Re-injecting Innovation Into the Space Test Process

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Abstract:

The U.S. Space industry is losing market share to the International community, both in the launch vehicle and satellite fabrication marketplaces. Although many argue that this is due to restrictive export controls, this paper presents the concept that the erosion of innovation in the U.S. Space Industry has caused this downturn in U. S. market share. As U.S. space programs have grown in scope and cost, the capacity to accept risk as part of the development process has diminished. As a result, the U.S. Space industry is experiencing erosion in innovation, the foundation of our national security and space commerce leadership for the past four decades. To restore and regain lost market share, we must develop rapid access to space for testing of new ideas and must couple these efforts to hands-on university programs in space technologies that will train future U.S. space technologists. This paper summarizes findings on an innovative approach to using dedicated pico-satellite (CubeSat) space test capabilities for low-cost and regularly scheduled component testing. Schafer Corporation and Stanford University's Space Systems Development Laboratory (SSDL) were awarded a contract in August, 2000 by the National Reconnaissance Office / Office of Space Launch (NRO/OSL) to investigate new, evolutionary and revolutionary approaches to facilitate low-cost space testing opportunities. The contract and study are entitled "Proactive Rideshare Opportunity Brokering Services (PROBS)". This paper is based on the interim findings of the PROBS study.

1.0 The Shrinking US Space Technology Market Share

In recent years, the International market for space launch and satellite systems has experienced dramatic growth. At the same time, the U.S. share of this market has been eroding. In 1998, of 82 orbital launch attempts worldwide, 56% originated from outside the United States. [1] Space News reported in calendar year 2000 that "Europe Bests U.S. in Satellite Contracts for 2000" (for commercial geostationary telecommunications satellites)[2] and that "Ariane Tops Geostationary Market in 2000" (for publicly announced new contracts in 2000 for launch of commercial geostationary telecommunications satellites)[3]

Vance Coffman, Chairman and CEO of Lockheed Martin Corporation recently stated that "Today, our precious legacy in space is at risk. Our space program finds itself without a clear focus or challenge. In many respects, our nation today seems more concerned now about not risking anything rather than trying to get somewhere. We seem more focused on what can go wrong than on what will go right, more fascinated with investigations than inventions." [4] According to a report on "Satellite Export Licensing: The Impact of Federal Export Control Laws on the California Space Industry," U.S. market share of satellite manufacturing has fallen from a 10-year average of 75 percent down to 45 percent in 2000.[5]

Many attribute the recent downturn in U.S. satellite manufacturing market share to the shift of U.S. satellite export controls from the Department of Commerce to the State Department in 1999 [note: satellites were then placed in the same export category as most military weapons systems]. Another longer term but less obvious factor in this downturn in U.S. market share is the erosion of our technological edge/dominance in space technology. This can be directly attributed to our risk-averse, mature space industry that has migrated too far from its innovative foundations.

The current ability of the U.S. space systems industry to maintain and expand their share of this rapidly growing market is questionable when compared with the recent growth in market share made by the international community. Launch services such as those provided by Ariane Space have captured a large share of the market by developing new launchers and modern launch facilities. In addition, they have captured a significant share of the secondary payload marketplace (i.e. testing new space technologies) by virtue of their innovative approaches to standardized, low-cost secondary payload launch capabilities. This capability is provided by the Ariane Structure for Auxiliary Payloads (ASAP) which first appeared on Ariane 4 in the early 1990s and was introduced on the Ariane 5 family of launch vehicles in 2000. No equivalent standardized payload launch capability exists operationally in the U.S. expendable launch vehicle marketplace. Lack of an ASAP-like capability in the U.S. launch vehicle marketplace has had several effects. It has reduced the availability of standardized, low-cost opportunities for rapid space qualification of new components. The result is that the space technology innovation cycle is slowed down and the contributions of the new component technology developers (often not a part of the space systems community) are stifled or completely eliminated. Another negative impact is the reduction of hands-on university training programs available for development of qualified space systems engineers in U.S. universities. In the late 1980s, the University of Surrey in the United Kingdom recognized the time critical value of the ASAP launch ring when coupled to an undergraduate and graduate level hands-on engineering curriculum. Their program has thrived and grown considerably. They have even spun off a commercial organization that builds small satellites for developing countries and trains the engineers for customer countries (i.e. South Korea and Portugal) during the satellite construction process.

2.0 The Need for Innovation

Innovation and risk are essential elements of any aggressive development organization, such as the US Space Industry during its early days. Given the proper opportunity environment, innovation and risk can work together to

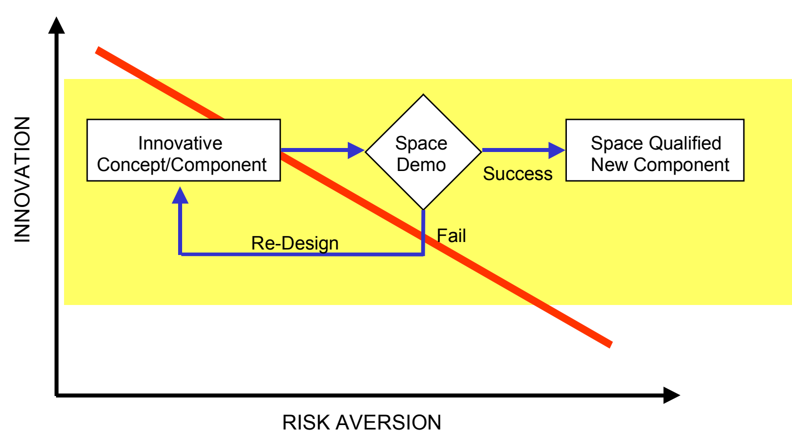


Figure 1 - Risk Aversion versus Innovation

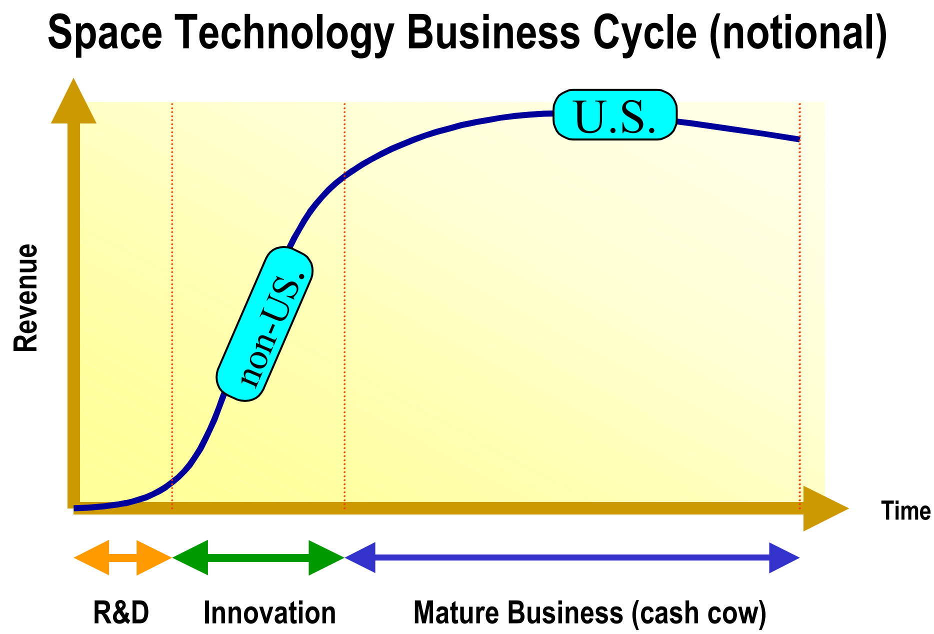


Figure 2 - Space Technology Business Cycle (notional)

stimulate an iterative loop of innovative design, development, successful and failed experiments, new designs based on lessons learned, and innovative products, as shown in figure 1. The key element of this innovation "loop" for the space industry is a short timeline with easy access to space testing.

If this key element is not in place, due to such factors as funding, program size and organizational biases, innovation and risk are perceived to be at odds and a risk aversion (i.e. low risk) approach is taken towards new development. The victim of such a low-risk approach is innovation itself. The innovation loop is shown in figure 1, overlaid on the risk aversion versus innovation curve. In its growth years, the U.S. Space industry depended heavily on space technology test activities to develop, demonstrate and deploy its advanced, high performance satellites. As U.S. space systems programs have grown in scope, and the costs associated with development and test programs have grown, the capacity to accept risk as part of the development process has diminished. As a result, the current U.S. Space industry is experiencing erosion in innovation, the cornerstone of our nation's security and defense for the past four decades.

Innovation is essential to the success of any new business venture. As products mature and grow in size and complexity (as have many U.S. satellites), the opportunity for injection of new technology and innovative approaches is overtaken by the need to avoid risk and to ensure the success and reliability of expensive hardware in space. The startup and emerging space industries outside of the U.S. are not as encumbered by a mature industry and are introducing innovative approaches to space technology that threaten to further erode our market share. A notional business cycle curve is shown in figure 2 depicting the relative locations of the mature US Space industry and the emerging International space industry.

Mature (or cash cow) product lines are not bad things. In most cases they are the foundations of successful industries. Enduring industries realize that the cash-cow phase has a finite duration and implement new and innovative processes in parallel with "cash-cow" production lines to make sure that they are developing the products of the future. The U.S. space market does not have a strong track record for innovation in the past 10 years when compared with the International space community. Innovation requires that the space testing process be accelerated to introduce and iterate new technologies on a time-scale closely coupled to commercial technology developments (i.e. months not years). An example where commercial technology is outpacing space technology is in the microprocessor industry as shown in figure 3.

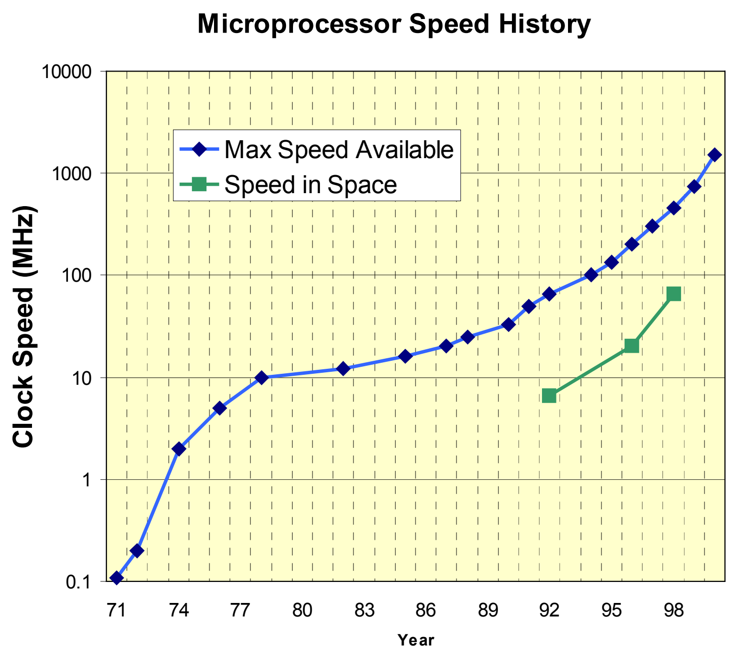


Figure 3 - Microprocessor Technology Development History[6]

The relatively slow pace of space testing cannot keep up with the accelerating pace of commercial microprocessor development. As a result, spacecraft operate with microprocessor capabilities that many of us have already donated to Goodwill industries.

Another key aspect of innovation is the willingness to accept failure as part of the development process. This is a viable business practice only when the cost of failure is low (or when the development is subsidized as in the U.S. race for the moon in the 1960s). There are very few (if any) space testing opportunities in the US Space Industry that allow failure as an expected outcome. This is mainly due to the cost of space testing but can also be attributed to lack of dedicated launch opportunities for innovative and high-risk space test articles. The PROBS program, described in the next section, has a specific focus on the identification of and proactive rideshare brokering for a critical category of payload technologists: the new/innovative developers of space component technology that do not have the knowledge, resources, or contacts necessary to successfully test their technologies in space. In order to implement and accelerate the process of space qualification of these new technologies, the testing cost must be low, the frequency of testing opportunities must be high, and the acceptance of risk must be much higher than allowable in traditional spacecraft development programs. This key concept of our approach is best summarized in Figure 4, the cost versus frequency of testing curve.

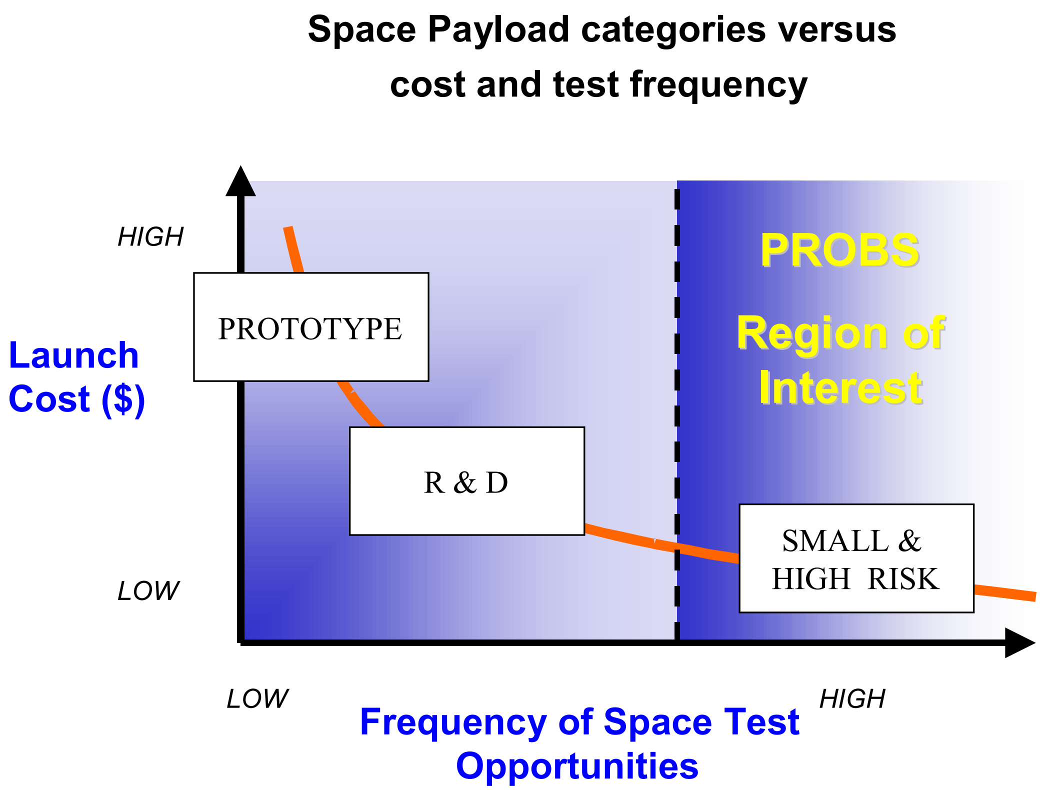


Figure 4 - Frequency of Test versus Launch Cost

To achieve a high frequency of space testing opportunities at very low cost, new space test approaches must be evaluated. The DARPA-sponsored Picosat program and the newly initiated CubeSat program developed at Stanford University have developed promising approaches for low-cost testing of small components. CubeSat is further described in Section 5. Criteria for selection of candidate technologies under the PROBS program are driven by the innovativeness of the technologies, potential for dramatic improvements in space systems capabilities, ease of testing in small payloads, technology availability and applications for university-based educational programs.

3.0 The PROBS Program

Schafer Corporation and their team member, Stanford University's Space Systems Development Laboratory (SSDL), are developing new, evolutionary and revolutionary approaches to facilitate low-cost space technology demonstrations under a Proactive Rideshare Opportunity Brokering Services (PROBS) study awarded by the National Reconnaissance Office of Space Launch in 2000. PROBS takes a proactive approach that no other government or industry service currently provides. Many commercial and government rideshare services have taken the approach "If you build it they will come". We don't feel this is sufficiently aggressive to attract the new technologists who know very little about space testing. PROBS takes a "You must go out and actively seek them" approach for high-payoff technology payloads.

The initial activities in the PROBS study focused on gathering data on candidate space test components and concepts. The results of this initial phase are summarized in this section. This paper is a key part of the outreach activities to extend the interaction with the space systems development community. Subsequent phases of the program will focus on a few selected technologies for space testing. These candidate technologies will then be brokered through the early stages of space testing and will be instructed on how to complete the process once this study effort is completed. Data from this program will be organized and delivered to the customer with a parallel objective of public release of the study results. The PROBS team provides proactive expertise that can be applied at any or all of the steps in the brokering process including: (1) identify emerging technologies that can significantly impact space systems, (2) evaluate their maturity, (3) provide a quantitative assessment of their benefits, (4) provide a roadmap for their development to a space demonstration, (5) assist in the space demonstration experiment design, (6) find the flight opportunities, (7) provide assistance to the PMs/customers in data analysis, and (8) insure that the results are communicated to the space community and, when appropriate, to the specific users we support.

A key finding of the PROBS study to date is that the proactive brokering process is only as successful as the availability of launch opportunities. From the PROBS study has emerged a new approach to accelerate the introduction of innovation into the U.S. Space Industry This approach is to implement a low-cost, small payload test capability that would support innovative cycles of testing, development and re-testing. The launch capability would provide:

- regularly scheduled launches
- defined interfaces
- low program cost (< $ 50K per launch)

Many readers will find a familiar thread in this approach. Affordable, standardized, regularly available secondary payload launch opportunities have been proposed before in general terms, but the implementation has always been for larger satellites and test capabilities in the 50kg and greater category. This is a category that lends itself to R&D development, not high-risk innovative proof-of-principle testing. The new approach we propose would utilize very small, self contained satellites (1 kg) like those currently under development in the CubeSat program initiated by Stanford University. Initiated in the fall of 2000, the CubeSat program currently has more than 15 CubeSat payloads in the final stages of development and integration for launching in November 2001. CubeSat fits the size, cost and standard interface objectives of the approach proposed under the PROBS program. The only detractor is that these CubeSat launches are on a Soviet Dnepr launch vehicle - which imposes significant export restrictions. Development of a similar capability that would support the US Space industry would require the design and development of standard interfaces for CubeSat launches from US launch vehicles. This is described in Section 4.2. The candidate technologies selected for the pilot brokering program under the PROBS contract will be identified and the role of small satellite test platforms, such as CubeSat will be quantified. Promising technology candidates such as radiation effects testing, fiber optic degradation in space, array technologies and others are being evaluated as candidates for the pilot phase.

4.0 CubeSat

The purpose of the CubeSat development is to define a standard bus that can be used by anyone needing a simple pico-satellite. Defining a standard bus, developing standard hardware components using commercial off the shelf components and a standard spacecraft frame will simplify the development of pico-satellites. The CubeSat development will provide a standard spacecraft frame, a spacecraft controller, radio transceiver, attitude determination and control, solar cells, batteries, and an interface for a payload. The developer needs only to concentrate on the payload. CubeSat is the name given a 4 inch cube (actually 10cm cube to not confuse units for space missions) satellite design developed by Stanford University under the leadership of Professor Robert Twiggs. Through a program at Stanford University and California Polytechnic State University over the last year, a launcher and standardized specifications for the physical dimensions have been developed for the CubeSat. The CubeSat satellite and launcher are shown in figure 5.

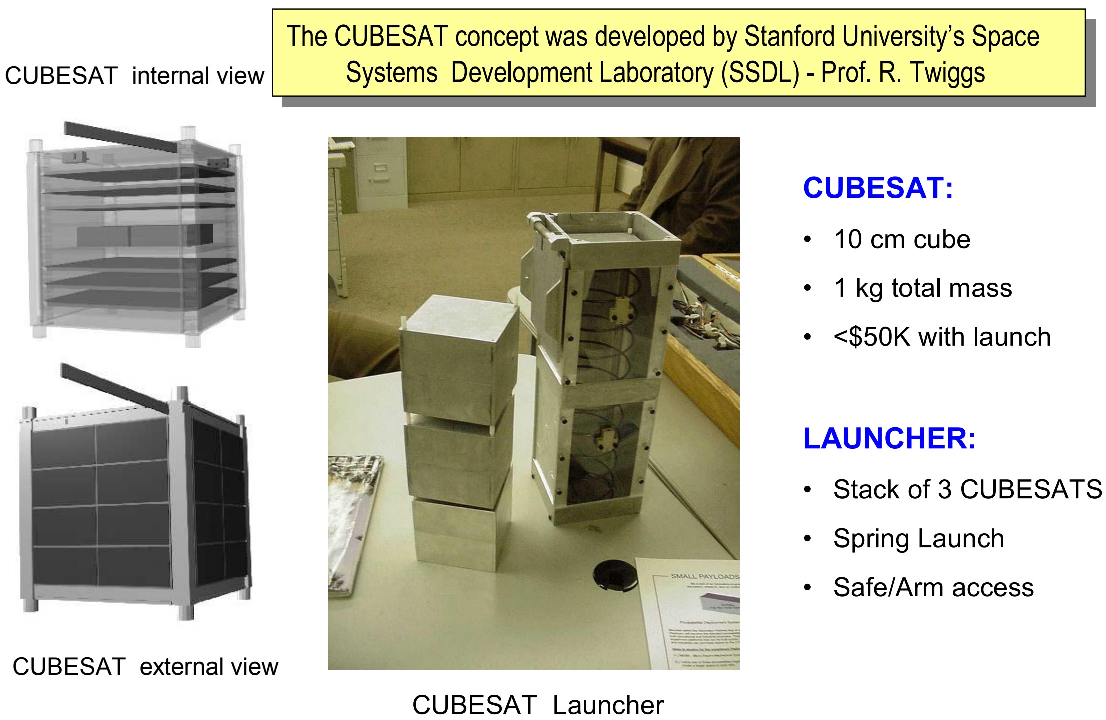


Figure 5 - CubeSat and Launcher

Stanford and Cal Poly have now teamed with One Stop Satellite Solutions (OSSS) from Ogden, Utah to provide universities a complete package for building and launching CubeSats. The launch cost for this program is $30,000 for each 1 kg CubeSat. This includes providing each developer a launch box provided by Cal Poly that is the same as the launch tube. This box allows physical fit check of the CubeSat, can be used for thermal, vibration and vacuum testing and is a shipping container for the CubeSat for launch integration. Once the Developer has completed the CubeSat and is ready for launch, it is shipped to Cal Poly where it is put into the final launcher, taken through the final vibration and thermal vacuum testing and shipped to OSSS. OSSS provides all of the licensing and final integration and contracting with the launch vehicle provider. The function and design of the CubeSat is challenge of the CubeSat developer. The only cost to the Developer for the CubeSat space mission other than the CubeSat itself is the launch cost. The first launches for CubeSats are scheduled for November 2001.

The "if you build it they will come" philosophy has been proven true in the case of the CubeSat program. Since the program's inception in late 2000, over 15 individual CubeSat programs were initiated at universities, high schools , amateur space organizations and government facilities to capitalize on the November 2001 launch opportunity provided by One Stop Satellite Solutions (OSSS) on the Soviet Dnepr (converted SS-18) launch vehicle. CubeSat payloads from a number of organizations are in the final stages of development for launch as summarized below. What is really amazing is that the total time from program inception to payload launch is one year! A cycle such as this can support innovative development, university hands-on training, and is sufficiently low in cost that developers can afford to take risks (i.e. they can learn even if they fail).

You may be thinking at this point that the CubeSat success story is counter to the PROBS approach of "you must go out and seek them" for identifying and proactively brokering new space test opportunities. In reality, the CubeSat success story is strong evidence that there is a "bow wave" of potential space test ideas just waiting for a readily available, low cost test opportunity. In addition to these candidates that have responded so quickly to the CubeSat opportunity, there are still a lot of new technologies out there that must be proactively identified and walked through the space test process. CubeSat missions can provide significant space test opportunities for these potential customers as well. The CubeSat manifest for the November 2001 launch (as of May, 2001) on Soviet Dnepr launch vehicle includes satellites from the following organizations:

- 1 - Calif. Polytechnic State University
- 1 - Montana State University
- 1 - Stanford University
- 2 - Taylor University
- 2 - University of Arizona
- 1 - University of Tokyo
- 1 - Tokyo Institute of Technology
- 1 - Wilcox High School - Santa Clara
- 1 - Leland High School - San Jose
- 1 - Private
- 6 - Government NASA Ames

Cal-Poly's POLYSAT is an Interdisciplinary student-run, educational project for the development of pico satellites program. The payload consists of a CPU & transceiver, temperature sensor, voltage & current characteristics, and a digital voice recorder. Future payloads may include solar power, more complex onboard computer, cameras, tethered system for expandability, and commercial payloads

The Montana State MEROPE is designed to measure Van Allen radiation belts. Specifically it will measure electron flux above 50 keV. Deployables on the satellite include the antennas and a gravity gradient boom.

Dartmouth College's DARTSAT is a design engineering/integration project. It contains a communications receiver/transmitter, power board (solar cells), and a control board. Although the mission is straightforward, the project provides the students with an end-to-end, hands-on example of satellite development.

The Wilcox High School's GOLO satellite is an amateur radio transceiver. The satellite will conduct an experiment in the use of computer-controlled motors to control pitch/roll/yaw attitude of the satellite. The project is funded for its space education benefits through the Santa Clara (CA) Unified School District and student-lead fundraisers in the local community.

4.1 Future Missions for CubeSat

The PROBS program has investigated a number of potential missions for the CubeSat category of space test vehicles. The real issue is whether or not meaningful testing could be done with such small payloads. The CubeSat configuration supports onboard processing and communications capabilities with low cost, small ground stations. With the trend towards miniaturization in components, it is logical that there would be a growing list of small components and concepts that would lend themselves to testing in a CubeSat-type space vehicle. To investigate the feasibility of this, a number of space-test organizations were contacted during the initial phase of the study to assess their payload requirements and desires. Organizations contacted during the data-gathering phase were:

- NASA New Millenium Program
- BMDO Materials and Structures Program
- DARPA Microelectronics Technology Office
- Naval Center for Space Technology
- Aero Astro Corporation
- Aerospace Corporation
- One Stop Satellite Solutions, Inc.

Additional technologies evaluated during the data-gathering phase of the PROBS effort included:

- Picosat launch and space test capabilities
- Spacecraft tethers
- MEMS INS and micro-thrusters
- Radiation testing of processors
- Radiation testing of fiber optics

- Array concepts
- Robotic inspection
- Internet-based control of spacecraft
- Frequency allocations from AMSAT

Three potential mission areas were highlighted for additional evaluation on CubeSat missions. These missions, shown in figure 6 below, represent capabilities that could support innovative testing of components and new satellite deployment concepts. The testing could be done with timelines and for costs consistent with innovative development programs. The concepts are, radiation testing of components (in the Van Allen belt), constellation architectures and MEMS components testing (such as microthrusters).

4.2 CubeSat launch interfaces on US Launch Vehicles

In order to support the space testing of US-developed technologies and components, the launches must be conducted on US launch vehicles to avoid export restrictions and to protect the competitive advantages of the US organizations developing the new technologies. Because of the small size of the CubeSat satellite and its P-POD launcher, many of these launchers could be located on primary payload support structures on US launch vehicles. A notional layout of multiple CubeSat launchers is shown in figure 7. These mounting points could also be designed for use as ballast attachment points to adjust launch vehicle center of gravity.

There is a fundamental difference in the way launch services are contracted in the US as compared with the international community. In the US the primary payload owner typically contracts for the entire launch vehicle. With this arrangement the primary payload sponsor has the decision authority on secondary payloads. In most cases, the primary payload sponsor does not want the schedule and performance risk that can be associated with secondary payloads. As a result, many US launches have excess, unused capacity that carries inert ballast. In the international launch vehicle community (Ariane is a principal example), the launch vehicle company provides launch services to the payload sponsors but retains overall control over the launch manifest. As a result, the launch vehicle provider can include secondary payloads when it makes sense. The launch vehicle provider takes the responsibility for overall performance for the primary and secondary payloads.

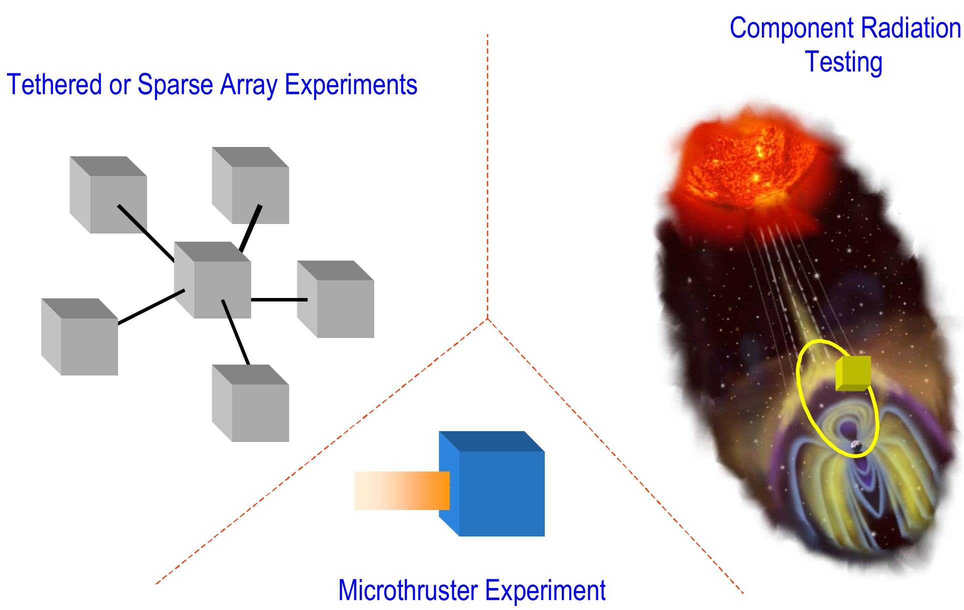


Figure 6 - Future CubeSat Missions

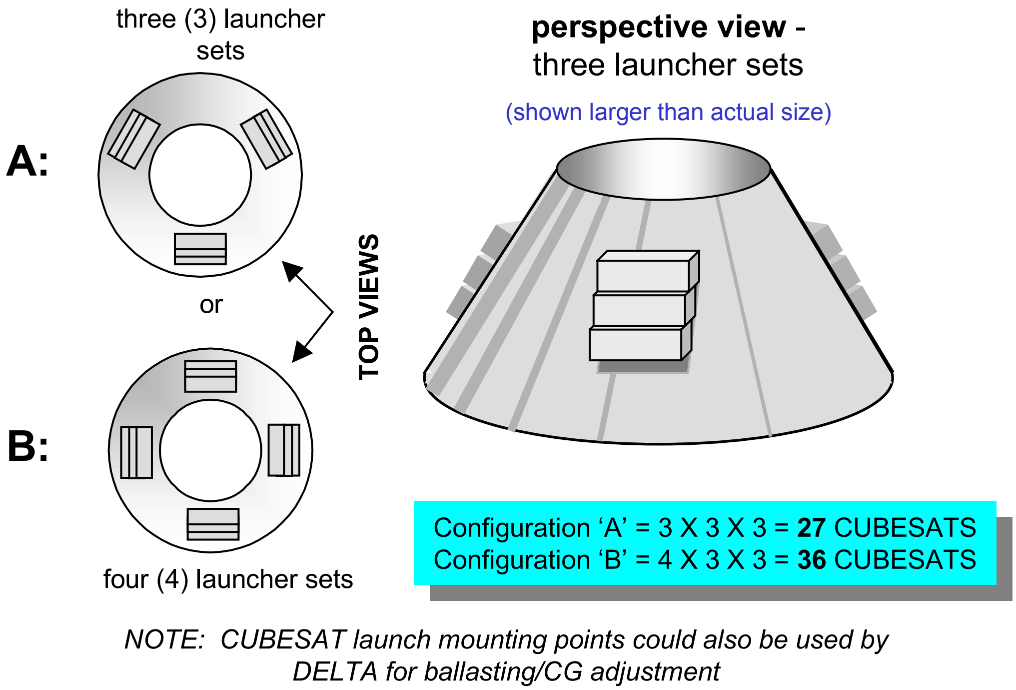


Figure 7 CubeSat on a US launch vehicle structure

In the early 1990s Ariane designed and implemented a standardized interface for secondary payloads (50kg or greater for Ariane IV) on the Ariane Structure for Auxiliary Payloads (ASAP). The US launch vehicle industry has been reluctant to include a standardized secondary payload interface. The U.S. Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter is a new design that will accomplish this for secondary payloads in the 180kg class. It will not be available until 2005 and then will be used by the Air Force Space Test Program on the Delta IV EELV. Additional uses of this secondary payload capability are not yet scheduled.

A picosatellite (or CubeSat) secondary payload interface for the Delta IV EELV would have very little impact (size, weight and risk) on the overall launch vehicle. Figure 8 provides a to-scale depiction of the CubeSat P-POD launcher integrated onto the Delta IV Payload Attach Assembly. You hardly notice it!

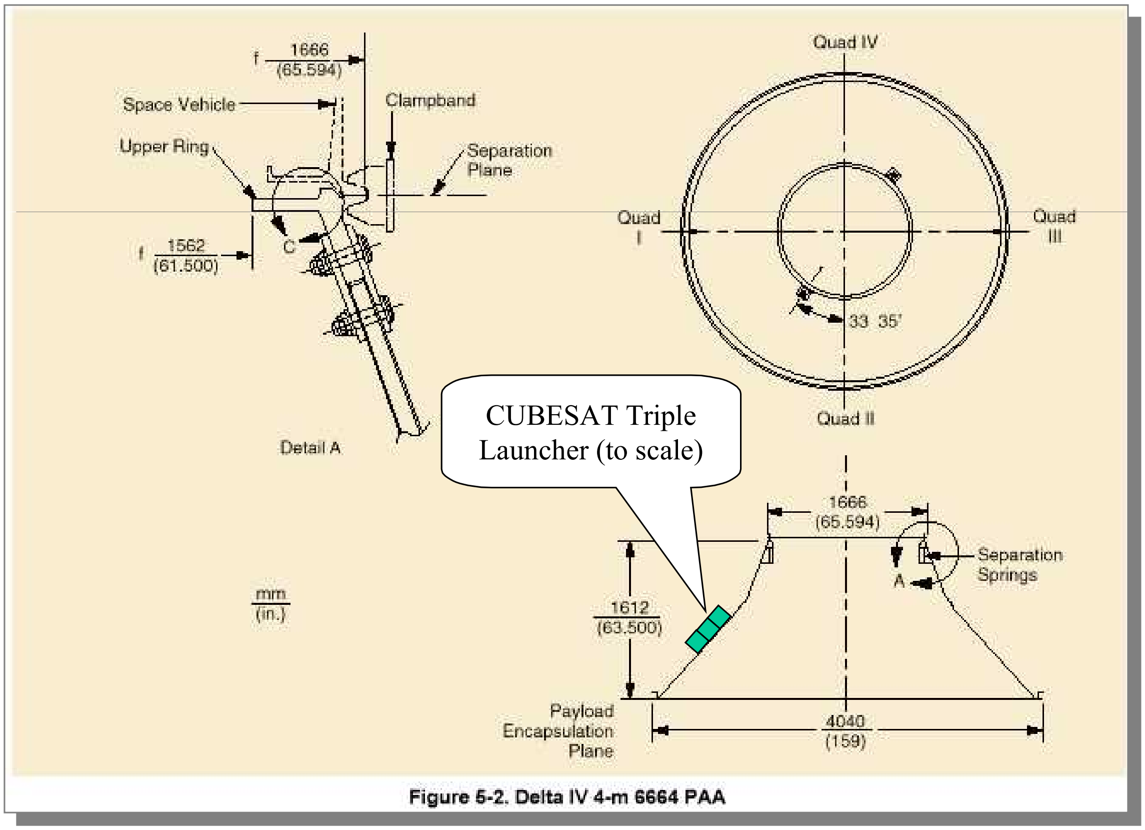
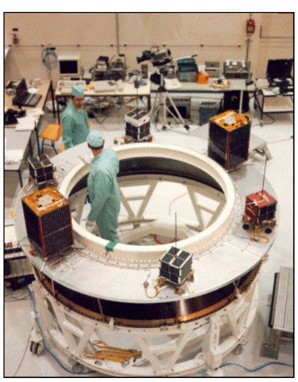


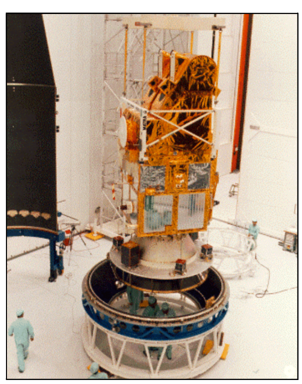
Figure 8 - CubeSat on Delta IV[8]

5.0 International Programs for Secondary Payloads

Many small satellites have been launched as secondary payloads - also known as "piggyback" - alongside the larger primary payloads on US and International launch vehicles. Ariane Space is the first commercial Launch Company to offer a standardized, low-cost, launch capability for small, secondary payloads. They remain the only company that provides this capability on a regular basis for expendable launch vehicles.



ASAP-4 ring with payloads



ASAP-4 and primary payload (SPOT-1)

ASAP -5 and STRV 1d and 1d (V135)

Figure 9 - Ariane ASAP structure[7]

Table 1 - Ariane ASAP launch record [7]

Launcher	Date	Primary	ASAP (secondary) payloads
Ariane IV V35	21 JAN 90	SPOT-2 (CNES - FR)	UOSAT-3 & 4 (U. of Surrey - UK) AO16,17,18 &19 (AMSAT N.A - USA)
Ariane IV V44	17 JUL 91	ERS-1 (ESA)	UOSAT-5 (SSTL - UK), SARA (FR) ORBCOMM-X (USA), TUBSAT (GER)
Ariane IV V52	10 AUG 92	SPOT-2 (CNES - FR)	S 80/T (SSTL - UK), KITSAT-1 (SSTL for SaTReC - S. Korea)
Ariane IV V59	25 SEP 93	SPOT-3 (CNES - FR)	STELLA (FR), KITSAT-2 (SSTL/S. Korea) PoSAT-1 (SSTL/Portugal), Eyesat (USA) ITAMSAT (AMSAT-Italy) Healthsat-2 (SSTL UK/USA)
Ariane IV V64	17 JUN 94	INTELSAT 7	STRV 1a & 1b (DRA/BMDO - UK/USA)
Ariane IV V75	7 JUL 95	Helios-1	CERISE (SSTL for DG - France) UPM-Sat (U of Madrid - Spain)
Ariane IV V124	3 DEC 99	Helios-1b	Clementine (SSTL for DGA - FR)
Ariane V V135	15 NOV 00	PanAmSat's PAS-1R	STRV 1c & 1d (DRA - UK), AMSAT Phase 3-D

SSTL - is Surrey Satellite Technology Limited, a commercial affiliate of the University of Surrey, UK

Figure 9 shows the Ariane Auxiliary Structure for Auxiliary Payloads (ASAP) for Ariane.

Table 1 summarizes the secondary payload launch record of Ariane. Close review of the table reveals two somewhat disturbing facts: 1) the majority of the payloads are non-US and 2) most of the payloads have been developed by the University of Surrey (and its commercial subsidiary SSTL). This is not disturbing for the non-U.S. space industry because it represents an impressive track record of innovation and new space program development at many countries outside of the U.S. A representative success story for South Korea's emerging space industry is described in section 6.1.

Other programs have evaluated the introduction of standardized payload adapters for the new U.S. Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter and the addition of secondary payload launch structures to existing Delta launch vehicles (such as Pucksat). Recently AeroAstro Corporation was awarded a contract to design a Universal Space Payload Interface (USPI) that could be used on a variety of US launch vehicles. Several other launch vehicle manufacturers offer capabilities for launch of secondary payloads (Pegasus, Taurus, Delta, Titan, etc.) - but these capabilities are provided on an ad-hoc basis.

5.1 US Secondary Payload Launch Capabilities

Additional sources of information currently exist for secondary payload opportunities, as summarized in Table 2. The principle drawback of these services is that they are rarely proactive and usually presume that the potential clients have a thorough understanding of the spacecraft payload integration process. This may be true for customers who have already conducted space experiments. However, when new and innovative firms explore their options in space test, they will require more coaching and interactive support to successfully complete the space qualification process. In order to support these new and innovative space test customers and to support university training programs for space systems engineers, proactive services must be put in place to match experiments to launch opportunities and these services must be actively maintained and presented to potential customers. Implementation of a CubeSat-type launch capability from US launch vehicles would support similar achievements at US Universities. The strong demand for CubeSat launch opportunities in the first year of the program is evidence of the need for university access to space.

Table 2 - Seconday Payload Providers

Group	Description of Services	Comments
U.S. Space Test Program (STP)	Provides the experience and expertise to fulfill space experiment requirements for DOD payloads.	Structured by SERB process - many payloads do not get rides
USRA	USRA provides a mechanism through which universities can cooperate effectively with one another, with the government and with other organizations to further space science and technology and promote education in these areas.	Principal focus is on University payloads
NASA GSFC	Access to Space Group has established a web site that facilitates frequent, affordable opportunities for access to space	Site offers an excellent template for access to information. Additional services available from GSFC.
Aero Astro	Innovative Space and Satellite technology development company designing low-cost orbital transfer capabilities for small payloads (SPORT) and standardized interfaces for small payloads on US launchers (Universal Space Payload Interface - USPI)	Aero-Astro is developing innovative capabilities for the R&D class of satellites and secondary payloads - less than 100kg in mass
Stanford University	CUBESAT picosatellite specification and P-POD multiple satellite launcher (Cal Poly University) provides a new class of satellites for space testing	This represents a unique category of satellites that can support innovative, high-risk testing where the price is low enough that failure can be re-introduced as an acceptable test outcome. The timelines also support university programs

6.0 Educational Impact

In the worldwide market for spacecraft systems development, education, training, and the availability of skilled engineers and scientists are the foundation "blocks" essential for a vibrant and innovative industry

The U.S. has been losing ground to the International community in the area of space technology training and education. Examples such as the University of Surrey and their extensive, hands-on, spacecraft systems curriculum do not currently exist on a similar scale in the United States. Although there are several space technology curriculums at US universities, they lack the availability of affordable, regularly scheduled launch opportunities to support hands-on training that matches student timelines. The International community has utilized the Ariane ASAP capability to provide a regularly scheduled launch interface and the University of Surrey has built a vibrant space technology curriculum around this unique capability for launching secondary payloads. Their results in innovation, new technology and education are impressive.

6.1 A non-US Success Story

There have been a number of success stories in the International Space technology community that are outgrowths of the innovative practices of the University of Surrey in the UK and the Ariane ASAP secondary payload launch capability. The Satellite Technology Research Center (SaTReC) [9] example provides one such example of how South Korea went from no space industry to an orbiting multispectral satellite imaging capability in just 10 years - about the life cycle for design and fabrication of one of the US industry's large satellites!

Established in 1989, the Satellite Technology Research Center (SaTReC) is a university based research center for satellite technology and applications research. SaTReC, which is located within the Korea Advanced Institute of Science and Technology (KAIST), promotes the education and training of satellite engineers through research programs in satellite engineering, space science and remote sensing. In 1992, SaTReC developed and launched the first satellite of Korea, KITSAT-1: a scientific microsatellite. Since then, SaTReC has continued to develop satellites with scientific and technology demonstration missions. acquired from the previous KITSAT programs. The KITSAT-3 satellite was launched on May 26, 1999 from the Shar Center in India on the Indian PSLV-C2 rocket carrying the IRS-P4, KITSAT-3 and DLR-TUBSAT. The 110 kg KITSAT-3 satellite carries a MEIS (Multispectral Earth Imaging System) and a

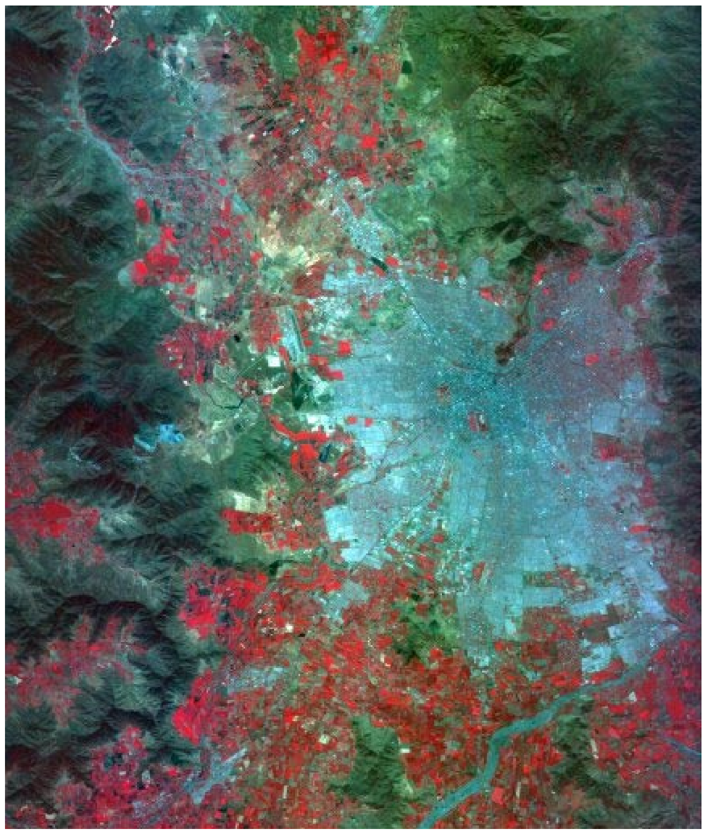


Figure 10 - Multispectral Image of Santiago, Chile from KITSAT-3

Developed through a collaborative program between SaTReC and the University of Surrey, the main objective of the KITSAT-1 program was to acquire satellite technology through the training and education of satellite engineers. The success of the KITSAT-1 program marked the beginning of space technology development for Korea. Based on the success of KITSAT-1, SaTReC developed and launched Kitsats 2 & 3.

The main objective of the KITSAT-3 program was to develop and perform the in-orbit test of an indigenous satellite system. KITSAT-3 was designed using the knowledge and experience

SENSE (Space ENvironment Scientific Experiment) instrument. The spatial resolution of MEIS is 15 m. A representative image of Santiago, Chile from KITSAT-3 (15 meter GSD) is provided in Figure 10.

The mission objectives of KITSAT-3 were to develop: 1) a 3-axis stabilized satellite, 2) a low cost remote sensing satellite system, 3) acquire scientific data for space plasma research, and 4) continue the education and training of satellite engineers. This is a primary example of how a viable satellite technology program was established through university involvement.

Prior to 1992 South Korea did not have its own satellite system capability. From this recent start, SaTReC and South Korea have rapidly progressed from very little spacecraft capability to the operation of their own orbiting earth imaging satellite with 15 meter multispectral imaging capability with the launch of KITSAT-3 in 1999. With success stories like this in the International space community, the U.S. will continue to lose market share.

7.0 Conclusions

This paper draws upon the findings and investigations of the PROBS program. With the large number of participants in the secondary payload "business", we feel that it is essential that the PROBS team establish a unique or niche capability to ensure that we provide value added to the brokering process.

The U.S. Space Industry is conducting business as usual by applying tried and true methods that have evolved from more than 30 years of experience. The international space systems industry has implemented newer approaches and infrastructures to accomplish things in what are often better ways - with increasing market share. To turn around the diminishing US space systems market share we must:

- Implement a proactive rideshare brokering process to support new technology injection
- Develop a standardized US secondary payload launch interface with low cost means to orbit
- Stimulate the space systems education process in the U.S. by implementing shorter timelines for the space qualification process

The US is facing a declining market share in the international space technology marketplace.
Development of a US standardized launch capability for low cost, innovative payloads is a necessary building block for the re-injection of innovation into the US space industry and educational programs.

More rapid space testing capabilities should be closely coupled to US educational programs for hands-on training of future engineers/scientists. Organizations willing to endorse and support this approach must be identified prior to the development of interface designs for US launchers.

8.0 References

1 Launchspace magazine, May/June 1999, page 44 “Stepping Stones to Orbit”, S. Barensky
2 source: SPACE NEWS, Vol. 12, No. 2 - JAN 15 2000, pg. 1
3 source: SPACE NEWS, Vol. 12, No. 4 - JAN 29 2000, pg.4
4 Article on "The Risk of Playing Safe", adapted from a speech by Vance Coffman at the Space Foundation Hall of Fame Dinner at Colorado Springs, Space News, April 30,2001, page15
5 Space News, 26 FEB 01, study by Futron Corp
6 plot generated from industry sources; INTEL, BAE
7 University of Surrey (SSHP) web site - http://www.ee.surrey.ac.uk/SSC/SSHP/launch_asap.html
8 Delta Payload Users Guide, SEP 1998, section 5.1.1
9 SATREC web site - http://satrec.kaist.ac.kr/

Author Biographies

Brian Horais has over 26 years experience in the design, development, implementation, operation and management of advanced technology systems in imaging, remote sensing, information technology and aerospace systems. He has been directly involved with spacecraft systems development and integration for the past thirteen years. Mr. Horais was Conference Co-Chairman of the August 2000 SPIE Small Payloads in Space Conference and Conference Chairman / Co-Chairman (1991 through 1994) for International Conferences on Remote Sensing Small Satellite Systems with the International Society of Optical Engineering

(SPIE) in Orlando, Florida and Rome, Italy. He has provided technical support to numerous government R&D space technology programs, including DARPA's Discoverer II and Pegasus, BMDO's Clementine and Skipper. In the mid 1980s, Mr. Horais established and managed a spacecraft systems electronics manufacturing facility in Boulder, Colorado, with contracts for OSC Pegasus space launch vehicle avionics components and AMROC launch vehicle guidance and control system design, fabrication and test. Mr. Horais is the author of numerous papers on space systems technology, published in SPIE, AIAA, and government technical journals. He has an MS in Aerospace Engineering from the U.S. Naval Postgraduate School an MBA from the University of New Haven and a BS in Aerospace Engineering from the U.S. Naval Academy. Mr. Horais is co-holder of two patents in sensor and projectile technologies.

Professor Twiggs has 18 years of university engineering teaching experience at both the undergraduate and graduate level and 20 years of industry experience. For the last 16 years he has managed student programs developing microsatellites for space experimentation. He is presently Director of the Space Systems Development Laboratory in the Department of Aeronautics and Astronautics, Stanford University. Prior to Stanford, he taught at Weber State University in Utah he was the director of the Center for Aerospace Technology which was responsible for the collaborative development and launch of two satellites - NUSAT launched from the Space Shuttle in 1985 and WeberSat launched from the French Ariane IV in 1990. Since coming to Stanford University in 1994, he has established the Space Systems Development Laboratory where students have completed two microsatellites. The first of these microsatellites, OPAL was launched in January 2000 on the first converted Minuteman II, Minotaur, from Vandenberg AFB, CA. Professor Twiggs was Conference Co-Chairman of the August 2000 SPIE Small Payloads in Space Conference. He has 20 years of industry experience in the development of high power microwave amplifiers and in software development working for companies such as Teledyne, National Semiconductor and TRW. Professor Twiggs has established outreach space education programs as part of the Space Systems Development Laboratory. There is presently a collaborative program with the University of Tokyo and Tokyo Institute of Technology in developing small satellites that fit in a Coca-Cola or Pepsi sized can. A similar program is being done with student and mentors at a Redwood City, California Jr. High School. He has an MS in Electrical Engineering from Stanford University.