Reducing Launch Costs

With Air-Breathing CubeSat Constellations

INTRODUCTION

Development and launch are expensive endeavors. In rough terms, small satellites with a dedicated launch can cost ~$8M to ~$10M, and larger platforms can exceed $100M. Expensive platforms are all too often crippled by on-orbit hardware failures, putting insurance providers, commercial businesses, and government missions at risk (Foust J. , 2023).

CubeSats are a low-cost alternative. At $325K per rideshare for up to 50kg, the price to reach Low Earth Orbit (LEO) is ~4% the cost of the next larger class of satellites on a dedicated rocket. Due to their small form factor (10x10x10cm, 2kg per 1U), CubeSats are much less capable than larger platforms at the same altitude. By integrating an air-breathing propulsion system with CubeSats in the Super Low Earth Orbit (SLEO) altitudes of 150km-250km, these smaller platforms gain an edge against larger satellites in LEO like:

- Unlimited fuel, high maneuverability
- Competitive payload performance
- Low-cost launch and fleet hardware resiliency

WHY SUPER LOW EARTH ORBIT

Many satellite payloads improve as they get closer to Earth. Cameras improve on a linear scale with decreasing “flight height” as described by the Ground Sampling Distance (GSD) equation (Wawrzyn, 2025):

$$GSD_h = \frac{Flight\ Height * Sensor\ Height}{Focal\ Length * Image\ Height}$$

Communication power lost to space, called “Free Space Path Loss” (FSPL), decreases by an order of 2 with decreasing altitude “d” (Free Space Path Loss, 2024):

$$\text{FSPL} = \frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2$$

LiDAR power improves by an order of 2 with decreasing altitude “R”, which in turn improves signal to noise (SNR) equivalently (LeddarTech, 2022):

$$P_r = P_t * \rho * {}^{A_o}/_{\pi R^2} * \eta_o * \exp(-2R\gamma)$$

Radar power improves by an order of 4 with decreasing distance “R” (Radar, 2025):

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R^4}.$$

Though additional constraints like volume, mass, power, propulsion, and payload miniaturization will be discussed in later sections, performance gains in SLEO are easily estimated using the equations above. In simple terms, a comparable satellite would have a 39 times stronger Radar signal, a 6 times better communications and LiDAR signal, and a 3 times higher camera resolution in the SLEO orbit of 200km than in a LEO orbit of 500km.

THE PROBLEM WITH SLEO

Unfortunately, such a satellite wouldn’t last long in the SLEO orbit. A “feature” of these orbits is a small but significant atmospheric drag, a force that causes SLEO spacecraft to come crashing down in a matter of hours. In the case of a 1U CubeSat at an orbit of 200km, the orbit can only be maintained for two days without propulsion (Bozhanov, 2017).

In 1973, Gordon L. Cann presented an analysis on thrust-to-drag sizing for electric propulsion which described this problem. The analysis indicated that any platform with a solar efficiency of less than 10% could not achieve an orbit lower than 400km (Cann, 1973). As solar efficiency has improved in the decades since, newer orbits have become available, but not to a degree that makes the SLEO regime of 150km to 300km accessible. For example, the lowest commercial platform in orbit is Starlink at 336km to 346km (Spektor & Jones, 2021), even though today’s solar panel efficiency should easily allow for sub-250km orbits.

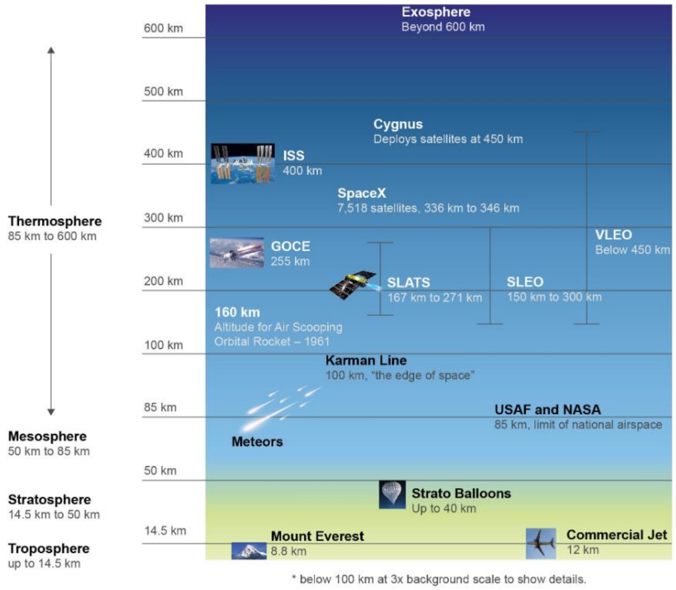

Figure 1. Layers of Earth’s Atmosphere

Technical innovations beyond solar efficiency were still needed to make SLEO a reality. While solar cells could provide enough power to make up the drag for their size, platforms couldn't store enough fuel to enable mission lifetimes justifying their cost. Nor could they lower power requirements enough at scale, often requiring kilowatts or megawatts for the thrust required (O'Reilly, Herdrich, & Kavanagh, 2021). In 2007, the European Space Agency (ESA) began studying a concept which might be a solution to this issue: utilize the incoming rarefied gas flow to generate thrust, like ramjets in the continuum flow regime (Di Cara, et al., 2007).

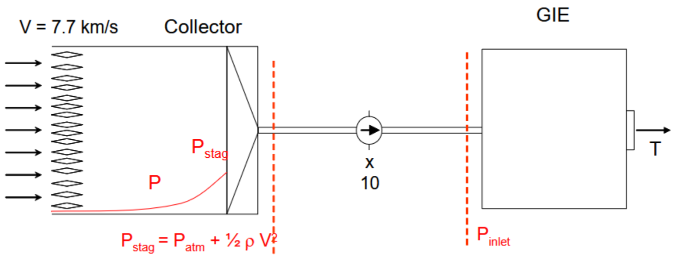

Figure 2. Schematic Showing Rarefied Gas Collector Concept

Academic and industry partners in Europe have conducted many studies and experiments on an air-breathing electric propulsion concept since, including a ground demonstration as part of AETHER (Horizon 2020 Research and Innovation Program, 2025), but the capability has yet to see orbit. The United States is just beginning to investigate this technology, with a recent award of DARPA's Otter program for a large air-breathing demonstrator to Phase Four and Redwire in 2024 (Werner D. , 2024).

The modeling (Ferrato, et al., 2022); analyses (Barral, Cifali, Albertoni, Andrenucci, & Walpot, 2015) (Crandall & Wirz, 2022); and Monte Carlo simulation (Parodi, 2019) of such systems are robust, though miniaturization and demonstration remain difficult prospects for such a technology. Thruster design is deeply technical, testing is expensive, and results are strongly dependent on fuel source, or in this case, the atmosphere.

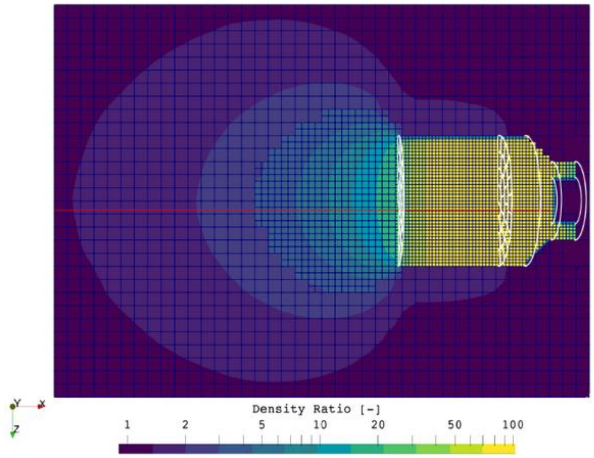

Figure 3: 3-D Simulated Density Ratio of Rarefied Gas Collector

The atmospheric composition of SLEO, while well modeled, has not been validated until recently. A Japanese spacecraft, the Super Low Altitude Test Satellite (SLATS), experimentally measured atomic oxygen flux in SLEO between 2017 and 2019 and made several discoveries. As one example, existing atmospheric models like NRLMSISE-00 overestimate the presence of molecules by between 30-50% (Kimoto, et al., 2022). Without such knowledge, air-breathing thrusters were surely destined for failure in orbit.

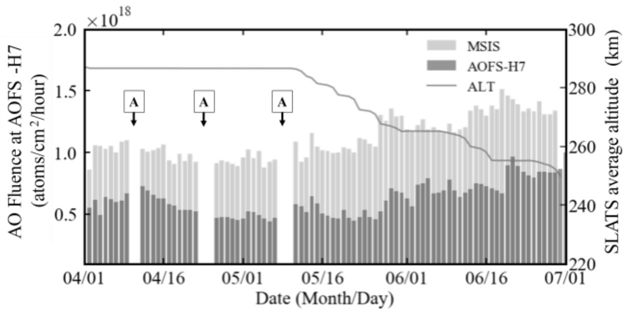

Figure 4. SLATS AO Fluence in Direction of Flight, 2019

NASA also published JPL's handbook on Ion and Hall Thrusters in 2008 (Goebel & Katz, 2008), making miniaturized electric thruster design more accessible than it's ever been before.

Miniaturized platforms like CubeSats experienced a similar renaissance in the late 2000's, where the NRO recognized the "utility of CubeSats and actively engaged with universities, service academies, laboratories and industry to advance the state of practice." Risk reduction, rapid development, and decreased costs were all touted as benefits of the technology (National Reconnaissance Office, 2019) and the market for CubeSats has grown to $375M since (Global Market Statistics, 2025). This market expansion paved the way for flight proven commercial-off-the-shelf (COTS) products, lowering the development ceiling for satellite operators and reducing CubeSat hardware risk, while creating a robust supply chain to support constellations at scale (Bomani, 2021).

Though there have been many advances in air-breathing research and designing SLEO systems is more accessible than ever before, problems remain for planned demonstrators. Using the JPL handbook above to design a large platform thruster demonstrates that propulsion systems for planned SLEO platforms are still constrained by extreme power needs, an assessment further supported by academic analyses (Andreussi, Ferrato, & Giannetti, 2022). Large platforms have greater than 20mN of drag to overcome and require more ingested air, bigger solar panels, larger energy stores, costlier mission design, and longer mission lifetimes to justify the delivered capability. One simple method of solving these problems is to adopt smaller platforms with less drag, like CubeSats. Such a platform would need to overcome less than 1mN of drag and its thruster design would have power requirements that scale well with predicted CubeSat payload power requirements in SLEO

(Shao, Koltz, & Wertz, 2014). Given that some payload capabilities improve by orders of magnitude at lower altitudes, a product which integrates the CubeSat form factor with air-breathing technology could open a new market to satellite operators.

CUBESAT CONSTELLATIONS AS A SOLUTION

It seems that a CubeSat platform is well suited for air-breathing integration as described above, but payload performance must be analyzed to show that SLEO CubeSats are competitive with larger platforms in LEO to be deemed a real solution. Ultimately, any new platform would only be desired by satellite operators if this were true and for a fraction of the cost.

To that end, the first scaling parameter to assess is self-evident: the amount of fuel available for maneuverability is truly limitless. Payload weight, volume, and performance previously limited by wet mass is no longer compromised: for example, up to 300% of relative payload mass would have previously been fuel on a LEO platform per COMPASS sizing (Gerberich & Oleson, 2014). All components equal, an equivalent payload on an air-breathing platform in SLEO should have three times the relative mass available. Atmosphere as fuel also allows for on-demand transfer into supported orbits without life-limiting fuel considerations, or "maneuvering without regret." For a constellation of satellites, orbital maneuverability can be an exceptionally important consideration of design (Nag, et al., 2017) and is shown in constellation trade-space analyses like TAT-C (Nag, Ravindra, & Le Moigne, 2019).

However, it is not sufficient to show that maneuverability and substitution of wet mass equates to the same payload performance at a lower orbit. Support for scaling a mass and power parameter must be demonstrated through the analysis of real satellite missions at different altitudes. Literature analyzing a model imagery mission compared to real systems shows that an order of magnitude **less** dry mass and power is required at a 200km orbit than the same mission at 400km (Shao, Koltz, & Wertz, 2014).

	Physical Parameters	Model Predictions			Examples		
					NanoEye	Quickbird	GeoEye-2
1	Orbital Altitude (km)	200	400	800	215	482	681
2	Resolution (m)	0.5	0.5	0.5		0.65	0.32
3	Payload Aperture Diameter (m)	0.22	0.44	0.88	0.23	0.60	1.10
4	Spacecraft Dry Mass (kg)	24.4	194.8	1,558.6	23.0	995.0	2,086.0
5	Non-Redundancy Mass Reduction	30.0%	20.0%	0.0%			
6	Corrected Spacecraft Dry Mass (kg)	17.0	155.9	1,558.6			
7	Spacecraft Wet Mass (kg)	292.5	181.2	1,559.4	76.4	1,028	2,540
8	Payload Power (W)	10.2	93.2	932.0			
9	Payload Datarate (kbps)	273,345	489,309	800,000			
10	Spacecraft Area Access Rate (km^2/sec)	4,858	8,696	14,217	5,177	10,034	12,819
11	Satellite Orbital Period (min)	88.5	92.6	100.9	88.8	94.2	98.4
12	Spacecraft Design Lifetime (yrs)	2	4	8	2.15	4.82	6.81
13	No. of Sats Needed for Same Coverage at Any Given Time	2.9	1.6	1.0	2.7	1.4	1.1
14	Number of Satellites Required for Entire Mission	11.7	3.3	1.0	10.2	2.4	1.3
15	Number of Redundant Satellites	1.2	0.3	0.0	1.0	0.2	0.0
16	No. of Satellites to Build w/ System Redundancy*	12.9	3.6	1.0	11.2	2.6	1.3
17	Total Launch Mass (kg)	3,767	652	1,559	859	2,659	3,309

* Note that fractions of satellites have been allowed in this model for purposes of comparison simplicity and a smoother display of results

Figure 5. Physical Parameters of 3 Select Mission Altitudes and Comparable Systems

Such literature demonstrates that LEO missions designed for SLEO altitudes can scale into the CubeSat form-factor without any loss of capability, while requiring much less mass and power. When considering that three times the relative payload mass is available without onboard fuel, that GSD/FSPL/LiDAR/Radar payloads vastly improve at lower altitudes, and that payload mass and power can be reduced by one order of magnitude as described above, some mission types may even outcompete the economics of heritage LEO systems (Berthoud, et al., 2022).

As the last consideration of payload performance at scale, constellations of today's LEO systems are onerous to deploy, especially when considering cost and development schedules. Future insurance premiums, regulations, and design constraints are all likely to make constellations even more burdensome and expensive (Chrystal, 2018). "But nowadays the majority of satellites being launched are going to LEO, and insurers are less inclined to insure them" (Rotoiti Consulting Ltd., 2022). Such a future could bring a real risk of losing an uninsured LEO platform that costs more than $10M. In stark contrast, the defining "feature" of SLEO provides additional protection against such loss: the increased drag results in an order of magnitude lower debris density than in the LEO regime (European Space Agency, 2025). The lower cost of platforms, lower collision probability, and improved constellation resiliency should result in lower insurance premiums and increase the appetite of insurers for SLEO platforms.

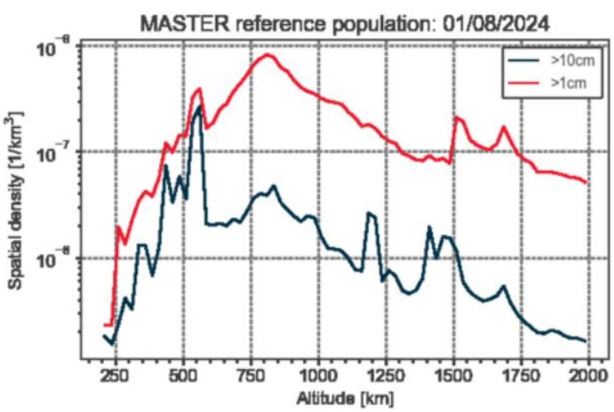

Figure 6. Spatial Density of Objects Larger Than 1cm and 10cm by Altitude

On improving resiliency, not only are constellations of SLEO CubeSats better protected from debris, future regulations, and increasing insurance premiums, but they may also mitigate the risk of on-orbit failures by "[spreading] technical risk across multiple small satellites in a constellation." Where "…the evaluation of success changes – the question becomes whether the constellation achieves its mission, not whether all parts of the system perform flawlessly" (Johnson, et al., 2018). Further, constellations that not only enhance the safety and reliability of a mission can also enhance the performance of the payloads for that mission. Utilizing advanced software processing techniques, constellations of payloads can be more performant than their single payload counterparts. “Resolution of conventional satellite imaging is largely limited to around one meter.” Novel approaches to software “can achieve imaging resolution well below a centimeter” when applied to a constellation of satellites supporting a single mission (Li, Dorje, Wang, Chen, & Ardiles-Cruz, 2022). CubeSat Intersatellite communication links that would enable this fleet processing capability have just recently been demonstrated as well (Werner D. , 2025).

Thus, in comparing the competitiveness of SLEO CubeSat constellations to larger LEO platforms, all scaling factors can be finally considered. SLEO CubeSat constellations shown to be an order of magnitude cheaper to launch, lower in mass and power, and more performant can also be made more capable and resilient by augmenting their performance with fleet software. For another perspective, the imagery company BlackSky is paying an estimated $7.5M to launch one Gen-3 small satellite into LEO on Rocket Lab’s Electron rocket (Foust J. , 2023). A fleet of 10 CubeSats, each as equally capable as one Gen-3, could launch to SLEO for $3M with all the benefits described above, *and then be further improved by another order of magnitude with fleet software.* This is an incredible value proposition for satellite operators, only possible by integrating air-breathing technology into the CubeSat form factor for use in robust SLEO constellations.

THE FUTURE OF LEO IS CUBESATS IN SLEO

The Department of Defense (DoD) is acutely aware that constellations are the way of the future and are a critical national need (Hitchens, 2019). CubeSats in SLEO have the potential to be the “drones” of space, providing miniaturized capability for big missions where larger platforms aren’t competitive. As congestion in LEO increases, satellite costs will rise due to regulation: SLEO provides a haven from these regulations, ideal for meeting FCC compliances (Federal Communications Commision, 2022). SLEO will enable fast demonstration of key DoD technologies, like those supporting the Proliferated Warfighter Space Architecture (PWSA), Space Development Agency (SDA) LEO demonstrators, and the Missile Defense Agency’s (MDA’s) “Golden Dome.” “The Pentagon is looking beyond traditional defense contractors to tackle one of the most ambitious components of its proposed “Golden Dome” missile defense system: space-based interceptors that would destroy enemy missiles in flight” (Erwin, 2025). Beyond the benefits previously described for payloads, even companies like SpaceForge who are pioneering space-based manufacturing of sensitive components would be better protected from radiation in SLEO vs LEO (Johnson-Groh, 2017). Most importantly, all satellite operators would see their launch costs reduced, the capability of their systems improved, and the resiliency of their platforms increased by CubeSat constellations in SLEO.

REDUCING LAUNCH COSTS

With Air-Breathing CubeSat Constellations

A new CubeSat system in development by startup AeriSat enables SLEO capabilities for the first time, greatly reducing satellite development and launch costs. Working in close collaboration with commercial and DoD customers, we seek to proliferate new missions on our maiden platform SWORDFISH, increasing the pace of innovation in this rapidly growing, highly specialized space industry. We look forward to serving new customers together with you while making space more accessible, resilient, and sustainable along the way. Please sign up to our mailing list and express your interest in our product today!

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