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Nanosatellites - The Tool for a New Economy of Space: Opening Space Frontiers to a Wider Audience

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Abstract

Space is still a frontier. The advantages of research in microgravity conditions are still somehow a private niche of big aerospace contractors and main space agencies. But the landscape is changing and an incipient effort is being pursued to open space frontiers to small and medium-sized companies, universities, under-developed countries and non-profits. We will revise the advantages of microgravity research and a tool to conduct it at low-cost, rapid response and flexibility through the use of nanosatellites opening thus space frontiers to a wider audience. These highly capable satellites can support a wide range of mission objectives, from pure research to technology demonstrators and space qualification tests. The small satellites market is valued 600 M USD to 1.000 M USD yearly with an estimated 2.200 to 2.700 needed launches in the 2015-2020 timeframe. We will also introduce a new launcher under development to serve specifically the nanosatellite incipient market to help solve the scarce launching opportunities served today by conventional launchers.

Keywords: Space; Economy; Nanosatellite; Microgravity

Introduction

The global space economy in 2012 was valued at over £200Bn in commercial revenue and government budgets, and is expected to double by 2030 [1]. This growth is expected to come from the commercial sector, driven primarily by entrepreneurs and new business models. With historical average growth of 37% per year over the last four years, and estimated growth of 24% per year over the next six years, the small satellite market [2] is expected to be an important driver of growth in the overall space sector [2,3].

The global SmallSat market is valued 600 M USD to 1.000 M USD yearly [4] (most conservative and most optimistic estimations, respectively) with an estimated 2.200 to 2.700 needed launches in the 2015-2020 timeframe, and all these, under the current restricted circumstances, that is: without a disruptive solution as the one we are proposing that could boost the former figures.

The Small Satellites Market

In a recent study by the company Commercial Spaceworks, projections indicate strong growth in nano/microsatellite (1-50 kg) development, with an estimated range of 121 to 188 nano/microsatellites that will need launches globally in 2020 (versus 33 in 2012). Projections are summarized in Figure 1 below. Historical and announced future data sets suggest that the average number of nano/microsatellites launched per year triples with every five year period.

Nano/microsatellite (1-50 kg) development continues to be led by the civil sector, but the defense/intelligence community is showing increased interest and involvement. Applications for nano/microsatellites are diversifying, with increased use in the future for science, Earth observation, and reconnaissance missions.

The Space works Commercial study focuses on nano/microsatellites with masses between 1 kg and 50 kg. The study limits the upper end of microsatellite mass to 50 kg given the relative large amount of satellite development activity in the 1-50 kg range by comparison to the 50-100 kg range; Pico satellites (masses below 1 kg) are not within the scope of the afore mentioned study. The data source for the study is the SpaceWorks Satellite Launch Demand Database (LDDB), a database of all known historical and future satellite projects, including all known nano/microsatellites:

- Currently 377 known future nano/microsatellites (1-50 kg) in the LDDB.
- Currently 47 known future picosatellites in the LDDB (not included in this study).

Two projections were developed from "Announced" and "Optimistic" data sets:

- The "Announced" data set contains all publicly announced nano/microsatellite projects and programs from the SpaceWorks LDDB.
- The "Optimistic" data set consists of the announced plus an inflating factor for known unknowns plus assumed sustainment of certain current projects and programs (e.g. follow-on to NASA Ames EDSN, Cubesat Launch Initiative, DARPA SeeMe).

Nano/Microsatellite CAGR (Compound Annual Growth Rate) indicates an average growth of 8.6% per year over the last 12 years (2000-2012). According to the Announced Dataset, the average growth is of 16.8% per year over the next 7 years (2013-2020); according to the Optimistic Dataset (see below), the average growth is of 23.4% per year over the next 7 years (2012-2020).

Projections derived from the referred study are summarized in Figures 1 and 2 below. Concerning nano/microsatellite purpose trend, there is an evidence of adoption of small satellites for applications beyond technology demonstration, summarized in Figure 3.

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As an assessment background for the launch demands projections, there is evidence for an emerging and sustained launch, market for small satellites as historical data indicates (Figure 4). A previous study by the same company, dating back to 2011, remarks also the impressive boost that the nano/microsatellite market has received with the adoption of the cubesat standard, technology developments, entrance of new developers, and furthering of applications, furthermore if one takes into account that these satellites have existed since the very beginning of the space age era - in fact, the first satellites were of these category - and the "sterile" era which followed, between 1972 and 1989, when no "active" nanosatellites were launched due to the focus on the big ones [5-10]. The last decade (2000-2011) has showed an impressive resurgence of the Nano/Microsatellite niche with evident cubesat popularity, throwing signs for an emerging and sustained market (Figures 5 and 6).

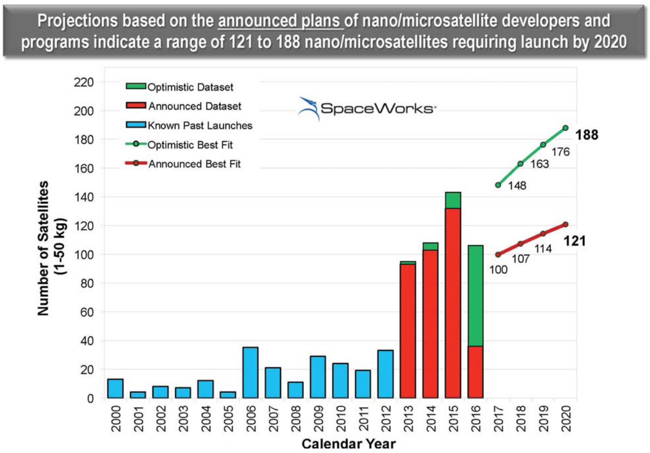


Figure 1: Nano/Microsatellite Launch History and Projections (2000-2020) [Source: Nano/Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

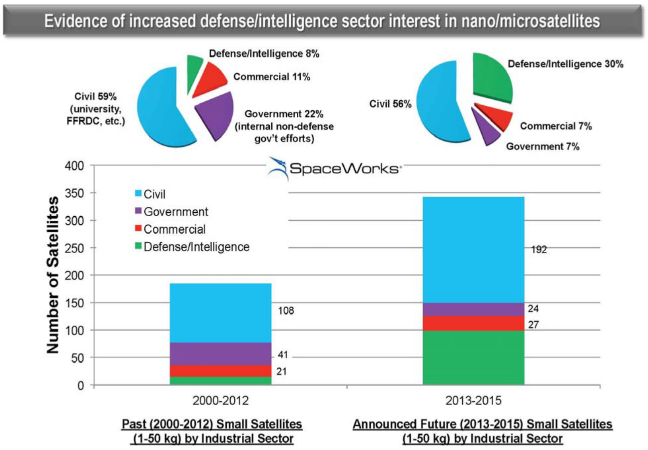


Figure 2: Nano/Microsatellite Launch Demand History and Projections (2000-2015) by target user [Source: Nano/Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

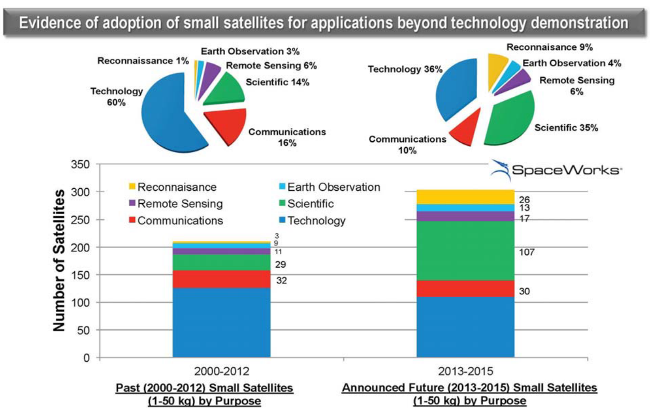


Figure 3: Nano/Microsatellite Launch Demand History and Projections (2000-2015) by Purpose [Source: Nano/Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

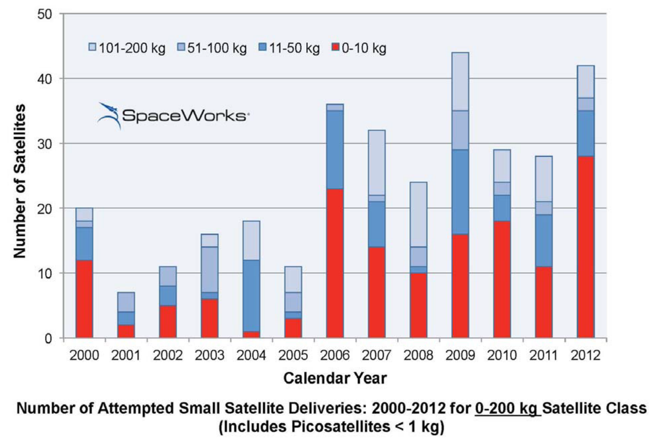
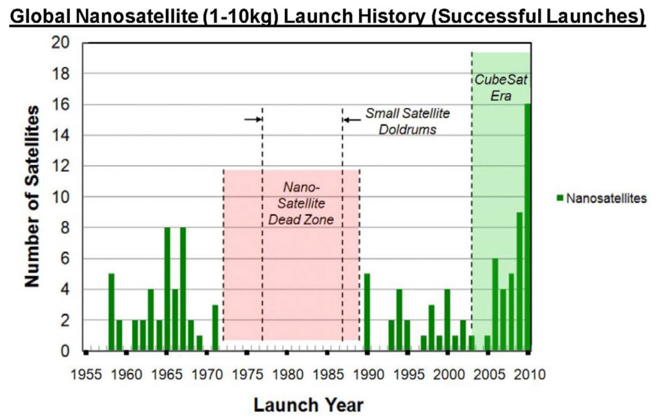


Figure 4: Historical Global Small Sats launched 2000-2012: Signs of an emerging and sustained Market [Source: Nano/Microsatellite Market Assessment February 2013 - Spaceworks Commercial].



Notes: Nanosatellites in chart are 1-10 kg (as opposed to 1-50 kg nano/microsatellites class referenced in other parts of this chapter). This does not include Russian Romb nanosatellites due to their passive nature.

Figure 5: Global Nanosatellite Launch Histroy. [Source: Source: Janson, Siegfried, 25 Years of Small Satellites. The Aerospace Corporation, 9 Aug 2011].

Futron's proprietary Electronic Library of Space Activities (ELSA) Database features over 20.000 interlocking records on all global past, current, and projected future space activity. ELSA contains comprehensive program and technical data on launch events, spacecraft, vehicles, launch sites, and space related organizations. Historical launch data, maintained in ELSA, covering the period from 2000 through all projected 2010 launches, for launches to all inclinations in LEO, indicates that an average of 12 spacecraft in the microsatellite mass class (10-100 kilogram launch mass range) have launched worldwide per year. This

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figure does not include launch of nanosatellites with a mass of less than 10 kilograms, at least 54 of which were successfully launched during the period from January 2005 through August 2010. Futron's analysis of historical launch data therefore indicates a baseline of 12 launches per year as estimate for the amount of launch demand which might be accessed by microsatellite launch vehicles under development. Figure 7 below shows the historical number of microsatellite-class launches per year. Historically payloads in this mass class have not represented a significant driver of launch vehicle demand because due in part to the small size of the satellites and their developers' often limited budgets they have traditionally flown as secondary payloads. But future trends can be modified with the entrance of a game changer such as a dedicated nanosatellites launcher.

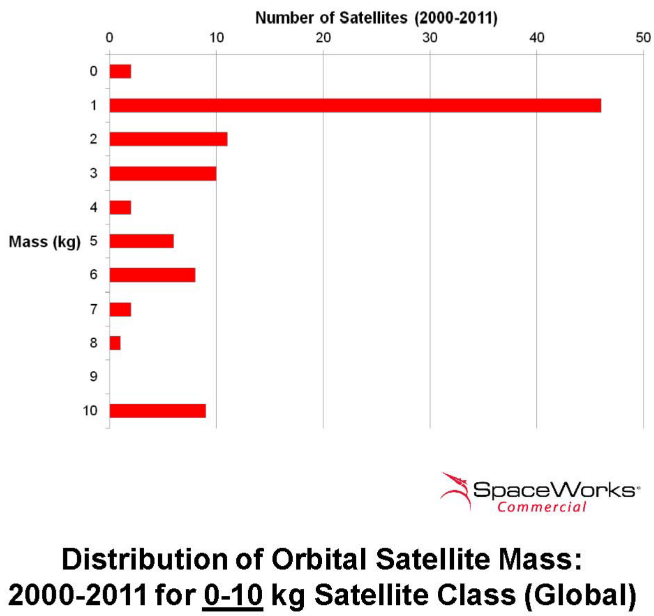

Figure 6: Distribution of Orbital Satellite Mass: 1U (1Kg) cubesat popularity is evident [Source: Nano/Microsatellite Launch Demand Assessment in 2011, DePasquale, D., Charania, A., Revision A, 22 November 2011 - Spaceworks Commercial].

Notes:

- Data values refer to attempted launches, and may include failures.
- The number of satellites "launched" may not equal the number of launches since many satellites are multiple-manifested (i.e. more than one satellite on a particular launch).
- Many times in this presentation, the term "launch" or "launches" may refer to the number of satellites launched (even though they may be multiple-manifested).
- Data aggregated by Spaceworks Commercial from its Orbital Satellite Database.

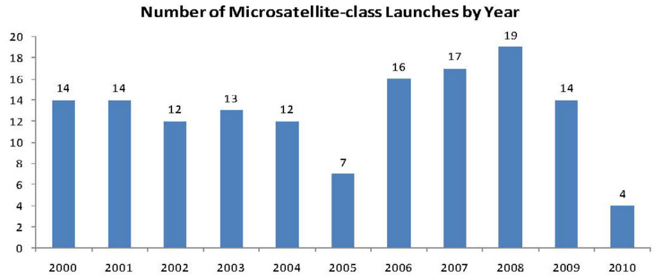

Figure 7: Historical Launch of Microsatellite-class Payloads (2000-2010) [Source: Futron Whitepapers "Market Characterisation: Launch of very-small and nano sized payloads enabled by new launch vehicles].

Vehicle Name	Organization (County)	Max Payload Capacity (LEO)	Development status	Target User/Buyer Markets
Aldebaran'	CNES, DLR, CDTI (France, Germany. Spain)	Up to 3004	Concept Study	Non-commercial, government science and tech. demo missions
Microsatellite Launch Vehicle [9]	Canadian Space Agency (Canada)	Up to 150 kg	Market Study	--
Multipurpose Nanomissile"	U.S Army Space and Missile Defense Command (United States)	Apx 23 kg	In design phases	U.S. Government military payloads, operationally responsive space
Neptune 30"	Interorbital Systems (United States)	30 kg	In-development	CubeSats. Universities and non-profits
Scorpius/ Mini- Sprite"	Microcosm Inc. (United States)	225 kg	Design	1) U.S Military and operationally responsive space 2) U.S Civil Government 3) Educational Organizations
Nano-Launcher [13]	IHI Aerospace, USEF, CSP Japan(Japan)	100 kg	Concept Study	Academia and government missions
Virgin Galactic Small Satellite Launch Vehicle	Virgin Galactic (United States)	100 kg	In-development	Science missions
NA	NASA NanoSat Launch Challenge (United States)	>1 kg and twice in one week	Innovation Prize	Cubesats

Source: Futron Whitepapers - Market Characterization: Launch of very-small and nano-sized payloads enabled by new launch vehicles.

Table 1: Dedicated microsatellite launch vehicles in development or planning.

Low cost piggy-back opportunities have historically attracted small satellite payloads to international launch vehicles as shown in Figure 8.

Within the historical baseline shown in Figure 7, Futron identifies payloads operated by 24 countries on five continents; indicating that the potential geographic extent of the microsatellite launches market is global. This conclusion is supported by an assessment of the geographic origins of organizations with expressed interest in developing dedicated launch vehicles targeted at this class of payloads. Interest in developing and operating such a vehicle has been expressed by governments and/or companies in locations including Canada, Europe, Japan and the USA. Table 1 below, includes a summation of expressed interest in dedicated microsatellite launch vehicles, including country of origin [11-13].

Furthermore, within the same historical baseline shown in Figure 7, payload operators are found within many sectors of the space community. These include civil and military government organizations, universities, non-profit organizations and research institutes, and for-profit companies. These operator groups represent the target buyer or user markets for those actors interested in supplying launch services in

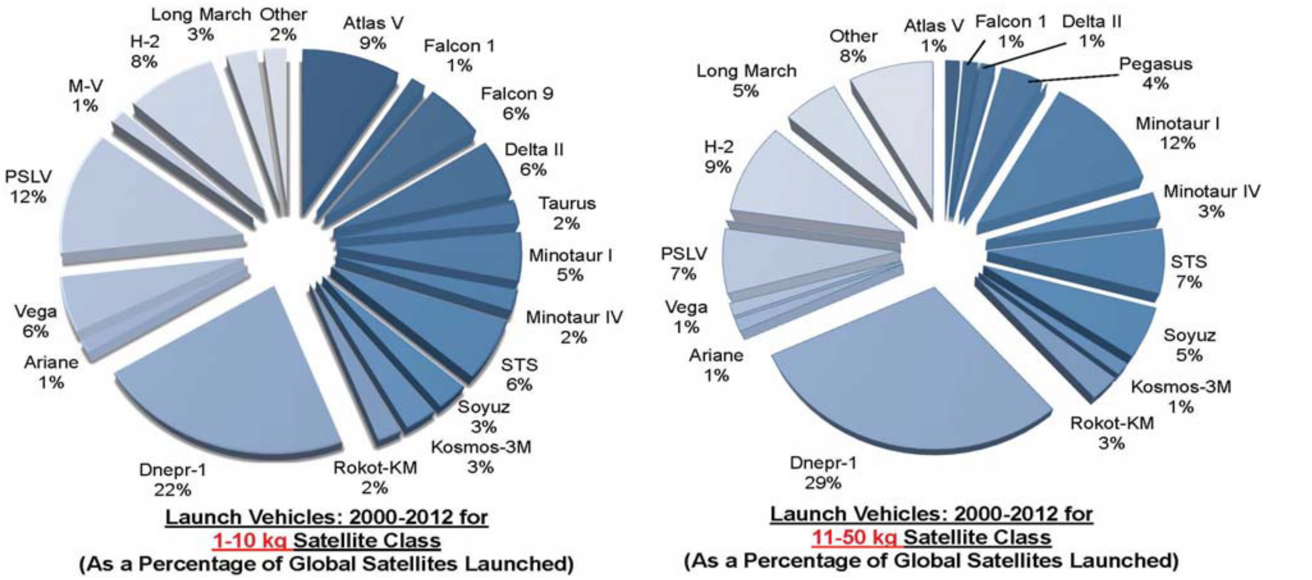

Figure 8: Historical Nano/Microsatellite Trends by Launch Vehicle [Source: Nano/Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

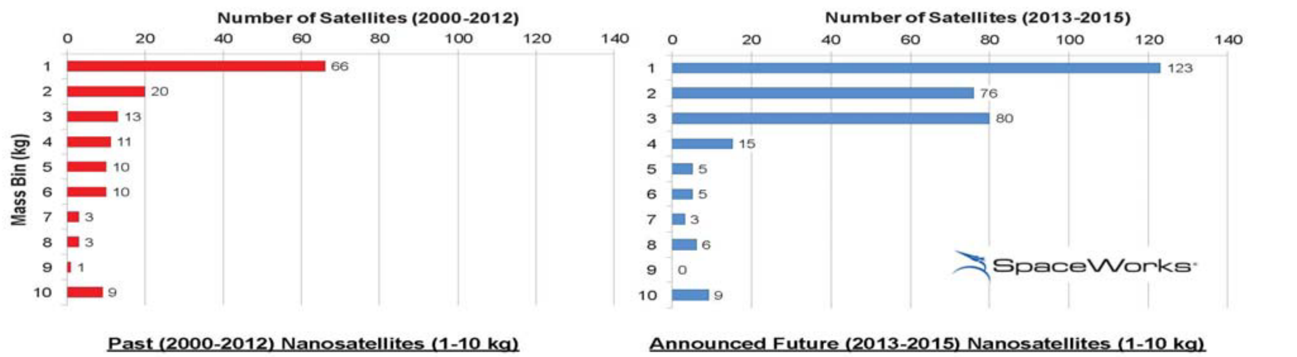

Figure 9: Nanosatellite Size Trends History and Projections (2000-2015) [Source: Nano/Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

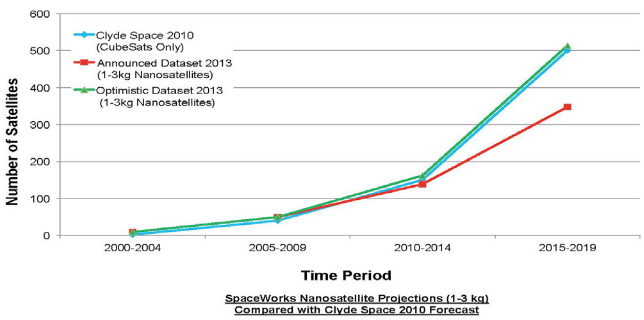

Figure 10: Nanosatellite Projections Comparison (2000-2020) [Source: Nano/ Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

this industry segment. Table 1, includes also a summation of targeted markets, where known, for dedicated microsatellite launch vehicles in development or planning (Figure 8).

The announced future nanosatellites suggest sustainment of the historically popular 1U (1 kg) Cubesat as well as the emerging 2U and 3U nanosatellites, showing also a future growth of the 6U (8 kg) class. The former is summarized in Figures 9 and 10 below.

Some ending notes are worthwhile taking into account following the Spaceworks Commercial study:

1. The number of satellites may not equal the number of launches since many small satellites are multiple-manifested (i.e., more than one satellite co-manifested on a particular launch vehicle). Data values refer to attempted launches and may include launch failures.

2. All data for nano/microsatellite projects and programs is from publically sourced information. This may not represent all global nano/ microsatellite activities.

3. All NSF satellites thus far have launched through the NASA CSLI. In the table, these historical NSF satellites are included in both the count of number launched for NSF and the count for CSLI (double counted in this sense). The bar graph of future launches shows only those NSF satellites that expected, but currently not manifested (thus they are appropriately single counted for future launches).

4. The Announced data set includes some known nano/microsatellite programs for which a specific launch date has not been announced. The satellites belonging to these programs are distributed across the period (date range) for launches according to the announced program objectives

5. Future projections from 2016-2020 are determined by Gompertz logistic curve "best fit" regression with market saturation point (asymptote for number of satellites) set at 170 nano/micro satellites in a year for the Announced Dataset and, 250 for the Optimistic Dataset.

• The Gompertz logistic regression provides an accurate market growth prediction for many industries, particularly high tech.

• Regression curve based upon best fit to data while still accounting for a market saturation point.

• Market saturation point (launch demand asymptote in 2030) set at 170 nano/micro satellites in a year, limited by:

i. Realistic number of manufacturers.

ii. Limits imposed by requiring a shared launch with a larger satellite.

iii. Others within Cubesat industry have proposed that total market just for Cubesats is over 600 Cubesats per year that will need launches

6. The Optimistic data set contains all currently known past and future nano/microsatellites from the SpaceWorks LDDB, with the addition of an inflating factor for known unknowns plus assumed sustainment of certain current projects and programs (e.g. follow-on to NASA Ames EDSN, Cubesat Launch Initiative, DARPA SeeMe).

7. These graphs are based on the Announced data set only, and do not include additional satellites contained in the Optimistic data set.

8. The sum number of future nano/microsatellites shown in this chart may not equal the sum shown on other charts. Nano/microsatellites for which the subject data of interest is unknown have been excluded from this chart.

9. Percentages may not sum to 100% due to rounding.

10. By some traditional definitions of space industrial sectors, non-defense government space activities are a subsector of the civil sector. Here we break out non-defense government activities into a separate sector. "Government" refers to those nano/microsatellite development efforts that occur within/by the government agency or organization (e.g. NASA, JAXA). Civil refers to all other non-defense development activities (e.g. universities, federally funded research institutions), though the funding source may be a government agency.

11. Nanosatellites are binned by rounding mass to the nearest whole number. Picosatellites less than 1 kg are not included.

12. 70 percent of future satellites in the Announced Dataset are less than 3 kg. This percentage is applied to the projections for 2012-2019 to arrive at the estimated number of satellites under 3 kg for each data point in the projection.

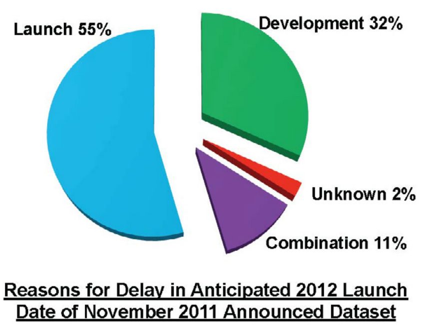

Figure 11: Nano/Microsatellite Launch Delays: 2012 Case Study [Source: Nano/ Microsatellite Market Assessment in February 2013 - Spaceworks Commercial].

13. Based on 2010 ClydeSpace analysis.

It is also worthwhile to point out that the methodology used to project the above figures has some risks implicit. First, it assumes launches will occur as planned, but launches are often delayed and projects may not launch due to lack of funding. Second, it is dependent on the market saturation assumption; and third, data sets contain an inflating factor based on unknown satellites that could potentially not exist.

Specifically concerning launch delays, Spaceworks Commercial analyzed in a case study published in 2013, the main causes for delay of launches during 2012, being the main one launcher delays/challenges as summarized in Figure 11 below.

Identified reasons for delay in anticipated launch date of nano/ microsatellites include the following:

Launch: A slip in schedule of the launch vehicle, delay in schedule of the primary payload, delay in development of the launch vehicle, inability of the satellite developer to identify or contract with a suitable launch provider.

Development: Satellite development technical or management challenges, delays in funding, delays due to suppliers, testing and qualification challenges, delays in government approvals (e.g. ITAR).

Combination: Both launch and satellite development delays occurred.

Unknown: The reason for delay cannot be readily determined.

In another study performed by the company Futron in 2006 focused on the small satellites segment characterized by satellites in the 100-200 kg weight class, development cost from $5M to 10M and 1-2 year life expectancy, results showed a potential addressable market size of 40-75 such satellites/year and $290-570M/year. Over 30 markets were identified, six of which emerged as most promising: Military (Science and technology; Intelligence, surveillance, and reconnaissance (ISR)); Civil/commercial communications (Polling of unattended sensors; Remote site communications); and Civil/commercial remote sensing (High-resolution Earth observation; Landsat-class data for environmental monitoring).

As a sum-up, in the current paradigm, that is, without a game changer in play such as a new launcher as Sagitarius, the projected estimate for nanosatellite launch demand in the optimistic scenario is 400 for the 2015-2019 timeframe, that is, around 100/year.

To the former figure, we may add up the new market scenario arising from the entrance of new and dedicated nanosatellites launchers, as Sagitarius,

Celestia Aerospace Products and Services

The cost associated to the production and launch of a satellite is very high.

The former has so far restricted space access to huge aerospace contractors, either public, private or a mixed formula of both, such as Space Agencies (ESA, NASA....) and main industry contractors (Astrium, Lockheed Martin, Space Systems Loral...). Meanwhile, newcomers to the space industry are pushing to get introduced to the sector and demand a cost-effective solution. Launch opportunities are still scarce whilst demand is increasing, thus resulting in a bottle-neck for the small satellites market.

Celestia Aerospace proposes a solution. On the one hand, Celestia Aerospace satellites are less costly to build, launch, operate and maintain.

On the other, Celestia Aerospace provides a unique proprietary launch system specifically devoted to service the nanosatellite market: Sagitarius.

Celestia Aerospace is a start-up company headquartered in Barcelona (Spain) founded with the purpose of providing an integral, accessible, low-cost service for small satellite users, covering the whole value chain from design to manufacture, launch, operations and data delivery.

Celestia Aerospace goal is to build a low-cost, miniaturized and "user-friendly" small satellite, the "i-Sat", the i-phone of the satellites, both for the professional market as well as for the general public one, and deliver it to orbit with a dedicated nanosatellite launcher: Sagitarius.

Our solution focuses on meeting the needs of the small satellite users experiencing two main roadblocks: first one, the existence of a launch bottle-neck due to the lack of a launch system dedicated specifically to small satellites; second one, the lack of an integral service provider.

Celestia Aerospace will build cube-shaped low-weight satellites – ranging from 1 to 10 kg – and small dimensions – from 10 centimeters of edge – termed nanosatellites. The manufacturing will be undertaken from the company premises in Barcelona, and the integration of the satellite with the launcher will take place in the company's hangar, based at an airport in Spain.

The goal is for the client company to have a single interlocutor in the aerospace chain: client needs are determined and a customized solution is designed, which then is developed into a nanosatellite.

One of the keys for the low development cost is standardization and the use of off-the-shelf technologies, that is, widely used commercial applications, from sectors such as the multimedia or mobile communications.

For the development of systems and standards Celestia Aerospace has built up teams and established collaborations with Universities, such as the Technical University of Catalonia - Barcelona Tech.

The launch, orbital operation, and data management are developed by Celestia Aerospace as well. Satellite operations services covers in-orbit control; servicing in orbit including repairing and de-orbit; data gathering; and data handling to final user format. Therefore, the final aim is that the client has just to sit in front of the computer and wait for the desired data to download.

For the first time ever, the small satellite users will be able to cover all the value chain interacting with just one provider and have a dedicated launch system specifically addressed to this market, allowing for fast response times.

Celestia will develop, own and operate five specific satellites: BioPharmaSAT, SemicondSAT, TestSAT, SnapSAT and ClusterSAT aimed at the pharmaceutics/biotechnology sectors, semiconductor industry, aerospace industry and commercial services for Earth observation and Communications, respectively, to take full advantages of the microgravity research opportunities and offer them to small and medium enterprises, emerging economies, as well as educational and non-profit entetitis, opening space access to a wider audience for the benefit of all.

The Benefits of Microgravity Research

BioPharmaSAT

There is growing interest in biotech research in space, primarily on the International Space Station (ISS), but with challenges of access and cost. Small satellites can potentially provide a lower-cost (and more responsive means) of access to space for this option. Previous missions such as GeneSat have served as pathfinders for the former. The International Space Station can itself also be a target market for BioPharmaSAT as there exist small satellite synergies through the use of Nanoracks, cubesat adapters specifically designed for the ISS.

According to a study by Andrews Space and Technology [5], current and on-going research demonstrates the significant advantages of on-orbit research and manufacturing which has attracted the interest of pharmaceutical market leaders.

Tissue engineering is enabled by microgravity and may lead to treatments for many medical conditions. Liver tissue is the most likely early candidate for commercially viable space-based tissue engineering. Tissue engineering technologies, for example, have the potential to address diseases and disorders that account for about half of the USA's total healthcare costs. Tissue culture experiments performed on the space Shuttle and Russian Mir station have demonstrated the positive effects of microgravity on three-dimensional tissue growth and differentiation, and thus the potential for improved products. Liver disease in the United States resulted in 25.175 deaths in 1997, while only 4.000 people received a liver transplant (in 1996). Based on 1985 data, liver and gall bladder disease cost the US health care industry around US$17 billion. Space based tissue engineering could possibly save tens of thousands of lives and has the potential of saving care industry billions of dollars.

Small yield increases of recombinant drugs produced in microgravity may save millions in production costs. Space-based manufacture of recombinant drug could represent a substantial market. Recombinant protein drugs and diagnostic agents are one of the fastest growing segments of the pharmaceutical industry generating US$20 billion in annual revenues. Microgravity production of recombinant drugs offers the potential of improved quality and yield. An improvement in yield of only a few percent has the potential to save millions in production costs.

Access to microgravity laboratories is needed to drive market development. While biotechnology firms are aware of some of the advantages of microgravity, very few have performed microgravity experimentation for the manufacturing of biotechnology products. Like the semiconductor industry, biotechnology firms are in an extremely competitive and risky market arena. Also like the semiconductor industry, biotechnology firms spend between 10% and 15% of their annual revenues on R&D. In addition to the products mentioned before and their potential revenues, there is a significant demand for unique research and development facilities, which would likely include an orbital R&D laboratory in the future and small satellites at present. The biotechnology industry has US$365 billion in global annual revenues, which translates to between US$700 million and US$1.05 billion in weekly R&D expenditures.

SemicondSAT

According to a study by Andrews Space and Technology [6], the potential of space-based semiconductor manufacturing for the foreseeable future seems to be low. Industry leaders are continuing to scale down geometry features via wet processes and limited vacuum application. The potentially cleaner environment of space may not reduce defects and increase yield of semiconductor production because 95% of the contamination in today's processes are believed to come from process tools and are thus inherently internal to those processes.

Radical tool redesigns, aimed at eliminating those contaminants, are needed. Also, in two more generations microchips will have features less than 30 nm and semiconductors as we know them will not function due to quantum mechanical limits (electronic tunneling through CMOS gates). There are a number of alternate approaches in work and the availability of laboratories with microgravity and ultra-hard vacuum were definitely of interest.

Although it was not the focus of the Andrews Space and Technology study, interviews with "traditional" semiconductor manufacturers did uncover a significant interest for an On-Orbit Research Facility. The study highly recommends the investigation of an On-Orbit R&D facility as part of future studies. This stems from the fact that, within the next years, semiconductor companies will reach physical limits of material and present manufacturing processes, which they have refined over the last decade. Currently, they are searching for "revolutionary" methods of manufacturing follow-on generations of products. If an on-orbit research facility existed today, interviewees of the afore mentioned study would be willing to pay up to US$20 million for a single flight to conduct tests and build certain production elements that could lead to breakthrough material and manufacturing advancements. However, this market is only addressable if the companies are offered routine access: no less than once a month. Demand would significantly increase if the price for a week's research could be reduced to less than US$1 million.

The semiconductor market spends between US$20B and US$30B annually on R&D. This works out to between US$385M and US$577M per week. Based on the study's interviews feedback, if a new launch vehicle could provide weekly access, semiconductor companies could spend up to US$20M per week (3% of the world semi-conductor R&D funds) for the use of an Orbital R&D facility.

TestSAT and SnapSAT

TestSAT is a standardized cubesat aimed at offering technology validator and component testing services in space conditions. The payload compartment is highly configurable to meet the specific customer needs. Celestia Aerospace engineering service will constitute a team with its customer to identify the technology validator/testing setting and equipment, and data gathering to meet customer needs. The mission will be carried out during the in-orbit time, with data gathering and handling managed and provided by Celestia Aerospace, who will directly provide the data under the final user format needed by its customer.

SnapSAT is a standardized cubesat aimed at servicing current and future "big satellites" - satellites of more than 1.000 kg developed by main Space Agencies and main industry contractors, covering communications, navigation and scientific missions-. SnapSAT will have a standardized data communications port to dock to its standardized complimentary port aboard the target satellite. This communication port will have to become an industry standard so that it is adopted by main industry contractors and incorporated in their satellites. Once docked, SnapSAT will transfer data to update the target satellite systems. An extended version of SnapSAT will include extended satellite docking capabilities and component handling to broaden satellite services, comprising target satellite orbit correction, de-orbit, re-fuelling, repair and equipment replacing. All the former capabilities will be under Celestia Aerospace patent technology.

ClusterSAT for communications

ClusterSAT is a constellation of standardized cubesats that will jointly work to provide Earth Observation and Communication services.

As far as communications is concerned, the applications are varied. One of them concerns access to remote areas. Internet access worldwide is not yet guaranteed: either due to isolation and lack of terrestrial infrastructure in remote areas – currently 2/3rds of the world have no internet access at all-; either by Government control of the information flux in some countries (for example, China, North Korea). And even in those countries with internet access guaranteed, another problem adds to the previous ones: privacy and secure communications.

A Constellation of around 100 nanosatellites populating different orbital planes in a low-Earth orbit (LEO) of around 500 Km altitude orbit could provide private communication networks. For remote areas coverage, Wi-fi enabled devices and/or home radio antennas similar to those from satellite TV connected to a computer, or receivers plugged directly to a PC, would communicate with the satellites in their region, which in-turn communicate with other satellites and ground-based networks, thus forming the global network providing internet access in remote areas.

An intensive research area in Delay and Disruption Tolerant Networking (DTN) also known as "Ring Road network" is being applied to cubesat constellations [7]. Basically the DTN allows a cubesat to act as a data "mule" storing uploaded "bundles" of data until the cubesat's orbit takes it over a ground station connected to the Internet. The height and speed of the cubesat's orbit provides wide area coverage and speedy transit to its next download link. Thus, the Ring Road network aims to provide reliable epistolary data transfer and as such, it need not ensure uninterrupted end-to-end connectivity to assets on Earth. By tolerating episodic contacts, Ring Road may comprise solely nadir-pointing cubesats in LEO: during the time that a satellite is out of the view of any ground station, it retains in-transit data in a queue in its own local storage medium, awaiting its next ground station over flight.

While the innately high latency of this DTN communication rules out some kinds of network services such as Internet telephony, highly interactive web browsing, and massive multiplayer games, for example, supported applications would include:

1. Warnings of disaster events.
2. Requests for relief services.
3. Relief worker consultation, reporting, and direction.
4. Search and rescue support in remote areas.
5. Disease control information.
6. Weather forecasts.
7. Fish and game migration data.
8. Commodity pricing.
9. Distance learning.
10. Acquisition of data from remote sensors.
11. E-mail.
12. Research queries.

DTN offers also another advantage: incremental deployment. Because cross-links need not be maintained amongst the satellites, each satellite functions independently as a data transfer device. Ring Road could provide data communication service – albeit with extremely high latency and at very low data rates – throughout its intended coverage area even if only a single satellite were in operation.

Due to the low cost of building and launching each satellite, deploying a very large network is relatively inexpensive. Perhaps more importantly, deployment of such a network need not be accomplished all at once, so no large initial investment is needed and satellites can be deployed individually and opportunistically over a period of years. Also network maintenance will be significantly lower than with other satellite concepts as failed satellites could be replaced quickly and at low cost.

Main current restrictions concerning the use of cubesats for internet communications are basically three: limitations in band-width; rapid velocity of the satellite due to its LEO orbit; and inter-satellite communication. Nevertheless the former can be overcome.

First one concerning the available band-width can be overcome by increasing the power available to the satellite by means of larger solar cell panels, and/or by means of future technology improvements in this area. Band-width of up to 2Mbs are available right now with current state-of-the art technology and our team is working on reaching up to 5 Mbps, thus making already possible the use of narrow-band internet communications.

LEO orbit causes rapid transition times of the satellite over the ground network stations, thus posing restrictions in window-time for ground-link communications. This is overcome by increasing the number of cubesats in orbit. Our proposal is using up to 150 cubesats in a 500 Km altitude near-circular polar orbit**.** This restriction can be further diminished by increasing the number of "ground stations". Keeping in mind that ground stations for cubesats could be as simple as a radio receiver plugged-in a PC, potentially a huge number for cubesats ground stations could exist.

The last restriction, inter-satellite communications is really the one posing the major issue. Even for big satellites, this issue is still an under development one in part because up to now big satellites, with some exemptions, have been working alone instead of being integrated in constellations or clusters. Exemptions are mainly in research missions by NASA or ESA, where big satellites need to work in constellations such as the missions Darwin or the under development one LISA, where coordination is needed to perform interferometry. Or the big satellite constellation in LEO of IRIDIUM. NASA is working in inter-satellite optical communications. In the domain of constellations of cubesats, as there is none yet in orbit, nothing has been implemented, constituting this, therefore, another technology niche. Many research papers are currently available in the literature dealing with this issue. The DTN or Ring Road Network introduced here could be a solution to this problem as it does not require inter-satellite communications.

Many applications are innately delay-tolerant, such as e-mail, news feeds, weather advisories, archiving, backups, documentation of events, etc…i.e., any communication where reliability and security are more important than timeliness. These include also much electronic commerce and finance: merchandise used to be purchased by e-mail order, from catalogues received in the email; Banking – deposits, payments, statements – used to be done by e-mail. In every case, applications on a high-latency network can provide the same functionality but much more quickly and securely.

ClusterSAT for Earth Observations (EO)

Earth Observation has wide spread applications: use of near real time imaginary for social media, to hydrology, agriculture, resource monitoring, environmental monitoring, forestry, intelligence services, topography, traffic or urban development.

These services have been provided so far by big satellites but nanosatellites could serve them at more affordable prices and with resolutions starting at 5 meters.

From the plethora of cubesat missions designed in the last decade, only nine missions were identified that perform or would perform Earth Observation measurements other than space weather. These missions carry optical cameras, GNSS receivers for occultation measurements, photometers, and millimeter-wave sounders. The small number or missions, and the lack of variety in their payloads, are noticeable. The reasons for that are not much of a surprise: the stringent mass and dimension requirements of the cubesat bus translate into reduced mass, power, and data rate capabilities offered to payloads when compared to those of larger missions. Many of the currently used Earth Observation payload technologies (SAR, lidar, high-resolution optical imagers, hyperspectral imagers) are simply not compatible with these constraints.

However, many studies [8] have identified at least a few technologies that are compatible of these stringent constraints. These technologies include spectrometers with limited imaging capability, precise accelerometers, and broadband radiometers. These technologies would enable a broad variety of measurements with high societal and scientific return including ocean color, ocean mass distribution, glacier mass distribution, vegetation state, and Earth radiation budget amongst others.

A cubesat-based component having large constellations of cubesat carrying these technologies and taking these measurements would be also an extremely high value added asset for the so-called Earth Observing System-of-Systems (EOSS). First, such a system could take care of a fraction of the requirements for the EOSS, thus reducing the burden on larger satellites, and allowing them to focus on the highest performance missions, which cubesats are incapable of. Second, it would help close some of the expected data gaps in key measurements (e.g., gravity measurements). And finally, they would provide unprecedented data products with very high temporal resolution and relatively high spatial resolution, which could potentially create new opportunities for science. In particular, such measurements could be combined with data products from higher performance instruments using disaggregation schemes.

Within the Earth Observation domain, we can concentrate also on three main market opportunities: small satellite manufacture; EO data sale; and resulting downstream applications.

Upstream technology – Manufacturing: Nano/micro-satellite supply chain

The market for Nano/Micro-Satellites is growing quickly. In 2013, the number of small satellites (weighing less than 50 kg) launched was nearly as many as were launched in the previous three years. Indeed, the adoption of constellations by new businesses and corporations' intent on activities such as monitoring terrestrial assets is driving a forecast of 2000-2750 small satellites to be launched from 2014-2020, more than four times the number launched from 2000- 2012 [9].

While only 12% of small satellites were for EO and Remote Sensing purposes in 2009-2013, this proportion is expected to grow dramatically. Not only are the number of small satellites expected to treble over the next three years, the number of Nano/Micro-Satellites purposed for EO and Remote Sensing is expected to grow from 12% to 52% (i.e., from 24 to 338 spacecraft).

A recent market study by Euroconsult agrees with these growth estimates, forecasting the number of Earth Observation satellites (non-meteorology) launched by civil government and commercial entities to more than double over the next eight years to 290 satellites and £17.4 billion in manufacturing revenues over the period, an 84% increase over the previous decade [10]. The market for EO satellite manufacturing is estimated to reach £2.1 billion in 2020 alone. While Euroconsult does provide a comprehensive industry analysis and forecast in the growing EO sector, it does not distinguish between Nano/Micro-Satellites and their larger brethren. One can however extrapolate the value of the Nano/Micro-Satellite manufacturing market [11] based on the number of small satellites forecasted by SpaceWorks and a representative cost per satellite of £250.000 [12]. Therefore, 1.040 Nano/Micro EO satellites (52% of 2.000), at an average cost of £250.000 per satellite, give an estimated market value of £260 million over the next six years, or approximately £100 million in 2020 alone, for EO Nano/micro satellites manufacturing.

EO Data sale – Disruptive nano/micro-satellite constellations

Conventional imaging satellites are the size of a van, weigh tones, and cost hundreds of millions to build and launch. As a result, there are only a handful of operators, and the world fleet of commercial imaging satellites consists of less than 20 (excluding the 28 Nano- Satellite constellations that was just launched by Planet Labs).

Additionally, commercial satellite operators have not embraced a proactive approach to drive innovation in the sector, and tend to only take pictures when their operators receive orders from customers. Indeed, a limited number of large expensive satellites have resulted in a product that is expensive and untimely, and as a result, has not been adopted by the applications market.

However, it is expected that new entrants will challenge the existing commercial data pricing strategies, moving EO data sales opportunities from an end to a means for delivering commercial value-added downstream applications. Small satellite trends are shifting away from one-time stints and moving toward more widespread adoption, enabled by constellations.

The challenge is that space assets are traditionally extremely valuable, extremely expensive, and extremely risky. So the next technological frontier for quality imaging from space involves systems that can both capture high quality (resolution) data to show economic activity and be cost-effective enough to deploy in large numbers (timeliness). Resolution and timeliness are the two critical elements required to realize the growth potential of EO, reach a critical mass of adoption, and ultimately become self-sustaining.

Since most businesses are interested in economic activity of some kind, the most valuable data is that which can monitor at the economic scale (≤ 1 m) and temporal scale (daily). Existing EO systems have not met the needs of many business applications because they lack the critical combination of timeliness and sub-meter resolution. High-profile start-ups such as Planet Labs have taken a huge step forward in terms of improving temporal resolution, but still lack the economic resolution to drive mainstream adoption.

The biggest customers of conventional commercial imaging satellites are governments, in particular intelligence agencies and the military. These high cost, high capability products are priced far out of reach for many other potential users, including researchers, in areas as diverse as farming, forest carbon management, regional and local planning, and environmental stewardship. By bringing the cost down and accessibility up, new entrants in this marketplace hope to spur a proliferation of innovative uses. Another innovative approach under discussion is to offer heavy discounts, or even make imagery free, to academics and non-governmental organizations, in order to increase usage.

Making EO data freely available in order to build services has been and will continue to deliver success. It is not expected that all data will lead to the development of revenue-generating services; however, the wider dissemination of EO data across applications, industries, and universities, etc., will increase adoption of EO as a new data set. In addition to creating more cost-effective services (by reducing the cost of the data product), it is felt that exposing more individuals and sectors to EO data will help increase the demand of paid- for commercial solutions if a higher resolution, high-accuracy product is required to support applications' development. The quality of service attached to the data is still recognized as carrying value: Co-existence of free and paying data is therefore still possible, provided that the paying data is delivered in a suitable approach.

Euroconsult estimates that the market for commercial EO data will reach £1.8 billion by 2020 (9% CAGR), with the greatest amount of growth coming from non-defense markets. According to their latest industry report, this is driven by demand to "support wider economic growth with applications spanning natural resources monitoring, engineering and infrastructure, and defense [13]".

The needs of the £1.8 billion market opportunity cannot be met entirely by future.

Nano/Micro-Satellite missions due to the following technical considerations:

a. Synthetic Aperture Radar (SAR): £340 million is attributed to SAR images, which are not currently feasible using a Nano/Micro-Satellite platform due to size and power constraints. While technology is improving, this is not likely feasible for another 5-10 years.

b. Very High Resolution (VHR): £1.1 billion is attributed to VHR optical images (ground resolution less than 1 meter) which are currently difficult to acquire from Nano/Micro- Satellite platforms, although new technologies are enabling greater capability. Additionally, £400 million of the VHR value is expected to come from US Defense, who demands resolution that is likely out of reach of Nano/Micro-Satellite platforms. Therefore, the VHR market captured by Nano/Micro-Satellite platforms in 2020 is expected to be £530 million, or 50% of the total.

c. High-Medium Resolution (H-MR): H-MR optical images (>1 meter ground resolution), an estimated £440 million market value in 2020, is fully within the reach of Nano/Micro- Satellite mission capabilities.

Therefore, the size of the commercial EO data market reachable by Nano/Micro-Satellites platforms is estimated to reach £970 million by 2020, or 54% of the total £1.8 billion market.

1. Downstream applications include increasing the profitability of business.

2. A strong upstream sector will enable the growth of the downstream sector (Figure 12). Indeed, the downstream sector will experience significant disruption with the arrival of Nano/Micro-Satellite constellations. For reference, the ratio of upstream turnover to downstream in other major space-faring nations such as Germany and

France (including satellite manufacturing, launch services, and ground systems) is approximately 1:12 (for example, for the United Kingdom this ratio is of 1:6).

The following examples have been identified as emerging opportunities already addressed by Nano/Micro-Satellite missions' precursors:

Agriculture health monitoring: Monitor crop health and forecast crop yields with timely sub-meter imagery. Identify pest infestation and plan irrigation levels to augment your precision agriculture techniques.

Humanitarian aid: Monitor refugee movements and infrastructure development in conflict areas to aid humanitarian efforts.

Insurance modelling: Inform risk exposure models to increase efficiency and profitability. Frequently monitor high value assets for change.

Oil storage monitoring: Monitor oil storage containers with sub-meter imagery for changes in volumes to inform commodity trading decisions.

Natural disaster response: Aid first responders in rescue coordination. Monitor long- term recovery and relief efforts.

Oil and gas infrastructure monitoring: Explore potential sites or monitor existing property and infrastructure for safety and security. Detect the intrusion of vehicles, new construction, or vegetation on pipeline corridors.

Financial trading intelligence: Access proprietary information to make more informed and competitive investment decisions. Identify changes in relevant metrics like the number of cars in a retailer's parking lot or size of stockpiles of natural resources in ports.

Mining operations monitoring: Explore new sites or monitor ongoing projects. Identify specific rock topologies and geological structures associated with mineralized areas. Obtain up to date imagery for evacuation planning.

Carbon monitoring: Create reliable carbon stock baselines and improve land cover maps.

Maritime monitoring: Monitor ships entering and exiting ports with HD video to inform supply chain optimization decisions. Validate AIS data and analyse container activity in ports.

Retail: Traffic gauging of parking lots to find out how many shoppers expected at every hour of every day.

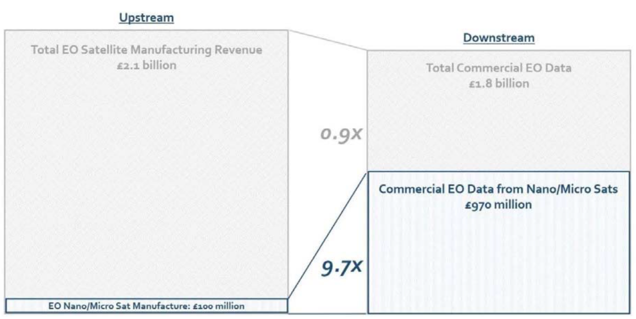

Figure 12: Nano/Micro-satellites downstream market nano/micro-satellites to deliver 54% of downstream market value in 2020 source: Satellite applications: Small is the new big – white papers.

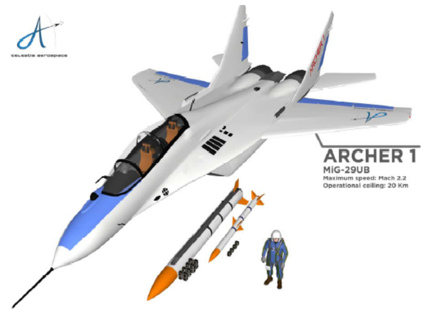

Figure 13: SALS (Sagitarius Airborne Launch System) SALS with its components: The Archer and Space Arrow. [Credits: Celestia Aerospace].

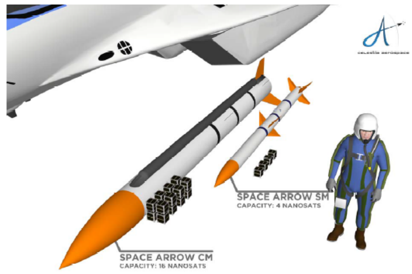

Figure 14: Space Arrow main configurations. Space Arrow in configurations SM (Simple Matrix) and CM (Complex Matrix) for nanosatellites launch [Credits: Celestia Aerospace].

Figure 15: Target Orbit for Sagitarius [Credits: Celestia Aerospace].

Celestia Aerospace unique launch solution: The Sagitarius Launch System (SALS)

The SALS is the first of its kind and it will service both Celestia Aerospace's own nanosatellites and other companies that require a fast, flexible, and affordable launch solution (Figure 12).

The Sagitarius launch system is an airborne platform capable of reaching orbits of 600 Km of altitude, and it is composed of two components: The Archer, a demilitarized MiG-29UB supersonic jet (Figure 13); and The Space Arrow, a launcher based on a modified missile, with two load configurations: simple matrix, with a load capacity of 4 nanosatellites; and complex matrix, with a load capacity of 16 (Figure 14). In a single flight, the Archer can deploy four simple matrix Space Arrows or a single one in the complex matrix set-up. Therefore, Celestia Aerospace can transport up to 16 nanosatellites to orbit in a single operation.

Sagitarius will operate from an airport in Spain with targets orbits reaching LEO (Figure 15). Celestia Aerospace will also offer its clients the possibility of actually taking part of the flight from the backseat of the MiG-29UB and deploy the Space Arrow carrying their own nanosatellite. This is a world-wide first. The Archer will also be used to offer space tourism flights to 20 Km of altitude, where the flier will be able to see the curvature of the planet and the darkness of space.

The advantages of this new launch system are varied: its low cost compared to normal launch platforms for this kind of satellites, which now have to fly as 'piggyback' cargo in larger rockets; the just-in-time service, allowing for a record waiting time of 2 weeks, radically more flexible than the average year-and-a-half for the available launch opportunities; total mission focus, as the launch is strictly prepared for the nanosatellites, compared to the limitations of flying as secondary cargo of a larger satellite; and total flexibility in terms of calendar, as the launch can be moved without problems to accommodate delays in the nanosatellite development.

Sagitarius will start operations from an airport located in Spain. Growth of the company will allow for operations from many airports not only in Spain.

Celestia Aerospace will also manage launch opportunities through third parties provided through agreements with main launch companies. This will also serve as the main launch service for Celestia during appropriate development of its own launching platform, Sagitarius, so that the customer can still get an integral service.

Conclusion

Performance of the MiG-29UB indicates the possibility of lifting even more weight to orbit. Celestia Aerospace will start first by securing the service for the nanosatellite community. Future upgrading of the systems can allow to place up to 50 kg satellites in orbit (microsatellites).

With SALS Celestia Aersopace can offer far reaching market opportunities and benefits:

1. Low cost services compared to normal launch platforms for this kind of satellites, which now have to fly as 'piggyback' cargo in larger rockets

2. Just-in-time service, allowing for a record waiting time of 2 weeks (1 week when operating with two Archers), radically more flexible than the average year-and-a-half for the available launch opportunities

3. Total mission focus, as the launch is strictly prepared for the nanosatellites, compared to the limitations of flying as secondary cargo of a larger satellite

4. Total flexibility in terms of calendar, as the launch can be moved without problems to accommodate delays in the nanosatellite development.

5. New experience for the customer who can take part of the launch flying aboard the launch platform.

6. Sagitarius is the final ingredient of a full-cycle service offered by Celestia Aerospace to help a wider audience to reach space.

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