Ph.D. Qualifying Examination

Fluid Mechanics

Spring 2021

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 book (1 textbook), open notes (one notebook), and calculator
- allowed.
- State your assumptions, methods, and procedures. Show your work on these exam sheets.
- (Add additional sheets, if needed.)
- Laptops, cell phones, tablets (any devices with Internet access) are not allowed.

Part 1 (20 points, closed book, closed notes).

1. A child holds a floating hydrogen-filled balloon while riding in a car. The car comes to a sudden stop at a stop sign. How does the balloon move, and why?

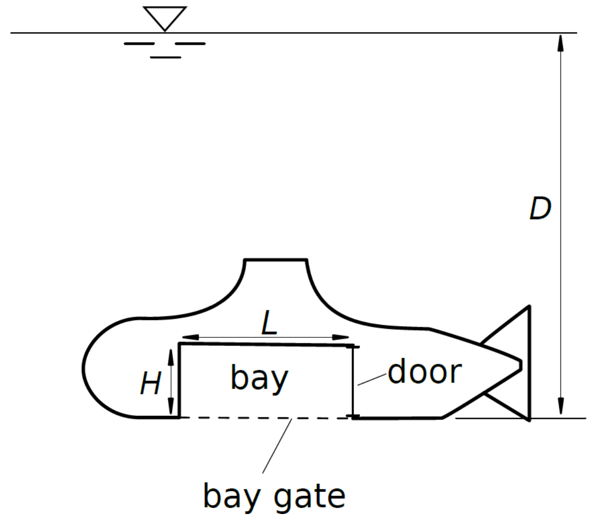
2. Explain why the ambient pressure increases linearly with depth when diving in the sea, but decreases exponentially when ascending in the atmosphere.

3. The Bernoulli equation is very useful, but it has some limitations. Is it reasonable to apply the equation through a turbine? Explain.

4. What is the difference between a Newtonian and a non-Newtonian fluid?

5. For laminar flow in a round pipe of diameter D, at what distance from the centerline is the actual velocity equal to the average velocity?

Part 2.
Problem 1 (20 points).

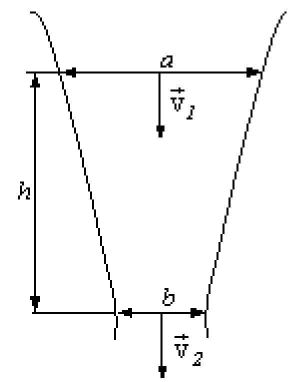


A submarine of mass m is submerged in water and balanced at rest so that its bottom is at depth D. The submarine bottom can be opened to allow access to a loading bay of length L, height H, and width t. From the loading bay, the submarine can be accessed through a door. The door is flush with the bay, rectangular, and measures $H \times t$. The bay gate is initially closed and the bay is filled with air. Knowing H, t, D, L, m, and water density ρ,

1. For a known mass m of the submarine, determine the volume V of the submarine (including bay) at rest.
2. After opening the bay gate, what is the absolute pressure of air required in the bay to withstand the water pressure and to keep the whole bay volume dry?
3. Through a malfunction, the bay is flooded completely with water. Assume the submarine bottom is still at depth D. What are the magnitude, direction, and point of attack of the gauge pressure forces acting on the door?

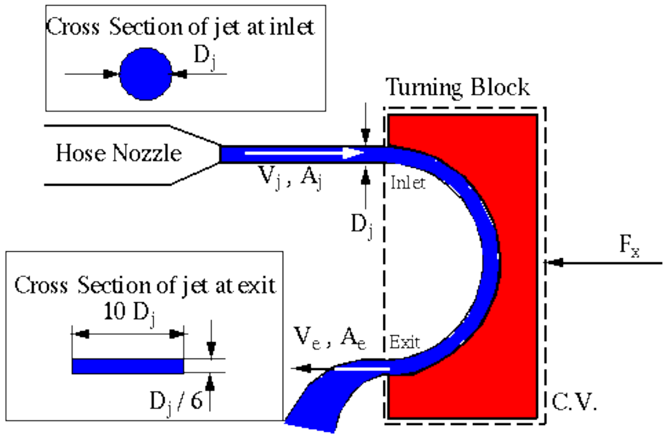
Problem 2 (20 points).

A gravity-driven vertical stream of water (from a kitchen faucet) has cylindrical cross-sections with diameters *a* and *b*, as shown, separated by a known vertical distance *h*. Based on this information and making the necessary assumptions, determine the volume of water delivered by the stream over time *t*.



Problem 3 (20 points).

An initially horizontal water jet from a hose nozzle with velocity V_j and diameter D_j impinges on a block with a semicircular cavity, as shown in the sketch. (Note: a similar arrangement is used to propel test rigs along a track at one of the NASA facilities).



After interaction with the block, the jet turns a full 180º and flattens to an approximately rectangular cross-section (10 D_j by $D_j/6$, as shown). Assuming the flow is steady, find

1. The exit velocity of the jet V_e
2. The force F_x required to hold the block in place

Problem 4 (20 points).

Consider a soap bubble of radius R. Assume the surface tension in the soap film γ is known, and so is the ambient pressure p_0 and the pressure inside the bubble p_1. The bubble is held in equilibrium by the balance between surface tension and the positive pressure differential $p_1 - p_0$. Using dimensional considerations, find the functional relationship between this pressure differential and the bubble radius. *Hint:* units of surface tension are N/m.