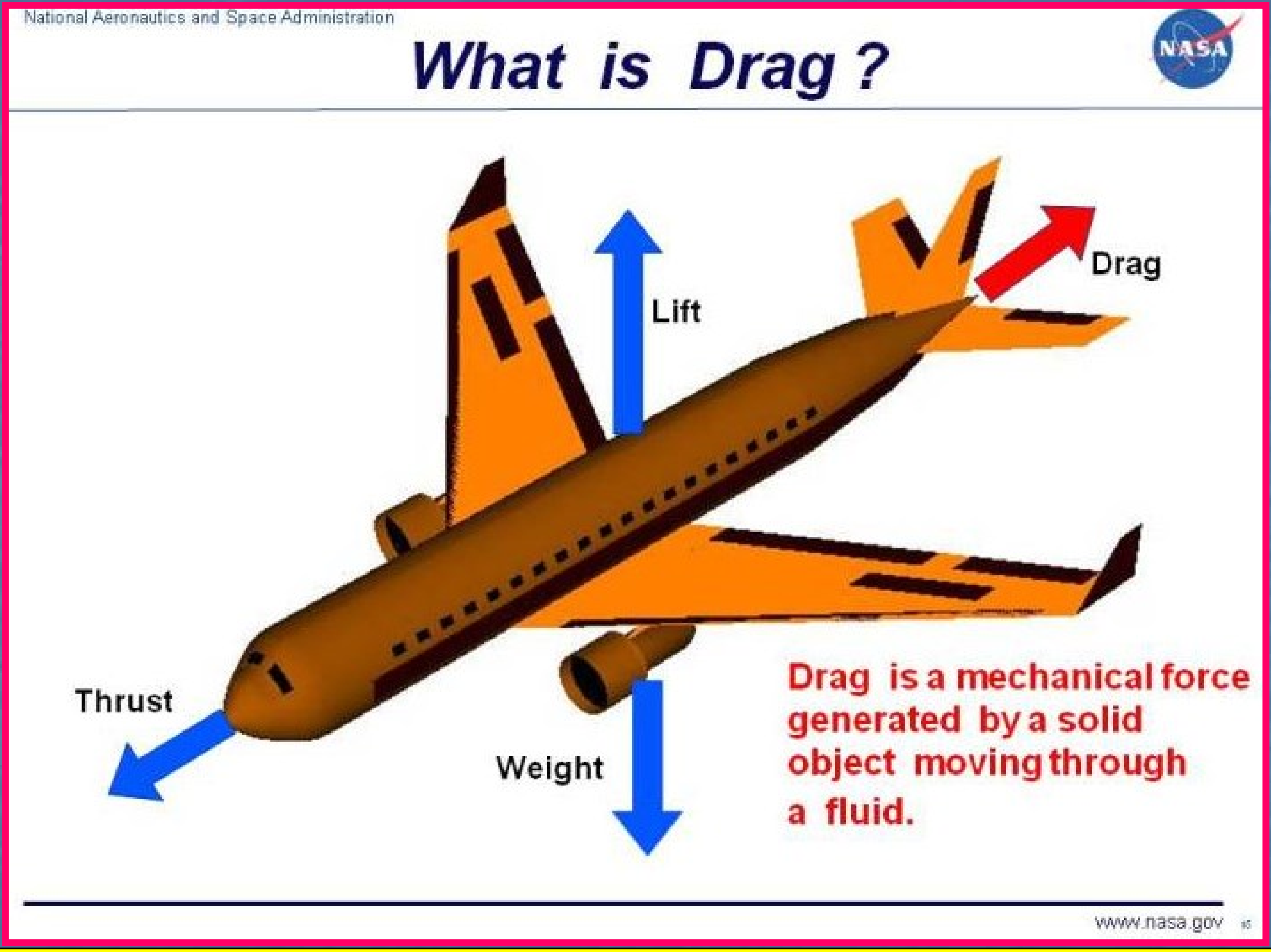
CHAPTER (11)

DRAG & LIFT

DR. MUNZER EBAID

Drag and Lift



Drag is the aerodynamic force that opposes an aircraft's motion through the air. Drag is generated by every part of the airplane

The total drag of a blunt body is partly due to viscous forces and partly due to pressure variation

Pressure drag is largely a function of the form or shape of the body, hence called

Form Drag

Viscous drag is largely a function of the surface of the body, hence called

Skin Friction Drag

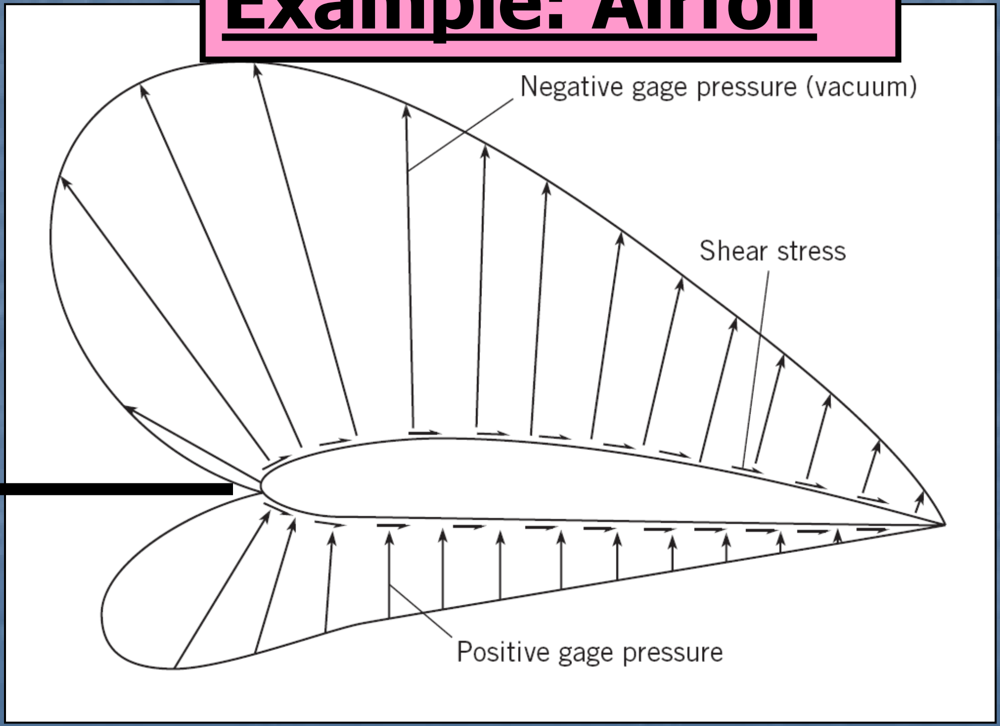
Drag and Lift

Lift : Is the sum of pressure forces, viscous forces or both forces that acts **Normal to free stream lines**

Drag: Is The sum of pressure forces, viscous forces or both forces that acts **Parallel to free stream lines.**

Note: Both Lift & Drag are due to dynamic action of the flowing fluid

Example: Airfoil



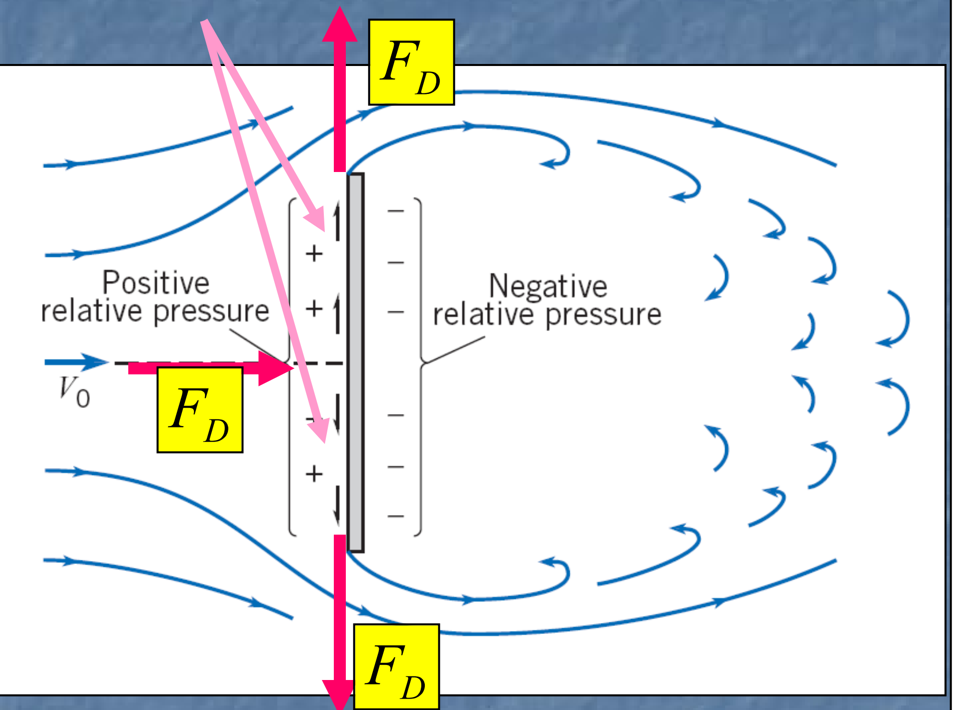
Direction of Motion of Body

Direction of flowing fluid

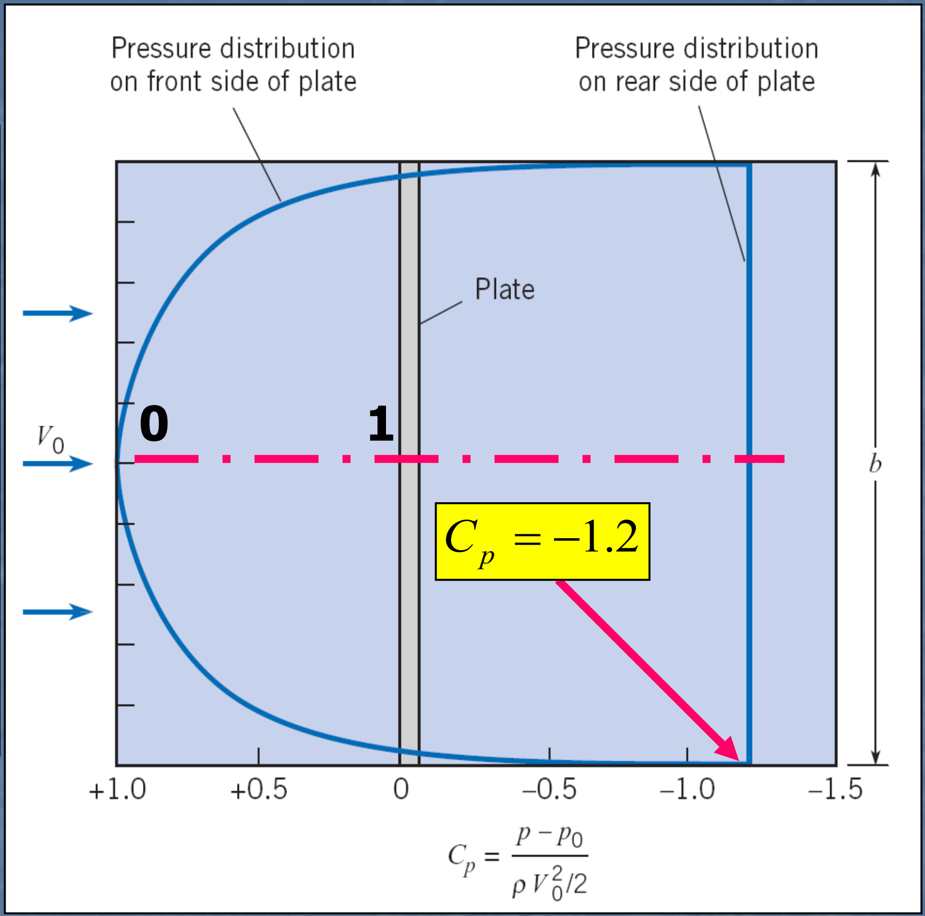
Pressure and shear stress acting on an airfoil

Drag of a Thin plate

Viscous forces cancel each other



Flat Plate Placed Normal to Flow



$$F_D = C_D A_p \rho \frac{V_0^2}{2} \qquad (11.5)$$

$$C_D = f(C_p)$$

$$C_p = f(\mathrm{Re})$$

$$C_D = f(\mathrm{Re})$$

Coefficient of Drag C_D (Two – Dimensional Bodies)

A two dimensional body is a body with a uniform section area and a flow pattern that is independent of the ends of the body.

Two dimensional bodies can be visualized as objects that are infinitely long in the direction normal to the flow.

$$\frac{L}{D} \geq 20$$

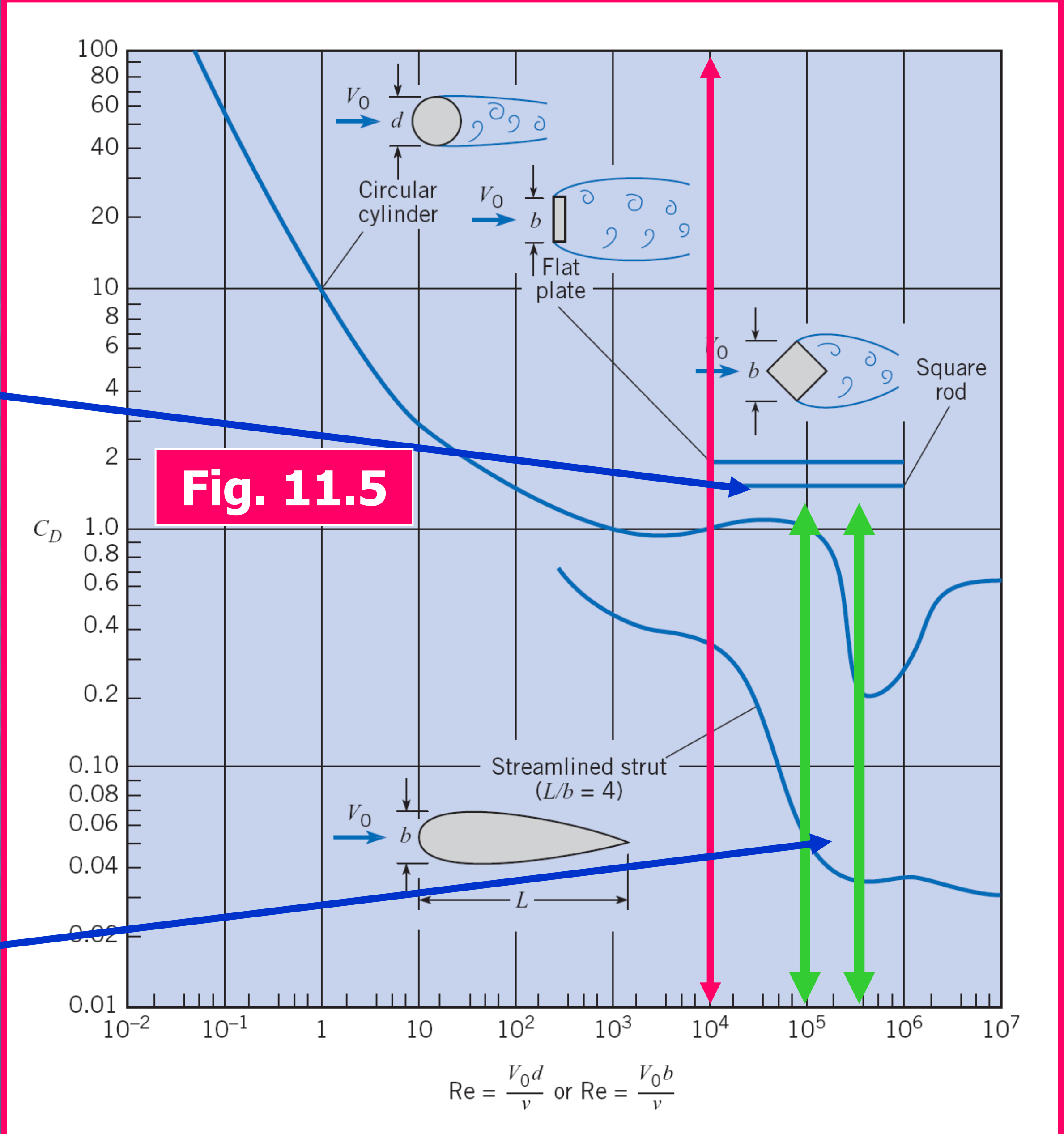
C_D For Various Two – Dimensional Bodies

The results C_D in the Figure are obtained experimentally using wind tunnel

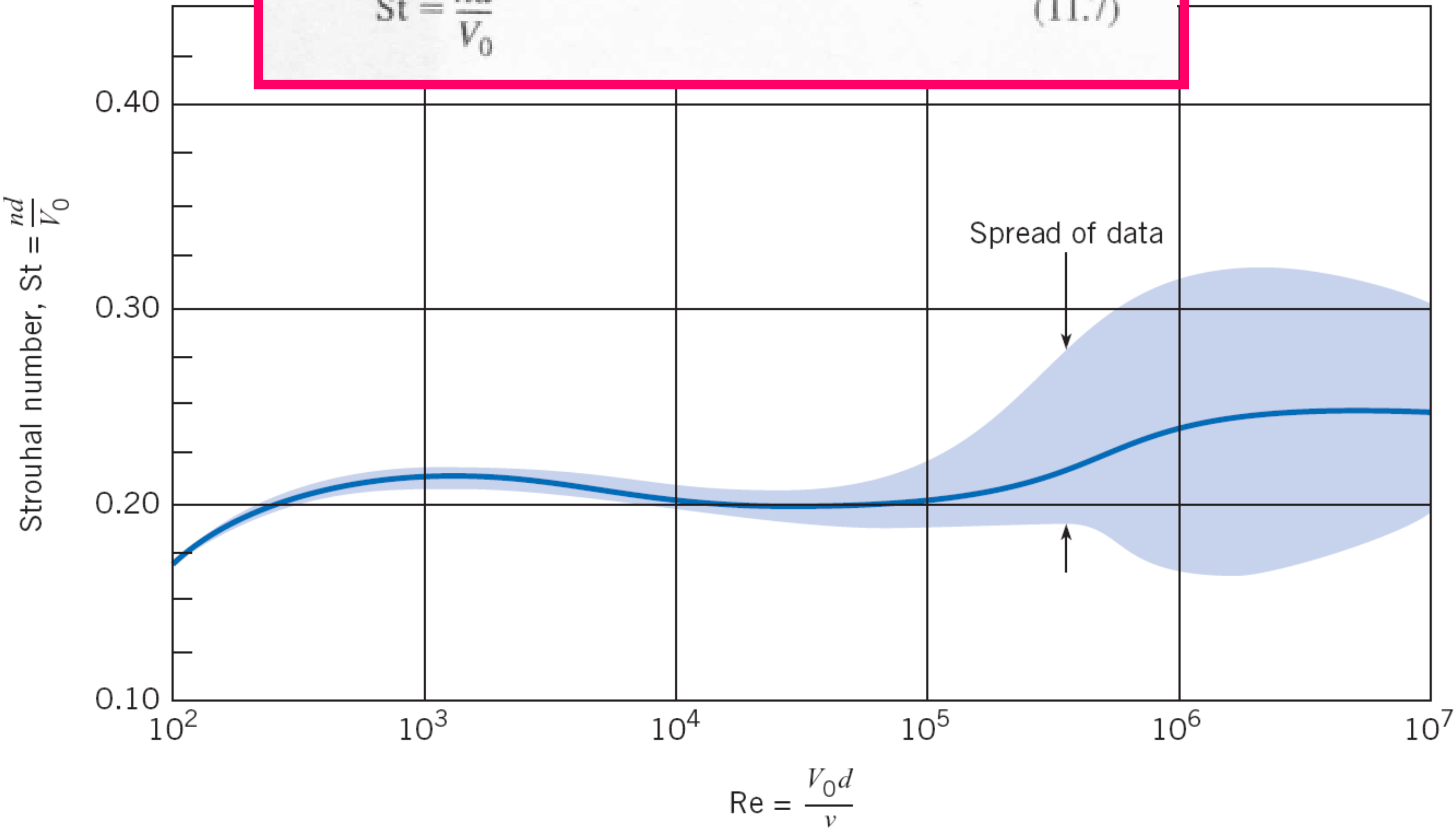
For Angular Bodies, C_D is constant as the flow pattern doesn't change as shown in Figure for $R_e > 10^4$

For rounded Bodies, C_D

decreases as the flow pattern does change as shown in Figure for $10^5 < R_e < 5\times10^5$



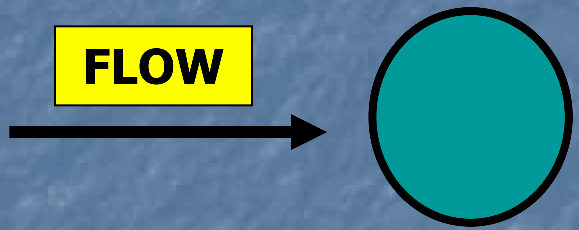
$$\mathrm{St} = \frac{nd}{V_0} \qquad (11.7)$$



Strouhal Number versus **Reynolds number for flow past a circular cylinder.**

Effect of Streamlining

For $R_e > 10^3$ the drag of a cylinder is predominantly due to pressure variation around the cylinder caused largely to Separation. Hence, if the separation can be eliminated, the drag will be reduced.



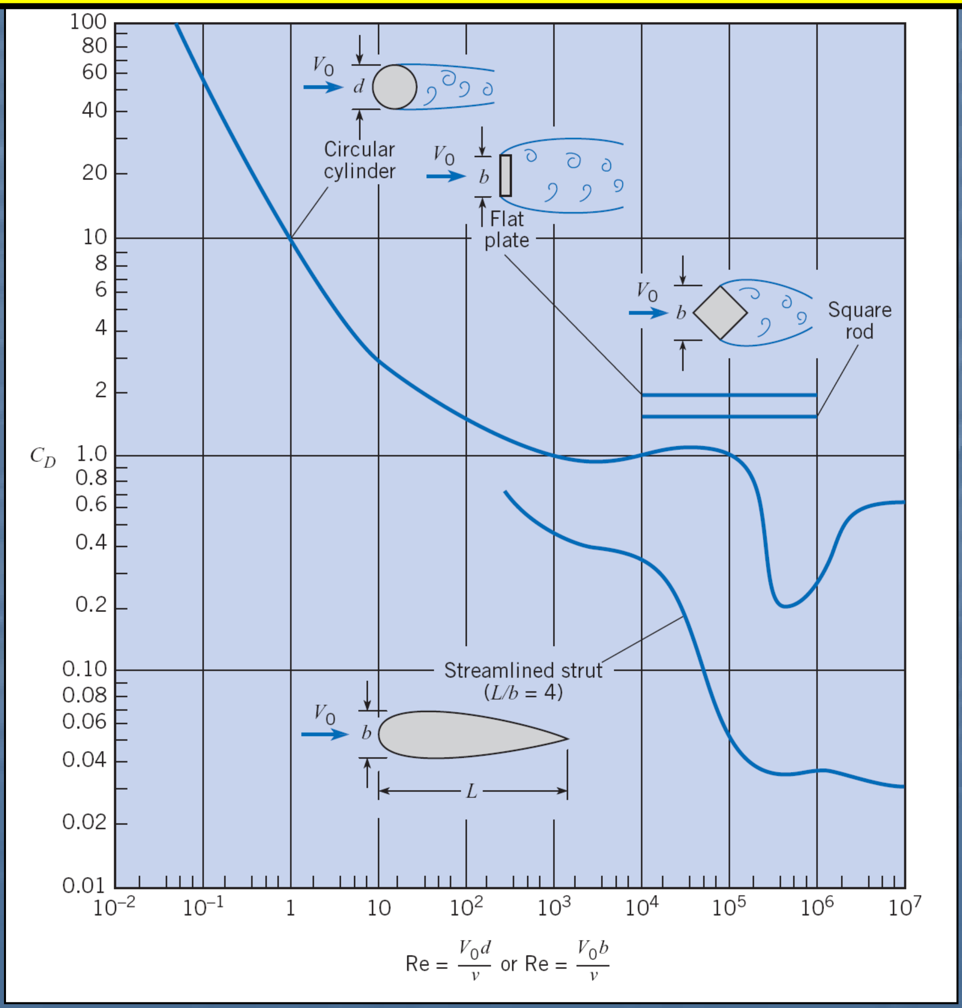
When a body is **Streamlined** by elongating it and reducing its curvature, the pressure drag is reduced. However, viscous forces are increased because the surface is increased.

The optimum condition for streamlining is when the sum of Surface drag and pressure drag is minimum.

Effect of Streamlining

Streamlining at high Re reduces the drag due to pressure and increase the viscous drag.

Streamlining at Low Re <1 increases the drag due to viscous forces.



Drag of Axisymmetric and Three – dimensional Bodies

Stokes' Law, for a Sphere, and for Laminar Flow: (Re<0.5)

$$F_D = 3\pi\mu V_0 d \qquad (11.8)$$

$$C_D = \frac{F_D}{A_p \rho V_0^2/2} \qquad (11.6)$$

Combining Eqns (11.8) & (11.6), we get,

$$C_D = \frac{24}{\mathrm{Re}} \qquad (11.9)$$

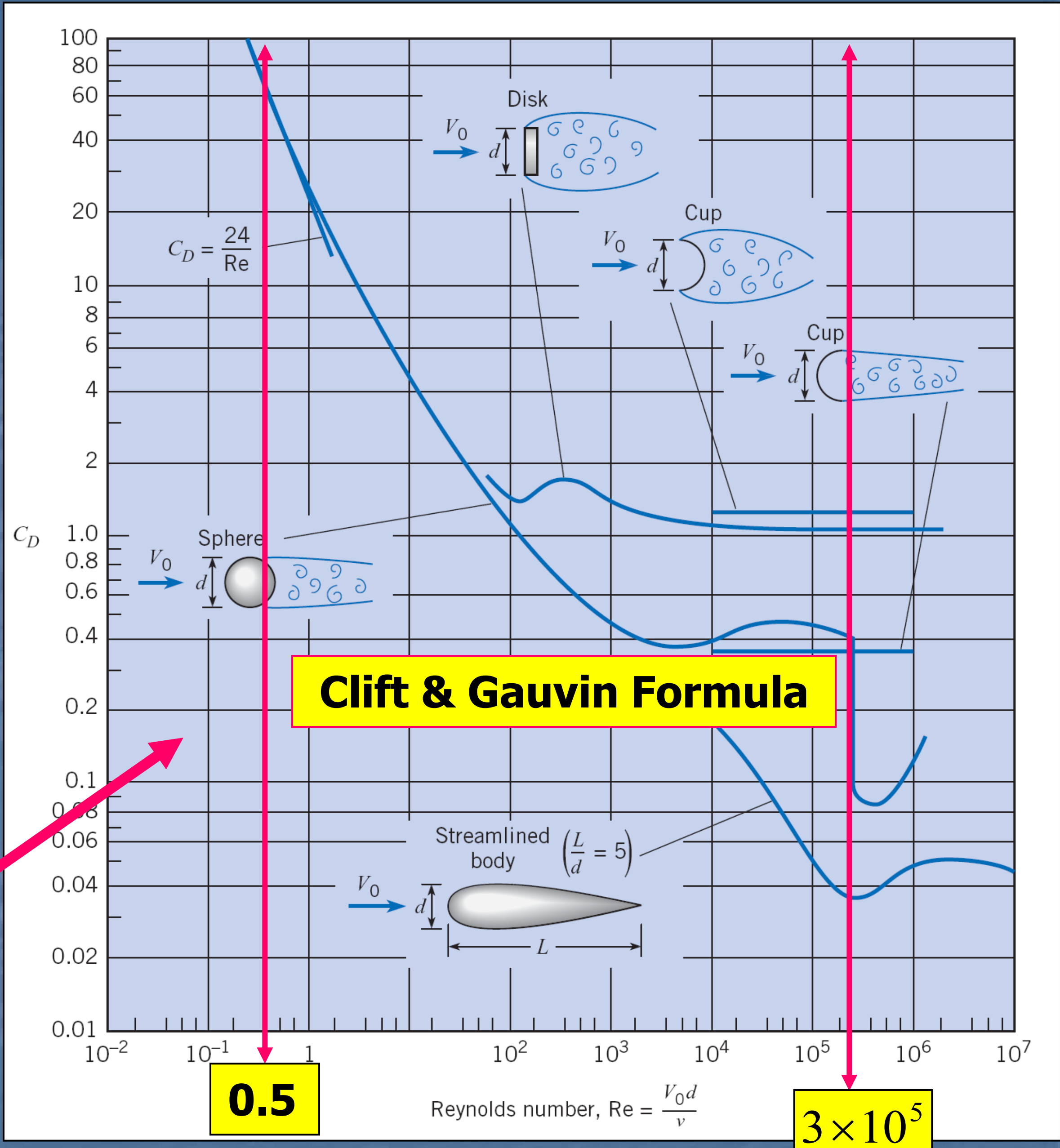
Correlation proposed by Clift and Gauvin For (Re) up to 3×10^5

$$C_D = \frac{24}{\mathrm{Re}}(1 + 0.15\mathrm{Re}^{0.687}) + \frac{0.42}{1 + 4.25\times10^4\mathrm{Re}^{-1.16}} \qquad (11.10)$$

Eqn (11.10) deviates from the standard curve (next slide) from (-4% to 6%) for Reynolds numbers up to 3×10^5

Fig. (11.11)

Coefficient of drag versus Reynolds number for **Axisymetric Bodies**. [Data sources: Abbott (9), Brevoort and Joyner (10), Freeman (11) and Rouse (12)]

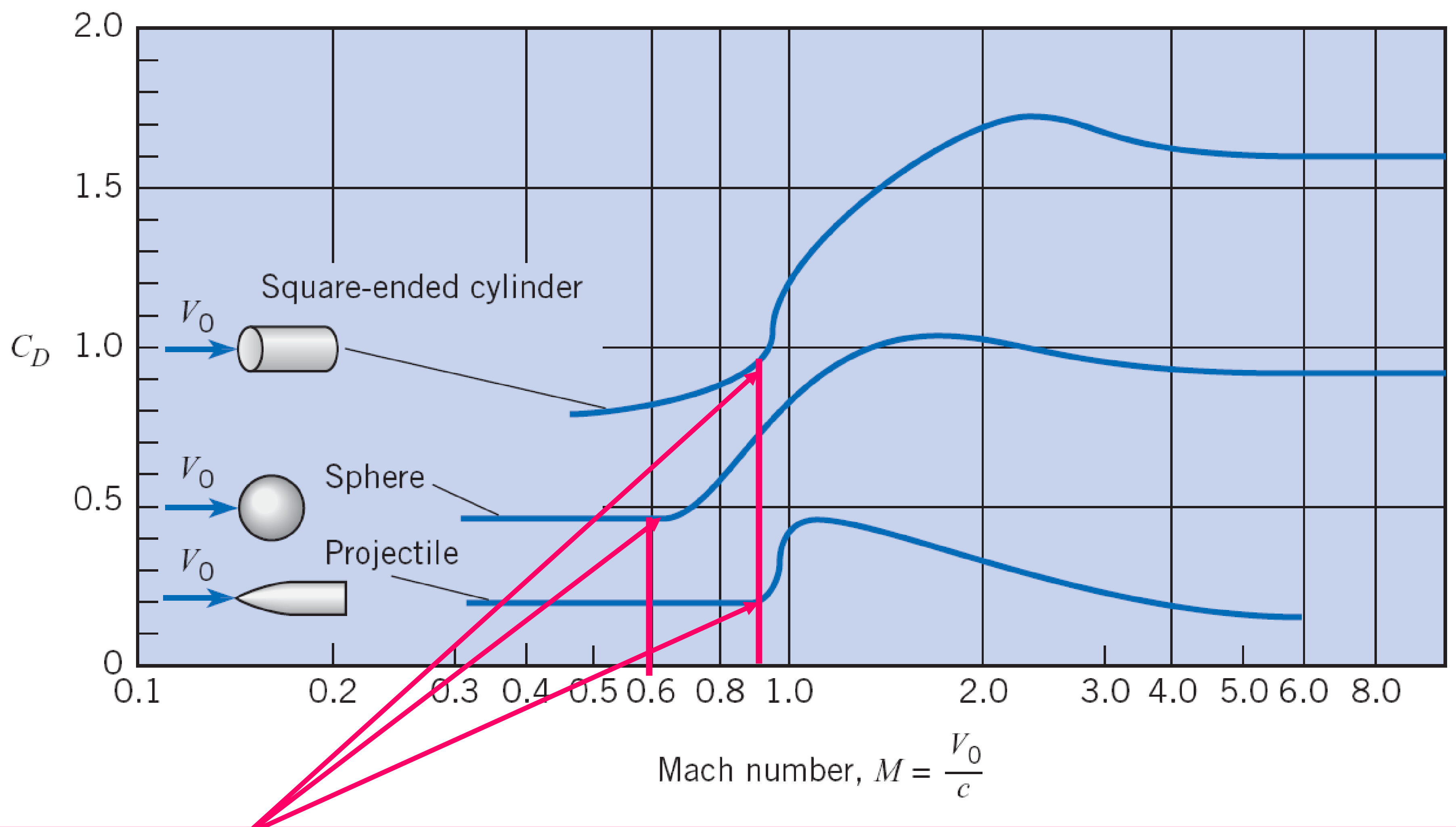


Stoke's Law for Re<0.5

Terminal Velocity

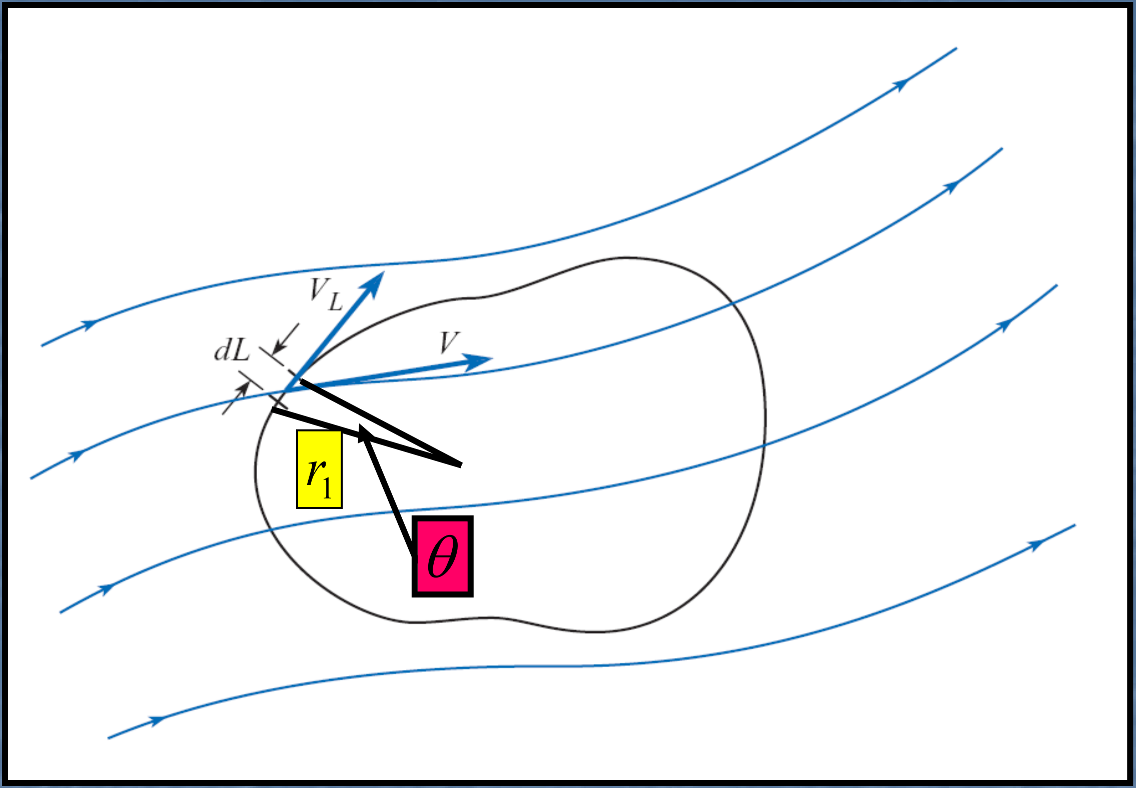
Terminal velocity is defined as the maximum velocity attained by a <u>falling body</u> <u>Under Equilibrium Conditions</u>

Effect of Compressibility on Drag



Critical Mach No. is the Number where an appreciable increase in drag coefficient occurs.

Circulation (Γ) For Irrotational Flow (Free Vortex)



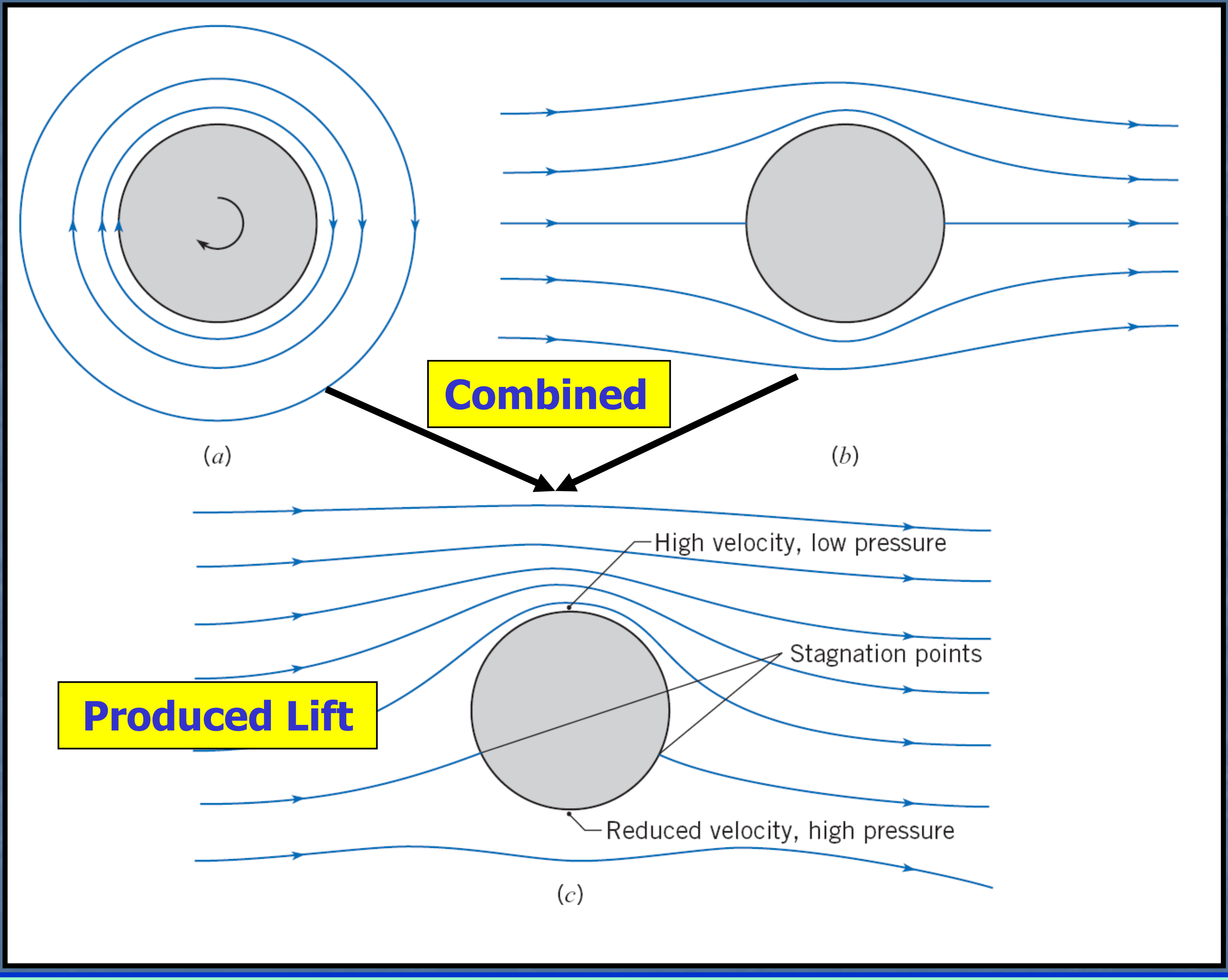
$Vr = C \left(Free\ Vortex\right)$

$$d\Gamma = V_L\, dL = \frac{C}{r_1} r_1\, d\theta = C\, d\theta \qquad (11.12)$$

Then, when we integrate this around the entire circle, we obtain

$$\Gamma = \int_0^{2\pi} C\, d\theta = 2\pi C \qquad (11.13)$$

Combination of Circulation and Uniform Flow Around a Cylinder



Ideal flow around a cylinder

(a) Circulation. (b) Uniform flow. (c) Combination of circulation and uniform flow.

For Ideal Flow Theory, the Lift per Unit Length of an <u>Infinitely Long Cylinder</u> is given by:

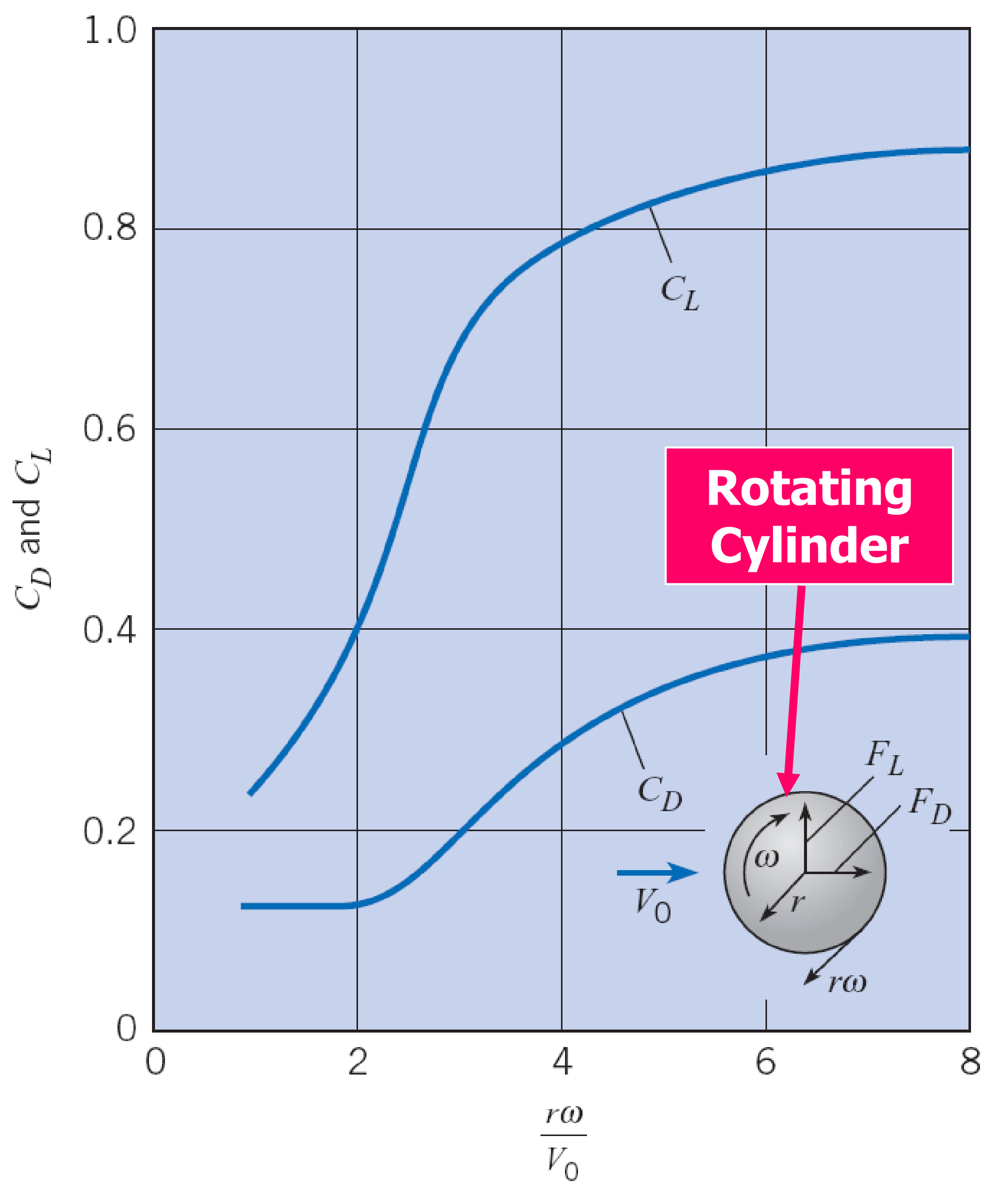
$$\frac{F_{Lift}}{L} = \rho V_0 \Gamma$$

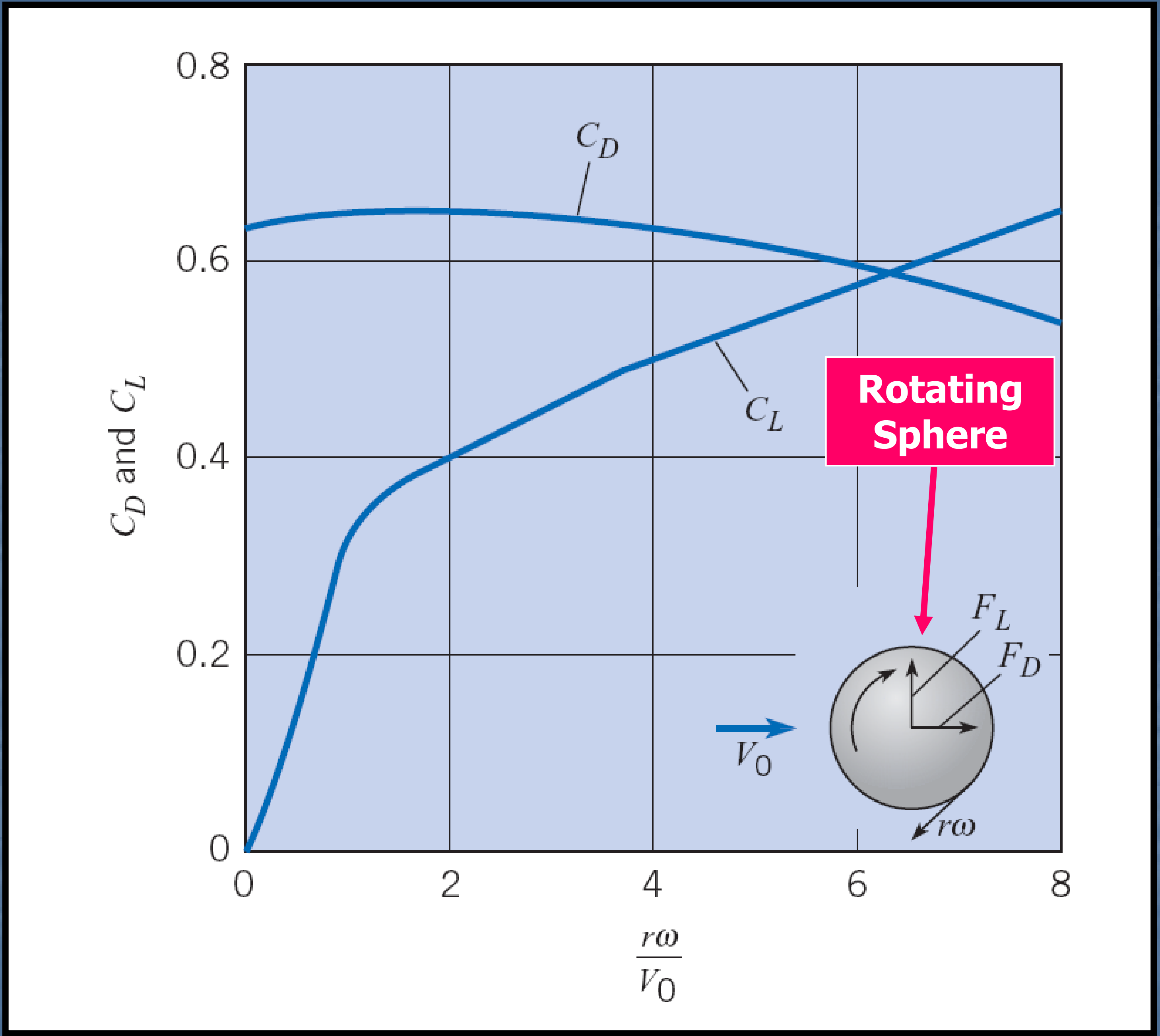
<u>Magnus Effect</u> is the lift produced by rotation of a solid body moving in a fluid.

The *lift coefficient* is defined as

$$C_L = \frac{F_L}{A_p \rho V_0^2/2}$$

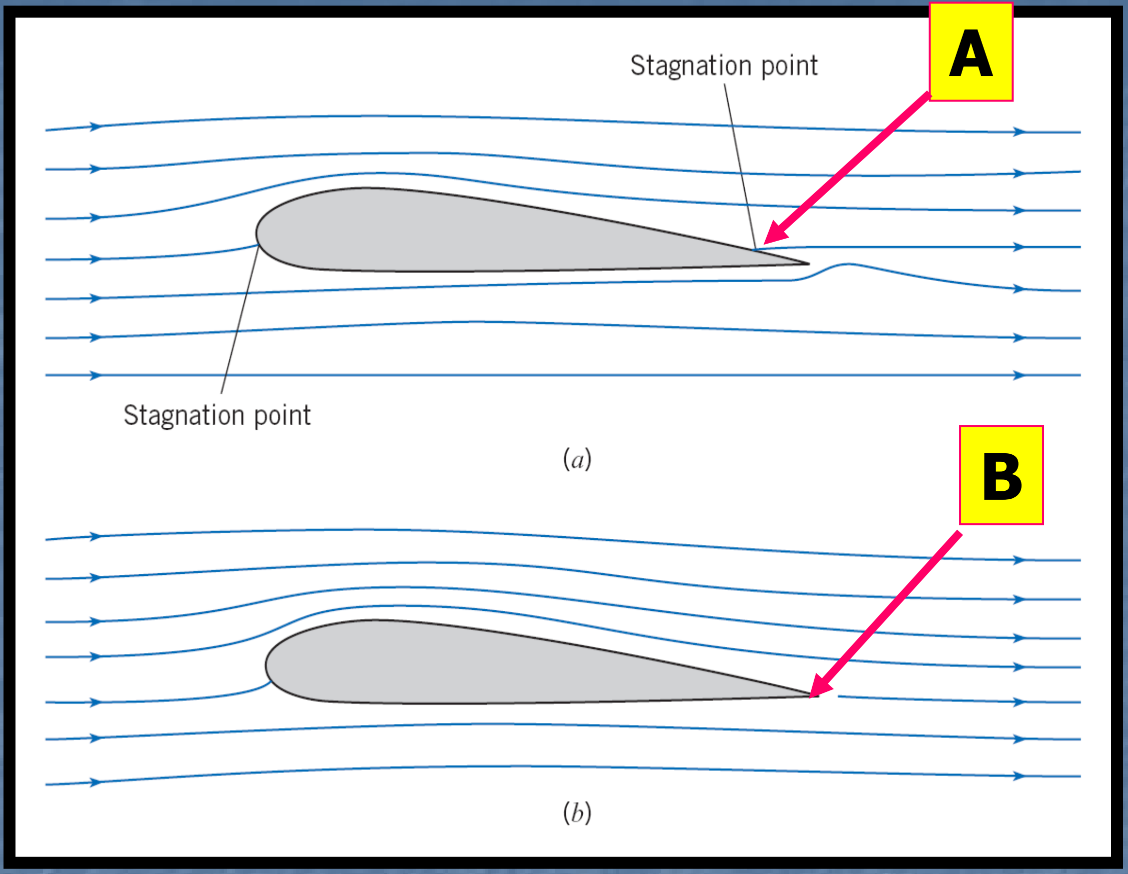
Coefficients of Lift and Drag as Functions of $r\omega/V_0$ for a Rotating <u>Cylinder.</u>



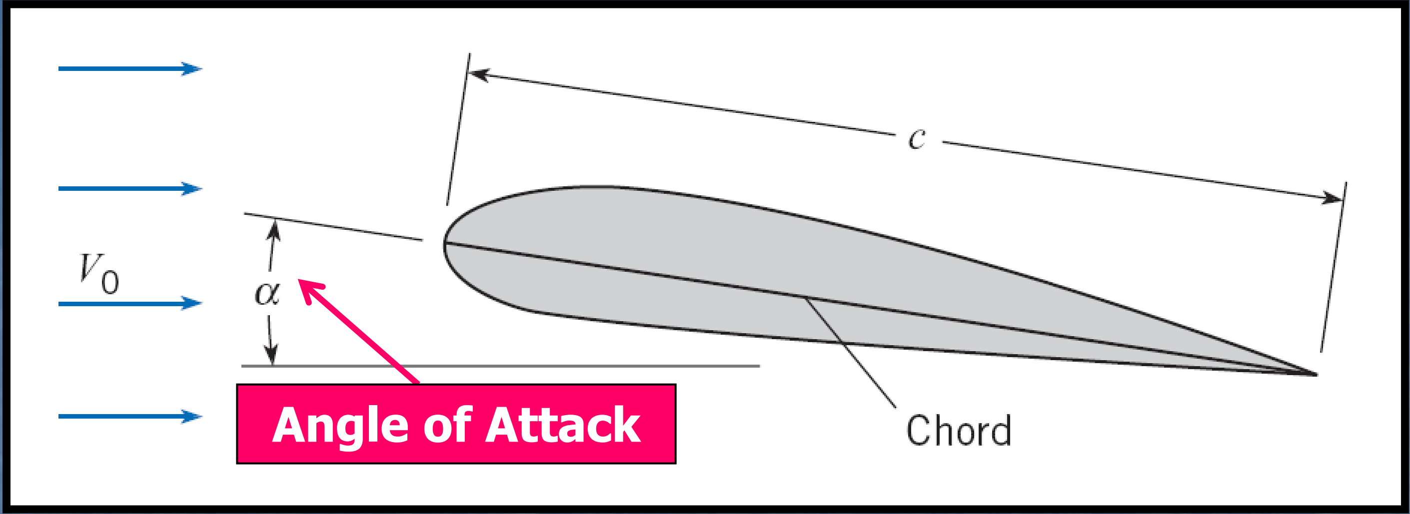


Coefficients of Lift and Drag for a Rotating Sphere

Lift of An Airfoil



Kutta Condition states that a **Circulation** around the airfoil ***must be induced in just the right amount*** so that the downstream stagnation point **(A)** is moved all the way back to the trailing edge **(B)** of the airfoil, thus allowing the flow to leave smoothly at the trailing edge.



Mathematical model of Kutta condition is given by: $\Gamma = \pi c V_0 \alpha$

$\Gamma = \pi c V_0 \alpha$

$F_L = \rho V_0^2 \pi c \ell \alpha$

$C_L = \frac{F_L}{S \rho V_0^2 / 2}$

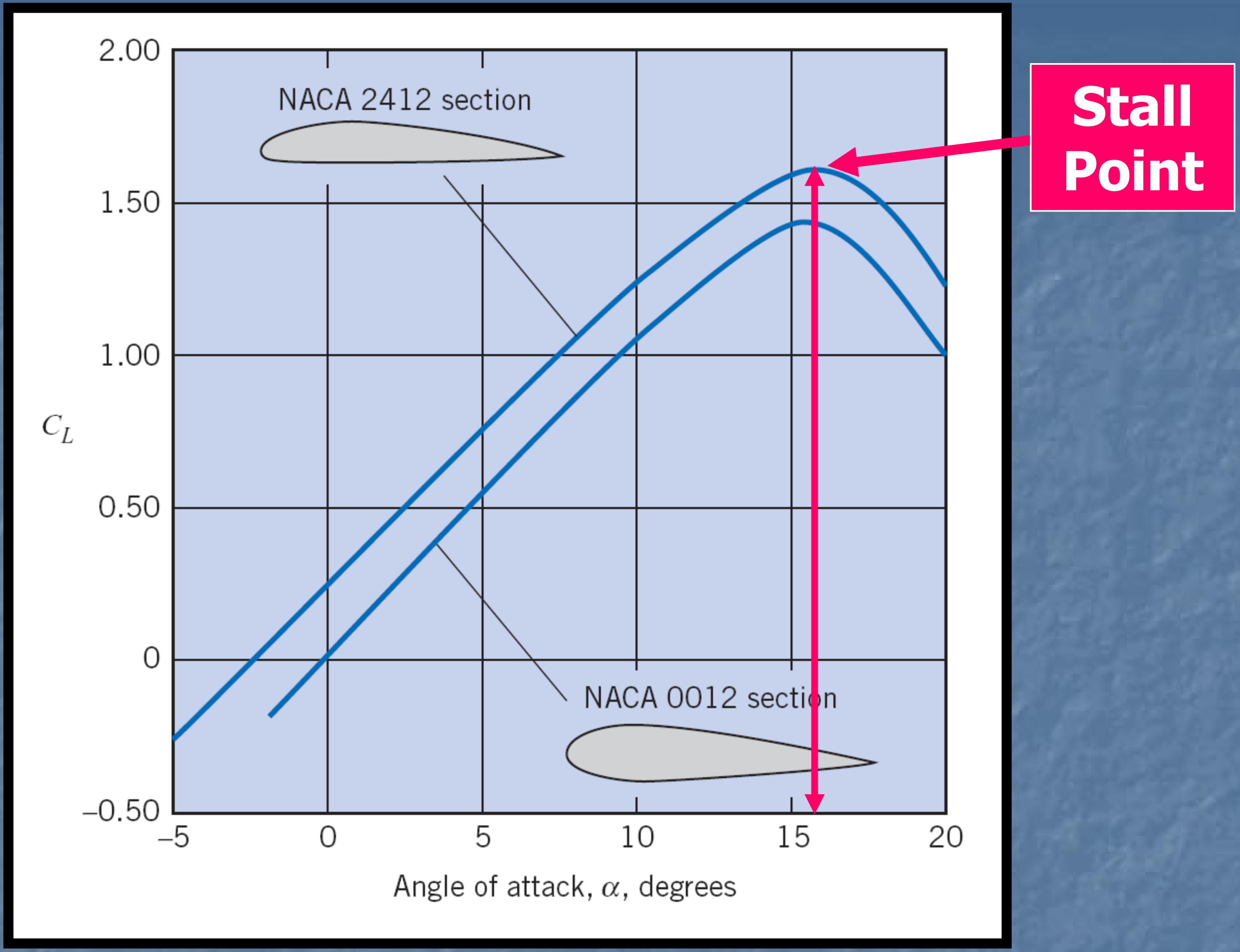
Combining the above three Eqns., we have,

$C_L = 2\pi\alpha$ **Eqn. (1)**

$F_L = \rho V_0^2 \pi c l \alpha$ **Eqn. (2)**

For Irrotational Flow

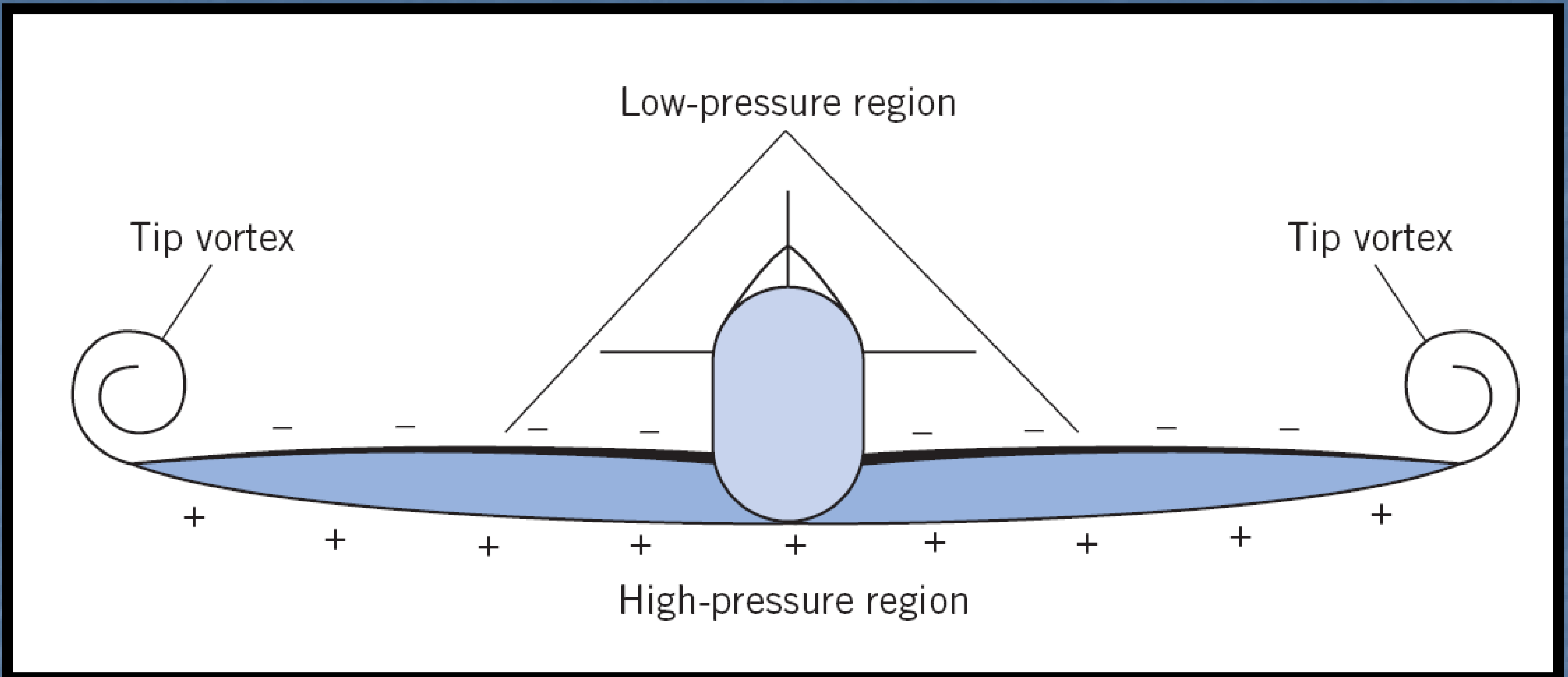
Eqns. (1) & (2) are the theoretical lift equations for an Infinitely Long Airfoil at a Small Angle of Attack



Values of *CL* for two NACA airfoil sections

Stall occurs when (C_L) starts to decrease with increasing of angle of attack (α)

Airfoil of Finite Length – Effect on Drag and Lift



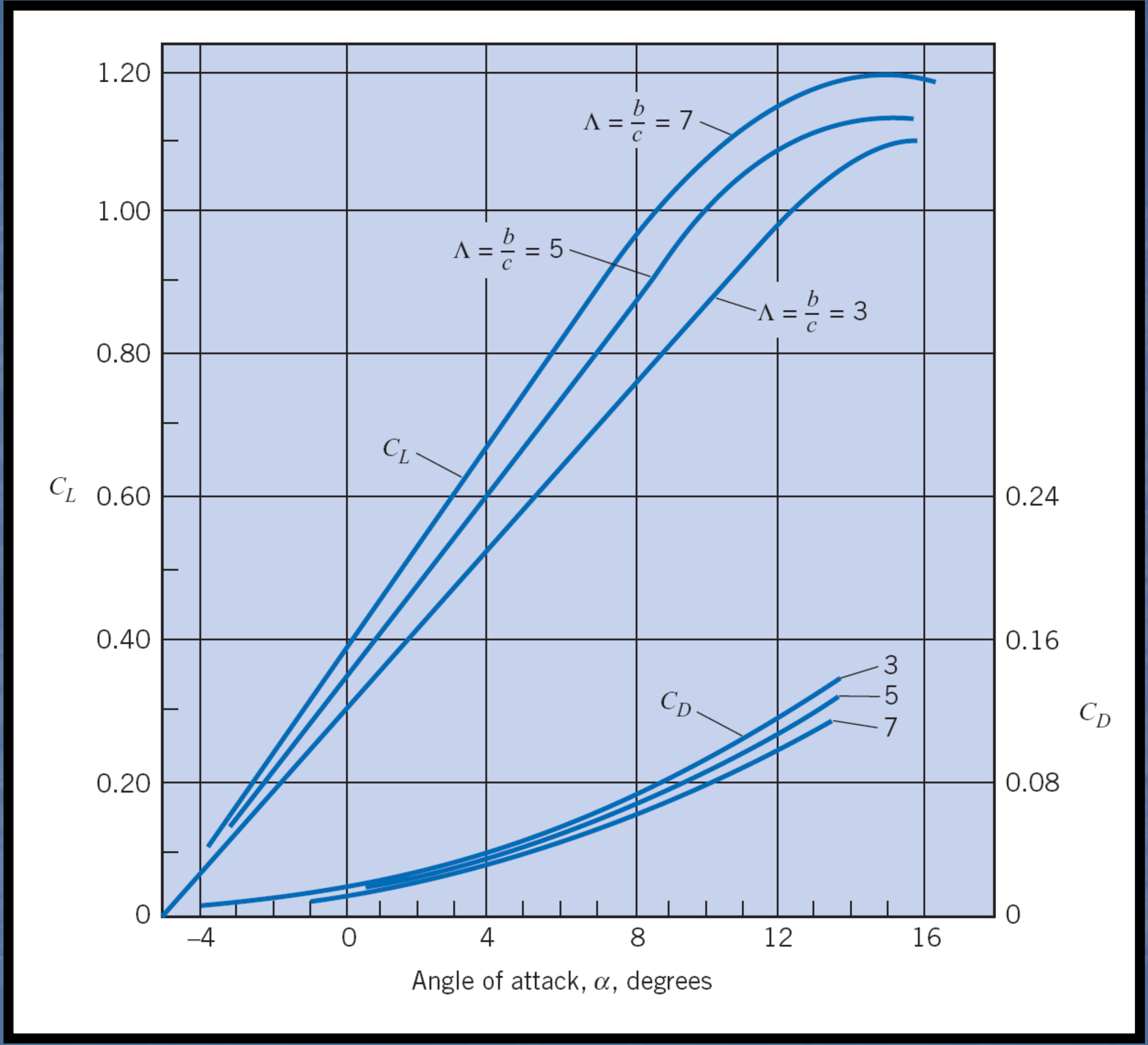
Due to the **Tip Vortices** induced as shown above, a Downward component of **velocity (w)** is induced to the **approach velocity** V_0

$$\phi = \frac{w}{V_0}$$

$$C_{Di} = \frac{C_L^2}{\pi(b^2/S)}$$

Aspect Ratio of the wing $\Lambda = \frac{b}{c}$

Fig. (11.23)

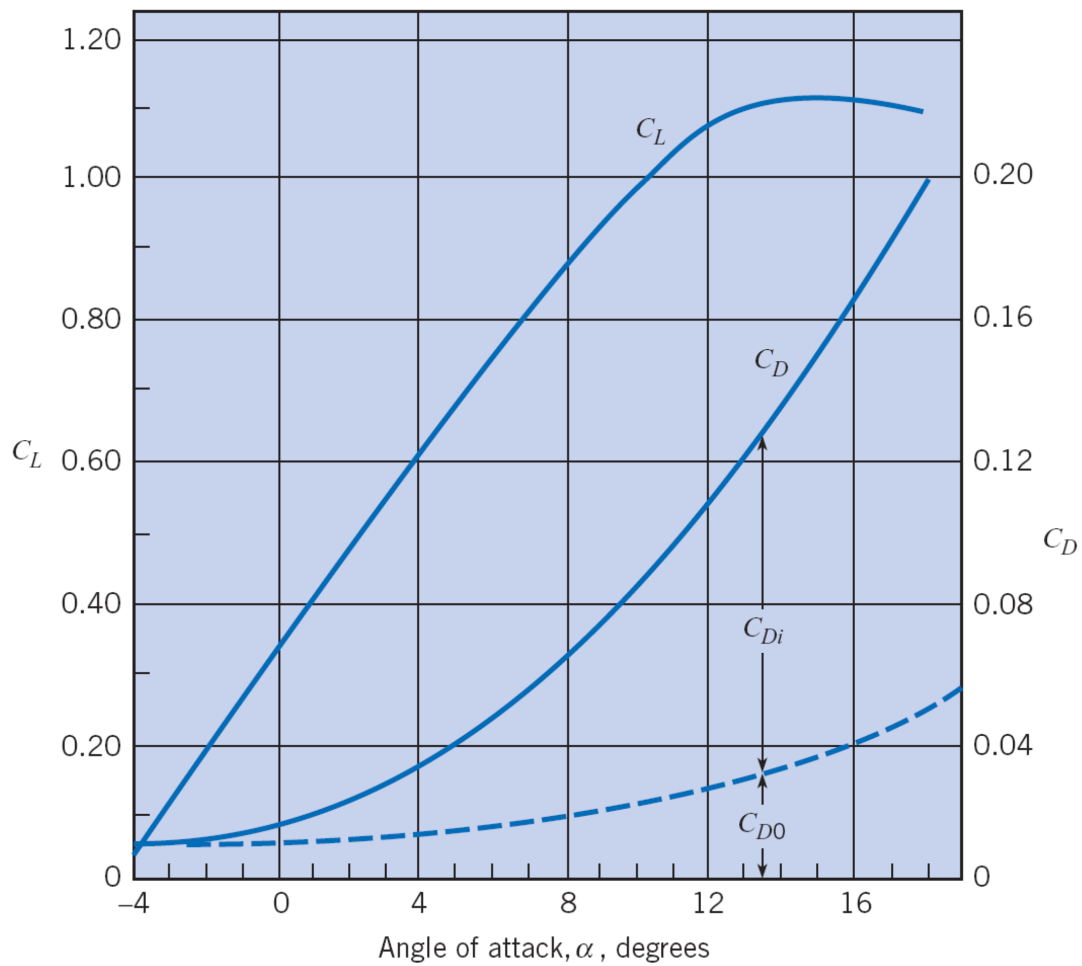


Coefficients of lift and drag for three wings with aspect ratios of 3, 5, and 7

The total drag of a rectangular wing is computed by

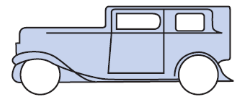
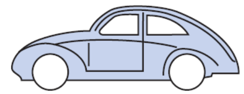
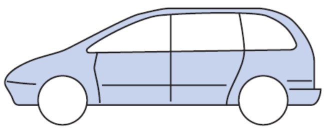
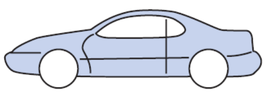
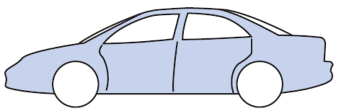
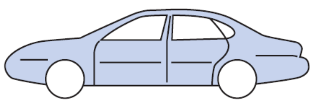
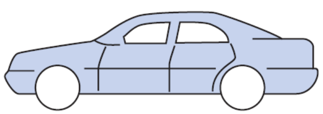
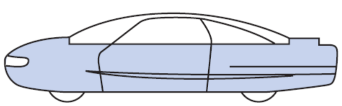
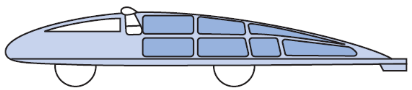
$$F_D = (C_{D0} + C_{Di})\frac{bc\rho V_0^2}{2}$$

where C_{D0} is the coefficient of form drag of the wing section and C_{Di} is the coefficient of induced drag.



Drag and Lift on Road Vehicles

TABLE 11.2 COEFFICIENTS OF DRAG FOR CARS

Make and Model	Profile	C_D
1932 Fiat Balillo		0.60
Volkswagen "Bug"		0.46
Plymouth Voyager		0.36
Toyota Paseo		0.31
Dodge Intrepid		0.31
Ford Taurus		0.30
Mercedes-Benz E320		0.29
Ford Probe V (concept car)		0.14
GM Sunraycer (experimental solar vehicle)		0.12

DECREASING

Drag and Lift on Road Vehicles

Year	CD Value
1920s	0.8
1940s	0.7
1970s	0.55
1980s	0.45
2000s	0.29-0.33

CD DECREASING

(CD) for racing cars usually below (0.2)

Drag and Lift on Road Vehicles

Factors effecting the drag of a car

1. The underside roughness of the car due to axels, mufflers, wheels, fuel tank and shock absorbers.
2. Interior air flow system.
3. Rear view mirrors.
4. Antennas.
5. Surface protrusions.

<u>General motors Carried out design modifications to reduce drag, these are:</u>

1. Installation of rear engine.
2. Cooling air for the engine is drawn in through inlets on the rear.
3. Rear mirrors are removed.

END OF SUMMARY (11)