# Small Satellites – Evolving Innovation for the Entire Market

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## ABSTRACT

The rapid growth in the small satellite market has created a tremendous opportunity for reinvention of the space business in the broader satellite market. With far lower barriers to entry, the small satellite market encourages many non-traditional entrants with new ideas to explore how they would satisfy their mission requirements. Enabled by lower development, launch, and operations costs and supported by a burgeoning ecosystem of component vendors, innovation is accelerating. Indeed, the net effect is that the small satellite market is serving as a laboratory for rapid evolution of approaches to both the business and technology of the space business. Inevitably, there will be cross-flow between the small satellite market and the “traditional” market.

The migration of concepts –technological and business – is already being seen. Business deals and practices are becoming more diverse. The spacecraft sector is adopting rapid design and manufacturing processes. The software sector is embracing commercial standards, practices, and tools. Operations are being modeled after lights out data centers. Change takes time, but concepts and ideas unleashed in the small satellite laboratory will continue to accelerate the pace.

Kratos is witnessing this evolution and participating in it. With many large satellite companies as customers, Kratos is a well-recognized entity in the traditional space market, but also is responding to the small satellite market and laboratory. Starting three years ago, Kratos surveyed the market and developed the quantumCMD appliance for small satellites. Through our broad outreach and product maturation process we have engaged many small satellite companies. Bridging this dichotomy provides the opportunity to present some of our observations and insight into the dynamic between the small satellite and traditional satellite markets.

## INTRODUCTION

Satellites started “small”, with Sputnik weighing in at a shade less than 84 kilograms,[1] and Vanguard 1 being a sliver of that at about 14 kilograms.[2] Since those launches in October 1957 and January of 1958, the primary technological trend for satellites has been to make them larger, more complex, higher performance, and more expensive. With that growth there has been a corresponding increase in the size of technical teams, depth and complexity for manufacturing and operations processes, business plans that are global in scope, and an aversion to risk that is a natural byproduct of programs dependent on or centered around a single very high expense item. However, the last few years have seen a quite dramatic change in satellite industry. That trend – a move towards small satellites – has been over a decade in the making, but within the past five years it has accelerated significantly.

Were it just the actual spacecraft mass, the changes from this trend would be limited in scope, but the trend is encompassing of more than just a single design parameter. Used colloquially, the term “Small Satellites” or “SmallSats” describes not just a focus on lower mass satellites, but also on a different approach to building, operating, financing, and managing risk for satellite systems. This can include simpler vehicles, a higher risk tolerance, easier acceptance of new technology and rapid change, and the fact that cost is a primary system driver. In short, the small satellite trend represents a divergent path for satellite systems as opposed to the “traditional” path that has evolved since the launch of Sputnik and Vanguard-1. In many respects, the SmallSat path is a “Disruptive Innovation”[3] for the satellite industry. A disruptive innovation has been defined as changes that “disrupt and redefine that trajectory by introducing products and services that are not as good as currently available products. But disruptive technologies offer other benefits-typically, they are simpler, more convenient, and less expensive products that appeal to new or less-demanding customers".[4] SmallSats certainly have that exact potential and in some cases are already exercising that disruptive force in the satellite industry.

The generation of that disruptive force is significantly due to the speed of change in the small satellite market. With lower barriers to entry with respect to capital and infrastructure, a modular and standards based vendor ecosystem emerging, frequent launch opportunities, and a higher tolerance for failure, the timeline for each iteration in the small satellite market is far shorter than in the traditional satellite market. Combined with a perspective that embraces change and new ideas, these are the fuel stocks to make the small satellite market a petri dish for new ideas that instantiate the disruptive force.

Considering the wide array of satellite mission requirements and physics challenges involved, it would be intemperate and technically unwise to make the case that the SmallSat path will ever fully replace the traditional satellite path in the industry. The disruptive force – successful concepts from the petri dish - will nonetheless have a deep and lasting impact on the traditional satellite market. Rather than wholesale replacement of traditional satellite industry path, the two paths will co-exist and should over time form a symbiotic relationship, beneficial to both and to the industry as a whole. That symbiosis will be a complex interplay of numerous factors, many driven by the nature of each market. At times, those markets will directly compete, but for many other cases they will feed off the technology, business, and culture of each other. The beginning of that symbiosis, as seen through the migration of technology and business practices, has already started.

Where the migration leads and how it reshapes both the traditional and smallsat paths is naturally of considerable interest. The potential for significant change on both paths is apparent, and those missions and entities that can anticipate and prepare for the change will reap the most benefits. Not all changes will be predictable, or potentially even comfortable, but overall the changes and process of change should be beneficial to the space industry writ large. Even as the petri dish environment continues to mature and the concept migration starts, some observations about what the changes may be are worth consideration.

The gap between traditional and SmallSat paths is not a bottomless canyon. There is, in fact, a continuum of solutions and companies from one extreme to the other but two things are worth noting. First, the endpoints of the spectrum are radically different. The traditional path endpoint can be global conglomerates with hundreds of thousands of employees and corporate revenue reaching tens of billions of dollars a year – and even though only a small portion of that may be in the satellite industry, it is still thousands of employees and billions of dollars per year in revenue. The endpoint on the SmallSat side of the spectrum can be private firms with a handful of employees and a few hundred thousand in revenue or a team of undergraduate students at a university. Second, it is valuable to remember that while it is a continuum, the majority of the participants tend to cluster more on one side or another, and the companies in the middle have been merging[5] or growing rather than staying in the middle.

Straddling the gap and being deeply engaged on both paths is a difficult challenge, but some companies have the depth of products and expertise to do so. Kratos Technology and Training Solutions (KTTS), a division of Kratos Defense and Security Solutions, is one of those companies. With decades of developing and delivering products and end to end solutions to support satellite manufacturers, operators, integrators, and large government agencies, KTTS continues to be deeply involved with the traditional satellite path. However, KTTS has also recognized the value of the vibrant SmallSat path and has been actively engaged in developing and delivering products tailored for that path, as well as working with new companies looking at new solutions and approaches to meet their unique technical, schedule, and financial requirements. With a strong cross flow of technology and personnel across projects and customers, KTTS is positioned in a unique observation point that provides insight into both paths and the interplay between them. The observations noted in this paper are supported across the projects and companies – many under Non-Disclosure Agreements – we have encountered on both paths. Sharing those observations of how the SmallSat path is a laboratory for new concepts, what migration of technology and concepts are already taking place, and what some potential impacts on each path are will help illustrate the dynamic relationship between the traditional and SmallSat markets.

## THE SMALLSAT LABORATORY

The rapid growth in the small satellite market has created a tremendous opportunity for reinvention of technology, business practices, and markets for the space industry. With far lower barriers to entry, the small satellite market encourages many non-traditional entrants with new ideas to explore how they would satisfy their mission requirements or deliver a new product. Enabled by lower development, launch, and operations costs and supported by a burgeoning ecosystem of component vendors, concepts are quickly attempted and refined. Indeed, the net effect is that the small satellite market is serving as a laboratory for rapid evolution of approaches to both the business and technology of the space industry.

At a macroscopic level, the concept of the smallsat domain laboratory is useful to the overall space industry. One facet of that concept that comes to the fore is how much easier it is for the efforts – the "Disruptive Innovations" – in the SmallSat domain to be tested and validated than in the traditional satellite market. In studying companies that have successfully thrived as "great" in their industries, Collins and Hansen discussed how "bullets" versus "cannonballs" were used to test new concepts.[6] Their book, "*Great by Choice*", provides a look at what makes a company succeed in changing times and how those companies used small experiments, or bullets, versus large scale experiments or changes – "cannonballs". Taking a step back and looking at this from a satellite industry in changing times as opposed to a corporate level, do the efforts in the SmallSat domain qualify as "bullets"? The three criteria they lay out for a bullet – low cost, low risk, and low distraction relative to the main focus of a company[7] – would seem to apply in general to the SmallSat domain versus the satellite industry as a whole. There are exceptions. The recently announced LEO constellations with hundreds or thousands of satellites – OneWeb,[8] SpaceX,[9] and LEOSat[10] – are closer to "Cannonballs", if for no other reason than the tremendous aggregate cost for each of them. Even with these exceptions, the "bullet" nature of the SmallSat domain is clearly shown when the cost for buying a comprehensive 3U CubeSat kit can be less than \$370,000[11] and the launch to LEO for that 3U CubeSat is less than three hundred thousand dollars.[12] Compared to list prices that start in the tens or hundreds of millions for many traditional satellites, these are certainly bullets.

### *Technical Innovation Patterns*

In the SmallSat domain, the bullets certainly include technical innovations and concepts. Listing all of these would be a difficult and lengthy process, and potentially obscure some patterns we have observed that are applicable across numerous programs and efforts. Three key patterns highlight the laboratory nature of the SmallSat domain. The first of these is an increased use of non-space rated COTS components, not on a piece part basis, but on a subsystem or assembly basis. In other words, buying complete consumer or industrial devices and incorporating them into a spacecraft design versus designing and building a space mission unique element. While it has been done for smaller items such as cameras or batteries, two examples stand out. The first is the PhoneSats, a series of CubeSats launched by NASA Ames Research Center in 2013, where smartphones were repackaged as the core of the spacecraft.[13] While PhoneSat was a success, perhaps an example that highlights a more sustainable model is ArduSat 1 and ArduSat X from Spire. Launched in 2014, these CubeSats utilized Audrino boards as the core of the avionics system.[14] However, not just a one-time technical demonstration, the ArduSat is now available as a kit, which can be programmed and augmented for a variety of missions or educational purposes.[15]

Another technical pattern that has emerged is a change in how software is viewed – for both the ground and space segments. For the ground, that change is a greater emphasis on using open source software as well as using COTS products that have standard interfaces to allow the mission developers to extend the software to quickly meet their mission needs by themselves. As a developer of satellite control products, that Open Source and COTS approach is one recurring theme across the entire range of SmallSat companies Kratos has engaged. Space segment software is also showing a trend towards the use of COTS tools and standards. As an example, while the Controller Area Network (CAN) Bus protocol has been used by SmallSat companies earlier, notably Surrey Space Technology Limited (SSTL),[16] it has gained ground as a COTS architecture upon which to base flight software communications. This is an application of an ISO protocol designed for microprocessor communications on "road vehicles"[17] – hardly the model of traditional satellite flight software where each line of code is optimized to the mission and the space hardened processors.

Highly automated Command and Control (C2) software has also a trend within the SmallSat domain. While automation is not unique to this domain, the approach that SmallSat companies have taken is not to look at automation as an adjunct to human operators, but rather as the primary operations path. Our experience in discussing CONOPS for SmallSat missions – across the range of missions and customers – has been that the baseline desired is lights out operations. In these scenarios, autonomous routine operations are augmented by tools that detect predefined anomalies and initiate corrective actions, and alert personnel through email or messaging systems when there are issues that cannot be resolved. Tyvak selected quantumCMD (a Kratos product) for command and control of its CubeSat Proximity Operations Demonstration (CPOD) mission, and one key factor in this was the automation capability of the system.[18] The C2 trends go well beyond automation; they also are disruptive to the traditional C2 system architecture. Here the discussion is focused on the use of Virtual Machines (VMs) and how the Cloud concept can be used to host the C2 software and tools. Where dedicated servers and standalone hardware suites have been the classic case for C2 systems, the question now is how much of the C2 system can be hosted on a commodity set of server resources, be it public or private. The largest payoff from using public, or more common so far, private clouds, is for the larger constellations or missions that require seamless backups. For smaller missions or high security missions, a private server hosting a few VMs or an appliance based approach has been attractive if no fully secured cloud is available. Once the leap is made to use VMs or an appliance for a server side solution, the user interface has been the next step, with the move to a web browser based user interface for what human interaction is required. The widespread use of HTML5, which provides a wide variety of capabilities for animating web pages and managing connections, has enabled this shift from thick clients to thin clients that open up new CONOPS that are now focused on network connectivity rather than the physical location of workstations. Not only have products been developed and sold that rely on HTML5 user interfaces – quantumCMD by Kratos is one of these[19] – but some small satellite constellations have developed their command and control systems in house and have used HTML5 for user interface, including Skybox Imaging.[20] These trends for SmallSat C2 point to a future where the command and control system is far more like a modern data center in a locked room than today's model of a room with operations staff, never mind the showcase command and control centers seen in movies.

Underpinning many of the technical trends is modularity and standardized interfaces emerging in the SmallSat domain. This is driven by two primary forces, and as a result has strongly influenced many of the technical solutions developed. The first force is the launch constraints. The CubeSat standard emphasizes the packaging requirements required to enable easy launch integration.[21] The broad adoption of the CubeSat standard has led to additional standards – such as the Poly-Picosatellite Orbital Deployer (P-POD) standard - for modular launch dispensers.[22] The modularity of these standards has allowed many new opportunities and sizes of SmallSats to be launched, with that success reinforcing the overall acceptance of standards and interfaces within the SmallSat domain. The second force is the vendor ecosystem that has emerged in the SmallSat domain. The volume of SmallSats being built and launched makes it economically viable to invest in developing products for larger volume sales, but the enabler to do so is that the products must have some level of interoperability so that spacecraft developers can continue to minimize their development and integration costs. This is unlike many of the traditional satellite component vendors. Those vendors generally offer a "standardized" product but still require detailed specifications and RFPs to tailor the component to the exact mission requirements. The vendors in the evolving and new paradigm tend to offer preconfigured products that adhere to either formal or informal standards used within the SmallSat domain. That is most apparent when looking at any of the leading CubeSat websites where a customer can browse the parts and price list, and even order desired components with a credit card on the spot – such as CubeSatShop.com[23] or ClydeSpace.com.[24]

***Business Practice Changes***

Complementing the technical changes from the SmallSat laboratory, there are also significant business practice evolutions. The first of these is the change in the business plan focus. For many SmallSat efforts, the focus is far more consumer oriented than in the traditional satellite domain. Most of the traditional satellite domain has focused on institutional sales, be it commercial entities or government agencies, with the notable exception of the Direct-to-Home (DTH) broadcast satellites. Even Iridium and GlobalStar historically focused on selling handsets to corporations or agencies that needed connectivity for their personnel versus selling to consumers for personal use, although that may change as they launch their next generation systems.[25] In the SmallSat domain, several notable efforts are focused on marketing their services to the consumer. Two high profile examples are OneWeb and the SpaceX constellations that will offer satellite-based Internet connectivity to consumer grade terminals.[26] Another prominent SmallSat effort that focuses on consumer use of their data is Planet Labs,[27] which makes it clear that a portion of their corporate mission is to provide "transparency" through making remote sensing data of Earth widely available. Along with the companies that make CubeSats widely available – the "storefront" companies like Clydespace, ISIS, Tyvak, and CubeSatShop.com – the educational kits from Spire also show a business plan predicated upon a customer basis far larger in size, albeit with smaller budgets, than the traditional satellite domain business plans.

On a small scale, some of these business plans have also been initially capitalized by an approach that is completely unique in the space industry – the use of Kickstarter, an online crowdfunding website. Crowdfunding is not used for traditional space industry projects, but the lower price point for many small satellite programs enables its use as a quasi-substitute for "angel" funding from venture capitalists. AdruSat was successfully funded by Kickstarter[28] and helped lead to the success of Nanosatisfi LLC., which is now known as Spire.

However, even in the SmallSat domain, the funding needs will quickly surpass the few hundred thousand dollars that crowdfunding can supply. SmallSat companies are also looking to fund new companies and projects internally. Millennium Space Systems has initiated a new program called "Bootstrap".[29] Bootstrap looks to provide cradle to grave space system capability for new ideas and concepts. Millennium Space Systems put out an open call for ideas in the summer of 2014 and pledged to work with the six best ideas, potentially helping them secure funding, or if they felt strongly enough, funding the ideas themselves. Speaking to Directions Magazine for their August 20, 2014 issue, Vince Deano the President of Millennium Space Systems stated, "Bootstrap has elements of an incubator, accelerator, business competition and investor. It is fundamentally a partnership and an entry point for new ventures..."[30]

Moving beyond that level of partnership and funding may require other new approaches. As Spire's plans have expanded and its constellation of AIS and GPS Radio Occultation satellites begins to take shape they have turned to another business trend that the SmallSat domain is becoming noted for: Venture Capital (VC) funding. In the summer of 2014, Spire raised $25M in a Series A funding round.[31] Spire is far from alone in turning to VCs for initial growth. In fact, a cottage industry has started in the VC community to support space industry startups. Space Angels Network, an investment company designed to connect new space ventures and investors on a global scale, versus local, started in 2006,[32] and now boasts among its portfolio a number of well-known companies including Firefly Space Systems, NanoRacks, XCOR Aerospace, and Zero Gravity Corporation.[33] Numerous other VC groups have become deeply involved with SmallSat ventures, including well known ones such as kholsa ventures.[34] To support these investors, specialized knowledge services have also sprung up, notably, NewSpace Global (NSG) starting in 2011.[35] With the mission statement of "Providing Our Customers with Market Data and Strategic

Analysis on the NewSpace Industry", NSG provides a variety of subscription based publications focused on various aspects of the industry, including ones devoted to SmallSats.

***Pace of Change***

One potential corollary of the "Bullets" versus "Cannonballs" proposition put forth by Collins and Hansen that could be derived is the utility of firing many bullets in the time it would take to fire a single cannonball. In a similar vein, SmallSat projects tend to have far shorter lifecycles than traditional satellite projects, so many SmallSat bullets can be fired in the time it takes for a cycle of a traditional satellite project. Between each bullet, the chance to adjust the aim – be it a technical or business "target" in the sights – affords the SmallSat domain a pace of change that reinforces its role as a laboratory for the space industry as a whole. From a purely technical front, one example that highlights this is the use of "additive manufacturing", also known as 3-D printing. Starting from a CAD model, 3-D printing uses a specially designed "printer" that builds up a part layer by layer at a time. Each layer may be only a few microns thick. There are 3-D printing solutions that use powdered metal and heat to make metallic parts and there are also ones that use plastics. This is no longer exotic technology, with well-respected consumer models starting under $1500.[36]

Several CubeSats have used 3-D printing for part of their satellite, including KySat-2 from the University of Kentucky[37] and satellites from the University of Montana, PrintSat[38] and RAMPART.[39] Highlighting the pace of change possible on a small level, the ability to make a new version quickly – including implementing changes through overnight reprints of parts was tested by the University of Rome and University of Bologna as they developed a CubeSat mission.[40] Stretching the experimentation further, PrintTheBus has the goal of using 3-D printing to build an entire SmallSat bus including integrated fuel tanks as a part of its competitive effort to win the NASA Cube Quest Challenge.[41] A more operationally oriented use of 3-D printing was the Altair bus proposed by Millennium Space Systems for the DARPA Space Enabled Effects for Military Engagements (SEE-ME) program. A 27-U CubeSat (30 cm x 30 cm x 30 cm) with the bus entirely 3-D printed, the Altair bus offered Millennium Space Systems a low cost, rapidly manufactured, and flexible platform for SEE-ME[42] and now is offered commercially.[43]

The exploitation of 3-D printing technology in the SmallSat domain does highlight the change of pace in the domain, but it is also instructive to look at how "bullets" within a single effort or company can be rapidly fired. The leading example of this is Planet Labs. Planet Labs is launching a constellation of LEO CubeSats whose mission is to perform rapid revisit imaging of the Earth's surface. Launched in clusters called "Flocks", each 'Dove" is a 3U CubeSat that can collect images with a resolution between 3 and 5 meters.[44] With hundreds of Doves to be launched, Planet Labs is not just copying a single design that is set in stone. Instead they are rapidly building each batch of Doves and making design changes based on the lessons learned from the previous generation of Doves performance. Planet Labs looks at this like the commercial software industry, with rapid design iterations and a mantra unusual in the space industry of "Release Early, Release Often".[45] In the "Bullets" analogy, Planet Labs is a machine gun compared to the traditional satellite domain model of heavy artillery, albeit that the scope of the bullets are improvements to their own product versus the cross domain technology bullet of 3-D printing.

## MIGRATION

Looking at the SmallSat domain, it is clear that it is serving as a laboratory, which then leads to the examination of what trends from that laboratory are migrating to the traditional satellite domain. It is early in the symbiosis and migration so those trends are less clear at this point, but it should be expected that as the relationships between the SmallSat domain and the traditional satellite domain mature, these trend will become emphasized and more crossflow will occur. With the slower pace of technical change and the much more competitive environment that results from fewer mission opportunities (albeit of a larger scale), technical trends are more difficult to capture, but some can be identified. As the traditional satellite domain is driven by risk and larger economic issues, initially the predominant migration is on the business practice side, as it carries less risk and offers more reward.

***Technology Migration***

From the technical perspective, one trend that has already started to migrate is the use of 3-D printing. Traditional satellites programs have started to experiment with additive manufacturing, looking to capitalize on the cost and weight savings that can come with creating lightweight parts with complex shapes that previously required complex and expensive castings, wasteful and time consuming machining, or were not possible without using multiple parts. Airbus cites the use of a 3-D printed bracket on the Eurostar 3000 geostationary communications satellite bus,[46] where the bracket itself is a complex shape that was more easily and effectively made through the use of 3-D printing. Going significantly further, Lockheed Martin is planning the use of additive manufacturing in their modernized versions of their A2100 communications satellite bus.[47] They advertise this as a key cost and technical advantage of the modernization. Considering that Lockheed Martin has sold 40 A2100 satellites over the past two decades,[48] this large and public adoption of 3-D printing is a significant sign that the risk as perceived by Lockheed Martin has been significantly reduced. While a small start, when compared to the use the 3-D printing in SmallSats, this trend can be expected to continue, especially as the SmallSat domain continues to prove out the expanded role 3-D printing can serve in satellite construction.

Modularity has become a trend in the traditional satellite market as well. While the reuse of flight proven systems has always been a key aspect of how systems were constructed, reuse does not necessarily equal modularity. While a modular component is inherently designed to be reused, it is also designed to be easily reused in the same way or in combination with other modular units in such as manner as to require little or no alteration. Reuse of components that are not designed to be modular from the start may require extensive alteration and engineering effort. Designing components to be modular can be more expensive and time consuming than a dedicated single use component. Modular systems also have overhead – in performance, data flow, or engineering effort – that must be accommodated that impose a penalty on the initial system deployment. The payoff is the significant cost and time reduction in later systems that use those components. Larger traditional satellites will start to become more modular as they enter redesigns and are refreshed. One example of a modular system produced by a traditional satellite domain manufacturer is the Boeing Phoenix line of small satellites. The line of satellites, introduced in 2014 highlights the reuse of flight proven systems, but also has the ability to quickly configure and deliver the satellite for a variety of missions, which is a result of a modular design.[49]

A trend only starting to be seen in the traditional satellite base is that of "data center"-like command and control operations. While the SmallSat domain has adopted a CONOPS based on lights out operations through comprehensive automation, VMs, Cloud based systems, and web browsers as the primary user interface, the traditional satellite domain has been more risk averse and is moving much more slowly in this direction. The major commercial satellite operators have tended to stick to the same paradigm they have used for decades of successful operations, meaning they have generally continued to embrace dedicated servers and "thick" client applications loaded on dedicated workstations. Sunk costs and tight budgets may be slowing the pace of change for this trend. While recently there have been some moves towards virtualization, it is primarily for consolidation of the same set of servers onto a smaller hardware footprint. This is in contrast to having a suite of commodity shared resource virtualized servers as a private cloud. Some small acceptance of web based user interfaces is occurring, but primarily only for remote monitoring planned for use of subject matter experts when not at the operations center. Automation among commercial operators is already commonly used, albeit it is not "lights out" in most cases. For most US Government (USG) systems, there is a use of automation that is not quite at the level used by most commercial satellite operators, but the gap between the two is not as large as it was several years ago. Again, most US Government systems still use dedicated servers and thick clients. As an exception to the paradigm, there is a system that is planning to use these technologies and approach. That system is now in development and leans forward towards the full use of cloud based architectures and web based clients. Operations will still be staffed, albeit at a greatly reduced level as compared to current operations, but this system will still be a significantly change from the previous systems in use.

***Business Migration***

Bridging between the technical and business aspects of the migration is a larger trend that shows just how seriously the traditional satellite domain is taking the SmallSat domain. Establishment of in-house small satellite centers of excellence that seek to leverage the technologies, processes, and culture of the SmallSat domain recognize the value of this migration and symbiosis. Several large companies have devoted a great deal of capital and energy into these centers. Perhaps the first notable effort in this area was the EADS Astrium (now Airbus) 2009 acquisition of Surrey Satellite Technology Limited (SSTL), a longtime leader in the SmallSat domain.[50] At the time of the acquisition, Colin Paynter, the CEO of Astrium in the UK noted, "SSTL has expertise in small satellites and an innovative approach to developing new markets for space."[51] Another clear example of this is Boeing. In 2013 Boeing announced the new line of "Phoenix" small satellites developed by their Phantom Works division.[52] The role of Boeing Phantom Works is to serve as a research and development arm for innovative systems that that incorporate rapid prototyping.[53] While building or acquiring an in house SmallSat center of excellence is one approach, another is to create deep partnerships with SmallSat domain experts. Here, the larger company can leverage the expertise without as much capital outlay or technical risk, and the SmallSat company can gain access to resources - in terms of business / market relationships, technology, and infrastructure – that it otherwise could not afford. One such example of this was signed in early 2014 when ST Electronics of Singapore signed a deal with ATK Space Systems to jointly develop and market small satellites.[54] While ATK has significant experience with small satellites, the deal with ST Electronics was seen as an opportunity to re-invigorate the market in regions where the demand for small satellite systems is on the rise.[55] Another example is where Northrop Grumman Aerospace Systems partnered with Sierra Nevada Corporation to offer a line of small satellites for small missions.[56] Clearly, these partnerships and strategies help them gain a foothold in the SmallSat market, but another key rationale for their effort is to generate crossflow of personnel and innovations to their traditional satellite programs, which are the majority of their space revenue, and enable them to be more competitive in that arena.

The perspective of what the traditional business deal looks like has changed as a result of SmallSats as well. For many decades the traditional satellite domain looked upon satellite manufacturing as a deal that could be structured with low financial risk and a fairly fixed return on that low risk. So, a satellite manufacturer would build the satellite and payload and the end user would finance the deal, and the contract between them was a straightforward contract for goods and services. However, the nature of that deal has begun to change. ViViSat, an on-orbit servicing system designed to dock with geostationary satellites and provide attitude and stationkeeping services, is a Joint Venture (JV) between US Space LLC and Orbital-ATK.[57] ViViSat provides an example of how the manufacturer, in this case Orbital-ATK, is accepting a share of the overall business risk in return for the end system profits. A more recent potential JV also highlights this. OneWeb, which has secured initial funding to start building out their 648 satellite constellation, is in the process of forming a JV with a company to perform final design and production of their satellites. The companies they are considering – Airbus, Lockheed Martin, OHB, Space Systems/Loral, and Thales Alenia[58] – are all well-established members of the traditional space domain, albeit several have initiated SmallSat efforts in house, or acquired them, as Airbus did with SSTL. One other example for the changing of business deal practices is worth noting, although it is not a JV. Space Systems/Loral made a deal with Skybox to build 13 of their follow on imaging satellites, which were designed by Skybox. As a part of the deal Space Systems/Loral gained license rights to reuse the design for their own purposes.[59]

The two points above help make case for business practices change, but underpinning all of this is the realization that price is more of a driver than ever before. This emphasis on price is another business trend for the traditional domain that shows the migration from the SmallSat domain. In very expensive and high risk systems where one failure can ruin a company that is dependent upon satellites, expertise and low risk were the primary features advertised. With the advent of the highly price conscious SmallSat domain, the price pressure has started to refresh how the traditional satellite domain advertises the smaller missions they propose. While larger missions – such as exquisite remote sensing missions or the upcoming surge of high throughput satellites (HTS) are not under the same pressure, it is seen when examining some of the lower mass offerings. This dichotomy is clear in the advertising brochures for two different satellites. The Lockheed Martin A2100 brochure – targeted at a high performance, large geostationary market touts, "Reliability: Our First Priority".[60] The Orbital-ATK advertising for the Geo-Star 2 busses, targeted at smaller geostationary missions highlight the affordability of the spacecraft, "Orbital ATK's GEOStar satellites are the most economical and reliable solution for the small to medium market providing a full complement of payload capabilities."[61]

## FUTURE TRENDS FROM SYMBIOSIS

The trends and migration discussed above touch on just a few of the areas where the symbiosis between the SmallSat and traditional satellite domain has started. Many other migrations and influences are still nascent and may not yet have publically citable data points that support them. Nonetheless, there are some items that are worth discussion and monitoring as they increase the crossflow between domains.

From a technical side, one of the first and most important of these is the change in focus with how the space segment of an end-to-end system is regarded. For several new commercial ventures in the SmallSat domain, the systems are viewed as consumer or commercial data systems. The fact that there is a space segment is secondary, and the company itself views the space segment simply as a medium to be used versus a focus of the company or a core competency. Perhaps Skybox, with its shift from manufacturing satellites to buying satellites is a good example of this, with the reallocation of resources onto data products and uses. This prompts a philosophical shift in how an end-to-end solution is realized. In other words, companies are less constrained by what satellites or sensors are available as a primary system design consideration. Some will use an approach that looks only at what is required to satisfy the data needs and the space segment design considerations are secondary at best.

There will be an increased evolution of COTS standards and modular design approaches. The standards based approach – even if not space standards – will propagate from the SmallSat domain as these continued to be proven on space and on ground. The traditional satellite domain has a number of standards (XTCE, CCSDS, etc.), but they tend to be satellite specific and thus lack the user base, rapid pace of innovations, and commercial tool support to make them as cost effective as many outside standards. As SmallSats prove out these in orbit and provide tools and reusable components they will become accepted as baseline standards usable for larger and more expensive satellites. That push to use outside standards will also assist in making systems more modular, not just at the subsystem or structural level, but also at the component interface level. This will help fuel the third party product marketplace and speed the cycle.

Commodity computing – in the form of VMs and Cloud based systems will also start to become an accepted as a mainstream approach to traditional satellite command and control. The success of efforts underway now will strongly influence this, but the benefits – both from a cost and a CONOPS perspective will drive towards a quicker usage of these types of command and control systems for newly fielded programs.

Both from a technical and a business perspective, there will be a blurring of lines between larger SmallSat and more compact traditional satellite domain offerings. The technology developed by the traditional satellite manufacturers will begin to take on many of the characteristics of the SmallSat domain – 3-D printing, modular construction, and increased use of COTS. The processes used to design, build, and deliver these satellites from the traditional satellite domain will begin to resemble the ones used in the SmallSat domain as the internal SmallSat centers of excellence that that have been stood up begin to take full responsibility for new programs or influence other programs through process reuse or personnel crossflow.

Business trends also bear monitoring. One to watch is the continued sharing of risk and profit. The boom in the small satellite market fueled by data products and services that will be used by a mass market instead of a limited slice of customers will feed this. The temptation for traditional satellite companies will be to look at how they can be more creative and share in the long term profit of the system. Some of these investments will take the form of joint ventures that focus more on the native skills of the traditional satellite domain vendors – such as the production JV that OneWeb is forming. Other new JVs or business partnerships may be for ideas that traditional satellite partners developed, but have only become possible now through the maturing capabilities and lower price points of the SmallSat domain.

In line with that move into the different business environment, a further move by the traditional satellite domain will be to turn partnerships into acquisitions. As key SmallSat vendors and operators prove to be profitable and have intellectual property that becomes more important to major traditional satellite vendors, they will become attractive acquisition targets for the generally much larger and better financed companies. With a highly fractured market for SmallSats already existing and the number of companies for a given product starting to outstrip the demand, the time will come soon when the SmallSat market will naturally need to consolidate. It may not be for one to three years, but when it starts, those companies with solid partnerships in place will be the initial round of targets for the traditional satellite industry.

A trend that will take significant research to explicitly describe will be the cross flow of personnel from the SmallSat domain to the traditional satellite domain. Without a doubt, that flow already exists, however in many cases it is the exception versus the rule. At what point will the flow become a torrent, due to the desire to tap into the knowledge base these engineers have developed? In line with that, what will be the overall impact of nearly every major university offering CubeSat design, development, and operations opportunities? As the pool of students with hands on SmallSat experience in college grows in proportion to the number of educational SmallSats, this experience will be directly applied to the traditional satellite companies where they land. Analysis of this trend will be difficult and will require industry buy-in and sponsorship, but it will be useful to watch and gain feedback on how well college is preparing students for industry and to see if it matches the expectations of both the SmallSat and traditional satellite companies?

## CONCLUSION

SmallSats have been a growing influence across the satellite industry for over a decade, and the recent announcements from major new systems have continued to keep SmallSats at the front of the conversation within the entire industry. Examining the trends within the SmallSat domain – technical and business – as well as the pace of change within that domain helps illustrate why the SmallSat domain is a Disruptive Innovation for the industry as a whole. That disruptive force and will bring change across the entire satellite industry. Which of the trends have migrated, or have started to migrate to the traditional satellite domain is also important, as recognition of the value of the SmallSat domain as a laboratory for the entire industry depends upon the use of those capabilities cultured in the laboratory. Finally, looking forward to any future trend is fraught with peril; however, it too is useful in understanding how the symbiosis between the SmallSat domain and the traditional satellite domain may evolve. In all, the interplay between the two domains is occurring, but is still in an early stage, with potential benefits for both now and in the future.

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