The Physics of Water Rockets

Newton's Laws of Motion

Principle of Inertia

$$F = 0 \Rightarrow v = \text{const}$$

Principle of Action

$$\vec{F} = m \cdot \vec{a}$$

Actio and Reactio

$$\vec{F}_{A \to B} = -\vec{F}_{B \to A}$$

Energy

$$E_{tot} = E_{kin} + E_{pot} = \frac{1}{2} m \cdot v^2 + m \cdot g \cdot h$$

Thermodynamics

Ideal Gas Law

$$p \cdot V = n \cdot R \cdot T$$

Energy of Compressed Air in Isothermal Compression

$$E = -m_{\text{air}} \cdot R_{\text{air}} \cdot T \cdot \ln\left(\frac{p_{\text{com}}}{p_{\text{atm}}}\right)$$

Specific Gas Constant for Air

$$R_{\text{air}} = 287.058\,\text{J}/(\text{kg}\,\text{K})$$

Ballistics - Projectile Motion without Air Resistance

Flight Altitude

$$h = \frac{v^2}{2 \cdot g}$$

Flight Duration

$$t = \frac{2 \cdot v}{g}$$

Throw Parabola as a Function of t

$$y(t) = -\frac{1}{2} \cdot g \cdot t^2 + v_{y,0} \cdot t + h$$

Throw Parabola as a Function of x

$$y(x) = -\frac{1}{2} \cdot \frac{g}{(v_0 \cdot \cos(\alpha_0))^2} \cdot x^2 + \tan(\alpha_0) \cdot x + h$$

Drag Resistance

$$c_d = \frac{2 \cdot F_d}{\rho \cdot v^2 \cdot A}$$

TSIOLKOVSKY Rocket Equation

$$v_{\text{end}} = v_{\text{exhaust}} \cdot \ln\left(1 + \frac{m_{\text{propellant}}}{m_{\text{initial}}}\right)$$

Numerical Simulation

The equations of motion of a rocket are difficult to solve completely analytically, as many properties are time-dependent, but there are simple numerical solution methods.

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