Indian Institute of Space Science and Technology

AE 111 - Introduction to Aerospace Engineering (I Semester)

Quiz 2

Duration: 60 minutes **Total Marks:30**

Standard sea level (SSL) atmospheric properties

- Pressure, P = 101.325 kPa = 1 atm
- Density, $\rho = 1.225$ kg/m^3
- Temperature, T = 15°C
- Gas constant of air, $R_{air} = 287.057$ J/(kg.K)
- Dynamic viscosity, $\mu = 1.789 \times 10^{-5}$ Pa.s
- Acceleration of gravity, $g_0 = 9.807$ m/s^2

1. A dimensionless combination of change in pressure Δp, density ρ, a length scale l and discharge $Q(m^3/s)$ is [2]

   A. $\sqrt{\frac{\Delta p}{\rho}}\frac{Q}{l^2}$ B. $\frac{\rho Q}{\Delta p l^2}$ C. $\frac{\rho l}{\Delta p Q^2}$ D. $\sqrt{\frac{\rho}{\Delta p}}\frac{Q}{l^2}$

2. Downstream of a normal shock, the following property changes happen [1]

   A. pressure increases, total pressure remains constant, total temperature increases

   B. velocity decreases, total pressure increases, total temperature remains constant

   C. Temperature decreases, total pressure decreases, total temperature increases

   D. Temperature increases, total pressure decreases, total temperature is constant

3. The relation between an airplane's true airspeed V_{TAS} and equivalent airspeed V_{EAS} in terms of the density ratio ($\sigma = \frac{\rho}{\rho_0}$), where ρ_0 is the air density at sea-level and ρ is the air density at the height at which the airplane is flying, is given by [1]

   A. $\frac{V_{EAS}}{V_{TAS}} = \sigma$ B. $\frac{V_{EAS}}{V_{TAS}} = \sigma^2$ C. $\frac{V_{EAS}}{V_{TAS}} = \sqrt{\sigma}$ D. $\frac{V_{EAS}}{V_{TAS}} = 1/\sqrt{\sigma}$

4. For a quasi-one-dimensional isentropic supersonic flow through a diverging duct, which of the following is true in the direction of the flow? [1]

   A. The Mach number increases and the static temperature decreases

   B. Both the Mach number and the static temperature increase

   C. The Mach number decreases and the static temperature increases

   D. Both the Mach number and the static temperature decrease.

5. Fill in the blank

   (a) The theoretical value of slope in $C_l - \alpha$ graph is _____. [1]

   (b) A positively cambered airfoil has a _____ $\alpha_{L=0}$. [1]

   (c) The expression for Mach angle is _____. [1]

(d) As an aircraft's weight increases, its stall speed _____. [1]

(e) An aircraft with mass of 400,000 kg cruises at 240 m/s at an altitude of 10‘km. Its lift to drag ratio at cruise is 15. The power (in MW) needed for it to cruise is _____. [1]

6. Write an expression for C_l as a function of angle of attack for a cambered airfoil. [1]

7. Write an expression which relates the drag coefficient C_d to the lift coefficient C_l. [1]

8. Give the expression for dynamic pressure, q. For high-speed flows, where Mach number is used frequently, it is convenient to express q in terms of pressure p and Mach number M. Derive an equation for $q = q(p, M)$ [2]

9. A Pitot tube is mounted in the test section of a high-speed subsonic wind tunnel. The pressure and temperature of the airflow are 1 atm and 270 K, respectively. If the flow velocity is 250 m/s, what is the pressure measured by the Pitot tube? [2]

10. Consider a Mach 2 airstream at standard sea-level conditions. Calculate the total pressure of this flow. Compare this result with

    (a) the stagnation pressure that would exist at the nose of a blunt body in the flow, and [2]

    (b) the erroneous result given by Bernoulli's equation. [1]

11. A student team is to design a human-powered submarine for a design competition. The overall length of the prototype submarine is 4.85 m, and its student designers hope that it can travel fully submerged through water at 0.440 m/s. The water is freshwater (a lake) at $T = 15°C$. The design team builds a one-fifth scale model to test in their university's wind tunnel. The air in the wind tunnel is at $25°C$ and at one standard atmosphere pressure. The viscosity of water is 8.90×10^{-4} Pa.s.

    (a) At what air speed do they need to run the wind tunnel in order to achieve similarity? [2]

    (b) The students measure the aerodynamic drag on their model submarine in the wind tunnel. Their measured drag force is 5.70 N. Estimate the drag force on the prototype submarine at the conditions. [2]

12. The wing of an airplane is approximately rectangular with a wingspan (the length perpendicular to the flow direction) of 17.5 m and a chord (the length parallel to the flow direction) of 3 m. The airplane is flying at standard sea level with a velocity of 200 m/s.

    (a) If the flow is considered to be completely laminar, calculate the boundary layer thickness at the trailing edge and the total skin friction drag. [1½]

    (b) If the flow is completely turbulent, calculate the boundary layer thickness at the trailing edge and the total skin friction drag. [1½]

    Assume that the wing is approximated by a flat plate. Assume incompressible flow.

13. An airfoil has a chord length of 4.7 m. At cruising velocity (84 m/s) at sea level, the moments per unit span at this airfoil location are $M_{c/4}$ = -1452 N-m and M_{LE} = -4357.5 N-m. Calculate the lift per unit span and the location of the center of pressure on the airfoil. [4]

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1. Isentropic process:
$$\frac{p_2}{p_1} = \left(\frac{\rho_2}{\rho_1}\right)^{\gamma} = \left(\frac{T_2}{T_1}\right)^{\gamma/(\gamma-1)}$$

2. Velocity measured by a Pitot tube in subsonic compressible flow:
$$V_1^2 = \frac{2a_1^2}{\gamma-1}\left[\left(\frac{p_0}{p_1}\right)^{(\gamma-1)/\gamma} - 1\right]$$

3. Rayleigh pitot tube formula:
$$\frac{p_{0_2}}{p_1} = \left[\frac{(\gamma+1)^2 M_1^2}{4\gamma M_1^2 - 2(\gamma-1)}\right]^{\gamma/(\gamma-1)} \frac{1-\gamma+2\gamma M_1^2}{\gamma+1}$$

4. Isentropic flow:
$$\frac{T_0}{T_1} = 1 + \frac{\gamma-1}{2}M_1^2$$