ELIZADE UNIVERSITY, ILARA-MOKIN, ONDO STATE, NIGERIA

DEPARTMENT OF MECHANICAL ENGINEERING

SECOND SEMESTER EXAMINATIONS

2018/2019 ACADEMIC SESSION

COURSE: MEE 502 – Fluid Dynamics (3 Units)

CLASS: 500 Level Mechanical & Automotive Engineering

TIME ALLOWED: 3 Hours

INSTRUCTIONS: Answer any 5 questions

HOD'S SIGNATURE

Date: July, 2019

Question 1

(a) i. What do you understand by Inviscid flow? State three (3) application areas of inviscid flows

ii. Briefly explain the following with the aid of mathematical equations:

Vorticity, Stream function, & Velocity potential **4 Marks**

(b) A flow has a potential function $\emptyset$, given by $\emptyset = 3xy^2 - x^3$.
Derive the corresponding stream function. **3 Marks**

(c) Consider a uniform flow, $\varphi = V_o\left(r - \frac{a^2}{r}\right) sin\theta$ past a circular cylinder, where V_o is velocity, a is the radius and φ is the stream function. If the cylinder diameter is 50 mm and the velocity is 1 m/s, determine the radial and normal components of velocity at a point on a stream where r = 60 mm and $\theta = 135°, measured\ from\ the\ posiive\ x\ axis.$
Hints: $V_r = \frac{1}{r}\frac{\partial\varphi}{\partial\theta}$ and $V_\theta = -\frac{\partial\varphi}{\partial r}$ **5 Marks**

Question 2

(a) Write a short note on the following:

i. Under-expanded nozzle
ii. Over-expanded nozzle
iii. Oblique shock wave
iv. Normal shock wave **3 Marks**

(b) i. Write the governing equations for compressible flow.

ii. Given that the mass flow from a reservoir through an orifice per unit time is

$$\dot{m} = A\rho_o\sqrt{\left[2\left(\frac{\gamma}{\gamma-1}\right)\frac{P_o}{\rho_o}r^{\frac{2}{\gamma}}\left(1 - r^{\left(\frac{\gamma-1}{\gamma}\right)}\right)\right]},$$

Show that for maximum discharge, throat velocity is $\bar{V} = \sqrt{\left(\frac{\gamma P_t}{\rho_t}\right)}$

Where A = Orifice area, V_0, ρ_o *and* P_o are reservoir velocity, density and pressure.

$r = \frac{P_t}{\rho_o}$, P_t *and* ρ_t are throat pressure and density **4 Marks**

(c) A supersonic wind tunnel consists of a large reservoir containing gas under high pressure which is discharged through a convergent-divergent nozzle to a test section of constant cross-sectional area. The cross-sectional area of the throat of the nozzle is 400 mm^2 and the Mach number in the test section is 4. Calculate the cross-sectional area of the test section assuming $\gamma = 1.4$ **5 Marks**

Question 3

(a)i. With the aid of a diagram, explain development of the boundary layer along a flat plate

ii. Discuss briefly four (4) factors that affect transition from laminar to turbulent flow regime. **4 Marks**

(b) Air at 20 ^{0}C and with a free stream velocity of 40 m/s flows past a smooth thin plate which is 3 m wide and 10 m long in the flow direction. Assuming a turbulent boundary layer from the leading edge, take density = 1.2 kg/m^3 and kinematic viscosity = $1.49 \times 10^{-5}\ m^2s^{-1}$ determine:

i. Shear stress and boundary layer thickness 6 m from leading edge

ii. Total drag on the plate. **4 Marks**

c) A smooth flat plate 1 m wide and 4 m long is towed through still water at 20 ^{0}C at a speed of 6 m/s. Given that density = 1000 kg/m^3 dynamic viscosity Ns/m^3. Determine:

i. The total drag on the plate.

ii. The drag on the first 3 m of the plate. **4 Marks**

Question 4

(a)i. What do you understand by the term 'closure problem' in turbulent modeling?

ii. List five (5) turbulent models you know and discuss any three. **4 Marks**

(b) Write the two-dimensional Reynolds Average Navier-Stoke Equations (RANS) and define all the terms. **4 Marks**

d.) At a point upstream of the throat of a convergent-divergent nozzle, the properties are $V_1 = 190\ m/s, T_1 = 305\ K$ *and* $P_1 = 120\ KPa$. If the exit flow is supersonic. The throat area is 35 cm^2. Compute from isentropic theory:

i. mass flow rate

ii. inlet area **4 Marks**

Question 5

(a) i. What do you understand by the term 'isentropic flow'?
ii. Describe Laval nozzle and its applications **3 Marks**

(b) An aircraft flies at an altitude of 10,000 m where the pressure and density are 0.265 bar and 0.41 kg/m^3 respectively.
- i. Determine the aircraft speed if the Mach number is 1.5
- ii. What is the speed of the plane at sea level if the Mach number is maintained?

4 Marks

(c) A venturi meter having an inlet diameter of 75 mm and a throat diameter of 25 mm is used for measuring the rate of flow of air through a pipe. Mercury U-tube gauges register pressures at the inlet and throat equivalent to 250 mm and 150 mm of mercury, respectively. Determine the volume of air flowing through the pipe per unit time in cubic meters per second. Assume adiabatic conditions ($\gamma = 1.4$). The density of air at the inlet is 1.6 kg/m^3 and the barometric pressure is 760 mm of mercury. Take density of mercury to be 13.6×10^3 kg/m^3 **5 Marks**

Question 6

(a) In a two-dimensional incompressible flow, the fluid velocity components are given by $V_x = x - 4y$ and $V_y = -y - 4x$. If the flow is potential, obtain the expression for the velocity potential. **4 Marks**

(b) Air is flowing through a duct and a normal shock wave is formed at a cross-section at which the Mach number is 3. If the upstream pressure and temperature are 105 bar and 15 °C, respectively, find the Mach number, pressure and temperature immediately downstream of the shock wave. Take $\gamma = 1.4$ **4 Marks**

(c) Determine the ratio of momentum thickness θ to the boundary layer thickness δ, when the layer velocity is given by $\frac{u}{U_s} = (\frac{y}{\delta})^{1/2}$. Where u is the velocity at a height y above the surface and the flow free stream velocity is U_s **4 Marks**

Question 7

(a) Discuss the effect of pressure gradient on boundary layer development **3 Marks**

(b) i. How do the temperature and the pressure at the stagnation point in isentropic flow compare with reservoir conditions?
ii. An airplane flies at 250 m/s through air at -10 °C and 40 KPa. Is the airplane subsonic? **4 Marks**

(c) Air (for which $\gamma = 1.4$) flows along a circular pipe with a diameter d of 50 mm. Assuming that conditions are adiabatic and that the Mach number at the entrance to the pipe is 0.2, take friction factor to be 0.00375, calculate the distance from the entrance of the pipe to the section at which the Mach number will be:
- i. 1.0
- ii. 0.6

5 Marks

Relevant formulae

1. $\frac{P_2}{P_1} = \frac{(1+\gamma M_{a1}{}^2)}{(1+\gamma M_{a2}{}^2)}$

2. $\frac{T_2}{T_1} = \frac{1+\left[\frac{(\gamma-1)}{2}\right]M_{a1}{}^2}{1+\left[\frac{(\gamma-1)}{2}\right]M_{a2}{}^2}$

3. $\frac{A}{A_t} = \frac{1}{M_a}\left[\frac{1+\left[\frac{\gamma-1}{2}\right]M_a{}^2}{\frac{(\gamma+1)}{2}}\right]^{\frac{(\gamma+1)}{2(\gamma-1)}}$

4. $\frac{A_i}{A_o} = \frac{[1+0.2Ma^2]^3}{1.728Ma}$

5. $\frac{\rho_2}{\rho_1} = \left[\frac{P_2}{P_1}\right]^{\frac{1}{\gamma}}$

6. $\left(\frac{\gamma}{\gamma-1}\right)\left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2}\right) = \frac{V_2-V_1}{2}$