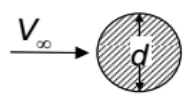
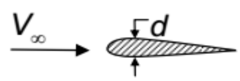
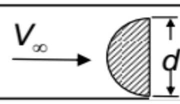
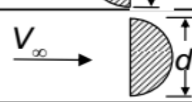
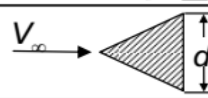
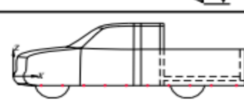
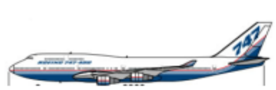
# Aerodynamics: Drag

- The drag is an important subject in aerodynamics.
- A reduction in drag can lead to a reduction in fuel consumption and better performance for a vehicle.
- The drag coefficient varies from one object to another depending on the particular geometry of that object.
- For streamlined body such as wing and airfoil, the drag coefficient is low compared to bluff body such as circular cylinder, sphere or road vehicle.

# Aerodynamics: Drag

| | | |
|---|---|---|
| Normal Plate |   | $C_D = 2.0$ |
| Circular Cylinder |   | $C_D = 1.2$ at Re = $10^5$ <br> $C_D = 0.6$ at Re = $10^7$ |
| Streamlined body |   | $C_D = 0.12$ |
| Half Cylinder |   | $C_D = 1.2$ |
| Half Cylinder |   | $C_D = 1.7$ |
| Equilateral triangle |   | $C_D = 1.6$ |
| Pickup truck |  | $C_D = 0.4\text{-}0.5$ |
| Piper PA-16 Clipper |  | $C_D = 0.037$ |
| Boeing 747 |   | $C_D = 0.017$ |

# Aerodynamics: Drag for Airfoil vs. Wing

• It is important to note that there is a difference between the drag of an airfoil and that of a wing.

• The drag acting on an airfoil section is the sum of the *skin friction drag*, $D_f$, and the *pressure drag*, $D_p$, which is due to flow separation. That is,

$$C_d = \frac{D_f + D_p}{q_\infty S}$$

The sum of the skin friction drag and the pressure drag is called *profile drag*.

• On the other hand, the total drag of a subsonic finite wing in a real case is the sum of the induced drag, $D_i$, and the profile drag,

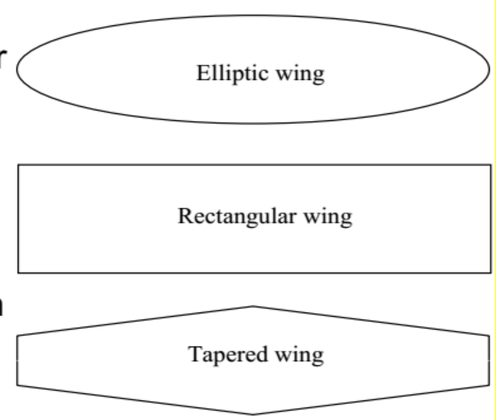
$$C_D = C_d + \frac{D_i}{q_\infty S}$$

where the subscript $D$ represents the drag of the wing and the subscript $d$ represent the drag of the airfoil.

• Using the lifting line theory it can be shown that for a general wing

$$C_{D,i} = \frac{C_L^2}{\pi e \Re}$$

where  is the induced drag coefficient and $e$ is the *span efficiency factor*. For elliptical wing, $e$ = 1 and for other platforms, $e$ < 1.




• Therefore, the induced drag is minimum for an elliptical platform.

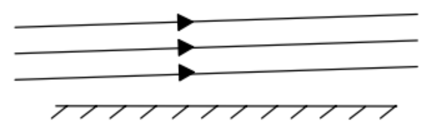
• In the past, several aircraft have been designed with elliptical wings.

• However, elliptical wings are more expensive to manufacture than other simple platform such as rectangular wings. The rectangular wing is considered far from optimum. A compromise between the elliptical wing (manufacturing difficulty) and rectangular wing (poor efficiency) is the tapered wing.

# Aerodynamics: Laminar and Turbulent Flows

• The drag coefficient of a body depends on the flow around the body whether it is laminar or turbulent.

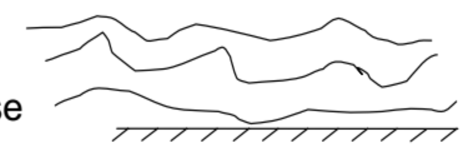
• When the streamlines are smooth and regular and a fluid element moves smoothly along a streamline the flow is called laminar.



Laminar flow

• On the other hand, when the streamlines break up and a fluid element moves in a random, irregular, and tortuous fashion the flow is called turbulent.

• Most of real flows are turbulent flows.



Turbulent flow

•In turbulent flow, the higher energy fluid elements from the outer regions of the flow are pumped close to the surface. Hence, the average flow velocity near a solid surface is larger for a turbulent flow in comparison with laminar flow. Figure 15 shows the velocity profile for laminar and turbulent boundary layers.

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• Hence, the average flow velocity near a solid surface is larger for a turbulent flow in comparison with laminar flow.

• Since the shear stress is proportional to the velocity gradient along the y-direction $\tau \propto \partial u / \partial y$ then the shear stress (friction) as well as aerodynamic heating at the wall surface is higher for turbulent flow than laminar flow.