learjet M25	232	5.0	5.6	$0.0260 + 0.0078C_L^2$	0.82	10.9 @ 0.58
G–II	800	6.0	?	$0.0230 + 0.0057C_L^2$	0.93	14.0 @ 0.63

Polare resistenza parabolica

La polare parabolica
(anche ad asse non spostato)
approssima bene i regimi in cui il velivolo OPERA effettivamente

Il velivolo solitamente vola in questo range di assetti:
- crociera veloce 0.20-0.30
- crociera lenta 0.30-0.50
- salita 0.90-1.20



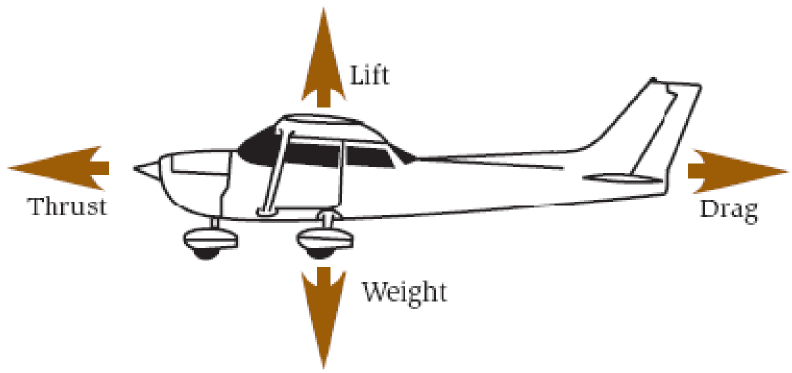
Polari tecniche – LEGAME V-CL

VOLO LIVELLATO UNIFORME

$$L = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_L = W$$

L=W

T=D



$$V = \sqrt{\frac{2}{\rho}}\sqrt{\frac{W}{S}}\sqrt{\frac{1}{CL}} = \sqrt{\frac{2}{\rho_o \sigma}}\sqrt{\frac{W}{S}}\sqrt{\frac{1}{CL}}$$

$$V \propto \frac{1}{\sqrt{CL}} \qquad CL = \frac{2}{\rho}\frac{W}{S}\frac{1}{V^2} \qquad CL \propto \frac{1}{V^2}$$

La velocità di stallo è la minima velocità di sostentamento a quota costante.

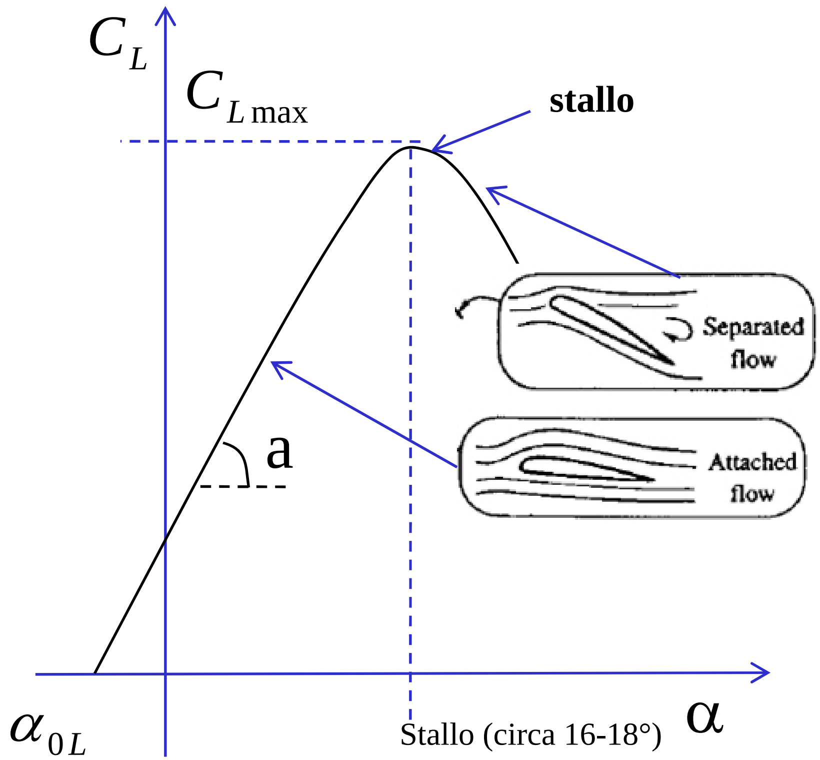
Quindi, incorrispondenza dello stallo CL=CLmax
Si avrà la velocità di stallo (minima velocità)

$$Vso = \sqrt{\frac{2}{\rho_o}\frac{W}{S}\frac{1}{CL_{MAX}}}$$

Velocità di stallo a quota S/L

$Vs = Vso / \sqrt{\sigma}$

Velocità di stallo in quota



Polari tecniche – LEGAME V-CL

$$V_{SO} = \sqrt{\frac{2}{\rho_o}\frac{W}{S}\frac{1}{CL_{MAX}}}$$

La velocità di stallo è la minima velocità di sostentamento a quota costante.

Il CL massimo in configurazione pulita (senza flap) è funzione del profilo, della forma in pianta (AR, rastremazione) e soprattutto della freccia.

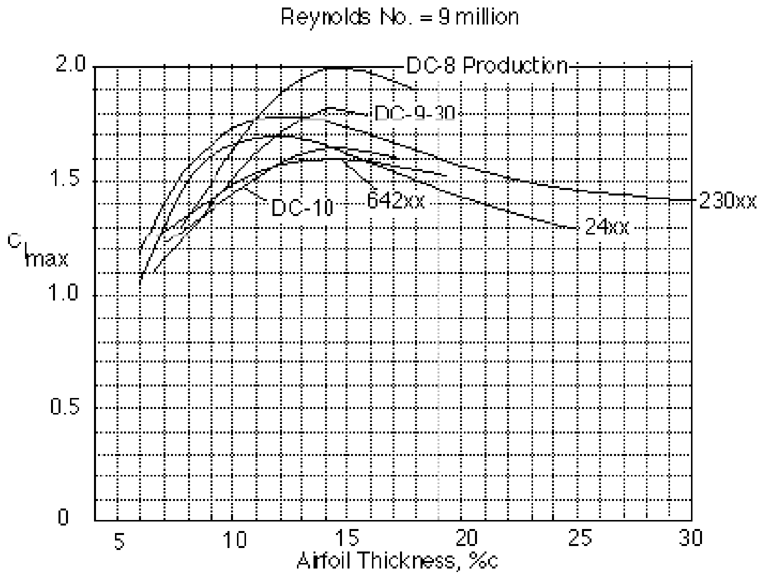
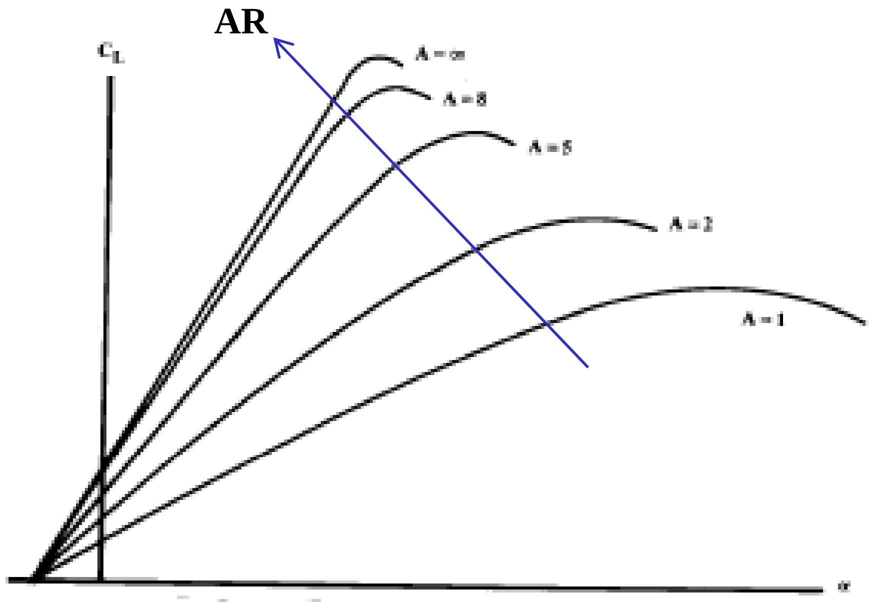
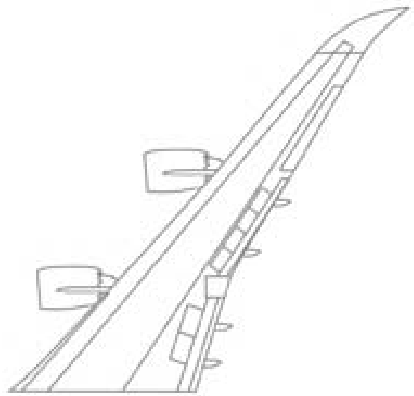


Figure 1. Section $C_{l_{max}}$ for Various Families of Airfoils.

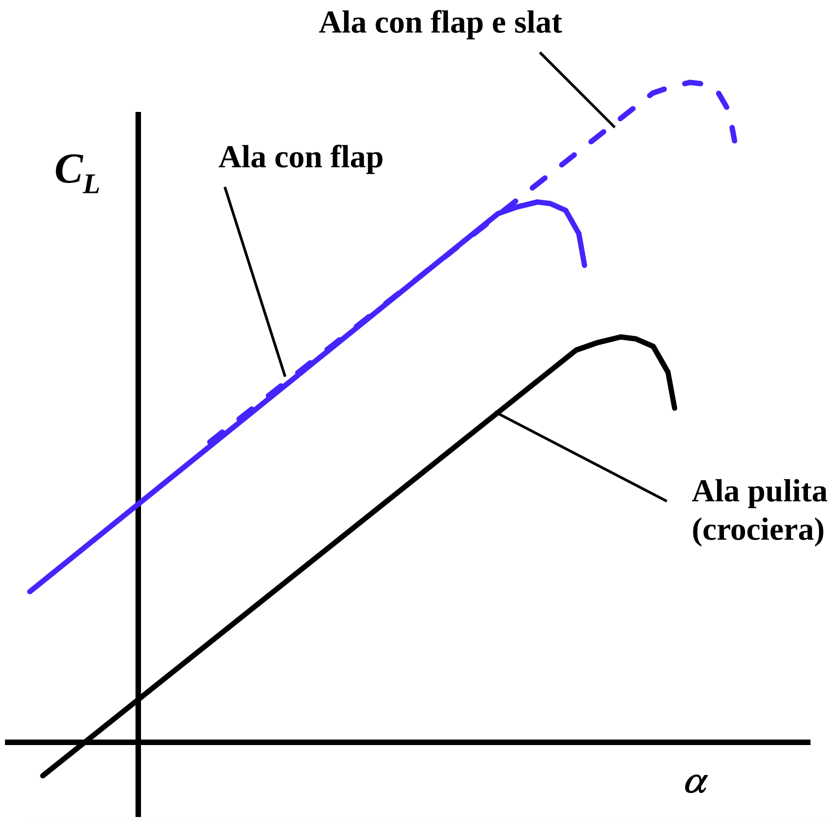


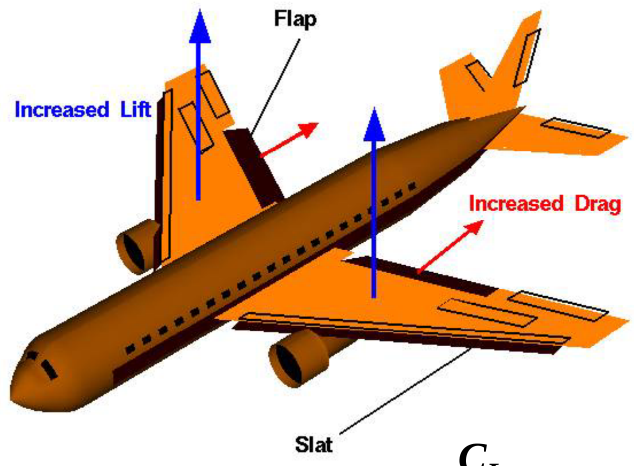
$$(C_{L_{max}})_{sweep}/(C_{L_{max}})_{zero\ sweep} = \cos\Lambda$$



Ipersostentazione

Si usano flap/slat per aumentare la capacità portante (il max CL) nelle fasi di decollo ed atterraggio.

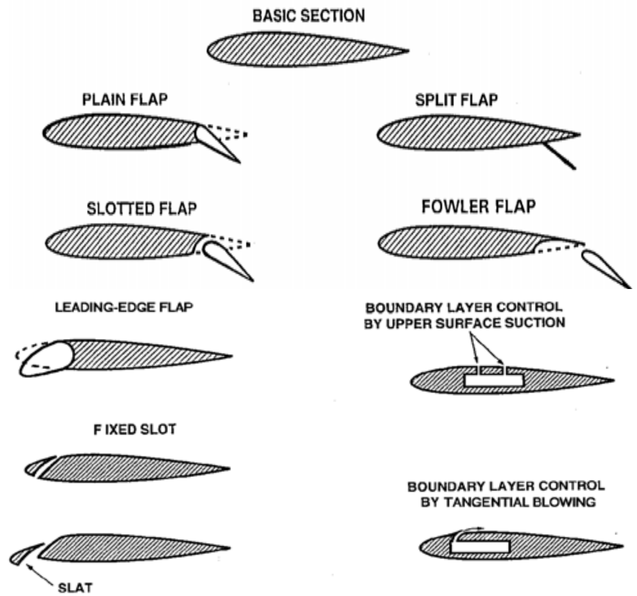




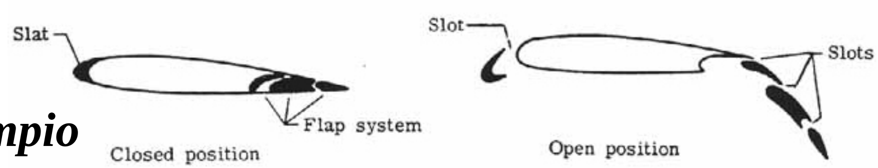
	$C_{L\,max}$
Pulito (crociera)	*1.4-1.6*
Decollo (flap e slat 15-20°)	*1.8-2.2*
Atterraggio (flap 35-40° e slat)	*2.3-2.9*

FLAP

SLAT



Esempio B737



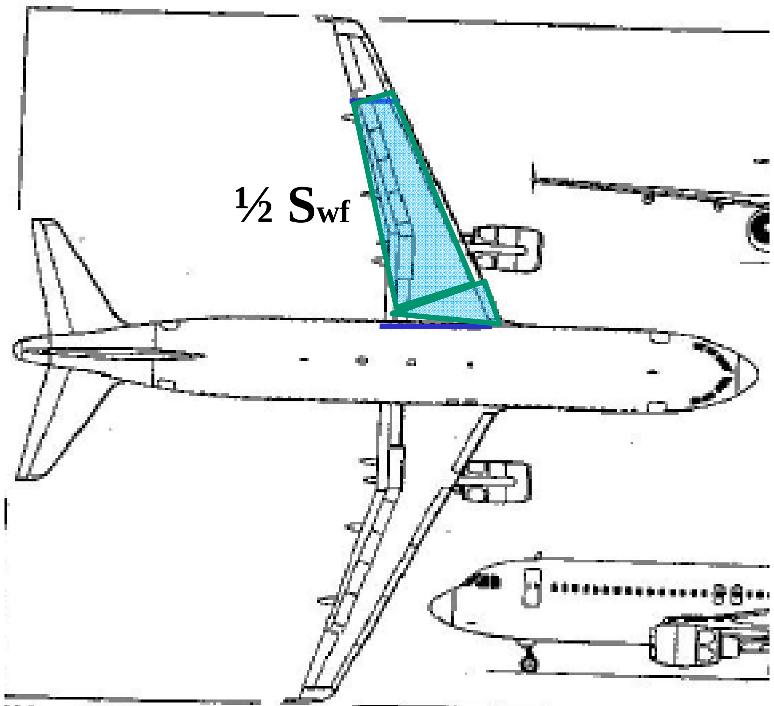
(b) Complex slotted flap of Boeing 737.

Ipersostentazione

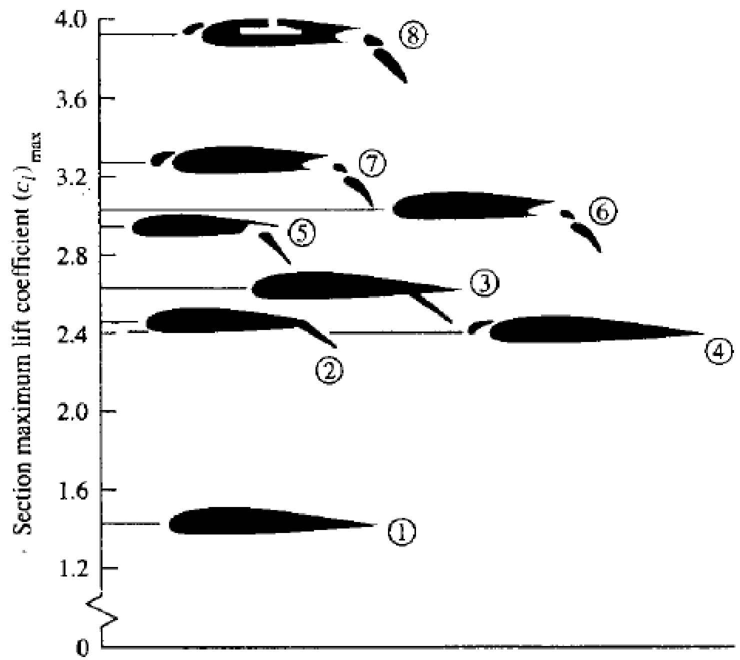
I valori bidimensionali possono arrivare fino a 4.0, per sistemi avanzati con fowler-multiple slotted flap e slat.

Il valore finale sul velivolo risente principalmente della limitata superficie flappata (o slattata) e dell'angolo di freccia.

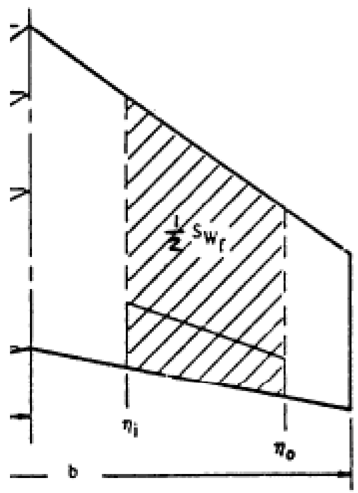
$$\Delta_f C_{L_{max}} = .92\ \Delta_f c_{\ell_{max}} \frac{S_{wf}}{S} \cos\Lambda_{1/4}$$



Airbus A320 twin-turbofan single-aisle 150/179-seat airliner (Dennis...



Valore del Clmax 2-D con flap e slat



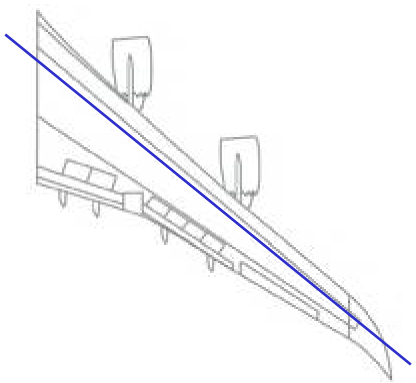
Ipersostentazione

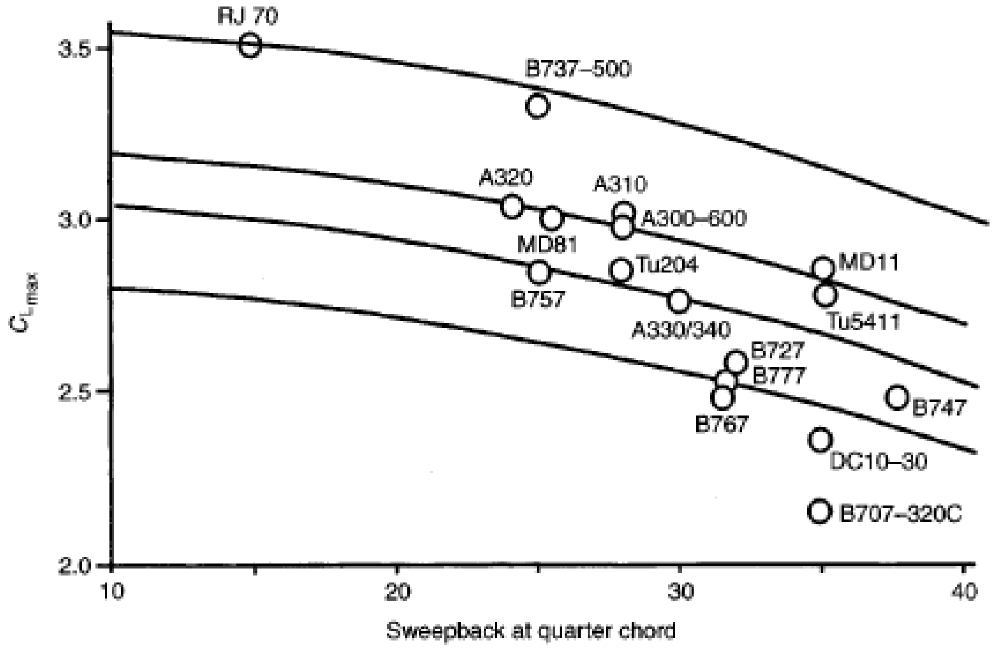
I valori bidimensionali possono arrivare fino a 4.0, per sistemi avanzati con fowler-multiple slotted flap e slat.
Il valore finale sul velivolo risente principalmente della limitata superficie flappata (o slattata) e dell'angolo di freccia.

High-Lift Device		Typical Flap Angle		$(C_L)_{max}/\cos\Lambda$	
Trailing Edge	Leading Edge	Takeoff	Landing	Takeoff	Landing
Plain flap		20°	60°	1.4–1.6	1.7–2.0
Single-slotted flap		20°	40°	1.5–1.7	1.8–2.2
Fowler flap					
single-slotted		15°	40°	2.0–2.2	2.5–2.9
double-slotted		20°	50°	1.7–1.95	2.3–2.7
double-slotted	slat	20°	50°	2.3–2.6	2.8–3.2
triple-slotted	slat	20°	40°	2.4–2.7	3.2–3.5

$$\Delta_f C_{L_{max}} = .92\ \Delta_f c_{\ell_{max}} \frac{S_{wf}}{S} \cos\Lambda_{1/4}$$

$\Lambda_{c/4}$





$\Lambda_{c/4}$

Polari tecniche – SPINTA RICHIESTA al volo livellato

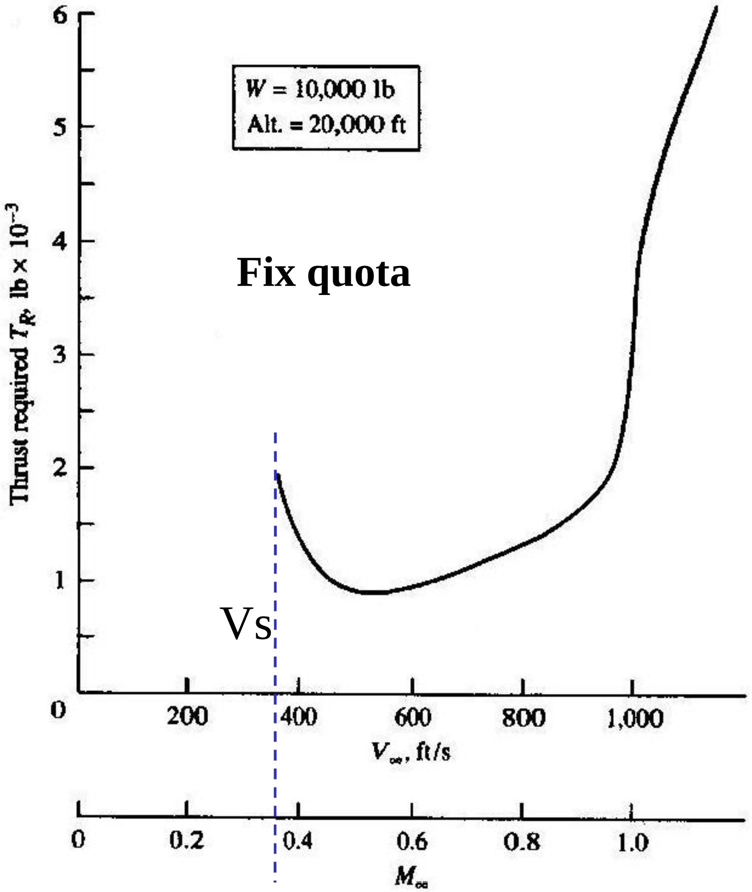
- La vel. Minima di sostentamento è la velocità di stallo

$$V_{so} = \sqrt{\frac{2}{\rho_o}\frac{W}{S}\frac{1}{CL_{MAX}}} \qquad V_s = V_{so} / \sqrt{\sigma}$$

$$V = \sqrt{\frac{2}{\rho}}\sqrt{\frac{W}{S}}\sqrt{\frac{1}{CL}} = \sqrt{\frac{2}{\rho_o \sigma}}\sqrt{\frac{W}{S}}\sqrt{\frac{1}{CL}}$$

$$CL = \frac{2}{\rho}\frac{W}{S}\frac{1}{V^2}$$

Legame tra coeff. di portanza e velocità di volo



Non ha senso calcolare la curva di resistenza per V<Vs

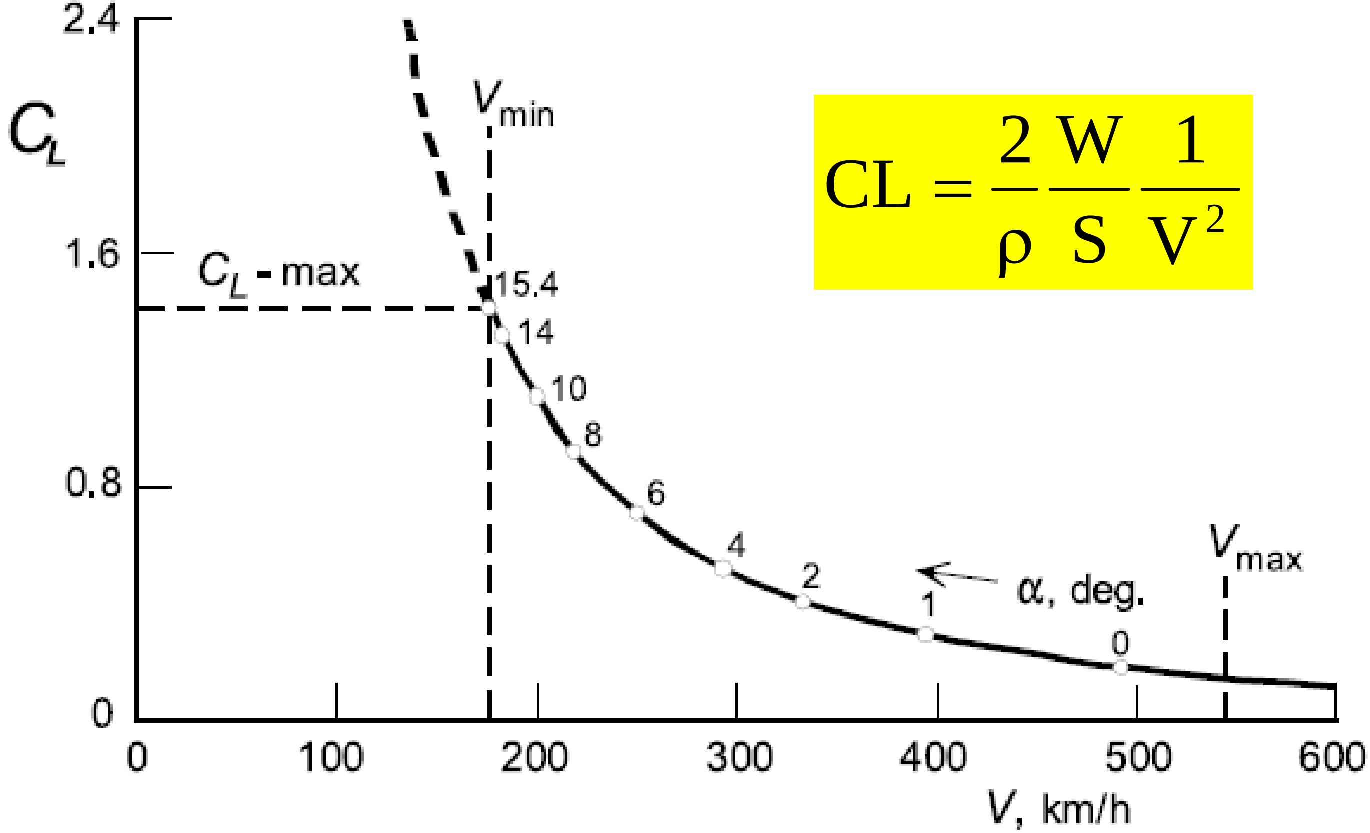
Per data quota

$$V \propto \frac{1}{\sqrt{CL}}$$

$$CL \propto \frac{1}{V^2}$$

Ricordiamo anche che CL è legato all'angolo di attacco α

Legame tra coeff. di portanza e velocità di volo
(per data:
- quota
- dati velivolo , cioè peso W e sup. alare S



$$CL = \frac{2}{\rho}\frac{W}{S}\frac{1}{V^2}$$

Polari tecniche – SPINTA RICHIESTA al volo livellato

RESISTENZA

$$D = \frac{1}{2}\rho V^2 S C_D$$

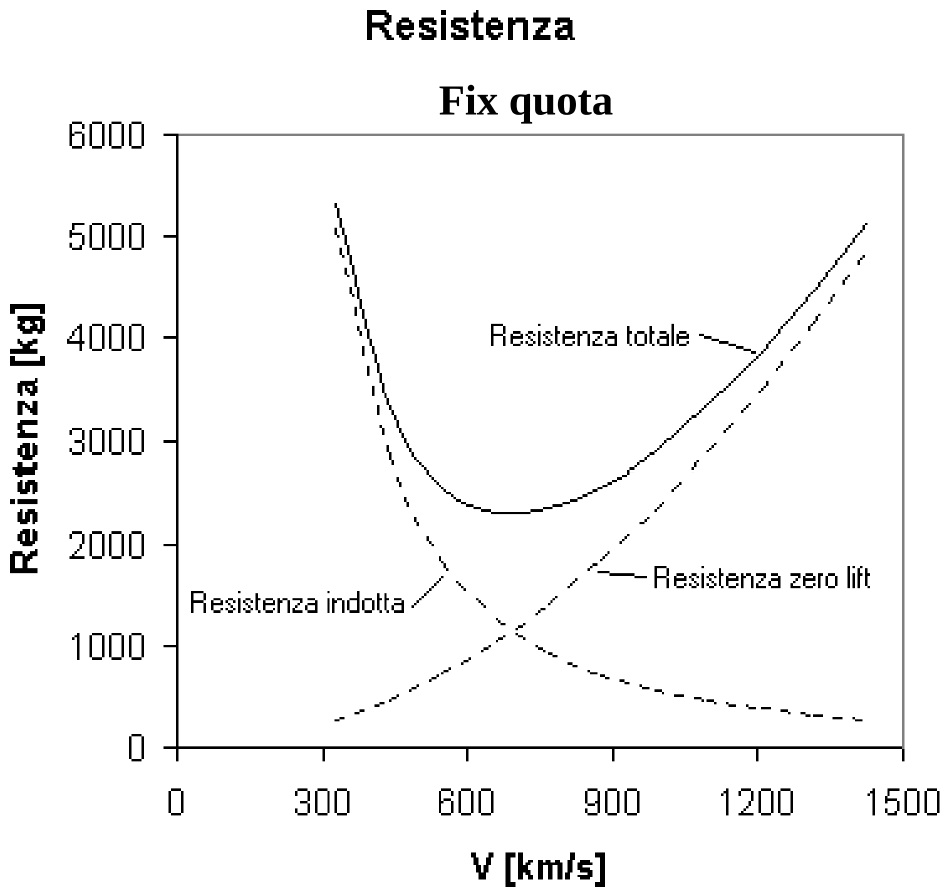
$$C_D = C_{Do} + K C_L^2$$

$$\mathbf{D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{1}{2}\rho V^2 S K C_L^2}$$

Essendo

$$CL \propto \frac{1}{V^2}$$

Il secondo termine è una funzione $= f\left(\frac{1}{V^2}\right)$

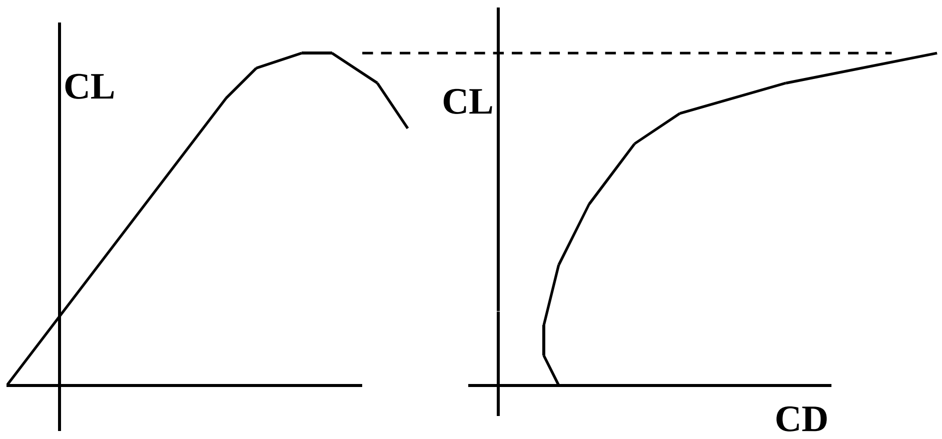


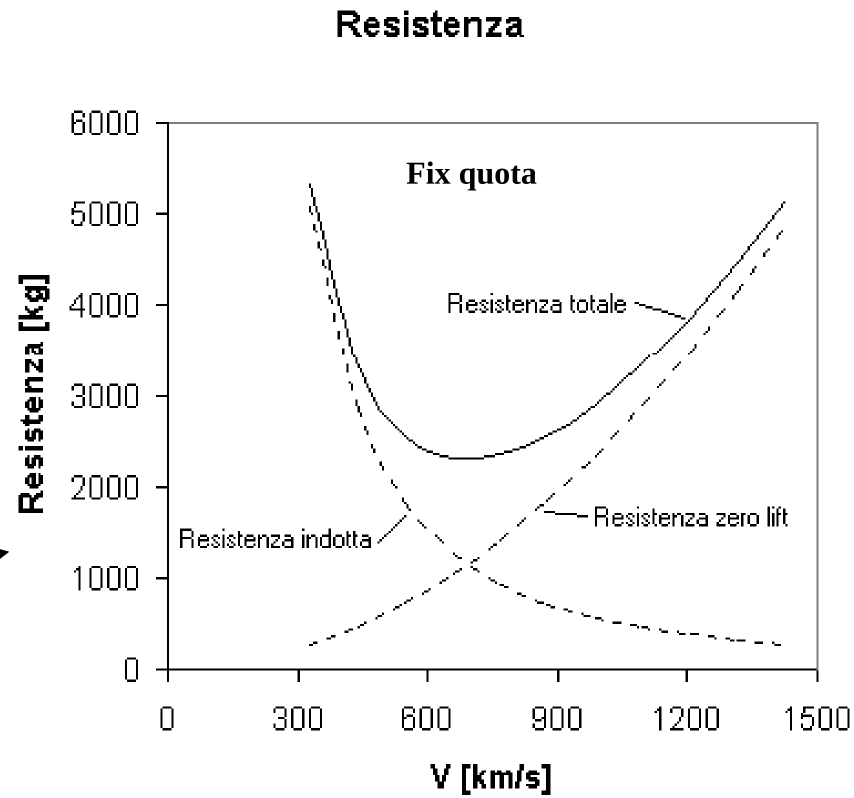
L'AEREO E' DIVERSO RISPETTO AGLI ALTRI MEZZI DI TRASPORTO
AUTO o TRENO => La resistenza aumenta all'aumentare della velocità

Polari tecniche – SPINTA RICHIESTA al volo livellato

RESISTENZA

$$D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{2KS}{\rho V^2}\left(\frac{W}{S}\right)^2$$





Polare (CL,CD)

\+

- Peso W
- Superficie alare S
- Quota ρ

\+ Ipotesi volo livellato L=W

Polari tecniche

SPINTA RICHIESTA al volo livellato

RESISTENZA

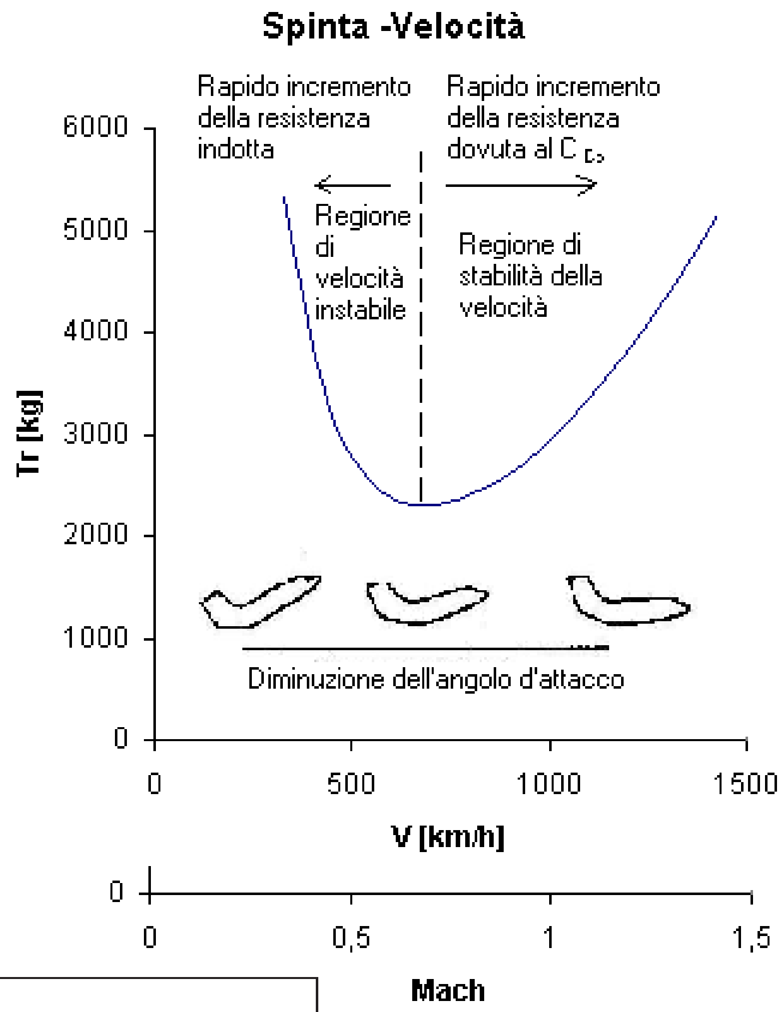
$$D = \frac{1}{2}\rho V^2 S C_D$$

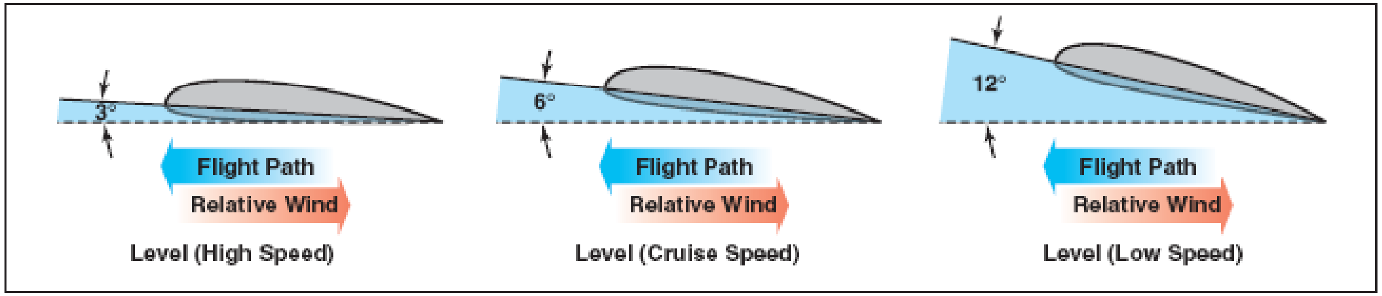
$$C_D = C_{Do} + K C_L^2$$

$$\mathbf{D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{1}{2}\rho V^2 S K C_L^2}$$

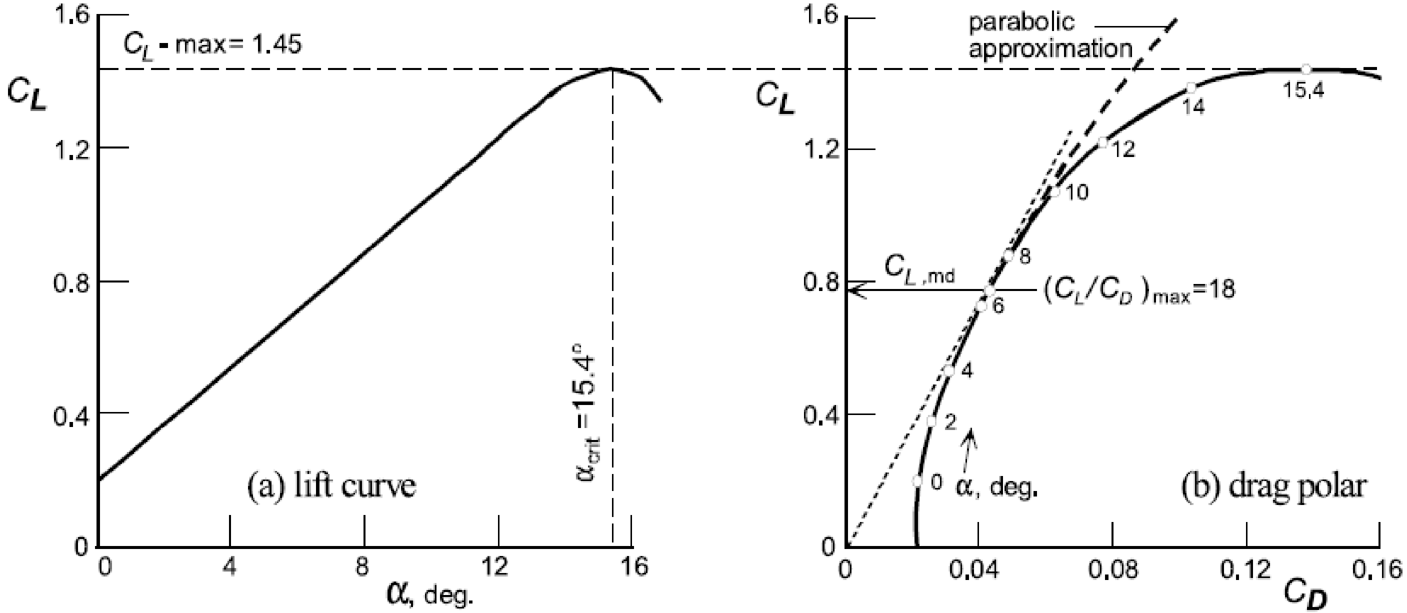
Legame tra V , CL ed α

$$V \propto \frac{1}{\sqrt{CL}} \qquad CL \propto \frac{1}{V^2}$$





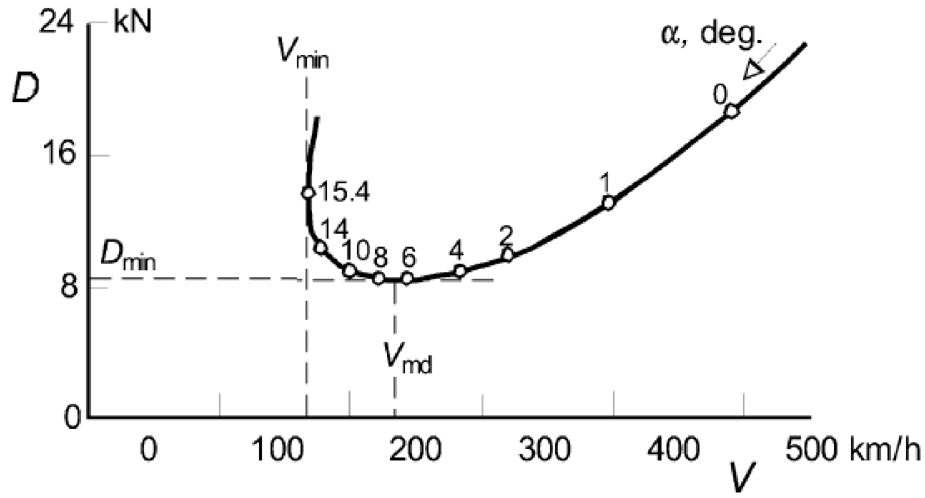
Legame tra coeff. di portanza, angolo d'attacco e coeff. di resistenza (polare del velivolo)



$$\mathbf{D} = \frac{\mathbf{1}}{\mathbf{2}}\rho \mathbf{V}^2 \mathbf{S} \mathbf{C}_{\mathbf{Do}} + \frac{\mathbf{1}}{\mathbf{2}}\rho \mathbf{V}^2 \mathbf{S} \mathbf{K} \mathbf{C}_{\mathbf{L}}^{\mathbf{2}}$$

$$D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{2KS}{\rho V^2}\left(\frac{W}{S}\right)^2$$

O anche $$D = \frac{W}{E}$$



(a) Drag versus flight speed

Polari tecniche – SPINTA RICHIESTA al volo livellato

RESISTENZA

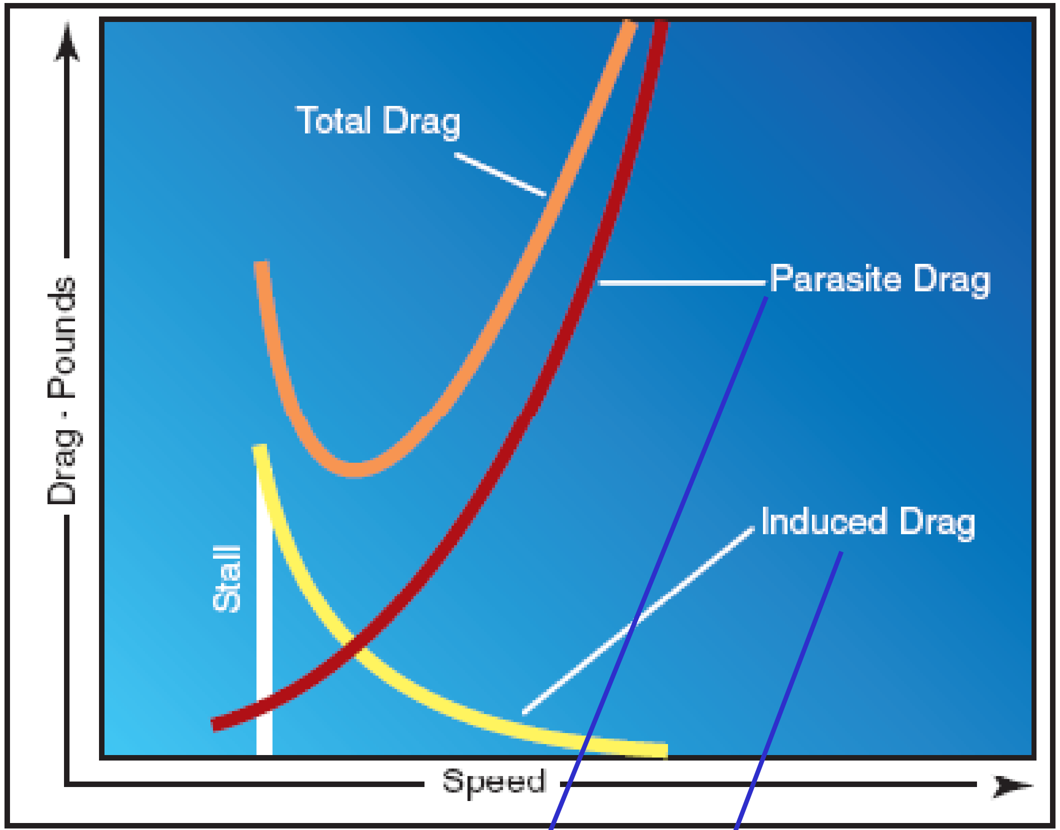
$$D = \frac{1}{2}\rho V^2 S C_D$$

$$C_D = C_{Do} + K C_L^2$$

$$\mathbf{D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{1}{2}\rho V^2 S K C_L^2}$$

Ed essendo $CL = \frac{2}{\rho}\frac{W}{S}\frac{1}{V^2}$

$$D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{2KS}{\rho V^2}\left(\frac{W}{S}\right)^2$$

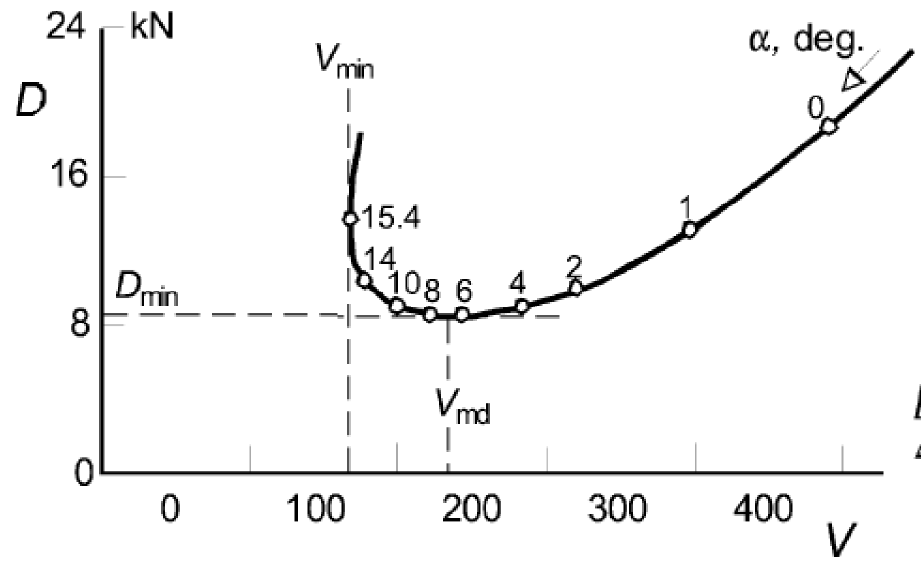


$$D = T_{no} = aV^2 + b\frac{1}{V^2}$$

Polari tecniche – SPINTA RICHIESTA al volo livellato

RESISTENZA

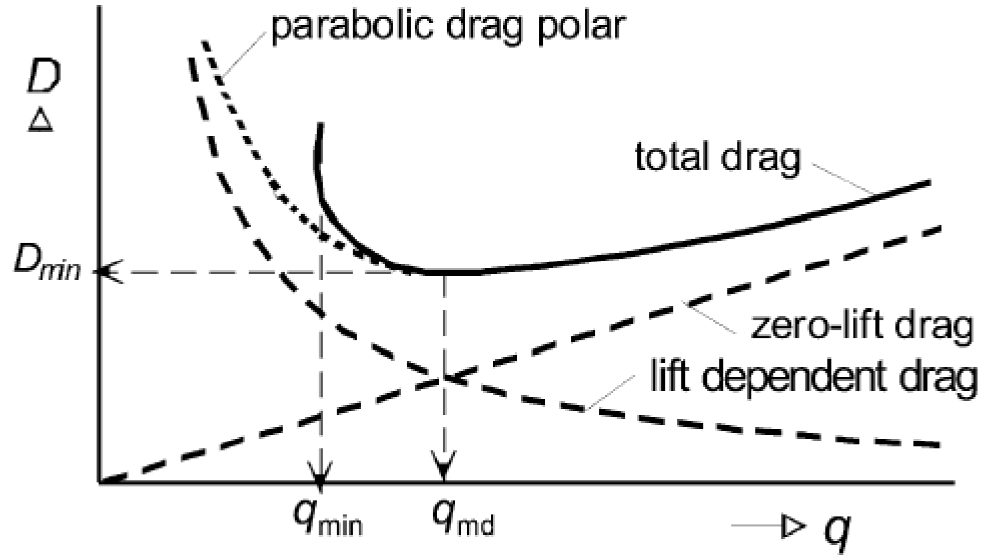
$$D = \frac{1}{2}\rho V^2 S C_{Do} + \frac{2KS}{\rho V^2}\left(\frac{W}{S}\right)^2$$



(a) Drag versus flight speed

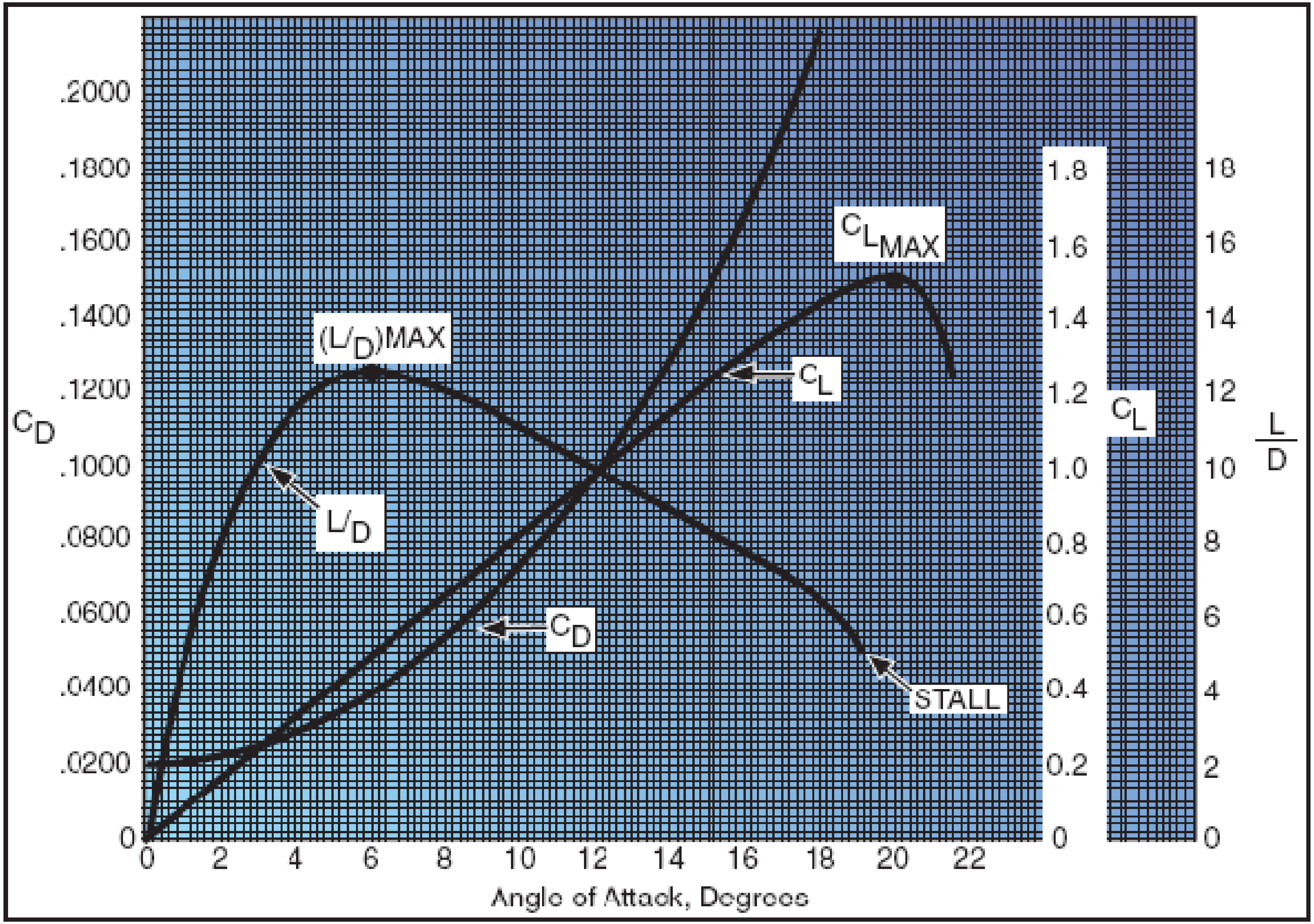
In termini di pressione dinamica

$$D = q \cdot S C_{Do} + \frac{1}{q} \cdot KS\left(\frac{W}{S}\right)^2$$



(b) Drag versus dynamic pressure

Polari tecniche – SPINTA RICHIESTA al volo livellato



Polari tecniche – SPINTA RICHIESTA al volo livellato

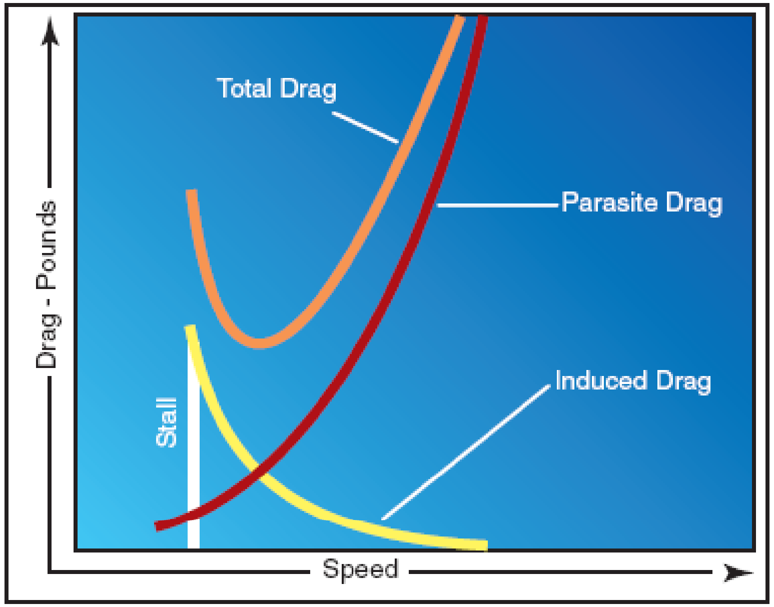
Approccio analitico

$$L = W = qSC_L = \frac{1}{2}\rho V^2 SC_L \longrightarrow C_L = \frac{2W}{\rho V^2 S}$$

$$D = qSC_D = qS\left(C_{Do} + KC_L^2\right)$$

$$D = \frac{1}{2}\rho V^2 S\left[C_{Do} + 4K\left(\frac{W}{\rho V^2 S}\right)^2\right]$$

$$D = \frac{1}{2}\rho V^2 SC_{Do} + \frac{2KS}{\rho V^2}\left(\frac{W}{S}\right)^2$$



$$D = T_{no} = \frac{1}{2}\rho f V^2 + \frac{2}{\rho}\frac{W^2}{S}\frac{1}{\pi A Re}\frac{1}{V^2}$$

$$D = T_{no} = aV^2 + b\frac{1}{V^2}$$

Polari tecniche – PUNTI CARATTERISTICI PUNTO E

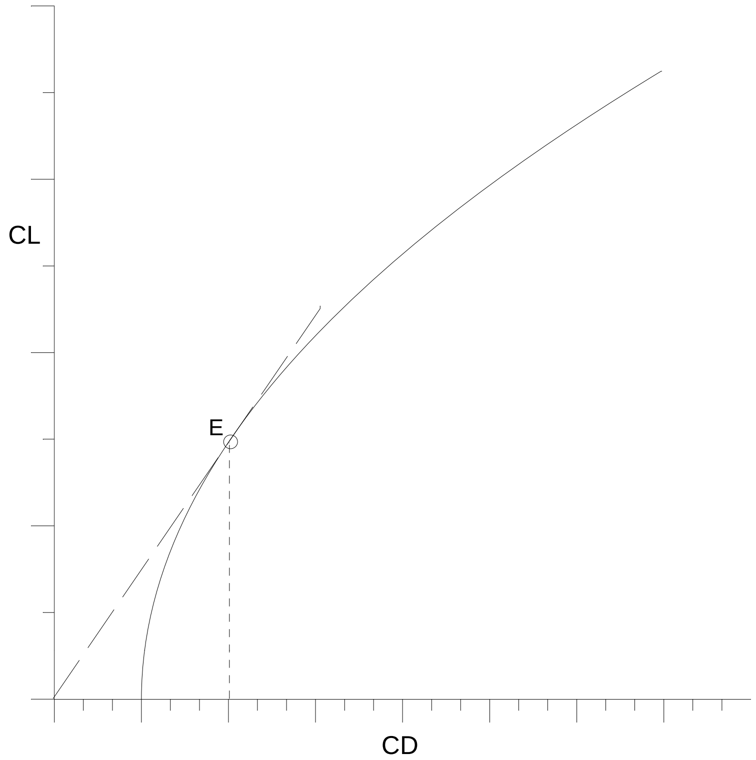
$$CL_E = \sqrt{\frac{CDo}{K}} = \sqrt{\pi \cdot AR \cdot e \cdot CDo}$$

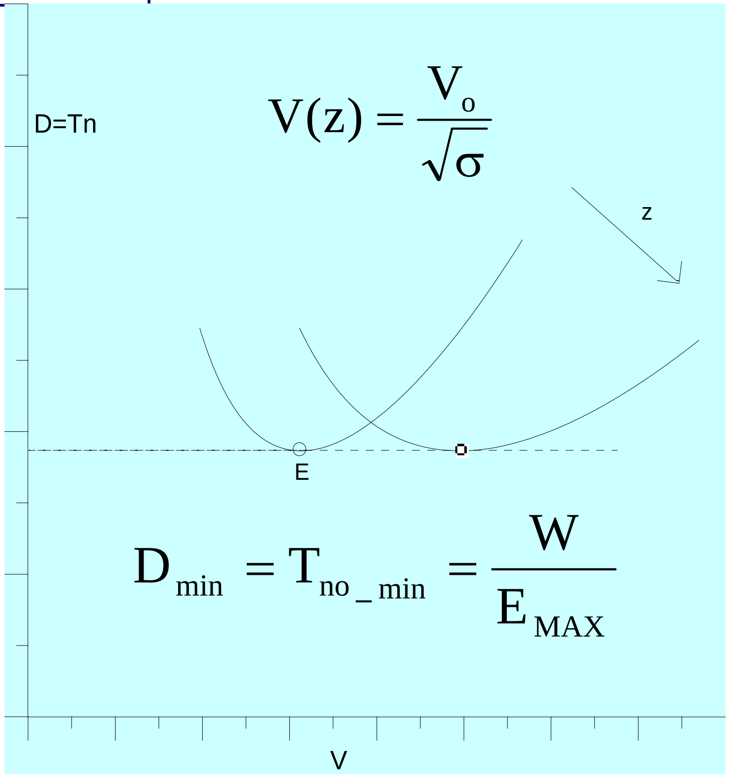
$$CD_E = CDo + KCL_E^{\ 2} = 2\,CDo$$

$$E_{MAX} = E_E = \frac{CL_E}{CD_E} = \frac{\sqrt{\pi \cdot AR \cdot e \cdot CDo}}{2 \cdot CDo} = \sqrt{\frac{\pi}{4}\frac{AR \cdot e}{CDo}}$$

$$V_E = \sqrt{\frac{2}{\rho}}\sqrt{\frac{W}{S}}\sqrt{\frac{1}{CL_E}}$$

$$E_{MAX} = \sqrt{\frac{\pi}{4}\frac{b_e^{\ 2}}{f}}$$

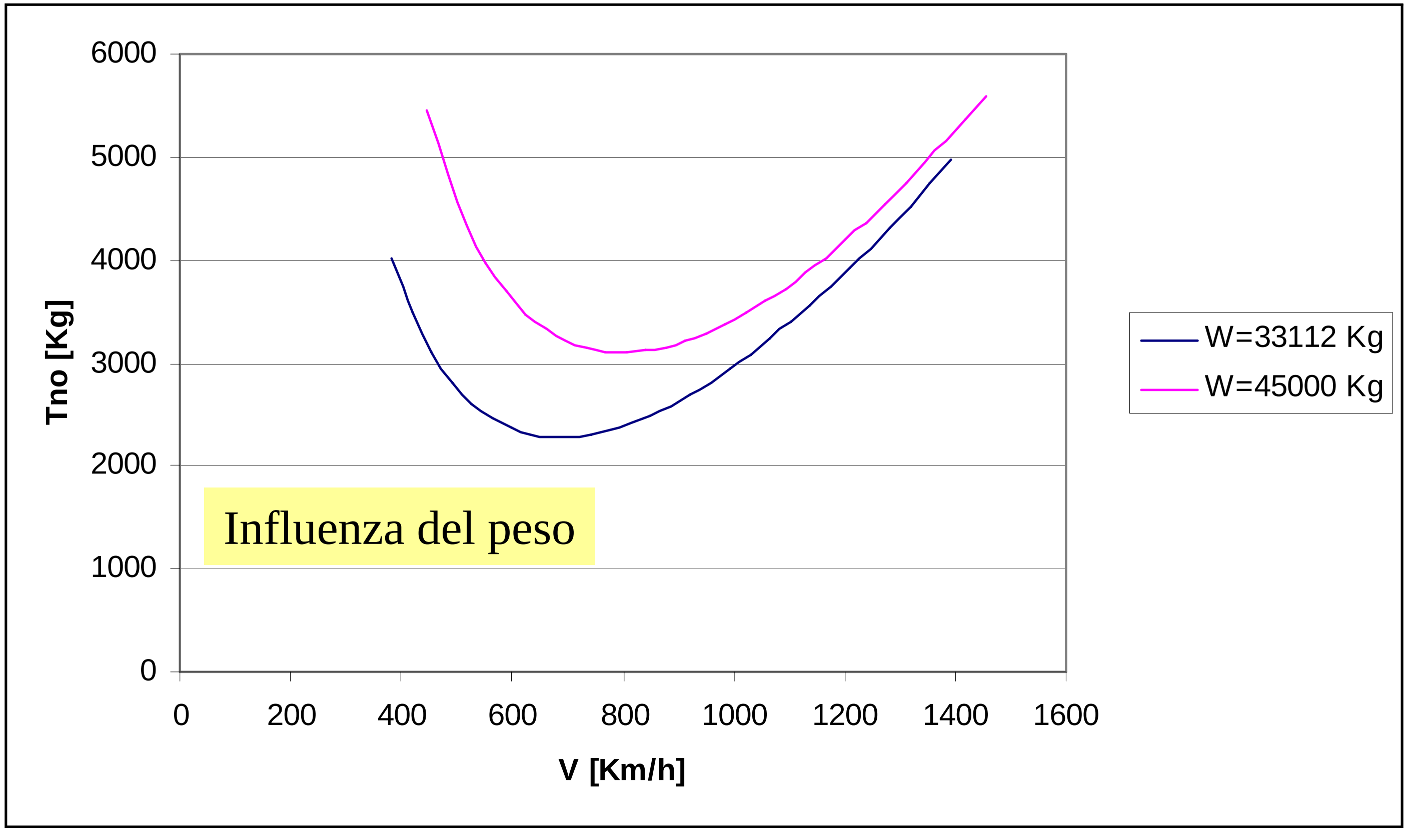




$$V(z) = \frac{V_o}{\sqrt{\sigma}}$$

$$D_{min} = T_{no\_min} = \frac{W}{E_{MAX}}$$

Polari tecniche – SPINTA RICHIESTA al volo livellato



La resistenza parassita non dipende dal peso.
La velocità massima è scarsamente influenzata dal peso del velivolo.
Il rateo di salita invece è molto influenzato.

Polari tecniche – POTENZA RICHIESTA al volo livellato

$$\Pi_{no} = T_{no} \cdot V = D \cdot V$$

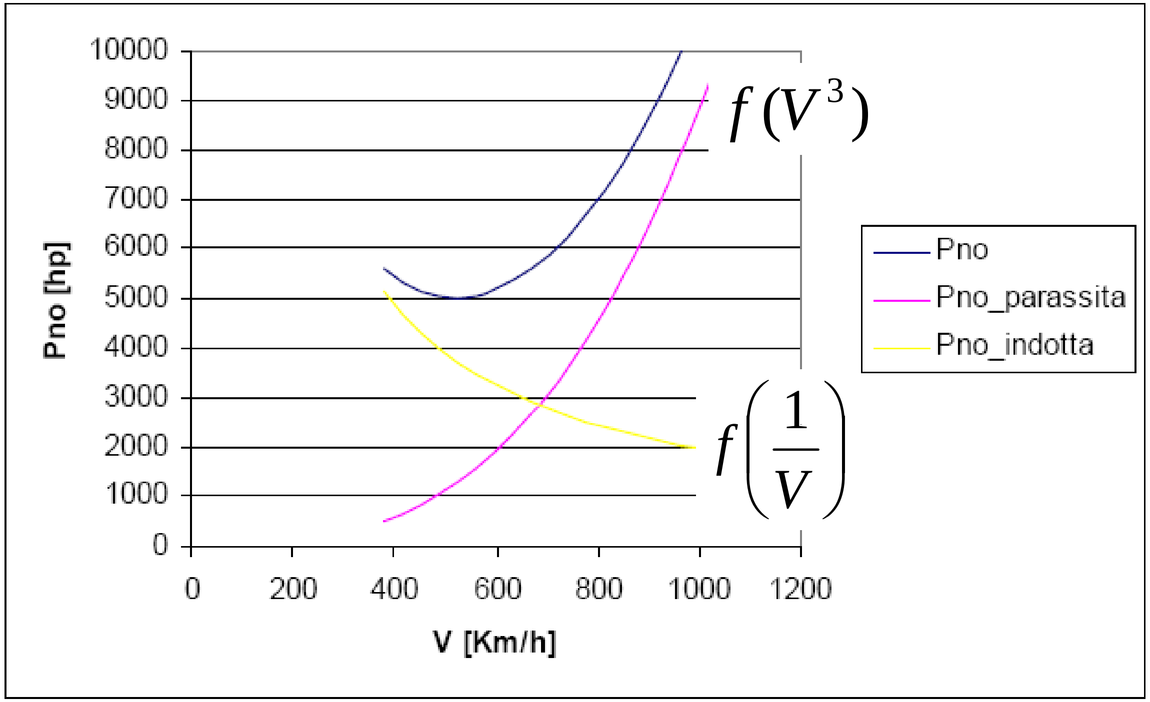
$$\Pi_{no} = D \cdot V = \frac{1}{2}\rho \cdot V^2 \cdot S \cdot (CDo + KCL^2) \cdot V$$

$$\Pi_{no} = \frac{1}{2}\rho \cdot CDo \cdot S \cdot V^3 + \frac{1}{2}\rho \cdot S \cdot V^3 \cdot KCL^2$$

$$CL = \frac{2}{\rho}\frac{W}{S}\frac{1}{V^2}$$

$$\Pi_{no} = \frac{1}{2}\rho \cdot CDo \cdot S \cdot V^3 + \frac{2}{\rho} \cdot S \cdot K \cdot \left(\frac{W}{S}\right)^2 \cdot \frac{1}{V}$$

$$\Pi_{no} = a \cdot V^3 + \frac{b}{V}$$



Polari tecniche – PUNTO P

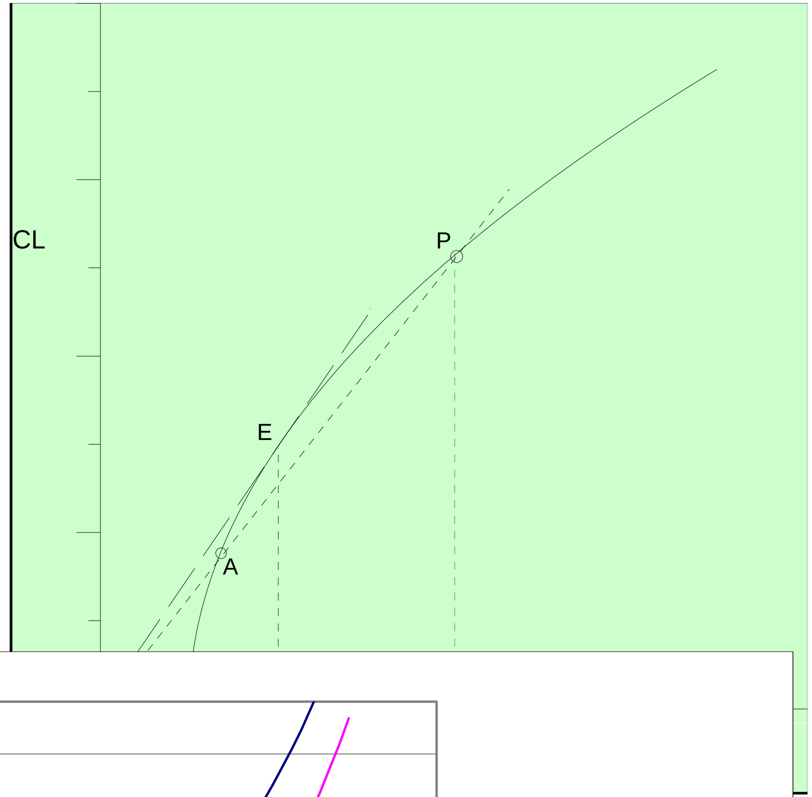
$$CL_P = \sqrt{3} \cdot CL_E = 1.73 \cdot CL_E$$

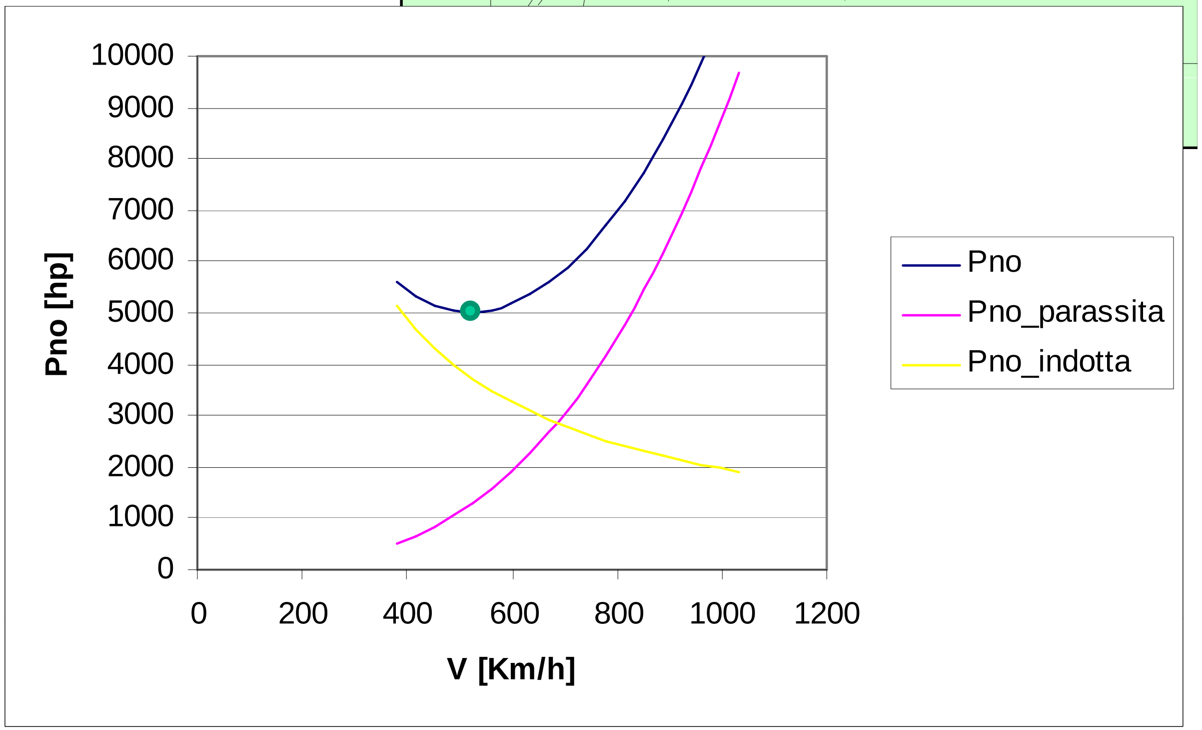
$$CD_P = 4 \cdot CDo$$

$$E_P = \frac{CL_P}{CD_P} = \frac{\sqrt{3} \cdot CL_E}{4 \cdot CDo} = \frac{\sqrt{3}}{2} \frac{CL_E}{CD_E}$$

$$V_P = \sqrt{\frac{2}{\rho}} \sqrt{\frac{W}{S}} \sqrt{\frac{1}{CL_P}} = \sqrt{\frac{2}{\rho}} \sqrt{\frac{W}{S}} \sqrt{\frac{1}{\sqrt{3} \cdot CL_E}}$$

$$V_P = \frac{V_E}{\sqrt[4]{3}} = \frac{V_E}{1.32}$$





Polari tecniche – POTENZA RICHIESTA al volo livellato

$$D = T_{no} = \frac{W}{E} \qquad \Pi_{no} = T_{no} \cdot V = \frac{W}{E} V = \frac{W}{(E/V)}$$

$$\Pi_{no\_MIN} => \left(\frac{E}{V}\right)_{MAX} \qquad \Pi_{no} = \frac{W}{E} V = W \cdot \frac{CD}{CL} \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{\frac{W}{S}} \cdot \sqrt{\frac{1}{CL}}$$

$$\Pi_{no} = \sqrt{\frac{2}{\rho_o \sigma}} \cdot \sqrt{\frac{1}{S}} \cdot W^{3/2} \cdot \frac{CD}{CL^{3/2}}$$

$$\Pi_{no\_MIN} = \sqrt{\frac{2}{\rho_o}} \cdot \frac{1}{\sqrt{\sigma}} \cdot \frac{1}{\sqrt{S}} \cdot W^{3/2} \cdot \frac{1}{\left(\frac{CL^{3/2}}{CD}\right)_{MAX}}$$

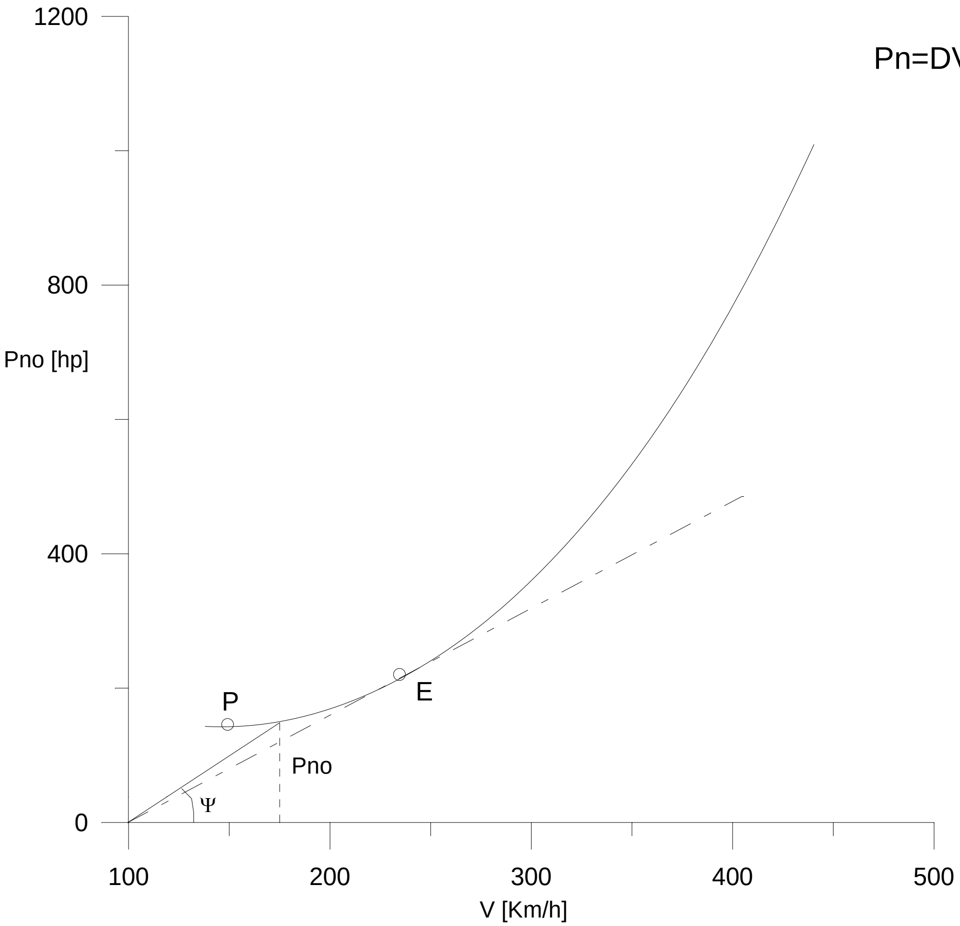
$$\Pi_{no\_MIN} => \left(\frac{CL^{3/2}}{CD}\right)_{MAX} = \left(E \cdot \sqrt{CL}\right)_{MAX}$$

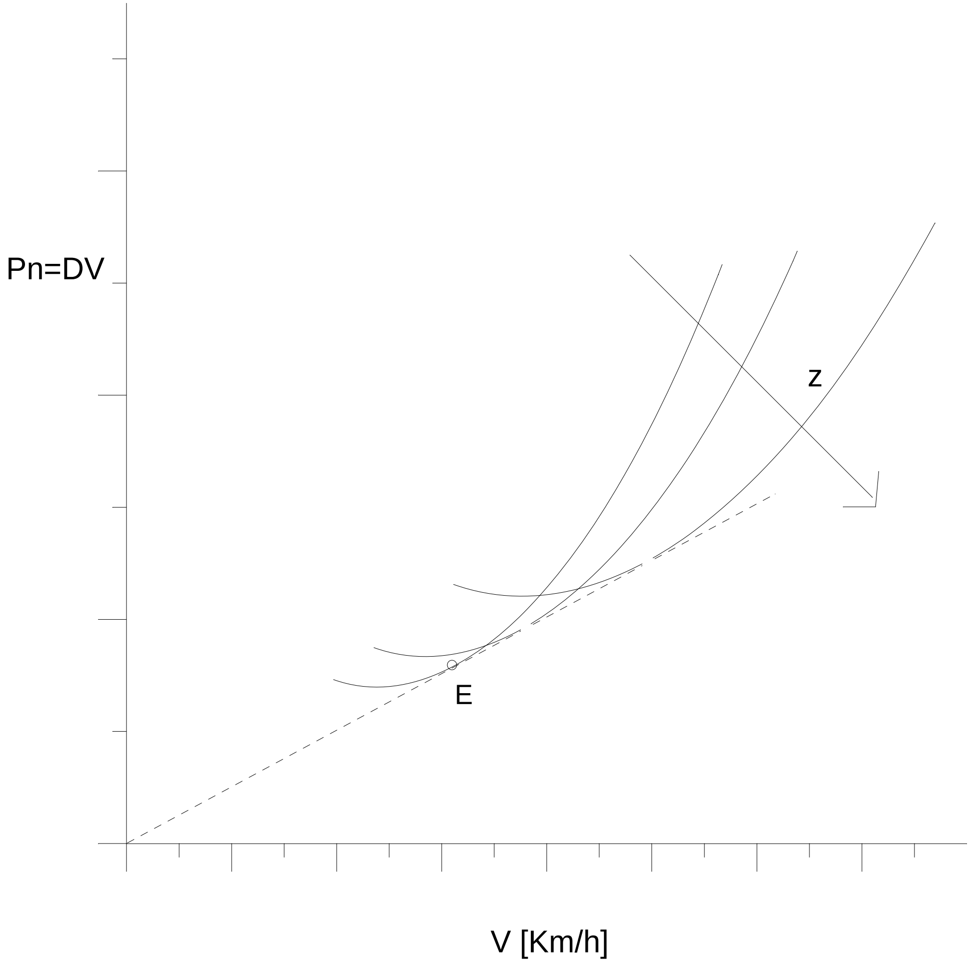
Polari tecniche – POTENZA RICHIESTA al volo livellato

PUNTO P – considerazioni grafiche

$$\Pi_{no} = V \cdot \tan\psi \qquad \tan\psi = T_{no} = D$$

$$\psi_{MIN} = ATAN(D_{MIN}) = ATAN\left(\frac{W}{E_{MAX}}\right)$$



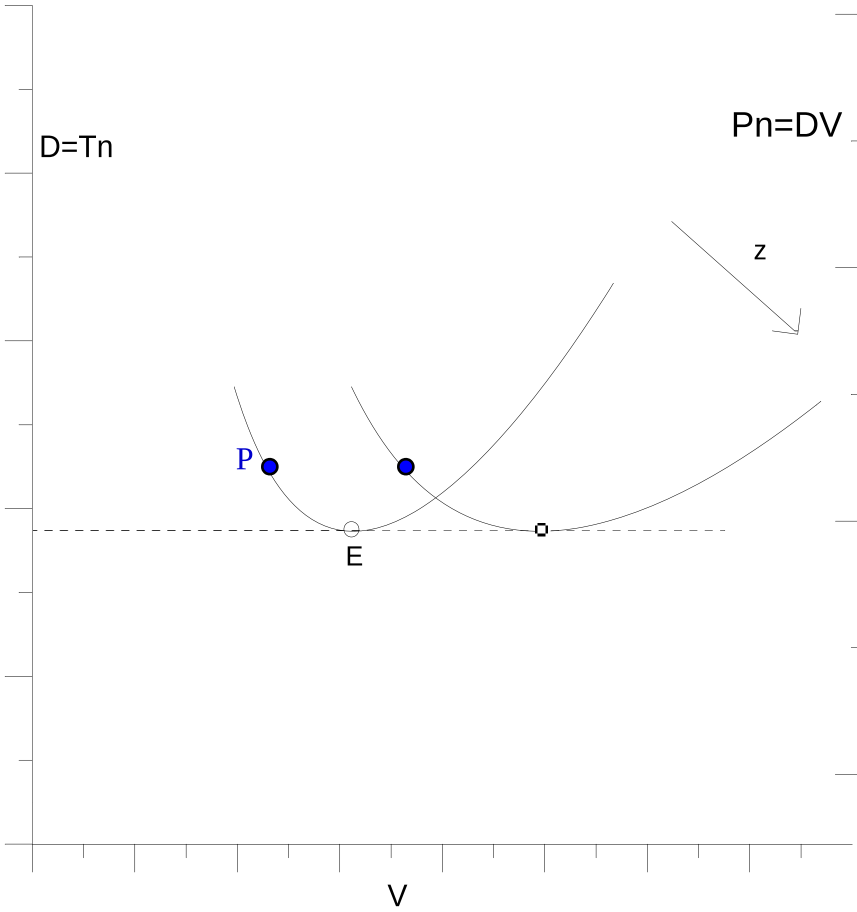


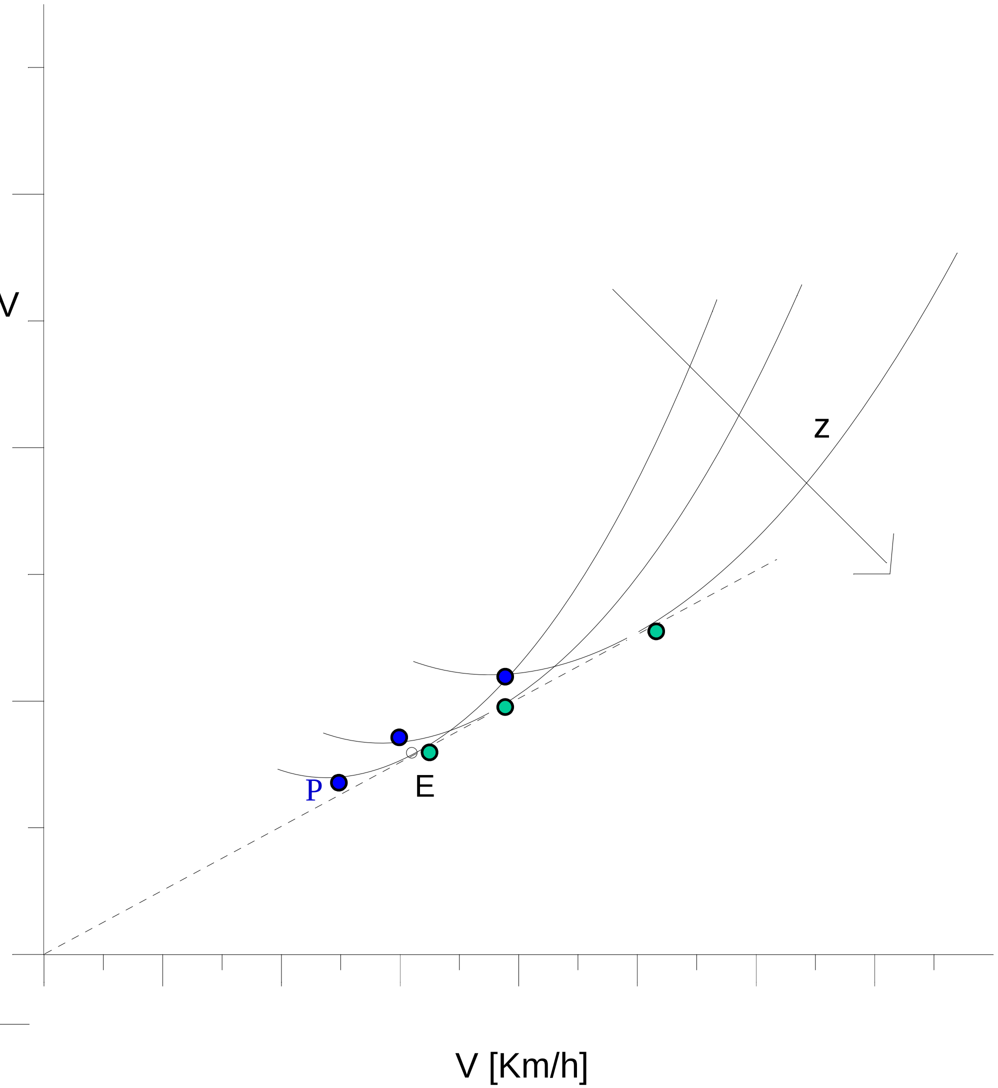
Polari tecniche

PUNTO E : Max Efficienza - Minima resistenza volo livellato $\left(E\right)_{MAX}$

PUNTO P : Min. Potenza volo livellato $\left(\Pi_{no}\right)_{MIN} = (D \cdot V)_{MIN}$ $\left(\frac{E}{V}\right)_{MAX} \Rightarrow \left(E \cdot \sqrt{CL}\right)_{MAX}$

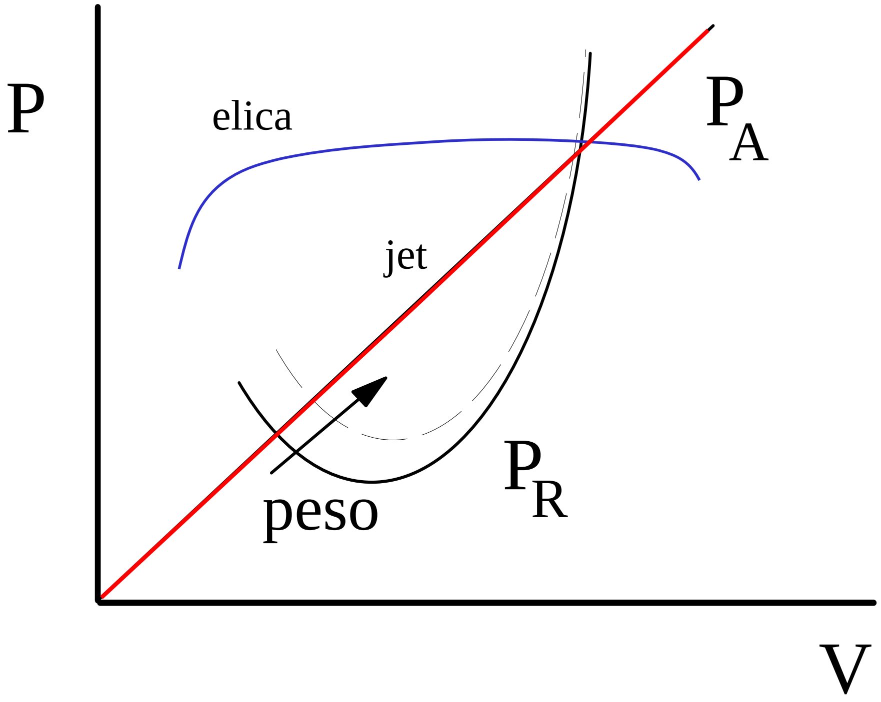
$$V_P = \frac{V_E}{\sqrt[4]{3}} = \frac{V_E}{1.32}$$

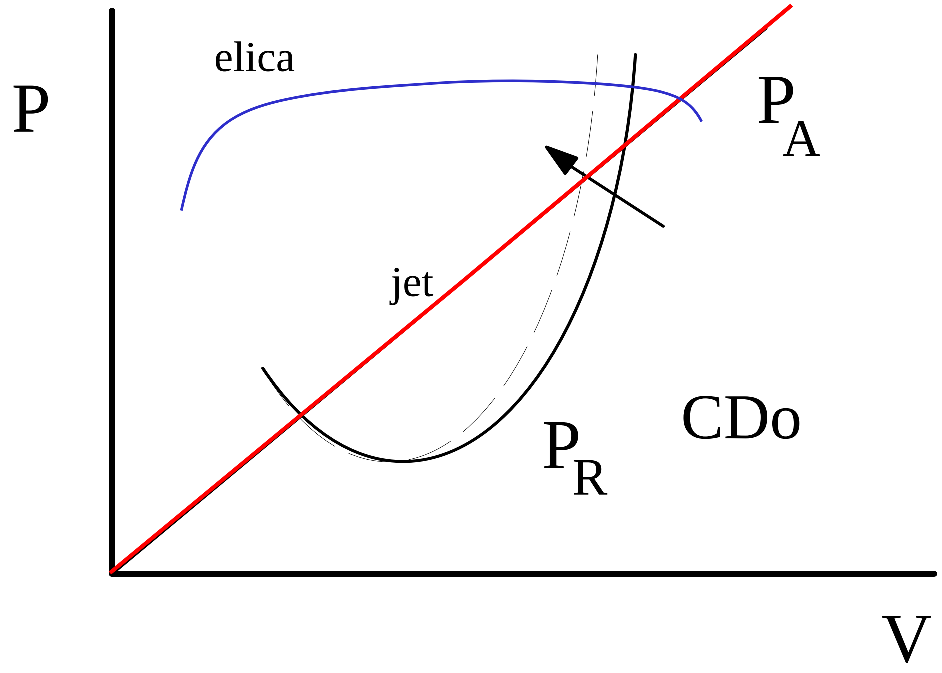




Polari tecniche – Influenze Peso e CDo su Potenza necessaria

$$\Pi_{no} = \frac{1}{2}\rho \cdot CDo \cdot S \cdot V^3 + \frac{2}{\rho} \cdot S \cdot K \cdot \left(\frac{W}{S}\right)^2 \cdot \frac{1}{V}$$





Polari tecniche – PUNTO A

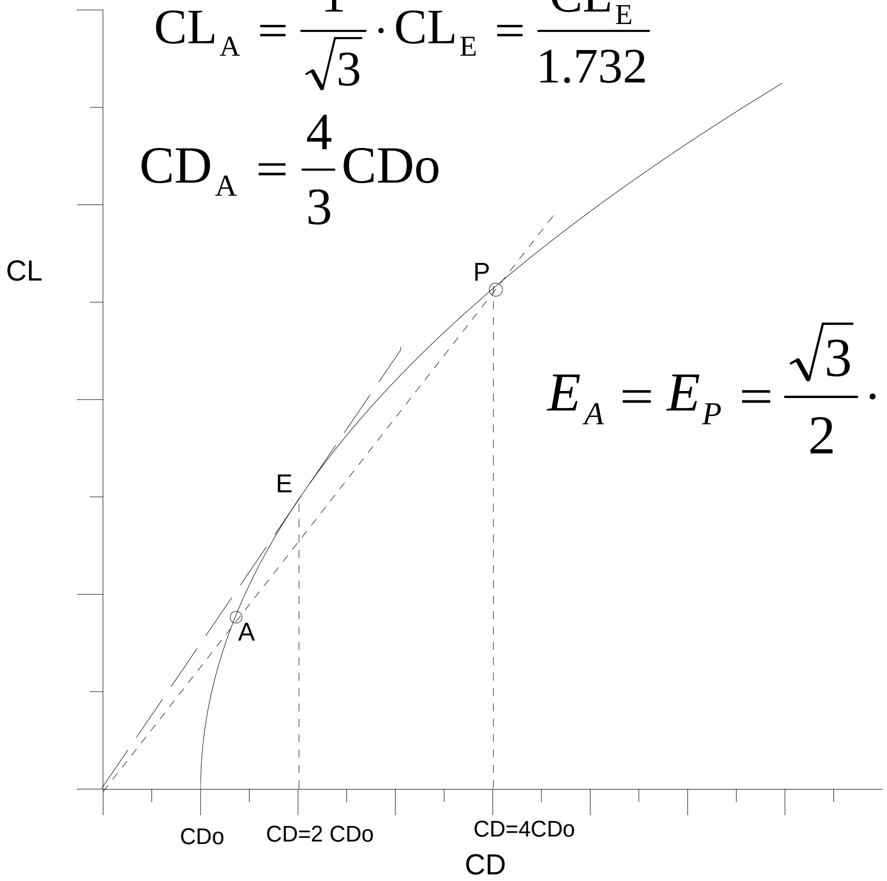
PUNTO A : $(E \cdot V)_{MAX} \Rightarrow \left(\frac{E}{\sqrt{CL}}\right)_{MAX} \Rightarrow \left(\frac{D}{V}\right)_{MIN}$

Do=3 Di

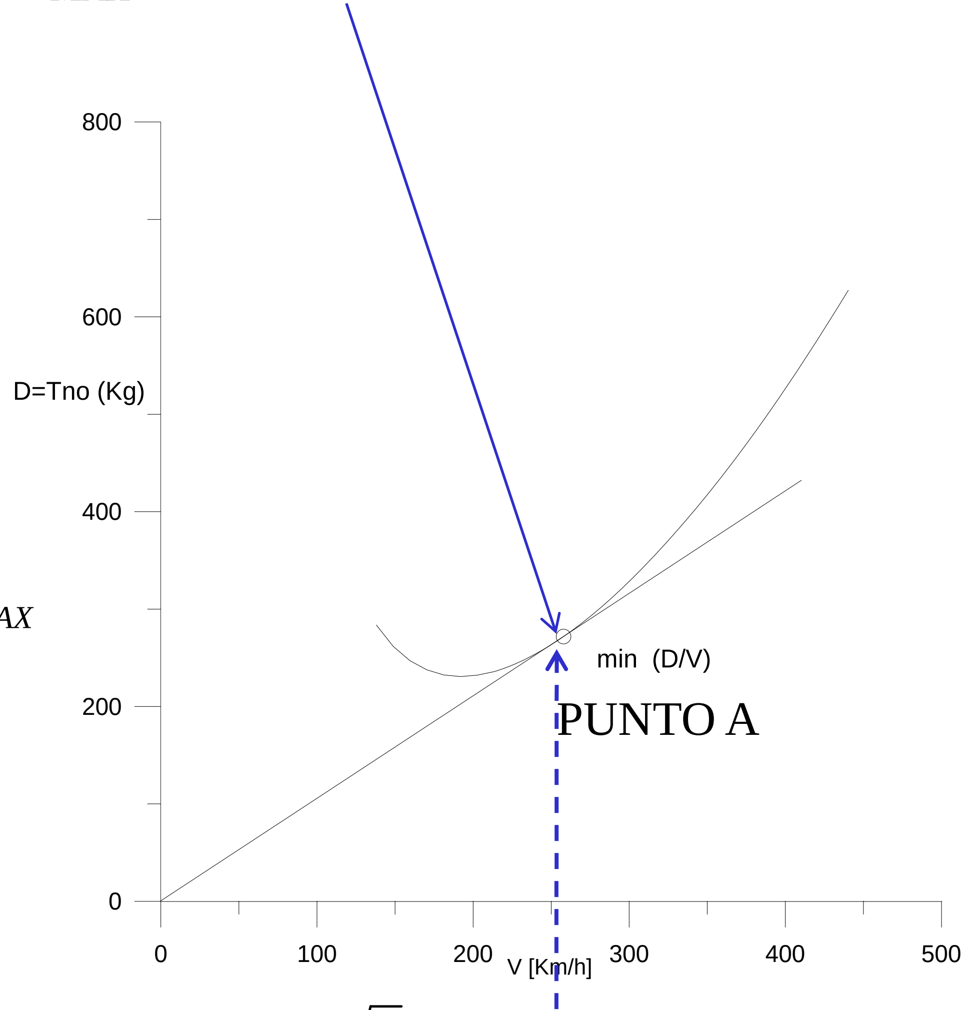
$$CDo = 3 \cdot CDi = 3 \cdot K \cdot CL^2$$

$$CL_A = \frac{1}{\sqrt{3}} \cdot CL_E = \frac{CL_E}{1.732}$$

$$CD_A = \frac{4}{3} CDo$$



$$E_A = E_P = \frac{\sqrt{3}}{2} \cdot E_{MAX}$$

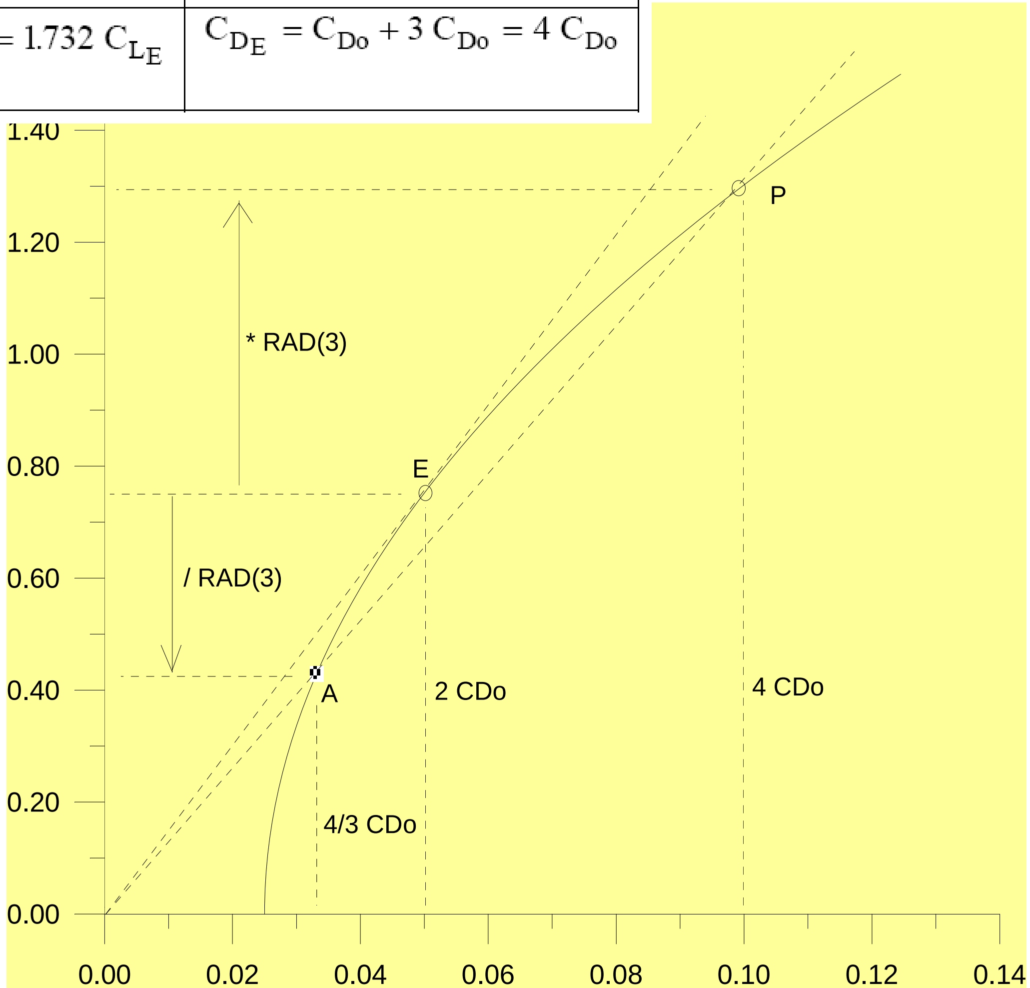


$$V_A = \sqrt[4]{3} \cdot V_E = 1.32\, V_E$$

PUNTI CARATTERISTICI POLARE

PUNTO	Efficienza CL/CD	C_L	C_D
A	$E=\sqrt{\frac{3}{4}}\,E_{max} = 0.866\,E_{max}$	$C_{L_A} = \frac{C_{L_E}}{\sqrt{3}} = 0.577\,C_{L_E}$	$C_{D_A} = C_{Do} + \frac{1}{3}C_{Do} = \frac{4}{3}C_{Do}$
E	$E=E_{max}=\sqrt{\frac{\pi}{4}\frac{AR_e}{C_{Do}}}$	$C_{L_E} = \sqrt{\pi\,AR_e\,C_{Do}}$	$C_{D_E} = C_{Do} + C_{Do} = 2\,C_{Do}$
P	$E=\sqrt{\frac{3}{4}}\,E_{max} = 0.866\,E_{max}$	$C_{L_P} = \sqrt{3}\,C_{L_E} = 1.732\,C_{L_E}$	$C_{D_E} = C_{Do} + 3\,C_{Do} = 4\,C_{Do}$

$$E_A = E_P = \frac{\sqrt{3}}{2}\cdot E_{MAX}$$



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$$\Pi_P = D_P \cdot V_P = \left(\frac{2}{\sqrt{3}} \cdot D_E\right) \cdot \left(\frac{V_E}{\sqrt[4]{3}}\right) = \frac{2}{\sqrt[4]{27}} \cdot \Pi_E = \frac{\Pi_E}{1.14}$$

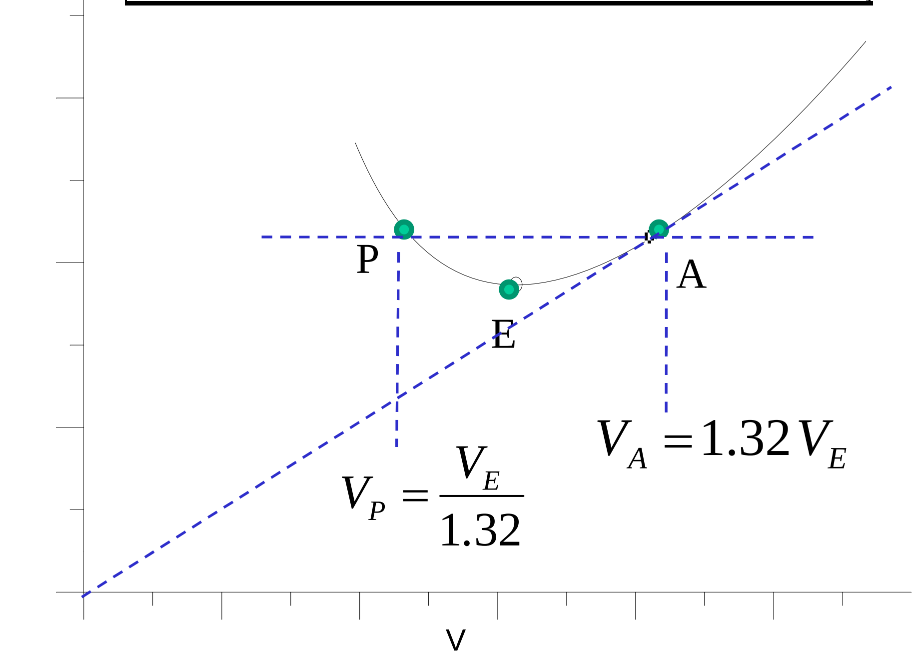
$$\Pi_A = D_A \cdot V_A = (D_P) \cdot \left(\sqrt[4]{3} \cdot V_E\right) = (D_P) \cdot \left(\sqrt[4]{3} \cdot \sqrt[4]{3} \cdot V_P\right) = \sqrt{3} \cdot \Pi_P$$

$$E_{MAX} = \sqrt{\frac{\pi}{4} \frac{AR \cdot e}{CDo}} = \sqrt{\frac{\pi}{4} \frac{b_e^{\,2}}{f}}$$

$$\Pi_{no\_MIN} = \Pi_P = \sqrt{\frac{2}{\rho_o}} \cdot \frac{1}{\sqrt{\sigma}} \cdot \frac{1}{\sqrt{S}} \cdot W^{3/2} \cdot \frac{1}{\left(\frac{C_{LP}^{\;3/2}}{C_{DP}}\right)_{MAX}}$$

$$D_E = \frac{W}{E_{MAX}}$$

$$D_A = D_P = \frac{2}{\sqrt{3}} \cdot D_E = \frac{D_E}{0.866} = 1.155 \cdot D_E$$



$$V_P = \frac{V_E}{1.32} \qquad V_A = 1.32\, V_E$$

Punto	V/V_E	T/T_E	Π/Π_P
P	$1/\sqrt[4]{3} = 1/1.32$	$2/\sqrt{3}$	1
E	1	1	$\sqrt[4]{27}/2 = 1.14$
A	$\sqrt[4]{3} = 1.32$	$2/\sqrt{3}$	$\sqrt{3} = 1.73$

$$\Pi_A = 1.73 \cdot \Pi_P$$

$$\Pi_E = 1.14 \cdot \Pi_P$$