

## Chapter 17

Forces exerted by motion  
between fluids and immersed  
objects - Drag & Lift

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## Motion between Fluid & Immersed Body

- The interaction is complicated, not described by exact equations
- Two resultant forces are drag & lift
- These forces are the same whether the fluid is moving (object still) or the object is moving (fluid still)

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## Drag

- Drag is a force on the body which resists relative motion between the fluid and body
- Caused by pressure in front of object much lower than the pressure following the object

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## Origin of Drag

- The pressure in front of the object is raised by the dynamic pressure
- To understand, consider fluid flowing past a stationary object. The pressure before the fluid is disturbed by the object is  $P_1$

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## Origin of Drag - 2

- Pressure immediately in front of object is the higher stagnation pressure  $P_s$  because the fluid is not moving
- Bernoulli from 1 to Point s shows

$$P_s = P_1 + \gamma \frac{v_{ave}^2}{2g}, \text{ but } \frac{\gamma}{g} = \frac{\rho}{g_c}, \text{ so}$$

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## Origin of Drag - 3

$$P_s = P_1 + \frac{\rho v_{ave}^2}{2g_c}$$

- Where the latter term is defined as the dynamic pressure

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## Origin of Drag - 4

- The pressure after the object is lower because of
  - frictional losses across surface of object and
  - Separation of a boundary layer of fluid from the surface of the object to produce a turbulent wake (& their frictional losses)

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## Streamlining To Reduce Drag

- The tear drop shape delays the onset of boundary layer separation back from the front of the object and minimizes the wake

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## General Drag Equation

$$F_d = C_d \rho A \frac{V_{ave}^2}{2 g_c}$$

- Units of  $lb_f$  or Newtons, using consistent units for terms in equation

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## The Drag Coefficient $C_D$

- $C_D$  = drag coefficient
- Coefficient is function of
  - for many non-streamlined shapes,  $\log C_D$  function of  $\log(Re)$ . Big drop in  $C_D$  when boundary layer flow changes from laminar to turbulent

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## Drag Coefficient $C_D$ Also Depends on

- Body shape, surface roughness (example is golf ball), how body is oriented with respect to flow (example is cylinder vertical vs. horizontal)
- For streamlined objects, not nearly as strong a function of  $Re$ , where  $Re$  is defined in terms of a length  $L$  (rather than  $D$ ) parallel to direction of flow

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## Other Terms in Drag Equation

- $\rho$  = mass density of fluid, not the object
- Area = the projected area perpendicular to the direction of flow, not the surface area of the object
  - For vertical cylinder, is (Diam)(Height)
  - For sphere, is  $\pi D^2/4$

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## Golf Balls and Streamlined Objects

- Dimples on golf ball add surface roughness, boundary layer becomes turbulent,  $C_D$  is less, drag is less, so ball goes further in the air.
- We streamline cars to get  $C_D$  of 0.25 to 0.45
- We streamline boats

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## Power to Overcome Drag

- Power = Work/time and Work is force x distance.
- But distance/time equals velocity, so for a constant drag force  $F_D$ , we have
- Power =  $F_D v_{ave}$  where  $v_{ave}$  is the average velocity of relative motion

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## Calculating Drag – Problem 17.2 in Text

- 2 m diameter sphere in 0 deg C, 15 km / hr. wind. What's drag force pushing on sphere?
- Solution(Do at board)
  - A = projected area = 2 m diam circle
  - Calculate Re from velocity, 2 m diam, & kinematic viscosity of 0 C air

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## Problem 17-2 in Text Concluded

Look up  $C_D$  on p. 490 of text for sphere  
Plug values into Drag equation

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## Problem 17-4 in Text

- Air blowing 150 km/ hr against a flag pole (a vertical cylinder) made of three progressively smaller diameters.(each section 3 meters tall)
- What's total drag force and moment against the base of the flagpole?

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## Solution to Problem 17-4 in Text

- For each vertical section, figure the projected area(diam x height), Re of flow, drag coefficient  $C_D$  (see text tables), drag force from drag equation, and distance from base to center of length ( where drag force acts)

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## Solution to Problem 17-4 Concluded

- Total drag force = sum of the three drag forces ( one on each section)
- Total moment = sum of the three moments (one on each section)

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## Nature Of Lift

- Defined as a force (caused by the relative motion between object and fluid )that is perpendicular to the direction of flow)
- Originates in air flowing over the top of an airfoil (airfoil is the cross section of a wing) at a higher velocity than that across the bottom of the airfoil.

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## More on Lift - 2

- Bernoulli equation says pressure is less on top of airfoil than bottom, so there's a net pressure force pushing perpendicular against the bottom area A of the wing

$$F_L = C_L \rho A \frac{v_{ave}^2}{2 g_c}$$

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## Plane Stalling- Loosing Lift

- Angle of attack is between the length of the wing(in direction of flow) and the direction of the flow.
- As we increase this angle (plane climbing sharply), the perpendicular (to wing) lift force has a - x direction component pushing in reverse direction to the plane's forward x motion

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## More on Stalling

- The lift coefficient  $C_L$  also increases with angle of attack up to a certain point, the stall point, where it abruptly decreases
- What's happening? Boundary layer separating from surface of wing, turbulence, and  $C_L$  drops suddenly

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