Ph.D. Qualifying Examination

Fluid Mechanics

Spring 2017

Notes:

- Time allowed: 2.5 hours.
- Part 1 of exam (20%) is closed-book and closed-notes, no calculator (turn it in before beginning work on part 2)
- Part 2 of exam (80%) is open-notes (no photocopies), calculator allowed, with 1 textbook allowed.
- State your assumptions, methods, and procedures. Show your work on these exam sheets. (Add additional sheets, if needed.)
- Laptops and cell phones are not allowed.

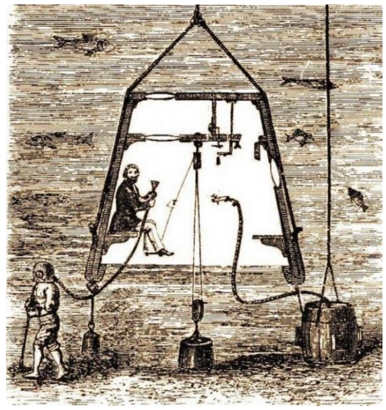
Fluids Sp 2017 **Part 1** (20%) **closed book and closed-notes, no calculator**

1. A rotor ship is propelled, at least in part, by large vertical rotors, sometimes known as rotor sails. German engineer Anton Flettner was the first to build a functional rotor ship, and the ships of this type are sometimes known as Flettner ships. During the ship motion, the cylindrical rotors are powered by motors to rotate. Explain how this rotation makes it possible for the rotor ship to utilize wind energy.

Rotor ship Buckau.

Continued: Fluids Sp 2017 **Part 1** (20%) **closed book and closed-notes, no calculator**

2. An eighteenth-century engraving shows a diving bell (open at the bottom) and a diver in a primitive diving helmet. Is the depiction physically possible? Explain.



3. Race cars improve traction by channeling air flow beneath the car in "tunnels" that are open to the moving ground under the car. Explain why the pressure of the air flowing over the car is less than atmospheric. Explain how these "tunnels" can produce a net downward force on the car.

4. Define each term below and discuss how it is used. *Select three of them* and cross out the one you do not want graded.

a) Newtonian fluid

b) Reynolds number

c) Drag coefficient

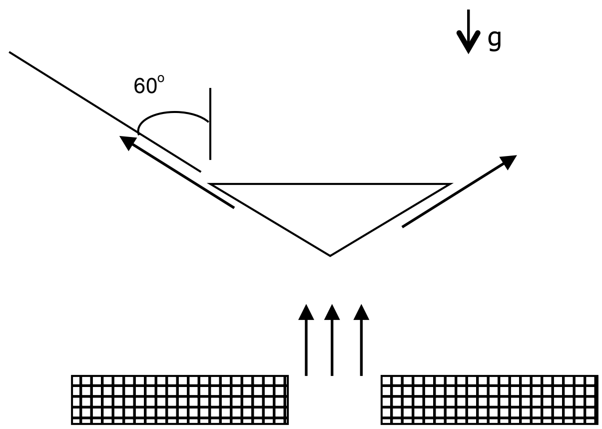
d) Hydraulic diameter

Fluids Sp 2017 **Part 2** (80%) **open book (1 textbook), open notes, calculator allowed**

1. The power required to drive a ship propeller depends on the streamwise flow velocity, propeller diameter, angular speed of the propeller, fluid absolute viscosity, fluid density and sonic velocity in the fluid. [Note: Since g is not included, Froude number effects are not included.]
   a) Perform a dimensional analysis to determine the relevant dimensionless groups; do not use viscosity as a repeating variable.
   b) Identify a Reynolds number from among your dimensionless groups; what variables comprise its velocity scale (L/T)?
   c) A full-scale propeller with 6 ft. diameter operates in seawater at 10 rpm when the velocity of the ship is 60 ft/s. For a 2 ft-diameter scale-model propeller operating in fresh water, what rotational and flow speeds are required to achieve dynamic similarity? Discuss the significance of any dimensionless group that cannot be matched in such tests.
   d) What is the ratio of model to full-scale power? Do you see any problem in making laboratory measurements of this power?

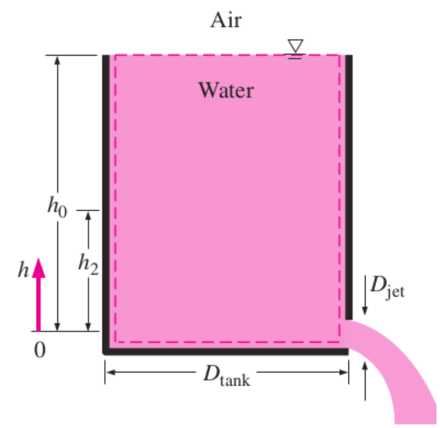
Fluids Sp 2017 **Part 2** (80%) **open book (1 textbook), open notes, calculator allowed**

2. Several conical bodies of different weights will be centered above a vertical water jet. Neglect any change in jet velocity or diameter with height above the nozzle before the jet strikes the cone. The circular jet of water, at V_j = 40 m/s with A_j=0.005 m^2, is turned (axisymmetrically) by the cone through an angle of 60°. Determine:
   a. the acceleration of a body with weight W_1 = 5 kN when it is moving down at 10 m/s;
   b. the weight W_2 (kN) of a body that would be suspended in the water jet without moving;
   c. the terminal velocity of a body with weight W_3 = 2 kN.



Fluids Sp 2017 **Part 2** (80%) **open book (1 textbook), open notes, calculator allowed**

3. A cylindrical tank has diameter D_{tank}=0.9 m and height h_0=1.2 m. Its top is open to the atmosphere. The tank is initially filled with disgusting pink fluid (see figure). At time t=0 the discharge plug near the bottom of the tank is pulled out, and a disgusting pink fluid jet whose diameter D_{jet} is 12.7 cm streams out. Determine how long it takes for the fluid level in the tank to drop to h_2=0.6 m from the bottom. For pink fluid properties, assume that it is like water, but disgusting and pink.



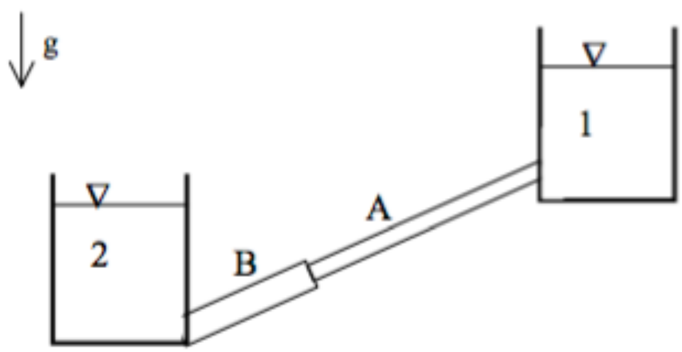
Fluids Sp 2017 **Part 2** (80%) **open book (1 textbook), open notes, calculator allowed**

4. Two reservoirs are connected by 200 ft of commercial steel pipe (D_A=2 in.) and 20 ft of cast iron pipe (D_B=3 in.) with square-edged entrance and exit and sudden expansion from pipe A to pipe B. Take $(fL/D)_B$=8 (fixed) in pipe B only. Compute the flow rate Q (gpm) of water at 60^{o}F if the level of reservoir 1 is 40 ft higher than that of reservoir 2.

One complete iteration for friction factor f_A and flow rate Q is sufficient. Use the *fully-rough (or wholly turbulent)* value of friction factor as your initial guess. List all values of Reynolds number, roughness ratio, friction factor and velocity used. Use the following explicit friction factor formula:

$$f = \frac{1.325}{\{\ln[(\varepsilon/3.7D) + (5.74/\mathrm{Re}^{0.9})]\}^2}$$

for $10^{-6} < \varepsilon/D < 10^{-2}$ and $5000 < \mathrm{Re} < 10^{+8}$



Problem #______, continued

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