PORTANZA E RESISTENZA

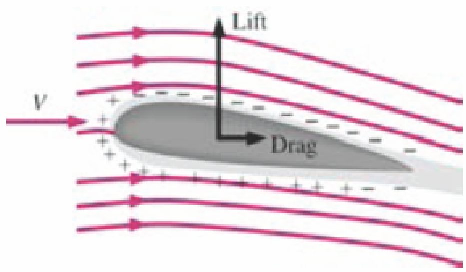
As engineers, we are primarily interested in the forces acting on a body moving through a viscous fluid:

$$\vec{F} = \int_{body\ surface} \mathrm{d}\vec{F} = \underbrace{\boxed{\int_{b.s.} \mathrm{d}\vec{F}_{shear}}}_{\text{viscous forces}} + \underbrace{\boxed{\int_{b.s.} \mathrm{d}\vec{F}_{pressure}}}_{\text{pressure forces}}$$

The resultant force $\vec{F}$ can be resolved into components parallel and perpendicular to the direction of motion:

Parallel: drag force F_D or $\hat{D}$

Perpendicular: lift force F_L or $\hat{L}$



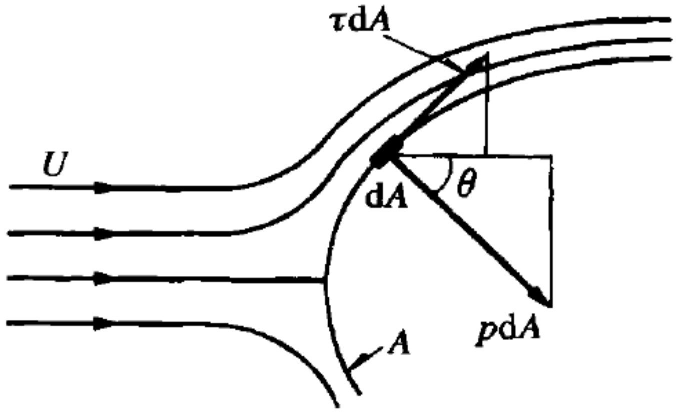
Recognizing that $d\vec{F}_{shear} = \vec{\tau}_w dA$ and $d\vec{F}_{press} = -p dA$

We note that total drag on a body has contributions from both shear stress and pressure.

Drag for a 2-D body $(x \,\&\, y)$ $\hat{D} = \left(\int_{\text{b.s.}} \vec{\tau}_w dA \right)_x + \left(\int_{\text{b.s.}} -p dA \right)_x$

However, shear stress does not contribute to lift.

2-D body: $\hat{L} = \left(\int_{\text{b.s.}} -p dA \right)_y$



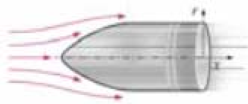
D = Drag = D_p + D_f = Pressure Drag + Friction Drag

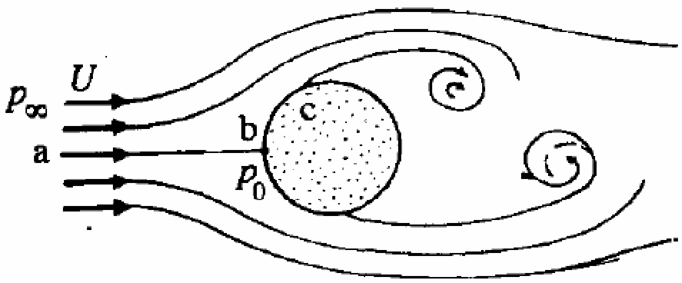
$$D_p = \int_A p \, dA \cos\theta \quad ; \quad D_f = \int_A \tau \, dA \sin\theta$$

We will investigate the experimental flow problems:

1. Drag of 2-D and 3-D bodies
   a. blunt bodies
   b. streamlined shapes

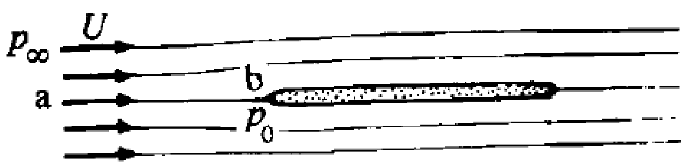
2. Performance of lifting bodies
   a. airfoils and aircraft
   b. projectiles





(a) Cylinder

Blunt Body

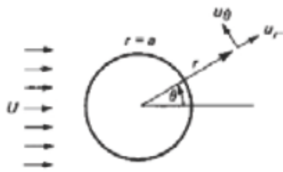


(b) Plate

Slender Body

Drag on Immersed Bodies

Consider the drag on a smooth sphere in viscous incompressible fluid of speed U.



In functional form: $\hat{D} = f_1(d, U, \mu, \rho)$

Using the Π theorem: $$\frac{\hat{D}}{\rho U^2 d^2} = f_2\left(\frac{\rho U d}{\mu}\right)$$

Note that d^2 is proportional to the cross-sectional area, $A = \frac{\pi d^2}{4}$

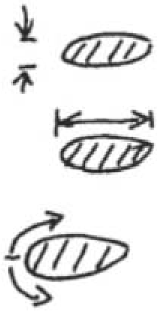
so $$\frac{\hat{D}}{\rho U^2 A} = f_3\left(\frac{\rho U d}{\mu}\right) = f_3\left(\mathrm{Re}\right)$$

Though this equation was derived for a sphere, it is valid for incompressible flow over any smooth body.

The characteristic length and area used by Re and C_D, respectively, depend on the body shape and application.

Define the coefficient of drag

$$C_D \equiv \frac{\hat{D}}{\rho U^2 A} \quad \text{where} \quad A = \begin{cases} \text{Frontal area} \\ \text{Planform area} \\ \text{Wetted area} \end{cases}$$



Note that while $\hat{D} = \underline{\text{friction drag}} + \underline{\text{pressure drag}}$ we find that C_D is a function only of Re.

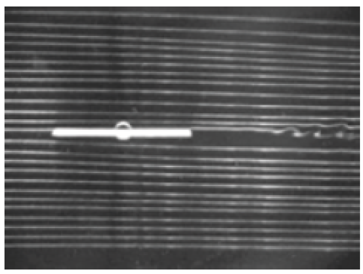
Example

A flat plate parallel to the freestream has negligible frontal area and wake.

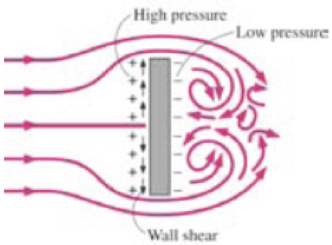
Therefore, in this case all drag comes from friction.

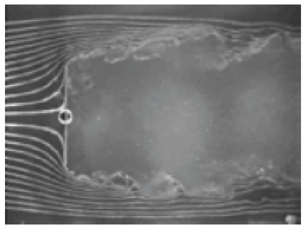
Recall, for laminar: $$C_D = \frac{1.328}{\left(\text{Re}_L\right)^{\frac{1}{2}}}$$

and turbulent: $$C_D = \frac{0.455}{\left(\log\left(\text{Re}_L\right)\right)^{2.58}}$$



For flow past a flat plate normal to the freesteam, τ_w is a negligible contribution to the drag. All drag comes from the pressure difference.





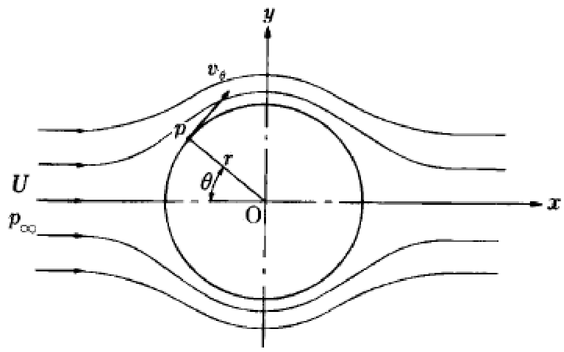
$$\hat{D} = \int_{surface} -p\,d\vec{A}, \qquad \text{A = frontal area}$$

$\hat{D}$ = function of frontal area and Re or $C_D = f(\text{Re})$ for $\text{Re} \le 1000$

For $\text{Re} > 1000$, the perpendicular plate (and all objects with sharp edges) are independent of Re because boundary layer separation is fixed by the body geometry.

Shape	Pressure drag D_p (%)	Friction drag D_f (%)
	0	100
	≈ 10	≈ 90
	≈ 90	≈ 10
	100	0

FLOW AROND A CYLINDER



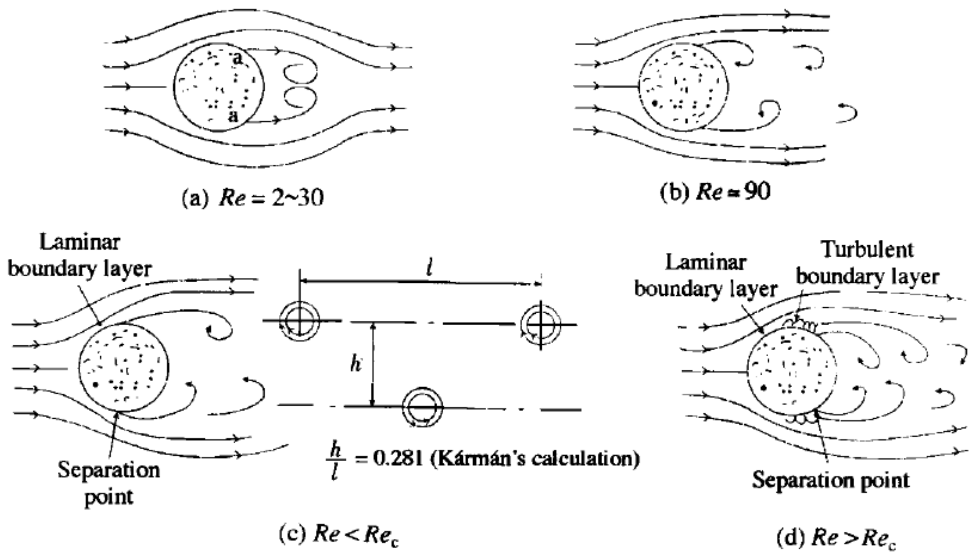
$$v_\theta = 2U\sin\theta$$

$$p_\infty + \frac{\rho U^2}{2} = p + \frac{\rho v_\theta^2}{2}$$

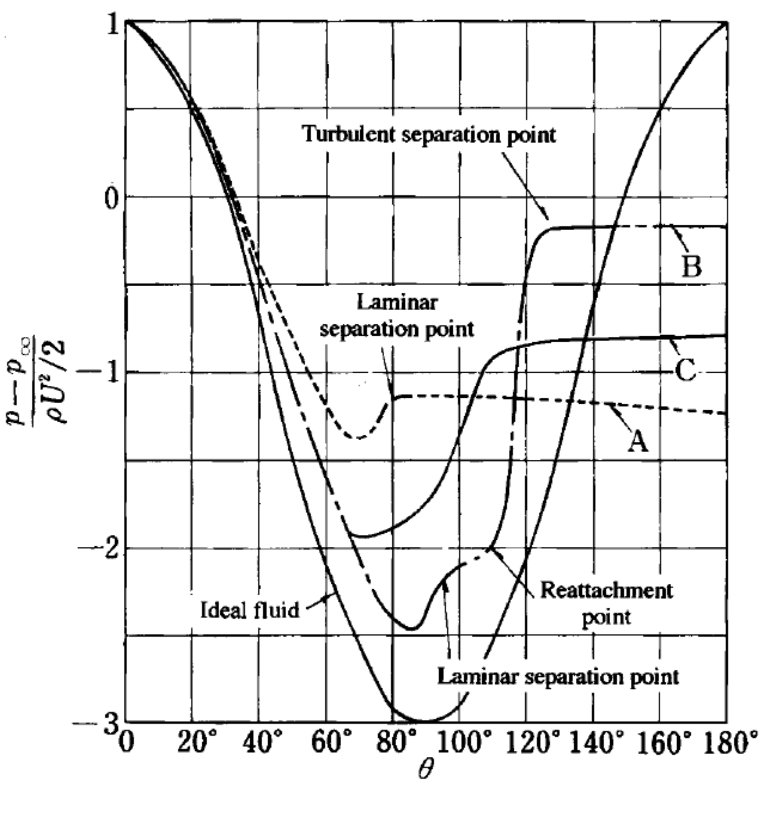
$$p - p_\infty = \frac{\rho(U^2 - v_\theta^2)}{2} = \frac{\rho U^2}{2}(1 - 4\sin^2\theta)$$

$$\frac{p - p_\infty}{\rho U^2/2} = 1 - 4\sin^2\theta$$

FLOW AROND A CYLINDER



FLOW AROND A CYLINDER



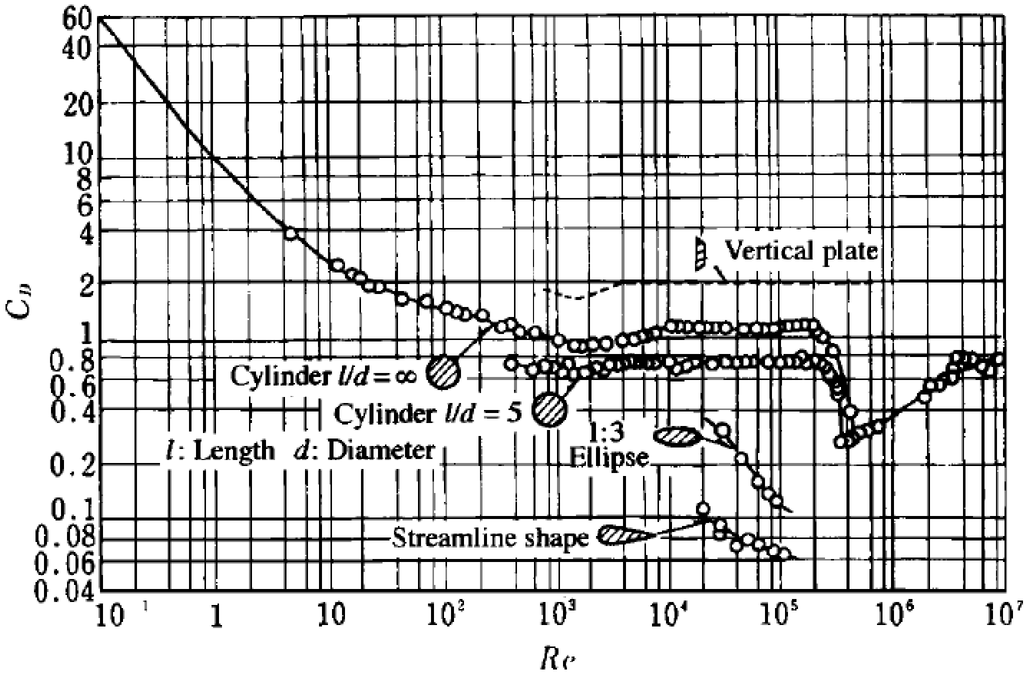
$Re = Ud/\nu$

A, $Re = 1.1 \times 10^5 < Re_c$

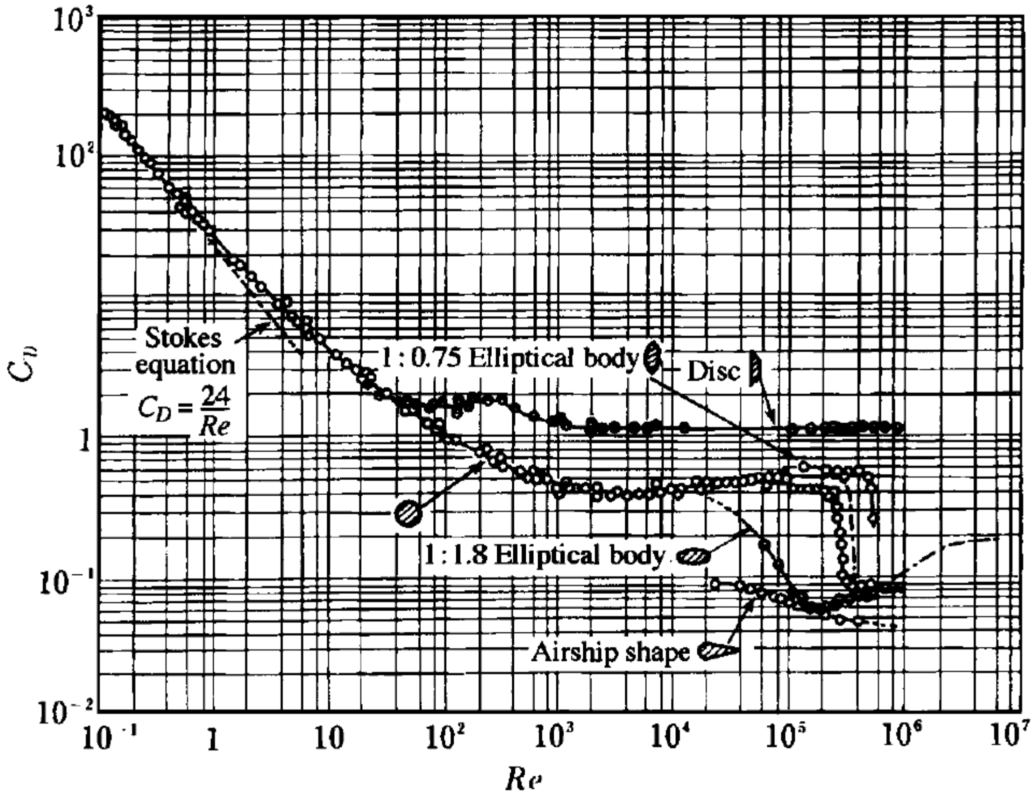
B, $Re = 6.7 \times 10^5 > Re_c$

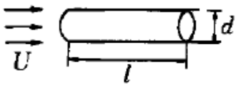
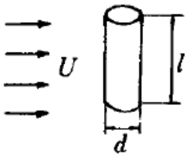
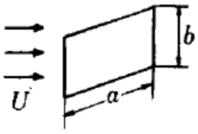
C, $Re = 8.4 \times 10^6 > Re_c$

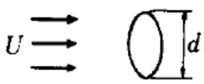
Drag coefficients for cylinders and other column-shaped bodies



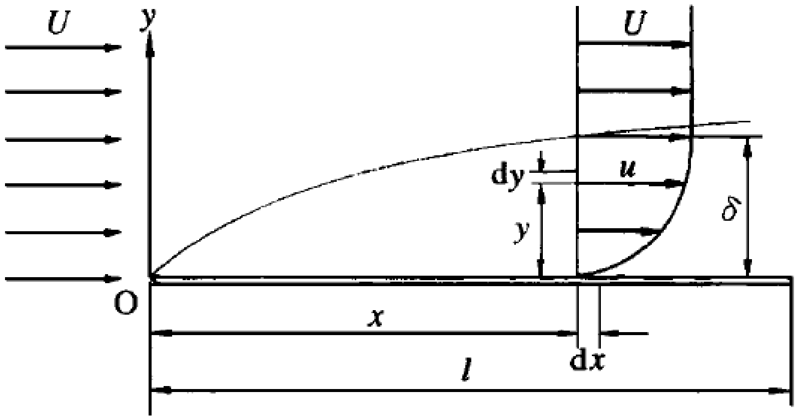
Drag coefficients of a sphere and other three-dimensional bodies



Body	Dimensional ratio	Datum area, A	Drag coefficient, C_D
Cylinder (flow direction)	$l/d = 1$		0.91
	2		0.85
	4	$\frac{\pi}{4}d^2$	0.87
	7		0.99
Cylinder (right angles to flow)	$l/d = 1$		0.63
	2		0.68
	5		0.74
	10	dl	0.82
	40		0.98
	∞		1.20
Oblong board (right angles to flow)	$a/b = 1$		1.12
	2		1.15
	4		1.19
	10	ab	1.29
	18		1.40
	∞		2.01

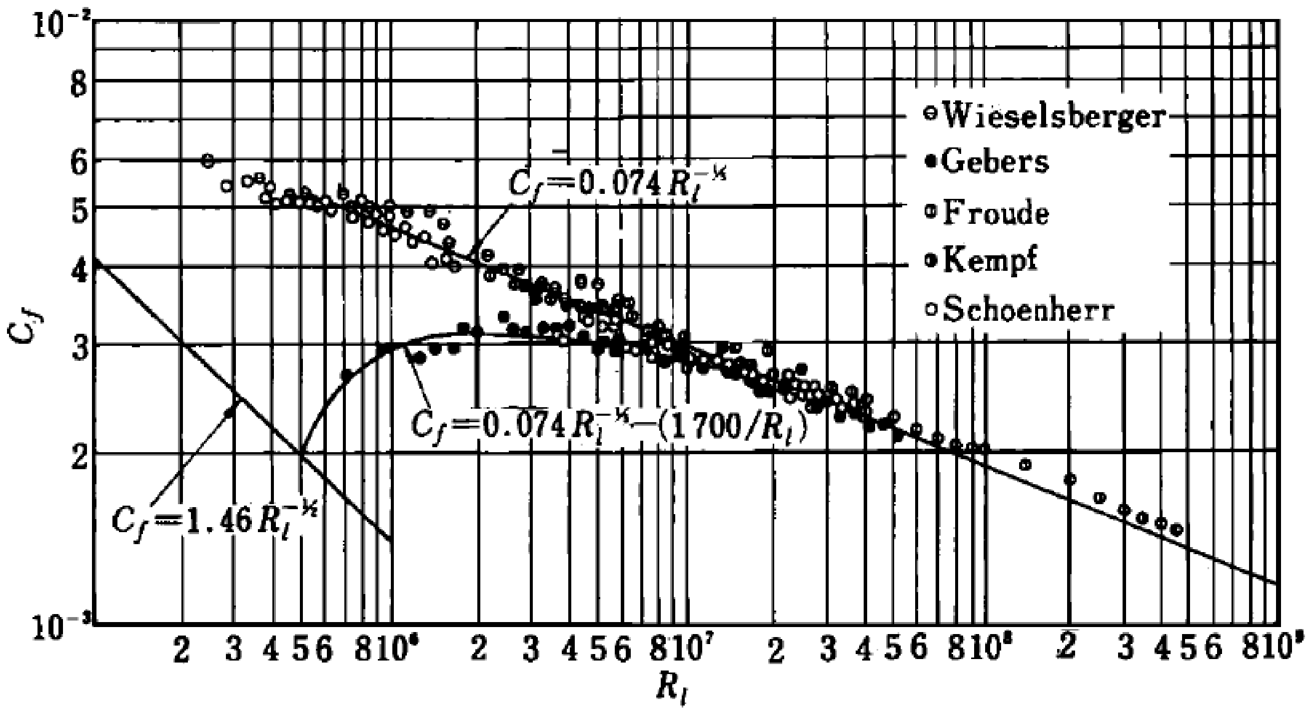
Body	Dimensional ratio	Datum area, A	Drag coefficient, C_D
Hemisphere (bottomless)	I	$\frac{\pi}{4}d^2$	0.34
	II		1.33
Cone	$a = 60°$	$\frac{\pi}{4}d^2$	0.51
	$a = 30°$		0.34
		$\frac{\pi}{4}d^2$	1.2
Ordinary passenger car		Front projection area	
			0.28–0.37

RESISTENZA DI UNA LASTRA PIANA

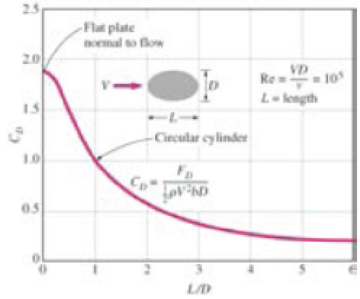


$$D = \int_0^\delta \rho u (U - u)\,\mathrm{d}y \qquad\qquad D = C_f l \frac{\rho U^2}{2}$$

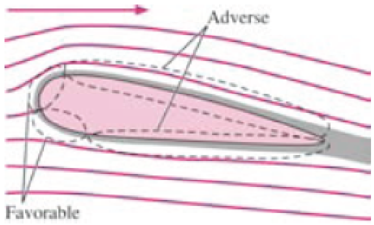
RESISTENZA DI UNA LASTRA PIANA



For bodies where the pressure drag is high due to boundary layer separation, we can add material to the upwind and/or downwind side in an effort to delay separation.



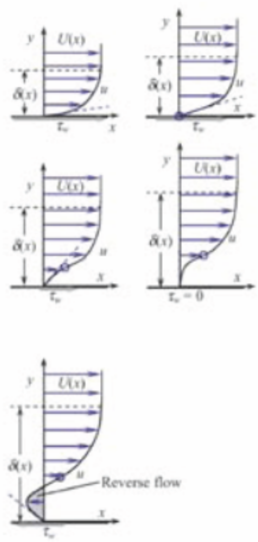
This is known as streamlining.



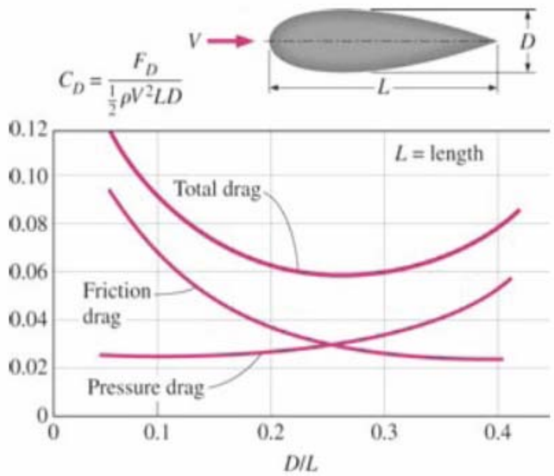
So, how can we reduce the pressure drag on bodies?

Pressure drag is caused by insufficient pressure recovery caused by boundary layer separation.

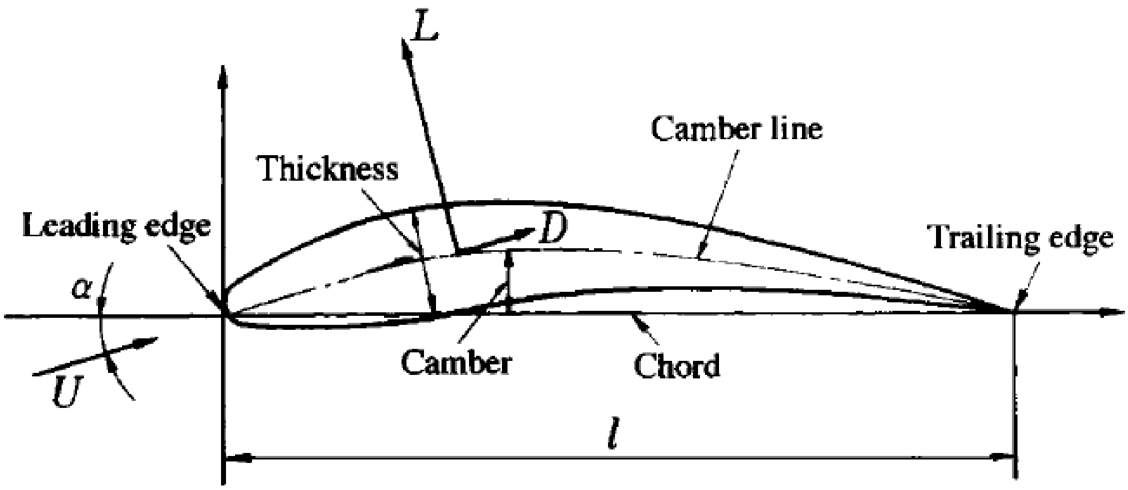
Boundary layer separation is caused by a sufficiently large adverse pressure gradient.



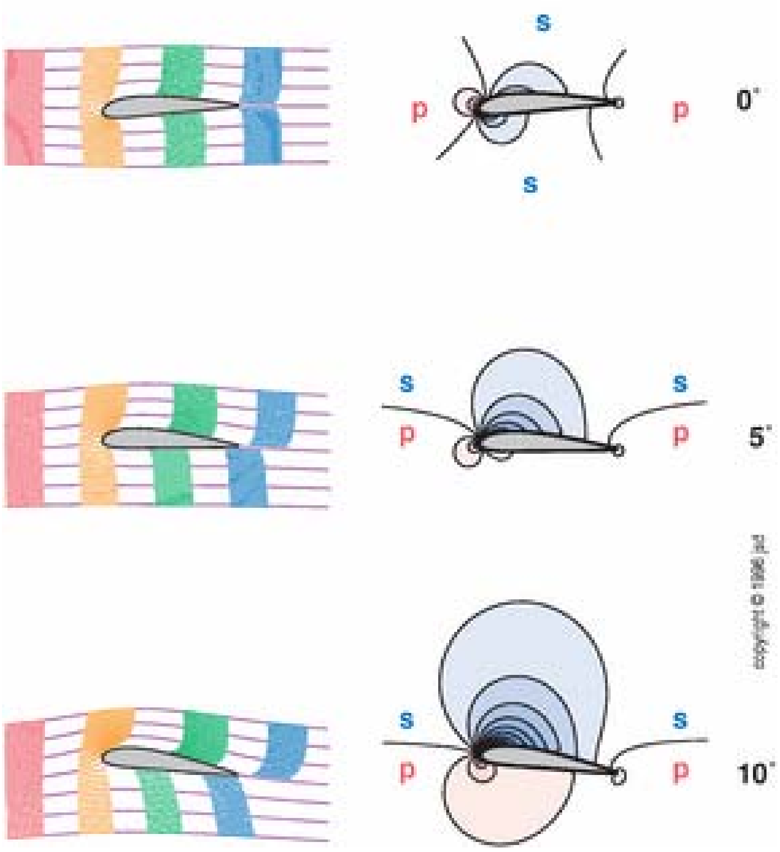
Streamlining will decrease the pressure drag, but it will increase skin friction by adding more surface. In order to decrease the total drag coefficient value, C_D, we need to find an optimal shape.



PROFILI ALARI



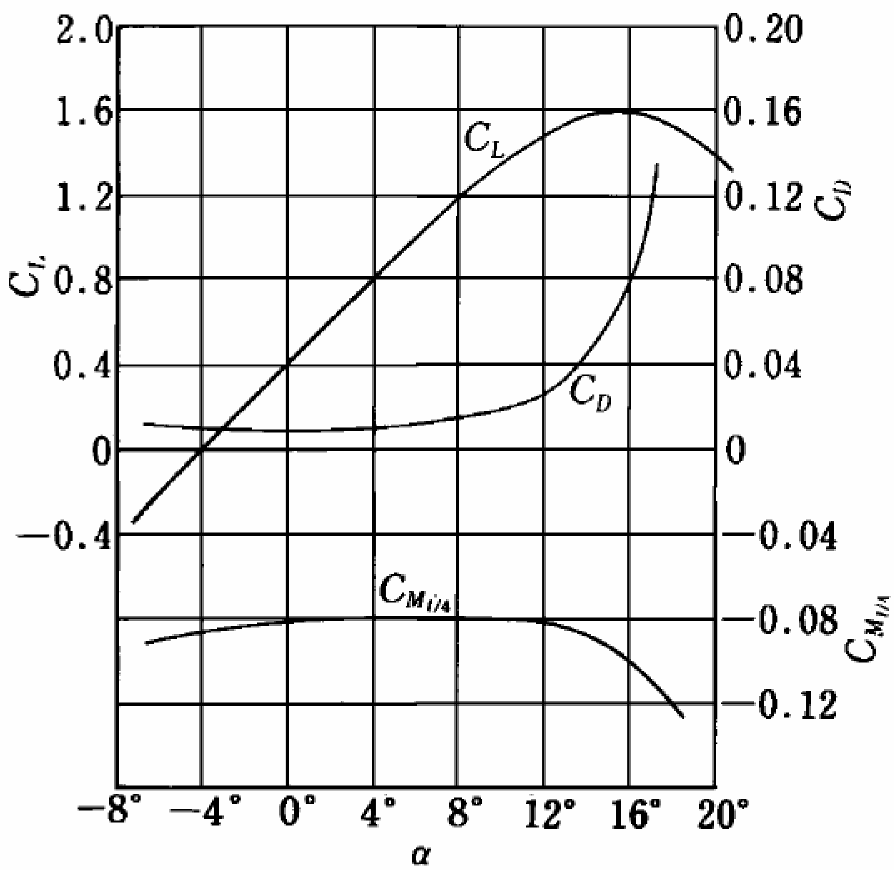
$$L = C_L l \frac{\rho U^2}{2}$$
$$D = C_D l \frac{\rho U^2}{2}$$
$$M = C_M l^2 \frac{\rho U^2}{2}$$



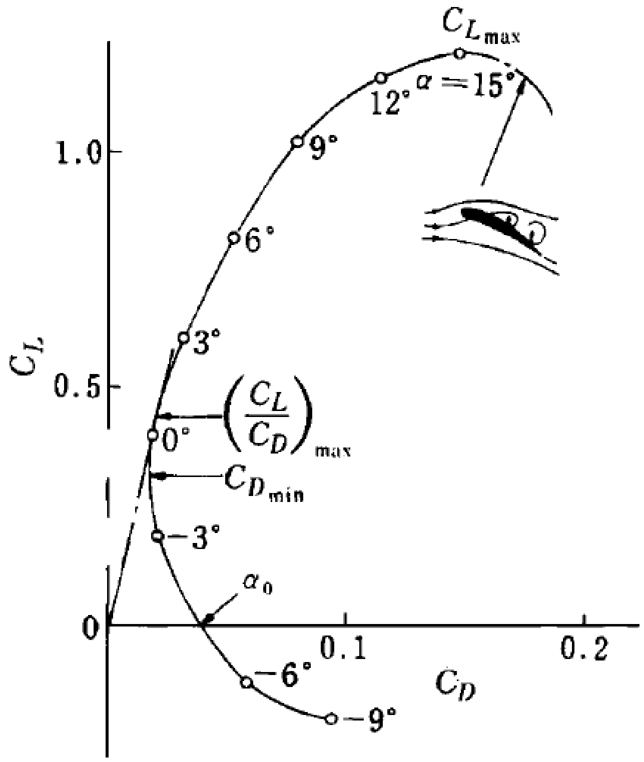
s, suction i.e. negative pressure relative to ambient

p, positive pressure relative to ambient

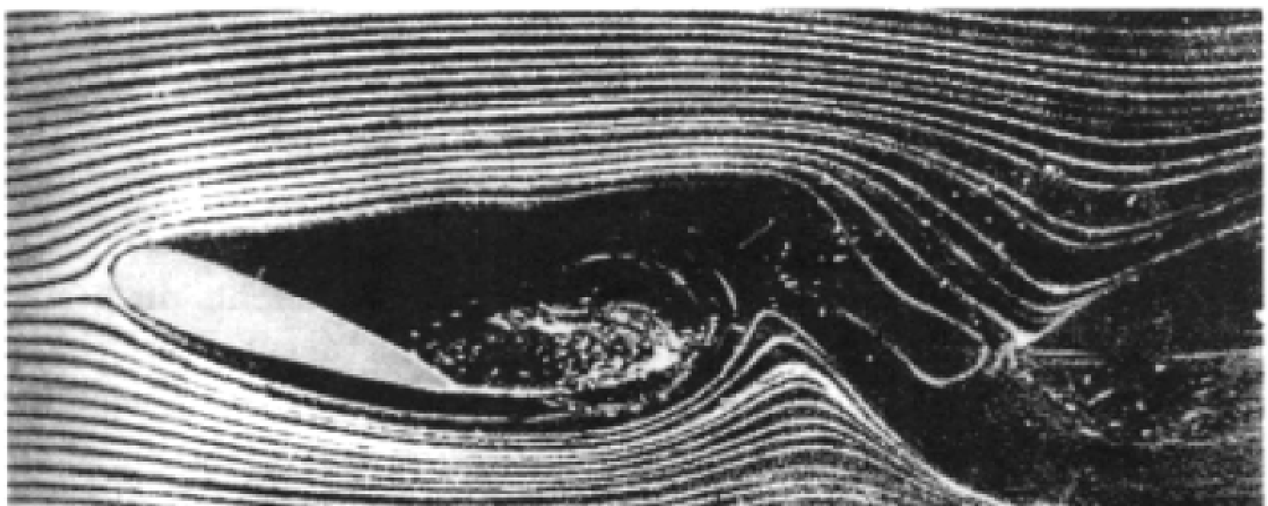
CURVE CARATTERISTICHE DI UN PROFILO



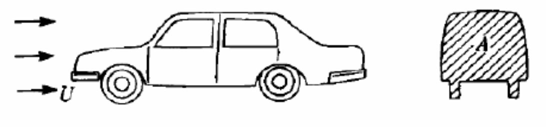
CURVA CARATTERISTICA C_L-C_D DI UN PROFILO



VISUALIZZAZIONE DEL CAMPO DI MOTO SU UN PROFILO IN CONDIZIONI DI STALLO



Calcolare la resistenza aerodinamica di un autovettura se C_d=0.28, A=1.7m^2, V=150 Km/h (P_{amb}=1atm, T_{amb}=20°C)



V=150 Km/h=150*1000/3600=41.66 m/s

$\rho_{aria}=p_{pamb}/RT_{amb}$=101300/287/293.15=1.2 Kg/m^3

D=1/2*ρ*V*V*C_d*A=0.5*1.2*41.66*41.66*0.28*1.7=495.7 N

Calcolare la portanza aerodinamica di un una ala bidimensionale (Corda =1m e lunghezza 10m) se C_L=0.7 e V=150 m/s m/s (P_{amb}=0.7atm, T_{amb}=-40°C)

$\rho_{aria}=p_{pamb}/RT_{amb}$=101300*0.7/287/233.15=1.06 Kg/m^3

L=1/2*ρ*V*V*C_L*Corda*L=0.5*1.06*150*150*0.7*1*10=83475 N