Making SENSE: The SMC/XR Space Weather CubeSat Demonstration
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Abstract — The Development Planning Directorate of the USAF Space and Missile Systems Center (SMC/XR) finds CubeSats to have a wide range of technological and economic potential for meeting a wide variety of the Air Force’s space program requirements. SMC/XR is bridging university research and experimentation to development of practical applications for future space missions by testing CubeSat technologies in an operationally relevant demonstration. The need to develop CubeSat technology for space missions is driven by the possibility of lowering escalating space system costs and creating new tools for space utilities by using a compact standardized form for faster production cycles. The CubeSat space weather mission includes economies of scale via standardized design and interfaces, greater technology refresh rates, increased responsiveness and flexibility, and lower launch costs. In the future, CubeSats may be able to augment operational missions by enabling disaggregation of secondary sensors from primary payloads and thus improve distributed sensing architectures. A quicker fabrication cycle will also enable the most advanced components available in the market and recent updated technology to provide low cost redundancy at multiple orbits and inclinations.

There is potential to expand AF space monitoring capabilities by linking together a network of multiple CubeSats. CubeSats will provide essential measurements from multi-point observations for space weather monitoring and space situational awareness. Space architectures can also be enhanced as planners understand CubeSat capabilities and begin developing future satellite technology within CubeSat standards. If this demonstration is successful, there is a high probability that SMC/XR will conduct additional CubeSat purchases to demonstrate the ability for CubeSats to meet other Air Force mission requirements.

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1. INTRODUCTION
The Space and Missile Systems Center (SMC) is the Air Force’s product center for the development and acquisition of space and missile systems. The role of the Development Planning Directorate (XR) within SMC is to perform development planning activities in order to start "high-confidence" programs of record. SMC/XR does that through focused demonstrations but also through decision support on future concepts to external customers for Analysis of Alternatives and other decision points.

There is currently a major drive by the Air Force to try to develop less expensive and more quickly fielded options for accomplishing its space missions. Among these options is the increased use of small satellites which are both less expensive to develop and launch and easier and faster to build and deploy. Besides being able to realize benefits in cost and scheduling by using smaller satellites, the Air Force will also be able to more quickly field new technologies before they become obsolete.

While the Air Force has already successfully experimented with some small satellites, on the TacSat missions for example, it has yet to test to ability for CubeSats to meet the requirements of an existing mission. The emerging CubeSat technology may lower future space system costs by miniaturizing and space qualifying spacecraft subsystem components and sensors, as well as by providing a much less expensive means for delivering specific mission requirements.

capabilities. The miniaturization of satellites and sensor components, while maintaining some robustness of capabilities, allows for lower costs by using a compact standardized form factor and faster production cycles. Advantages of the CubeSat approach include economies of scale via standardized design and interfaces, greater technology refresh rates, increased responsiveness and flexibility, and lower launch costs. In addition, disaggregation of secondary sensors from a primary satellite has the potential to decouple secondary payload acquisitions from the primary payload and allow for data collection in more diverse orbits than if all sensors were on one spacecraft.

For its first demonstration and assessment of CubeSat’s operational utility, SMC/XR will explore and assess CONOPS for collecting space weather phenomena and ingesting the data into existing and future space weather models while constraining the spacecraft to the Size, Weight, and Power (SWaP) of a 3U CubeSat form factor. To this end, the goal of this demonstration is to mature CubeSat component Bus and Sensor technology and develop a better model for CubeSat life cycle costs in the SEM mission area. The Defense Meteorological Satellite Program Systems Group at SMC (DSMG) will receive data from the demonstration for analysis of potential alternatives for decisions related to determining future architectures and systems. The demonstration will leverage existing CubeSat components and technology investments, as available, to address NPOESS IORD-II threshold requirements in Electron Density Profile, and Ionospheric Scintillation, as stated in EDR 4.1.6.7.5 and EDR 4.1.6.7.9 respectively. 5

2. CUBE S A T S AS PART OF THE AIR FORCE’S FUTURE

It is a reality that many of the air platforms and other systems that the Air Force employs will continue to be needed and remain in use long after they are first introduced into operation. Yet such long-life systems often make integrating new technology-derived updates into them inherently difficult and costly. This is particularly true when systems are not developed with architectures specifically designed to accommodate such future upgrades. At the same time, technologies continue to advance at an increasingly faster pace, and worldwide access to the resulting military systems developed from them is also increasing rapidly.6

The result is that the global “technology refresh rate” is now far faster than just a decade or two ago. Air Force capabilities based on systems designed for long-life use will remain appropriate for some applications, however adversary capabilities obtained with less exquisite systems may have increasing access to faster technology refresh cycles. For many types of systems, it will become increasingly difficult for the Air Force to maintain sufficient technology advantage without itself having access to substantially faster technology refresh rates.7

Technologies need to be developed to allow subsystems, if not entire systems, to be inherently “expendable by design” in the sense that they are designed and integrated with the specific intent to replace them with newer technology after far shorter usage than is the case today. In part, this requires new technologies that can enable key system functions to be implemented at much lower cost. It also requires advances in technologies for “open architectures” that are secure but can enable ready integration of successive generations of newer subsystems.8 CubeSats fit nicely into this forecast mission requirement.

Technologies are enabling a range of ‘small sats’ with masses below about 200 kg, some of which can already today provide significant military capabilities. They include microsatellites with masses between 10-100 kg, nanosatellites with masses between 1-10 kg, and picosatellites with masses below 1 kg. The latter include “CubeSats” measuring just 10-cm on a side, which meet published design standards that allow their deployment by common low-cost mechanisms. Combined materiel and launch costs for such systems are as low as $100K. They are drawing extensive interest from universities, companies, and others around the world, and numerous such systems have been launched. Efforts are underway to develop low-cost, standardized, on demand orbital imaging systems for such small satellites. They represent a further aspect of the increasing low-cost access to space that is available to numerous potential adversaries.9

Table 1. CubeSat mission capability today, in 5 years, and in 10 years

<table>
<thead>
<tr>
<th>Mission</th>
<th>Today</th>
<th>5 years</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDR</td>
<td>ISIM</td>
<td>ISIM</td>
<td>ISIM</td>
</tr>
<tr>
<td>CMD</td>
<td>ISIM</td>
<td>ISIM</td>
<td>ISIM</td>
</tr>
<tr>
<td>SDR</td>
<td>ISIM</td>
<td>ISIM</td>
<td>ISIM</td>
</tr>
<tr>
<td>SSL</td>
<td>ISIM</td>
<td>ISIM</td>
<td>ISIM</td>
</tr>
<tr>
<td>SRT</td>
<td>ISIM</td>
<td>ISIM</td>
<td>ISIM</td>
</tr>
</tbody>
</table>

7 Id. at 48-49.
8 Id. at 49.
9 Id. at 26.
3. SMC/XR NANO SAT CONCEPT DEVELOPMENT

Concurrently with the development of SENSE, SMC/XR started to lay the foundation to a broader effort to fully understand the technical, operational, and programmatic implications of using NanoSats for Air Force missions. SMC/XR acknowledges that the technical aspect of a system concept is not the complete picture. The operational aspects, such as launch and ground systems, and the programmatic aspects are equally important. Through SMC/XR processes, NanoSat concepts are considered and understood when developing alternatives for future system development. This effort will have achieved its stated purpose when NanoSat concepts are naturally considered for future Air Force missions and the implications of using them are fully understood. However, future demonstrations in SMC/XR after SENSE will have to show a needed military capability rather than proving the NanoSat form factor.10

SMC/XR develops concepts and captures them in Concept Characterization and Technology descriptions (CCTDs) through its development planning process.11 These concepts are based on identified capability needs and are designed to meet specific requirements as identified by the user. The NanoSat effort aims to contribute to the development planning process by writing CCTDs that use NanoSats to deliver the needed capability. As part of the CDTD description, needed technology development is described. These technology needs will be communicated to technology development centers both internal and external to government. Currently, the NanoSat team is identifying communication concepts to support a larger development planning effort for the Military Satellite Communication capability area being performed within SMC/XR. Additionally, externally available is the ability to submit concepts to SMC/XR at any time. The desired format for CCTDs can be provided by request to this paper’s authors.12

The operational aspects of NanoSats are also being studied within SMC/XR. Because of the lower cost of NanoSats compared to larger satellites, many concepts involve deploying larger numbers of them into a constellation. A byproduct of larger constellations is that the criticality to the overall objectives of the mission from any one spacecraft can decrease. These two factors change the operational tempo while also possibly changing the necessary mission assurance required when commanding any one particular spacecraft. Larger numbers of spacecraft will also contribute to the space debris problem requiring plans for mitigation and disposal. SMC/XR is exploring the implications of Nanosats and future Nanosat constellations as it relates to satellite operations in collaboration with SMC Space Development and Test Wing (SDTW) and internally with satellite operations developmental planning efforts.13

Reliable access to space is a key enabler for NanoSat missions. The first significant problem is the ability to access the appropriate orbit if a rideshare method for launch is employed. The second concern is the ability to access space on a regular and predictable timeline to enable continued replenishment that shorter life NanoSats could require. SMC/XR is involved in the rideshare community, which includes participation at the Small Payload Rideshare Workshop and staying abreast of launch vehicle options and launch vehicle interface mechanisms being developed in other organizations. While currently SMC/XR has no intention to take a leadership role in defining launch options, its involvement with those who are is critical to the development of realistic system concepts that can be promoted and explored for the Air Force.14

Often the allure of NanoSats is based on the promise they offer a lower cost alternative to more traditional satellite approaches. While we have seen extremely low cost satellites developed, launched, and operated, it is not yet fully known what the impact will be from increased mission assurance requirements on operational satellites, launch costs based on the need to continually replenish assets into specific orbits, the development of a dedicated ground architecture and other operational costs. SMC/XR is examining these issues in several ways. First, spacecraft cost models, which are largely based on parametric techniques, are being extended into this class of spacecraft to allow for more accurate development cost estimates. Additionally, as more missions are conducted, a greater understanding of system reliability and design life will emerge which allows for a better understanding of how this approach compares to larger spacecraft. Future development and demonstrations, to include SENSE, will eliminate some of these unknowns.15

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13 Id.
14 Id.
15 Id.
4. CUBESAT MARKET RESEARCH

SMC/XR conducted a two-pronged market research effort by doing the following: (1) a CubeSat feasibility study to analyze the maturity of the current capability of a CubeSat form factor, and (2) issuing a request for information (RFI) in December 2009 to request industry and academic feedback on the feasibility of performing a space weather mission with CubeSats.

CubeSat Feasibility Study

SMC/XR has been involved in the development of NanoSats in an indirect way for at least 5 years through its support of the The Aerospace Corporation’s PicoSatellite and AeroCube efforts. Since January 2009, SMC/XR has focused on the military applicability of NanoSats for Air Force missions. During spring 2009, SMC/XR conducted a study to determine which Air Force mission areas could be addressed by CubeSats.

CubeSat technology has come a long way from its initial conception. The low cost of entry has the potential for a tremendous increase in space developers. It moves a class of satellites close to a commodity item that could be made from a kit or ordered online, customized from a menu-selected set of options. However, there still is plenty of development in key bus technology to be done. Areas needing further work include propulsion, attitude determination and control, power, and communication. Table 3 shows the current, five-year, and ten-year projections of capabilities for a 1U and 3U CubeSat in these four technology areas.16

The standard 1U CubeSat form-factor is a 10cm x 10cm x 10cm cube. This demonstration will focus on the 3U form factor that has the following dimensions: 10cm x 10cm x 34cm. A deployment mechanism, the Poly Picosat Orbital Deployer (P-POD), has been standardized on many launch opportunities. 3U CubeSats have been standardized on many launch vehicles decreasing integration complexity and cost to deploy satellites that meet the CubeSat form factor. The procurement consists of two launch-ready CubeSats, each with one unique SEM payload, two P-PODS, and the execution of a single launch with one year on-orbit operations and additional 1 year options for periodic contacts with the CubeSat. These options would further demonstrate long term reliability and provide additional data to improve the space weather model at low cost. Additional tasks include final reports upon completion of on-orbit check-out by the space vehicle provider and data analysis reports upon completion of 1 year on-orbit time to be completed by AFRL and the space weather model owner.

Also, a new thought process for satellite design is emerging to support rapid design, assembly, checkout, launch and on-orbit checkout. AFRL developed a satellite called PnPSat17 (Plug-and-Play Satellite) to mature this approach, and design features are now being applied to CubeSats through an AFRL/RV approach called nanoSPA18 (nanometer Space PnP Avionics). Part of the success in such projects is setting up standardized interfaces. With standardized interfaces one opens the architecture of CubeSats much like IBM’s PC revolutionized the personal computer market. Having some degree of a design abstraction where the operational basics can be covered is useful. All CubeSats will need TT&C, a ground terminal, satellite bus management, scheduling of resources, and payload control.19

CubeSats provide a means to demonstrate and validate new technologies. There is more work that has to be done to determine the functions best suited to CubeSats within military mission areas. CubeSats will always be limited in capability compared to the performance levels of larger satellites. However, focused capabilities can be manifested on the CubeSat platform so larger space assets can do more exquisite functions that require their superior performance. Work is under way to develop modest CubeSat remote sensors, environmental monitors, and simple communication repeaters.20

The main outcome of this study was the identification that the Space Environmental Monitoring (SEM) mission area leant itself to the most immediate application of CubeSats. This was based on the availability of space weather sensors that fit the small form factor as well as less stringent

Table 3. Key 1U and 3U CubeSat technology today, in 5 years, and in 10 years

<table>
<thead>
<tr>
<th>Technology</th>
<th>Today</th>
<th>5 Years</th>
<th>10+ Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>Capability</td>
<td>Technology</td>
<td>TRL</td>
</tr>
<tr>
<td>Example(s): 1U Cubesat - 10 Watts</td>
<td>Solar cells – TRL 4</td>
<td>Example(s): 1U Cubesat - 10 Watts</td>
<td>Solar cells – TRL 4</td>
</tr>
<tr>
<td>Uses:</td>
<td>comm., electric thrusters, payload</td>
<td>Uses:</td>
<td>comm., electric thrusters, payload</td>
</tr>
<tr>
<td>Communication (data rates)</td>
<td>Capability</td>
<td>Technology</td>
<td>TRL</td>
</tr>
<tr>
<td>Example(s): 1U &amp; 3U Cubesat - 10 Mbps</td>
<td>Enhanced triple junction solar cells – TRL 5</td>
<td>Example(s): 1U &amp; 3U Cubesat - 10 Mbps</td>
<td>Enhanced triple junction solar cells – TRL 5</td>
</tr>
<tr>
<td>Uses:</td>
<td>orbit plane changes, LEO to GEO</td>
<td>Uses:</td>
<td>orbit plane changes, LEO to GEO</td>
</tr>
<tr>
<td>Power (orbit average power)</td>
<td>Capability</td>
<td>Technology</td>
<td>TRL</td>
</tr>
<tr>
<td>Example(s): 1U Cubesat - 5 Watts</td>
<td>Thin film solar cells – TRL 5</td>
<td>Example(s): 1U Cubesat - 5 Watts</td>
<td>Thin film solar cells – TRL 5</td>
</tr>
<tr>
<td>Uses:</td>
<td>orbit plane changes, LEO to GEO</td>
<td>Uses:</td>
<td>orbit plane changes, LEO to GEO</td>
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</table>


20 Id.
spacecraft bus requirements such as pointing control and data downlink capacity.²¹

RFI

XR’s RFI asked industry and academia for viable CubeSat solutions that: (1) fit the CubeSat 3U SWaP; (2) meet the specific NPOESS IORD requirements regarding TEC and scintillation; (3) provide a 12-month solution for the requirements; (4) de-orbit within five years; (5) contain Type 1 or AES 256 encryption; (6) use TT&C compatible with existing AF infrastructure; (7) address mission operations concepts; and (8) describe data analysis concepts.

XR received a substantial quantity of responses, mainly from industry but also some from academia and national labs. Generally, the responses indicated that options exist to feed data into operationally representative model. Responses also indicated SEM payloads that fit within the CubeSat form factor.

5. PROJECT DESCRIPTION

The SENSE CubeSat Demonstration is a SMC/XR concept as a first step assessing CubeSats applicability to perform AFSPC missions. The selection of the SEM mission area was driven by a March 2009 XR funded study of CubeSat capabilities and applicability to AFSPC missions. The study looked across all AFSPC mission areas and selected SEM as the first CubeSat demonstration mission area due to technical feasibility.

The risk of miniaturizing SEM payloads has been moderated by previous development efforts. At the August 24 – 25 Air Force 2009 Space Experiments Review Board (SERB), six of the approximately 34 proposed experiments were SEM related payloads with advertised Technology Readiness Level (TRL) of at least 5. Several had size, weight and power that were compatible with CubeSat payload constraints. A successful CubeSat demonstration would raise the maturity of a variety of components and processes to TRL level 7 or higher.

On 16 February 2010, at the Space and Missiles Center (SMC) Development Planning (XR) Program Management Review (PMR), SMC/CC stated that the Air Force should invest in CubeSats and directed XR to investigate the applicability of CubeSat technology to perform future operational AFSPC missions. The XR Director authorized the Space Projects Office (XRF) to pursue a SEM mission as the first demonstration utilizing the CubeSat form factor.

The main objectives of the project are the following:

1) Leverage investment in miniaturized sensors to address National Polar-Orbiting Environmental Satellite System (NPOESS) IORD-II requirements in Ionospheric, Electron Density Profile characteristics, and Scintillation measurements.
2) Integrate and launch two 3U CubeSats to collect space weather phenomena compatible with the Global Assimilation of Ionospheric Measurements Model (GAIM).
3) Conduct 12 months of space weather data collection.
4) Mature low risk bus technologies, such as miniaturized S-band radio for Tracking Telemetry and Command (TT&C), required for an operational system.
5) Leverage rideshare opportunity from Space Test Program (STP).
6) De-orbit within 25 years per DoD requirements.

XR will oversee and manage the project cost, schedule, and performance via a set of programmatic and technical working groups with participation from all relevant SMC offices managing various aspects of the project. Specifically, XR will directly lead the space segment. XR will be collaborating with leads at Space Development Test Wing (SDTW) and Air Force Research Laboratory (AFRL). SDTW will lead the launch services segment and the ground segment. AFRL Space Weather Center of Excellence has extensive experience working with the operational Air Force Weather Agency (AFWA) ionospheric model and will be responsible for the mission data analysis. XR will share data analysis and final reports with DMSG.

Contract award is expected in the second quarter of FY11. SEM development, fabrication and integration will require approximately 14 months from the date of contract award. A launch opportunity has not been identified at this time. The earliest launch that could be supported would be in summer 2012. SEM operations and data analysis and mission validation efforts are scheduled to last for 12 months following launch.

5. CONCLUSION

The CubeSat FY11 demonstration is SMC/XR’s first step toward the advancement and potential deployment of CubeSat technology for an operational AFSPC mission. XR’s intent is to investigate the utility of leveraging excess launch capacity as rideshare opportunities for CubeSats and to mature a CONOPS to procure such launch opportunities. The recent evolution of CubeSat technology has demonstrated that every twelve to eighteen months a significant advancement in CubeSat technology can be accomplished. This first demonstration will test the applicability of CubeSat technology to provide limited SEM capability in an operationally relevant environment. Future demonstrations will leverage the results of applied research to rapidly develop next generation bus and payload technologies. Additionally, they will continue to mature both bus and payload technologies to TRL 7 and focus on validating CONOPS before transitioning to a system wing for procurement. Future acquisition plans will be developed when authority is granted and funding made available to pursue additional CubeSat demonstrations for test or technology transition purposes.

REFERENCES


BIOGRAPHIES

Joseph Simonds is the Director of Contracting for SMC/XR. He has served as a senior advisor in the Acquisition Center of Excellence and the Contract Review Committee. He is the former Deputy Director of Contracting for Launch Vehicles and worked in the GPS program office and the Satellite Control office as a business advisor and contracting officer. He has a BA from Antioch University and attended Boston University and UCLA. He set the Alternate Infrared Satellite System (AIRSS) and the Conventional Strike Missile (CSM) programs. He also recently completed a successful joint-forces demonstration of space-based radar exploitation. He co-authored the following works:


Captain Peter Mastro is a Developmental Engineer with the United States Air Force’s Space and Missile System Center. He has spent the majority of his career working on pre-acquisition concept maturation and technology development, first in the Air Force Research Laboratory’s Human Effectiveness Directorate and currently in SMC’s Development Planning Directorate (SMC/XR). Within SMC/XR, Captain Mastro leads the effort to consider NanoSatellites for use as Air Force operational systems. Captain Mastro received a Bachelor’s degree in Electrical Engineering from the United States Air Force Academy and a Master’s degree in Systems Engineering from the Air Force Institute of Technology. He co-authored the following works:

David O’Brien is a Contract Specialist in the Federal Career Intern Program (FCIP) for the Development Planning Directorate (XRC) at Space and Missile Systems Center (SMC). Prior to government service, Mr. O’Brien was the business strategist and co-launched BetterGrads, a Silicon Valley based nonprofit startup focusing on the education of high school students in the opportunities and transitions beyond high school. Mr. O’Brien earned a Masters of Business Administration through Regent University’s school of Global Leadership and Entrepreneurship in 2008. Prior to His MBA activities, he studied Leadership and Innovation at Oxford University in 2006. Mr. O’Brien received his Bachelor of Science degree in Organizational Leadership and Management from Regent University in 2006.

George Sullivan is a Presidential Management Fellow working as a senior contract specialist in SMC/XR. Prior to SMC/XR, George also worked as a contract specialist in the Range Division of the Launch and Range Space Wing, Space and Missile Systems Center, Los Angeles Air Force Base. Before SMC, George has worked for BP in managerial accounting, as a business plan consultant for the Sequoia National Forest and for four years as an investment banker in Moscow, Russia. George received his Bachelor of Arts in Russian Studies from the University of California, Los Angeles in 1996. He also received an MBA in International Management (Focus – Finance) with distinction from Thunderbird School of Global Management in 2003 and a Juris Doctor (cum laude) from Florida International University in 2008. George is an active member of the Florida Bar Association and American Bar Association. George co-authored the following works: