16.512, Rocket Propulsion
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Lecture 1: Introduction

Types of Rockets (Engines)

- **Depending on gas acceleration mechanism / force on vehicle mechanism.**

"Thermal"	Gas pushes directly on walls by P (pressure) forces Nozzle accelerates gas by P forces (most large rockets, chem, nuclear, some electric…)
Electrostatic	Ions accelerated by $\vec{E}$ field (a) Electrostatic force (push) on electrodes (Ion engines) (b) Force (push) on magnetic coils through gas $\vec{j}$ (Hall thrusters)
Electromagnetic	Gas accelerated by $\vec{j}\times\vec{B}$ forces Force (push) on coils or conductors (MPD thrusters, PPT's)

16.512 concentrates on Thermal

- Depending on energy source:

- Chemical (always "thermal")
  - Solid Propellant
  - Liquid Propellant
    - Monopropellant
    - Bipropellant
  - Hybrid
- Nuclear (Thermal)
- Nuclear (Electric) — can be Thermal, ES or EM
- Solar (Thermal)
- Solar (Electric) — can be Thermal, ES or EM

16.512 deals mostly with Chemical.

- Depending on Thrust level (per unit mass)

- High thrust ($\geq 1g$) for launch, fast space maneuvering (16.512)
- Low thrust ($10^{-5} - 10^{-2}\ g$) for efficient in-space maneuvers (16.522)

Performance Measures

Specific Impulse $Isp = \frac{F}{\dot{m}g}$ (sec) $\left(\text{or } c = \frac{F}{\dot{m}}\right)$ (m/sec)

Dominant for chem. Rockets, range 200-500 sec
Trade-off vs. mass for EP, range 500-6000 sec

Thermal Efficiency $\eta_{th} = \frac{\text{Jet kinetic power}}{\text{Thermal input power}}$

(Thermal Rockets)
Also for electrical thrusters

$$\eta = \frac{\text{Power to jet}}{\text{Input electrical power}}$$

~ 30-80 %

η_{th}

Very close to 100% in chem. (non-issue) important in solar thermal (60-80%) electrothermal, etc.

Thrust/weight F/W

Very large ~ (20-100) for Chem.
Medium (5-20) for Nuclear
Very low (~10^{-3}) for (Solar, EP, power limited)

Others (design selection factors)

- "Life", most meaningful in total impulse capacity
- Re-start capability
- Throttleability
- Dispersion
- Cost

Rocket Selection Guide (by mission)

1) <u>Non-Space missions</u>	<u>Rocket Type</u>
Atmospheric/Ionospheric Sounding	Solid Propellant, 1-4 stages
Tactical Missile	Solid Prop., 1-2 stages
Medium-Long Range Missiles	Solid or Liquid Prop., 2-3 stages (very high acceleration)
2) <u>Launch to space</u>	Solid, liquid or combinations, 2-4 stages (2-4g) Possible: hybrid, 2-4 stages
3) <u>Impulsive ΔV in space</u> (time-critical maneuvers, energy change from elliptic orbits, plane change from elliptic orbits, non-fuel-limited situations...) $\Delta V \leq 1000$ m/s	Small Solid Prop. (Apogee kick, etc) Bi-propellant (storable) liquids, Monopropellant (storable) liquids, Future: Nuclear thermal
4) <u>Low-Thrust ΔV in space</u> (Mass-limited missions $\Delta V \geq 2000$ m/s non time-critical missions, small, continuous orbit corrections near-circular orbits...)	Solar-electric systems: Arcjets (a bit faster, less Isp) Hall, Ion (slower, higher Isp) PPT (precision maneuvers) Nuclear-electric systems Direct solar-thermal