Part IA Paper 1: Mechanical Engineering

THERMOFLUID MECHANICS

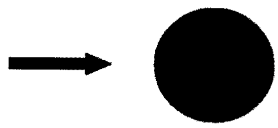
Examples Paper 3

Voluntary starter questions are marked "s", Elementary ones are marked †, Tripos standard are marked *.

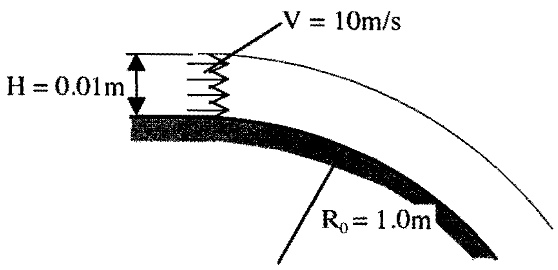
Pressure variation normal to streamlines

sQ1. (a) Why does the pressure decrease towards the centre of a cyclone?
(b) An often-used demonstration for the Bernoulli equation is to hold a sheet of paper between both hands in front of (and slightly below) your mouth so that it drops away from you face. As you blow over the upper surface of the paper it should rise. Why is this **not** a demonstration of Bernoulli's equation?
(c) Why does the paper rise? What is the name of this effect?
(d) Give some examples of the Magnus effect and explain how it works.

†Q2. Sketch the streamlines for a flow around a circular cylinder, assuming inviscid flow (i.e. no separation). Based on an inspection of the curvature of the streamlines, identify regions of high and low pressure (relative to the free stream pressure). Sketch the surface pressure distribution starting at the stagnation point.



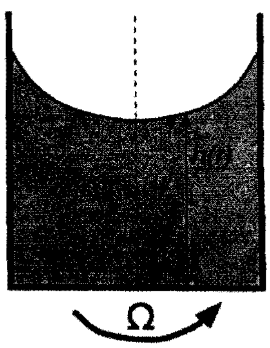
†Q3. A jet of air (ρ=1.22kg/m^3) is ejected tangentially onto a curved surface as shown below. On the assumption that the jet height does not change and that the jet velocity is uniform across its area, determine the gauge pressure on the solid surface.



Q4. A beaker filled with water rotates at an angular velocity Ω. The water rotates at the same rate as the beaker and its upper surface adopts a curved profile. Show that the depth of the water varies with radius according to

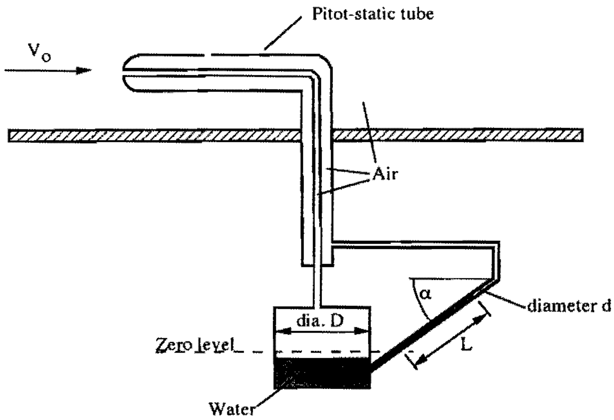
$$h(r)=h(0)+\Omega^2 r^2 / 2g$$

Hint: Consider the pressures at the bottom of the beaker.



Questions combining more than one topic

Q5. The figure below shows a Pitot-static tube connected to a sloping-tube water manometer for the measurement of a low speed airflow. Working from first principles, explain the working of the device. For $\alpha = \sin^{-1} 0.1$, $d/D = 1/5$, $\rho_{water}/\rho_{air} = 850$ and a scale reading $L = 50$ mm (read from zero level), determine the velocity V_0. (Hint: Note the change in water level in the manometer's reservoir)

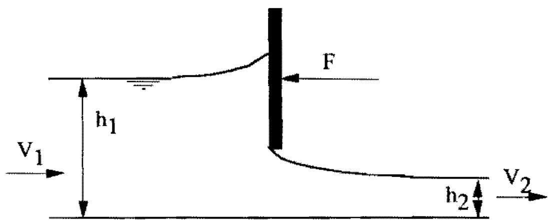


*Q6. Water flow in open channels can be controlled and measured with the sluice gate shown below. The flow is uniform at a moderate distance upstream and downstream of the gate, i.e. at sections '1' and '2'.

(a) Explain why the pressure variation at '1' and '2' is hydrostatic.

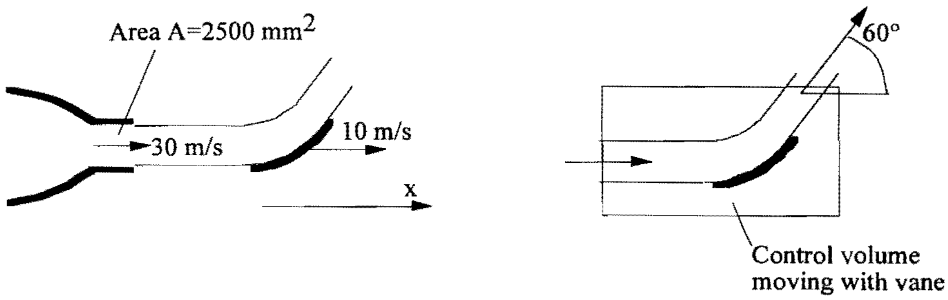
(b) Show that the force per unit width, F, required to hold the gate in place is:

$$F = \rho V_1^2 h_1 - \rho V_2^2 h_2 + \frac{\rho g h_1^2}{2} - \frac{\rho g h_2^2}{2}$$



*Q7. The Steady Flow Momentum Equation applies equally well to control volumes moving with constant velocity, provided the velocities are interpreted as velocities relative to the control volume.

Consider the moving vane shown below. It travels with a constant speed of 10 m/s in the x-direction and receives a jet of water that leaves the nozzle at an absolute velocity of 30 m/s. The nozzle has an exit area of 2500 mm^2.



(a) Show that the neglect of shear stress implies that, in a frame of reference moving with the vane, the fluid enters and leaves with the same magnitude of velocity, and with the same flow area. Why do we use a moving control volume around each vane?

(b) What would be a good choice of non-dimensional force coefficient to describe the total force on the vane? Calculate its value and show that the force acts at an angle of –60° to the x-axis.

(c) Show that the power transmitted to the vane is 5kW.

Heat, Work and the 1st Law of Thermodynamics

sQ8. (a) Is "pdv" work done by a system of fixed volume?

(b) Is shaft work done by a jet engine?

(c) A gas is compressed by a piston in a cylinder and as a result its temperature rises. Is heat or work transferred to the gas?

sQ9. An unheated kitchen (which may be considered as a closed system) is equipped with an electrically driven refrigerator.

(a) Assuming that the kitchen is at a steady state temperature, indicate on a suitable sketch any heat and work transfers between the system and its surroundings, specifying whether they are positive or negative.

(b) A careless student accidentally leaves the refrigerator door open. Explain what will happen to the temperature in the kitchen.

Q10. Calculate the work transfer in each of the following processes:

†(a) An elastic band is stretched from 5cm to 10cm by a force that increases from zero to 10N according to Hooke's law.

†(b) A bolt on a mechanical assembly is tightened half a turn by a torque that increases linearly with angular displacement from 40 Nm to 60 Nm.

(c) A 1.0μF capacitor (the system) initially at 100V is discharged completely through a 10Ω resistor. Would the answer be different if (i) the 10Ω resistor were replaced with a 20Ω resistor, (ii) the whole circuit, including the resistor, were taken as the system?

Describe briefly any heat transfer and / or change in internal energy that is likely to occur in each case, taking care to specify an appropriate system.

†Q11. A quantity of steam is enclosed in a vertical cylinder by a frictionless piston above the steam. The piston has a diameter of 250 mm and a mass of 250 kg. Atmospheric pressure of 770 mmHg acts on the back of the piston. (The density of mercury is 13,600 kg/m^3, and the acceleration due to gravity is 9.81 m/s^2.) The cylinder is heated by a Bunsen burner and the piston moves slowly (i.e. the process is quasi-equilibrium) through 150 mm, thereby doubling the volume of the steam.

(a) Calculate the gauge pressure and absolute pressure of the steam.

(b) How much work is done by the steam on the piston?

(c) How much work is done by the piston on the atmosphere?

(d) Account for the difference between your answers to (b) and (c).

(e) If the final density of the steam is 0.34 kg/m^3, estimate the change in its gravitational potential energy and comment on the result.

†Q12. A bomb calorimeter is to be used to measure the energy released by a chemical reaction. The calorimeter consists of a closed rigid vessel surrounded by a large water tank which is thermally insulated on the outside. When the reaction occurs, heat is transferred to the water tank. To ensure a uniform water temperature, a 0.05 kW electrical stirring device is contained within the tank.

During a particular experiment, the temperature rise of the water is found to be equivalent to a change in internal energy of 1405 kJ, 25 minutes after the reaction took place.

In answering the following questions, draw an appropriate system boundary in each case and indicate any heat and / or work transfers.

(a) What was the heat transfer from the bomb to the water?

(b) What was the change in internal energy of the bomb and its contents?

Q13. A wire is kept at ambient temperature while it is stretched by 1 m by a force which rises linearly from zero to 1000 N. Its length is then fixed while it receives 10 kJ of heat and its tension falls to zero. It is then released and returned at zero tension to its original state while losing 11 kJ of heat.

(a) Sketch the complete process on a T-L (tension vs. length) state diagram.

(b) Find the work done by the wire during the first process.

(c) For the second process, find the work done, the heat transfer and the change in energy of the wire.

(d) Find the work done by, the heat transfer to and the change in energy of the wire during the third process.

(e) Find the heat transfer to and the change in energy of the wire during the first process.

*Q14. The specific internal energy, pressure and specific volume of a particular gas are related by:

$$u = \frac{pv}{\gamma - 1} + \text{constant} \ ,$$

where $\gamma = 1.4$. A quantity of this gas is enclosed in a cylinder by a piston. Starting from an initial state of $p = 1$ bar and $v = 0.85$ m^3 / kg, the gas undergoes the following cyclic process: (i) the piston is fixed in position while the gas is heated and its pressure doubles, (ii) the gas expands slowly with the pressure varying in inverse proportion to the volume, (iii) the gas is returned to its initial state at constant pressure.

(a) Sketch the cycle on a p-v diagram.

(b) Assuming quasi-equilibrium throughout, calculate the heat and work transfers and the internal energy changes per kilogram of gas for each stage of the cycle.

(c) Calculate the net work done per kilogram of gas during the cycle, and express this as a fraction of the total positive heat input (i.e. that occurring during the first two stages).

ANSWERS

sQ1	Discuss with your supervisor					
†Q2	-					
†Q3	-1.2 Pa					
Q4	-					
Q5	10.8 m/s					
*Q6	-					
*Q7	-					
sQ8	Discuss with your supervisor					
sQ9	Discuss with your supervisor					
Q10	(a) −0.25 J	(b) -50π J	(c) 5 mJ	(i) No	(ii) Yes	
Q11	(a) 50 kPa, 152.7 kPa		(b) 1124 J	(c) 756 J	(e) 3.7 mJ	
Q12	(a) 1330 kJ	(b) −1330 kJ				
Q13	Stretching:	$Q = 0.5$ kJ	$W = -0.5$ kJ	$\Delta E = 1$ kJ		
	Heating:	$Q = 10$ kJ	$W = 0$	$\Delta E = 10$ kJ		
	Cooling:	$Q = -11$ kJ	$W = 0$	$\Delta E = -11$ kJ		
Q14	(b)	(i)	$w = 0$	$\Delta u = 212.5$ kJ/kg	$q = 212.5$ kJ/kg	
		(ii)	$w = 117.8$ kJ/kg	$\Delta u = 0$	$q = 117.8$ kJ/kg	
		(iii)	$w = -85$ kJ/kg	$\Delta u = -212.5$ kJ/kg	$q = -297.5$ kJ/kg	
	(c)	32.8 kJ/kg (9.93%)				

Fluid Mechanics: 2001 Q3, 2003 Q1, 2003 Q3

Thermodynamics: See next examples paper.

H. Babinsky
A.J. White
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