ARMY NANOSATELLITE TECHNOLOGY DEMONSTRATIONS FOR THE TACTICAL LAND WARFIGHTER

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ABSTRACT

Our nation has a truly impressive array of space-based capabilities supporting our armed forces. However, much of this support is focused at the strategic and operational levels of war. There are several areas of desired improvement in the space force enhancement mission area at the tactical level of war that could be addressed by small, very inexpensive satellites dedicated for use by tactical land warfighters. New trends in the miniaturization of electronic components are leading to smaller satellites with significant capabilities in the nanosatellite (1-10 kg) and microsatellite (10-100 kg) classes. US Army Space and Missile Defense Command/Army Forces Strategic Command is pursuing a number of technology demonstrations to validate the concept of nanosatellite/microsatellite constellations that could be tasked by the tactical land warfighters at and below the Brigade Combat Team echelon. Current projects include several very small satellites, namely the Space and Missile Defense Command – Operational Nanosatellite Effect (SMDC-ONE), Kestrel Eye, NanoEye, and Small Agile Tactical Spacecraft (SATS). Related enabling capabilities include a user-friendly ground segment and the dedicated launch capability provided by the Multipurpose NanoMissile System (MNMS). These demonstrations can help establish the case for inexpensive space force enhancement for the tactical land warfighter through low cost, rapidly developed nanosatellite/microsatellite constellations.

1. INTRODUCTION

The United States Army is the largest user of space systems within the Department of Defense. Despite this heavy dependence on data from space, the Army has historically elected to leverage 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 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, that have opened the door for small, highly affordable satellites designed to perform limited

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14. ABSTRACT
Our nation has a truly impressive array of space-based capabilities supporting our armed forces. However, much of this support is focused at the strategic and operational levels of war. There are several areas of desired improvement in the space force enhancement mission area at the tactical level of war that could be addressed by small, very inexpensive satellites dedicated for use by tactical land warfighters. New trends in the miniaturization of electronic components are leading to smaller satellites with significant capabilities in the nanosatellite (1-10 kg) and microsatellite (10-100 kg) classes. US Army Space and Missile Defense Command/Army Forces Strategic Command is pursuing a number of technology demonstrations to validate the concept of nanosatellite/microsatellite constellations that could be tasked by the tactical land warfighters at and below the Brigade Combat Team echelon. Current projects include several very small satellites, namely the Space and Missile Defense Command ? Operational Nanosatellite Effect (SMDC-ONE), Kestrel Eye, NanoEye, and Small Agile Tactical Spacecraft (SATS). Related enabling capabilities include a user-friendly ground segment and the dedicated launch capability provided by the Multipurpose NanoMissile System (MNMS). These demonstrations can help establish the case for inexpensive space force enhancement for the tactical land warfighter through low cost, rapidly developed nanosatellite/microsatellite constellations.

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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.

One of the major shortcomings of LEO satellites is that individually they do not provide a persistent presence over a specific geographic area of the earth – Keplerian physics demands otherwise. From a systems standpoint, global persistence can only be achieved by the use of multiple satellites in a constellation. The best example of this kind of persistence is the Global Positioning System (GPS) that is always available to any user worldwide.

Taking all of these realities into account, the CubeSat-class satellite today offers a unique opportunity to address certain mission requirements 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 classes of 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. It is important to recognize that a number of possible constellations may not be required by the Army to provide global coverage. 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, low detection probability, able to leverage manufacturing economies of scale, having good signal strength in 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 urgent requirements gaps 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.

The US Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT) is investigating a number of nanosatellite/microsatellite technologies. These technology demonstrations include SMDC-ONE, Kestrel Eye, NanoEye, and SATS, together with a user-friendly ground segment and a dedicated launch capability provided by the Multipurpose NanoMissile System. Through these demonstrations the command hopes to validate the utility of the emerging trend in satellite miniaturization for the tactical land warfighter.

2. NANOSATELLITES FOR BEYOND-LINE-OF-SIGHT COMMUNICATIONS

This section will describe the nanosatellites/ 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 of eight flight-qualified nanosatellites designed to address a specific warfighter mission need.

2.1. The Need for Beyond-Line-of-Sight Communications

On today's battlefield, the tactical land warfighter does not always get the exact communications support he or she desires from the existing constellations of large, expensive military and commercial communications satellites in geosynchronous orbits. Constellations of satellites dedicated to tactical warfighters would greatly benefit command, control and communications as well as intelligence 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 image and video transmission. Data exfiltration and text messaging are both fairly low data rate satellite communications applications and are relatively straightforward technologically.

To be practical in terms of utility to the tactical warfighter, satellites 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 be truly usable everywhere within a given area. Because a large constellation would be needed, individual satellite unit cost would need to be very low, in the range of a few hundreds of thousands of dollars. Finally, the satellites should be responsively deployable and easily replenishable on orbit in accordance with the rapid deployment principles put forth by the Department of Defense's Operationally Responsive Space Office.

Figure 1. SMDC-ONE

2.2. SMDC-ONE Technical Approach

To investigate the feasibility of a 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, or SMDC-ONE, technology demonstration. The SMDC-ONE initiative succeeded in designing, developing, building and qualification testing two nanosatellite engineering qualification units as well as acceptance testing eight flight units within a one-year timeframe. Delivery was in April 2009. Three of the flight units are already manifested on launch vehicles bound for low earth orbit. A custom communications payload will provide a capability to support simulated ground sensors and text message relay. More complex communications applications are under consideration.

USASMDC/ARSTRAT's initial focus for SMDC-ONE was on communications with emphasis on data exfiltration; that is, to uplink data of interest from unattended 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 beyond-line-of-sight (BLOS) communications. This is especially the case in areas of mountainous terrain where line-of-site access to satellites or airborne communications is limited or non-existent. A constellations 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 nanosat (0-10 kg) class while using the Cal Poly CubeSat form. In early 2009 the SMDC-ONE program completed the construction and testing of two qualification nanosat followed by eight flight nanosats. Each is designed to be deployed from a Poly-Picosatellite Orbital Dispenser (P-POD). One of the qualification units underwent rigorous shock, random vibration and thermal-vacuum testing at the prime contractor and 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, Stanford University and SRI International representatives to ensure conformity with the Cal Poly standards and leveraging of their experiences with CubeSats.

2.3. SMDC-ONE Concept of Operations

The objective of the first flight demonstration involves a single SMDC-ONE satellite which will receive its tasking from the Forward Operating Base (FOB) or Command and Control (C2) station as shown in Figure 4. The initial SMDC-ONE satellites do not have on-board

GPS, so the tasking and timing information will be provided from the C2 station after preliminary on-orbit checkout of the satellite occurs. The program is planning to have two C2 stations, one at USASMDC/ARSTRAT Headquarters in Huntsville, AL and the other at USASMDC/ARSTRAT's Battle Lab in Colorado Springs. The first demonstration consists of simulated sensor data transmitted from one or both of the C2 stations. The tasking data and other data files will be received by the satellite (as its ground track accesses Huntsville and/or Colorado Springs), stored on-board, and then transmitted to the C2 station(s) as directed.

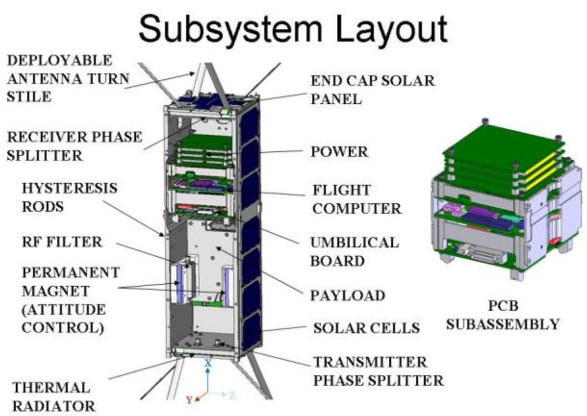

Figure 2. SMDC-ONE Subsystem Layout

On some orbits the ground track will cover both C2 stations which are separated by 1200 miles. A text message will be transmitted from the first station in the ground track and quickly relayed to the second station. In some cases the ground track will first cover Huntsville while in others, Colorado Springs will come into satellite view first.

After initial on-orbit checkout of the satellite by prime contractor (Miltec) and USASMDC/ARSTRAT personnel is completed, testing and experiments will be conducted by the Space and Missile Defense Command Future Warfare Center's Battle Lab. Both ground segments (Huntsville and Colorado Springs) will be used in the checkout and experimentation phases.

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 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.

3. SMALL MICROSATELLITES FOR ELECTRO-OPTICAL IMAGERY

The unmanned aerial vehicle revolution is putting on-demand imagery into the hands of tactical land warfighters. Warfighter-tasked electro-optical imagery from orbiting small microsatellites could complement unmanned aerial vehicles and even substitute for them in denied areas. USASMDC/ARSTRAT is developing the 14-kilogram Kestrel Eye electro-optical imagery satellite as a technology demonstration to show how the tactical land warfighter can task a dedicated small microsatellite to take and download multiple 1.5 meter resolution images within the single-digit-minute time span of a single overhead pass. USASMDC/ARSTRAT is also developing the NanoEye imagery microsatellite, which will have a propulsion system enabling it to lower its orbit to enhance image resolution and then —fly” back up to its normal orbital altitude. Another Army microsatellite effort is the Small Agile Tactical Satellite study, which is investigating the possibility of frame-based video from space.

3.1. Kestrel Eye

The USASMDC/ARSTRAT is developing the Kestrel Eye technology demonstration as an electro-optical near-nanosatellite-class imagery satellite that will be tasked by the tactical ground component warfighter. Weighing only about 14 kilograms and capable of producing 1.5-meter resolution imagery, Kestrel Eye's data will be downlinked directly to the same warfighter via a data relay network that is also accessible by other warfighters in theater without any continental United States (CONUS) relay or data filtering. At the low cost of only about $1M per spacecraft in a production mode, the intent is to demonstrate a tactical space-based imagery small microsatellite that could be proliferated in large numbers to provide a persistent capability to ground forces. Each satellite would have an operational life of greater than one year in low earth orbit.

Figure 3. Kestrel Eye Imagery Small Microsatellite

The primary objective of the demonstration will be to task the satellite to take a picture of a designated ground object of interest and have that image relayed back to the ground Warfighter during the same satellite pass (i.e., within an approximately 10-minute tasking-to-product cycle). This tactical responsiveness, coupled with the potential persistence enabled by large numbers of these low cost satellites in orbit, make up the key advantages Kestrel Eye would have over existing orbital imagery assets today.

The Kestrel Eye program will extend the Unmanned Aerial Vehicle (UAV) paradigm into space: a dramatically lower unit cost and proliferated numbers of satellites enabling the system to be dedicated to and operated by Warfighters who today receive only parceled-out service from more powerful, expensive and far less numerous orbital assets. The eventual goal is persistent coverage available to every Soldier on a handheld device – as GPS is today. The CONOPS for this experiment involves very small satellites, laptops and S-Band receiver antennae.

Kestrel Eye advantages include:

- Higher altitude than UAVs: coverage above denied areas and invulnerable to surface-to-air missile threats
- Smaller size and greater number: affordable, persistent presence, lower probability of detection, less vulnerable to anti-satellite weapons
- Graceful degradation: no single shot, launch failure or anomaly causes complete loss of service

Kestrel Eye could provide in-theater tactical land warfighters with the ability to directly task an orbital asset and receive tactically relevant imagery within minutes. It could complement unmanned aerial vehicle (UAV) imagery or even substitute for UAV imagery if necessary. The Kestrel Eye technology demonstration could prove out the utility of on-orbit imagery assets dedicated for use by Soldiers in the field.

3.2. NanoEye

USASMDC/ARSTRAT is developing another small, low cost imagery microsatellite called NanoEye. Under development through the DoD's Small Business Innovative Research (SBIR) program, NanoEye cost estimates at $1.4M or less per satellite are 100 to 1000 times lower than would be the case in a traditional NASA or DoD program. The program's development timeline is close to an order of magnitude shorter as well. Several factors make these cost and schedule reductions possible. One is a new, dramatically lightweight, lower cost telescope. Another is that NanoEye's unibody spacecraft structural design developed by Microcosm allows the possibility of an integrated spacecraft/payload. The use of CubeSat components developed by many universities and small companies also contributes to lower cost and rapid development. Finally, SBIR contracting can eliminate many of the typical roadblocks to getting things done rapidly and at low cost.

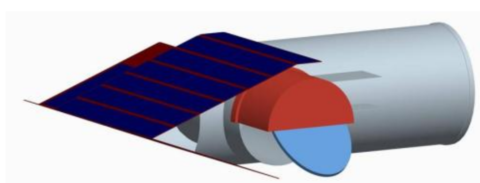

Figure 4. NanoEye

A key feature of the NanoEye design is the ability to lower its orbital altitude for ―close up" shots of the earth's surface. The major benefit of low altitude is high resolution with a small payload and spacecraft. Low altitude also means doing without deployable solar arrays that have excessive aerodynamic drag. NanoEye's solar arrays are symmetrically arranged about the spacecraft's velocity vector to minimize any aerodynamic torque and drag when at low orbital altitudes. Solar arrays are also becoming far more efficient, and responsive mission duty cycles tend to be low, allowing body mounted solar arrays to adequately power the spacecraft. The bottom line is that operating at low altitude is dramatically cheaper than incorporating larger aperture. So long as we are willing to give up exquisite resolution and 10 to 15 year orbital lifetimes, we can achieve dramatic benefits in terms of cost.

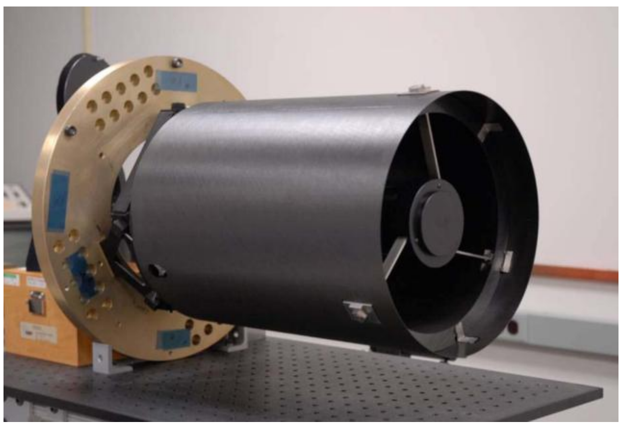

Figure 5. NanoEye Telescope (also used for Kestrel Eye)

Like Kestrel Eye, the NanoEye technology demonstration has a great potential to prove the utility of space-derived near-realtime imagery to tactical land warfighters at a low cost. It represents an alternative low cost design with a unique maneuvering capability to tailor its orbit to meet the needs of the user.

3.3. Small Agile Tactical Spacecraft (SATS)

A third imagery microsatellite under development by USASMDC/ARSTRAT is the Small Agile Tactical Spacecraft (SATS). Similar in performance to Kestrel Eye and NanEye, SATS would have a ground sample distance resolution of 1.5-2.0 m (~4-6 feet) at a cost of around $3M per microsatellite. The satellite will weigh about 32 kg (70 lbs) and have an on-orbit life of 36 months.

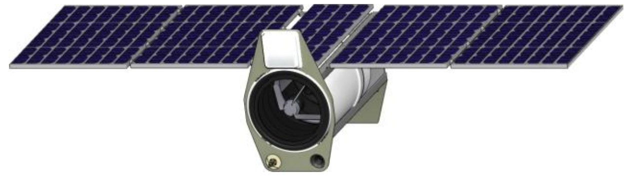

Figure 6. Small Agile Tactical Spacecraft (SATS)

What sets SATS apart is its ability to switch between three modes of operation. In point and shoot mode, SATS would have the ability to capture multiple images within a theater on a single pass, similar to the other Army imagery microsatellites. A unique feature of SATS is its scene mode, which captures still images or video along a pre-planned path defined by a series of latitude and longitude coordinates. It can capture 5 megapixel images at 4 frames per second with 50% image overlap. In real-time video mode, SATS will have the ability to track user defined targets with real-time, human-in-the-loop targeting. It will provide monochrome 1 megapixel video at 1-2 frames per second streamed ―live" to a user or store and forward in a replay mode for higher resolution post pass data analysis.

The potential for video from a space-based asset represents a new benchmark in capability for situational awareness. SATS represents leading edge technology in this new field at an affordable cost.

4. INEXPENSIVE, RESPONSIVE LAUNCH FOR NANOSATELLITES/MICROSATELLITES

Tactical nanosatellite and microsatellite launch needs cannot be met by strategic (―big") launch vehicles. Currently, these spacecraft are launched as secondary payloads on large launch vehicles. While these launches are adequate for test demonstrations, the nanosatellite/microsatellite's orbital location is confined to the primary payload's orbital destination. More importantly, these launches are scheduled years in advance, and are not able to meet the immediate needs of users. In order to maximize the benefit of the next generation of nanosatellites and microsatellites, SMDC initiated a program to enable a dedicated, low cost, small payload launch system to ensure rapid deployment and precise placement of nanosatellites and microsatellites to meet user requirements.

4.1. Multipurpose NanoMissile System (MNMS)

Concurrent with the shrinking size and cost of militarily useful satellites is a need for an appropriately sized and priced launch vehicle. USASMDC/ARSTRAT is developing a very low cost launch vehicle called the Multipurpose NanoMissile System. This innovative rocket is designed to take advantage of low cost yet modern technologies and non-exotic materials to provide launch for a 10 kilogram (25 lb) payload to low earth orbit for about $1 million per launch vehicle.

Figure 7. MNMS

Table 1. MNMS Multiple Configurations

Suborbital, Single Stick, 2-Stage	$277K
Suborbital, Single Stick, 2-Stage, with ATACMS Booster	$153K
Suborbital, Single Stick, 3-Stage, with ATACMS Booster	$306K
Suborbital/Orbital*, Core & 4 Strap-ons, 4-Stage	$1M

**1-10 kg to 250 nmi circular; incl=43^o*

4.2. MNMS Design Philosophy

The Multipurpose NanoMissile System is low cost because it is very simple: it is an integrated tank/booster/engine design, it has a benign bi-propellant liquid propulsion system (ethane & nitrous oxide), and it uses existing launch support and launch site hardware. It can also accommodate existing Army Tactical Missile System (ATACMS) and Multiple Launch Rocket System (MLRS) motors to augment performance as well as provide an important application for these surplus Army assets. The configurable boosters can be tailored to many specific missions: missile defense target vehicle, infrared and radar sensor exerciser, hypersonic test vehicle for aerospace components, pop-up reconnaissance system, and highly responsive orbital launch vehicle for very small payloads (10 kg to LEO). Perhaps the most significant feature of MNMS is that it is designed for minimum cost. Even the orbital configuration unit cost is only projected to be around $1M.

Figure 8. MNMS Flight-Like Booster Module 60-Second Test Fire at Redstone Arsenal, AL

4.3. MNMS Operational Capabilities

To achieve enhanced capabilities for the warfighter from space, a necessary requirement is to have the ability to fly into and through space to include both sub-orbital and orbital missions. To test and exercise key space and missile defense technologies, a dedicated missile is required to boost these technologies into their required trajectories or orbits. Currently the U.S. Army has no such capability despite being the largest user of missile defense and space technologies. The Army also has the largest inventory of missiles and rockets, yet they have been designed primarily as weapons and not platforms to test missile defense and space technologies. The Multipurpose NanoMissile System will combine the Army's great requirement for these technologies with an enormous surplus of ATACMS and MLRS motors to produce a low cost, simple missile dedicated to bringing enhanced capabilities from space to the U.S. Army ground component warfighter. The design will enable the MNMS to be operationally responsive enough to meet a 24 hour requirement from garrison storage call up to launch ready, a timeline that is unheard of among current launch vehicle capabilities.

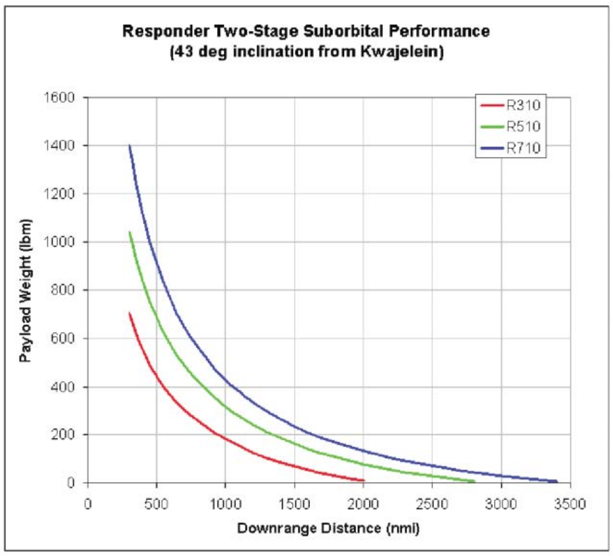

Figure 9. MNMS Projected Performance

For suborbital performance & capabilities, the graph in Figure 9 depicts the expected performance for three different MNMS configurations. The nomenclature in the legend, e.g., ―R310", refers to the configuration of booster modules that make up the first, second and third stages. R310 means there are three identical booster modules in the first stage, one in the second stage and none in the third stage; thus it is a two-stage rocket. The "R" stands for ―Responder", the missile's nickname. The data in Figure 8 assumes a 9 deg azimuth (due east) launch from Reagan Test Site at the Army's Kwajalein Atoll complex in the Marshall Islands in the Pacific Ocean

CONCLUSIONS

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 GPS is today. The presence of a proliferated constellation of relatively short life nano- or microsatellites allow for technology refresh opportunities and are problematic to adversaries who might want to eliminate space-based support to the warfighter. Technology demonstrations such as SMDC-ONE, Kestrel Eye, NanoEye, and SATS, together with the dedicated launch capability provided by the Multipurpose NanoMissile System, can help establish the case for inexpensive space force enhancement for the tactical warfighter through low cost, rapidly developed nanosatellite constellations.

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