FLOW PAST A CIRCULAR CYLINDER

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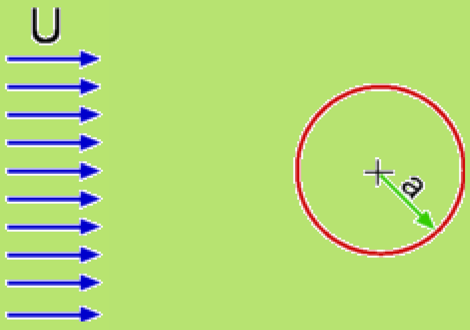
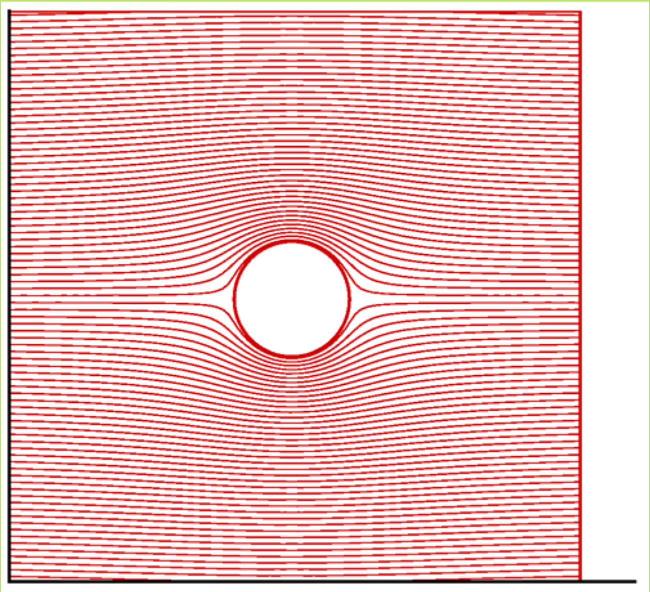
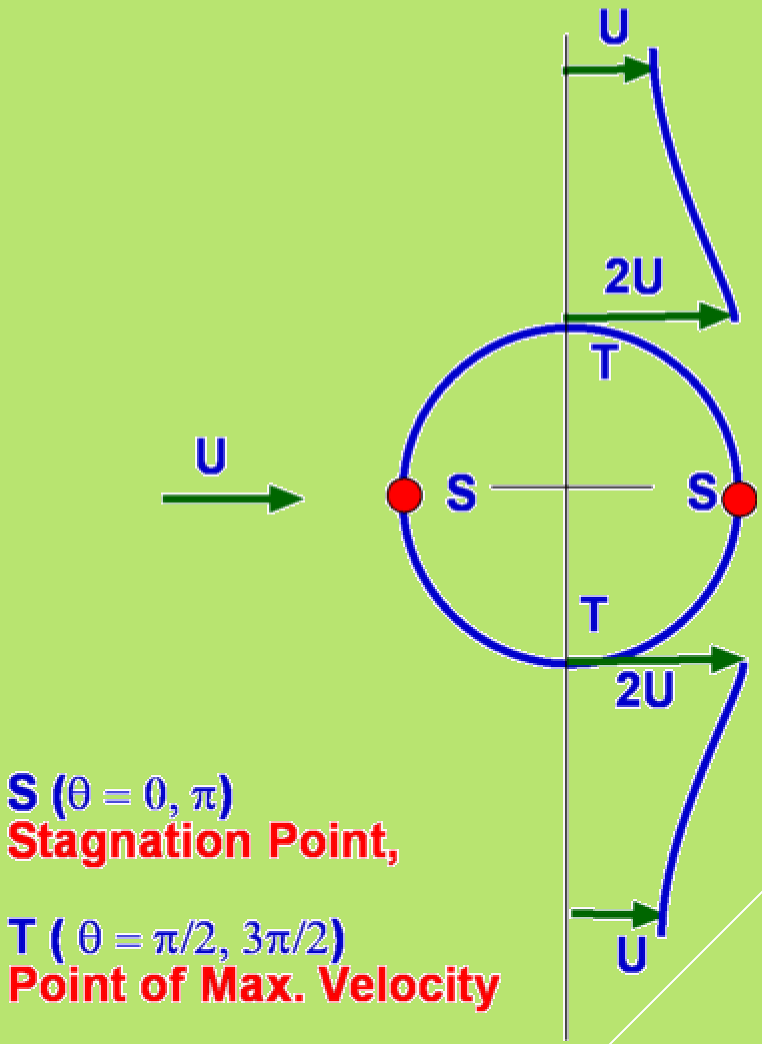


Schematic for Flow past a Circular Cylinder





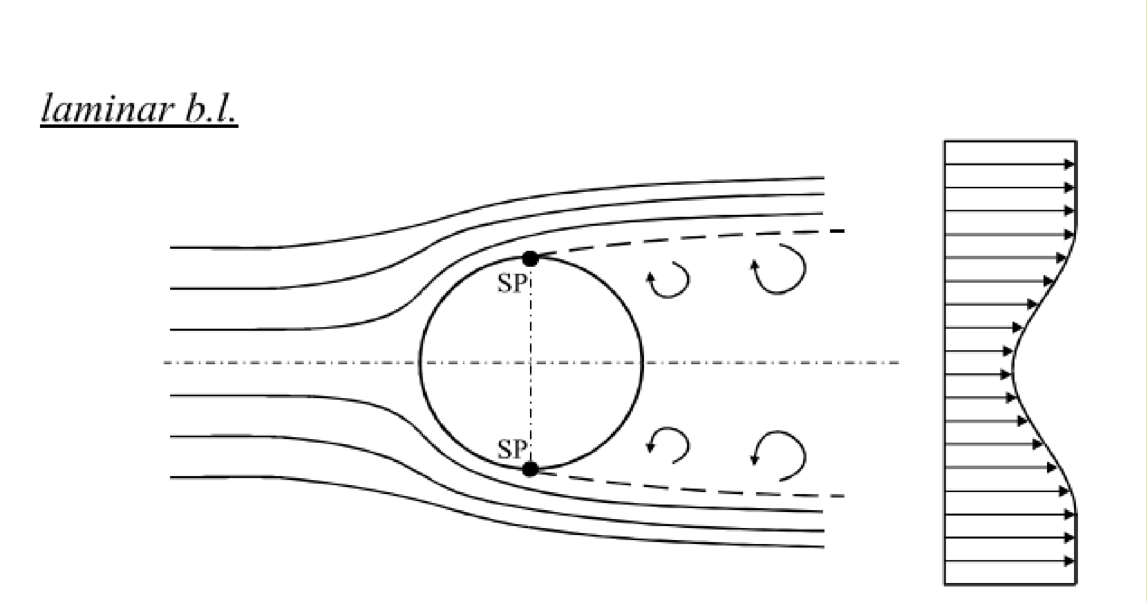
Stagnation Points for Flow about a Circular Cylinder

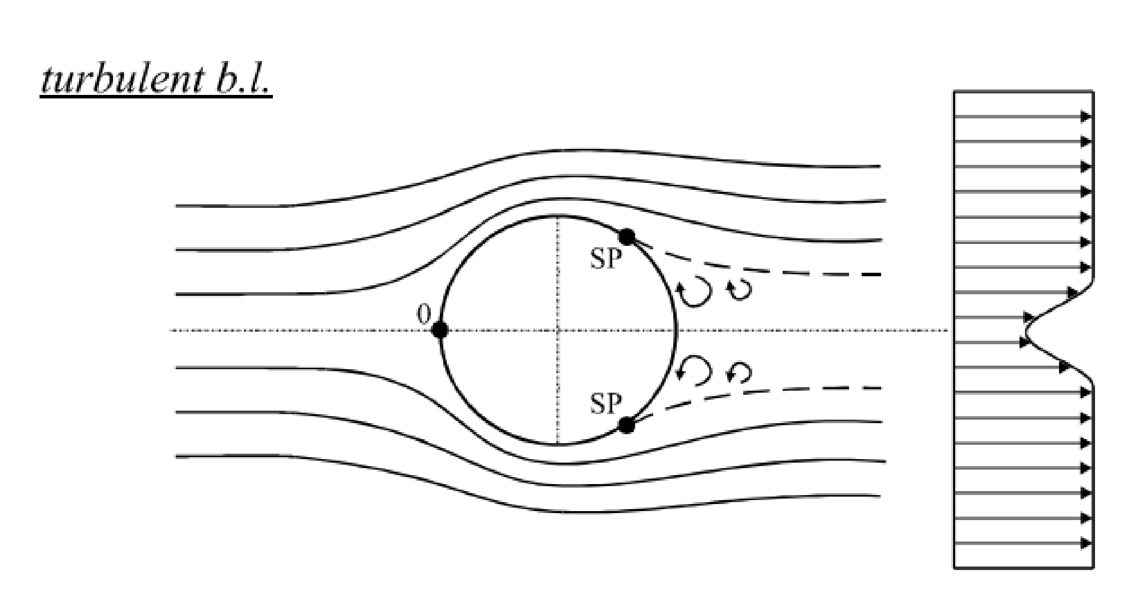
- External flows past objects have been studied extensively because of their many practical applications. *For example, airfoils are made into streamline shapes in order to increase the lifts, and at the same time, reducing the aerodynamic drags exerted on the wings.*
- On the other hand, flow past a blunt body, such as a **circular cylinder**, usually experiences boundary layer separation and very strong flow oscillations in the wake region behind the body. In certain Reynolds number range, a periodic flow motion will develop in the wake as a result of boundary layer vortice being shed alternatively from either side of the cylinder. This regular pattern of vortices in the wake is called a Karman vortex street. It creates an oscillating flow at a discrete frequency that is correlated to the Reynolds number of the flow.
- The periodic nature of the vortex shedding (вихреобразование) phenomenon can sometimes lead to unwanted structural vibrations, *especially when the shedding frequency matches one of the resonant frequencies of the structure*. One example is the famous Tacoma Narrow bridge incident. (From the history of the Tacoma bridge .mp4)
- In this presentation, the flow past a circular cylinder is investigated and study the turbulent wake flow field using the Particle Image Velocimetry (PIV) technique.

FLOW SEPARATION

- The presence of the fluid viscosity slows down the fluid particles very close to the solid surface and forms a thin slow-moving fluid layer called a boundary layer. The flow velocity is zero at the surface to satisfy the no-slip boundary condition. Inside the boundary layer, flow momentum is quite low since it experiences a strong viscous flow resistance. Therefore, the boundary layer flow is sensitive to the external pressure gradient (as the form of a pressure force acting upon fluid particles). If the pressure decreses in the direction of the flow, the pressure gradient is said to be favorable. In this case, the pressure force can assist the fluid movement and there is no flow retardation (торможение). However, if the pressure is increasing in the direction of the flow, an adverse pressure gradient condition as so it is called exist. In addition to the presence of a strong viscous force, the fluid particles now have to move against the increasing pressure force. Therefore, the fluid particles could be stopped or reversed, causing the neighboring particles to move away from the surface. This phenomenon is called the boundary layer separation.

FLOW SEPARATION





✓ for $\Theta \approx 90^{\circ}$ adverse pressure gradient occurs

$$\frac{\partial p}{\partial x} < 0 \quad \Rightarrow \quad \frac{\partial p}{\partial x} > 0$$

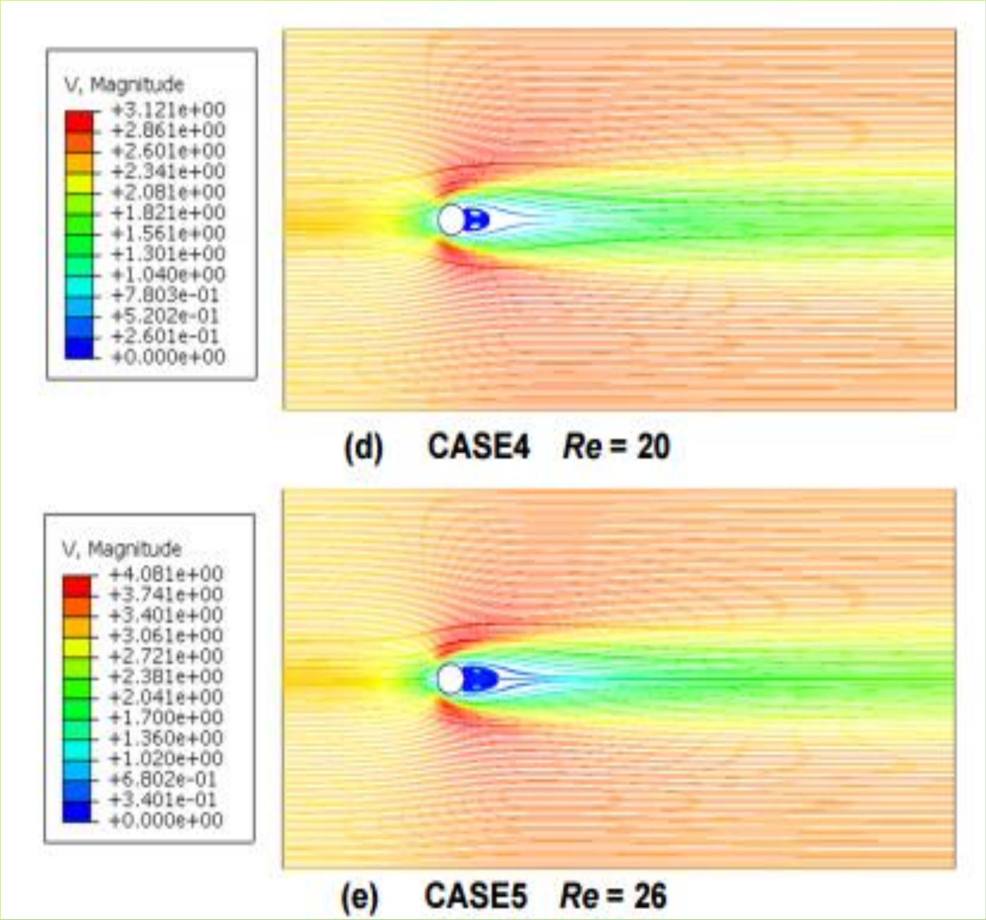
➢ separation point (SP) is moved further downstream

$$\Theta_{SP} = 130^{\circ} \div 140^{\circ}$$

WAKE

Consider a fluid particle flows within the boundary layer around the circular cylinder. From the pressure distribution measured in an earlier experiment, the pressure is a maximum at the stagnation point and *gradually decreases along the front half of the cylinder*. The flow stays attached in this favorable pressure region as expected. However, the pressure ***starts to increase*** in the rear half of the cylinder and the particle now experiences an ***adverse pressure gradient***. Consequently, the flow separates from the surface and creating a highly turbulent region behind the cylinder called the wake. The pressure inside the wake region remains low as the flow separates and a net pressure force (pressure drag) is produced.

TURBULENT WAKE FLOW BEHIND A CIRCULAR CYLINDER



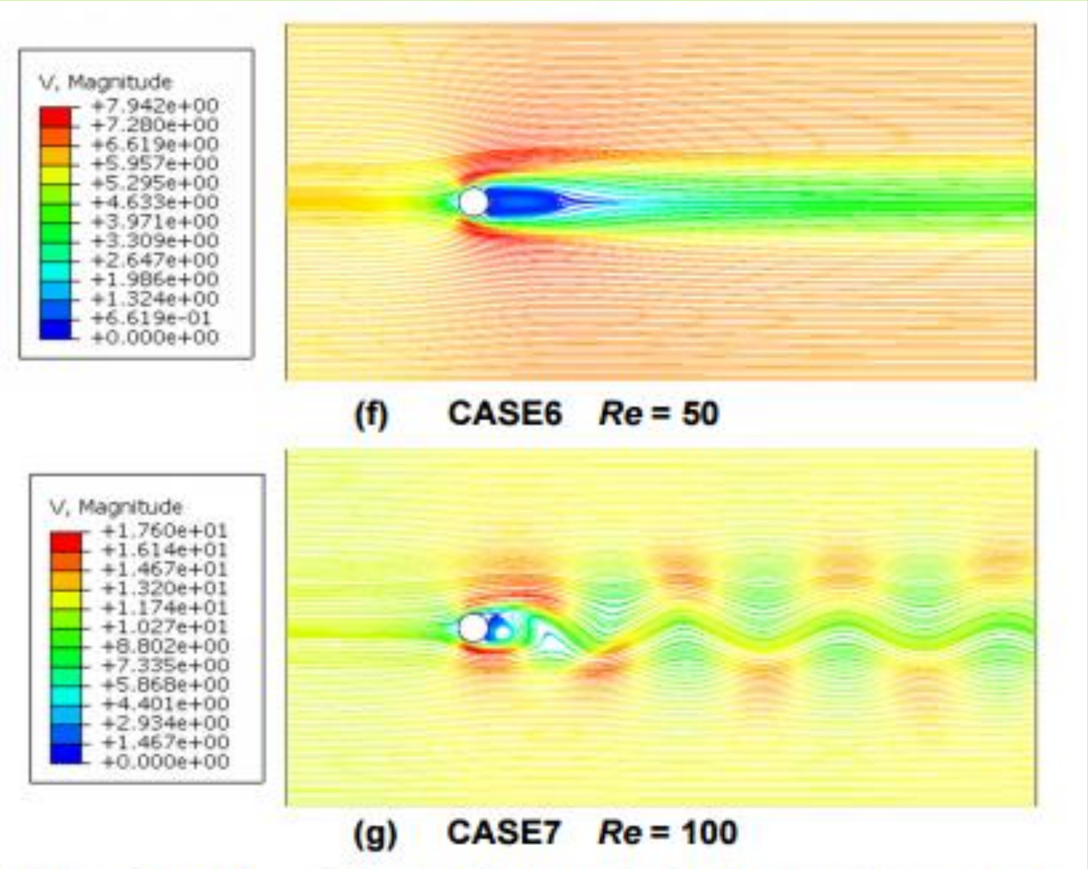
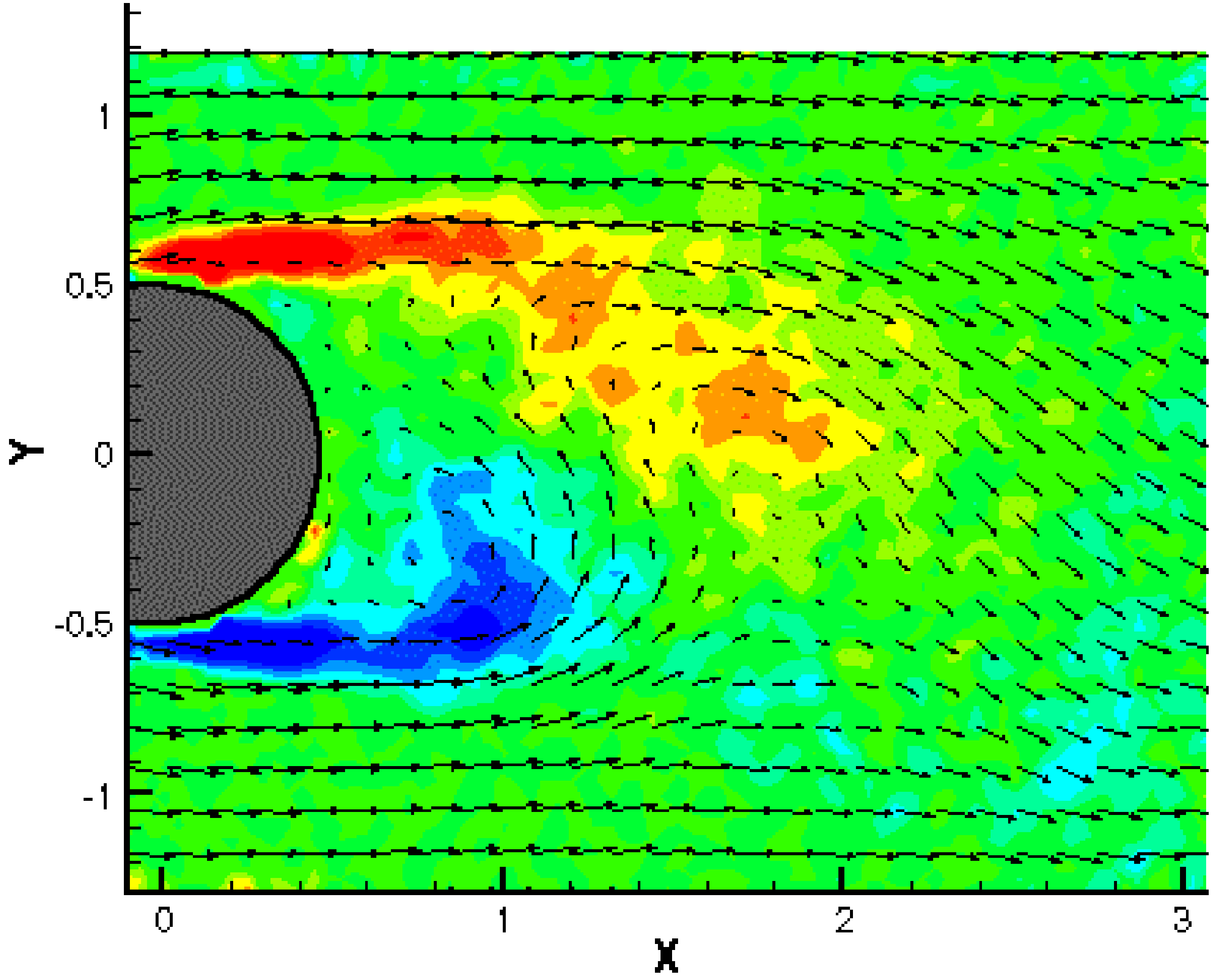
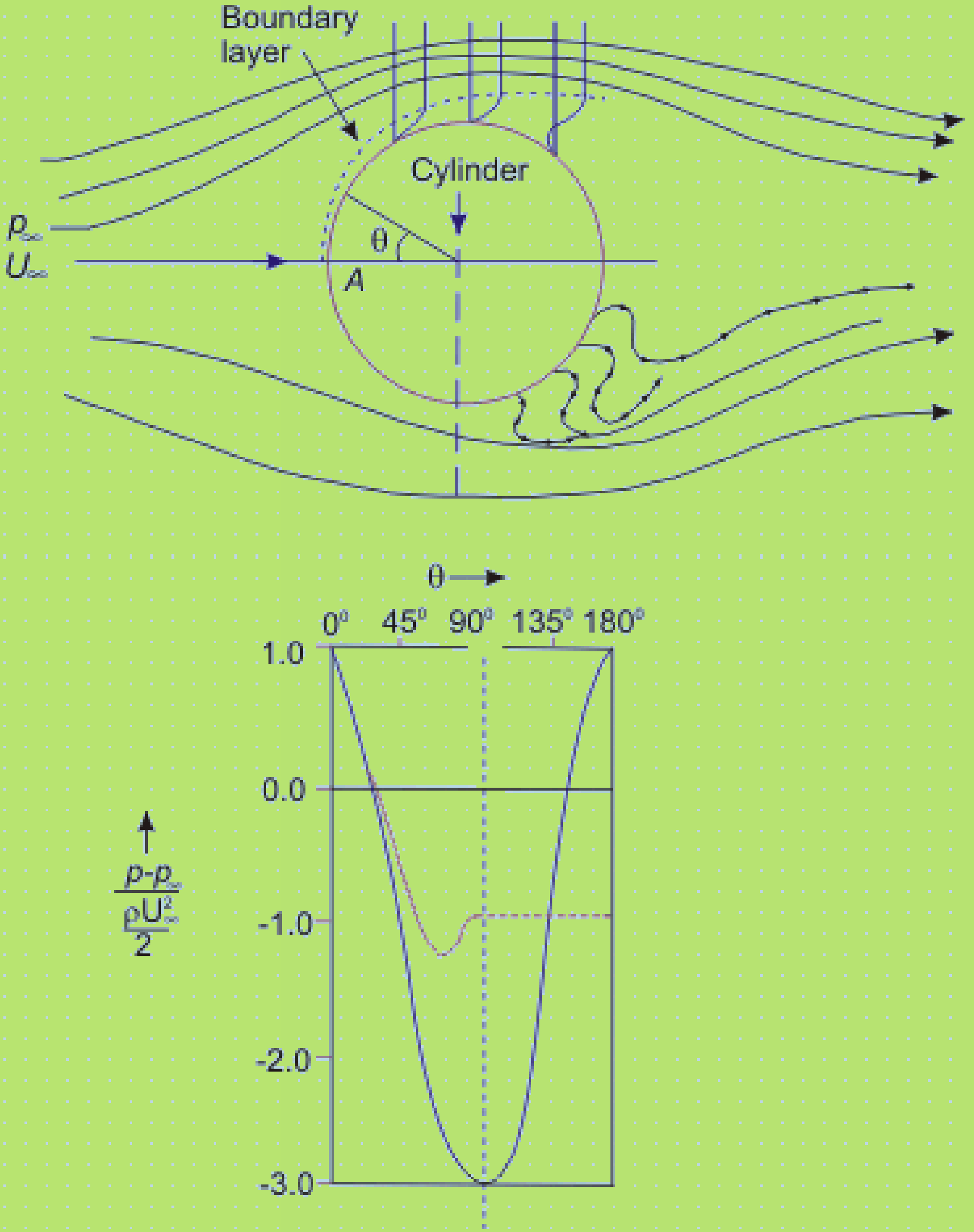
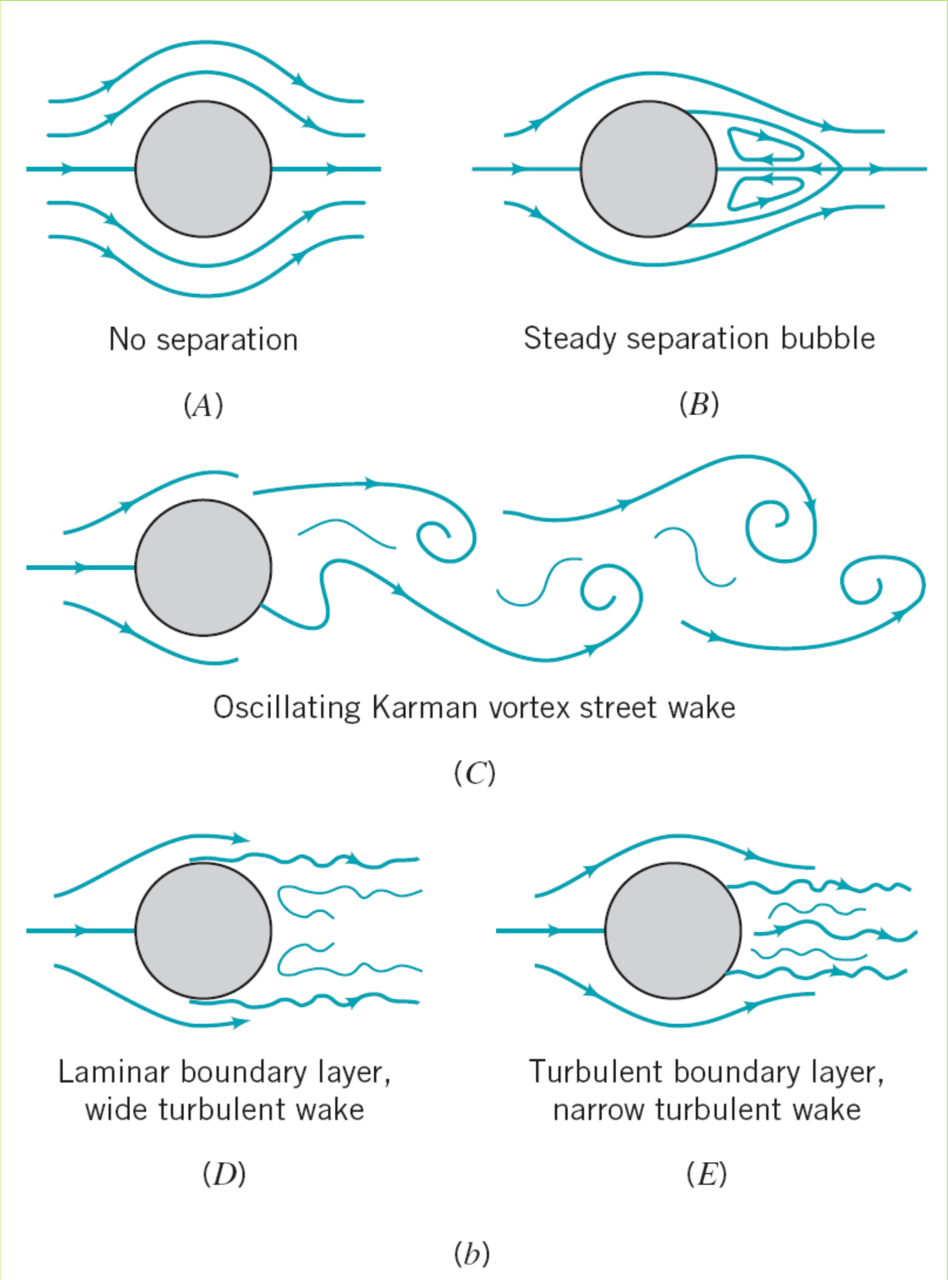


Figure 3 (cont). **Results of the analysis of streamline patterns**


1
0.5
0
-0.5
-1
Y
0
1
2
3
X

FLOW SEPARATION AND FORMATION OF WAKE BEHIND A CIRCULAR CYLINDER



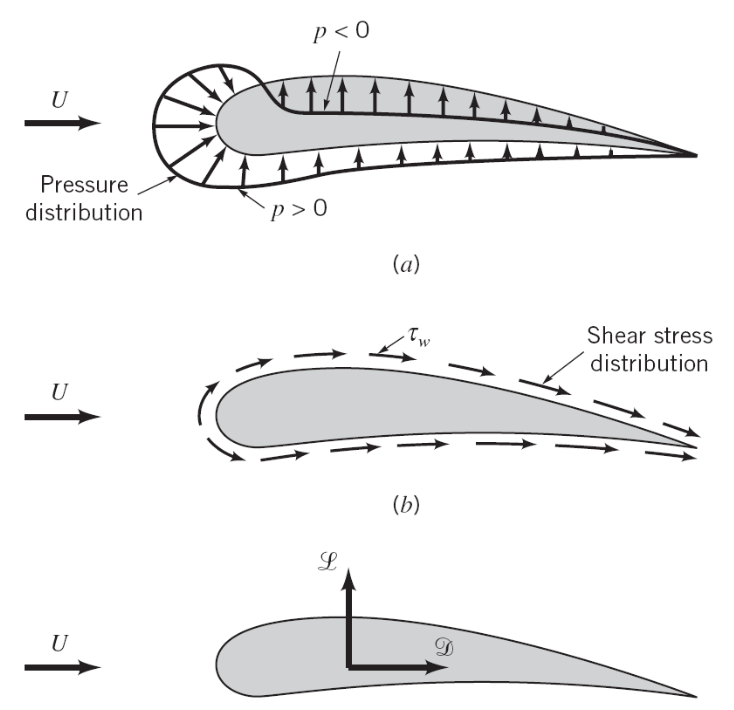


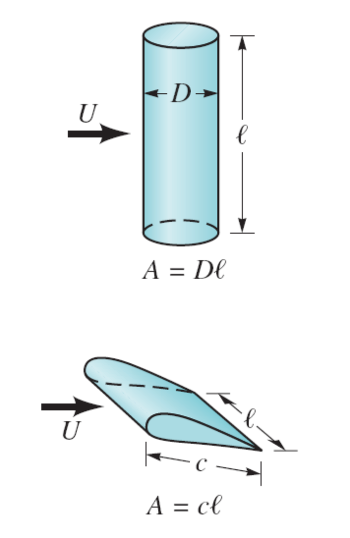
AERODYNAMIC LOADING

According to the Newton's second law, time rate change of the linear momentum is equal to the sum of all external forces acting on a system. Therefore, an integration of the linear momentum inside a control voulme surrounding the circular cylinder can provide information of the aerodynamic forces (lift and drag) acting on the cylinder. As shown in figure , and animated PIV vortex shedding sequence, and particle pathline visualization sequence, there are alternative upward and downward flows in the wake as the result of vortex shedding. Consequently, there must be also an oscillatory up and down force acting periodically on the cylinder. This periodic forcing exerting on the cylinder body is responsible for the vortex-induced vibrations as described earlier.

Lift and Drag

- shear stress and pressure integrated over the surface of a body create force
- **drag:** force component in the direction of upstream velocity
- **lift:** force normal to upstream velocity (might have 2 components in general case)





$$D = \int dF_x = \int p\cos\theta dA + \int \tau_w \sin\theta dA \qquad C_D = \frac{D}{\frac{1}{2}\rho U^2 A}$$

$$L = \int dF_y = \int p\sin\theta dA + \int \tau_w \cos\theta dA \qquad C_L = \frac{L}{\frac{1}{2}\rho U^2 A}$$

- http://imechanica.org/files/Sato_MDAC_final_2232012.pdf
- https://ru.wikipedia.org/wiki/%D0%A2%D0%B0%D0%BA%D0%BE%D0%BC%D1%81%D0%BA%D0%B8%D0%B9_%D0%BC%D0%BE%D1%81%D1%82
- https://www.eng.fsu.edu/~shih/succeed/cylinder/cylinder.htm