National Exams December 2009

07-Mec-B6, Advanced Fluid Mechanics

3 hours duration

Notes:

1. If doubt exists as to the interpretation of any question the candidate is urged to submit with the answer paper a clear statement of the assumptions made.
2. Candidates may use any non-communicating calculator. The exam is OPEN BOOK.
3. Answer all 4 questions in **part A** and any 2 of the 3 question of **part B**. If more questions are attempted, these will be marked in the order presented.
4. Weighting: Part A: 50%; Part B: 50% . Within part A, weighting of each question is shown in brackets. For part B, the questions have equal weighting.

PART A: Answer all 4 of the questions in this section. Weighting is indicated in brackets.

Question A.1 [10]: Estimate the tension in the cable and the terminal speed (and direction) of the vertical block for the system shown below. Both blocks are cubical, made of aluminium (SG=2.7), and have a side dimension of 20cm. The left hand block is placed on a 30° ramp (to the horizontal) and slides on a 0.1mm thick layer of SAE 10W oil, for which the density and dynamic viscosity are given as 886 kg/m^3 and 0.29 N-s/m^2. The pulley may be considered frictionless. The velocity distribution in the oil film may be taken as linear. Neglect any drag due to the air.

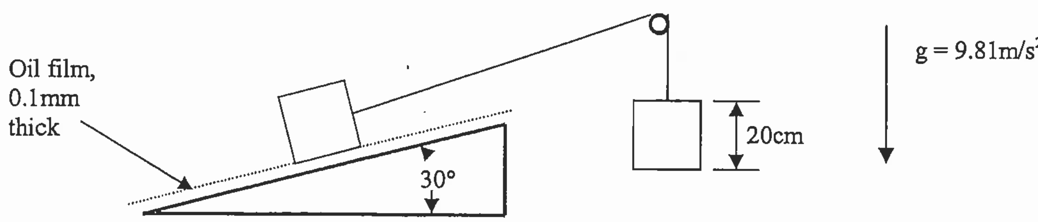


Figure A.1: Schematic representation of pulley-block system

Question A.2 [15]: A compressed air cylinder of internal volume 0.15 m^3 is pressurized at 0.5 MPa and a temperature of 300K. The valve is opened and air exhausts to atmosphere (100 kPa). If the valve flow area is 0.1 cm^2, estimate how long is required for the internal pressure of the cylinder to reach 200 kPa. What is the mass of air which has escaped from the cylinder? Neglect frictional losses and changes of temperature inside the cylinder. For air: $\gamma = 1.4$, $R = 287$ J/kg-K

Question A.3 [15]: Consider the system shown in Fig. A.3. If the flow rate thourhg a 10-cm diameter wrought iron pipe is 0.04 m^3/s, find the differnece in elevation H of the two reservoirs. The valuve is a globe valve 1/3-closed. The entrance loss coefficient is given as 0.5. For water, use ρ = 1000 kg/m^3 and μ = 0.001 kg/m-s. The reservoirs may be considered large. Pipe is of constant diameter 10cm (all segments).

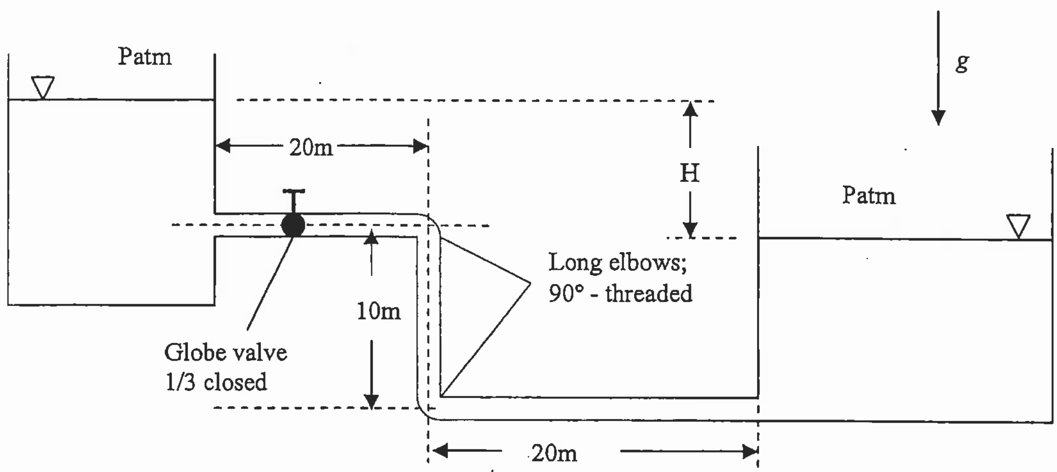


Figure A.3: Pipe network connecting two large reservoirs at different elevations.

Question A.4 [10]: A centrifugal pump having an inpeller diameter of 1 m is to be constructed so that it will supply a head rise of 200 m at a flow rate of 4.1 m^3/s of water when operating at a speed of 1200 rpm. To study the characteristics of this pump, a 1:5-scale, geometrically similar model operated at the same speed is to be tested. Determine the required discharge and head rise assuming the same efficiency. What will be the power ratio?

Section B Answer any 2 of the 3 questions in this section. Each question is weighted equally (25 marks)

Question B.1: An incompressible fluid flows past a horizontal impermeable flat plate (i.e. no flow through the plate) as shown in the figure below. The flow is two-dimensional (i.e. no velocity component into/out of the page), the inlet profile is constant, $u = U_o$, and the exit profile has the form of a cubic polynomial:

$$u = U_o\left(\frac{3}{2}\eta - \frac{1}{2}\eta^3\right) \qquad \text{where : } \eta = \frac{y}{\delta} .$$

a) Compute the volumetric flow rate across the top of the control volume spanning $y = 0$ and $y = \delta$. The plate has a width of b into the page.
b) Estimate the drag (friction force) on the top face the plate.

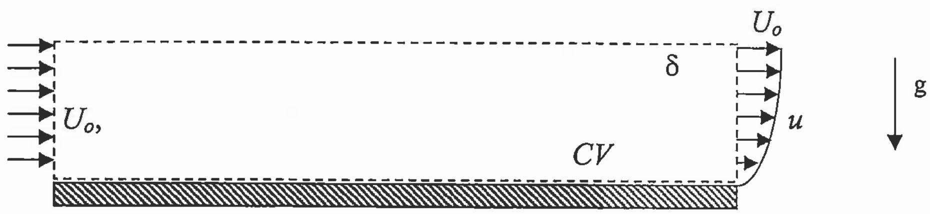


Figure B.1: Schematic of boundary layer flow over a plate

Question B.2: Air ($\gamma = 1.4$, R = 287 J/kg-K) flows from a large reservoir through a convergent-divergent channel. The air in the reservoir is kept at a constant pressure of 1 MPa and a temperature of 300K. The throat (minimum) area of the channel is 100 cm^2 and the exit area is 240 cm^2. The flow may be assumed adiabatic for all conditions and isentropic in the absence of shocks.

(a) Determine the design exit Mach number, back pressure and flow rate.
(b) What is the lowest back pressure for which the flow will be subsonic throughout the channel? What will be the mass flow rate at this back pressure?
(c) Determine the back pressure and the exit Mach number if a shock is located directly at the exit of the channel.
(d) What will be the flow rate and pressure at the exit of the channel if the back pressure is given as 20 kPa?

Question B.3: Water flows at a constant rate, Q, under a sluice gate as shown in the figure below. If the upstream water level is constant at 5m, and the discharge coefficient, Cq, is 0.65, due to the sharp edge of the sluice gate, determine the flow rate and the force acting on the sluice gate. Neglect frictional losses. The channel upstream and downstream of the sluice gate are rectangular of width b = 10m. The sluice gate opens to a height of h = 2m. The gate opens the entire width of the channel. The velocity distribution can be assumed uniform. Is the flow supercritical? What will happen if it is?

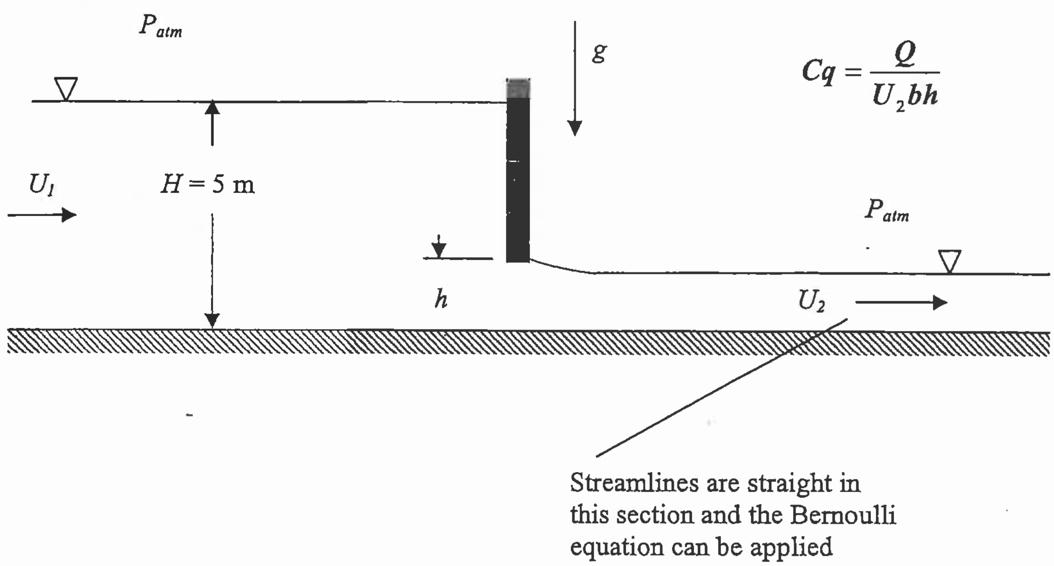


Figure B.3: Schematic of flow through and past a an open sluice gate.

MAJOR LOSSES

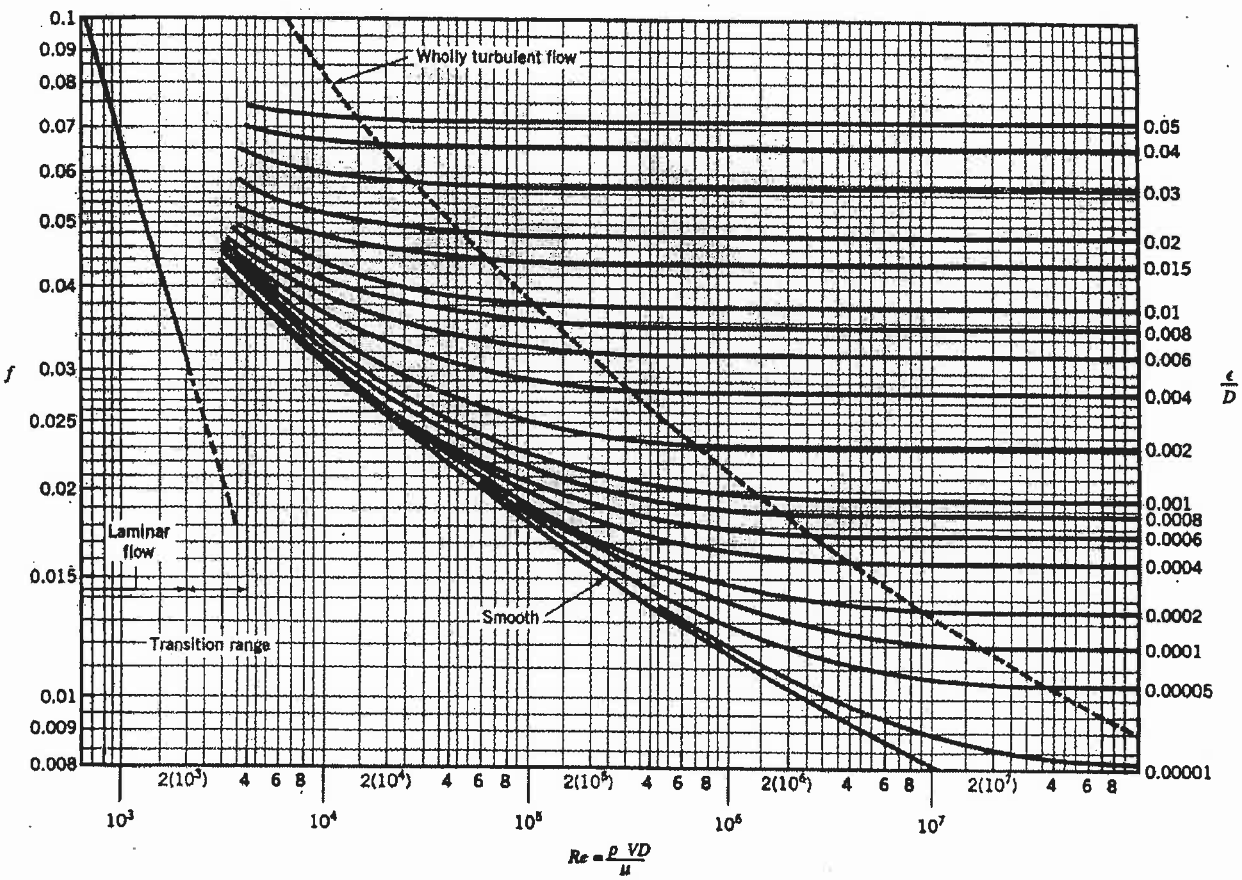
FRICTION COEFFICIENTS:

Colebrook Equation: $$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left[\frac{\varepsilon / D}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right]$$

Laminar Flow Equation: $$f = \frac{64}{\text{Re}} \qquad \text{Re} < 2000$$

$$\text{Re} = \frac{\rho VD}{\mu} = \frac{VD}{\nu}$$

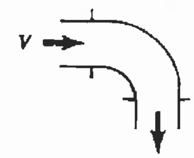
MOODY CHART for PIPE FRICTION

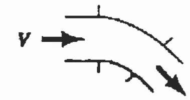


MINOR LOSSES

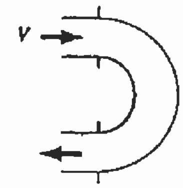
Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4

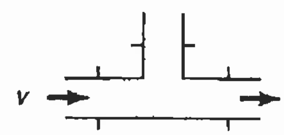


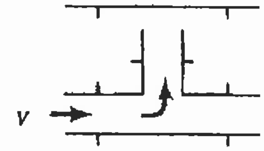


Component	K_L
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5



Component	K_L
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0





Component	K_L
d. Union, threaded	0.08

Component	K_L
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210