Pioneering Innovation in Space - 30 Years of International leadership

Brian J. Horais
Independent Consultant
1112 Cotton Briar Way, Knoxville, TN, 37923; 703-300-3079
brian@horais.com

ABSTRACT

In its early years, during the 1960s and 1970s, the emerging space industry was founded on a strong undercurrent of risk taking that stimulated innovation and the rapid development of new technologies in space. No prior art existed, so innovation was essential. As the space industry matured and focused on larger and larger satellites and systems, the ability to take risks was overshadowed by the need to succeed. Space industries rapidly expanded and the world was introduced to new technologies in space previously envisioned by only the science fiction authors such as Arthur C. Clarke. Risk taking, and its accompanying innovative energy, dwindled because the growing space industry could not afford to fail. Additional barriers to innovation in space emerged, include the lack of easy and low-cost access to space for experimental payloads and the growing list of regulations that limited international development of new technologies and ready access to communications. Despite these limitations, small groups of innovative space technologists emerged, such as AMSAT (The Radio Amateur Satellite Organization) and found ways to launch and prove new technologies in space. The space industry took little notice of these innovators and continued to proceed on its low risk, high payoff path of space commercialization. Recognizing the need to harness and motivate these scattered small groups of space innovators, the Small Satellite Conference was founded in 1987 and has grown dramatically over the past 30 years. The strength of this truly International Conference is rooted in its ability to gather, share and inspire the space innovators of today and the future. As a frequent participant, contributor and conference chair in the small satellite community, the author will chronicle and explore the significant role that the Utah State Small Satellite Conference has performed in the development and expansion of space technology for the past three decades. As a result of its innovative leadership, space industries worldwide are now beginning to embrace and integrate many of the innovative developments that have their origins within the small satellite community and the Utah State Small Satellite Conference.

INTRODUCTION

Over the last three decades the small satellite community and its premier gathering, the AIAA/USU Small Satellite Conference, have demonstrated the curiosity, creativity and courage to turn the 'nonsense' of small satellites into the lifeblood of innovation in the space industry today. Those of you who have been a part of this community for any length of time recognize the pioneering spirit that exists and realize that 'nonsense' is really a matter of view. Burt Rutan used the 'nonsense' term in a recent Aviation Week and Space Technology article on 'The Next 100 Years'. His description, which included the three 'C's of innovation (Curiosity, Creativity and Courage), identified that "Any important breakthrough, before it happens, is often dismissed as nonsense. Those who find the breakthroughs need to have confidence in nonsense. Successful innovators tend to look more like idiots than the sensible, straight-A students who spend their careers being careful to never fail. The "sensible" do not recognize the importance of the third 'C.'" [1]

Accolades aside there are some important questions to address. These include:

- How did the Small Satellite community of today develop and evolve?
- How has the Small Satellite community and the AIAA/USU Conference on Small Satellites been a pioneering force in the development of new space technologies?

SPACE INNOVATION – THE EARLY YEARS

Many attribute the beginning of the 'Space Race' to the launch of Sputnik, the world's first artificial satellite, by the Soviet Union on October 4, 1957. "Visible with binoculars before sunrise or after sunset, Sputnik transmitted radio signals back to Earth strong enough to be picked up by amateur radio operators. Sputnik was some 10 times the size of the first planned U.S. satellite, which was not scheduled to be launched until the next year [1958]." [2]

By the time the United States launched its first satellite, Explorer, on January 31, 1958, the Soviet Union had already achieved another milestone with the launch of a dog into orbit onboard Sputnik 2. Explorer 1 was launched onboard a modified Army Redstone rocket after a failure of the first attempt to launch Explorer on a Vanguard rocket failed in early December 1958. During the early 1960s the Soviets continued to achieve a number of firsts in space while the United States was playing 'catch up'. Innovation, risk and failure were integral parts of the early space race because there was no foundation of knowledge on space launch, the space environment or operations in space. During the two year period from December 1957 through September 1959, the U.S. Vanguard program's launch success rate was nothing to applaud. Of eleven launch attempts, only three successfully placed payloads into orbit. [3]

The Space Race continued throughout the 1960s with an impressive list of achievements (and failures), culminating with the first landing of man on the moon on July 20, 1969. Numerous technologies had to be developed in rapid fashion and the space industry quickly adopted the practice of using secondary payloads to conduct experiments and establish 'space heritage' on components and systems. In the United States, The Atlas launch vehicle became a workhorse of the 1960s and launched numerous manned and unmanned payloads as well as hundreds of secondary payload experiments. A total of 467 experimental payloads were launched by Atlas onboard the OV (Orbiting Vehicle) series of satellites during the 1960s and early 1970s. "The satellites were essentially of a scientific and technology nature and demonstrated the use of a standard platform." [4]

Commercial and government space programs continued to grow in size and complexity during the 1970s and 1980s, with the launch of communications satellites, earth resources monitoring satellites and planetary exploration satellites. With the increased cost of launchers and satellites, the ability to accept risk (and failure) dramatically decreased and the ability to develop and test new space technologies dropped off as well.

EXPERIMENTERS EMERGE

Despite the downturn in space experimentation, there were some glimmers of hope beginning in the 1960s and extending well past the 1980s when the Conference on Small Satellites was established in 1987. One of the first pioneering small satellite organizations to develop capabilities to build, launch and operate experimental satellites in orbit was the Radio Amateur Satellite Corporation, better known as AMSAT. AMSAT was formed in 1969 as a not-for-profit, 501(c)(3) educational organization chartered in the District of Columbia. AMSAT is a worldwide group of Amateur Radio Operators (Hams) with a common interest in building, launching and communicating with each other through non-commercial Amateur Radio satellites. AMSAT has had an impressive track record of on-orbit successes with over 60 Amateur Radio satellites placed into Earth orbit. Today, over 20 of these satellites are operational.

As summarized on their website, *www.amsat.org*, AMSAT utilizes primarily volunteer labor and donated resources to design, construct, and, with assistance from international government and commercial agencies, successfully launch their amateur satellites. Launched in 1965, OSCAR III's transponder operated for 18 days and about 1000 amateurs in 22 countries were heard operating through it. The satellite was the first to clearly demonstrate multiple stations could successfully use a satellite simultaneously, a technology that is largely taken for granted in satellite telecommunications today. Reportedly, TELSTAR, one of the first commercial communications satellites, was worried about being upstaged by an amateur satellite. The UoSaT OSCARs 9 and 11, both of which were built by a team of AMSAT members and students at the University of Surrey in England, were designed for longer life low earth orbit (LEO) communications missions. Over half of the 20 Amateur Radio satellites now in orbit carry what can best be described as "flying digital bulletin boards". Many of these satellites allow Radio Amateurs to communicate with them using little more than laptop computers and "shoe box" sized radios.

"The story of AMSAT is one of simplicity, selfless donation of time and resources, and a pioneering spirit. The Amateur Radio Operators of Project OSCAR, and their later counterparts in AMSAT and other organizations, have built and launched over 60 OSCAR satellites since 1961. Their efforts are largely responsible for many of the commercial satellite technologies we take for granted today." [5]

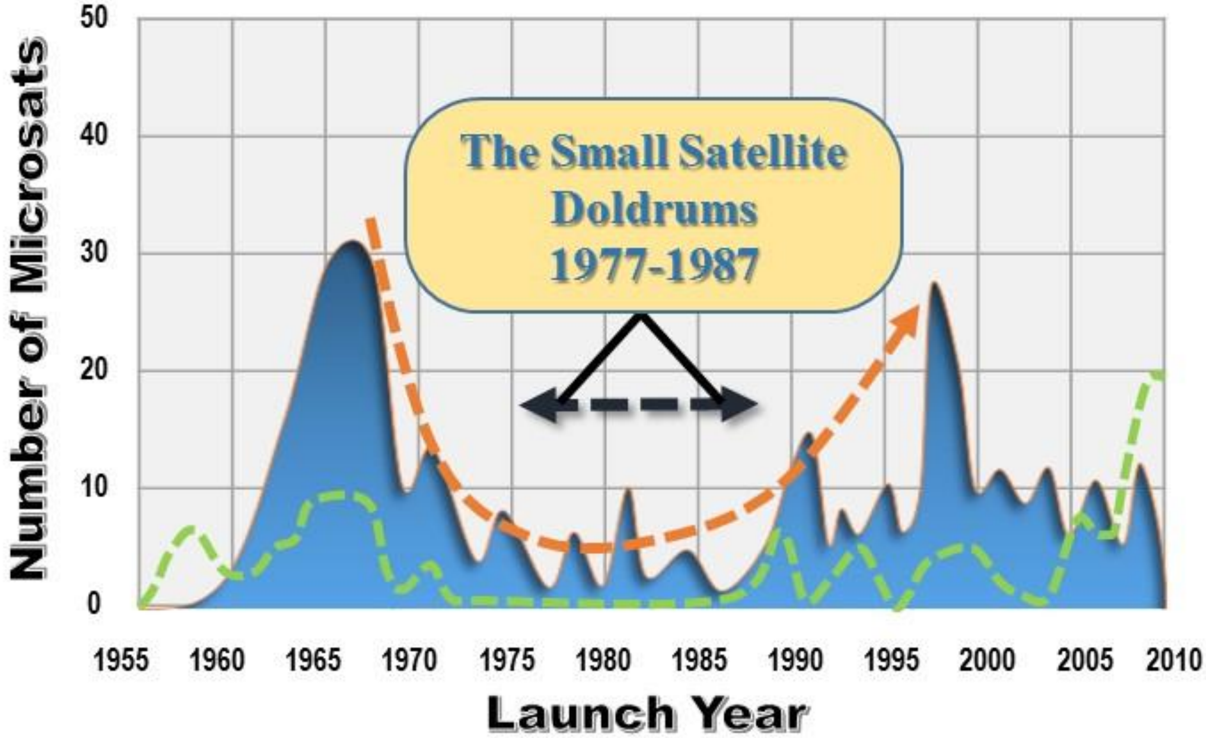

Figure 1- The Small Satellite Doldrums

"In the late 1970s, a group of highly-skilled aerospace researchers working at the University of Surrey, including a young Professor (Now Sir) Martin Sweeting, decided to experiment by creating a satellite using commercial off-the-shelf (COTS) components. The results were surprising. That first satellite, UoSat-1, was launched in 1981 with the help of NASA and the mission was a great success, outliving its planned three year life by more than five years. Most importantly, the team showed that relatively small and inexpensive satellites could be built rapidly to perform successful and sophisticated missions. In 1985 the University of Surrey formed Surrey Satellite Technology Ltd as a spin-out company to transfer the results of its research into a commercial enterprise. The growth of the company has accelerated, and their innovative approach to the design, build, test and operation of spacecraft has propelled SSTL to the forefront of the small satellite industry." [6]

A RISK-AVERSE SPACE INDUSTRY EVOLVES

During the early years of the Space Race (1960s and 1970s), innovation and risk taking were essential to the development of new technologies in space. Numerous new space and propulsion technologies were developed and tested, often with failure. During the early years, the space industry accepted failure as part of its development and growth, because it had to develop the new technologies. As the space industry matured and began to develop and launch larger commercial satellites, such as communications satellites (COMSATS), its capacity to handle risk was dramatically reduced due to the increased cost of the satellite and launch vehicle. The space industry could no longer afford to fail. Innovation in space requires an ability to take risk and document failure so that the development process can continue. This is best accomplished with small, discrete payloads where the experiments can be controlled and have specific objectives. These payloads were typically launched as secondary payloads during the early years of the space industry. In the U.S., the launch industry became unwilling to carry secondary payloads due to their potential risk to the larger paying satellites. Small payload launch opportunities dramatically declined once the dedicated space experiment launch vehicles, such as Scout, went out of service.

By the late 1970s, there was a dramatic decrease in the availability of secondary payload launch opportunities as shown in Figure 1[7] This period, from 1977 through 1987 has been called the Small Satellite Doldrums, highlighted by the orange dotted line. Microsat (10 to 100 kg) launches are shown by the solid blue region. Nanosat (1 to 10 kg) launches are shown by the lower green dotted line.

In response to this lack of opportunity to develop and launch small satellites, the community organized two significant conferences on Small Satellites in 1987. The first of these was a joint conference on Lightweight Satellite Systems organized by the American Institute of Aeronautics and Astronautics (AIAA) and the Defense Advanced Research Projects Agency (DARPA). This conference was held in Monterey, CA, at the Naval Postgraduate School in August 1987.[8]

The second of these was the First Annual Utah State University (USU) Conference on Small Satellite Technology, held October 7-9, 1987 in Logan Utah. Participation in both of these conferences was strong and indicative of the increased interest in small satellite technology and the expansion of space technology itself. As shown in plots of satellite launches versus years in Figure 1, these conferences signaled the end of the Small Satellite Doldrums.

It was clear to the Small Satellite Community that small satellites provided the most efficient means to develop and test new space components and devices in the space environment. They recognized that small satellites were affordable and could be developed in short timelines. They also understood that although their small satellite experiments may be risky, they could be launched as low-risk, benign, secondary payloads on primary launch vehicles. This would allow space technology developers to try and sometimes fail and then try again as they developed their new technologies. This is the cycle of innovation that fuels all new development activities, on the earth as well as in space.

Figure 2a Ariane ASAP Ring with Payloads

In the U.S., the launch industry became unwilling to carry secondary payloads due to their potential risk to the larger paying satellites. In direct contrast to the lack of secondary payload opportunities in the U.S. during the 1980s and 1990s, many new international space organizations got their start by launching research satellites as secondary payloads on platforms such as the Ariane Auxiliary Structure for Auxiliary Payloads (ASAP) and converted Soviet ICBMs. The first launch of the Ariane ASAP secondary payload adapter occurred on January 21, 1990 on Ariane 40. SPOT-2 was the primary payload and six secondary payloads were launched, including 4 AMSAT Microsats and 2 University of Surrey UoSats as shown in Figures 2a and 2b. [9]

Figure 2b ASAP Ring and Primary Payload (SPOT-1)

In addition to the Ariane ASAP launch opportunities, a converted Soviet R-36 ICBM named the Dnepr emerged as an important secondary payload launch capability. "The Dnepr launch vehicle made its maiden flight in 1999 when it carried the UoSat-12, a small satellite, built by Surrey Satellite Technology, UK, to orbit. One year later, the launcher made its first multi-payload mission delivering five satellites to orbit. Multiple satellite launches were to become common with Dnepr as the launcher was planned to deliver one main payload and a number of smaller satellites and CubeSats to orbit." [10]

Many U.S. universities and small companies were forced to seek launch services for their small satellite payloads with foreign providers due the lack of affordable (or even available) U.S. secondary payload launch opportunities. This imposed additional constraints on U.S. small satellite developers due to the requirements of the U.S. International Traffic in Arms Regulations (ITAR) implemented by the U.S. State Department to control the export and import of defense articles and defense services. [11]

Scientists and engineers at universities and small businesses in the U.S. were forced to fill out and process extensive paperwork to enable them to launch their secondary payloads outside of the U.S., even though there were essentially no opportunities for U.S. secondary payload launches in the late 1980s through the early 2000s. Complying with detailed ITAR regulations and paperwork was one of the least desired tasks a researcher would seek out, but it is a tribute to the perseverance of the U.S. Small Satellite community that they complied in great numbers.

With the advent of small payload secondary launch opportunities in the international launch community, the number of small satellite launches began to increase. By the late 1980s, the Small Satellite Doldrums were becoming a distant memory and it is no 'small' surprise that two pioneering small satellite organizations, AMSAT and the University of Surrey, were among the first to capitalize on the emerging secondary payload launch opportunities. AMSAT continued to build and operate small communications satellites in space and pioneered such items as low-cost ground stations, tracking software for personal computers, store-and-forward communications among amateur radio operators worldwide. One of AMSAT's most important contributions was the establishment of international frequency allocations for communication between Radio Amateurs and amateur/university satellites. The University of Surrey continued to develop its line of UoSat small satellites and in 1985 established a commercial spinoff, Surrey Satellite Technology Limited (SSTL). Throughout this, the AIAA/USU Conference on Small Satellites continued to grow as the principal annual gathering and innovation forum of the small satellite community.

With all of this activity in small satellite development and secondary payload launch opportunities in the International community in the 1990s and early 2000s, the U.S. Launch Community still did not see the need to host commercial and university secondary payloads on their primary launch vehicles. In many instances, U.S. Launch vehicles carried ballast to ensure proper performance of their launch vehicles for certain payloads. It's no surprise that the international space launch community was making inroads into the commercial space launch industry once dominated by the U.S. During the year 1998, of 82 orbital launch attempts worldwide, 56% originated from outside the U.S. [12] Some launch experts have suggested that the rapid growth of the international launch industry is partly due to their desire and willingness to support both small and large paying customers.

The U.S. was never completely out of the space test business. An organization has existed within the U.S. Air Force for years, the Space Test Program (STP) with the mission to place small experimental payloads and experiments into orbit. In the early 2000s a comparison was made between the launch rate of the USAF STP Program and the Ariane ASAP secondary payload launch capability and the results are dramatic. From 1962 through 2002 STP launched 37 free-flyer small satellite payloads, or approximately 1 small satellite payload per year. The Ariane ASAP, during the 11-year period 1990 through 2000 launched 26 free-flyer small satellite payloads for a rate of approximately 2.4 payloads per year. Why did Ariane have such a dramatically better rate than STP of launching secondary payloads? The general consensus is that the regularly scheduled availability of standardized ASAP secondary payload launch interfaces, at a reasonable cost, are the basis for Ariane's significantly better R&D payload launch record than U.S. programs. [13]

INNOVATION MARCHES ON

Despite the lack of secondary payload launch support in the U.S., experimenters, small space commerce companies and universities worldwide continued to develop and expand their small satellite activities in the 1990s and 2000s. These pioneering innovators continued to attend and present their results in open forums at the increasingly important AIAA/USU Conference on Small Satellites. "The concept of fully commercial systems was also developed during the 1980–1997 period, but the systems that were launched were restricted to satellites of the microsat class (10–100 kg). Perhaps most notable in this class were the commercial microsats from Surrey Satellite Technology Limited (SSTL) in the United Kingdom. The first of these microsats, UoSAT-5, was launched in 1991. UoSAT-5 provided "snapshots" of the Earth acquired under the control of the United Kingdom but made available to Ham radio operators worldwide. SSTL built and sold similar microsats to South Korea (KITSAT-1) and Portugal (PoSat) in a program of international technology transfer." [14]

The KITSAT story provides a significant example of commercial expansion of a university-based small satellite development capability. KITSAT was developed jointly by the University of Surrey and the Satellite Technology Research Center (SaTReC) established in 1989 in South Korea. SaTReC is a University-based center for satellite technology research. Leveraging the expertise of the University of Surrey's commercial outgrowth company, Surrey Satellite Technology Ltd (SSTL), SaTReC constructed and successfully launched a UoSat bus scientific satellite, KITSAT-1 in 1992, on the Ariane IV Launch (ASAP). By 1999 SaTReC built and launched KITSAT-3, a multi-spectral earth imaging satellite on an Indian launch vehicle, ISRO PSLV-C2, as a secondary payload. A multispectral image from KITSAT-3 is shown in Figure 3. [15] With the guidance and technical expertise of SSTL, a new space technology entity, SaTReC, emerged in South Korea and within 10 years, developed their own remote sensing satellite capability, without U.S. participation. SSTL expanded their collaborative development of small satellites with emerging international programs by developing the first satellites for the nations of Portugal (1993), Chile (1995), Algeria (2002) and Nigeria (2003).

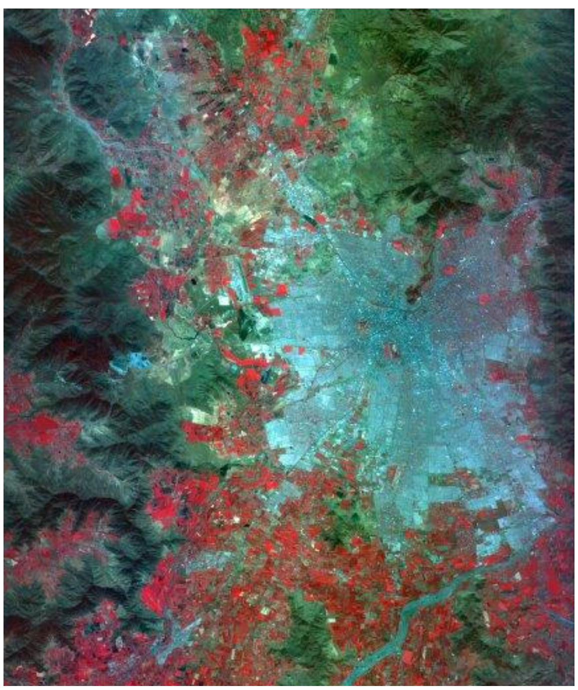

Figure 3 Multispectral Image of Santiago, Chile from KITSAT-3 (15 meter resolution)

The University of Surrey and SSTL expanded their development of very capable small remote sensing satellites. In September of 1998 a tiny 50kg microsatellite built by British company SSTL at the Surrey Space Centre transmitted its first high-resolution multispectral images monitoring the Earth - achieving LANDSAT-TM quality imaging but with a satellite built at fraction of the cost. Launched on 10 July '98, TMSat was built by SSTL through a collaborative technology transfer program between the Thai Micro Satellite Company Ltd (TMSC) and the Mahanakorn University of Technology (MUT) in Bangkok.

"SSTL continued to build upon their small remote sensing satellite successes. The launch of the University of Surrey's UoSAT-12 in April 1999 heralded a new era in small-satellite Earth observation. The UoSAT-12 mission, Surrey's first mini-satellite (100$^+$kg), supported a variety of payloads, including a 10-m panchromatic imager and a 32-m multispectral imager - both built at Surrey using commercial off-the shelf (COTS) technology." [16] It is worth noting that UoSAT-12 was the first successful orbital injection by the Dnepr launch vehicle in April 1999. This launch established another milestone as the world's first commercial satellite launch from Dnepr, a converted SS18, once the world's most powerful intercontinental ballistic missile (ICBM). The new 350kg minisatellite was launched to demonstrate advanced high resolution multispectral and panchromatic Earth observation payloads, low Earth orbit microwave digital communications, as well as a number of innovative propulsion and attitude control technologies. Results of this and several other pioneering small satellite successes were presented and discussed in depth at the AIAA/USU Conference on Small Satellites.

CUBESATS EMERGE

Beginning in 1999, California Polytechnic State University at San Luis Obispo (Cal Poly) and Stanford University developed a very small and relatively inexpensive spacecraft concept to help universities worldwide enable students and researchers to perform space science and exploration. The CubeSat reference design was proposed in 1999 by professors Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University. Their aim was to come up with a concept that would not only allow university groups to rapidly implement a small space mission, but also to ensure that the chances of obtaining a space launch as a secondary passenger were maximized. This was accomplished by standardizing interfaces and prohibiting or limiting design aspects that could be potentially hazardous and would reduce the chances of being allowed to be launched next to larger, more expensive spacecraft. The first CubeSats were launched in June 2003 on a Rockot (converted Soviet SS-19) launch vehicle. The CubeSat era had begun!

A CubeSat is a type of very small satellite which is based on a standardized unit of mass and volume. The basic CubeSat design standard measures 10x10x10 centimeters with specific interfaces for a standardized containerized launch. It has a maximum mass of 1 kilogram (subsequently increased to 1.33 kilograms). CubeSat launches are far less expensive than larger satellite launches and have thus become a cost-effective way for schools and universities to get a payload into orbit. A representative CubeSat from *firebird.unh.edu* is shown in Figure 4. It was quickly realized that the basic CubeSat units could be combined to form slightly larger spacecraft while following the same requirements and constraints. "Multiples of the basic CubeSat unit were combined together to establish larger CubeSats. For example, a 1-Unit (1U) CubeSat measures one single basic CubeSat unit as described above, while a 3-Unit (3U) CubeSat consists of 3 standard CubeSat units stacked together. The CubeSat concept has become very popular, both in university groups, as well as for researchers, space agencies, governments, and companies. CubeSats offer a fast and affordable way for a wide array of stakeholders to be active in space and allow for a fast innovation cycle." [17]

Figure 4 Representative 1 Unit (1U) CubeSat

THE TIDE BEGINS TO TURN

During the 1990s and early 2000s, several authors pointed out the lack of secondary payload launch opportunities in the U.S. and raised concerns that the rest of the international space technology community was advancing faster than in the U.S. due to their ease of access to space launch capabilities. Small satellite developers in the U.S. continued to build and launch their small satellites and CubeSats, but they were forced to seek launch opportunities outside of the U.S. which required them to comply with challenging and time-consuming ITAR regulations. Some of the headlines of papers and presentations made on this subject included:

- Re-Injecting Innovation into Space Test –2001 AIAA/USU Small Satellite Conference
- New Technology in Space – is the U.S. Losing Ground? – 2003 AIAA/USU Small Satellite Conference
- Smallsats – Solutions in Search of Problems – Space News – August 2003
- Potential Benefits of Increased Access to Space for Secondary Payloads [in the U.S.] – 2006 Rideshare Conference
- The Emperor Needs New Clothes – OCT 2009 Space Review Editorial

Other organizations in the U.S. were watching the progress of the CubeSat community and came to the realization that the multiple unit CubeSats offered significant opportunities for scientific exploration and the development of new concepts. The National Reconnaissance Office (NRO) initiated a CubeSat program and worked with United Launch Alliance to develop a secondary payload launch capability for the Atlas V launch vehicle they called the Aft Bulkhead Carrier (ABC). "An Atlas V Centaur upper stage design was modified by United Launch Alliance (ULA) for longer missions – three small spherical helium tanks replaced with two large cylindrical tanks where the third 26" helium sphere used to be located. NRO's Office of Space Launch (OSL) funded the development of the system to use available volume to enable the launch of small Auxiliary Payload(s). This made available a volume of approximately 20"x20"x30" for auxiliary payloads." [18]

An important distinction for the development of the ABC was that the sponsoring organization, the NRO, was also the customer for the primary payloads launched by ULA on the Atlas V. As a result, the NRO was able to dictate the use of secondary payloads with their primary payload and break the 'risk averse' constraints that previously had hindered U.S. launch of secondary payloads. The Director of the NRO, Bruce Carlson, reported on their plans to develop the ABC at the 2011 AIAA/USU Conference on Small Satellites. First launch of the ABC, which included 11 CubeSats, was in September 2012 on primary mission NROL-36 from Vandenberg Air Force Base (VAFB). Since that time the NRO has sponsored four launches of secondary payloads with over 40 CubeSats launched to date. CubeSat technology was beginning to enter the mainstream in terms of its research potential.

In 2008 another U.S. R&D agency, the, the National Science Foundation (NSF) announced support for the use of CubeSats in science missions dedicated to space weather and atmospheric research. Since that time the NSF has sponsored over 10 CubeSat atmospheric science development activities at U.S. Universities. "The NSF CubeSat program pursues a dual goal: to promote original and stimulating STEM education and workforce development as well as frontline, interdisciplinary scientific research and technology advances by exploring untraditional, creative, and low-cost ways to provide space measurements for scientific research. Launches are not part of the program but are provided by the DOD on a collaborative or reimbursable basis and by NASA through their Educational launch program (ELaNa)" and their CubeSat Launch Initiative (CSLI). [19]

NASA has expanded its capabilities to launch small satellite launch initiatives by incorporating the International Space Station (ISS) as a launch platform for CubeSats. In September of 2009 NanoRacks, LLC got their start by signing their first Space Act Agreement with NASA. Within six months, their first privately funded Platform (NR-1) was launched on STS-131. NR-2 followed on STS-132 and in August of 2010 astronaut Shannon Walker installed the NanoRacks Platforms in the U.S. National Lab. "On May 18, 2016 the 111th customer CubeSat was deployed from the Company's NanoRacks CubeSat Deployer (NRCSD)." [20]

As the Small Satellite Community has evolved, the naysayers have always been quick to point out that small satellites can't accomplish any real missions. Prof. Dave Klumpar, an expert on small satellites from Montana State University, points out that "One should not consider whether very small satellites might eventually replace larger traditional satellites. Rather one should ask how this potential new tool might be used advantageously to complement more traditional space research approaches. Perhaps the greatest scientific advance that very small low-cost satellites will enable is the ability to make many simultaneous synergistic measurements from multiple observing locations." [21] Small satellite constellations are not a new idea, but they have not been successfully implemented until recently. With the increased technological capability provided by the multiple unit CubeSats, there have been recent successes in this area, supported by the ability to rapidly launch multiple small CubeSat payloads into low earth orbit (LEO) from the International Space Station.

Planet Labs

A new startup earth imaging company, Planet Labs, couldn't agree more about the value of constellations of small satellites. Planet Labs, Inc. is an American Earth imaging private company based in San Francisco, CA. founded in 2010. As summarized on their website, *www.planet.com*, the company designs and manufactures 3U CubeSats called Doves that are delivered into orbit as passengers on other missions. Each Dove Earth observation satellite continuously scans Earth, sending data once it passes over a ground station. Together, Doves form a satellite constellation that provides a complete image of Earth at 3-5 m optical resolution and open data access. Small size and a relatively low cost enable the company to quickly prototype and test new designs, while avoiding a loss of significant assets in a disaster. The images gathered by Doves provide up-to-date information relevant to climate monitoring, crop yield prediction, urban planning, and disaster response. With acquisition of BlackBridge in July 2015, Planet Labs had 87 Dove and 5 RapidEye satellites in orbit. Two launch failures in 2014 and 2015 caused the loss of 34 Doves for Planet Labs, Inc. The company was able to respond with a "group of 14 satellites launched by the HTV (Japan's ISS transfer vehicle) puts Planet Labs over the century mark. The successful delivery makes it 101 Planet Labs satellites successfully placed into orbit". [22]

Planet Labs is an innovative new company that embodies the concepts Professor Klumpar suggests for the roles and future potential of small satellites. They are not alone. A number of other companies and organizations are pursuing initiatives that leverage the potential for small satellites to explore new technologies. Among these new missions are LightSail, and Mars Cube One (MarCO).

LightSail

"LightSail™ is a citizen-funded project by The Planetary Society, the world's largest non-profit space advocacy group. The project's goal is to demonstrate solar sailing, an innovative method of propulsion using the sun's energy, as a viable propulsion for CubeSats. Solar sail spacecraft capture light momentum with large, lightweight mirrored surfaces—sails. As light reflects off a sail, most of its momentum is transferred, pushing on the sail. The resulting acceleration is small, but continuous. Unlike chemical rockets that provide short bursts of thrust, solar sails thrust continuously and can reach higher speeds over time." [23]

LightSail carries large, reflective sails measuring 32 square meters (344 square feet). They successfully completed a test flight in June 2015 that paved the way for a second, full-fledged solar sailing demonstration in 2016.

Mars Cube One (MarCO)

NASA will launch a pair of CubeSats into deep space in 2018 to provide real-time landing coverage for the space agency's next mission to Mars, officials report. Known as Mars Cube One or MarCO, the CubeSats will be launched in May 2018 as secondary payloads aboard an Atlas V rocket carrying NASA's InSight lander. The two CubeSats will separate from the booster after launch and travel along their own trajectories to the Red Planet. One of the MarCO spacecraft will serve as a relay satellite to send data back to Earth during InSight's entry, descent and landing operations at the Red Planet in late 2018. The other spacecraft will serve as a backup. The InSight program was originally scheduled for a 2016 launch, but primary payload problems lead to a 2 year delay in the program. “NASA’s Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission to study the deep interior of Mars is targeting a new launch window that begins May 5, 2018, with a Mars landing scheduled for Nov. 26, 2018.” [24]

Recent success aside, not all organizations are onboard with the CubeSat movement. The U.S. Geological Survey (USGS), is more skeptical about the value of CubeSats to provide imagery and other data. Jennifer Lacey, observing systems branch chief at the USGS Earth Resources Observation and Science Center, said the types of data most in demand, such as shortwave infrared observations, “sort of drives us out of the CubeSat area” because those instruments require larger satellite buses. Lacey, though, would not rule out making use of CubeSats in the future as their capabilities improve.” [25] Despite this skepticism, The USGS signed a technical assistance agreement in 2013 with Planet Labs, to make sure it (USGS) stays current with the technology.

HOW ARE WE DOING SO FAR?

The initial successes of small satellite launches in the 1960s and 1970s were a result of the need to rapidly develop space technologies that had not previously existed. The pace of development and the associated willingness to accept risk (and failure) were driven by

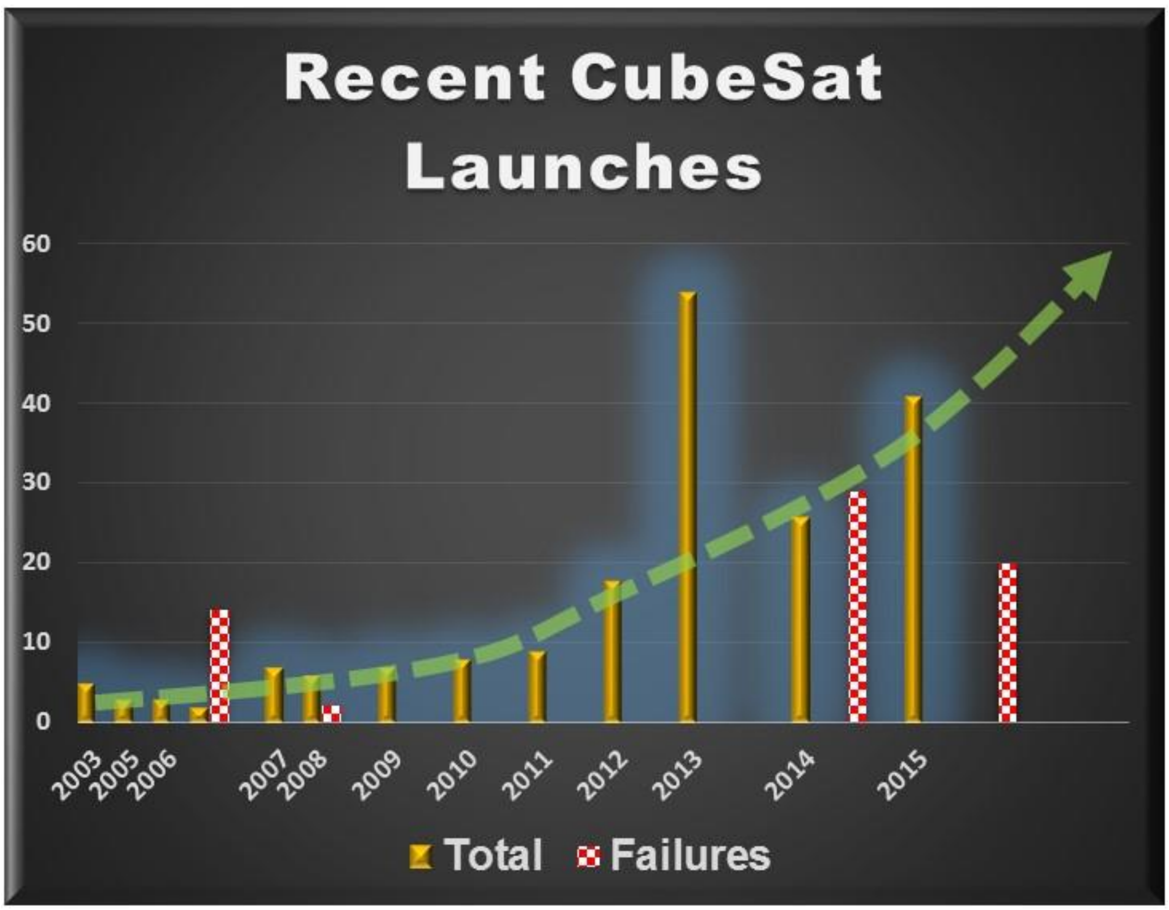

Figure 5 - Recent CubeSat Launches - Source: www.cubesat.org/missions

the Space Race and the U.S. objective of beating the Soviet Union to place man on the moon. As discussed in earlier sections, the space industry matured and began to lose its willingness and its financial ability to accept risk as part of the overall launch and development strategy. Small satellites were no longer welcome as secondary payloads in the U.S. and the international launch community stepped up to the plate and began to offer small payload launch opportunities. The small satellite doldrums from 1977 through 1987 were surpassed once the increase in small secondary payload launch opportunities and overall interest in developing small payloads began to respond to these new opportunities. A very important milestone, the first USU Conference on Small Satellites in Logan, Utah, in 1987 signaled that the small satellite community was poised to become a source of new space technology development and a pioneering force in the space industry despite what the naysayers were describing as the 'nonsense' of small satellites.

Table 1- Recent CubeSat Missions
Source: www.cubesat.org/missions

Year	# of Cubesats	Launch Vehicle
2015	12	*Super Strypi Nov 5, 2015** LAUNCH FAILURE*
	13	NRO Atlas V GRACE Launch 2015 Oct 8, 2015
	8	*SpaceEx CRS-7, 28 JUN 15 ** LAUNCH FAILURE*
	10	NRO Atlas V ULTRASat Launch 2015 May 20, 2015
	14	HTV ISS Resupply mission, 19 August, 2015
	4	Delta II SMAP Launch 2015 Jan 31, 2015
2014	21	Dnepr UniSat-6 Launch 2014 Jun 19, 2014
	29	*OSC Antares ISS, 28OCT15 ** LAUNCH FAILURE*
	5	Falcon 9 CRS-3 Launch 2014 Apr 18, 2014
2013	12	NRO Atlas V GEMSat Launch 2013 Dec 6, 2013
	14	Dnepr Cluster launch 21 NOV 2013
	28	Minotaur I ORS-3 Launch 2013 Nov 20, 2013
2012	11	NRO Atlas V OUTSat Launch 2012 Sep 13, 2012
	7	Vega Maiden Launch 2012 Feb 13, 2012
2011	6	Delta II NPP Launch 2011 Oct 28, 2011
	3	Taurus XL Glory Launch 2011 Mar 4, 2011
2010	1	Falcon 9 Dragon Launch 2010 Dec 8, 2010
	7	Minotaur IV STP-S26 Launch 2010 Nov 20, 2010
2009	4	PSLV-C14 Launch Sep 23, 2009
	3	Minotaur I TacSat-3 Launch 2009 May 19, 2009
2008	*2*	*Falcon 1 2008 Aug 3, 2008 **LAUNCH FAILURE*
	6	PSLV-C9 Launch 2008 Apr 28, 2008
2007	7	DNEPR Launch 2007 Nov 2, 2007
2006	1	Minotaur I TacSat-2 Launch 2007 Dec 16, 2006
	14	*DNEPR EgyptSat Jul 26, 2006 **LAUNCH FAILURE*
	2	M-V-8 ASTRO-F Launch 2006 Feb 22, 2006
2005	3	Kosmos 3M SSETI Express Launch 2005 Oct 27, 2005
2003	5	Eurokot Launch 2003 Jun 30, 2003
		NOTE: LAUNCH FAILURES SHOWN IN RED ITALICS

The Small Satellite Industry, represented and encouraged by the annual AIAA/USU Conference on Small Satellites, expanded their ability to demonstrate the curiosity, creativity and courage to turn the 'nonsense' of small satellites into the lifeblood of innovation in the space industry today. The dramatic increase in small satellite development and launch activities in the last decade is very promising and indicates that there is a significant role that the small satellite community will continue to play in the advancement of space technology.

The launch statistics for CubeSats alone paint a very positive picture, aided by the expansion of CubeSat launch opportunities. Figure 5 and Table 1 (based on data from *www.cubesat.org/missions* plus additional data) indicate a recent trend that is the very opposite of the Small Satellite Doldrums (1977-1987) and offers a vision of distinct promise for the next decade. The successful launches are shown in the gold (solid) bars and the launch failures are shown in the red/white (crosshatched) bars. A trend line has been drawn (dotted green line).

WHAT WILL THE FUTURE HOLD?

You can often envision what the future may bring by reviewing the headlines that highlight promising new space technologies. Some recent headlines, listed below, provide a very positive view of upcoming missions and technology innovations relevant to the continued development and expansion of the small satellite community. If these trends continue, the pioneering spirit of the Small Satellite Community is poised to make significant contributions to the development of future space technologies and missions.

- Lunar CubeSats to the Moon
  - 6th International Workshop on LunarCubes – Bellevue WA - 9/16
- NASA Solar Sail *[Space News, JUL 2015]*
  - NASA is developing a pair of solar-sailing, science-collecting CubeSats that will hitch a ride on the Space Launch System's inaugural July 2018 launch
- Large (1.53 m^2)Deployable S-Band Antenna for 6U CubeSats
  - Presented in 2015 at 29th AIAA/USU Smallsat Conference
- Spire Raises $40 Million For Weather Satellite Constellation [Space News, June 2015]
  - By SEP 2015 Spire launched four Lemur-2 CubeSats from India, and began deployment for the world's first commercial weather satellite network.

- United Launch Alliance (ULA) announced the Competition for a CubeSat Launch (April 7, 2016)
  - The application and request for proposals was released with announcement of winners in the *Summer of 2016*
- The NRO continues to expand secondary payload opportunities on Atlas V launches through the use of its ABC (Aft Bulkhead Carrier) System
  - By OCT 2015, the NRO had placed 46 CubeSats on orbit in 4 successful launches

With the announcement of ULA's CubeSat launch competition, even the U.S. Launch community is 'getting onboard' with secondary payload launch opportunities. This, coupled with the U.S. launch opportunities on SpaceX Falcon launches, Orbital Sciences Minotaur launches, Delta launches and NRO/Atlas launches, is providing a significant increase in U.S. secondary payload launch opportunities.

CONCLUSIONS

You may remember the opening paragraph of this paper offered a bold statement by Burt Rutan that "Any important breakthrough, before it happens, is often dismissed as nonsense." [26] When applied to the Small Satellite Industry and participants in the AIAA/USU Conference on Small Satellites, the term 'nonsense' has often been synonymous with small satellites themselves and those who choose to pursue this area of development. The last 30 years of pioneering effort by the small satellite community have shown that what many in the mature space industry considered 'nonsense' is in truth the driving force for the development of new space technologies and concepts.

Burt Rutan also went on to state that "Research, as opposed to development, requires a goal most people see as impossible. You cannot encourage progress on research breakthroughs that are yet to be discovered. Could we have encouraged the invention of today's Internet in 1980?" [25] The members of the small satellite community have shown that they have Burt Rutan's three 'C's'(curiosity, creativity and courage) plus a fourth 'C', Conviction. This community, centered about the pioneering mentorship of the AIAA/USU Conference on Small Satellites, has demonstrated 30 years of the 4 'C's' needed to persevere in the development of new space technologies despite the technological, financial, infrastructure and regulatory barriers that have existed. If the increase in small satellite activity over the last five years is any indication, the pioneering spirit and dedication this community continues to devote to the 'nonsense' of small satellites is paying off. Keep going!

ABOUT THE AUTHOR

Brian Horais is a former DARPA Program Manager, involved in space and materials technology development. He has been a frequent participant in and contributor to the AIAA/USU Satellite Conference with 6 papers presented over the period 1992 through 2016. He was co-chair, along with Professor Bob Twiggs, of five international conferences on Small Satellite Remote Sensing during the period 1991 through 2000 for the International Society of Optical Engineering (SPIE) and has authored small satellite articles in numerous publications, including Space News, Laser Focus World, The Space Review, ONR European Space Notes and other publications. In his earlier career Mr. Horais was a Naval Aviator, piloting the A-6E Intruder off the carrier U.S.S. John F. Kennedy. He is a 1971 graduate of the U.S. Naval Academy with a Bachelor of Science Degree in Aerospace Engineering and a 1972 graduate of the Naval Postgraduate School with a Master of Science Degree in Aeronautical Engineering. He also holds a Master of Business Administration Degree granted in 1986 by the University of New Haven. Mr. Horais currently resides in Knoxville, Tennessee where he is an independent consultant.

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