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**

\[ Isp = \frac{F}{mg} \]  
\[ \text{or} \ c = \frac{F}{m} \]  

(sec) (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

\[ \eta = \frac{\text{Power to jet}}{\text{Input electrical power}} \]
\[ \sim 30-80\% \]

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

**Thrust/weight**  \( F/W \)

Very large \( \sim (20-100) \) 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) **Non-Space missions**
- Atmospheric/Ionospheric Sounding
- Tactical Missile
- Medium-Long Range Missiles

<table>
<thead>
<tr>
<th>Rocket Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Propellant, 1-4 stages</td>
</tr>
<tr>
<td>Solid Prop., 1-2 stages</td>
</tr>
<tr>
<td>Solid or Liquid Prop., 2-3 stages</td>
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<tr>
<td>(very high acceleration)</td>
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</tbody>
</table>

2) **Launch to space**

| Solid, liquid or combinations,       |
| 2-4 stages (2-4g)                    |
| Possible: hybrid, 2-4 stages         |

3) **Impulsive ΔV in space**
- (time-critical maneuvers,
  energy change from elliptic orbits,
  plane change from elliptic orbits,
  non-fuel-limited situations...)
- ΔV ≤ 1000 m/s

| Small Solid Prop. (Apogee kick, etc) |
| Bi-propellant (storable)             |
| Bi-propellant liquids, Monopropellant |
| (storable) liquids, Future: Nuclear thermal |

4) **Low-Thrust ΔV in space**
- (Mass-limited missions ΔV ≥ 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                 |