AUBURN UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING

AEROSPACE

AERO 4970/7970 — Rocket Propulsion I — SET II

Nozzle Theory and Thermodynamic Relations

1. A certain nozzle expands a gas under isentropic conditions. Its chamber or nozzle entry velocity equals 70 m/s, its final velocity 1,500 m/s. What is the change in enthalpy of the gas? What percentage of error is introduced if the initial velocity is neglected?
   Answers: 1.122×10^3 kJ/kg; -0.22%.

2. Nitrogen at 500°C ($k = 1.38$, molecular mass is 28.00) flows at a Mach number of 2.73. Compare its actual velocity to its acoustic velocity.
   Answers: $a = 562.856$ m/s; v
   $= 1536.6$ m/s.

3. The following data are given for an optimum rocket:

Average molecular mass	24 kg/kmol
Chamber pressure	2.533 MPa
External pressure	0.09 MPa
Chamber temperature	2900 K
Throat area	$0.0005\ \text{m}^2$
Specific heat ratio	1.30

   Determine: (a) throat velocity; (b) specific volume at throat; (c) propellant flow and specific impulse; (d) thrust; (e) Mach number at throat.
   Answers: (a) 1,065.7 m/s; (b) $0.632\ \text{m}^3/\text{kg}$; (c) 0.843 kg/s, 220.43 s; (d) 1822.9 N; (e) 1.

4. Determine the ideal thrust coefficient for Problem 3 above by two methods.
   Answers: 1.44.

5. A rocket operates at sea level ($p = 0.1013\text{MPa}$) with a chamber pressure of $p_1 = 2.068\,\text{MPa}$ or 300 psia, a chamber temperature of $T_1 = 2,222\,\text{K}$, and a propellant consumption of $\dot{m} = 1\ \text{kg/s}$. Let k = 1.30, and R = 345.7 J/kg-K. Calculate (a) the ideal thrust and the ideal specific impulse; (b) the maximum velocity if the nozzle was designed to expand into a vacuum, and the expansion area ratio was $2,000$.
   Answers: (a) 1,827 N, 186 s; (b) $2,576.4$ m/s..

6. Construction of a variable-area nozzle has often been considered to make the operation of a rocket thrust chamber take place at the optimum expansion ratio at any altitude. Because of the enormous design difficulties of such a device, it has never been successfully realized. Assuming that such a mechanism can eventually be constructed, what would have to be the variation of the area ratio with altitude (plot up to 50 km) if such a rocket had a chamber pressure of 20 atm? Assume that k = 1.20.

7. For Problem 5, determine (a) the actual thrust; (b) the actual exhaust velocity; (c) the actual specific impulse; (d) the velocity correction factor. Assume that the thrust correction factor is 0.985 and the discharge correction factor is 1.050.
   Answers: (a) 2375.65 N; (b) 2338.97 m/sec; (c) $242.14\ \text{N-sec}^3/\text{kg-m}$; (d) 0.938.

8. An ideal rocket has the following characteristics:

Chamber pressure	27.2 atm
Nozzle exit pressure	3 psia
Specific heat ratio	1.20
Average molecular mass	21.0 lbm/lb-mol
Chamber temperature	$4,200\ ^\circ\text{F}$

   Determine the critical pressure ratio, the gas velocity at the throat, the expansion area ratio, and the theoretical nozzle exit velocity.
   Answers: 0.5645; 3470 ft/s; 14; 8,570 ft/s.