

## The First US Army Satellite in Fifty Years: SMDC-ONE First Flight Results

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### ABSTRACT

Miniaturization trends are enabling development of small, inexpensive nanosatellites with significant capabilities in the “CubeSat” form factor. Although widely used within the academic community as teaching tools, CubeSats have recently been recognized as having the potential to provide capabilities relevant to military operations. CubeSats could be tasked from within theater to directly support the land warfighter’s need for real-time tactical information. The US Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT) Technology Center has successfully carried out an on-orbit technology demonstration of a low-cost nanosatellite called the Space and Missile Defense Command - Operational Nanosatellite Effect, or SMDC-ONE.

Ten SMDC-ONE nanosatellites were developed within one year and delivered in April 2009. These nanosatellites have a communications payload to 1) receive data from unattended ground sensor (UGS) “gateway” transmitters and 2) relay text and image data. SMDC-ONE Flight A was launched into a 300-kilometer orbit on 8 December 2010 on a SpaceX Falcon 9 rocket.

Technology Center engineers along with several student engineers performed command and control of SMDC-ONE. The team established ground stations at Redstone Arsenal in Huntsville, AL and at Colorado Springs, CO. Where technical challenges were encountered, procedures were developed to address them. SMDC-ONE Flight A remained functional until its reentry on 12 January 2011 after 35 days on orbit. Having demonstrated low data rate beyond line-of-sight communications and unattended ground sensor data exfiltration, SMDC-ONE achieved Technology Readiness Level 7 and provided a firm foundation for future Army nanosatellite development.

This paper discusses the highly successful on-orbit demonstration of the first SMDC-ONE spacecraft.

**KEYWORDS:** Nanosatellite, CubeSat, microsatellite, low-cost, low earth orbit, LEO, space force enhancement, communications, tactical space, Army, USASMDC/ARSTRAT , SMDC.

## INTRODUCTION

The United States Army is the largest user of space systems data within the Department of Defense. Despite this heavy dependence on data from space, the Army has historically elected to leverage existing space systems. The last Army-developed satellite, until now, was the Courier 1B, a communications satellite developed by the Signal Corps and launched on 4 October 1960. The Army has and will continue to depend largely on existing and future “big space” systems to conduct the full spectrum of combat operations.

As the Army combat regime evolves from a Cold War set piece engagement modality to today’s environment of asymmetric warfare and continuous multi-theater operations, a number of single requirement niche operations in localized areas have emerged that are either underserved or not supported at all by current satellites. Unmanned Aerial Vehicles (UAVs) have become ubiquitous in addressing some of these operational gaps, and the Operationally Responsive Space (ORS) Office was formed to focus technologies to meet warfighter needs more responsively with lower cost and more rapidly fielded space systems.

Concurrent with the changing nature of Army combat operations is the rapid advancement of many technologies, particularly in the field of electronics miniaturization (e.g. smart phones), that have opened the door for small, highly affordable satellites designed to perform limited niche missions. These tremendous technical advances were first exploited in this country by universities seeking to rapidly develop satellites at very low cost for educational purposes. The CubeSat emerged as the standard for many academic institutions seeking to place student projects into space quickly and inexpensively. Although valued greatly by the academic community, CubeSat-class satellites were initially viewed by most traditional satellite developers and users as having little practical value for government and industrial applications.

Taking all of these realities into account, the CubeSat-class satellite today offers a unique opportunity to address certain mission needs for the Army. New trends in the miniaturization of electronic components driven to a large degree by advances in cell phone and Personal Digital Assistant (PDA) technologies are leading to smaller satellites with significant capabilities in the nanosatellite (1-10 kg) and microsatellite (10-100 kg) classes. From an individual satellite standpoint, these very small space vehicles can be developed

rapidly within the ORS Tier 3 timeline (one year) at very low unit cost. From a systems standpoint, nanosatellites/microsatellites can be proliferated inexpensively into constellations that would achieve useful and affordable persistence over multiple regions of interest to the Army. Since the Army’s geographic focus may not stretch to the earth’s poles for many missions, constellations of nanosatellites/microsatellites can be limited in number to provide coverage in latitudinal swaths that address specific regions of interest at greatly reduced cost.

Constellations of nanosatellites/microsatellites could be sufficiently affordable to allow application against a specific mission need in a limited geographical area. Such constellations would have additional benefits such as being highly survivable; amenable to being frequently refreshed with technology advances due to shorter on-orbit life expectancy; able to leverage manufacturing economies of scale; having good signal strength in Low Earth Orbit (LEO); and having the potential for being rapidly reconstituted on a per-unit basis.

Based on the promise that nanosatellites/microsatellites potentially hold for the Army, and because of capability niches that this class of satellite could address, the Army’s Space and Missile Defense Command decided in the spring of 2008 to once again move the Army into the satellite development arena.

## NANOSATELLITES FOR BEYOND-LINE-OF-SIGHT COMMUNICATIONS

This section describes the nanosatellite/microsatellite efforts that took a government organization and its industry partner, neither of which had ever developed a satellite, from a standing start to the delivery within twelve months and eventual launch of the first of eight flight-qualified nanosatellites designed to address a specific warfighter mission need.

### *The Need for Beyond-Line-of-Sight Communications*

On today’s battlefield, the tactical land warfighter does not always get the communications support he or she desires from the existing constellations of large, expensive military and commercial communications satellites. Constellations of satellites dedicated to tactical warfighters would greatly benefit command, control and communications as well as situational awareness data dissemination to tactical land forces.

There is an emerging niche for satellites focused on tactical missions such as data exfiltration from ground sensors, text message relay, voice communications and other missions. Data exfiltration and text messaging are both fairly low data rate satellite communications applications and are relatively straightforward technologically.



**Figure 1. Space and Missile Defense Command - Operational Nanosatellite Effect (SMDC-ONE).**

To be practical in terms of utility to the tactical warfighter, nanosatellites used for beyond-line-of-sight communications must have an intuitive user segment that is simple to employ. Ideally any new satellites should simply be interoperable with existing hand-held or mobile communications equipment. The satellites should also be available 24/7 to provide persistent access within a given area. Because a fairly large constellation would be needed, individual satellite unit cost would need to be very low, in the range of a few hundred thousand dollars. Finally, the satellites should be responsively deployable and easily replenished on orbit in accordance with the rapid deployment principles put forth by the Department of Defense's ORS Office.

#### ***SMDC-ONE Technical Approach***

To investigate the feasibility of a beyond-line-of-sight (BLOS) communications nanosatellite constellation, the US Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT) is executing the Space and Missile Defense Command – Operational Nanosatellite Effect (SMDC-ONE) technology demonstrations. The SMDC-ONE initiative succeeded in designing, developing, building and

acceptance testing eight nanosatellite flight units as well as qualification testing of two qualification units within a one-year timeframe. Delivery was in April 2009. One of the flight units has already been launched and operated in low earth orbit. A custom communications payload provided a capability to support simulated and actual ground sensors and text message relay. More complex communications applications are being developed.

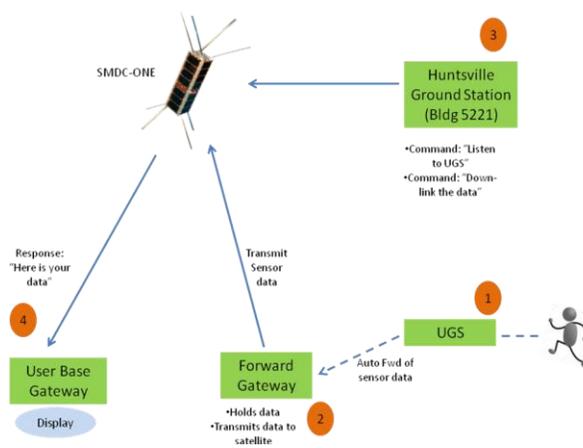
USASMDC/ARSTRAT's initial focus for SMDC-ONE was on communications with emphasis on data exfiltration; that is, to uplink data of interest from ground sensors and then downlink that data to a site beyond the line of sight from the originating sensor location. While there are military and commercial assets that can and do routinely provide communications from warfighters in one area to another location within or outside that theater, the challenge for the soldier in the field is to obtain the critical data that he or she needs in a timely manner. It would be strongly advantageous for land warfighters to have their own space assets to provide BLOS communications. This is especially the case in areas of mountainous terrain where line-of-sight access to satellites or airborne communications is limited or non-existent. A constellation of small satellites in low earth orbit could provide communications access that heretofore has not existed.

The approach that USASMDC/ARSTRAT took for its first indigenous satellite program is to explore the nanosatellite (1-10 kg) class while using the California Polytechnic State University (Cal Poly) CubeSat 3U form. In early 2009 the SMDC-ONE program completed the construction and testing of two qualification nanosatellites followed by eight flight nanosatellites. The qualification units underwent more rigorous testing in order to verify or qualify that the SMDC-ONE design would work after exposure to launch and space conditions. Each was designed to be deployed from a Poly-Picosatellite Orbital Deployer (P-POD). One of the qualification units underwent rigorous shock, random vibration and thermal-vacuum testing at the prime contractor and National Aeronautics and Space Administration (NASA) locations. Thermal balancing and antenna deployment tests were conducted during thermal-vacuum testing at the prime contractor's location. Radio frequency characterization testing was conducted at US Army facilities on Redstone Arsenal. Careful coordination was conducted with Cal Poly and SRI International representatives to ensure conformity with the Cal Poly standards and leveraging of their experiences with CubeSats.

#### ***SMDC-ONE Concept of Operations***

The first SMDC-ONE flight demonstration involved the SMDC-ONE Flight A nanosatellite, which was launched on 8 December 2010 as a secondary payload on a Falcon 9 from Cape Canaveral, Florida. The nanosatellite was placed into a very low 300 km (186 mi) altitude orbit due to the mission requirements of the primary Falcon 9 payload. While designed for a one-year functional life, the extremely low orbit only allowed for 35 days of experimentation before SMDC-ONE Flight A re-entered the earth's atmosphere. The SMDC-ONE nanosatellite received its tasking from a simulated Forward Operating Base (FOB) or Command and Control (C2) ground station as shown in Figure 4. The initial SMDC-ONE satellites do not have on-board GPS, so the tasking and timing information was provided from the C2 ground stations after initial on-orbit checkout of the nanosatellite.

The program has three C2 ground stations: one at the USASMDC/ARSTRAT Headquarters Concept Analysis Lab in Huntsville, AL; a second unit held in reserve at the same location; and the third at USASMDC/ARSTRAT's Battle Lab in Colorado Springs. After initial on-orbit checkout of the nanosatellite by USASMDC/ARSTRAT Huntsville personnel, other tests and experiments were conducted by the USASMDC/ARSTRAT's Battle Lab in Colorado Springs. Both ground stations were used in both the checkout and experimentation phases. On some orbits the ground track covered both C2 stations, which are separated by about 1687 km (1047 mi). Text messages and images were transmitted from the first station in the ground track and quickly relayed to the second station.



**Figure 2. SMDC-ONE Concept of Operations.**

The first demonstration consisted of text and imagery data transmitted from one or both of the C2 ground stations to the other. The tasking data and other data

files were received by the nanosatellite (as its ground track accessed Huntsville and/or Colorado Springs), stored on-board, and then transmitted to the C2 ground station(s) as directed. Follow-on demonstrations involved tasking the SMDC-ONE Flight A nanosatellite to collect simulated ground sensor data as well as data from actual ground sensors and relay it to one or the other C2 ground station.

SMDC-ONE is the first Army-developed satellite since Courier 1B in 1960. It has taught a new generation of Army engineers much about developing on-orbit technology and conducting satellite operations for the tactical land warfighter, and is just the first in what may likely be a long line of new Army-developed nano- and microsatellites.

## DEVELOPMENT

The SMDC-ONE nanosatellite development was initiated by the USASMDC/ARSTRAT Commanding General at the time, Lieutenant General (LTG) Kevin Campbell, at the 2008 National Space Symposium in Colorado Springs, Colorado when his speech included a statement that the command would build eight nanosatellites in a year.

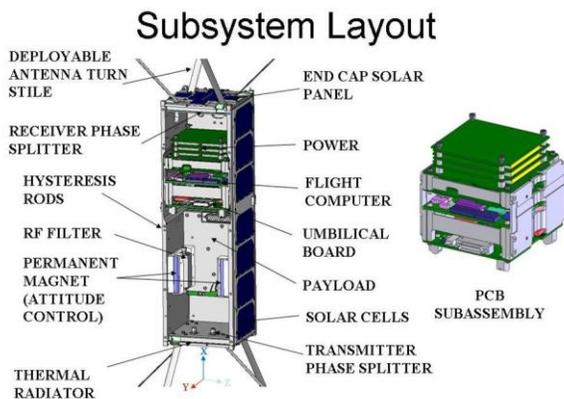
The Army quickly got to work, finalizing contractual details the following month as Miltec, the prime contractor, began designing the spacecraft. A preliminary design review was conducted in August followed by a critical design review in October. In November, the prime contractor provided working space for a USASMDC/ARSTRAT Responsive Space team member to co-locate among the design/development/test team. This was crucial in ensuring adequate communications between the government and contractor teams as well as facilitating prompt technical and programmatic decisions.

As time progressed, the Concept Analysis Lab and the Battle Lab became increasingly involved, especially as plans for the ground segment developed. These organizational elements deepened their knowledge of the satellite design and contributed radio frequency (RF) expertise and experience in working with military satellites as well as practical amateur radio operator skills.

## Satellite Design

SMDC-ONE was designed for an orbital life of approximately one year. The satellite was designed to a reference mission with an altitude of 400 km. The change from the design reference orbit to the slightly elliptical initial orbit at approximately 304 x 285 km

altitude and higher inclination did little to affect functionality due to the robust design of the satellite. The satellite design team did decide to make the frame heavier upon learning that the satellite would be in a lower, higher drag orbit than previously anticipated and that with the turnstile antennas deployed, the drag coefficient would be significantly increased. This meant that the on-orbit life would be reduced to only a few weeks. Increasing the mass of the spacecraft from 3.2 to 4.0 kg increased the on-orbit life projection to approximately one month. This decision helped SMDC-ONE to remain on orbit longer than all but one of the eight CubeSats flying on the same mission.



**Figure 3. SMDC-ONE Subsystem Layout.**

The satellite subsystems and layout are depicted in Figure 3. The satellite was designed with a passive Attitude Determination and Control System (ADACS) to dampen motion in yaw and pitch. The mission requirements for this demonstration did not dictate the need for roll stabilization.

### **Ground Segment**

The ground segment consisted of a laptop computer, radio/RF unit, antenna rotator and antennas. These stations were designed to be highly transportable and easy to use. The ground station has two operational modes: Command and Control (C<sup>2</sup>) and Unattended Ground Sensor (UGS).

Most of the ground station functionality can be accessed in the C<sup>2</sup> mode. C<sup>2</sup> mode allows the user to collect satellite telemetry data, send satellite tasking requests, retrieve relayed data, and extract ground sensor data. In C<sup>2</sup> mode, the ground station initiates all communications with the passing satellite in the form of manual or automated script commands. Typical operations in this mode include requesting information from the satellite or scheduling future satellite

operations; i.e., the C<sup>2</sup> mode is the satellite tasking mode.

The UGS mode requires one station to be the C<sup>2</sup> tasking agent and one ground station serves only as a passive host of data which can be read by the passing satellite. All communication between the satellite and the station in UGS mode is initiated by the satellite.

Both the ground radio and the antenna rotator are controlled through applications on the laptop computer. Prior to a typical satellite pass the ground station user would use the Mission Planner application to generate Doppler tables and pointing tables to tune the radio and antenna rotator respectively. The operator would then switch to C<sup>2</sup> or UGS mode and set up the mission. Typically the operator would initiate transmission at approximately 5 degrees elevation and receive confirmation of a good transmission between 7-10 degrees elevation depending on terrain masking, slant range and other factors.

### **The Months Before Launch**

The satellites were ready for launch in the April 2009 time frame. We identified a launch opportunity in the fall of 2008 when a demonstration mission was arranged by another government organization. During the SMDC-ONE design phase we had submitted paperwork requesting frequency approval/allocation from the Army Spectrum Management Office. This process proved to be long, taking nearly two years to obtain authority to radiate.

An integrator was named (SRI International) and appropriate paperwork was initiated. SRI, working closely with Cal Poly, processed the necessary paperwork with the launch provider, Space Exploration Technologies, Inc. (SpaceX), as preparations were begun to fly on the Falcon 9's second flight. This flight was the first NASA Commercial Orbital Transportation Services (COTS) mission. SpaceX made provisions for accommodating six P-PODs in the Trunk unit of the rocket, located between the second stage and the payload section. The primary payload was the Dragon capsule, designed to carry astronauts and pressurized cargo to and from the International Space Station as well as support other space missions.

The other P-PODs on this journey carried four 1.5U CubeSats from the Los Alamos National Laboratory (LANL), two Colony I 3U CubeSats from the Naval Research Laboratory, and the Mayflower 3U CubeSat from Northrop Grumman Aerospace Systems.

After each organization qualified its design and acceptance tested its satellite(s), the satellites were delivered to SRI where they were integrated into the P-PODs and then acceptance tested as integrated units. Then the seven government CubeSats were moved to the Naval Research Laboratory (NRL) where they were stored. Our government team made several trips to NRL to re-charge the satellite battery every other month to ensure that we would launch with a fully charged battery.

In August 2010, the eight CubeSats and their associated P-PODs were moved to Cape Canaveral, ready for integration with the Falcon 9 rocket.

## LAUNCH

Finally, the launch day arrived. The day before launch, a problem was discovered in the rocket's second stage engine nozzle extension. SpaceX made a dramatic decision to cut 44 inches from the nozzle skirt and to go ahead with launch the following day. Their mission was to deploy the Dragon capsule, have it orbit the earth nearly two times and then re-enter Earth's atmosphere to make a water landing and recovery in the Pacific Ocean. The plan was to launch, drop off the first stage, ignite the second stage, enter orbit around the Earth, deploy the Dragon capsule while the rocket trunk unit remained attached to the second stage, wait until about 55 minutes after launch, and then begin deployment of the CubeSats from their P-PODs. The plan worked on all counts as the Falcon 9 rocket gave the CubeSats a nice ride to orbit, with SMDC-ONE starting in a 304 km apogee by 285 km perigee orbit at the prescribed 34.5 degrees inclination. The orbital altitude was perfect for the Dragon mission but with CubeSats you normally take what orbit you can get, knowing that an orbit this low means that you will not stay up very long. The inclination at 34.5 degrees was near perfect for Huntsville which is located at about 34.7 degrees North latitude. This meant that Colorado Springs, at 38.8 degrees North latitude, would not have quite as good a ground pass view of the satellite.

## ON-ORBIT OPERATIONS

### Orbit One

As planned, 30 minutes after deployment from the P-POD, SMDC-ONE's timer initiated operations. The satellite checked for sufficient battery charge and then initiated current flow through the nichrome wire cutter. The cutter melted through the monofilament antenna restraint line allowing the receiver antennas to snap into position. (The transmitter antennas had automatically deployed upon exiting from the P-POD.) The

communications link was verified on the first orbit as the Huntsville ground station successfully communicated with the satellite 96 minutes after launch and approximately 41 minutes after deployment from the P-POD. This quick response demonstrates the fast reaction capability that these nanosatellites are able to provide in a rapidly evolving theater scenario.

### Identifying CubeSats on Orbit

On the first orbit after the satellites were ejected from the trunk unit, both SMDC-ONE and several other nanosatellites were given Two Line Element (TLE) sets and were cataloged by the generic names of OBJECT A, OBJECT B, etc. A concept of operations (CONOP) was developed to determine which object was SMDC-ONE. Ground station operators left the ground antennas stationary and let the group of satellites fly through the beam. LANL and other CubeSat operators on this mission had also used this technique. There was great sharing of information among all the operators of the CubeSats deployed on this mission. SMDC-ONE operators used contact times and signal amplitude to infer the correct ephemeris. It took 12 days to know with high certainty which of the eight CubeSats was SMDC-ONE.

The satellite continued to function until it reentered the atmosphere on 12 January 2011.

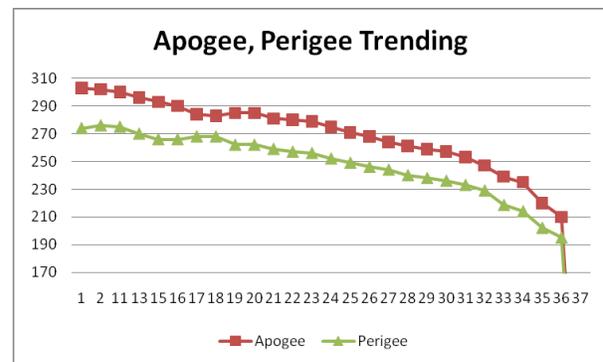


Figure 4. Apogee, Perigee Trending vs Days on Orbit.

### Satellite State-of-Health Data

Beginning with the first revolution around the Earth by SMDC-ONE, the ground station operators downlinked telemetry from the spacecraft. Over the 35 day period, a total of 1.5 MB of satellite bus state-of-health data were downlinked, giving the team a great look at internal temperatures, battery charge, gyro rates, etc. Additionally, during these requests for and receipt of bus data, the team took the strength of signal data to ensure our link margins matched well again the

predicted values. The satellite maintained a nominal health status until reentry.

### ***Data Relay – Simulated Unattended Ground Sensor (UGS) Data***

An objective of the SMDC-ONE flight demonstrations was to relay mission pertinent data between ground stations in Huntsville and Colorado Springs within one orbit. This was intended to demonstrate the relay of information from remote locations that are underserved by traditional terrestrial and orbital assets. The data passed ranged from short text to large images and were demonstrated to be passed within the time specified. Even with the compressed timeline dictated by the orbital insertion, a total of approximately 0.5 Mb of data were passed between ground stations.

### ***UGS Demo***

Demonstrating communications with a particular type of ground sensor was not included as an initial objective. This capability was added well after the satellite was delivered to the launch integrator, about a month before launch. This demonstrated the flexibility of the architecture to adapt to mission requirements.

In this mode, the data were a timestamp and location of an event detected by the ground sensors. These data were displayed natively in a freely available satellite imagery tool. The ground sensors communicate through a terrestrial gateway that is tuned to the satellite's radio link. The flight demonstration used three ground sensors but the satellite would easily be able to accommodate several hundred ground sensors.

On one cold December evening in Huntsville, LTG Richard P. Formica, USASMD/ARSTRAT's Commanding General, joined the UGS team to observe and participate in the demonstration. He purposefully tripped three sensors and then watched as the satellite responded to a ground station request for UGS data. The tripped sensor data in the gateway was relayed by the satellite to be displayed on the UGS base field station display as markings and data on a Google Earth© backdrop. This illustrated a key capability enhancement for the warfighter. The warfighter can now have a tool to retrieve ground sensor data covertly and with minimal exposure to potentially hostile areas.

### **TELEMETRY ANALYSIS**

Because this class of satellites normally rides as secondary or tertiary payloads, launch is tied to the timeline of the primary payload and the launch vehicle. This can translate into some concern about battery state-of-health upon launch. The Falcon 9 launch in

December 2010 occurred about four months after the last battery re-charging at NRL. On the first orbit after ejection from the P-POD the satellite telemetry was collected by the C2 station in Huntsville, AL. The battery voltages were sufficient to power the spacecraft and quickly returned to full charge once the spacecraft was deployed. During the mission, battery voltages were monitored and were seen to stay near full charge, only dipping slightly during dark portions of the orbit.

### **NEED FOR A DEDICATED LOW-COST LAUNCHER**

The fact that it took over a year and a half from SMDC-ONE flight unit delivery to launch underscores the pressing need for a low-cost, dedicated nanosatellite launcher. Many ideas for small, affordable means of space access are being proposed. There are several ongoing activities in this area with USASMD/ARSTRAT being among the group of potential users.

USASMD/ARSTRAT is proposing that several organizations pool resources to ensure that such a capability is developed in the near-term. Our need is for a \$1 M launch vehicle (recurring cost, in production mode of ten launch vehicles per year) capable of launching within 24 hours of call up. The vehicle should be able to deliver 25 kg of payload to a circular, 750 km altitude low earth orbit when launched. A vehicle of this performance level could deliver three 3U CubeSats or one small microsatellite to a desired orbit at a desired time.

Rideshares will continue to be important to the CubeSat community but presently (and for the foreseeable future) there is a long wait period for many CubeSats desiring rides on U.S. launchers. Low-cost dedicated nanosatellite launchers can greatly alleviate this wait and the inconvenience of accepting less than optimal orbital inclinations and altitudes.

### **NEXT STEPS**

USASMD/ARSTRAT is developing new communications CubeSats and imaging microsatellites that are low-cost and dedicated to the tactical needs of disadvantaged warfighters. These satellites are not intended to compete with existing satellites, remotely piloted vehicles or high altitude airships; instead they are aimed at filling support gaps which currently exist while complementing existing systems. The emphasis remains on low-cost systems which meet tactical needs.

For SMDC-ONE's next steps, two SMDC-ONE nanosatellites will undergo software modifications to

make them compatible with Army field radios. A third SMDC-ONE will be modified to incorporate a software defined radio and certified encryption hardware, under the sponsorship of the ORS Office. All three of these satellites will hopefully fly in 2012.

USASMDC/ARSTRAT has developed plans for both a constellation of three CubeSats in non-coplanar orbits and a constellation of multiple CubeSats in coplanar equatorial orbits to meet warfighter needs. If developed, these satellites would be ready for launch in 2013.

## CONCLUSIONS

SMDC-ONE was a great re-entry point for the development of dedicated Army satellites. Demonstrating a robust satellite bus and communications payload, SMDC-ONE is paving the way for the next generation of Army satellites. Appropriate constellations of nanosatellites and microsatellites in low earth orbit can provide a high degree of persistence for the warfighter which he or she can depend upon, much like the Global Positioning System (GPS) is today. The presence of a proliferated constellation of relatively short life nano- and microsatellites allow for technology refresh opportunities. Technology demonstrations such as USASMDC/ARSTRAT's SMDC-ONE and imagery microsatellites Kestrel Eye, NanoEye, and the Small Agile Tactical Satellite (SATS), together with the dedicated launch capability provided by a low-cost dedicated nanosatellite launcher such as the Multipurpose NanoMissile System, can help establish the case for inexpensive support for the dismantled, disadvantaged tactical warfighter through low cost, rapidly developed nanosatellite constellations.

## ACKNOWLEDGEMENTS

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effort in 2008 with then Commanding General LTG Kevin T. Campbell. We thank them for their leadership.

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