Rocket Propulsion Overview

Rocket Definition

**Rocket** ≡ Device that provides thrust to a vehicle by accelerating some matter (the **propellant**) and exhausting it from the rocket

- Most significant difference between rocket and air-breathing engines is the **rocket carries all its own propellant**
Rocket: Performance Issues

- **Thrust**
  - important when there are minimum allowable acceleration requirements, e.g., launch in gravity field

- **Impulse**
  \[ \int F(t)dt \]
  - measure of rocket performance – usually normalized by mass of propellant required (specific impulse, Isp)

- **Other issues**
  - structural weight, size, complexity, reliability,…
Examples: Pressure Rocket

- **Cold Gas Thruster**
  - Cold gas (N\textsubscript{2}, hydrazine,...) stored at high pressure with thrust provided by acceleration through nozzle
  - Propellant=Energy source (storage pressure)
  - Feed system: piping from storage to nozzle
  - Accelerator: nozzle (thermal to kinetic energy)

Examples: Chemical Rocket

- **Bipropellant: LH\textsubscript{2}-LOX (H\textsubscript{2}/O\textsubscript{2})**
  - Combust pressurized H\textsubscript{2} and O\textsubscript{2} in combustion chamber, nozzle exhaust
  - Propellant=Energy source (chemical)
  - Storage: liquid (cryogenic) tanks
  - Feed system: liquid pumps and piping
  - Energy conversion: chemical to thermal energy (combustion)
  - Accelerator: nozzle
Examples: Electrical Rocket

- **Ion Engine**
  - Ionize neutral gas (Xe); ions accelerated by E field; ions recombined with e⁻
  - **Propellant**: neutral gas
  - **Energy source**: e.g., nuclear
  - **Energy conversion**: nuclear to thermal to electrical
  - **Accelerator**: high voltage electrostatic field across electrodes

Applications

- **Space Propulsion**
  - Launch: from “planetary” body to orbit
  - Orbit Insertion: from launch orbit to mission orbit
  - Maneuvering: maintain or change orbit or trajectory
  - Attitude Control: orientation of vehicle

- **Aircraft Propulsion**
  - High thrust/acceleration (sustained or boosters)
  - High speed flight (> ramjet/scramjet capability)
Chemical Rockets

- Thrust produced by conversion of
  - chemical energy to thermal energy
  - thermal energy to kinetic energy
- Common Applications
  - Usual choice for high thrust rockets, e.g., launch, orbit change, aircraft propulsion
  - Also used for maneuvering and attitude control

Chemical Rockets – Types

- **Gas** rockets
  - fuel/oxidizer stored as gases ⇒ large storage volumes
- **Liquid** rockets
  - stored as liquids, more complex but high impulse
- **Solid** rockets
  - propellant is solid, lower impulse but simpler
- **Hybrid** rockets
  - usually solid fuel+liquid/gas oxidizer
- **Motors vs. Engines**
  - **Motor** = propellant stored inside comb. chamber
  - **Engine** = storage outside combustion chamber
Chemical Rockets – Liquid System

- Primary subsystems
  - storage
  - feed system
  - thrust chamber assembly (TCA)

Chemical Rockets – Liquid Propellants

- Monopropellants
  - exothermic decomposition
    - hydrogen peroxide $\text{H}_2\text{O}_2$
    - hydrazine $\text{N}_2\text{H}_4$
- Bi-propellants
  - fuel/oxidizer combustion
    - $\text{H}_2 / \text{O}_2$
    - RP-1 (kerosene) / $\text{O}_2$
    - MMH ($\text{CH}_3\text{NH-NH}_2$) / $\text{N}_2\text{O}_4$
      - hypergolic: self-igniting on contact

Adapted from grc.nasa.gov
Chemical Rockets - Solid

- Nothing but TCA
- Casing
  - cooling not required, protected by propellant
- Grain
  - geometry (surface area/shape) of solid propellant
  - no feed system to control propellant flow rate, grain design to "program" burning rate – can be very high
- Nozzle
  - no coolant available, higher T material required

Chemical Rockets - Solid Propellants

- Homogeneous
  - fuel/oxidizer mixed at near molecular level
- Heterogeneous
  - separate "fuel" and "oxidizer"
  - usually oxid. particles in solid binder
    - AP/rubber
    - AP/rubber/Al
Other Rockets: Applications

- **Pressure (cold gas)**
  - attitude control + maneuvering: reduced thrust as pressure used up, rendezvous

- **Electrical**
  - Arcjet thrusters - maneuvering + attitude control
  - Ion engines - space propulsion

- **Advanced systems**
  - Nuclear thermal: like chemical rockets with nuclear-based heat addition, high thrust
  - Solar thermal
  - Magnetoplasmadynamic and other electrodynamic devices, high impulse
  - **Combined Cycles**: typically combine air-breathing with rocket cycles for single-stage to orbit (SSTO)

“Propellantless” Space Propulsion

- **Solar sails**: use momentum from solar wind, out-bound trajectories only

- **Magnetic sails**: use magnetic fields instead of solid material to capture “wind”

- **Tethers**:
  - rotating (momentum exchange, “catch and throw”)
  - electrodynamic: conducting material moving through (Earth’s) magnetic fields can produce currents/voltages or passing current through tether \( \Rightarrow \) produce forces

- **Warp drive…..(space-time/ gravity manipulation)**
Rocket vs. Air-Breathing Propulsion

- **Air-breathing**
  - doesn’t have to carry most of the propellant (higher Isp)
  - limited to lower Mach nos.

- **Rocket**
  - can operate without atmosphere
  - higher M operation (no “ram drag”)
  - usually higher internal pressures

\[ \tau/m \quad \text{turbojet/turbofan} \]
\[ \text{ramjet/scramjet} \quad \text{rocket} \]
\[ M \]