An Exploration of the Small Satellite Value Chain and the Future of Space Access

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ABSTRACT

"Space is hard" is a saying that has been made popular in the last few years. It is not just the engineering that is challenging, but also applies to the business of space as well. From supply chain to regulation, the space industry's infrastructure is not prepared to handle the influx of demand forecasted through the next decade, especially in the small satellite segment. Accordingly, space businesses are looking to cost effectively and quickly build and deploy space payloads while being able to refresh their technologies as advancements are made on Earth. In this paper, we will explore a small satellite customer's journey from ideation to launch and operations including a survey of the commercial and government entities involved. We will discuss the costs associated with the current processes from both a financial and schedule perspective. An important aspect to this study is to understand that there are many trade-offs to be made, from a whole turn-key solution from ideation to operations, to an entire a la carte solution with space customers "DIY-ing" it. We will provide a broad overview of the providers in each of the value chain segments from payload development, manufacturers, testing, regulatory, launch, and operations. Finally, we will discuss opportunities to make space access easier and the outlook of the value chain as space commercialization becomes a reality over the next decade, including new impactful technologies such as on-orbit servicing and repair. Reusable infrastructure is the key to solving these customers' pain points as satellites are disposable assets today.

INTODUCTION

"Space is hard" is a saying that has been made popular in the last few years. However, it isn't just the engineering that is challenging, the business of space is difficult as well. From supply chain to regulation, the space industry's infrastructure is not prepared to handle the influx of demand forecasted through the next decade, especially in the small satellite segment. The process of developing, launching, and operating a small satellite is not only difficult, it also can be confusing, especially for those that do not have experience in the aerospace and defense sectors. From designing a payload to eventual launch and operations involves coordination through many different organizations, ranging from commercial to government — leaving to-be space users frustrated by the inefficient processes in the sector. Although the New Space industry and the small satellite revolution have brought down the barriers to entry for those wanting to utilize space, the challenges and inefficiencies of the past have not disappeared.

Currently, there are more than 3,000 satellites in orbit [1], but this number is set to grow more than threefold through the next decade [2]. However, the satellite industry is currently not built to support the explosive growth. Space businesses suffer from three main problems — large up-front costs, extended times to market due to specialized component manufacturing, and unserviceable assets that are built to be disposable. As the commercialization of space increases, with small satellites at the cornerstone, more commercial services will enter the market, making the process of getting payloads into space streamlined. These services span from a complete turn-key solution to resource sharing through hosted payload solutions. For cost conscious space users, such as those in the scientific and academic community, the hosted payload solution offers a unique value proposition. However, hosted payloads come at the price of reduced volume, power, and pointing ability. Therefore, there is a trade-off to be made between developing your one's own satellite or constellation and sharing resources with reduced capabilities in the case of a hosted payload.

Space businesses are looking to cost effectively and quickly build and deploy space payloads while being able to refresh their payload technologies as advancements are made on Earth. In-space infrastructure is the key to providing cost and schedule efficiency. Accordingly, Plutonics Technologies Inc. ("Plutonics") is developing the technology needed to enable satellite reusability. The demand for this solution has been confirmed by potential customers with expertise in the space business, having tried other solutions. The global market size for satellite manufacturing was over $23.2 Billion in 2020 and is expected to grow at a rate of 4.2% per year reaching $30.1 Billion by 2027 [3]. This growth has been driven by the lowered cost of launch from commercial entities such as SpaceX, and the miniaturization of satellite components [4]. There is significant demand for satellite systems, and the improvements that can be achieved by deploying reusable satellite systems, such as one being developed by Plutonics offer a compelling business opportunity. From the business side, reusable infrastructure allows costs to be amortized over time and across multiple customers, like other Software-as-a-Service businesses.

Outside of the commercial sector, various US government organizations have expressed interest in the concept of a persistent platform as an orbital test platform [5], or for rapid deployment capabilities [6]. A reusable satellite system would be the first steps to enabling a persistent platform capability.

CURRENT MARKET OVERVIEW

Global Market

Over the last ten years, there has been a dramatic increase of satellite activity in Low Earth Orbit (LEO). Currently, there are 3,372 operational satellites in Earth's orbit [1]. The total number of satellites launched per year is projected to increase from 181 in the previous decade, to 1,011 by 2029 [7]. Two thirds of these will be operating in LEO, providing a growing variety of services such as imagery, telecommunications, scientific experiments, and new technology development. By any measure, the market is massive — currently the space market is estimated to be $360B and estimated to be $1T by 2040 [8]. The global satellite market is a subset of the space industry and estimated to be $154B and includes government, commercial, and consumer services. The proposed reusable satellite development addresses the challenges in efficiently supporting the over 8,000 satellites that are expected to be launched through the next decade.

Market Opportunity

By every measure an enormous amount of money is spent each year designing and building satellites. Despite the size, the fragmented nature of this activity has led to increased costs and schedule delays. We estimated the market size based on publicly available information and vetted assumptions with industry leaders seen in Figure 1 [2], [8], [9]. It is worth noting that the market will be riding the wave of several major, long-term business trends:

Lowered launch cost. With 100+ launch companies competing for space, launch is no longer the bottleneck for space missions. This opens the trade space for many different architectures to come to fruition. This increased competition will drive down the cost for launch and make space a more appealing medium for business, driving demand for innovative space solutions.

Need for mid-tier satellite performance. Over the past year, many satellite manufacturers have been building larger and more high-performance satellite buses because customers need more than what a CubeSat can offer. As space becomes commercially viable, the needs will drive towards more performance, not less. Imagery payload users have told us that CubeSats do not have the required performance for their needs. Thus, much consideration can be given at looking to providing a high-performance system without the associated high cost.

Technology refresh. As new sensor technologies are built on Earth, payload developers and data providers want to provide this technology to end-users as soon as

Figure 1: Predicted addressable market size for small satellite-based payload services [2][8][9]

possible to maintain their competitive advantage. Customers have told us that they expect their technology to be upgraded within 6 months to 2 years and need a quick way accomplish the refresh instead of buying an entire satellite that may last for years.

OPTIONS FOR PAYLOAD DEVELOPERS

Case Study of Current Satellite Options

As an example, let's assume a space startup called Space Image Co. is trying to test their new imagery sensor in space. Space Image Co. plans to use their new imagery technology in a constellation of satellites to provide daily images for their customers.

Jane is the CEO of Space Image Co. and has been busy working with her team to develop their imager technology. They've been hard at work for over 2 years and talking to customers about their requirements and believe they have a clear business plan. Over the past couple of years, they've built and tested their sensor on Earth, getting as close as possible to simulating a space environment. They've spent hundreds of thousands of dollars in thermal vacuum chambers, vibration tests, and simulations. Jane is confident her team's imager will work in its current state, but her customers want proof through a demonstration in space. Jane worries that this test will be overly costly and faces a tough decision. As a satellite user, she is looking to use a satellite to provide imagery to customers, and her team is an expert at optical technologies, not satellites. Jane has the following options.

Build own satellite. Space Image Co. can build their own satellite, say a CubeSat-class satellite for ease of development, but risk it failing as CubeSats have a high rate of failure and it will take technical expertise not currently on the team.

Find a satellite manufacturer. This will be an expensive up-front cost and on-going operational cost since satellites last years in service and these satellites need a 12 to 18-month lead time for custom development.

Find a hosted payload provider. A hosted payload provider does spread the cost across multiple payloads, but there are still on-going operational costs and comes with highly restrictive operation.

Jane looks at her options and opts for the hosted payload provider as it is the cheapest cost option on the market. However, to conform to the hosted payload provider's requirements, Space Image Co. needs to build a smaller version of their optical payload — not what she has discussed with customers and not what she is planning to sell. The hosted payload provider is limited in the power they can provide to each payload and has strict scheduling restrictions between the multiple parties on the platform. Jane is frustrated by the complications with scheduling between the different parties, the lengthy integration time, and testing that is required.

Inefficiency in Current Options Available

The Space Image Co. example illustrates the key inefficiencies in the satellite industry. The industry lacks a comparable system to the way that aircraft components and sensors are tested. Every satellite payload goes through an orbital demonstration to gain "flight heritage" or an on-orbit demonstration. The space industry has a need for the following —

- A reusable test platform that will allow developers to test their technology in the space environment for a short period of time (3-6 months)
- Standard interfaces that provide short turn-around times to reduce integration times
- A satellite technology to provides a low-cost access to space

The industry lacks the ability to serve these critical problems that nearly all satellite payload developers face when first launching their satellites, the current options are shown in Table 1. Just as aircraft perform flight tests to test their systems before they are ready for production, satellites must be able to test payloads and systems.

Table 1. Aggregated options for payload developers

	Cost	Schedule	Available Payload Volume	Resources	Notes
DIY	+ Starting at ~$250k	− 3 – 4 years	− Restricted volume, bus takes up to 50% of the volume	− Limited by CubeSat size 15 – 120W	− Lower reliability + High customization
Turnkey Hosted Payload	− Starting at ~$0.8M	− Dependent on available opportunities	+ Up to 50% of the bus volume can be used for payload	+ Based on base spacecraft Up to 1kW	− Dependent on main customer payload destination + Simple operations
Turnkey Free Flyer	− Starting at ~$1M	+ 12 – 15 months	− Restricted volume, bus takes up to 50% of the volume	− Limited by CubeSat size 15 – 120W	− Customization comes at a cost + Simple operations

PROPOSED APPROACH: DEPLOYMENT OF REUSABLE SATELLITES

Target Market

One of the key target markets for small satellites are customers looking to demonstrate their technologies in orbit. These customers are the most risk taking and cash constrained. They are looking for a solution that provides them with the shortest time for testing in space without committing to a large satellite development project.

As one of the potential solutions for meeting these demands, reusable satellite systems will reduce the overall cost of operating a payload in space and reduce the time to market. These savings will be captured by the company as well as satellite users. We can estimate the potential initial addressable market by understanding the percentage of the market that are technology demonstrators, experimental payloads, and not constellations. The overall serviceable obtainable market is estimated to be $2B per year. Currently the global satellite manufacturing market is $12.5B per year and the small satellite constellations account for 83% of the market. Payload deployment service providers may initially target 17% of the market [2] that are not constellations in the small satellite sector, the fastest growing satellite segment.

The key innovation of the reusable satellite system is that it is a platform that will have many different use cases. From our initial research, early adopters are those looking to test their technology for short durations in space. However, we believe there are many other applications, as follows —

<u>Scale to Adjacent Markets.</u> Since the proposed reusable satellite system is a platform, it can be expanded to other space industry verticals such as imaging, RF & signals, environmental, asset tracking, and even medical experiments.

<u>Constellation-as-a-Service.</u> As more reusable satellite buses are deployed in different orbits, small constellations can be enabled. Instead of customers building a satellite, an the reusable bus can serve as an asset already in orbit, quickly enabling many different constellation business cases from high revisit imagery to telecommunications.

<u>Higher Altitude Orbits.</u> There are opportunities to scale our system up to cover Medium Earth Orbit (MEO), Geosynchronous Earth Orbit (GEO), cis-lunar, lunar, and even Martian orbits. Having assets already in place in various orbits will ensure that customers from both commercial and government will have access to assets so they can focus on their payload not an entire satellite.

Reusable Small Satellite Vision

There are different methodologies and CONOPS that can take advantage of this reusable small satellite bus concept. Figure 2 shows a graphical representation of the overall Plutonics' vision. To minimize cost, the customer payload(s) are launched on a pallet, and the reusable satellite bus (RSB) will maneuver close to the pallet and dock. RSB will then take the payload(s) to the target orbit and provide all required resources such as power, communications, attitude control, etc. to the payload. At the end of mission for the payloads, RSB will then deorbit the payload(s), and pick up the next pallet that is brought up from the ground.

A notional RSB architecture design is shown in Figure 3. Customer payloads will be loaded on to the payload integration pallet, as shown in the figure. This assembly can be either launched together with the RSB as a standalone satellite, or can be launched as an assembly, to be "picked up" by RSB on orbit.

In this scenario, the rendezvous, proximity operation, and docking (RPOD) technology is a key element in enabling the overall architecture. RPOD has been

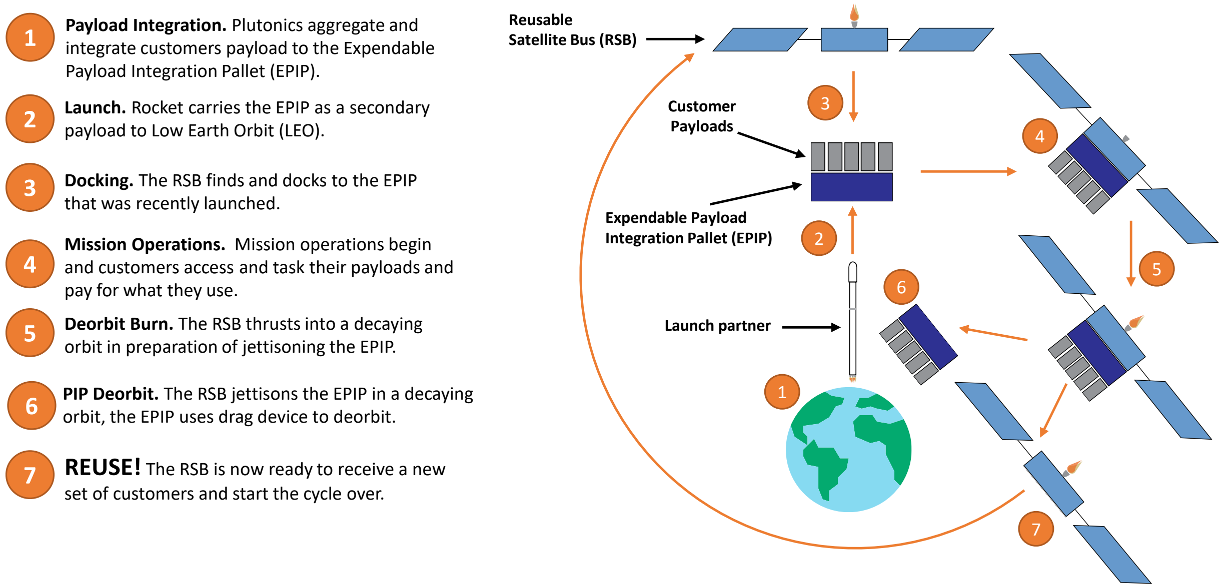

Figure 2: Reusability in space enables affordability, speed, and reliability

demonstrated in orbit in the past, but only for large satellites. These satellites are quite large in scale and have the luxury of having ample onboard resources in terms of volume, electrical power, and computing resources. However, the key space innovations and technology advancements cannot leverage these large, expensive satellites that have development schedules measured in decades. Small satellites designed to be reusable that can drastically lower the bar for on-orbit testing and payload deployment will be the key to the future satellite technology advancement.

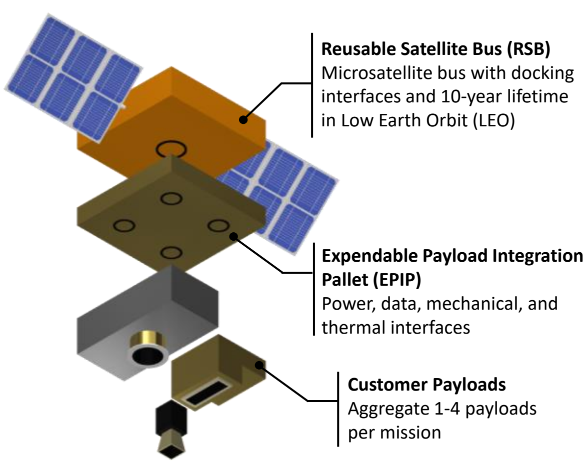

Figure 3: Depiction of notional Reusable Satellite System architecture

Reusable Satellite Bus Case Study

Space Image Co. is presented with the reusable satellite bus as an option for testing their payload in orbit. Jane likes this option because she doesn't have to worry about the satellite bus at all since it is already in orbit. Jane and her team test and confirm their compatibility with the reusable satellite bus on the ground through a simulated interface. Next, she sends her payload to Plutonics to be integrated to the EPIP. Plutonics takes care of the back-end operations of integration, functional and environmental testing, securing licensing, and finding a launch partner that will get Jane's payload to space as soon as possible.

With a reusable satellite system, flexible time commitments can be served. Jane wants to host her payload to be test on orbit for 6 months and she only pays for the time she is on the platform on a monthly basis and the utilities she uses such as data connectivity and electrical power. During her mission, Jane can task her payload through a secure web interface, upload new software that she wants to test, and download the data she needs to validate that her imagery payload works as intended. After the mission is complete, Jane does not need to worry about de-orbiting, as it is an integral part of the reusable process. This business model allows Jane to focus on her business, not building, operating, and maintaining a satellite.

Conversations from payload developers such as Jane have shown that there is value in this concept because

Reduction in Frustration. These companies currently have the most frustration with the inability to test their technologies for a short duration, and instead are required to buy or be hosted on a dedicated satellite.

Cash Constraints. These companies are startups that are cash constrained now, but with a flexible pricing model such as ours, would be able to afford access to space. By enabling their businesses, we generate brand awareness and loyalty of the company and network effects for the larger commercial space market.

Fast Cycle Times. From our discussions with our target market, they are looking for the ability to have fast development timelines and the ability to test quickly in orbit.

CONCLUSION

This paper discusses the costs associated with the current processes from both a financial and schedule perspective. As presented in the paper, there are many trade-offs to be made when considering operating a payload in space. There are different options available to deploy a payload to orbit, but the limitations of the current satellite technology may lead to the current options not being able to meet the customer requirements. We provided a broad overview of the services available and their limitations. Key focus of the paper was on a new opportunity enabled by emerging reusable satellite system technology that will make space access easier, and the associated outlook of the value chain as space commercialization becomes a reality over the next decade, including new impactful technologies such as on-orbit servicing and repair. Reusable infrastructure, such as the one currently under development by Plutonics, is the key to solving these customers' pain points. They have also expressed that they are looking for relatively fast technology refresh cycles for their sensors and currently without a reusable system, they are constrained by satellite design lives. In a perfect world, customers would like to refresh their technology every 2 years to stay competitive — this is especially true for imagery payloads. With a reusable satellite system, a single bus would be efficiently used across multiple customers lowering the cost basis for payload developers and enabling the commercialization of space.

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