

Franklin W. Olin College of Engineering  
ENGR 3310: Transport Phenomena

Problem Set 6

Assigned: 10/22/04  
Due: 10/28/04 by 5:00 pm

Fall 2004

1. A common estimate for the distance between you and an approaching storm is to count the seconds between the flash of lightning and the sound of the thunder. The number of seconds is supposed to correspond to the number of miles. Determine whether or not this estimate is reasonably accurate.
2. A bicycle tire is filled with air at an absolute pressure of 169.12 kPa, and the temperature inside is 30 °C. Suppose the valve breaks, and air starts to exhaust out of the tire into the atmosphere ( $P_a = 101.3$  kPa absolute and  $T_a = 20$  °C). The valve exit is 2.00 mm in diameter and is the smallest cross-sectional area of the entire system. Frictional losses can be ignored and 1-D isentropic flow is a reasonable assumption.
  - a) Find the Mach number, velocity, and temperature at the exit plane of the valve (initially).
  - b) Find the initial mass flow rate out of the tire.
  - c) Estimate the velocity at the exit plane using the incompressible Bernoulli equation. How well does this estimate agree with the “exact” answer of part (a). Explain.
3. Air, at a stagnation temperature of 100 °C, expands isentropically through a nozzle of 6 cm<sup>2</sup> throat area and 18 cm<sup>2</sup> exit area. The mass flow is at its maximum value of 0.5 kg/s. Estimate the exit pressure (static) for a) subsonic, and b) supersonic exit flow.
4. A perfect gas (not air) expands isentropically through a supersonic nozzle with an exit area 5 times its throat area. The exit Mach number is 3.8. What is the specific heat ratio,  $k$ , of the gas? What might this gas be? If  $P_o = 300$  kPa, which is the exit pressure (static) of the gas? (The attached table may come in handy.)
5. The exterior walls of a building are a composite consisting of 10 mm thick plaster board, 50 mm thick urethane foam, and a 10 mm thick soft wood. On a typical winter day the outside and inside air temperatures are -15 °C and 20 °C, respectively with outer and inner convection coefficients of 15 W/m<sup>2</sup> K and 5 W/m<sup>2</sup> K, respectively.
  - a) What is the heating load (the heat transfer rate) for a 1 m<sup>2</sup> section of the wall?
  - b) What is the heating load if the composite wall is replaced by a 3 mm thick glass plane window?
  - c) What is the heating load if the composite wall is replaced by a double glazed window consisting of two 3 mm thick glass panes separated by a 5 mm thick stagnant air gap?

6. Urethane ( $k = 0.026 \text{ W/m K}$ ) is used to insulate the sidewall and the top and bottom of a cylindrical hot water tank. The insulation is 40 mm thick and is sandwiched between sheet metal of thin wall construction. The height and inside diameter of the tank are 2 m and 0.80 m, respectively, and the tank is in ambient air for which  $T_\infty = 10 \text{ }^\circ\text{C}$  and  $h = 10 \text{ W/m}^2 \text{ K}$ . If the hot water maintains the inner surface at  $55 \text{ }^\circ\text{C}$  and energy costs amount to  $\$0.15/\text{kWh}$ , what is the daily cost to maintain the water in storage? (Bonus points for anyone that wants to check is the energy cost given is still accurate in today's market.)

Properties of some common gases at 1 atm and  $20 \text{ }^\circ\text{C}$  (Problem 4)

Gas	Molecular weight	$R, \text{ m}^2/(\text{s}^2 \cdot \text{K})$	$\rho g, \text{ N/m}^3$	$\mu, \text{ N} \cdot \text{s/m}^2$	Specific-heat ratio	Power-law exponent $n^*$
H <sub>2</sub>	2.016	4124	0.822	9.05 E-6	1.41	0.68
He	4.003	2077	1.63	1.97 E-5	1.66	0.67
H <sub>2</sub> O	18.02	461	7.35	1.02 E-5	1.33	1.15
Ar	39.944	208	16.3	2.24 E-5	1.67	0.72
Dry air	28.96	287	11.8	1.80 E-5	1.40	0.67
CO <sub>2</sub>	44.01	189	17.9	1.48 E-5	1.30	0.79
CO	28.01	297	11.4	1.82 E-5	1.40	0.71
N <sub>2</sub>	28.02	297	11.4	1.76 E-5	1.40	0.67
O <sub>2</sub>	32.00	260	13.1	2.00 E-5	1.40	0.69
NO	30.01	277	12.1	1.90 E-5	1.40	0.78
N <sub>2</sub> O	44.02	189	17.9	1.45 E-5	1.31	0.89
Cl <sub>2</sub>	70.91	117	28.9	1.03 E-5	1.34	1.00
CH <sub>4</sub>	16.04	518	6.54	1.34 E-5	1.32	0.87

\*The power-law curve fit, Eq. (1.27),  $\mu/\mu_{293\text{K}} \approx (T/293)^n$ , fits these gases to within  $\pm 4$  percent in the range  $250 \leq T \leq 1000 \text{ K}$ . The temperature must be in kelvins.