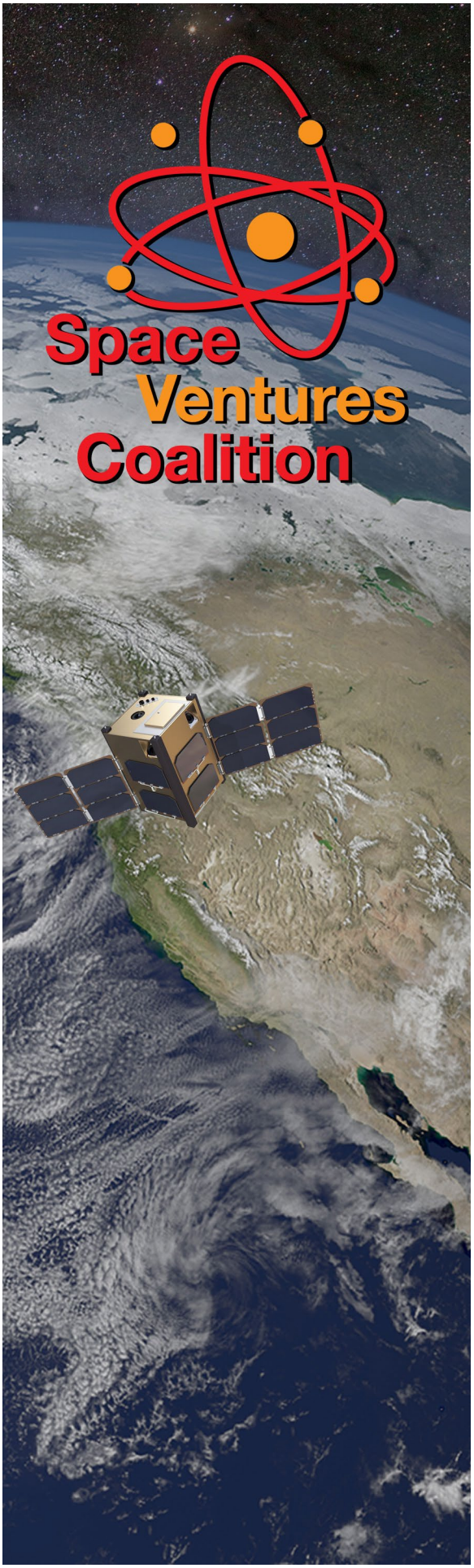

Space Technology Surging as Leading SoCal Tech Sector

Summary

Southern California is experiencing an aerospace resurgence, especially in space technology. In part, this resurgence draws on larger national and international trends that make space more accessible (e.g., the shrinking size, weight, and cost of key components, and reduction in launch costs). In addition, aerospace in Southern California is uniquely fueled by favorable geographic conditions, a large base of local universities, and a large and growing tech sector supporting advertising, entertainment, and information technology (IT) industries. The biggest driver of this renaissance is arguably the strong and experienced space technology workforce that continues to attract talent. This paper provides a snapshot of the space technology ecosystem in Southern California as well as adjacent technology trends and sectors. Both will be powerful engines of growth for government and commercial markets to harness in the decades to come.

About the Space Ventures Coalition

The Space Ventures Coalition (SVC) is the Space Track of the Alliance for Southern California Innovation. The SVC consists of a partnership between The Aerospace Corporation and the Jet Propulsion Lab (JPL), as well as numerous space-oriented organizations including USC, Starburst Accelerator, MD5, Northrop Grumman, and the Los Angeles Economic Development Corporation (LAEDC) Aerospace Cluster, among others. We work with universities and start-ups to expose them to commercial and government space programs. We are interested in software, hardware, materials, and new manufacturing techniques with potential application to the space industry. We help new technologies connect with partners, mentors, customers, and investors. For more information, please contact Andre Doumitt (andre.doumitt@aero.org) or Richard French (Richard.T.French@jpl.nasa.gov).

Disclaimer: Mention of a specific company in this prospectus should not be considered as an endorsement by the Space Ventures Coalition, its members, or the Alliance for Southern California Innovation.

The Home of Aerospace Heritage

Southern California has been home to aviation and aerospace R&D and manufacturing since the early 1900s, spawning a generations-deep, well-educated aerospace workforce that continues to support the industry to this day. Given its dry weather and flat land, Southern California hosted the International Aviation Meet in 1910 and subsequently saw a dramatic creation and expansion of new aviation companies in the 1920s and 1930s including Lockheed Corporation, Douglas Aircraft, Northrop Corporation, Hughes Aircraft, and North American Aviation. These companies later found success as suppliers of aircraft and missiles to the Department of Defense during World War II and the Cold War. When NASA initiated its series of space exploration missions in the late 1950s, aerospace companies in Southern California became primary partners. The Explorer 1 probe, Apollo command module, the Surveyor lunar landers, the Viking Mars landers, and all five space shuttles were built in SoCal. As a result, the region quickly became the country's economic hub for rocket and spacecraft design and construction.

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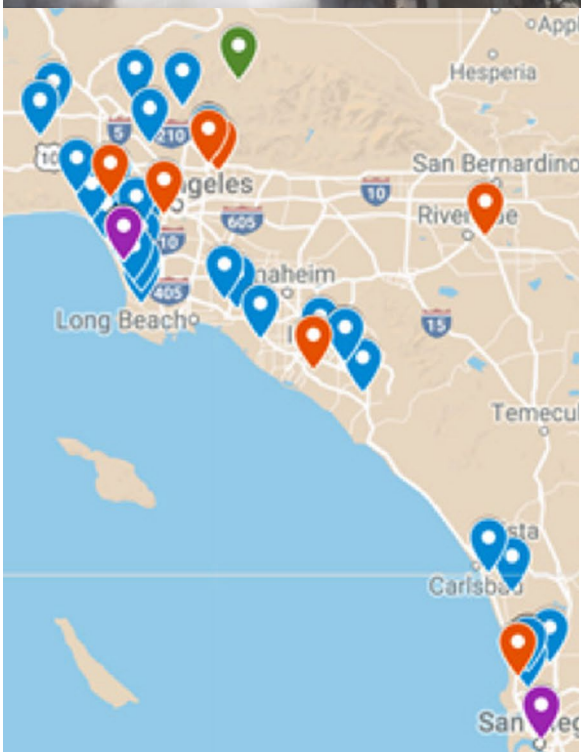
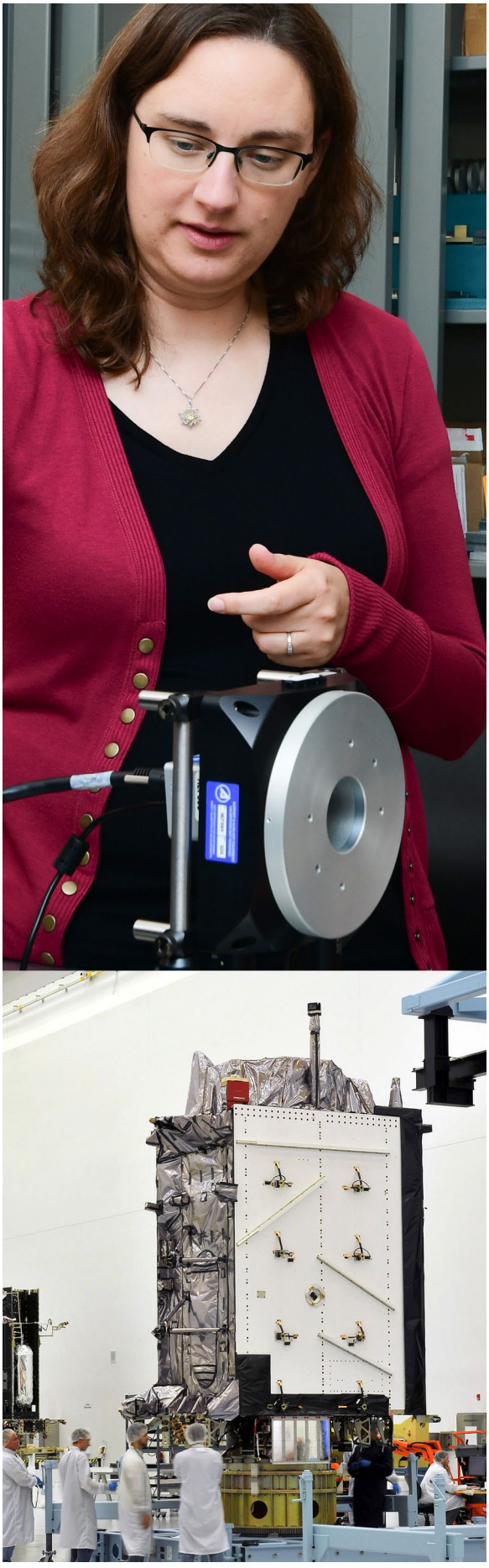
University and Government Research Institutions

Local universities and research institutions are a key part of the landscape in Southern California. The California Institute of Technology (Caltech), University of Southern California (USC), and four nearby University of California (UC) campuses have cadres of bright students looking to learn and explore.

In catering to these students' thirst for knowledge, California Polytechnic Institute, San Luis Obispo (CalPoly-SLO) and other universities collaborated to develop the CubeSat standard in 1999. A year later, in partnership with The Aerospace Corporation (a national nonprofit corporation that operates a federally funded research and development center based in SoCal), CalPoly-SLO flew the first CubeSat. This standard allowed undergraduate and graduate students to build, test, and fly their own inexpensive spacecraft on short timelines. Other university programs have continued the tradition, encouraging students to launch their own rockets to space; prominent examples include Rocket Propulsion



Selected universities and FFRDCs (red), government centers (green), incubators and VCs (purple), and companies (blue) in Southern California that influence and develop space technologies. https://drive.google.com/open?id=113Tb8W5gfN-AHAOaY7k9wIbe7sON3jhL&usp=sharing.



Diverse workforce, diverse technology.

Lab at USC and the Triton Rocket Club at UC San Diego. These universities produce well-trained scientists and engineers ready to enter the workforce upon graduation.

On the government side, the U.S. Air Force Bases at Edwards, Vandenberg, and Los Angeles are key contributors to the space community along with NASA Armstrong and Naval Air Weapons System China Lake, all of which utilize both civil servants and military personnel. NASA Armstrong has a long history of pushing the boundaries of the nation's aeronautics capabilities; the agency's Jet Propulsion Lab planted its legendary roots in the Arroyo Seco where young graduates launched rockets in the 1930s. Other federally funded research and development centers, such as The Aerospace Corporation and Rand Corporation, play a key role in maintaining U.S. space superiority and providing important space policy analysis. Altogether, numerous government-sponsored and commercial employment opportunities withinthe space enterprise are available to the Southern California aerospace workforce.

Closer inspection, however, reveals considerable cross-pollination between the entertainment and space sectors.

Hollywood Plays a Role

Southern California is also home to the entertainment industry, which at first glance might appear to be an unrelated sector. Closer inspection, however, reveals considerable cross-pollination between the two industries. In the early days of film, movies often depicted aircraft built in the region. Later, computer graphics from groups such as JPL's Digital Image Animation Lab (DIAL) crossed into the entertainment industry—along with elements of the workforce—and sometimes back again to aerospace. Some examples from DIAL alone include erasing the power lines from the Egyptian skyline in the 1981 movie *Raiders of the Lost Ark*, repairing old *Star Trek* television prints, and producing detailed sequences for *Star Trek II: The Wrath of Khan*. JPL and other companies also made indirect contributions to Hollywood visual effects by ejecting basic research into the public domain, where other specialists could continue development.

Hollywood continues to make space more accessible to the public with fantastic depictions of the space environment, ranging from orbiting the Earth in a space shuttle to visualizing orbital debris in the film *Gravity* and the highly futuristic experiences in the new *Star Trek* films, *Interstellar*, and *The Martian*. Foundational technologies from the entertainment industry include data processing, data visualization, cloud computing, data analytics, and artificial intelligence. These are all applicable to the space industry, too.

The Incumbents and a Market Disruption

By far, the largest space customer in Southern California (and the country) is the Department of Defense, which has a historical group of suppliers. As such, established space companies (e.g., Lockheed Martin and Boeing) have focused on their government customer's priorities: reliability and predictability of highly capable space systems fulfilling critical, long-duration missions.

Today, changes in the marketplace and pressure from the private-sector "New Space" players (e.g., SpaceX and Virgin Orbit) are disrupting what had been a settled industry for the past several decades. The emerging model for the future space industry focuses on smaller, cheaper satellites, lower launch costs, and faster technology refresh to support growing government and commercial customer needs. Funded by venture capitalists and billionaires such as Elon Musk, Jeff Bezos, and Richard Branson, New Space companies have excelled in applying the entrepreneurial tactics of Silicon Valley to the space arena, including accelerated production and a "constant beta" mindset. In all, New Space players embrace space as a service, rather than a collection of goods procured.

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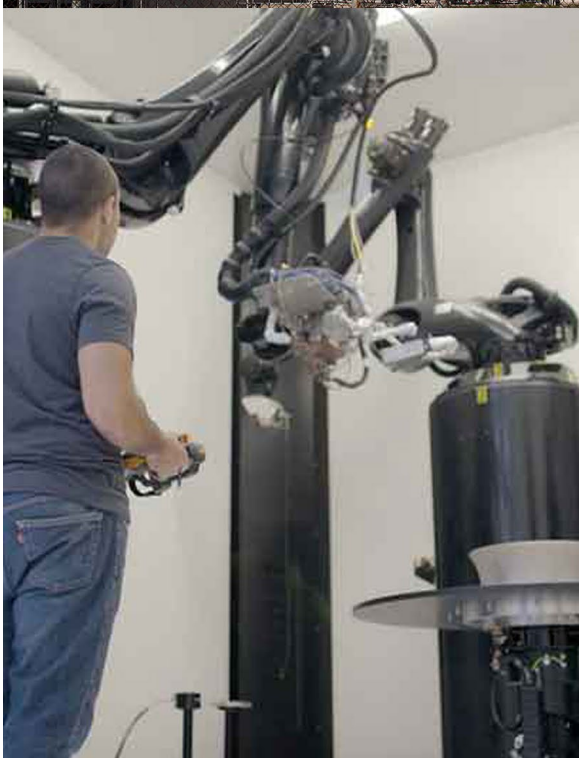
A Change in the Money

Non-government R&D dollars flowing into space technology have upended the industry. According to reports by Morgan Stanley, Amazon's Jeff Bezos is believed to have invested more than $1 billion in Blue Origin since 2000 and plans to quicken that pace with a $1 billion-per-year investment going forward. Google and Fidelity poured $1 billion into SpaceX in 2015.

On the satellite side of the market, Euroconsult estimates that some 7,000 small satellites worth approximately $38 billion are due to be launched over the next decade, a six-fold increase from the 1,200 units launched over the past decade. About 50 constellations, two of which are commercial "mega constellations," account for more than 80% of the total small satellite count. This suggests that, by 2022, an average of 580 small satellites will be launched every year—a number that will jump to 850 each year through 2027. This compares with an annual average of 190 satellites launched over the past five years. Much of this small satellite boom and the associated forthcoming launch vehicles are funded by venture capital; $2.5 billion has been invested in start-up space companies in 2017 alone. For example, SoftBank and others invested $1.2 billion in satellite constellation start-up OneWeb in 2016. A SpaceAngels report

ULA's Atlas V launching NASA's SDO (Solar Dynamics Observatory).



Space X Falcon 9 (Courtesy: SpaceX)
Relativity Space robotic 3D printer (Courtesy: Relativity Space)

claims that nearly $1 billion was invested in commercial space in the first quarter of 2018. Overall, Bank of America Merrill Lynch analysts estimate the space market is worth $339 billion today and predict it will grow to $2.7 trillion by 2045.

Non-government R&D dollars flowing into space technology have upended the industry. A staggering $2.5 billion was invested in start-up space companies in 2017 alone.

Snapshot of New Space in SoCal

SpaceX was founded in 2002, establishing its headquarters in Hawthorne, California. It currently has more than 5,000 employees. As part of a NASA public-private partnership, SpaceX was awarded a commercial resupply contract which has since been renewed multiple times. In 2012, SpaceX became the first commercial company to deliver supplies to the International Space Station (ISS), ushering in the era of commercial launch providers and low-cost access to space. In 2017 alone, SpaceX had 18 successful launches. As of April 2018, SpaceX has an estimated valuation of $25 billion, making it one of the world's most valuable venture capital-backed start-ups.

Tyvak Nanosatellite Systems was founded in 2011. It is headquartered in Irvine, California, and provides nanosatellite and space vehicle products and services. Tyvak focuses on offering advanced capabilities for both government and commercial customers.

Relativity Space was founded in 2015 and constructs 3D-printed rocket engines with considerable robotic automation. In March 2018, Relativity entered a Series B round of funding and was awarded use of NASA Stennis Space Center as a test site for the next 20 years. The company is based in Los Angeles, California.

ExoAnalytic Solutions is a commercial space situational awareness company that uses a network of ground-based telescopes to track customers' satellites in orbit. Based in El Segundo, California, ExoAnalytics was launched in 2010 with Small Business Innovation Research (SBIR) Phase I funding from the Department of Defense.

Umbra Lab was founded in Santa Barbara, California in 2015 and is developing a constellation of microsatellites that will provide its customers with synthetic aperture radar (SAR) imagery at very high resolution.

Millennium Space Systems was founded in El Segundo, California in 2001 and delivers satellite components and buses to a variety of customers. These deliveries occur on rapid timescales, anywhere from one to four years from start to launch. In August 2018, Boeing announced it had acquired Millennium and will fold it into its Phantom Works group.

Rocket Lab is a privately held company headquartered in Huntington Beach, California, with launch operations in New Zealand. The company operates out of its new 150,000-square-foot base in Orange County, which primarily focuses on research and development and engine and electronics manufacturing. Rocket Lab's Electron is a rocket that stands 55 feet tall—about the size of a five-story building. Its sole purpose is to be a dedicated ride for small satellites, as the rocket can only carry payloads weighing 330-500 pounds into low Earth orbit.

Phase Four Propulsion is a privately held company headquartered in El Segundo, California. The company, incubated at Northrop Grumman, is building electric radio frequency thrusters for small satellite propulsion, with the distinguishing characteristics that its thrusters are designed for manufacturability and scale to meet the needs of several classes of satellites. Phase Four recently announced the sale of its thrusters to NASA.

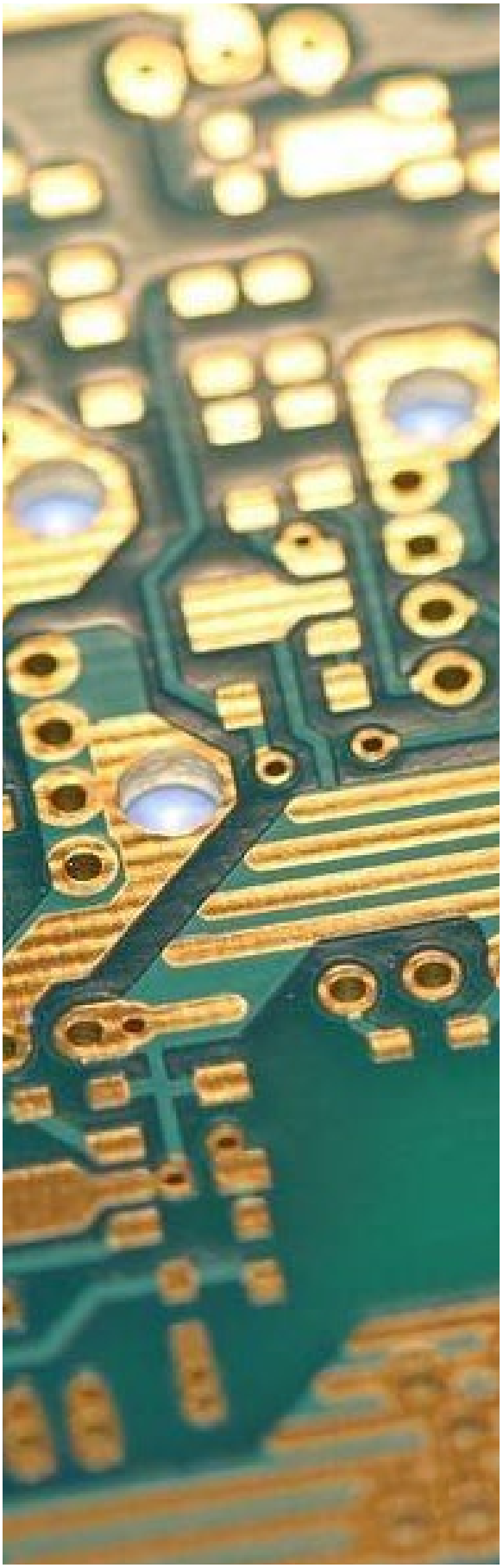
Virgin Galactic, LLC, was founded in 2004. Based in Mojave, California, Virgin Galactic licensed the technology utilized to win the Ansari X-Prize and performed a commercial space flight twice in two weeks with a commercially manufactured vehicle. The company is currently performing flight tests in Mojave, and plans to use an advanced version of the prize-winning spaceflight system for space tourism.

Virgin Orbit is an additional company held within the Virgin Group and based in Southern California. Virgin Orbit hosts 400 employees at its Long Beach, California headquarters, where it is developing launch services for small satellites.

Technologies Adjacent to Space

Considered from the perspective of the meticulous and creative engineering that is required, space is not extremely different from other industries. In the end, assets communicate information so that humans can perform a task more effectively. For example, in the healthcare industry, instruments collect and communicate information so that humans can make better decisions earlier, and positively impact a patient's health. As in healthcare, finance, or entertainment, the space industry can benefit from a number of foundational capabilities that we call "adjacent space" technologies. Fields that have high relevance to the aerospace industry, but are not directly related to aerospace itself, include artificial intelligence, machine learning, nanotechnology, data

Virgin Galactic's VSS Unity climbs to the edge of space



Companies like Lucid Circuit have many applications for their products, including space tech.

analytics, automation, biotechnology and bioinformatics, robotics, cyber security, advanced manufacturing, cloud computing, and autonomous systems. A key opportunity for space industry growth and innovation is the integration of robotic, cyber, and information technology into aerospace products. Southern California is replete with such companies and we highlight a few here.

Snapshot of Adjacent Space in SoCal

DreamWorks is one of the many animation companies with offices in Southern California. Founded in Glendale, California in 1994, it boasted more than 2,500 employees worldwide and made over $14 billion on its feature films worldwide by 2014. In its R&D department, artists and engineers build realistic visual effects for animated movies. This expertise and application of engineering skills could apply to fluid dynamical modelling of aerospace systems.

Allele Biotechnology in San Diego, California was formed in 1999 and specializes in developing cell therapy techniques using stem cell generation and differentiation and drug discovery using engineered nanoantibodies. A clear connection of this technology to the aerospace industry would be to run cell line experiments on the ISS in order to learn how astronaut health can be affected in a low-gravity environment.

Lucid Circuit in Santa Monica, California is developing radiation-tolerant and energy-efficient processors for reliable high-performance cognitive applications in edge devices (e.g., sensors). Currently, edge devices process data in the cloud. Lucid is working to develop devices that process more of the data on-board rather than sending it to the cloud. Additional applications that involve on-board processing include 3D virtual reality (VR) headsets and mobile communications, as well as drones, satellites, and other autonomous vehicles.

Zoic Labs has 400 employees and offices in Los Angeles, California, as well as in Vancouver, Canada and New York City, New York. Zoic Labs is a visualization company that develops various software and production tools for its sister company Zoic Studios, known for its visual effects in such films as Avengers, Age of Ultron, and District 9. Zoic also consults for private companies and for the Department of Defense.

Sally Ride Science is a STEM (Science, Technology, Engineering, and Math) outreach non-profit headquartered at UC San Diego, founded by Sally Ride in 2011. This non-profit serves the community by encouraging students to enter STEM fields and by promoting STEM literacy.

Technicolor has long-time roots in Southern California and continues to contribute to the entertainment industry. Based in Los Angeles, California, the company's research and innovation branch includes cutting-edge imaging science and artificial intelligence labs.

Applied Minds was established in Burbank, California in 2000 where it maintains a staff with diverse backgrounds, hosting both an art department and prototyping facilities. Applied Minds performed major renovations to the Renwick Gallery in Washington, D.C., and has provided consulting services to many aerospace and technology firms.

Riot Games is an online gaming development company founded in 2006. The company is most noted for developing League of Legends, known as the most-played PC game in the world and a cornerstone of the eSports genre of gaming. The company now hosts 23 offices worldwide, but maintains its headquarters in Los Angeles, California.

The Hyperloop Movement: SpaceX founder Elon Musk proposed the concept of a Hyperloop as "a combination between a Concorde, a railgun, and an air hockey table" in 2012 as a hypothetical solution to the problem of growing urban congestion. A joint team of Tesla and SpaceX engineers subsequently released a preliminary design of the concept as a basis for an open-source dialogue among the technical community at large. Several privately funded spin-off companies have received venture funding based on related concepts, including Los Angeles-based Virgin Hyperloop One and Arrivo, among others, giving rise to the term "the Hyperloop Movement." While Musk and Musk-founded companies refrain from endorsing any one of the many companies developing Hyperloop technologies, Musk continues to show support for the Hyperloop Movement. In fact, in 2017 SpaceX sponsored the first "SpaceX Hyperloop Pod Design Competition" at a specially designed 1-mile long subscale test track near SpaceX headquarters.

Extensively leveraging commercial capabilities likely means "mainstreaming" U.S. Government procurement practices toward a more typical enterprise-class customer, so that the government can more easily and more quickly buy technology and services.

Gaming and entertainment technologies crossing over to aerospace manufacturing, simulations, and visualizations

This government shift is likely to create new demand for many of the launch and satellite systems and component suppliers in Southern California.

Convergence of Government, Commercial, and Adjacent Space

In recognition of commercial and non-traditional space industry capabilities, the government has now begun to exercise greater use of its commercial buying abilities. A government market orienting itself toward the commercial space market and seeking to leverage commercial investments, hardware, and services will soon find and initiate more options and more funding to carry out critical missions.

NASA has developed public-private partnerships (PPPs) to engage the services of New Space firms and to spur their investment in the rapid development of specifically identified technologies. PPPs have become increasingly popular, especially with the success of commercial launch providers. It is through these contracts that New Space companies can perform resupply missions to the ISS.

The Air Force's Space and Missile Systems Center (SMC) initiated an Other Transaction Authority (OTA) with a $500 million ceiling in 2017. Together with SMC's commercially focused Space Enterprise Consortium (SpEC) of some 200 commercial member companies, SMC can quickly acquire space technology prototypes from commercial companies outside of the Federal Acquisition Regulations.

The U.S. Defense Advanced Research Projects Agency (DARPA) aims to reach into the commercial space market by leveraging planned commercial satellite mega-constellations. In a program called Blackjack, DARPA will integrate reconnaissance and communications payloads into standard commercial satellite buses and take advantage of the high launch rate and high-volume satellite production required to field the mega-constellations. DARPA plans to launch its network of 20 prototype satellites to low Earth orbit (LEO) in 2021.

Extensively leveraging commercial capabilities likely means "mainstreaming" U.S. Government procurement practices toward a more typical enterprise-class customer, so that the government can more easily and more quickly buy technology and services. Taken together with commercial marketplaces for large new satellite constellations, this government shift is likely to create new demand for many of the launch and satellite systems and component suppliers in Southern California, as well as strengthen the industrial base for space technology in Southern California and throughout the U.S.

Conclusion

Southern California has played and continues to play a key role in serving the nation's space goals. Paired with the region's strong aerospace heritage, the emergence of New Space companies means Southern California is poised to push the boundaries of the technology and the business models that define the space industry. Given the shift from government as the majority funder of R&D to commercial market leadership, we are likely to see a convergence where New Space and established space begin to meld together and jointly mature. New technologies and business practices will provide greater diversity and choice for commercial and government customers alike. The U.S. Government, for its part, is likely to begin establishing more formalized outreach, assessment, and prototyping capabilities (accelerator programs, competitions, etc.) that allow it to more efficiently leverage the investments and capabilities emerging from the commercial space sector. With the breadth and diversity of the Southern California space industry and its geographic, educational, and workforce attributes, the region is well positioned to experience exceptional growth in space technology in the coming years and decades.

Space Ventures Coalition

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