Rocket Nozzle Equations

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Contents

Nomenclature

A	Area
c	Speed of sound
$\dot{m}$	Mass flow rate
M	Molecular mass
Ma	Mach number
$mol\%$	Mole percentage
P	Pressure
R'	Universal gas constant
R	Specific gas constant
T	Temperature
v	Velocity
ϵ	Nozzle area ratio
γ	Ratio of specific heats
ρ	Density

Subscripts

$_a$	Ambient
$_c$	Chamber
$_e$	Exit
$_t$	Throat
$_{x,y}$	Given position
$_0$	Stagnation

1 Thermodynamic Relations [1]

1.1 Gas Constant

$$R = \frac{R'}{M} \tag{1.1}$$

1.2 Sonic Velocity

$$c = \sqrt{\gamma R T} \tag{1.2}$$

1.3 Isentropic Flow Relation

$$\frac{T_x}{T_y} = \left(\frac{P_x}{P_y}\right)^{\frac{\gamma}{\gamma-1}} \tag{1.3}$$

1.4 Isentropic Total To Static Temperature Relation

$$0 = \frac{T}{T_0}\left[1 + \frac{1}{2}\left(\gamma - 1\right) Ma^2\right] \tag{1.4}$$

1.5 Isentropic Total To Static Pressure Relation

$$0 = \frac{P}{P_0}\left[1 + \frac{1}{2}\left(\gamma - 1\right) Ma^2\right]^{\frac{\gamma}{\gamma-1}} \tag{1.5}$$

1.6 Isentropic Mach Number

Equations (1.4) and (1.5) can be rearranged to solve for the Mach Number

$$Ma = \sqrt{\frac{2}{\gamma - 1}\left(\frac{T_0}{T} - 1\right)} \tag{1.6a}$$

$$Ma = \sqrt{\frac{2}{\gamma - 1}\left(\frac{P_0}{P}^{\frac{\gamma-1}{\gamma}} - 1\right)} \tag{1.6b}$$

1.7 Isentropic Nozzle Area Ratio

$$\frac{A_y}{A_x} = \frac{Ma_x}{Ma_y}\sqrt{\left\{\frac{1 + \left[\frac{\gamma-1}{2}\right] Ma_y^2}{1 + \left[\frac{\gamma-1}{2}\right] Ma_x^2}\right\}^{\frac{\gamma+1}{\gamma-1}}} \tag{1.7}$$

References

[1] O. B. George P. Sutton, *Rocket Propulsion Elements*, 9th ed. Wiley, 2017.