Electrifying delta-v for the Space Force

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A little-noticed patent concerning propellantless space propulsion technology issued in late 2022 could lead to a remedy for key deficiencies in Space Force capabilities and transform the US space enterprise in the areas of orbital maneuver, proximity operations, and especially survival against pacing threats. Drawing from publicly released information, patent filings, presentations, interviews, and personal conversations with the author, this article investigates electric thrust—apparently from zero point fluctuations—which enables unlimited freedom of maneuver and non-Keplerian orbits, presents intractable problems for attackers, and obviates the need for on-orbit refueling. Such technology is key to meeting the Space Force's objectives for a resilient and effective force.

Urgently-needed improvements in maneuverability and survivability of assets in space are directly related to the need for improved on-demand propulsive acceleration, or delta-v. This in turn is tied to the availability of propellants for on-orbit maneuvering thrusters, which has long been the limiting factor for evasion from attack, avoidance of orbital debris hazards, retasking to support operations, and end-of-life disposal. The clear requirement is for increased on-orbit propulsive capability, which is presumed to require providing more propellant and using it more efficiently. But is this the only answer?

US patent #11511891 represents a breakthrough in propellant-less propulsion, replacing traditional thrusters with electromagnetic forces generated by a revolutionary "physics package" employing a divergence of electric fields.[1] This effect—demonstrated repeatedly in laboratories and under vacuum conditions—is the climax of a century-long pursuit of all-electric propulsion based on asymmetric capacitors. Starting in the 1920s, American scientist T. Townsend Brown and his many successors have repeatedly produced tantalizing evidence of a link between the forces of electromagnetism and gravity. Theoretical understanding has been lacking, however, preventing engineering improvements that might allow laboratory one-offs to achieve practical utility.

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1. Andrew Neil Aurigema and Charles Raymond Buhler IV, System and Method for Generating Forces Using Asymmetrical Electrostatic Pressure, US Patent 11511891B2, filed 19 November 2019, and issued 29 November 2022, https://patents.google.com/patent/US11511891B2/en.

Background

This understanding changed when, in the period from 2020 to 2021, researchers in Florida moonlighting from the US space program established the equations of force that result from diverging electric fields. No magnetism is involved, only high electric field intensities created by electric charges at high voltages but extremely low currents, thus consuming astonishingly little power. The resulting implementation and its related patent claims went through 12 months of scrutiny by both the National Aeronautics and Space Administration (NASA) and the Defense Department prior to the United States Patent and Trademark Office issuing a foundational utility patent—not merely a provisional one—to the inventors, NASA physicist Charles Buhler and engineer Andrew Neil Aurigema, who started Exodus Propulsion Technologies LLC to further develop and commercialize this revolutionary technology. Lab-scale prototypes are currently producing thrust levels suitable to satellite propulsion (millinewtons, mN) and are scalable, while ongoing materials research and efficiency improvements have steadily raised thrust levels and thrust-to-weight ratios achieved.[2]

Such propulsion is a major advance over currently available thrusters. Because these use electric fields to ionize and accelerate propellant rather than heating via conventional chemical reactions, such thrusters are often marketed as "electric." This is misleading, however, since these electric ion thrusters are still just rockets, entirely dependent on propellant and useless once their supply runs out. The truly all-electric propellantless devices can never run out of fuel because they simply do not use any. The devices' specific impulse—the conventional metric for rocket engine efficiency—would technically be calculated as infinity. Once charged up, Exodus devices continue to generate a force as long as the charge remains, much like electrostatic repulsion—the Coulomb force, or the amount of force between two electrically charged particles—remains as long as like charges are present.

Buhler has led the development of the theory behind the Exodus technology. He leads NASA's electrostatics and surface physics lab at the Kennedy Space Center, where his team addresses mitigation measures for lunar dust, among other things. After over 30 years of studying electromagnetic theory as it might apply to propellantless propulsion, Buhler co-founded Exodus, where he serves as chief scientist.

After the company recently emerged from years in "stealth mode," Buhler is now discussing his theory and how it fits within currently accepted foundations of physics.[3] He and Aurigema discovered that a force occurs in the presence of intense but diverging electric fields resulting from a unique, separate manipulation of embedded and mobile electric charges. Significantly, these researchers have achieved the ability to model their

2. Author's personal communications with Charles R. Buhler and Andrew N. Aurigema.

3. See, for example, Christopher Plain, "NASA Scientist Says Patented 'Exodus Effect' Propellantless Propulsion Drive That Defies Physics Is Ready to Go to Space," *The Debrief*, 19 July 2024, https://thedebrief.org/.

devices computationally, reflecting a theory which led to designs that produce experimental results as predicted—all are in agreement.

In recent years, other claims of propellantless thruster inventions have appeared. Much attention was attracted beginning in 2001 by the so-called EmDrive, an asymmetric resonant microwave cavity.[4] Claims of thrust generation were exhaustively tested by Dresden University of Technology; no net thrust was found, and no further work appears to be occurring on this device.[5] An offset-rotating mechanical device, called a centrifugal impulse drive, is claimed to produce net thrust without propellant. It was exhibited for the first time at the SpaceCom 2024 conference by Quantum Dynamics Enterprises Inc., but no patent has been issued and no demonstration in vacuum has been performed so far.[6] Finally, the IVO Limited company recently has claimed an all-electric "quantum drive" with similar properties to the Exodus thruster, though no patent has been granted.[7]

Implications

Assuming eventual success of propellantless thruster technology, the implications for space applications are simply immense, and for the specific needs of the Space Force, they are immediately game-changing. These include the following: the implications for meeting current requirements, the entirely new capabilities which become possible, and the additional possibilities that can be expected from further engineering improvements in taking advantage of new physics devices which can produce thrust indefinitely with little or very little power input.

The prospect of unlimited freedom to maneuver presents intractable problems for an attacker, no matter what anti-satellite weapon is used. Ground-based lasers, jammers, and missiles all require their operators to first pick out their target from among an increasingly bewildering cosmos of satellites of all kinds, with as many as 48 more being added by a single SpaceX launch. The one exploitable weakness an attacker can depend on today is the predictability of the orbit of its target. But propellantless propulsion enables "maneuver without regret," allowing constant orbital modifications without cost, making literally every overhead pass different from the one before.[8]

Space-based or co-orbital attackers will face the same problem, and limited by their own fuel, they will have little hope of chasing down a constantly accelerating and decelerating target. By thus complicating the enemy's targeting challenges, what one analysis

4. emdrive.com (website), accessed 2 February 2025, http://www.emdrive.com/.

5. Martin Tajmar, Marcel Weikert, and Oliver Neunzig, "High-Accuracy Thrust Measurements of the EMDrive and Elimination of False-Positive Effects," *CEAS Space Journal* 14 (2022), https://link.springer.com/.

6. Quantum Dynamics Enterprises Inc. (website), accessed 23 May 2024, https://qde-inc.com/.

7. IVO Limited (website), accessed 30 January 2025, https://ivolimited.us/.

8. See Brigadier General Kristin L. Panzenhagen, program executive officer for the Assured Access to Space directorate, as qtd. in Greg Hadley, "Dynamic and Responsive: Space Force Leaders Plan for a New Kind of Operations," *Air & Space Forces Magazine*, 20 December 2023, https://www.airandspaceforces.com/dynamic-responsive-space-force-operations/.

calls "maneuver warfare in space" can be fully exploited.[9] This could include "super-orbital" vehicles traveling faster than orbital mechanics require, accelerating Earth-ward to maintain a circular path while outrunning threats.

Likewise, proximity operations in space become vastly more practical when the maneuvering fuel budget is a thing of the past. Fly-by inspections, rendezvous for repairs and upgrades, and even debris cleanup missions will be affordable. There will be no need to invest in on-orbit refueling: no tankers, no fuel depots, no fill ports, or tricky handling of liquids. The Space Force has been preparing for such a future, marshalling resources and alerting industry to anticipated needs for extra fuel sources on orbit.

More recently, however, public statements by Chief of Space Operations General B. Chance Saltzman indicate second thoughts about the economics of refueling in a future paradigm which will also emphasize proliferating small satellites.[10] These are intended to be replaced frequently so as to enable frequent technology refresh, but this short design life makes the idea of refueling questionable. As a *SpaceNews* analysis noted shortly after General Saltzman's remarks, "Redesigning these satellites [adding fill ports] for a 15-year design life so they can be refueled would compel the US Space Force to rely on absurdly obsolete computers for most of the satellites' orbital life."[11] Satellite refueling ports are not free and have not even been demonstrated in space yet, and fluid transfer in zero-g is considered risky by some. Skeptics argue that without refueling, even cheap satellites will last for years, and the Space Development Agency's Proliferated Warfighter Space Architecture constellation's satellites are designed for at least five years on orbit.[12] How long should Space Force satellites really last?

Yet, there are clear exceptions, such as expensive spy satellites and large geosynchronous equatorial orbit satellites, as both General Saltzman and the head of Space System Command's Commercial Space Office have emphasized.[13] Contrary to the commercial world, some of the Pentagon's needs do not change that much. So long as an asset remains useful and continues to operate, why not leave it in service? Thus, the need for extended maneuvering ability is not exactly the same as the need for additional propellant. These have been synonymous in the past, but with propellantless electric thrusters the Space Force can buy only what it needs. If fuel-based thrusters are about to become dinosaurs, it is best that the Space Force recognize this before over-investing in an obsolescent paradigm.

9. Christopher Stone, *Maneuver Warfare in Space: The Strategic Mandate for Nuclear Propulsion* (Mitchell Institute for Aerospace Studies, 2022), https://mitchellaerospacepower.org/.

10. Sandra Erwin, "Saltzman: Space Force Still Grappling with Refueling Math," *SpaceNews*, 30 April 2024, https://spacenews.com/.

11. Charles Beames, "Why the Math on Refueling Just Doesn't Add Up," *SpaceNews*, 9 May 2024, https://spacenews.com/.

12. Josh Luckenbaugh, "JUST IN: Space Development Agency Preparing for New Satellite Solicitations," *National Defense*, 19 November 2024, https://www.nationaldefensemagazine.org/.

13. Colonel Rich Kniseley, as qtd. in Sandra Erwin, "Space Force Plans Deep-Dive Study on Pros and Cons of Orbital Refueling," *SpaceNews*, 20 May 2024, https://spacenews.com/.

It may be that "it is already much cheaper to build and launch new satellites than it is to refuel them," but this takes no account of survivability.[14] The point of maneuvering Space Force assets is not merely to remain in a desired stable orbit but to remain alive in wartime. The conventional expectation of three-to-five-year satellite lifetimes will only apply in peacetime. Thus, for reasons of both practical economics and wartime resilience, Space Force assets need maneuvering capacity without the logistical burden of fuel infrastructures in orbit. With propellantless thrusters, the Space Force can have the best of both worlds.

In addition, the replacement of propellant tanks in satellite designs with compact electric propulsion will reduce overall vehicle size and weight. Based on the current state of the art, Exodus thrusters are of a size comparable to conventional thrusters of the kind commonly used today for the same thrust level, while eliminating fuel tanks entirely. For example, a Busek model BHT-600 Hall thruster offering 40 mN weighs 2.6 kilograms (kg) and is typically paired with 100 kg or more of propellant. The benefits of this alone are huge, starting with launch costs and including less obvious advantages such as reduced satellite cross section. The latter translates into reduced susceptibility to being struck by orbital debris or a deliberate pellet ring attack, in addition to being a smaller target for any other weapon.

Applied to current systems under development, these benefits could be enjoyed by the Joint All-Domain Command and Control constellations, the Evolved Strategic Satellite Communications system, and others on the way. Fortunately, the Space Force anticipated the likely opportunities that emerging technologies would offer for these major programs, and the acquisition strategies facilitate tech insertion throughout the systems' production lifetime.

Nuclear Thermal Rocket Alternative

This new technology's advantages contrast dramatically with long-advocated nuclear thermal rocket (NTR) propulsion, a technology approach being advanced by the Defense Advanced Research Projects Agency (DARPA) under a program dubbed DRACO (Demonstration Rocket for Agile Cislunar Operations).[15] Such technology aims to provide a qualitatively different kind of propulsion, capable of very high thrust but still fuel-limited. Thus any host asset would need to be designed for the high accelerations an NTR thruster would produce. How many space asset designs could justify the cost, design impacts, and mass of an attached NTR simply to provide maneuvering thrust?

Another key justification exists for NTR, however: extended high thrust for cislunar or interplanetary missions. These are quite different from the near-term needs of Space Force orbital assets, of course, but even an aspirational system for such long-range missions

14. Beames, "Math on Refueling."

15. "DRACO: Demonstration Rocket for Agile Cislunar Operations," Defense Advanced Research Projects Agency (DARPA), accessed 29 January 2025, https://www.darpa.mil/.

could be served by the low-thrust propellantless systems, because the latter can continue thrusting indefinitely. Over days and weeks, a little acceleration adds up quickly. Since the impacts to the host vehicle are minimal, its structural mass can remain low, with synergistic effects including an even shorter travel time for a given thrust. So, given an emerging low-thrust propellantless capability, even the hypothetical long-distance missions may not favor technologies such as NTR and certainly will not require them.

In the over 60 years of NTR technology's history, its expense, hazards from its nuclear core and exhaust, testing limits, and formidable political hurdles have never all been surmounted. If all-electric thrusters of even low thrust levels prove out, elaborate alternatives like NTR may never be needed.

As for existing satellites, these too could benefit from propellantless propulsion technology thanks to the retrofit capability being devised now by Northrop Grumman Corporation for its mission robotic vehicle (MRV). Designed to extend satellite lifetimes by providing supplemental propulsion of the conventional type, Northrop Grumman's system in its initial iteration simply grapples the customer satellite and maneuvers it, for up to five additional years. The next generation system will carry propulsion systems in a standalone package which the MRV will attach to the host satellite, leaving the servicing vehicle free to move on to the next customer and attach more propulsion units.[16] These units could just as easily be propellantless electric propulsion systems, allowing the Space Force to leverage an emerging commercial servicing capability to upgrade its legacy fleet. Equipping the MRV itself with propellantless thrusters will make its operation much more economical and straightforward, eliminating refueling stops. It would also become practical to use MRVs to perform debris cleanup in any and all orbits.

All these innovations will directly address the number one operational imperative defined by former Secretary of the Air Force Frank Kendall: "Defining resilient and effective space order of battle and architectures."[17] Additionally, of the key focus areas identified by former Space Force Chief Technology and Innovation Officer Dr. Lisa Costa, the new thrusters address these: 1) improving freedom of action in space, 2) improving survivability and resilience, and 3) improving mobility.[18]

New Capabilities

Consider now some entirely new capabilities enabled by the all-electric propulsion breakthrough. Thrust levels demonstrated in laboratories allow the possibility of satellites

16. "Space Logistics," Northrop Grumman (website), accessed 3 April 2025, https://www.northropgrumman.com/.

17. Erwin, "Space Force Plans."

18. Lisa Costa, remarks, 2022 Air Force Association Air, Space and Cyber Conference, 19–21 September 2022, National Harbor, Maryland; and see also Nick Adde, "Six Space Technologies the USSF Needs in Order to Maintain the US Advantage," *Air & Space Forces Magazine*, https://www.airandspaceforces.com/.

positioned in entirely new ways which do not even qualify as orbits. No longer limited by Kepler's laws of motion, space systems could:

- maintain a geostationary position while being much closer to the Earth than 35,786 kilometers or 22,300 miles, making their payloads more effective in observing the Earth or relaying communications;
- sit above one of the Earth's poles, continually observing and relaying over the northern or southern hemisphere, with a horizon defined by the chosen altitude;
- cross the sky faster than any satellite, unpredictably, by accelerating inward toward the Earth so as to exceed the orbital speed of satellites at the same altitude;
- maintain a position identical to the sidereal background—that is, remaining stationary in the absolute sense, rather than geostationary—so as to "disappear" into the starfield as observed from Earth; and
- "impersonate" enemy space systems by appearing to orbit directly beneath them, as seen from the ground, while in fact maintaining a safe separation distance at a lower orbit, thus daring an attacker to risk their own space asset in order to attack US ones.

Other uses will no doubt emerge as creative Guardians grasp the new possibilities of non-Keplerian orbits.

In addition, deflection of threatening asteroids to avoid collision with Earth becomes much more practical if a source of constant thrust can be affixed to the threat. Fuel-based rockets never offered a practical means of doing this, but a propellantless system finally would.

Occasional remarks from Space Force leaders suggest an interest in safeguarding cislunar space via some sort of future patrol ship capability. With electric propulsion, a patroller could be made by updating the Cold War-concept known as Blue Gemini. This was a proposal to make an Air Force-owned and -operated version of the two-man Gemini capsule, which at the time was the state of the art in the civilian space program.[19]. The Orion capsule from NASA's current Artemis program is designed for reuse after reentry and refurbishment, and thus quite a lot of what it includes is extraneous to a potential cislunar patrol mission.[20]

For a conceptual "Blue Orion" variant, consider a capsule sent to space for permanent stationing, with no intention to return it to Earth. Based at a future space station such as those planned to succeed the International Space Station—and making sorties to the future Lunar Gateway station—the craft would need no heat shield, saving weight and expense. Its service module, which on Orion is devoted almost entirely to rockets and propellant tanks, could be replaced with a solid-state propellantless system. The existing

19. Dwayne A. Day, "A Darker Shade of Blue: The Unknown Air Force Manned Space Program," 12 September 2022, *The Space Review*, https://www.thespacereview.com/.

20. See Charles S. Galbreath, *Securing Cislunar Space and the First Island Off the Coast of Earth* (The Mitchell Institute for Aerospace Studies, January 2014), https://www.mitchellaerospacepower.org/.

parachute compartments could be repurposed to host a remote manipulator arm, operated from within the capsule by the crew. Compared to a standard NASA Orion mission to the Moon, fewer crew might be needed as well, freeing up more volume for consumables or mission equipment. Under this concept of operation, only minor servicing of Blue Orion might be needed between missions, making permanent basing in space feasible.

As for weapon application concepts able to exploit continuous electric thrust, consider a kinetic impactor constantly accelerated over a long journey to the Moon on a free-return trajectory. Upon returning to Earth and reentering, it would be traveling at many times the speed of sound, as unstoppable as a meteor.

Conclusion

Of course, the industry is eager for such propellantless propulsion to someday replace rockets for space launch, "rocket cargo," and other demanding uses of high-thrust propulsion. The path to these applications lies through improvements in efficiency and maturation of the underlying fundamental technology principles as applied to propellantless propulsion. The inventors at Exodus say they have identified promising approaches to achieve this, and indeed all progress to date has been only that achievable by self-funded garage inventors.[21] The physics of the propulsion sets no limits on the improvements that can be engineered, nor on scaling. Once teamed with the Space Force's trusted prime contractors and their resources, remaining engineering obstacles will be fully addressed to evolve the technology as needed by Space Force systems. It is not too early for the Space Force to prepare for a new era beyond that anticipated by twentieth-century planners .

21. Author's personal conversations with Buhler and Aurigema.