**ES 202 Fluid and Thermal Systems**
**Final Exam Review Session (2/25/03)**

- Concept of a boundary layer on a solid surface
  - no-slip kinematic boundary condition
  - steep velocity gradient
  - dominance of viscous force within a boundary layer
  - momentum deficit manifests itself as skin friction drag (result from momentum analysis)

- Dimensional analysis/scaling of
  - Boundary layer thickness
    - growth of boundary layer thickness over a flat plate in both laminar and turbulent regimes
  - Skin friction
    - skin friction coefficient over a flat plate (local versus total)
  - Drag
    - drag coefficient for object of various geometry (combined drag)

- Significance of Reynolds number
  - ratio of inertial force to viscous force

- Phenomenon of laminar-turbulence transition in a boundary layer on a flat plate
  - Laminar boundary layer:
    - molecular diffusion as main mechanism for momentum transfer
    - gradual velocity gradient
    - mild viscous stress
    - found near the beginning portion of a boundary layer (leading edge), *i.e.* low local Reynolds numbers
  - Turbulent boundary layer
    - random, turbulent motion adds more efficient mechanism for momentum transfer
    - steep velocity gradient
    - high viscous stress
    - found in the developed region of a boundary layer, *i.e.* high local Reynolds numbers

- Categorization of drag components
  - Skin friction drag
  - Pressure (form) drag
    - phenomenon of flow separation as an artifact of fluid friction
    - boundary layer takes away too much fluid momentum
    - fluid cannot negotiate the pressure recovery leading to flow separation

- Fundamental difference between a slender body and a blunt body
  - emphasizes the insight in determining the dominant drag components for a given body shape
  - emphasizes the strong Reynolds number dependency of drag
  - Slender body:
    - due to good pressure recovery along body surface, skin friction drag is the dominant drag component
  - Blunt body:
    - at low Reynolds numbers,
      - flow separation is not significant
      - skin friction drag is dominant

        - at high Reynolds numbers,
            - flow separation becomes severe (presence of a large wake region)
            - pressure drag becomes the dominant drag component
            - concept of streamlining: reduction of pressure drag

- Application of Bernoulli's equation in boundary layer and wake region is strictly forbidden!
    - recall the assumptions behind Bernoulli's equations

- Applicability of Bernoulli's equation outside boundary layer to relate pressure variation along a streamline
    - relationship between flow acceleration and pressure variation over an object

- Notion of terminal velocity
    - perfect balance between body weight and drag force
    - "explicit" quadratic variation of drag force with free-stream speed
    - "implicit" Reynolds number dependency (hence velocity dependency) of drag coefficient
    - determination of drag coefficient from a given terminal velocity is straight forward
    - determination of terminal velocity from a given drag coefficient curve requires iterations

- Laminar-turbulent transition in a boundary layer on a curved surface
    - more efficient momentum transfer mechanism in turbulent boundary layers delays flow separation
    - size reduction of the wake region behind a blunt body relative to that from an otherwise laminar boundary layer
    - results in lower pressure drag at the expense of a higher skin friction drag
    - dimples on golf ball as an example

- Lift
    - origin of lift: imbalance of pressure forces along body surface in a direction normal to flow direction as a result of flow asymmetry
    - overall higher pressure force on bottom surface relative to that on top surface
    - definition of lift coefficient

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 A_w}$$

      where $A_w$ is the wetted area in the flow direction (slightly different from the frontal area used in drag coefficient)
    - operating conditions at take-off and cruise
    - notion of stall
        - drastic reduction in lift as angle of attack reaches the stall angle
        - highly unstable operating condition
        - maximum lift coefficient, stall speed

- Properties of the atmosphere at various altitudes
    - Table A-26 in textbook