Balls and Air

Turn off all electronic devices

Observations about Balls and Air

- Air resistance slows a ball down
- The faster a ball moves, the quicker it slows
- Some balls have textured surfaces to affect the air
- Spinning balls curve in flight

4 Questions about Balls and Air

1. Why do balls experience air resistance?
2. How does air flow around a ball?
3. Why do some balls have dimples?
4. Why do spinning balls curve in flight?

Question 1

Q: Why do balls experience air resistance?

A: Balls interact with and transfer momentum to air

- When a ball moves through air, drag forces arise
  - Air pushes ball downstream, ball pushes air upstream
  - Air transfers downstream momentum to ball
- When a ball deflects passing air, lift forces arise
  - Air pushes ball to one side, ball pushes air to other side
  - Air transfers sideways momentum to ball

Types of Aerodynamic Forces

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

Question 2

Q: How does air flow around a ball?

A: That depends on Reynolds number

- At low Reynolds number, the flow is laminar
  - Only viscous forces transfer momentum to the ball
  - The ball experiences only viscous drag
- At high Reynolds number, the flow is turbulent
  - Pressure forces also transfer momentum to the ball
  - The ball also experiences pressure drag

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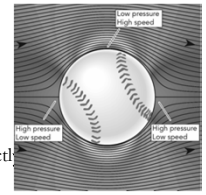
Laminar Flow around a Ball

- Air bends away from ball's front
  - At front: high pressure, slow flow
- Air bends toward ball's sides
  - At side: low pressure, fast flow
- Air bends away from ball's back
  - At back: high pressure, slow flow
- Pressures on opposite sides balance perfectly
- Ball experiences only viscous drag



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The Onset of Turbulence

- Air flowing into the rising pressure behind ball
  - accelerates backward (decelerates)
  - and converts kinetic energy into pressure potential.
- Air flowing nearest the ball's surface
  - also experiences viscous drag forces
  - and converts kinetic energy into thermal energy.
  - If it runs out of total energy, it stops or "stalls"
- If air nearest the ball stalls, turbulence ensues

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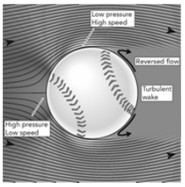
Turbulent Flow around Slow Ball

- Air flowing near ball's surface
  - stalls beyond ball's sides
  - and peels main air flow off of ball.
- Big wake forms behind ball
  - Since wake pressure is ambient,
  - ball experiences unbalanced pressures.
- Ball experiences a large pressure drag force



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Question 3

Q: Why do some balls have dimples?

A: To produce a turbulent boundary layer

- Air affected by ball's surface is the boundary layer
- Reynolds # <100,000: laminar boundary layer
  - Nearest sublayer is slowed relentlessly by viscous drag
- Reynolds # >100,000: turbulent boundary layer
  - Sublayers tumble and interchange; they help each other
  - Boundary layer penetrates deeper into rising pressure

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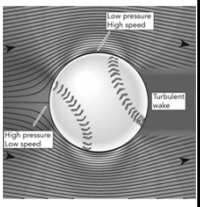
Turbulent Flow Around Fast Ball

- Air flowing near ball's surface
  - stalls beyond ball's sides
  - and peels main air flow off of ball.
- Boundary layer is turbulent
  - and retains total energy farther,
  - so it resists peeling better.
- Small wake forms behind ball
- Ball experiences a small pressure drag force



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Tripping the Boundary Layer

- To reduce pressure drag, some balls have dimples
  - Dimples "trips" the boundary layer
  - Cause boundary layer to become turbulent.
  - Turbulent boundary layer resists peeling better
  - Ball's main airflow forms smaller turbulent wake.
- Example: Golf balls

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Question 4

Q: Why do spinning balls curve in flight?

A: They experience two aerodynamic lift forces

- Laminar effect: Magnus force
  - Turning surface pushes/pulls on the air flow
  - Air on one side makes longer bend toward the ball
- Turbulent effect: Wake deflection force
  - Turning surface alters point of flow separation
  - Flow separation and wake are asymmetric

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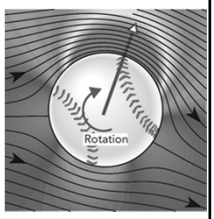
Spinning Balls, Magnus Force

- Turning surface pushes/pulls on the air flow
  - Air on one side makes long bend toward ball
  - Air on other side makes shorter bend away from ball
  - Pressures are unbalanced
- The overall air flow is deflected
  - Ball pushes air to one side
  - Air pushes ball to other side
- Ball feels Magnus force



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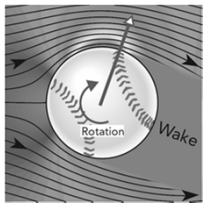
Spinning Balls, Wake Force

- Turning surface alters point of flow separation
  - Flow separation is delayed on one side
  - and hastened on the other side,
  - so wake is asymmetric
- The overall air flow is deflected
  - Ball pushes air to one side
  - Air pushes ball to other side
- Ball feels wake deflection force



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Summary about Balls and Air

- Balls in air experience aerodynamic forces
- Downstream forces are drag forces
- Sideways pressure forces are lift forces
- Moving particles experience viscous drag forces
- Moving balls experience pressure drag forces
- Spinning balls experience Magnus and wake deflection lift forces