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Cubesat Propulsion Systems in Space: A Technology Review of Miniaturized in-Space Propulsion

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Abstract — Propulsion has long been the most difficult subsystem to fit inside a CubeSat. The earliest CubeSats carried no propellant at all — they accepted whatever orbit they were placed in and relied on passive stabilisation to function. That works for simple missions, but it falls apart the moment you need to change your orbit, hold a precise formation, dodge a piece of debris, or come back down in a controlled way. This paper reviews the five propulsion technologies that come up most often in CubeSat mission design: cold-gas thrusters, resistojets, pulsed plasma thrusters (PPTs), electrospray ion engines, and solar sails. For each one, the underlying physics, real performance numbers, flight history, and practical limits inside a CubeSat are examined. The paper then covers delta-v budgeting at the mission level, the regulatory constraints that propulsion adds to a CubeSat program, and where the field is headed in the near term.

Keywords— CubeSat; nanosatellite; in-space propulsion; electric propulsion; cold gas; solar sail; electrospray; delta-v

I. INTRODUCTION

CubeSats are small, standardised satellites built around units (U) of 10 × 10 × 10 cm. They have made space access far cheaper and faster, allowing universities, startups, and national space agencies to run missions that would have been out of reach a decade ago. But one problem has followed them from the beginning: propulsion. The first generation of CubeSats carried no propellant. They were released into orbit, pointed themselves with magnetorquers or reaction wheels, and transmitted data until their batteries died or their orbit decayed naturally. For a short technology demonstration, that is often enough. For anything more ambitious, it is not.

If a CubeSat needs to raise its orbit, it needs thrust. If it needs to maintain a fixed separation from another satellite in a formation, it needs fine, repeatable thrust. If it needs to avoid a collision on short notice, it needs thrust available immediately. And if regulations require it to deorbit within 25 years of mission end — which they increasingly do — it again needs thrust. All of that has to fit inside a box that might weigh less than 4 kg and run on a few watts of solar power.

This paper looks at the propulsion options that are actually used or seriously considered for CubeSats: cold-gas thrusters, resistojets, pulsed plasma thrusters, electrospray ion engines, and solar sails. Each technology is examined from first principles through to flight heritage and practical constraints (Lemmer, 2017; Tsay et al., 2019). The paper then addresses mission-level delta-v planning and the regulatory side of flying a propulsive CubeSat, before closing with an outlook on where the technology is going.

II. PROPULSION FUNDAMENTALS

1. The Rocket Equation

Every propulsion system, whatever its working principle, obeys the Tsiolkovsky rocket equation (Tsiolkovsky, 1903):

$$\Delta v = Isp \cdot g_0 \cdot \ln(m_0 / mf)$$

Here, Δv is the total velocity change the spacecraft can achieve (m/s), Isp is specific impulse in seconds, g_0 is standard gravity (9.81 m/s²), m_0 is the initial wet mass, and mf is the dry mass after propellant is exhausted. The logarithm means that Isp has an outsized effect: doubling Isp is far more valuable than doubling propellant mass.

To put numbers to this: a 3U CubeSat with a wet mass of 4 kg and 0.5 kg of propellant has a mass ratio of 1.143. At an Isp of 65 s — typical of cold gas — that gives roughly 85 m/s of Δv, enough to compensate for a year or two of atmospheric drag but not much else. The same 0.5 kg of propellant in an electrospray thruster running at 2,000 s Isp would theoretically yield over 2,600 m/s — enough for orbit transfers and deep-space trajectories (Krejci & Lozano, 2018). Isp is not an abstract number; it is the single most important figure of merit in propulsion selection.

2. Thrust and Specific Impulse Trade-off

High Isp always comes at a cost: low thrust. Electric thrusters achieve their efficiency by accelerating ions to very high exhaust velocities, but the amount of mass they can push through in a given time is tiny — limited directly by how much electrical power is available. A 3U CubeSat might sustain 3 to

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5 watts on average. That is not much. The result is that electric thruster outputs are measured in micro-Newtons to milli-Newtons, which means manoeuvres that a chemical thruster completes in seconds can take an electric thruster days or weeks of continuous firing (Krejci & Lozano, 2018).

This trade-off shapes every propulsion decision on a CubeSat. A mission that needs to respond quickly — say, to avoid a predicted collision — cannot rely solely on an electric thruster. A mission that needs to accumulate hundreds of metres per second of Δv over months cannot afford the propellant mass a cold-gas system would require. Understanding where a mission sits on the thrust-versus-efficiency spectrum is the starting point for any propulsion trade study.

III. CUBESAT PROPULSION TECHNOLOGIES

1. Cold Gas Thrusters

Cold gas thrusters are the most straightforward propulsion system in spaceflight. A tank of compressed inert gas — typically nitrogen, butane, or a refrigerant such as R-236fa — is connected to a solenoid valve and a converging-diverging nozzle. When the valve opens, the gas expands through the nozzle and produces thrust. There is no combustion, no ionisation, and no heating. The only energy stored is the pressure in the tank.

The advantages are real: cold gas systems are mechanically simple, respond in milliseconds, and use propellants that no launch provider will object to. The PRISMA formation-flying demonstration and Surrey Space Centre's SNAP-1 nanosatellite both flew cold gas systems without incident (Tsay et al., 2019). The limitation is equally real: Isp sits between 50 and 80 s, which means that for any mission requiring more than about 100 m/s of Δv, the propellant mass becomes impractical for a CubeSat. Cold gas makes sense for attitude control, short station-keeping periods, and situations where simplicity and reliability matter more than efficiency.

2. Resistojets

A resistojet is essentially a cold gas thruster with a heater added upstream of the nozzle. The propellant — water, ammonia, or occasionally a hydrazine blend — passes over an electric heating element before it expands through the nozzle. The added heat raises the enthalpy of the flow and increases Isp to the 100–300 s range, without requiring any ionisation or high-voltage power conditioning (Rafalskyi & Aanesland, 2020).

Water resistojets have attracted particular interest for CubeSats. Water is non-toxic, non-flammable, and can be stored as a liquid at room temperature — properties that make launch vehicle providers considerably more cooperative. The Pale Blue water resistojet has been demonstrated on 6U CubeSats, delivering around 150 s Isp and 1–15 mN of thrust while consuming 5–15 W. That power demand is achievable on a 6U platform with deployed solar panels. Resistojets occupy a useful middle ground: more efficient than cold gas, simpler than electric propulsion, and with a propellant safety profile that does not complicate integration (Rafalskyi & Aanesland, 2020).

3. Pulsed Plasma Thrusters (PPTs)

Pulsed plasma thrusters work by discharging a capacitor bank across the face of a solid Teflon (PTFE) propellant rod. The electrical discharge ablates a thin layer of Teflon, ionises the resulting plasma, and accelerates it electromagnetically through the Lorentz force (J × B). Each pulse ejects a very small mass at high velocity, giving Isp values of 500–1,500 s, though the average thrust is correspondingly tiny: 1–100 μN (Lemmer, 2017).

PPTs have been flying on small satellites since 1964, when Zond-2 carried one into deep space. More recently, university CubeSat programs at Utah State University (FalconSAT-3) and elsewhere have flown PPT systems. Their appeal is straightforward: solid propellant means no pressurised tanks, no fluid management, and no leak paths. A complete PPT unit can weigh under 100 g. The pulse-by-pulse operation also fits naturally with the intermittent power of a small solar panel. The downside is that accumulating meaningful Δv takes a very long time at these thrust levels (Tsay et al., 2019).

4. Electrospray / Ion Thrusters

Electrospray thrusters — also called field emission electric propulsion (FEEP) or ionic liquid electrospray thrusters — are the most propellant-efficient option available at the CubeSat scale. They work by applying a strong electric field between a sharp emitter tip wetted with ionic liquid propellant and an extractor electrode. The field is strong enough to pull ions directly off the liquid surface and accelerate them to exhaust velocities of 20–60 km/s, corresponding to Isp values of 2,000–6,000 s (Krejci & Lozano, 2018).

MIT's Accion Systems (now part of CesiumAstro) produced the TILE thruster — a chip-scale array of electrospray emitters that fits in a package under 100 g, draws about 3 W, and delivers 100 μN at roughly 2,000 s Isp (Accion Systems, 2021). NASA's Busek BIT-3 RF ion thruster reached 1.15 mN at 2,150 s Isp during the TEMPEST-D validation (Busek Co., 2020). The

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main engineering challenge is power conditioning: the emitter-extractor voltages run from 1,000 to 10,000 V, and getting a high-voltage power processing unit down to CubeSat mass and volume without sacrificing efficiency remains an active area of development.

5. Solar Sails
Solar sails are in a different category from the other technologies in this paper — they carry no propellant at all. Instead, they use radiation pressure: photons from the Sun exert a small but continuous force on a large, highly reflective membrane. At 1 AU, radiation pressure is approximately 4.56×10^{-6} N/m². A 32 m² sail on a 6U CubeSat produces around 0.15 mN of thrust. That sounds small, and it is, but it never stops. As long as the sail is deployed and sunlit, Δv accumulates without consuming any propellant.

The Planetary Society's LightSail 2 mission proved this was not just theory. Launched in 2019, it deployed a 32 m² sail from a 3U CubeSat and raised its apogee by 3.2 km over 30 days of solar sailing before deliberately deorbiting (Spencer et al., 2021). The practical constraints are real: the sail cannot produce thrust in eclipse, pointing must be maintained precisely, and the membrane — typically 2–5 μm of aluminised Mylar — is vulnerable to micrometeoroid puncture. Solar sails are not a general-purpose propulsion system, but for the right mission — slow, continuous, long-duration, propellant-free — they are genuinely compelling.

Table 1. Comparative performance parameters of CubeSat-compatible propulsion technologies. TRL = Technology Readiness Level (NASA scale 1–9).

IV. MISSION DELTA-V BUDGETING

1. Typical Δv Requirements
A mission Δv budget adds up every manoeuvre the spacecraft must perform across its operational life. For a 3U CubeSat in a 500 km circular orbit, three categories dominate: drag compensation, collision avoidance, and deorbit (Tsay et al., 2019).

Atmospheric drag at 500 km costs roughly 15–30 m/s per year, depending on where the Sun is in its activity cycle. A five-year mission accumulates 75–150 m/s from drag alone. A controlled deorbit manoeuvre to lower perigee enough for rapid natural re-entry adds another 50–100 m/s. A margin for collision avoidance is typically 15–30 m/s. Total: 150–280 m/s, depending on mission length and solar conditions.

That number drives the propulsion trade. A cold gas system at 65 s Isp needs to put 36.5% of the satellite's initial wet mass into propellant to deliver 200 m/s — completely impractical for a 3U platform. An electrospray system at 2,000 s Isp needs only about 1% of the initial mass for the same Δv. This is why electric propulsion is not just preferred for long-duration CubeSat missions — it is often the only option that fits (Krejci & Lozano, 2018).

2. Technology Selection Criteria
Choosing a propulsion system is not just about picking the highest Isp. The operational context matters as much as the efficiency numbers. A mission that needs to execute an avoidance manoeuvre within hours of deployment cannot rely on an electric thruster that takes days to accumulate meaningful Δv — it needs the immediate, high thrust of a cold gas system, even at low efficiency. A constellation mission that needs to phase satellites into slots over several weeks can afford the slow, efficient push of an electrospray thruster. A solar sail mission only makes sense if the mission can tolerate thrust interruptions every orbit during eclipse, and if attitude control during sailing has been budgeted for (Lemmer, 2017).

In practice, the selection criteria are: required Δv, required thrust level and response time, available power, propellant safety class, available volume and mass, and the regulatory environment of the launch. These constraints together usually narrow the field to one or two realistic options.

V. REGULATORY AND SAFETY CONSIDERATIONS

Adding propulsion to a CubeSat changes its regulatory profile substantially. Most CubeSats fly as secondary payloads on rideshare launches, where the launch provider's primary concern is that nothing on the secondary payload can harm the primary payload or the vehicle. Propulsion introduces new risks: pressurised vessels, flammable or toxic propellants, and components that could fragment if they fail. Launch providers have strict rules about all of these.

Compressed gas tanks must meet pressure-vessel safety requirements, often including burst discs rated to at least 1.5 times operating pressure. Flammable propellants — and in many cases any propellant the provider classifies as hazardous — require dedicated integration procedures that most CubeSat programs cannot support. Hydrazine, despite being highly efficient and widely used on larger spacecraft, is toxic and carcinogenic, and it is generally not accepted on rideshare CubeSat missions without exceptional justification (Lemmer,

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2017). Water, ionic liquids, and inert gases are the propellants that survive the scrutiny most often.

The debris mitigation side is increasingly important. The IADC guidelines recommend that spacecraft deorbit within 25 years of end of mission (IADC, 2007). For CubeSats above roughly 600 km, natural orbital decay does not reliably meet that target. The US FCC now requires satellite operators to submit a deorbit plan as part of their radio frequency licence application. That requirement pushes CubeSat designers toward including at least a small propulsion system capable of a deorbit manoeuvre — which in turn feeds back into the propellant selection and tank design from the very beginning of the project.

VI. NOTABLE FLIGHT HERITAGE

Table 2 lists selected missions that have demonstrated CubeSat propulsion in flight. A few are worth discussing in more detail. SNAP-1, launched by Surrey Space Centre in 2000, was one of the earliest demonstrations of propulsion on a nanosatellite-class platform. FalconSAT-3 from the US Air Force Academy was the first 3U-class satellite to fly a PPT. LightSail 1 and LightSail 2 from The Planetary Society marked the first deployment and first orbit-raising demonstration of a CubeSat solar sail, respectively. MarCO A and B, built by NASA JPL, became the first CubeSats to reach another planet, flying past Mars during the InSight lander's entry in 2018 using cold gas propulsion (Klesh et al., 2018). CAPSTONE, launched in 2022, placed a CubeSat into a lunar near-rectilinear halo orbit using a hydrazine blowdown system — the most demanding CubeSat propulsion mission to date (NASA, 2022).

Table 2. Selected CubeSat missions demonstrating in-space propulsion. TPS = The Planetary Society; USAFA = US Air Force Academy.

Future Outlook

Three trends are converging in CubeSat propulsion development. The first is miniaturisation of electric propulsion. Electrospray emitter arrays are now being fabricated using MEMS processes on silicon wafers, with some designs fitting a complete propulsion unit — thruster, propellant, and power conditioning — below 50 g while delivering Isp above 3,000 s (Nanoavionics, 2023). This is a significant shift: propulsion that previously required a dedicated 1U module is approaching integration as a subsystem within the structure itself.

The second trend is propulsive attitude control. Separating propulsion from attitude control hardware — having a thruster system for Δv and a reaction wheel or magnetorquer system for pointing — adds mass and complexity. Several groups are developing thruster configurations that serve both functions simultaneously, using differential thrust across multiple nozzles or emitters. If this approach matures, it could remove the need for dedicated attitude control hardware on many CubeSat missions.

The third trend is in-orbit refuelling. Currently being explored for larger platforms, the concept of shared propellant depots in orbit could eventually allow CubeSat constellations to top up propellant after launch, decoupling mission lifetime from the propellant mass that can be fit within the launch mass budget. This is further away than the first two trends, but the underlying physics and orbital mechanics are straightforward, and the economics of large constellations make it increasingly attractive.

On the more speculative side, photonic laser propulsion — where a ground-based laser ablates material from a reflective sail to push a spacecraft — has been proposed under the Breakthrough Starshot initiative as a route to interstellar flight at significant fractions of the speed of light. The engineering challenges are enormous and the timescale is measured in decades, but the physics that LightSail 2 demonstrated is the same physics at a vastly different scale.

VII. CONCLUSION

CubeSat propulsion has moved from a curiosity to a core requirement. The first generation of CubeSats got by without it. The current and next generation largely cannot, because the missions they are being asked to do — orbit maintenance, formation flying, collision avoidance, controlled deorbit — all demand thrust.

Each technology reviewed in this paper occupies a different part of the performance space. Cold gas systems are simple, reliable, and safe, but their low Isp makes them unsuitable for missions with significant Δv requirements. Resistojets improve efficiency while keeping the propellant simple and launch-safe. PPTs offer high Isp from a solid propellant with no fluid systems, at the cost of very low average thrust. Electrospray thrusters deliver the highest Isp available at CubeSat scale, enabling missions that would be impossible with any other technology, but they demand careful power conditioning and are still maturing in terms of flight heritage. Solar sails prove that propellant-free propulsion works in practice, not just in theory, but they are only applicable to a specific class of missions.

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No single technology is the right answer for all CubeSats. The correct choice depends on the Δv budget, the required thrust response time, the available power, the regulatory constraints of the launch, and the mass and volume left over after the payload is accounted for. As the ecosystem continues to mature and more propulsion systems accumulate flight heritage, propulsive capability is likely to become a standard feature of CubeSat platforms — extending what these small satellites can do and continuing the broader trend of making space access available to a wider range of organisations and missions.

REFERENCES

1. Accion Systems. (2021). TILE Electrospray Thruster Product Datasheet. Accion Systems, Inc.
2. Busek Co. (2020). BIT-3 RF Ion Thruster Specification Sheet. Busek Space Propulsion.
3. IADC. (2007). IADC Space Debris Mitigation Guidelines (Rev. 1). Inter-Agency Space Debris Coordination Committee.
4. Klesh, A., Clement, B., Colley, C., Essmiller, J., Forgette, D., Krajewski, J., Marinan, A., Martin-Mur, T., Steinkraus, J., Sternberg, D., Werne, T. & Young, B. (2018). MarCO: Early operations of the first CubeSats to Mars. 32nd Annual AIAA/USU Conference on Small Satellites, SSC18-WKIX-04.
5. Rafalskyi, D. & Aanesland, A. (2020). Assessment of a micropropulsion system unifying water ion thrusters and water resistojet thrusters. Journal of Spacecraft and Rockets, 57(3), 539–550.
6. Krejci, D. & Lozano, P. (2018). Space propulsion technology for small spacecraft. Proceedings of the IEEE, 106(3), 362–378.
7. Lemmer, K. (2017). Propulsion for CubeSats. Acta Astronautica, 134, 231–243.
8. Tsay, M., Lafontaine, J. & Hohman, K. (2019). Survey and performance evaluation of small-satellite propulsion technologies. Journal of Spacecraft and Rockets, 56(5), 1510–1523.
9. Nanoavionics. (2023). CubeSat Propulsion Module EPSS Technical Manual. NanoAvionics UAB.
10. NASA. (2022). CAPSTONE Mission Overview: Lunar Navigation Technology Demonstration. NASA Ames Research Center.
11. Spencer, D.A., Betts, B., Bellardo, J.M., Diaz, A., Plante, B. & Mansell, J.R. (2021). The LightSail 2 solar sailing technology demonstration. Advances in Space Research, 67(9), 2878–2889.
12. Tsiolkovsky, K. E. (1903). Exploration of outer space by means of rocket devices. Science Review, 5.

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