## **Micro-GEOs: An Emerging Small Satellite Bus Class**

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#### ABSTRACT

Over the last few years, Orbital has witnessed the emergence of a new spacecraft bus market class we call Micro-GEO. Micro-GEO spacecraft operate in high-altitude orbits such as Geosynchronous Earth Orbit (GEO) and typically weigh an order of magnitude less than traditional GEO communications satellites. Initial demand has primarily been driven by defense needs, but NASA is expected to have an interest in this capability as well. This paper describes the market class and some of the bus design drivers.

The obvious challenge to this class bus is access to space. Two basic means are available, direct injection into GEO and launch into geosynchronous transfer orbit (GTO), with the spacecraft responsible for boosting itself to GEO. The launch approach has a substantial impact on both the availability of launch opportunities as well as the complexity of the spacecraft bus design.

Operation of spacecraft in high-altitude orbits such as GEO has many similarities to their low-Earth orbit (LEO) counterparts, but there are important differences as well. The paper addresses technical similarities and differences between the two orbital regimes and the resulting design implications.

#### INTRODUCTION

Over the last 30 years, small satellites have carved out an important niche in the world's space portfolio. Their simplicity, low cost, and rapid time to launch have made them an invaluable resource for a wide range of missions including science investigation, technology demonstration, Earth observation, communications, and education. However, most of these missions have been constrained to low Earth orbit (LEO).

To date, the benefits of small satellites have not been realized by geosynchronous satellites. Indeed, when discussing GEO, one must carefully define the term "small." A "small" geosynchronous communications spacecraft weighs several thousand kilograms.<sup>1</sup> The traditional definition of a microsatellite is one with a mass between 10 and 100kg. The Micro-GEO described in this paper are expanded to consider a higher upper limit, extending up to 200-300kg, in other words, a full Pegasus-class spacecraft.

Similarly, the term Micro-GEO is not strictly limited to geosynchronous orbits, but instead considers a broader range of high-energy orbits from below GEO (perigee

of 5-6 Earth radii ( $R_E$ )) to those well beyond GEO (up to 8-9  $R_E$ ). This breadth of orbit options has important design implications that will be discussed later.

### **MICRO-GEO MISSIONS**

Many mission areas can be well served by a Micro-GEO bus, including: science missions, technology demonstrations, fractionated or cluster formation spacecraft, inspection missions, and space situational awareness. Each of these mission areas often makes use of microsatellites, and the GEO orbit could be of use to these missions, as will be discussed in the following sections.

#### Science Missions

Although earth observing science missions are often satisfied by microsatellites in a LEO orbit, some science missions would benefit from a higher orbit. This higher orbit could either be geosynchronous, if studying a particular area of the Earth, or another highenergy elliptical orbit. One of the primary challenges facing a scientific mission at GEO is that, to date, few scientific satellites have flown in the GEO region. This presents numerous challenges to both spacecraft design and spacecraft operation. These challenges will be further discussed in the Design Considerations Section.

### **Technology Demonstrations**

Technology demonstration satellites, whether in the commercial, science, or defense arena, are meant to be inexpensive (relatively speaking) risk reduction measures. The cost of demonstrating one or two technologies on a small spacecraft, rather than an entire new system in large spacecraft form, will be considerably lower than alternative options. Historically, most microsatellite-class technology demonstration missions have been conducted in low Earth orbit. LEO offers numerous technical and cost benefits. However, a subset of technologies cannot be demonstrated in LEO or the value of the demonstration is greatly diminished in LEO. For example, a GEO demonstration mission might be ideal for a new sensor intended for a large weather satellite.

These pathfinder missions can be predecessors to fullsize spacecraft missions after demonstration. It is also a possibility that these Micro-GEO technology demonstrations will perform well and segue into operational Micro-GEOs. There are certainly cost benefits to be gained from many small, diversified spacecraft versus large monolithic platforms.

## Fractionated or Cluster Formation Spacecraft

Along the same lines as a technology demonstration, there is increasing interest in the community for fractionated spacecraft, in which functionality is divided among separate small spacecraft that work together to achieve the overall functionality of one, larger spacecraft. This class of spacecraft has utility in both LEO and GEO.

As mentioned in the Technology Demonstration section, constellations of microsatellites can offer cost savings over monolithic platforms. Not only are the cost savings of development and launch attractive, but multiple microsatellites also improve sustainability since they are cheaper to replace. In addition, the loss of a single microsatellite would have much less effect that the loss of a large, multi-mission asset.

## Inspection

A capability that is desired by the commercial, science, and defense sectors is that of on-orbit inspection. In the case of a failure, time-relevant imagery could be extremely helpful for anomaly resolution. Each commercial GEO communications satellite could be launched with a Micro-GEO satellite, whose sole purpose would be to perform inspection of the primary satellite. Not only would this be of use during the initial deployment and checkout phases on orbit, but the Micro-GEO could maintain a relative close proximity to the primary satellite and continue to monitor status throughout its lifetime.

### Space Situational Awareness

Another mission that an inspection Micro-GEO could perform is that of local Space Situation Awareness (SSA). In addition to imaging and monitoring the primary spacecraft, an SSA Micro-GEO would also monitor the local space around the primary satellite for any possible collision hazards. This service has obvious appeal to national assets for defense and communication, but also could be useful for commercial communication satellites as the GEO belt becomes more populated.

# ACCESS TO SPACE

The emergence of a Micro-GEO bus class is largely dependent upon the availability of access to the desired high-energy orbits. To date, very few microsatellites have been launched to GEO.

At this time, access is only economically viable as a secondary payload. Launches can either be direct inject, where the launch vehicle places the spacecraft directly into the target orbit, or geosynchronous transfer orbit (GTO). GTO is a highly elliptical orbit with perigee of a few hundred kilometers and apogee near GEO altitude.

# GTO Launches

Piggybacking a microsatellite on a launch to GTO is not a new concept. In 2000 AeroAstro introduced the Small Payload Orbit Transfer (SPORT<sup>TM</sup>) vehicle. SPORT was designed to enable microsatellites to leverage the plethora of launches to GTO.<sup>2,3,4</sup> In 2007, for example, sixteen GTO launches were conducted.<sup>5</sup> SPORT was designed to transfer a small satellite from GTO back into a LEO.

Micro-GEOs, of course, need to go in the opposite direction. Hitching a ride to GTO is an excellent start, but it leaves the satellite well short of its intended orbit. Transfer from a 500 km x 35,900 km to a GEO requires approximately 1,500 m/s delta-V. The cost of overcoming this challenge has confined microspacecraft largely to LEO.

The Interstellar Boundary Explorer (IBEX) mission represents a dramatic step forward in the development of a small satellite capable of transferring itself from GTO to GEO or near-GEO orbits.<sup>6</sup> IBEX is a NASA Small Explorer mission, one in a series of low-cost, focused science missions managed by NASA's Goddard Space Flight Center.

Although IBEX does not strictly fit the definition of a Micro-GEO orbit, it illustrates the applicability of microsatellites in high-energy orbits. The IBEX spacecraft will be placed into an orbit with a 7,000 km perigee and a 50  $R_E$  apogee (319,000 km or more than 80% of the distance to the moon). Remarkably, this orbit is achieved using a Pegasus launch vehicle. After launch into a 200 km circular orbit, a STAR 27 solid rocket motor is fired to raise the orbit. After several days of on-orbit checkout, an on-board hydrazine propulsion system is used to fine tune the orbit apogee to the desired 50  $R_E$  altitude and to raise perigee. The perigee raising maneuver lowers the radiation dose accumulated by the spacecraft over its two year design life.

IBEX is designed to investigate "the global interaction between the solar wind and the interstellar medium."<sup>7</sup> This is achieved by imaging energetic neutral atoms (ENA) originating at the boundary between the solar wind and the interstellar medium. Energetic neutral atoms are also generated by the interaction of the Sun with the Earth's magnetic field. Therefore, the spacecraft must operate outside this regime. Science operations only occur when the spacecraft altitude is greater than 10 R<sub>E</sub>.<sup>8</sup> It is this limitation that drives the need for such a high-energy orbit.

The IBEX example illustrates multiple key points about the potential for Micro-GEO spacecraft. First, it



Figure 1: NASA's IBEX Mission Demonstrates Key Capabilities for Micro-GEO Spacecraft

demonstrates that microspacecraft can perform groundbreaking science investigations. The IBEX spacecraft weighs just 105 kg (wet) and consumes 72W, yet is it making key measurements of a region only now being visited by the Voyager spacecraft.<sup>9</sup> Second, IBEX demonstrates that large propulsive maneuvers can be performed on small satellites. The IBEX orbit raising maneuver requires approximately 3,000 m/s delta-V, about double the value needed to raise a spacecraft from GTO to GEO. Thus, IBEX has provided a pathway to much greater exploitation of GEO and GEO-like orbits for small spacecraft. Finally, IBEX shows that Micro-GEO spacecraft may come in many different configurations. IBEX is a sun-pointed spinning spacecraft with a very simple design.

### GEO Launches

Most geosynchronous spacecraft are launched into GTO and are responsible for propelling themselves to GEO. The few spacecraft that are launched directly into GEO are typically government missions that are especially unlikely to be open to secondary payloads.

However, one intriguing option could be considered. In this scenario, a commercial geosynchronous communications satellite serves as the microsatellite upper stage.

Commercial geosynchronous communications satellites offer several benefits as Micro-GEO launch platforms. First and foremost, they could dramatically change the launch availability to Micro-GEO spacecraft, with a launch rate in 2007 of more than one per month.<sup>5</sup> This approach can offer access to multiple orbits. Orbit raising from a slightly inclined GTO orbit to a zero inclination GEO orbit is typically performed in several stages. The Micro-GEO could be released at any point in the process. Regardless of the deployment orbit, the Micro-GEO can use on-board propulsion to achieve the final desired orbit.

The commercial geosynchronous launch concept must overcome some technical, programmatic, and business challenges. However, the concept is feasible on all of these fronts and offers the prospect of regular, costeffective access to GEO for Micro-GEO spacecraft.

## GEO Hosted Payloads

Of course, the most cost-effective approach for some missions could be to do away with the Micro-GEO spacecraft altogether and place the desired payload directly on a geosynchronous spacecraft. Although this can be the lowest-cost method of placing a payload in space, it has a number of technical and business challenges that are likely to be satisfied only by a limited set of payloads. Considering their size and complexity, commercial geosynchronous spacecraft buses are relatively inexpensive. This is because these buses have been custom designed for a specific purpose. These basic designs can be reused from mission to mission, allowing the spreading of non-recurring design costs across many units. Adding a separate payload can disrupt the established design. Redesigning the standard geosynchronous satellite bus to accommodate a secondary payload is likely to be prohibitively expensive. Areas of potential incompatibilities include:

- Pointing requirements (commercial communications satellites must remain nadir/sun pointed)
- EMI/EMC (problems could occur in either direction)
- Cleanliness (commercial communications satellites cleanliness requirements are typically lower than those of many imaging instruments)
- Electrical interfaces (this can be mitigated if the secondary payload is willing to accept the interfaces offered by the host spacecraft; however, most missions work the other way around)
- Pointing accuracy/stability (commercial geosynchronous communications spacecraft have modest pointing accuracy requirements and are not sensitive to jitter)
- Data processing (the relatively simple requirements for commercial geosynchronous communications spacecraft demand little processing power)

If a particular payload can demonstrate compatibility with a GEO spacecraft bus then this could be a very attractive alternative. However, most payloads will probably violate one or more of these restrictions and require a dedicated Micro-GEO bus.

## **DESIGN CONSIDERATIONS**

Geosynchronous spacecraft, especially commercial communications spacecraft, have well-established designs honed over decades of development. However, Micro-GEOs are likely to be more similar to LEO than GEO spacecraft. This is driven by several factors:

• Micro-GEOs are expected to perform a wide variety of missions with many different

payload types. This demands the design flexibility built into LEO product lines.

- Micro-GEOs may be operated in a variety of high-energy orbits, so design assumptions incorporated into GEO bus designs may not be valid.
- Micro-GEOs would generally be expected to have a relatively short operation life of 1-5 years, compared to operational lives of 15 years or more for GEO spacecraft. Singlestring or partially redundant designs will be acceptable for many Micro-GEO missions.
- Micro-GEOs are an order of magnitude smaller than even "small" GEO communications spacecraft

Although Micro-GEOs have greater design similarity to LEO than GEO spacecraft buses, the high-energy orbits used by these spacecraft create some unique design considerations.

### **Radiation Environment**

Many microsatellites operate in relatively protected low Earth orbits. Most Micro-GEO orbits are above the Earth's radiation belts and thereby avoid the most difficult environment. However, the total dose in these orbits can be several times that encountered in LEO. Furthermore, the total dose can climb rapidly if the spacecraft spends a considerable amount of time in a highly elliptical orbit like GTO prior to raising to the final operational orbit.

This higher dose environment can pose a challenge for some components. In order to reduce cost, some microsatellite components are designed for the low total doses encountered in LEO orbits. This may reduce the potential supplier base for some items.

### Power

The two primary differences from LEO spacecraft are that the spacecraft spends a much greater percentage of its time in the sun. The worst case sun time is 94% for a GEO spacecraft compared to 65% for a LEO orbit. However, the eclipses are much longer, at 82 minutes compared to about 35 minutes. For elliptical orbits, the worst-case eclipse can be even longer.

### Guidance, Navigation, and Control

Many LEO spacecraft now rely upon GPS for navigation information. GPS navigation is feasible in GEO orbit, but it is not a feature in commonly available products. Using GPS becomes increasingly difficult for orbits with apogees above GEO. If GPS is not used then a requirement is typically levied on the communications and ground systems to perform orbit determination by ranging.

Attitude control is also affected by the weakness of the Earth's magnetic field in GEO-like orbits. As a result, torque rods cannot be used for attitude control or for desaturating reaction wheels. As a result, a propulsion system is typically required to provide one or both of these functions.

### **Communications**

The communications function is affected primarily by the increased distance to the earth. Compensating for the added distance involves a combination of increased antenna sizes on the spacecraft and the ground, antenna steering mechanisms, higher RF power output, and decreased data rates. Lower data rates can be compensated for by dramatically higher visibility times. Of course, taking advantage of the increased availability requires more ground station contact time that could drive operations costs.

# CONCLUSION

Microsatellites have proven to be a powerful tool for a wide range of applications in LEO orbits. A Micro-GEO satellite bus could raise these benefits to higher energy orbits. To date, the primary impediment to this bus class has been access to space. However, new approaches and opportunities for secondary launches are now coming available that could dramatically improve the availability and the cost of small satellites launches to GEO and similar high-energy orbits.

A high-level overview of Micro-GEO design considerations shows that these satellites are likely to have greater similarity to small LEO spacecraft than traditional GEO buses. However, the high-energy GEO and near-GEO orbits introduce a number of different factors that must be considered in the spacecraft design process.

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