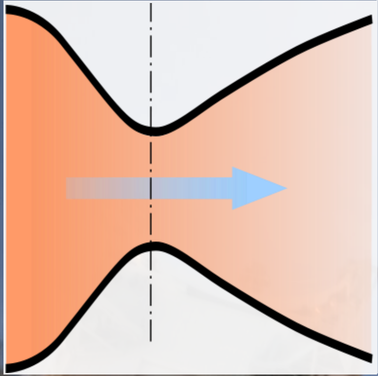

AE3534 – Spacecraft Technology

Rocket & Onboard Propulsion – Chapter 1

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photo: en.wikipedia.org

Rocket & Onboard Propulsion - Contents

1. Rocket **performance** equations
   - **Liquid** and **solid** propellant engines
2. **Electric** and **advanced** propulsion
3. **Micro-propulsion** concepts and challenges

Chapter 1 - Contents

1. Introduction: **thrust** and **specific impulse**
2. Space propulsion **types** and **concepts**
3. Performance equations: **ideal rocket theory**
4. **Liquid** propellant engines
5. **Solid** propellant engines
6. **Real** rockets: deviations from ideal rocket theory

1.1

Introduction: thrust and specific impulse

What is rocket propulsion?

- A rocket engine is a **pure reaction system**:
- A large quantity of fluid (**propellant**) is expelled in a direction opposite to the rocket motion
- If the rocket pushes the propellant out, the propellant also pushes the rocket in the opposite direction (**Newton's third law**)
- Differently to aircraft engines, the propellant is carried **on board**

Main performance parameters

Thrust [N]

The force produced by a rocket

Specific Impulse [s]

The ratio of total impulse to weight of propellant used

Delta-V [m/s]

The velocity change of a spacecraft, when a given mass of propellant is used

Main performance parameters

Thrust [N]

$$F_T = \dot{m} \cdot v_e + \left(p_e - p_a\right) \cdot A_e$$
$$= \dot{m} \cdot v_{eq}$$

Specific Impulse [s]

$$I_{sp} = \frac{v_{eq}}{g_0}$$

Delta-V [m/s]

$$\Delta v = v_{eq} \cdot \ln\left(\frac{M_0}{M_0 - M_P}\right)$$

Rocket Thrust

Thrust

$$F_T = \dot{m} \cdot v_e + \left(p_e - p_a\right) \cdot A_e$$

Momentum term

Pressure term

$\dot{m}$ = propellant mass flow rate [kg/s]

v_e = propellant exit velocity [m/s]

(or *jet velocity*)

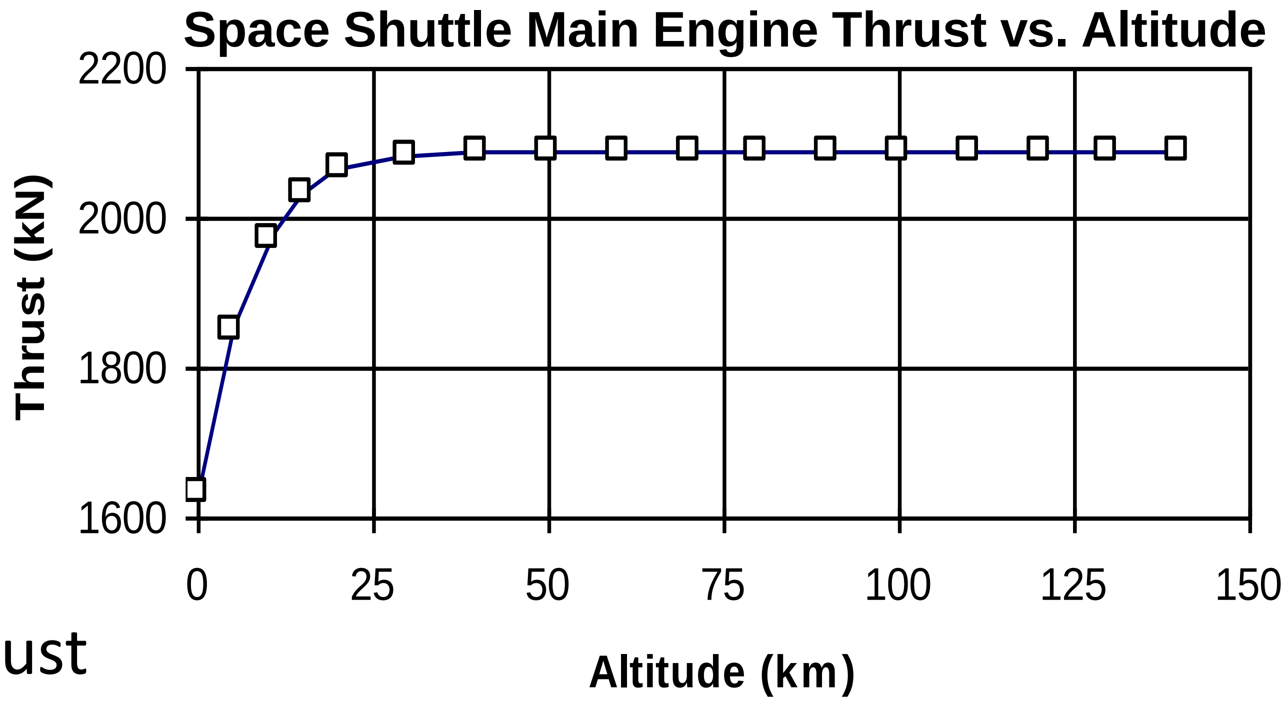
p_e = propellant exit pressure [Pa]

p_a = ambient pressure [Pa]

A_e = propellant exit area [m^2]

Rocket Thrust

$$F_T = \dot{m} \cdot v_e + (p_e - p_a) \cdot A_e$$



Pressure term

- Function of **altitude** (through p_a ; thrust is maximum in vacuum at $p_a = 0$)
- Often negligible, but usually not in **big rockets** at **low altitudes**
- A more compact equation is written by defining the **equivalent jet velocity** v_{eq}

$$v_{eq} = v_e + \frac{(p_e - p_a) \cdot A_e}{\dot{m}}$$

$$\rightarrow F_T = \dot{m} \cdot v_{eq}$$

Specific Impulse

$$I_{sp} = \frac{\int_0^{t_b} F_T \cdot dt}{\int_0^{t_b} \dot{m} g_0 \cdot dt}$$

Definition of I_{sp} : total impulse divided by propellant weight

Higher I_{sp} → ***Less propellant*** *to deliver* ***same total impulse***

t_b = burn time [s]

g_0 = Earth's gravitational acceleration at sea level [m/s^2]

When the equivalent jet velocity v_{eq} is **constant over time** →

$$I_{sp} = \frac{v_{eq}}{g_0}$$

Delta-V

$$\Delta v = v_{eq} \cdot \ln\left(\frac{M_0}{M_0 - M_P}\right)$$

Rocket equation (or *Tsiolkovsky equation*)

M_0 = initial spacecraft mass [kg]

M_P = mass of propellant used [kg]

This equation gives the **velocity change** of the spacecraft **ONLY IF** :

- *No external forces (gravity, atmospheric drag, etc.)*
- *Equivalent jet velocity constant over time*
- *Propellant expelled in a direction opposite to flight direction*

If at least one of these assumptions is not true, Delta-V is still a good indicator of the **energy** transferred by the propulsion system to the spacecraft