**a.** If 50 kg per minute flows at an absolute velocity of 200 m/sec, what will be the force on the plate?

**b.** What will this force be when the plate moves in the flow direction at $u = 50$ km/h? Explain your methodology.

*Answers:* 167 N; 144 N.

**2.** The following data are given for a certain rocket unit: thrust, 8896 N; propellant consumption, 3.867 kg/sec; velocity of vehicle, 400 m/sec; energy content of propellant, 6.911 MJ/kg. Assume 100% combustion efficiency.
Determine **(a)** the effective velocity; **(b)** the kinetic jet energy rate per unit flow of propellant; **(c)** the internal efficiency; **(d)** the propulsive efficiency; **(e)** the overall efficiency; **(f)** the specific impulse; **(g)** the specific propellant consumption.

*Answers:* **(a)** 2300 m/sec; **(b)** 2.645 MJ/kg; **(c)** 38.3%; **(d)** 33.7%; **(e)** 13.3%; **(f)** 234.7 sec; **(g)** 0.00426 $sec^{-1}$.

**3.** A certain rocket engine (flying horizontally) has an effective exhaust velocity of 7000 ft/sec; it consumes 280 lbm/sec of propellant mass, and liberates 2400 Btu/lbm. The unit operates for 65 sec. Construct a set of curves plotting the propulsive, internal, and overall efficiencies versus the velocity ratio $u/c$ $(0 < u/c < 1.0)$. The rated flight velocity equals 5000 ft/sec. Calculate **(a)** the specific impulse; **(b)** the total impulse; **(c)** the mass of propellants required; **(d)** the volume that the propellants occupy if their average specific gravity is 0.925. Neglect gravity and drag.

*Answer:* (a) 217.4 sec; (b) 3,960,000 lbf-sec; (c) 18,200 lbm; (d) 315 $ft^3$.

**4.** For the rocket in Problem 2, calculate the specific power, assuming a propulsion system dry mass of 80 kg and a duration of 3 min.

**5.** A Russian rocket engine (RD-110 with LOX-kerosene) consists of four thrust chambers supplied by a single turbopump. The exhaust from the turbine of the turbopump then is ducted to four vernier nozzles (which can be rotated to provide some control of the flight path). Using the information below, determine the thrust and mass flow rate of the four vernier gas nozzles. For individual thrust chambers (vacuum):

$$F = 73.14\,\text{kN}, c = 2857\,\text{m/sec}$$

For overall engine with verniers (vacuum):

$$F = 297.93\,\text{kN}, c = 2845\,\text{m/sec}$$

*Answers:* 5.37 kN, 2.32 kg/sec.

**6.** A certain rocket engine has a specific impulse of 250 sec. What range of vehicle velocities ($u$, in units of ft/sec) would keep the propulsive efficiencies at or greater than 80%. Also, how could rocket–vehicle staging be used to maintain these high propulsive efficiencies for the range of vehicle velocities encountered during launch?

*Answers:* 4021 to 16,085 ft/sec; design upper stages with increasing $I_s$.

**7.** For a solid propellant rocket motor with a sea-level thrust of 207,000 lbf, determine: (a) the (constant) propellant mass flow rate $\dot{m}$ and the specific impulse $I_s$ at sea level, (b) the altitude for optimum nozzle expansion as well as the thrust and specific impulse at this optimum condition and (c) at vacuum conditions. The initial total mass of the rocket motor is 50,000 lbm and its propellant mass fraction is 0.90. The residual propellant (called slivers, combustion stops when the chamber pressure falls below a deflagration limit) amounts to 3 % of the burnt. The burn time is 50 seconds; the nozzle throat area ($A_t$) is 164.2 in.$^2$ and its area ratio ($A_2/A_t$) is 10. The chamber pressure ($p_1$) is 780 psia and the pressure ratio ($p_1/p_2$) across the nozzle may be taken as 90.0. Neglect any start/stop transients and use the information in Appendix 2.

*Answers:* (a) $\dot{m} = 873$ lbm/sec, 237 sec., (b) $F = 216{,}900$ lbf, $I_s = 248.5$ sec., (c) $F = 231{,}000$ lbf, $I_s = 295$ sec.

**8.** During the boost phase of the Atlas V, the RD-180 engine operates together with three solid propellant rocket motors (SRBs) for the initial stage. For the remaining thrust time, the RD-180 operates alone. Using the information given in Table 1–3, calculate the *overall effective exhaust velocity* for the vehicle during the initial combined thrust operation.

*Answer:* 309 sec.

**9.** Using the values given in Table 2–1, choose three propulsion systems and calculate the total impulse for a fixed propellant mass of 20 kg.

**10.** Using the MA-3 rocket engine information given in Example 2–3, calculate the overall specific impulse at sea level and at altitude, and compare these with $I_s$ values for the individual booster engines, the sustainer engine, and the individual vernier engines.

*Answers:* $(I_s)_{\text{oa}} = 238$ sec (SL) and 258 sec (altitude)

**11.** Determine the mass ratio **MR** and the mass of propellant used to produce thrust for a solid propellant rocket motor that has an inert mass of 82.0 kg. The motor mass becomes 824.5 kg after loading the propellant. For safety reasons, the igniter is not installed until shortly before motor operation; this igniter has a mass of 5.50 kg of which 3.50 kg is igniter propellant. Upon inspection after firing, the motor is found to have some unburned residual propellant and a motor mass of 106.0 kg.

*Answers:* **MR** = 0.1277, propellant burned = 720.5 kg.

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