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?

Observations About Balls and Frisbees

- Balls slow down in flight
- The faster a ball goes, the quicker it slows
- Spinning balls curve in flight
- Frisbees use air to support themselves

Aerodynamic Forces

- Drag Forces
  - push the object directly downstream
  - result from slowing the fluid flow
  - transfer downstream momentum to the object
- Lift Forces
  - push the object at right angles to the flow
  - result from deflecting the fluid flow
  - transfer sideways momentum to the object

Drag & Lift

- Surface friction causes viscous drag
- Turbulence causes pressure drag
- Deflected flow causes lift
- Deflected flow causes induced drag

Perfect Flow Around a Ball

- Outward bend in front
  - high pressure, slow flow
- Inward bend on sides
  - low pressure, fast flow
- Outward bend in back
  - high pressure, slow flow
- Pressures balance, so only viscous drag

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?

Onset of Turbulence

- Rising pressure slows fluid
  - Fluid accelerates backward as pressure rises
  - Fluid loses speed but its pressure rises
- Viscous drag slows flow near surface
  - Surface layer of fluid loses total energy
  - Fluid loses both speed and pressure
- If surface flow stops, turbulence ensues

Imperfect Flow, Low Speeds

- Pressure rises in front
- Pressure drops on side
- Big wake forms behind
- Wake pressure is approximately ambient
- Ball experiences 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 much

Imperfect Flow, High Speeds

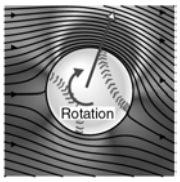
- Pressure rises in front
- Pressure drops on side
- Small wake forms behind
- Wake pressure is approximately ambient
- Ball experiences small pressure drag

Tripping the Boundary Layer

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

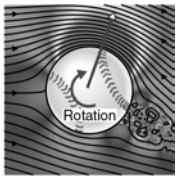
Spinning Balls, Magnus Force

- Surface pulls flow with it
- One side experiences longer inward bend
- That side has lower pressure and faster flow
- Overall flow is deflected
- Magnus lift force



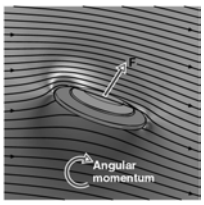
Spinning Balls, Wake Force

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



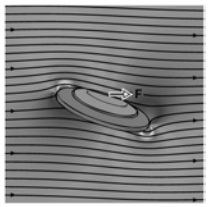
Frisbees

- Above Frisbee
  - airflow bends inward
  - low pressure, high speed
- Below Frisbee
  - airflow bends outward
  - high pressure, low speed
- Pressure imbalance lifts the Frisbee



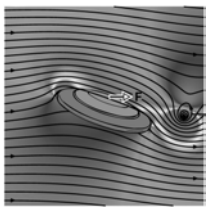
Starting Flight

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



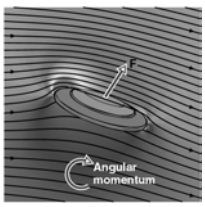
Vortex Shedding

- 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 overall
- Frisbee is pushed upward by air
- Airflow around Frisbee has angular momentum



Summary About Balls and Frisbees

- The air pressures around these objects are not uniform and result in drag and lift
- Balls experience mostly pressure drag
- Spinning balls experience Magnus and Wake Deflection lift forces
- A Frisbee's airfoil shape allows it to deflect the air to obtain lift