



A.L.I.E.N.S

Aerospace Leaders, Investors,
Engineers & Students



ENTREPRENEURSHIP IN AEROSPACE

INSIGHTS. OPPORTUNITIES. IMPACT.

A Guide for Founders and Investors

Exploring the forces reshaping aerospace —
from finance, defense, and manufacturing to
autonomy and AI.



FINANCE

Capital strategies
driving the future



DEFENSE

National security
meets innovation



MANUFACTURING

Scaling the next
generation



AUTONOMY & AI

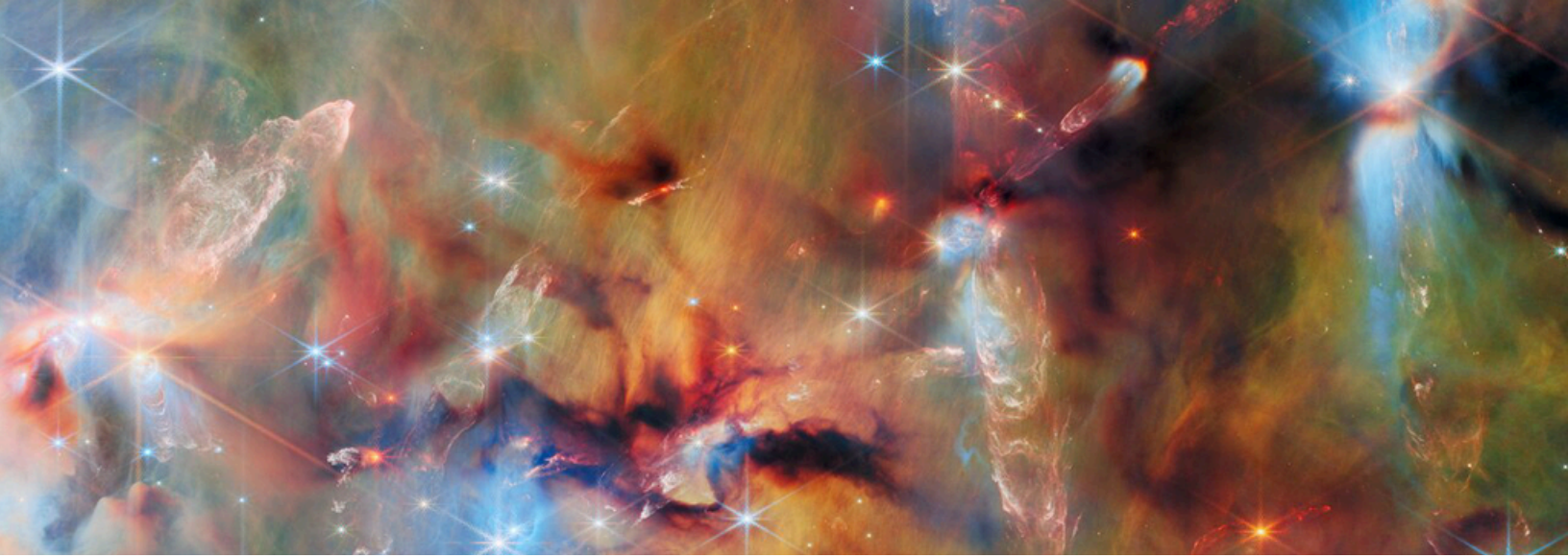
Intelligence beyond
the payload



PEOPLE

The minds behind
the mission

AT THE FRONTIER OF INNOVATION. FOCUSED ON THE PEOPLE.



Preface

We are grateful for Professor David Mindell's teachings in Entrepreneurship in Aerospace and Mobility Systems at MIT. The course is unlike anything else in Cambridge. It is not a survey of the industry. It is not a case study collection. It is a live conversation with the people actively building the new aerospace: founders, investors, and operators brought into the room by a professor who has been in each role.

This paper is the product of the environment you cultivated. All of the interviews we conducted, the frameworks we developed, and the bold claims we are willing to make all trace back to what we learned in your classroom and from the guests you invited into it. Your insistence to engage with the real industry shapes every chapter.

We are thankful for your time, your generosity, and your care for students who want to build things for the future of aerospace. This paper is, in part, our attempt to honor that.

MIT ALIENS, 2026

MIT ALIENS, 2026

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Executive Summary

We are at the earliest stages of the most consequential industrial transformation of our generation. And no, it is not AI.

Aerospace is an industry that once ran on cost-plus contracts, a handful of prime contractors, and the logic of Cold War competition, and it has given way to something categorically different. Launch costs have fallen by orders of magnitude. Constellations that once required nation-state budgets are being built by startups, though still leaning on government anchor demand.

Why this matters if you have never thought about space: you already depend on it. The timing signal from GPS satellites synchronizes the networks that clear card payments and timestamp stock trades, not just the map on your phone. Satellite links now carry internet to places fiber never reached. Weather forecasting, shipping, farming, and power grids all run on data from orbit. That is today. The bet in this paper is that the dependence deepens. The compute behind AI starts moving to orbit for power and cooling, energy generation follows, and the most land and carbon heavy industry slowly leaves Earth. If even part of that happens, space stops being a sector you can ignore and becomes the infrastructure the rest of the economy runs on.

To understand what is happening in this industry, we conducted over fifty interviews with founders, operators, engineers, and investors. This paper is not a neutral survey. It is a series of arguments grounded in primary research, and we are willing to defend every claim in it.

Four forces define the opportunity: capital, dual-use markets, lifecycle economics, and AI. Private investment in the sector exceeded \$58 billion in 2025 alone. The Golden Dome program carries an estimated lifecycle budget of up to \$3.6 trillion. On-orbit servicing is opening a profit pool that will rival commercial aviation MRO within a generation. And AI is reshaping every layer of the stack, from design and simulation to autonomous operations and intelligence delivery.

We make five predictions:

- 1 The big shift: the terrestrial economy will move to space**
- 2 Robots and humans: supervised autonomy**
- 3 The money runs ahead of the economics**
- 4 Government buys at venture speed: defense becomes the founder's cheapest money**
- 5 A mostly fragmented regulatory regime: a global deal is years away**



These are not forecasts. They are bets we are willing to make and arguments we are willing to have. Those who build for the world that is coming rather than the one that existed will define what aerospace becomes. *The party is just getting started.*

A note on how to read this paper. What follows blends three kinds of content, and we have tried to keep them distinct. Some of it is what we heard directly in our interviews with founders, operators, and investors. Some of them are external research and market data, which we cite. And some of it is our own analysis and judgment, including the frameworks we built and the five predictions in Part 4, which are ours to defend and yours to argue with. Where we move from what we heard or found to what we believe, we say so. The predictions are the most opinionated part of the paper by design and the landscape in Part 2 is the most grounded in outside data.

A note on scope. This is a report about space. We sometimes reach outside it, to drones in Ukraine, to aviation MRO, to drone regulation, because the patterns we care about show up there first and more clearly. Those are illustrations, not the subject. Each time we use one, we flag it and return to space.



We are MIT's **Aerospace Leaders, Investors, Engineers, & Students** (ALIENS)

Our sixteen members span aerospace engineering and manufacturing, space sciences, entrepreneurship, and management. Our members have worked at SpaceX, Blue Origin, NASA, Boeing, Rocket Lab, Stoke Space, and the SETI Institute.

Now we are students across MIT AeroAstro, MIT Sloan, and Wellesley College, positioned at the intersection of technical depth, business acumen, and entrepreneurial ambition. We study the forces reshaping aerospace: finance, defense, manufacturing, autonomy, and AI. We translate what we find into research, ideas, and honest takes on where the industry is going. Draper Laboratory, once known as the MIT Instrumentation lab, is well-known for designing the Apollo guidance computer and sits right on our doorstep. Alumni from the Aeronautics and Astronautics Department have started compelling aerospace startups, from early ventures with lunar heritage to newer companies like Apex Space, Rendezvous Robotics, and Raptor Maps, and the MIT alumni network remains one of the strongest founder pipelines in the industry. And with MIT Sloan next door, we also maintain the crucial business lens needed to build the future of aerospace with a healthy balance sheet. Several of us have also studied the economics of the space sector directly, through Professor Matthew Weinzierl's space economics course at Harvard Business School.

As ALIENS at MIT, we want to contribute something useful to the industry and the people building it. On that note, this paper is written primarily through a US lens. Our team, our interviews, and the institutional context of MIT all sit inside the American space ecosystem, which remains the largest in the world but is far from the whole of it. Where our claims are specific to the US market, we have tried to flag them, and readers elsewhere should weigh them against their own national context.

We are not neutral observers. We have opinions about where this industry is going, and we are willing to put them in writing. The predictions in this paper are grounded in research and interviews, and only ours to defend. We welcome all pushbacks you have, especially if you don't use AI.

"WE ARE NOT NEUTRAL OBSERVERS."

What Do AI Tools Not See?

AI would give you a major overview of the entire aerospace industry. Market size, key players, technology trends, funding data, and regulatory frameworks. Its conclusions come only from public information, so it doesn't really know what's happening behind the doors. Ask it about new versus old space and it will describe the primes and how SpaceX rewrote the playbook. It will cite market size projections and lean on the growth of companies. The description appears deep. It is not. AI works only with the data it has.

What's happening behind closed doors? AI doesn't know what it feels to watch a lunar lander program get canceled or what a program manager at Boeing thinks about what's said on the news. It's the cycles of failure, iteration, and challenges that public datasets don't necessarily reflect. AI sees the press releases, the quarterly earnings, and the published research. It does not see the internal roadmaps, the honest frustrations, or the visions people hold privately for the future of aerospace.



AI is a great tool for data gathering, pattern recognition, and synthesizing what's already been written. We are grateful for what it says, but this is where we do our diligence. Our one-on-one interviews with founders, investors, industry veterans, and newcomers have been distilled to their essence, bringing us closer to the roots of what we believe will continue to shape our industry. The individuals interviewed have cumulatively raised over \$1 billion and lead some of the current leading programs in aerospace. We focused on learning what excites them about this industry, where their optimism or pessimism lies, and how they are working to shape their organizations to overcome challenges. Resoundingly, many agree AI is transforming aerospace, though many have not published these thoughts. Their views surfaced in our interviews and have been incorporated into our content, beyond what AI could infer on its own.

We have worked to dive deep and surface insights more substantial than just an industry overview. We trust that this paper will yield more meaningful lessons than a document assembled quickly with an AI tool. And yet, we live in an unprecedented time with AI. It is likely that several months after this document is published, its insights will be absorbed by the tools, and their ability to compile such reports will improve by a small percentage. With that framing in mind, here is what we found.

Part 1: Setting the Stage

1.1 How did we get here?

The aerospace industry spent most of the 20th century trapped in two self-reinforcing patterns: a cost-plus contracting model born of wartime emergency, and a consolidated military industrial complex that discouraged competition. The 2010s and 2020s changed that.

To analyze cost models in the aerospace industry, we must examine government contracting and procurement. In the aerospace industry, contracting comes down to two approaches: cost-plus-fixed-fee contracts and firm-fixed-price contracts, as defined in the Federal Acquisition Regulation [1]. In a cost-plus contract, the government reimburses the contractor for actual costs and pays a fixed fee or percentage on top. In this format, the risk of inefficient spending falls entirely on the customer. In contrast, under fixed-price contracts, the customer and contractor agree on a price up front, based on the expected costs of the work and an additional fee. Fixed-price contracts put the burden of inefficient spending on the contractor, who must cover any costs above the agreed price. The first contract in modern aerospace history was a fixed-price contract awarded to Wilbur and Orville Wright in 1908 [2]. However, the First World War brought a need for large, innovative projects that contractors did not feel they could confidently price, and the cost-plus contract was born.

Defense spending in the United States has long supported the country's global posture and its response to the array of risks it faces. During major wars and periods of strategic competition, the Federal Government spends more on defense. Conversely, when threats and conflicts fade, spending falls, and the defense market restructures and consolidates under a smaller budget. After World War II, national defense spending fell from roughly 36.6% of GDP in 1945 to 3.6% by 1948 [3]. Defense spending rose through the Korean War and the Cold War, fluctuating between 6% and 9% of GDP through the late 1980s. Following the end of the Cold War, spending fell to 4% of GDP. This reduction drove the consolidation of 51 prime contractors in the early 1990s into just five: Lockheed Martin, Raytheon, General Dynamics, Northrop Grumman, and Boeing [4]. This is a US story. Other major space powers followed different paths, with the UK, France, Japan, and Korea leaning more on scientific satellites and multilateral collaboration than on commercial competition.

After 2000, cracks in the industry began to show. Customers such as NASA started moving away from cost-plus contracts, and new entrepreneurial companies emerged to fill the vacuum left by consolidation. The most notable company to emerge at this time was SpaceX, founded in 2002. SpaceX rewrote the playbook in three ways: a venture mindset, vertical integration, and fixed-price contracts.

Elon Musk's tabula-rasa mindset and his early capital enabled SpaceX to take risks and demand efficiency in ways incumbents would not, bringing a Silicon Valley culture of speed to aerospace. Speed itself is not new to the industry. During Gemini, McDonnell moved just as fast in the 1960s, and agility tends to fade as companies age. What is different now is the combination of that culture with fixed-price contracts and falling launch costs, which reward speed in ways the cost-plus era did not. But private money did not carry the company alone. By late 2008, after three Falcon 1 failures, SpaceX was nearly out of cash, and NASA's Commercial Orbital Transportation Services award and the \$1.6 billion Commercial Resupply contract that December were existential. Government has been a major customer ever since.

Vertical integration, while capital-intensive, let SpaceX control costs and timelines in a fragmented industry. Engineers were no longer slowed by supplier negotiations, and talent could be shared across teams to solve problems as they emerged. SpaceX integrated because its whole thesis was radical cost reduction, and controlling the stack was the only way to hit those targets, starting from a blank slate with no supplier relationships or cost-plus revenue to protect. Few have followed, and the reasons are structural. Vertical integration is enormously capital-intensive, and SpaceX survived only because Musk self-funded through years of negative cash flow. The legacy primes are built the other way, with supplier networks, cost-plus accounting, and distributed-manufacturing politics that all reward fragmentation. And it only pays where it pays, since as launch costs have fallen, outsourcing parts of the stack has become the rational choice for most.

SpaceX also embraced fixed-price contracts. Rather than adding features to earn more money, the company drove costs down. This model paid off on contracts like the 2014 NASA Commercial Crew Transportation Capability award [5].

Fixed-price contracts proved difficult for the legacy primes. Higher overhead, longer development cycles, and complex organizational processes made them less competitive against new entrants. Collins Aerospace reportedly pulled back from the NASA spacesuit contract because of its fixed-price structure [6]. Boeing's CST-100 Starliner program generated more than \$2 billion in losses under similar conditions [7].

After initial skepticism and lawsuits, SpaceX proved the model worked. The government responded in kind: it restructured contracting mechanisms to stimulate innovation and expand the industrial base. For example, the Space Development Agency (SDA) ignited demand for lower-cost hardware in the satellite market. The Proliferated Warfighter Space Architecture (PWSA) offered the first predictable, high-volume contracts for small satellites. This pivot disrupted the legacy prime development cycles designed for higher orbits and higher capacity, favoring high production speed and low unit costs and creating an industrialized space environment.

In 2014, the Department of Defense launched the "Third Offset" strategy, acknowledging that the US had eroded its warfighting advantage [8]. The 2018 National Defense Strategy reinforced this. The strategy warned that complacency was not an option and called for a more lethal, resilient, and adaptable Joint Force [9]. In the eight years since its release, much has changed. Founders have taken notice, and new entrants have raced in, achieving significant success in raising capital. In 2025, 27 defense startups achieved "unicorn" status (startups with a valuation over \$1 billion [10]), compared with only 15 in 2015 [11]. The door for new entrants has never been more open.



1.2 Where do we stand today?

Figure 1 shows hundreds of companies betting that the future of critical infrastructure extends into space. Launch costs have dropped by orders of magnitude. Constellations that once required nation-state budgets are now being deployed by startups, though rarely with private capital alone. Starlink's growth leaned on government-funded terminals in Ukraine, and OneWeb was pulled out of bankruptcy by a UK government investment. The pattern is mixed funding: private builders, public anchors, and the application layer is beginning to mature alongside the infrastructure supporting it.



"THE INDUSTRY IS STILL EARLY."

Defense spending has accelerated the timeline, creating urgency that commercial markets alone could not sustain. The companies emerging as leaders today look more like software companies that happen to build hardware than the primes that defined the last half century. The industry is still early. We believe this transformation creates a genuine opening for ambitious founders.

We began with a simple question: "What map best highlights the current space industry?" Search engines and AI tools repeatedly returned the same answer: the SpaceTech Ecosystem Map by Generation Space, shown in Figure 1. Generation Space, a US subsidiary of Seraphim Space, maps more than 400 companies across the aerospace value chain. At first glance, it is a useful starting point, organizing companies by how we access space, operate in it, and deliver products to end users. But the industry is far more interconnected than this structure suggests. Many relationships, dependencies, and competitive dynamics shaping the sector remain absent from the SpaceTech Ecosystem Map.

Comparing the 2025 and 2026 maps tells a story on its own. New categories appeared that barely existed a year earlier, including Energy and Compute, Life Sciences, and In-Space Materials Manufacturing. The organizing logic shifted from Upstream, Downstream, and In-Space Economy to Space Access, Space Segment, and Downstream. The shift suggests that getting to space and operating in space have matured into distinct enough markets to warrant separate categories, while other segments appear to have lost momentum entirely: high-altitude platform stations (HAPS) disappeared from the 2026 map altogether.

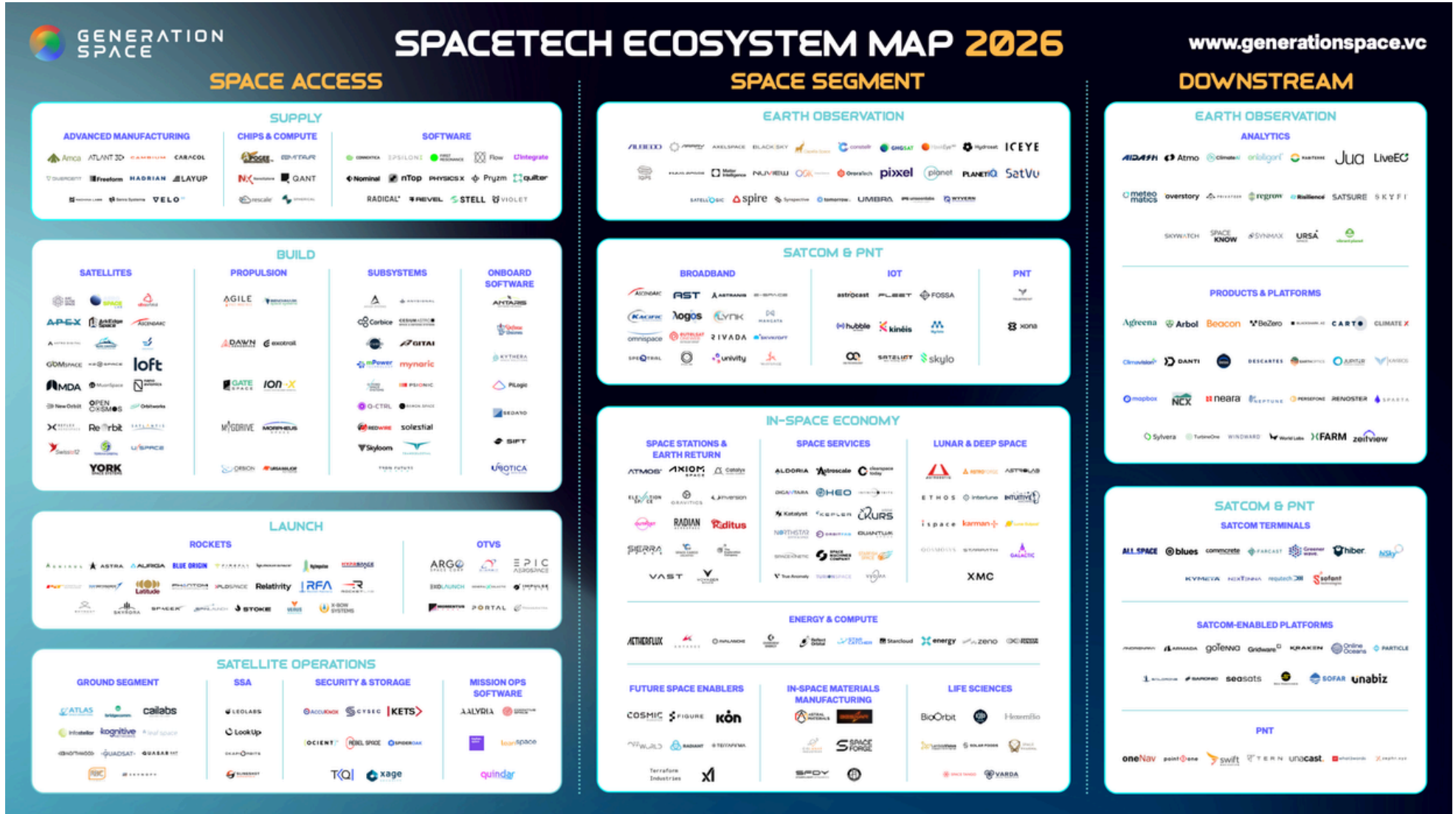


Figure 1: Generation Space Ecosystem Map 2026 [12]
 High-resolution version: <https://generation.space/research/>

Mapping the Landscape

Every map reflects the lens through which it was built. The Generation Space map was built with a commercial, venture-backable focus, emphasizing its portfolio companies. As a result, several dimensions fall outside its scope: defense and dual-use players such as Anduril, Shield AI, L3Harris, and Northrop; regulatory bodies such as the FAA; accelerators; and research institutions that produce aerospace talent. This is not a flaw. It is a reflection of the map's purpose.

THE AEROSPACE ENTREPRENEURSHIP FRAMEWORK

5 LAYERS OF BUILDING AND WINNING IN AEROSPACE



CAPITAL BUILDS. TALENT CREATES. POLICY SHAPES. GEOPOLITICS DECIDES.

Figure 2: ALIENS Framework for Aerospace

No single map can capture the full complexity of an industry that is interconnected and fast-moving. A startup founder, a defense procurement officer, a venture investor, and a regulatory counsel would each organize the space industry differently, and each would be right for their purposes. This is what motivated us to develop our own framework. As ALIENS, we wanted an organizing logic that accounts for defense, regulation, talent, financial viability, and the geopolitical forces shaping the industry's trajectory. Figure 2 presents that framework as a complementary lens for founders, investors, and operators who want to see the full landscape.

Part 2: Defining the Moment

This part is primarily descriptive. It maps the forces operating in the industry today, grounded in our interviews and in published data, before we turn to our own arguments in Parts 3 and 4.

2.1 The Space Economy faces a number of significant opportunities

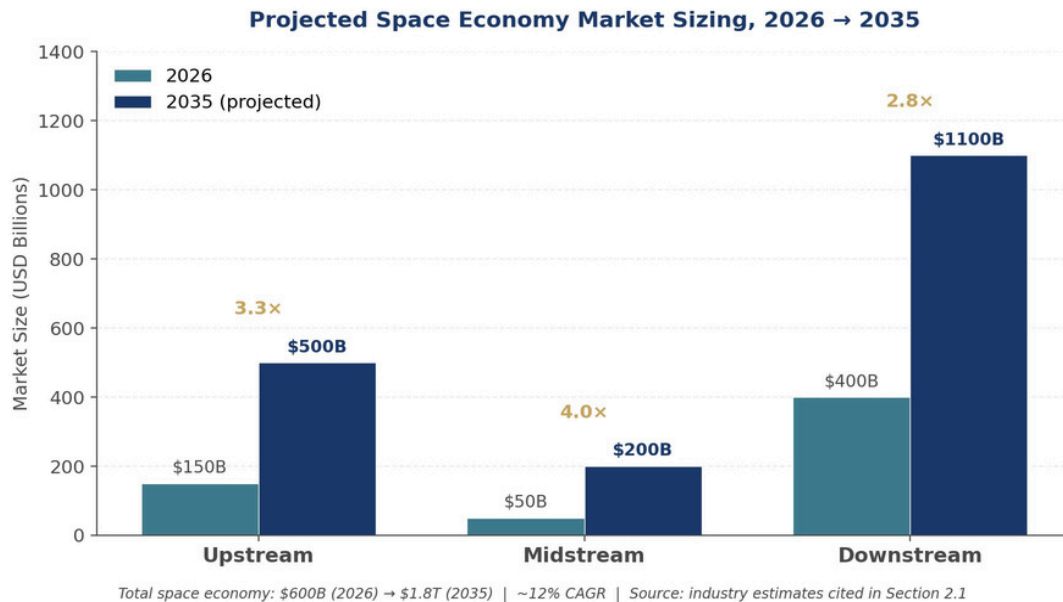


Figure 3: Projected Space Market Growth

As Chad Anderson, CEO of Space Capital, puts it, the space industry serves as the invisible backbone of the global economy. McKinsey & Company estimates the space industry will reach \$1.8 trillion by 2035, up from roughly \$600 billion today, representing a 12% compound annual growth rate (CAGR) [13]. The industry is segmented into four categories: upstream, midstream, downstream, and emerging.

Upstream. Satellite manufacturing, launch services, and ground operations are expected to reach \$150 billion by the end of 2026 and \$500 billion by 2035. The technology is mature, and demand is strong. SpaceX, Blue Origin, Lockheed Martin, Northrop, and Airbus will continue to lead.

Midstream. In-orbit logistics, satellite operations and maintenance, and orbital habitats will reach about \$50 billion in 2026 and \$200 billion by 2035. Astroscale, Starfish Space, Vast, and D-Orbit are among the companies making progress here.

Downstream. These services include communications and connectivity; Earth observations and remote sensing; global navigation systems; data, cloud & analytics; and precision manufacturing. Downstream services and applications will account for roughly \$400 billion in 2026, reaching \$1.1 trillion by 2035. Many of these services are established, but new market segments and use cases continue to emerge. Startups, mid-sized companies, and large incumbents such as Planet, Maxar, Astranis, and Orbital Insight are active in the downstream market. This year alone, over 400 new space companies in the United States received venture capital funding.



Emerging. Several compelling categories are still in research and development or remain highly niche. Space tourism, offered by Virgin Galactic, Halo, Space Perspective, and Blue Origin, has captured the public imagination. Asteroid mining, led by Matt Gialich's AstroForge, Karman+, and others, is high-potential but long-horizon. It is far from commercially scalable, and an earlier generation, including Planetary Resources, went bankrupt before getting there. Orbital “gas stations” are in the early stages of development, led by Orbit Fab. Space elevators, investigated by the International Space Elevator Consortium, NASA, the Japan Space Elevator Association, and MIT, are at various levels of planning and development. A dozen or more categories exist beyond these, though all remain early in their path to commercialization.

Falling launch costs, increased venture investment, improved manufacturing, and AI are all driving the industry forward. Defense spending is taking up a smaller share of the overall market over time as commercial activity grows, even as defense continues to catalyze industry growth.

Today, the United States accounts for 55-60% of the global space economy. That dominance is real but shrinking, so much of this paper's evidence and examples are drawn from the US market. The dynamics we describe often apply elsewhere, but not always. As other nations invest more and their entrepreneurs seize opportunities, the United States' share of the global space economy will fall from roughly 55% today to about 35% by 2035. China, India, Japan, and the European Union will each have substantial industries of their own.

Four forces explain the shape of this opportunity. Each is substantial on its own. The most interesting companies operate at the intersection of two or more.

2.2 The four drivers of opportunity in the new space economy

Four drivers explain the highly favorable shape of the opportunity in the new space economy:

- 1 The healthy and robust flow of investment capital
- 2 The rise of dual-use markets and opportunities
- 3 The rapid emergence of lifecycle economics and manufacturing
- 4 The prominence of AI infrastructure, autonomy, and process innovation

Each of these drivers is substantial enough to serve as an important strategic anchor on its own; however, the most successful and high-potential companies tend to operate at the intersection of two or more of these drivers. Below, we examine each driver's impact on the opportunities facing the new space economy. We'll examine the financial transformation that has made the sector investable; dual-use demand that is accelerating timelines and underwriting risk; the lifecycle economics shift that is opening a profit pool around servicing, manufacturing, and infrastructure; and AI capabilities that are reshaping every part of the stack, from initial design and development through operations and servicing.

2.3 The large but cyclical flow of investment capital

The space economy has shifted from a predictable government-led domain to a more commercial one, though less smoothly than the headline numbers suggest. According to Space Capital, private capital deployed over \$58 billion across more than 400 companies in 2025, up 72% from 2024 [14]. That jump follows a slump: private funding peaked around 2021, fell through 2022 and 2023, and has been roughly flat since 2018 once the cycle is smoothed. Government funding still accounts for roughly 70% of total spending (\$137 billion in 2025 [15]). Private investment has grown at a 12% CAGR since 2009, compared with the government's 4 to 5%, but most of the recent growth in total spending has been government-led. In absolute terms, the two added similar amounts over the period, on the order of \$50 to \$65 billion each, but private did so from a far smaller base, which is why its compound rate is higher even as the government's line climbs more steeply in dollar terms.

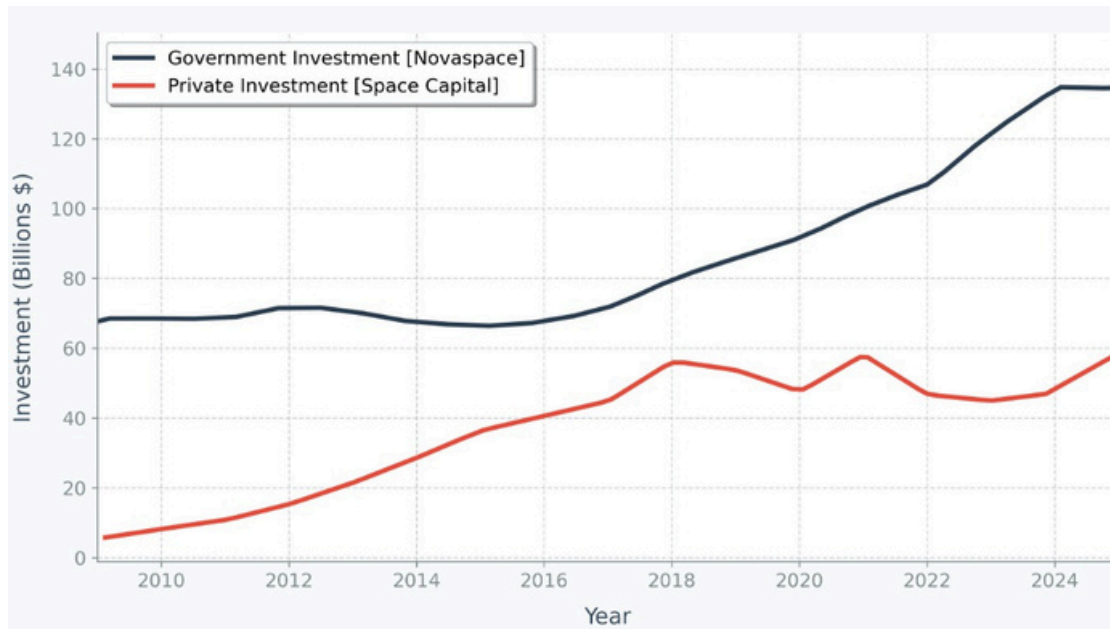


Figure 4. Private and public space investment from 2009 to 2025 [14] [15] [16]

SBIRs have been fundamental to supporting the development of the space economy

Investors are more likely to pay closer attention to commercially oriented space startups that use well-established technologies and have a clear commercialization pathway. At the same time, startups that focus on nascent or unproven technologies, where commercialization is less clear, face hurdles in attracting investment. For firms pursuing these technologies, the federal government has expanded the SBIR and STTR programs to support early-stage development.

The SBIR program provides non-dilutive funding to small businesses developing technologies with government or commercial applications. STTRs serve a similar purpose but require collaboration between a small business and a nonprofit research institution, such as a university or national laboratory. SBIRs and STTRs can be awarded in 3 phases based on the state of the technology:

- Phase 1 (up to ~\$320 thousand) - Feasibility and development
- Phase 2 (up to ~\$2 Million) - Prototyping
- Phase 3 - Commercialization

Phase 3 does not provide capital, but it offers a significant advantage: qualifying firms can secure follow-on contracts without competitive bidding. These programs are competitive, and winning requires a compelling proposal aligned with specific agency objectives.

In April 2026, the SBIR program was reauthorized after a 6-month gap, with a few notable changes. One significant change was the introduction of the Strategic Breakthrough Awards, which provide up to \$30 million in funding, matched 1:1 by private or non-SBIR government capital [17] [18]. This combined \$60 million vehicle can help bridge the "Valley of Death" by requiring a formal Program of Record and a directed commitment of funding from a senior acquisition official.



Non-dilutive capital can add value even as a small share of a startup's total funding. Stoke Space, which has raised over \$1 billion to fund its Nova rocket and ancillary technologies, received its initial capital from a modest SBIR award. This award not only provided funding to de-risk several early-stage technology hurdles facing Stoke's engineering team but also demonstrated to investors the company's traction, illustrating SBIR's value beyond the benefits of non-dilutive funding.

Founders should know that the government is actively working to broaden SBIR and STTR access for first-time applicants seeking to commercialize new technologies beyond government buyers. To further this aim, the government has introduced submission limits to discourage "SBIR mills," firms that specialize in securing grants at the expense of more worthy applicants.

Views vary on government funding through SBIRs and Other Transaction Agreements (OTAs). Some investors worry these distract startups from their core mission. Others, like Mandala Space Ventures, see them as an effective way to validate technology without giving up equity. One thing is clear: non-dilutive capital protects founder ownership.

More participants are providing capital to fund the future

A wider range of investors is now funding the next generation of space companies.

Historically, generalist venture firms like Founders Fund, Benchmark, NEA, Lightspeed, and Sequoia were among the few willing to back space companies. For decades, most Silicon Valley investors avoided aerospace and dual-use altogether. That has changed.

In recent years, the funding landscape for the new space economy has broadened considerably to include family offices, high-net-worth individuals, specialist deep-tech venture capital firms, the corporate venture capital divisions of the primes, the direct investment arms of sovereign wealth funds, and traditional investment companies. Public-market and hybrid routes have featured as well, including a wave of SPAC listings (most of which performed poorly), a handful of IPOs, and matched-funding vehicles like STRATFI and AFWERX that pair government and private capital.

Family offices and high-net-worth individuals can move faster and do not face fixed time horizons. This contrasts with traditional venture firms, which must meet limited partner (LP) liquidity requirements and often evaluate investments on shorter fund cycles. Several family offices have been long-term SpaceX investors.

The emergence of specialist deep-tech and space funds has positively contributed to the funding environment. Lux Capital, Seraphim Space, SpaceFund, Alpine Space Ventures, Mandala Space Ventures, and Balerion Space Ventures are a few firms committed to supporting the development of the new space economy. Their general partners bring specialized knowledge of the space economy, deep technical understanding, and access to key customer relationships in both the public and private sectors.

Large primes also have venture arms. Lockheed and Airbus Ventures have each invested in more than 100 startups and provide real strategic value. Unlike generalist VCs, corporate venture arms tend to focus on investments that are synergistic with their parent company's existing business. Founders should be aware of the signaling effect. A large prime on the cap table may attract other investors, but it may also make competing primes reluctant to engage. JP Morgan Chase recently announced it would invest \$10 billion of its own capital into critical sectors, including space, through its "Security and Resilience" initiative. Additionally, the bank indicated it would facilitate financing of up to \$1.5 trillion. Most of this capital will go to larger, established companies, but there will be a spillover effect for startups. Other institutions will follow. Besides banks, asset management companies such as Wellington, Fidelity, and T. Rowe Price are investing in the new space economy, albeit at a later stage than venture capital firms. These firms and others also offer space-themed funds and ETFs, which allow the general public to invest in the space economy.

Sovereign wealth funds, including Singapore's Temasek and GIC, Saudi Arabia's Public Investment Fund, and Norway's Norges Bank, have historically invested as LPs in venture funds. In recent years, they have begun co-investing directly alongside those funds. It is becoming more common to see a sovereign wealth fund's name on the cap table of a rapidly growing, early-stage company in the space economy.

The range of funding sources available today is genuinely good news for founders. But not all capital is equal. While experienced founders may not need much from their investors beyond capital, specialist funds and corporate venture arms can leverage their industry knowledge to offer real strategic value. Generalist VCs bring different but valuable experience that can help founders scale.

New strategies for venture investment that we need to keep in mind

The combination of improved small-business funding, the success of SpaceX, the emergence of commercially serious players like Rocket Lab, and many new and interesting ideas promoted by entrepreneurs has convinced investors of the financial viability of new space ventures. The new wave of commercial investment highlights two primary investment philosophies:

1

Funding the safe – technologies and applications with present-day demand for terrestrial use

2

Funding the visionary – technologies and applications that build ahead of market demand

The *safe* includes traditional satellite communications, GPS, earth observation, and associated applications such as weather monitoring, navigation, logistics, and satellite-enabled transportation (Uber, Lyft, Waymo). These industries have clear revenue pathways that exist outside of the space industry. We consider these opportunities *safe* because they do not rely upon external government funding to become economically and commercially viable. On the other hand, the *visionary* includes in-situ resource utilization (ISRU) for propellant production, on-orbit manufacturing and servicing, lunar terrain vehicles, space elevators, and space stations.

These visionary opportunities, while compelling, face significant technical, regulatory, and market uncertainty. Many of these opportunities depend on a sustained cislunar economy to achieve an acceptable level of commercial viability. For *the visionary*, success will unquestionably require investment capital with a longer, more patient time horizon to match the lengthier development and commercialization timeline indicative of these visionary opportunities.

Although venture capital firms will provide capital to safe far more frequently than to visionary firms, we are entering an era when the opportunity for visionary firms has never been greater. Hundreds of startups focused on the space economy are raising venture capital. Some have already achieved “unicorn” status. According to Tracxn, there are already 17 unicorns, and more will certainly arrive in the near future. Along with the increase in private-sector funding, demand for secondary shares has also risen. In fact, secondaries are firmly becoming a distinct asset class, with specialist funds providing the necessary liquidity to match sellers with new buyers. The liquidity provided by the secondary market helps venture investors “take money off the table,” enabling these VC funds to better balance their financial exposure to their portfolio companies, which, although very promising, have a much longer time horizon to reach commercial viability.

Venture capital’s increased willingness to fund the visionary fills a gap in government-affiliated entities’ (NASA, DOE, DARPA, etc.) funding models. The government has typically funded a select few near-term ambitions, betting that these initiatives would catalyze new industry growth in the mid-to-long term. For example, the federal government initially funded GPS and surveillance satellites to meet immediate military and intelligence needs. Today, a wide range of commercial applications enabled by GPS provide countless benefits to consumers. However, these organizations do not have the mandate to move the basic research they fund through to commercial adoption. NASA, for example, developed and successfully ground-tested the Integrated Powerhead Demonstrator (IPD), the first American Full-Flow Stage Combustion Cycle engine, but it was not until SpaceX developed its Raptor engine that this technology achieved commercial viability. NASA has historically been an agency with bigger dreams than its budget allows. Private capital’s willingness to fund the visionary has been instrumental in filling the gap for technologies with high commercial potential that are considered lower priorities by government funding agencies. The financial payoff could be substantial, but it will only be realized if the commercial markets the visionary anticipates indeed materialize.

Private Capital is starting to set the direction

Cheaper access to orbit has shifted the industry from a race to build rockets to a race to capture what those rockets unlock. Two things are easy to conflate here. Government still provides most of the money, roughly 70% of space spending, and remains the largest single customer. What has changed is direction-setting: private capital increasingly decides what gets built, when, and by whom, even when the eventual buyer is public. The counterview is worth stating: on the numbers, government is still the engine. Public budgets fund the anchor demand, the basic research, and the early contracts most commercial markets are built on, and private money largely follows those signals. Private capital now sets direction at the margin; public money still sets the scale. Furthermore, a range of ancillary industries are beginning to recognize high-value business opportunities in the space economy. As launch and hardware costs decline, capabilities expand, and more industries recognize the value space offers to their core operations, the space economy is steadily migrating from a standalone sector to a foundational layer of the global economy. As shown, both private and public investment have been instrumental in that migration.



2.4 The rise of dual-use markets and opportunities

Defense programs dominated early space spending, but commercial investment has grown rapidly. Defense spending is expected to keep pace, driven by the Department of Defense's renewed focus on space. In 2023, the World Economic Forum reported that the DOD spent \$94 billion on space applications, or about 15% of the total space economy. The Department of Defense's expenditure is expected to rise to \$251 billion by 2035 [13].

“Space technologies fundamentally changed the execution and scope of maneuver warfare in the 21st century.” [19]

The DOD, now redesignated the Department of War, has recognized the growing importance of space. For the first time since the U.S. Air Force was established in 1947, the DOD consolidated the military's existing space assets into a standalone branch, the U.S. Space Force (USSF). Officially launched on December 20, 2019, the new branch signaled to the world that space was now a war fighting domain. The Space Force underscores the importance of space to all other domains, land, sea, air, and cyber, and consolidates space operations and acquisitions under a single command. The USSF provides a framework for rapid procurement and focused pursuit of space technologies. Maintaining that momentum is critical. Space superiority remains a national priority [20].

“The establishment of the USSF resulted from widespread recognition that space is a national security imperative. When combined with the growing threat posed by strategic competitors in space, it became clear that a military service focused solely on achieving superiority in the space domain was needed.” [21]

One notable program that will significantly increase spending is the Golden Dome. As of 2026, \$40 billion has been allocated, with a 20-year lifecycle budget of \$542 billion. Between 60% and 80% of this spending will be dedicated to satellite systems. Beyond this, an independent estimate by Todd Harrison of AEI suggests total program spending could reach as high as \$3.6 trillion to meet every listed requirement [22].

Defense entrepreneurship does not simply rise when defense budgets rise. It rises when government demand signals are strong, when a technology shift weakens incumbent advantages, and when clearer funding pathways allow startups to survive long enough to move from prototype to adoption.

The same five primes that dominated defense procurement in the early 2000s no longer control it. Software-defined defense has opened the door for startups of all sizes to compete. Palantir is the most striking example, with a market valuation exceeding that of any of the five primes. Figure 5 compares these companies and their recent market caps.

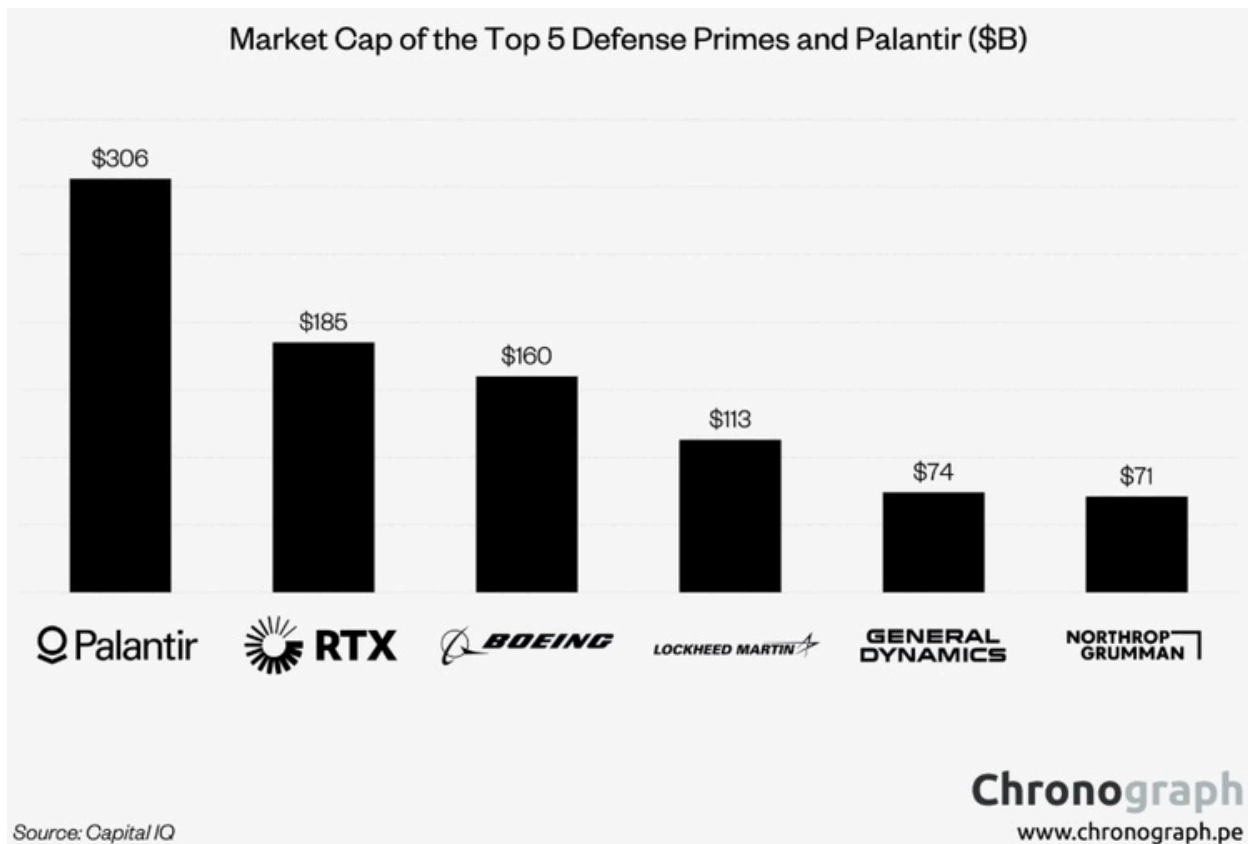


Figure 5. Market Cap of top U.S.-based commercial primes and neo-prime, Palantir[23]

Note: SpaceX is not shown here. Its June 2026 IPO valued it above two trillion dollars, more than all these primes combined, but its newly listed stock has swung widely enough that any figure would be outdated.

Consistent access to venture capital for promising ideas has enabled the emergence of a large number of startups offering a wide range of innovative solutions. Figure 6 highlights a 10-fold increase in defense venture funding between 2014 and 2025 [23]. Among the more than 17,000 dual-use and defense-tech startups, some of which focus on space tech, several ‘unicorns’ have already been funded, including Anduril and Shield AI. We expect many more unicorns to emerge (Vannevar, Skydio, etc.) [24]. Abundant venture capital has become a vital bridge across the ‘Valley of Death,’ allowing non-traditional defense firms to sustain product development and operations while navigating the slow and arduous path to qualification as a Program of Record [24]. It is important to emphasize that VC funding is not the only avenue for obtaining capital to sustain a company through this transition. As mentioned in the prior section, Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) are federal programs that provide non-dilutive research and development funding for innovative and ambitious startups. As discussed above, drawdowns not only reduce demand but also harden the market around incumbents. In a buildup, this dynamic plays out differently.

As threats rise and become more unpredictable, the government prioritizes speed, capacity, and new capabilities. While a founder might ride this wave, they need to convert that demand into a meaningful wedge. That wedge is easier to find today than in the 1990s and early 2000s, when the market was dominated by the primes. Successful startups in aerospace and defense rely more on software, autonomy, sensing, data fusion, communications, and low-cost production. These are areas where startups can move faster than legacy acquisition systems.

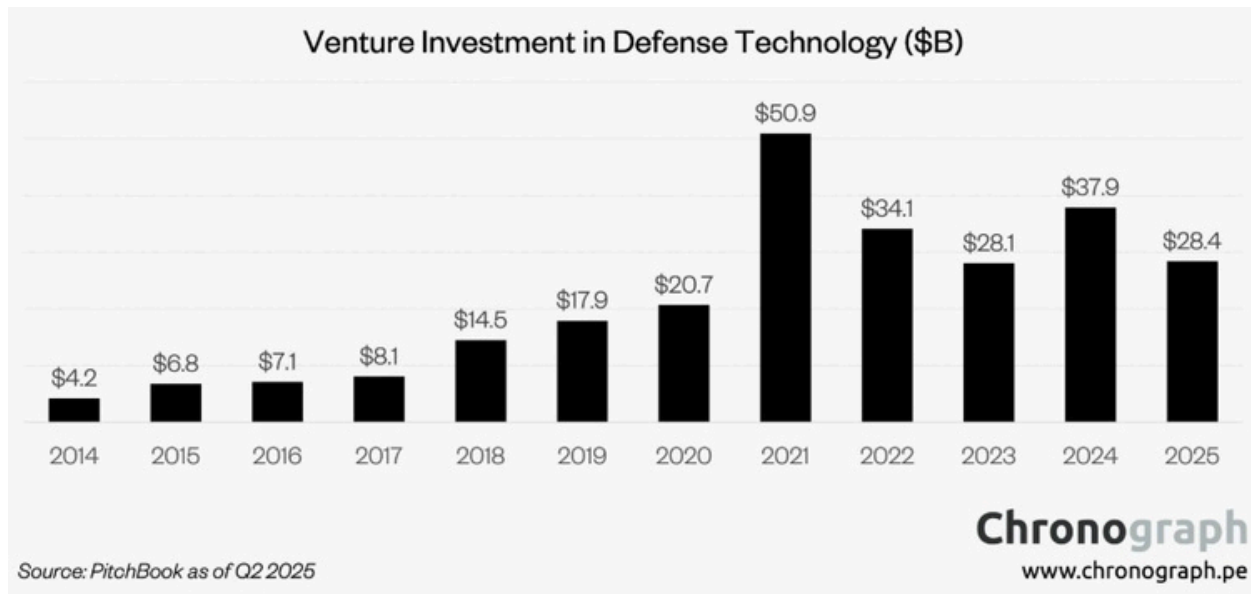


Figure 6. Venture Investments from 2014 to 2025 (\$ Billions) [23]

Venture capital activity has become important to defense entrepreneurship. As CSIS reports, defense ventures have continued to grow since 2014; refer to Figure 6. The areas receiving the most funding include advanced computing, software, security, and more recently, space technologies. Venture capital provides the runway startups need to keep building while the government moves through the process of testing, budgeting, and contracting.

The dual-use ecosystem offers huge benefits to all stakeholders

Dual-use technology has become a key consideration for investors and entrepreneurs. Dual-use applications of many technologies often serve as a gateway to VC funds, SBIR grants, and other contracts. The benefit is twofold, serving both government and commercial objectives. The government gains a subsidized production pipeline, higher technology readiness levels, and lower costs through commercial investment and purchases. Simultaneously, the commercial investor can establish a shorter path to profitability while preparing a technology that may experience significant success during a conflict or defense appropriation cycle. From the entrepreneur's perspective, this relationship provides a safety net for surviving the Valley of Death. During the 18 to 24 months when a product or program transitions to a Program of Record, VC funding keeps innovation moving and the company staffed. This forward progress and retention enable long-term success. What follows is a discussion of how an entrepreneur with an idea might transition that idea into a successful dual-use enterprise.



A shift in priorities – Costs are becoming an important consideration

Legacy defense sought performance at any cost. Today the focus has shifted to cost per shot and manufacturing timelines. Legacy systems cost millions per unit, took years to produce, and could not scale. To be relevant on today's battlefield, a product must cost no more than the system it defeats and be available in the thousands.

The clearest version of this shift is not in space. Ukraine showed it to the world: off-the-shelf commercial drones, modified with minimal hardware and software changes, ran intelligence and surveillance missions that previously required expensive purpose-built aircraft. First-person-view drones, costing a few hundred dollars, flew as one-way munitions. This is not an anomaly. It is a signal of where warfare is heading. It's also a sign for companies in space to not lose focus of cost in the long term, after technologies and methods have been proven out.

The 2026 conflict with Iran has reinforced this narrative. The LUCAS drone, at \$35,000 per unit, performed a mission traditionally reserved for \$2 million Tomahawk Cruise missiles [25]. High-end systems will not disappear. But low-cost alternatives will be used wherever they are suitable, preserving the critical stockpile required for peer conflicts. This logic applies unevenly in space: Golden Dome and Starshield-class systems are multi-billion-dollar architectures, not cheap attritable hardware. This pivot places a real burden on the modern aerospace founder: achieving industrial scale without the safety net of billion-dollar, decades-long platform contracts. To navigate this, entrepreneurs must address the evolving landscape of government and private funding, both of which have changed rapidly.

Funding is both a public and private game

The Department of Defense allocates at least \$2.3 billion through SBIR and is committing significantly more [26]. A significant share of these funds is dedicated to the space domain, with SpaceWERX alone distributing \$510 million in 2025 [27]. These budgets create thousands of opportunities each year to de-risk critical technologies without the drawbacks of dilutive funding. Founders can build on their SBIR successes to transition to private capital at higher valuations.

Venture capital's relationship with defense has transformed over the past decade. In 2016, most top-tier VCs avoided the sector entirely, deterred by ethical concerns, long acquisition cycles, and single-customer risk. Geopolitical volatility and the rise of the "American Dynamism" movement changed that. By 2026, the sector had reached record levels of capitalization, with over \$50 billion in dedicated defense-tech funds. Investors shifted from funding science projects to backing neo-primes such as Anduril and Shield AI, companies that challenge legacy incumbents by building software-first autonomous systems at commercial speed. VCs in defense prioritize speed to ramp, cost-per-shot, and clean cap tables.



Insights from acquisitions will be essential for new space startups

We asked Active-Duty Acquisitions Officers in the Army and the Space Force (USSF) how a startup might begin to gain traction. A USSF officer stated, “Don’t just come with a good idea.” Prototypes, whether hardware or software, really get traction. He further emphasized an obvious but often forgotten fact: the startup’s product should solve a real problem, and the CEO should be able to articulate exactly how.

Naturally, acquisition teams focus on cost, schedule, and performance. An Army Acquisitions Officer highlighted a recent increase in emphasis on scheduling, which has been a persistent shortcoming in prior contracts. Clearly articulating the ability to deliver on time is absolutely critical. Notably, performance is more than just technical achievement – the quality of a contractor’s systems and processes is also considered. Supporting this, the USSF officer pointed to cost accounting systems as an important priority for startup founders to consider.

Several unsolved challenges, but there’s optimism

We asked each defense professional the same question: what is an unsolved problem you see today? Answers ranged from technology gaps to organizational challenges, shaped by the daily realities each person navigates.

Regarding technology, we heard concerns about the challenges of deploying solutions to counter communications constellations, hypersonic missiles, and anti-satellite attacks. One Operations Officer noted that tactics and techniques developed in recent years are no longer sufficient, and that adversaries' new technologies may risk overwhelming current capabilities.

Challenges extend beyond technical capability to systems and procurement. Rapidly evolving priorities do not always reach the operational level, leaving acquisition efforts misaligned with strategic intent. A retired prime engineer reinforced this: the biggest bottlenecks are long procurement cycles, funding models that reward predictability, and a reluctance to innovate when it threatens existing margins.

Capital and defense demand have set the stage. The next shift is about how we sustain what we build.

2.5 The Rapid Emergence of Lifecycle Economics & Manufacturing in Space

Bigger spacecraft will always have their place, but the economy's next big shift is also about keeping valuable assets in orbit longer, while cheaper ones keep getting replaced. As satellites, orbital stations, and future lunar infrastructure become more numerous and valuable, the industry will need capabilities that extend far beyond initial production. These capabilities span the full aftermarket: inspection, refueling, repair, upgrades, and eventually in-space manufacturing. This section examines how the industry is moving from one-time hardware delivery toward full-lifecycle infrastructure. Near-term value is still likely to stem from improving terrestrial production systems and building on-orbit servicing markets, while longer-term opportunities will include in-space manufacturing, whose commercial readiness depends on firmer demand, lower operational risk, and more advanced orbital logistics.

Terrestrial Manufacturing and Operations

Before value can move into orbit, it must be built on the ground, and the terrestrial manufacturing base is the foundation on which the rest of the lifecycle economy depends. The terrestrial manufacturing of space systems is not constrained by technical capabilities. Instead, the largest constraints stem from fragmentation that affects supplier relationships and data infrastructure, a deteriorating pipeline of experienced and qualified workers, and the difficulty of modernizing to meet customer requirements. The core limitation is not a lack of manufacturing tools and capabilities, but a system that cannot effectively connect these tools and capabilities in a more meaningful and effective way. Modernization efforts must integrate existing tools across a supply chain that remains disconnected, under-digitized, and difficult to coordinate at scale.

Fragmented Supply Chain

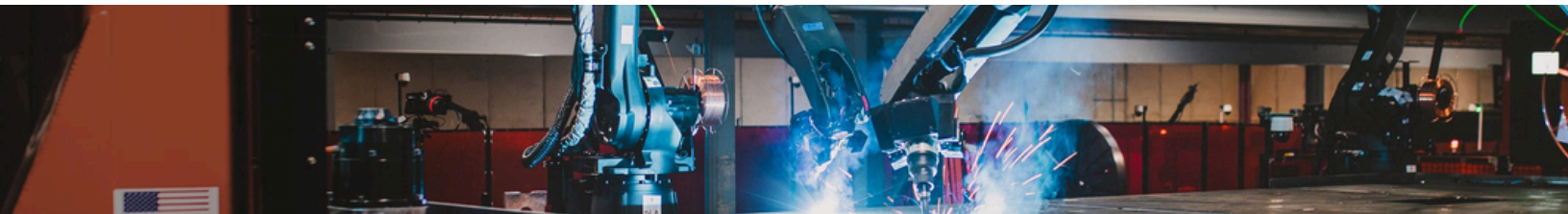
The US space manufacturing base comprises thousands of small and mid-sized suppliers, many of which operate as dual-use vendors for both defense and space programs. Approximately 43% of aerospace-certified businesses have fewer than 25 employees [28]. The proliferation of small firms creates risk: if revenue gaps between major contracts force some to close, critical knowledge disappears with them. A second risk: the workforce is retiring faster than it is being replaced. Fragmentation creates severe interoperability challenges, leaving most firms with incomplete data and weak digital connectivity.



Case Study 1: Robotic Welding at Path Robotics

Some companies have changed the typical operating model to mitigate fragmentation that causes disjointed datasets. For example, Path Robotics leases equipment to manufacturers monthly. They can address three problems that smaller aerospace manufacturers face. First, the pricing model makes the introduction of the robotic welding process remarkably easy because the leasing payment is a monthly operating fee rather than an upfront capital fee that is depreciated over time. Second, the operator can scale their operation more quickly. Instead of waiting until they are over capacity to justify the purchase of a new machine, they can quickly order a leased asset and avoid the need to hire additional highly skilled welders who are in short supply. Finally, Path Robotics can collect data from welds performed in the field into a single central repository. This consistent data allows them to tune their models. There is a strong positive feedback loop in which welds become higher quality and more efficient as more data is collected. This central repository sidesteps the issue of fragmentation among the large number of US aerospace manufacturers and may be applied elsewhere in the industry.

Fragmentation persists because of the industry's structure. Program-specific contracting, low volumes, and high certification costs have discouraged standardization and long-term digital investment. Firms have optimized for short-term execution rather than system-wide efficiency, reinforcing silos across the supply chain. Without long-term program visibility, operators are reluctant to invest in capital equipment. Additionally, large integrators often lack strong incentives to invest in supplier digitization, as value capture remains concentrated at the program level rather than across their entire supplier network. This is changing as the industry shifts from bespoke satellites to production constellations. In this new paradigm, repeatability and lifecycle documentation matter more than one-off performance.



Standardization

Space systems are also standardizing as the technology matures and more companies demand the same components. While many components and services remain bespoke and proprietary, increasing commonality across subsystems encourages suppliers to specialize and sell to a wide range of customers. This evolution mirrors the growth of early aviation manufacturing, where standardized components led to the emergence of dedicated, specialized suppliers. Functions currently handled within vertically integrated firms may shift to providers serving multiple programs. The standardization of maritime launch and recovery infrastructure illustrates this pattern in action.

Case Study 2: Maritime Launch and Recovery

Each launch company developed its own offshore maritime platform specifically for its rockets to launch and land. Sea Launch was the first significant company to provide this service [29]. SpaceX poached its talent and developed its own maritime platform [30]. The pattern continued with Rocket Lab and Blue Origin hiring many maritime aerospace experts from SpaceX after the technology matured at SpaceX and those other companies desired similar capabilities. Now, those same experts are starting companies such as The Spaceport Company and Seagate Space to provide a standard launch recovery service to future launch companies, drawing on their prior expertise across multiple companies. Seagate Space just entered a partnership with Firefly Aerospace and Lockheed Martin to use the Seagate Space platform, Gateway S, which demonstrates this outsourcing of shared, standardized capabilities [31]. This pattern is likely to continue across other aspects of operations and manufacturing, including the space economy, as certain aspects of the space manufacturing ecosystem are commoditized.

Weakening Workforce Ecosystem

Workforce dynamics further compound the constraints facing the industry. US manufacturing faces a shortage of 1.9 million workers if current trends continue [32][33]. Much expertise in aerospace manufacturing resides with experienced technicians, whose knowledge is poorly documented. Machine-specific parameters, sequencing decisions, and informal troubleshooting methods are rarely captured in writing. In some cases, retirees have been recalled to perform tasks understood by only a few individuals, highlighting the extent of tacit knowledge loss [32]. Engineering enrollment has increased, but new graduates don't address the immediate deficit of experience [34].

Industrial AI and automation are often presented as the solution. In some cases, robotic welding is the clearest example, and they are beginning to deliver. In practice, deployment still requires process redesign and integration with legacy equipment, which depends on the same experienced operators the industry is losing.

Firms are compounding this problem by cutting entry-level roles. Positions that once served as training pipelines are being automated away, removing the pathway through which skills and knowledge have always been transferred. The result is a negative feedback loop: the workforce needed to design, implement, and sustain automation never fully develops.

Adjusting to Modern Space Requirements

Efforts to modernize legacy manufacturing have had limited success. Frameworks like the Toyota Production System work well in greenfield settings but struggle in facilities with legacy equipment, low volumes, and high variability. Brownfield transformation remains one of the hardest problems in US manufacturing. In China, production lines can be deployed in weeks. US firms face higher costs and slower timelines, largely because of limited in-house capability and greater reliance on outside expertise.

Most aerospace factories were originally designed as job shops for bespoke, high-cost satellites. As the industry shifts toward constellation-scale production, these facilities are being retrofitted for higher-rate manufacturing, and the resulting inefficiencies are significant. Northrop Grumman has successfully adapted its facilities to produce PWSA satellites on brownfield sites, matching the production of other products like SpaceX's Starlink and Amazon's Project Kuiper [35][36][37]. However, even those brownfield sites may encounter similar problems as demand for new production already exceeds built capacity. Renovations and new manufacturing techniques will be required to meet the new demand [36].

Reshoring alone does not address the underlying challenges. Fragmentation, weak data infrastructure, and workforce constraints remain barriers to meaningful capacity improvement [38]. Human knowledge, much of it undocumented, is disappearing faster than it is being replaced. Without capturing and standardizing this knowledge, efforts to integrate systems and scale production will stall. These challenges extend beyond manufacturing into lifecycle performance, where fragmented production systems lead to fragmented maintenance and limited data continuity across asset lifetimes.

On-Orbit Satellite Servicing: Where the Space Industry's Profit Pool Will Form

On Earth, the industry refers to maintenance and servicing capabilities as MRO: Maintenance, Repair, and Overhaul (or Operations). In space, the official term is On-Orbit Satellite Servicing, or the "S" in ISAM (In-Space Servicing, Assembly, and Manufacturing). Same idea, different physics, and, of course, a different cost structure. To see where space servicing is heading, look first at where aviation MRO has already been. The same forces are now lining up in space.

Aviation should serve as a cautionary tale for satellite original equipment manufacturers (OEMs) that still treat hardware sales as the main event. Some already price the aftermarket into their bids, but for most, it remains an afterthought rather than a core part of the business.

Case Study 3 - The Aviation Cautionary Tale

For decades after the 1978 Airline Deregulation Act, major aircraft and engine OEMs earned most of their revenue from new aircraft sales. Aftermarket services, parts, and MRO lagged far behind. That balance has flipped. GE Aerospace's installed base of 70,000 commercial and defense engines now drives an aftermarket services business worth roughly 70% of company revenue [39]. Pratt & Whitney looks much the same. The global aviation MRO market reached about \$90 billion in 2024 and should nearly double by the mid-2030s [40], with engine overhaul alone capturing close to 40% of that revenue [41]. Three forces drove the shift: a growing and aging fleet, tougher reliability and safety standards, and the spread of preventive (and now predictive) maintenance.

Why the Same Shift Is Coming for Space

Satellite primes such as Boeing, Lockheed Martin, and Maxar still earn most of their revenue by selling fully developed platforms to military and commercial customers. That model worked when satellites were rare, custom-built, and expected to fail in place. Those assumptions will not hold as the orbital population scales.

The numbers tell the story. The active satellite population grew from about 1,400 in 2015 to more than 11,000 by 2025. The GAO projects that another 18,000 will reach orbit by 2030 [42]. Novaspaces expects 43,000 launches by 2035, representing \$665 billion in build-and-launch activity [43]. Operators flying that many assets cannot afford to treat each one as disposable, at least not in every orbit or for every application. The economics begin to favor refueling, repositioning, and component replacement over building and launching new satellites on multi-year development cycles. In civil aviation, sustaining existing aircraft proved far more economical than replacing fleets. We expect a similar shift in parts of the space economy. But the parallel is not absolute; MRO in space deviates from the historical norm. Aviation's lifecycle dominance was not preordained. It happened because the per-unit cost of a new aircraft is enormous, the asset can be serviced on the ground, and the FAA mandates inspection cycles that effectively guarantee aftermarket demand. None of those three conditions translate cleanly to space at the moment. A breakeven point will arrive in some orbits and never arrive in others. The question is not whether space will copy aviation. It is which segments will follow the aviation model and which will follow consumer electronics, where replacement beats maintenance.

The Tradespace: When Servicing Beats Replacement

The literature on this question is more developed than most people realize, and it points to four distinct regimes [44][45][46][47]. The boundaries between them mark where entrepreneurial action sits.

1. Always-serviceable: high-value GEO assets. Liu et al. (2021) conducted a real-options analysis of geosynchronous communications satellites and identified a dollar threshold (though a more accurate value needs to be determined on a case-by-case basis): servicing is more valuable when the satellite costs more than \$242M and the servicer costs less than \$140M [44]. Both constraints are satisfied by today's Geostationary Earth Orbit (GEO) comm sat market. About 70% of GEO satellites die from fuel exhaustion, not subsystem failure [45], which means a ton-class fuel delivery is enough to add years of revenue. Northrop Grumman's MEV-1 docking with Intelsat 901 in 2020 demonstrated this in practice. Intelsat's historical willingness to pay for life extension is well-established; in 1992, the operator paid roughly \$90 million to rescue the uninsured Intelsat 603 satellite, which ultimately generated over \$800 million in extended lifetime revenue [45].

2. Government-anchored: medium LEO/MEO and smaller GEO assets. In the next regime down, where the satellite costs less than a GEO comm sat but remains a serious capital asset, the math still favors servicing. The Naval Research Lab's 1998 SMARD study modeled a classified low Earth orbit (LEO) system with a first-unit cost of about \$790M and follow-on units near \$250M, and found that on-orbit servicing could cut lifecycle costs by up to 28% while raising payload availability by roughly an order of magnitude [46].

NASA Goddard's 2010 study put the breakeven differently: a servicer needs to refuel three to five customer satellites before its own cost amortizes [48]. Reach that customer count and the unit economics work. Fall short, and they don't, which is why the 2012 MDA-Intelsat refueling deal collapsed despite Intelsat's willingness to pay [45].

3. Replacement-wins: cheap LEO smallsats. A \$1M Starlink-class satellite replaced via a \$2,700/kg launch is hard to beat with any servicer. This is the real counterargument to servicing: when launch is cheap and tech moves fast, a newer satellite often beats a refueled one. Servicing wins where the asset is expensive, scarce, or hard to replace, not everywhere. The per-unit economics straightforwardly favor disposal, and the constellation's structure absorbs individual losses. This is the regime where lower launch costs in 2026 most strongly reinforce the existing model. Designed-for-obsolescence wins because the hardware was never expensive enough to justify the rendezvous and because the constellation operator has already priced in the replacement cycle.

4. Emerging-serviceable: very large LEO constellations at scale. Levchenko et al. (2026) make a system-level argument: once a constellation exceeds 10,000 satellites, fleet-level economics (tangible and intangible) begin to dominate per-unit economics [47]. Fleet capex, debris generation, atmospheric reentry impact, and launch cadence limits all create pressure for some form of sustainment beyond the disposable default. Servicing may win not on cost-per-asset but on cost-per-fleet at scale, and the winning service may not be repair at all. It may be active debris removal, fleet rebalancing, or controlled deorbit.

The takeaway: lower launch costs do not necessarily kill the servicing case but instead reshape it. Cheap launches make single-use LEO smallsats more viable in regime 3, but they also make refueling shuttles, depot architectures, and orbital tugs cheaper to deploy, collectively lowering the servicer side of every other trade space equation. The aviation analogy holds, but only in regimes 1, 2, and 4. In regime 3, space looks more like the smartphone industry than the airline industry. One technology area cuts across every regime: autonomy. Rendezvous and proximity operations remain the core technical challenge, and the difficulty increases with distance from Earth. In LEO through GEO, human-in-the-loop control is feasible. Once servicing extends into cislunar space, latency makes constant human oversight impractical, so onboard autonomy, fault detection, and the rules for control authority must take on work previously done from the ground.

Defense as the Bridge Market

The economic math is favorable in three of the four regimes. Although orbital servicing provides substantial value to customers operating in both the commercial and defense spheres, defense customers will most likely be the early adopters of these services.

Commercial operators typically wait for pricing data, insurance models, and repeated demonstrations before signing servicing contracts. Defense customers already have a deep appreciation for the value of orbital servicing, including maneuverability and on-orbit logistics. A Space Force officer working on servicing, mobility, and logistics described near-term servicing capabilities as more relevant to military use cases than to a broadly profitable commercial market today [49]. The 41st Space Symposium in Colorado Springs reinforced that direction, with the

Space Force pivoting toward maneuver warfare and treating dynamic maneuver, on-orbit logistics, and refueling as priority pathways [50].

The USSF's priority framework highlights defense as a high-potential bridge market. Defense missions can fund early flights and generate the operating data that commercial buyers will eventually want. For founders, the practical takeaway is that the first viable product probably won't look like aviation MRO. It will look like maneuverability, asset recovery, or mission flexibility, sold to a customer who already values those capabilities.

What Space Servicing Looks Like Today

NASA Goddard's 2010 On-Orbit Satellite Servicing Study set out the framework that still shapes how the industry discusses this work [48]. The report breaks down servicing capabilities along seven key axes: task type, execution mode (human, robot, or both), rendezvous and capture, location, communication latency, customer design, and customer attitude (whether the target is cooperative, partially cooperative, or tumbling). See Figure 7 below. Some items on each axis have been demonstrated in flight, either as experiments or as part of missions (historical), whereas others remain untested (unsampled). Notably, one item warrants an update as of 2026: missions in GEO have been completed by Northrop Grumman's MEV platform [51].

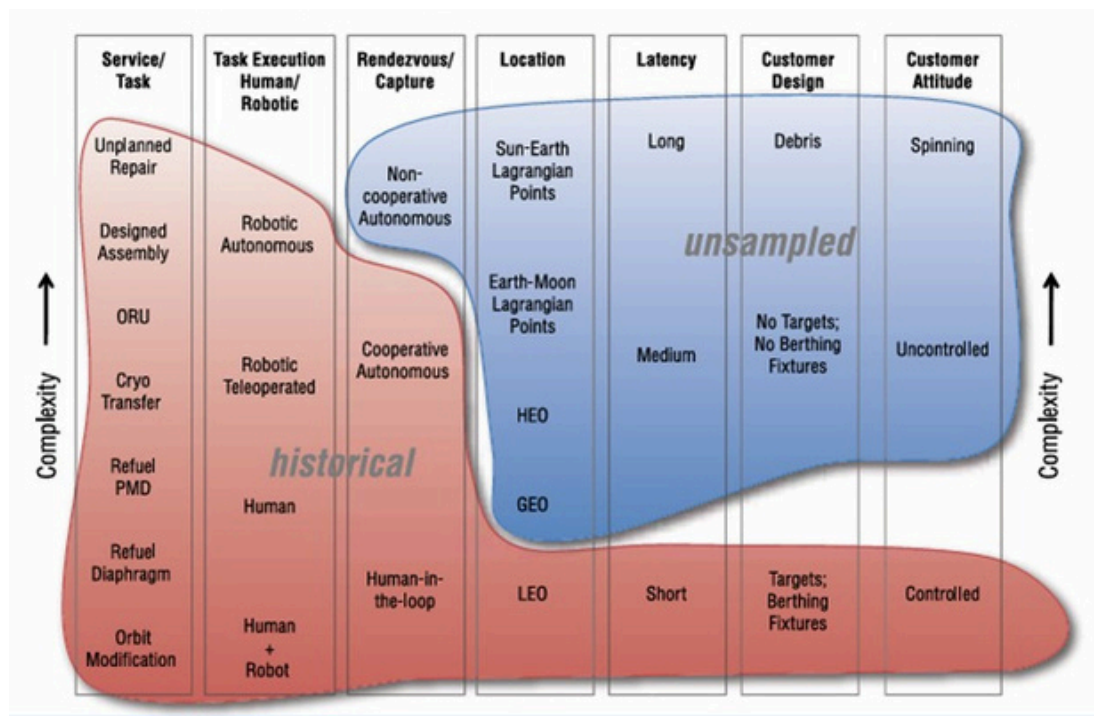


Figure 7: On-Orbit Space Servicing technical map [48]

NASA's central findings still hold fifteen years later: the technical tasks themselves are not the binding constraint. Most relevant servicing tasks have previously been demonstrated in flight, often by humans during shuttle missions.

The unsampled regions of the space servicing technical map cover distance, autonomy, and customers that were never designed to be serviced [48]. That maps cleanly to the commercial activity we see now:

- **Life extension and orbit modification.** Northrop Grumman's Mission Extension Vehicles, MEV-1 and MEV-2, docked with Intelsat 901 and Intelsat 10-02 to provide propulsion and attitude control [51]. The follow-on Mission Extension Pods are smaller and less expensive, designed to attach without taking over the host's full propulsion stack.
- **Refueling.** Two architectures are emerging in parallel. Mission-based refueling delivers a servicer directly to the customer (Orbit Fab's Tanker-001 and the company's RAFTI standardized fluid transfer interface [52]). Infrastructure-based refueling uses orbital depots to supply multiple shuttle vehicles, lowering the marginal cost per refill once the depot is in place [53].
- **Inspection, repair, and component replacement.** Maxar's SPIDER and the NASA OSAM programs are relevant examples [54]. NASA canceled OSAM-1 in 2024 after Maxar's performance fell short, a development that is itself instructive. Even with \$2 billion in funding, the demonstration stage remains technically challenging [55].
- **Active debris removal and end-of-life services.** Astroscale's ELSA-d demonstrated capture of a prepared client; ELSA-M targets retired OneWeb satellites [56]. ClearSpace-1 and Starfish Space's Otter Pup expand the catalog of approaches for non-cooperative targets [57].
- **Power delivery.** Star Catcher Industries is building space-based power transmission to beam energy to customer satellites, extending their operational life the same way refueling does, without docking with them.
- **Hardware upgrades and capability insertion.** Hubble is the precedent. Five servicing missions extended its operational life by decades and added capabilities (including COSTAR, the corrective optics that fixed the original mirror flaw) that were not available when the telescope launched [48]. The commercial analog has not yet emerged at scale.

These are funded missions, several already flown. The point is not that the technology is mature, but that the technical objections of fifteen years ago have largely been retired. What remains is economic and regulatory.

The Software Layer: Why AI Fits Servicing Better Than OEM

Hardware capability is half the picture. Software is the other half, and it may be where the most underappreciated value ultimately accrues.

Probabilistic tools, predictive analytics, and advanced statistical models fit servicing better than they do OEM manufacturing. The reason is structural: every part in service is slightly different. A turbine blade with 4,000 cycles is not the same as it was at 400 cycles, and no two airframes wear identically. Deterministic models built around design specifications break down when the input is a fleet of thousands of components from multiple vendors, each with its own wear-and-tear history. Probabilistic models thrive on exactly these variances.

The civil aviation industry has been an early mover. Delta uses the Advanced Predictive Engine (APEX) platform to collect and analyze real-time engine data for predictive maintenance [58]. Vendors such as IBM Maximo, Siemens, and Rockwell Automation have built large predictive maintenance businesses around vibration monitoring, IoT telemetry, and asset management.



Space-native applications will need to adapt or develop similar tools and approaches used in civil aviation. In space, telemetry is sparser, latency is higher, and physical access is challenging, but the underlying mathematical principles are similar.

A final lens worth considering: software retrofit of legacy space assets. Could a 10-year-old GEO satellite significantly extend its useful life by onboarding an operating system or firmware updated and pushed from the ground? Could an Earth-imaging satellite benefit from updated solar power management firmware? Could a high-value reconnaissance satellite improve its imaging capabilities with a camera software upgrade that leverages new AI capabilities? These software servicing opportunities are certainly high-potential but largely unexplored.

The Build vs. Maintain Tension

A structural conflict sits at the center of this market: from the point of view of a satellite OEM, the economics of selling new satellite hardware still outweigh the economics of extending the life of existing assets. However, from the point of view of the customer, the inverse applies in many cases. In other words, in many cases, the economics of extending the life of a satellite are much more favorable than purchasing and deploying a new one. Of course, every additional year of service from an existing asset delays new-build revenue. This tension between OEM and customer shaped the rise of independent MROs in the civil aviation industry, where airlines learned that OEM-controlled service contracts could be expensive and constraining, and where independent or airline-owned shops won meaningful market share by offering flexibility, multi-platform capability, and price competition.

The same dynamic is expected to play out in space. The OEM incumbents with existing satellite businesses (Boeing, Lockheed Martin, Maxar) face a strategic choice: Meet their customers' economic needs by partially cannibalizing their new-build revenues through servicing, or cede a large share of their market to independents like Starfish, Astroscale, and Orbit Fab, which are much more willing to meet their customers' economic requirements. Experience in both civil aviation and the automotive industry, where independent aftermarkets captured enormous value once OEM service proved too expensive and constraining, suggests that ceding the market is the more common and more costly mistake. A second-order point is harder to address: Most satellites in orbit today were not designed to be serviced. No standardized docking interfaces, no refueling ports, no modular subsystems. The shift to serviceable architectures is itself a design revolution, and groups like the DARPA-backed CONFERS consortium are working to define the standards that would make it possible [59]. NASA Goddard's 2010 study made the same point: Design commonality (modularity, standardized interfaces, common fasteners, accessible subsystems) is the precondition for an affordable servicing ecosystem [48]. Building serviceable hardware also tends to make integration and test on the ground substantially cheaper, which is the dual-use case for serviceability that designers have historically underindexed.

The Regulatory Bottleneck

Designed-for-service hardware is one barrier. Regulation is another, arguably the more binding one in the near term. Current U.S. government policies and practices are not equipped to authorize and supervise commercial ISAM activities, particularly in cislunar space [60]. The Outer Space Treaty of 1967 makes states internationally responsible for the activities of their non-governmental entities in orbit [61]. The domestic licensing regimes that translate that responsibility into operating permits were built for launch, communications, and remote sensing, not for a single spacecraft approaching another and making physical contact.

The risks are real, and a strong regulatory framework is required. Servicing missions require close-proximity operations, sometimes culminating in direct contact with another space object. A failed rendezvous can create debris in already-congested orbits. Without clear licensing pathways, liability frameworks, and interoperability standards, capital that would otherwise flow into servicing companies remains on the sidelines. The companies that move early will operate under regulatory ambiguity, which is itself a competitive moat for those willing to absorb the cost.

The list of gaps extends beyond licensing. Spectrum allocation is one example. Tahara Dawkins, Sr. Director of Policy at Astroscale U.S., notes that ISAM inspection is not on the WRC 2027 agenda, even though the agenda is heavily space-related, leaving servicers without a coordinated spectrum framework [62]. The mission authorization framework is similarly unsettled: which agency regulates, how enforcement works, and how the United States coordinates with international partners on contested operations are all open questions [63].

The Lifecycle Argument

Without space-native servicing, the orbital economy hits a ceiling. LEO satellites today typically last 5-10 years; GEO satellites can last 15+ years until station-keeping fuel runs out [64]. Those lifecycles were tolerable when launch was expensive and constellations were small. They become a bottleneck when launch is cheap, constellations are massive, and software and hardware innovation cycles outpace the assets they upgrade.

Where long lifecycles and high asset value justify it, on-orbit servicing has to become a native part of the space ecosystem rather than an afterthought, as it did in aviation. In those segments, keeping pace with ground-based innovation means designing for service from the start. The companies that build the servicing layer, on Earth and in orbit, will sit where GE Aerospace and Pratt & Whitney sit today: at the center of a recurring-revenue business that compounds over decades. Not in every orbit, and not for every satellite. The decision to design for service or for obsolescence is the question every satellite developer should now be asked to defend.

Beyond sustainment: building what comes next

In-space manufacturing is not a new concept. Materials processing and life-sciences experiments date back to Skylab, the Salyut stations, and Mir's Kristall module, which was built specifically for in-space materials manufacturing. What is new is the prospect of doing it commercially, with cost structures that close. Since we looked at extracting more value from satellites already in orbit, we turn to building the things that aren't there yet.



The demand-first lens

The first question any in-space manufacturing pitch should face is whether the product needs to be made in space at all. Chad Anderson made this point directly in his interview: many products can technically be manufactured in orbit, but the economic case rarely beats making them on Earth [65]. Cheaper launch raises the bar a microgravity advantage has to clear, because Earth-based manufacturing becomes more competitive across every cost line at the same time. A useful screen has three parts. Does the product gain something from space that Earth cannot replicate, such as microgravity, vacuum, or the radiation environment? Is it valuable enough per kilogram to absorb launch and reentry costs? And does a paying customer exist today, in this market and not some future one? Pharmaceuticals and high-quality fiber optics pass all three. Most other candidates pass one or two.

“Many products are technically possible to manufacture in orbit, but the economic case rarely beats them on Earth” -- Chad Anderson, Space Capital

AIAA and McKinsey both rank in-space manufacturing as a strategically important capability over the next two decades [63] [66]. Neither argues that the market has matured to match that importance. The window for entrepreneurs lies in the gap between strategic importance and commercial readiness.

The market today

The market that has emerged on the other side of that filter is real but small. AIAA estimates global investment in in-space manufacturing at roughly \$3 billion across about 80 companies [63]. That ecosystem is the size of a single mid-cap aerospace supplier. The companies in it sit at different layers of a tech stack (refer to Figure 8): full systems at the top (a manufacturing platform, a station module), then subsystems (manufacturing and processing, robotic handling, autonomy, in-space logistics, health monitoring), assemblies (robotic arms, end effectors, feedstock storage and transfer, measurement units, docking mechanisms), components, and feedstocks [63]. Founders do not all need to build the platform. The picks-and-shovels positions in tiers 3 and 4 reach revenue faster than the system layer, and they are where supplier economics will concentrate once standardization arrives.

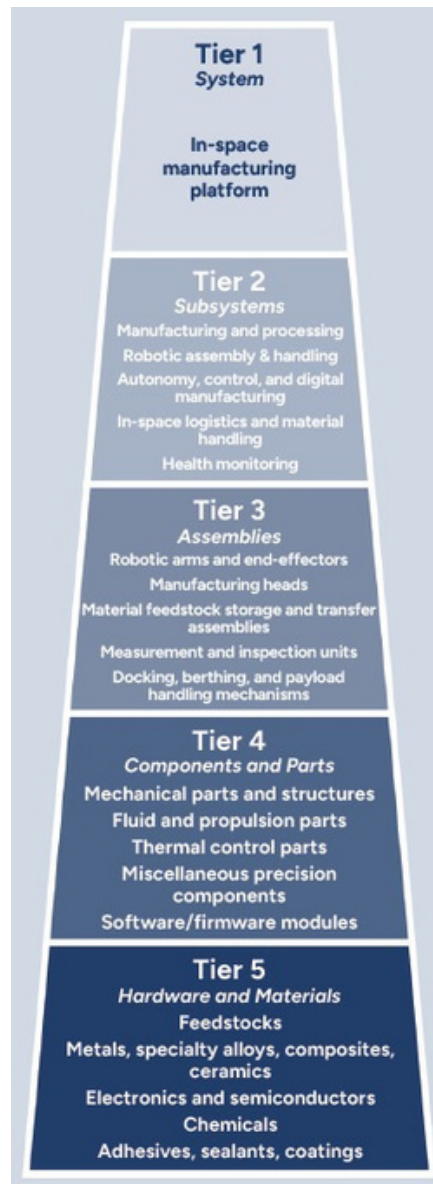


Figure 8: In-space manufacturing tech-stack [63]

Pharma and the microgravity materials stack

Pharma is the strongest near-term candidate for a reason that is often underplayed. The moat is regulatory, not just technical, though the commercial market is still forming rather than fully formed. A microgravity-grown polymorph of an existing active pharmaceutical ingredient may qualify as a new composition of matter for IP purposes, restarting the patent clock and circumventing the standard generic-erosion cliff. Varda's own biopharma materials describe the opportunity as both "new chemical entities" and "lifecycle management of marketed products" [67]. This is the language drug companies use when they want to extend the protected revenue window on a successful asset. Patent extension plus an independent regulatory pathway gives pharma something most space businesses lack, a customer with an economic reason to prefer the orbital version. That reason is real but still early. Pharma companies, including Merck and United Therapeutics, have paid for microgravity crystallization experiments, but no one is yet running recurring commercial drug production in orbit.



Flight cadence, throughput, and mass-to-orbit costs all have to improve before that demand becomes operational rather than experimental. Varda Space Industries built the first commercial reentry capsule around exactly this thesis. The W-1 mission grew the metastable Form III of ritonavir in orbit in 2023 and recovered the crystals after reentry in February 2024, with the published stability study confirming that radiation and reentry conditions did not convert the polymorph back [67]. A follow-on Varda paper in 2026 characterized Form III in detail and described the company's broader infrastructure for synthesizing novel pharmaceutical molecules in microgravity for partner companies [68]. The W-Series capsules now operate as free-flying production platforms for additional customers [66]. Varda did not wait for a station to dock to. Backed by venture capital and early government reentry-data contracts, it built the hardware while developing the pharmaceutical pipeline its longer-term thesis depends on.

The supporting cast spans materials whose microstructure improves in microgravity. ZBLAN heavy-metal fluoride glass produces optical fiber with fewer defects than terrestrial methods can achieve, and several ISS payloads have moved that work toward early production [66]. Higher-purity semiconductors are being tested through MSTIC and similar platforms [66]. Other candidates (exotic alloys, ceramic turbine components, bioprinted tissues) have technical interest but weaker commercial signals. Fiber and semiconductors are a credible second tier. The rest is research with optionality on it.

Commercial LEO Stations

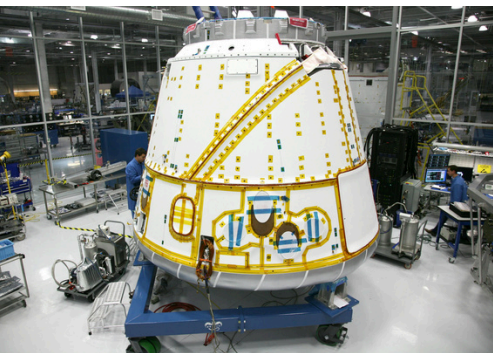
Even pharma's path to scale runs through commercial destinations, and those destinations are unsettled. NASA's Commercial LEO Destinations program was designed to anchor demand for private stations, much as COTS anchored commercial cargo in the early 2000s. That structure has changed twice in eight months. In July 2025, NASA moved Phase 2 from a FAR-based fixed-price certification contract to funded Space Act Agreements, citing budget shortfalls and the need for industry flexibility [69]. In March 2026, NASA went further. Dana Weigel, the agency's ISS program manager, told industry that NASA does not yet believe a commercial business case exists in LEO. She added that independent market research has put a mature commercial market about 10 years away for the better part of a decade, and that projection has not advanced as time passes [70]. Associate Administrator Amit Kshatriya raised a second concern: the companies proposing to build destinations do not yet have direct experience operating space stations [70]. NASA's proposed alternative is to procure a core module that attaches to the ISS and provides power, propulsion, life support, and docking ports. Commercial modules would attach to that NASA-procured core and detach with it as a standalone station once the ISS is retired [70]. NASA also signaled it would increase private astronaut missions from one to two per year and let companies sell the commander seat, potentially back to NASA, to seed near-term commercial revenue [70].

The immediate effect is that the anchor-tenancy assumption underlying private station business cases, including those of Vast, Sierra Space, and Starlab, has weakened. For in-space manufacturing, this matters because most near-term production happens on or near a station. If the destination layer takes longer to consolidate, manufacturing customers have three choices: wait, fund their share, or build vertically integrated reentry architectures like Varda's. Each option carries different capital requirements and different time-to-revenue. The cleanest commercial cases will be those that pick a path early, rather than assuming the station layer will arrive on the original schedule.

In-space assembly

Assembly is distinct from manufacturing. Manufacturing produces finished parts. Assembly joins them into larger functional structures. The capability matters for missions that exceed what fits in a launch fairing: large-aperture telescopes, deep-space arrays, modular habitats, space-based solar power, data centers, and lunar surface infrastructure [63][66]. Most of this work is still in research. NASA Ames demonstrated ARMADAS, an autonomous voxel-based assembly system that built a 256-unit reconfigurable structure on the ground with solar panel and wire routing outfitting capabilities [66]. NASA Langley demonstrated a 4.5-meter prototype of the Tall Lunar Tower, with a scaled design supporting 1,000 kg payloads at 50 meters of height and roughly 110 kg of structural mass [66].

Commercial assembly is still in the early stages. Rendezvous Robotics, founded by Ariel Ekblaw at the MIT Media Lab, is developing self-assembling modular hardware. The Aurelia Institute is advancing TESSERA, self-assembling reconfigurable tiles that flew on Axiom's Ax-1 mission in 2022, with a follow-on demonstration of a full 32-tile buckyball assembly scheduled on the ISS [66]. Three preconditions stand between the lab and a commercial market: standardized interfaces, robotic manipulation reliable enough for beyond-LEO latency, and customers willing to pay for structures that cannot be launched whole. Each is a multi-year program. Together, they explain why assembly companies are still mostly pre-revenue. Maxar's SPIDER program is the clearest example of the gap between technical progress and commercial readiness in this space.



Case Study 4: Maxar's SPIDER and Autonomous In-Space Construction

Maxar Technologies developed SPIDER (Space Infrastructure Dexterous Robot) for NASA's OSAM-1 mission to robotically assemble large spacecraft structures in orbit, particularly communications antennas and other systems too large to fit inside existing launch fairings [71][72]. Rather than launching fully integrated spacecraft from Earth, SPIDER was designed to demonstrate how modular components could launch separately and assemble in orbit under robotic control. NASA viewed the program as a way to open new orbital architectures and circumvent the size limits imposed by fairing geometry [73]. NASA canceled the mission before launch in 2024. The program still matters as a reference point in the development of in-space assembly and modular orbital infrastructure.

The cancellation reflected how difficult it is to move experimental assembly systems into operational programs. Years of schedule delays, cost growth far beyond original estimates, and persistent technical integration challenges led NASA to terminate OSAM-1 [71]. Independent reviews also flagged the complexity of autonomous rendezvous, robotic assembly, and spacecraft integration. The cancellation did not erase what SPIDER revealed. The program confirmed the strategic case for autonomous orbital assembly and supported the broader industry view that future space infrastructure will rely on modular construction rather than monolithic spacecraft. What SPIDER shows most clearly is the gap between technical progress and commercial readiness: the capability is advancing, but the economic, operational, and institutional conditions for a sustained market are still taking shape.

Surface infrastructure: Moon & Mars

Lunar and Martian surface manufacturing operates under a different cost equation than orbital manufacturing. The launch math for delivering bulk infrastructure to the lunar surface is harsh enough that in-situ resource utilization is no longer optional. NASA's Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) is developing laser-melted regolith processes for landing pads, roads, and blast shields [66]. Redwire's Mason project pursues similar surface construction using microwave sintering [66]. Blue Origin's Blue Alchemist has demonstrated production of silicon solar cells using only lunar regolith simulant, aiming for Earth-independent power generation on the surface [66]. The 3D Printed Habitat Challenge, ARMADAS, and the GITAI Lunar Communication Tower demonstration round out a portfolio of NASA-funded developers working under Artemis and adjacent programs [66]. Artemis itself serves as anchor tenancy for surface infrastructure, much as COTS once did for cargo: a government commitment large enough to underwrite early commercial investment, with the goal of a Commercial Lunar Payload Services (CLPS) market for surface payloads, power, and communications.

Resource extraction and the equation check

Asteroid mining is the prototypical "great if it works" bet, and it is where the demand-first discipline matters most. Matt Gialich, co-founder of AstroForge, frames the question without sentiment: mining is mining, and unit economics must close before anything else matters. How much does it cost to get there? How much does it cost to refine the material? What is the material worth on Earth? If those numbers do not work, the venture does not work, and pivoting to "validate on Earth, do space later" is a bet that the orbital market will eventually exist [74]. AstroForge's own bet is that platinum-group metals (PGM) from near-Earth asteroids can clear the equation, a bet that depends on terrestrial PGM ore grades continuing to deteriorate, reductions in refining costs, and successful reentry of the refined product [74]. The discipline generalizes. Every long-term in-space manufacturing or extraction concept faces the same equation, and the founders who answer it tend to do better than those who route around it. The Artemis program's approach to ISRU and additive manufacturing shows how this equation is being tested on the lunar surface.

Case study 5: ISRU and Additive Manufacturing in Artemis

The Artemis program is betting heavily on In Situ Resource Utilization (ISRU): using local lunar resources to produce oxygen, water, fuel, and construction materials on the Moon. Every kilogram launched from Earth costs money. Producing materials locally reduces launch mass and cost, making long-term lunar infrastructure at least plausible [75].

One promising approach pairs ISRU with additive manufacturing. Researchers at The Ohio State University developed a method that uses high-powered lasers to melt simulated lunar regolith into structural material for habitats and surface infrastructure. The printed material showed strong thermal resistance and withstood simulated radiation and extreme temperature swings [76].

That matters because the Moon is not a forgiving environment. Materials that crack under thermal cycling or degrade under radiation are useless. The Ohio State results suggest laser-sintered regolith could survive those conditions. If the method transfers to actual lunar soil, Artemis bases could build structural components on-site rather than shipping them from Earth. A base that can build, repair, and upgrade with local materials does not wait for the next resupply flight. That is the real argument for combining ISRU and additive manufacturing: not just efficiency, but resilience.

What's ahead for in-space manufacturing

AIAA frames the in-space manufacturing pathway around three enablers and two binding constraints [63]. The enablers are autonomy, transportation, and standard interfaces. Autonomy means continuous robotic manufacturing without human-in-the-loop oversight at every step. Transportation means low-cost, frequent movement of mass to and from orbit, which makes both production and recycling viable. Standard interfaces mean regular transport, common specifications, and abundant energy. The barriers are technical and operational risk on one hand and market uncertainty on the other. The technical risk is straightforward: launch, in-space operations, and failure tolerance remain unforgiving.

The market uncertainty is more nuanced. Subsidized access to ISS demonstrations is ending. FDA approval pathways for space-manufactured medical products are being defined in real time. Ownership rights for in-space resources are unsettled at the global scale. Founders entering this market are betting that the enablers mature faster than the barriers harden.

That bet is more honest when framed against the chapter as a whole. Earlier, we looked at how to do terrestrial manufacturing for space better, where the work is less about new technology than about integrating data and labor across a fragmented supplier base. Now we know how to extract more value from satellites already in orbit, where the technical case is largely settled and the binding constraints are economic and regulatory. This subsection looked at the longer bet, where the technical case is almost in place but the demand case still needs to be made. The companies that build complete cases on demand that already exist will define what gets built in the next decade. The companies betting on architectures that may or may not arrive will fund a lot of interesting research and a much smaller number of commercial wins.

2.6 The prominence of AI infrastructure, autonomy, and process innovation

Introduction and Background

The space economy, like many other industries, is inseparable from the high-impact capabilities enabled by the rapid adoption of artificial intelligence. AI and autonomy now touch nearly every layer of the space industry's value chain, enabling humans to operate (or, in some cases simply oversee) systems too complex, data-rich, and distant for continuous manual control. But paradoxically, the farther humanity ventures into space and the greater the sophistication of the space economy, humans will still play an all-important role in problem solving. A human-in-the-loop will be absolutely essential for years or even generations to come. While AI certainly excels at retrieving precedent, optimizing decisions, and managing knowledge at scale, deep-space exploration will increasingly demand human adaptability in situations where precedent does not exist at all. A key question going forward will be how to navigate AI's increasing shift from a tool to an indispensable co-pilot supporting society's expansion beyond Earth.

As one early joiner at a space startup told us, “[AI] touches every element of the value chain when it comes to space.” While continuing to advance opportunities in the space domain, AI is not a future aspiration; it is an accelerating present reality. NASA's Perseverance Rover is one excellent example of how these new technologies are transforming space exploration and operations. Launched in 2020, Perseverance now operates under the guidance of an algorithm called Mars Global Localization which allows the rover to determine its location without human operators, by utilizing comparisons of live sensor data and orbital terrain maps [77].

So, what is AI? Artificial intelligence encompasses machine learning, computer vision, natural language processing, and autonomous decision-making. It is the ability of applications and devices to comprehend instructions, interact with their environment (both digital and physical environments), and react in response to external stimuli [78]. While similar, we define autonomy as the ability to operate in a pre-defined environment to execute tasks in line with a given objective(s) [79].

Although often conflated, autonomy and artificial intelligence are not synonymous. Autonomous systems can operate independently using deterministic rules and predefined logic without any AI capability. Artificial intelligence, however, can expand the adaptability, reasoning capacity, and decision-making sophistication of autonomous systems operating in uncertain environments.

In this chapter, AI means computational systems that work with data to perceive, classify, predict, generate, optimize, or support decisions. [80] Autonomy is about how much a system can run mission functions without humans at the controls, including both semi-autonomous and fully autonomous systems. An AI model might analyze satellite imagery, predict component degradation, or recommend a maneuver; an autonomous system might carry out the actual navigation, collision avoidance, or task planning on its own. We therefore treat AI as the intelligence layer, and autonomy as the control-authority layer.

Setting the Stage

As we highlighted earlier in this paper, the global space economy is projected to reach \$1.8T by 2035. Clearly, lower launch costs and wider access to satellite communications, Positioning, Navigation, and Timing (PNT), and Earth observation services drive much of the expected growth of the industry. In parallel, significant participation by private investment capital and continued government demand have pushed the new space economy toward establishing scalable infrastructure, recurring operations, and a range of software-enabled services. [22]

These new space industry services and infrastructure create opportunities for AI. For example, as space systems scale, companies must process more telemetry, inspect more assets, task more satellites, and manage more risk with the same level of human attention and resources. AI helps alleviate these operating burdens, and at the same time, provides the benefit of speed and control.

Using the same upstream, midstream, downstream, and emerging structure introduced in Section 2.1, the more useful question here is where AI and autonomy create value across each layer. Figure 9 frames the maturity of each, and the sections that follow take them in turn.



Figure 9: AI and Autonomy Value Creation Across the Space Economy

The real players in the space economy - analytics, AI, and autonomy

There are similarities between the history of space exploration and the development of AI, with deeply intertwined milestones that have acted as a testing ground for new capabilities. Those new capabilities include:

- Remote Sensing Initiation
- Autonomous Control Proof Point
- Machine Learning Revolution
- Autonomous Systems Norm

Historically, autonomy in space has been constrained but is not new. Early examples include robotic exploration missions such as planetary rovers and autonomous maneuvering systems, as well as satellite-based automation for data processing. These largely pre-programmed and deterministic systems had limited scope and adaptability. In the past year, however, AI and autonomy in space has been rapidly advancing. Free-flying robots that are used on-board the International Space Station, called Astrobees, have increasingly used machine learning controls to navigate in zero-gravity in the ISS [81].

The US Naval Research Laboratory is launching “Autosat” which aims at increasingly using autonomous methods to reorient their cameras to avoid cloud cover during Earth observation [82]. SpaceX’s Starlink has conducted countless autonomous collision avoidance maneuvers since its debut in 2019. NASA’s Starling mission, in conjunction with Starlink, is testing autonomous swarms of satellites, initiating its first success in May 2024 and continuing to execute missions until December 2025 [83]. In March 2026, NVIDIA introduced plans to build out space-based AI computing to enable space system local computation, which can improve autonomous operations for real-time decision making [84].

These are a few of the many examples of AI and autonomy in space, with more research directed toward autonomous in-space manufacturing, servicing, and other high potential categories. The space ecosystem has been fundamentally transformed with satellite proliferation, advanced computing and edge processing, and breakthroughs in AI/ML technologies, which enable a shift to adaptive, learning-based autonomy. Founders see AI as a horizontal capability that can drive value across the entire space stack. Three companies illustrate how this plays out at the upstream, midstream, and downstream layers; Rocket Lab, Astroscale, and Planet Labs.

Upstream Case Study 6: Rocket Lab

Rocket Lab illustrates how the upstream layer is becoming a proving ground for AI in aerospace engineering and manufacturing. Its business integrates launch vehicle development, satellite component production, and mission support under a single production architecture – one of the few companies outside SpaceX to achieve this scale of vertical integration. The AI entry points are primarily engineering and operational. Design and simulation are the highest value targets, as AI can accelerate iteration and improve fidelity across propulsion and structural analysis. Manufacturing quality inspection is a natural second application, where high tolerances at sustained production volumes make automated tooling a practical investment. As Rocket Lab continues consolidating the component supply chain, including its recent acquisition of Motive Space Systems for precision mechanisms, the data infrastructure for AI-assisted manufacturing is building alongside the hardware.

Midstream Case Study 7: Astroscale

Astroscale illustrates the midstream layer’s defining constraint: operating autonomously where ground-loop latency is a liability. The company is building infrastructure for a category of operations that had no commercial market a decade ago: in-orbit servicing. Its portfolio covers debris removal, proximity inspection, life extension, and on-orbit refueling. These missions require sustained close-range operations under communication constraints and with minimal margin for error. Navigation is the central technical problem here. For instance, at long range, ADRAS-J processed visual camera imagery through Angles-Only Navigation algorithms to estimate the position of a non-cooperative debris object; as it closed within a few kilometers, it transitioned to Model Matching Navigation, comparing infrared imagery against a pre-existing 3D model to estimate relative distance. The spacecraft reached 15 meters from the target with no real-time ground control. In this layer, AI enables conditions for a technology, not optional enhancements.

Downstream Case Study 8: Planet Labs

Planet Labs illustrates the downstream layer’s core dynamic: as data collection scales, the competitive advantage shifts to what happens after capture. The company operates the largest commercial Earth observation constellation, capturing imagery of Earth’s landmass daily. As collection capacity has scaled, the bottleneck has moved downstream: from acquiring imagery to processing, prioritizing, and converting raw pixels into analysis that reaches customers within a decision-relevant window. AI applies across this pipeline in classification, change detection, and object detection on the analytics side. It also allows non-specialists to extract insight from the interfaces. On March 25, 2026, Planet Labs demonstrated how inference can move from the ground to the vehicle. Pelican-4 used an onboard NVIDIA Jetson Orin module to run an object detection model over Alice Springs, Australia, identifying aircraft at an airport directly from the raw image.

However, the rapid development and adoption of AI and autonomy introduce a fundamental tension within the industry. While AI has the potential to significantly reduce costs and increase operational speed, it also introduces non-trivial risks in specific safety-critical, highly regulated environments. As a result, the adoption of AI in space is best understood as a balancing act between accelerated innovation and effective controls, primarily for safety reasons. On the innovation side, AI is enabling faster iteration cycles, reduced reliance on ground infrastructure, and new mission capabilities. On the control side, its deployment must be accompanied by evolving standards for testing, validation, governance, human oversight, and compute constraints. The research presented in this chapter relates to three core findings that are projected to shape the future of AI and autonomy in space sector entrepreneurship.

Key Findings

1. Because aviation and aerospace largely rely on fragmented, disjointed software and analog data tracking (such as paper binders and verbal handoffs), there is a massive opportunity for founders to build integration layers and data infrastructure. Startups that focus on "process innovation," making existing workflows dramatically more intelligent with AI, can create highly defensible moats and enable small teams of 10 to produce the output of a 50-person incumbent team.
2. AI and autonomous technologies are ready for use in aerospace and are helpful for aerospace applications. The two major bottlenecks holding back a plethora of advances due to AI are compute power and the lack of a regulatory landscape for how stakeholders should be using the technologies.
3. To address the bottleneck caused by the lack of a regulatory landscape, thought should be given to the decision-making frameworks we choose to use when deploying AI architectures and autonomous technologies.



Upstream AI Applications

The cost of reaching orbit has fallen by orders of magnitude in the past decade. So has the cost of designing and building space-ready vehicles. A propulsion test campaign still takes months. Upstream launch services, where the leading players have already achieved significant engineering maturity, are less immediately impacted by AI. We do expect AI to compress the design, simulation, and manufacturing cycles that gate every new vehicle program.

Compressing the design-simulation-manufacturing cycle matters most for new entrants. Incumbent primes can absorb long timelines through scale, resources, and cost-plus contracts. Startups cannot. The Space Development Agency's two-year tranches and the broader shift to fixed-price contracting reward companies that can iterate quickly enough to meet aggressive delivery schedules without the engineering headcount of a Lockheed or Boeing. AI-driven design, simulation, and manufacturing are proving effective.

The economics also depend on closing the loop between design and hardware. Traditional aerospace treats simulation and manufacturing as sequential phases: design, validate, hand over to production. AI-native pipelines collapse this into a single iterative loop, where each test feeds the model, each manufacturing run validates the next design, and each simulation refines the next geometry. This is what makes orbital-class hardware tractable for teams of dozens rather than hundreds. AI is now reshaping how aerospace companies design, simulate, and manufacture systems. Current technology trends are enabling this realization:

- Physics-aware AI surrogates, ML models trained on simulation data, can predict aerodynamic and thermal behavior far faster than running high-fidelity CFD from scratch.
- Generative design for additive manufacturing: AI-generated geometries that exploit the freedoms of 3D printing rather than translating subtractive-manufacturing intuitions
- In-house manufacturing data: Vertically integrated production lines that generate clean, consistent training data for quality and process models
- Digital twins: Continuous synchronization between physical hardware and simulated counterparts, enabling predictive maintenance and faster iteration cycles

These trends create demand for design and manufacturing software that can credibly produce flight hardware, not just prototypes — a capability the established CAD/CAE incumbents have been slow to deliver. The commercial space ecosystem is seeing the emergence of companies developing innovative solutions to meet this need for AI-native aerospace engineering.

For instance, LEAP 71 is a Dubai-based computational engineering company that builds AI systems that autonomously design, analyze, and validate rocket propulsion. Its Noyron Large Computational Engineering Model encodes first-principles physics, engineering logic, and manufacturing constraints into software that outputs directly to fabrication. In December 2025, the company hot-fired two 20 kN methalox engines: a conventional bell nozzle and a full-scale aerospike, both designed entirely by the model. Both went from specification to first flame in under three weeks. The bell nozzle reached steady state at nominal chamber pressure, with combustion efficiency above 93 percent.

That timeline matters because traditional clean-sheet rocket engine development can take years and require large, specialized teams, a workforce constraint that determines which organizations can compete against established primes. Noyron compresses the design phase into something a small team can run. The manufacturing pathway compounds that: single-piece 3D-printed copper monoliths eliminate the assembly steps that have historically capped production rates. The physics encoding is what makes this credible for flight hardware rather than just faster prototyping. As cofounder Lin Kayser put it: “Noyron is our ongoing attempt to comprehensively encode the process of engineering into a computational model that can operate independently of humans.” LEAP 71 is now applying the framework to 200 kN and 2,000 kN thrust classes, both derived from the same underlying model. Let's not overlook that these larger classes introduce turbopumps and integration complexity the model has yet to prove against.

Midstream AI Applications

The rapid growth in satellites, with the active population rising from roughly 11,000 today toward an estimated 30,000 to 40,000 by 2030 [42], has created an explosion in available data. AI, particularly edge AI, enables real-time processing directly in orbit, reducing latency and reliance on ground stations. This is especially valuable for defense, intelligence, and time-sensitive commercial applications. As a result, companies that control data pipelines or specialize in analytics are positioned to capture disproportionate value. Ground infrastructure is the overlooked half of this layer. Northwood Space builds phased-array ground stations to replace legacy dish antennas and won a Space Force contract in early 2026 to upgrade the satellite control network. Without the ground segment, a satellite is just an expensive piece of metal in orbit.

Autonomous systems, such as navigation and mission execution applications, are critical in communication and time-limited environments. These applications will be useful during longer lunar and Martian missions, where communication delays or disruptions make real-time human control or interaction infeasible. Autonomous navigation in this sense relies heavily on reliable sensors and onboard flight software to interpret environmental conditions safely and respond to dynamic conditions.

The emergence of space-based data centers addresses both terrestrial constraints (energy) and in-space limitations (latency). These systems, while emerging and still proving feasibility, create a new layer of infrastructure for the broader space economy. Orbital data centers, as they relate to autonomy and AI in space, may be useful for their edge computing benefits. [85] Satellites are typically limited by their compute power due to constrained power and mass budgets. With orbital data centers, satellites can increase their computing power by accessing and relaying information to and from nearby orbital data centers. This may have massive implications for trusting autonomous space systems by enabling more robust compute and data analysis, thus improving real-time decision making for autonomous satellites and other systems. A more rigorous analysis of the implications of orbital data centers for ground-based economic and industrial benefits can be found in section 4.1.

The accessibility fueling the growth of the commercial space ecosystem creates concerns about collisions as well. This dynamic sets the stage for technologies that can build, expand, and adapt infrastructure directly in orbit, a capability that will become increasingly critical for commercial and defense applications. Autonomous systems enable in-orbit servicing, assembly, and manufacturing.

These trends create demand for in-space assembly, swarm robotics, and scalable infrastructure, allowing operators to build larger, more capable systems than a launch vehicle alone can support. Companies like Rendezvous Robotics, whose TESSERA tiles self-assemble into large structures in orbit, and Starfish Space, which is running some of the first autonomous docking missions in LEO, are early movers.

What ties these midstream players together is that AI is the enabling condition, not an add-on. Autonomous rendezvous and docking can't be run from the ground at scale because latency and the number of simultaneous operations exceed what human controllers can handle in real time. In midstream, AI is the moat.

Downstream AI Applications

The downstream layer, encompassing Earth observation, communications, and analytics, generates the largest share of space economy revenue and is projected to exceed \$1.1 trillion by 2035. As constellations proliferate and sensors generate more data, the binding constraint has shifted from collection to processing.

Customers no longer pay for raw pixels. They pay for the insights those pixels enable, delivered on a clock. AI closes that gap. This shift creates a clear architectural choice: run inference on the ground, where compute is abundant but latency is high, or run it onboard, where compute is constrained but the observation-to-decision window collapses. Defense, emergency response, and time-sensitive commercial customers increasingly require the latter.

Even ground-based players are restructuring around AI workflows that aggregate decades of archival imagery to train predictive models, shifting the value proposition from “what does this image show” to “what is about to happen here.” The result is an emerging class of AI-native operators that compete on insight speed and predictive depth, not resolution and revisit rate alone. AI is now restructuring how downstream space companies extract value from data. Current technology trends are enabling this realization:

- Edge compute on satellites: Modules like NVIDIA's Jetson Orin bring meaningful inference capabilities to the ~10W power envelopes typical of small satellites
- Inter-satellite links: High-speed laser communications between satellites allow constellations to behave as distributed sensor networks rather than independent assets
- Foundation models for geospatial data: Pre-trained models that can be fine-tuned for specific detection tasks rather than trained from scratch
- Archive-trained predictive models: Decades of accumulated commercial imagery now serve as training data for models that anticipate events rather than just detect them

These trends create demand for AI infrastructure that can run reliably in space-grade environments, deliver insights within minutes rather than hours, and integrate across multiple data sources. The commercial space ecosystem is seeing the emergence of companies creating innovative solutions to support this need for AI-native downstream operations.

For example, Maxar Intelligence is a geospatial intelligence company that has built one of the largest aggregation plays in the downstream layer, anchored by a 250+ petabyte commercial imagery archive accumulated over two decades. Its Sentry product, launched in June 2025, combines tasking, automated production, and analytics into a workflow that ingests data from Maxar's own satellites alongside third-party sources, including Satellogic, then applies AI/ML models trained on the historical archive to deliver predictive intelligence at global scale. In 2024, Maxar won Delivery Order 01 under the National Geospatial-Intelligence Agency's Luno A program, which required AI-generated detections of aircraft, ships, ground vehicles, and railcars within hours of image capture across persistent monitoring sites.

Why This Matters: customers have shifted from purchasing pixels to purchasing insights delivered on a clock. Object detection is becoming a commodity capability. The next layer of value is predictive intelligence: combining archival data with current observations to anticipate what is about to happen at a location, hours or days before it does. Unlike pure imagery vendors that compete on resolution and revisit rate, Maxar's archive depth creates a training-data moat that newer constellations cannot replicate by collecting more.

Two decades of historical context is itself the product.

Looking ahead: the future of software and talent

How will AI change how space startups organize themselves? It is not just about AI applications. It is about how companies restructure internally across talent, procurement, and operations.

Generative AI is improving workflows across industries. GE Aerospace, Lockheed Martin, Honeywell, and SpaceX, following its acquisition of xAI, all use generative AI tools internally. These tools have increased productivity by assisting with data analysis, documentation, and software development. Quality varies, but they generally streamline workforce processes.

The use of AI also raises the question of tacit knowledge. Many aerospace decisions depend not on written procedures but on the experience of people who understand how systems behave under uncertainty. This knowledge is hard to document, yet it shapes when engineers trust automation, question an output, or decide that human intervention is needed. As autonomy grows more central to space operations, startups will need to consider how to preserve human judgment while still benefiting from AI-enabled speed and scale.

In time-critical mission scenarios, experienced human judgment remains essential. But as AI software takes over more of that decision-making, we expect a significant rise in space-focused SaaS companies. Kayhan Space is a good example. Its software removes delays and errors from decision-making before and during critical mission scenarios. Its two products, Satcat and Dynamics, provide data aggregation, intelligence exchange, astrodynamics estimation, and orbit simulation, giving operators the data points and tools to automate satellite operations.

AI and autonomy in satellite operations may reduce the need for human decision-making in some safety-critical scenarios, but they will likely drive demand for decision-making tools and simulations that enable trust in autonomous systems. It will be worth watching whether companies build in-house autonomous decision-making tools or rely on SaaS providers. This will shape how the workforce is organized, with talent shifting toward modeling and simulation rather than being simply reduced.

Regulation & Risks

AI integration in the space industry raises questions about standardized regulation (norms, processes, procedures, and other requirements for implementation and use) and HITL. No global standardized framework exists for aspects such as levels of autonomy, requirements for human oversight, and validation protocols for AI models in safety-critical environments. This lack of bona fide guidance creates uncertainty for all stakeholders and may lead to fragmented approaches.

While society's adoption of Generative AI for both personal and commercial use has driven productivity in tasks such as knowledge management, coding assistance, and analysis, its integration into more critical domains will take time. Aerospace startups should look to AI to expedite manual tasks around data compilation, analysis, and insights; however, its use in high-risk applications should be approached with extreme caution, with heavy testing and validation expected. As one founder emphasized, "we don't want probabilistic answers in domains that require a high degree of safety. We need to give more thought for how you close that gap and grade the confidence in the results that come out." Additional topics that the merging of AI and space calls attention to include:

- A doubling down on cybersecurity
- Dual-use bifurcation, especially as related to algorithms and asset sovereignty
- Hype cycles and lofty expectations driven by private capital

Starlink is an instructive case study in regulating autonomous maneuvering. By the end of May 2024, Starlink had executed more than 50,000 collision-avoidance maneuvers in low Earth orbit using onboard AI with no human in the loop. As of March 2026, Starlink accounts for over 66% of satellites in low Earth orbit.

A problem emerges when examining the implications. SpaceX triggers maneuvers at a collision probability of 1 in 1,000,000, far stricter than the industry standard of 1 in 10,000. More frequent maneuvers increase fuel consumption and sensitivity to low-risk scenarios. Starlink satellite positions update only every 30 minutes. Together, these factors create complications: when satellites maneuver frequently but positions update slowly, predicting future collisions becomes harder for other operators. This raises legitimate questions about whether one constellation's autonomy standards amount to an effective monopoly over shared orbital space.

AI-enabled systems expand the attack surface in space architectures. Risks include cyberattacks on AI models, hijacking of autonomous systems, and data interception. Given the strategic importance of space assets, cybersecurity will remain tightly coupled with AI deployment. Beyond space traffic management, Starlink has major implications for data sovereignty. Its global coverage and ability to rescind access for specific countries give it outsized geopolitical leverage.

The militarization of space raises concerns about the dual nature of algorithms. AI in space is inherently dual-use; autonomous navigation, real-time monitoring, and situational awareness all serve both commercial and military ends. As geopolitical competition intensifies and space becomes a more contested domain, this raises concerns over escalation, asset safety, governance, and international norms.

Venture capital plays a catalytic role in space innovation. The point worth drawing here is not that VC is present, which Section 2.3 already covers, but the pressures it imposes. Speed and premature scaling can outpace what aerospace validation timelines safely allow.

Novel Frameworks & Tools for Analysis and Decision Making

Making sound decisions about AI and autonomy in space requires a holistic approach that accounts for regulatory, technical, and political risks. The aerospace literature addresses parts of this question, but few frameworks are designed around the early architectural decisions commercial space founders must make before achieving product-market fit.

EASA's AI Roadmap 2.0 and Concept Paper Issue 2 provide detailed guidance on Level 1 human augmentation and Level 2 human-AI teaming systems, with frameworks for learning assurance, explainability, and continuous safety management [86][87]. Although aviation-specific, EASA's framework serves as a reference point for safety-critical AI assurance rather than direct guidance for space ventures. Traditional Technology Readiness Levels originated in aerospace engineering; Lavin et al. 's MLTRL adapts TRL-style maturity thinking to machine-learning systems, including data pipelines, models, software components, and deployment contexts [88]. Both are valuable. Both are written for certification authorities and program managers, not for founders deciding whether to run inference on the satellite or the ground, what operator data to capture, or how to keep the system learning after deployment.

Adoption science fills part of that gap. The Task-Technology Fit framework [89] and the Unified Theory of Acceptance and Use of Technology [90] have been applied extensively to healthcare AI clinical decision support [91]. The aviation AI literature increasingly engages with similar adoption-focused questions around human factors, safety, and operational deployment [92].

These frameworks share a recognition that technology fails to be adopted not because it is technically unsound, but because it does not fit the workflow, the operator's mental model, or the institutional capacity to maintain it. Healthcare implementation science [93][94] has built nearly two decades of evidence on this point.

For early-stage founders, the most consequential risks are not model performance risks. They are deployment risks: whether the tool fits the workflow, whether operators can rely on it safely, and whether performance holds as conditions change. Borrowing from implementation science, three questions matter most. They are not new. Their application to early-stage space ventures is.

Fit: does the system match the operator's actual workflow?

In healthcare, the canonical finding is that interventions fail not because they do not work but because they do not fit the environment they are deployed in. The same pattern appears in aerospace. Kayhan Space's co-founders have framed the gap concretely: even satellite missions under the same NASA umbrella struggled to coordinate basic collision avoidance because the operational data sources required for timely decisions were siloed across organizations [95][96].

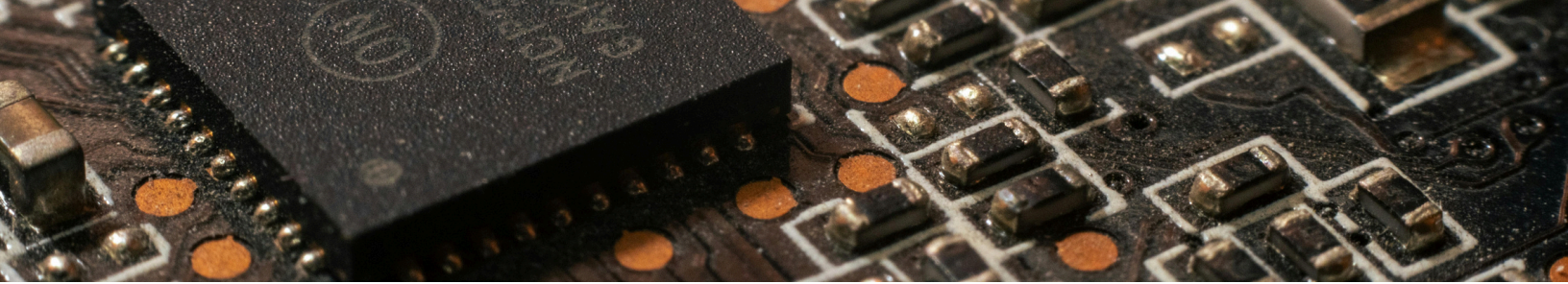
The technology to coordinate existed. The fit with how operators worked did not. Founders building operational AI need to ask this question first: what does the operator do today, where do they get the inputs, who do they hand off to, and where in that flow does the new system have to slot in? A model that requires three new data integrations, two new login credentials, and a workflow change before it produces useful output will sit unused next to operators still doing the work by hand.

Trust: can operators and affected counterparties understand, contest, or respond to the system's decisions?

Healthcare implementation research distinguishes between automation and decision support, a distinction that maps directly to the aerospace tacit knowledge problem. Automation replaces a human decision, while decision support augments it. The core trust question is whether everyone affected by the system's decisions can observe, calibrate, and respond to its behavior.

In November 2024, Astroscale's ADRAS-J spacecraft closed to 15 meters of a non-cooperative rocket upper stage, the closest commercial approach ever achieved to space debris, with no real-time ground control authorizing the final approach [97]. What made that mission credible was not the autonomy itself, but the autonomous abort maneuver that triggered when relative attitude control showed an anomaly during the fly-around [98]. This designed failure mode allowed the team to observe, diagnose, and learn from the behavior.

Starlink's autonomous collision avoidance shows the opposite pattern: a private operational choice with public consequences. As discussed earlier, SpaceX has unilaterally tightened its maneuver threshold far beyond the industry standard, with each change reported in FCC semiannual filings [99][100]. This strictness is defensible from SpaceX's own risk perspective. For other operators in low Earth orbit, however, each tightening multiplies maneuver volumes, fuel consumption, and the coordination burden they must absorb without visibility into why each specific maneuver was triggered. Both systems are autonomous, but only one is designed to let outside affected parties calibrate trust.



Maintenance: does the system get smarter, or does it decay?

Implementation of science for sustainability is the part technologists skip most often. Systems that work on day one often break by year three, not because the tech degrades but because the people and processes around it move on. Aerospace makes this worse. As the manufacturing chapter showed, the workforce is thinning, so any AI system deployed today inherits a maintenance problem from the start. For founders, maintenance isn't a post-launch support task. It's part of the architecture.

The screen for founders

Three questions to ask before architecture is locked. Does the system fit the operator's workflow as it is, not as we wish it were? Can operators and counterparties calibrate trust? Does the system fail in ways they can observe, diagnose, and learn from? Is there a sustainable mechanism for the system to keep improving as the operator's environment changes? A startup that can answer all three is closer to an operational product; one that cannot is still closer to a technical demonstration.

For investors and regulators, the same screen distinguishes operational AI plays from research projects dressed in commercial language. The questions are not “does the model work”; they are “does the deployment work, in the environment it has to live in, over the time horizon the customer needs it for.” This is not a softer set of questions than technical diligence. In this sector, it is a harder one.

Looking Forward in AI and Autonomy

AI and autonomy in the space industry are a fast-growing field, where regulations and compute demand have not yet caught up to the technology's requirements. Overall, the technologies underpinning AI and autonomy are rapidly maturing, and the space industry must learn to use them responsibly and economically, given constraints on computing capacity. Operating companies need to be ready to harness these capabilities for space system maneuverability and monitoring when orbital data centers eventually become a reality. In addition to taking advantage of the advanced capabilities these technologies enable, we should be prepared to address the geopolitical complications that arise from increased AI and data use.

Part 3: Challenges Facing the Industry and Founders

This part is more interpretive than Part 2. The four challenges are real, but the reframes we put on them, that each is an architectural decision rather than a deployment problem, are our analysis and are open to debate.

3.1 The Tension Between Venture Speed, Customer Readiness and Insurance Willingness

The conventional account says aerospace startups fail because they were rushed: venture capital imposed a timeline the engineering couldn't support, certification was compressed, and companies crashed or burned through capital before reaching a flightworthy product. This account is misleading. Most aerospace startups that failed in the last decade didn't fail on speed. They ran out of one of three things before the engineering converged: capital, customer demand, or insurance capacity. Speed is what founders and investors talk about because it's the variable they think they control. The variables that decide outcomes run on different clocks.

Take the failures. Astra reached orbit, then couldn't raise its next round at a valuation that let it keep operating. Virgin Orbit had a working vehicle and a customer pipeline, then ran out of capital twelve months before the next contract cycle. Boeing's Starliner has cost over two billion dollars in a decade and flown crew once. None is a speed-versus-safety failure: Astra and Virgin Orbit failed on capital duration; Starliner on the procurement mismatch between a fixed-price contract and a development arc that needed the cost-plus pacing the customer had abandoned.

The companies that succeeded, SpaceX, Rocket Lab, Anduril, Shield AI, Stoke, and Varda, didn't win by going slower. They designed so all three clocks could be survived at once.

Together, the four challenges describe the constraints any company in this sector has to design around. We return to what they mean for founders, investors, and students in Section 5.2, once the predictions in Part 4 are in place.

Three clocks, not two

The three clocks are independent, each with its own failure mode. The capital clock, the one most discussed, measures how long funding lasts and how long the next round takes to raise. The customer clock runs from a customer's decision to buy to the point where the customer can pay under a contract, constrained by federal budget cycles, certification gates, and the customer's own buying process. The insurance clock runs from a new system's first flight to the point where a market exists that will insure it in service. Without that market, the customer cannot field the system at scale, even when the engineering works.

These clocks run at different speeds and are only loosely linked. A company can have eighteen months of cash, a buyer who commits in twenty-four months, and an insurer who won't touch the category for forty-eight. A founder who solves only the first clock hasn't solved the problem; they've moved it. The survivors are the founders who time each stage so that every clock's binding constraint is addressed before it bites.

What the capital base has actually done

Survival starts with capital, and the founder conversation is out of date. The claim that venture capital simply doesn't fit aerospace was fair in 2015 and increasingly wrong in 2026. American Dynamism at a16z, Founders Fund, Lux, 8VC, and a long tail of defense-specific firms now run multi-billion-dollar funds with stated fifteen-to-twenty-year timelines, and investors have signed up for that length. Anduril raised at a \$30 billion valuation in 2024. Stoke raised over a billion before its first orbital launch. Varda built a regulatory and customer path before raising serious money and now runs a recurring re-entry business. None of this was possible a decade ago.

The secondary market has done some of the work the primary market could not. SpaceX, Anduril, and a handful of others trade with enough liquidity that early investors and employees can realize partial returns on a horizon shorter than the underlying company's exit. The binding constraint of a ten-year fund life has loosened in categories where secondary liquidity exists. The adaptation is not complete. The generalist multi-stage funds that still dominate venture by dollars deployed have not changed their underwriting, and founders who raise from a generalist firm with no aerospace thesis still face the seven-year fund clock and the implicit pressure to behave like a SaaS company. The honest current state: the right capital exists, it is concentrated in a small number of vehicles, and founders who do not raise from them inherit a problem the field has partially solved.

The customer clock is doing most of the work people blame on capital

That partial fix still leaves the procurement cycle, which causes the most failures and receives the least attention. A defense customer that signs a contract in year one does not pay on a venture-friendly schedule. Milestone payments are tied to deliverables the customer's buying office must verify, which often takes quarters. The Space Development Agency's two-year tranches have shortened this for satellite programs, and the broader shift to fixed-price contracts and Other Transaction Agreements is the most important answer to the speed problem. Founders who win SDA tranches, OTAs, or SBIR Phase III commitments get a buying pace that roughly matches startup capital. Founders who don't are stuck on the old DoD timelines, and those will not bend for them.

Commercial customers have their own version, often worse. Airlines, satellite operators, and launch customers run buying cycles that were never redesigned for startups. A satellite operator weighing a new propulsion subsystem in 2026 is making a decision about vehicles that launch in 2029, with payments spread across that gap. A founder who chases capital runway without matching the customer's real buying cycle has built a company that can be funded but cannot be sold. This is the Starliner pattern at startup scale: a working vehicle tied to a customer relationship that has outgrown the contract the program was built for. Matching the customer cycle is a design choice made before the cap table exists, not a back-office detail.

Insurance is the constraint nobody underwrites until they hit it

The third clock never appears in pitch decks and still ends companies. Aerospace operations at any scale need insurance: for the vehicle, third-party liability, cargo or payload, and service.

Lloyd's space underwriting is the deepest market for new space risk, but it is small. Total annual capacity sits in the low single-digit billions of dollars, about the size of one major constellation's launch program for a year. New categories, such as autonomous cargo aircraft, in-space servicing, and hypersonic transport, usually have no insurance market at all in their first flight years because there is no track record to price the risk against.

Without insurance, the customer cannot field the system at scale. A logistics company will not put an uninsured autonomous cargo aircraft into routine service. A satellite operator will not contract for orbital servicing on an asset the insurer won't cover. The pattern: the engineering works, the customer is willing in principle, and deployment stalls because underwriting is two or three years behind. The fix is partly engineering, with design choices that produce data the insurance market can use, backup designs that price well, and telemetry that lets underwriters watch risk in real time, and partly policy: government indemnification (the FAA's commercial space launch program is the clearest example) can stand in for private cover while the market builds confidence. The companies that handle this best bring underwriters in as design partners from the first architecture review, not as vendors after the vehicle exists.

[A working test, before the cap table closes](#)

Three questions, asked in order, before the structure becomes hard to change.

How long is the capital clock on the architecture as designed, from one raise to the next? If that is shorter than the customer's procurement cycle for the product, the company has a capital-structure problem that no amount of engineering speed will fix.

What is the customer's real procurement timeline, from decision to first payment against a recurring contract? Founders who can't name this number for their target customers are guessing at the most important variable for the company's survival. Customers know it; founders who don't ask inherit a constraint they could have priced.

Does an insurance market exist for putting the system into service, and if not, what is the path to one? Good answers: a named underwriter with a path to real capacity, a government indemnification route, or a plan to produce the data the market needs. The bad answer is that someone will figure it out later. Some will not. Asked honestly before the architecture is locked, these don't guarantee survival; the engineering still has to work, and the team still has to execute.

3.2 Regulation is a design constraint, not a deployment problem:

The typical founder treats regulation the way an architect treats the building code: a set of rules you check against once the design is mostly done, with a lawyer for the corner cases. That works in industries whose rules were settled before the company existed. It does not work in aerospace, and it fails fastest in the categories where the most interesting companies are being built. Autonomous aircraft, in-space servicing, hypersonic transport, and on-orbit manufacturing all lack a complete regulatory framework that lets a founder treat compliance as a later step.

The rules either don't exist yet, exist in pieces across bodies that don't coordinate, or exist in forms written for a different kind of system and make no sense when applied to the new one. On top sits a separate layer of operational compliance, export control, cybersecurity certification, quality management, and foreign ownership rules that applies whether the main framework has caught up.

Founders who treat this as a deployment problem, build the product, get it certified, then add compliance on top, are the ones whose products don't deploy. Founders who treat it as a design constraint, letting the regulatory and compliance picture shape what the product is, where it is built, and how the company is structured, are the ones who reach scale. The difference is not lobbying skill. It is when the regulatory work starts. By the time the system is designed, the cap table has closed, and the first defense contract is signed, the biggest regulatory decisions have already been made, silently, by the engineers and founders, in choices that did not feel regulatory at the time.

Standards bodies are upstream of regulators, and that is where the action is

Regulators move slowly on new systems less because they are cautious or short-staffed (though both are partly true) than because they can certify only against existing standards. The FAA does not write airworthiness standards from scratch. It adapts work from RTCA, the consensus body behind most US civil aviation standards since the 1930s. EASA does the same with EUROCAE. ICAO sets the international floor. ASTM F38 covers unmanned aircraft. JARUS produces operating standards for drone integration across more than seventy national authorities. When a founder complains that the FAA will not certify their autonomous vehicle, the truer complaint is that RTCA has not produced the standard the FAA would certify against. The same dynamic governs space: orbital servicing, debris removal, and on-orbit manufacturing all wait on standards bodies like CONFERS to write the rules before regulators can authorize them, which is why standards engagement matters as much in space as in aviation.

That distinction matters because the standards process is the lever a founder can actually pull. Regulators do not write standards on demand for a single company. Standards bodies do, and their committees are open to industry in ways most founders don't realize and almost none use. RTCA Special Committee 228, which produces the Detect-and-Avoid and Command-and-Control Link standards that will decide when large, unmanned aircraft can fly in controlled airspace, has met quarterly for more than a decade. The companies that put senior engineering time into the committee, primes plus a few well-funded startups, have shaped the standard around their own designs. The companies that didn't inherit standards built for someone else's system.

The regulator is plural, and most founders only know one of them

Even with the standards work done, the regulatory surface is broader than most founders realize. US aerospace founders usually find the FAA first and assume it is the whole surface. It is not.

A commercial space company answers to the FAA for launch and reentry licensing, the FCC for spectrum and satellite authorization, NOAA for commercial remote sensing, the Bureau of Industry and Security at Commerce for dual-use export control, the State Department for ITAR-controlled defense articles, and the relevant DoD components for any defense-adjacent work. A drone company adds the FAA's UAS Integration Office, the FCC for command-and-control spectrum, state UAS authorities, and city airspace coordination. An autonomous aircraft company adds airworthiness, type, production, and operator certification as four separate processes within the FAA, each run by a different organization with its own backlog.

State-level regulation is the layer most often missed. Texas, California, Florida, Colorado, New Mexico, and Virginia each run spaceport authorities with their own approval processes, environmental reviews, and operating restrictions. A company based in California that wants to launch from Texas is dealing with two state regimes on top of the federal one. The international version is worse. EASA, the CAAC, Japan's MLIT, India's DGCA, the UAE's GCAA, and Australia's CASA each run their own certification processes. Mutual recognition covers parts of aviation but not most new categories. A founder who wants to deploy in three jurisdictions usually runs three certification programs at once, with three evidence packages and three inspection regimes. Primes amortize this across global programs; startups pay it as a fixed cost on a smaller revenue base.

Compliance overhead is the price of admission

On top of certification sits a separate layer governing how the company operates, not what it sells. Export control, cybersecurity certification, quality management, foreign ownership rules, and clearance requirements apply whether or not the main regulator has finished the product rules. This is where most aerospace startups get into real trouble, and it has the least to do with engineering and the most with how the company is organized.

The acronym stack is dense. ITAR governs the export of defense articles and pulls a startup under export-control rules the moment it starts work on anything that might count as a defense article, which in practice includes most autonomous aerospace platforms. The Export Administration Regulations (EAR) cover dual-use items and often overlap with ITAR. The National Defense Authorization Act (NDAA) Section 889 bars certain Chinese-origin telecom and surveillance components from any system sold to the federal government, and the ban runs several tiers down the supply chain. The Defense Federal Acquisition Regulation Supplement (DFARS) 252.204-7012 sets cybersecurity requirements for contractors handling controlled unclassified information, and CMMC 2.0 adds a third-party certification on top, with audit costs of \$100K to \$200K for Level 2 and \$300K to \$500K for Level 3 at small-company scale. AS9100 is the aerospace quality-management standard. FedRAMP applies to cloud services touching federal data. FOCI mitigation applies to any company with foreign ownership that wants classified work.

The combined load is most of a senior compliance lead's full-time job from the first defense contract on, and that cost barely shrinks for a smaller company. A prime with a billion dollars of defense revenue can amortize a compliance team across thousands of program-hours. A startup with five million dollars of revenue cannot, yet the compliance duties it inherits from a single prime contract are often much the same. This is not a complaint about the regimes themselves: ITAR exists for reasons that have not gone away, NDAA 889 reflects a real problem with adversary-controlled supply chains, and AS9100 is a real stand-in for the process discipline that keeps people alive. The problem is that these regimes were built for large primes with stable programs and long contracts, and they fit poorly in an ecosystem with hundreds of venture-backed entrants.

FOCI deserves its own attention because it is the rule most founders haven't heard of when they raise their first round, and it decides whether the company can compete for the work that justifies it. Foreign Ownership, Control, or Influence requirements set eligibility for classified contracts. With venture capital now global, almost every startup has non-US investors, including sovereign wealth funds, foreign family offices, and multinational corporate VCs, who create some FOCI exposure. The fixes are real and expensive: voting trusts that strip foreign investors of governance rights, proxy boards that put US persons between foreign owners and operations, and Special Security Agreements that place the company under ongoing DCSA oversight. The founder who takes a check from a Singapore-based fund at seed and finds during Series C diligence for a defense contract that the cap table now needs FOCI mitigation is paying for a decision made years earlier without knowing its consequences. The fix is doable but costs more than the same restructuring done at incorporation, and in some categories of work it is no longer possible at all.

Compliance is a moat that bites both ways

The usual founder reflex on compliance is to treat it as overhead: a cost to cut, a task to put off, work to hand to someone else. This is partly right and mostly wrong. The same burden that makes compliance fall hardest on startups is also, once built, a moat that a competitor with the same funding cannot rebuild within eighteen months. A company with full CMMC Level 3 certification, an established ITAR program, mature FOCI mitigation, and a cleared workforce holds a position the next entrant cannot buy with a check. The cost is real; so is the moat. Founders who build for the moat beat founders who build to dodge the cost, because the cost gets paid either way.

So the timing of compliance spending is a strategic choice, not a defensive one. A founder who hires a compliance lead before the first defense contract closes is paying for capability they won't use for twelve months. A founder who waits until the contract closes pays twice: once to retrofit compliance under audit pressure, and once for the delay that retrofit adds to the customer relationship. The first approach is much more capital-efficient. The second is what most founders do, because the first feels like wasted money in the seed round, when cash is tightest. What sets apart founders who scale into defense markets is the willingness to spend before it feels necessary.

Personal liability is the part founders rarely think about, and the part that changes behavior most once they do. ITAR violations carry criminal penalties for the individuals responsible, not just civil penalties for the company. False Claims Act exposure on government contracts means unlimited treble damages, and *qui tam* provisions let employees sue on the government's behalf for a large share of the recovery. FOCI violations can cost a facility its security clearance, usually a company-ending event. Senior officers who sign certifications about export control, cybersecurity, or supply-chain origin are personally vouching for facts that may later be tested under criminal standards. The DOJ's National Security Division and Commerce's BIS have both stepped up enforcement over the past five years, and the cases involve real people facing real charges. Founders who take this seriously allocate compliance resources differently from those who treat the rules as a company-level abstraction.

The patchwork is permanent. Design for it.

The talk of regulatory harmonization assumes the split across certification and compliance regimes is temporary. It is not. Full harmonization across the FAA, EASA, CAAC, and the rest is not coming on any timeline that matters to a founder today. The incentives, legal traditions, and safety cultures are too different. Over the next fifteen to twenty years, agreement on a few high-value items will arrive: a shared vocabulary for autonomy levels, mutual recognition of flight-test data, common formats for telemetry and incident reporting, and aligned operational design domain definitions. The rest will remain fragmented, and founders who plan for full harmonization are planning for a future that won't come.

This makes regulatory and compliance geography a strategic choice, not an operational one. Where the company is based, where it tests, where it builds, where it deploys first, which certification it pursues first, and which investors it takes all shape what the company can become. Luxembourg, the UAE, Singapore, Japan, India, and Australia have each built strong positions in particular aerospace and space niches by pairing clear regulatory paths with capital and infrastructure. The UK's CAA has been ahead of the FAA on commercial drone integration for most of the last decade. New Zealand's approach to commercial launch produced Rocket Lab. These jurisdictions made deliberate bets to attract categories that the larger regulators were slower to welcome, and the founders who built there are now defining what those categories look like.

Step changes happen after accidents, and the math is asymmetric

Regulation in this sector does not change steadily. It moves in step changes, and accidents trigger them. The MAX 8 grounding reset what the FAA expects of certification paperwork across all transport-category aircraft. The Columbia accident reshaped NASA's risk posture for a decade. Long March 5B uncontrolled reentries are slowly producing new international debris rules. Every founder pushing hard on the regulatory frontier is quietly betting their company won't be the trigger for the next step change. Most have not priced this bet.

The asymmetry matters. A step change triggered by a competitor's accident is a tailwind for companies already held to higher standards. A step change triggered by your own accident may end the company and often the wider market's tolerance for the technology.

The companies that survived accidents, such as SpaceX's early Falcon 1 failures and Blue Origin's uncrewed New Shepard mishap, did so because the failures stayed within bounds the public and regulators were ready to accept. What sets survivors apart is not the absence of failures. It is the willingness to treat accident scenarios as first-class engineering work, assuming the company's regulatory future turns on how its worst day is handled, not how its best day is marketed.

A working checklist, before the architecture is locked

Five questions, asked in order, while the design is still malleable.

Which standards bodies produce the standards that will govern this product, and where are those bodies in their work cycle? If the answer is unknown, the company has accepted the regulatory architecture being developed by someone else. The fix is to identify the two or three working groups whose outputs will most directly govern the product and to engage with their work. Read the position papers. Attend a meeting. Submit comments on open drafts.

Which regulators have jurisdiction over this product, and have they all been mapped? For most US aerospace startups, the regulatory landscape is more extensive than they realize: FAA, FCC, NOAA, BIS, State, plus state authorities, plus international regulators wherever the product will operate. The company that maps this in year one is in a far better position than one that finds out in year four.

Which compliance regimes will the company inherit when it signs its first defense contract, and does the cap table fit them? ITAR scope changes the talent pool. NDAA 889 changes the supply chain. CMMC 2.0 changes the IT setup. FOCI changes the investor pool. The honest founder maps this before raising the round that funds the first defense push, not after.

Which jurisdiction's regulatory and compliance environment fits the product best, and is the company built to use that fit? Building everything in the United States and taking any willing capital is right for some products and wrong for others. Founders who treat geography and cap-table composition as strategic choices capture value that default builders leave behind.

What is the company's posture for the worst-case accident, and is it credible? Designing the company so its survival doesn't depend on never having an accident is different from designing it to be safe. Both are needed. Only the first can be addressed in advance.

These don't remove the regulatory void or the compliance overhead, since both are permanent. They turn regulation and compliance from deployment-stage surprises into design-stage constraints, the only kind of regulatory work that produces companies that can deploy at all.

3.3 Feasibility Is Not Viability

There are two kinds of aerospace startups, and the difference is not technical sophistication, team strength, or capital raised. It is the order in which the founder does the work. Demand-first companies start with a customer who will pay for something, then engineer the minimum technical achievement that captures that spend. Feasibility-first companies start with a technical capability they want to build, then go looking for someone willing to pay for it. The first model produces companies that scale. The second produces an extended valley of death, a series of bridge rounds, and a long tail of technically impressive ventures that never reach commercial deployment.

Varda illustrates the demand-first model. The company did not begin with a reentry capsule and look for things to make in it. It began with a regulatory and commercial insight: a microgravity-grown polymorph of an existing pharmaceutical may qualify as a new composition of matter, restarting the patent clock on assets drug companies would otherwise lose to generic erosion. The W-series capsule was designed around a specific molecule for a specific customer, not built first and matched to a use later. Early revenue came from government reentry-data work, funding the path toward the longer-term pharmaceutical market, which is the demand-first discipline in practice. The W-1 mission grew ritonavir Form III, recovered it after reentry, and confirmed stability, with a partner pipeline already waiting for what the company would do next.

AstroForge is the mirror image and the more interesting case. AstroForge CEO Matt Gialich is explicit: the unit economics of asteroid mining either close or they do not, and the question is settled by what it costs to get to a near-Earth asteroid, what it costs to extract platinum-group metals there, and what those metals are worth on Earth when they return and are refined. AstroForge is, on its founder's own terms, a research program funded as a company. That is a legitimate posture. Investors who back AstroForge know what they are funding. The pitches that fail the test here are the ones that take AstroForge-style technical bets while presenting Varda-style commercial confidence. Be one or the other. Feasibility-first companies dressed as demand-first companies cannot be funded by anyone, because the cap table will discover the truth eighteen months in and the company will not survive the discovery.

The miracle count, and what it actually tells you

The diagnostic tool for distinguishing the two postures is the miracle count: the number of independent breakthroughs the company's terminal economics depend on. One miracle is a venture bet. Two is a hard bet that requires aligned capital and patient investors. Three or more is a research program, and research programs should be funded as research programs, through SBIR, DARPA, university partnerships, or sovereign-backed deep tech vehicles, not as venture-backed companies on a fund-cycle clock.

Counting honestly is harder than it sounds. Every founder underweights the miracles in their own plan because each one looks tractable when examined alone. The discipline is to ask: if the engineering works, does the company work? If yes, and the only open question is whether the team can build the thing, the count is one. If no, and the technology working still leaves the customer to be invented, the regulation to be written, and the supply chain to be built, each of those is its own miracle. Reusable launch was one miracle when SpaceX was raising in the early 2010s, because the customer and the regulatory pathway were already in place. Asteroid mining is at least three: the technical mission, the refining process, and the existence of a market for the recovered material at projected unit economics.

The count also tells the founder what kind of capital to raise. A one-miracle company can raise from generalist venture funds. A two-miracle company needs aerospace-specific or defense-specific vehicles with fifteen-to-twenty-year horizons. A three-miracle company should not be raising venture capital at all in most of its lifecycle, and founders who try are either deceiving their investors or, more commonly, themselves.

The honest answer in some cases is that the company should not exist yet; the technology needs another five to ten years of government-funded research before it can support a commercial enterprise. Founders who can say this out loud are the ones whose companies, when they do form, tend to work.

SpaceX is the case where the miracles compounded into a closed model, and its S-1 shows how. With SpaceX now public, its May 2026 S-1 gives the first audited look at the company's finances, and the real story is sharper than the headline. One caveat shapes the numbers. The filing recasts results to fold in xAI and X, acquired in early 2026 under common control, so the consolidated figures bundle rockets, Starlink, and the AI and social businesses together. Read that way, 2025 revenue was \$18.7 billion, up 33% from 2024, on a \$2.6 billion operating loss against a positive \$6.6 billion in adjusted EBITDA. The gap is depreciation on the Starlink constellation, stock compensation, and AI capital spending.

The lesson is where the money comes from. Starlink, not launch, is the engine. The recurring subscription business is what consistently earns a profit, while launch is now scaled but lower-margin. The model closes on the recurring revenue the rockets made possible, not on the rockets themselves.

The success factors line up as a sequence. A reusable-launch cost advantage, vertical integration to control the cost curve, government anchor contracts through the lean years, then a recurring consumer business layered on top. The losses are front-loaded investment, not distress, but they show even the industry's defining success runs on patient capital and a flywheel two decades in the making.



The customer procurement cycle is the demand-first test in practice

Section 3.1 made the point that the customer's procurement timeline is one of the three clocks aerospace founders have to design around. The same point serves as the demand-first test here. A founder who knows the customer's procurement cycle has, by definition, spoken with customers about purchasing on a specific timeline under a specific contract structure. A founder who does not interact with the demand side in any operationally meaningful way should not construct TAM slides.

The harder version is the one founders find uncomfortable: which actual person at which actual company has the willingness to write an actual purchase order on what specific timeline for what specific deliverable? Most in-space manufacturing, on-orbit servicing, and frontier-aerospace pitches cannot answer this for a single named customer. Founders who do this work before the seed round are doing demand-first development. Founders who plan to do it after the seed round are funding feasibility-first development with capital raised against a demand-first story. The cap table eventually finds out.

The TRL 6–9 valley is a customer problem, not a capital problem

The deep-tech valley of death, the gap between TRL 6 and TRL 9, is conventionally described as a financing problem. A deeper diagnosis is that the valley is a customer problem. Capital would arrive, in most categories, if a customer existed at the relevant scale, willing to pay under a defined contract structure. Capital does not arrive because the customer-formation work has not been done, and no amount of additional capital can substitute for that work.

The institutional response is largely underappreciated by founders. SBIR Phase III provides non-competitive contract authority that allows the government customer to bypass standard procurement competition. OTAs provide a faster path to operational deployment for defense-adjacent technology. The Strategic Breakthrough Awards, introduced in the April 2026 SBIR reauthorization, provide up to \$30M, matched 1:1 by private or non-SBIR government capital, conditioned on a formal Program of Record commitment. All three mechanisms address customer formation rather than capital. They identify a specific government customer, commit that customer to a procurement pathway, and use that commitment to make the technology fundable through other channels. Winners are not just receiving non-dilutive capital; they are exiting the valley of death by acquiring an anchor customer with the institutional authority to actually field the product. The commercial analogue is the structured anchor customer agreement, where a single large buyer commits to a defined volume or revenue stream conditional on technology milestones. NASA's Commercial Orbital Transportation Services (COTS) program for commercial cargo was the canonical example. CLPS for lunar surface payloads has been a more recent one. The xEVAS spacesuit program is another:

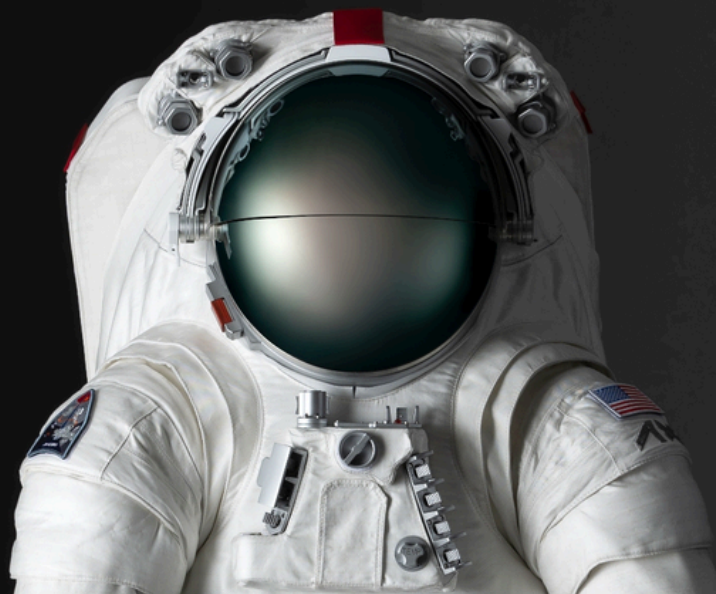
These are not subsidies. They are the mechanism by which customer-formation work is done at sufficient scale to make the technology investable. Founders who orient their company around becoming the next anchor-customer winner are doing demand-first development against the only customer category that can credibly close the TRL 6–9 gap for many aerospace technologies.

Case Study 9: xEVAS Procurement Model and Spacesuit Manufacturing Market

Spacesuits illustrate what an emerging in-space manufacturing market looks like in practice. The Extravehicular Mobility Unit served NASA for more than four decades through internal development and incremental refinement [101][102]. NASA has now shifted to commercial procurement under the Exploration Extravehicular Activity Services (xEVAS) program. Private companies design, build, maintain, and operate EVA systems for NASA missions. NASA buys the service, not the hardware.

The contracts are large enough to seed an industry. NASA selected Axiom Space and Collins Aerospace under agreements with a combined ceiling of \$3.5 billion. Axiom received the first task order in 2022, valued at roughly \$228.5 million, for the lunar EVA system on Artemis III [103]. This structure rewards private investment in iterative design and supplier development, mirroring the pattern seen in commercial LEO destinations and CLPS-style surface payload services.

The opportunity extends well beyond the prime contractors. Pressure garments, advanced materials, biomedical sensors, modular components, thermal management systems, and suit maintenance infrastructure all sit within the supply chain. Mars-surface and long-duration mission requirements add further demand. NASA roadmap assessments suggest gas-pressurized suit architectures may not hold up under extended Martian surface operations, raising open questions about new designs and the lifecycle support they require [104][105][106]. Sustained exploration will likely need distributed maintenance infrastructure able to service, repair, and produce replacement parts across LEO, the lunar surface, and Mars, with additive manufacturing as the enabling production technology [16]. In-space manufacturing could supply replacement parts and custom components built directly in orbit or on planetary surfaces. This is the same capability the surface infrastructure section describes for habitats and power.



A working diagnostic

Four questions, asked before the company's posture is locked in by the cap table.

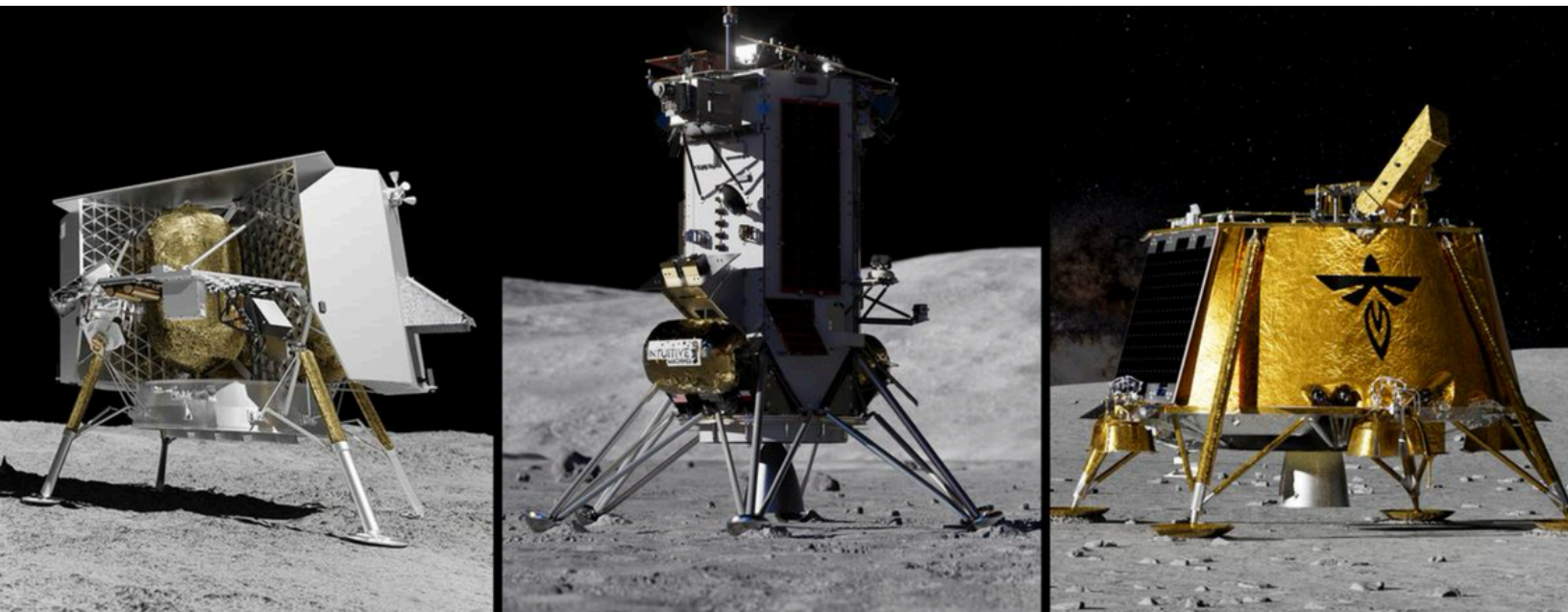
How many miracles does the terminal economics depend on? One is a venture bet. Two is a hard bet. Three or more is a research program.

Is the company demand-first or feasibility-first, and is the cap table consistent with that posture? Both can be legitimate. The failure mode is feasibility-first companies masquerading as demand-first companies, raising venture capital based on a customer story they have not actually built.

Which specific person, at which specific company, is willing to write a purchase order, on what timeline, for what deliverable? If the founder cannot answer this for at least one named customer, the company is feasibility-first, regardless of how the pitch is framed.

Is there an anchor-customer pathway that closes the TRL 6–9 valley? SBIR Phase III, OTAs, Strategic Breakthrough Awards, and COTS or CLPS-style contracts are not subsidies. They are how customer formation is achieved at scale to make the technology investable. Founders who are not pursuing one for a feasibility-heavy product are betting that private capital will indefinitely fund their TRL progression without a customer, and that bet has not historically paid off.

Four questions asked honestly. They do not eliminate the gap between technical feasibility and commercial viability. That gap is the structural feature of the deep-tech sector that creates the opportunity in the first place. What they do is place the company on the right side of the gap, with a cap table and capital structure that match the company's actual posture.



3.4 The Industrial Base is the People

Two of the most-discussed challenges in aerospace are the fragility of the supply chain and workforce turnover. These are typically presented as separate problems. They are not. They are the same problem at two scales. The supplier tier is people aggregated into companies. The hiring market is people considered individually. Both are draining at rates the institutional response has not matched, and both fail for the same reason: the human capital that aerospace runs on was built up over decades by institutions that no longer function as they did when the capital was accumulated, and that accumulation has not been replaced.

Nothing in this section will surprise the CEO of Boeing or the COO of Lockheed Martin. The fragility, the lack of tier-2 and tier-3 consolidation that occurred when the primes consolidated, the workforce demographics, and the under-digitization of small suppliers have all been on the agenda of every major aerospace company for at least a decade. The conclusion is not that the industry is unaware. It is that awareness has not translated into resolution, because remedies require coordination across primes, suppliers, government, and the education system, and no individual actor has the authority to compel it. Each actor optimizes for its own time horizon, the time horizons do not align, and the problem persists across boardrooms full of executives who could each describe it in detail.

Five mechanisms of erosion

The supply chain and workforce problem decomposes into five mechanisms that are often discussed together but operate differently.

First, foreign outsourcing. Primes and tier-1 suppliers moved component manufacturing offshore in the 1990s and 2000s to reduce costs. The transfer of engineering capability was partial; in some categories, the offshore source is now the only source. CHIPS Act funding, Defense Production Act Title III investments, and the BUILD Act's reshoring incentives have made measurable progress in semiconductors and rare earths, less so in specialty metals and precision optics.

Second, the tier-2 and tier-3 supplier base did not consolidate when the primes did. The 1990s consolidation reduced the number of primes from fifty-one to five, but the suppliers below them remained fragmented, with thousands of small shops, each holding pieces of capability no individual prime could afford to absorb. Approximately 43 percent of aerospace-certified businesses have fewer than 25 employees. Coordination, digital integration, standards adoption, and skills transfer are harder across thousands of small suppliers than across five primes. The structure was sustainable when program volumes were predictable and contracts were long. It is harder to sustain under variable demand and short program cycles.

Third, knowledge loss from outsourcing. When a component category moves offshore, domestic capability atrophies on roughly a ten-year cycle. Engineers who designed the previous generation retire. Apprenticeship pipelines stop producing technicians. Tooling is decommissioned.

Tribal knowledge about why parts are built the way they are disappears as the people who carry it are no longer employed. Reshoring manufacturing does not bring back that knowledge. Building a Mach 3 airframe in the 2020s requires substantially rediscovering capabilities the United States demonstrably had in 1964.

Fourth, knowledge loss from talent attrition. The aerospace median age is materially higher than in adjacent technology sectors. The pandemic accelerated retirement decisions, and the cohort that should be in its forties and fifties, the missing middle, mostly is not there. Many of those people left aerospace in the 2000s for software or finance, and they did not come back. The result is a barbell distribution: senior engineers in their sixties holding institutional memory, junior engineers in their twenties learning the ropes, and a thin band of mid-career talent that should be doing knowledge transfer but does not exist in sufficient numbers.

Fifth, under-digitization of the small-supplier base. Most tier-2 and tier-3 shops operate with minimal digital connectivity to upstream or downstream partners, so even when advanced tools are available to the primes, deployment is limited by incomplete and inconsistent data. The cause is economic (thin margins limit capex), incentive-based (large integrators capture value at the program level), and workforce-driven (deploying industrial AI in legacy shops requires operators who understand both the physical systems and the digital layer). These mechanisms compound. Outsourcing depleted the domestic supplier base, weakening the apprenticeship pipelines that produced the technicians the remaining suppliers needed, which raised the cost of skilled labor, which reduced capital available for digitization, which limited competitiveness against further offshore alternatives. The cycle has been running for a generation. The combined system, addressed piecemeal, has been getting worse despite individually well-intentioned interventions.

The aerospace-uniqueness claim

It is fashionable to argue that aerospace manufacturing is structurally different from electronics or automotive. This is partly right and partly an excuse. Volumes are low for crewed transport-category aircraft and large satellites. Tolerances are tight. Materials are exotic. Certification regimes mean that changing a supplier or a machine setting is a recertification event that can take eighteen months. These constraints explain a real share of why the supply chain looks the way it does.

But not all aerospace looks like this. Drone manufacturing has supply chain dynamics that resemble consumer electronics. Small-sat manufacturing at constellation scale, such as Starlink, Amazon Leo, and OneWeb at its peak, operates at volumes (thousands per year) and unit economics that allow the standardization and learning-curve effects the uniqueness argument denies. Northrop Grumman has adapted production lines to produce PWSA satellites at Starlink-comparable rates. Uniqueness is a category-by-category claim, not an industry-wide one.

The founder building a crewed Mach 3 transport faces a different supply chain problem than the founder building a thousand-satellite constellation.

What AI can recover, and what it cannot

The natural reflex for an industry trying to capture knowledge before it leaves with retirees is to reach for AI. The opportunity is real, and a generation of factory-OS and industrial-AI startups is forming around it. The honest answer to how much AI actually addresses is: a meaningful minority, not a majority.

Three categories of tacit knowledge exist in aerospace manufacturing, and each yields differently. Procedural knowledge, including step sequences, parameter settings, vendor-specific quirks, and inspection rules of thumb, yields best; 30 to 50 percent is recoverable if capture work is done while the people carrying it are still on the floor. Pattern-recognition judgment, such as the felt sense that a process is drifting or the intuition that a supplier's delivery commitment is performative, yields partially in narrow domains where patterns can be exposed to sensors, maybe 10 to 20 percent. Social and institutional knowledge, including who decides what, which contracts are flexible, and the political map of a customer organization, does not yield at all. It transfers human-to-human or not at all.

In aggregate, AI handles perhaps a quarter to a third of the tacit knowledge loss problem at reasonable cost, with most benefit in the procedural category. Reshoring addresses a different overlapping share by recreating conditions under which knowledge could be regenerated, but regeneration takes a generation. Education addresses a third overlapping share on a longer timeline still. None of these is sufficient alone. The combined package plausibly addresses two-thirds of the problem on a fifteen-to-twenty-year horizon. The remaining third is permanent loss, and the strategic implication is that the aerospace industry of 2045 will operate on a meaningfully different knowledge base than the one of 1985, with capability gaps no additional investment will fully close.

The talent picture

The new graduate cohort is technically strong and culturally distinct from the one that built the primes. They are comfortable with software, simulation, and probabilistic methods; less patient with bureaucratic processes; and less deferential to hierarchy. They want to ship hardware that flies within two or three years, not work on a program that may or may not see test in their first decade. A new graduate at a startup typically owns more, learns faster, and reaches decision authority sooner than the same person at a prime. The honest counter is that the prime offers training infrastructure, mentorship, program continuity, and clearance pathways the startup does not. A 22-year-old optimizing for skill development at scale may be better off at a prime for three to five years before transitioning out.

Loyalty to the institution is essentially gone in the current cohort. Senior engineers move between aerospace companies with frequencies that look more like those in the software industry. The cost of a senior hire is no longer captured by the salary line; it is the equity grant required to make the hire stick for at least four years, and that grant is larger than the equity model most founders inherit from generic startup playbooks. Companies that handle this well invest in documentation, internal training, and knowledge-capture systems that assume turnover. Companies that handle it poorly discover, on the third departure, that nobody currently employed knows why a particular subsystem was designed the way it was.

The role most aerospace founders should be hiring for, and find hardest to fill, is the electro-mechanical engineer, the person who can read a schematic, design a wiring harness, debug a mixed-signal board on a vibration table, and translate between firmware and structures teams. These people are not produced in volume by any university; the discipline sits awkwardly between EE, ME, and aerospace, and most programs treat it as something students figure out on the job. Electro-mechanical talent is the bottleneck for almost every drone company, satellite startup, and avionics-heavy program currently fundraising. Founders should identify a few leads they need before they raise the round that requires them, and treat finding those people as a year-long search.

Three talent sources most founders ignore

The standard founder hiring funnel draws from university pipelines and prime-alumni networks. Three other sources are systematically underused.

Immigration and foreign-born talent: A meaningful share of US engineering graduates and a much larger share of senior research talent are not US persons. H-1B caps, STEM OPT, and the O-1 pathway determine whether companies can hire from this pool. The constraint is asymmetric. ITAR-scoped companies face additional restrictions on foreign-person access to controlled technical data. Companies that build immigration sponsorship into early hiring have access to roughly twice the senior talent pool of companies that wait.

Veteran talent flow: Approximately 200,000 service members transition out of the US military annually, and a meaningful share carry directly transferable skills: avionics, propulsion, electronics, machining, systems integration. The DoD's SkillBridge program provides a pathway for service members to work at private-sector companies during their final months of service. Founders who tap this pipeline access experienced technicians and engineers at compensation levels below market, with the benefit of clearance retention for defense-adjacent work.

Mid-career transitions from adjacent industries: Automotive safety engineers transfer to aviation functional safety. Industrial automation engineers transfer to manufacturing process design. Semiconductor process engineers transfer to specialty material production. These transitions historically did not happen because compensation differentials favored the originating industry. The differential has compressed in the last five years as automotive restructured. Founders willing to retrain mid-career engineers access a pool invisible to the conventional channel.

Additive manufacturing and what it actually changes

The most disruptive force on the aerospace supply chain in the current decade is not policy or AI but additive manufacturing. Industrial-scale 3D printing of titanium, Inconel, copper, and ceramic components has crossed a threshold where parts that once required tier-2 and tier-3 supplier networks can now be produced in a single facility. SpaceX's Raptor production, Norsk Titanium, and Sintavia operations have demonstrated that the supply chain depth required to produce a complex aerospace component can be reduced by orders of magnitude. Relativity is an instructive counterexample. It originally aimed to 3D-print nearly entire rockets, but by 2025 it had pivoted to a hybrid approach, printing engines and complex components while using friction stir welding for primary structures.

This does not eliminate the tier-2 and tier-3 base. Most space manufacturing remains high-mix and low-volume, closer to a job shop than an automotive line, with mega-constellations like Starlink and OneWeb as the main exceptions where volume finally justifies true production-line economics. Many components are still better produced by traditional subtractive manufacturing, and additive has its own quality-control, certification, and process-repeatability challenges. What it does is provide a partial route around supplier fragmentation for specific categories.

A startup that 3D-prints its propulsion components in-house does not face the same supplier-coordination problem as one that contracts the same parts out. Founders should be evaluating, category by category, which parts of the bill of materials are candidates for additive in-house versus traditional networks. The default of outsourcing everything inherits the entire fragmentation problem. The default of printing everything inherits the entire process-development burden. The right answer is component-specific.

A working checklist

Five questions, asked while the supplier and hiring strategy is still being designed.

Which of the five erosion mechanisms is the binding constraint for this company's specific category and bill of materials? If the answer is unknown, the company is treating supply chain as procurement rather than strategy. The mechanisms are distinct problems with distinct responses, and addressing the wrong one is worse than addressing none.

Where on the aerospace-uniqueness spectrum does the product sit, and which comparison industry informs the supply chain strategy? Crewed transport-category aircraft inherit the full job-shop legacy. Small-sat manufacturing looks more like consumer electronics. Drones still look more like consumer electronics.

Which components are candidates for in-house additive manufacturing versus traditional supplier networks? The right answer is component-specific, and most founders have not done the work.

Where are the three or four senior engineering hires that will gate the company's progress, and what is the timeline to find them? Electromechanical leads, senior systems engineers, and Experienced manufacturing engineers are the binding constraints. Year long searches should start in year zero, not year three.

Which government procurement policy levers, including Section 889, ITAR scope, allied-jurisdiction sourcing requirements, and SBIR set-asides, is the company positioned to take advantage of or be constrained by? The procurement policy environment is not static, and founders who treat it as a fixed constraint miss the optionality that policy movement creates.

Five questions, asked while the design is still malleable. They do not solve the underlying erosion, because the erosion is decades deep. What they do is locate the company strategically within the current state of the industrial base, with a supplier and hiring strategy that match the actual problem the company is facing. The industrial base is the people, the people are the constraint, and founders who design around that constraint will operate companies that founders who ignore cannot.

3.5 The pattern under the four challenges

Read in sequence, the four challenges in Part 3 are not four separate problems. They are four expressions of one principle. The conventional framing of each, venture speed versus aerospace safety, regulatory voids, feasibility outpacing viability, and fragmented supply chains and talent loss, puts the consequential action at deployment time. The reframes put the action at architecture time. Survivability across three clocks is a decision made when the capital structure is being assembled, not when the funding round is being burned through. Regulation is a constraint that shapes the product, not a hurdle the product meets at the end. Demand-first sequencing is established before the first technical milestone, not in the year-four bridge round. Supplier and workforce strategy is set when the architecture is locked, not when the first part fails inspection. The decisions that determine whether the company survives are made early, in choices that do not feel architectural. Founders who recognize them as architectural are the ones whose companies scale.

This is the part of the sector's discourse that is currently underserved. The conventional aerospace founder narrative treats each of the four challenges as something to be managed at the point of impact, raise more capital when the runway shortens, hire a compliance lead when the audit arrives, find suppliers when the bill of materials is final, and recruit when a position opens. Each response is reactive, and each produces worse outcomes than the same response made eighteen months earlier. The companies that have scaled, SpaceX, Anduril, Shield AI, Rocket Lab, Stoke, and Varda, share a willingness to make architectural decisions before they had to. The companies that did not scale, in most cases, made the right decisions on the right problems but put them at the wrong time.

Part 4: Predictions - What Do The ALIENS Think?

This part is the most speculative and the most our own. The five claims below are not findings from our interviews or settled conclusions from the data. They are bets we are willing to make and defend. They are not forecasts in the consultancy sense, with point estimates and confidence intervals. They are bets about the structural shape of the space economy over the next two to five decades, grounded in the interviews, the research, and the architectural framework laid out in Parts 2 and 3. We expect to be wrong on the details and approximately right on the direction. Each claim is calibrated to be falsifiable, which is the only honest position to take over a long horizon.

4.1 The big shift: the terrestrial economy will move to space

Most people treat space as a fast-growing add-on to Earth's economy, useful but always a small slice of world GDP. We bet against that. We think space overtakes Earth within fifty years, not just by adding to it. It grows partly at Earth's expense, as the most energy- and land-hungry, dirtiest work moves off-world. Space is about 0.5% of the total today. We expect it to pass 1% of world GDP by 2035 and reach ten times Earth's size within fifty years.

History shows that societies prefer to move heavy industry, energy production, and advanced manufacturing away from population centers. The trend will continue, with these functions shifting from on-world to off-world. Human GDP today, terrestrial and space combined, is roughly \$120 trillion, and we assume it grows near 3% a year to about \$520 trillion by 2076. The near-term marker is concrete: 1% of world GDP by 2035 is roughly \$1.5 trillion, in line with McKinsey's \$1.8 trillion projection for the space economy by then. What changes is that this mix flips. Space rises from under \$1 trillion today to most of the output, while the terrestrial figure falls in absolute terms as the most energy- and resource-intensive work moves off-world. For that to hold, space must compound to roughly 14% a year for fifty years, above the 12% the sector has managed lately but not unheard of for an industry still this small, and Earth's dirtiest sectors must move rather than just grow. The four transitions below are the mechanism. The 10x ratio is the headline, but the bet underneath is that four substantive transitions occur over a fifty-year horizon and compound. Computation moves to where power is continuous and virtually infinite. Energy generation scales beyond what terrestrial land use can absorb. Heavy industry relocates production whose externalities Earth no longer wants to carry. Resource extraction reaches a scale at which orbital, lunar, and near-Earth asteroids' feedstock outcompetes terrestrial alternatives. The macro frame underneath is that Earth has run out of cheap levers, and the next lever in scale order, after the ones Earth has already pulled, is access to a resource environment whose volume exceeds Earth's by factors that are hard to write down.

Computation is the strongest near-term bet. AI training and inference are already power-, water-, and land-use-constrained on Earth, and these constraints bind faster than the terrestrial grid can expand. Orbital data centers offer continuous solar power, passive radiative cooling, and zero competition with the terrestrial water supply. The thesis does not require space-based compute to replace terrestrial compute; it requires it to capture the marginal workload that terrestrial compute cannot serve economically. By 2076, the share of global compute running off-planet plausibly reaches double digits.

The other three transitions are slower and more contested. Orbital energy generation has been promised for fifty years and delivered none, and the case for change rests on launch costs continuing to fall, in-space assembly becoming credible at scale, and terrestrial siting constraints tightening more than they have. Heavy industry relocation is a bet that the socio-political economy of Earth-side externalities becomes less, not more, tolerant of carbon-intensive processes by mid-century. Resource extraction has the longest horizon and the highest miracle count, but the case for inclusion is the same: terrestrial alternatives degrade over time, and the off-planet option does not need to be cheap to win, only available to bidders who cannot accept the terms of the terrestrial supply.

The 10x economy is almost certainly bifurcated into blocs, including a US-and-allied space economy, a Chinese space economy, and possibly a third pole built around India and other smaller partners. The aggregate is the bet, not an integrated single market. The reason this matters to ordinary people on Earth is not the prestige of an off-planet civilization. It is the second-order effects of relaxing the constraints that have shaped every previous projection of long-term growth: cheaper baseload electricity, AI workloads moving off the terrestrial grid, and the dirtiest industrial processes finding a credible pathway off-planet. Space is the largest growth lever the global economy has access to. The question is not whether to pull it but how fast, who captures the value, and what Earth looks like once the levers we have been pulling for two centuries finally exhaust.

Where serious people disagree: the size of this bet is contested. The 10x ratio requires space to grow far faster than it ever has and Earth's economy to shrink in absolute terms, both outside any published forecast. The McKinsey number we cite in Part 2 keeps space at low single digits of world GDP, not the majority. Orbital energy and heavy industry have been promised for fifty years and delivered for none, and a fair case says nothing in current trends points to the economy moving to space within three decades.

4.2 Robots and Humans: Supervised Autonomy

Two camps split the debate over humans in space. One says full autonomy makes crews pointless. The other says crews do the hands-on work. We bet against both. The winning model, in orbit and on the first lasting Mars base, is a mixed team: one person supervising three or four robots across a multi-minute delay. For founders, the prize is the layer almost no one is building: supervised-autonomy software, human-robot interfaces, and systems humans can override and learn from.

Given the constraints, AI and autonomous systems will be the enabling feature of the space economy. We expect humans to operate primarily as supervisors of autonomous systems, with minimal intervention as the ideal and supervision intensity varying by mission profile. In-orbit servicing, assembly, and manufacturing will be carried out primarily by autonomous systems and robots. Human judgment will matter most in novel environments where precedent does not exist and the supervised system encounters problems it was not programmed to solve.

Where serious people disagree: a first lasting Mars presence within fifty years is a strong claim, and current trends don't clearly support it. Starship is still proving itself out, NASA's budget has been cut, and the lunar program has narrowed. Others argue the mixed team is a passing phase that full autonomy will erase sooner than we think. We bet supervised autonomy is the lasting model.

The first human presence on Mars within fifty years is almost certain. Every credible analyst expects it, several national programs are organized around it, and the engineering challenges that have gated it for two generations are now tractable. The interesting question is not whether boots arrive but what operating model is established when they do. Apollo-style flag-planting followed by program cancellation is a real possibility and would be a failure. The bet we are making is that the first sustained Mars presence runs on a mixed-team model, with humans supervising autonomous robotic agents in a partial-autonomy regime where one supervisor manages three or four robotic agents simultaneously under communication delays of eight to twenty-four minutes.

The case for the mixed-team model is not that robots cannot do everything alone (they cannot) or that humans need to be there for symbolism (they do). The case is that the failure modes of pure-robot and pure-crew missions are complementary. Robots handle the radiation, dust, thermal cycling, and distance-from-rescue work that is uneconomic or unsafe for humans. Humans handle the problems the robots were not programmed to solve, which is where most of the science and engineering surprise will sit. Apollo produced more lunar science in eighteen months of crewed surface time than fifty years of robotic missions had before it, because the astronauts encountered problems the operators on Earth did not know to instrument for. The Mars analogue is stronger, not weaker, and the reason is the communication delay. On the Moon, Earth operators could diagnose problems in real time. At four to twenty-two minutes each way, Mars removes that safety net entirely, which makes on-site human judgment far more valuable.

The forcing function for founders today is the supervised-autonomy stack itself. A mixed-team architecture requires robots controllable by humans on a latency profile that allows mixed-initiative work; autonomy stacks that fail in ways humans can diagnose, override, and learn from; and human-machine interfaces good enough that an astronaut on a planetary surface can supervise robotic operations without cognitive load becoming the bottleneck. Most of this is not being built today because current priorities split between fully autonomous robotic missions and fully crewed missions with humans doing all the EVA work. The most high-potential startups will figure out how to build the in-between, such as supervised-autonomy stacks, human-robot interface layers, and autonomy frameworks with superior performance. The next decade of aerospace risk capital and most talented employees will make their way toward these startup founders who recognize and ultimately exploit the in-between.

4.3 The money runs ahead of the economics

Capital and attention will keep pouring into emerging categories: orbital data centers, space tourism, space elevators, and on-orbit manufacturing. We do not doubt the money. We think it will run well ahead of the economics, and that most of these categories will not show a workable business case on the timeline implied by the funding. The counterbet is that today's capital identifies the winners. We think it identifies the loudest stories, not the soonest returns.

Space data centers have received an outsized share of attention in recent months. The terrestrial economy is already feeling the effects of a massive AI build-out, with energy and compute as building constraints. Orbital data centers could ease both.

Whether the economics make sense in the near term remains unclear, but the long-horizon case is real. Starcloud, Axiom's Orbital Data Center initiative, Lonestar's lunar-cached storage, and NVIDIA's March 2026 announcement of space-based AI computing are early commercial entries. We do not think all of these specific initiatives will survive, but we do think the category itself will survive and flourish.

Space tourism captures the public's imagination in a way other categories do not, and public imagination influences government spending. Travel and tourism is a \$12 trillion industry, roughly 10 percent of the terrestrial economy. Space tourism will capture only a small fraction of that, but the absolute opportunity is still enormous. Suborbital flights, stratospheric balloons, and orbital experiences are already in commercial service or development. Halo and Space Perspective are notable providers of stratospheric balloon rides. The ISS hosts visitors at multimillion-dollar price points, and Axiom is building toward a space hotel. The near-term picture is softer than it looks, though: timelines at Axiom, Vast, and Voyager have slipped, Blue Origin shelved Orbital Reef, and the ISS is nearing retirement before any successor has proven itself, even as several remain in the running.

Space elevators sit further out on the horizon, but the engineering and policy community is taking them seriously. A number of scientists and theorists believe a space elevator is the only way to build a truly sustainable space economy, because it would collapse the cost per kilogram of access to orbit by orders of magnitude. Universities around the world, including MIT, Shizuoka University, and Tsinghua, are conducting advanced research. The Obayashi Corporation, the International Space Elevator Consortium, Carbon Designs, NASA, and the LiftPort Group have all produced studies. We would not be surprised if real progress is made within the next decade.

Cislunar logistics is the connective tissue that makes the other emerging opportunities credible. By 2046, we expect lunar launches to exceed 20 per year, supported by reusable super-heavy lift from Starship and Blue Moon and by anchor tenancy from Artemis. Lunar ISRU, which produces oxygen, water, and propellant from local resources, becomes the keystone that enables the Moon to function as a staging post for Mars and for orbital infrastructure servicing. A robust cislunar transportation network turns each of the emerging opportunities above from a research program into a sustainable market.

Where serious people disagree: the money may not be mispriced at all. The AI compute crunch gives orbital data centers a real near-term customer, which is why capital is moving now. Blue Origin shelving Orbital Reef may say more about one company than about the category. We still think economics will lag funding across most of these. The strongest counterargument is that compute may already have enough demand to justify the investment.

4.4 Government buys at venture speed: defense becomes the founder's cheapest money

Of course, defense will continue to matter in space. That is not our bet. We bet that government starts buying at venture speed and that defense grants become the fastest, cheapest money a young company can raise. They are cheap because they take no equity.

The April 2026 SBIR reauthorization, with \$30M Strategic Breakthrough Awards matched 1:1 by private money, is the template. We bet it spreads, against the usual view that defense buying stays slow, prime-dominated, and best left until a company is mature.

The USSF is entering a period of unprecedented expansion, requesting \$71 billion for 2027, double its previous funding level. The Department of War and, no doubt, adversarial organizations globally are pursuing long-term strategies to contest and control the space domain. Key programs include Golden Dome (referenced earlier in this report), a next-generation missile-tracking system, space control systems, and space data networks. The signal to founders is clear: defense demand is structural, not cyclical, for the foreseeable future.

Government funding is also expected to become as adroit, quick, and strategic as private venture capital. Policymakers recognize that a vibrant defense-tech startup sector yields strategic dividends for generations and that efficient allocation of non-dilutive capital to defense-tech is essential to producing the innovations the nation requires. We expect increased SBIR and STTR funding alongside new incentive programs modeled after the Strategic Breakthrough Program. DARPA will continue its flexible and speedy grantmaking. The April 2026 SBIR reauthorization, which introduced \$30 million in Strategic Breakthrough Awards matched 1:1 by private capital, is the template we expect to see replicated and expanded.

None of this means founders will have it easy. Policymakers intend to level the playing field and discourage bad behavior, but accessing non-dilutive funds remains competitive. Navigating procurement requires specialized knowledge and experience most founders lack when they start. Companies that build customer relationships early, through SBIR Phase III, OTAs, and direct engagement with acquisition shops at SDA, SpaceWERX, and Defense Innovation Unit (DIU), will be the ones that capture the structural defense tailwind. Companies that wait for defense procurement to come to them will quickly discover it does not work that way.

Where serious people disagree: defense demand may be more cyclical than structural. Budgets get cut, and government buying at venture speed has been promised before and stalled in practice. The harder counter is that startups still lose the programs that matter to the primes, and that grant money comes with strings that bend how a company is built.

4.5 A mostly fragmented regulatory regime: a global deal is years away

The common view is that space regulation will end up like biopharma's ICH or shipping's IMO: one global framework, eventually. We bet against it. Shared rules would help everyone, but within the next decade we don't see them coming. Fragmentation is where this settles.

The mechanism that produces and will continue to produce fragmentation is the political economy of the standards bodies themselves. International standards are written by people who show up to the working groups, and those who show up represent the institutional interests of the jurisdictions that send them. China currently chairs an outsized share of ISO and IEC technical committees with aerospace and space relevance and has been deliberate about its strategy for two decades. The US has historically punched below its weight in comparable forums, with most engagement happening at the company level rather than through coordinated national policy.

The standards that govern emerging aerospace categories are increasingly written with Chinese national champions in mind, in technical configurations that favor their architectures and, as a result, disadvantage Western entrants. The patchwork is not a regulatory failure; it is a regulatory success from the perspective of the jurisdictions writing the rules.

Fragmentation is not absolute. Operational design domain definitions, autonomy levels, and incident classification taxonomies are obvious areas of common interest, because disagreements there impose costs on everyone with no strategic payoff to any party. Mutual recognition of flight test data has partially converged in civil aviation and will continue to inch forward where products are physically similar across jurisdictions. Telemetry and incident reporting formats are converging because the cross-border safety case for sharing them is overwhelming. What does not converge is anything with strategic content. Export control will diverge because each jurisdiction's export control reflects its national security posture. Cybersecurity certification will diverge because each jurisdiction has reasons not to trust the others' audit regimes. Mission authorization frameworks for novel categories, in-space servicing, debris removal, and on-orbit manufacturing will diverge because each jurisdiction has its own posture on liability, sovereignty, and the use of force in space.

For founders, the implication is that the strategic question is not how to navigate the fragmented landscape but which segments of it to compete in. The default of building everywhere and serving every market is a luxury that scales only for primes with global manufacturing footprints. For everyone else, the discipline is to pick the markets where the company's product, capital base, and team best fit the regulatory environment, build deep regulatory and customer relationships there, and expand only when the underlying economics justify the additional overhead. Rocket Lab built in New Zealand. Skyroot built in India. ICEYE built in Finland. ICON built in the UAE. Each made a strategic bet on geography that the founders defaulting to El Segundo did not, and each is now extracting value the defaulters cannot replicate. We expect this pattern to intensify, not weaken.

Where serious people disagree: the strongest counter is the opposite of the single-framework view. In practice, the US already dominates space regulation, so the field may be less fragmented than "patchwork" suggests. We hold that fragmentation is the resting state for anything with strategic content, but grant that safety and telemetry standards are converging.



Part 5: As We Look Forward

5.1 Summary

The conventional summary of a paper like this restates the headline numbers, lists the predictions, and ends on a note of measured optimism. We are going to do something different. The paper's contribution is not the inventory of opportunities in Part 2, the inventory of challenges in Part 3, or the five predictions in Part 4, considered separately. The contribution is the underlying structure that runs through the three lists, the same structure in all three cases, which we believe is the right frame for the next decade of company-building in this sector. This closing section names that structure, identifies the claims we are willing to defend, and is honest about the parts of the argument that the next five years will likely prove wrong.

The Bet

Aerospace in 2026 is in the early years of a structural transition from a cost-plus, prime-dominated industry to a fixed-price, dual-use one, still mostly government-funded but increasingly founder-directed, whose economics increasingly resemble those of energy and telecommunications rather than defense. The transition is not complete; it will not be complete on a ten-year horizon, and the companies that win in the second phase will not all be the companies that look strongest in the first phase. Falling launch costs are the enabling condition, not the bet. The bet is that the four substantive shifts described in Part 2 (capital duration, dual-use convergence, lifecycle economics, and AI-driven design and operations) compound across the four challenges described in Part 3 (capital and customer and insurance clocks, regulation as a design constraint, demand-first sequencing, and the industrial-base-as-people problem) over a horizon long enough to deliver the five predictions in Part 4. None of these is a sure thing. All of them are defensible. The companies that recognize the structure compound; the companies that treat each shift as an isolated tactical problem do not.

Three lists, One Argument

The opportunities, challenges, and predictions are not three independent assessments. Read in sequence, they are the same argument expressed at three different time horizons. Part 2 names the forces operating today. Part 3 names the constraints those forces must navigate to produce a viable company. Part 4 names what the cumulative effect looks like at fifty years if the constraints are navigated. We organized the paper this way, rather than as a more conventional opportunities-and-risks dichotomy, because the conventional structure encourages the reader to treat opportunities and risks as separate balance-sheet items to be weighed against each other. They are not separable. The opportunity in dual-use markets is the same phenomenon as the regulatory-compliance challenge of operating across ITAR, EAR, NDAA Section 889, and CMMC. The opportunity in lifecycle economics is the same phenomenon as the demand-first sequencing problem of selling MRO before the orbital fleet is large enough to need it.

The opportunity in AI infrastructure is the same phenomenon as the tacit-knowledge problem of building autonomy that operators can actually calibrate trust around. Founders who internalize this and design their companies against the integrated picture extract value that founders who pick from a menu of opportunities cannot. The five predictions in Part 4 are not aspirations for the sector. They are the compound outcome of the first two sets, navigated correctly by enough companies, for enough cycles, on the required horizon.

The architectural reframe is the central thesis

If the reader takes only one claim from this paper, it should be the one explicitly stated in Section 3.5 and operating quietly through every other section: in aerospace, the decisions that determine whether a company survives are made early, in choices that do not feel architectural at the time, and the founders who recognize them as architectural are the ones whose companies scale. Capital structure is architectural. Regulatory exposure is architectural. Customer-cycle alignment is architectural. Supplier and workforce strategy is architectural. The reactive version of each of these decisions, made later under time pressure when the constraint binds, produces measurably worse outcomes than the same decision made eighteen months earlier, when conditions allowed for deliberation. This is not a generic observation about startups. It is a feature of this sector specifically, because the time constants in aerospace, including the procurement cycles, the certification gates, the standards-body output cadences, and the insurance market formation timelines, are long enough that the gap between an architectural decision and a reactive one is the difference between a company that ships and one that does not. The conventional founder discourse treats year one as operational and year three as strategic. The successful aerospace founders we interviewed treat year one as strategic and year three as operational, and the inversion is consequential.

What we are willing to defend

Four claims in this paper are the ones we will defend most vigorously, because they are most likely to be uncomfortable for the sector's current consensus. First, the speed-versus-safety framing of aerospace failure is wrong; the failures of the last decade were failures of capital duration, customer-cycle alignment, and insurance market formation, not failures of going too fast. Second, the venture capital base has substantially adapted to this sector, and the founder narrative that VC is structurally incompatible with aerospace is roughly a decade out of date; the right capital exists, it is concentrated in a small number of vehicles, and founders who do not raise from those vehicles are inheriting a problem the field has already partially solved. Third, technical feasibility is not viability, and the sector's pitch decks systematically over-index on the former at the expense of the latter; the founders who pass the miracle count test honestly and sequence demand before architecture are running a different company than the founders who do not, even when the technology slides look identical. Fourth, the industrial base problem is not a supply chain problem; it is a workforce and tacit-knowledge problem, and the policy and capital instruments that treat it as a supply chain problem will continue to underperform those that treat it as a human-capital problem. Each of these claims has implications that the next few years will test.

We have stated them in a form that allows them to be falsified.

What this paper is, and what it is not

This is a snapshot of a moving industry, written by a cohort of MIT students, engineers, and operators after more than 50 interviews and conversations with people actively building within it. It is not a neutral survey. It is not a forecast in the consultancy sense, with point estimates and confidence intervals. It is an argument, grounded in primary research, and the parts we expect to age worse are those where we have committed to specific numbers on specific timelines. The space economy scale prediction in Section 4.1 will be wrong on the year. The robots-over-humans prediction in Section 4.2 will be wrong on the specific operating model. The emerging opportunities prediction in Section 4.3 will be wrong on which categories mature first. The defense prediction in Section 4.4 will be wrong on which programs define the decade. The regulatory fragmentation prediction in Section 4.5 will be wrong on which blocs converge and on what timeline.

Each of these is calibrated to be approximately right on direction and approximately wrong on detail, which is the only honest position to take on a multi-decade horizon. The contribution we hope is durable is the structural argument: that opportunities, challenges, and predictions are three views of one phenomenon; that architectural decisions in year one compound differently than reactive ones in year three; and that the founders, investors, and operators who internalize this will build the companies that the conventional discourse, focused on tactics and timelines and quarterly milestones, will fail to identify in time. If a reader five years from now finds that we got specific predictions wrong, but the structural frame still applies, the paper has done what we set out to do. If they find that the structural frame itself was wrong, the contribution will be smaller, and the failure will be ours.

The party is just getting started

The current cohort of aerospace companies, the SpaceX-Anduril-Shield AI-Rocket Lab-Stoke-Varda generation, has laid the groundwork for the playbook. The next cohort, the companies founded between now and 2030, will be the ones that test whether the playbook generalizes to lifecycle services, dual-use convergence, in-space manufacturing, and the harder-to-finance categories the first cohort largely did not touch. The decade after that will be the one in which the five predictions in Part 4 either start to look like base cases or quietly slip past their probable dates.

Either way, the volume of capital, talent, and policy attention now flowing into this sector is structurally different from any prior point in the industry's history, and the founders, investors, students, and operators who treat this as the consequential industrial moment it is will build the institutions on which the next several decades of the space economy will run.

The paper is our argument for why that moment is real. The companies are yours to build.

5.2 What does this mean for you?

The opportunities, challenges, and predictions above are the same argument presented across three time horizons. The implications for the people who will build, fund, and join the next wave of the new aerospace are not three separate sets of advice. They are a single set of disciplines, applied differently depending on where you sit.

Founder

The window of opportunity is open in a way it has not been for a generation. Launch costs have fallen by orders of magnitude. Government contracts have shifted toward fixed-price vehicles that align with startup capital cadence. Defense-specific and deep-tech funds with fifteen- to twenty-year horizons are deploying at scale. The four drivers in Part 2, capital duration, dual-use convergence, lifecycle economics, and AI-driven design and operations, are most valuable at their intersections, and the companies capturing disproportionate value over the next decade will operate across two or more of them rather than within one. Pick the intersection your team is genuinely credible in, raise from the capital base whose duration fits that intersection, and let the other three drivers shape your second-act optionality rather than your founding thesis.

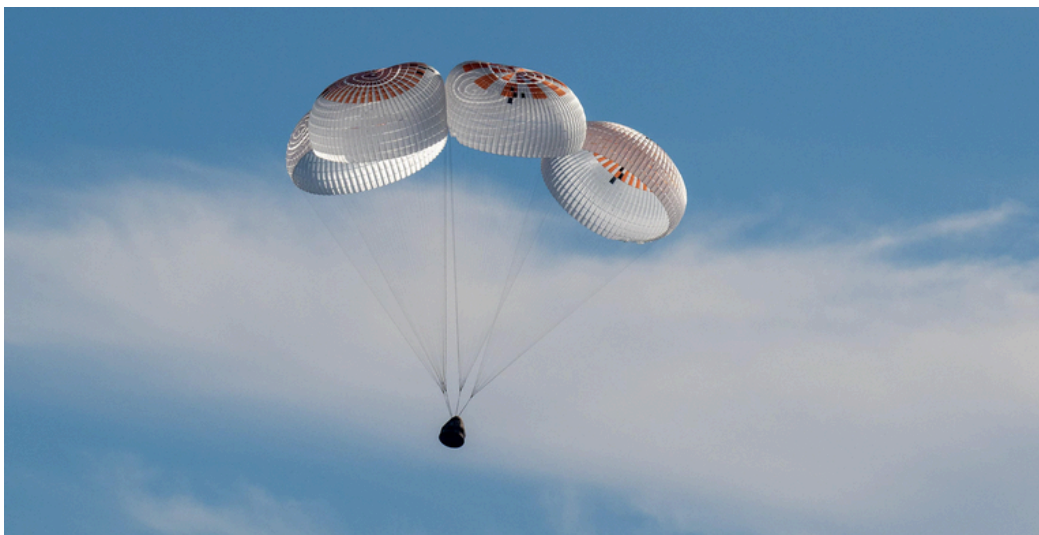
That positioning only matters if the company survives long enough to compound. The founders we interviewed who are building well share a common discipline: they treat the first eighteen months as architectural, not operational. They know their customer's procurement cycle before they have a product. They engage standards bodies before they have hardware. They choose capital sources whose duration matches the cycle they have to survive. They identify the three or four senior hires that will gate the company's progress and treat that search as a yearlong activity. They map the compliance regimes they will inherit at the first defense contract and structure the cap table to be compatible with them. None of this shows up in a pitch deck, and most of it does not feel like founder work in the moment. It is also the difference, in this sector, between companies that ship and companies that do not. The founder who treats year one as operational has, by year three, accumulated a stack of architectural decisions made by default, by other people, under time pressure. The founder who treats year one as architectural has accumulated optionality the first founder no longer has access to.

Be honest about the miracle count of your technology and raise from the capital base whose duration fits it. Identify the customer and the revenue path before the technology, even if the technology vision is fifty years out. Find the operators who have failed in this sector and learned something from it. The lessons are not transferable from other industries and are not available in the conventional founder discourse. The companies founded over the next five years will define what the second wave of the new aerospace looks like.

Investor

The space economy is no longer a bet on rockets. It is a bet on infrastructure, data, autonomy, and lifecycle services, whose economics increasingly resemble energy and telecommunications rather than traditional aerospace, with the duration, capital intensity, and customer dependencies that comparison implies. The diligence template inherited from software venture is necessary but insufficient. The existing template correctly prices team, technology, market, and capital plan; the four reframes from Part 3, the three-clock survivability problem, regulation as a design constraint, demand-first sequencing, and the industrial-base-as-people problem, are not standard diligence boxes, and they are the questions that actually price the variance in outcomes.

The dual-use lens matters because the categories with the most attractive risk-adjusted returns over the next decade touch both commercial and defense markets, and the funds that have built the underwriting muscle for both will see opportunities the single-market funds will not. Look hard at the categories that the Generation Space ecosystem map misses or under-represents, including spectrum management, manufacturing software, MRO and on-orbit servicing, the integration infrastructure between commercial constellations and defense customers, and the workforce and standards-body adjacent businesses that the conventional aerospace VC narrative treats as picks-and-shovels rather than as the actual investable surface. The companies that compound across the predictions in Part 4 are not, in most cases, the launch and satellite companies that dominate current portfolio construction. They are the layer-two and layer-three businesses, the ones that benefit from launch costs falling without having to drive that fall themselves. Funds that allocate accordingly will outperform those that continue to underwrite rockets as if rockets were the bet. Do not miss the second wave because the first wave was so visually compelling.



Student

One last word for students. In this industry, if your learning ever stops, so do you.

This is the best moment in a generation to enter aerospace, and the entry point matters less than the conventional career narrative suggests. Students who join early-stage hardware companies are building skills that prime alumni do not have. Students who join prime rotational programs that touch flight hardware early are building skills that startup alumni do not have. Students who join government acquisition programs, the Space Development Agency, SpaceWERX, DIU, or NASA's commercial programs are building skills neither of the above acquires by default, and those skills are increasingly the binding constraint on the sector's growth. The cohort of senior engineers and operators who will lead this industry in 2045 will be drawn from all three pools.

The discipline that matters more than the brand of the first employer is optimizing proximity to flight hardware, customer relationships, and architectural decision-making. Get your hands dirty. Build something. The technical skills that translate into venture-backable founder credibility in this sector are not earned in a classroom. They are earned on hardware that has flown, in supply chains that have failed, in customer conversations where the customer said no for reasons you did not initially understand. Talk to the people who have built and the people who have failed. The honest accounts of what is hard about this sector are not in press releases or LinkedIn posts. They live in the conversations operators are willing to have once they trust that you are seriously trying to build.

The window is open. The cost is that you will need to make career decisions that do not optimize the safest immediate path. The reward is access to the consequential industrial moment of your generation, and the opportunity to shape what it becomes rather than read about what it became.

**The choice is yours.
- MIT ALIENS**



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Jon Arenberg

Fellow & Chief Mission Architect, Northrop Grumman

35-year aerospace veteran and Northrop Grumman Fellow who served as chief engineer on the James Webb Space Telescope and contributed to the Chandra X-ray Observatory. Co-invented the Starshade concept for detecting exoplanets.

Mitch Ayoob**Consultant, Mitchell Ayoob Consulting · Former Engineering Director, Raytheon**

Former Engineering Director at Raytheon specializing in radar, C4I systems, and the adoption of commercial innovation models for defense markets. Experience leading complex departments with over 100 engineers and scientists while managing programs valued in the \$100Ms.

Natalya Bailey**Co-Founder, Accion Systems (now Revolution Space) · Fractional COO**

MIT-trained aerospace engineer who co-founded Accion Systems and led it for a decade, commercializing ion propulsion for small satellites. Now a fractional COO and investor advising deep tech companies.

Tejpal Bhatia**CEO & Founder, Nebex · Former CEO, Axiom Space**

Three-time startup founder and former Google executive who served as Chief Revenue Officer and then CEO of Axiom Space, securing over \$1 billion in contracts. Now founder and CEO of Nebex.

Christian Carpenter**COO, Atomic-6 · Former Production Manager, SpaceX**

Scaled SpaceX's Hall thruster manufacturing to full-rate production, launching more Hall thruster systems in a single year than all others in world history combined. At Atomic-6, leads high-performance composite manufacturing and deployable space structures.

A.C. Charania**SVP of Space Business Development, Zeno Power · Former NASA Chief Technologist**

Served as NASA's Chief Technologist from 2023 to 2025, advising the Administrator on technology strategy. Previous executive at Blue Origin, Virgin Galactic, and Reliable Robotics. Now leading space business development at Zeno Power.

Cindy Chin**CEO & Founder, Planetary Systems AI · Co-Founder & Member of Board of Directors, CLIPr**

Founder of Planetary Systems AI, focused on data flow and decision-making infrastructure for the space sector. Co-Founder of CLIPr, a video analysis and management platform that leverages AI to help users identify key moments within a video.

Bobby Collins**Co-Founder & CTO, Revere Defense Technologies**

Harvard and Stanford trained engineer with experience as Staff Scientist at Raytheon. Now a defense entrepreneur and co-founder of Revere Defense Technologies, building autonomous, adaptive, and resilient mesh networks.

John Conafay**CEO & Co-Founder, Integrate**

US Air Force veteran and space industry entrepreneur with experience at Spire, Astranis, Spaceflight Inc., and ABL Space Systems. Co-founded Integrate to build project management software for programs with complex hardware.

Alex Coultrup**Director of Business & Policy, Starfish Space**

Director of Business and Policy at Starfish Space, a satellite-servicing company building toward affordable, accessible satellite servicing.

Tahara Dawkins**Senior Director of Policy, Astroscale**

Space policy leader with 25+ years of experience. Now leading regulatory and government affairs for Astroscale's U.S. operations, working at the intersection of space law, orbital servicing regulation, and emerging frameworks for proximity operations.

Riccardo del Teonno**Venture Associate, Mandala Space Ventures**

Politecnico di Milano and USC trained aerospace engineer with experience in guidance and control systems. Venture professional supporting technical and strategic efforts across Mandala Space Venture's space portfolio companies.

Daniel Erkel**Research Fellow, MIT Initiative for New Manufacturing**

Having recently completed his postdoctoral research in MIT's AeroAstro Engineering Systems Lab, where he focused on space systems engineering, strategy, policy, and optimization, Daniel is now a Research Fellow at MIT's Initiative for New Manufacturing, helping advance the next generation of manufacturing.

Michael Falcon**Partner, In-Q-Tel**

Experienced VC professional with over 25 years of experience across investing and operations. Now responsible for the oversight and investment strategy for In-Q-Tel's Intelligent Connectivity and Compute (IC2) Practice.

Vincent Finello**Sr. Associate of Business Operations, Relativity Space**

Experienced finance professional with a proven track record in investment strategy, having served as a Senior Technical Associate at Mandala Space Ventures before transitioning to Relativity Space, where he evaluates the operational impact of investment decisions.

Matthew Gialich**Co-Founder & CEO, AstroForge**

Co-founder and CEO of AstroForge, an aerospace startup building technology to mine asteroids for critical minerals.

Gerry Hudak**CTO, Rendezvous Robotics**

Engineer with experience at SpaceX and Blue Origin. Currently serving as CTO of Rendezvous Robotics where he brings hands-on spacecraft systems expertise to further their mission of autonomous in-orbit spacecraft assembly.

Steve Isakowitz**Former President & CEO, The Aerospace Corporation**

Led The Aerospace Corporation for nearly a decade as the nation's trusted partner for the space enterprise. Previously held senior leadership roles at Virgin Galactic, NASA, and the Department of Energy.

Philip Johnston**CEO & Co-Founder, Starcloud**

Currently serves as Co-founder and CEO of Starcloud, which recently raised a \$170 million Series A at a \$1.1 billion valuation to advance its mission of building data centers in space.

Scarlett Koller**CEO & Co-Founder, Mithril Technologies**

Co-founder of Mithril Technologies, an MIT-spinout developing a new space-based RF reflector antenna. Previously worked on Life Support Systems at SpaceX and on the Perseverance Rover at NASA JPL

Brian Komlos**Co-Founder, Stealth Startup · Former Director of Recovery & Marine Ops, Rocket Lab**

U.S. Coast Guard veteran with leadership experience overseeing recovery operations at SpaceX and Rocket Lab. Now pursuing entrepreneurship as the co-founder of a stealth maritime technology startup.

Amit Kshatriya**NASA Associate Administrator and Chief Engineer**

NASA's highest-ranking civil servant and chief operating officer, leading the agency's 10 center directors and mission directorate associate administrators. Previously deputy associate administrator for the Moon to Mars Program, after a NASA career since 2003 spanning robotics, spacecraft operations, and space station flight director.

Joe Landon**President & Co-Founder, Rendezvous Robotics**

Space entrepreneur with roles spanning Co-founder and Chairman of the Board of Space Angels, CFO of Planetary Resources, VP of Advanced Programs at Lockheed Martin, and CEO of Crescent Space. Now Co-founder and President of Rendezvous Robotics, building autonomous in-orbit assembly of spacecraft.

Greg Loboda**Head of Manufacturing Engineering: Space, Anduril Industries · Co-Founder, Dark Fission Space Systems**

Aerospace professional with over 25 years of experience in program, engineering, and enterprise leadership across startups and Fortune 100 companies. Now serving as Head of Manufacturing Engineering, Space at Anduril and Co-Founder of Dark Fission Space Systems, leading development of the first commercial nuclear thermal rocket engine.

Jeffrey Manber**President of International and Space Stations, Voyager Space · Co-founder and Chairman, Nanoracks**

Pioneer of commercial space station access through co-founding of Nanoracks, serving as its CEO from 2009 to 2021 and overseeing the development of the first commercial airlock on the ISS. Now leading commercial space station efforts at Voyager.

Aaron Marsh**CFO, Unless**

CFO of Unless, where he leads financial analysis and public market product development. Before Unless, he was CFO and COO of Signal Infrastructure Group, and spent a decade across two multi-billion-dollar investment funds, Duquesne Capital and Amaranth Advisors, working in private equity, credit, and public equity strategies. He holds a B.A. in Mathematics and Economics from Williams College.

Rob Meyerson**Co-Founder & CEO, Interlune · Former President, Blue Origin**

Co-founder and CEO of Interlune, a lunar resources company, and founder of the aerospace consultancy Delalune Space. As President of Blue Origin from 2003 to 2018, he grew the company from a small research team into a 1,500-person organization, overseeing development of New Shepard, the BE-4 engine, and the New Glenn launch vehicle.

Halen Mattison**CEO & Co-Founder, General Galactic**

CEO and Co-founder of General Galactic, an LA-based startup building manufacturing platforms for space mobility and propellant generation. A SpaceX veteran bringing hands-on spacecraft systems experience to next-generation responsive space platforms.

Nick Newell**Director of Space Programs, Astrobotic**

Leads Astrobotic's full portfolio of spacecraft and lunar infrastructure programs. Previously led engineering organizations at Boeing, with Certification of Flight Readiness authority across 21 Space Shuttle missions and product team leadership on the Artemis Space Launch System.

Aaron Pickard**MBA Candidate, UChicago Booth · Former Lead Systems Engineer, Terran Orbital**

Currently pursuing his MBA at the University of Chicago Booth School of Business. Aaron has experience as former senior associate at MFV Partners, managing partner at Dorm Room Fund, and as Lead Systems Engineer at Terran Orbital.

Matthew Rhodes-Kopf**Senior Lecturer, MIT Sloan · Managing Partner, Tectonic Ventures**

Venture capitalist and educator with nearly 30 years across entrepreneurship, investing, and academia, with prior faculty roles at Harvard Business School and Columbia. Formerly CFO of Avid Radiopharmaceuticals, where he helped launch the world's first Alzheimer's imaging agent.

Felix Scheuffelen**Co-Founder & Partner, Assembly Ventures**

Co-founder and Partner of Assembly Ventures, a VC firm that invests in mobility companies in the Western world. Brings a venture perspective to advanced manufacturing, logistics, and aerospace.

Eric Schmidt**President & Co-Founder, Exquadrum (now Mach Energetics)**

A rocket propulsion engineer with nearly three decades in the field. In 2002 he co-founded Exquadrum, leading it for over twenty years as it delivered advanced propulsion, hypersonics, and energetics work for the DoD and NASA.

Brandon Seifert**Senior Manager, Space Business Development, Radiant Nuclear**

Deep techcommercialization expert who co-founded Atomos Nuclear and Space. Brings extensive experience capturing major government contracts and securing VC funding to scale nuclear and aerospace startups, currently leading space business development at Radiant.

John Tylko**Chief Innovation Officer, Aurora Flight Sciences · Lecturer, MIT AeroAstro**

Co-founder of Aurora Flight Sciences and a lecturer in MIT's Department of Aeronautics and Astronautics, with deep experience in aerospace autonomy and advanced aircraft programs.

Olivier de Weck**Apollo Program Professor of Astronautics & Engineering Systems, MIT**

A leading scholar in systems engineering and space logistics, and Editor-in-Chief of the Journal of Spacecraft and Rockets. His research focuses on how complex aerospace systems are designed and evolve over time, spanning lifecycle value, design optimization, and the economics of reusable launch.

Matthew Weinzierl**Senior Associate Dean and Professor, Harvard Business School**

A leading scholar on the economics of the space sector, whose research examines the role of private markets and policy in the emerging space economy.

Chris Zareck**1st Lt., U.S. Space Force · MIT Human Systems Lab, Graduate Student**

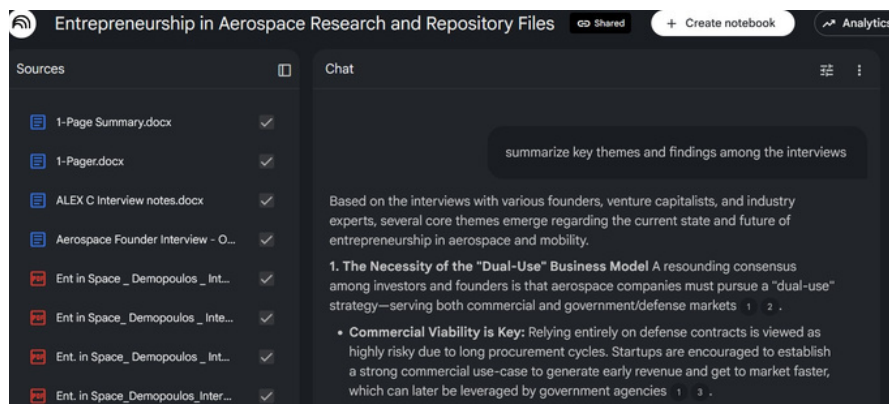
1st Lt. in the U.S. Space Force currently pursuing MS in Aerospace engineering at MIT. Chris has experience in space mobility, servicing, and logistics, focusing on how emerging on-orbit capabilities can support future national security and commercial space operations.

Use of AI in this report

This paper was researched and written by the members of MIT ALIENS. Artificial intelligence tools were used in a limited and defined capacity during this paper's preparation. Specifically, Claude (Anthropic), ChatGPT/GPT-4 (OpenAI), and Gemini/NotebookLM (Google) were used for two purposes: supporting background research and information gathering during the early stages of the project, and editing and proofreading of drafted sections for clarity, grammar, and consistency. All analytical frameworks, conclusions, predictions, and arguments in this paper are the original work of the authors and were not generated by AI.

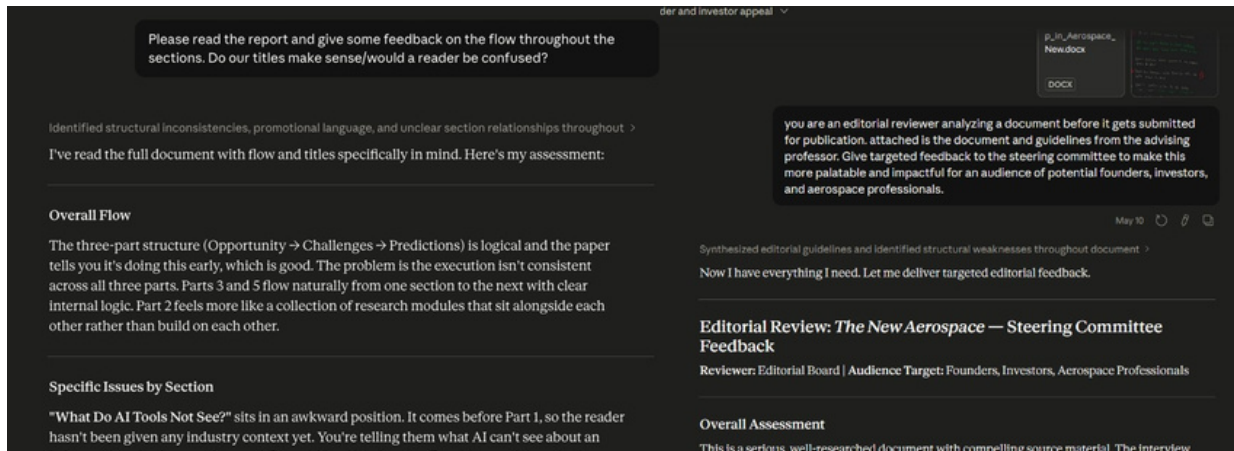
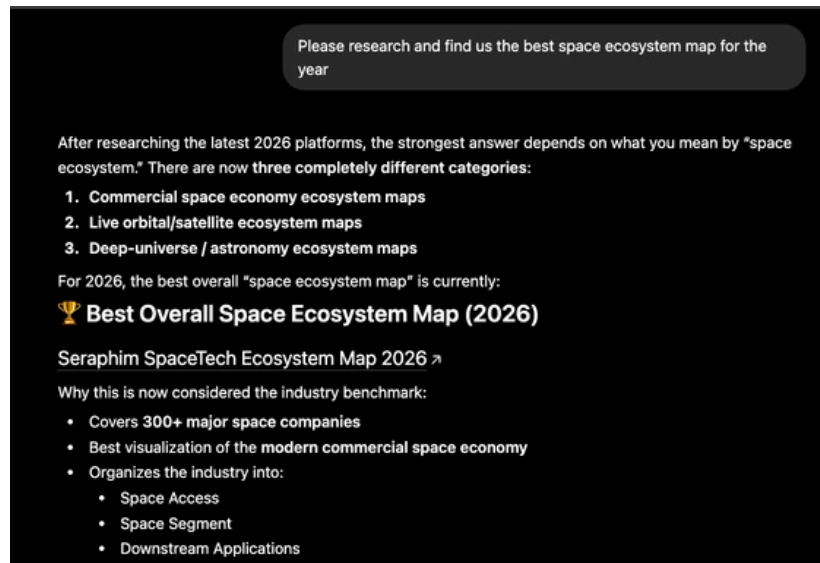
All interviews reflect primary conversations conducted by ALIENS members, the only AI used was preliminarily identifying consistent themes among the conducted interviews to prompt further analysis and discussion among the team. In completing this report, the ALIENS members worked on various sub-teams in parallel for developing content, so AI was used to standardize formatting at a broad level, but specific editing and adaption was completed by ALIENS. Representative example prompts used during this process are documented below in the interest of transparency and reproducibility. A reader wanting a fast overview of the industry could try prompts like: "Summarize the major segments of the space economy and the leading companies in each," or "Explain the difference between upstream, midstream, and downstream in the space industry and why margins differ," or "What are the main regulatory bodies governing commercial space in the US, and what does each control?"

Identifying themes with NotebookLM:

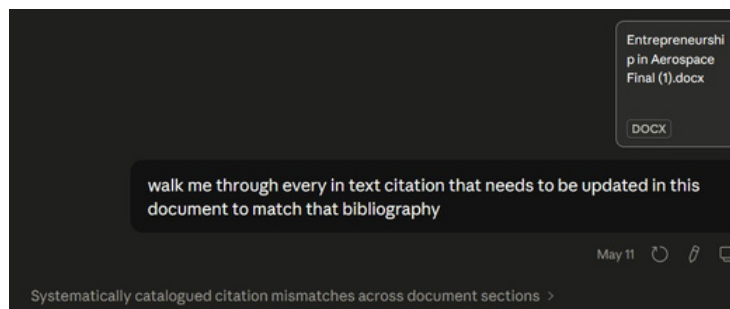


NotebookLM proved a great way to benchmark our analysis and predictions across several dozen interviews. We were able to ask things like “who disagrees with this sentiment” and get a clear picture of when we were aligning with our supportive contributors and when we were pushing into truly controversial stances.

Using ChatGPT for research:



Seeking feedback from Claude:



Acronyms & Abbreviations

Key acronyms used throughout this paper, listed alphabetically for reference.

AI	Artificial Intelligence
AIAA	American Institute of Aeronautics and Astronautics
ALIENS	Aerospace Leaders, Investors, Engineers & Students (MIT)
AS9100	Aerospace Quality Management System standard
ASTM	ASTM International (standards body); F38 covers unmanned aircraft
BIS	Bureau of Industry and Security (US Dept. of Commerce)
CAGR	Compound Annual Growth Rate
CLD	Commercial LEO Destinations (NASA program)
CLPS	Commercial Lunar Payload Services (NASA program)
CMMC	Cybersecurity Maturity Model Certification
CONFERS	Consortium for Execution of Rendezvous and Servicing Operations
COTS	Commercial Orbital Transportation Services (NASA program)
DARPA	Defense Advanced Research Projects Agency
DFARS	Defense Federal Acquisition Regulation Supplement
DIU	Defense Innovation Unit
DOD	Department of Defense (now Department of War)
EAR	Export Administration Regulations
EASA	European Union Aviation Safety Agency
ESA	European Space Agency
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FCC	Federal Communications Commission
FEED	Field Emission Electric Propulsion
FOCI	Foreign Ownership, Control, or Influence
GAO	Government Accountability Office

GDP	Gross Domestic Product
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
HAPS	High-Altitude Platform Stations
HITL	Human-in-the-Loop
IP	Intellectual Property
ISAM	In-Space Servicing, Assembly, and Manufacturing
ISR	Intelligence, Surveillance, and Reconnaissance
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ITAR	International Traffic in Arms Regulations
LEO	Low Earth Orbit
LP	Limited Partner
MEO	Medium Earth Orbit
MEV	Mission Extension Vehicle
ML	Machine Learning
MOU	Memorandum of Understanding
MRO	Maintenance, Repair, and Overhaul
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NOAA	National Oceanic and Atmospheric Administration
OEM	Original Equipment Manufacturer
OSAM	On-Orbit Servicing, Assembly, and Manufacturing
OTA	Other Transaction Agreement
PGM	Platinum-Group Metals
PNT	Positioning, Navigation, and Timing
PWSA	Proliferated Warfighter Space Architecture
RAFTI	Rapidly Attachable Fluid Transfer Interface
RTCA	Radio Technical Commission for Aeronautics

SBIR	Small Business Innovation Research
SDA	Space Development Agency
STTR	Small Business Technology Transfer
TAM	Total Addressable Market
TRL	Technology Readiness Level
UAS	Uncrewed Aircraft System
USSF	United States Space Force
VC	Venture Capital
ZBLAN	Zirconium-Barium-Lanthanum-Aluminum-Sodium (heavy-metal fluoride glass)

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09. Astroscale
10. Orbit Fab
11. Starfish Space
12. Lonestar Data Holdings
13. Chronograph
14. Seraphim Space (Generation Space)
15. AIAA
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