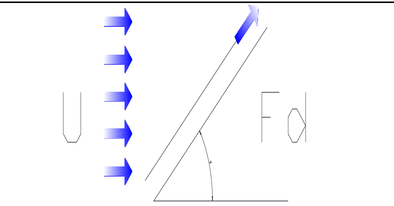
12. FLOW OVER SUBMERGED BODIES

1. When a fluid flows and passes the submerged body with a relative velocity (U_∞), every differential surface area experiences a pair of forces due to Pressure & Wall shear stress(τ_0).
2. Therefore, the body observes a net resultant force, which has 2 components,
   a. Drag Force: Along the axis of U_∞
   b. Lift Force: Perpendicular to the direction of U_∞



$dF_D = \tau_0 dA\cos\theta + PdA\sin\theta$	$\tau_0 dA\cos\theta$= Shear or Friction Drag	$PdA\sin\theta$ = Pressure Drag

CLASSIFICATION OF BODY	
STREAMLINE BODY	**BLUFF BODY**
A body whose surface coincides with the streamlines of flow.	A body Which obstructs the streamlines of flow is known as bluff or blunt body.
Pressure Drag is very low & total drag is also less.	Relatively Higher Pressure Drag & Total Drag is high.
Boundary layer separation is low. Hence, lesser eddies and subsequent losses.	Boundary layer separation is high. Hence, Higher eddies and subsequent losses.
E.g. Fishes Shape, Aerofoil, Hydrofoils, etc…	E.g. Cylinders, etc…

DRAG FORCE:

$F_D = C_D A_{ch} \frac{1}{2}\rho U_\infty^2$	C_D =Coefficinet of Drag= $f(Re, Geometry, Ma\ (For\ compressible\ flow))$ A_{ch} = Characteristic area
$A_{ch} = A_{Proj}(For\ Blunt\ Body)$	$A_{ch} = A_{Plan}(For\ Streamline\ Body)$

POWER LOST DUE TO DRAG: $P_D = F_D U_\infty$

F_D mostly acting in the direction opposite to desired motion of the body.

LIFT FORCE:

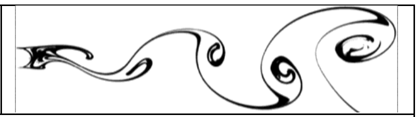
$F_L = C_L A_{Plan} \frac{1}{2}\rho U_\infty^2$	C_D =Coefficinet of Lift= $f(Re, Geometry, Ma\ (For\ compressible\ flow))$ A_{Plan} = Plan area

Note: If effective area is mentioned, then replace A_{Plan}&A_{Proj} With A_{eff}.

DRAG ON SPHERES: 1. $Pressure\ Drag/Shear\ Drag = 0.5$ 2. If $Re \le 1$, the flow is known as **Stokes Flow**. And Stokes Law is valid.	**STOKES LAW:** $F_D = 3\pi\mu D U_\infty$ **For Stokes Law,** $\boldsymbol{C_D = 24/Re}$ $\because A_{ch} = \pi D^2/4$ & $Re \le 1$
Q. Obtain Terminal Velocity of a sphere falling(down) under gravity in a dense and viscous fluid. Assume stokes law is valid. At equilibrium Condition, $W = F_B + F_D \Rightarrow \boldsymbol{U_\infty = (\gamma_b - \gamma_f)D^2/(18\mu)}$	**TERMINAL VELOCITY:** The constant Velocity obtained by a body when it reaches equilibrium.

DRAGS ON CYLINDERS:

When the $Re \ge 45$, The vortices in the region of wake become highly unstable loading to shading of vortices. This phenomenon is referred as "Karman Vortex Trails" (Shown in fig.).



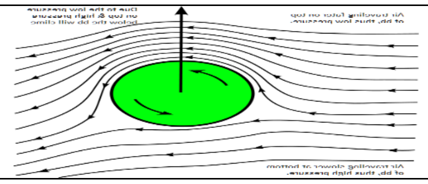
Frequency of vortex Shading= n	$\boldsymbol{Strouhal\ Number = \frac{nD}{U_\infty} = 0.198\left(1 - \frac{19.7}{Re}\right)}$

If the Frequency of vortex shading matches with the natural frequency of cylinder, then resonance takes place. Due to resonance a sound is developed & it's known as singing of wires.

MAGNUS EFFECT: The lifting effect generated on rotating body when it's placed in a stream of flow. E.g. Lifting of table tennis ball When given a spin, etc…

LIFT ON CYLINDER:

$\boldsymbol{F_L = \rho U_\infty \Gamma L} = 2\pi R\rho U_\infty V_T L$	ρ =Density of Fluid
U_∞ = Free Stream Velocity of Fluid relative to the body	$\boldsymbol{\Gamma}$ = **Circulation** $= \boldsymbol{V_T(2\pi R)}$ L = Length of the Cylinder



1. $C_L$on Cylinder Experiencing Magnus Effect $= 2\pi\, V_T/U_\infty$
2. Velocity on a cylinder Experiencing magnus Effect: $V_A = V_T + 2U_\infty \sin\theta$

Condition for a single stagnation point, $V_A = 0$ & $\theta = -90° \Rightarrow C_L = 4\pi$

If $V_A < 2U_\infty \Rightarrow C_L < 4\pi(2\, St.Pt)$

If $V_A = 2U_\infty \Rightarrow C_L = 4\pi(1\, St.Pt)$

AEROFOILS: Stall Condition: $\alpha > \alpha_{@maxLift}$

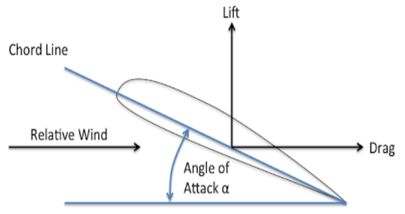
Area $= LC$	Aspect Ratio $= L/C$	$L =$ Span	$C =$ Chord
$\alpha =$ Angle of Attack			

At stall Condition, 1) BL Separation take place, 2) C_D drastically increases

Circulation around an aerofoil, $\boldsymbol{\Gamma = \pi C\, U_\infty \sin\alpha}$

Lift Force on aerofoil, $\boldsymbol{F_L = \rho U_\infty \Gamma L} = \pi \sin\alpha\, CL\rho U_\infty^2$

For Aerofoil, $C_L = 2\pi \sin\alpha$



UNDER STEADY LIFT OF AEROPLANE:

In the Steady State Condition,

$$\sum \vec{F} = 0$$

Forces Acting/Developed in the Aeroplane,

$F_D =$ Drag Force	$F_L =$ Lift Force
$W =$ Weight of The Aeroplane	$F_T =$ Thrust Developed by Aeroplane

Power Required to overcome Drag, $P_D = F_D U_\infty$