Department of Mechanical Engineering
MEL 715 Fluid Mechanics and Gas Dynamics
Major Test

Nov 28, 2006

Max Marks : 60 **Duration : 2 hours**
Note: Please clearly indicate the relations used for the calculations

1. A converging-diverging nozzle having throat diameter of 1 cm and exit diameter of 1.5 cm receives air (γ=1.4, R=0.287 kJ/kgK) from a reservoir with pressure of 5 bar and temperature of 350 K. The back pressure at the exit of the nozzle can be varied as per requirement of the experiment. The diverging section of the duct is 5 cm long and the diameter of the duct in the diverging section can be assumed to vary linearly.
(i) What should the back pressure be if the nozzle has to operate under design conditions, i.e. continuous acceleration of flow without a shock in any region of the duct? What would be the exit temperature of air and the mass flow rate of air under this condition?
(ii) What should the back pressure be if a shock must occur just before the exit of the duct? How will the mass flow rate change as compared to the case in (i) above ?
(iii) Compute temperature, pressure, stagnation pressure and stagnation temperature upstream and downstream of the shock for the case (ii) above.
(iv) What should the back pressure be if the diverging section of the duct were to act as a diffuser with the Ma at the throat just reaching the sonic conditions? Assume no shock in the duct and hence isentropic conditions prevail. Also determine T, T_o, P_o at the exit.
(v) **Without doing any calculation**, enumerate the steps required to analyze the flow through the duct for the following situation
The user wants the shock to occur at 2.5 cm from the nozzle exit (in the middle of the diverging section), and wants to determine what back pressure he should maintain for the purpose? Also, T, T_o, P, P_o are to be determined upstream as well as downstream of the shock and also at nozzle exit. How does the A^* change across the shock? Will that affect the computations of the qunatities downstream of the shock?
(vi) draw a sketch of the CD nozzle and below that show the qualitative variation in pressure as well as stagnation pressure along the length of the nozzle for the cases in (i), (ii) and (v). Except in the shock region, the flow may be assumed to be isentropic. (18)

2. A 100 metre long constant area pipeline carries compressed natural gas (γ=1.3, C_p= 2.25 kJ/kgK, R=0.518 kJ/kgK). The line leads to a reservoir downstream where the pressure is maintained to be 1.5 bar. The average friction factor for the conditions of the flow and the pipe is found to be 0.0242. The duct diameter is 0.5 m. The stagnation temperature of the gas at entry of the duct is 500 K. Assume the flow is adiabatic.
(a) What should be the pressure at the inlet of the duct if maximum possible flow has to be pumped through the line but without any shock anywhere in the line?
(b) What will be the Ma at the duct entry and exit for the case in (a)?
(c) What should be the pressure in the upstream reservoir which supplies the gas to the pipeline for the above conditions to be maintained.
(d) What will be the mass flow rate of the gas under above conditions?
(e) Also compute the pressure, temperature, stagnation temperature and stagnation pressure at the inlet and the exit of the pipeline. Comment on the variation in these quantities along the duct.
(f) The entropy change of a perfect gas (constant C_p) due to change in its state is given by

$$s_2 - s_1 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

If subscript **1** stands for the specific entropy at the duct inlet and **2** at the duct exit, discuss whether (s_2-s_1) will be positive or negative in the above case? How do changes in temperature and pressure, as computed in (e) contribute to the change in entropy?

(g) Sketch the variation in the stagnation pressure and stagnation temperature and entropy along the duct.

(12)

3. Answer the following briefly. (3× 10=30)

(a) What is Direct Numerical Simulation (DNS) of turbulent flows and how does it circumvent the closure problem encountered in most other methods of solving turbulent flows?

(b) Comment whether the following is correct

$$\overline{u'v'} = \overline{u'}\ \overline{v'}$$

(c) Identify two situations where turbulent flow regime is preferred over laminar flow regime.

(d) Why is the log law considered as the universal velocity profile in turbulent flows?

(e) Expand the following

$$\epsilon = \nu \overline{\frac{\partial u_i'}{\partial x_k}\frac{\partial u_i'}{\partial x_k}}$$

(f) A fluid mechanics problem can be modelled as a 2D problem. A student wants to attempt solving it analytically/semi-analytically for the inherent advantage that an analytical solution gives over a numerical solution. He wants to try one of the two most widely used methods in fluid mehcanics ; similarity method and the momentum integral method. How should he decide which of these to use?

(g) A CFD expert is trying to solve a problem numerically with a very fine grid near the wall. With the knowledge of fluid mechanics you have gained so far, can you recommend how he can decide the distance of the first grid point from the wall?

(h) It is said that in a boundary layer flow, where boundary layer approximations are applicable, the conditions downstream do not affect the upstream flow. Please comment.

(i) Please give an example of a fluid flow situation where the downstream condition immediately affects the flow upstream.

(j) What is the physical significance of the substantial derivative of a quantity?