Basics of Rocket Propulsion

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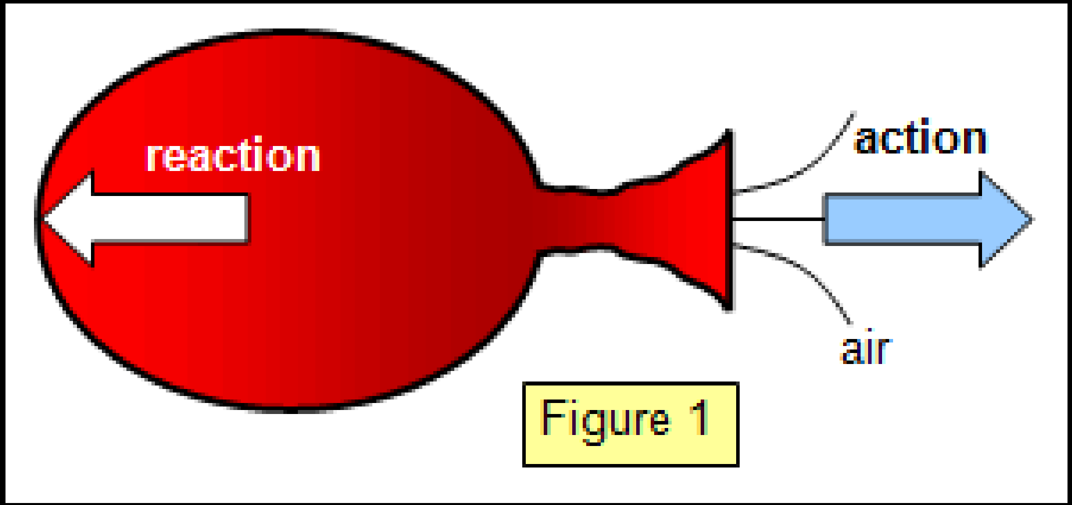
Core Physics Concepts: Newtons 3rd Law

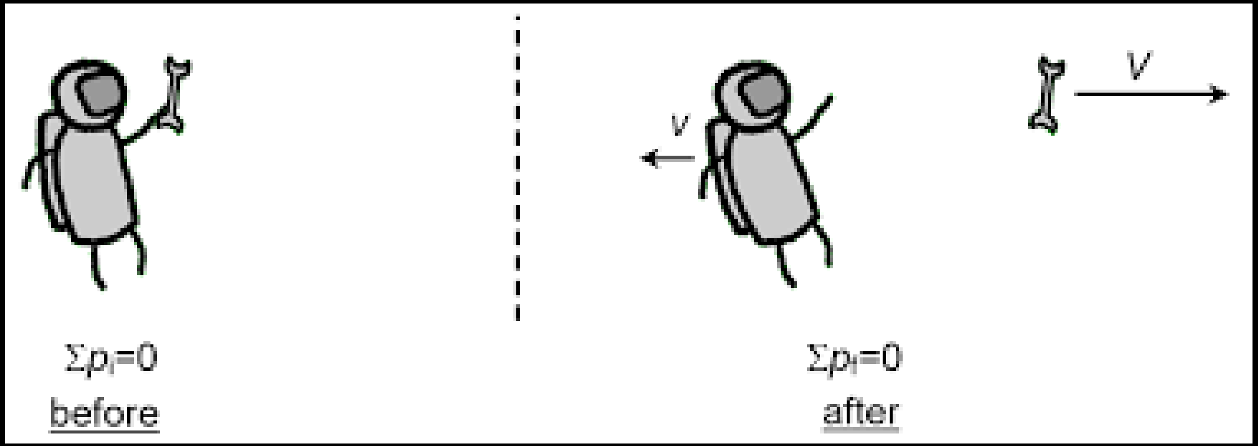
- Every action has an equal and opposite reaction
- Rockets use this to their advantage by expelling mass in the opposite direction to where they want to travel, like the balloon in the diagram



(Gibbs, n.d.)

Core Physics Concept: Conservation of Momentum

- Momentum is the mass of an object multiplied by the velocity of the same object
- Because rockets constantly expel propellants and thus decrease their mass, the velocity of the rocket must increase to conserve momentum (Hall, 2021)



The Rocket Equation (Tsiolkovsky Equation)

The rocket equation combines these physics concepts into one simple equation (Sutton, 2001, p. 732)

$$\Delta v = v_e ln \frac{m_0}{m_f}$$

Δv – change in velocity

v_e – exhaust velocity

m_0 – initial mass (wet mass)

m_f – final mass (dry mass)

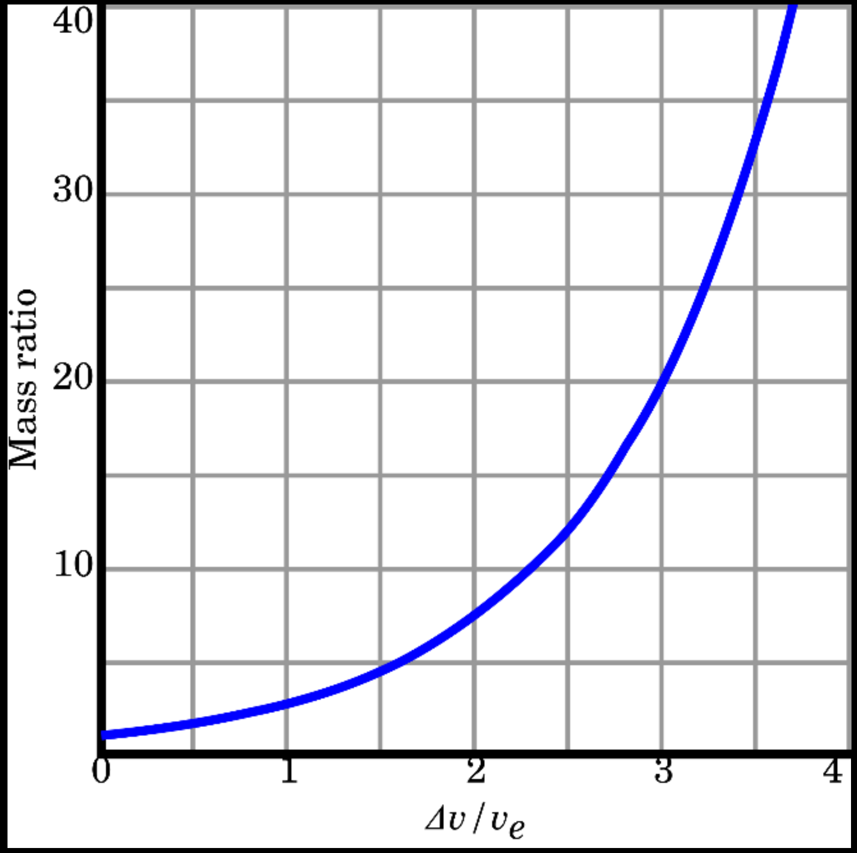
- The change in velocity, or *Δv* is the single most important quantity of a rocket. This is because the *Δv* determines how far and fast a rocket can go and thus is the limiting factor of spacecraft maneuvers and orbits.
- By relating *Δv* to exhaust velocity and the propellant mass ratio, a rocket's performance can be characterized

The Problem – Exponential Growth

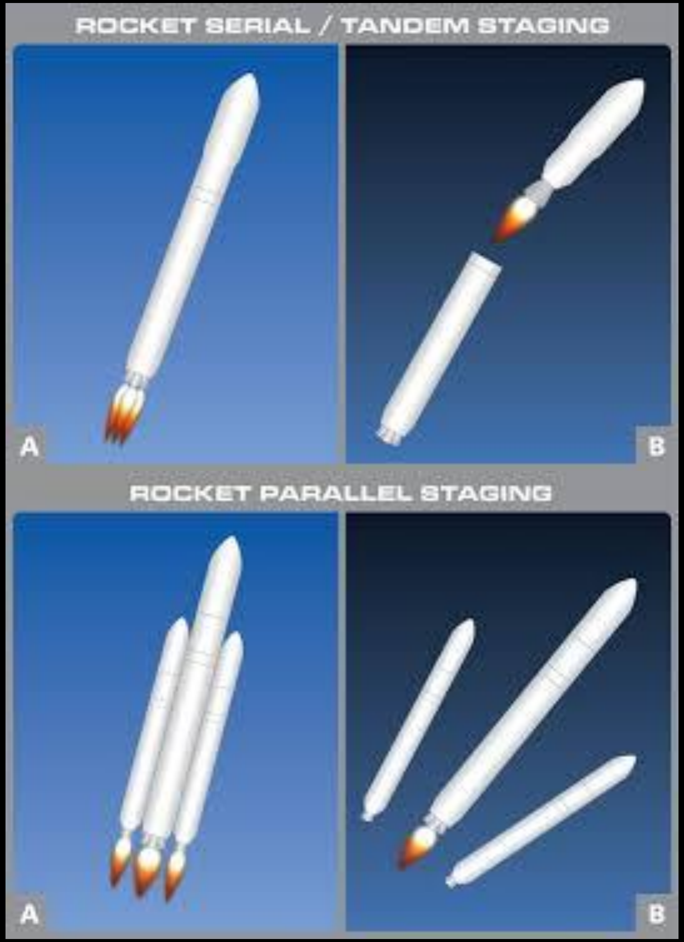
If the equation is solved for the required propellant mass to reach a desired *Δv*, we get:

$$m_0 - m_f = m_f \left(e^{\frac{\Delta v}{v_e}} - 1\right)$$

- The mass of propellant required to achieve a desired *Δv* increases at an exponential rate
- If we want to make rockets achieve larger orbits or travel to further planets, we must use exponentially more propellant



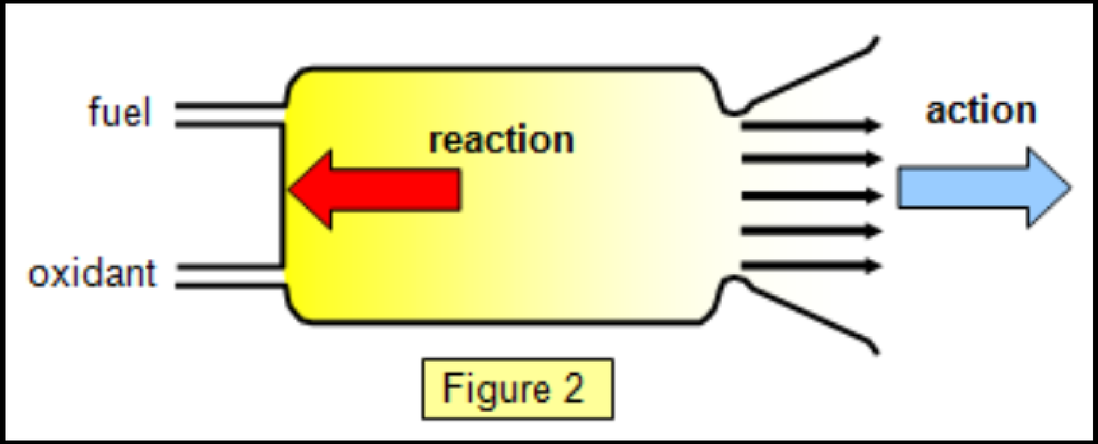
The Solution – Staging



(Wessels, 2022)

- By *staging* a rocket, it can drop off the unnecessary weight of spent tanks or boosters mid-flight
- Staging can be accomplished in many ways. Some rockets, like the Saturn V, employ *tandem staging*, where each stage fires one after another (Schulman, 2025, p. 16–17)
- Other rockets, like the Space Shuttle, use *parallel staging*, where multiple stages fire at the same time, and are jettisoned at different times (Hurley, 1972)

The Rocket Engine



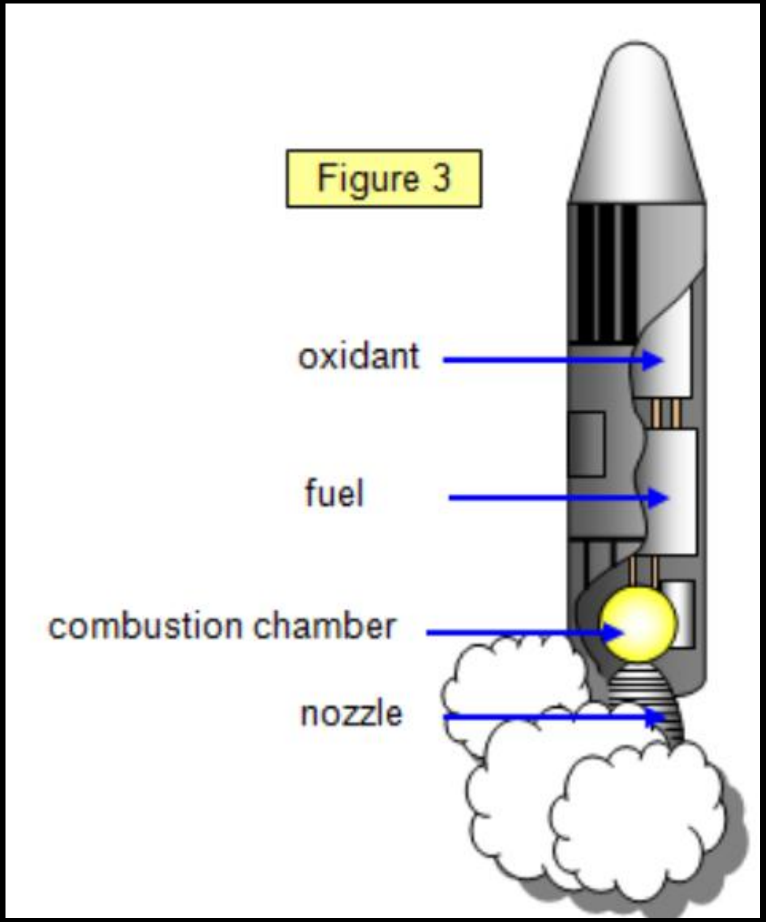
(Gibbs, n.d.)

- The engine's job is to take the stored chemical energy of the propellants and convert it into kinetic energy through high velocity exhaust (Sutton, 2001, ch. 3)
- Recall the balloon diagram from earlier; the engine has the same action-reaction pair

Fundamental Parts of a Rocket Engine

A rocket engine consists of three main components (Sutton, 2001, ch. 6)

- The propellant, which is where the chemical potential energy is stored and is the mass expelled from the nozzle
- The combustion chamber, where the energy stored in the propellants is converted to kinetic energy
- The nozzle, which converts the massive amounts of energy stored in the temperature and pressure of the combusted propellants into velocity



(Gibbs, n.d.)

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