INDIAN INSTIUTE OF TECHNOLOGY, KHARAGPUR

Date: Time: 3 Hrs, Full Marks: 50, AEROSPACE ENGG DEPARTMENT

No. of Students: 9 Supplementary Examination 2013

AE21001 **Introduction to Aerodynamics**

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

Answer any five full questions. All questions carry equal marks.

Different parts of a multi-part question must be answered together.

Some important vector identities:

$$\nabla\times\left(s\vec{u}\right)=s\nabla\times\vec{u}-\vec{u}\times\nabla s$$

$$\nabla\times\left(\vec{u}\times\vec{v}\right)=\vec{v}\nabla\vec{u}+\vec{u}\nabla\cdot\vec{v}-\vec{u}\nabla\vec{v}-\vec{v}\nabla\cdot\vec{u}$$

$$\nabla^2\vec{u}=\nabla\cdot\nabla\vec{u}=\nabla\left(\nabla\cdot\vec{u}\right)-\nabla\times\left(\nabla\times\vec{u}\right)$$

$$\vec{u}\nabla\vec{u}=\frac{1}{2}\nabla\left(\vec{u}\cdot\vec{u}\right)+\left(\nabla\times\vec{u}\right)\times\vec{u}$$

Complex velocity at a point in the circle (f) plane (radius of the circle is R):

$$W\left(f\right)=q_\infty\ e^{-i\alpha}+\frac{i}{2}\frac{\Gamma}{\pi}\frac{1}{f-f_0}-\frac{q_\infty R^2\ e^{i\alpha}}{\left(f-f_0\right)^2}$$

Notations have their usual meaning unless specified otherwise.

1(a) Considering the Eulerian velocity at two neighbouring positions in space show that the fluid velocity is the superposition of a uniform velocity, a pure straining motion without change in volume, an isotropic expansion and a rigid body rotation.

(b) Assuming incompressible flow of a constant property fluid show that the local rate of change of vorticity in a flow is given by the sum total of vorticity convected with the flow, vorticity diffused by the viscous action and local redistribution of vorticity due to rotation and stretching.

2(a) Show that a vortex filament cannot end within a fluid.

(b) Compute the velocity difference across a surface vortex of strength Γ.

(c) If $u=\frac{kx}{x^2+y^2}, v=\frac{ky}{x^2+y^2}$ are the velocity components for a 2D incompressible flow, what will be the equation of the streamlines?

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

(b) What is Kutta condition? State and explain its' physical significance.

(c) Calculate the theoretical lift coefficient of a 16% thick Zhukovsky airfoil with 2% camber set at 5^o incidence. If the camber is altered to 3.5%, what will be the lift coefficient? Derive the formula you used.

4(a) Define singly-connected and multiply-connected domains. How many irreconcilable circuits can be drawn in doubly-connected region? If the velocity field in a doubly connected region of space is solenoidal and irrotational, what conditions are required to be satisfied so that the velocity field can be determined uniquely?

(b) Under what conditions a flow can be approximated as incompressible and inviscid? Show that in such a flow the rate of change of circulation around a material closed curve is zero if the body force field is conservative.

5(a) Show that the viscous force per unit volume acting on an incompressible fluid element can be computed from the vorticity alone. Since vorticity represents rigid body rotation, which does not contribute to viscous stresses, how is it possible?

(b) What is a potential flow? Is it possible to have non-zero rate of expansion in a potential flow? Obtain the equation that describes incompressible potential flow and write down the boundary conditions. Do you need any additional information other than the equation and boundary conditions to solve the flow over a given geometry?

(c) What is zero-lift angle of attack and how is it related to airfoil camber?

6(a) An elliptic cylinder of thickness to chord ratio of $\frac{1}{9}$ 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.

(b) A long elliptic cylinder of thickness to chord ratio of $\frac{1}{7}$ is set at 0^o incidence to an air stream flowing at 35.4 m/s. Calculate the pressure difference between pressure holes set at the nose and at the point of maximum thickness.