INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

AEROSPACE ENGINEERING DEPARTMENT

Date: Time: 3 Hrs, Full Marks: 50

No of Students: 58 End-Autumn Semester Examination

AE21001 **Introduction to Aerodynamics**

2nd Year B. Tech. (H) & DD

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*Answer **all** questions. All parts of a multi-part question must be answered together. Assumptions, if required, can be made with appropriate justifications.*

Notations have their usual meaning unless specified otherwise.

Complex velocity at a point on the circle of radius R (*in the circle* (ζ) *plane*):

$$W(\zeta) = q_\infty e^{-i\alpha} + \frac{i\Gamma}{2\pi}\,\frac{1}{\zeta - \zeta_0} - \frac{q_\infty R^2 e^{i\alpha}}{(\zeta - \zeta_0)^2}$$

1(a) Show that the stress tensor in a fluid at rest is everywhere isotropic and only normal stresses act.

(b) A closed vessel full of water is rotating with constant angular velocity Ω about a horizontal axis. Show that the surfaces of equal pressure are circular cylinders whose common axis is at a height g/Ω^2 above the axis of rotation.

(c) A velocity field associated with a fluid motion is described by the components

$$u(x,y,z) = cx + 2\omega_0 y + u_0, \quad v(x,y,z) = cy + v_0, \quad w(x,y,z) = -2cz + w_0$$

where c, ω_0, u_0, v_0, and w_0 are constants. Compute the rate of strain tensor. Does this motion represent a rigid body rotation? If not then compute the vorticity.

2(a) Under what conditions the Eulerian velocity field in a fluid can be approximated as solenoidal? Note that a solenoidal velocity field characterizes an incompressible flow.

(b) The incompressible irrotational velocity field around a circular cylinder of radius R is given by

$$u_r(r,\theta) = -U_\infty\left(1 - \frac{R^2}{r^2}\right)\cos\theta$$

$$u_\theta(r,\theta) = U_\infty\left(1 + \frac{R^2}{r^2}\right)\sin\theta$$

Find the pressure, in terms of pressure coefficient, associated with this velocity field. The parameter U_∞ represents the undisturbed stream and is a constant.

Determine the positions on the surface where the pressure is equal to that of undisturbed stream.

(c) Define/explain the following terms: wing planform and aspect ratio, angle of attack, lift force and yawing moment, aerodynamic centre and centre of pressure.

3(a) Explain conformal mapping. Distinguish between a critical point and a singular point of a transformation.

(b) Show that the Zhukovsky airfoils have cusped trailing edge.

(c) Show that an ellipse of semi-axes 'a' and 'b' will be mapped on to a circle of radius $\frac{1}{2}(a+b)$ in the f plane by the transformation $z = f + \frac{a^2 - b^2}{4f}$. What are the critical points of this transformation?

4(a) What is Kutta condition? State and explain its' significance in the solution of inviscid and incompressible flow.

(b) An elliptic cylinder with fineness ratio of 9 is set at an angle of incidence of 5^o in an air stream flowing at 20 m/s. Calculate the resultant velocity vector at a point one chord ahead of the centre of the cylinder along the major axis. Assume that the circulation generated is two-third of that required to bring the rear stagnation point to the end of the major axis.

(c) Determine the ideal flow pressure coefficient at any point on the surface of a 2-dimensional semi-infinite fairing of maximum thickness 0.2 m immersed in a uniform stream with undisturbed velocity of 40 m/s.

5(a) A small symmetrical Zhukovsky airfoil has a thickness ratio of 0.1 and is fitted with pressure holes on both surfaces at 12% of the chord behind the leading edge so that it can be used as a yaw-meter. Find the pressure difference that would be observed when it is set at $1\frac{1}{2}^0$ incidence to the flow. Express the result in terms of the pressure rise at the stagnation point. Assume two-dimensional ideal flow.

(b) Explain boundary-layer displacement thickness.

(c) The velocity profile within the laminar boundary layer over a flat plate at zero incidence can be approximated by $\frac{u}{u_e} = \frac{3}{2}\frac{y}{\delta} - \frac{1}{2}\left(\frac{y}{\delta}\right)^3$. Find the momentum thickness and skin friction at any point on the plate in terms of the local Reynolds number. Also find the overall skin friction coefficient for one surface of the plate.