SPACE GAME CHANGERS: DRIVING FORCES AND IMPLICATIONS FOR INNOVATION INVESTMENTS

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The advancement of new space technologies, architectures, applications, and emerging business models will continue with many breakthroughs as well as some disappointments. A rapid and relentless pace of change requires timely analysis. This report offers a framework for government decisionmakers as they consider complex space sector innovation strategies and how best to prioritize investment decisions. The framework calls for recognizing innovations that offer market disruption for new users or applications, breakthrough capabilities, or incremental improvements and suggests a strategy for investment and risk management to advance these innovations to game changers that benefit civil, military, and national security interests. Ultimately, a portfolio management approach is needed across the whole-of-government to rationalize U.S. government investments in space innovation.

Background

Frequent technology disruption is the new normal in all aspects of our lives, and the space industry is no exception. The advancement of new space technologies, architectures, applications, and emerging business models will continue with many breakthroughs as well as some disappointments. A rapid and relentless pace of change requires timely analysis. This report offers a framework for considering complex innovation strategy and prioritizing investment decisions, and capsule descriptions of several emerging space gamechangers.

As government space stakeholders make critical innovation investment decisions, they should be mindful that much of the innovation is occurring outside government laboratories and research and development (R&D) centers. Establishing an innovation portfolio management strategy can start by broadly exploring technologies, applications, or business trends that could potentially disrupt the status quo by:

- propelling a product or service ahead of its competitors;
- introducing new products, services or capabilities; or
- rearranging the space value chain.

Government and business leaders need sound analyses to separate the hype from reality so they can make informed decisions regarding those space sector game changers that:

- Require seed funding and other types of financial levers to evolve and adapt.
- Are critical to national security space (NSS) needs.
- Are vulnerable to supply chain or industrial base security risks.
- Provide the U.S. with an asymmetric advantage.
- Require trade and intellectual property (IP) protection to prevent adversaries from gaining asymmetric advantage.

While most organizations who follow the satellite industry, including banks, agree that the space sector has grown significantly over the past 20 years, estimates vary widely.[1] According to Bryce Space and Technology, from 2000 to 2005, the industry received more than $1.1 billion in investment from private equity, venture capital, acquisitions, prizes and grants, and public offerings. During a later time period, between 2012 and 2017, the industry had received more than $10.2 billion.[2] Although private investment has fueled unprecedented growth in the space industry, recent global satellite industry revenues[*] have decreased by 1.5 percent to $271 billion during 2019, according to Satellite Industry Association's "State of the Satellite Industry Report."[3] The space sector has reached an inflection point where reduced satellite manufacturing revenues reflect a more modest sized GEO industrial base, a competitive shakeout of the low Earth orbit (LEO) industrial base, and a SATCOM capacity surplus. Adding to this market challenge, rising government deficits due to the COVID-19 pandemic has set the stage for a more constrained government budget environment. These market challenges underscore the importance of a broad, agile, and strategic approach to space innovation investing.

Five Forces Driving Space Evolution

Industry game changers are those technologies, applications, business models, or architectures that significantly change the status quo, often by defining a new product technology or service and by meeting a previously unmet customer need. The following five driving forces are worth noting, along with how these trends may converge, to further accelerate game changers across key space elements or technologies, applications, business models, and architectures.

1. From Spin-off to Spin-in. In the past, the space industry was a key starting point for technology creation. NASA, for instance, has developed technologies for space exploration that have made their way into everyday life. A few eclectic examples include memory foam; aerogel insulation; ultraviolet-resistant sunglasses; improved cloud computing; advanced digital imaging; and translucent polycrystalline alumina, which is now used in invisible dental braces.[4] Klaus Schwab notes in "Shaping the Fourth Industrial Revolution" that "today, the space sector is experiencing a huge degree of innovation, but it is largely being driven by 'spin-in' benefits from other sectors."[5] This implies that space stakeholders and decisionmakers must be prepared to determine the potential application of emerging game changers *outside* the space sector and take action to encourage awareness, investment, and adoption.

2. Billionaire Investors. Fifty years ago, the space race involved a fierce rivalry between Russia and the United States. Today's space race is now partially fueled by private billionaires, driven by a mix of motivations, including idealism, vision, and a conviction that investments in space travel and applications will pay off in the long run. Capital infusion from serial entrepreneur billionaires has supported the space sector's growth over the past several years. These billionaires include:

- Jeff Bezos – Blue Origin (space launch for cargo and tourism) and Project Kuiper (Internet satellite constellation)
- Elon Musk – SpaceX (reusable rockets) and Starlink (Internet satellite constellation)
- Richard Branson – Virgin Galactic (space tourism) and Virgin Orbit (air-launched rocket)

[*] This satellite industry growth statistic does not include government space budgets and commercial human space flight. The total global space economy grew by 1.7 percent to $366 billion during 2019.

3. Democratized Space Disrupters. Clayton Christensen, a business consultant who popularized the theory of disruptive innovation, wrote a seminal book called *The Innovator's Dilemma*.[6] A central theme of the book is that it is *not* ineptitude that prevents leading companies from predicting disruption. Instead, it is the companies' rational approach to building better products and their focus on their most attractive customers and markets. This rational approach can blind them from seeing an undercapitalized upstart erode their market share. The disruptor starts at the bottom of the market and moves up by improving a technology or product.

Disruption in the space sector appears to have accelerated after SpaceX, founded in 2002, challenged the established launch firms by offering rocket launches at half the price of its more traditional competitors.[†] SpaceX, now valued at $36 billion, further disrupted the launch business by introducing reusable rockets.[7] Within the satellite sector, for example, we have seen the emergence of inexpensive CubeSats and nanosats, including do-it-yourself satellite kits that started primarily to serve academic users for research projects. In classic disruptor style, CubeSats are working their way up the value chain and are now serving larger-scale civil missions for weather, remote sensing, and communications. The space sector is also being disrupted by tools that were not available just a few years ago, such as enterprise class mission control and spacecraft flight software using open source software and standards. For instance, the 2019-2020 NASA Software Catalog offers free and downloadable software programs for a wide variety of technical applications such as propulsion, vehicle management system testing, operations, data and image processing, electronics, and electric power.[8]

4. Fourth Industrial Revolution or Industry 4.0. Professor Klaus Schwab, founder and executive chairman of the World Economic Forum, describes the fourth industrial revolution's enormous potential along with the possible risks.[‡] There is no precedent for the speed of current breakthroughs. Industry 4.0 is characterized by a fusion of technologies that blur the lines between physical, digital, and biological spheres.[9] This digital revolution is characterized by exponential change through smart devices, cloud computing, Internet of things, advanced robotics, big data analytics, smart manufacturing, and augmented reality.

Riding on the coattails of fourth industrial revolution, open data and the proliferation of data-sharing continues to break down information silos. This allows for the data network effect to gain traction. *Data network effects occur when an application or product, powered by artificial intelligence (AI) and machine learning (ML), becomes smarter and potentially more valuable as it accumulates more data from users.* For the space enterprise, this means that greater value will accrue over time, as space-based remote sensing data becomes more useful through increased data source, fusion, and AI, and ML.

5. The Sharing and Virtualized Space Economy. Similar to Uber, and its ability to revolutionize the on-demand ground transportation market, the space industry has started to find efficiencies for transportation to orbit. Smallsat rideshare companies have discovered that small satellites can now be packed into a rocket faring to share the same ride into space. This is now a common practice. Spaceflight Industries (Seattle, Washington), for example, provides launch services, on rockets such as SpaceX's Falcon 9, for those launch companies seeking small or secondary payloads.

Infrastructure as a Service (IaaS) models are attractive to new space entrants who may desire flexibility, scalability, speed to market, and lower capital expenditure models, while harnessing the "know-how" of experienced infrastructure operators. Various IaaS models are growing rapidly in many industries, including space. These IaaS models allow for the "virtualization" of the space enterprise, which can result in lower barriers to entry. IaaS models also dynamically apply assets as needed, while avoiding excess capacity. Examples include:

[†] SpaceX advertises Falcon 9 rocket launches for $62 million compared to Arianespace's Ariane 5 or United Launch Alliance's Atlas V for $165 million each. Michael Sheetz, "Elon Musk touts low cost to insure SpaceX rockets as edge over competitors," CNBC, April 16, 2020.

[‡] The *first* industrial revolution refers to water and steam power to mechanize production; the *second* involves electric power for mass production; the *third* involves electronics and information technology.

- **Ground Station as a Service (GaaS)** is a fully managed service that allows satellite operators to control satellite communications, process data, and scale their operations as they grow without the need to invest in expensive ground-based infrastructure. Examples include Amazon's AWS Ground Station (United States), Kongsberg Satellite Services' KSAT Lite (Norway), and Atlas Space Operations' Freedom Platform (United States).

- **Cloud Services**, which underpin the transformation and growth in digital enterprises, offer virtualized network functions for GaaS and for an enormous variety of value-added analytic services using space data. Satellite operators are rapidly embracing a range of commercial cloud services. According to the Gartner Group, the global market for cloud system IaaS hit $44.5 billion in 2019, up 37.3 percent over 2018. The top five IaaS cloud providers, listed in order of 2019 revenue, are Amazon, Microsoft, Alibaba, Google, and Tencent, which collectively represent 80 percent of the market.[10]

- **Software-as-a-Service (SaaS)** allows users access to cloud-hosted software and data analytics remotely from any web browser. Potential applications could include data analytics from remote sensing data, and tools to navigate and manage space missions.

Taking the sharing concept even further, space capabilities such as Internet broadband connectivity and mobile communications can offer augmented infrastructure services to terrestrial broadband operators and mobile carriers, including 5G networks. Leveraging IaaS arrangements, satellite-terrestrial network convergence can create cooperative networks to address seamless coverage, broadcasting and multicasting capabilities, and Internet backhaul services.

Innovation Portfolio Strategy

While game changers can emerge from a range of trends, the forces driving space evolution can provide a spotlight for identifying key innovations. Once specific technologies, applications, or business models are identified, the next step is to analyze the lifecycle maturity, potential market impact, and degree of progress or improvement that the innovation could offer. Emerging innovations can then be categorized into breakthrough, disruptive, and incremental innovations. These innovation categories follow general strategies to advance to game changers in order to appeal to certain types of investors, project management styles, and goals, discussed below.

Lifecycle Maturity. Figure 1 illustrates various influential space elements (technologies, applications, business models, and architectures) in various lifecycle phases. Triggers are inflection points that may cause the space element to advance due to changes in market demand or adoption, performance or efficiency, regulation or policies, or societal expectations and norms.

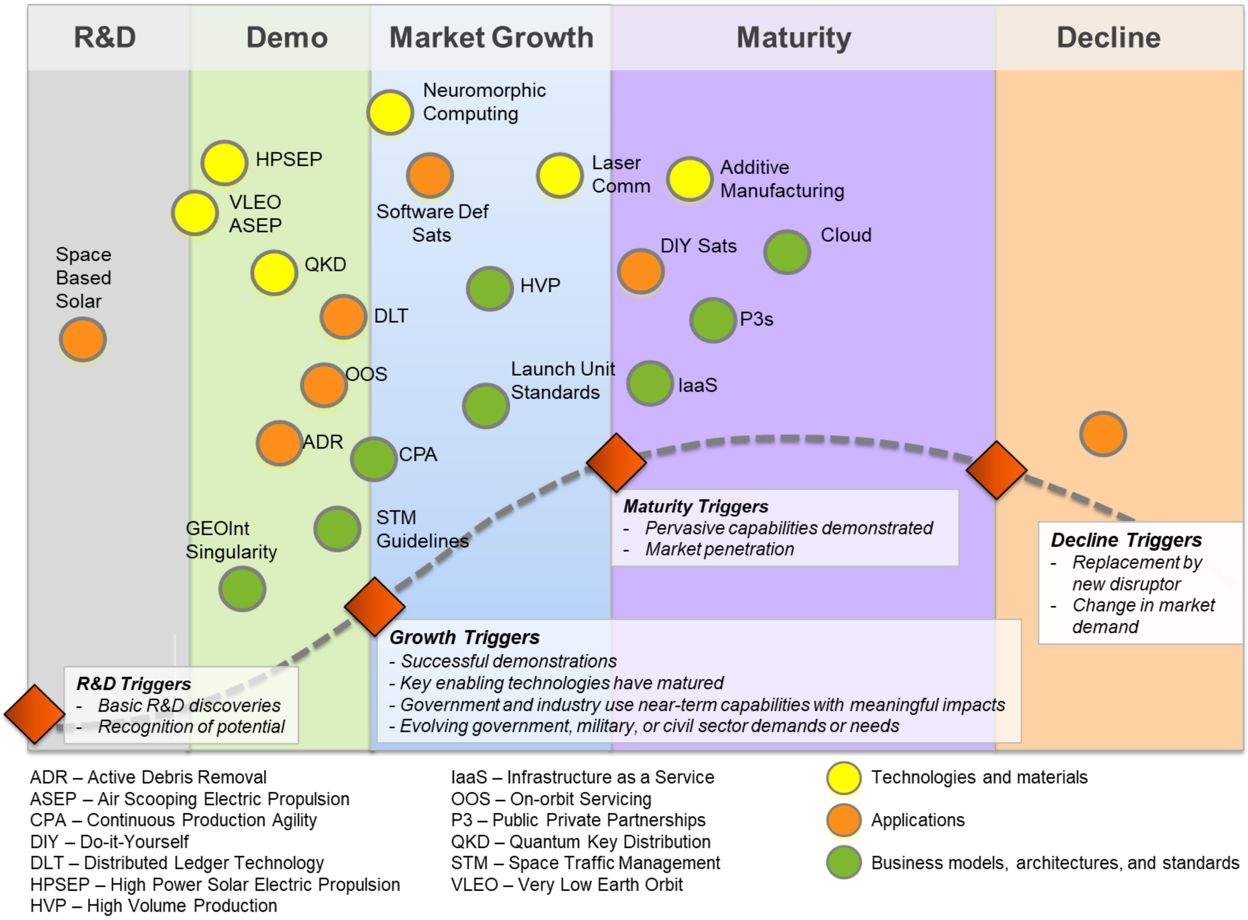

Figure 1: Lifecycle Maturity Curve. *Emerging space technologies, applications, business models, architectures, and standards span a range of lifecycles. Triggers are inflection points that can cause the technology, application, or business model to evolve based on innovation advances, increased market adoption or demand, regulatory or legal changes, and emerging social or cultural norms. Lifecycle phases include:*

- ***R&D.*** *Technology is new, most resources are spent on research and development.*
- ***Demo.*** *Some promising demonstrations emerge; there is a narrowing of potential designs, concepts and prototypes.*
- ***Market Growth.*** *After a successful demonstration, early adopters notice and rapid growth follows.*
- ***Mature Market.*** *Now widely adopted. Improvements and innovations are incremental, such as improved production processes and increased standards.*
- ***Declining Market.*** *This typically occurs after the market is disrupted by emerging innovation(s).*

Advancing to a Game Changer. The first step toward developing an optimal investment strategy is to identify key space elements that could support a range of space missions (e.g., national defense, weather, emergency response, environmental, etc.). These critical space elements can be mapped along two axes to categorize innovations as incremental, disruptive, breakthroughs, or game changers (see Figure 2):

- Market Impact (x-axis)
- Progress/Improvements (y-axis)

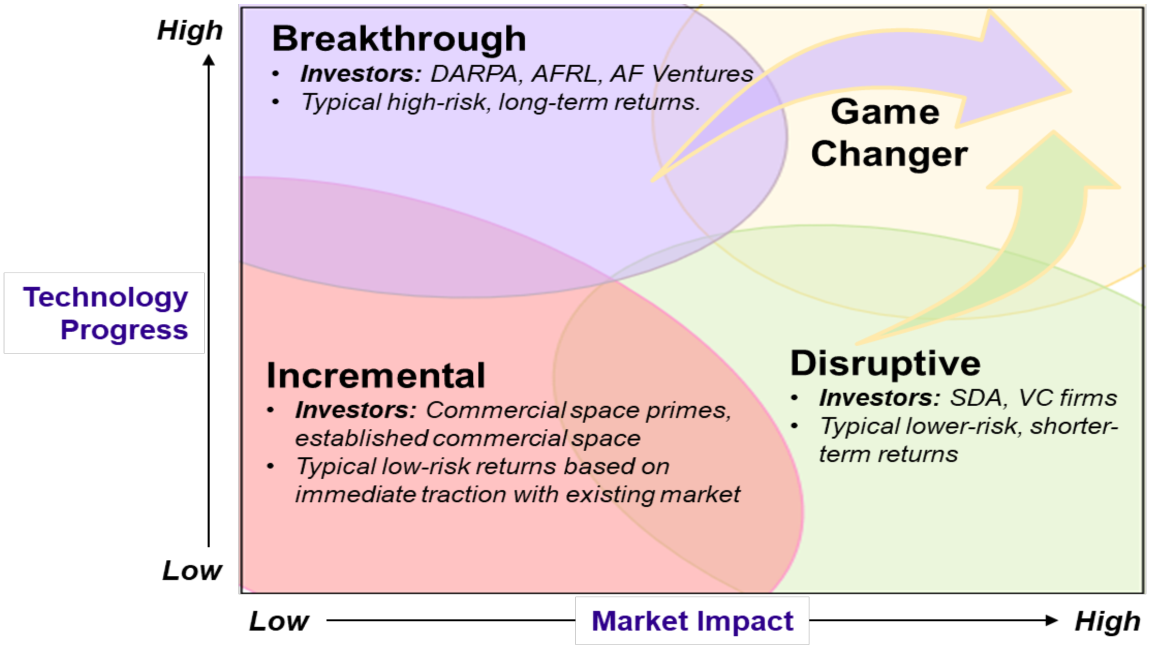

Figure 2: Advancing to a Game Changer. *For various technologies, applications, architectures, or business models:*

- ***Breakthrough.*** *Offers significant improvements and capabilities but may not change the market landscape.*
- ***Disruptive.*** *"[T]akes root initially in simple applications at the bottom of a market and then relentlessly moves up market, eventually displacing established competitors."*[11]
- ***Incremental.*** *Grows and improves gradually within an existing market or customer base.*
- ***Game Changer****. Offers both significant technological and/or service progress and can result in high market impact.*

Source: Adapted from "Four Zones of Innovation" by Jim Kalbach.[12]

Space innovation decisionmakers who manage innovation funding (e.g., seed funding, grants, research agendas, etc.) should review their entire investment portfolio across incremental, breakthrough, and disruptive space elements. *Over time, and depending on the context or use case, innovations are fluid and can shift between breakthrough, incremental, disruptive or game changing.*

Breakthrough to Game Changer. Breakthroughs can transform into game changers with increased market traction and adoption (Figure 2, purple swoosh arrow).[13] A former Defense Advanced Research Programs Agency (DARPA) program manager, Jeremy Palmer, noted that "aiming for *Incrementa*l technology improvements is not part of DARPA's charter. Instead, the agency must focus on funding *Breakthrough* technologies—not so much the disruptive" because the focus is to look for novel technologies in the longer-term investment horizon.[14]

Investors. Typical investors for breakthrough technologies include DARPA, Air Force Research Labs (AFRL), AF Ventures, and In-Q-Tel. These organizations are emphasizing dual-use approaches for national space capabilities with the intent to adopt commercially viable innovations to gain a technological edge against our adversaries while encouraging the national competitiveness of the U.S. industrial base.

Also, a considerable amount of internal research and development (IR&D) by federally funded research and development centers such as The Aerospace Corporation or the Jet Propulsion Laboratory (JPL) can introduce breakthroughs in new technical capabilities.

Goals. Typical outlook is 20 years; high-risk and long-term returns, seeking market traction and adoption of novel technologies and applications.

Examples. A breakthrough technology can increase market adoption to become a game changer through a series of successful technology demonstrations, trials, and flight tests. These tests and demos must be carefully vetted and tailored to specific market applications. Moreover, the results must be shared widely with interested market participants who might be willing to fund the next stage of development. A few breakthrough examples in the space sector include:

- **Direct satellite to cellular phone link.** Research, tests, and demonstrations are currently underway to explore how existing cell phones (with minimal changes) can connect directly to satellites. This could be a significant breakthrough for both satellite and terrestrial mobile connectivity. The following three companies are pursuing direct satellite to cell phone links to exploit the Narrowband Internet of Things (NB-IOT) applications:
    - Apple Inc. (Cupertino, California) – internally funded “secret project” to beam internet services directly to devices, according to Bloomberg.[15]
    - Lynk (Falls Church, Virginia) – $20 million total funding; Lynk reported a successful text message demonstration from the Cygnus cargo spacecraft in February 2020.
    - AST & Science (Midland, Texas) – $110 million Series B, $128 million total.
- **High power solar electric propulsion (HPSEP).** Combines advancements in solar array and electric propulsion technologies. HPSEP enables spacecraft injection into LEO and can be used for orbit raising. HPSEP reduces the launch capacity needs and allows multi-manifesting of spacecraft, increased spacecraft mass for more mission hardware, or the use of smaller launch vehicles for lower launch cost. The tradeoff is longer transfer time to the mission orbit. Once on-orbit, HPSEP also provides greater electrical power to support advanced spacecraft mission needs.[16]
- **Additive manufacturing.** 3D printing for single piece-parts is already mature. However, printing complex components and systems for on-demand manufacturing capability is still emerging and being funded by NASA small business innovative research (SBIR) funding.
- **Solar power satellites (SPS)**. Space-based solar power transmission systems have been studied for the past 50 years and could have dramatic implications for all sectors of space activity. Key technical challenges include whether the system can be scaled up sufficiently and whether transmission across the long distances of cislunar space and through Earth’s atmosphere is safe and practical. This technology is still relatively nascent, and funding has largely been fueled by U.S. and foreign-led space and research programs.[17]
- **The GeoInt singularity**. Data feeds from a plurality of sensors, combined with analytics and AI can create global intelligence for geospatial information. The convergence of existing technologies establishes new possibilities and opportunities that did not exist before.[18]
- **Very low Earth orbit (VLEO) airbreathing solar electric propulsion (ASEP) satellite.** Flying at VLEO utilizes ambient air as propellant. A constellation of VLEO satellites may offer significant advantages for connectivity and communication by reducing latency. An ASEP satellite can extend reach for excursions to higher elevation, such as

LEO, medium Earth orbit (MEO), and even geosynchronous Earth orbit (GEO), to provide tugging, deorbiting, and other servicing capabilities.

- **Neuromorphic computing (NC). NC** mimics the brain's efficiencies for neuro-biological architectures. NC could emerge as a game changer where mission success relies on fast and autonomous analysis of a vast array of incoming information from multiple sources.[19]

Disruptive to Game Changer. Some game changers emerge as disruptive technologies, applications, or architectures. A disruptive technology, in classic "innovator's dilemma" form, may start as a modest application or technology and over time, increase its functional capabilities or performance to become a game changer (see the green swoosh arrow in Figure 2). Derek Tournear, director of the Space Development Agency (SDA), has noted that the agency's Latin motto of *semper citius*, meaning always faster, is intended to emphasize that good-enough capabilities are preferable to delivering the perfect solution too late.[20] SDA intends to focus on disruptive technologies, where it can start with some immediate market traction (see the x-axis on the right in Figure 2) and realize performance or efficiency improvements with time. These disruptive products can dramatically lower the barriers to entry and encourage new players to enter the market.

Investors. Typical investors for disruptive technologies seek shorter-term rewards. For instance, SDA seeks to change the culture of national security space investments by leveraging smaller satellites and proliferated constellations. SDA is planning a "disruptive-to-game-changing" path by achieving persistent global coverage through proliferation of medium and wide field of view, hypersonic and ballistic tracking sensors. SDA intends to move quickly to provide a high capability return. Venture capitalists also look to disruptive technologies for long-term high returns. According to a report from Space Angels, during 2019, venture capitalists invested $5.8 billion in 178 commercial space startups worldwide, an increase of 38 percent from 2018.[21]

Goals. The outlook is five years or less, short-term returns; large return on investment; medium risk; seeking "good enough capabilities" that meet existing customer needs.

Examples. Strategically partnering with existing startup companies. Focus on AI, autonomy and robotics, cybersecurity, materials and manufacturing, next generation electronics and sensors, quantum technology, signals and communications, and new business models that can change the status quo. Examples include:

- **Do-it-yourself satellite applications for citizen space**. Citizen participation in space is now enabled by commercial picosatellite do-it-yourself (DIY) kits, and associated services and expertise to customize their missions and place payloads into orbit. With increased participation and new demographics of space actors, the possibility for technological advancement and unforeseen uses of picosatellites increases exponentially.[22]

- **Software-defined satellites (SDS)**. The need for flexible business cases combined with advances in digital technology are creating opportunities for satellite manufacturers to provide software-defined solutions that can respond to a dynamically changing business environment. Operators can upload applications on an as-needed basis to in-orbit SDS.

- **Distributed ledger technology (DLT) or blockchain.** As DLT gains traction in various space applications, many centralized third-party trust organizations focused on financial, legal, security, and logistical oversight functions will likely consider adapting their operating models to gain incremental efficiencies. DLT can also provide disruptive advantages by introducing new products and services and decentralizing traditional business models. DLT could be a critical enabling technology for sensor webs, the internet of things in space, deep space networking, and a token-based system for requesting and controlling satellite services on demand.[23]

- **Continuous production agility (CPA)**. An acquisition strategy and cultural shift from point solutions to agile solutions based on modular architecture principles. CPA's high-tempo, launch-on-schedule strategy will deliver an entire operational constellation over a short period (targeting five years for most constellations) and will replenish the constellation on a schedule-certain basis with frequent technology insertions to adapt and innovate at the speed of relevance.[24]

Incremental Improvements. The commercial satellite sector serves existing customers while concurrently introducing incremental improvements to expand products and revenues. According to Jeremy Palmer, "big aerospace [defense and national security] primes build mission and customer specific products, and their goal is to boost the margins." Palmer adds that venture capitalists and startups are "more willing to make the big bets."[25] Instead, following the classic *Innovator's Dilemma* archetype*,* a traditional space prime incumbent embraces a rational approach to introduce incremental innovation to existing products for its customers.

Investors. Typical investors include commercial space operators, primes, and payload providers.

Goals. The outlook is five years or less; low-risk returns.

Examples. Projects include proprietary technologies and solutions to grow customer base or expand mission, incremental improvements and demonstrations, customer outreach, and training. Incremental improvements could also result from investing in the development of best practices, guidelines, or standards (e.g., high-volume production best practices, launch unit standards, or space traffic management guidelines).

- **On orbit servicing (OOS).** On-orbit activities conducted by a space vehicle that performs up-close inspection of, or results in intentional and beneficial changes to, another resident space object.[26]

- **Quantum key distribution (QKD).** QKD could significantly advance the secure transmission of government and business information.[27] Seraphim Capital and other investors funded ArQit (London, United Kingdom), a satellite constellation that will use QKD for cyber-related applications using a blockchain ecosystem for tokens.

- **Laser Communication.** The European Data Relay System (EDRS) is one of the most sophisticated laser communication networks operating today. It was built to accelerate the flow of information from Earth-observation satellites. Laser communication is viewed as an incremental improvement because it could replace radio frequency communication links with faster data rates. After the initial laser development in the 1960s, there was a protracted period of research before the first bidirectional ground-to-orbit laser communication test in 1995.[28] Today R&D continues as the satellite communication industry seeks the advantages of laser communications, including low-error and high-throughput data communications.

- **Public private partnerships (P3s).** The public sector leverages commercial efficiencies and innovation while sharing risk with the private sector in exchange for profits linked to performance. Traditional infrastructure (e.g., roads, airports, and bridges) have leveraged P3s for decades. The space sector is now maturing its knowledge to optimize these risk and cost-sharing arrangements.[29]

- **Infrastructure as a service (IaaS).** A space enterprise rents or leases services such as ground station services, network operation centers, or storage in the cloud.

- **Cloud architectures and software as a service** These cloud computing architectures are characterized by fast growth and rapid maturation. The U.S. government's FedRAMP program, which verifies that cloud technologies meet rigorous security standards. The cloud hosts Amazon, Google, and Microsoft.

- **High-volume production (HVP).** New methods for mass production, adapted from other industries, could be applied to complex space systems. Design-for-production (DFP) principles can improve, simplify, and standardize to optimize the manufacturing process. Over time these methods could gradually transform the space sector particularly as large constellations of the future will need large-scale, efficient, and economical production.[30]

- **Launch unit standards.** A smallsat launch standard could facilitate the finding and utilization of excess space by standardizing the physical properties of the smallsat (size, volume, and vibrational modes) as well as the mechanical and electrical connections to the launch vehicle.[31]

- **Space traffic management guidelines and standards.** As space becomes more crowded, increased rules of the road for a variety of space activities is inevitable, including space object trackability and management, information sharing, orbit selection, post-mission disposal reliability, remote proximity operations, and dozens more technical and operational requirements.[32]

Conclusion: A Portfolio-Driven Strategy to Balance Risks and Rewards

Recognizing and understanding potential space game changers will inform stakeholders about possible large-impact advancements in the space sector and prepare national security, and civil and commercial space stakeholders for innovations that could significantly drive future policy or strategy decisions.

The private sector manages innovation investments in sophisticated ways using a variety of frameworks. These frameworks typically categorize innovations across a range of independent factors including:

- Lifecycle maturity.
- Type of transformation – e.g., breakthroughs, disruptive, incremental, or some other classification scheme.
- Risks – including market uncertainty and technical uncertainty.
- Rewards – benefits for bringing a successful innovation to market.
- Scale – size of investment.
- Time frame for development and implementation.

There is no one right or wrong innovation portfolio framework; instead, the mistake would be to *not* select one and *not* apply it consistently across the space enterprise. Without a portfolio management approach, the enterprise is often left to rely on simplistic decision gates for funding requests. A portfolio management approach allows a view where innovation investments can be compared to each other on a relative basis according to specific criteria such as return on investment, risk, long-term gains, etc. This yields a more strategic view and allows government managers the ability to see how various investment strategies could yield different results.

> ***There is no one right or wrong innovation portfolio framework; instead, the mistake would be to* not *select one and* not *apply it consistently across the space enterprise.***

The National Security Space enterprise should institutionalize a research and development portfolio management framework to advance commercial, civil, and national security capabilities in space to serve the interests of the nation. A portfolio-driven innovation strategy across the space enterprise could achieve completeness of vision surrounding current government programs and better resource management and risk management. Unfortunately, the public sector is decentralized and not typically organized to allow this type of enterprise approach. However, as national security space moves forward with a new organization, this is an appropriate time to adopt a portfolio-driven strategy to optimize investments and ensure appropriate coverage across disruptive technologies (short-term returns), breakthrough technologies (long-term returns), and incremental (lower-risk, incremental improvements).

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About the Author

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