Geosynchronous Orbit CubeSat Operating Guidelines to Help the Space Situational Awareness Community

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ABSTRACT

Today's space environment is trending towards the cost-effective deployment of small satellites (SmallSats). Cube Satellites (CubeSats) have become a popular SmallSat platform of choice due to their low cost and increasing capability. CubeSat operations have steadily advanced from Low Earth Orbit (LEO) in 2003 to Geosynchronous Orbit (GEO) in 2019. The CubeSat's small size along with the rapid nature of this expansion makes it increasingly difficult to maintain Space Situational Awareness (SSA) as CubeSats proliferate. This difficulty is magnified as CubeSats spread to GEO, given the satellite's small size and GEO belt's extreme distance from earth. One potential approach to this challenge is to expand the existing SSA system accordingly. This approach advocates for new capabilities and sensors, which are important, but will lead to excessive data collection and analysis, thus increasing cost. A more efficient option is to create operating guidelines that focus on a CubeSat's design and operations within the GEO belt. This method ensures that CubeSats developers are utilizing standards during the design phase as well as standard operating procedures when on orbit to help minimize the load on the SSA system. This paper establishes an initial set of guidelines for utilizing CubeSats at GEO and recommends a path to implementation that will help maintain SSA around valuable assets in GEO.

Architectural analysis has been performed that identified several factors that can drive down the demands of the SSA system. The operational altitude in GEO is a major factor due to the unstable nature of the orbit. Following this, the tradeoff between fault tolerance and orbit regime is analyzed in detail. The stable Geopotential wells are examined as potential operating environments due to their unique phenomenology that traps low energy objects. CubeSat constellations are thoroughly reviewed, and specific operational criteria are established which differ from the operating guidelines of singular CubeSats. Potential requirements for providing position data are discussed, as publishing ephemeris could benefit the SSA community. Also, requirements for adding retro reflectors are examined alongside potentially having each CubeSat provide a unique self-identification signal. The specific focus of the GEO CubeSat operating guidelines as proposed encompass the following points:

1. Operate at -300km to +300km of the GEO belt
2. Operate with single fault tolerance to disposal when near GEO
3. Operation at the Geopotential wells for missions that support these locations
4. Operation of CubeSat constellations
5. Provide position and velocity data to the SSA community
6. Laser retro reflectors
7. Provide unique signal that identifies the satellite

In addition, other beneficial guidelines will also be examined such as standards for CubeSat parts testing, shared databases for GEO tolerant parts, coordination of maneuvers, scarring for potential debris removal systems, among others.

Implementing these CubeSat operating guidelines will require a minimum of time and effort from both satellite operators as well as SSA community members. With GEO being an international domain, the enforcement of these guidelines will be an important factor. The most expedient way to enact this change would be to gain recognition from a space oriented international governing body, who could facilitate discussion between industry, operators, and SSA community members that would allow the operating guidelines to be reviewed, enacted, and enforced. This governing body would facilitate agreement on the operating procedures from all associated stakeholders. Furthermore, a way to create/edit these guidelines would be established to respond to changing space conditions and new industry trends. Discussing, optimizing, and establishing these CubeSat operating guidelines will help maintain SSA of the GEO belt.

INTRODUCTION

Today's space environment is trending towards the cost-effective deployment of thousands of small satellites (SmallSats). Proliferated architectures at LEO are underway while it is only a matter of time before the trend migrates to GEO. Cube Satellites (CubeSats) have become quite popular due to their low cost and increasing capability. CubeSat operations have steadily advanced from Low Earth Orbit (LEO) in 2003 to Geosynchronous Orbit (GEO) in 2019. The CubeSat's small size along with the rapid nature of this expansion makes it increasingly difficult to maintain Space Situational Awareness (SSA) as CubeSats proliferate. This difficulty is magnified as CubeSats spread to GEO, given the satellite's small size and GEO belt's extreme distance from earth. Fig. 1 highlights some factors that contribute to increased demand for CubeSats as well as a greater demand for SSA.

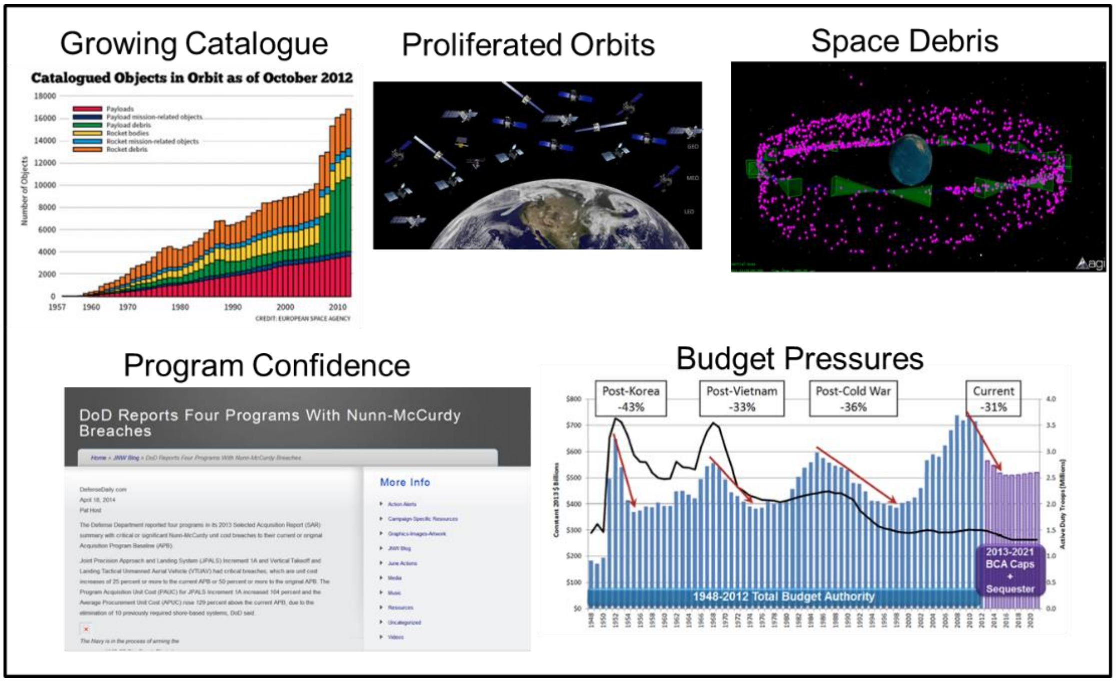

Fig. 1 –Increased demand for CubeSats directly correlates to increased demand for SSA

As seen in Fig. 1, the SSA community is also under significant budget pressure. It is paramount that community members invest in novel ideas that will provide cost effective solutions to the growing challenge of tracking space debris, particularly objects in GEO. This may entail thought leadership in new areas that differ from the traditional way of thinking (integration and collaboration vs specific technologies). Solutions to this SSA challenge will benefit all space fairing nations who would like to utilize the GEO environment.

CUBESAT DILEMMA

The number of CubeSats in LEO is increasing exponentially, and they are starting to proliferate to GEO. Based on their small size, CubeSats are hard to track at GEO and their increasing quantity will strain the current SSA systems.

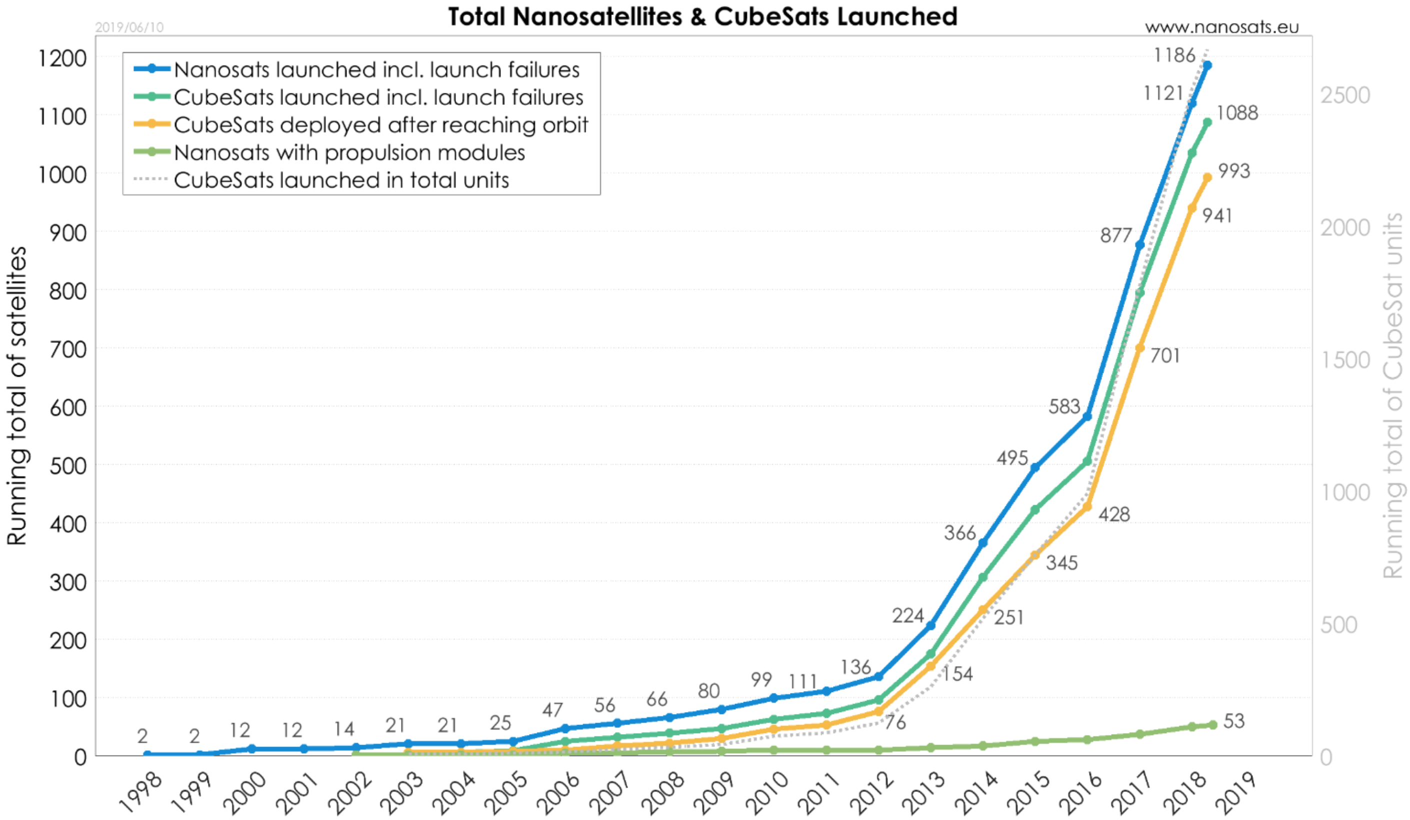

Fig. 2 – SSA system development must synchronize with proliferating CubeSats [1]

This proliferation causes various concerns among space operators. The sheer numbers of CubeSats that could potentially be deployed at GEO may overwhelm the Space Surveillance Network (SSN). This would require more sensor time to get quality tracks which inevitably reduces other important observations. In addition, CubeSats are generally built with lower mission assurance standards and a lack of redundancy due to the cost and SWAP available. This causes higher failure rates among CubeSats. At LEO, when failures occur, the satellites lose control and drift downward based on drag and the lack of orbit raising maneuvers. At GEO, when failures occur, the CubeSats will lose station keeping ability and drift within the GEO belt, potentially increasing the risk of collision with other GEO satellites.

POTENTIAL SOLUTIONS

One potential solution to dramatic CubeSat growth is to expand the existing SSA system accordingly. This plan advocates for new capabilities and sensors, which are important, but may lead to excessive data collection and analysis, thus increasing cost beyond what is deemed affordable. The cost increase comes from the improved ground radars, new optical telescopes, and augmented space-based sensors. A more efficient option is creating operating guidelines that focus on the CubeSat's design and operations at GEO. This method ensures that CubeSats developers are utilizing standards during the design phase as well as the operational phase to minimize the load on the SSA system.

The current SSA architecture consists of ground sensors (ex. telescopes and RADAR) and space sensors (such as SBSS) that produce observations singularly and collectively. A fundamental understanding of these sensing systems identifies several potential areas of improvement for CubeSat operations:

1. Operate at -300km to +300km of the GEO belt
2. Operate with single fault tolerance to disposal when near GEO
3. Operation at the Geopotential wells for missions that support these locations
4. Operation of CubeSat constellations
5. Provide position and velocity data to the SSA community
6. Laser retro reflectors
7. Provide unique signal that identifies the satellite

Operating at +/- 300km of the GEO Belt – Station keeping is required to keep spacecraft in their GEO slot. Once this ceases (due to failures or lack of propellant), a CubeSat would slowly drift east or west of the GEO belt. This creates collision problems with every satellite the CubeSat drifts by. In April of 2010 Intelsat lost control of the Galaxy 15 satellite while it was still transmitting, and it began to drift east along the GEO belt. This created the potential for collisions as well as electromagnetic interference with neighboring satellites. Fig. 3 shows a potential solution - requiring all CubeSats to operate 300km above or below the GEO belt. These graveyard orbits are already used to dispose of GEO satellites so it would be safe for CubeSats to operate and eventually fail in. This would reduce the strain on the SSN because these CubeSats would not require the same level of observation as the ones within GEO orbit due to the decreased risk of collision with larger GEO satellites.

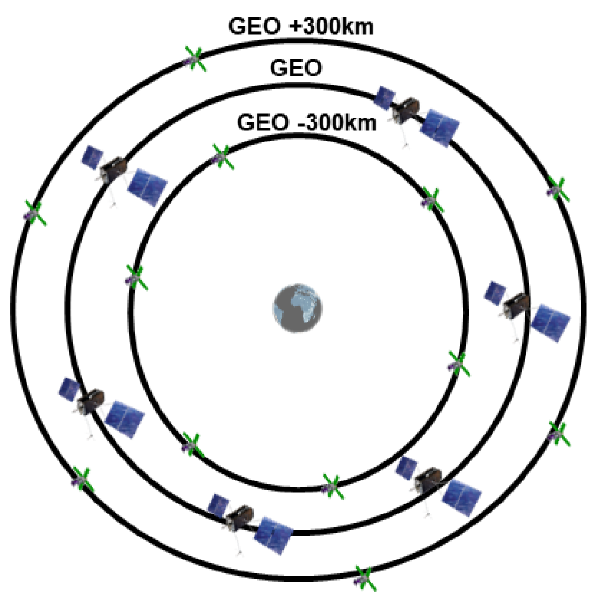

Fig. 3 – Notional CubeSat operating orbits enable decongestion of GEO

Operate with single fault tolerance to disposal within GEO – Some missions require station keeping over a prescribed point on the earth. If these missions are accomplished by CubeSats, then it is imperative to require single fault tolerance to disposal. This means the CubeSat can withstand more than one failure to the subsystems required to execute orbit raising/lowering. This does not mean that every subsystem requires redundancy, just the ones that are required to maneuver. Once a failure is detected in the subsystems and the CubeSat is no longer single fault tolerant, the CubeSat operator would be required to move the CubeSat to one of the graveyard orbits above or below GEO. This could be verified during the application phase to ensure the CubeSat developers are complying with the single fault tolerance guidelines.

Operate at the Geopotential wells – The GEO orbit has two geopotential wells that are created by the extra mass from the mountainous regions over the rocky mountains and the Himalayan mountains. These areas essentially trap all slow-moving objects near GEO as shown in Fig. 4. If there are missions that require a stationary location at GEO and they could be accomplished near the longitude of these wells, then CubeSats could operate in that location without the redundancy described in the previous section. If these CubeSats were to fail, they would remain near the wells indefinitely and would not cause interference with other GEO satellites.

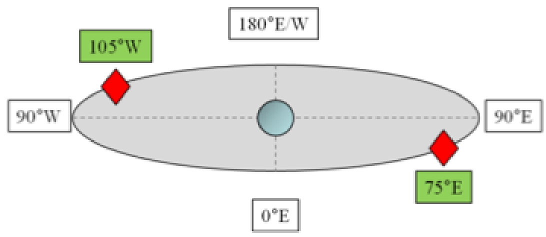

Fig. 4 – Geopotential wells offer stationary orbital regimes for CubeSat missions

Operation of CubeSat Constellations – Singular CubeSats can adopt the above features to lessen the burden on the SSN by keeping them out of critical orbits. However, operating constellations of CubeSats creates additional challenges. Formation flying CubeSats have the added challenge of collisions with each other if they are required to be in proximity to one another – notionally shown in Fig. 5. Also, CubeSats in constellations in proximity will be hard for the SSN to distinguish and develop individual tracks. Certain rules could be put in place to avoid these collisions like a minimum distance between nodes of the formation, or where in the GEO belt these constellations could be operated (i.e. not near crowded GEO slots). This topic requires more research as CubeSat constellations increase in popularity.

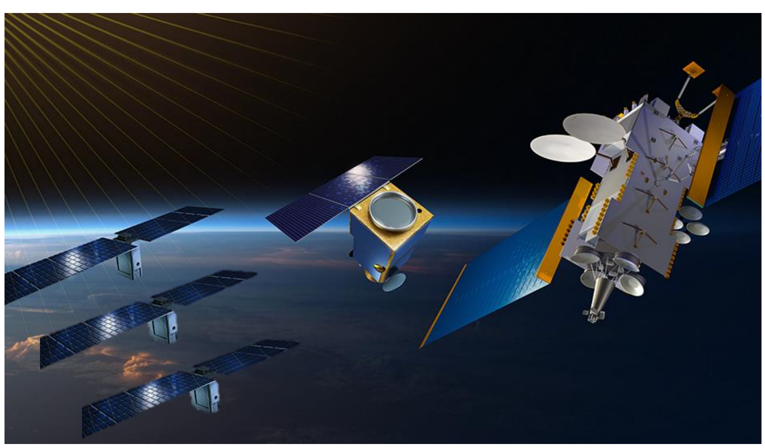

Fig. 5 – CubeSat constellations require increased SSA to avoid collisions

Provide position and velocity data to the international SSA community – Normal operation of the SSN requires a search function to find new objects (or anything that has moved since the last observation), followed by targeted observations to reduce the covariance of the orbit parameters. These orbit parameters are published as part of the SSA catalog. CubeSat operators could be required to provide the SSN with position and velocity data acquired through system operation, such as deriving range through the communications system or on-board GPS. Also, any maneuvers could be required to be coordinated with the SSN along with providing the position and velocity data recorded immediately before/after the maneuver. This would help the SSN reduce the search and dedicated observation time required for tracking that specific maneuver and free up valuable sensors to track other objects. Each CubeSat may not be able to provide this information as some operators rely on the SSN for that very same data (in order to communicate with their asset), however, providing position data should still become a best practice for operators who are able.

Require Laser retro reflectors – By illuminating an area of the GEO belt with laser light, the reflections could be used for orbit determination. However, large lasers would be required to ensure enough power is returned in the direction of the receiving optics. If it was required to house a small retro reflector on the CubeSat exterior, this would direct the laser reflection directly back at the source and focus the energy. This method would reduce the laser power required and provide a strong return in any orientation. However, this would also add mass to the CubeSat, which may inconvenience some manufacturers, launch providers, and ultimately operators. Implementing this would involve an agreement between enough operators to make the purchase of the large laser stations cost efficient.

Provide a unique signal for each CubeSat – CubeSats in LEO sometimes have difficulty distinguishing between specific downlinks when they are in close proximity. When multiple CubeSats are deployed in succession, there have been examples where ground operators could not identify which RF signal belonged to their specific CubeSat, and thus could not lock onto it. This has previously resulted in CubeSats not being commanded to appropriate attitudes and caused them to reenter the atmosphere earlier than planned. This problem compounds when deploying CubeSats in GEO as the distance will make it harder to distinguish specific RF signals. One potential solution is to require CubeSat developers to put out a unique signal that will allow ground operators to better identify which RF output belongs to which CubeSat. This will help reduce the load on the SSN by not requiring many detailed observations during the deployment from the launch vehicle. In the LEO challenge mentioned above, the SSN network was tasked to help identify which RF signal belonged to which CubeSat to help the operators establish communications. Establishing a unique signal will help eliminate this troublesome situation.

Additional Considerations – In addition to the above guidelines, the following concepts merit supplementary research. CubeSats tend to utilize commercial parts that do not have the extensive spaceflight experience due to cost and SWAP concerns. Therefore, testing standards could be implemented to ensure the CubeSats are tested appropriately and uniformly to provide assurance that they will operate on orbit for their prescribed lifetime. In addition, a database could be shared with the CubeSat community that highlights radiation tolerant commercial parts as well as general parts that CubeSat operators have demonstrated successfully on orbit. This could help future CubeSat designers create spacecraft that have reliably tested components. With maneuvers being a challenge for the current SSN, the CubeSat operators could be required to coordinate any maneuvers with the SSN so that the sensors could be utilized most efficiently. Finally, future CubeSat designs could be required to include scarring for potential debris removal systems such as hardpoint features for robotic arms to grab or external fuel ports so the CubeSats could be refueled. These concepts are harder to incorporate but could be included in any design or operational standards.

IMPLEMENTATION OF THE OPERATING GUIDELINES

Implementing these CubeSat operating guidelines will require time and effort from both satellite operators and SSA community members. With GEO being an international domain, the enforcement of these guidelines will be an important factor. The most expedient way to enact this change would be to gain recognition from a space oriented international governing body, who could facilitate discussion between industry, operators, and SSA community members that would allow the operating guidelines to be reviewed, enacted, and enforced. This governing body would encourage agreement on the operating procedures from all associated stakeholders. Furthermore, they would establish a way to create/edit these guidelines to respond to changing space conditions and new industry trends.

The International Telecommunications Union (ITU) is a great example of a large organization with well-established standards. Formed through the United Nations (UN), the ITU caters to users of the global radio spectrum by establishing current/future technical standards for radio communications. This organization enables users by having one set of common standards for the industry. This increases collaboration and gives users a sense of what "normal" is. The ITU paints a good example for forming space operational procedures due to the way that governments, commercial industry, and influential private citizens must come together and agree on operating principals and standards to enable effective system operations. This example can be replicated in the space domain.

The U.N.'s Committee on the Peaceful Uses of Outer Space (COPUOS) recently approved 21 guidelines focused on sustainability of space which will be voted on by the UN General Assembly for endorsement. These guidelines result from a 10-year working group devoted exclusively to this task. This group emphasized coordination and agreement between member countries with vastly different goals and views. Of note, this group also included commercial space operators. It will be important for the SSA community to learn from COPUOS's example by maintaining a balance between both government and industry when establishing operating principals.

The Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) is another good example to learn from. This organization is responsible for publishing notational operating procedures and standards for rendezvous and proximity operations (RPO) and on-orbit satellite servicing (OOS). The guidelines provided by this group are taken to international governing bodies such as international governments, the Inter-Agency Space Debris Coordination Committee (IADC), International Organization for Standardization (ISO), and the Consultative Committee for Space Data Systems (CCSDS). These organizations will then debate and adopt any suggested measures as operating principals. The SSA community should establish a similar group that can propose ideas to international organizations to form SSA best practices and operational procedures. Adopting an operating methodology similar to CONFERS may be the best way to ensure that CubeSat operations take place safely while maintain awareness of the entire domain.

CubeSat manufacturers can also use this international governing body to establish design standards to ensure that spacecraft will function to the same tolerance level once operational. The ITU currently has a Telecom division which proves that their methodology of standard creation will succeed in the space domain. Utilizing the same standards ensures that all CubeSats will operate uniformly within this difficult environment.

CONCLUSION

It is paramount that the SSA community effectively create and find a way to enforce GEO CubeSat operating guidelines. Further technical research is recommended on the 7 potential solutions recommended in this paper as well as the additional considerations. Further work is also necessary on the policy end – the SSA community must establish operating procedures for CubeSats at GEO. Careful thought leadership is necessary before CubeSats reach this orbit in large numbers. Discussing, establishing, and optimizing these CubeSat operating guidelines will help maintain SSA of the GEO belt.

REFERENCES

[1] Erik Kulu, Nanosats Database, www.nanosats.eu