Colony: A New Business Model for Research and Development

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ABSTRACT

Since 2007 the National Reconnaissance Office (NRO) has made a significant commitment to leveraging CubeSats to enhance Research and Development activities. SmallSats, CubeSats in particular, allow the NRO to perform research and development at a rapid pace, enabling us to mature a broad spectrum of new technologies for future systems while accepting higher levels of risk. Technology maturation can be conducted quickly and economically using CubeSats, due to their low cost, rapid development cycle, and the potential for more frequent launch opportunities. CubeSats provide the opportunity to keep up with Moore’s Law, advancing on a six to twelve month development cycle. On-orbit testing provides bigger systems with higher Technology Readiness Level (TRL) components, lowering program developmental risks and cost growth. Examples of near-term technologies to be proven on CubeSats include advanced multi-junction solar cells and carbon nanotube batteries. These technologies promise to improve overall size, weight, and power of future systems. Recent investments in CubeSats provide the NRO access to innovative methods to rapidly exploit technologies to address changing needs, while offering a new business model for adapting new technologies to tackle hard problems in the future.

INTRODUCTION

The rapid development of aircraft since the Wright brothers underlies the dramatic advances that have shaped the nature of our daily lives. Through design iterations, risk taking, and technology evolution, we now fly sophisticated airplanes that whisk us from Washington, D.C. to Paris, France in comfort and style. While highly advanced in comparison to the original Wright brothers’ aircraft, our modern methods of air travel have grown somewhat commonplace and incorporate only modest advances within the same paradigm. However, when Burt Rutan and the Spaceship-1 aircraft reached the lower perimeter of space, a whole new paradigm for air travel was born. Similarly, since Sputnik first amazed the world in 1957, space technologies have experienced equally dramatic advances. Every aspect of our modern lives is touched by sophisticated spacecraft of one type or another. GPS enables personal navigation, pinpointing our location anywhere on the globe. Weather satellites enable us to map and track the course of storms, thereby allowing us to predict and perform contingencies – saving lives. As Spaceship-1 (a disruptive technology) promotes a new view on travel, what will be the next transforming innovation in space development?

The National Reconnaissance Office (NRO) has looked closely at using small satellites, in particular CubeSats, to reduce cost and delivery time, and to improve
capabilities. By taking advantage of the relatively low cost to build and launch these small satellites, we can conduct experiments that will allow us to mature satellite technologies in space while developing our scientists and engineers. The low cost and rapid design to flight time that CubeSats offer, enables us to assume higher levels of risk in proving-out new capabilities that would otherwise not be acceptable for higher cost or mission essential systems.

WHEEL NOT INVENTED HERE

The NRO has made a significant commitment to the CubeSat approach. Today we have 12 satellites being built with a goal of building and flying as many as 50 within the next three years. A significant part of our near-term investment focuses on maturing the bus components needed to provide the foundation for future experiments under an effort we call Colony. By providing and evolving a “common” CubeSat bus, Colony allows designers to focus on developing experiments and demonstrating Concepts of Operation (ConOps) rather than re-inventing supporting subsystems (e.g., structures, power systems, attitude determination and control system (ADCS), processing, thermal, and communications) which has been common practice with many of the purpose-built CubeSats flown to date. Thus, the Colony effort has established a standard that we can use to develop technologies and mission concepts at lower cost by providing a documented standard vehicle that can be built using quantity purchased parts and assembled by people with experience building other identical craft.

Until now, a major portion of on-orbit demonstrations have involved custom-built bus components, software, perhaps a ground station, and many more “supporting” efforts. The end result is more than just making the particular experiment more expensive, it decreases the number and scope of other worthwhile activities we can accomplish within our budgets. Since our mission is to deliver some kind of improved capability to our users, spending on ancillary items does not represent good return on investment. Because the Advanced Systems & Technology Directorate (AS&T) is chartered to seed technologies for all of the NRO, the needs for a low-cost, high-rate demonstration capability is acute, and the non-productive non-recurring engineering (NRE) costs of the bus proportionally higher. While a traditional mission-driven organization would, rightly, develop a vehicle optimized for its mission to host a specific type of sensor, AS&T needs a vehicle to perform its mission to demonstrate a wide range of basic technologies on the same one- to three-year research and development (R&D) cycle as our current technology development efforts. By managing space R&D projects as a portfolio of diverse capabilities, the costs of designing, building, and testing non-payload sub-systems become obvious not only by their dollar cost but, also by the lost opportunities to fund other technologies. Being an organization with the opportunity and interest to fund a range of technologies, we have been especially hampered by these costs over the years. Within our traditional portfolio of technologies, a high percentage currently goes to non-payload supporting technologies where we would prefer to utilize our Directors Innovation Initiative (DII) and Innovative Solutions Initiative (ISI) annual award solicitations to advance a wider range of useful technologies for our customers. However, there is no return in just advancing technology if we lack the means to put those advances back into the “capability generating stream” to the war-fighters and decision makers – CubeSats answer this need, too.

CONTAINERIZATION

Traditionally, systems are closely coupled to specific launch vehicles (LVs). Satellite mass, volume, and unique interfaces generally impose limitations on what LV a satellite system can utilize. This can lead to schedule delays and additional costs. Since CubeSats can leverage a standard container (e.g., Poly Picosatellite Orbital Dispenser, or P-POD), there is an added benefit of “containerization” allowing any CubeSat meeting standard specifications to be launched on virtually any launch vehicle with P-POD capacity. In direct analogy to the shipping container, invented in 1954 by trucking industry entrepreneur Malcolm McLean (which sparked a revolution in worldwide transport), the P-POD may very well have sparked a revolution in low-cost access to space.

One of the key aspects of containerization is that the specifics of the CubeSat(s) within the container are not important to the launch vehicle, as long as core standards are met (e.g., CalPoly CubeSat Design Specification). Having a containerization standard allows any CubeSat to be rapidly changed out for another CubeSat and flown on a moment’s notice. CubeSats in their containers have been integrated and flown on a variety of launch vehicles to date including; M-V, Kosmos-3M, Rockot, PSLV, Falcon-1, Minotaur I, and DNEPR. Soon to be added to the list include; Minotaur IV, Falcon-9, Vega, Delta II, Taurus-XL, Falcon-1e, Super-Strypi, and Atlas-V.

This flexibility in both launch vehicle and satellite allows us to react to changing needs without costly delays. CubeSats provide compelling alternatives to augment traditional development methods.
INNOVATION

The relatively low cost of these systems allows us to accept higher levels of risk as we test new capabilities and new components. It also fosters a culture of creativity in our laboratories, a healthy environment where trial and error is encouraged and the understanding that we learn faster by trying and failing, and then trying again. In the long run, an environment that promotes innovation and makes room for experimentation saves us time and money – and the results often exceed our expectations.

For example, the “innovation cycle” that characterized the development of the Apple iPod can also be applied to satellites. In the commercial world, technologies refresh approximately every 6 months. Using CubeSats as an element of our research and development, we are able to test out new technologies and applications in timelines significantly shorter than if those same applications were “space qualified” on traditional large satellites.

Keeping-Up with the Moore’s

One of the most important aspects of small satellites is the ability to keep pace with Moore’s Law. Small satellites, in general, allow rapid innovation and novel applications. Typically, a small satellite program will take approximately 24 months from award to flight. The satellite will operate for 3 to 5 years on orbit. This is allows technology refresh to occur every 5 to 7 years. Larger satellites take 10 years to build (or more) and their technology lags even further behind (on the order of 10-15 years in some cases). Since these satellites can stay on orbit for decades, technologies find few opportunities to prove themselves. It is much more difficult to upgrade an on-orbit spacecraft – and it’s even more difficult to persuade the oversight organizations that control our budgets that new capabilities are needed while older vehicles remain on orbit.

CubeSats, however, offer a unique opportunity. With small satellites that can be built in less than 6 months, technology can stay at the leading edge and keep pace with evolving requirements. The key to keeping up with Moore’s Law is to keep a continuous flow of CubeSats in production and a management philosophy that allows new technologies to be inserted in both the payload and the satellite bus. The current NRO Colony program is set to build 10 CubeSats every 12 months. The payloads for these spacecraft are chosen each year, allowing for the maximum opportunity for new technologies to address new requirements. Additionally, the spacecraft bus contract is intended to be re-competed every 24 months. This allows for new capabilities and advances in satellite bus technologies to be rapidly incorporated.

Small satellites leverage commercial technologies in a much more exciting way than traditional programs. For example, the batteries that are the primary power source for several CubeSats on orbit are exactly the same as the batteries used in Apple iPods today. Leveraging these evolving technologies in a large, complex satellite program is inconceivable due to the time and risk involved in incorporating new, non-space qualified parts.

Our CubeSats are allowing new technology to gain flight heritage that might take years to earn on traditional satellite programs. The NRO is pursuing several near term research and development activities centered around small satellites. Technologies such as solar cells, batteries, commercial processors and radios are being integrated as CubeSat payloads and will be demonstrated on-orbit. Small satellites can accelerate these development activities by providing rapid feedback to developers, allowing them to refine their processes. The mature, proven technologies can then be transitioned to larger platforms, allowing us to keep pace with national needs.

Two examples of such technologies are the Gravity-gradient boom and the modular attitude control system. The NRO is developing a lightweight boom with integrated solar cells to greatly increase available power. The boom will also provide low cost and completely passive gravity-gradient attitude stabilization for a two-segment CubeSat spacecraft. This added capability will increase system power by a factor of 5 and will enable higher power payloads to be demonstrated on orbit. This approach uses passive strain energy for deployment, which could also be adapted to larger spacecraft systems.

Another example is a low cost precision pointing Control Moment Gyro (CMG) system. This attitude control system, based on a redundant four gimbal CMG configuration, will enable future CubeSat systems to actively maintain peak tracking and sensor positioning for more demanding demonstrations. The modular architecture enables the system to be easily retrofitted within the CubeSat framework.

Little Fish in a Big Pond

The NRO will be conducting multiple flight experiments with small satellites over the next several years. Among the areas of interest, environmental sensing and monitoring are key areas being studied. Worldwide environmental and economic impacts of global warming have increased concern over declining...
stability in third world countries and the resulting impact to national security policy. This and the desire to accelerate U.S. leadership in climate projection has prompted the NRO to take a critical look at tackling global climate monitoring via non-conventional means. For example, the NRO is currently investigating the use of CubeSats to deliver timely multi-point space weather data for ingestion into mathematical models such as Global Assimilative Ionospheric Models (GAIM). As a demonstration, two CubeSat pairs will be equipped with sensors capable of measuring neutral/ion density, neutral/ion winds, temperature, B-field, radiation, spacecraft charging, and GPS occultation (for ionospheric mapping). It is strongly believed that a multi-nodal distributed constellation of these weather sensors could provide significant data to fulfill gaps in high fidelity models required by the space weather community. In this regard, advances in miniaturized terrestrial and middle atmospheric sensors could also be utilized to monitor greenhouse gases and their thermal/environmental impacts to global climate change. Timely and distributed measurements of these climate change indicators are critical inputs to climate models which predict thermal effects, atmospheric cloud screening, aerosols, snow/ice cover, and ocean currents.

WE ARE NOT ALONE

Another exciting aspect of small satellites is the rapidly expanding community. There is an emerging, open development community consisting of dozens of Industry participants along with 90-plus Universities worldwide. These non-traditional developers bring new ideas and new enthusiasm to the market, providing much needed competition. There are companies selling CubeSat kits online, that can be purchased by anyone with a credit card. These companies are building partnerships with other small companies that produce specialized components for these versatile small satellites. Just like collaboration, competition can help discover better technical and more cost-effective solutions. We are supporting non-traditional satellite builders and universities through efforts such as our initial Innovative Experiments Initiative (IEI) and our significant investment in U.S. academic endeavors. The IEI has now been folded into the Director’s Innovation Initiative (DII) and seeks to further advance CubeSat subsystem technologies. The results of these CubeSat initiatives seem promising and have prompted the pursuit of some exciting new concepts in AS&T. These investments stimulate further research and development and allow an avenue for our scientists and engineers to do things differently.

There are a number of other formal and informal groups working on leveraging CubeSats for their needs and working to establish improved standards to further lower the barriers to a basic, but capable platform. Some examples of these are the US Government Forum on CubeSats (GFC) and the Advanced Space Technologies Research & Engineering Center (ASTREC).

Some of our British counterparts have been flying smallsats for over 25 years and have demonstrated their utility for a wide variety of uses. As members of this emerging international space community, we are all benefiting from the advances of our partners, and we all can lead in different areas. It is important that we continue to leverage the lessons learned and benefit from the synergy that smart minds across the world can bring to the table when focused on a common field of endeavor.

MINDS OF THE FUTURE

Small satellites allow a wonderful opportunity for our space professional work force development. This is an extremely critical issue in the U.S., especially in the defense sector. Building a complete satellite in less than 6 months allows new space professionals to see satellite development through a complete lifecycle, and helps them develop the program management skills that will help them succeed in the future. This valuable experience will pay dividends on larger, more complex satellites.

The new generation of space professional is accustomed to fast-paced technology adoption, and expects rapid results. Small satellites provide avenues for the new generation to apply that technological enthusiasm in a way that benefits the entire community. The NRO is actively working to train the next generation of space professionals by providing CubeSats to universities to augment academic programs and inspire enthusiasm for future space development. These projects provide an opportunity for students to develop key engineering skills as well as hands-on experience. Participating universities build coursework around these CubeSats, which can be built within a 1-year academic program. We are also working with high schools to generate enthusiasm for aerospace engineering before they head off to the universities.

CONCLUSION

Along with reduced timelines, reduced risk, and enhanced capabilities, the evolution of small satellites is introducing a new R&D and demonstration paradigm into the national space community, challenging both government and commercial entities to leverage the
possibilities. Engaging students with CubeSats educates and inspires, opening the minds of the next generation of space professionals to new possibilities.

As we work to improve our technologies and deliver better value to our customers, CubeSats open new opportunities to innovate, expand, and improve capabilities. While these small systems are not the answer to every satellite requirement, they can play an important role in solving many of the challenging technology and development questions we face today and will characterize the space domain for the years to come.