ENGINEERING TRIPOS PART IB

Tuesday 2 June 1998 2 to 4

Paper 4

FLUID MECHANICS AND HEAT TRANSFER

Answer not more than **four** *questions.*

Answer at least **one** *question from each section.*

The **approximate** *number of marks allocated to each part of a question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

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SECTION A

Answer at least **one** *question from this section*

1 (a) Show that the pressure drop due to friction in a horizontal circular pipe may be expressed as $\Delta p = 4c_f \frac{1}{2}\rho V^2 l/d$ where l and d are the length and diameter of the pipe and ρ and V are the density and mean velocity of the flow. c_f is the skin friction coefficient which equals $\tau / \frac{1}{2}\rho V^2$, τ being the shear stress per unit area. Discuss the variation of skin-friction coefficient with Reynolds number. [5]

(b) A furnace and chimney are modelled as shown in Fig. 1. The furnace is represented as a heated grid at the foot of the chimney and air passes from the atmosphere at ground level through the grid and up the chimney. The effect of the grid is to reduce the density of the air after it by 20% and to produce a pressure drop across it of $0.1\,\rho V^2$ where ρ and V are the density and velocity *just before* the grid.

(i) Assuming that air is flowing in the chimney, that is ignoring all products of combustion and that the diameter of the grid is the same as that of the chimney, and equal to 2 m, what is the velocity of the air just after the grid in terms of the velocity just before the grid? [5]

(ii) Skin friction is important after the grid with c_f taking a value of 0.007. If the chimney is 20 m high what is the velocity at the top of the chimney? [10]

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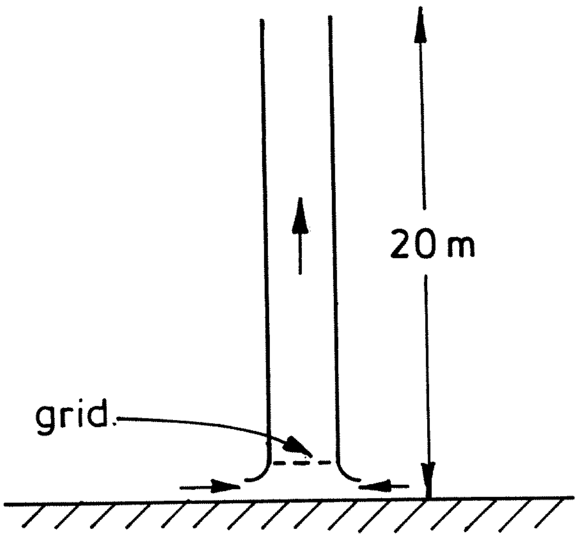

Fig. 1

2 Derive equations for the pressure gradient along a streamline and normal to a streamline for inviscid flow. In both cases gravity may be ignored. [10]

The flows (a) and (b) are two-dimensional and have circular concentric streamlines. For flow (a) the velocity along a streamline is given by $V = k_1 r$ and for (b) the velocity is given by $V = k_2/r$ where r is the radius of the streamlines and k_1 and k_2 are constants.

Find expressions for the pressure p in both flows as a function of r. [5]

A combined flow is formed such that for $r \leq R$ the velocity is given by $V = k_1 r$ and for $r \geq R$, $V = k_2/r$. At $r = 0$ the pressure is p_0 and at $r = \infty$ the pressure is p_∞. Find expressions for k_1 and k_2 in terms of p_0, p_∞, R and the density. [5]

(TURN OVER

3 Figure 2 shows a cylindrical body with base diameter 0.5 m fixed inside a circular duct of internal diameter 1.5 m. There is a uniform velocity V_1 before the body where the pressure is p_1 and a jet issues from the entire base of the body with velocity $2V_1$. If there are no losses in the flow up to the base of the body calculate the value of the non-dimensional pressure coefficient $\left(p_2 - p_1\right)/\frac{1}{2}\rho V_1^2$, where p_2 is the pressure in the flow at the point 2 shown in the figure and ρ is the density of the fluid flowing. The pressure p_2 is constant across the duct and the base, and the flow is incompressible. [8]

The jet, which is of the same fluid, mixes with the main flow and far downstream of the body at the point 3 mixing is complete and the velocity and pressure are uniform across the duct. Assuming that skin friction on the sides of the duct are negligible calculate the value of the pressure coefficient $\left(p_3 - p_2\right)/\frac{1}{2}\rho V_1^2$. [12]

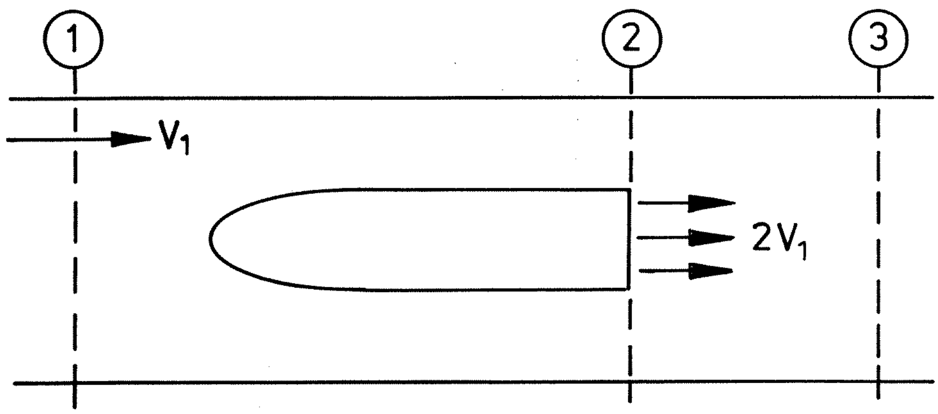

Fig. 2

4 Figure 3 shows a two-dimensional channel with laminar flow. The bottom wall is stationary and the upper wall, distance h away, is moving with velocity U. There is no pressure gradient dp/dy but there is a constant pressure gradient dp/dx acting. The velocity profile $u(y)$ is not a function of x.

Find an expression for the velocity profile $u(y)$ across the channel in terms of dp/dx, y, U, h and μ the coefficient of viscosity. [8]

Hence for *zero net flow* in the channel find the value of the constant in the equation

$$\frac{dp}{dx}\frac{h^2}{\mu U} = \text{constant}.$$ [7]

Show that this equation, without the value of the constant, can be derived solely by dimensional analysis. [5]

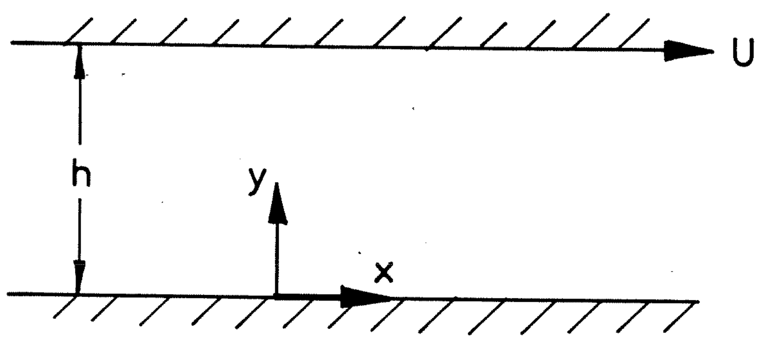

Fig. 3

SECTION B

Answer at least **one** *question from this section*

5 A model of a greenhouse comprises the soil, which may be considered as a black body, and 50 cm above it a glass panel of thickness 2 mm and thermal conductivity $\lambda_g = 1$ Wm^{-1}K^{-1}. The glass panel may be assumed to be perfectly transparent to the incident solar radiation of 600 Wm^{-2}.

The convective heat transfer coefficient outside the glass is $h = 10$ Wm^{-1}K^{-1} and the outside temperature is 5°C. The internal Nusselt number between the glass and the soil due to air convection is 500 and the thermal conductivity of the air, $\lambda_a = 0.025$ Wm^{-1}K^{-1}.

It may be assumed that the glass panel is a black body for the radiation coming from the soil and that there is no net heat transfer to the soil. There are no variations along the glass or the soil.

Set up equations for the steady-state heat transfers inside the greenhouse, for the glass and for the air outside. [8]

Show that the outside surface temperature of the glass panel is about 22°C and determine [3]

(i) the inside surface temperature of the glass panel [4]

and (ii) the surface temperature of the soil. [5]

6. Write down the chemical equation for the combustion of carbon monoxide with excess dry air. [5]

Carbon monoxide with a flow rate of 10 kg s^{-1} is burned with dry air in a combustion chamber, both reactants being at 25°C. The heat loss from the combustion chamber is $Q = H(T_f - T_0)$, where T_0 = 25°C is the outside temperature, T_f is the final temperature of the products and $H = 10^4$ WK^{-1}.

Determine the excess of dry air when T_f = 2000 K. [15]

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