16.522 Session 1

Missions and Thrusters

Missions Requiring High Thrust

Planetary takeoff

Photo is in public domain from NASA.

Shuttle, Delta, Proton...

Planetary landing

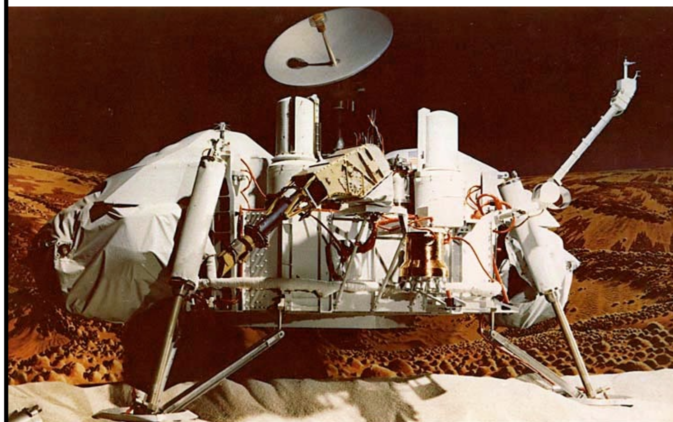

Image is in public domain from NASA.

Viking, Lunar lander...

Rapid maneuvering

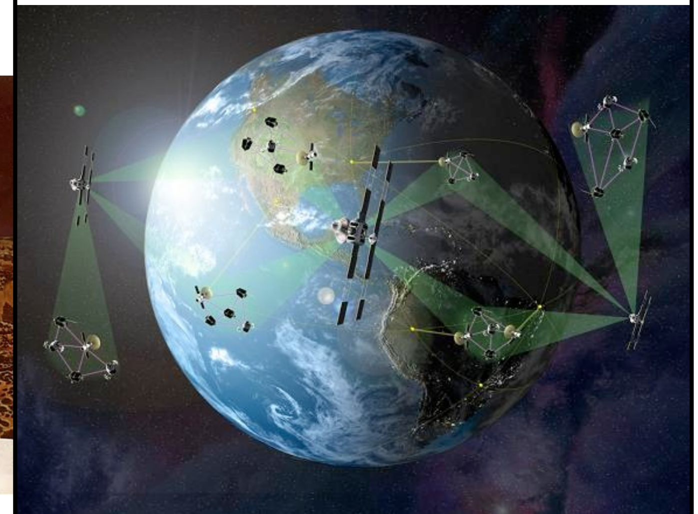

Image is in public domain from DARPA.

Scatter (DARPA F6)...

Apogee kick

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GTO-Escape, STAR motors...

Perigee kick

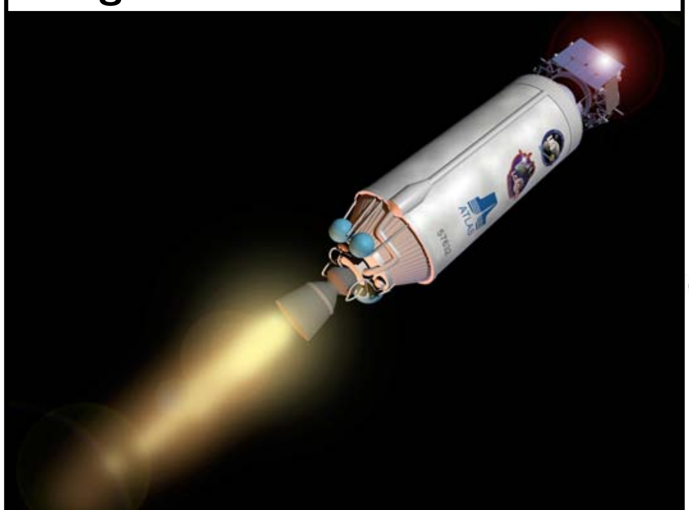
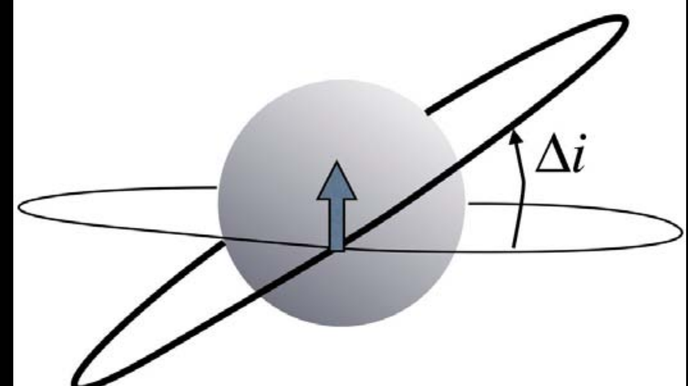


Image is in public domain from NASA.

GTO-GEO' Centaur upper stage

Fast plane change



Missions Requiring High Isp (>1000 sec)

Deep space missions (ΔV > 2 km/s)

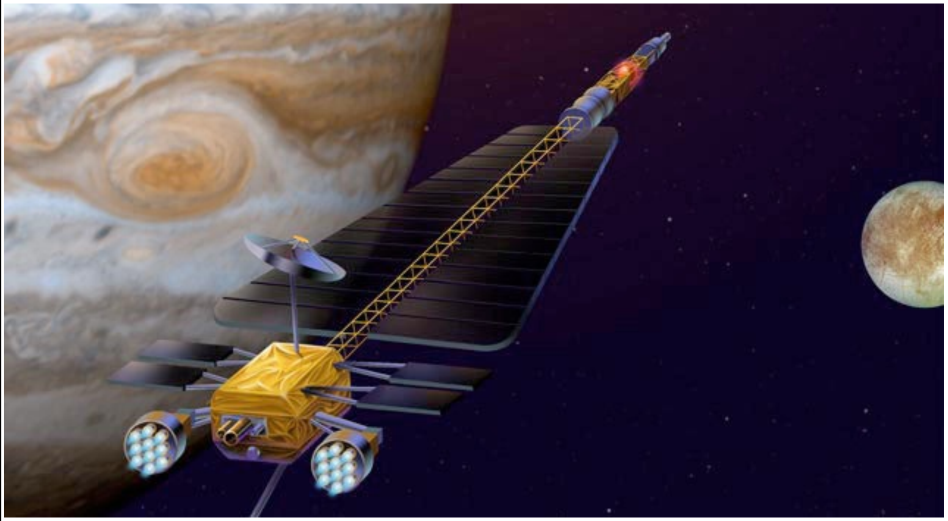


Image is in public domain from NASA.

Planetary explorers, JIMO...

Long-term drag cancellation

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LEO, LMO, LSO, LVO, GOCE...

Long-term formation flight

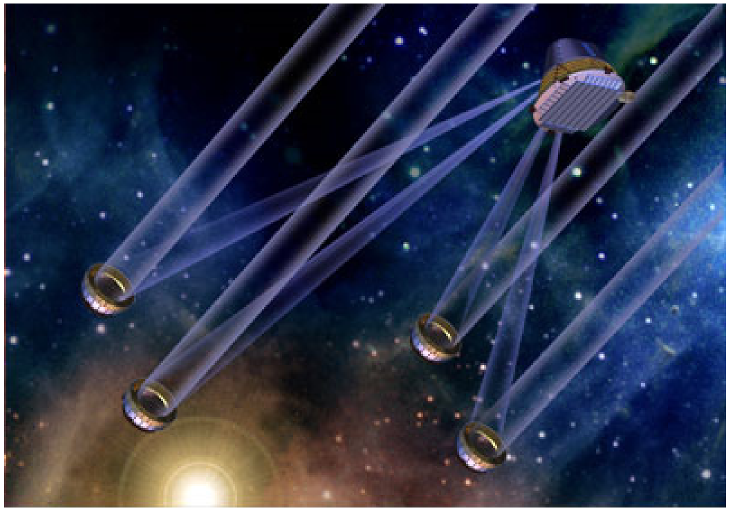


Image is in public domain from NASA.

Interferometers, collaborative, TPF...

Non-Keplerian orbits

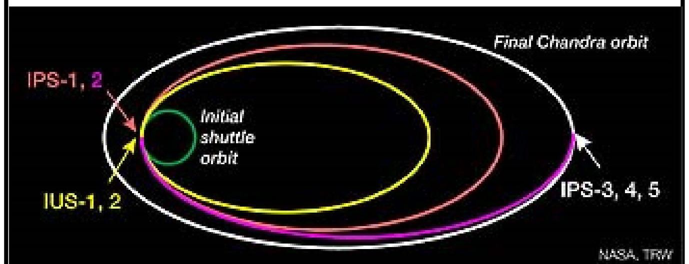
Image is in public domain from NASA.

Parallel to rings of Saturn, Comet chaser...

Missions where high Isp is beneficial

These missions could be done otherwise, but benefit from high Isp propulsion (electric propulsion), some due to their high-power capacity. *Communications, radar, most military satellites.*

Orbit raising



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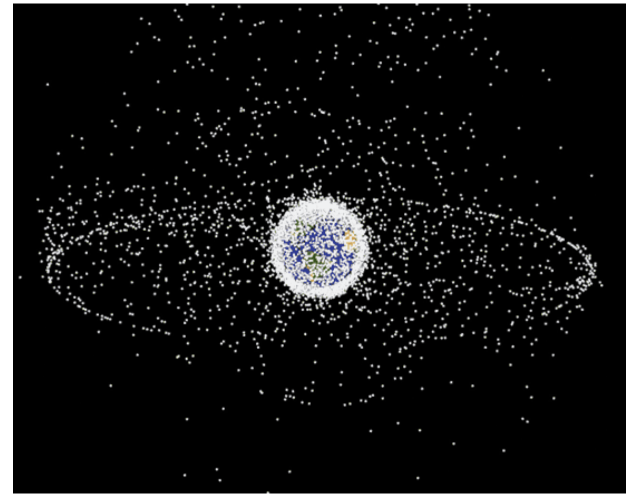
LEO-MEO, LEO-GEO, SMART...

End-of-life de-orbiting



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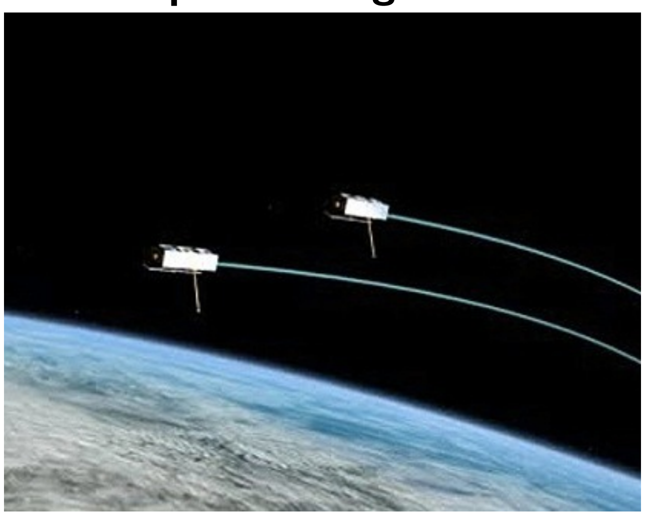
Reduce space debris...

Orbit-repositioning



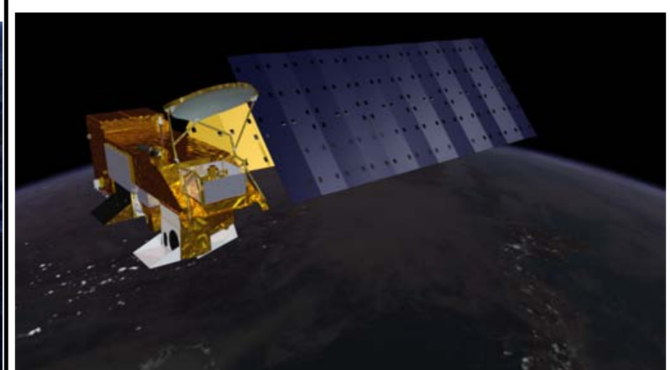
Courtesy of DLR (German Aerospace Center).

Walking, separation, TanDem-X...

Slow plane change

Image is in public domain from NASA.

Orbit corrections



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NSSK, EWD, HS601 (Boeing)...

Chemical Thrusters (1)

Cold-gas thrusters Isp ≈ 40-60 sec F ≈ 0.1 mN → 1 N Reliable and simple Safe (popular in university satellites) Amenable for miniaturization Very limited ΔV (~ 1 m/s) Not appropriate for fine thrusting Inexpensive	PRISMA Cold Gas Experiment Photo removed due to copyright restrictions. Please see the Swedish Space Corporation (SSC) website for ECAPS' 1N (HPGP) engine. Uppsala University, Sweden (0.01-1 mN)
Monopropellants Isp ≈ 230 sec F ≈ 500 mN → 500 N High reliability, large experience base Simple system Capable of pulsing (>10ms, 10^6 pulses) Strict handling processes, fuel warming Limited to small ΔV's Moderate cost	Hydrazine (N_2H_4) Thruster Image removed due to copyright restrictions. Please see the monopropellant rocket engines from Aerojet. Aerojet

Chemical Thrusters (2)

Bipropellants
Isp ≈ 305-325 sec
F ≈ 10 N → 120 kN
Large experience base
Relatively complex
Difficult to pulse, re-startable
Toxic propellants
Better Isp than monoprops
High cost

MMH + N_2O_4 Thruster

Aerojet

Image courtesy of Steve Jurnetson on Flickr. CC license BY.

Solid Propellant
Isp ≈ 280-300 sec
F ≈ 50 N → large boosters
Simple integration (no plumbing)
Light casing (15-20% propellant)
Non-restartable
Potentially dangerous handling
1-5% dispersion in impulse/direction
Moderate to high cost

HTPB/AP Thruster

Image is in public domain from NASA.

ATK STAR Series

Electric Thrusters (1)

Electrothermal
High efficiency, low Isp
Simple, limited by material temperature
With monopropellant, Isp ~ 310 sec
(Intelsat satellites)
With H_2, Isp ~ 700 sec
(storage an issue)
F ≈ 10 N → 100 N
Enables efficient waste disposal (ISS)

Butane/Water Thruster

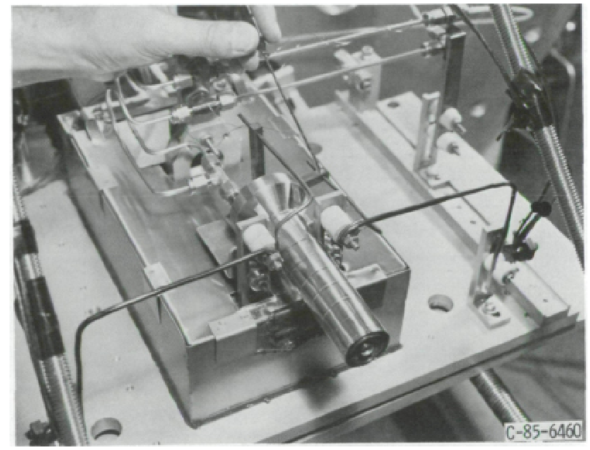
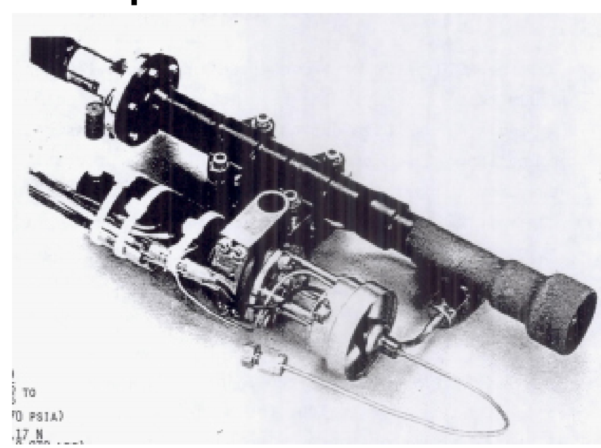


Image is in public domain from NASA.

Surrey (SSTL) ΔV~10 m/s

Arcjets
Efficiency ~ 0.4
Isp ~ 600 s (MMH), 1000 s (H_2)
Power ~ 0.5 → 30 kW (or available)
Close to optimal Isp for some missions
Therefore high F/P
Some flight experience (Telstar)
Relatively simple PPU

Ammonia, Isp = 800 s, 2 N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Aerojet, ARGOS Satellite

Electric Thrusters (2)

Hall Thrusters
Efficiency ~ 0.4 → 0.6
Power ~ 0.05 → 10 kW
Isp ~ 1500 → 1800 sec (up to 3000 s)
Favorable for many missions
Reasonable efficiency, adequate life
Flight experience (Russian thrusters)
Contamination, EMI concerns
Complex PPU

Xenon Low Power Hall Thruster

Image is in public domain from NASA.

Busek BHT-200, 200 W, 1390 s, 44% eff

Ion Engines
Efficiency ~ 0.5 → 0.75
Power ~ 0.05 → 10 kW
Isp ~ 2500 → 4000 sec (7000 s, NASA)
Favorable for high ΔV missions
Good efficiency, adequate life
Flight experience
Very complex PPU
Large, relatively heavy engine

30 cm Xenon Ion Engine

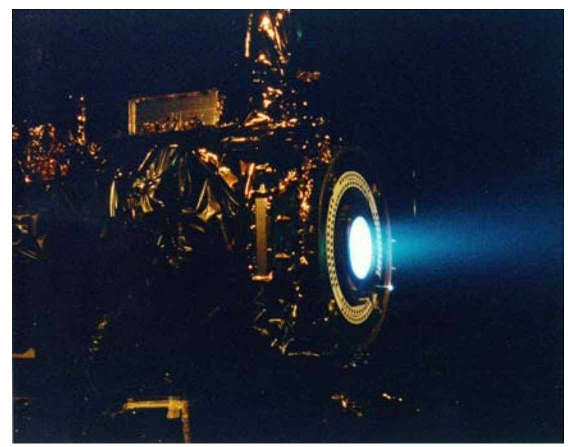

Image is in public domain from NASA.

NASA NSTAR, 1kW, 3900 s, 50% eff

Electric Thrusters (3)

<table>
<tr>
<td>Pulsed Plasma (PPT)
Efficiency ~ 0.05 → 0.1
Power ~ 0.05 → 1 kW
Isp ~ 1000 → 1300 sec
Simple system, solid propellant
Short pulse operation (micro-s)
Controllable pulse rates
Suitable for precision maneuvering
Very low efficiency (large PPU)</td>
<td>70 W, Teflon PPT
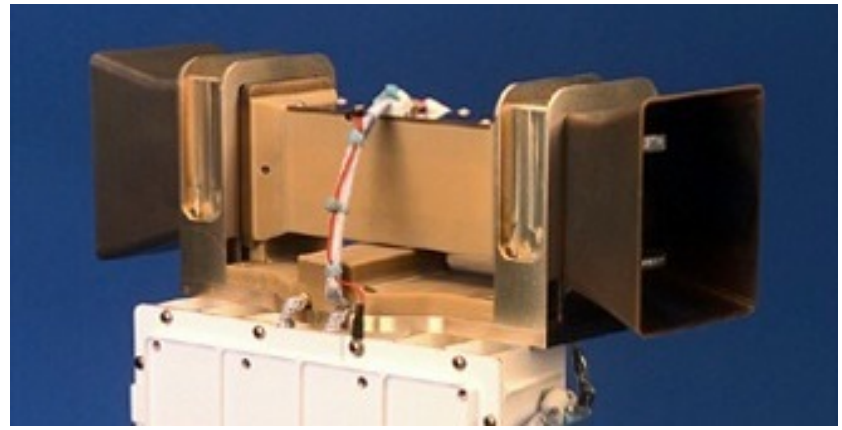
Image is in public domain from NASA.
NASA GRC, 0.86 mN, 1300 s, 8.4% eff</td>
</tr>
<tr>
<td>MPD
Efficiency ~ 0.2 → 0.6(?)
Power ~ 1 MW
Isp ~ 2000 → 6000 sec
Favorable for high power missions
Low efficiency at low/medium power
Steady or pulsed
Heat dissipation challenges
Difficult to test in the ground</td>
<td>Argon MPD
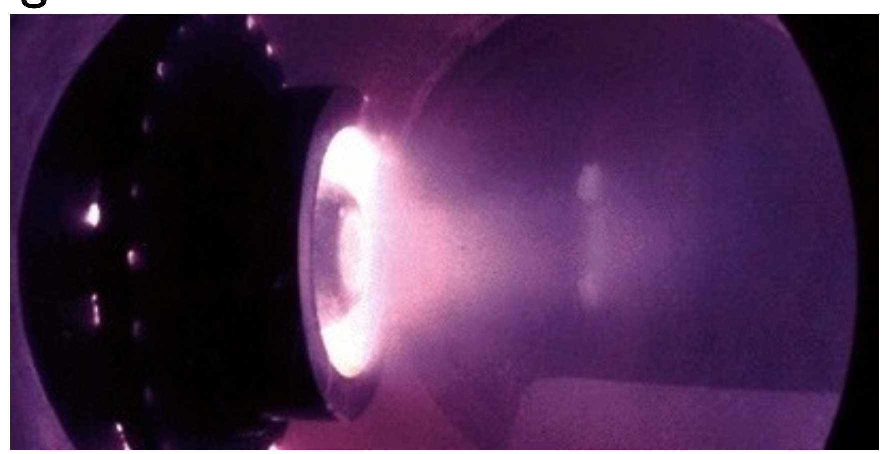
Image courtesy of MIT.
MIT-SPL, Astrovac (GTL)</td>
</tr>
</table>

Electric Thrusters (4)

Electrosprays

Efficiency ~ 0.3 (mixed) → 0.8 (pure)

Power ~ 1 mW → 1 W (scalable)

Isp ~ 200 (droplet) → 4000 sec (ion)

Micro-propulsion technology

Good efficiency

Low TRL

Life limited by corrosion

Bipolar operation

Electrospray Thrusters for CubeSats

MIT-iEPS, 1 W, 3000 s, 80% eff (est.)

FEEP

Efficiency ~ 0.6 → 0.7

Power ~ 10 mW → 10 W

Isp > 6500 sec

Micro-propulsion technology

Requires heat to melt metals

Requires electron neutralizer

Life limited by source erosion

Contamination issues

Array of 3 Indium FEEP Thrusters

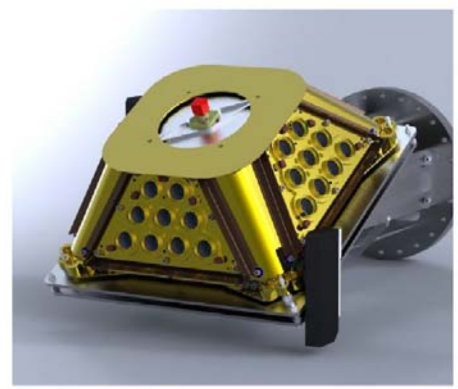

Figure from M. Tajmar and C. A. Scharlemann. "Development of Electric and Chemical Microthrusters." *International Journal of Aerospace Engineering* 2011 (2011): 10. Article ID 361215, doi:10.1155/2011/361215. CC license BY.

ARC, Austria, ~5 W, 6000 s

16.522 Space Propulsion
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