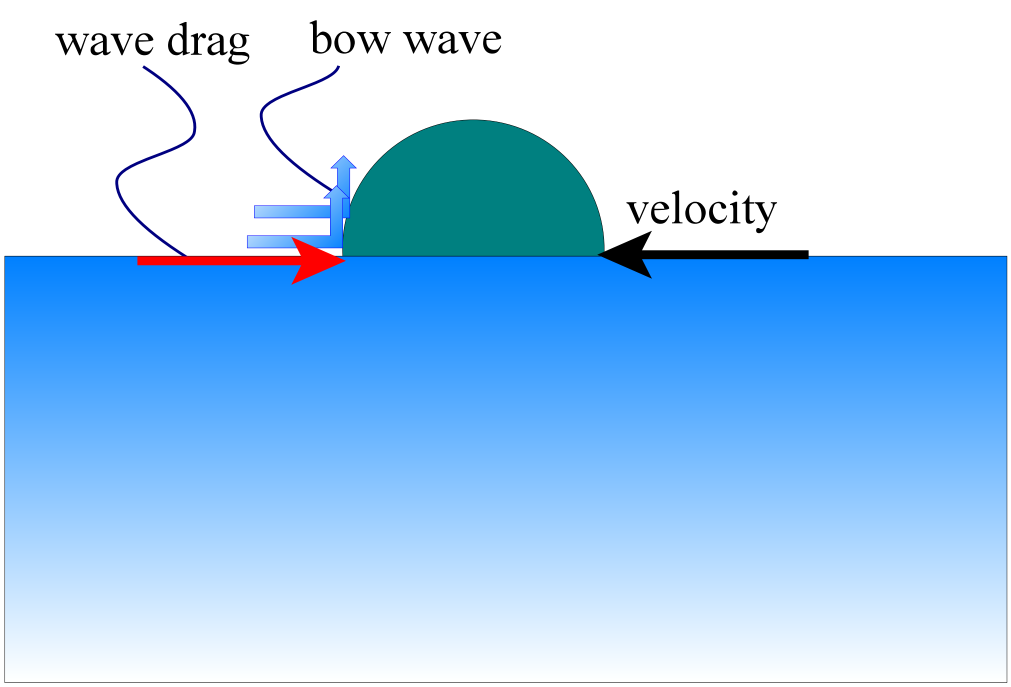
Drag Forces (Wave)

Wave Drag -due to interaction between two surfaces of different viscosity (e.g., bow wave)

An object moving along the surface of the water will create a **bow wave**. Work is required to lift the water and thus slow the motion. This is the reason why swimming underwater is easier. The amount of this drag depends upon the shape of the leading edge.



Drag Forces (Viscous)

Viscous or Surface Drag -due to interaction of molecules moving past each other at the **boundary layer** at slow velocities, i.e., when flow is laminar (Stokes' Law)

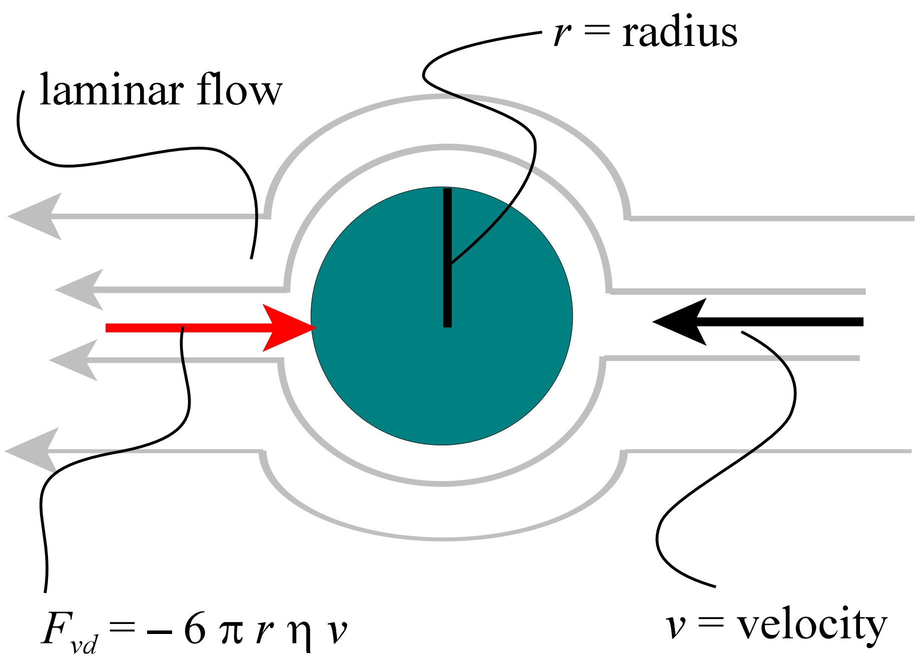
$$F_{vd} = -6 \quad r \quad v$$

where *r* = radius of the sphere

= viscosity of fluid (*eta*, flow resistance in pascal seconds, Pa.s, also called poiseuilles)

v = velocity through fluid (must be slow)

As velocity increases, turbulent flow increases and viscous drag becomes less important than form drag. Viscous drag increases linearly with velocity but form drag increases with velocity squared.



Drag Forces (Form)

Form or Pressure drag -due to turbulent flow around an object

$$F_{fd} = -\tfrac{1}{2}\, C_{drag} \quad A_n\, v^2$$

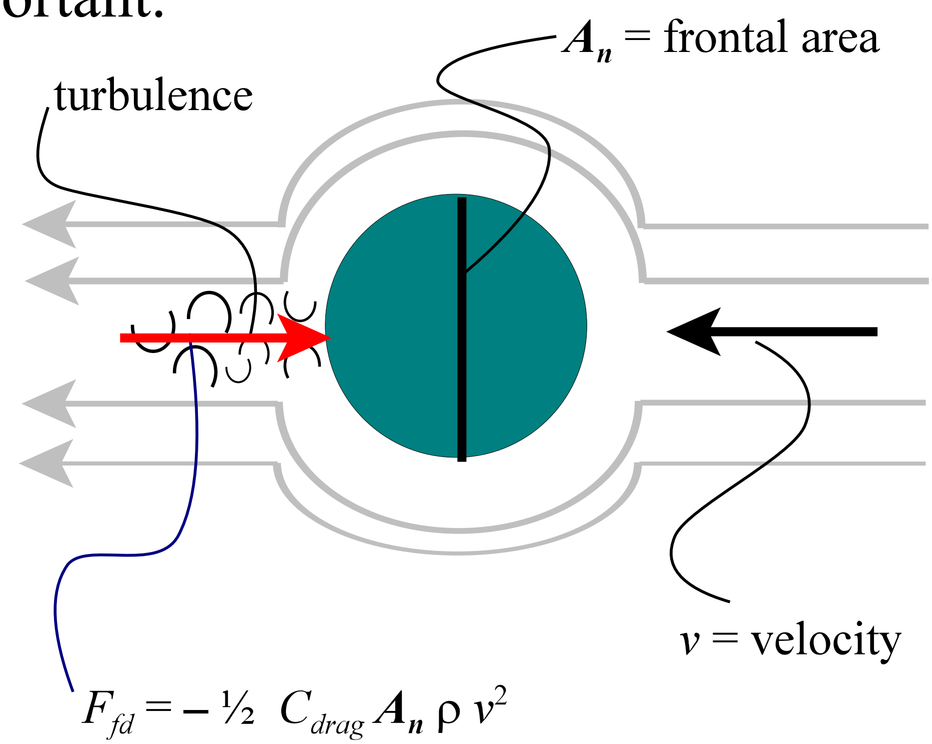
where C_{drag} = drag coefficient

= fluid density

A_n = surface area perpendicular (normal) to motion

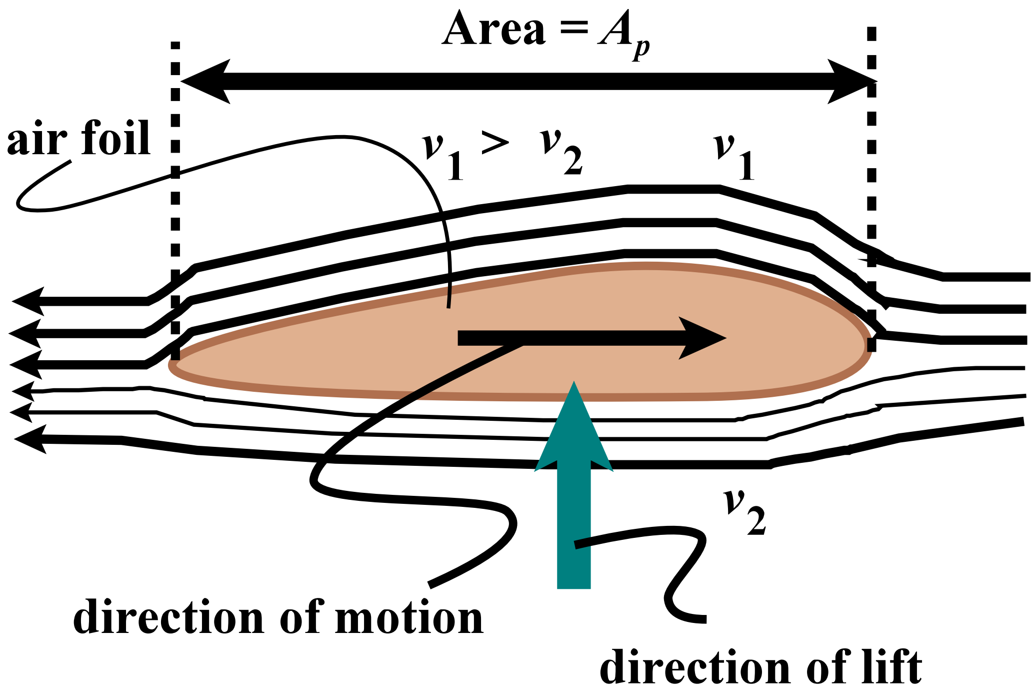
v = velocity through fluid (relative velocity)

Streamlining reduces turbulence and drag. Decreasing frontal area is also an important factor but minimizing changes in velocity is most important.



Air Foil and Bernoulli's Principle

- lift force on an air foil may be explained by Bernoulli's Principle
- higher air flow on top of wing reduces pressure producing a lift force (Bernoulli)



$$F_{lift} = \tfrac{1}{2}\, C_{lift} \quad A_p\, v^2$$

where C_{lift} = coefficient of lift

= fluid density

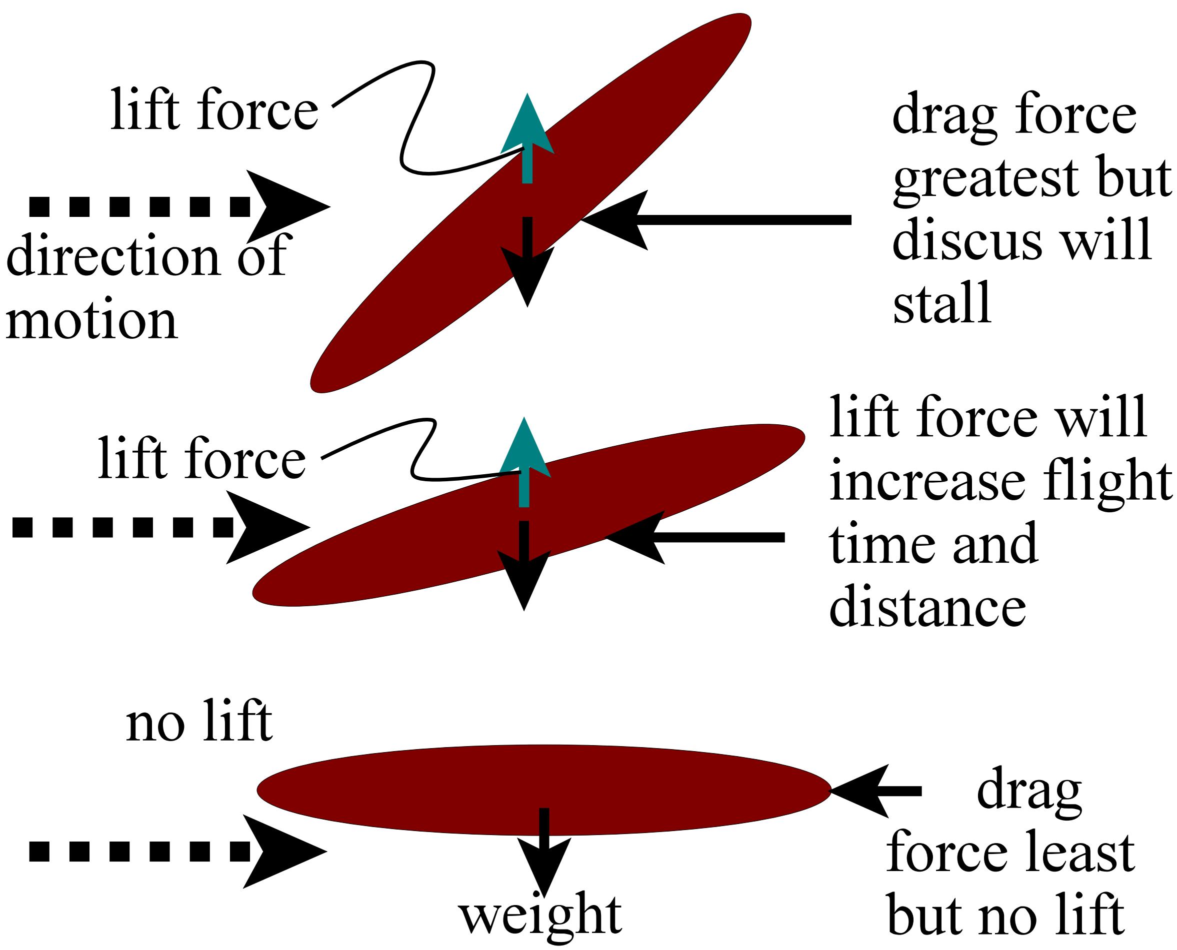
A_p = area parallel to velocity

v = relative velocity of air foil

- Note, Newton's Third Law may also explain (i.e., reaction force due to angle of attack)

Lift and Drag Forces on a Discus

- angle of attack changes relationship between lift and drag
- too steep creates excessive drag
- not steep enough reduces lift
- discus and javelin throwers prefer to throw into the wind? Planes always takeoff flying into the wind.



Magnus Effect on a Spinning Ball

- possibly due to Bernoulli Principle or turbulent flow around roughly surfaced object (see below)
- roughness can be caused by laces (baseball), dimpling (golf ball), wear (table tennis) or nap (lawn tennis)