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

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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,…

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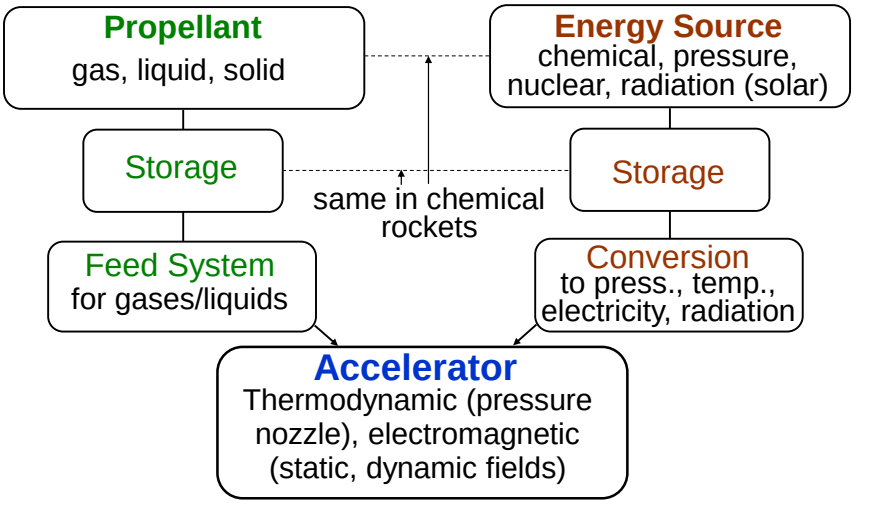
Rocket Propulsion Elements



Examples: Pressure Rocket

- Cold Gas Thruster

⇒Cold gas (N_2, hydrazine,…) stored at high pressure with thrust provided by accel-eration 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 (H_2/O_2)

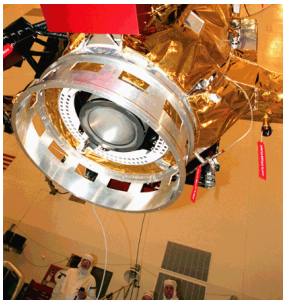
SSME

⇒Combust pressurized H_2 and O_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

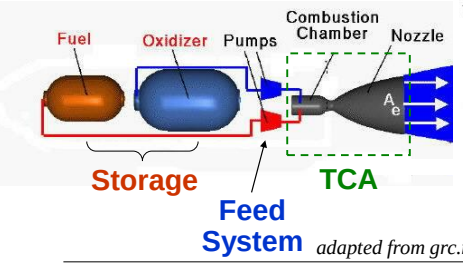
- Thrust produced by conversion of
  - chemical energy to thermal energy
  - thermal energy to kinetic energy
- Common Applications
  - Usual choice for high thrust rockets, e.g, launch, orbit change, aircraft propulsion
  - Also used for maneuvering and attitude control

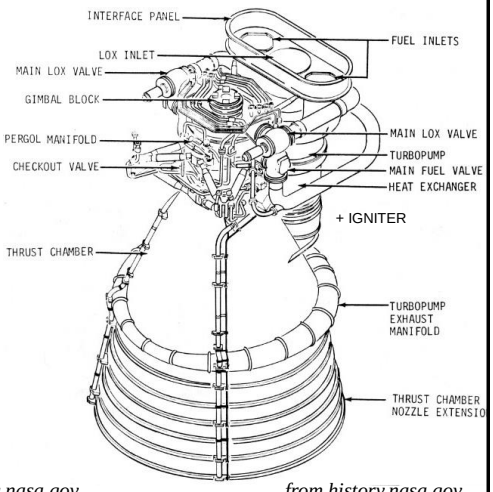
Chemical Rockets – Types

- 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)





adapted from grc.nasa.gov

from history.nasa.gov

Chemical Rockets – Liquid Propellants

- Monopropellants
  - exothermic decomposition
    - hydrogen peroxide H_2O_2
    - hydrazine N_2H_4
- Bi-propellants
  - fuel/oxidizer combustion
    - H_2 / O_2
    - RP-1 (kerosene) / O_2
    - MMH ($CH_3NH\text{-}NH_2$) / N_2O_4
      - **hypergolic:** self-igniting on contact

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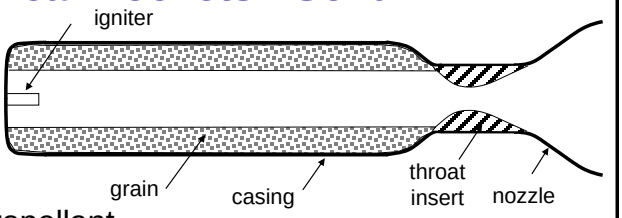
Chemical Rockets - Solid



- 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

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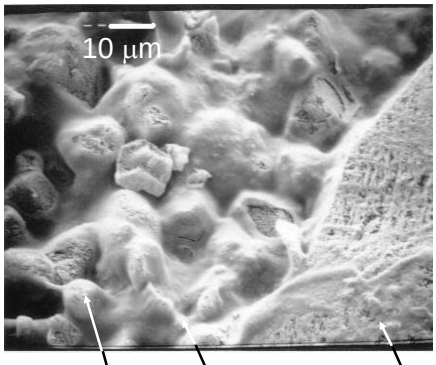
Chemical Rockets- Solid Propellants

- 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, rendevous
- 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)

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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