No. of pages........6
No. of questions....5
Total marks.......100

THE UNIVERSITY OF ADELAIDE

Examination for the Degree of B.E.

4023 Advanced Topics in Fluid Mechanics

Department of Mechanical Engineering

Semester 2, November 2002

Duration: 2 hours + 10 minutes

Allocate the first 10 minutes to reading the paper.

Answer FOUR of the five questions.

All questions are of equal value.

Calculators, notes and textbooks are permitted.

The "problem solving protocol" is NOT required.
State all assumptions.
Unless otherwise stated, use $g = 9.81\ m/s^2$.

PLEASE SEE NEXT PAGE

Problem 1

(a) [5 marks] Describe qualitatively the mechanism by which shear layers become unstable and roll up to form vortices.

(b) [3 marks] What are vortex lines, vortex tubes and vortex sheets?

(c) [5 marks] Consider a vortex tube which is being stretched (elongated) along its axis. If it is stretched to the extent that its cross-sectional area is halved, what is the effect on the vorticity contained within the tube? What is the effect on the total circulation of the vortex tube?

(d) [7 marks] Use some of the concepts you have outlined in parts (a), (b) and (c) of this question to describe qualitatively the evolution of a high Reynolds number (Re > 100,000) jet from the jet nozzle to the far field. The fluid surrounding the jet is still.

(e) [5 marks] Describe qualitatively the concept of self-similarity of jet velocity profiles. Why are the half-width and velocity excess used to normalize the velocity profiles?

Problem 2

(a) [11 marks] In the lectures on biological locomotion, many and varied methods of animal locomotion were described. In spite of the differences in the methods, there is a remarkable similarity between the flow patterns generated by the animals.

(i) Describe this similarity in your own words. Give two examples (eg. hovering and swimming).

(ii) How do these patterns compare with the flow pattern generated by an aircraft wing in steady flight?

If appropriate, use streamline patterns and vortex line/circulation concepts to support your answer.

(b) [14 marks] As an engineer with advanced training in fluid mechanics you have been asked by your Chief Engineer to measure the mean velocity distribution at the exit of a tall chimney. The diameter of the chimney is 2 m, its height is 50 metres and the mean velocity is about 5 m/s. The chimney is shown in Figure 1 below.

(i) How would you measure the mean velocity distribution? Explain your choice of method.

(ii) List at least two other techniques and why you did not choose them.

(iii) What questions would you ask your chief engineer?

(iv) What ambient conditions would you choose for the tests?

(v) Having obtained the profiles, how would you know whether the flow was behaving in an unusual or unexpected way?

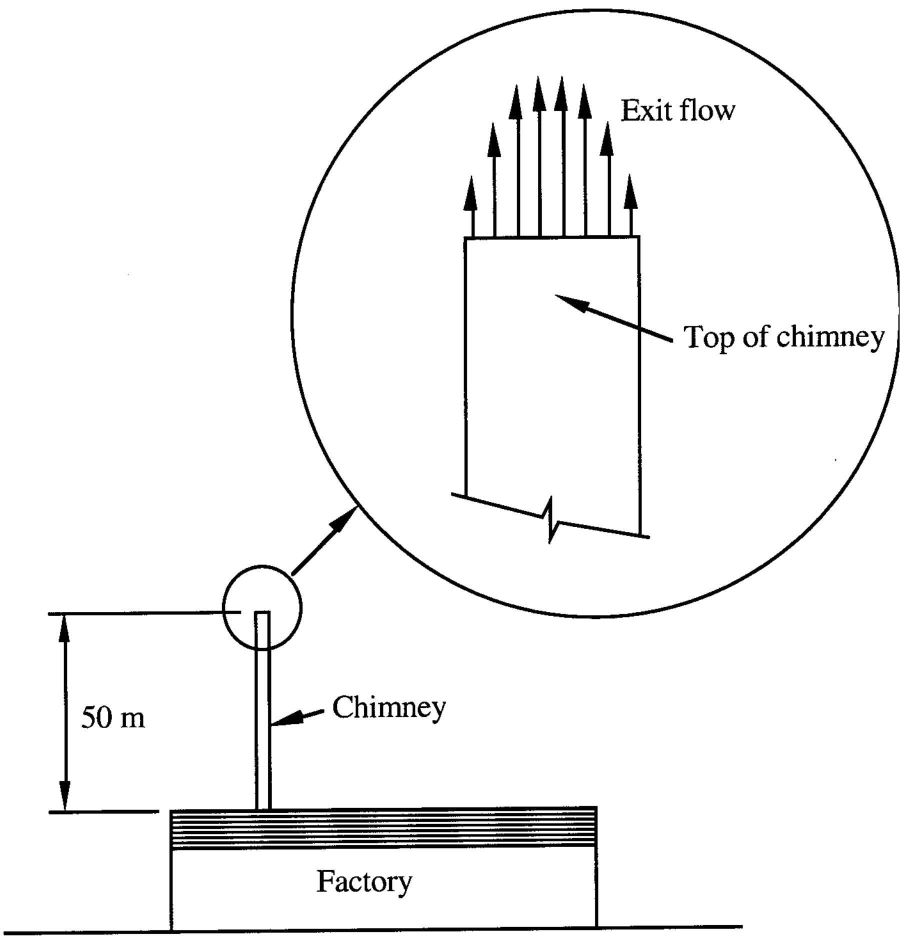

Figure 1. Factory with chimney

Problem 3

A ship of 16 m waterline length and wetted area 90 m^2 travels in a still fresh water lake at 3 m/s. The ship is of such a shape that the form effect coefficient is 0.2. The displacement-length ratio is 300. At the cruising speed of 3 m/s the total resistance on the ship hull is 1690 N. Assuming that the boundary layer on the hull is turbulent over the entire length of the ship, answer the following:

(a) [10 marks] What proportion of the ship's resistance can be attributed to the formation of surface waves? Explain this result in terms of the wavelength of the waves relative to the waterline length (see Figure 2).

(b) [3 marks] A fluid mechanics researcher devises a way to reduce the form effect coefficient to 0.1 without altering the waterline length, wetted area or wave resistance of the hull in any way. What power saving will this deliver at the given cruising speed?

(c) [2 marks] Independently, another researcher suggests that the waterline length of the ship be increased to 20 m without changing the displacement (weight of the ship). When tested, this proves to reduce the wave resistance by 20%. The skin friction resistance is unchanged. What power saving will this deliver at the given cruising speed?

(d) [7 marks] Explain why the above resistance changes occur. Support your explanations with some calculations of relevant parameters.

(e) [3 marks] How would you design the ship to minimize the total resistance.

Note:
i) 1 m/s = 2.85 knots
ii) Fresh water at 20 °C: $\rho = 998.2$ kg/m^3, and $\mu = 1.002 \times 10^{-3}$ N.s/m^2.
iii) The ITTC (1957) plane turbulent skin friction is given by: $C_f = \dfrac{0.075}{\left[(\log_{10}\mathrm{Re}) - 2\right]^2}$

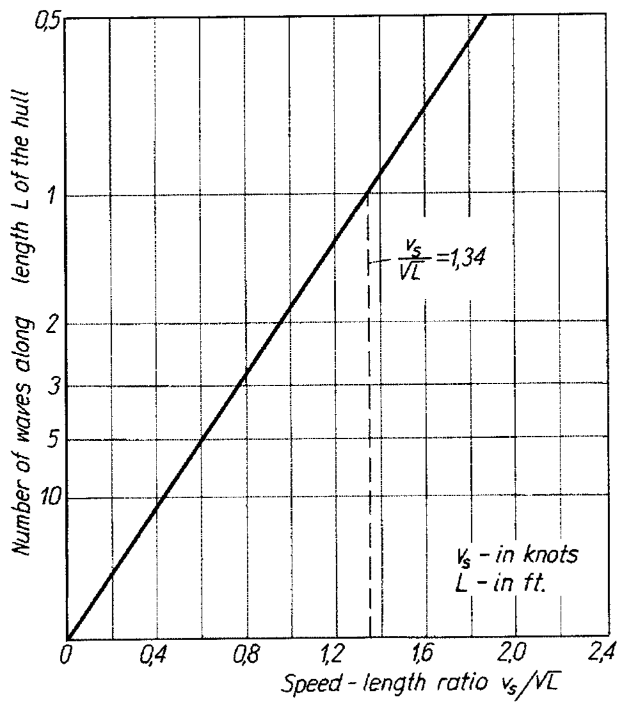

Figure 2. Number of waves along the length of the hull, versus speed-length ratio.

Problem 4

The cross-sectional flow field of a smoke ring (or vortex ring) can be approximated by a pair of line vortices held fixed in space in a uniform cross-flow (velocity U_∞) as shown in Figure 3(a).

(a) [4 marks] Write down the stream function for this flow.

(b) [10 marks] Calculate the positions of the stagnation points for a complete range of values of the parameter:

$$\frac{\Gamma}{aU_\infty}.$$

Hint. If you find that xy = 0, try x = 0 and/or y = 0.

(c) [4 marks] Sketch the flow pattern for the case where the stagnation points lie at

$x = \pm a\left(\frac{\Gamma}{\pi a U_\infty} - 1\right)^{0.5}$ and y = 0. This pattern is known as a "Kelvin Oval".

(d) [4 marks] In the Kelvin Oval pattern described above, the stagnation points are connected by streamlines, known as "stagnation streamlines". One of these lies along the x-axis and the other (hereafter known as the "Oval Streamline") is a curve enclosing the two line vortices. This Oval Streamline can be replaced by a solid cylindrical body. Find the stream function of the Oval Streamline.

(e) [3 marks] If the x-axis is replaced by a solid boundary as shown in Figure 3(b), how would the flow pattern differ from the pattern discussed above. Give reasons for your answer.

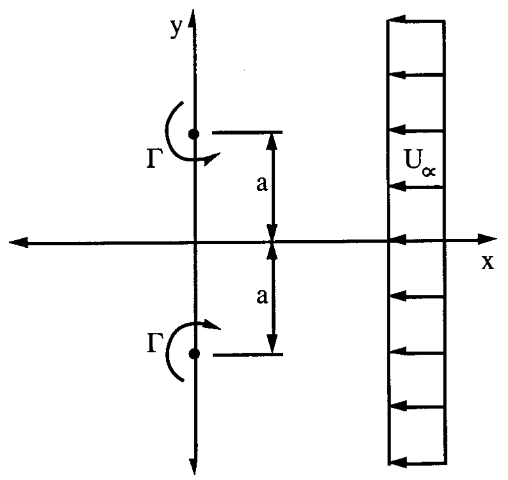

Figure 3(a).

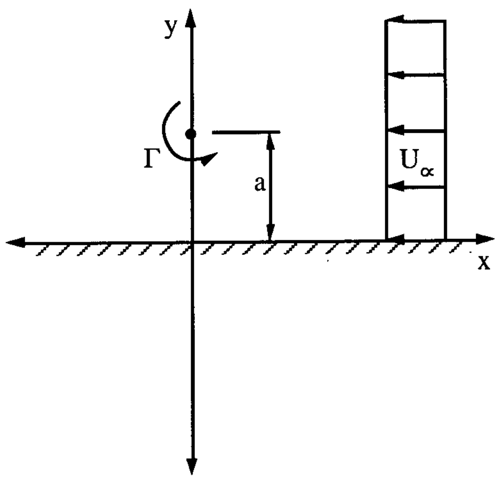

Figure 3(b).

Additional Information:

For an **anti-clockwise** vortex located at (x = a, y = b): $\psi_{vortex} = -\frac{\Gamma}{4\pi}\ln\left[(x-a)^2 + (y-b)^2\right]$.

For a uniform cross flow from **left to right**: $\psi_{cross\ flow} = U_\infty\, y$.

Problem 5

a) [5 marks] Why is secondary flow downstream of a pipe bend considered to be undesirable? Suggest three ways by which secondary flows can be reduced downstream of a pipe bend.

b) [20 marks] You are asked to design a pipe system to carry water from a header tank to a lower tank, as shown in Figure 4 below. The pipe must connect to the tank walls at the locations shown and may extend into the tank. To achieve this you are given several pre-fabricated components. These are:

- 1 x 10 m long section of 50 mm ID pipe
- 1 x 5 m long section of 100 mm ID pipe
- 1 x 10° included-angle transition piece to connect a 100 mm pipe to a 50 mm pipe
- 1 x compact transition piece to connect a 100 mm pipe to a 50 mm pipe
- 1 x 50 mm elbow
- 1 x 100 mm elbow.

Some of these components are sketched (not to scale) below. Note that the transition pieces can be used as expansions or reducers in the pipe system. The pipes can be cut to any length.

The pipe system may take any shape, so long as only the provided components are used. One possible pipe orientation is shown by the dashed line.

(i) Design a pipe system to **maximize** the flow rate between the tanks.
(ii) Now design a pipe system to **minimize** the flow rate between the tanks.

Justify the arrangements you have chosen. No calculations are required.

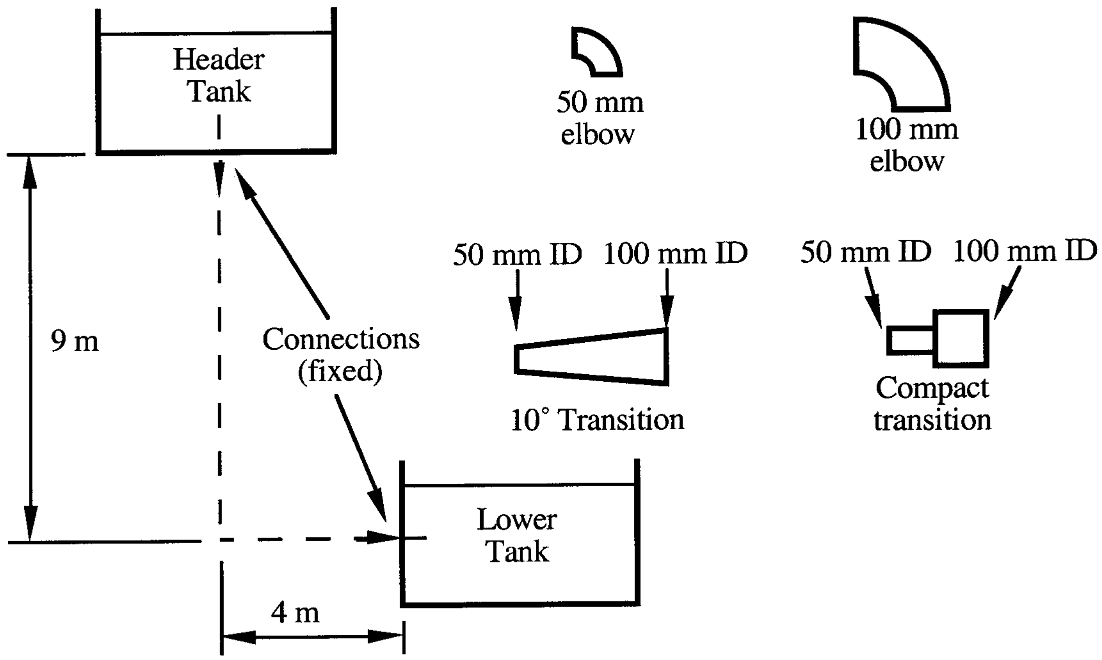

Figure 4. Tank-pipe system and some components.

END OF EXAMINATION