ADELAIDE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING

EXAMINATION FOR THE DEGREE OF B.E.

2632: ADVANCED TOPICS IN FLUID MECHANICS

November 2001

TIME: 2 HOURS and 10 MINUTES

[It is recommended that you spend ten minutes reading the paper and planning your approach before the examination begins.]

[The use of notes, books and calculating devices is permitted in the examination room.]

Candidates may attempt any **FOUR** problems.

All problems are of equal value.

State all assumptions. Unless otherwise stated, use $g = 9.81\ \text{m/s}^2$.

Problem 1

Determine graphically or otherwise the velocity (magnitude and direction) with which the vortex will move. Show all working. The circulation of the vortex is $\Gamma = 1\ \text{m}^2/\text{s}$. At the instant in time shown the vortex is 1 m from each wall.

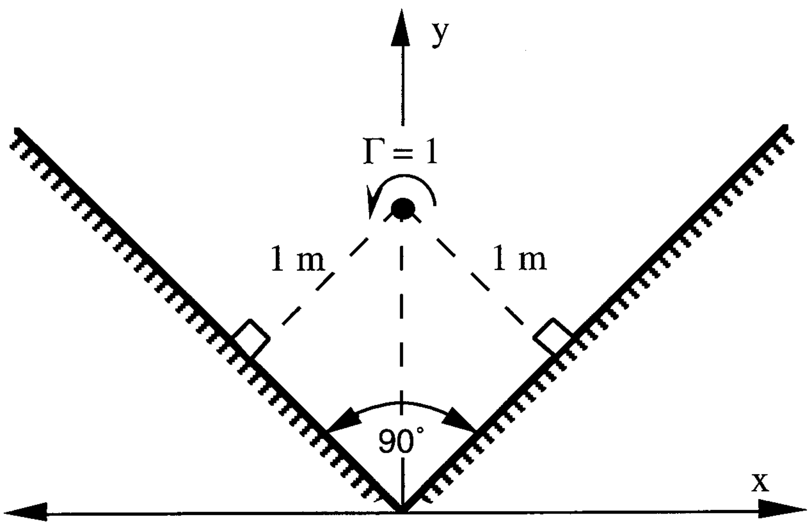

Figure 1. Vortex located in a notch

Problem 2

(a) Describe how Thunniform fish propel themselves. Use streamline patterns and vortex line or circulation concepts to support your answer. Discuss the similarities and differences between the flow behind a Thunniform fish and the flow generated by a jet discharging from an oscillating pipe (as was used by Perry & Lim in the movie "Eddies in Captivity").

(b) An air velocity measurement device called a Cobra probe is shown in the figure below. Each of the four surfaces of the Cobra probe contains a pressure transducer capable of measuring average pressure as well as high frequency pressure fluctuations on that surface. The angular faces allow the direction and velocity of flow to be measured very accurately. If the design flow speed of the Cobra probe is 10 m/s, estimate the spatial and temporal resolution of the probe.

(c) A constant-temperature hot-wire probe is shown in the figure below. The probe consists of two hot wires. The probe is well suited to measure flow velocities in a turbulent flow. If the design speed of the probe is 10 m/s, estimate the spatial and temporal resolution of the probe.

(d) Compare the performance of the two probes in terms of their ability to resolve small scale fluid motions and high frequency fluid motions.

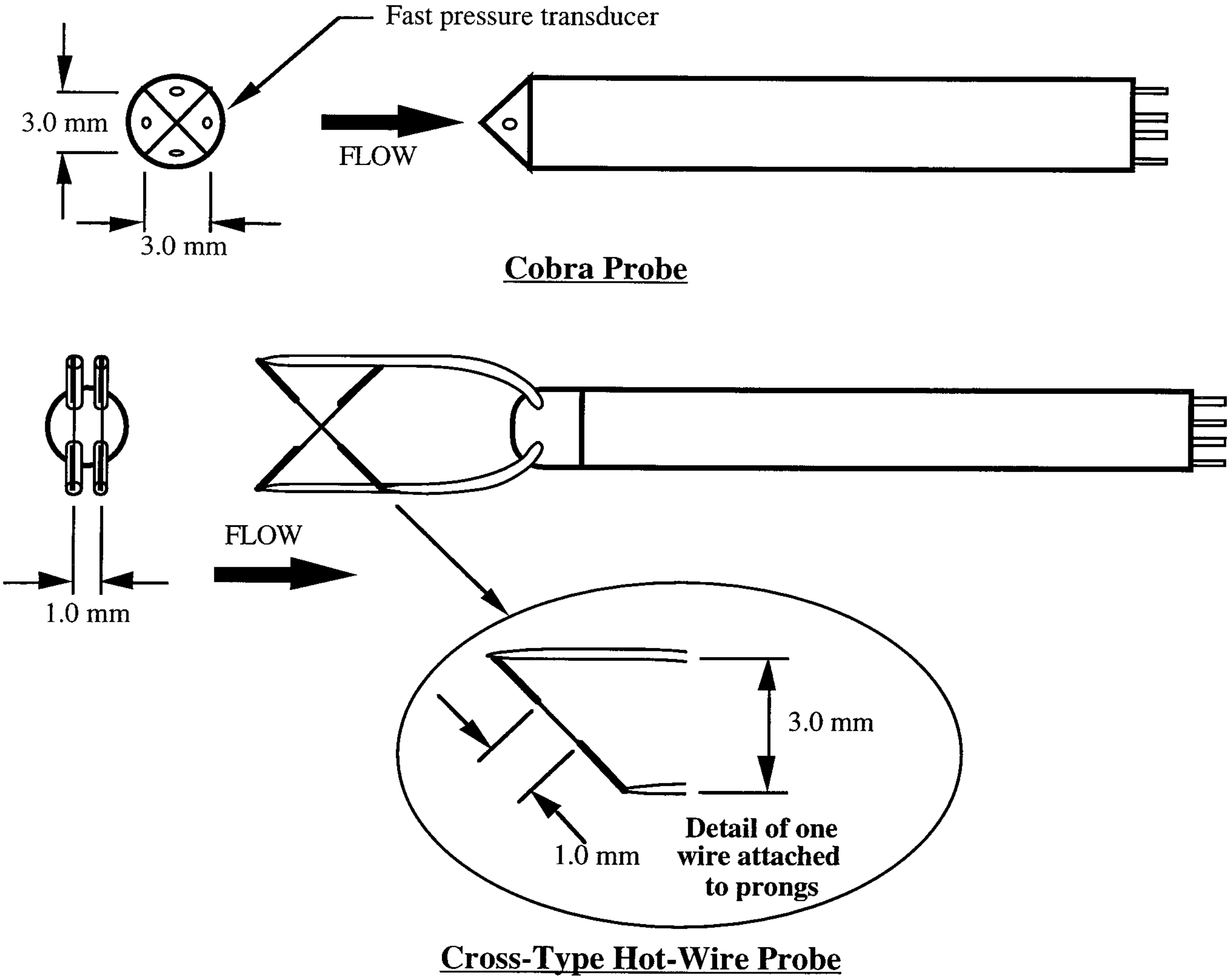

Figure 2. Cobra Probe (above) and Hot-Wire Probe (below).

Problem 3

Consider the flow with the following velocity field:

$$u = 3x^2 + 2xy^2 + 2x + 5y$$

$$v = 2x^2 + yx + 3x + y$$

(a) Show that the linearised velocity components about the origin are:

$$u = 2x + 5y$$

$$v = 3x + y$$

by taking the Taylor series expansion about the origin and keeping only the first two terms.

The formula for the Taylor series expansion about a point (a_1, a_2) for a function f(x, y) of two variables is:

$$f = \sum_{j=0}^{\infty} \left\{ \frac{1}{j!} \left[\sum_{k=1}^{2} (x_k - a_k) \frac{\partial}{\partial x_k} \right]^j f\Big|_{(a_1, a_2)} \right\}$$

(b) Determine the nature of the critical point at the origin and sketch the critical point and show the directions of the streamlines.

(c) Look at the 2D continuity of the non-linearised flow field. Is 2D continuity satisfied? Based on this result, describe the physical nature of the 3D flow.

(d) Consider the linearised velocity field:

$$u = 2x - 5y$$

$$v = 3x + y$$

Determine the nature of the critical point at the origin and sketch the critical point. Is the feature stable or unstable?

Problem 4

(a) A two-dimensional flow field is defined by:

$$u = 3y^2 + 7 \quad \text{m/s},$$
$$v = 8x + 2 \quad \text{m/s}.$$

(i) Is this flow field possible in an incompressible fluid?

(ii) Can a potential function exist in this flow?

Show all working.

(b) A long porous pipe runs parallel to the horizontal floor of a factory building as shown in Figure 3 below. (The longitudinal axis of the pipe is perpendicular to the plane of the paper.) The pipe is located 3 metres above the factory floor. Air flows radially from the pipe at a rate of π m^3/s per metre of pipe length.

Making appropriate assumptions, do the following:

(i) Write down the stream function that describes this flow.

(ii) Locate the stagnation point on the factory floor and determine the equations for the two streamlines passing through the stagnation point. Show all working.

(iii) Sketch the flow pattern.

(iv) Determine the velocity at point A in Figure 3.

(v) Determine the difference in pressure between point A and point B.

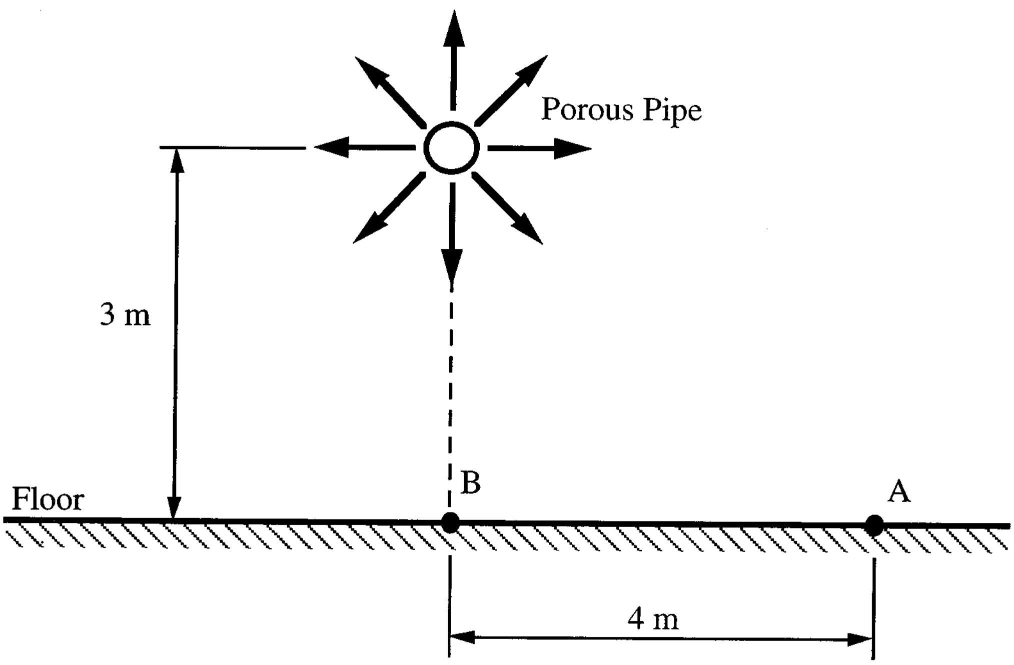

Figure 3.

Problem 5

a) If a water pump causes a pressure rise of 200 Pa at a constant flow rate of 1 m^3/s, estimate the power absorbed by the water.

b) You are asked by a senior manager of a petrochemical company to design a pipe system to carry air at 500 °C to a heat exchanger along a 2.0 m diameter pipe. The exit of the pipe joins a 4 m x 4 m square duct. The area averaged velocity in the 2.0 m diameter pipe is approximately 10 m/s. The design shown in Figure 4 has been proposed by the company. The velocity distribution of the flow entering the pipe is expected to be uniform (ie. essentially constant velocity over the entire cross section). The company requires the velocity profile leaving the pipe at B to be uniform (ie. constant velocity) to within ± 10% and the boundary layers to be thin.

- In your expert opinion, will this design provide the required performance? Explain your answer.
- What questions would you ask the senior manager of the petrochemical company to help you make your assessment.
- Answer **either** Part (i) or Part (ii) below.

  (i) If the design WILL meet the performance requirements, are there any improvements that can be made to reduce the pressure loss, the flow noise or to improve the uniformity of the flow into the heat exchanger?

  (ii) If the design WILL NOT meet the performance requirements, how could the design be modified to meet the specified velocity tolerance? If a complete re-design is required, show your proposal or proposals and justify why it/they would improve upon the previous design.

Caution: take care not to spend too much time on this question.

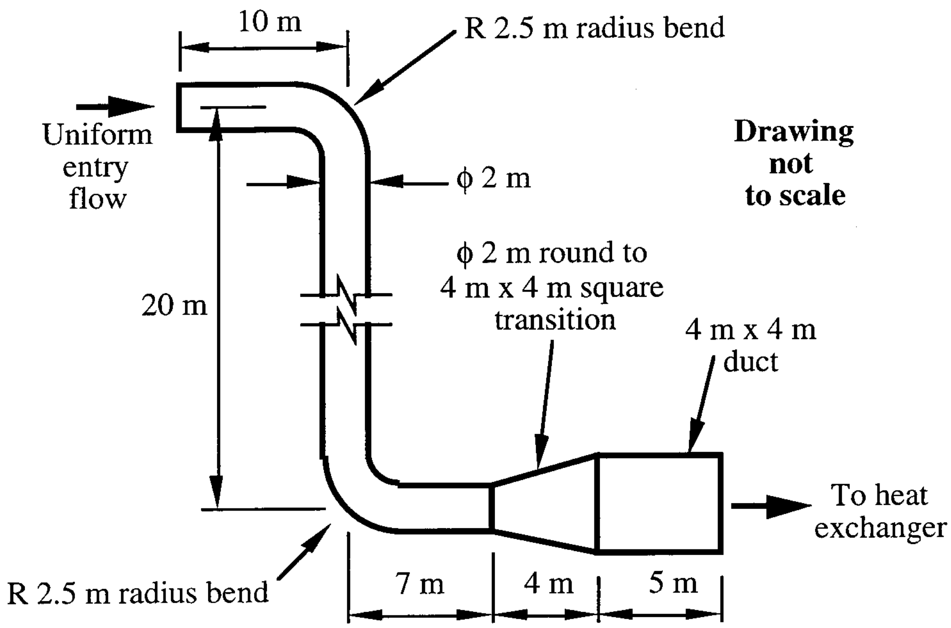

Figure 4. Heat exchanger supply pipe.

END OF EXAMINATION

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