New Space Innovation in Earth Orbit & Beyond

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Introduction

The global space industry is undergoing significant changes in the way it accesses and conducts business in orbit. Once the exclusive domain of national government space programs and large corporate contractors, access to space is now expanding to include many new players. Technological developments such as small satellite technology, reusable rockets, more efficient propulsion, and new business models like rocket rideshare and commercial Earth imaging are reducing the cost required to develop and launch space-based technology. As space becomes more affordable, it is becoming accessible not just to governments and large corporations, but startups, universities, and even individuals.

Often referred to as "New Space", this shift toward an increasingly diverse and privatized space environment presents many challenges and opportunities as new interests enter the market and traditional players adjust to meet the changing dynamic. New Space is already expanding how we access and use space, and could soon expand the global economy beyond Earth orbit and out into the solar system.

The Entrepreneurial Space Age

Before diving into how New Space is changing the industry and policy implications, it is first important to better understand the term itself. New Space is often used to describe small, entrepreneurial space startups which exist in opposition to the large, bureaucratic prime contractors of "Old Space". However, at this point some of the most visible paragons of New Space, including SpaceX and Blue Origin, have actually grown into organizations that rival or even surpass the space divisions of their more traditional counterparts. Furthermore, many well-established space companies have started to shift their own practices to better fit the New Space culture.

Perhaps the best definition of New Space I have heard is that it is more a "how" than a "who". This past January, I spoke with Jeff Feige, the chair of the Space Frontier Foundation which hosts the annual NewSpace (one word) conference. When asked for his thoughts on what defines New Space, Feige mentioned that the key for him is that "New Space is disruptive. If all you wanted to do is build tech and make money, you wouldn't be doing it." For Feige and the Space Frontier Foundation, the practice of changing how we access and utilize space is key to the culture, regardless of who is instigating that change. In general, New Space culture distinguishes itself as more risk tolerant, agile, and iterative than traditional development methods. Companies resistant to the New Space paradigm often respond to its lean and agile challenge by touting their record of dependability and mission assurance.

The culture of New Space borrows a great deal from the computer technology startups of Silicon Valley. Many of the billionaires who have established themselves as the most visible ambassadors of New Space made their fortune in software development. In the United States, clusters of new space development have risen up among the tech hubs in places like Los Angeles, Seattle, and Silicon Valley south of San Francisco. The rising space sector is hungry for talent with advanced programming skills and often seeks to recruit employees from Microsoft, Google, and other tech giants. Many New Space companies are also dependent on the venture capital funds which financed earlier tech booms of the dot com age. This reliance necessitates business models that are flexible enough to pivot to the next opportunity wherever and whenever it may arise. The Space Angels Network, a venture capital group focused on the aerospace industry, refers to this shift as the Entrepreneurial Space Age, which distinguishes itself from the Government Space Age that defined the first 50 years of space exploration *(Chart)*.

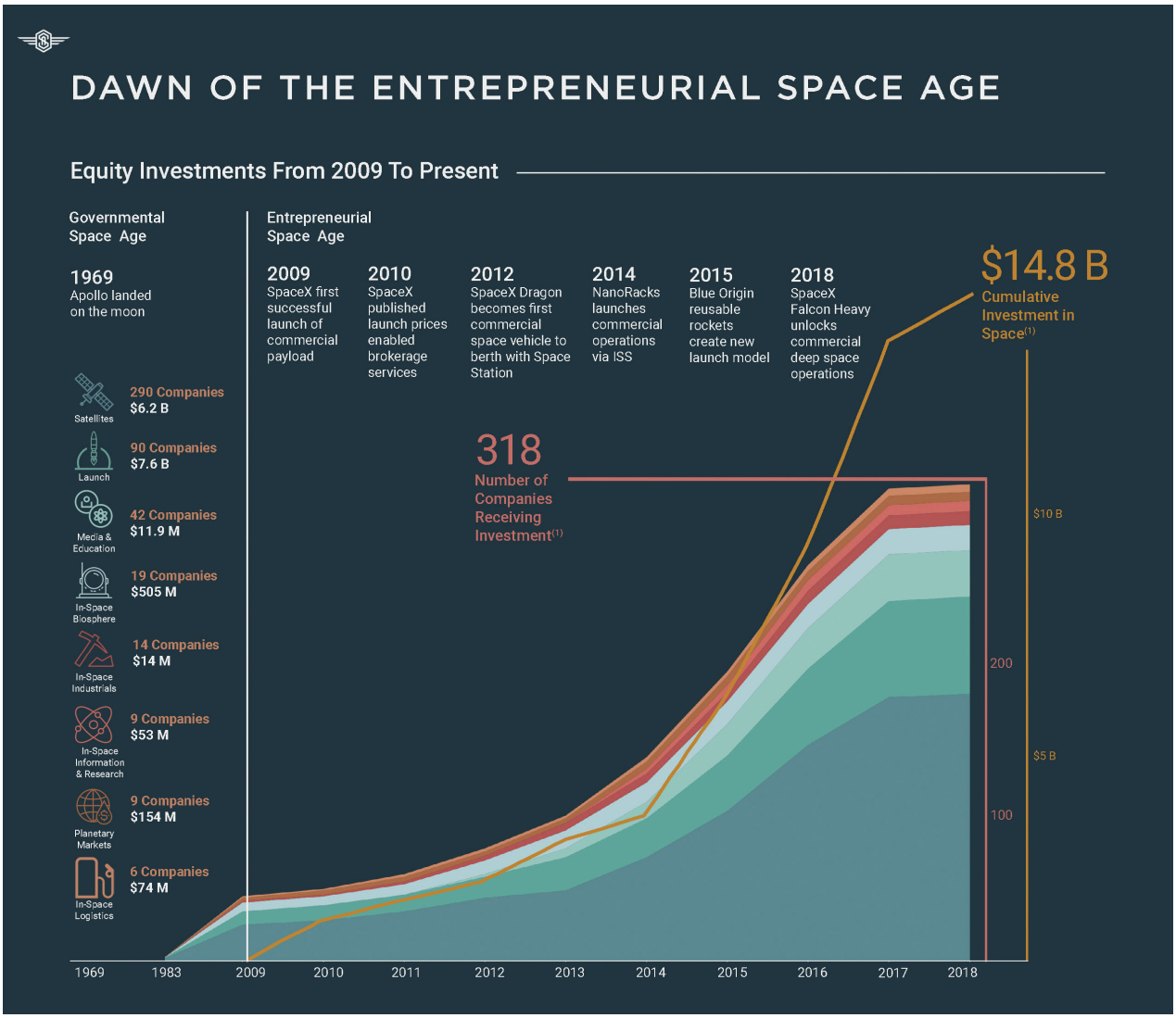
The Changing Role of Government

Though New Space is often defined by the rise of commercial and entrepreneurial endeavors, government still plays an important, if changing, role. Governments worldwide are simultaneously implementing policies to help incentivize New Space development, and scrambling to update existing policy frameworks in response to the rapid changes taking place. The United Nations' 1967 Outer Space Treaty, which served as the world's first global space policy, may have been an adequate framework during the first 50 years of Government-led space, but is proving inadequate and a potential stumbling block for governing entrepreneurial interests.

In the US, the National Aeronautics and Space Administration (NASA) has cast its gaze beyond Earth orbit to focus on planning for human missions to the Moon and eventually Mars. Meanwhile, the agency is helping to incentivize the development of commercial space vehicles by acting as the prime customer for servicing of the International Space Station (ISS), and the launching of robotic satellites and spacecraft.

In 2006, with the Space Shuttle's retirement planned for 2010,

CHART



Source: Space Angels Holdings, Inc.

NASA established the Commercial Orbital Transport Services (COTS) program, which offered milestone-based contracts for private companies to develop vehicles capable of delivering cargo to the ISS. In 2010, NASA solidified its commitment to commercial solutions for Earth orbit servicing when it established the Commercial Crew Development (CCDev) program to provide a crew vehicle to replace the Shuttle, and committed additional funds toward incentivizing the commercial development of space. The COTS and CCDev programs spurred the growth of companies like SpaceX, Sierra Nevada Corporation, and Orbital ATK. In 2012, SpaceX's Dragon spacecraft became the first privately-operated vehicle to dock with ISS.

Japan has been taking similar steps to encourage the development of its own commercial space industry. I reached out to Naoko Sugita, a manager for the Enterprise Expansion Division of the Japan Aerospace Exploration Agency (JAXA), to get a sense of how Japan is incentivizing New Space development. Sugita stated: "While Japan boasts high levels of space technologies, the Japanese space industry, especially the space equipment industry, faces major challenges such as competitiveness in overseas markets and sales almost entirely dependent on public sector demand." The 2008 Basic Space Law sought to begin addressing some of those challenges and has served as a guiding policy for this effort. This law includes Article 16, which encourages the "Promotion of Space Development and Use by Private Business Operators". The law was followed by a series of policies which align with what Sugita asserted is Prime Minister Shinzo Abe's view that "Space is now regarded as one of the pillars to revolutionize productivity in Japan." One of the most recent of these policies, the Space Industry Vision 2030 published in May 2017, seeks to double Japan's current ¥1.2 trillion investment in space by the early 2030s.

European countries have also enacted policies to encourage New Space development. Luxembourg is positioning itself as an incubator for space resource extraction. In 2016, the country established a $227 million fund to encourage asteroid mining companies to

establish their businesses there. Meanwhile, the United Kingdom has also been heavily investing in commercial development and working to identify a suitable location for a spaceport. In March of 2018, the UK's plans for a spaceport took a step forward with the passage of the Space Industry Act, which authorizes commercial launch activities from UK soil. The BBC reports that the British space sector has grown five times as fast as the country's economy as a whole with space activity worth about £14 billion annually.

Growth of the Industry

According to the Federal Aviation Administration's Office of Commercial Space Transportation, the global space industry is estimated to be worth $345 billion worldwide with less than one quarter of that value now coming from government space budgets. Private venture investment represents an expanding part of New Space funding and provides an indicator of the sector's vigorous growth.

The Space Angels Network indicates that as of the first quarter of 2018, of more than 1,300 space companies tracked, 318 are receiving venture investment. Rocket manufacturers and satellite companies receive the most investment, with the largest monetary amount going toward new rockets, while satellites receive more numerous smaller investments. The Space Angels data shows just how dramatically the New Space industry has expanded over the past decade. In 2009, approximately 50 space companies worldwide were receiving venture investment. That number has grown at an exponential rate to the 318 companies identified this year.

Space Tourism

A common public perception of New Space is that it is predominantly about billionaires building rockets to offer joyrides to millionaires. Indeed, many companies include plans to fly paying customers to space, but this is only one part of a rapidly diversifying space ecosystem.

The idea of space tourism only became a reality in the early years of the 21st century. In 2001, American businessman Dennis Tito kicked off what became a series of visits to the ISS by private individuals called "spaceflight participants". A company called Space Adventures booked the flights aboard Russian Soyuz spacecraft at a cost of about $20 million apiece.

In the midst of Space Adventures' flights to the ISS, another company called Scaled Composites won the Ansari XPRIZE in 2004. Their vehicle, SpaceShipOne, successfully made two flights to space in two weeks carrying mass models for two passengers in addition to the pilot. The success prompted Virgin's Richard Branson to launch his space company Virgin Galactic, which is developing the larger SpaceShipTwo based on the XPRIZE-winning design.

Space tourism capitalizes on the ubiquitous human desire to visit and explore space — a feat which has to date been achieved by just over 550 individuals. In the next few years, companies like Virgin Galactic and Blue Origin in the US, and PD Aerospace in Japan plan to begin flying passengers on suborbital flights to experience a few moments of weightlessness and the spectacular view from space. These plans represent the equivalent of NASA's Mercury program for the general public. Though still costly, the ticket prices for a suborbital flight are two orders of magnitude lower than Tito's flight to the ISS.

If successful, the advent of widespread space tourism has the potential to rapidly expand the number of people who get to experience space firsthand. However, as space travel expands from the exclusive experience of professional astronauts to include astronaut passengers, serious questions arise about appropriate expectations of safety in a still very challenging and dangerous endeavor. Currently, space tourism companies operate under a regulatory framework similar to adventure sports like bungee jumping or mountain climbing. Spaceflight participants give informed consent, and acknowledge the danger in advance. As companies begin carrying paying customers, the industry will need to walk a fine line to ensure customer safety without stifling emerging business.

Photo: Blue Origin

Launch of Blue Origin's reusable New Shepard rocket

Lowering the Cost of Space

Several key technologies are helping to drastically reduce the cost of reaching orbit. Space has traditionally been an incredibly expensive endeavor, which is a major reason it has been limited to national space programs. Reducing that cost has been key to making space affordable and potentially profitable for the entrepreneurial interests which define the New Space movement.

Reusable launch vehicles represent one of the most significant of these technologies. Traditional launch methods have long relied on disposable rockets, which were used once and left to crash back into the ocean or burn up in Earth's atmosphere. The classic analogy within the space community is that the expense of this practice is akin to the ticket prices that would result if airlines threw away their aircraft after every flight. Launching a payload to Earth orbit under this paradigm costs upwards of $10,000 per kilogram, depending on the vehicle. NASA's partially reusable Space Shuttle was intended to

help reduce this cost, but the low flight rate and heavy maintenance requirements kept the cost per kilogram little changed.

Then, in 2015 two New Space companies successfully demonstrated their own reusable launch vehicles. In November, Blue Origin, the rocket company created by Amazon.com founder Jeff Bezos, successfully launched and landed its New Shepard rocket on a suborbital test flight. One month later, Elon Musk's SpaceX raised the bar by successfully landing its orbital class Falcon 9 back at Cape Canaveral, Florida, near its launch site. SpaceX has since matured its ability to land its rockets on land or at sea aboard the company's special "drone ship" recovery barge.

SpaceX's efforts appear to be finally driving down the cost of launch. The Falcon 9 can deliver payloads to Earth orbit for around $3,000 per kg. This has encouraged other, more traditional space players to pursue their own reusable technologies to compete. In 2015, United Launch Alliance, a space partnership between Boeing and Lockheed Martin, announced the development of its partially reusable rocket, Vulcan. Arianespace and the European Space Agency have since followed suit with proposals for a reusable engine called Prometheus, which could power the Ariane 6 rocket, and a separate reusable rocket development program called Callisto. The Russian, Indian, and Chinese space agencies have also announced plans to pursue reusable rocket technology.

Another technology that is driving down cost is rocket rideshare. A Seattle-based company called Spaceflight Industries brokers rides for small satellites aboard rockets with leftover payload capacity. Spaceflight has launched payloads aboard SpaceX's Falcon 9, India's PSLV, Russia's Soyuz, and more. For those interested in launching a smaller payload, rocket rideshare offers a more cost-effective option than purchasing an entire orbital class rocket.

Yet another option for small payloads is the development of smaller orbital launch vehicles. Rocket Lab, founded by New Zealander Peter Beck, is developing its Electron rocket to serve as a dedicated launcher for small satellite payloads. Japan is also working on a dedicated small launch platform. In February of 2018, JAXA launched a modified suborbital rocket called the SS-520-5 into orbit with a small Earth observation satellite. The SS-520-5 became the smallest rocket in history to deliver a payload to orbit.

The Small Satellite Revolution

Another key factor in the emerging New Space era is the rise of small satellite technology, in particular, the CubeSat. Based on a standard 10 centimeter cube called a "Unit" or "U", CubeSats typically come in 1U, 2U, 3U or 6U configurations. Miniaturized computer technology has helped make CubeSats a viable platform for performing real work in orbit. Some satellites, including NASA's PhoneSat experiments, have even used commercial smartphones to provide onboard computing power. CubeSats are typically housed in a pre-packaged module for easy deployment using systems like JAXA's Small Satellite Orbital Deployer aboard the ISS.

CubeSat technology has drastically reduced the cost of developing satellites. Basic kits and components can even be purchased online

Photo: NASA

A pair of CubeSats deploy from the Small Satellite Orbital Deployer held by JAXA's Kibo laboratory robotic arm on the ISS.

with starter kits costing around $6,000-$8,000. This makes the CubeSat an ideal platform for universities developing research satellites and for space startups to conduct orbital tests of their technologies. Asteroid mining company Planetary Resources, for example, has launched a series of test vehicles built around the CubeSat standard to prototype the technologies they plan to eventually use to prospect for and mine resources from near Earth asteroids.

Small satellites have also made it feasible to develop large constellations of satellites in low Earth orbit. New Space companies like OneWeb, Iridium, and SpaceX are developing massive constellations of communications satellites to deliver space-based Internet and mobile access all over the world. When complete, each will number hundreds or even thousands of individual satellites. Meanwhile, other startups like BlackSky, Planet, and EarthNow are developing similar constellations to provide real-time imaging of the entire globe.

The commercial small satellite revolution has the potential to dramatically alter global access to data and Earth imagery. Real-time imaging of the planet could greatly improve maritime domain awareness, allowing countries to more effectively monitor problems like piracy or illegal fishing. Commercial satellite imagery is also of potential interest to the agricultural industry for monitoring crop health and cycles of drought.

However, commercially available imagery can also potentially be used to conduct industrial or corporate espionage. Counting cars in a competitor's parking lot or inventory in a supply yard could provide insight into a competitor's business. It could also be used as a workaround for governments without their own space program to conduct reconnaissance. Concerns about national security and economic bad actors helped prompt the adoption of policies like Japan's 2016 Remote Sensing Records Act, which establishes a licensing system to ensure that such imagery is only captured and used by authorized operators, and that access can be limited by the government for national security purposes.

Large constellations of satellites also raise concerns about orbital

debris. Spacecraft in low Earth orbit travel at approximately 17,500 miles per hour. At that speed, debris the size of paint flecks impacts with the force of a bullet. Satellite collisions have the potential to generate hundreds or thousands of pieces of debris in uncontrolled orbits. Concerns about an increasingly cluttered space environment have prompted companies like Singapore-based Astroscale to begin developing solutions for removing debris from orbit.

Active debris removal technology raises its own questions. First and foremost, who is responsible for preventing the creation of space junk? Who has permission to remove it should the technology become available? Complicating the issue, the same technology required to remove space junk could also potentially be applied to deorbit an enemy nation's active satellite. Policymakers are working to expand guidelines for debris mitigation to accommodate active debris removal.

Toward Space for Space

Successful business models for New Space currently depend on serving an Earth-bound customer base. This reality has changed little since the development of the first telecommunications satellites in the 1960s. However, one of the long-term goals of New Space is to expand Earth's economy into the solar system.

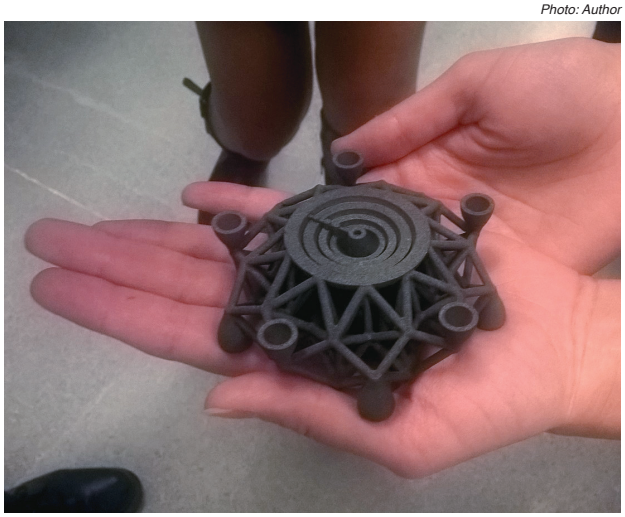
Currently, every space mission must haul all its necessary equipment and supplies from Earth. This is why lowering the cost of launch is such an important first step to expanding the economic viability of space. Figuring out ways to reduce mission dependence on Earth, both as a source of supply and, eventually, demand represents a crucial next step for expanding the space industry. NASA and other government space agencies are also interested in developing Earth-independent capabilities, as they will be necessary when traveling farther into the solar system where resupply and even efficient communication to and from Earth become difficult, if not impossible.

Earth-independent use of space requires the development of many new capabilities, perhaps the most significant of which are space-based resource extraction, known as in situ resource utilization (ISRU), and in-space manufacturing and repair. JAXA demonstrated one of the key first steps to ISRU with its Hayabusa spacecraft, which became the first mission to rendezvous with and return a sample from an asteroid in 2010. Today, asteroid mining companies like Planetary Resources and Deep Space Industries are working on expanding this capability to include in-space resource prospecting, extraction, and processing technologies. Water, which is known to be locked away as ice and hydrated minerals on the Moon, asteroids, and other planetary bodies, can be used for everything from providing food, water and oxygen for astronauts, to radiation shielding, and rocket fuel.

While these companies work on ways to collect resources, others are developing technologies to manufacture tools and spacecraft parts from raw materials found in space. Made In Space provided the first permanent 3D printer, called the Additive Manufacturing Facility (AMF) aboard the ISS. Astronauts have used the AMF to print hand tools for test and station maintenance tasks. Made In Space and other companies like Tethers Unlimited are also working on ways to construct much larger structures in orbit. Both companies envision fabricators that act like 3D printers turned inside out to print large structures and spacecraft components in orbit. Planetary Resources has even demonstrated the capability to potentially bridge the extraction and manufacture technologies by 3D printing a test object out of meteoritic material similar to that which could be found on asteroids.

Shifting Earth's economy into the solar system is reaching a potentially delicate inflection point. These technologies currently represent long-term R&D projects. Converting these demonstrations into a successful business model will require a customer base in space. Establishing that customer base while still Earth dependent, however, will be challenging. If successful, these New Space projects could at last shift the business of space from exclusively space-for-Earth to include space-for-space, thus establishing a true solar system economy.

Photo: Author



Planetary Resources 3D printed this test structure from meteoritic material.

Conclusion

The emergence of New Space over the past decade is rapidly expanding access to and diversifying how we think about and use space. As the industry grows, new opportunities and challenges arise, including issues of policy and governance. Industry must work together with government to address these challenges without stifling opportunities. As industry gains increasing access to Earth orbit and new, innovative business models, it frees up government space agencies like NASA and JAXA to push the boundaries of Earth's influence further into the solar system, hopefully to be followed soon by the establishment of a true solar system economy.

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