PROBLEMS

4.1. Compute and compare sonic velocity in air, hydrogen, water, and mercury. Assume normal room temperature and pressure.

4.2. At what temperature and pressure would carbon monoxide, water vapor, and helium have the same speed of sound as standard air (288 K and 1 atm)?

4.3. Start with the relation for stagnation pressure that is valid for a perfect gas:

$$p_t = p\left(1 + \frac{\gamma - 1}{2}M^2\right)^{\gamma/(\gamma-1)}$$

Expand the right side in a binomial series and evaluate the result for small (but not zero) Mach numbers. Show that your answer can be written as

$$p_t = p + \frac{\rho V^2}{2g_c} + \text{HOT}$$

Remember, the higher-order terms are negligible only for very small Mach numbers. (See Problem 4.4.)

4.4. Measurement of airflow shows the static and stagnation pressures to be 30 and 32 psig, respectively. (Note that these are gage pressures.) Assume that $p_{amb} = 14.7$ psia and the temperature is 120°F.

(a) Find the flow velocity using equation (4.21).

(b) Now assume that the air is incompressible and calculate the velocity using equation (3.39).

(c) Repeat parts (a) and (b) for static and stagnation pressures of 30 and 80 psig, respectively.

(d) Can you reach any conclusions concerning when a gas may be treated as a constant-density fluid?

4.5. If $\gamma = 1.2$ and the fluid is a perfect gas, what Mach number will give a temperature ratio of $T/T_t = 0.909$? What will the ratio of p/p_t be for this flow?

4.6. Carbon dioxide with a temperature of 335 K and a pressure of 1.4×10^5 N/m^2 is flowing with a velocity of 200 m/s.

(a) Determine the sonic velocity and Mach number.

(b) Determine the stagnation density.

4.7. The temperature of argon is 100°F, the pressure 42 psia, and the velocity 2264 ft/sec. Calculate the Mach number and stagnation pressure.

4.8. Helium flows in a duct with a temperature of 50°C, a pressure of 2.0 bar abs., and a total pressure of 5.3 bar abs. Determine the velocity in the duct.

4.9. An airplane flies 600 mph at an altitude of 16,500 ft, where the temperature is 0°F a the pressure is 1124 psfa. What temperature and pressure might you expect on the no of the airplane?

4.10. Air flows at $M = 1.35$ and has a stagnation enthalpy of 4.5×10^5 J/kg. The stagnation pressure is 3.8×10^5 N/m^2. Determine the static conditions (pressure, temperature, and velocity).

4.11. A large chamber contains a perfect gas under conditions p_1, T_1, h_1, and so on. The gas is allowed to flow from the chamber (with $q = w_s = 0$). Show that the velocity cannot be greater than

$$V_{max} = a_1 \left(\frac{2}{\gamma - 1} \right)^{1/2}$$

If the velocity is the maximum, what is the Mach number?

4.12. Air flows steadily in an adiabatic duct where no shaft work is involved. At one section, the total pressure is 50 psia, and at another section, it is 67.3 psia. In which direction is the fluid flowing, and what is the entropy change between these two sections?

4.13. Methane gas flows in an adiabatic, no-work system with negligible change in potential. At one section $p_1 = 14$ bar abs., $T_1 = 500$ K, and $V_1 = 125$ m/s. At a downstream section $M_2 = 0.8$.

(a) Determine T_2 and V_2.

(b) Find p_2 assuming that there are no friction losses.

(c) What is the area ratio A_2/A_1?

4.14. Air flows through a constant-area, insulated passage. Entering conditions are $T_1 = 520°\text{R}$, $p_1 = 50$ psia, and $M_1 = 0.45$. At a point downstream, the Mach number is found to be unity.

(a) Solve for T_2 and p_2.

(b) What is the entropy change between these two sections?

(c) Determine the wall frictional force if the duct is 1 ft in diameter.

4.15. Carbon dioxide flows in a horizontal adiabatic, no-work system. Pressure and temperature at section 1 are 7 atm and 600 K. At a downstream section, $p_2 = 4$ atm., $T_2 = 550$ K, and the Mach number is $M_2 = 0.90$.

(a) Compute the velocity at the upstream location.

(b) What is the entropy change?

(c) Determine the area ratio A_2/A_1.

4.16. Oxygen with $T_{t1} = 1000°\text{R}$, $p_{t1} = 100$ psia, and $M_1 = 0.2$ enters a device with a cross-sectional area $A_1 = 1$ ft^2. There is no heat transfer, work transfer, or losses as the gas passes through the device and expands to 14.7 psia.

(a) Compute ρ_1, V_1, and $\dot{m}$.

(b) Compute M_2, T_2, V_2, ρ_2, and A_2.

(c) What force does the fluid exert on the device?

4.17. Consider steady, one-dimensional, constant-area, horizontal, isothermal flow of a perfect gas with no shaft work (Figure P4.17). The duct has a cross-sectional area A and perimeter P. Let τ_w be the shear stress at the wall.