

F from 2.25 lb ($\approx 10\text{ N}$) to 26,000 lb (Shuttle RCS)

Large experience base (but less than monop.)
Relatively complex system
Short Pulsing difficult, but can do re-starts
Toxic propellants
Better Isp than monoprops.
High cost

(1c) Solid Propellant (Aluminized HTPB/AP typically)

$I_{sp} \approx 280 - 300\text{sec}$

F from $\approx 10\text{lb}$ to very large boosters

Simple integration (no plumbing)
Very light casing and inerts ($\approx 15 - 20\%$ of propellant)
Isp comparable to biprops.

Non-restartable

1-5% dispersion in impulse, direction (requires trim engines for precise maneuvers)

Moderate-to-high cost

(2) Electrical Broad range of power and Isp. Cost moderate to high (excluding power systems)

$$\eta = \frac{F^2 / 2\dot{m}}{IV} = \frac{Fc/2}{IV}$$

(2a) Electrothermal (Heated hydrazine, heated H_2 or heated waste gas).

High η , low Isp

Very simple, limited by material T

Can raise monoprop. N_2H_4 to $I_{sp} \approx 310\text{sec}$ (Intelsats)

With H_2 , $I_{sp} \approx 700\text{sec}$ (but storage problems)

Allows efficient waste gas disposal (Space Station)

(2b) Arcjets (with hydrazine, ammonia, H_2)

$\eta \approx 0.4$, $I_{sp} \approx 600\text{s}$ (hydrazine)

700s (ammonia)

1000s (H_2)

P from 0.5 KW to 30 KW (or as available)

Moderately high $F/P = \frac{2\eta}{C}$ (good if mission time limited)

High operating T (thermal isolation difficult)

Efficiency not very high

Some flight experience base (Telstar)

Relatively simple Power Processing Unit (PPU)

(2c) Hall Thrusters (with Xenon propellant)

$$\eta \cong 0.4 - 0.6 \quad I_{sp} \cong 1500s - 1800s \Rightarrow 3000 \text{ (NASA)}$$

P from 0.5KW to 10KW (can be increased)

Isp in very favorable range for many missions (reasonable F/P, good fuel efficiency)

Reasonable efficiency

Some flight experience (mostly in Russia), more coming on many missions

Life adequate

Some concerns on contamination, EMI, interference

Complex PPU

(2d) Ion Engines (with Xe propellant)

$$\eta \approx 0.6 - 0.75 \quad I_{sp} \cong 2500s - 4000s \Rightarrow 7000 \text{ (NASA)}$$

P from 0.3KW to 5KW (can be increased)

Very good efficiency

High ISP good for high ΔV missions

Some flight experience (from 1970's), more coming soon (Hughes' XIPs on Galaxy busses)

Adequate life

Very complex PPU

Large, relatively heavy engine

(2e) Pulsed Plasma Thrusters (PPT's with Teflon propellant)

$$\eta \cong 0.05 - 0.1 \quad I_{sp} \cong 1000 - 1200\text{sec}$$

P from 0.1 to 1 KW

Very short (μs) pulses, widely controllable pulse rate

Excellent for precise maneuvering

Solid fuel, very simple systems

Very low efficiency

Difficulty handling large propellant mass

Some flight experience (VELA satellites), more coming

(2f) Colloid Engine, Field Emission Electrostatic Propulsion (FEEP)

Very small unit power (from $F \sim 0.1 \mu N$, $P \sim 0.5 \text{ mW}$)

Ideal for high precision missions

Isp from	500 s to 1500 s	(colloid)
	2000 - 6000 s	(colloid in ion - emitting mode)
	6000 s FEEP	(liquid metal)

Can be multiplexed for mN Thrust.

Relatively heavy ancillary components