Code No: RR422104 **Set No.1**

IV B.Tech. II Semester Regular Examinations, April/May -2006
VISCOUS FLOW THEORY
(Aeronautical Engineering)

Time: 3 hours **Max Marks: 80**

Answer any FIVE Questions
All Questions carry equal marks

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1. (a) Explain the shearing action of a viscous fluid flow over a surface. What happens in case of a perfect fluid? Elaborate with sketches/ plots. [8]

   (b) Explain the significance of curl of the velocity field and Divergence of the velocity field. Express these in cartesian and cylindrical co-ordinates. [8]

2. (a) Given the velocity field
   $\overrightarrow{V} = (6 + 2xy + t^2)\,\hat{i} - (xy^2 + 10t)\,\hat{j} + 25\hat{k}$.
   What is the acceleration of a particle at (3,0,2) at time t=1? [8]

   (b) Sketch velocity profiles of boundary layer flows under following conditions.
      i. Favourable pressure gradient
      ii. Zero pressure gradient
      iii. Weak adverse pressure gradient
      iv. Critical adverse pressure gradient
      v. Strong adverse pressure gradient.
      Explain the phenomenon in each plot. [8]

3. Given a velocity field with components at P(x,y,z)
   u(x,y,z) = cx + $2w_o y$ + u_o
   v(x,y,z) = cy + u_o
   w(x,y,z) = -2cz + w_o
   Where c, w_o, u_o, v_o and ω_o are constants.
   Determine
   (a) Translational velocity
   (b) Rotational velocity
   (c) Rate of strain. [16]

4. (a) Write Navier-Stokes equations for viscous, incompressible fluid flow in Cartesion and vector form. Explain the terms on LHS and RHS. [8]

   (b) Show that parallel flow through a straight channel of width '2b' is given by $\mu = -\frac{1}{2\mu}\frac{dp}{dx}(b^2 - y^2)$. [8]

5. A flat plate is suddenly moved to a velocity U_∞ in oil with $\rho = 920\,kg/m^3$ and $\mu = 0.07\,kg/ms$. Plot the velocity ratio $\frac{u}{U_\infty}$ as a function of distance form the plate for t=0.01s, 0.05s, and 0.1s. If U_∞ = 3m/sec., calculate the shearing stress at the plate. [16]

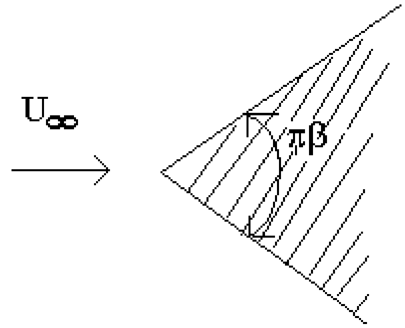

Figure 1:

6. Consider viscous flow part a wedge of included angle $\pi\beta$. Shown in figure 1.

   Show that the velocity distribution in the laminar boundary layer over the wedge surface is given by Falkner Scan equation. $f''' + f\,f'' + \beta\left(1 - f'^2\right) = 0$ [16]

7. (a) Consider viscous flow past a flat plate at zero angle of attack. The temperature at the plate is maintained constant. Describe the thermal boundary layer in a laminar flow, if V_∞ is the free stream velocity and T_∞ is the free stream temperature. [8]

   (b) The given velocity profile in laminar boundary layer $\frac{U}{U_\infty} = 6\eta^2 - 8\eta^3 + 3\eta^4$. where $\eta = \frac{y}{\sigma}$ Obtain the shape parameter H. What is the significance of this value of H? [8]

8. (a) Describe the Law of the wall for a turbulent flow along a wall with illustrations. [8]

   (b) Prandtl's mixing length theory appears better than the 'apparent kinematic viscosity ε' concept. Elaborate the statement in regard to the semi-empirical theories of turbulence. [8]

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1. (a) Prove from fundamental considerations that vorticity vector in a viscous flow is twice the angular velocity vector. [8]

   (b) A flat plate is kept in a viscous fluid flow. Depict the velocity boundary layer and thermal boundary layer over this flat plate in a single plot. Does the velocity boundary layer thickness equal the thermal boundary layer thickness? Explain with the physics of the flow field. [8]

2. A velocity field is given with the components
   u(x,y,z) = cx + 2w$_o$y + u_o
   v(x,y,z) = cy + v_o
   w(x,y,z) = -2cz + w_o
   Where c, w_o, u_o, v_o and ω_o are constants. Hence work out in flow filed

   (a) Translational velocity

   (b) Rotational velocity

   (c) Rate of strain velocity.
   Sketch the flow fields representing above velocity components. [16]

3. (a) Write Navier-stokes equations for viscous imcompressible fluid flow in Cartesian co-ordinates and vector form. Explain all terms on LHS and RHS. [8]

   (b) The differential form of the equation for conservation of mass can be used to evaluate the relative rate of change of density of a fluis particle as it waves through a flow. Show that $\frac{1}{\rho}\frac{D\rho}{Dt} = -\nabla.\overrightarrow{V}$. Explain the physical significance of $\nabla.\overrightarrow{V}$ [8]

4. Show with appropriate work out that the Vorticity Transport Equation in 2-D flow in x-y plane follows from Navier-stokes equation. Make use of sketches to explain your answer. [16]

5. (a) A velocity field for motion parallel to the x-axis with constant shear is shown in figure 2. [8]
   The shear rate is $\frac{du}{dy} = A = 0.1\,Sec^{-1}$. Obtain an expressin for the velocity field $\vec{V}$. Calculate the rate of rotation.

   (b) Show that parallel flow through a straight channel of width '2b' is given by
   $u = -\frac{1}{2\mu}\frac{dp}{dx}(b^2 - y^2)$. [8]

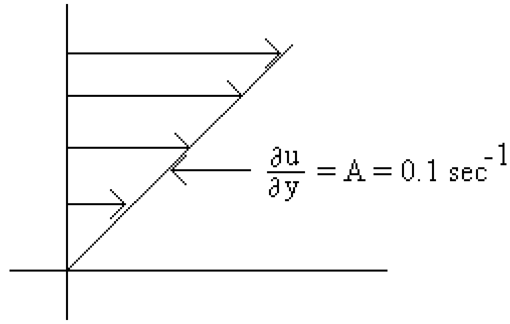

Figure 2:

6. (a) An approximate solution for a plane surface which suddenly starts moving in its own plane with a constant velocity U_∞ is assumed to be $u = U_\infty e^{\frac{-ay}{\delta}}$ Where a is an arbitrary constant. Calculate the boundary layer thickness δ. [8]

   (b) Consider an airfoil sector in an air stream at $\alpha \neq 0$, shown in figure 3. [8]

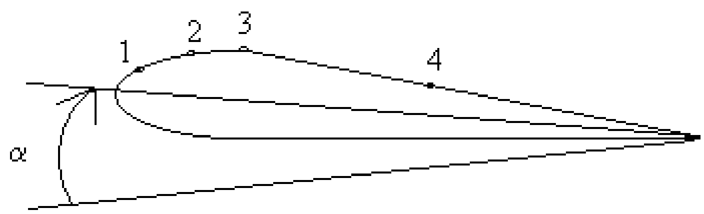

Figure 3:

Sketch velocity profiles at pts 1,2,3 and 4. Hence explain the phenomenon of separation.

7. The velocity along the center line of Hayen-Poisenille flow in a 0.1m ϕ pipe is 2 m/sec. If the viscosity of the fluid is 0.07 kg/ms and its specific gravity is 0.92, calculate

   (a) The volumetric flow in m^3/sec

   (b) The shearing stress of the fluid at pipe at pipe wall

   (c) The local friction coefficient c_f. [16]

8. (a) Explain Prandtl's mixing length theory as one of the semi-empirical theories of turbulence. [8]

   (b) Describe the structure of a turbulent Boundary Layer over a flat plate at $\alpha = 0$. Hence explain that the energy level in a turbulent boundary layer is more as compared with that in a Laminary boundary layer in this case. [8]

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1. (a) Consider boundary layer flow given by $u = V_\infty \left(\frac{y}{\delta}\right)^{0.25}$ calculate
   i. Time rate of change volume of a fluid element per unit volume
   ii. Vorticity. [8]

   (b) Consider flow part a flat plate at zero angle of attack. The temperature at the plate is maintained constant as T_w. Describe the variation of temperature T perpendicular to the wall at any station, if the free stream velocity is V_∞ and T_∞ is the temperature. [8]

2. (a) Explain the concept of velocity boundary layer. Hence workout the expressions for flow past a flat plate.
   i. Displacement thickness
   ii. Momentum thickness
   iii. Energy thickness. [8]

   (b) Consider a velocity field in 2-D, polar co-ordinates. Establish that the vorticity vector is twice the angular velocity vector. [8]

3. (a) Write Navier-Stokes equation for viscous, incompressible fluid flow in cartesian co-ordinates and vector form. Explain all the terms on LHS and RHS. What if the viscous term on RHS vanishes? [8]

   (b) Elaborate from Navier-Stokes equations that flows with small velocities (or creeping motions), form exact solutions of these equations in the limiting case of very small Reynolds Number (Re $\rightarrow$ 0). [8]

4. Consider a rectangular fluid element in a viscous flow. Develop expressions for Normal strains and shearing strains when the fluid element is deformed under certain flow conditions. [16]

5. (a) The Hagen-Poisenille flow is one of the well known exact solutions of Navier stokes equations. Hence show that the axial velocity distribution in this case is of the form of a paraboloid of revolution. [8]

   (b) Oil of dynamic viscosity 0.07 kg/ms flows through a 20 mm ϕ pipe with a mean velocity of 0.5 m/sec. Calculate the pressure drop which occurs over a length of 50m of the pipe. [8]

6. Consider $\overrightarrow{V} = u\,(x, y, t)\,\hat{i} + v\,(x, y, t)\,\hat{j}$. Prove that $\frac{Dw}{Dt} = \upsilon\nabla^2 w$, where w is the angular velocity. Interpret the equation. Show that $w = -\frac{1}{2}\nabla^2\psi$ where $\psi\,(x, y)$ is the stream functions. [16]

7. Consider Laminar boundary layer along a flat plate at zero angle of attack. Obtain the Blasius equation $ff''+2f'''=0$ (with usual nomenclature). State the boundary conditions. [16]

8. (a) Consider boundary layer flow along a flat plate. The flow initially laminar turns out turbulent along the flat plate aligned with the flow.
   i. Describe the velocity profiles in laminar and turbulent flow
   ii. Explain the distribution of velocity in the turbulent Boundary layer as a universal velocity profile. [8]

   (b) Estimate the frictional drag force on a plate 3m. long, 10m.wide, placed in a wind tunnel at a velocity of 50 m/sec. Assume that the boundary layer over this plate is considered turbulent over the entire length of the smooth surface of the wall. ($\rho = 1.18kg/m^3$, $\nu = 14.7\,mm^2/\,\text{sec}$). [8]

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1. (a) Explain the significance of curl of the velocity field and Divergence of the velocity field. Express these in Cartesian and cylindrical co-ordinates [8]
   (b) A velocity field is given by $u = \frac{y}{x^2+y^2}, \nu = \frac{-x}{x^2+y^2}$
   Calculate the circulation around a circular path of radius 5m. u and v are given in the units of m/sec. [8]

2. (a) A flat plate is kept in a viscous fluid flow. Depict the Velocity Boundary Layer and Thermal Boundary Layer over this flat plate in one plot. Explain the physics of the flow field. [8]
   (b) A velocity field is given by $\overrightarrow{V} = ax\hat{i} - ay\hat{i}$; x and y are in meters, a = 0.1/sec. At (2,8,0) evaluate the equation of stream line, equation of pathline and velocity. What would be the position of the particle at (2,8,0) at t=20. [8]

3. (a) Show that the following velocity components represent a rigid body rotation.
   u = a + by - cz; v = d - bx + ez; w = f + cx-ey
   (b) Write Navier-Stokes equations for visions, incompressible fluid flow in cartesian co-ordinates and vector form. How does the Euler equation differ from this. [8]

4. Consider flow near a flat plate suddenly accelerated from rest, moving in its own plane with constant velocity V_o. Work out and plot the velocity distribution above this suddenly acceleerated plane wall. [16]

5. Starting from Navier-stokes equation, verify for plane Poiscnille flow that the shearing stress becomes zero at the middle plane and that $\frac{\partial T_{yx}}{\partial y} = \frac{dp}{dx}$ [16]

6. Prove that karman's momentum Integral relation for flat plate Boundary layer flow is given by $\tau_w = \rho U^2 \, \frac{d\theta}{dx}$
   If $u\left(x,y\right) \cong, U\left(\frac{2y}{\delta} - \frac{y^2}{\delta^2}\right), 0 \leq y \leq \delta\left(x\right)$
   then show that the shear stress estimate along the plate is given by
   $C_f = \frac{2\tau_w}{\rho U^2} \approx \frac{0.73}{\mathrm{Re}_x^{1/2}}$ [16]

7. Consider viscous flow past a circular cylinder shown in figure 4.
   Sketch and explain the velocity profiles at $\theta = 0^o$, 30^o, 60^o, 90^o, 120^0 and 150^o. Hence explain the phenomenon of separation. [16]

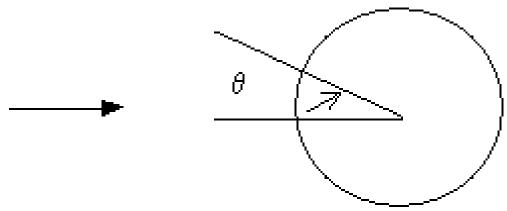

Figure 4:

8. Consider turbulent flow past a plane wall. Describe various regimes of flow, (due to the velocity profile) in this flow field. Hence show that the universal flow profile is given by
$\frac{\bar{u}}{u_*} = 5.5 + 5.75 \log_{10} \frac{u_*}{\nu} y$ and explain it with a plot. [16]

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