

CARLETON UNIVERSITY

Department of Mechanical and Aerospace Engineering

Fluids I (MAAE 2300) Mid - Term Test

Tuesday, February 12, 2013

This mid-term test is a take-home test meaning that you may use your course notes, any material from the course website, the course manual, or any textbook.

Your mid-term test should be done individually and all pages that you want marked should be submitted on or before **16:00 on Wednesday, February 13, 2013**. Your materials must be either handed-in through the appropriate slot of the Orange Box outside the main Mechanical & Aerospace Engineering office (3135ME) or it must be handed directly to a TA.

Please make certain that every page has your name and student number clearly printed.

Any mid-term test that is not submitted prior to this time will be considered as not submitted for grading and given a mark of zero. **It is your responsibility to ensure that your test is submitted by the deadline stated above.**

Question 1 (30 marks)

A heavy, inverted cylinder of length L and radius R is initially held above the surface of the ocean (density of sea water is 1030 kg/m^3). The interior of the cylinder is filled with air (at a pressure of 101.3 kPa and at a temperature of 15°C). As the cylinder is lowered into the ocean (as shown in the sketch) the air within the cylinder is trapped and compressed.

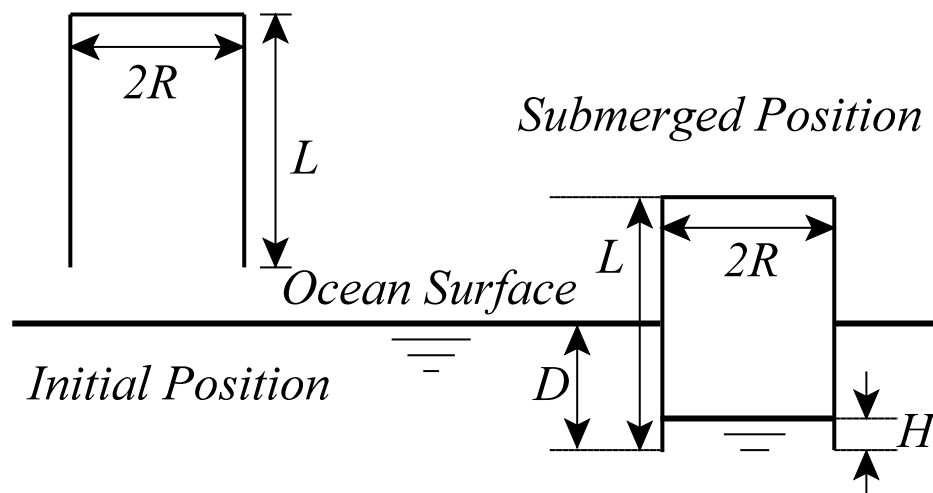
You may assume that the temperature of the air and of the sea water are 15°C and that they remain constant during the cylinder's lowering into the ocean.

(1) Determine the mass of air within the cylinder before the air is compressed when the cylinder is submerged in the sea water.

(2) Determine the distance, H , that the sea water rises within the cylinder as a function of the depth, D , of the lower edge of the cylinder.

(3) Perform calculations to determine H for depths of 0 , $0.25L$, $0.50L$ and $0.75L$ and plot your results for $0 \leq D \leq L$ when the length L is equal to one metre.

Hint: You may find an iterative approach to be useful.

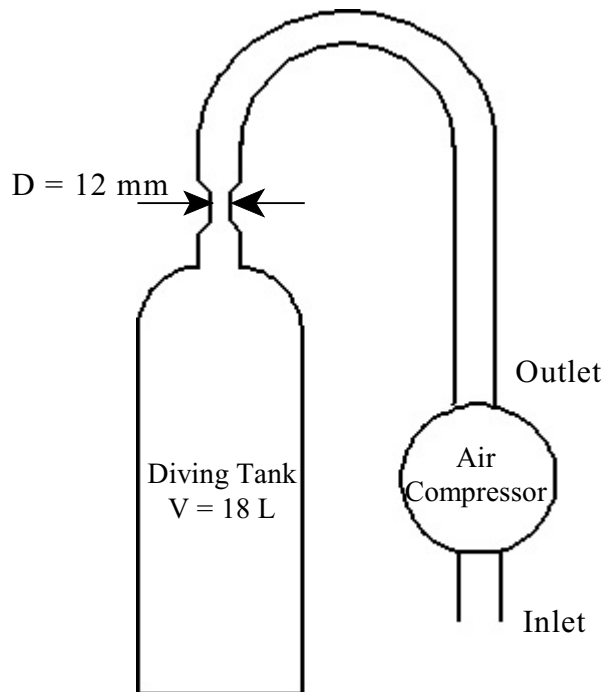


Question 2 (50 marks)

Consider a self-contained underwater breathing apparatus (SCUBA) diving tank with a volume of 18 litres and a maximum pressure rating of 200 bar (gauge). The tank can be pressurized to this 200 bar pressure limit. Before diving, the tank should be filled with air via a compressor, capable of delivering air at a $4.2 \text{ ft}^3/\text{min}$ flow rate. The valve, through which air enters (or leaves) the tank, has a throat diameter of 12 mm.

The tank is to be filled on a nice sunny day, when the temperature is 30°C and the atmospheric pressure is 102 kPa. For simplicity, you may assume that while filling the tank the temperature throughout the compressor, the feed lines and the tank remains uniform and equal to the ambient temperature of 30°C .

Note that the universal gas constant for air is $R = 287.053 \text{ J/kg/K}$.



Your task is to determine various details of the filling and discharging of the tank, namely:

(1) Determine the mass of air (in terms of kg units) inside the tank just before the filling process begins. You may assume at the beginning that the pressure inside the tank is equal to the atmospheric pressure.

(2) In order to be able to pressurize the tank to 200 bar (gauge), what should be the compressor outlet pressure? Please select one answer from the choices below:

- (a) Vacuum
- (b) Between vacuum and atmospheric pressure
- (c) Between atmospheric pressure and 200 bar (gauge)
- (d) Higher or equal to 200 bar (gauge)

(3) Determine the amount of air (again, in terms of kg units) to be pumped into the tank so that the tank pressure reaches 200 bar (gauge). Note: This should be the amount of air to be pumped into the tank on top of what you have already calculated in part (1) above.

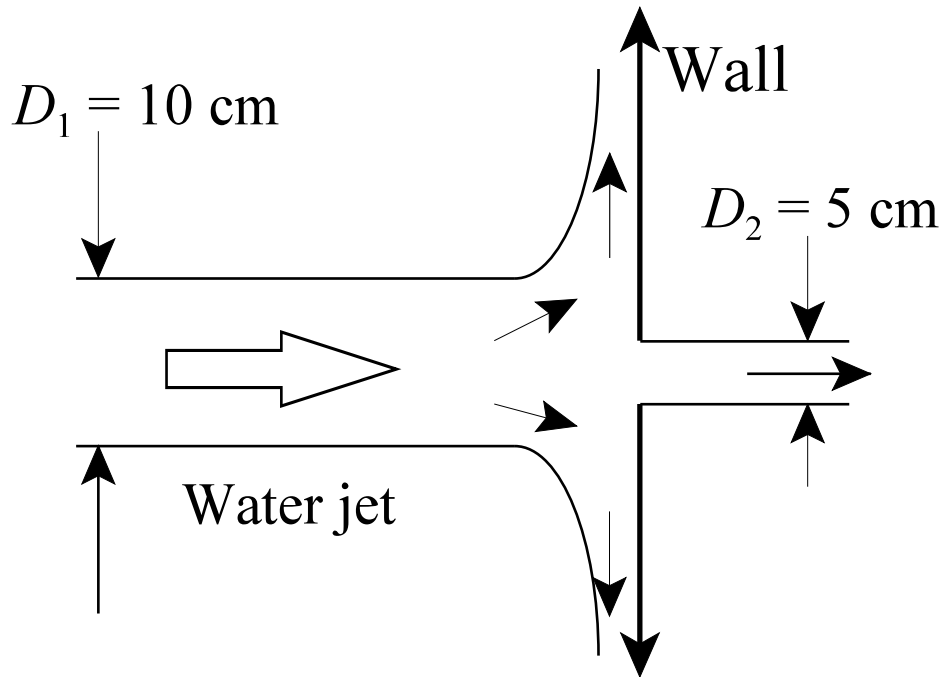
(4) Determine the time required to fill the tank. You may assume that the compressor's given flow rate refers to air density corresponding to atmospheric conditions.

(5) Now that the tank is filled, it can be used for SCUBA diving. For this, air is discharged from the tank through the same valve used for filling the tank. Assuming that the air outflow velocity through the valve throat is a constant 0.1 m/s throughout the discharge (i.e. roughly the rate at which we breathe), and considering that the density and pressure in the tank drops continuously in time (i.e. $\rho_{TANK} = f(t)$), then determine the time required to reduce the air density in the tank by 90%.

Hint: This is an unsteady problem. You may assume that the mass flow rate through the valve can be expressed as $dm/dt = C \cdot \rho_{TANK}(t)$ where C is a constant and $\rho_{TANK}(t)$ is the instantaneous density inside the tank..

Question 3 (20 marks)

A 10 cm diameter jet of water at 20°C strikes a flat wall containing a hole of 5 cm diameter. As a result, part of the jet passes through the hole and part of the jet is deflected as shown in the sketch below.



(1) If the jet velocity is 20 m/s and part of the jet passes through the hole at the same velocity, then determine the horizontal force required to hold the flat wall stationary. You may assume that the pressure on either side of the wall is 101.3 kPa and that the wall is self-supported so that the wall's weight is not a factor.

(2) If the pressure behind the wall (i.e. on the right-hand side of the wall) is increased above the pressure 101.3 kPa, then this would reduce the water flow through the 5 cm hole. Explain if it is possible to increase the pressure sufficiently to reduce the water flow through the hole to approximately zero while still holding the wall stationary. Please state any of your assumptions explicitly before you attempt to determine this pressure (in units of kPa).