IV. Rocket Propulsion Systems

A. Overview

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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 we have examined so far is that 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 normalized by mass of propellant required

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

- **Cold Gas Thruster**
  - Cold gas (N₂, 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: LH₂-LOX (H₂/O₂)**
  - Combust pressurized H₂ and O₂ 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

• **Common Applications**
  – Usual choice for high thrust rockets, e.g., launch, orbit change, aircraft propulsion
  – Also used for maneuvering and attitude control

• **Monopropellants vs. Bipropellants**
  – Monopropellants (no separate fuel and oxidizer, e.g., hydrazine)
  – Bipropellants (e.g., hydrocarbon/oxygen, hydrogen/oxygen, nitrogen tetroxide/monomethyl hydrazine)

Chemical Rockets (continued)

• **Propellant Types**
  – **Gas** rockets: fuel/oxidizer stored as gases – requires 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+liq./gas oxidizer

• **Motors vs. Engines**
  – **Motor** = propellant stored inside comb. chamber
  – **Engine** = storage outside combustion chamber
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

• Future systems
  – Nuclear thermal: like chemical rockets with nuclear-based heat addition, high thrust?
  – Magnetoplasmadynamic and other electrodynamic devices, high impulse

Non-Rocket Space Propulsion

• Combined Cycles: typically combine air-breathing with rocket cycles for single-stage to orbit (SSTO)
• Solar sails: use momentum from solar radiation
• Magnetic sails: use magnetic fields
• Tethers: conducting material moving through EM fields can produce currents/voltages or passing current through tether can produce forces
• Gravity assist: sling shot effect
• Warp drive…..