CubeSat Integration into the Space Situational Awareness Architecture

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ABSTRACT

Lockheed Martin Space Systems Company has recently been involved in developing GEO Space Situational Awareness (SSA) architectures, which allows insights into how CubeSats can augment the current national systems. One hole that was identified in the current architecture is the need for timelier metric track observations to aid in the chain of custody. Obtaining observations of objects at GEO can be supported by CubeSats. These types of small satellites are increasingly being built and flown by government agencies like NASA and SMDC.

CubeSats are generally mass and power constrained allowing for only small payloads that cannot typically mimic traditional flight capability. CubeSats do not have high reliability and care must be taken when choosing mission orbits to prevent creating more debris. However, due to the low costs, short development timelines, and available hardware, CubeSats can supply very valuable benefits to these complex missions, affordably. For example, utilizing CubeSats for advanced focal plane demonstrations to support technology insertion into the next generation situational awareness sensors can help to lower risks before the complex sensors are developed. CubeSats can augment the planned ground and space based assets by creating larger constellations with more access to areas of interest. To aid in maintaining custody of objects, a CubeSat constellation at 500 km above GEO would provide increased point of light tracking that can augment the ground SSA assets. Key features of the CubeSat include a small visible camera looking along the GEO belt, a small propulsion system that allows phasing between CubeSats, and an image processor to reduce the data sent to the ground. A simple communications network will also be used to provide commands to and data from multiple CubeSats. Additional CubeSats can be deployed on GSO launches or through ride shares to GEO, replenishing or adding to the constellation with each launch. Each CubeSat would take images of the GEO belt, process out the stars, and then downlink the data to the ground. This data can then be combined with the existing metric track data to enhance the coverage and timeliness.

With the current capability of CubeSats and their payloads, along with the launch constraints, the near term focus is to integrate into existing architectures by reducing technology risks, understanding unique phenomenology, and augment mission collection capability. Understanding the near term benefits of utilizing CubeSats will better inform the SSA mission developers how to integrate CubeSats into the next generation of architectures.

Background

Space Situational Awareness (SSA) has become more important as the United States increasingly relies on space assets. Space has become more crowded and congested and the risk for collisions has exponentially increased. The figure below shows all of the objects in the catalog in LEO, GEO, and other orbits. It also focuses on GEO where there are over one thousand objects that need to be tracked. The GEO orbit, due to the distance, is inherently harder to detect objects and creates a different set of challenges than LEO. Lockheed Martin has recently been involved in developing GEO SSA architectures that include space and ground assets along with repurposing or sharing other national assets. One hole that was identified during these studies was the need for more metric track observations. The basic data required for Metric Track is point of light observations. Currently, the ground SSA sensors do not have the capacity to obtain the number of observations required and do not have the sensitivity to see smaller objects at GEO. The purpose of this concept is to highlight how CubeSats can be integrated into the SSA architecture.

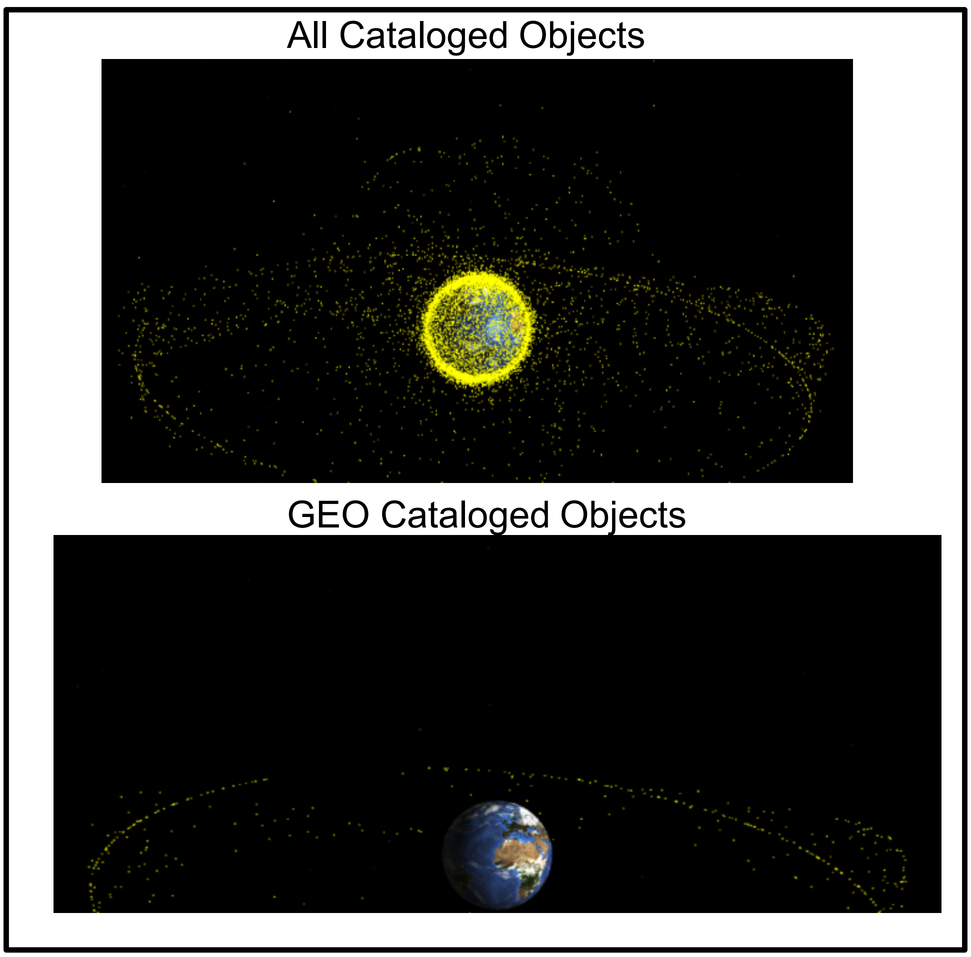
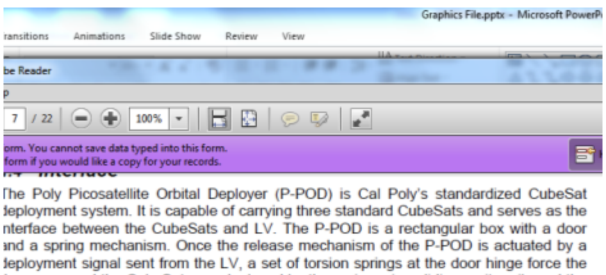


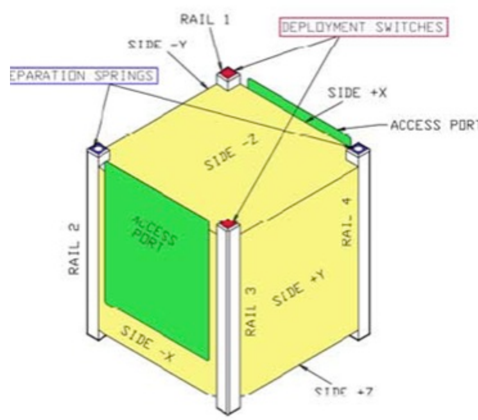
Figure 1 – Cataloged Objects in Earth Orbit and GEO

CubeSat Heritage

CubeSats have exploded in popularity in the last five years as they are a cheap, accessible way to build small satellites. Everyone from government customers such as SMDC and NASA as well as universities are utilizing CubeSats for missions and education. CubeSats are 10 cm x 10 cm x 10 cm units that can be combined to form larger spacecraft. Standardized components and deployment mechanisms are heavily produced for this form factor and, thus, help to create low cost access to space. The figure below shows the standardized deployers (P-PODs) along with examples of CubeSats.



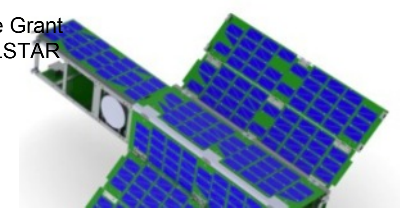
P-POD Launcher



1U CubeSat

"CubeSat Design Specification Rev. 12". *California State Polytechnic University*. Retrieved 2010-10-16.

Colorado Space Grant Consortium ALLSTAR Satellite



Example 3U CubeSat

Figure 2 – CubeSat Hardware and Deployer Options

Because of their low cost, CubeSats can be an ideal platform for performing technology demonstrations. There are, however, constraints on a CubeSat that require innovative approaches in order to provide mission utility. CubeSats have limitations in that they cannot carry a large payload so payload sizes must be reduced or novel ways of performing the mission must be created. CubeSats generally do not have the same life expectancy as traditional spacecraft. This can limit the length of missions before replenishments are needed. Also, care must be taken when choosing orbits as failures can turn the CubeSat into a piece of debris. Low LEO orbits have generally been the orbits of choice but the graveyard at GEO can also allow missions without the worry of debris. Even though CubeSats have these limitations, many mission areas can utilize these small satellites to enhance their mission. You can fly the next generation focal planes to demonstrate their ability to survive the space environment. CubeSats can also help to demonstrate mission concepts. For example, they can help prove out formation flying techniques needed for a variety of complex missions. CubeSats can be used for earth imaging missions using lower altitudes for increased resolution, or multiple CubeSats to increase coverage of areas of interest. There is a significant number of ways that CubeSats can be utilized to aid the current missions.

Mission Architecture

To obtain the point of light observations that the SSA architecture requires, several CubeSats in the GEO graveyard were chosen. GEO + 500 km creates a 6 deg/day drift with respect to GEO that provides access to the entire GEO belt over time. Utilizing a direct to GEO launch vehicle or a rideshare with a GTO spacecraft; one launch can place several CubeSats into the mission orbit. The upper stage could maneuver to GEO+500 km before it disposes of itself while a rideshare with a GTO spacecraft would require larger amounts of propellant onboard the CubeSat to maneuver from the spacecraft to the mission orbit. A small propulsion system on each CubeSat allows the vehicles to be phased around the belt more evenly and can maintain the spacing. Since the lifetime of the CubeSats are relatively small, additional CubeSats would be launched with every direct inject GEO launch or on launches of opportunity with GTO spacecraft. Figure 3 below shows an STK view of nine CubeSats and their field of views distributed around the GEO belt. The CubeSats will rotate 180° based on where the Sun is to prevent damage and to ensure data collection with optimal sun lighting. Figure 4 below shows the operational view of the mission.

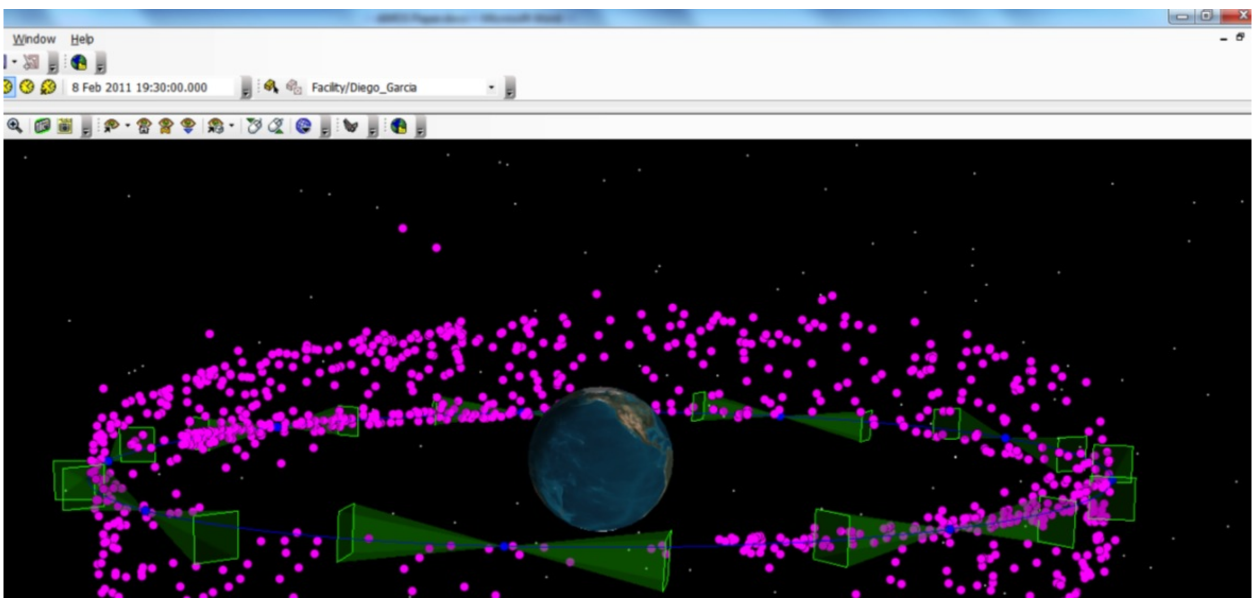


Figure 3 – GEO Belt with CubeSats Spaced Forty Degrees Apart

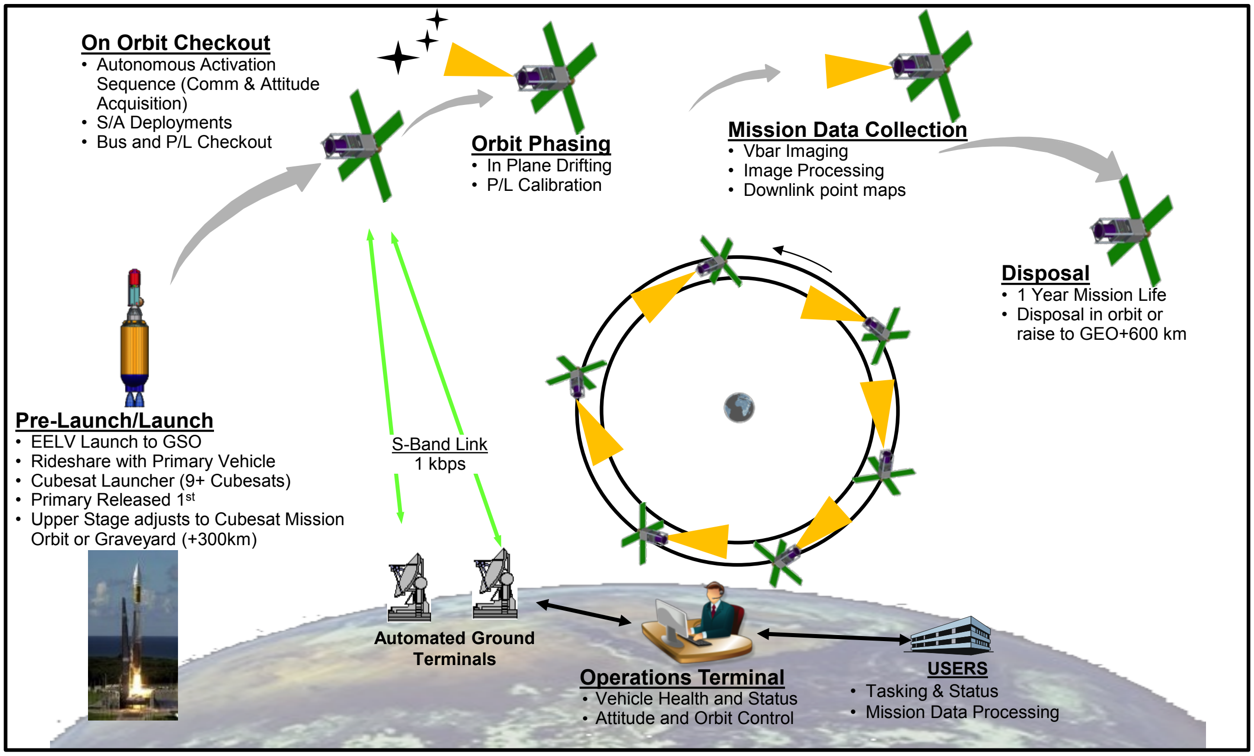


Figure 4 – Operational View of the CubeSat SSA Mission

Once the CubeSats are in place, they will use the visible camera to capture pictures of the +Vbar and –Vbar direction. The 18 deg field of view will provide access to objects below and above GEO without having to slew the vehicle. A slew profile could be used to increase the probability of detection or increase the number of observations on a single object. The CubeSat will take pictures, process the images to get rid of the background stars, and then download the intensity information to the ground. The camera will need to take pictures and process them continuously in order to capture the highly inclined targets. Once the data is on the ground, it will be disseminated to the existing SSN ground network. A simple Vbar stare will maintain constant custody of the low inclined objects. A slew profile could be used on the CubeSat in order to detect the highly inclined objects. Figure 5 below shows the range limits of the camera. This figure shows that for the larger objects at GEO, detection ranges are on the order of 10,000 km with an integration time of one second. The figure also shows 4,000 km is needed for 2.0 m diameter targets. The smaller objects would require longer integration times or less range for detection.

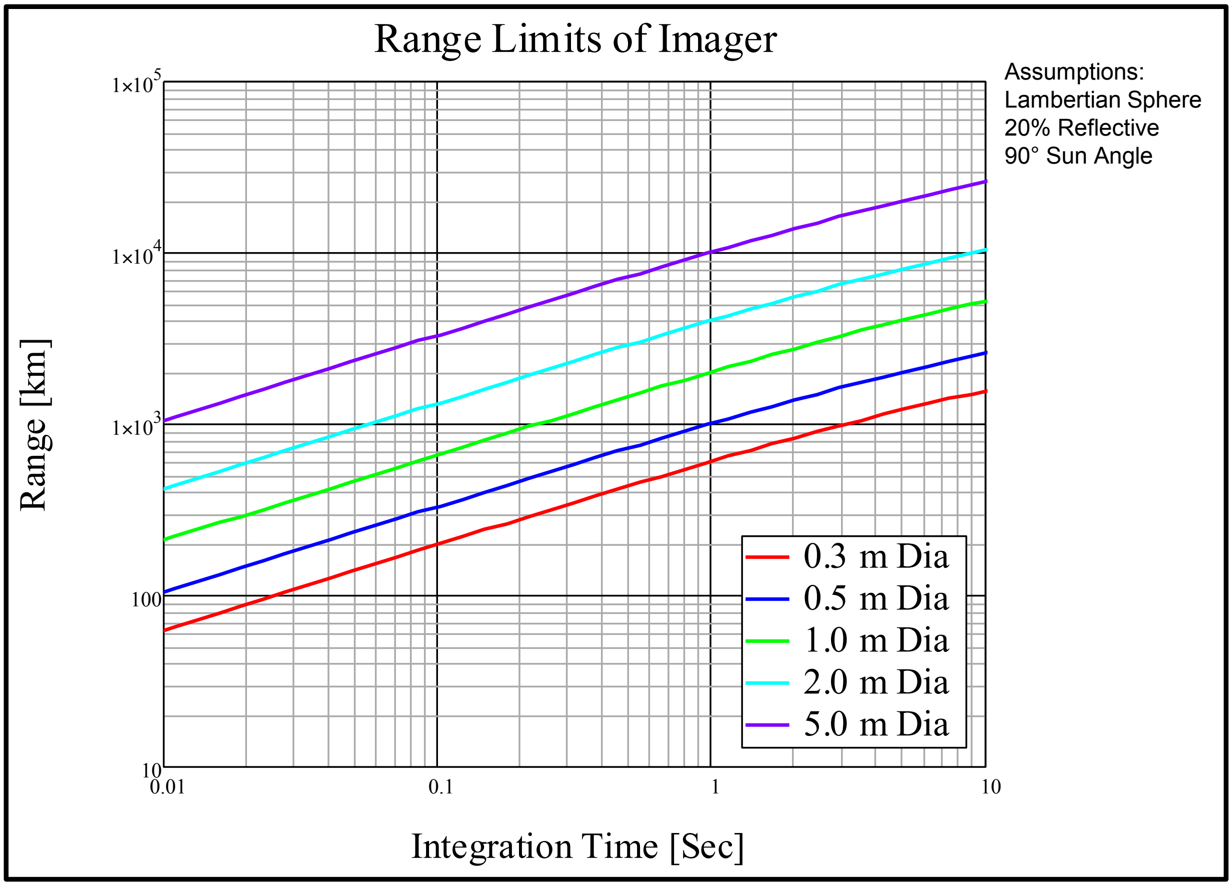


Figure 5 – Detection limits of the Camera System

CubeSat Design

For this mission, a 3U CubeSat is large enough to accomplish the mission. A 3U CubeSat will fit into a single P-POD, which allows more CubeSats on a given launch. The main components of the design are a visible camera system with a small propulsion system for location phasing, and a reaction wheel assembly for pointing and control. Many visible cameras are available that meet the SWAP requirements of a CubeSat. Based on resources available on the CubeSat, camera performance will need to be sacrificed to ensure low power operations which could require duty cycling the camera. The propulsion system will also be used to phase the different CubeSats around the mission orbit to provide the most coverage and revisits. For communications, the CubeSat will use a standard S-band system to communicate with AFSCN. This provides worldwide coverage but has limitations on when the vehicle can be communicated with. The limited power available on the CubeSat forces a low data rate to the ground. Therefore, an image processor will be required to reduce the amount of data needed to a minimum. With image processing and a limited set of state of health data required as well as duty cycling the communication system based on availability, the data rate should be kept to less than 1 kb/s. An avionics card with input/outputs will be used for processing the images and to support the bus functions. The visible camera will also be used as a star tracker when it is not imaging. Reaction wheels will be used to slew the vehicle as needed with the propulsion system providing the capability to de-saturate the reaction wheels. The reaction wheels provide the capability to slew the vehicle as needed for looking at the higher inclined targets without having to utilize the propulsion system. Figure 6 below shows the CubeSat design and layout.

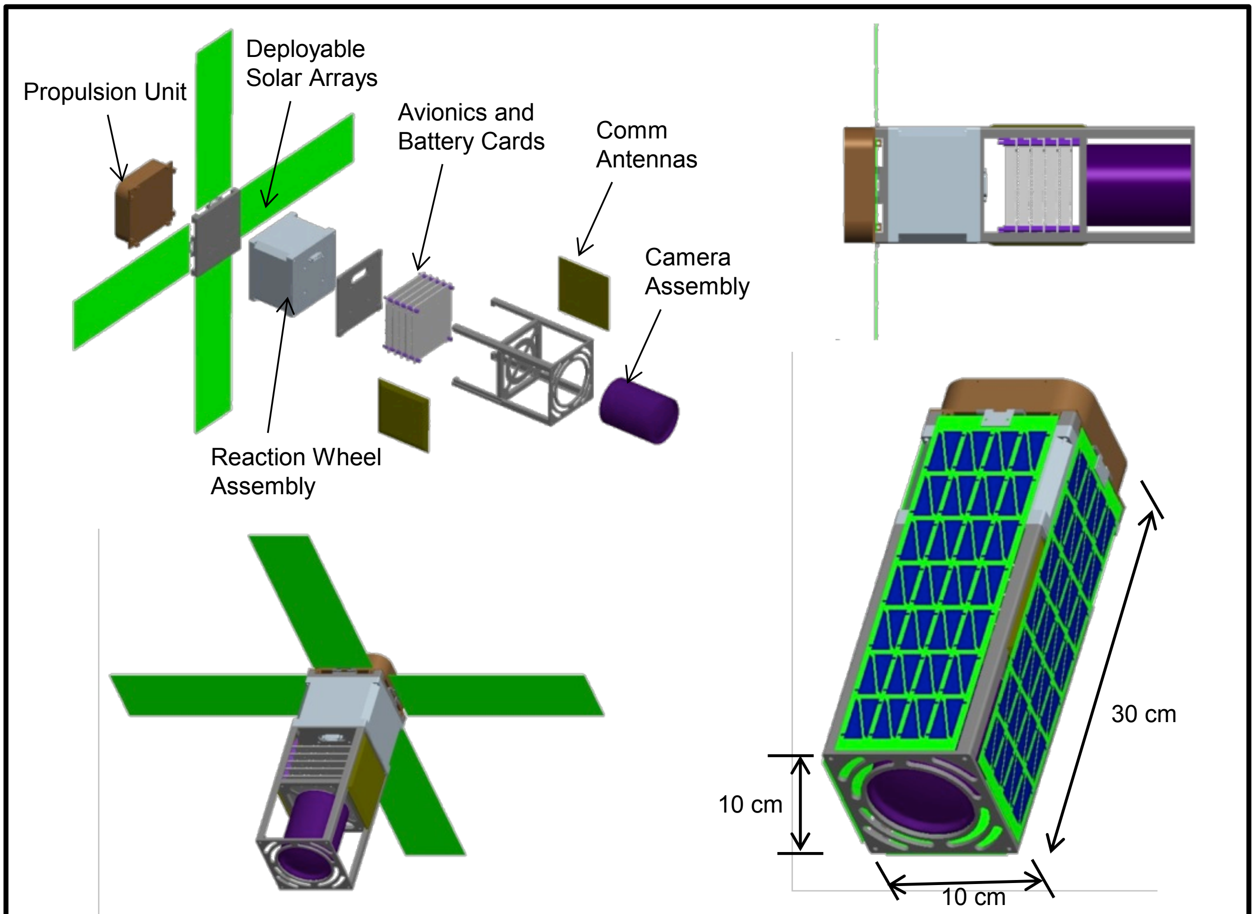


Figure 6 – CubeSat Overview and Design

Mission Effectiveness

Obviously, this CubeSat will not be the 100% solution to GEO SSA, but for the cost of the development, they can provide mission data sufficient to augment the current national assets. Satellite Tool Kit (STK) and Matlab simulations were run in order to quantify the benefits of the architecture. The scenarios were setup up to examine the number of GEO objects detected, maximum period between detections and the percentage of time the object is tracked. Figure 7 below shows a single day of observations that provides 61% percent of the objects at GEO with nine CubeSats. Figure 8 shows the gap between observations for the same single day run. This shows the mean time between observations is 16 hours.

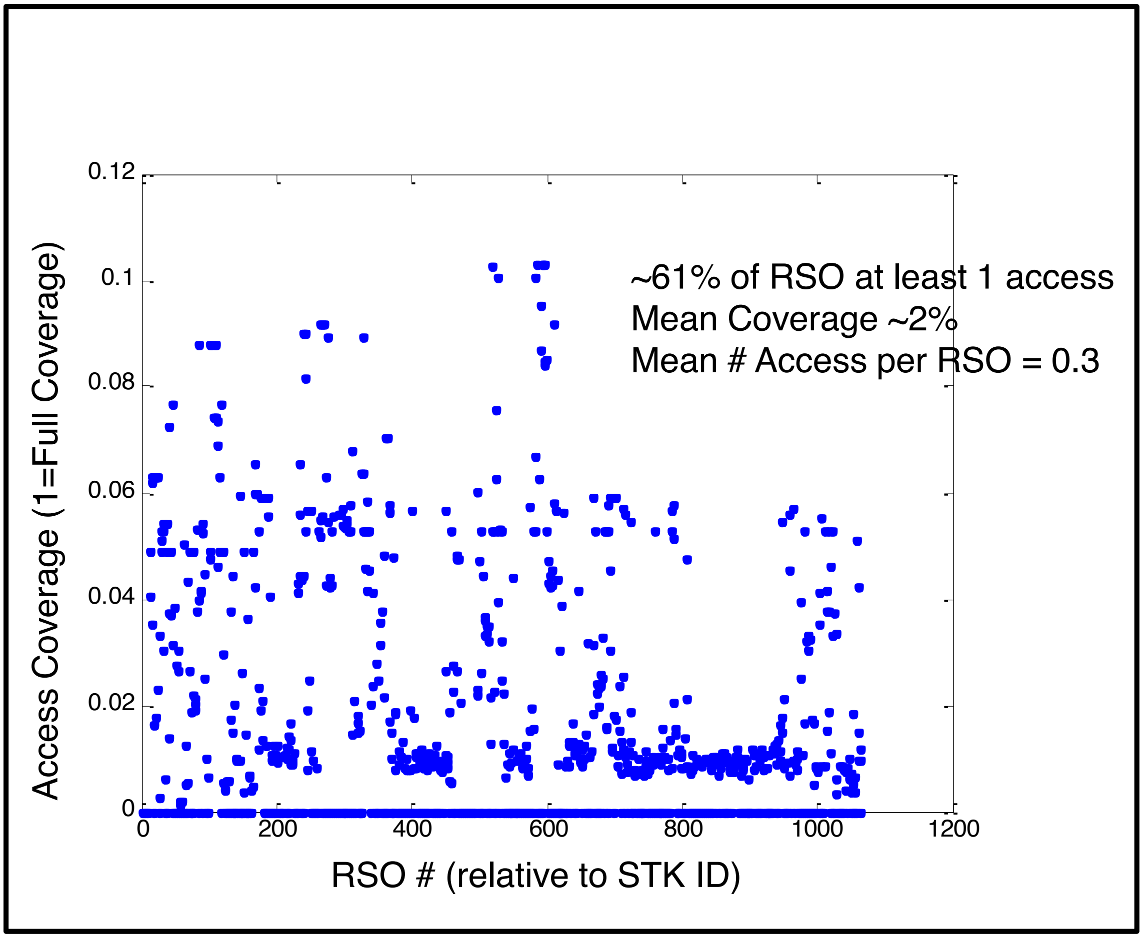


Figure 7 Single Day Coverage with Nine CubeSats

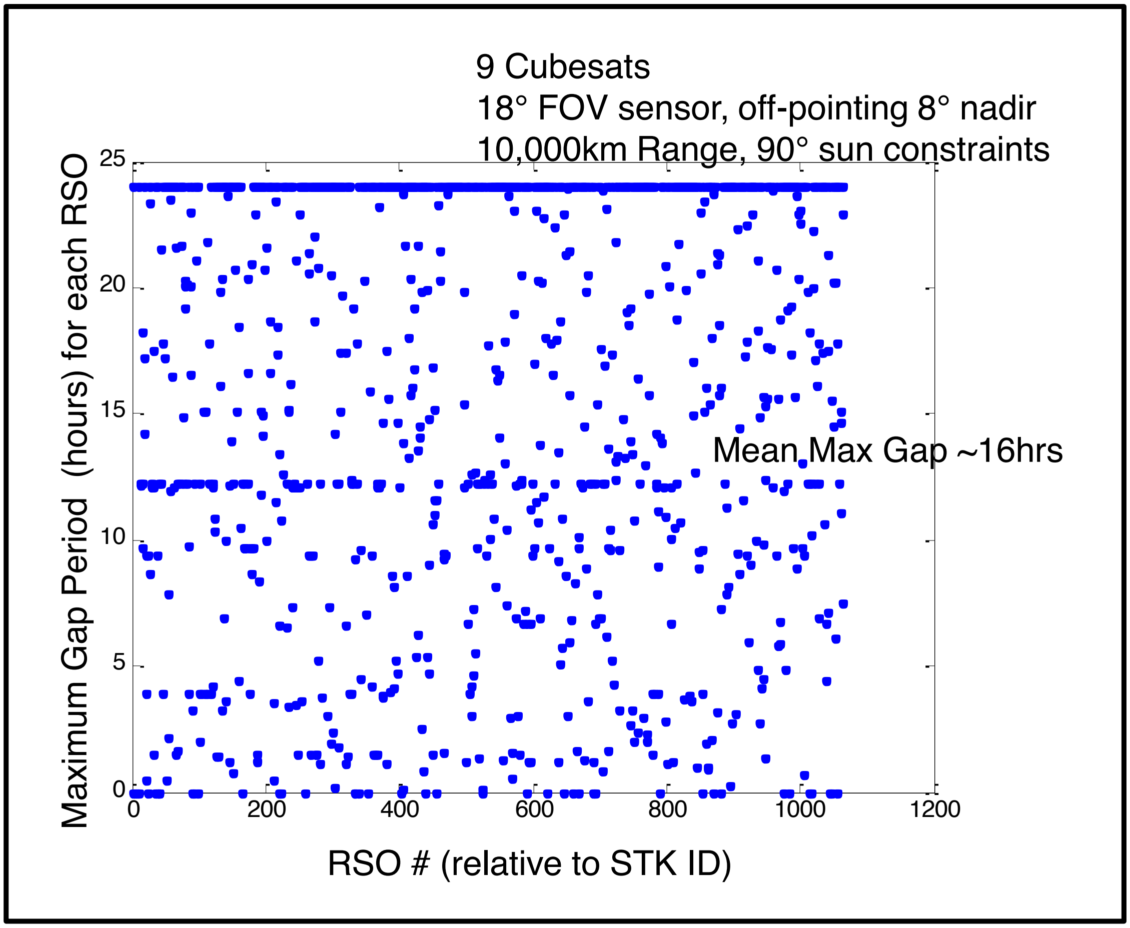


Figure 8 – Single Data Gap Periods for 9 CubeSats with Nine CubeSats

If you were to look at the number of objects detected over a 10 day scenario, the numbers jump up dramatically with 96% of the objects detected with the average coverage at 20% of the time. This is shown in figure 9 below.

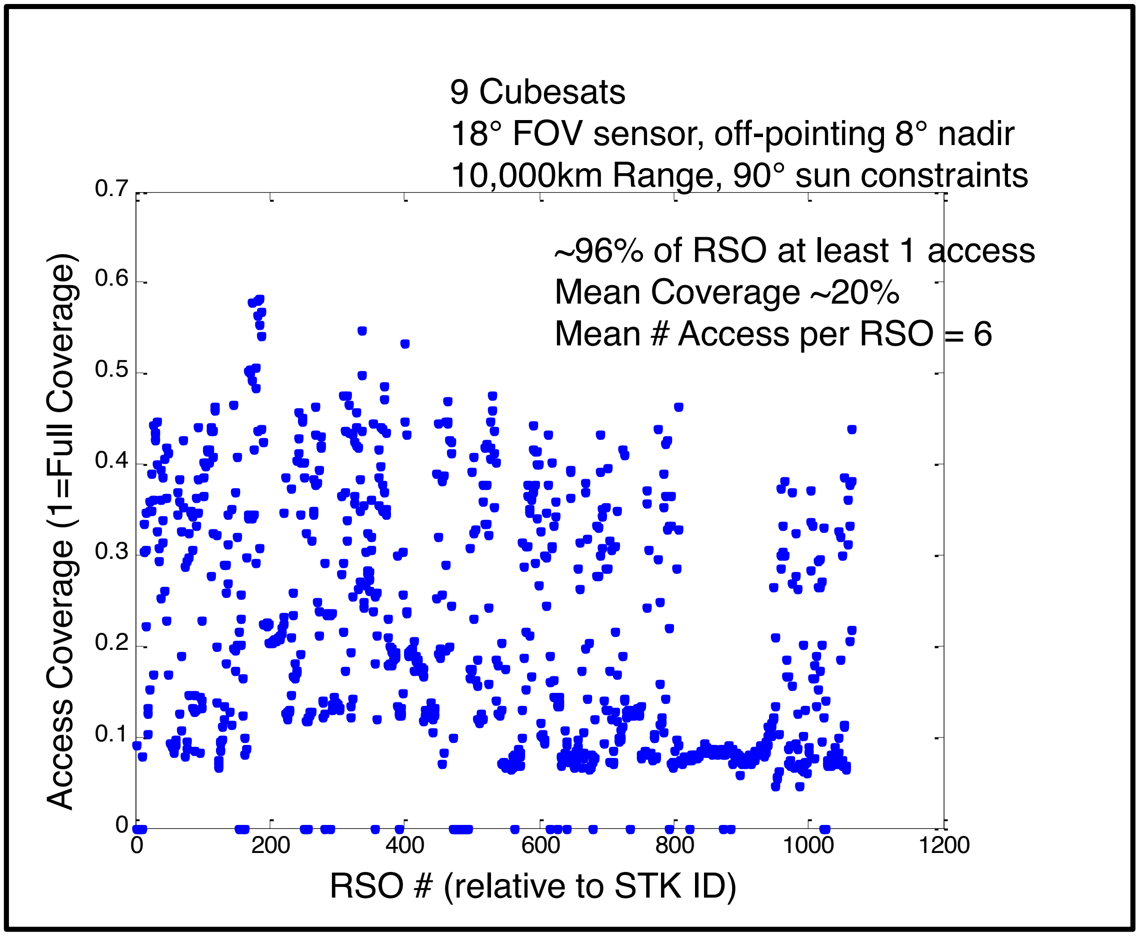


Figure 9 – Ten Day Scenario Coverage with Nine CubeSats

These scenarios were developed using nine CubeSats, which is a based on a simple launch concept. There are several concepts that would be able to launch many more CubeSats on a single launch vehicle. Launching more would help to improve these statistics. Figure 10 below shows the scenario where 18 CubeSats are on orbit at the same time. Also, if the CubeSats survive on orbit until the next launch of CubeSats, the number of CubeSats could be even greater than the single launch concept.

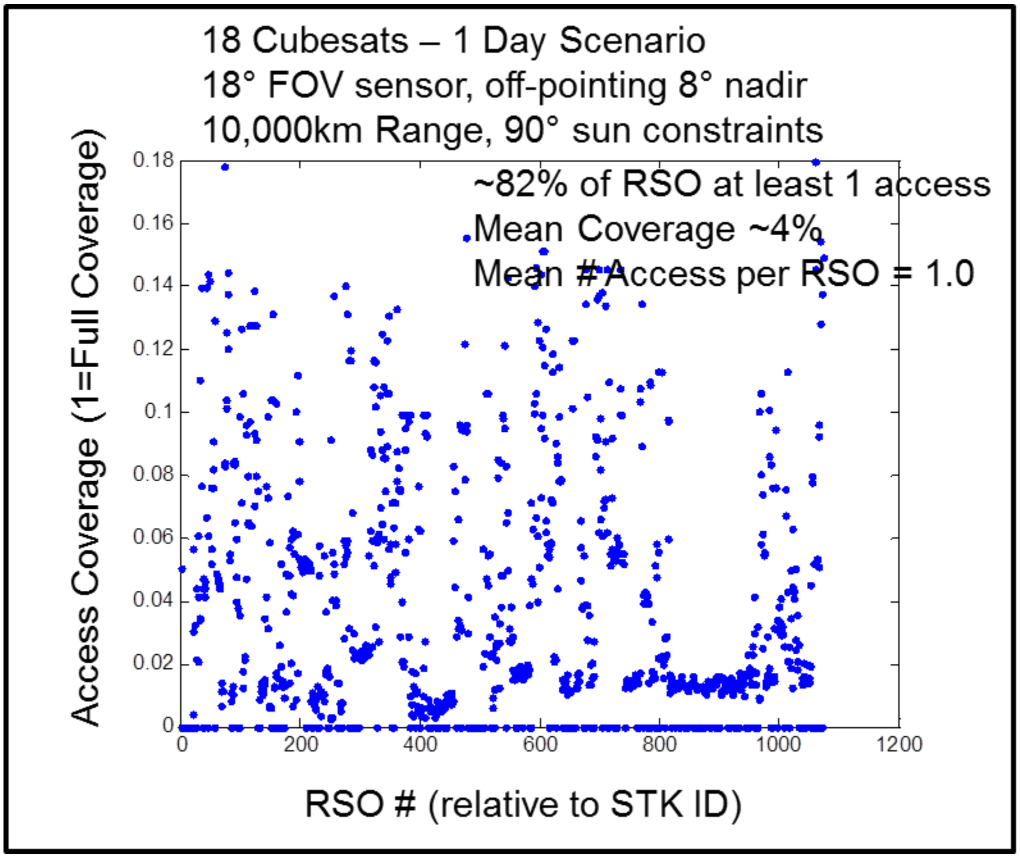


Figure 10 – Single Day Scenario Coverage with Eighteen CubeSats

Summary

As the world is increasingly becoming dependent on space assets, space situational awareness is required to ensure continued operations. With the explosion of CubeSats and their associated hardware, government customers are looking for ways to integrate these affordable satellites. Utilizing a CubeSat constellation at GEO+500 km can help offset the current ground assets while providing additional sensitivity and revisit rates. Collecting observations on nearly all of the objects at GEO will significantly increase the safety of satellites at that orbit. The increased revisit rates from the CubeSat constellation, ensures that when objects change their trajectory, the satellite operators are aware of potential issues quicker than with the current assets. Doing this mission with CubeSats significantly adds value to the SSA architecture without significant cost and risk. This example is used to highlight one method to integrate CubeSats into the SSA architecture. Other constellations exist that also could provide significant value to the SSA architecture and should be considered.