Important Rocket Propulsion Formulas PDF

Formulas
Examples
with Units

List of 33
Important Rocket Propulsion Formulas

1) Nozzles Formulas

1.1) Area Ratio of Nozzles Formula

Evaluate Formula

Formula

$$\epsilon = \left(\frac{1}{M_2}\right) \cdot \sqrt{\left(\frac{1 + \frac{\gamma - 1}{2} \cdot M_2^{\,2}}{1 + \frac{\gamma - 1}{2}}\right)^{\frac{\gamma + 1}{\gamma - 1}}}$$

Example

$$2.8471 = \left(\frac{1}{2.5}\right) \cdot \sqrt{\left(\frac{1 + \frac{1.33 - 1}{2} \cdot 2.5^{\,2}}{1 + \frac{1.33 - 1}{2}}\right)^{\frac{1.33 + 1}{1.33 - 1}}}$$

1.2) Characteristics Velocity Formula

Evaluate Formula

Formula

$$C^* = \sqrt{\left(\frac{[R] \cdot T_1}{\gamma}\right) \cdot \left(\frac{\gamma + 1}{2}\right)^{\frac{\gamma + 1}{\gamma - 1}}}$$

Example with Units

$$68.5902\,\text{m/s} = \sqrt{\left(\frac{8.3145 \cdot 256\,\text{K}}{1.33}\right) \cdot \left(\frac{1.33 + 1}{2}\right)^{\frac{1.33 + 1}{1.33 - 1}}}$$

1.3) Nozzle Thrust Coefficient Formula

Evaluate Formula

Formula

$$C_F = \frac{F}{A_t \cdot P_1}$$

Example with Units

$$198.9313 = \frac{154569.6\,\text{N}}{0.21\,\text{m}^2 \cdot 0.0037\,\text{MPa}}$$

1.4) Propulsion Efficiency Formula

Evaluate Formula

Formula

$$\eta_{prop} = \frac{2 \cdot \left(\frac{v_0}{v_9}\right)}{1 + \left(\frac{v_0}{v_9}\right)^2}$$

Example with Units

$$0.0197 = \frac{2 \cdot \left(\frac{234\,\text{m/s}}{2.31\,\text{m/s}}\right)}{1 + \left(\frac{234\,\text{m/s}}{2.31\,\text{m/s}}\right)^2}$$

1.5) Specific Temperature at Throat Formula

Evaluate Formula

Formula

$$T_t = \frac{2 \cdot T_1}{\gamma + 1}$$

Example with Units

$$219.7425\,\text{K} = \frac{2 \cdot 256\,\text{K}}{1.33 + 1}$$

1.6) Specific Volume at Throat Formula

Evaluate Formula

Formula

$$V_t = V_1 \cdot \left(\frac{\gamma + 1}{2}\right)^{\frac{1}{\gamma - 1}}$$

Example with Units

$$10.0076\,\text{m}^3 = 6.3\,\text{m}^3 \cdot \left(\frac{1.33 + 1}{2}\right)^{\frac{1}{1.33 - 1}}$$

2) Propellents Formulas

2.1) Fuel Mass Flow rate Formula

Evaluate Formula

Formula

$$\dot{m}_f = \frac{\dot{m}}{r + 1}$$

Example with Units

$$3.2916\,\text{kg/s} = \frac{11.32\,\text{kg/s}}{2.439024 + 1}$$

2.2) Oxidizer Mass Flow Rate Formula

Evaluate Formula

Formula

$$\dot{m}_o = \frac{r \cdot \dot{m}}{r + 1}$$

Example with Units

$$8.0284\,\text{kg/s} = \frac{2.439024 \cdot 11.32\,\text{kg/s}}{2.439024 + 1}$$

2.3) Propellant Mass Flow Rate Formula

Evaluate Formula

Formula

$$\dot{m} = \left(A_t \cdot P_1 \cdot \gamma\right) \cdot \frac{\sqrt{\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma + 1}{\gamma - 1}}}}{\sqrt{\gamma \cdot [R] \cdot T_1}}$$

Example with Units

$$11.3282\,\text{kg/s} = \left(0.21\,\text{m}^2 \cdot 0.0037\,\text{MPa} \cdot 1.33\right) \cdot \frac{\sqrt{\left(\frac{2}{1.33 + 1}\right)^{\frac{1.33 + 1}{1.33 - 1}}}}{\sqrt{1.33 \cdot 8.3145 \cdot 256\,\text{K}}}$$

2.4) Propellant Mixture Ratio Formula

Evaluate Formula

Formula

$$r = \frac{\dot{m}_o}{\dot{m}_f}$$

Example with Units

$$2.439 = \frac{10\,\text{kg/s}}{4.1\,\text{kg/s}}$$

3) Theory Of Rockets Formulas

3.1) Effective Exhaust Velocity of Rocket Formula

Evaluate Formula

Formula

$$c = V_e + \left(p_2 - p_3 \right) \cdot \frac{A_2}{\dot{m}}$$

Example with Units

$$178110.402\,\text{m/s} = 118.644\,\text{m/s} + \left(1.239\,\text{MPa} - 0.1013\,\text{MPa} \right) \cdot \frac{1.771\,\text{m}^2}{11.32\,\text{kg/s}}$$

3.2) Mass Ratio of Rocket Formula

Evaluate Formula

Formula

$$MR = \frac{m_f}{m_0}$$

Example with Units

$$1.4667 = \frac{22\,\text{kg}}{15\,\text{kg}}$$

3.3) Payload Mass Fraction Formula

Evaluate Formula

Formula

$$\lambda = \frac{m_d}{m_p + m_s}$$

Example with Units

$$0.5965 = \frac{34\,\text{kg}}{13\,\text{kg} + 44\,\text{kg}}$$

3.4) Propellent Mass Fraction Formula

Evaluate Formula

Formula

$$\zeta = \frac{m_p}{m_0}$$

Example with Units

$$0.8667 = \frac{13\,\text{kg}}{15\,\text{kg}}$$

3.5) Rocket Exhaust Gas Velocity Formula

Evaluate Formula

Formula

$$V_e = \sqrt{\left(\frac{2 \cdot \gamma}{\gamma - 1}\right) \cdot [R] \cdot T_1 \cdot \left(1 - \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}\right)}$$

Example with Units

$$118.6448\,\text{m/s} = \sqrt{\left(\frac{2 \cdot 1.33}{1.33 - 1}\right) \cdot 8.3145 \cdot 256\,\text{K} \cdot \left(1 - \left(\frac{1.239\,\text{MPa}}{1256\,\text{MPa}}\right)^{\frac{1.33 - 1}{1.33}}\right)}$$

3.6) Structural Mass Fraction Formula

Evaluate Formula

Formula

$$\sigma = \frac{m_s}{m_p + m_s}$$

Example with Units

$$0.7719 = \frac{44\,\text{kg}}{13\,\text{kg} + 44\,\text{kg}}$$

3.7) Throat Velocity of Nozzle Formula

Evaluate Formula

Formula

$$v_t = \sqrt{\frac{2 \cdot \gamma}{\gamma + 1} \cdot [R] \cdot T_1}$$

Example with Units

$$49.2947\,\text{m/s} = \sqrt{\frac{2 \cdot 1.33}{1.33 + 1} \cdot 8.3145 \cdot 256\,\text{K}}$$

3.8) Total Velocity Required to Place Satellite in Orbit Formula

Evaluate Formula

Formula

$$V_T = \sqrt{\frac{[G.] \cdot M_E \cdot \left(R_E + 2 \cdot h\right)}{R_E \cdot \left(R_E + h\right)}}$$

Example with Units

$$10509.5796\,\text{m/s} = \sqrt{\frac{6.7\text{E-}11 \cdot 100000000000000000000000\,\text{kg} \cdot \left(6378100\,\text{m} + 2 \cdot 375000\,\text{m}\right)}{6378100\,\text{m} \cdot \left(6378100\,\text{m} + 375000\,\text{m}\right)}}$$

3.9) Velocity Increment of Rocket Formula

Evaluate Formula

Formula

$$\Delta V = V_e \cdot \ln\left(\frac{m_i}{m_{final}}\right)$$

Example with Units

$$82.2378\,\text{m/s} = 118.644\,\text{m/s} \cdot \ln\left(\frac{1500\,\text{kg}}{750\,\text{kg}}\right)$$

4) Thrust and Power Generation Formulas

4.1) Acceleration of Rocket Formula

Evaluate Formula

Formula

$$a = \frac{F}{m}$$

Example with Units

$$13.8526\,\text{m/s}^2 = \frac{5825\,\text{N}}{420.5\,\text{kg}}$$

4.2) Compressible Area Ratio Formula

Evaluate Formula

Formula

$$A_r = \left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma + 1}{2 \cdot \gamma - 2}} \cdot \frac{\left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{\gamma + 1}{2 \cdot \gamma - 2}}}{M}$$

Example

$$1.1203 = \left(\frac{1.33 + 1}{2}\right)^{-\frac{1.33 + 1}{2 \cdot 1.33 - 2}} \cdot \frac{\left(1 + \frac{1.33 - 1}{2} \cdot 1.4^2\right)^{\frac{1.33 + 1}{2 \cdot 1.33 - 2}}}{1.4}$$

4.3) Exit Velocity given Mach Number and Exit Temperature Formula

Evaluate Formula

Formula

$$C_j = M \cdot \sqrt{\gamma \cdot \frac{[R]}{M_{molar}} \cdot T_{exit}}$$

Example with Units

$$248.3706\,\text{m/s} = 1.4 \cdot \sqrt{1.33 \cdot \frac{8.3145}{6.5\,\text{g/mol}} \cdot 18.5\,\text{K}}$$

4.4) Exit Velocity given Molar Mass Formula

Evaluate Formula

Formula

$$C_j = \sqrt{\left(\frac{2 \cdot T_c \cdot [R] \cdot \gamma}{M_{molar}} \Big/ (\gamma - 1)\right) \cdot \left(1 - \left(\frac{P_{exit}}{P_c}\right)^{1 - \frac{1}{\gamma}}\right)}$$

Example with Units

$$248.87\,\text{m/s} = \sqrt{\left(\frac{2 \cdot 24.6\,\text{K} \cdot 8.3145 \cdot 1.33}{6.5\,\text{g/mol}} \Big/ (1.33 - 1)\right) \cdot \left(1 - \left(\frac{2.1\,\text{MPa}}{6.49\,\text{MPa}}\right)^{1 - \frac{1}{1.33}}\right)}$$

4.5) Exit Velocity given Molar Specific Heat Capacity Formula

Evaluate Formula

Formula

$$C_j = \sqrt{2 \cdot T_{tot} \cdot C_{p\,molar} \cdot \left(1 - \left(\frac{P_{exit}}{P_c}\right)^{1 - \frac{1}{\gamma}}\right)}$$

Example with Units

$$248.086\,\text{m/s} = \sqrt{2 \cdot 590\,\text{K} \cdot 213.6\,\text{J/K*mol} \cdot \left(1 - \left(\frac{2.1\,\text{MPa}}{6.49\,\text{MPa}}\right)^{1 - \frac{1}{1.33}}\right)}$$

4.6) Mass Flow Rate through Engine Formula

Evaluate Formula

Formula

$$m_a = M \cdot A \cdot P_t \cdot \sqrt{\gamma \cdot \frac{M_{molar}}{T_{tot} \cdot [R]}} \cdot \left(1 + (\gamma - 1) \cdot \frac{M^2}{2}\right)^{-\frac{\gamma + 1}{2 \cdot \gamma - 2}}$$

Example with Units

$$23.4985\,\text{kg/s} = 1.4 \cdot 8.5\,\text{m}^2 \cdot 0.004\,\text{MPa} \cdot \sqrt{1.33 \cdot \frac{6.5\,\text{g/mol}}{590\,\text{K} \cdot 8.3145}} \cdot \left(1 + (1.33 - 1) \cdot \frac{1.4^2}{2}\right)^{-\frac{1.33 + 1}{2 \cdot 1.33 - 2}}$$

4.7) Photon Propulsion Thrust Formula

Evaluate Formula

Formula

$$F = 1000 \cdot \frac{P_e}{[c]}$$

Example with Units

$$5825.3367\,\text{N} = 1000 \cdot \frac{1746392\,\text{kW}}{3\text{E}{+}8\,\text{m/s}}$$

4.8) Power required to produce Exhaust Jet Velocity Formula

Evaluate Formula

Formula

$$P = \frac{1}{2} \cdot m_a \cdot C_j^2$$

Example with Units

$$722.3645\,\text{kW} = \frac{1}{2} \cdot 23.49\,\text{kg/s} \cdot 248\,\text{m/s}^2$$

4.9) Power required to produce Exhaust Jet Velocity given Mass of Rocket and Acceleration Formula

Evaluate Formula

Formula

$$P = \frac{m \cdot a \cdot V_{eff}}{2}$$

Example with Units

$$722.1667\,\text{kW} = \frac{420.5\,\text{kg} \cdot 13.85\,\text{m/s}^2 \cdot 248\,\text{m/s}}{2}$$

4.10) Rocket Exit Pressure Formula

Evaluate Formula

Formula

$$P_{exit} = P_c \cdot \left(\left(1 + \frac{\gamma - 1}{2} \cdot M^2 \right)^{-\left(\frac{\gamma}{\gamma - 1} \right)} \right)$$

Example with Units

$$2.0979\,\text{MPa} = 6.49\,\text{MPa} \cdot \left(\left(1 + \frac{1.33 - 1}{2} \cdot 1.4^2 \right)^{-\left(\frac{1.33}{1.33 - 1} \right)} \right)$$

4.11) Rocket Exit Temperature Formula

Evaluate Formula

Formula

$$T_{exit} = T_c \cdot \left(1 + \frac{\gamma - 1}{2} \cdot M^2 \right)^{-1}$$

Example with Units

$$18.5885\,\text{K} = 24.6\,\text{K} \cdot \left(1 + \frac{1.33 - 1}{2} \cdot 1.4^2 \right)^{-1}$$

4.12) Thrust given Exhaust Velocity and Mass Flow Rate Formula

Evaluate Formula

Formula

$$F = m_a \cdot C_j$$

Example with Units

$$5825.52\,\text{N} = 23.49\,\text{kg/s} \cdot 248\,\text{m/s}$$

4.13) Thrust given Mass and Acceleration of Rocket Formula

Evaluate Formula

Formula

$$F = m \cdot a$$

Example with Units

$$5823.925\,\text{N} = 420.5\,\text{kg} \cdot 13.85\,\text{m/s}^2$$

4.14) Total Impulse Formula

Evaluate Formula

Formula

$$T_t = \int \left(F, x, t_i, t_f \right)$$

Example with Units

$$58250\,\text{s} = \int \left(5825\,\text{N}, x, 20\,\text{s}, 30\,\text{s} \right)$$

Variables used in list of Rocket Propulsion Formulas above

- $\in$ Area Ratio of Nozzle
- **a** Acceleration *(Meter per Square Second)*
- **A** Area *(Square Meter)*
- A_2 Exit Area *(Square Meter)*
- A_r Area Ratio
- A_t Nozzle Throat Area *(Square Meter)*
- **c** Effective Exhaust Velocity *(Meter per Second)*
- C_F Thrust Coefficient
- C_j Exit Velocity *(Meter per Second)*
- $C_{p\ molar}$ Molar Specific Heat Capacity at Constant Pressure *(Joule Per Kelvin Per Mole)*
- C^* Characteristics Velocity *(Meter per Second)*
- **F** Rocket Thrust *(Newton)*
- **F** Thrust *(Newton)*
- **h** Height of Satellite *(Meter)*
- **m** Mass of Rocket *(Kilogram)*
- **M** Mach Number
- $\dot{m}$ Propellant Mass Flow Rate *(Kilogram per Second)*
- m_0 Initial Mass *(Kilogram)*
- M_2 Mach at Exit
- m_a Mass Flow Rate *(Kilogram per Second)*
- m_d Payload Mass *(Kilogram)*
- M_E Mass Of Earth *(Kilogram)*
- m_f Final Mass *(Kilogram)*
- $\dot{m}_f$ Fuel Mass Flow Rate *(Kilogram per Second)*
- m_{final} Final Mass of Rocket *(Kilogram)*
- m_i Initial Mass of Rocket *(Kilogram)*
- M_{molar} Molar Mass *(Gram Per Mole)*
- $\dot{m}_o$ Oxidizer Mass Flow Rate *(Kilogram per Second)*
- m_p Propellant Mass *(Kilogram)*
- m_s Structural Mass *(Kilogram)*

Constants, Functions, Measurements used in list of Rocket Propulsion Formulas above

- constant(s): **[G.]**, 6.67408E-11
  Gravitational constant
- constant(s): **[c]**, 299792458.0
  Light speed in vacuum
- constant(s): **[R]**, 8.31446261815324
  Universal gas constant
- Functions: **int**, int(expr, arg, from, to)
  The definite integral can be used to calculate net signed area, which is the area above the x -axis minus the area below the x -axis.
- Functions: **ln**, ln(Number)
  The natural logarithm, also known as the logarithm to the base e, is the inverse function of the natural exponential function.
- Functions: **sqrt**, sqrt(Number)
  A square root function is a function that takes a non-negative number as an input and returns the square root of the given input number.
- Measurement: **Length** in Meter (m)
  Length Unit Conversion
- Measurement: **Weight** in Kilogram (kg)
  Weight Unit Conversion
- Measurement: **Time** in Second (s)
  Time Unit Conversion
- Measurement: **Temperature** in Kelvin (K)
  Temperature Unit Conversion
- Measurement: **Volume** in Cubic Meter (m^3)
  Volume Unit Conversion
- Measurement: **Area** in Square Meter (m^2)
  Area Unit Conversion
- Measurement: **Pressure** in Megapascal (MPa)
  Pressure Unit Conversion
- Measurement: **Speed** in Meter per Second (m/s)
  Speed Unit Conversion
- Measurement: **Acceleration** in Meter per Square Second (m/s^2)
  Acceleration Unit Conversion
- Measurement: **Power** in Kilowatt (kW)
  Power Unit Conversion

- **MR** Mass Ratio
- **P** Power Required *(Kilowatt)*
- p_1 Pressure at Chamber *(Megapascal)*
- P_1 Inlet Nozzle Pressure *(Megapascal)*
- p_2 Nozzle Exit Pressure *(Megapascal)*
- p_3 Atmospheric Pressure *(Megapascal)*
- P_c Chamber Pressure *(Megapascal)*
- P_e Power in Jet *(Kilowatt)*
- P_{exit} Exit Pressure *(Megapascal)*
- P_t Total Pressure *(Megapascal)*
- **r** Propellant Mixture Ratio
- R_E Radius of Earth *(Meter)*
- t_i Initial time *(Second)*
- T_1 Temperature at Chamber *(Kelvin)*
- T_c Chamber Temperature *(Kelvin)*
- T_{exit} Exit Temperature *(Kelvin)*
- t_f Final time *(Second)*
- T_t Specific Temperature *(Kelvin)*
- T_t Total impulse *(Second)*
- T_{tot} Total Temperature *(Kelvin)*
- v_0 Vehicle Speed *(Meter per Second)*
- V_1 Inlet Volume *(Cubic Meter)*
- v_9 Exhaust Speed *(Meter per Second)*
- V_e Jet Velocity *(Meter per Second)*
- V_{eff} Effective Exhaust Velocity of Rocket *(Meter per Second)*
- v_t Throat Velocity *(Meter per Second)*
- V_t Specific Volume *(Cubic Meter)*
- V_T Total Velocity of Rocket *(Meter per Second)*
- γ Specific Heat Ratio
- ΔV Velocity Increment of Rocket *(Meter per Second)*
- ζ Propellant Mass Fraction
- η_{prop} Propulsion Efficiency

- Measurement: **Force** in Newton (N)
  Force Unit Conversion
- Measurement: **Mass Flow Rate** in Kilogram per Second (kg/s)
  Mass Flow Rate Unit Conversion
- Measurement: **Molar Mass** in Gram Per Mole (g/mol)
  Molar Mass Unit Conversion
- Measurement: **Molar Specific Heat Capacity at Constant Pressure** in Joule Per Kelvin Per Mole (J/K*mol)
  Molar Specific Heat Capacity at Constant Pressure Unit Conversion

- λ Payload Mass Fraction
- σ Structural Mass Fraction

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