Compressible Flow Tutorial

1. Air being released from a tyre through its valve is found to have a temperature of 15°C. Assuming that the air in the tyre is at the ambient temperature of30°C, find the velocity of the air at the exit of the valve. The process can be assumed to be adiabatic.

2. A gas with a molecular weight of 4 and a specific heat ratio of 1.67 flows through a variable area duct. At some point in the flow, the velocity and temperature respectively are 180 m/s and 10°C. At some other point in the flow, the temperature is -10°C. Find the velocity at this point in the flow assuming that the flow is adiabatic.

3. A very weak pressure wave, i.e., a sound wave, across which the pressure riseis 30 Pa moves through air which has a temperature of 30°C and a pressure of 101 kPa. Find the density change, the temperature change, and the velocity change across this wave.

4. An aeroplane can fly at a speed of 800 km/h at sea level where the temperature is 15°C. If the aeroplane flies at the same Mach number at an altitude where the temperature is -44°C, find the speed at which the aeroplane is flying atthis altitude.

5. The test section of a supersonic wind tunnel is square in cross-section witha side length of 1.22 m. The Mach number in the test section is 3.5, thetemperature is -100°C, and the pressure is 20 kPa. Find the mass flow rateof air through the test section.

6. A converging nozzle has an exit area of 0.001 m2. Air enters the nozzle with negligible velocity at a pressure of 1.0 MPa and a temperature of 360 K. For isentropic flow of an ideal gas with k =1.4, determine the mass flow rate, in kg/s, and the exit Mach number for back pressures of 500 kPa and 784 kPa.

7. Air enters a converging-diverging nozzle at 1.5 MPa and 900 K with negligible velocity. The flow is steady, one-dimensional, and isentropic with k = 1.4. For an exit Mach number of Ma = 2 and a throat area of 20 cm^2, determine (*a*) the throat conditions, (*b*) the exit plane conditions, including the exit area, and (*c*) the mass flow rate through the nozzle.

8. Air flows through a convergent-divergent duct with an inlet area of 5 cm^2 and an exit area of 3.8 cm^2. At the inlet section, the air velocity is 100 m/s, the pressure is 680 kPa, and the temperature is 60°C. Find the mass flow ratethrough the nozzle and, assuming isentropic flow, the pressure and velocityat the exit section.

9. The exhaust gases from a rocket engine can be assumed to behave as an ideal gas with a specific heat ratio of 1.3 and a molecular weight of 32. The gas is expanded from the combustion chamber through a nozzle. At a point in the nozzle where the cross-sectional area is 0.2 m^2 the pressure, temperature, and Mach number are 1500 kPa, 800 °C, and 0.2 respectively. At some other pointin the nozzle, the pressure is found to be 80 kPa. Find the Mach number.

10. A pitot-static tube is placed in a subsonic air flow. The static temperature and pressure in the air flow are 30°C and 101 kPa, respectively. The difference between the pitot and static pressure is measured using a manometer and isfound to be 250 mm of mercury. Find the air velocity, assuming (i) the flow to be incompressible and (ii) taking compressibility effects into account

11. Air at p_0 = 1.4 bar, T_0 = 280 K expands isentropically through a converging nozzle and discharges to the atmosphere at 1 bar. The exit plane area is 0.0013 m^2. (a) Determine the mass flow rate, in kg/s. (b) If the supply region pressure, p_0, was increased to 2 bar, what would be the mass flow rate, in kg/s?

12. Air is stored in a tank 2 m^3 in volume at a pressure of 3 MPa and a temperature of 300 K. It is discharged through a purely convergent nozzle with an exitarea of 12 cm^2. For a back pressure of 101 kPa, determine the time requiredfor the tank pressure to drop to 300 kPa. Assume that (i) the pressure in the reservoir is uniform at any instant of time, and (ii) the temperature in the reservoir remains the same throughout this process. Rework the problemif the reservoir pressure and temperature are related through the isentropiclaw, with all other data remaining the same.

13. An ideal gas mixture with a specific heat ratio equal to 1.31 and a molecular weight of 23 is supplied to a converging nozzle at p_0 = 5 bar, T_0 = 700 K, which discharges into a region where the pressure is 1 bar. The exit area is 30 cm^2. For steady isentropic flow through the nozzle, determine (a) the exit temperature of the gas, in K. (b) the exit velocity of the gas, in m/s. (c) the mass flow rate, in kg/s. Note that the isentropic flow tables are for a specific heat ratio of 1.4, and hence cannot be used here. Use fundamental relations developed in class.

14. A converging-diverging nozzle operating at steady state has a throat areaof 3 cm^2 and an exit area of 6 cm^2. Air enters the nozzle at 8 bar, 400 K,and a Mach number of 0.2, and flows isentropically throughout. If the nozzle is choked, and the diverging portion acts as a supersonic nozzle, determine the mass flow rate, in kg/s, and the Mach number, pressure, in bar, and temperature, in K, at the exit. Repeat if the diverging portion acts as a diffuser.

15. A convergent-divergent nozzle was designed assuming isentropic airflow with stagnation conditions of 1 MPa, 1400 K, and back pressure of 0.1 MPa, and for a supersonic exit flow with a mass flow rate of 10 kg/s. Determine the exitarea and the throat area of the nozzle. When deployed in the application it was designed for, it was realized that the stagnation conditions were actually 1.2 MPa and 1400 K. The objective was to obtain the mass flow rate of 10 kg/s, and hence the engineer, in charge of this design, suggested changing the back pressure to an appropriate value to achieve the desired mass flow rate.Outline the process that the engineer must have employed to achieve this objective, assuming that the engineer had access only to the isentropic flow tables. Perform as many calculations as possible to demonstrate the process (if possible, arrive at the required value of the back pressure).