Balls and Frisbees

Question:

A smooth, gentle river is flowing past a cylindrical post. At the sides of the post, is the water level higher, lower, or equal to its level in the open river?

Aerodynamic Forces

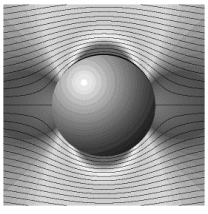
- Drag Forces
  - point directly downstream
  - are caused by slowing the fluid flow
  - transfer downstream momentum to object
- Lift Forces
  - point at right angles to flow
  - are caused by deflecting the fluid flow
  - transfer sideways momentum to object

Drag & Lift

- Viscous drag: surface friction
- Pressure drag: turbulence
- Induced drag: side effect of deflecting flow
- Lift: deflecting flow

Perfect Flow

- Pressure rises in front
  - slow flow, high pressure
- Pressure drops on side
  - fast flow, low pressure
- Pressure rises in back
  - slow flow, high pressure
- Only viscous drag



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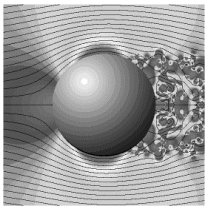
Onset of Turbulence

- Viscous drag slows flow near surface
- Flowing into higher pressure slows flow
- When surface flow stops, turbulence ensues

Imperfect Flow – Low Speeds

- Pressure rises in front
- Pressure drops on side
- Large wake forms in back
- Ambient pressure in wake
- Large pressure drag

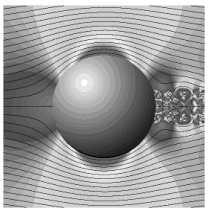


Boundary Layer

- Flow near surface forms "boundary layer"
- At low Reynolds number (<100,000)
  - boundary layer is laminar
  - slowed by viscous drag
- At high Reynolds number (>100,000)
  - boundary layer is turbulent
  - not slowed very much faster

Imperfect Flow – Fast

- Pressure rises in front
- Pressure drops on side
- Small wake forms in back
- Ambient pressure in wake
- Small pressure drag

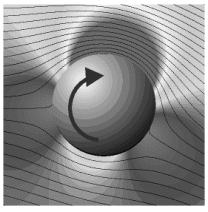


Tripping the Boundary Layer

- To reduce pressure drag
  - trip the boundary layer
  - initiate turbulence in the boundary layer
  - delay flow separation on back of ball
  - shrink the turbulent wake
- Examples: Tennis balls and Golf balls

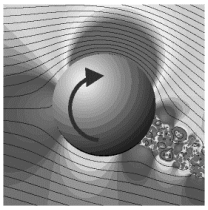
Spinning Balls – Magnus Force

- Surface pulls flow with it
- Flow is faster on one side
- Flow is deflected overall
- Magnus lift force



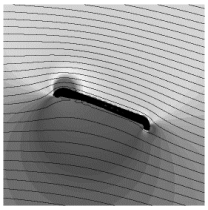
Spinning Balls – Wake Force

- Surface pulls flow with it
- Wake is asymmetric
- Flow is deflected overall
- Wake deflection lift force



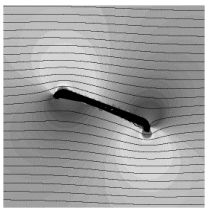
Frisbees

- Above Frisbee
  - airflow bends inward
  - pressure drops
  - speed increases
- Below Frisbee
  - airflow bends outward
  - pressure rises
  - speed decreases
- Pressure imbalance lifts Frisbee



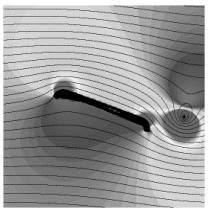
Starting Flight

- Airflow starts symmetric
- No net deflection of air
- No lift



Vortex Shedding

- Trailing airflow unstable
- Vortex peals away with ccw angular momentum
- Remaining airflow has cw angular momentum



Stable lift

- After vortex is shed, Frisbee has lift
- Air is deflected downward
- Frisbee is pushed upward
- Airflow around Frisbee has angular momentum